WMO Global Ozone Research and Monitoring Project
Report No. 57

Report of the Tenth Meeting of the Ozone Research Managers of the Parties to the Vienna Convention for the Protection of the Ozone Layer

(Geneva, Switzerland, 28 - 30 March 2017)

WEATHER CLIMATE WATER

WORLD METEOROLOGICAL ORGANIZATION

GLOBAL ATMOSPHERE WATCH

UN environment
United Nations Environment Programme

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INTRODUCTION

The 10th meeting of the Ozone Research Managers (ORM) of the Parties to the Vienna Convention for the Protection of the Ozone Layer was held at the Headquarters of the World Meteorological Organization (WMO) in Geneva, from 28 to 30 March 2017.

The meeting was organised by the Secretariat for the Vienna Convention and Its Montreal Protocol (the Ozone Secretariat), United Nations Environment Programme, in cooperation with WMO, in accordance with decision I/6 of the Conference of the Parties to the Vienna Convention for the Protection of the Ozone Layer. A list of participants is provided in Annex A to the present report.

OPENING OF THE MEETING

The meeting started on Tuesday, 28 March 2017.

Opening Statement *(Tina Birmpili, Executive Secretary, Ozone Secretariat)*

Ms Tina Birmpili, Executive Secretary of the Ozone Secretariat, welcomed the meeting participants, and thanked the WMO for hosting the meeting and working with the Secretariat to organize the 10th meeting of the ORM. She highlighted that, at their 28th Meeting in October 2016, the Parties to the Montreal Protocol had adopted the Kigali Amendment to phase down the production and consumption of global-warming hydrofluorocarbons (HFCs) used in the same sectors addressed under the Protocol. By ratifying the Kigali Amendment, countries would commit to cutting the production and consumption of HFCs by more than 80% over the next 30 years. Most developed countries would start reducing HFCs as early as 2019. Developing countries were divided into two groups, each of which would start reducing HFCs following their respective schedule, with the bigger group of countries freezing the use of HFCs in 2024 and the smaller one in 2028. In anticipation of hearing from participating experts what the Kigali Amendment meant in terms of actual and potential climate benefits, she thanked the scientific community for having provided the parties with the necessary information to consider taking a decision to address HFCs. She also expressed her appreciation to the Protocol's three Assessment Panels – the Scientific Assessment Panel (SAP), the Technology and Economic Assessment Panel (TEAP), and the Environmental Effects Assessment Panel (EEAP) – for playing a key role in providing a knowledge platform and supporting, therefore, parties in taking informed decisions. With contributions from hundreds of scientists and experts around the world, working on a voluntary basis, the Panels had been preparing for their 2018 Quadrennial Assessments to be considered by the Meeting of the Parties to the Montreal Protocol in 2019, along with the Synthesis Report for policy makers to be based on those assessments.

Ms Birmpili further emphasised the need to convey to policy makers that the stratosphere is a critical part of the Earth system, and that observing and monitoring ozone will reveal critical data and linkages with other areas of Earth science, such as climate change. Therefore, it is crucial to convey the importance of ozone measurements to decision makers, and, in particular, to the Conference of the Parties to the Vienna Convention that will convene in Montreal in November 2017. In that respect, she expressed hope that the meeting would provide clear responses to some key questions pertaining to the real value of measurements to science and to society; the importance of long-term monitoring, whether conducted from the ground or from space, and the manner in which this can be leveraged with funding agencies; the added value of building capacity in developing countries and countries with economies in transition for improving long-term monitoring; the importance of maintaining and ensuring the efficient operation of measuring stations; and making the research and observation-related data and information more relevant to the needs of observatories, institutes, and countries.

Speaking of the work of the Advisory Committee of the Trust Fund for Financing Activities on Research and Systematic Observations Relevant to the Vienna Convention (hereinafter the "Trust Fund" or "VCTF"), established by the Conference of the Parties in 2014 following a recommendation of the 9th ORM, Ms Birmpili invited participants to contribute to the discussions on the Committee's work by providing suggestions and specific input. One of the

major tasks of the Committee was to develop a long-term strategy and priorities for the Trust Fund, taking into consideration the four overarching goals identified by the 9th ORM: the coupling between ozone layer depletion and climate change; maintenance and enhancement of stratospheric observations and their analysis; capacity building; and enhancement of the Trust Fund for monitoring and research to support these overarching goals.

The Committee had also been tasked to develop a short-term action plan that would take into account the most urgent needs of the Global Ozone Observing System, make the best possible use of the resources available in the Trust Fund, ensure quality control of the individual project proposals, and identify possibilities for complementary funding to maximise resources.

In her concluding remarks, Ms Birmpili expressed her deep appreciation to all the countries that had submitted their national reports, and to the experts who would be presenting the research and monitoring situation of the regions they were representing.

Welcome Statement *(Deon Terblanche, WMO)*

Mr Deon Terblanche, Co-Director of the WMO Research Department, welcomed all delegates to the 10th ORM. He echoed the words of the Executive Secretary of the Ozone Secretariat, highlighting the importance of commitment to long-term investment in observations of value to society. He recalled the emphasis that the WMO Global Atmosphere Watch (GAW) Programme placed on the concept of "observations and science for services and policy support" which would be discussed further during the 2017 GAW Symposium to take place 10-13 April at WMO Headquarters. GAW coordinates international stratospheric ozone observations and research, and plays a key role in making this connection. Stratospheric ozone is not only important in relation to the Montreal Protocol, but also since improved understanding of ozone and stratospheric processes could advance predictive skill from seasonal to decadal timescales.

He also highlighted the good collaboration between WMO and the United Nations Environment Programme in the fields of stratospheric ozone and UV as a shining example of the approaches needed to address many of the environmental challenges humanity continue to face. The good collaboration was related to:

- Meetings of the Ozone Research Managers, all but one of which have taken place in Geneva since 1991, and which represent an important vehicle to provide the parties with information on needs for research, observations, data stewardship, and capacity building.
- The WMO/United Nations Environment Programme Scientific Assessment of Ozone Depletion, which has been produced approximately every four years since the 1980s, with the next assessment due for publication in 2018.
- The Trust Fund, which, despite limited funds, has supported several activities that have helped to maintain the quality of the ozone-observing system through calibration of Dobson and Brewer spectrophotometers, and by providing training to station personnel on instrument operation and data processing.

The Ozone Research Managers (ORM) Recommendations and the Interface with the Scientific Assessment of Ozone Depletion: 2018
(*Paul Newman, SAP Co-Chair, and Michael Kurylo, 9th ORM Co-Chair*)

Mr Paul Newman and Mr Michael Kurylo addressed three questions: What is the ORM and how was it established? What are the Assessment Panels? How do they interact?

The Conference of the Parties, in Decision VCI/3 of its first meeting (Helsinki, 1989), decided that:

- The Vienna Convention is the most appropriate instrument for harmonizing policies and strategies on research; and

- The Montreal Protocol is the appropriate instrument for achieving the harmonization of policies, strategies, and measures for minimizing the release of substances causing, or likely to cause, modifications of the ozone layer.

The ORM is composed of: (a) Government Atmospheric Research Managers and (b) Government Research Managers of research related to health and environmental effects of ozone modifications. The ORM is meant to review ongoing national and international research and monitoring programmes to ensure proper coordination of these programmes, and to identify gaps that need to be addressed.

Under Article 6 of the Montreal Protocol on Substances that Deplete the Ozone Layer there were established three Panels: SAP, EEAP, and TEAP. The Panels prepare their Assessment reports every four years; the next report will be submitted at the end of 2018.

The ORM and Assessment Panels have separate, yet highly complementary roles. The ORM is required under the Vienna Convention, while the Assessments are required under the Montreal Protocol. The Assessments and ORM reports serve to enhance communication between the research community (striving for better understanding) and decision makers (for informed action). The 2018 Assessment Panel Summaries will be presented to the Meeting of the Parties to the Montreal Protocol (MoP) in late 2018. The 10th ORM Report will be presented to the Convention of the Parties in Montreal in November 2017.

Review of the Recommendations of the Ninth Meeting of the Ozone Research Managers and the Resultant Decisions of the Tenth Conference of the Parties to the Vienna Convention (*Michael Kurylo and Gerrie Coetzee, 9th ORM Co-Chairs*)

On behalf of Mr Gerrie Coetzee and himself (Co-Chairs of the 9th Meeting of the Ozone Research Managers of the Parties to the Vienna Convention), Mr Kurylo first summarised the 9th ORM Recommendations formulated in the four topical areas of Research Needs, Systematic Observations, Data Archiving and Stewardship, and Capacity Building. He pointed out that those recommendations took note of specific accomplishments in each area in response to the Recommendations from the 9th ORM, and that highlights had been presented at the Joint Meeting of the 10th Conference of the Parties to the Vienna Convention (CoP) and 26th Meeting of the Parties to the Montreal Protocol (MoP) (Paris; 17-21 November 2014). He recommended that a framework be adopted for drafting the 10th ORM Recommendations, similar to how the 9th ORM recommendations had been formulated. That framework consisted of the four overarching principles, that:

1) Climate change should be encompassed in ozone-layer protection efforts
2) Observational and analysis capabilities for climate and ozone-layer variables must be maintained and enhanced
3) The VCTF should be continued and enhanced
4) A continued dedication to build capacity for meeting those goals is essential.

A few recommendation highlights followed, drawn from the full 9th ORM Report, which was published as WMO Global Ozone Research and Monitoring Project Report No. 54. A key component of these recommendations was that the United Nations Environment Programme Ozone Secretariat and WMO establish a VCTF Advisory Committee for the purpose of developing a long-term strategic plan and a short-term action plan, and of assisting in setting project priorities and developing project budgets. Mr Kurylo reported that the recommendation framework and the recommendations themselves had received a very positive reception at the 10th CoP / 26th MOP, and had been fully endorsed in the 10th CoP Resultant Decisions (Annex C of this report).

Personal Remarks by Mr Michael Kurylo on his Legacy as ORM Co-Chair (*Michael Kurylo, 9th ORM Co-Chair*)

Mr Kurylo announced to the Delegates and Representatives at the 10th ORM Meeting that, after more than 25 years of serving as Chair or Co-Chair of these important assemblies, he wished

to step down from such leadership involvement. He briefly reviewed the history of the ORM Meetings, and of his own participation in them. He acknowledged the benefits that they had provided to his career both as a scientist and as a science manager. He then emphasised that, by increasing the linkage of the ORM Recommendations to the Montreal Protocol Assessment Science, their usefulness to the Parties of the Vienna Convention became enhanced.

Mr Kurylo gave credit to the Ozone Secretariat and to the Delegates themselves for the recent changes in the ORM Meeting process that had helped to achieve such increased linkage. He reported that evidence for some success in that direction had been provided by the increased detail in the Resultant Decisions of recent CoPs. The 9th ORM Recommendations received special CoP acknowledgement for being structured under a framework of overarching goals, their emphasis on the linkages among specific recommendations in four key categories, and for their strong statement of a clear strategic planning need for the Vienna Convention Trust Fund.

Mr Kurylo expressed his sincere gratitude to the current Delegates, and to the men and women who preceded them, for giving him the opportunity to serve the Parties at these important assemblies. He further expressed his appreciation for the support that he had received from the Ozone Secretariat and from the WMO over the years. He expressed his eagerness to participate in the 10th ORM Meeting and the formulation of the ORM Recommendations, and to continue as a member of the Advisory Committee for the Vienna Convention Trust Fund. In closing, he offered his sincere thanks to all of the past and present Delegates and Representatives for accepting him as a scientific colleague and friend and for joining him on what he classified as an incredible journey.

Election of the 10th ORM Co-Chairs
(Tina Birmpili, Executive Secretary, Ozone Secretariat)

On the basis of a suggestion put forward by the Ozone Secretariat, the meeting decided to have two Co-Chairs, one from a developed-country Party and another from a developing country Party, to conduct the 10th meeting of the Ozone Research Managers. Having one Co-Chair from an Article 5 (developing country) Party and one from a non-Article 5 (developed country) Party was a formula that had been used successfully in the working group meetings of the Montreal Protocol.

Mr Kenneth Jucks (United States of America) and Mr Gerrie Coetzee (South Africa) were unanimously elected Co-Chairs of the 10th ORM meeting.

Adoption of the 10th ORM Agenda *(10th ORM Co-Chairs)*

The agenda was unanimously adopted as contained in Annex B. The summaries of the presentations given under sessions 1 to 7 are provided below. Full presentations are also available at: http://conf.montreal-protocol.org/meeting/orm/10orm/presentations/SitePages/Home.aspx.

SESSION 1: ISSUES RELATED TO THE VIENNA CONVENTION FOR THE PROTECTION OF THE OZONE LAYER

Activities under the Vienna Convention Trust Fund for Research and Systematic Observation Relevant to the Vienna Convention

The Status of the Trust Fund *(Sophia Mylona, Ozone Secretariat)*

The Trust Fund was established in accordance with decision VI/2 of the 6th meeting of the Conference of the Parties to the Vienna Convention (CoP). In that decision, the CoP requested that the United Nations Environment Programme, in consultation with WMO, establish an extra-budgetary fund for receiving voluntary contributions from the parties and international organisations for the purpose of funding certain research and observation activities related to

the Vienna Convention in developing countries and countries with economies in transition. In 2005, the United Nations Environment Programme, represented by the Ozone Secretariat, and WMO signed a memorandum of understanding on the institutional arrangements for making decisions on the allocation of funds in the Trust Fund, which was approved by the 7th CoP later that year.

The Trust Fund was initially established in February 2003, with a five-year term ending on 31 December 2007. Upon request of the CoP in decisions VII/2 and X/3, the United Nations Environment Programme extended the life of the Trust Fund to 31 December 2015, and then to 31 December 2019, respectively.

The total funds received by the Trust Fund from its inception in 2003 until 28 February 2017 amounted to US $338,539 (contributors: Andorra, Australia, Czech Republic, Estonia, Finland, France, Kazakhstan, South Africa, Spain, Switzerland, and the United Kingdom); the total expenditure of all nine activities completed by February 2017 was US $176,788; and the existing balance was US $161,751.

Furthermore, the Advisory Committee decided to allocate funds for the disbursement of four additional activities that were listed for priority funding at the 9th ORM, and were planned to take place in 2017 and 2018. The total amount of funds allocated to those activities was US $140,000. As a result of this allocation, the total amount that remained available for the disbursement of new activities was: US$21,751.

Upon consultation with the Advisory Committee, in March 2016 the Secretariat invited all developing countries and countries with economies in transition to submit project proposals for possible support under the Trust Fund. In response, six proposals were received in 2016 from Belarus, Ecuador, Kenya, Oman, Togo, as well as from WMO/GAW and the Southern Hemisphere Additional Ozonesonde (SHADOZ) network (joint proposal) requesting a total of US$282,469. The Committee reviewed the proposals, and planned to send feedback to the proponents; however, given the current situation of the Trust Fund, it was apparent that it would not be possible to support any of the new proposals in full.

The Conference of the Parties to the Vienna Convention, during its 11th meeting in November 2017, is expected to consider the status of the Trust Fund and the outcomes of the current meeting, as well as the work of the Advisory Committee. This includes the development of a long-term strategy for the implementation of objectives and priorities under the Trust Fund, a short-term action plan to deal with urgent needs, and identification of possibilities for complementary funding to maximise resources. She also informed the meeting that information about activities under the Trust Fund and the role of the Advisory Committee can now be found on the Ozone Secretariat's website at the following links: http://ozone.unep.org/en/activities-under-vienna-convention-trust-fund-research-and-systematic-observation and http://ozone.unep.org/en/advisory-committee-vienna-convention-trust-fund-research-and-systematic-observation.

Report on Activities under the Trust Fund *(Geir Braathen, WMO)*

The activities that have been carried out so far under the Trust Fund have been very important and useful. In particular, training courses, such as the one organised in the Czech Republic in 2011, have been received very well by the participants. Intercomparison campaigns are important to maintain the high quality of the ozone observations.

Since the 9th ORM in 2014, the following activities have been carried out with support from the Trust Fund:

- Relocation of Dobson no. 14 (formerly deployed in Tromsø, Norway) to Tomsk, Russia. A training course for two Russian station operators was held in Hradec Králové, Czech Republic, in April 2015, and the instrument was then shipped to Tomsk during the summer of 2015.

- An expert from the Czech Hydrometeorological Institute travelled to Amberd, Armenia, in October 2015, and provided training to the Dobson station personnel.
- A Dobson intercomparison for Asia was held in Tsukuba, Japan, in March 2016, with support by experts from Japan and the USA. Dobson spectrophotometers from China, Pakistan, and Thailand were calibrated along with instruments from Japan against a standard instrument from the USA.
- A Dobson intercomparison for the South-West Pacific region was held in Melbourne, Australia, in February 2017, with help from experts from Australia and USA. Instruments from Australia, New Zealand, Japan, and the Philippines were calibrated against a standard instrument from the USA.

More details on the Tsukuba and Melbourne intercomparisons can be found in the regional presentations given during this meeting.

For the period 2017-2018, the following activities have been approved by the VCTF Advisory Committee:

- Relocation of Dobson no. 8 (formerly in Svalbard, Norway) or Dobson no. 92 (formerly in Greenland) to Singapore. Estimated cost is approximately US $20,000. This will be done through a swap with Dobson no. 7, currently in Singapore, that needs repair. After repair, Dobson no. 7 will be available for deployment to a new site.
- Two Dobson intercomparisons for Africa. Estimated total cost is approximately US $50,000. The first campaign is planned for September 2017 in Spain, and will involve instruments from the northern part of Africa. The second campaign will take place in South Africa during the Austral spring of 2018 (around September / October), and will involve instruments from countries in the southern part of the African continent.
- A Brewer Users' Group meeting and training course will be held in Sydney, Australia, in September 2017. The cost will be shared between the Canadian Brewer Trust Fund and the VCTF, with approximately US $20,000 from each of these two funds.
- A Dobson Intercomparison for Latin America is planned to be held in Buenos Aires, Argentina, in November 2017. The estimated cost is approximately US $50,000.

There are some additional Dobson instruments available for relocation. Italy has one or two such instruments that possibly can be lent out, while Hungary has one instrument that could be made available. If Dobson no. 92 goes to Singapore, Dobsons no. 7 and 8 will become available.

If an institution wants to receive a Dobson instrument, they must commit 50% of a full-time equivalent employee.

Report of the Trust Fund Advisory Committee
(A.R. Ravishankara, Chair, VCTF Advisory Committee)

The Montreal Protocol, having successfully led to the phase out of ozone-depleting substances (ODSs), has entered the "accountability phase," where one needs to know that the actions taken by the Parties to the Protocol are resulting in the intended outcomes. One of the pillars of the accountability phase is the long-term monitoring of ozone from ground-based instruments. The VCTF has accomplished a great deal since its inception, even given the modest investment. In accordance with the CoP decision, a Trust Fund Advisory Committee has been established. A website listing the activities of the VCTF has been created. The current balance in the Trust Fund is not sufficient to fund the many proposals that have been received and evaluated by the Advisory Committee. In accordance with decision X/3 of the 10th CoP, the Advisory Committee is developing a long-term strategy for the VCTF, and a short-term plan of action. The strategy includes a number of elements such as the development of a clear portfolio of activities and their expected outcome, a fund-raising campaign through a multi-pronged approach, criteria for prioritizing the types of activities best suited for VCTF and metrics to measure retention of capacity and development of data/science. The short-term action plan includes the preparation of a "needs and gaps document",

identification of potential source of funding, the establishment of a sub-group to document gains made and providing feedback on project proposals received in 2016.

Appointment of Discussion Leaders and Rapporteurs for the Various Recommendation Areas – Research Needs, Systematic Observations, Data Archiving, Capacity Building *(10th ORM Co-Chairs)*

Discussion leaders and rapporteurs for the recommendation areas were selected as follows:

- "Research Needs" - Discussion leaders: David Fahey and Michael Kurylo; Rapporteurs: Paul Newman and A. R. Ravishankara.
- "Systematic Observations" - Discussion leaders: Wolfgang Steinbrecht and Jean-Christopher Lambert; Rapporteurs: Nis Jepson and Richard McPeters.
- "Data Archiving and Stewardship" - Discussion leaders: Martine De Mazière and John Rimmer; Rapporteurs: Stephen Montzka and Sum Chi Lee.
- "Capacity Building" - Discussion leaders: Bonfils Safari and Geir Braathen; Rapporteurs: Richard Querel and Matt Tully.

SESSION 2: THE STATE OF THE OZONE LAYER

Past, Current, and Future States of the Ozone Layer *(Wolfgang Steinbrecht, DWD)*

The presentation provided a report on the past decline of stratospheric ozone, the current situation since the turnaround of ODSs in the stratosphere after about 1997, and on expectations for the future evolution of the ozone layer. It is very clear that the previous decline of ozone has been stopped, and that the Montreal Protocol and its later amendments were successful. As ODSs are now declining, ozone increases are observed in the upper stratosphere, but so far there are no clear signs of increases in total column ozone. These are not yet expected, because the decline of ODSs is much slower than their historical increase by a factor of about three. Therefore, large natural ozone variations, especially those due to meteorological fluctuations from year to year, are still masking the relatively small signal of chemical ozone recovery from ODSs. A clear recovery signal for total ozone is not expected before 2020 to 2040. However, apart from the signal in the upper stratosphere, first signs may now be seen for a decline in the size of the Antarctic ozone hole in September.

Simulations of past and future ozone with state-of-the-art chemistry-climate and chemistry-transport models (CCMs and CTMs) show that, as ODSs and their importance for the ozone layer decline over the next 50 to 70 years, emissions of greenhouse gases (GHGs), especially carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4), will become more and more important. These gases will have effects on ozone that could be as large as the maximum ozone depletion due to ODSs (outside of the ozone hole region). CO_2 warms the troposphere and cools the stratosphere. This affects climate and the global transport of ozone and other trace gases by the stratospheric Brewer-Dobson Circulation (BDC). N_2O and CH_4 are also GHGs, but they also affect ozone chemistry directly by releasing N_2O, carbon monoxide (CO), and water vapour in the stratosphere. Monitoring these gases, and predicting their future concentrations, is becoming more and more important. Generally, more N_2O will result in less ozone, while more CO_2 and more CH_4 will result in more ozone. However, the balance varies with latitude and altitude, and depends on the specific concentrations of these species.

Climate change is intimately connected to the future evolution of the ozone layer. Model simulations predict an acceleration of the global BDC. This is expected to increase ozone columns over most of the globe, but it may reduce ozone columns over the tropics. The evolution depends on the future emissions of GHGs, predicted e.g. by the Representative Concentration Pathway (RCP) scenarios. Future changes of tropospheric ozone columns also play a role. Since ozone is a key player in the radiative balance of the atmosphere, ozone itself feeds back onto atmospheric transport changes. This results in a very complex intertwining of possible changes in the BDC and ozone changes. Many of these processes are currently not well understood. Observational evidence is scarce, and inconclusive. It is

especially difficult to compare decadal variations available from the observations, with the centennial changes predicted by the models. This is, however, very relevant for the expected recovery of the ozone layer. It requires that ozone and other trace gases are monitored for the coming decades. High-quality, long-term observations remain important, as are state-of-the-art model simulations that are key for the interpretation of the observations and for predicting the future.

The Mystery of Carbon Tetrachloride *(Paul Newman, SAP Co-Chair)*

The key findings of the "SPARC Report on the Mystery of Carbon Tetrachloride" are available at http://www.sparc-climate.org/publications/sparc-reports/sparc-report-no7. The Stratosphere-troposphere Processes And their Role in Climate (SPARC) project is a core project of the World Climate Research Programme (WCRP). Under SPARC auspices, a workshop was held in Dübendorf, Switzerland, from 4-6 October 2015 to examine the carbon tetrachloride (CCl_4) budget discrepancy reported in the SAP assessment reports, most recently in the "Scientific Assessment of Ozone Depletion: 2014."

The key findings included new estimates of CCl_4 emissions. In particular, the four emission pathways for CTC were reported to be:

A. Fugitive: 2 Gg yr^{-1}, from United Nations Environment Programme Reports
B. Unreported non-feedstock: 13 Gg yr^{-1}
C. Unreported inadvertent emissions
D. Legacy: Combined C. and D. ~10 Gg yr^{-1}

The four pathways emissions total 20±5 Gg yr^{-1}. Only Pathway A can be estimated from the Article 7 United Nations Environment Programme reports.

Observations from the atmosphere, oceans, and soils, along with modelling tools, for estimating top-down emissions were highlighted. A new 33-year total lifetime [SPARC, 2016[1]]) lowered the observations-based top-down emissions estimate to about 40 kilotonnes yr^{-1}. In addition, a second technique used the persistent CCl_4 difference between the Northern and Southern Hemispheres to estimate total emissions of 30 kilotonnes yr^{-1}. The combination of these two observations-based estimates yields a top-down emissions estimate of 35 kilotonnes yr^{-1}.

The difference between the top-down 35±16 kilotonnes yr^1 and the industrial bottom-up emissions estimates of 20±5 kilotonnes yr^{-1} is about 15 kilotonnes yr^{-1}, which is greatly reduced from the 54-kilotonnes yr^{-1} discrepancy reported in WMO [2014][2]. While the SPARC [2016] bottom-up value is still less than its top-down value, these estimates reconcile the CCl_4 budget discrepancy when considered at the edges of their uncertainties.

Previous assessments have omitted some CCl_4 emissions sources from bottom-up emissions estimates, and therefore Article 7 data reported to the United Nations Environment Programme are not adequate on their own for deriving bottom-up global CCl_4 emissions estimates. Further scientific research is needed in order to tighten observations-derived top-down emissions estimates. Finally, there is a continuing need to develop improved methodologies for estimating bottom-up CCl_4 emissions.

The presentation concluded with recommendations for consideration for the ORM. Those included the following:

- Re-evaluate and improve industrial reporting of CCl_4 production and emissions.

[1] SPARC (2016), *SPARC Report on the Mystery of Carbon Tetrachloride*. Q. Liang, P.A. Newman, S. Reimann (Eds.), SPARC Report No. 7, WCRP-13/2016.
[2] WMO (World Meteorological Organization), *Scientific Assessment of Ozone Depletion: 2014*, Global Ozone Research and Monitoring Project – Report No. 55, Geneva, Switzerland, 416 pp., 2014.

- Maintain and improve CCl4 spatial and temporal atmospheric measurement capabilities.
- Improve the atmospheric estimations of emissions on all scales – global, regional, point sources – through modelling analysis of pollutant transport prior to detection.
- Global three-dimensional (3D) model simulations should be updated to include all known CCl4 sources and sinks – atmospheric, oceanic, and soil losses.
- Atmospheric lifetime: The uncertainty in the atmospheric lifetime is the largest contributor to the overall CCl4 total lifetime uncertainty. Reduction in this atmospheric lifetime uncertainty is needed to narrow the uncertainty of the atmospheric mean circulation.
- Ocean lifetime: Improve the understanding of mechanisms for the CCl4 ocean degradation.
- Soil lifetime: Refine estimates of the minor soil lifetime by conducting more measurements in different terrestrial biomes, especially in tropical ecosystems.

Technology- and Economy-Related Issues under the Montreal Protocol: Progress made and challenges ahead

(Marta Pizano, Technology and Economic Assessment Panel (TEAP) Co-Chair)

The Panel and its technical options committees have brought together the experience and expertise of nearly 150 experts from over 30 countries. Global production of foams currently exceeds 25 million tonnes per year, all of which is chlorofluorocarbon (CFC)-free, and is increasing by 3% per year in Article 5 parties. In Article 5 parties, almost half of foam applications using hydrochlorofluorocarbons (HCFCs) have converted, of which 80% has converted directly to a range of low-global warming potential (GWP) blowing agents. Foams in insulation are important to energy efficiency, and therefore important in mitigating climate change.

An historic agreement reached in October 2016 at the International Civil Aviation Organization (ICAO) to control CO_2 emissions from international aviation. At the same meeting, a breakthrough for the Montreal Protocol with regard to halons also occurred, as ICAO had approved a requirement to replace halons in cargo bays in all new aircraft designs by 2024. Therefore, as of 2024, there no longer will be a need to use halons in any new designs for fire-protection application. However, halons will be needed for existing equipment and current aviation designs for the foreseeable future (excluding those covered by European Union retrofit requirements), and will require careful management. Many new designs continue to require high GWP HFCs, although two new low-GWP agents have been introduced recently that might be suitable for some applications.

The successful phase-out of CFCs used in metered-dose inhalers was achieved in 2016, following 30 years of concerted global action. Affordable CFC-free inhalers have been developed over the past 20 years, and are available worldwide.

Successes in the chemicals sector include the Russian Federation's phaseout of CFC solvents in aerospace applications, and the decrease in ODS process agents. Global use of ODSs for feedstock is still increasing, however, and laboratory and analytical uses of ODSs continue. TEAP is closely following the international study providing insights on CCl_4 emissions, and further investigations to better understand their sources.

Almost all controlled uses of methyl bromide (CH_3Br) have been phased out and replaced successfully, and the critical-use process has evolved successfully from non-Article 5 parties to Article 5 parties. However, global atmospheric measurements show that about 30,000 tonnes of CH_3Br still are emitted annually. Of that amount, 11,000 tonnes is for quarantine and pre-shipment uses, for up to 40% of which there might be alternatives. However, it is unclear where the remaining emissions (around 15,000 tonnes) are coming from (possibly unreported or erroneously reported amounts). Addressing those issues would have a positive impact on the ozone layer.

In the refrigeration and air-conditioning sectors, refrigerants have evolved over the previous two centuries. While the volumes used have increased, there has been a continuous

improvement in energy efficiency, and a reduction in total environmental impact per unit. CFCs have been completely phased out, and HCFC phaseout is almost complete in non-Article 5 parties and advancing in Article 5 parties. Low-GWP solutions are now available for many applications, and alternatives are being tested under high-ambient-temperature conditions. Refrigeration and air-conditioning is a rapidly evolving technology environment, with industries actively looking for best solutions, and a comprehensive approach balancing energy efficiency, flammability, and toxicity in choosing alternatives is needed.

The Panels are currently planning the preparation of their 2018 assessment reports, as mandated by Montreal Protocol decision XXVII/6.

Surface UV Radiation in the 21st Century: Environmental effects of changes in ozone and climate *(Alkis Bais, EEAP Member)*

The role of the EEAP is to assess the influence of ozone depletion and the interactive effects of climate change to human health, ecosystems and services, air quality, and materials – effects that mainly are mediated through changes in solar UV-B radiation. There is confidence that stratospheric ozone depletion was a major driver of Southern Hemisphere climate processes over the late 20th century, with significant implications for ecosystems in this region. Although stratospheric ozone is no longer decreasing, risks for human health continue to exist due to changes in personal behaviour and clothing, partly caused by warming climate. Due to increasing GHGs, ozone is projected to increase above 1960 levels by 2100 outside the polar regions, resulting in reduced UV-B radiation compared to pre-1960 levels. However, if GHGs are rigorously reduced in the coming decades, then UV-B radiation would increase everywhere, except at high latitudes in spring. Therefore, projections of UV-B radiation for the future depend on the GHG emissions scenario, especially in the tropics. In the coming decades, UV-B radiation at the surface will be controlled mainly by changes in other factors, such as clouds, aerosol, air pollution, and, in aquatic ecosystems, by dissolved organic matter.

SESSION 3: INTERACTIONS BETWEEN OZONE LAYER DEPLETION AND CLIMATE CHANGE – PHASING DOWN OF HYDROFLUOROCARBONS UNDER THE MONTREAL PROTOCOL

Links between Stratospheric Ozone, Ozone-Depleting Substances, and Climate *(John Pyle, SAP Co-Chair)*

The presentation discussed the two-way interaction between ozone and climate. The influence of changes in stratospheric temperature and circulation on ozone has been known for many years; research on how changing stratospheric ozone impacts surface climate has advanced considerably in the last decade. How these interactions will affect the precise trajectory of ozone recovery was discussed. The importance of monitoring the HFCs and of assessing their role in atmospheric processes was also emphasised.

Observations and Trends of HFCs *(Stephen Montzka, NOAA)*

Recent observations of HFCs were presented. Independent observation networks show increases in global HFC concentrations and global HFC emissions at rates that are similar or slightly slower than projections made within the past decade. Emissions of HFCs are offsetting a portion of the climate benefits provided by the Montreal Protocol. The observed HFC increases also were shown to exceed totals reported by Annex 1 countries to the United Nations Framework Convention on Climate Change (UNFCCC). Regional measurement programs offer the opportunity to assess country-specific emission reporting by the UNFCCC.

HFC Scenarios and Projected Climate impacts of the Kigali Amendment
(Guus Velders, RIVM)

The Montreal Protocol has been very successful in phasing out the global production and consumption of ODSs. In response, the use of HFCs as ODS replacements has increased strongly since the mid-1990s for refrigerants and foam-blowing agents, medical aerosol propellants, and miscellaneous products. HFCs do not deplete the ozone layer, but they are GHGs, and therefore contribute to the radiative forcing of climate.

In 2015, baseline scenarios for 10 HFC compounds, 11 geographic regions, and 13 use categories were formulated [Velders *et al.*, 2015][3]. The scenarios rely on detailed data reported by countries to the United Nations, projections of gross domestic product and population, and recent observations of HFC atmospheric abundances. In the baseline scenarios, China (31%), India and the rest of Asia (23%), the Middle East and northern Africa (11%), and USA (10%) are the principal source regions for global HFC emissions by 2050; and refrigeration (40-58%) and stationary air conditioning (21-40%) are the major use sectors. The corresponding radiative forcing could reach 0.22-0.25 W m^{-2} in 2050, which would be 12-24% of the increase from business-as-usual CO_2 emissions from 2015 to 2050. Using the MAGICC6 climate model, we calculated that, under the baseline scenario, HFCs would contribute 0.3-0.5°C to global surface temperatures in 2100.

In 2014 and 2015, regional (EU) and national (Japan, USA) regulations were implemented to limit the use of high-GWP HFCs. In October 2016, the Kigali Amendment to the Montreal Protocol was agreed by all Parties to the Protocol. With this amendment, HFCs are included in the Protocol, and their use will be reduced globally by 80-85% from baseline levels before 2050. The contribution from HFCs to global surface temperatures is now expected to be reduced from 0.3-0.5°C to about 0.06°C in 2100.

SESSION 4: INTERNATIONAL MONITORING POGRAMMES

The International Ozone Commission (IO3C) *(Sophie Godin-Beekmann, IO3C President)*

The International Ozone Commission (IO_3C) was established in 1948 as one of the special commissions of the International Union of Geodesy and Geophysics (IUGG), which represents the community of geophysical scientists around the world. The purpose of the IO_3C is to help organise the study of ozone around the world, including ground-based and satellite measurement programs and analyses of the atmospheric chemical and dynamical processes affecting ozone. The study of ozone is important because of the large role it plays in protecting the Earth's surface from harmful levels of ultraviolet solar radiation, and because of its role as a GHG in the Earth's climate system. Membership in IO_3C is limited to approximately 30 of the leading scientists in the study of atmospheric processes from around the world. Membership is determined by an election of peers. Members serve for four years, with possible renewal for an additional term. The first president of the IO_3C was Mr Gordon Dobson of Oxford University, a pioneer in the study of atmospheric ozone.

The WMO Global Atmosphere Watch (GAW) Programme *(Oksana Tarasova, WMO)*

WMO's GAW Programme facilitates global cooperation and provides a platform for integrated long-term observations and analysis of atmospheric composition changes.

- GAW is a part of the WMO Research Department, and is governed by WMO's Commission for Atmospheric Sciences.

[3] Velders, G. J.M., D. W. Fahey, J. S. Daniel, S. O. Andersen, M. McFarland, Future atmospheric abundances and climate forcings from scenarios of global and regional hydrofluorocarbon (HFCs) emissions, *Atmospheric Environment*, doi:10.1016/j.atmosenv.2015.10.071, 2015.

- GAW is a partnership involving contributors from more than 100 countries, including many contributions from the research community.
- GAW implements an end-to-end approach, from quality-assured observations through research to delivered products and services that are relevant to society.
- GAW supports diverse applications, including climate studies, air quality forecasting, numerical weather prediction, etc.

A major objective of GAW is to promote a "value chain" from observations to services through:

- Increased efforts towards enhancing observing systems with a broader use of GAW observations and research activities to support the development of services with high societal impact
- Enhanced modelling efforts
- Improved information management infrastructure
- Stronger efforts towards building collaborations, capacity, and communications

In order to be of relevance to society, GAW adheres to the 2030 Agenda for Sustainable Development with its 17 Sustainable Development Goals and its 169 associated targets, the Sendai Framework for Disaster Risk Reduction 2015–2030 with seven global targets, and the Paris Climate Agreement.

The new GAW Implementation Plan, which runs from 2016 to 2023, has an overarching theme of "science for services." The implementation plan builds on the premise that atmospheric composition matters to climate, weather forecasting, human health, terrestrial and aquatic ecosystems, agricultural productivity, and aeronautical operations. In order to tackle these challenges, a new Scientific Advisory Group (SAG) for Applications has been established. Three broad application areas drive the plan: 1) atmospheric composition forecasting, 2) atmospheric composition analysis and monitoring, and 3) urban services.

Examples of applications in the GAW Programme include:

- *Support of climate negotiations*: The Integrated Global Greenhouse Gas Information System (IG^3IS)
- Ecosystem services: Analysis of total deposition (e.g. through measurement-model fusion), nitrogen cycle, and deposition to the oceans/marine geoengineering
- Health: Sand and dust storms, urban air quality (GAW Urban Research Meteorology and Environment (GURME)), and biomass burning
- Food security: Atmospheric composition and agriculture
- Transport *security*: Volcanic ash forecasting

The GAW observing system should evolve to support the growing services by:

- Responding to user requirements
- Addressing multiple applications
- Allowing near-real-time provision of data
- Creating provisions for integration of surface, vertical profile, and column datasets from different platforms to provide a unified understanding of aerosol and gas distributions
- Minimizing gaps in the measurement networks in data-poor regions

A key element in the new GAW implementation plan is to enhance data management architectures to facilitate improved metadata exchange and interoperability, data discovery, and analysis, and to promote and facilitate the near-real time delivery of data.

Another key element is, through modelling, to expand GAW's role in enhancing predictive capabilities of atmospheric composition and its uses.

Capacity building has a high priority in GAW and this is accomplished through:

- Formal training programs at the GAW Training and Education Centre (GAWTEC)

supported by Germany
- Specialised training schools and workshops
- Training of station personnel and knowledge exchange during station audits and intercomparison campaigns
- Twinning programmes and personnel exchange where new and established stations or labs are paired to fast-track the development of new stations to full operational status

The GAW Secretariat has developed an outreach strategy to communicate the value of science and long-term high-quality observations. This communication is accomplished through:

- WMO/GAW Bulletins (aerosols, GHGs, ozone)
- Scientific assessments
- GAW thematic reports
- A quarterly electronic newsletter (eZine)

More information on the GAW Programme can be found at: http://www.wmo.int/gaw. Detailed information about GAW stations and their observational programmes, with links to the GAW World Data Centres, can be found at: https://gawsis.meteoswiss.ch/GAWSIS.

The Global Atmosphere Watch Ozone Observing System *(Alkis Bais, Ozone SAG Chair)*

Monitoring of total ozone by ground-based instruments is an essential component of GAW. These long-term records, some of them dated back to the mid-1950s, have provided invaluable information for the assessment of trends and variability of total ozone before and after the onset of the ozone depletion. Currently, the ground-based network is comprised mainly of Dobson and Brewer spectrophotometers, filter instruments, and Système d'Analyse par Observation Zénithale (SAOZ) instruments in the high latitudes. Calibration and quality control methods applied on Dobson and Brewer spectrophotometers ensure consistency in the measurements to within 1%. The decline of operational stations and delayed data submission are major threats for the global ozone observing system.

The Network for the Detection of Atmospheric Composition Change (NDACC)
(Martine De Mazière, BIRA-IASB and Anne Thompson, NASA)

The presentation provided information on the evolution of NDACC since the 9th ORM, and how it has responded to the 9th ORM recommendations. NDACC's capabilities encompass total column and vertical profile observations, from the ground up to the mesosphere, of a suite of many species. Cooperation and co-location of sites with other networks like the Total Carbon Column Observing Network (TCCON) enhance the capabilities. Further developments towards more cost-effective instrumentation are progressing, like Pandora and Multi Axis Differential Optical Absorption Spectroscopy (MAXDOAS), microwave wind- and temperature-profile measurements, etc. New stations have been added in many Article 5 countries. Nevertheless, some stations – sometimes with a long history - are threatened. The sustainability of the Network is a continuous worry, and actions are being taken to improve that sustainability.

NDACC is well on its way to becoming a mature reference network, and to be a more operational network. Many ongoing activities are aimed at reaching better data consistency across the Network and across techniques; data homogeneity (among others through reprocessing); improved data characterisation, including quantitative evaluation of uncertainty budgets; data documentation; and traceability to standards. The data archive is in better shape as far as the quality of the data files. Also, the speed of data delivery has been increased; data are publicly available no more than one year after acquisition, but many are available much sooner. The maturity matrix concept clearly highlights where reference quality has been attained, and where more work is needed.

NDACC is an active and key-player in satellite validation, many international research initiatives, programmes like the European Copernicus and European Space Agency (ESA) Climate Change Initiative programmes, and in support of SPARC initiatives like

SPARC/IO_3C/IGACO-O_3/NDACC (SI^2N), Long-Term Ozone Trends and Uncertainties in the Stratosphere (LOTUS), Stratospheric Sulphur and its Role in Climate (SSiRC), etc., as well as in ozone and climate-related assessments.

NDACC celebrated its 25th anniversary in 2016. To mark that occasion, there is an NDACC inter-journal Special Issue in *Atmospheric Chemistry and Physics*, *Atmospheric Measurement Techniques*, and *Earth System Science Data* (*ACP/AMT/ESSD*). So far more than 30 papers have been accepted or are in review.

Ground-Based Networks for Measuring Ozone and Climate-Related Trace Gases and the Current State of the Atmosphere *(Stephen Montzka, NOAA)*

Multiple global networks for monitoring concentrations of ODSs and HFCs around the globe were discussed. Increasing capabilities related to this monitoring were noted, and relate to the increased capability for deriving regional emission magnitudes from some global regions, but not all. Also, the expansion of measurement networks to include vertical information throughout the troposphere was noted.

International Ozonesonde Activities (*Michael Kurylo, on behalf of Anne Thompson, NASA*)

The four ozonesonde activities covered in Ms Thompson's presentation were:

1) A list of major meetings and interactions within the ozonesonde community since the last ORM
2) Ozonesonde data reprocessing efforts
3) Collaborative validation with the satellite and ground-based ozone measurement communities
4) Data collection, maintenance, and growth of ozonesonde archives, including the World Ozone and UV Data Centre (WOUDC)

The September 2016 Quadrennial Ozone Symposium was a major forum for showing ozonesonde results. Ozonesonde data were featured in satellite, modelling, and keynote talks. For three days prior to the Symposium, a workshop on the Ozonesonde Data Quality Assessment (O_3S-DQA), chaired by Mr Herman Smit (Forschungszentrum Jülich) and attended by 35 ozonesonde experts, surveyed current reprocessing guidelines and future needs. The ozonesonde community is active in NDACC through an Ozonesonde Working Group, and is working with the Global Climate Observing System (GCOS) Reference Upper Air Network (GRUAN) to provide guidelines for ozonesonde stations that want to be certified for the GRUAN protocol.

Major progress in data reprocessing has been accomplished since the 9th ORM, with almost 30 of 60 major long-term stations having completed one round of reprocessing to compensate for inhomogeneities in ozonesonde instrument type, processing software, sensing solution composition, etc. Some of these records extend back to the 1960s. Documentation of the reprocessing effort has appeared in two publications to date, with five more papers in review or in preparation. Remaining transfer functions, to account for solution recipes that have not been evaluated, will be developed in the 2017 Jülich Ozone Sonde Intercomparison Experiment (JOSIE-2017), planned for October-November 2017 in the World Calibration Centre for Ozonesondes at the Forschungszentrum Jülich. A significant advance of JOSIE-2017, compared to earlier JOSIE campaigns (seven of which have taken place since 1996), is capacity building. This will be done through the pairing up of ozonesonde partners from tropical SHADOZ stations with principal investigators from "extra-tropical" ozonesonde sites, who will supply equipment and coaching. Eight instrument combinations, being supported by 2-3 stations each, are represented in the JOSIE-2017 configuration. The JOSIE-2017 data protocol, as with previous JOSIE exercises, is double-blind; preliminary results are prepared by non-participant referees. Sharing of data, analysis, and recommendations will be developed at a 2018 JOSIE Workshop. The O3S-DQA and JOSIE activities for ozonesonde instrument changes eventually will need to develop guidelines for reprocessing data from the changing complement of radiosondes being used by the ozonesonde community.

Ongoing comparisons of ozone data with satellites and co-located ground-based instruments are part of continuous evaluation of ozonesonde profiles and of evaluating reprocessed data. The ozonesonde community continues to provide references for model intercomparison studies and efforts like the SPARC LOTUS activity.

The holdings of the World Ozone and Ultraviolet Data Centre (WOUDC) show that data entries to the archive have declined from a 2700-record annual average during the period 1998-2008, to fewer than 2000 after 2013. Reasons for this are unclear. Neither the number of stations nor launch frequencies are known to have dropped so sharply. Some networks, like SHADOZ, have added more than 100 launches per year, but there may have been fewer campaigns globally.

Global Climate Observing System (GCOS) including GRUAN
(Geir Braathen, WMO, on behalf of Caterina Tassone, GCOS Secretariat, and Ruud Dirksen, DWD)

GCOS drives the global climate observation agenda through a three-phase approach, driven by users, in order to:

1) Identify and review Essential Climate Variables (ECVs) through science panels
2) Conduct a regular review of how these ECVs are observed
3) Develop plans to ensure continuity and improvement of observations

Two recent GCOS reports are:

- Status of the Global Observing System for Climate (GCOS-194 (executive summary) and GCOS-195 (full report)). These documents can be downloaded from: http://www.wmo.int/pages/prog/gcos/index.php?name=Publications
- The Global Observing System for Climate: Implementation Needs (GCOS-200). This document can be downloaded from: http://unfccc.int/files/science/workstreams/systematic_observation/application/pdf/gcos_ip_10oct2016.pdf

The Atmospheric Observation Panel for Climate (AOPC) is a group under the GCOS Steering Committee whose role is to implement atmosphere-related actions from the Implementation Plan. These include:

- Establish and monitor ECV requirements
- Review ECV Observation networks
- Coordinate GCOS networks
- Establish the Global Reference Surface Network
- Promote the use of weather radar data for climate needs
- Promote cross-cutting issues with other science panels

In addition to GCOS comprehensive and baseline networks that are run by other programmes, such as GAW, there are two networks that are operated directly by GCOS and managed by the GCOS Secretariat: GCOS Surface Network (GSN) and GCOS Upper Air Network (GUAN). Then there is GRUAN, which is managed by the Lead Centre at the Lindenberg Observatory of the German Weather Service (Deutscher Wetterdienst, DWD).

The talk then transitioned to a presentation of GRUAN. GRUAN is a network for ground-based reference observations for climate in the free atmosphere. It was started in 2008 in response to the need from WMO and GCOS for the highest accuracy data possible. GRUAN currently consists of 22 sites, with the aim of expanding to 30-40 sites worldwide. There is close cooperation with other networks, such as GAW, GUAN, NDACC, and others.

The goals of GRUAN can be summarised as follows:

- Maintain consistent observations over decades
- Validation of satellite systems
- Numerical weather prediction
- Deliberate measurement redundancy
- Standardisation and traceability
- Quality management and managed change

Stations that wish to join GRUAN must prove that there is:

- A long-term, continuous upper-air measurement program with proper change management
- Quantification of systematic and random errors
- Verification by redundant observations (overlap)
- Collection of raw and meta data

In addition, new systems, new software, and new procedures must be evaluated prior to implementation.

The Stratosphere-Troposphere Processes and their Role in Climate Project of WCRP: The joint SPARC/IO_3C/WMO/NDACC initiative on past trends in the vertical distribution of ozone, SI^2N, and new initiatives such as OCTAV-UTLS and LOTUS
(Sophie Godin-Beekmann, CNRS)

SI^2N (2011-2015) was a joint initiative under the auspices of SPARC, IO_3C, the ozone focus area of the Integrated Global Atmospheric Chemistry Observations (IGACO-O_3) programme, and NDACC. The main objective of SI^2N was to assess and extend the current knowledge and understanding of measurements of the vertical distribution of ozone, with the aim of providing input to the WMO/United Nations Environment Programme Scientific Assessment of Ozone Depletion published in 2014.

The SPARC LOTUS activity started in late 2016. For the WMO/United Nations Environment Programme 2018 Ozone Assessment, a clear understanding of ozone trends and their significance as a function of altitude and latitude is still needed, nearly 20 years after the peak of ODS concentrations in the stratosphere. A thorough evaluation of uncertainties in trend studies and, in particular, the consideration of errors linked to the sampling and stability of (merged) data sets, could not be achieved by the end of SI^2N. Since then, new merged satellite data sets and long-awaited homogenised ozonesonde data series are being produced. Thus, there is a strong interest from the scientific community to use these newer observations to evaluate ozone recovery, and to understand the limitations in determining the significance of long-term trends.

Observed Composition Trends and Variability in the Upper Troposphere and Lower Stratosphere (OCTAV-UTLS) is an emerging SPARC activity. It focuses on improving the quantitative understanding of the role of the UTLS region in climate, and the impacts of stratosphere-troposphere exchange (STE) processes on air quality. Achieving this goal requires a detailed characterisation of existing measurements from aircraft, ground-based, balloon, and satellite platforms in the UTLS, including understanding how their quality and sampling characteristics (e.g. spatial and temporal coverage, resolution) affect the representativeness of these observations.

The European COST Action EUBrewNet: Towards consistency in quality control, quality assurance, and coordinated operations of the Brewer Instrument
(John Rimmer, University of Manchester)

The European Brewer Network (EUBrewNet) is a network of Brewer Ozone Spectrophotometers primarily within Europe, but now also including other areas of the world. Characterisation and calibration methodologies have been developed that have allowed corrections for instrument

specific nonlinearities in measurements. A central processing, quality assurance (QA), and database system has been established that will provide consistent, near-real-time data for column ozone, spectral UV, and aerosol optical depth in the UV. The database will have direct links to the WOUDC so that near-real-time data will be publicly available. All data transfers are automated, so data submissions are reliable and timely.

The establishment of EUBrewNet was made possible through funds from the European Cooperation in Science and Technology (COST) Action ES1207. One of the COST instruments is the provision of training schools, which also has allowed EUBrewNet to be active in capacity building, particularly in Article 5 countries. This can only assist with reversing the downward trend in data submissions.

SESSION 5: SATELLITE RESEARCH AND MONITORING

Current and Planned Ozone and Climate Observations from Space

U.S. Satellite Programmes: NASA, NOAA, and other agencies *(Kenneth Jucks, NASA)*

The United States (U.S.) continues to have a strong ozone- and stratospheric-observing system from space that dates back to the late 1970s. This will continue into the near future with the continuation of the U.S. systematic meteorological satellite program. These observations include NOAA Solar Backscatter Ultraviolet Instrument (SBUV) and National Aeronautic and Space Agency (NASA) Total Ozone Mapping Spectrometer (TOMS) observations for total ozone, that have been continued by the Ozone Monitoring Instrument (OMI) instrument on the NASA Aura satellite, and now the Ozone Mapping Profiler Suite (OMPS) nadir instruments on the Suomi National Polar-orbiting Partnership (Suomi-NPP). These observations will continue on the Joint Polar Satellite System (JPSS-1 and JPSS-2) satellites as part of the operational meteorological satellite system for the U.S. Ozone and related variables with high-altitude resolution in the stratosphere cover a similarly long time frame from the Stratospheric Aerosol and Gas Experiment (SAGE) observations, the Upper Atmosphere Research Satellite (UARS) observations in the 1990s and early 2000s, and the follow-on Aura satellite from 2004 to present. These latter two satellites provide a robust set of key atmospheric parameters to understand better the key photochemical and atmospheric transport processes that control ozone in the stratosphere. NASA now has the OMPS-Limb observations on Suomi-NPP, providing accurate ozone and aerosol observations in the stratosphere from 2014 to present. In early 2017, a follow-on SAGE-III instrument was launched on the International Space Station that will obtain ozone, aerosol, and water vapour profiles for at least the next three years.

After SAGE-III and the OMPS-Limb on Suomi-NPP, the only planned high-altitude ozone satellite is another OMPS-Limb on JPSS-2 in about 2022. This will provide only ozone and aerosol profiles, and not the other key observations currently provided by the Microwave Limb Sounder (MLS) instrument on Aura. Aura is projected to keep operating until roughly 2023, at which time it is expected to run out of fuel to maintain orbit. NASA may choose to allow the satellite orbit to drift after that time, but this decision will not be made for a number of years. Any future stratospheric observations from NASA will be decided by the NASA-contractedDecadal Survey, carried out by the U.S. National Academy of Science. The results of this study are expected by around the end of 2017. It is unclear and unlikely that this report will put a high priority on stratospheric observations, given the nature of the review committees that have been assembled for the report. If this remains the case, the continuation of key stratospheric parameters to help understand changes in ozone will cease in 6-8 years.

European Space Agency (ESA) Activities *(Claus Zehner, ESA/ESRIN)*

The ESA Earth Observation Satellites include the Meteorological, Sentinel, and Earth Explorer Missions. ESA is building these missions in cooperation with the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), the European Commission, and on behalf

of its member states. The Meteorological missions are operated by EUMETSAT, and include the geostationary Meteosat and polar-orbiting Meteorological Operational (MetOp) satellite families.

The Sentinel satellites are the space segment of the European Copernicus programme, and are/will be operated by ESA and EUMETSAT. Six Sentinel missions are currently planned and funded, each consisting of a constellation of two to four satellites to fulfil operational requirements of the Copernicus services, and to be launched by 2030. Since 2014, five Sentinel satellites have been launched, and are being operated by ESA. Furthermore, ESA has specific agreements with owners of missions to acquire, process, archive, and distribute data from their satellites – the so-called Third Party Missions (e.g. Canada's Science Satellite (SCISAT) and Sweden's Odin satellite).

Satellite ozone measurements were provided in the past by the European Remote Sensing-2 (ERS-2) Global Ozone Monitoring Experiment (GOME), Envisat's Scanning Imaging Absorption Spectrometer for Atmospheric Chartography (SCIAMACHY), Michelson Interferometer for Passive Atmospheric Sounding (MIPAS), and Global Ozone Monitoring by Occultation of Stars (GOMOS) instruments. The SCISAT (e.g. Atmospheric Chemistry Experiment (ACE)) and Odin (e.g. Optical Spectrograph and InfraRed Imager System (OSIRIS)) missions continue to provide limb/occultation measurements, while the MetOp A and B (GOME2/Infrared Atmospheric Sounding Interferometer (IASI)) missions continue delivering nadir-viewing ozone measurements. These data sets will be extended in the future by the MetOp C, Meteosat Second Generation InfraRed Sounder (MSG-IRS), MetOp Next Generation (MetOp-NG), Sentinel-5 Precursor, Sentinel-4, and Sentinel-5 missions. Sentinel-4 and -5 are instruments hosted on EUMETSAT platforms. This future constellation will insure continuous, long-term European nadir-viewing ozone-measurement capabilities over the next 20 years.

The Atmospheric Limb Tracker for the Investigation of the Upcoming Stratosphere (ALTIUS) mission was proposed by the Royal Belgian Institute for Space Aeronomy (BIRA-IASB), and was accepted by ESA member states as an Earthwatch Mission in December 2016. ALTIUS is a limb spectral imager (250-1800 nm), operating in multimode observation geometries from a microsatellite platform, with a target vertical resolution of 0.5-1.0 km. The main objective is stratospheric ozone monitoring.

ESA has specific ongoing programmes focused on the preservation and exploitation of its Earth Observation (EO) archives/data sets. In particular, ERS and Envisat Phase F activities will further improve the quality of Level-1 and Level-2 data sets. Within the Long-Term Data Preservation Programme, all ESA EO archives (including raw data) will be preserved.

Ozone climate data sets are also being generated within the ESA Climate Change Initiative (CCI). The ESA CCI programme started in 2010, and recently has been extended by an additional six years. The objective of the CCI is to realise the full potential of ESA's long-term global EO archives as a significant and timely contribution to the ECV databases required by the UNFCCC, and is based on the satellite ECV requirements as specified by GCOS.

The Ozone_CCI project provides long-term data sets for total ozone columns, nadir profiles, limb profiles, and tropospheric columns on its website (http://www.esa-ozone-cci.org/). These data sets have been generated after a careful review of all existing retrieval algorithms available in Europe, and by selection of the "best" one for each ECV parameter. These selection / intercomparison activities included very detailed validation against independent reference data. All data sets are available to the public at http://www.esa-ozone-cci.org/?q=node/160.

Close interaction with users (chemistry climate modellers) throughout the project supported product definition, and provided product assessment on the "fitness for purpose" (climate monitoring) of the ECVs produced.

Based on the lessons learned from the Ozone_CCI project, it is recommended that the generation/provision of the long-term time series of data should be done by:

- Ensuring independent validation of all Level-2 and Level-3/4 data sets (algorithm intercomparison and development, including final product assessment by end users)
- Ensuring consistent error analysis for all sensors
- Ensuring traceability (e.g. algorithm / validation documentation)
- Providing simple and open data access (e.g. via website or ftp server)
- Providing a common format (e.g. use of the same height grid and units for different satellite data sets)
- Doing data merging very carefully: There is no "universal recipe" for data merging, as different applications need different data sets, sampling errors are significant for instruments with coarse sampling and have to be taken into account, merging does not necessarily make sense for all data (e.g. limb profiles), and 'pure' satellite data sets should be provided.

KNMI Space-Based Measurement Activities *(Peter van Velthoven, KNMI)*

An overview was presented of ozone products based on GOME, SCIAMACHY, OMI, and GOME-2 satellite observations provided through the http://www.temis.nl/ website. Among those products, there are assimilated total ozone maps and Antarctic ozone hole diagnostics. An update, version 2, of the Multisensor Reanalysis Set (MSR-2) is also made available on this website. MSR-2 assimilated satellite observations from 1970-2012 from Backscatter Ultraviolet (BUV) on Nimbus 4, TOMS on Nimbus 7,TOMS-Earth Probe (TOMS-EP), SBUV, GOME, SCIAMACHY, OMI, and GOME-2.

Most of the presentation focused, however, on the TROPOspheric Monitoring Instrument (TROPOMI), which is a new spaceborne nadir-viewing spectrometer with bands in the ultraviolet, visible, and near-, and shortwave-infrared. TROPOMI is the payload of the ESA/Copernicus Sentinel-5 Precursor mission, planned for launch in 2017. The objective of the TROPOMI mission is to provide high-quality and timely information about global atmospheric composition for climate and air quality applications. TROPOMI will make daily global observations of key atmospheric constituents, including ozone, nitrogen dioxide (NO_2), sulphurdioxide (SO_2), CO, CH_4, formaldehyde (CH_2O), and aerosol properties. The Sentinel-5 Precursor mission will extend the current data records from OMI on NASA's Aura satellite, and is the link between current scientific missions and the planned operational Sentinel-4/-5 missions. It will connect with planned atmospheric composition geostationary missions by providing in-flight calibration / validation and intercomparison opportunities. Compared to OMI, TROPOMI has a six-times higher spatial resolution (7x7 km), an improved signal-to-noise ratio, and additional near- and shortwave-infrared bands, allowing CH_4 and CO retrievals as well as more accurate cloud corrections. TROPOMI is an initiative from the Netherlands, and is developed in cooperation with ESA. Pepijn Veefkind of the Royal Netherlands Meteorological Institute (KNMI) is the TROPOMI Principal Investigator, and Ilse Aben of the Netherlands Institute for Space Research (SRON) is the Co-Principal Investigator.

Lessons Learned in Creating Long-Term Ozone Datasets: Recommendations for the future *(Richard McPeters, NASA)*

NASA has created a more than 40-year merged ozone data time series by combining data from 8 backscatter ultraviolet (BUV) instruments. This required a full reprocessing of all the data, using a coherent calibration based on our best understanding of the characteristics of each instrument. The merging of the reprocessed data was based on anchoring the early data to the SBUV 1990 calibration, while later data were anchored to the NOAA-17 SBUV/2 2003 calibration. Validation was carried out through comparison with the Dobson/Brewer network for total column ozone, and comparison with ozonesondes and other satellites such as MLS for profile ozone. The ozonesonde network remains critical for climatologies, validation, replication, and homogenisation of satellite ozone data below 20 km. Data from double Brewer stations and the new charge-coupled device (CCD)-based instruments would be most useful for column ozone validation.

Summary of the Key Issues in Space-Based Measurements: Identification of future needs and opportunities *(Jean-Christopher Lambert, BIRA-IASB)*

Research and monitoring relevant to the Vienna Convention and the Montreal Protocol require the following, non-exhaustive list of space-based measurements of atmospheric composition:

- The vertical column and vertical distribution of ozone
- The vertical distribution of trace gases influencing global ozone and climate changes (e.g., nitrogen oxides, hydrogen chloride (HCl), chlorine monoxide (ClO), and bromine monoxide (BrO); but also CO_2, CO, N_2O, CH_4, and water (H_2O))
- Stratospheric aerosols
- ODSs regulated by the Montreal Protocol, as well as their substitutes and their degradation products

The connection between changes in ozone, climate, and atmospheric transport, and, in particular, expected changes in the meridional BDC and unexpected events like the recent break of the quasi-biennial oscillation (QBO), also require monitoring and analysis of temperature, winds, and dynamical tracers like N_2O and sulphur hexafluoride (SF_6). Observations are particularly needed to advance modelling tools like CTMs, general circulation models (GCMs), and chemical data assimilation systems, e.g. for multi-decadal assessments and for the residual circulation derived from data assimilation systems.

In preparation of the 10th ORM meeting, updated information on satellite programmes was collected from the following agencies (by alphabetical order): Canadian Space Agency (CSA), Centre National d'Etudes Spatiales (CNES), Chinese Academy of Sciences (CAS), EUMETSAT, ESA, German Aerospace Centre (DLR), Indian Space Research Organization (ISRO), Japan Aerospace Exploration Agency (JAXA), Korea Aerospace Research Institute (KARI) and Yonsei University, NASA, NOAA, National Satellite Meteorological Centre (NSMC) of China Meteorological Administration (CMA), BIRA-IASB, and KNMI.

Operational monitoring programmes from China, Europe, and the U.S. include BUV-type nadir instruments operating on uninterrupted series of polar orbiting satellites: Feng-Yun Total Ozone Unit and Solar Backscatter Ultraviolet Sounder (TOU/SBUS), MetOp GOME-2 and Copernicus Sentinel-5 Precursor, and NPP/JPSS OMPS. Altogether, they will extend until at least 2030 the global ozone measurements initiated in the 1970s by the U.S. SBUV (-2)/TOMS series. While multi-spectral UV instruments – like the U.S. OMPS-nadir and the Chinese SBUS – measure the ozone column, aerosol index, and low-resolution ozone profile, the European series of hyper-spectral ultraviolet-visible (UV-visible) instruments started in 1995 with ERS-2 GOME, and later continued with Envisat SCIAMACHY, Aura OMI, and three MetOp GOME-2, will extend the global monitoring of NO_2, BrO, chlorine dioxide (OClO), and ozone precursors throughout the 2017-2030 era within the Copernicus Sentinel-5 Precursor programme. The Chinese Gaofen-5 Greenhouse-gases Monitoring Instrument (GMI), planned for 2018, has similar measurement capabilities.

OMPS-limb on Suomi-NPP (since 2011) and SAGE-III on the International Space Station (launched in February 2017) continue the long-term measurement of ozone and aerosol extinction profiles at a vertical resolution of about 1-2 km. This monitoring, initiated in the late 1970s with the SAGE and Nimbus-7 instruments, will be extended further by another OMPS-limb planned for JPSS-2 (after 2022), and by the ALTIUS limb mission recently approved as an ESA Earth Watch Programme component.

A constellation of geostationary satellites focusing on air quality and regional climate monitoring (GEO-AQ) will be deployed between 2018 and 2022, consisting of the Korean Geostationary Environmental Monitoring Spectrometer (GEMS) / GEO Ocean Colour Imager-2 (GOCI-2), the U.S. Tropospheric Emissions: Monitoring Pollution (TEMPO), and the European Copernicus Sentinel-4 satellites. Equipped with nadir UV-visible and near-infrared hyper-spectral instruments, the GEO-AQ constellation will offer typical spatial resolutions of 8x8 km^2, and temporal sampling of 1 hour. Thus, the constellation will provide information about short-term variations of atmospheric composition, including tropospheric ozone, its precursors, and

aerosols, over Southeast Asia, North America, and Europe at unprecedented spatial and temporal scales,

Increased monitoring of other source gases and tracers, especially CH_4, CO_2, CO, N_2O, and water vapour, is an objective of several nadir-viewing instruments dedicated to measurements in the near and thermal infrared. Current missions include:

- The European MetOp-A/B IASI (since 2006 and 2012)
- The Japanese Greenhouse Gases Observing Satellite (GOSAT) (2009)
- The U.S. Orbiting Carbon Observatory-2 (OCO-2) (2014)
- The Chinese TanSat (2016)
- The aging U.S. Earth Observing System (EOS) missions Terra Measurements Of Pollution In The Troposphere (MOPITT) (operating since 1999), Aqua Atmospheric Infrared Sounder (AIRS) (since 2002), and Aura Tropospheric Emission Spectrometer (TES) (since 2004)

For the future, the following missions have been planned or are in preparation:

- The ESA/Netherlands Sentinel-5 Precursor TROPOMI (2017)
- The Chinese Gaofen-5 GMI (2018)
- The German/French Merlin (2018)
- The Russian Meteor-M Infrared Fourier Spectrometer (IKFS) series
- The U.S. OCO-3 and Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS)
- The European MetOp-C IASI, IASI-NG (Next Generation), and CarbonSat
- The Japanese GOSAT-2
- The Indian Environmental Satellite (EnvironSat) High-Resolution SWIR Spectrometer (HRSS)

It must be noted, however, that most of these nadir-viewing instruments primarily measure the integrated column of various species, and not vertical profiles.

While global monitoring of the vertical column of ozone, aerosols, several ozone precursors, tracers, and GHGs is envisaged until about 2030, there is serious concern about profiling capabilities at the required high-vertical resolution, particularly of several high-priority species. ALTIUS will measure the vertical profile of NO_2, H_2O, CH_4, and a few other trace gases; however, no space programme to-date includes the limb emission and infrared (IR) solar occultation profiling facilities required to continue the monitoring of key ozone-related species and reservoirs (e.g. HCl, ClO, nitric acid (HNO_3), CCl_4, etc.); of tracers of the BDC and other atmospheric transport (e.g. N_2O, SF_6, CO_2, etc.); and of ODSs and their substitutes. The drastic reduction of atmospheric limb and solar occultation profiling capabilities experienced in the last decade will turn into a real gap in the coming years with the anticipated end of currently aging missions, namely, Odin OSIRIS and Submillimetre-wave Radiometer (SMR) (in operation since 2001); SCISAT-1, the Atmospheric Chemistry Experiment Fourier Transform Spectrometer (ACE-FTS), and Measurements of Aerosol Extinction in the Stratosphere and Troposphere Retrieved by Occultation (MAESTRO) (since 2003); and Aura MLS (since 2004). Without the data currently provided by these limb emission and solar occultation profilers, the predictions made by data assimilation systems and related services to policy makers will degrade, unexpected events like the recent break of the QBO and the severe 2011 Arctic ozone depletion will not be able to be analysed, the detection and interpretation of changes in atmospheric circulation will be hampered, and climatological assessments will become biased by large under-sampling errors.

Ground-based networks of Brewer and Dobson spectrophotometers, UV-visible differential optical absorption spectroscopy (DOAS) and Fourier transform infrared spectroscopy (FTIR) spectrometers, lidars, ozonesondes, millimetre-wave radiometers, and ground-level *in situ* measurements) constitute the primary source of correlative reference observations for the validation of satellite data. Such networks should be maintained, and even extended, to cover a wider range of atmospheric states, of regions of interest, and of the quantities influencing

the accuracy of satellite data (e.g. solar zenith angle from 10°-20° up to 90°, regions with low- and high-temperature contrast, etc.). In certain cases, the steady decrease in the number of stations reporting data to central data archives has already become a concern. The deployment of measurement facilities in the tropics, in Asia, and in the Southern Hemisphere is recommended. For some species and instruments, it is advised to continue ongoing efforts to improve the station-to-station homogeneity of networks, and to consolidate long-term data records, especially in view of data assessments addressing the links between atmospheric composition change and climate change.

With scientific needs emphasising the study of interactions between ozone, atmospheric transport, and climate change, ground-based and satellite measurement systems are facing new challenges and more stringent data-quality requirements. Traceability and consistency of QA methods, and of quality information from end to end (i.e. from the acquisition of binary data by an instrument to the delivery of four-dimensional atmospheric fields by modelling and assimilation systems), is of particular concern. Multi-mission / multi-sensor / multi-agency projects and strategies like the GEO Quality Assurance framework for Earth Observation (QA4EO), SPARC and WMO assessments, ESA's CCI, NASA's Global Ozone Chemistry and Related Trace Gas Data Records for the Stratosphere (GOZCARDS), and topical intercomparison campaigns aimed at understanding and reducing discrepancies between different types of observations have been successful. Further initiatives in these directions are strongly encouraged. New steps in the integrated exploitation of satellite and ground-based data may require the development of dedicated methods and tools, and should be supported by adequate research activities. In particular, emerging approaches coupling models and observational aspects, like observing system simulation experiments, could be developed further, and used for strategic planning of monitoring station locations.

SESSION 6: NATIONAL AND REGIONAL REPORTS ON OZONE RESEARCH AND MONITORING

In this session, each representative of a region presented the regional and national situations with ozone monitoring and research, focusing on the key issues raised by the countries in the region based on the national reports submitted for this meeting (Annex D of this report).

Region 1: Africa *(Gerrie Coetzee, South African Weather Service)*

The number of country reports received for the 10th ORM meeting from the African region were few. Reports were received from Burkina-Faso, Cabo Verde, Comoros, Egypt, Kenya, Madagascar, Nigeria, South Africa, and Zimbabwe. Although reports were not received, it is known that ozone monitoring and research activities continue in countries such as Algeria, Botswana, Seychelles, Uganda, and at a new GAW regional station recently established at Hentiesbaai, Namibia.

Ozone monitoring and research activities are largely occurring only in the few countries mentioned above, and Africa remains a continent with very sparse data and ozone-research capabilities. In general, the United Nations Environment Programme Ozone offices established in most countries have reported well on Montreal Protocol implementation issues, submitting both data and figures of their achievements on curbing ODSs. All countries are also actively involved in awareness campaigns and other more general environmental actions.

Specific activities to note have taken place in the three countries that manage WMO Global GAW stations, namely Algeria (Tamanrasset), Kenya (Mt Kenya), and Cape Point (South Africa). These three countries also have strong regional GAW station representation within their region, with valuable long-term systematic monitoring records spanning 30-40 years. Egypt, Algeria, Kenya, and South Africa have well-established ground-based networks consisting of Dobson and Brewer instruments (northern Africa) for monitoring atmospheric ozone and UV monitoring. Routine ozonesonde balloon soundings are only conducted at the Kenya, Nairobi NMS (with MeteoSwiss twinning), and at the Irene weather office, South Africa. Both of these stations are part of the SHADOZ network.

Published science papers, particularly with African lead-authorship, remain difficult to find, and thus there still is a great lack of research capacity on the continent. Satellite activities and interest therein are limited to only a few users, and mainly to support their ground-based research and monitoring activities.

It has been stated that capacity among many African universities does exist, but capacity building and twinning with developed nations or neighbouring countries still largely remains an aspiration. It seems that finding suitable twinning partners for Africa is difficult. This also relates to earlier ORM meetings and previous discussions regarding the transfer or relocation of spare instruments from the developed world to this data sparse region. Despite the VCTF noting this as a priority goal, this is still a complex process. Therefore, the limitations of VCTF resources cannot address the needs for empowering willing nations on the continent to initiate even modest monitoring and/or research activities.

Lastly, the enhancement of a few air-quality-monitoring networks in countries like Egypt, Nigeria, and South Africa resulted in a few additional UV-monitoring stations that have been added.

Overall, the situation in Africa remains more or less at the concerning levels of past ORM reporting. Most countries are doing an excellent job of complying with the Montreal Protocol. However, those who do have existing ozone monitoring and research infrastructure and capabilities find it difficult to maintain them at operational levels. The main recommendation remains one of resources, collaboration, and assistance from the developed world to contribute to improving the situation in the African Region.

Region 2: Asia *(Nomuru Ohkawara, JMA)*

Status of observations and research activities

- According to the national reports and data availability at the WOUDC, ground-based observations of ozone, UV, ODSs, and other minor atmospheric constituents have not been enhanced effectively in the past three years.
- Many informative scientific results have been obtained from recent research activities using observations and model simulations.

Implementation of the recommendations of the 9th ORM

- Data availability at the WOUDC has improved in terms of primary (0-level) Dobson data.
- The Japanese Meteorological Agency (JMA) successfully held a regional Dobson intercomparison campaign for Asia in March 2016 to provide Asian countries with technical support and training on ozone observation. This was supported by the VCTF.
- JMA provided technical support via e-mail about ozone observations as part of the WMO Quality Assurance / Science Activity Centre activities.
- Model studies have continued to provide better future ozone projections.
- Research projects have been conducted to reveal chemical and dynamical processes related to atmospheric ozone.

Recommendations and needs

- Systematic observations to evaluate the changing state of the ozone layer, including detection of ozone-layer recovery, should be continued in cooperation with international monitoring networks.
- Several countries have plans to start ozone /UV observations.
- Several countries need financial and technical support to start / continue these observations.
- Training on observation, data submission, and data analysis is necessary for systematic ozone monitoring.

- Systematic calibration activities on a regular basis within an international programme are necessary to ensure observation data quality.
- In the future, CCMs need to be coupled to the ocean.
- Chemistry-climate interaction studies using CCMs need to be developed. These include investigations of stratospheric and tropospheric ozone change, UV change, stratospheric and tropospheric aerosol change, and solar activity change.

Region 3: South America *(Eduardo Luccini, CONICET-CEPROCOR)*

The region expressed a general concern about the state of maintenance and calibration of their instruments, as well as for the continuity of ozonesonde programmes. The presentation included information on the location of stations in each country where monitoring of ozone and/or UV solar radiation is being carried out, and details of the principal activities that occurred in the region in the period 2014-2017, related to calibration, state and management of installed instruments, installation of new instruments, ozonesondes, national and international cooperation, training of operators, etc. An overview of the confirmed future activities for the period 2017-2020 was also provided including the Dobson instrument calibration planned for November 2017 in Buenos Aires, Argentina (supported by the VCTF); the installation of four new Pandora instruments at Argentinean stations; and the installation of a new lidar, developed in Argentina, at the Pilar station. Finally, the urgent need for carrying out regional calibration campaigns for Brewer and UV-Biometer instruments was emphasized, and it was recommended to include those campaigns in the official calibration agenda of the next few years, even though funds for them are still not assured.

Region 4: North America, Central America and the Caribbean

USA *(Kenneth Jucks, NASA and Stephen Montzka, NOAA)*

The USA has a comprehensive research programme dedicated to understanding changes in ozone, ODSs, and UV flux changes. While funds for these activities come primarily from NOAA and NASA, the U.S. Environmental Protection Agency (EPA), National Science Foundation (NSF), and Department of Agriculture (USDA) also fund key activities. NASA and NOAA collaborate strongly on ground-based observations of key ODSs and substitute chemicals, using significant international collaborations, to form the basis for long-term ODS observations. Data for ODSs and ozone provided by these activities enable an assessment of the success or failure of international Protocols on ozone and climate, and are key inputs to the WMO/United Nations Environment Programme Ozone Assessments. NASA and NOAA also contribute significantly to the international NDACC and SHADOZ networks for ground-based remote sensing and ozonesondes, respectively. NOAA maintains a long-term series of ground-based UV spectroradiometer observations of column ozone, and provides and maintains the calibration standards for several international networks. NOAA, EPA, NSF, and USDA support long-term observations of surface UV fluxes. NASA, in collaboration with agencies such as NOAA and NSF, maintains a significant airborne science programme that is designed to address open and important questions in atmospheric science related to ozone and climate. Recent activities include the NASA-funded Pacific Oxidants, Sulphur, Ice, Dehydration, and convection (POSIDON) campaign; the Korea–United States Air Quality Study (KORUS-AQ); as well as the Earth Venture missions, including the Atmospheric Tomography Mission (ATom), the Atmospheric Carbon and Transport – America (ACT-America) mission, and the ObseRvations of Aerosols above CLouds and their interactions (ORACLES) mission. These latter three will continue for two more years. Both NASA and NOAA also invest heavily in data analysis and modelling for their atmospheric observations to maximise the science return of these activities.

Canada *(Sum Chi Lee, Environment and Climate Change Canada)*

Canada's ozone- and UV-monitoring program is operating with no major changes, continuing measurements at ground-based sites with long records and in the Arctic region. All Dobson/Brewer and ozonesonde sites opened in the 1950s and 1960s remain operational. The real-time Brewer data are used to produce hourly bulletins for UV index forecasts, and for

other applications such as satellite data validation and reporting on the state of the ozone layer. The Canadian ozonesonde record was re-evaluated, with results published in 2016 showing reduced scatter and drift in trends. The WOUDC system was renewed in March 2015. Key enhancements to the WOUDC include provision of near-real-time data; validation services; self-service metrics / reporting; Network Common Data Form (NetCDF) data delivery; standards (e.g. International Organization for Standardization (ISO), Open Geospatial Consortium (OGC)); geospatial capabilities; and alignment with WMO drivers (WMO Information System (WIS), GAW, WMO Integrated Global Observing System (WIGOS), etc.).

The performance of the Pandora spectrometer was evaluated for total ozone column through a comparison with the Brewer Triad in Toronto. From the comparison results, the Pandora spectrometer seems promising. Currently, Canada provides daily UV index forecasts in weather reports and daily bulletins. The new UV index prediction project based on ozone data assimilation is being tested and evaluated. The 2015 Toronto Pan American and Para-Pan American Games were used to demonstrate the new UV index forecast that will be implemented in the near future. Modelling studies are ongoing to improve understanding of the relationship between ozone and climate. Operation of Canadian satellite missions Odin/OSIRIS and SCISAT continues, along with related research activities.

Canada's international activities were also detailed, including the renewal of the Brewer Trust Fund (2015-2020), the Brewer World Calibration Centre, the WOUDC, and the global Brewer travelling standard. Future plans include satellite validation activities for satellite missions such as TROPOMI and TEMPO with Canada's ground-based remote sensing network that includes ozone monitoring.

Central America, Mexico and the Caribbean *(Juan Carlos Peláez Chávez, INSMET)*

Measurements of total ozone currently are systematically undertaken in only Mexico and Cuba. The measurements, being made in Mexico, include total ozone in Mexico City (since 2014) and several UV sites, both in Mexico City and elsewhere in the country. The federal government also is planning to replace 30 such instruments in the coming months. The ozone and UV data are regularly submitted to the WOUDC, while aerosol observations from two sites are submitted to the Aerosol Robotic Network (AERONET). The Dominican Republic currently has no measurement activities for either stratospheric ozone or UV but they have requested support to fund such sites. Cuba currently has a Dobson instrument to measure total column ozone in Havana; however, the instrument stopped functioning in August 2015. It was recommended that it would be extremely helpful for a Cuban technician to participate in a Dobson training course, particularly to be able to repair their instrument. Similar to Mexico, Cuba also undertakes aerosol observations, which are submitted to AERONET.

Region 5: South-West Pacific *(Matt Tully, BoM)*

Observational activities

A number of long-term Dobson stations have continued operations in Region 5 since the 9th ORM, some of which have records now stretching back sixty years: Brisbane, Aspendale / Melbourne, and Macquarie Island (Australia); and Wellington / Invercargill / Lauder (New Zealand). The Dobson programmes at Samoa, Manila, Singapore, and Darwin have also operated for more than thirty years, although the Singapore Dobson is currently in need of repair. A smaller number of Brewers are also currently in operation in Malaysia, Indonesia, and Australia.

Three very important ozonesonde programmes have continued since the 9th ORM at Broadmeadows, Lauder, and Macquarie Island, measurements that are crucial for the Southern Hemisphere midlatitudes (spanning 38° to 55°S). In addition, a number of SHADOZ sites are located at lower latitudes in Region 5 – Kuala Lumpur, Watukosek (Java), Pago Pago (American Samoa), and Suva (Fiji). In Antarctica, Region 5 countries Australia and New Zealand also have continued to operate an ozonesonde programme at Davis, and a Dobson at Arrival Heights, respectively.

NDACC sites in Region 5 include Alice Springs, Wollongong, Lauder, and Macquarie Island. The FTIR instrument at Wollongong contributes to both the NDACC and TCCON networks, while Lauder has continued operations since the 9th ORM, with long time series of more than 25 years continuing for instrumentation such as FTIR, lidar, microwave, UV-Visible, UV spectrometer, Dobson, and ozonesondes. Long-term *in situ* measurements of ODSs and ODS replacements have continued at Cape Grim, which in 2016 celebrated its 40th anniversary. Finally, the Lauder lidar, operated in New Zealand on behalf of RIVM for more than 20 years, is continuing observations while future arrangements are being settled.

These stations play a significant role in Southern Hemisphere measurements of both ozone and ozone-related trace gases.

Intercomparisons and training

In February 2017, a regional Dobson intercomparison campaign, hosted by the Australian Bureau of Meteorology (BoM), was conducted in Melbourne, Australia. Participating institutions were NOAA (USA), the National Institute of Water and Atmospheric Research (NIWA) (New Zealand), the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA), and JMA (Japan). The Region 5 Standard instrument (#D105) was referenced against the World Standard (#D083), with training and instrument refurbishment provided to the participants from the Philippines.

In September 2017, a Brewer workshop for the Asia / Pacific area will be hosted by BoM in Sydney, Australia. Both the VCTF and the Canadian Brewer Trust Fund will provide support for this event. It is expected that this workshop will provide extremely useful training for the operators of Brewers in Asia and the western Pacific.

Modelling

Coupled chemistry-climate modelling is being undertaken in both Australia and New Zealand, and is contributing to the SPARC / International Global Atmospheric Chemistry (IGAC) Chemistry-Climate Modelling Initiative (CCMI) project. A particular focus is the interconnection between climate and ozone in the Southern Hemisphere, including the impact of the Antarctic Ozone Hole on tropospheric weather and climate.

Macquarie Island

In October 2017, the Australian Minister for the Environment and Energy announced that the permanent station on Macquarie Island would be rebuilt at a cost of fifty million Australian dollars. This news was warmly welcomed by the international ozone community, who had been concerned about the potential loss of long-term observations made with Dobson spectrometers (since 1957) and ozonesondes (1994) when the future of the station was in doubt.

Future directions

The Malaysian Meteorological Department (MetMalaysia) has received funding to purchase one replacement Brewer and five new instruments to form a network of six Brewers across the country.

A UV-visible MAX-DOAS intercomparison was held in Melbourne, Australia in February 2017, during which four similar instruments (owned by NIWA, BoM, the University of Melbourne, and the University of Wollongong) were co-located for a number of weeks. Pandora instruments currently are operating in Melbourne and Lauder, with the aim of conducting long-term comparisons with established instrumentation.

Polar Regions

Antarctica *(Jonathan Shanklin, British Antarctic Survey)*

There is a need to maintain measurements of the climate and ozone variables in Antarctica, particularly since there currently is concern about diminishing observational capabilities on the

continent. Such ground-based observations are essential to anchor and supplement satellite observations for trend detection. The satellite community, for example, regards the data from the Halley station as extremely valuable.

There is also a need for a good low-cost ozone-monitoring instrument. Several questions could be asked: Could the Natural Environment Research Council (NERC) support capacity building by contributing to the VCTF, or by funding research with developing countries? Could we get official development assistance (ODA) funding for Dobson calibration of an instrument to go to the Vernadsky station as part of capacity building? One option is the Pandora spectrometer, an automated ozone-monitoring instrument that costs about US $40,000, though it is less reliable (bigger offset compared to Brewer) at high air masses.

The tropics are becoming an important area, with predictions of future changes still somewhat unclear. In addition, the QBO, which plays a vital role in these regions, broke down in 2016, and it is currently not understood why or how this occurred. Globally, observations suggest no clear ozone-layer recovery as yet, and models show considerable variation in their predictions. It is not yet clear what conditions will be like by 2100, but it is likely that there will be more ozone globally, but less in the tropics.

Changes in UV have not yet been detected over Antarctica; however, UV levels are expected to decrease due to ozone layer recovery. The situation may be different in the tropics, depending on what happens to ozone. Exposure to UV has both risks and benefits (e.g. vitamin D production). Benefits to skin and eyes are under investigation. Increases in dissolved organic matter, creating browning of inland waters, blocks UV and, hence, increases human pathogens that would otherwise be killed. Also, this may influence aquatic carbon cycling and increase CO_2 release. Research into the full environmental effects is underfunded, due to the perception that the problem is solved.

Finally, a question was posed as to whether there is any duplication in coordinating groups, with IO_3C, GAW, and NDACC possibly serving similar functions. It was pointed out that it would be interesting to do a cost-benefit analysis of funding international groups compared to funding more direct capacity building both for instrumentation and developing countries.

Other Activities in Antarctica and in the Arctic *(Geir Braathen, WMO)*

A map was presented first showing the 23 stations that contribute data to the WMO Antarctic Ozone Bulletins. The purpose of the WMO Ozone Bulletins (Arctic and Antarctic) is to:

- Show the importance of ground-based measurements, including soundings
- Compare ground-based and balloon data to satellite data
- Interpret ground-based data in view of the meteorological conditions
- Pay tribute to the station staff who go through hardship in order to take the measurements

Stations outside of the Antarctic region, such as Macquarie Island, occasionally can be affected by the ozone hole. Several stations in Antarctica, such as Halley, Macquarie Island, Syowa, and Vernadsky, have long time series of total ozone, dating back to the late 1950s or early 1960s. A table summarising the instruments currently deployed in Antarctica and surrounding areas showed that there are eight Dobsons, four Brewers, eight ozonesonde stations, seven DOAS (including SAOZ) instruments, three filter instruments, one lidar, and one FTIR.

With regard to the comparison of the 2015 Antarctic ozone hole with that of other recent years, the 2015 Antarctic vortex was characterised by low Eddy heat flux, a sign of a stable polar vortex. The area with temperatures low enough for the formation of polar stratospheric clouds was larger than the long-term (1979-2014) average, albeit not of record size. The ozone hole area in 2015 was one of the largest ever seen, and if one averages over the worst 60 consecutive days, the 2015 ozone hole was the largest on record. This record large ozone

hole has been explained in a paper by Ivy *et al.* [2017][4], which uses model simulations to show that chemical ozone depletion due to volcanic aerosols from the Calbuco volcanic eruption on 30 April 2015 played a key role in establishing the record-sized ozone hole in October 2015.

Finally, results were shown from ozone loss studies in the Arctic. The most severe winter/spring ozone loss observed to-date happened in 2011. That year, the column ozone loss inside the vortex amounted to 38%. In 2015/2016, the winter started out unusually cold, and there was some significant ozone loss, but a stratospheric warming that occurred in late February and early March precluded further ozone loss. By mid-March, the inside-vortex column ozone loss amounted to 27%. More details on ozone observations and ozone loss in the polar regions can be found at:
http://www.wmo.int/pages/prog/arep/gaw/ozone/index.html

Region 6: Europe

European Union *(Vincent-Henri Peuch, on behalf of the European Commission)*

The European Union (EU) remains committed and interested in the science underlying changes in the ozone layer, and will do all it can to ensure that the necessary scientific information continues to flow. A key issue in the region is to ensure the maintenance of monitoring stations, and the European Commission (EC) encouraged meeting participants to consider how best to finance these stations in a long-term sustainable way, including by possibly working with non-public partners. Specific research foci of interest include a better understanding of European CCl_4 emissions, as well as the presence and sources of short-lived climate forcers (including HFCs). A major achievement of the EC is the Copernicus Programme, which not only produces a wide number of satellite products, but also goes all the way to providing services. Such services are focused on air quality, GHGs, and the ozone layer. The skill of their modelling system is very much reliant on the satellite data that are assimilated, and thus there is significant interest in maintaining good satellite observations. Furthermore, the Programme relies on aircraft and ground-based observations, which are used for validation and anchoring data assimilation. Copernicus has partnered with many organisations around the world to provide products such as a UV index for Australia, or to determine the best times to launch ozonesondes in Argentina. The Programme is a real-life example of how science can be used to provide services, but also how services can feed back to science. For example, without assimilating ozone profile information from MLS, their model fails to accurately represent the vertical ozone structure, which in turn is important for medium- to long-term weather forecasts.

Northern Europe *(Weine Josefsson, SMHI)*

The presentation started with three maps to illustrate the variety of observations related to ozone and UV made at stations in the region. Observations in this region are vital, since it is part of the Arctic where the stratospheric polar vortex (with potentially strong ozone depletion) appears every winter. The Arctic is also where the climate-change signal is very strong.

The deployment of mini-SAOZ ozone spectrophotometers in Russia in recent years is welcomed, and operative availability of their and other ozone measurements (including ozonesondes) for the scientific community is very important, especially in winter and spring. Unfortunately, many sites in northern Europe have had to reduce or even close their activity due to decreased funding. Examples are the abandoning of profiling measurements (ozonesondes and ozone lidar) in Norway, and Denmark's closed observations at Thule, Greenland. Dedicated personnel, regular service, and frequent calibrations are essential at all sites to keep data quality at current high levels. The representatives from the Northern Europe and Northern Asia region emphasised the importance of stable funding to keep long-term monitoring running, and to keep the quality as high as possible.

[4] Ivy, D. J., S. Solomon, D. Kinnison, M. J. Mills, A. Schmidt, and R. R. Neely III, The influence of the Calbuco eruption on the 2015 Antarctic ozone hole in a fully coupled chemistry-climate model, *Geophys. Res. Lett.*, *44*, 2556–2561, doi:10.1002/2016GL071925, 2017.

Western, Central, and Eastern Europe *(Wolfgang Steinbrecht, DWD)*

The report for Western, Central, and Eastern Europe summarised ozone and UV research activities from 10 countries: Austria, Belarus, Belgium, Czech Republic, France, Germany, the Netherlands, Poland, Switzerland, and the United Kingdom. All of these countries have long-term programmes for ozone column and UV monitoring, usually at several stations. Most countries also make regular ozone balloon soundings. In addition, routine ozone monitoring is carried out at stations in the Arctic and Antarctic, and several stations in the tropics also are supported. Furthermore, European countries are key players in space-based ozone and trace-gas monitoring, contributing in many ways to the satellite measurements led by ESA and EUMETSAT. GOME, SCIAMACHY, and GOME-2 have provided continuous global monitoring of total ozone (and some trace gases and aerosol) since 1996. This will continue with future MetOp and Sentinel satellites, also using a TROPOMI instrument operating in the UV-visible and near-infrared wavelength regions, and with IASI and IASI-NG instruments operating in the infrared. The European Envisat satellite, and the multiple instruments onboard, were very important for detailed process-oriented studies using its unique comprehensive data record covering the 2002-2012 period. The planned ALTIUS instrument will be key, because it should reduce the expected critical gap for ozone (and other trace-gas) profile measurements in limb geometry. This gap will open when the MLS instrument on the Aura satellite and the OSIRIS instrument on Odin break down in the coming years (well after their expected lifetime, however).

The world's longest total ozone record dating back to 1926 at Arosa, Switzerland very clearly shows the decline of total ozone caused by anthropogenic ODSs, but also the success of the Montreal Protocol in stopping this decline. Records from other European countries confirm these findings, but also show some regional differences. For example, the long UV record from Belsk, Poland, starting in 1976, shows decadal UV radiation increases until the late 1990s, and decadal decreases since around 2000 – largely following ozone levels. These changes are harder to see in shorter UV records, e.g. in the Netherlands or in Austria, where UV variability due to cloud and aerosol changes dominates. European countries host a number of large observatories, monitoring a wide range of meteorological, chemical, and other parameters, some of which fall within the GAW programme. In addition, stratospheric balloons have been flown to follow the evolution of age-of-air tracers, ODSs, and other important gases. While flights with large balloons have effectively come to an end, efforts are now geared towards flying small meteorological balloons with new-technology "air-core" samplers. Another important European contribution is the In-service Aircraft for a Global Observing System (IAGOS) measurements on commercial airliners.

In most countries, state-of-the-art CCMs and CTMs are developed and used, both for interpreting the observations, and for predicting future climate and the ozone layer. European modelling activities have been instrumental in international CCM validation initiatives, and in the Climate Modelling Intercomparison Project (CMIP), which is now in Phase 6, and is paying much more attention to the close interactions between the ozone layer and surface climate. With measurements, modelling, interpretation, and research, European scientists have been important contributors to the WMO/United Nations Environment Programme Scientific Assessments of Ozone Depletion, including the previous 2014 report and the ongoing 2018 activity. With these activities, Western, Central, and Eastern European countries have fulfilled many of the needs outlined in the recommendations of the 9th ORM meeting. Long-term observations of ozone, UV, and other climate variables have largely been maintained. Europe also provides data centre and calibration services (e.g. the World Data Centre for Remote Sensing of the Atmosphere (WDC-RSAT), WMO Regional Association VI (RAVI) Dobson calibration centre, EUBrewNet, etc.), and helps in capacity building, e.g. twinning ozone soundings in Kenya, or by supporting tropical stations in Paramaribo, Palau, etc.

Thanks to the success of the Montreal Protocol, we are now moving from a period when the ozone layer was threatened by ODSs to one where increasing source gases like N_2O, CH_4, and CO_2, as well as climate change, will have effects that are as large as the past ozone depletion. European countries need to maintain measurements and scientific expertise so that we can follow and understand changes of the ozone layer during its expected recovery in the second half of this century. It is absolutely necessary to continue European long-term monitoring

activities, which are a key component of the global ozone and stratospheric observing systems. Another need is to maintain the required technical and scientific expertise, and to support activities that bundle resources and promise more effective collaborations, e.g. EUBrewNet.

Southern Europe *(Alberto Redondas Marrero, AEMET)*

There is a decline in the number of observations submitted to the WOUDC from the Southern European Region, with only 50% of the region's stations actively reporting. Particularly of importance is the complete stop of the Portuguese monitoring program. Further country updates include:

Armenia:

Armenia continues to maintain and operate Dobson instrument #410 at the regional meteorological station in Amberd. They received training in 2015, and the instrument is calibrated regularly.

Italy:

Total ozone columns are observed on a routine basis at the L'Aquila ozonesonde station. UV-A and UV-B instruments also have been in operation since 2004. Consiglio Nazionale delle Ricerche (CNR) also performs measurements of the ozone column and surface solar UV irradiance at Ny-Ålesund (Svalbard), Bologna (Italy), and Concordia station (Antarctica), making use of very narrow band filter radiometers designed and built at the Institute of Atmospheric Sciences and Climate (ISAC).

Italy plans to continue observational activities, improve various databases (e.g. the ESA-CCI), and form a regional network integrating the stations in East Antarctica, Concordia, Mario Zucchelli Station (MZS), Mendel Station (MS), and the instruments used by other Italian groups in cooperation with Argentina. More frequent quality control of these instruments is required. Furthermore, more efficient coordination among the different Italian research institutions and universities involved in ozone research is advisable.

Spain:

There is a good cooperation between monitoring agencies (Agencia Estatal de Meteorología (AEMET) and Instituto Nacional de Técnica Aeroespacial (INTA)) and universities. Currently they participate together in 14 research projects, half of which are international, and cover topics such as satellite validation, trend analysis, chemistry-climate interactions, Antarctic research, and instrument development. So far, these projects have produced 41 refereed publications.

Spain has a comprehensive ozone- and UV-monitoring network, with nine ozone stations, including the ozonesonde programmes at Madrid and Tenerife, as well as three Antarctic stations operated in cooperation with Argentina. UV radiation is monitored in a network with 40 stations, and QA is carried out by two calibration facilities. All ozone and UV observations are publically available on the AEMET website: http://www.aemet.es/es/eltiempo/observacion/radiacion/radiacion. AEMET also has hosted the European Regional Brewer Calibration Centre (RBCC-E) since 2003, and so far has contributed to the calibration of 15 Brewer spectrometers in regular campaigns. Finally, AEMET hosts the EUBrewNet data protocol application.

The Izaña Atmospheric Research Centre (IARC) conducts a "twinning" program with the GAW stations at Tamanrasset-Assekrem (Algeria) and Ushuaia (Argentina), while the RBCC-E organises regular Brewer training courses, the next of which will take place in Australia for the Asia-Pacific region.

*Turkey***:**

Turkey has operated the Ankara Brewer station since 2006, the instrument of which was calibrated in 2016. Turkey also has a complete network of 20 broadband radiometers across

the country to measure UV radiation. Ozone and UV observations are publically available on the Meteorological Data and Information System (MEVBIS) website.

SESSION 7: DISCUSSION ON AND ADOPTION OF THE RECOMMENDATIONS

Recommendations arising from the meeting were discussed under four topics. For each topic, selected resource persons made a short introductory presentation based on the attendees' presentations, followed by discussion. Rapporteurs for each topic led the drafting of the recommendations on the basis of the discussions. The national reports formed an important basis for the discussions and the recommendations. The resource persons and rapporteurs were as follows:

Research Needs: Introduction by David Fahey, SAP Co-Chair and Michael Kurylo, 9th ORM Meeting Co-Chair; Rapporteurs – Paul Newman and A. R. Ravishankara, SAP Co-Chairs

Systematic Observations: Introduction by Jean-Christopher Lambert, Belgium, and Wolfgang Steinbrecht, Germany; Rapporteurs – Nis Jepsen, Denmark, and Richard McPeters, USA

Data Archiving and Stewardship: Introduction by Martine De Mazière, Belgium, and John Rimmer, UK; Rapporteurs – Sum Chi Lee, Canada, and Stephen Montzka, USA

Capacity Building: Introduction by Geir Braathen, WMO, and Bonfils Safari, SAP Co-Chair; Rapporteurs – Richard Querel, New Zealand, and Matt Tully, Australia

The following section on overarching goals introduces the final recommendations in the areas of research needs, systematic observations, data archiving and stewardship, and capacity-building.

Recommendations

A. Overarching Goals

The ozone layer is critical to the protection of all life on Earth. As with other major threats to human health and the environment, it is crucial that the scientific community remain vigilant, by continuing to monitor it closely, and by increasing our understanding of existing and new threats.

1. *Improve the understanding and accuracy of future projections of global ozone amounts*, recognising that ozone is sensitive to increasing greenhouse gases (GHGs) and associated changes in climate parameters, as well as to ODSs. In addition, ozone depletion has been linked to meteorological changes in the stratosphere and troposphere. Developing accurate ozone projections challenges our ability to simulate how the stratospheric ozone layer is coupled to chemical, radiative, and dynamical processes in the stratosphere and troposphere.
2. *Maintain and enhance existing observation capabilities for climate and ozone layer variables.* Given the strong coupling between ozone layer behaviour and changes in climate, the observations of climate and ozone layer variables should be carried out and analysed together whenever possible.
3. *Continue and enhance the Trust Fund for Financing Activities on Research and Systematic Observations Relevant to the Vienna Convention (hereinafter referred to as "the Trust Fund") to better support the above goals.* It is essential to continue and significantly enhance the Trust Fund to make it more effective in addressing some of the scientific issues that arise from the above. It also is essential that the Trust Fund Advisory Committee develops a strategic plan for the Fund, and assists

the United Nations Environment Programme Ozone Secretariat and World Meteorological Organization (WMO) in setting priorities and ensuring implementation.

4. *Dedicate to build capacity to meet the above goals.* Given the above, it is very important to carry out capacity building activities in the Montreal Protocol Article 5 countries to expand scientific expertise, with the added benefit of expanding the geographical areas for the measurements and data archival of key variables related to the ozone layer and changing climate.

B. Research Needs

Understanding the complex coupling of ozone, atmospheric chemistry, transport, and climate changes remains a high priority, and the need for further research in this area has been heightened since the 9th ORM recommendations. Further research is needed to better understand the underlying climate processes, and to improve model projections of the ongoing changes in both ozone and temperature distributions of the middle atmosphere. In support of WMO/United Nations Environment Programme Ozone Assessments, there is a need for coordinated simulations of future ozone changes using suitable models. These simulations should include those with fixed GHG concentrations and fixed ozone-depleting substance (ODS) concentrations to permit an attribution of changes in global ozone to separate changes in GHGs and ODSs, and to increase understanding of how stratospheric and tropospheric climate parameters are coupled to global tropospheric and stratospheric ozone changes.

The understanding in climate-ozone coupling also has increased since the 9th ORM recommendations. One of the robust features of the global ozone response to increasing GHGs (e.g. CO_2, CH_4, and N_2O) is the difference in column ozone changes between the tropics and mid-to-high latitudes. In the tropics, ozone column amounts are expected to decrease below historical values (e.g. 1980), while mid- to high-latitude values will increase above historical values. These responses have profound implications for the range of possible future ultraviolet (UV) exposures of humans and ecosystems. Furthermore, changes in tropospheric chemistry and transport in response to global climate change will enhance the importance of understanding the contribution of tropospheric ozone to total column ozone in both latitude regions. Finally, the special chemical and dynamical conditions that characterise the transition region between the troposphere and stratosphere (i.e. upper troposphere and lower stratosphere (UTLS)) require further study to understand the roles of the UTLS region and tropics in influencing global ozone.

From a climate change perspective, the effects of changing climate on stratospheric temperature and chemistry, and of increased GHG concentrations on other aspects of atmospheric chemistry, require attention. In particular, increasing CO_2 levels will lead to cooling of the upper stratosphere, and a consequent upper stratospheric increase of ozone. In addition, changes in tropospheric chemistry induced by climate change are expected to influence tropical ozone through, for example, changes in the BDC.

Significant progress has been made in addressing the recommendations made at the 9th Ozone Research Managers meeting. Some areas in which progress has been documented include:

- There is a better quantification of the lifetime of carbon tetrachloride (CCl_4) in the Earth's atmosphere, thereby reducing, but not completely eliminating, the discrepancy between bottom-up and top-down emission estimates.
- Increased vertical information and spatial density in trace-gas abundance measurements are leading to an improved understanding of sources and sinks of other ozone- and climate-related trace gases.
- The characterisation of long-term ozone changes from multiple observations has been improved and updated, and additional studies are underway to update and improve (i.e. with better uncertainty characterisation) the determination of ozone trends from multiple data sets for use in the 2018 Ozone Assessment.

- Progress has been made in projections of UV radiation in the 21st century that were based on projections of ozone and other factors affecting UV radiation (e.g. clouds, aerosols, albedo, and air pollution). Spectral UV measurements at several locations have been analysed to assess current long-term changes in UV radiation, and to attribute these changes to different factors, all of which are more or less related to changes in climate.

However, there are some areas that still require significant work, as indicated in the following recommendations.

Key research needs recommendations arising from the 10th ORM:

(i) Chemistry-climate interactions and monitoring the Montreal Protocol

It is now well established that the future evolution of the stratospheric ozone layer will depend not just on the decline of ODS concentrations, but also on how climate will affect stratospheric temperatures and circulation.

It is incumbent on the scientific community to monitor the continued effects of the Montreal Protocol through detailed analyses of the wide range of data on ozone, ODSs, their replacements, and related gases so that the impacts of the Protocol can be assessed. Further research, combining state–of-the-art chemistry-climate models (CCMs) and reference-quality, altitude-resolved data records, is needed. This will explain past changes, and will provide an improved understanding of, and a firmer basis for, future projections of composition and climate.

The Delegates to the 10th ORM (hereinafter referred to as "the Delegates") continue to endorse the general recommendations of the 9th ORM. Selected new, specific recommendations include:

1) *Carbon Tetrachloride (CCl_4):* There is a need for further studies to refine the various loss processes contributing to the lifetime of CCl_4 (stratosphere, ocean, and soil), along with studies to better define emissions sources.
2) *Emissions:* Techniques to determine regional fluxes of ODSs and their substitutes need to be developed further and exploited (e.g. inverse modelling methods).
3) *Methyl Bromide (CH_3Br):* There continues to be an imbalance in the global budget of methyl bromide, suggesting that there may be larger amounts of emissions than expected, or that our understanding of methyl bromide removal is somewhat incomplete. Further research into the methyl bromide budget and loss processes are warranted.
4) *Ozone in climate models:* It is now fully recognised that the inclusion of stratospheric and tropospheric ozone in atmospheric models improves the quality of long-term climate change projections, and also creates new opportunities, e.g. for seasonal to decadal weather predictions. Further research is required to understand better those surface climate processes affected by changes in the stratosphere, including changes in tropospheric circulation, tropospheric temperature, precipitation, sea ice, ocean-atmosphere exchange, etc.
5) *The changing Brewer-Dobson Circulation (BDC)*: CCMs predict a strengthening of the BDC under increased GHG concentrations. Detailed studies of tracer data are required to test the projected increases of the BDC. New data in the tropics would be especially useful.
6) *Tropical changes:* The tropics are a key area for chemistry-climate interactions. Future ozone change in the tropics will depend on climate change, affecting changes in the tropical circulation and tropopause temperature, as well as on tropospheric chemistry. The recent unusual behaviour of the quasi-biennial oscillation (QBO) needs to be understood.

7) *Trends in ozone:* Research is required to better quantify trends in vertically resolved ozone data records throughout the stratosphere in different geographical regions, and in particular over the polar regions where observed ozone trends have been largest, and in the upper stratosphere where CO2-induced cooling will increase ozone. Trends in ozone and associated trace gases need to be analysed in detail to assess whether their evolution observed to date is consistent with our understanding of the chemical and physical process affecting their trends and variability. The length of measurement series required to confirm the effectiveness of the Montreal Protocol need to be investigated.

The Delegates wish to stress again the crucial importance of some long-term research efforts highlighted at the 9th ORM, many of which have strong applicability to systematic observations:

1) *Constructing Data Records:* Improved, long-term data records of stratospheric ozone, other trace gases associated with ozone chemistry (e.g. HNO_3, ClO, BrO, H_2O, CH_4, N_2O), and other atmospheric state variables (e.g. temperature) need to be constructed to assess the physical consistency of ozone and temperature trends, and to aid the interpretation of the causes of long-term changes in ozone. A temperature climate data record of the free troposphere and stratosphere is needed to interpret the interactions between changes in the thermal structure of the atmosphere, which will be forced by changes in GHG concentrations, and changes in ozone. Such a temperature data record will also support the construction of ozone data records, since many remote-sensing measurements of ozone mixing ratio often depend on accurate geopotential height, which is temperature-dependent. These temperature time series must be stable over multiple decades to avoid aliasing false temperature trends into false ozone trends. Inhomogeneities in current meteorological reanalyses suggest that this approach to generating temperature time series for the stratosphere is inadequate.
2) *Data Quality:* There is a need for:
    - Studies characterising and better quantifying the measurement uncertainties of ozone and associated parameters by various monitoring instrument types,
    - Continued studies for homogenising long-term ozone data records obtained from various measurement systems, and
    - Continuation of the development and intercomparison of gas standards and their long-term stability required by the international *in situ* trace-gas networks.

(ii) Processes influencing stratospheric evolution and links to climate

The stratosphere is a highly coupled chemistry-radiation-dynamics system. Models need to incorporate the understanding of these processes. In some cases, our knowledge base is incomplete. More and improved laboratory measurements of kinetic, photolytic, thermodynamic, and spectroscopic parameters are required. Field measurements are required to improve understanding, ranging, for example, from the surface emissions of very short-lived substances (VSLS) to the transport and transformation of species between the troposphere and stratosphere (and back again).

1) *Non-ODS gases that affect the ozone layer:* The role played by gases, other than the ODSs controlled under the Montreal Protocol, in ozone-depletion chemistry (e.g., N_2O, CH_4, biogenic bromocarbons) needs to be investigated. Gases such as N_2O and CH_4 not only force climate as GHGs but also influence ozone through their chemical roles. Areas that require attention include:
    (a) Emission data for CH_4 and N_2O need to be improved to permit more realistic modelling of their impacts on ozone. Recently reported tropospheric trends in CH_4 need to be researched and understood.

(b) Changes in atmospheric concentrations of ODS replacements need to be reconciled with their reported/deduced emissions and their atmospheric lifetimes. The effects of changes in tropospheric OH on the lifetimes of short-lived gases that potentially provide a source of chemically active species to the stratosphere need to be better quantified. Seasonally resolved tropospheric OH climatologies, validated against appropriate measurements (see Systematic Observations section), are required to reduce uncertainties in model simulations of the chemically active gases, including the short-lived compounds, that are transported from the surface to the stratosphere.

(c) Great reliance has been placed on methyl chloroform abundances and variations to deduce global OH concentrations and its trends. However, methyl chloroform is nearly depleted from the atmosphere, and a future surrogate for this compound that is as ideally suited to determine global OH abundance needs to be determined.

(d) OH concentrations and their variability are poorly characterised on regional scales, especially where levels of OH sources and sinks are highly variable (e.g., in the transition region from urban to rural areas). Such regional and local information is essential for understanding the degradation of short-lived hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs), and VSLS that influence stratospheric ozone. It is possible that careful monitoring of some of the fluorinated gases themselves could provide a way to deduce regional OH abundances and their trend. To test this approach, more accurate laboratory data and emission information are needed.

2) *HFCs and their replacements:* HFC concentrations continue to grow in the atmosphere. The Kigali Amendment to the Montreal Protocol will limit the production and use of many of the HFCs, requiring the monitoring of their atmospheric evolution. Very short-lived chemicals such as hydrofluoroolefins (HFOs) are being used as substitutes for high global warming potential (GWP) HFCs. The concentrations of these very short-lived HFOs and other chemicals will be highly variable in space and time, owing to transport and rapid atmospheric oxidation by OH. It is essential that good geographic coverage of high-quality, systematic measurements be obtained to allow sectoral, regional emission information to be inferred. The formation of toxic trifluoroacetic acid (TFA) and its analogues, as well as tropospheric ozone from these chemicals, is a concern. Such effects require further research and evaluation.

3) Improvements *to observation sites, their locations, and their utilities:* As noted throughout these recommendations, observations are the foundation of much of ozone layer science. Efforts should be pursued to use atmospheric models, together with Observing System Simulation Experiments (OSSEs), to prioritise new measurement locations. Such an approach also will assist in optimising the co-location of ozone measurements with observations of other atmospheric species and parameters. Such strategic considerations also are essential for monitoring new very short-lived chemicals for which higher spatial and temporal resolution will be required. In addition, maintaining long-term, research-quality observational data requires continued calibrations and intercomparisons.

4) *Laboratory measurements of photolytic, kinetic, and heterogeneous uptake parameters:* Laboratory measurements provide the foundation for satellite retrievals and observations from ground, aircraft, and other platforms, as well as model simulations. There are different classes of information that are needed. They include the following:

(a) *Photolytic processes:* The quality and precision of O_2 and UV ozone absorption cross sections still need to be improved, despite the improvements in ozone absorption cross sections since the 9th ORM. Ground-based, remote-sensing measurements of ozone should be using the updated ozone UV cross sections. The O_2 cross sections have a major impact on the modelling of lifetimes for species that are photolysed in the stratosphere. They also are fundamental to calculating the rate of ozone formation, as well the rates of photolysis of other chemicals such as N_2O. Improvements in laboratory measurements of ozone

absorption lines in the infrared (IR) also are required for improving ground-based retrievals of other trace gases that absorb in the IR.

(b) *Loss processes for chemical modelling:* As new gases (e.g. HFCs and their substitutes) are proposed, it is necessary to make accurate laboratory estimates of their fundamental loss processes (viz. reactions with OH, UV cross-sections, IR absorption spectra, heterogeneous uptake, and products of heterogeneous reactions). Such measurements will ensure better representation of these chemicals in atmospheric models, provide information for their measurements in the atmosphere, and help identify any unintended consequences of their use.

(c) *Data evaluation and curation:* It also is essential that the laboratory data are critically evaluated by groups of experts having deep knowledge of the kinetics, photochemical, spectroscopic, and heterogeneous chemistry. Stewardship and curation of the laboratory data are important to having a trustworthy database for modelling, analyses, and understanding.

5) *Stratospheric aerosols:* Stratospheric aerosols comprising the Junge layer are important as surfaces for heterogeneous chemical processes and for their background radiative forcing. In recent years, aerosols other than sulphuric acid also have been recognised. These aerosols have influences beyond the stratosphere, where they reside. Hence, understanding the processes that control the formation and distribution of aerosols is fundamental to modelling the stratosphere. New research has shown that transport of sulphur dioxide (SO_2) across the tropical tropopause has been systematically overestimated by some models and remote-sensing observations. In light of these new observations, research efforts are required to re-evaluate the background sulphur budget, including both SO2 and carbonyl sulphide (OCS), in the lower stratosphere.

   Volcanic eruptions are a frequent and episodic source of sulphur compounds to the troposphere. Occasional large explosive eruptions (e.g. Mt. Pinatubo in 1991) also inject substantial quantities of sulphur into the stratosphere. Sulphur gases ultimately produce sulphate aerosol, which warms the stratosphere, cools the troposphere, and enhances ozone destruction for several years following an eruption. Accounting for mass emissions of sulphur and their fate is an important component of quantifying past and present global ozone changes. The observed surface cooling effect of sulphate aerosols has led to suggestions for radiation management (climate engineering) activities that use injections of anthropogenic sulphur or other materials to reduce surface temperatures. In atmospheric models, sulphate injections lead to significant changes in stratospheric chemistry and dynamics, especially on ozone levels. Future research directions should include the potential role of climate engineering in future stratospheric ozone scenarios.

6) *Stratosphere-troposphere exchange (STE):* Research is required to improve understanding of the processes controlling the two-way exchange of gases and aerosols between the troposphere and the stratosphere, such as: (i) the Asian Monsoon circulation that provides an efficient pathway for pollutants from close to the surface through the tropical tropopause layer and into the stratosphere, (ii) injection of water vapour through meso- and synoptic-scale events, and (iii) stratospheric intrusions that bring ozone downwards to the troposphere and surface. The fidelity of CCM simulations of STE processes must be assured to have confidence in projections of STE changes through the 21st century, which alter ODS lifetimes and influence the timescales for ozone-layer recovery. Systematic and targeted field campaigns are required to better characterise many of the key processes. They include understanding tropical and extra-tropical processes, and processes active in the UTLS region that modulate the chemical and dynamical two-way coupling between the stratosphere and troposphere.

(iii) UV changes and other impacts of ODS changes

Simulations of ozone changes through the 21st century suggest that there will be increases of surface UV in the tropics. This poses the risk of elevated skin cancer incidence and cataracts

for humans, and adverse effects on ecosystems. Projected UV decreases at mid-to-high latitudes enhance the risk of insufficient UV doses for production of Vitamin D. In addition, there is little information on the impact of lower levels of UV on the biosphere and on the tropospheric chemistry processes. Various needs for research remain, including:

1) *Factors affecting UV*: There is a need to disaggregate the factors affecting UV radiation at the surface so that the influence of factors other than ozone (e.g. aerosols, clouds, albedo, air pollution) can be better assessed.
2) *UV change impacts*: The effects of stratospheric ozone change, and the resulting changes in UV radiation on human health, ecosystems, and materials, require further study. These studies should include quantitative analyses that allow an assessment of the magnitude of specific impacts in relation to UV changes. Research also should account for interactions between the effects of both positive and negative UV change and those of climate change, particularly effects that may lead to feedbacks to climate change, e.g. through altered carbon cycling or tropospheric chemistry. For example, how will UV-B radiation changes affect the CO2 budget by breaking down dissolved organic matter that enters aquatic ecosystems?
3) *ODS substitutes:* Further studies are needed to investigate the environmental effects of ODSs and their substitutes, as well as their degradation products, on human health and the environment, particularly TFA.

C. Systematic Observations

As already stated in Article 3 of the Vienna Convention, and emphasised in the previous section, systematic observations are critical for monitoring and understanding long-term changes in the ozone layer, as well as changes in atmospheric composition, circulation, and climate. In order to verify the expected ozone recovery from ODSs and to understand interactions with changing climate, continuing observations of key trace gases, UV radiation, and parameters characterising the role of chemical, radiative, and dynamical processes will be required for many decades.

The stratosphere is now moving from a period when increasing concentrations of ODSs were threatening the ozone layer, to a regime where ODSs are no longer increasing and ozone layer depletion has not worsened. It is a period that does not yet unambiguously show the influences of ODS changes, and, furthermore, a period when gases other than ODSs (especially CO_2, N_2O, CH_4, and H_2O) also influence global ozone changes. Future emissions of these non-ODS gases are quite uncertain. These impacts are complex and are interconnected. Therefore, robust long-term monitoring is also essential in this period moving towards the recovery of the ozone layer in the latter part of this century.

Monitoring also needs to be expanded to include important new species and parameters, e.g. emerging ODS replacements and tracers of circulation. Such long-term measurements need to be of sufficiently high quality so as to provide for unambiguous analyses. Key measurement regions include the UTLS, regions of stratosphere-troposphere exchange in the extra-tropics such as Monsoon circulations, as well as the polar caps and the upper stratosphere.

Key systematic observations achievements since the 9th ORM:

1) Despite various difficulties, ground- and space-based measurements of ozone, most relevant trace gases, temperature, and stratospheric aerosol have continued over the last years. The Trust Fund has played an important role in providing support, especially for the ground-based global observation network.
2) The limb-observing component of the Ozone Mapping and Profiler Suite (OMPS) on the current Suomi National Polar-orbiting Partnership (Suomi-NPP) platform, and the planned continuation on the second Joint Polar Satellite System (JPSS-2) platform; the current deployment of the Stratospheric Aerosol and Gas Experiment III (SAGE III) solar occultation instrument on the International Space Station; and the planned Atmospheric Limb Tracker for the Investigation of the Upcoming Stratosphere

(ALTIUS) satellite mission have reduced the imminent gap in atmospheric limb sounding instruments for ozone, aerosol, and water vapour. However, as indicated in the key recommendations below, a significant loss of limb measurement capabilities is still expected for many other important gases.

3) Several Dobson and Brewer instruments have been refurbished and installed in Article 5 countries. However, some are not yet in regular operation. More support, e.g. via the Vienna Convention Trust Fund, could help to remedy this. As an example, Egypt is requesting financial support for calibration of their Brewer instrument. The Trust Fund Advisory Committee is evaluating this and other proposals, prioritizing them for support.

4) New UV ozone absorption cross sections have been agreed upon, and are now used in most applications. However, they still need to be implemented by some established ground-based networks. This requires accounting for ozone layer temperatures and recalculation of the historic records.

5) Substantial progress has been made with understanding and improving the historical ozonesonde records within the Ozonesonde Data Quality Assessment (O3S-DQA) activity.

6) Global stratospheric aerosol records have been re-evaluated and homogenised, and the newly deployed SAGE III instrument promises to continue these global observations.

7) Progress has been made in terms of timely delivery of ozone and related data from ground-based stations, and in the use of these data for validation of services, such as the Copernicus Atmospheric Monitoring Service, as well as for satellite validation. These activities went hand-in-hand with better characterisation of uncertainties in all data sources, with improved practices and standards, and have resulted in improved data quality. Further progress in these directions is encouraged.

8) New and more modern instrument types are being tested and integrated into ground-based networks. Examples include Pandora and Multi Axis Differential Optical Absorption Spectroscopy (MAX-DOAS) spectrometers for ozone, and Air-Core samplers on small balloons for other trace gases.

9) Substantial progress has been made in assessing and improving the quality of long-term ozone profile records from satellites. Key to this were intercomparisons of all existing data sources, and much-improved approaches to merging the records from different individual instruments. Several improved records are now available, but comprehensive assessment of all the uncertainty sources for these long-term records still is required. Activities in this direction are underway, e.g. the joint Global Atmosphere Watch / Stratosphere-troposphere Processes And their Role in Climate (GAW/SPARC) Long-term Ozone Trends and Uncertainties in the Stratosphere (LOTUS) and the SPARC Towards Unified Error Reporting (TUNER) activities.

Key systematic observations recommendations arising from the 10th ORM:

1) The important connection between changes in ozone, climate, and atmospheric transport, and, in particular, the expected changes in the global meridional BDC and unexpected events like the recent break of the QBO, require appropriate monitoring of temperature, winds, and trace-gas profiles, especially of dynamical tracers like N2O and SF6, as well as ozone and water vapour. Observations particularly are needed for the analysis and improvement of the BDC derived from data assimilation systems.

2) Continuation of ground-based stations, especially those with long-term records of ozone, trace gases, UV, temperature, and aerosols, is necessary to provide a reliable baseline for trend estimation and for assessments of polar ozone loss such as the MATCH polar campaigns. The steady decrease in the number of stations, especially for profile measurement capabilities, is endangering the unambiguous determination of trends and the capturing of unexpected events, as well as our ability to validate satellite data records. To ensure trustworthy data, it is essential that global

calibration and quality assurance systems continue to be fully supported with the relevant calibration facilities and protocols.

3) Continuation of limb emission and IR solar occultation observations from space is necessary for global vertical profiles of many ozone and climate-related trace gases and parameters. Without such observations, the accuracy of the predictions of data assimilation systems and related services to policymakers degrade, the detection and interpretation of changes in atmospheric circulation are hampered, and events like the severe 2011 Arctic ozone depletion cannot be analysed.

4) Where scientific needs are clearly identified, regular, long-term monitoring should be restored, and, in some cases, expanded. Key regions are those of troposphere-stratosphere exchange, such as Monsoon regions, Southeast Asia, the maritime continent, and the Himalayas and Central Asia mountainous regions. Measurements also should be targeted to data-poor areas like South America, Africa, and Asia, and in the inter-tropical region for accurate detection of BDC changes and other transport phenomena.

5) Emerging approaches coupling models and observational aspects, like OSSEs, should be developed further, and used for strategic planning of new monitoring station locations, for developing station priorities where needed, and for the optimum (or required) co-location of observations. Such strategic considerations are essential for monitoring, for example, new very short-lived chemicals. In addition, model development may be needed for the effective utilisation of data from new measurement techniques.

6) As most of the concentrations of ODSs are declining, other source gases, especially N_2O, CH_4, and water vapour, are becoming more important for their impacts on the ozone layer and climate change. Increased efforts to monitor vertical profiles of these gases through the troposphere and stratosphere, understand their changing fluxes, and better assess their impacts will be required.

7) Measurements of emerging ODS substitutes (HFCs, HFOs, etc.) and very short-lived halogen-containing substances at global and regional scales need to be included in baseline monitoring programmes.

8) The community should continue the implementation of new and cost-effective instruments for ozone and trace gases, as well as data analysis protocols. This includes further progression with network harmonisation. Examples include the European Brewer Network (EUBrewNet), Pandora, DOAS/Système d'Analyse par Observation Zénithale (SAOZ), Air-Core, etc. Current regional harmonisation initiatives should be expanded to global partners, e.g. Indian ozonesondes could be included in WMO's O3S-DQA.

9) Mechanisms should be set up to give appropriate recognition to data providers, and to exchange findings and feedback on data quality. For example, the contribution of individual stations or networks to satellite validation could be acknowledged by an exchange of letters between space agencies and observational stations.

D. Data Archiving and Stewardship

Progress made on the recommendations made at the 9th Ozone Research Managers meeting includes the following:

- The need for comprehensive reporting of national ODS production and consumption to improve emission inventories continues to be addressed. Reporting continues successfully for most ODSs, although some discrepancies of unknown origin between reported production and atmospheric observations remain for CCl_4. Global reporting of non-ODS substitutes (e.g. HFCs to the United Nations Framework Convention on Climate Change (UNFCCC)) is currently insufficient for reconciling global-scale observations. In addition, countries should be encouraged to submit revised production and/or consumption figures from past years, when warranted.

- There has been some progress in the development of robust automated data submission with centralised and standard processing wherever feasible, and quality assurance (QA) schemes to ensure timely – or even near-real-time (NRT) – submission, to the appropriate data centres.
- Progress has been made towards more cost efficient and effective data archiving. Recommendations from the 9th ORM in this regard were adopted by EUBrewNet, and will automatically apply to new members of this Network.

  Similar archiving developments are underway for other measurement systems (e.g. Network for the Detection of Atmospheric Composition Change (NDACC), Southern Hemisphere ADditional OZonesondes (SHADOZ), SKYNET, and In-service Aircraft for a Global Observing System (IAGOS)).
- There is a need to digitise historical data for ozone and related species. Some stations have pre-SHADOZ data, and some of this has been digitised, but resources are not available to complete this process for all stations. The Copernicus climate change service has initiated some actions to aid in this regard.
- Funding agencies need to recognise long-term archiving as a resource-intensive, but critical, part of any measurement program. Stewardship and succession must be a consideration. Long-term data preservation (LTDP) must be supported further. By way of progress, it was noted that ESA recognises the asset of LTDP, and supports a dedicated LTDP programme. In addition, NASA continues to archive all data stored in the NASA Earth Science Distributed Active Archive Centres (DAACs), per the long-standing NASA Earth Science data policy.
- Progress with the submission of level-0 Dobson data has been made, e.g. Dobson data to WOUDC. The enhancement of these actions is highly encouraged.

Key data archiving and stewardship recommendations arising from the 10th ORM:

1) The Delegates re-emphasize the past Recommendation regarding the continuing need to develop robust automated data submission with centralised and standard processing wherever feasible, and QA schemes to ensure timely – or even NRT – submission, to the appropriate data centres. All necessary information to process and reprocess data, e.g. calibration histories, should be included in the processing facility. Scientific oversight is required. Satellite overpass data and metadata with tools to determine co-locations with ground- and aircraft-based programs should be readily accessible to the data centre, data users, and data providers to allow for initial quality assessments in near-real time. Vice versa, ground station data should be readily accessible to the satellite teams. Databases should be configured to store multiple versions with full traceability.
2) There is a continuing need to allocate resources to digitise historical data for ozone and related species, as well as for ancillary data (e.g. laboratory spectroscopic data, station information, etc.), where available and before the information gets lost, in order to include the data in modern database systems.
3) Continue to encourage data providers to submit or link to established databases to avoid a proliferation of databases, and to avoid the loss of data after the end of a campaign or project.
4) Funding agencies need to continue to recognise long-term archiving as a resource-intensive, but critical, part of any measurement or modelling programmes. Stewardship and succession should be a consideration. LTDP should be supported further. For example, member States of ESA have made progress in supporting the ESA LTDP program. Solutions for the long-term sustainability of databases should be sought (e.g. the Carbon Dioxide Information Analysis Centre (CDIAC), EUBrewNet).
5) Central data archives for satellite data sets (e.g. the Distributed Active Archive Centre (DAAC) at NASA) should be established by other agencies, and linked via a central portal (e.g. the Committee on Earth Observation Satellites (CEOS) portal), on a sustainable basis. The WDC-RSAT (World Data Centre for Remote Sensing of the

Atmosphere, operated by the German Aerospace Centre (DLR) in Oberpfaffenhofen, Germany) may play this role in Europe. Satellite overpass data and subsets coincident with ground-based network stations should be readily available (e.g. facilities like the Aura Validation Data Centre (AVDC), the ESA Validation Data Centre (EVDC), and the Tropospheric Emission Monitoring Internet Service (TEMIS) should be sustained).

6) Enhanced linkage among data centres should be targeted further. This requires that data centres coordinate more, and further progress with the exchange of metadata and interoperability. Open and user-friendly formats and data access should be encouraged; data that are not open to the community should be made widely available. Different data levels (L0 to L3; merged data sets) may be required for different users. Efforts should be continued to generate homogenous long-term data records from available sources.

7) Data centres should be able to provide data in several accepted standard formats. It should be the data centres' responsibility to provide tools to re-format, read, and view the data, and, if possible, carry out initial quality checks on submitted data using scientific oversight. Other responsibilities for data centres should be clearly established.

8) Data publishing with an associated digital object identifier (doi), e.g. in Pangaea or Earth System Science Data (ESSD), should be encouraged to provide data to the scientific community, and to give recognition to scientists and the funding agencies for providing the data. This also may offer a good solution for the archiving (including traceability) of model output or single data sets.

9) An open data policy is encouraged to allow the maximum return on data collection or modelling activities.

10) Pro-active communication between data centres and data providers should be encouraged to reduce the risk of data loss.

11) Actions should be taken by monitoring stations operating Brewer spectrophotometers or other types of spectral and broadband instruments towards increasing the submission rate of UV Index data to the World Ozone and UV Data Centre (WOUDC). Ensuring the quality of this data is imperative, as their use is directly related to effects of UV radiation on human health and ecosystems.

E. Capacity Building

While capacity building for ozone monitoring and research in developing countries and in countries with economies in transition comes from the general commitments anchored in the Vienna Convention, it is of itself an essential component of achieving a truly successful Montreal Protocol.

The atmosphere covers the globe, and does not recognize national borders, thus requiring measurements with full global coverage for a proper scientific understanding of ozone. To be full participants in the Montreal Protocol, all countries need to be partners in our ever-growing scientific understanding, and the global need is for all countries to make contributions to research efforts, particularly in the decades to come. When this occurs, local experts will exist who can communicate with regional policymakers, and who can speak with authority on the importance of compliance with the Montreal Protocol.

One of the main goals of capacity building is the enhancement of ozone-monitoring networks, such as that of GAW, and the creation of local scientific communities contributing to global ozone science. This can be achieved through partnerships that exchange knowledge between the industrialised world and developing countries. The rapid advancement of modern communications technology brings new opportunities to establish and conduct such partnerships.

Decision X/2, Paragraph 3 of the Conference of the Parties to the Vienna Convention states: "To accord priority to capacity building activities, in particular the specific projects identified for priority funding under the General Trust Fund for Financing Activities on Research and Systematic Observations Relevant to the Vienna Convention, related to the inter-calibration of instruments, the training of instrument operators, and increasing the number of ozone observations, especially through the relocation of available Dobson instruments."

Key capacity building achievements since the 9th ORM:

1) Activities completed under the Trust Fund

- *Activity 1:* Dobson intercomparison; Dahab, Egypt; 23 February–12 March 2004.
- *Activity 2:* Calibration of Brewer instrument no. 116 in Bandung, Indonesia; 5–9 September 2006.
- *Activity 3:* Calibration of Brewer instrument no. 176 in Kathmandu, Nepal; 20–26 September 2006.
- *Activity 4:* Dobson intercomparison in Irene, South Africa; 12–30 October and 15–26 November 2009.
- *Activity 5:* Workshop on data quality in the total ozone network in Hradec Králové, Czechia; 14–18 February 2011.
- *Activity 6:* Relocation of Dobson no. 14 (formerly deployed in Tromsø, Norway) to Tomsk, Russian Federation, and Dobson training course in Hradec Králové, Czechia; 7–14 April 2015.
- *Activity 7:* Dobson training course in Amberd, Armenia; 28 September–4 October 2015.
- *Activity 8:* Dobson intercomparison campaign for Asia, hosted by the Japanese Meteorological Agency, in Tsukuba, Japan; 7–25 March 2016.
- *Activity 9:* Dobson intercomparison campaign for Australia and Oceania, hosted by the Australian Bureau of Meteorology, in Melbourne, Australia; 13-24 February 2017.

2) Planned activities

The following activities were listed for priority funding at the 9th ORM meeting in 2014. They have been approved by the Trust Fund Advisory Committee, and will be financed by the Trust Fund:

- Relocation of Dobson no. 8 (formerly deployed in Spitsbergen, Norway, and the property of the Norwegian Polar Institute) to Singapore, following repair and calibration in Germany, and sending Dobson no. 7, currently located in Singapore and out of order, to Germany for possible repair. These activities are tentatively scheduled to take place in the second half of 2017.
- Training course on making ozone measurements with a Brewer instrument in conjunction with a Brewer Users Group meeting. The meeting is to be held in Sydney, Australia, 4–9 September 2017. The budget will be shared between the Vienna Convention Trust Fund and the Canadian Brewer Trust Fund.
- Dobson intercomparison campaigns for Northern and Southern Africa. The campaign for Northern Africa is to be hosted by the Spanish State Meteorological Agency, and will be held in El Arenosillo, Spain, from 4–15 September 2017. The campaign for Southern Africa is to be hosted by the South African Weather Service, and will be held in Irene, South Africa, in September/October 2018.
- A Dobson intercomparison campaign for South and Latin America, to be hosted by the National Meteorological Service of Argentina, is scheduled to take place in Buenos Aires, from 13 November–1 December 2017.

In response to the Ozone Secretariat's invitation to all developing countries and countries with economies in transition for the submission of project proposals, six proposals were received in 2016, and considered for financing by the Trust Fund Advisory Committee in March 2017. Implementation depends on the availability of funds. Feedback from the Advisory Committee's evaluations is being provided to the proposers. The six proposals are:

- *Belarus:* Preparing and realising intercomparison sessions of three instruments engineered and currently operated at the National Ozone Monitoring Research and Educational Centre, Belarusian State University, to monitor total ozone and UV radiation in Belarus.
- Ecuador: The Ecuadorian Highlands Ozonesondes (ECHOZ) project.
- Kenya: Capacity building on data management and instrument calibration.
- Oman: Measurement of the diurnal and seasonal variation of ozone towards improving knowledge on ozone trend estimates: A case study of Oman.
- Togo: Construction of and equipping a laboratory for continuous measurement of the stratospheric ozone layer and atmospheric ozone.
- Joint *project proposal by WMO/GAW and SHADOZ:* Jülich Ozone Sonde Intercomparison Experiment (JOSIE) 2017.

Key capacity building recommendations arising from the 10th ORM:

1) To identify the needs of individual countries, and improve communication within regions to better serve and support those needs. Before any education and training can be offered, there first needs to be an understanding of the level of knowledge, training, instrumentation, and support in local communities. There also needs to be an understanding of how newly established capacity will be continued under national support. Long-term support through twinning and having specific contact points with regional experts is essential.
2) To provide training opportunities for local station operators in developing countries. These human resources with valuable local knowledge could then help train others within their countries. The participants at the 10th ORM expressed the need for more training on basic measurement techniques, data handling, and analysis methods. Such training could be supplemented with online materials, videos, software tools, and real-time communication with trainers. This will improve the level of local scientific understanding, data-taking capabilities, and quality assurance. Supporting materials and guidebooks appropriate to the level of instruction need to be produced and shared.
3) To provide fellowships to support the scientific development of students from developing countries. These students are a critical link, and will help improve the level of engagement and understanding in their respective countries. Student exchanges and knowledge transfers between developed and developing countries are vital to building these relationships.
4) To maintain the quality of the global ozone-observing system through the continuation and expansion of regular calibrations and intercomparison campaigns. The quality of the data from ozone-observing networks depends on such exercises. Calibration and intercomparison campaigns also include the transfer of knowledge from experts in developed countries to station managers in developing countries. Offering instructional courses and workshops alongside these campaigns would be the ideal venue to train local operators.
5) WMO and the Ozone Secretariat to facilitate bridging the gap between different communities. Collaboration between Ozone Officers and National Meteorological Agencies should be enhanced. In many Article 5 countries, there is a large disconnection between the two. The Ozone Secretariat should establish a list of ozone/UV/climate research institutions in each country to be sure the communication is effective.

6) To increase outreach activities by finding alternate funding streams (e.g. manufacturers, private sector, etc.) and helping to support development activities.

7) Article 5 countries and countries with economies in transition should be assisted and encouraged to expand their scientific capacity to allow them to participate actively in ozone research activities, including assessment activities under the Montreal Protocol.

8) A working group should be formed, under the guidance of the Trust Fund Advisory Committee, to allow continued and enhanced scientific capacity among all parties of the Montreal Protocol. This working group could include scientists from organizations with significant scientific capacity, and those with a need to increase their scientific capacity.

Closure of the Meeting

Statements of appreciation were made by Mr Geir Braathen on behalf of WMO, Ms Tina Birmpili on behalf of the United Nations Environment Programme and the Ozone Secretariat, as well as the Parties to the Vienna Convention, and Mr Kenneth Jucks and Mr Gerrie Coetzee, the Co-Chairs of the 10th ORM.

ANNEX A

WMO/UNITED NATIONS ENVIRONMENT PROGRAMME TENTH MEETING OF THE OZONE RESEARCH MANAGERS OF THE PARTIES TO THE VIENNA CONVENTION FOR THE PROTECTION OF THE OZONE LAYER (Geneva, 28-30 March 2017)

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Group Photo of Participants at the Tenth Meeting of the Ozone Research Managers of the Parties to the Vienna Convention for the Protection of the Ozone Layer

Geneva, Switzerland, 28-30 March 2017

ANNEX B

WMO/UNITED NATIONS ENVIRONMENT PROGRAMME TENTH MEETING OF THE OZONE RESEARCH MANAGERS OF THE PARTIES TO THE VIENNA CONVENTION FOR THE PROTECTION OF THE OZONE LAYER (Geneva, 28-30 March 2017)

FINAL AGENDA

Tuesday, 28 March 2017

08:00 onwards Registration

09:00 – 09:30 Opening of the Meeting
- Opening statement, Tina Birmpili, Executive Secretary, Ozone Secretariat
- Welcome statement, Deon Terblanche (WMO)
- The Ozone Research Managers (ORM) recommendations and the interface with the Scientific Assessment of Ozone Depletion: 2018, Paul Newman, Co-Chair of the Scientific Assessment Panel (SAP) and Michael Kurylo, 9th ORM Co-Chairs

09:30 – 09:45 Review of the Recommendations of the 9th Meeting of the Ozone Research Managers and the Resultant Decisions of the 10th Conference of the Parties to the Vienna Convention, Michael Kurylo and Gerrie Coetzee, 9th ORM Co-Chairs

09:45 – 9:50 Personal remarks on his legacy as ORM Co-Chair, Michael J. Kurylo, 9th ORM Co-Chair

09:50 – 10:00 Election of the 10th ORM Co-Chairs

10:00-10:10 Adoption of the 10th ORM agenda

SESSION 1: ISSUES RELATED TO THE VIENNA CONVENTION FOR THE PROTECTION OF THE OZONE LAYER

10:10 – 10:40 Activities under the Trust Fund for Financing Activities on Research and Systematic Observations Relevant to the Vienna Convention
- The status of the Trust Fund, Sophia Mylona, Ozone Secretariat
- Report on activities under the Trust Fund, Geir Braathen, WMO
- Report of the Trust Fund Advisory Committee, A. R. Ravishankara, Advisory Committee Chair

10:40 – 11:00 Discussion

11:00 – 11:10 Appointment of discussion leaders and rapporteurs for the various recommendation areas: Research Needs, Systematic Observations, Data Archiving and Stewardship, and Capacity Building

Tuesday, 28 March 2017 (continued)

SESSION 2: THE STATE OF THE OZONE LAYER

11:10 – 11:30 Past, current and future states of the ozone layer, Wolfgang Steinbrecht, DWD

11:30 – 11:45 The mystery of carbon tetrachloride, Paul Newman, SAP Co-Chair

11:45 – 12:00 Technology- and economy-related issues under the Montreal Protocol: Progress made and challenges ahead, Marta Pizano, Technology and Economic Assessment Panel (TEAP) Co-Chair

12:00 – 12:15 Surface UV radiation in the 21st century: Environmental effects of changes in ozone and climate, Alkis Bais, Environmental Effects Assessment Panel (EEAP) member

12:15 – 13:45 Lunch

SESSION 3: INTERACTIONS BETWEEN OZONE LAYER DEPLETION AND CLIMATE CHANGE – PHASING DOWN OF HYDROFLUOROCARBONS UNDER THE MONTREAL PROTOCOL

13:45 – 14:05 Links between stratospheric ozone, ozone-depleting substances, and climate, John Pyle, SAP Co-Chair

14:05 – 14:25 Observations and trends of HFCs, Stephen Montzka, NOAA

14:25 – 14:45 HFC scenarios and projected climate impacts of the Kigali Amendment, Guus Velders, RIVM

14:45 – 15:30 Discussion

SESSION 4: INTERNATIONAL MONITORING PROGRAMMES

15:30 – 15:45 The International Ozone Commission (IO_3C), Sophie Godin-Beekmann, IO_3C President

15:45 – 16:00 The WMO Global Atmosphere Watch (GAW) Programme, Oksana Tarasova, WMO

16:00 – 16:15 The Global Atmosphere Watch Ozone Observing System, Alkis Bais, Ozone Scientific Advisory Committee (SAG) Chair

16:15 – 16:30 The Network for the Detection of Atmospheric Composition Change (NDACC), Martine De Mazière, BIRA-IASB and Anne Thompson, NASA

16:30 – 16:45 Coffee/tea

16:45 – 17:00 Ground-based networks for measuring ozone and climate-related trace gases and the current state of the atmosphere, Stephen Montzka, NOAA

17:00 – 17:15 International ozonesonde activities, Michael Kurylo on behalf of Anne Thompson, NASA

17:15 – 17:30 Global Climate Observing System (GCOS), including GRUAN, Geir Braathen, WMO

Tuesday, 28 March 2017 (continued)

17:30 – 17:45 The stratosphere-troposphere processes and their role in climate project of WCRP: The joint SPARC/IO_3C/WMO/NDACC initiative on past trends in the vertical distribution of ozone, SI^2N, and new initiatives such as OCTAV-UTLS and LOTUS, Sophie Godin-Beekmann, CNRS

17:45 – 18:00 The European COST Action EUBrewNet: Towards consistency in quality control, quality assurance, and coordinated operations of the Brewer Instrument, John Rimmer, University of Manchester

18:00 – 18:30 Discussion

18:30 – 20:00 Cocktail Reception (WMO Attic, 9th floor)

Wednesday, 29 March 2017

SESSION 5: SATELLITE RESEARCH AND MONITORING

09:00 – 10:00 Current and planned ozone and climate observations from space
- U.S. satellite programmes: NASA, NOAA, and other agencies, Kenneth Jucks, NASA
- European Space Agency activities, Claus Zehner, ESA/ESRIN
- KNMI space-based measurement activities, Peter van Velthoven, KNMI

10:00 – 10:20 Lessons learned in creating long-term ozone datasets: Recommendations for the future, Richard McPeters, NASA

10:20 – 10:40 Summary of the key issues in space-based measurements: Identification of future needs and opportunities, Jean-Christopher Lambert, BIRA-IASB

10:40 – 11:40 Discussion: Initial framing of recommendations

SESSION 6: NATIONAL AND REGIONAL REPORTS ON OZONE RESEARCH AND MONITORING

11:40 – 12:00 Region 1: Africa, Gerrie Coetzee, South African Weather Service

12:00 – 12:20 Region 2: Asia, Nozomu Ohkawara, JMA

12:20 – 12:40 Region 3: South America, Eduardo Luccini, CONICET-CEPROCOR

12:40 – 14:00 Lunch

14:00 – 15:00 Region 4: North America, Central America, and the Caribbean
- USA, Kenneth Jucks, NASA and Stephen Montzka, NOAA
- Canada, SumChi Lee, Environment and Climate Change Canada
- Central America, Mexico, and the Caribbean, Juan Carlos Peláez Chávez, INSMET

15:00 – 15:20 Region 5: South-West Pacific, Matt Tully, BoM

15:20 – 15:40 Polar regions
- Antarctica, Jonathan Shanklin, British Antarctic Survey
- Other activities in Antarctica and in the Arctic, Geir Braathen, WMO

Wednesday, 29 March 2017 (continued)

15:40 – 16:00 Coffee/tea

16:00 – 17:00 Region 6: Europe
- European Union, Vincent-Henri Peuch, ECMWF, European Commission
- Northern Europe, Weine Josefsson, SMHI (Sweden)
- Western, Central and Eastern Europe, Wolfgang Steinbrecht, DWD (Germany)
- Southern Europe, Alberto Redondas Marrero, AEMET (Spain)

17:00 – 18:15 Discussion: Breakout groups meet to frame initial recommendations
- Review of Research Needs, Systematic Observations, Data Archiving and Stewardship, and Capacity Building activities conducted by Parties by Decision VCX/2; identification of needs and gaps

18:15 – 18:30 Long-term strategy and short-term plan of action of the Trust Fund, A. R. Ravishankara, Trust Fund Advisory Committee Chair

Thursday, 30 March 2017

SESSION 7: DISCUSSION ON AND ADOPTION OF RECOMMENDATIONS

09:00 – 10:00 Breakout groups meet to work on recommendations

Ongoing Coffee/tea served outside the main meeting hall

10:00 – 11:00 Research Needs: Presentation of initial draft by David Fahey and Michael Kurylo, (Paul Newman and A. R. Ravishankara, Rapporteurs)

11:00 – 12:00 Systematic Observations: Presentation of initial draft by Jean-Christopher Lambert and Wolfgang Steinbrecht, (Nis Jepsen and Richard McPeters, Rapporteurs)

12:00 – 13:00 Data Archiving and Stewardship: Presentation of initial draft by Martine De Mazière and John Rimmer, (Sum Chi Lee and Stephen Montzka, Rapporteurs)

13:00 – 14:15 Lunch

14:15 – 14:45 Capacity Building: Presentation of initial draft by Geir Braathen and Bonfils Safari (Richard Querel and Matt Tully, Rapporteurs)

14:45 – 15:30 Breakout groups meet to finalize recommendations

15:30 – 17:00 Discussion and adoption of the recommendations

17:00 – 17:30 Other matters

17:30 Closure of the meeting

ANNEX C

WMO/UNITED NATIONS ENVIRONMENT PROGRAMME TENTH MEETING OF THE OZONE RESEARCH MANAGERS OF THE PARTIES TO THE VIENNA CONVENTION FOR THE PROTECTION OF THE OZONE LAYER

(Geneva, 28-30 March 2017)

DECISIONS OF THE TENTH MEETING OF THE CONFERENCE OF THE PARTIES TO THE VIENNA CONVENTION

X/1: Status of ratification of the Vienna Convention, the Montreal Protocol and the London, Copenhagen, Montreal and Beijing amendments to the Montreal Protocol

1. To note with satisfaction the universal ratification of the Vienna Convention for the Protection of the Ozone Layer, the Montreal Protocol on Substances that Deplete the Ozone Layer, and the London Amendment, the Copenhagen Amendment and the Montreal Amendment to the Montreal Protocol;

2. To note that, as at 1 November 2014, 196 parties had ratified the Beijing Amendment to the Montreal Protocol;

3. To urge Mauritania, which has not yet done so, to ratify, approve or accede to the Beijing Amendment to the Montreal Protocol, taking into account that universal participation is necessary to ensure the protection of the ozone layer;

X/2: Recommendations of the ninth meeting of the Ozone Research Managers

Recalling that, pursuant to the objectives defined in decision I/6 of the Conference of the Parties to the Vienna Convention for the Protection of the Ozone Layer, the Ozone Research Managers review ongoing national and international research and monitoring programmes with a view to ensuring the proper coordination of those programmes and identifying gaps that need to be addressed,

Recognizing the importance of continuing and enhancing the monitoring of changes in the ozone layer, including its projected recovery in an atmosphere whose conditions are different from pre-1980 conditions owing to changes in its composition,

Recognizing also that the latest assessment by the Scientific Assessment Panel suggests a potential influence of climate change on the ozone layer, especially in the tropics,

Recognizing further the need to increase knowledge and understanding of the atmosphere and its processes, with regard to which many uncertainties remain, including the intricate linkages between the ozone layer and climate and, therefore, the need to monitor and analyse the ozone layer and climate variables together whenever possible,

Noting the importance of capacity-building activities in parties operating under paragraph 1 of Article 5 of the Montreal Protocol that expand scientific expertise and have the added benefit of expanding the geographic area that can be measured and data archives in respect of the key variables related to the ozone layer and changing climate,

1. To take note with appreciation of the report of the ninth meeting of the Ozone Research Managers, published in 2014 (World Meteorological Organization Global Ozone Research and Monitoring Project Report No. 54);

2. To encourage parties to adopt and implement as appropriate the recommendations of the Ozone Research Managers under the topics of research, systematic observations, data archiving and capacity-building;

3. To accord priority to capacity-building activities, in particular the specific projects identified for priority funding under the General Trust Fund for Financing Activities on

Research and Systematic Observations Relevant to the Vienna Convention, related to the inter-calibration of instruments, the training of instrument operators and increasing the number of ozone observations, especially through the relocation of available Dobson instruments;

4. To encourage the Ozone Research Managers to review, at their tenth meeting, in 2017, the capacity-building activities that have been conducted, with a view to assessing their effectiveness, and to include further specific recommendations in their report to the Conference of the Parties;

5. To encourage the national ozone focal points, or other appropriate officials, to distribute information on, and coordinate where relevant, monitoring, research and scientific activities in their countries;

X/3: General Trust Fund for Financing Activities on Research and Systematic Observations Relevant to the Vienna Convention

Recalling decision VI/2, by which the Conference of the Parties established the General Trust Fund for Financing Activities on Research and Systematic Observations Relevant to the Vienna Convention for the Protection of the Ozone Layer, and noting that the current life of the Trust Fund will expire at the end of 2015,

Noting with appreciation the contributions to the Trust Fund by several parties and the joint efforts of the World Meteorological Organization and the Ozone Secretariat in the implementation of the activities funded by the Trust Fund since it became operational in 2003,

Noting that important activities, including calibrations, inter-comparisons and relevant training, have been implemented successfully under the Trust Fund to date,

Noting with concern, however, that the resources available in the Trust Fund are not sufficient to enable substantial and sustainable improvements to be made to the global ozone observing system,

Noting that the coming decade is a crucial time during which the status of the recovery of the ozone layer will become clearer, but that such clarity will be dependent on continued high-quality observations,

Aware that improvements in ozone observations should take into account the existing strong and intricate linkages between ozone and climate, and carry out relevant observations and analyses for both ozone and climate wherever possible,

Noting that the Ozone Research Managers, at their ninth meeting, in 2014, reviewed the status and activities of the Trust Fund, considered options for the way forward for the Fund and provided specific recommendations on the matter,

1. To request the Executive Director of the United Nations Environment Programme to extend the life of the General Trust Fund for Financing Activities on Research and Systematic Observations Relevant to the Vienna Convention up to 31 December 2020;

2. To request the Ozone Secretariat to coordinate with the World Meteorological Organization to establish a small advisory committee for the Trust Fund, which would convene electronically or in the margins of other relevant meetings, consisting of not more than 10 members, including two co-chairs of the Scientific Assessment Panel, the two co-chairs of the Ozone Research Managers, one representative of the Ozone Secretariat and up to five scientists and experts in ozone observations, and one representative of the World Meteorological Organization as an observer, striving for equitable geographical and gender representation, with a mandate:

   (a) To develop a long-term strategy and implementation objectives and priorities in the light of the four overarching goals identified by the Ozone Research Managers at their ninth meeting;

   (b) To develop a short-term action plan that takes into account the most urgent needs of the Global Ozone Observing System and which will make the best possible use of the resources available in the Trust Fund;

   (c) To ensure quality control of the individual project proposals developed under the Trust Fund, striving for regional balance in the projects supported by the Fund

and identifying possibilities for complementary funding to maximize its resources;

3. To request the Ozone Secretariat to continue inviting parties, and relevant international organizations as appropriate, to make financial and/or in-kind contributions towards well-defined and well-budgeted project proposals developed under the Trust Fund;

4. To request the Ozone Secretariat to report to the Conference of the Parties at its eleventh meeting on the operation of, contributions to and expenditures from the Trust Fund and on the activities funded by the Trust Fund since its inception, as well as on the activities of the advisory committee;

X/4: Financial reports and budgets for the Vienna Convention

Recalling decision IX/3 on financial matters,

Taking note of the financial report on the Trust Fund for the Vienna Convention for the Protection of the Ozone Layer for the biennium 2012–2013, ended 31 December 2013,

Recognizing that voluntary contributions are an essential complement for the effective implementation of the Vienna Convention,

Welcoming the continued excellent management by the Secretariat of the finances of the Trust Fund for the Vienna Convention for the Protection of the Ozone Layer,

1. To take note with appreciation of the financial statement of the Trust Fund for the biennium 2012–2013, ended 31 December 2013, and the report on the actual expenditures for 2012 and 2013 as compared with the approvals for those years;

2. To approve the establishment of a working capital reserve equivalent to 15 per cent of the proposed budget for 2015 to be used to meet the final expenditures under the Trust Fund, noting that the working capital reserve shall be set aside from the existing fund balance;

3. To approve the revised 2014 budget for the Trust Fund in the amount of $1,280,309, the budget for 2015 in the amount of $800,937, the budget for 2016 in the amount of $773,578 and the budget for 2017 in the amount of $1,363,368, as set out in annex I to the report on the tenth meeting of the Conference of the Parties to the Vienna Convention and the Twenty-Sixth Meeting of the Parties to the Montreal Protocol;[5]

4. To authorize the Secretariat to draw down the amounts of $197,937 in 2015, $170,578 in 2016 and $760,368 in 2017 from the Fund balance;

5. To approve, as a consequence of the drawdowns referred to in paragraph 4 of the present decision, the payment of contributions by the parties amounting to $603,000 for each of the years 2015, 2016 and 2017, as set out in annex II to the report of the tenth meeting of the Conference of the Parties to the Vienna Convention and the Twenty-Sixth Meeting of the Parties to the Montreal Protocol;

6. To request the Secretariat to indicate in future financial reports of the Trust Fund for the Vienna Convention the amounts of cash in hand in the section entitled "Total reserves and fund balances," in addition to contributions that have not yet been received;

7. To urge all parties to pay their outstanding contributions as well as their future contributions promptly and in full;

8. To request the Executive Director of the United Nations Environment Programme to extend the Trust Fund until 31 December 2025;

X/5: Eleventh meeting of the Conference of the Parties to the Vienna Convention

To convene the eleventh meeting of the Conference of the Parties to the Vienna Convention back to back with the Twenty-Ninth Meeting of the Parties to the Montreal Protocol.

[5] UNEP/OzL.Conv.10/7-UNEP/OzL.Pro.26/10.

ANNEX D

WMO/UNITED NATIONS ENVIRONMENT PROGRAMME TENTH MEETING OF THE OZONE RESEARCH MANAGERS OF THE PARTIES TO THE VIENNA CONVENTION FOR THE PROTECTION OF THE OZONE LAYER

(Geneva, 28-30 March 2017)

NATIONAL REPORTS AVAILABLE TO THE MEETING

Argentina
Armenia
Australia
Austria
Bangladesh
Belarus
Belgium
Brazil
Burkina Faso
Cabo Verde
Canada
Chile
China
Colombia
Comoros
Croatia
Cuba
Czech Republic
Denmark
Dominican Republic
Ecuador
Egypt, Arab Republic of
Estonia
Finland
France
Germany
India
Iran, Islamic Republic of
Iraq
Italy
Japan
Kazakhstan
Kenya, Republic of
Kyrgyzstan
Madagascar
Malaysia
Mexico
Mongolia
Nepal
Netherlands
New Zealand
Nigeria
Norway
Poland
Russian Federation
Samoa
South Africa
Spain
Sri Lanka
Sweden
Switzerland
Thailand
Turkey
Turkmenistan
United Kingdom
United States of America
Zimbabwe

ARGENTINA

1. OBSERVATIONAL ACTIVITIES



Geographic location of the present Argentine ozone/UV monitoring network sites

1.1 to 1.3 Ozone and UV measurements in period 2014-2017 by institution

- ***Servicio Meteorológico Nacional (SMN - Argentine National Weather Service)***

SMN is the WMO South-American Regional Calibration Centre (RCC IV) for Dobson Spectrophotometers, surface ozone analysers and solar UV-Biometers.

Contact: MSc. Gerardo Carbajal Benítez
Servicio Meteorológico Nacional. Av. de los Constituyentes 3454, C1427BLS, Ciudad Autónoma de Buenos Aires. Phone: 54-911-51676767 ext. 18456. Email: gcarbajal@smn.gov.ar.

		Measured parameters			
Station	**Location**	**Total O_3 Column**	**Surface O_3**	**Vertical O_3 Profile**	**Broadband Surface UV Irradiance**
La Quiaca	22.11ºS, 65.57ºW, 3459 m. a.s.l.	X	X		X
Resistencia	27.45ºS, 59.05ºW, 52 m. a.s.l.				X
Pilar	31.66ºS, 63.88ºW, 338 m. a.s.l.		X		X
Mendoza	32.88ºS, 68.87ºW, 704 m. a.s.l.				X
Buenos Aires	34.59ºS, 58.48ºW, 25 m. a.s.l.	X			X
Comodoro Rivadavia	45.78ºS, 67.50ºW, 46 m. a.s.l.	X			X
San Julián	49.32ºS, 67.75ºW, 62 m. a.s.l.		X		X
Ushuaia	54.85ºS, 68.31ºW, 17 m. a.s.l.	X	X	X	X
Marambio	64.24ºS, 56.62ºW, 300 m. a.s.l.	X	X	X	X

- ***Centro de Investigaciones en Laseres y Aplicaciones (CEILAP - Center for Laser Research and its Applications) UNIDEF-CONICET-CITEDEF***

Contacts: Dr Elian Wolfram, ewolfram@gmail.com
Dr Jacobo Salvador, jacosalvador@gmail.com
División Lidar - UNIDEF- CEILAP (CITEDEF-CONICET). Phone: 54-11-47098100 int. 1410.
Juan B. de La Salle 4397. B1603ALO - Villa Martelli, Buenos Aires. Argentina.

Station	**Location**	
Río Gallegos/OAPA	51.60ºS, 69.32ºW, 15m. a.s.l.	
Instrument	**Measurement**	**Institution**
DIAL LIDAR	Ozone profile between 15-45 km	CEILAP/Argentina
YES UVB-1	Broadband UV erythemal irradiance	CEILAP/Argentina
YES UVA-1	Broadband UVA	CEILAP/Argentina
SAOZ UV-Vis. Spectrometer	Ozone and NO_2 total column	SAOZ Network/France
Pyranometer Kipp&Zonen CMP21	Total solar radiation	CEILAP/Argentina
GUV 2511	Spectral bands at 305, 313, 320, 340 and 380, 395 nm, PAR	CEILAP/Argentina
Brewer Spectrophotometer S/N 229	Total ozone, NO_2 and spectral UV every 0.5 nm	CEILAP/Argentina
Milimetric waves radiometer	Upper stratospheric-mesospheric ozone profiles between 35 and 80 km	Nagoya University/Japan

Station	**Location**	
Buenos Aires-Villa Martelli	34.57ºS, 58.30ºW, 15m. a.s.l.	
Instrument	**Measurement**	**Institution**
YES UVB-1	Broadband UV erythemal irradiance	CEILAP/Argentina
YES UVA-1	Broadband UVA	CEILAP/Argentina
Pyranometer Kipp&Zonen CMP21	Total solar radiation	CEILAP/Argentina
GUV 2511	Spectral bands at 305, 313, 320, 340 and 380, 395 nm, PAR	CEILAP/Argentina

Station	**Location**	
Bariloche	41.15ºS, 71.16ºW, 840m. a.s.l.	
Instrument	**Measurement**	**Institution**
YES UVB-1	Broadband UV erythemal irradiance	CEILAP/Argentina
YES UVA-1	Broadband UVA	CEILAP/Argentina
Pyranometer Kipp&Zonen CMP21	Total solar radiation	CEILAP/Argentina
GUV 2511	Spectral bands at 305, 313, 320, 340 and 380, 395 nm, PAR	CEILAP/Argentina

Station	**Location**	
Neuquen	38.95ºS, 68.14ºW, 271m. a.s.l.	
Instrument	**Measurement**	**Institution**
YES UVB-1	Broadband UV erythemal irradiance	CEILAP/Argentina
YES UVA-1	Broadband UVA	CEILAP/Argentina
Pyranometer Kipp&Zonen CMP21	Total solar radiation	CEILAP/Argentina

Station	Location
Comodoro Rivadavia	45.79ºS, 67.46ºW, 49 m. a.s.l.

Instrument	Measurement	Institution
YES UVB-1	Broadband UV erythemal irradiance	CEILAP/Argentina
YES UVA-1	Broadband UVA	CEILAP/Argentina
Pyranometer Kipp&Zonen CMP21	Total solar radiation	CEILAP/Argentina
GUV 2511	Spectral bands at 305, 313, 320, 340 and 380, 395 nm, PAR	CEILAP/Argentina

- ***Instituto Antártico Argentino (IAA - Argentine Antarctic Institute)***

Contact: Téc. Héctor A. Ochoa
Dirección Nacional del Antártico - Instituto Antártico Argentino. Dpto. Ciencias de la Atmósfera. 25 de Mayo 1143, San Martín, Provincia de Buenos Aires, Phone: +54 (11) 2033-1420.
Email: haochoa@dna.gov.ar

		Instruments and Measured Parameters					
Station	**Location**	**Total O_3 Column**	**Surface O_3**	**NO_2 (DOAS)**	**O_3 Profile**	**UV**	**LIDAR**
Marambio	64.23ºS, 56.72ºW, 300m. a.s.l.	X		X	X	X	
San Martín	68.13ºS, 67.13ºW, 40m. a.s.l	X				X	
Belgrano II	77.86ºS, 34.62ºW, 250m. a.s.l.	X	X	X	X	X	X

- ***Estación Fotobiológica "Playa Union" (EFPU - Photo-Biological Station "Playa Union")***

Contact: Dr Walter Helbling
Estación de Fotobiología Playa Unión. Casilla de Correos N°15 (9103). Rawson, Chubut, Argentina. Te: 54–280-4498019. Email: whelbling@efpu.org.ar, efpu@efpu.org.ar

Station	Location	Measured Parameters	Instrument
Playa Union	43.30°S, 65.03°W, 10m. a.s.l.	Surface broadband UVB, UVA and PAR solar irradiance	ELDONET surface spectrometer
		Resolution: 1nm. Range: 190-1100 nm	Ocean Optics spectroradiometer
		Underwater broadband UVB, UVA and PAR solar irradiance	ELDONET submersible spectrometer
		Underwater solar irradiance	Ocean Optics submersible radiometer
		- Weather station - Laboratory equipment for biological-sample analysis	

1.4 Calibration and audit activities

1. The surface ozone Primary Standard (TEI49-PS S/N 56084-306, Buenos Aires) was calibrated in EMPA (Swiss Federal Laboratories for Materials Science and Technology) Switzerland, 2014.

2. During 2016, the Regional Calibration Centre for tropospheric ozone in Buenos Aires has repaired and calibrated the following instruments:

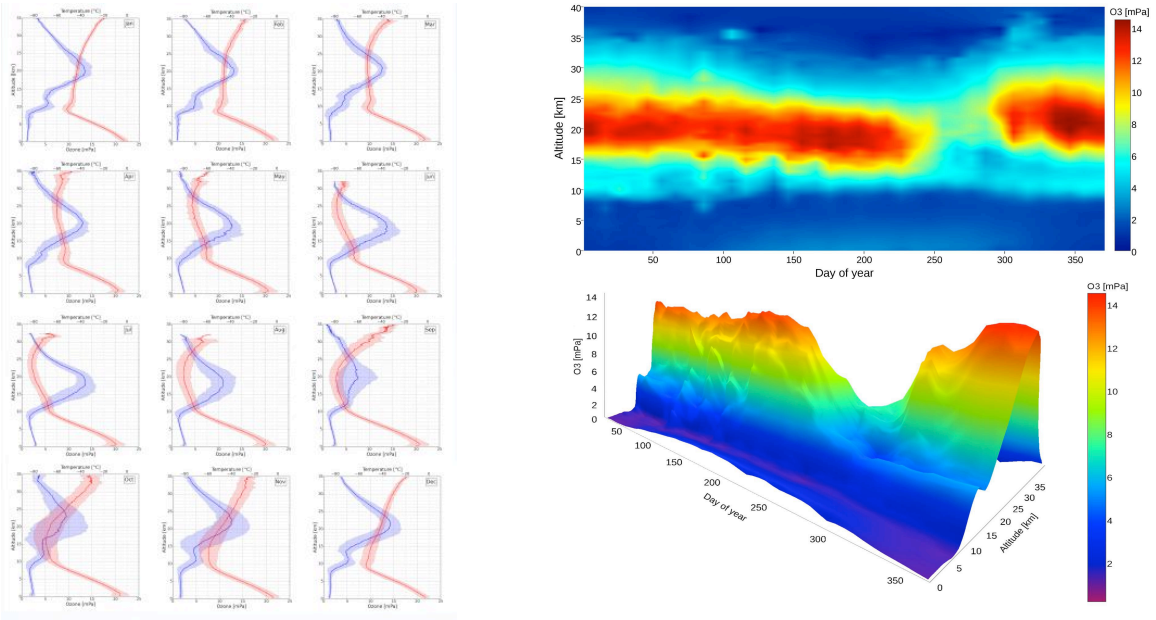
- TEI49C S/N 61161 – 330 Regional GAW La Quiaca, 2016. State: Good!
- TEI49 S/N 54577 – 300 Regional GAW Pilar, 2016. State: Good!
- TEI49 S/N 54947 – 302 Regional GAW San Julián, 2016. State: Not Good! (Discarded).
- TEI49C S/N 58546 – 318 Global GAW Ushuaia, 2016. State: Good!
- TEI49 S/N 47306 – 278 Regional GAW Marambio, 2016. State: Good!

3. Instituto Antártico Argentino (IAA) and Instituto Nacional de Técnica Aeroespacial (INTA, Spain), requested the calibration of two surface ozone analyzers:

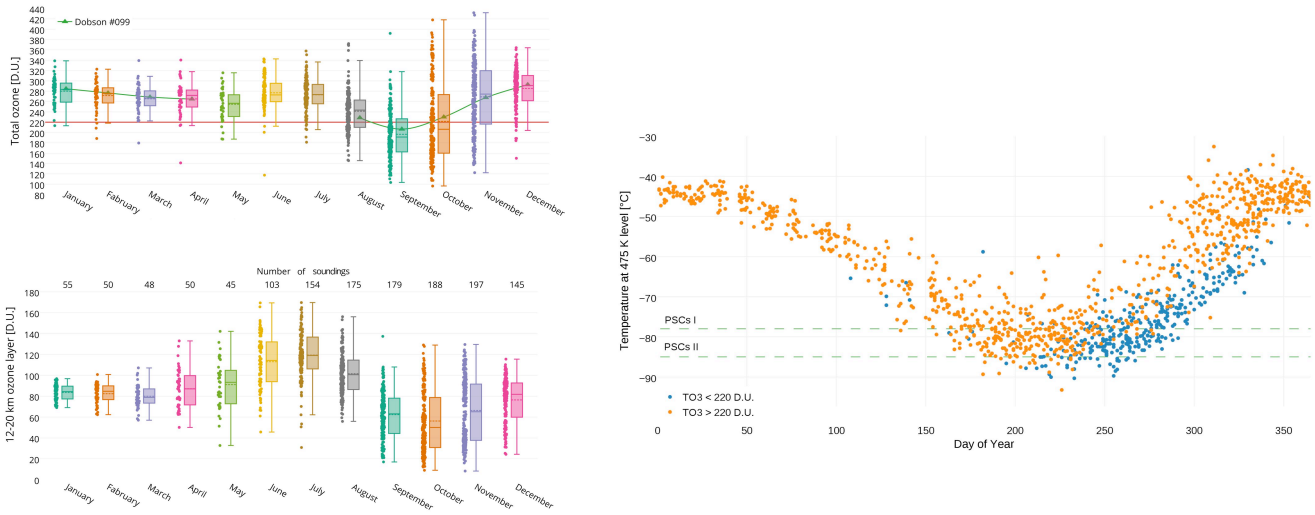
- TEI49i PS S/N 0628518938 (Antarctic Belgrano II Station), 2016. State: Good!
- TEI49C S/N 75719-380 (Antarctic Belgrano II Station), 2016. Repaired, State: Good!

4. The Ushuaia GAW Station was audited by the WMO World Calibration Centre WCC-EMPA, Switzerland (Dr. Christoph Zellweger), February 2016.

2. RESULTS FROM OBSERVATIONS AND ANALYSIS



Vertical profile climatology from 28-year (November 1988-August 2016) ozone soundings at Marambio Station, Antarctic Peninsula (Sanchez et al, 2016). Left: monthly average ozone profile. Right: daily average ozone profile.



Vertical profile climatology from 28-year (November 1988-August 2016) ozone soundings at Marambio Station, Antarctic Peninsula (Sanchez et al, 2016). Left: 12-20 km ozone-soundings and total Dobson-measured monthly average column. Right: daily measured temperature at 475 K level for each sounding along the calendar year.

3. THEORY, MODELLING, AND OTHER OZONE RELATED RESEARCH

- The Team for Studies of Climate, Environment and Society (formerly PEPACG – Catholic Argentine University)

  Contact: Dr. Eduardo Agosta Scarel.
  Pontificia Universidad Católica Argentina - Av. Alicia Moreau de Justo 1300, C1107AAZ, Buenos Aires, Argentina. Tel: +54 114349-0200 int. 7092. E-mail: eduardo_agosta@uca.edu.ar

  Carries on research focused on the understanding of the climate dynamics and climatology of the regional coupled troposphere-stratosphere-ozone layer climate system and the impacts of the observed changes, due to both ozone depletion and climate change, including local/regional climate change drivers, on social and productive systems of Argentina.

- Modeling of UV radiative transfer in the atmosphere based on 1-D codes using principally the Discrete Ordinates algorithm with semi-spherical correction in the direct component, which is useful for cases of homogeneous-layers composition of the atmosphere. Applications include the UVIndex daily forecasted by SMN.

4. DISSEMINATION OF RESULTS

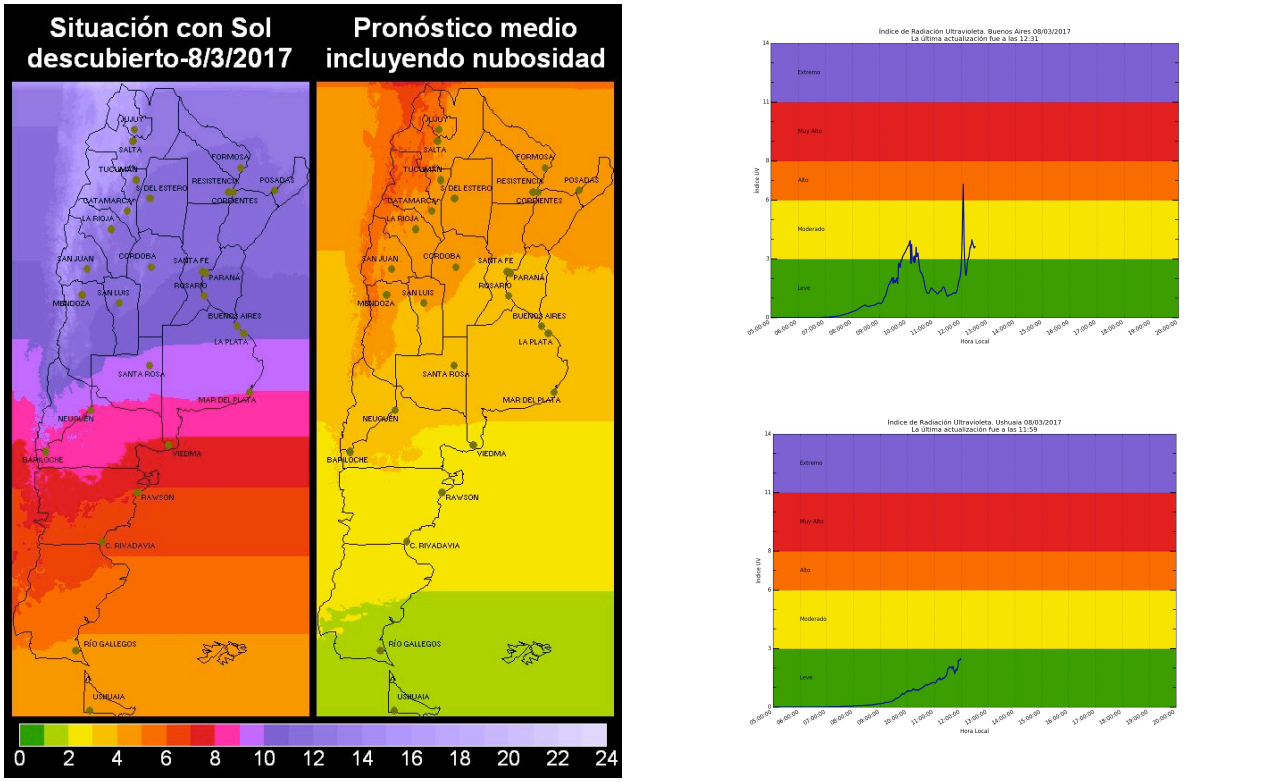
4.1 Data reporting

- SMN and CEILAP send regularly their data (ozonesoundings, UV-B Radiation, total ozone column, surface ozone, Lidar profiles) to the corresponding global gathering centres: WOUDC (Canada), WDCGG (Japan), NILU (Norway), etc.

4.2 Information to the public

- SMN UV daily forecast web site was updated by 2015 adopting both the official World Health Organization risk color scale and risk numeric scale. Additionally, SMN implemented

during 2016 the real-time online availability of UVIndex measured by UVBiometers at their stations of Buenos Aires and Ushuaia:



Left: map of SMN daily forecasted UVIndex around solar noon for Argentina (http://www.smn.gov.ar/), day 08 March 2017, for uncovered direct sun (left map) and the expected average UVI including the forecasted cloud field along the country. Right: real-time online UVIndex measurements at Buenos Aires (top) and Ushuaia (bottom) stations during 08 March 2017.

4.3 Relevant scientific papers 2014-2017

Cooper O.R., D.D. Parrish, J. Ziemke-N.V. Balashov, M. Cupeiro, I.E. Galbally, S. Gilge, L. Horowitz, N.R. Jensen, J-F. Lamarque, V. Naik, s. J. Oltmans, J. Schwab, D. T. Shindell, A.M. Thompson, V. Thouret, Y. Wang, R. M. Zbinden. Global distribution and trends of tropospheric ozone: An Observation-based review. Elementa: Science of the Anthropocene: 000029, doi: 10.12952/Journal .elementa.000029. 2014.

Parrish D.D., J.-F. Lamarque, V. Naik, L. Horowitz, D.T. Shindell, R. Derwent, S. Gilge, M. Steinbacher, S.J. Oltmans, I.E. Galbally, M. Cupeiro "Systematic comparison of seasonal cycles of tropospheric ozone between observations and models" 3° Chemistry-Climate Model Initiative (CCMI) Workshop, Lancaster (UK). 2014.

van Peet, J. C. A., van der A, R. J., Tuinder, O. N. E., Wolfram, E., Salvador, J., Levelt, P. F., and Kelder, H. M. Ozone ProfilE Retrieval Algorithm (OPERA) for nadir-looking satellite instruments in the UV–VIS. Atmos. Meas. Tech., 7, 859-876, doi:10.5194/amt-7-859-2014. 2014.

Albarracín V., Daniel Kurth, Omar Ordoñez, Carolina Belfiore, Eduardo Luccini, Graciela Salum, Ruben Piacentini and María E. Farías. High-Up: A Remote Reservoir of Microbial Extremophiles in Central Andean Wetlands. Review paper. Frontiers in Microbiology, 6:1404, doi: 10.3389/fmicb.2015.01404, 2015.

Wagner A., A.–M. Blechschmidt, I. Bouarar, E.G. Brunke, C. Clerbaux, M. Cupeiro, P. Cristofanelli, H. Eskes, J. Flemming, H. Flentje, M.George, S. Gilge1, A. Hilboll, A. "Evaluation of the MACC operational forecast system potential and challenges of global near-real-time modeling with respect to reactive gases in the troposphere". Atmospheric Chemistry and Physics, 15, 14005–14030, 2015.

Carbajal Benítez G., Cupeiro M., Agüero D. y Blanco O. Comparación y validación de los datos de la Columna de Ozono Total del Re-análisis ERA40, ERA inetrim, y las observaciones con el Espectrofotómetro Dobson. CONGREMET XII, Mar del Plata. 2015.

Parrish D.D., I.E. Galbally, J.-F. Lamarque, V. Naik, L. Horowitz, D.T. Shindell, S.J. Oltmans, R. Derwent, H. Tanimoto, E Brunke, M. Cupeiro. J. "Seasonal cycles of O3 in the marine boundary layer: Observation and model simulation comparisons". J. Geophys. Res.,121, doi:10.1002/2015JD024101. 2015.

D. Hubert et al. Ground-based assessment of the bias and long-term stability of fourteen limb and occultation ozone profile data records. Atmos. Meas. Tech. Discuss., 8, 6661-6757. doi:10.5194/amtd-8-6661-2015. 2015.

Villafañe, V.E., S. Guendulain-García, F. Valadez, G. Rosiles-González, E.W. Helbling & A.T. Banaszak - Antagonistic and synergistic responses to ultraviolet radiation and increased temperature of phytoplankton from cenotes of the Yucatán Peninsula, México. Freshwater Science, 34: 1282–1292. 2015.

Helbling, E.W., A.T. Banaszak & V.E. Villafañe - Global change feed-back linking water transparency, mixing, and solar UVR inhibits cyanobacterial photosynthesis. Nature Scientific Reports, 5, 14514; doi: 10.1038/srep14514. 2015.

Valiñas, M. S., E.W. Helbling - Sex-dependent effects of ultraviolet radiation on the marine amphipod Ampithoe valida (Ampithoidae). Journal of Photochemistry and Photobiology B: Biology, 147: 75-82. 2015.

Jose Adame, Manuel Cupeiro, Margarita Yela, Emilio Cuevas, and Gerardo Carbajal Ozone and carbon monoxide at the Ushuaia GAW-WMO global station. Geophysical Research, EGU General Assembly, Vol. 18, EGU2016-8474. 2016.

Luccini E., Miguel Rivas, Elisa Rojas. Cloud optical depth from total and UV solar irradiance measurements at two sites of the Atacama Desert in Chile. Atmospheric Research, 175, 18–30, doi:10.1016/j.atmosres.2016.01.007, 2016.

Mizuno A., N. Sugimoto., E. Wolfram., F. Zamorano., H. Ohyama., J. Salvador., T. Nagahama., T. Sugita., H. Akiyoshi., F. Orte., T. Nakajima., S. Sanchez., G. Carbajal., F. Nollas., A. Acquesta., E. Quel., and Y. Misu. SAVER-Net: An Observing and Data Distribution Network of Atmospheric Ozone, UV Radiation, and Aerosols for the Southern Part of South America. QOS2016-147, 2016 Quadrennial Ozone Symposium of the International Ozone Commission. 2016.

Sanchez R., R. Kivi., G. Carbajal., G. Perez-Fogwill., G. Gambarte., G. Copes., M. Albertini., J. Ferrara., M. Mei. Long-term ozonesonde observations at Marambio, Antarctic Peninsula. QOS2016-147, 2016 Quadrennial Ozone Symposium of the International Ozone Commission. 2016.

Carbajal Benítez G., Sánchez R., Agüero J.D., Cupeiro M., y Barlasina M.E. Downscalling of The Total Ozone Column Data of Reanalysis Era40,Through The RCM PRECIS, and Validation with The Espectrophotometer Dobson Data In Argentina. QOS2016-147, 2016 Quadrennial Ozone Symposium of the International Ozone Commission. 2016.

Sofen E D, D Bowdalo, M J Evans, F Apadula, P Bonasoni, M Cupeiro, R Ellul, I E Galbally, R Girgzdiene, S Luppo, M Mimouni, A C Nahas, M Saliba. "Gridded global surface ozone metrics for atmospheric chemistry model evaluation". Earth Syst. Sci. Data, 8, 41–59, 2016

Hubert, D. et al. Ground-based assessment of the bias and long-term stability of 14 limb and occultation ozone profile data records. Atmos. Meas. Tech., 9, 2497-2534, doi:10.5194/amt-9-2497-2016. 2016.

Salvador J., Wolfram J., Orte F., D'Elia R., Quiroga J., Quel E., Zamorano F., Pérez R., Villa I., Oyama H. and Mizuno A. Intercomparison of Ozone and Temperature Profiles During OZITOS+ 2014 Campaign in Río Gallegos, Argentina. ILRC 25, New York. EPJ Web of Conferences 119,. 13002 (2016). http://dx.doi.org/10.1051/epjconf/201611913002. 2016.

Palancar G. G., Luis E. Olcese, Bethania Lanzaco, Mariana Achad, Maria L. Lopez, Beatriz M. Toselli. Aerosol radiative forcing efficiency in the UV-B region over central Argentina. Atmospheric Research, vol. 176, p. 1 - 9. 2016.

M.P. Utrillas et al. UVER and UV index at high altitude in Northwestern Argentina. Journal of Photochemistry and Photobiology B: Biology. Volume 163, Pages 290–295. 2016.

Villafañe, V.E., M.J. Cabrerizo, G.S. Erzinger, P. Bermejo, S.M. Strauch, M.S. Valiñas & E.W. Helbling - Photosynthesis and growth of temperate and sub-tropical estuarine phytoplankton in a scenario of nutrient enrichment under solar ultraviolet radiation exposure. Estuaries and Coasts. 2016.

Valiñas, M. S. and E. W. Helbling - Metabolic and behavioral responses ofthe reef fish Patagonotothen cornucola to ultraviolet radiation: Influence of the diet. Journal of Experimental Marine Biology and Ecology, 474: 180-184. 2016.

Durán Romero, C., V.E. Villafañe, M.S. Valiñas, R.J. Gonçalves & E.W. Helbling - Solar UVR sensitivity of phyto- and bacterio-plankton communities from Patagonian coastal waters under increased nutrients and acidification. ICES Journal of Marine Sciences. 2017.

5. PROJECTS, COLLABORATION, TWINNING AND CAPACITY BUILDING

- SMN Projects in collaboration with: Finnish Meteorological Institute, through the Ozonesounding programme in Antarctic Marambio Station. Agencia Estatal de Meteorología (AEMet, Spain), Instituto Nacional de Técnica Aeroespacial (INTA, Spain) through MAX-DOAS (O_3, NO_2 and IO Column) spectrophotometer and ozonesoundings at Ushuaia GAW Station. Argentine CITEDEF Institute, Japan (JICA) and Magallanes University, through SAVER-NET Project. Argentine CITEDEF Institute, through other special scientific project (PIDDEF). The SMN translates the Ozone Hole Bulletin of the WMO (Dr. Geir Braathen) into Spanish and puts it at the disposal of the Spanish speaking countries. Project in evaluation (Financial Support) for air pollution measurement in Buenos Aires city (PIDDEF), 2016. Project in evaluation (Financial Support) for UVB radiation measurement in collaboration with Dr. Eduardo Luccini CONICET-CEPROCOR (PIDDEF), 2016. The Project "Enlargement and improvement of the solar radiation sensors network in Argentina" has been submited to the BAPIN in order to obtain finacing to purchase new and better ultraviolet radiation sensors among others.

- CEILAP Projects in collaboration with: Laboratorio de Investigaciones Atmosféricas de la Universidad de Magallanes, Punta Arenas - Chile, and Nagoya University in Japan. The main project that the three institution are held is the SAVER-Net project (http://www.savernet-satreps.com supported by Japan International Cooperation Agency (JICA) and Japan Science and Technology (JST). The data of Ozone Differential Absorption Lidar of Rio Gallegos station are submitted to Network for the Detection of Atmospheric Composition Change (NDACC/NOAA).

- IAA Projects in collaboration with: Servicio Meteorológico Nacional (Argentina), Instituto de Física Atmosférica de Roma (IFAR, Italia), Instituto Nacional de Técnica Aeroespacial (INTA, España), el Instituto Nacional de Meteorología (INM, España), Instituto Meteorológico Finlandés (IMF, Finlandia), Observatorio Solar y de Ozono del Instituto Hidrometeorológico de la República Checa.

6. IMPLEMENTATION OF THE RECOMMENDATIONS OF THE 9th OZONE RESEARCH MANAGERS MEETING

➢ Principal activities within the period 2014-2017

1. A new measurement activity started in 2015 at the regional GAW La Quiaca. The SMN installed a Dobson spectrophotometer (#D097) for the monitoring of stratospheric ozone.
2. A new MAX-DOAS spectrophotometer for O3, NO2 and IO (surface and column) measurements were installed at the Ushuaia GAW Station in 2015.
3. Active participation in the creation of the project "Tropospheric Ozone Assessment Report (TOAR)(IGAC-NOAA-WMO)", whose purpose is to generate easily accessible, documented data on ozone exposure and dose metrics at hundreds of measurement sites around the world (urban and non-urban), freely accessible for research on the global-scale impact of ozone on climate, human health and crop/ecosystem productivity.
4. 50th anniversary celebration of the start of measurements with the Dobson spectrophotometer (#D094, #D097, and #D070) in Buenos Aires (1965 - 2015).
5. The SMN is collaborating with the submission of data for the elaboration of the Ozone Hole Bulletin (Ushuaia and Marambio Stations).
6. SMN contributes with surface ozone data in near-real-time for the validation of analysis and forecast of global atmospheric composition developed by the Copernicus Atmosphere Monitoring Service (CAMS), European Union.
7. Technical support to regional activity. In 2014 the Salto regional GAW station (Uruguay) was set up with the SMN collaboration.
8. Four UV radiation sensors were compared in Buenos Aires against the standard purchased in the same year.
9. Change of the Solar Light sensor at Pilar due to the malfuncion of the YES sensor which operated there.
10. The SMN participated at meetings organized by the MINCyT in order to form a risk team with the aim of implementing a risk protocol to face the UV radiation threat.
11. The SMN participated at DAVOS in the comparison of IPC XII radiation sensors which was held by the (WRC/PMOD) World Radiation Centre where a pyrheliometre and a UV sensor were calibrated.
12. SMN personnel has been trained in the courses organized by the GAWTEC at the Schneefernerhaus Observatory, in Germany.
13. SMN updated the colour and risk scale presented in the daily national UV Index forecast map for clear and cloudy conditions in its web page (http://www.smn.gov.ar).

7. FUTURE PLANS

➢ Principal planned activities for next period

- The 5th Intercomparison of the Ozone Surface Analyzers, 23-27 October, 2017. SMN. Buenos Aires, Argentina.
- The 5th Intercomparison of the Dobson Spectrophotometers, from 13th Nov to 1st December, 2017. SMN. Buenos Aires, Argentina.
- SMN will participate in the International UV Filter Radiometer Comparison, summer 2017. Physikalisch-Metorologisches Observatorium Davos/World Radiation Centre (PMOD/WRC), Davos, Switzerland.
- SMN will Celebrate the 30th anniversary of the beginning of measurements with the Dobson spectrophotometer (#D099) at the Antarctic Marambio Station (October, 1987 – October, 2017).
- Installation of 2 (Two) Pandora-DOAS instruments for total ozone (O_3) and nitrogen dioxide (NO_2) measurement into SAVER-net Project at Stations Tucumán (26.49°S, 65.13°W, 452 m. a.s.l.) and Pilar Observatory (31.66ºS, 63.88ºW, 338 m. a.s.l.)

8. NEEDS AND RECOMMENDATIONS

- The first need at present for Argentina is to maintain their current monitoring networks in qualified operation. Argentina is aware of the importance of their data in view of the strategic geographical location to study the atmospheric ozone problem, and the authorities of their monitoring institutions are searching for alternative solutions to maintain their databases within high quality standards, but coordination and support from the international scientific and funding institutions is primordial to avoid a critical situation.

- Additionally, Argentina is making their own efforts to develop sophisticated instruments that contribute to widen their present networks, such as atmospheric Lidars, whole-sky cameras, etc., some of them in strong international cooperation.

- Fluid communication is necessary to assure that information disseminate about training courses and scientific workshops on ozone- and UV- related international activities and support, devoted specifically to developing countries, and particularly to Region III South America.

Other scientific concerns are still common to previous reports and must consider the strategic geographical location of Argentina to study and to understand the consequences of this global environmental problem:

- Antarctica and the Southern Cone of South-America must be still for many years considered the most critical region in the world related to ozone depletion and its consequences.

- The Antarctic Ozone Hole must be continuously monitored by all means for many years. Permanent ground-based and satellite-based instruments are an essential complement for this task.

- There is growing evidence that the ozone layer is both acting in response to current climate variability and change as well as affecting climate over the Southern Hemisphere. Such coupled studies are an important component of understanding needed to assess climate variability and climate change processes. Hence it is important to strength all atmospheric measurements relevant to both processes. This also requires a strong support in capacity building at the technician and research levels to continue both with monitoring and relevant research as proposed by SPARC-WCRP and its links with the various WCRP initiatives.

- It is essential that research activities be enhanced regionally and globally in the double-pronged aspect of ozone depletion and change within the framework of Climate Change due to the many joint aspects and couplings that are now starting to be known. Hence it is essential to sustain national and international projects regarding these as relevant issues.

- Until the recovery of the ozone layer does not become evident and sustained in time and as long as the international scientific community does not have a clear and fully developed picture of the linkages between the ozone layer, the stratosphere and the troposphere, within the scope of climate change and variability such research must be supported, nationally, regionally and internationally.

This report was prepared by Dr Eduardo Luccini, Dr Elian Wolfram and Msc. Gerardo Carbajal based on the infrastructure, activities and achievements of the Argentine institutions and research groups involved in Vienna-Convention-related monitoring and research activities. We gratefully acknowledge the institutions that provided the information to elaborate this report.

ARMENIA

1. OBSERVATIONAL ACTIVITIES

1.1 Column measurements of ozone and other gases/variables relevant to ozone loss

The Global Atmosphere Watch (GAW) regional meteorological station #410 in Amberd, Armenia, carries out regular measurements of total ozone since 2000. The station is equipped by Dobson spectrophotometer D-044 (Fig.1). Location: 40.38N, 44.25E, 2070.



Figure 1: ***Dobson Spectrophotometer at the GAW Regional Station #410 Amberd***

The measurements of total ozone on the local level are also carried out at Yerevan Arabkir meteorological station using filter ozonometer M-124 (since 1990). The activities are still on-going although the equipment is morally and physically obsolete. Location: 40.20N, 44.50E, 1113.

1.2 Profile measurements of ozone and other gases/variables relevant to ozone loss

No profile measurements of ozone and other gases/variables relevant to ozone loss are carried out in Armenia.

1.3 UV measurements

No UV measurements are carried out in Armenia due to the insufficient technical base (lack of equipment).

1.4 Calibration activities

The calibration of Dobson spectrophotometer D-044 in European RDCC was held in Hohenpeißenberg in 2010. Next calibration service of Dobson D-044 shall be organized in Hohenpeißenberg in June 2017 (subject to funding availability).

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

The results of measurements of total ozone at Dobson-station (Amberd) showed that during 2012-2016 the minimal value of total ozone was observed in 2014, and maximum values in 2016. These data can be interpreted as testifying about gradual recovery of ozone layer in middle latitudes of the Northern Hemisphere of the Earth.

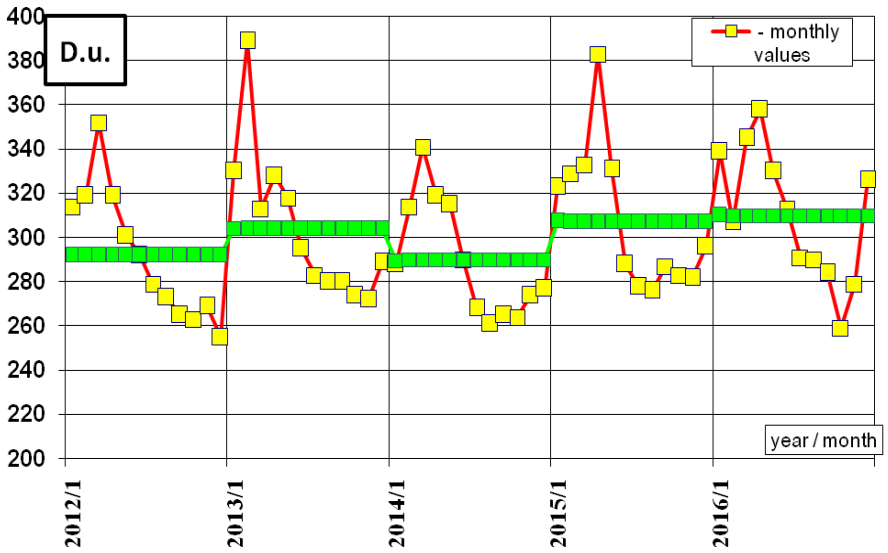


Table 1. ***Dynamics of total ozone over Armenia during 2012-2016***

3. THEORY, MODELLING, AND OTHER OZONE RELATED RESEARCH

The reference books [3], [4] were developed using the constructed early computer model of solar radiation transfer in atmosphere and its distribution on the territory of Armenia. The estimations of climatic parameters of solar radiation on the territory of Armenia [2] were also taken into account.

Research was initiated to determine calibration corrections related to wear and tear of ozonometer filters used at Yerevan Arabkir (ozonemeter M-124) and Amberd (Dobson spectrophotometer) stations. The study is on-going.

Research on revealing the connection between changes of total ozone, ultraviolet radiation and the mortality rate of population resulting from skin cancer (as per different geographic locations in Armenia) was initiated in 2011[1] by the former Ozone Research Manager Dr. Davit Melkonyan. The continued research was left incomplete due to the researcher's decease.

Measurements of total ozone at Amberd and Yerevan Arabkir stations are regularly collected and currently stored in the computer. The database software is still under development.

4. DISSEMINATION OF RESULTS

4.1 Data reporting

Results of monthly measurements of total ozone at Amberd station are regularly submitted to the WMO/GAW, World Ozone and UV radiation Data Centre WOUDC.

4.2 Information to the public

The model was developed to calculate intensity of solar radiation and distribution of UV Indexes using the forecasts of total ozone distribution above northern hemisphere from WMO/GAW ozone maps. The estimations and forecasts of UV Indexes for different

regions of Armenia were calculated according to "UV Index for Public" (COST-713 Action UVB Forecasting) using local forecast of cloudiness. Forecasted and observed results are included in the daily hydrometeorological bulletin.

The Bulletin is submitted to decision makers as well as disseminated to public via internet, TV, and radio. In case of high UV index a special warning is announced to avoid direct solar radiation.

4.3 Relevant scientific papers

1. D. Melkonyan, G. Bazikyan, P. Pogsyan (2011) Estimations of influence of ultraviolet radiation on the morbidity of the population of Armenia by a skin cancer // Yerevan, "Issues of theoretical and clinical medicine ", v. 14, N1 (61), c.11-12.

2. D. Melkonyan (2011) Estimation of climatic parameters of solar radiation on the territory of Armenia // Yerevan, "Agricultural Sciences", NN3-4, s. 201-204.

3. D. Melkonyan **(**2011) Reference book for sun radiation on the territory of Armenia // UNDP & GEF, Project UNDP/GEF/00035799, Yerevan.

4. R. Mkrtchyan, D. Melkonyan, V. Badalyan (2011) Reference book for estimation of hydrothermal and radiating resources of agricultural cultures of Armenia // UNDP & GEF, Project UNDP/GEF/00035799, Yerevan**.**

5. PROJECTS, COLLABORATION, TWINNING AND CAPACITY BUILDING

Measurements on concentrations of pollution in precipitations and on solid particles in the air, including SO_2, NO_x and surface ozone O_3 are continuously carried out at the Amberd station.

After the former Ozone Research Manager's decease, Armenia expressed a need in training which was immediately attended to by UNEP, and the on-site Dobson training on practical measurements of ozone and regular tests and data processing was organized correspondingly. The training was carried out by Mr. Martin Stanek from the Czech Hydrometeorological Institute at the Amberd station, Armenia and on the premises of the Hydrometeorological Service of Armenia on September 28 - October 4, 2015. Technical staff of the WMO/GAW Dobson station and scientists attended the training.

6. IMPLEMENTATION OF THE RECOMMENDATIONS OF THE 9th OZONE RESEARCH MANAGERS MEETING

Based on the below recommendation of the 9th meeting: to recognize the issue of changes in climate and in the stratospheric ozone layer is intimately coupled – it was decided to include ozone data in the Climate change projects in Armenia.

7. FUTURE PLANS

To organize the calibration of the Dobson spectrophotometer D-044 to continue regular measurements of ozone and ultra-violet radiation.
To obtain UV measuring equipment to enable carrying out UV measurements in Armenia.

To organize the research of the climatic regime of UV radiation in different regions of Armenia to study the health impact in rural and urban areas. The research is based on results of total ozone measurements and long-term statistics on population mortality (from skin cancer).

8. NEEDS AND RECOMMENDATIONS

- Technical assistance is requested to allow UV measurements, hence Armenia would like to request the Ozone Secretariat to investigate the opportunities of providing technical assistance and procuring the UV measuring equipment.
- Assistance has been requested from the WMO to organize the calibration of the Dobson spectrophotometer D-044 in 2017.
- A training course at the WMO training centres for ozone experts is desirable.
- It is recommended to use the capacities of Amberd meteorological station in order to monitor solar radiation and vertical distribution of ozone.

AUSTRALIA

1. OBSERVATIONAL ACTIVITIES

1.1 Column measurements of ozone and other gases/variables relevant to ozone loss

The Australian Government's Bureau of Meteorology (BoM) has primary responsibility for monitoring total column ozone.

- The BoM Dobson network consists of stations located at Brisbane, Darwin, Macquarie Island, Melbourne, and Perth (Perth is operated in conjunction with NOAA). Brisbane, Macquarie Island and Melbourne have records stretching back to 1957.

A number of universities also undertake some total ozone monitoring:

- A Brewer spectrophotometer operated by the University of Tasmania (financially supported by the BoM).
- Remote sensing FTIR operated by the University of Wollongong - the measurements are made as part of the Network for the Detection of Atmospheric Composition Change, (NDACC).

The New Zealand National Institute of Water and Atmospheric Research (NIWA) operates a zenith viewing spectrometer at Macquarie Island for NO_2 column and profile information as part of NDACC.

1.2 Profile measurements of ozone and other gases/variables relevant to ozone loss

Weekly ozonesonde measurements are taken by the BoM at:

- Broadmeadows (Melbourne)
- Macquarie Island
- Davis station, Antarctica, in conjunction with the Australian Antarctic Division (AAD) and the Chinese Academy of Meteorological Sciences (CAMS)

The ozonesonde program at Davis dates from 2003, Macquarie Island from 1994, and Broadmeadows continues the program originally located in Aspendale (1965-1982) and Laverton (1983-1998). Collaboration with CAMS includes information exchange and research associated with atmospheric chemistry measurements at China's Zhongshan station, near Davis.

- In conjunction with some of these ozonesonde flights, the AAD has operated a Rayleigh/Mie/Raman lidar at Davis to measure temperature and aerosol loading in the stratosphere (the lidar operated from 2001-2012 and is anticipated to collect further data from 2018).
- Coarse vertical resolution profiles from Dobson Umkehr measurements have been made at BoM Dobson network sites dating back to 1962. Umkehr observations are still made at Brisbane, Darwin and Perth (Stone et al., 2015).

1.3 UV measurements

1.3.1 Broadband ultraviolet

The Australian Radiation and Nuclear Safety Agency (ARPANSA) has maintained a network of UV detectors in capital cities around Australia since 1989. In 1996 the instruments were changed over to Solar Light UVB 501 broadband biometers. Kingston, Tasmania was added in 2007 Canberra was added in 2010, and more recently Alice Springs was added as a new site (2011). Biometers have also been collecting data at Macquarie Island since 2001 and the Australian Antarctic stations Mawson, since 2002, and both Davis and Casey since 1996. The biometers are intercompared at Yallambie before placement in the field.

1.3.2 Spectral ultraviolet

The BoM owns and operates two NIWA-designed spectroradiometers at Alice Springs and Melbourne.

ARPANSA currently uses a Bentham spectroradiometer based at the Melbourne site to simultaneously measure solar UVR and transfer a traceable calibration to the biometers before installation. This instrument commenced measurements in December 2008 and has been operating continuously since then. Spectral measurements with traceable calibrations at Antarctic mainland stations commenced in 2010 at Davis and Mawson. In 2011 a Bentham spectral system was installed at Davis for at least two summers with the aim of providing a longer duration series of calibrated spectral measurements and replaced in 2013 and is still recording UV spectral data. A Bentham spectral system was installed in Casey in December 2012 and removed in May 2014.

1.4 Calibration activities

The BoM holds the Region V Dobson standard and operates the Regional Dobson Calibration Centre (RDCC) for the south-west Pacific. The regional standard Dobson is inter-compared regularly with the world standard Dobson, most recently in Boulder in August 2013 and in Melbourne in February 2017. ARPANSA meets the WMO's instrument specifications and characterization as a health advisory agency that provides the daily UV levels. CSIRO/BoM ODS measurements employ calibration standards supplied by the Scripps Institution for Oceanography (USA) and the data are regular compared to data collected at Cape Grim by NOAA (USA), U. East Anglia (UK) and NIES (Japan).

In Melbourne in 2013 APRANSA was involved with an international intercomparison of solar UVR spectral measurements involving the ARPANSA Bentham spectroradiometer intercompared with the BoM owned NIWA-designed spectroradiometer and solar UVR spectroradiometer from Public Health England (PHE).

A Regional Dobson Intercomparison campaign is being held in Melbourne in February 2017, including participation from the Philippines supported by the Vienna Convention Trust Fund for Research and Systematic Observations.

1.5 Ozone Depleting Substances

Australian activities in ODS research are focused on *in situ* ODS observations at the WMO Baseline Station at Cape Grim, Tasmania (funded and managed by the Australian Bureau of Meteorology, with the science program jointly undertaken with CSIRO) and at the CSIRO Oceans and Atmosphere laboratory at Aspendale, Victoria, analysing air samples from the Cape Grim Air Archive, from the CSIRO Australian and global flask sampling networks and from firn air samples

from Antarctica. Australian activities also include ODS modelling, and all ODS observational and modelling research involve collaborations with AGAGE (Advanced Global Atmospheric Gases Experiment) and other colleagues in the USA, Europe and Japan.

ODSs monitored and modelled in the Australian program include species from all the major ODS groups – CFCs (chlorofluorocarbons), HCFCs (hydrochlorofluorocarbons), halons, chlorocarbons, bromocarbons and nitrous oxide. HFCs (hydrofluorocarbons), which are regulated under the Montreal Protocol following the Kigali Amendment (2016), are also monitored and modelled.

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

2.1 Ozone Depleting Substances

Australian research on ozone depleting substances (ODSs) made major contributions (Carpenter, Reimann *et al*., 2014; Liang, Newman, Reimann *et al*,, 2016) to the WMO/UNEP *Scientific Assessment of Ozone Depletion: 2014* and the 2016 *SPARC Report on the Mystery of Carbon Tetrachloride.*

ODS contributions to Equivalent Effective Stratospheric Chlorine (EESC) and global radiative forcing (RF) have been derived from Cape Grim data and data from other global AGAGE stations, from the Cape Grim Air Archive and from Antarctic firn air (Fraser *et a*l., 2014a; Rigby *et al*., 2014; Klekociuk *et al*., 2014a,b, 2015).

Global and Australian regional estimates of carbon tetrachloride (CCl_4) emissions and a revised global atmospheric CCl_4 lifetime have been derived for this important ODS from Cape Grim, global AGAGE and NOAA data. The previously report gap between so-called 'top-down' and 'bottom-up' estimates of global CCl_4 emissions has been reduced significantly (Fraser *et al*., 2014b; Chipperfield *et al*., 2016; Liang *et al*., 2016).

Global emissions of the three major halons (H-1211, H-1301, H-2402) in the atmosphere have been derived from Cape Grim Air Archive and global AGAGE halon data (Vollmer *et al*., 2016).

Several new ODSs, minor chlorofluorocarbons (CFCs-112, -112a, -113a, -114a, 216ba, 216ca) and minor hydrochlorofluorocarbons (HCFCs: -31, -133a, -225), some of which are growing in the background atmosphere, have been identified in the Cape Grim Air Archive and their emissions and lifetimes have been estimated (Laube *et al*., 2014, 2016; Kloss *et al*., 2014; Schoenenberger *et al*. 2015; Vollmer *et al*., 2015).

The chlorine isotopic composition of the major CFCs (-11, 12, -113) are consistent with the finding that these CFCs are entirely anthropogenic in origin (Allin *et al*., 2015).

Global HCFC emissions have remained approximately constant over the past 5 years despite a global cap on production and consumption since 2013. This is due to growing emissions in developing countries and declining emissions in developed countries (Simmonds *et al*., 2016).

Cape Grim and AGAGE global *in situ* nitrous oxide (N_2O) concentration and isotopic data from the CSIRO global monitoring network have been used to further advance the understanding of the sources and sinks of this important ODS, confirming that the major source of growing N_2O in the atmosphere is agricultural soils (Saikawa *et al*., 2014; Wells *et al*., 2015; Prokopiou *et al*., 2016)

2.2 Ozone and UV

Gies et al 2013 studied a low ozone event observed over southern Australia in August 2011, which led to anomalously high UV exposure for this time of year.

The Melbourne Dobson record from 1978-2012 was analysed in Tully et al. (2013) who found total ozone has been closely tracking mid-latitude EESC over this period.

Analyses of ozonesonde data from Davis station (Antarctica) are used in the following areas;

- Investigation of polar ozone loss processes and ozone variability through projects 737, 4012 and 4293 of the Australian Antarctic program (e.g. Alexander et al., 2013a; Klekociuk et al., 2015a, 2015b, 2016; Hope et al., 2015; Stone et al., 2016; see also https://secure3.aad.gov.au/proms/public/projects/report_project_public.cfm?season=1112&project_no=737 https://secure3.aad.gov.au/public/projects/report_project_public.cfm?season=1516&project_no=4012, and https://secure3.aad.gov.au/public/projects/report_project_public.cfm?season=1516&project_no=4293)
- Near real-time analyses of ozone in the Southern Hemisphere winter (WMO Antarctic Ozone Bulletins; see http://www.wmo.ch/pages/prog/arep/gaw/ozone/index.html)
- Satellite and instrument validation (e.g. Sofieva 2017).
- Assimilation into global atmospheric composition reanalysis (e.g. Benedictow et al., 2013).

There has also been an assessment of stratospheric incursion events bringing ozone from the stratosphere into the troposphere (Greenslade, 2017). This has used ozone sonde data from Davis, Macquarie Island and Melbourne (Broadmeadows).

An assessment of long-term trends in the vertical distribution (Harris et al., 2015) has included data from ozone sondes, Umkehr and FTIR measurements made in Australia and Antarctica.

Measurements at Cape Grim, Tasmania (2000 – 2005) of the UV-B driven photolysis of ozone producing reactive oxygen atoms have been analysed to quantify the impact of the key drivers (ozone, solar zenith angle and cloud) (Wilson 2015)

A study of HCl loading in the stratosphere has been carried out using both ground and satellite based instruments. The work found increases in stratospheric HCl in the northern hemisphere despite reductions in the anthropogenic sources. This increase is believed to be due to changes in stratospheric circulation that are important for predicting changes in the ozone layer (Mahieu et al., 2014).

Kay et al. (2015) looked at internal model variability using improved ozone forcing for the simulations, ensuring the Antarctic ozone hole was simulated in a more realistic manner than previous simulations had done.

3. THEORY, MODELLING, AND OTHER OZONE RELATED RESEARCH

Using the UK Chemistry and Aerosols (UKCA) model within the Australian Community Climate and Earth-Simulation System (ACCESS) framework, researchers at the University of Melbourne and CSIRO, along with collaborators at the New Zealand National Institute of Water and Atmospheric Research (NIWA) and the Australian Antarctic Division (AAD) are developing the capability of a fully coupled atmosphere-chemistry (and eventually ocean) model. The model is being used to simulate the stratospheric ozone layer chemistry and dynamics with the goal of a better understanding of the impacts of the development and recovery of the Antarctic Ozone Hole on the climate of the Southern Hemisphere (see Stone et al., 2016). Specific simulations are being performed for the 1st Chemistry-Climate Model Initiative (CCMI-1). This work operates under project q90 of the National Computational Infrastructure, and Project 4012 of the Australian Antarctic Science (AAS) scheme:

https://secure3.aad.gov.au/proms/public/projects/report_project_public.cfm?season=1213&project_no=4012.

AAS Project 4012 (Polar Feedbacks of Ozone Recovery on Climate in the Southern Hemisphere) is using the model output to investigate the influence of ozone zonal asymmetries on Antarctic surface climate.

Siddaway et al. (2013) examined the timing of the return to pre-ozone hole conditions in spring and summer ozone recovery using model simulations from the 2nd Chemistry-Climate Model Validation activity (CCMVal-2), finding that recovery is slower in the later months.

CSIRO is planning to develop a new coupled-chemistry model based on the latest version of ACCESS with a fully coupled ocean in 2017-18 in collaboration with the University of Melbourne.

4. DISSEMINATION OF RESULTS

4.1 Data reporting

Ozonesonde and Dobson data from all Bureau of Meteorology stations are archived at the World Ozone and UV Data Centre (WOUDC) and widely used in the literature, including for satellite validation and model comparisons.

Measurements of column amounts from the FTIR system at Wollongong are reported via the Network for Detection of Atmospheric Composition Change (NDACC) database (see http://www.ndsc.ncep.noaa.gov/data/), as are spectral UV data from Alice Springs.

Cape Grim and AGAGE global ODS data, and N_2O data from the CSIRO global flask monitoring network are regularly archived at the WMO World Data Center for Greenhouse Gases (WDCGG) in Japan: http://ds.data.jma.go.jp/gmd/wdcgg/

ARPANSA provides UVR data from its Solar Light UVB 501 broadband biometers in Casey, Davis, Mawson and Macquarie Island to the Australian Antarctic Division Data Centre.

4.2 Information to the public

A UV forecast is issued daily by the Bureau of Meteorology, and provided to the media as part of the weather report (Deschamps et al., 2006). It is also available at:

http://www.bom.gov.au/uv/index.shtml, and it is extensively used in Australia's SunSmart promotional and educational campaigns.

ARPANSA provide measured real-time UV levels which are updated every minute. A plot of the UV levels for Australian sites is available on the ARPANSA web site at: http://www.arpansa.gov.au/uvindex/realtime/index.cfm. Historical UV index data since 2004 is also available on the ARPANSA web site at http://www.arpansa.gov.au/uvindex/monthly/ausmonthlyindex.htm

The University of Melbourne Earth Sciences' website provides five-minute UV index updates for Melbourne:

http://earthsci.unimelb.edu.au/engage/dynamic-earth-updates/weather-station

Ozone analyses and forecasts are used by a number of groups to issue statements on the development of the ozone hole each year.

During spring of each year, CSIRO provides a weekly update on the status of the ozone hole, based primarily on satellite data from OMPS, OMI and TOMS, which is posted on the Department of Environment and Energy website and publicly available.

4.3 Relevant scientific papers

Alexander S.P., Murphy D.J., Klekociuk A.R. (2013a) High resolution VHF radar measurements of tropopause structure and variability at Davis, Antarctica (69° S, 78° E), *Atmospheric Chemistry and Physics* 13. 3121-3132; doi:10.5194/acp-13-3121-2013

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5. PROJECTS, COLLABORATION, TWINNING AND CAPACITY BUILDING

Information on Australian activities related to ozone and UV is shared through the *Australian Ozone Science Group,* co-ordinated by the Australian Government Department of Environment & Energy, which has led to greatly increased co-operation and co-ordination between agencies and institutions in both Australia and New Zealand, and is appreciated by all.

A number of Australian scientists contributed as lead-authors, co-authors, contributors or reviewers of the 2014 Scientific Assessment of Ozone Depletion, supported by the Department of Environment & Energy, and a similar number are also expected to take part in preparing the 2018 Assessment. Professor David Karoly is a member of the Scientific Steering committee for the 2018 Scientific Assessment of Ozone Depletion, as he was for 2014, again supported by the Department of Environment & Energy.

Similarly, the assessment of the Environmental Effects of Ozone Depletion has a significant number of Australian scientists involved. This includes involvement in the environmental assessment of trifluoroacetic acid, a product of the decomposition of a number of the HFCs introduced under the Montreal Protocol (Solomon et al, 2016).

The Bureau of Meteorology has ongoing collaboration projects with the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) on UV Index validation against surface measurements and with SunSmart (Cancer Council Australia) on the use of the UV Index to promote sun protection.

The BoM/AAD ozonesonde and AAD lidar measurements at Davis station in Antarctica have contributed to the International Polar Year cluster project ORACLE-O3, and the CONCORDIASI and MATCH campaigns.

ARPANSA has an ongoing collaborative project with the Australian Antarctic Division entitled Determination of the ultraviolet radiation environment at the Australian Antarctic Stations using broadband and spectral instrumentation (AAS 4115).

The Australian Research Council has funded a 5 year project looking at a number of atmospheric "grand challenges" in the southern hemisphere involving the University of Wollongong, the University of Melbourne and several overseas collaborators. (2016 – 2020, DP160101598)

Other projects and collaborations are also discussed in Section 3.

6. IMPLEMENTATION OF THE RECOMMENDATIONS OF THE 9th OZONE RESEARCH MANAGERS MEETING

Progress towards implementing the specific recommendations of the 9th ORM include the following actions:

- Research work has continued regarding the development and validation of Chemistry-Climate models in Australia, recognising the interactions between ozone and climate.
- The BoM has nominated 5 candidate sites for participation in the GCOS Reference Upper Air Network (GRUAN) to maintain reference quality measurements of temperature in the upper troposphere and stratosphere
- Long-term ozone monitoring sites have continued, in particular total ozone and ozonesonde programs at Macquarie Island
- High quality baseline measurements of emerging ODS substitutes such as HFCs are being made by CSIRO at Cape Grim
- The BoM is conducting intercomparisons of modern instrumentation for ozone measurement such as the "Pandora".
- Digitisation of historic (1960s and 1970s) Dobson umkehr observations has now been completed (University of Melbourne and BoM).
- A Region V Dobson intercomparison is being held in Melbourne (February 2017), including participants from the Philippines.
- An Asia/Pacific Brewer Workshop is to be held in Sydney in September 2017, hosted by the BoM.

7. FUTURE PLANS

Further chemistry-climate simulations using the ACCESS model will be archived for the CCMI-1 project.

The historic Umkehr Dobson record is to be reanalysed for the Australian region (BoM – University of Melbourne). The Dobson total ozone record is also being progressively reprocessed as is the ozonesonde dataset according to the international O3S-DQA homogenisation project.

8. NEEDS AND RECOMMENDATIONS

It is recommended that the ORM urge the Parties to continue long-term ozone observations, and request the Parties remind responsible agencies and institutions in their own countries of the importance of continuing long time-series.

Continued financial support for the Vienna Convention Trust Fund for Research & Systematic Observations is important to continue the work of building capacity and improving the global ozone observing system.

Space agencies are requested to make more effort to explicitly support the ground-based measurements required for calibration and validation, either by making a financial contribution to their operation or simply by directly communicating with the relevant agencies.

AUSTRIA

1. OBSERVATION ACTIVITIES

Long-term monitoring activities with respect to ozone column and UV are performed in Austria by Universities, especially by the Institute of Meteorology at the University of Natural Resources and Life Sciences Vienna (BOKU-Met) and by the Division of Biomedical Physics at the Medical University of Innsbruck (iMED-Phys). Activities have been financed since the early 1990ies by the Federal Ministry responsible for the environment – currently the Federal Ministry for Agriculture, Forestry, Environment and Water Management.

1.1 Column measurements of ozone and other gases/variables relevant to ozone loss

1.1.1 Brewer Spectrophotometer



Sonnblick observatory
© Michael Staudinger

Measurement of total ozone by the Brewer MkIV #93 Spectrophotometer at the high altitude station Hoher Sonnblick by BOKU-Met has been initiated in 1993. A time series of daily observations of total ozone is available from 1994 onwards.

The observatory at Hoher Sonnblick provides meteorological data from uninterrupted observations starting in 1886. Due to its remote location, largely uninfluenced by tropospheric confounding factors and human activity, it has grown to an environmental monitoring and research station in the 80ies of the last century. It hosts a. o. various measurements of radiation and atmospheric components. Having been a regional GAW station for a long time, it has become a global station in 2016.

Location	Lat/Lon	Altitude	Instrument	Start
Hoher Sonnblick	47.05°N, 12.95°E	3106 m asl	Brewer Mk IV No. 093	1994

1.2 Profile measurements of ozone and other gases/variables relevant to ozone loss

Apart from measurements of total ozone, measurements of the vertical distribution of ozone have been carried out with the Brewer spectrophotometer by applying the Umkehr retrieval algorithm UMK04 (Petropavlovskikh et al., 2005). The comparison between Brewer observations and the space-borne EOS MLS (NASA Earth Observing System Microwave Limb Sounder onboard the Aura satellite) data showed good agreement with low bias.

Figure 1 shows the climatological seasonal Umkehr profiles for the period from 1994 to 2011. The seasonal changes in the topmost layers' contributions are generally smaller, not exceeding −0.8% in spring and summer and +0.6% during fall. These numbers underpin the importance of (mainly dynamically induced) changes in ozone concentrations in the lower layers, as opposed to the upper layers, which contribute considerably less to total ozone column.

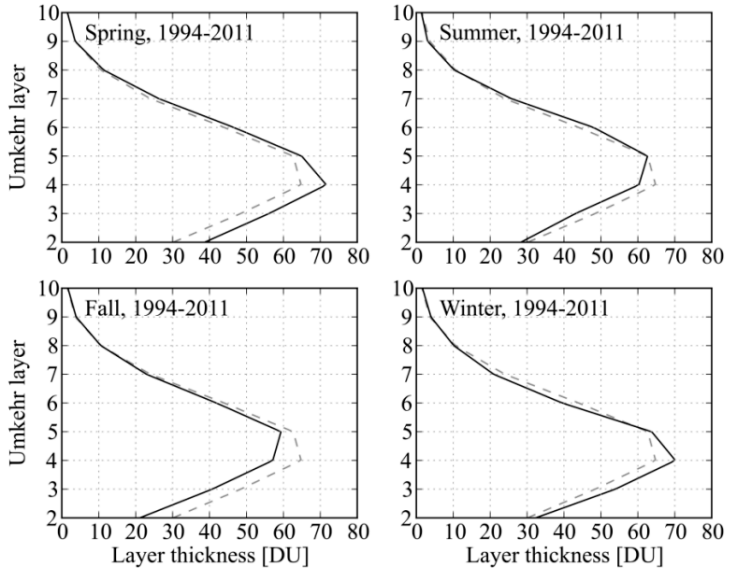


Fig. 1: Climatological Umkehr profiles, seasonal means (black line) and mean over the whole year (dashed line, grey) for spring, summer, fall and winter.

1.3 UV measurements

1.3.1 Broadband measurements

A network for the monitoring of erythemal UV radiation in Austria has been established in the 1990ies by iMED-Phys. Currently the network consists of 13 UV biometers distributed all over Austria, at altitudes between 150 and 3100 m asl. Continuous time series are available starting with 1997. The monitoring is performed in co-operation with the Department for Biomedical Sciences of the University of Veterinary Medicine Vienna, the Institute of Physics of the University of Graz, BOKU-Met, the Austrian Met Office (ZAMG) and the Federal Environment Agency (Umweltbundesamt).

In addition, monitoring of UV-A (310–400 nm, global radiation and diffuse radiation) has started in 2012 at three stations.

Location	Lat/Lon	Altitude	Instrument	Start (–End)
Wien	48.26°N, 16.43°E	153 m asl	Solar Light Mod. 501	1999
Wien	-"-	-"-	CMS Schreder J1034	2012
Grossenzersdorf	48.20°N, 16.57°E	156 m asl	Solar Light Mod. 501	2009
Bad Vöslau	47.97°N, 16.20°E	286 m asl	Solar Light Mod. 501	1997
Steyregg	48.29°N, 14.35°E	335 m asl	Solar Light Mod. 501	1997
Graz	47.10°N, 15.42°E	348 m asl	Solar Light Mod. 501	1997
Dornbirn	47.43°N, 9.73°E	410 m asl	Solar Light Mod. 501	1997
Klagenfurt	46.65°N, 14.32°E	448 m asl	Solar Light Mod. 501	1997
Kirchbichl	47.49°N, 12.09°E	526 m asl	Solar Light Mod. 501	2016
Kirchbichl	-"-	-"-	GigaHertz Optik UVA	2016
Innsbruck	47.26°N, 11.38°E	577 m asl	Solar Light Mod. 501	1998
Innsbruck	-"-	-"-	GigaHertz Optik UVA	2012–16
Mariapfarr	47.15°N, 13.75°E	1153 m asl	Solar Light Mod. 501	1998
Gerlitzen	46.68°N, 13.91°E	1526 m asl	Solar Light Mod. 501	2005
Gerlitzen	-"-	-"-	CMS Schreder J1034	2012
Hafelekar	47.32°N, 11.39°E	2275 m asl	Solar Light Mod. 501	2009
Hoher Sonnblick	47.05°N, 12.95°E	3106 m asl	Solar Light Mod. 501	1998

1.3.2 Spectroradiometers

Monitoring of spectral UV irradiance by BOKU-Met with Bentham instruments has been initiated in the second half of the 1990ies. Measurements are performed at two quite different stations in Austria: At Hoher Sonnblick (see above) and at a station in the east of Austria in the vicinity of an urban agglomeration (Grossenzersdorf). The stations are part of the NDACC.

Location	Lat/Lon	Altitude	Instrument	Start
Grossenzersdorf	48.20°N, 16.57°E	156 m asl	Bentham DM 150	1998
Hoher Sonnblick	47.05°N, 12.95°E	3106 m asl	Bentham DM 150	1997

1.4 Calibration activities

Calibration of the Bentham instruments with a self-built secondary 1000 W FEL lamp assembly is performed every one to two months over the whole measurement range of 290-500 nm. The secondary lamp itself is regularly calibrated to a NIST (National Institute of Standards and Technology, United States) and a PTB (Physikalisch-Technische Bundesanstalt, Germany) calibrated 1000 W lamp at the optical laboratory of BOKU-Met and in the laboratory facility in Großenzersdorf.

Calibration of the Brewer instrument with a 50 W standard lamp is performed periodically by BOKU-Met. Calibration against the standard instrument #017 is performed by the International Ozone Service Ltd. every three years. Since 2009 both Bentham UV spectrophotometers are part of NDACC, fulfilling the network's tight requirements in quality control and assurance. Intercomparison campaigns for the portable Bentham instrument are performed on a regular basis and were last conducted 2014 in Hannover, Germany. The results of the intercomparison show that the spectral irradiance measured by the BOKU-Met instrument deviates less than 3% from the reference instrument for a large variety of measuring conditions, which is well within the NDACC specifications and is very satisfactory

Annual calibration of the UV broadband sensors is performed by CMS Schreder (http://www.schreder-cms.com/) in the laboratory and by comparison with a national standard spectroradiometer. Intercomparison of the national standard with the travelling standard QASUME from PMOD/WRC has been done in 2010 and 2015.

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

The UV-Index data since 1998 together with measurements of global radiation and ozone levels from OMI are used to study long term trends for the stations of the monitoring network. Besides a strong variability from year to year, no statistically significant trend is found for the UV-Index and for ozone neither for all weather conditions nor for clear sky conditions (cf. Fig. 2).

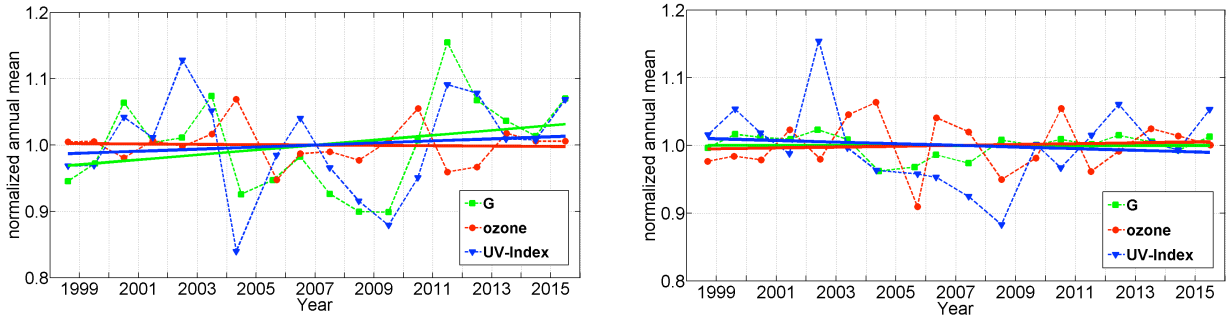


Fig. 2: Annual mean values (dots) of UV-Index, ozone and global radiation (G) for all weather conditions (left) and for days with clear sky conditions (right) at 19° solar elevation in Innsbruck, normalized to the respective mean value over 18 years. Straight lines show the linear fit.

The relation between UV-Index and ozone level can be expressed with the radiation amplification factor RAF in the power law formulation UVI $\propto O_3^{-RAF}$. For Innsbruck at 19° solar elevation a value of 0.91+0.05 was found for low ground albedo and 1.03+0.08 for days with high ground albedo due to snow cover.

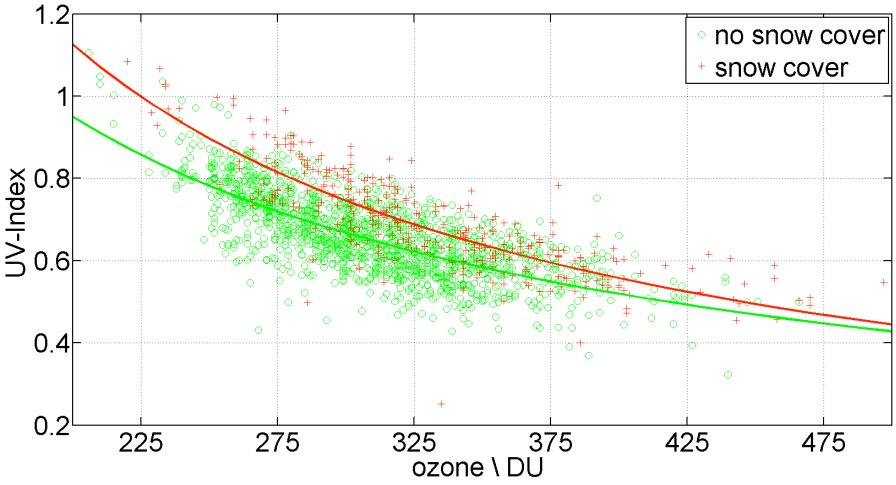


Fig. 3: Relation between UV-Index and ozone column

Continuous long-term measurements of ozone and spectral UV radiation have been investigated for estimates of trends and long-term changes. Trend estimates for total ozone measured by the Brewer spectrophotometer were realized with monthly mean anomalies of detrended total ozone data. With +0.3±1.0 %/dec the year round trend of total ozone in Fig. 4 shows little increase and no significance (≤ 95 %).

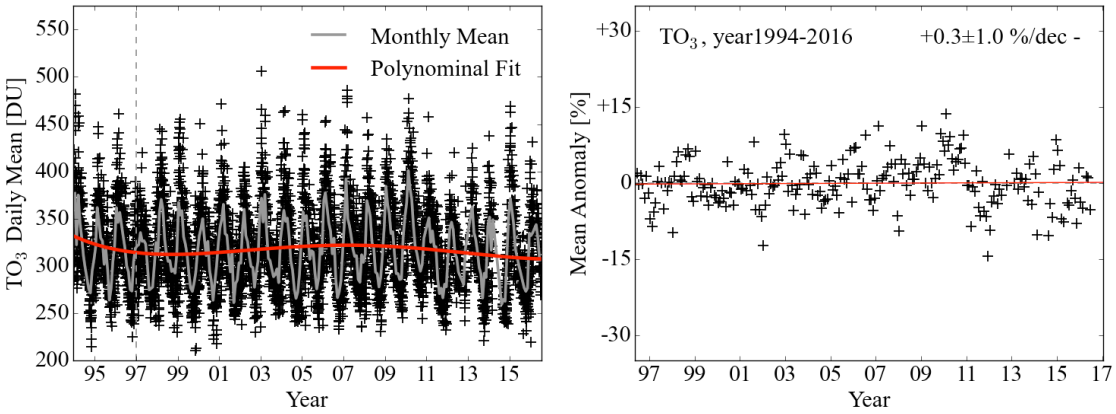


Fig. 4: Left: total ozone measured with the Brewer MkIV #93 spectro-photometer between 1994 and 2016 and monthly means; Right: year round trend estimates of monthly mean anomalies of total ozone

Figure 5 shows the complete series of measurements of erythemal radiation at Hoher Sonnblick from 1994 to 2016. The diurnal variation with maxima during summer and minima during winter is clearly visible.

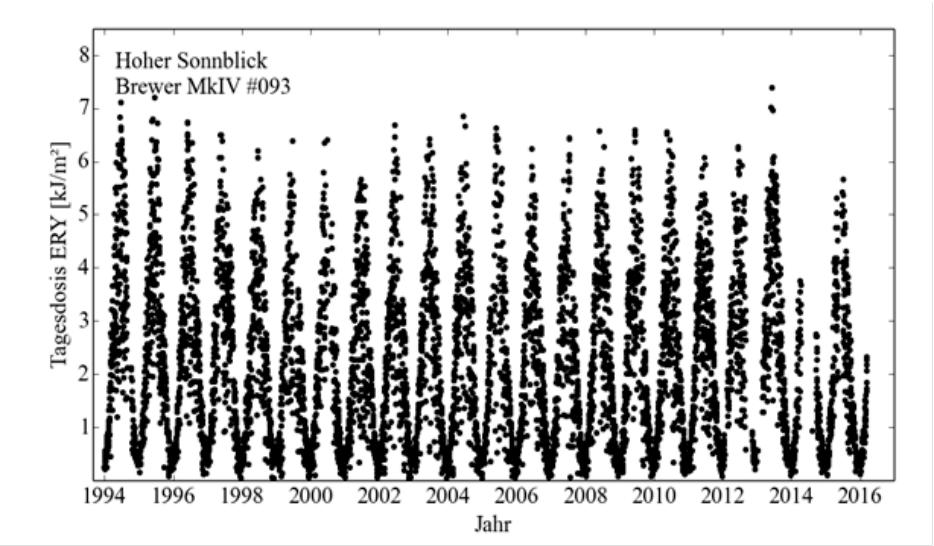


Fig. 5: Daily erythemal dosis from Brewer MkIV #093 spectrophotometer between 1994 and 2016

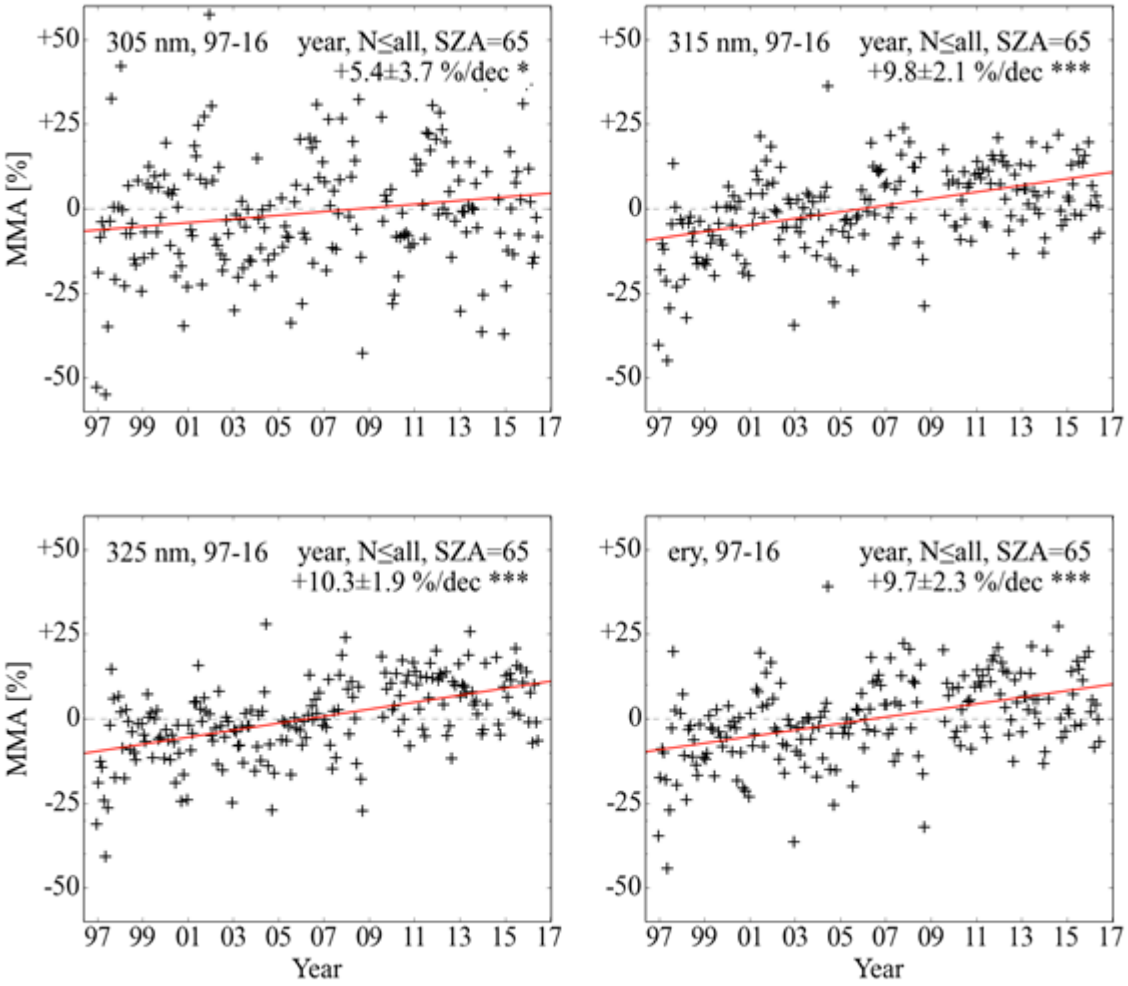


Fig. 6: Year-round trend estimates in monthly mean anomalies at Hoher Sonnblick at three selected wavelengths and ERY; solid red lines indicate trend, significance is given for 95 % (*), 99 % (**), and 99.9 % (***)

Long-term records of spectral UV irradiance from Bentham spectroradiometer measured at the high-altitude mountain site Hoher Sonnblick from the period 1997–2016 have been investigated for potential trends. Linear trend estimates were established using Sen's Q method while the nonparametric Mann-Kendall trend test was used to assess the linear changes' significance levels. The trend estimates were calculated for wavelengths between 305 nm (strong ozone absorption) and 325 nm (weak ozone absorption) and erythemally weighted irradiance (ERY) according to McKinlay and Diffey (1987). Fig. 6 shows the trend estimates of spectral UV irradiance on a basis of monthly mean anomalies, measured by the Bentham spectroradiometer for the period 1997–2016.

Significant upward trends are found at wavelengths of 315 and 325 nm and for erythemally weighted irradiance (ERY) with +9.8±2.1%/dec, +10.3±1.9%/dec and +9.7±2.3%/dec, respectively, and overall high significance (99.9%), while the trend at 305 nm is considerably smaller (+5.4±2.1%/dec) with less significance (95%).

Consequently, it is believed that the increases in UV irradiance are mainly caused by changes in cloudiness and aerosol optical depth (AOD) along with potential contributions to effective surface albedo through clouds below the observatory. It has also been found that the selection of the investigation period has a substantial influence on trend results and assessment. It can therefore be stated that prolonged, continuous high-quality measurement series still play a crucial role for the unambiguous assessment of ozone recovery and trends of surface UV radiation.

3. THEORY, MODELLING, AND OTHER OZONE RELATED RESEARCH

A new method was developed to combine the ground-based UV measurements with regional data about cloudiness from Meteosat and with radiative transfer modeling in order to calculate a map of the regional distribution of the UV-Index over Austria in near real time every 15 minutes.

Due to the impact of UV radiation on human health, an attempt was made to combine both meteorological and medical aspects of this subject (e.g. Haluza et al., 2014). As part of the project *UVSkinRisk*, studies of UV variability in the past, future estimations, influence of climate change and expected impacts on skin health risks, like skin cancer in Austria, have been carried out (Simic et. al, 2015). UV radiation from the past and the future has been modeled using meteorological standard observations and regional climate scenarios. A new approach has been chosen to estimate the UV exposure of humans by using a 3-dimensional model of a human body, considering the complex geometry of the radiation field (Schrempf et. al., 2016).

4. DISSEMINATION OF RESULTS

4.1 Data reporting

Data from the Austrian broadband measurements (erythemal radiation) are step by step reported to WOUDC. Data from the spectroradiometers are reported to the NDACC.

4.2 Information to the public

Daily total ozone values are published by BOKU-Met via teletext (television text service) and in the internet (https://imp.boku.ac.at/strahlung/messwert.htm). Near real-time UV-index data from the Austrian stations (and also from neighbouring countries) is made available in the internet by iMED-Phys, as well as an area-wide UV-Index map based on measurement, Meteosat cloud data and modelling (http://uv-index.at).

4.3 Relevant scientific papers

Blumthaler, M. (2004): Quality assurance and quality control methodologies within the Austrian UV monitoring network. Rad. Prot. Dos. 111, 359-362.

Blumthaler, M., Klotz, B., Schwarzmann, M. and Schreder, J. (2017): The Austrian UV monitoring network. AIP Conference Proceedings, International Radiation Symposium 2016, Auckland, New Zealand. In press.

Fitzka, M., Hadzimustafic, J. and Simic, S. (2014). Total ozone and Umkehr observations at Hoher Sonnblick 1994–2011: Climatology and extreme events. J. Geophys. Res.-Atmos. 119.2, 739-752.

Fitzka, M., Simic, S. and Hadzimustafic, J. (2012): Trends in spectral UV radiation from long-term measurements at Hoher Sonnblick, Austria. Theor. Appl. Climatol. 110.4, 585-593.

Haluza, D., Simic, S. and Moshammer, H. (2014): Temporal and spatial melanoma trends in Austria: an ecological study. Int. J. Environ. Res. Public Health. 11(1), 734-748.

Schallhart, B., Blumthaler, M., Schreder, J. and Verdebout, J. (2008): A method to generate near real time UV-Index maps of Austria. Atmos. Chem. Phys. 8, 7483-7491.

Schrempf, M., Haluza, D., Simic, S., Riechelmann, S., Graw, K. and Seckmeyer, G. (2016): Is Multidirectional UV Exposure Responsible for Increasing Melanoma Prevalence with Altitude? A Hypothesis Based on Calculations with a 3D-Human Exposure Model. Int. J. Environ. Res. Public Health, 13(10), 961.

Simic, S. (2015): UVSkinRisk- Health at risk through UV induced Skin Cancer in the Context of a Changing Climate. AUSTRIAN CLIMATE RESEARCH PROGRAMME in ESSENCE, 20-25.

Simic, S., Fitzka, M., Schmalwieser, A. , Weihs, P. and Hadzimustafic, J. (2011): Factors affecting UV irradiance at selected wavelengths at Hoher Sonnblick. Atmos. Res., 101(4), 869-878.

5. PROJECTS, COLLABORATION, TWINNING AND CAPACITY BUILDING

National Projects:

- Long-term measurements of total ozone and high-resolution spectral UV radiation at Hoher Sonnblick and Groß-Enzersdorf (STRATO-UV).
- Health at risk through UV induced Skin Cancer in the Context of a Changing Climate (UVSkinRisk).
- Analysis of total ozone and UV-radiation in Austria (UVKlim).
- Collaboration for the operation of measurement sites for the Austrian UV-B Network.

International Collaboration:

- The international Network for the Detection of Atmospheric Composition Change (NDACC).
- Global Atmosphere Watch (GAW).
- Close cooperation is established with PMOD/WRC in order to assure high quality of the calibration of the broadband UV detectors.

BANGLADESH

INTRODUCTION

Bangladesh ratified Vienna Convention for the Protection of Ozone Layer and the Montreal Protocol on Substances that Deplete the Ozone Layer on 2 August 1990 and Country Programme was approved in 1994 chalking out a strategy to phase-out consumption of Ozone Depleting Substances (ODS). National Ozone Unit (NOU) was established in 1996.

Since ratification, Bangladesh is a proud nation to implement the obligations under Montreal Protocol in right time and it has successfully achieved 100% reduction target of CFCs and other ODSs in 2010 in the refrigeration & Air-conditioning sector along with the solvent and other sector include MDIs.

Bangladesh has already started using environment friendly Hydrocarbon (HCs) in the refrigeration sector. In the foam sector, we have adopted zero ODP and low GWP Cyclopentane for conversion of HCFC-141b insulation foam producing process. Now we are implementing HCFC Phase-out Management Plan-Stage I in such a manner that the alternatives would be environment friendly and energy efficient.

By this time, Bangladesh achieved 10% reduction in HCFCs consumption in 2015 in accordance with Montreal Protocol obligation. It has also amended rules and regulations and an efficient HCFC licensing system. Bangladesh is now in full compliance.

2. OBSERVATIONAL ACTIVITIES (CURRENT STATUS)

Bangladesh is yet to undertake observational activities on ozone using methodologies including Column Measurement, Profile measurements of ozone and other gases /variables relevant to ozone loss. Our ozone office is not yet equipped with Narrowband filter instruments or Spectroradiometers and other necessary instruments for measurement of UV through Broadband.

However, we do have the Meteorological Department called, Bangladesh Meteorological Department (BMD) has historical experience in meteorological observation and monitoring. But 1st meteorological observatory was established in Jessore (1864) long before IMD established under British Government. Dhaka Meteorological Observatory was established in 1949.

BMD at present has 34 meteorological observatories, 10 pilot balloon observatories, 3 Rawin Sonde (RS) observatories, 12 agro-meteorological observatories, 5 Radar stations and 10 Seismological observatories. BMD is also installing new AWSs over the country gradually. All the observations are taken as per WMO standard and equipments are also standardized accordingly.

3. PROJECTS AND COLLABORATION

Currently, we don't have any project or activities relating to research/monitoring on the status of ozone over Bangladesh as well as to determine the level of ground UV/ozone.

4. FUTURE PLAN

As BMD is the authorized Department of the Government of Bangladesh for Meteorological and Geophysical observation, and is also a member of WMO. Our ozone office has chalked out a plan to start ozone research activities and enhance observational capacities in terms of column measurements, profile measurements and also for ground UV measurements by utilizing the

skill and present infrastructure of BMD, subject to the procurement of necessary instruments for the purpose. NOU of the Department of Environment will coordinate and facilitate the activities.

5. IMMEDIATE NEEDS

5.1 For Column measurement and Profile measurement

One Dobson or Brewer Spectrophotometer and one pilot ozonesondes observatory to be setup in BMD. Dhaka station would be linked to the World Ozone and Ultraviolet Radiation Data Centre (WO_3UDC).

5.2 For UV measurements

At present total radiation is continuously taken by Eppley Pyranograph by BMD at its all stations throughout the country. Introduction of UV Sensor to the present Eppley Pyranograph or by procuring additional digital UV measuring instruments to the BMD observatories located in Dhaka and for other field stations.

Conclusion

Necessary funds for procurement of instruments and operational costs along with necessary human resource development are utmost necessary for the said activities.

Upcoming efforts of Bangladesh on Ozone Research if materialized will strengthen NOU to contribute significantly by providing with the surface data in WMO format to the World Ozone and Ultraviolet Radiation Data Centre (WO_3UDC), Canada for real Ozone mapping supplement to the satellite measured global coverage. Also it shall be able to effectively contribute to the ongoing research by the various institutes on impact of UV-B radiation on human health and eco-systems.

BELARUS

Over the past several years, large efforts have been undertaken to adapt Belarusian legislation in the field of ozone depleting substances (ODS) following accession of Belarus to the Eurasian Economic Union. In 2014, changes were adopted in the Law of the Republic of Belarus of 12.11.2001 “On the Protection of the Ozone Layer" aiming to further advancing ozone research activities. In 2017, the National Ozone Monitoring Research and Education Center of the Belarusian State University (NOMREC BSU), the leading scientific institution in the field of ozone studies in Belarus, marks its twentieth anniversary.

1. OBSERVATIONAL ACTIVITIES

1.1 Total ozone monitoring

Continuous monitoring of total ozone (TO) has been maintained at the Minsk Ozone Station (53.83 °N, 27.46 °E, № 354) of NOMREC since 1998. Between 1998 and 2002, TO measurements were performed employing the “direct-sun” and “zenith-sky” procedures by means of PION spectrometer-ozonometer. Since 2002, column ozone values have been retrieved from spectral irradiance measurements made with a spectroradiometer PION-UV and a PION-F photometer using a specially elaborated technique.

TO measurements are performed continuously throughout the daylight hours with ~5 min intervals. Registered data scope is used to determine the average daily TO values.

Since 2011, TO monitoring has been also held at the Training and Research Center of the G.G. Winberg "Narach Biological Station" (53.89 °N, 27.55 °E) and the Francysk Skaryna Gomel State University (52.44 °N, 31.00 °E). These two sites are equipped with PION-F double-channel filter photometers and included in the overall ozone network of NOMREC BSU.

Since 2007, TO monitoring has been periodically conducted within the annual seasonal Belarusian Antarctic Expeditions (BAEs) at the Russian Antarctic Stations "Molodyozhnaya" (67°41′ S, 46°08′ E) and "Gora Vechernyaya" (67°41′ S, 46°10′ E). TO measurements are realized utilizing PION-UV-II polar modified double grating spectroradiometer and PION-FN double-channel filter photometer using combined absorption-interference filters. Seasonal expeditions usually cover December-March period.

1.2 Monitoring of surface ozone

In Belarus, monitoring of the concentration of surface (tropospheric) ozone has been maintained at the Minsk Ozone Station since 2004. The monitoring is realized using an optical path (DOAS) ozone meter TrIO-1 designed at NOMREC BSU and a certified gas analyzer (ozonometer) TEI-49C made by Thermo Environment Instruments (USA).

Besides the NOMREC BSU Minsk Ozone Station, there are four points of observation in Minsk operated by the Hydrometeorological Center of Belarus, in which impact measurements of tropospheric ozone, carbon and nitrogen oxides, sulfur dioxide, volatile organic compounds (benzene, toluene, xylene), and aerosol particles are conducted.

Monitoring of surface O_3 concentrations in seasonal Belarusian Antarctic Expeditions is carried out with a PION-PO surface ozone concentration meter that has been developed at NOMREC BSU on the basis of a semiconductor SnO_2 gas sensor.

1.3 Monitoring of nitrogen dioxide

Instruments for measurements of total nitrogen dioxide (NO_2) amount in the atmospheric column by means of DOAS and MAX-DOAS techniques have been developed in NOMREC BSU on the basis of Oriel MS-260 and MS-257 spectrometers. When operating in automated mode, the instruments provide spectra registration for daylight period at an interval of 5 minutes.

Continuous NO_2 total amount monitoring is maintained at the Minsk Ozone Station, while in summertime experimental observations are also conducted at the Narach Biological Station from time to time.

The device has passed a validation procedure against the regional reference NDACC in Zvenigorod (Moscow region, Russia), and has been included in the network of similar instrumentation participating in a synchronous measurement experiment: NOMREC BSU (Minsk), Moscow State University (Moscow), IAF (Moscow), Zvenigorod (Moscow Region), Zotino (Omsk Region).

MARS-B (Multi Axis Recorder of Spectra) instrument has been developed in NOMREC BSU for MAX-DOAS measurements of differential slant column densities (DSCDs) of NO_2 and other trace gases. Measurements with MARS-B were conducted in several points of observation (in Minsk and Narach in Belarus, and in Germany and the Netherlands during two international intercomparison campaigns). In 2014, measurements of NO_2 and ozone with MARS-B were also conducted in Eastern Antarctica near the Russian Station "Progress" during the 6th Belarusian Antarctic Expedition (BAE-6).

1.4 Vertical profiles retrieval for ozone, nitrogen dioxide, and aerosols

MAX-DOAS measurements made by the MARS-B instrument in different points of observation are used for retrieval of ozone, nitrogen dioxide and other trace gases profiles. Furthermore, a new experimental procedure for vertical profile retrieval using spectra recorded by the MARS-B instrument, PION-UV spectroradiometer, and another instrument on the basis of Oriel 260i imaging spectrometer is currently under development and testing.

Vertical profiles of ozone and atmospheric aerosols are also measured by lidar techniques at the B.I. Stepanov Institute of Physics of the National Academy of Sciences of Belarus. Aerosol parameters are measured using a lidar with wavelengths of 355 and 532 nm. Ozone vertical profile is measured at a wavelength of 266 nm and also at 281.7 nm utilizing a solid-state Raman converter.

1.5 Monitoring of levels and doses of surface solar UV radiation

Monitoring of levels and biological doses of surface solar UV radiation is maintained at three sites in Belarus (Minsk Ozone Station, Narach Biological Station, Gomel State University) and also in places of location of the seasonal Belarusian Antarctic expeditions (BAEs).

Preliminary studies and observation results have demonstrated differences between climatic norms of UV radiation for Narach and for Minsk, UV norm for Narach being significantly higher. Research in this direction will be continued.

1.5.1 Spectroradiometers

A double diffraction spectrophotometer PION-UV and its polar modification PION-UV-II, developed at NOMREC BSU, are able to record irradiance spectra (IS) in a wavelength range of 290÷450 nm with a spectral resolution of 0.8 nm. In addition to a working channel, devices are equipped with a special "reference" channel to monitor the state of clouds. In automated mode, the instruments measure spectra with an interval of 5 minutes during daylight hours.

Based on the measurement results, UV index as well as the dose rates of basic biological effects of UV radiation (erythema, DNA damage, skin cancer, cataract, etc.) can be automatically determined.

1.5.2 Double-channel filter photometers

A series of double-channel photometers PION-F1, PION-F2, PION-PAR, and PION-FN for UV monitoring in network has been developed in NOMREC BSU. These all-weather network combined (absorption-interference) filter photometers are designed for automated measurements of irradiance from the total (direct plus diffusely scattered down) solar UV radiation in two spectral ranges with peaks at 293 nm and 325 nm wavelengths. The duration of one measurement is ~5 sec, measurement frequency equals two measurements per minute. The shape of the spectral sensitivity of the short channel allows to calibrate the recorded signal directly from the values of the UV Index (erythema dose).

PION-F2 photometer is operated at the Gomel State University. PION-PAR photometer additionally provides PAR (photosynthetically-active radiation) measurements, which are important for biological studies, and is currently used at the Narach Biological Station.

1.5.3 Submersible photometer

Propagation of solar UV radiation in aqueous medium of natural water bodies has been an active area of research in Belarus for the past several years, involving NOMREC BSU and other institutions of the Belarusian State University. Accordingly, PION-Aqua submersible photometer has been developed in NOMREC BSU and has been used for underwater UV measurements in lakes on different depths in Belarus (Narach lakes) and Antarctica. Preliminary results both in Belarusian and Antarctic lakes demonstrate significant impact of the UV-B irradiance level on the aquatic ecosystem state.

The device consists of two portable modules: submersible and surface. Their parallel operation makes it possible to measure solar radiation values at different depths in the water body and also to measure the water layer transparency (from the surface to the current depth) in the 285÷400 nm spectral range. UV-B filter is an integral part of the submersible module providing underwater measurements specifically in the biologically active UV-B spectral range (285÷315 nm), which is especially important, since UV-B radiation has been observed to penetrate as deep as 15 meters below the surface.

1.6 Calibration activities

Total ozone instruments were calibrated using the WMO regional standard (Dobson N108 spectrophotometer) in Voeikov Main Geophysical Observatory (MGO), St. Petersburg, Russia.

Spectral irradiance calibrations of PION-UV and other instruments in a spectral range of 285÷450 nm were regularly carried out at NOMREC BSU using its own set-up with a 300 W tungsten band-lamp certified by the Russian National Standard Agency.

MARS-B instrument participated in the international intercomparison campaign CINDI-2 (“Cabauw Intercomparison of Nitrogen Dioxide Measuring Instruments 2”), conducted under the auspices of the Royal Netherlands Meteorological Institute in August-October 2016 in Cabauw, the Netherlands. During participation in CINDI-2 campaign, which was based on the principle of half-blind comparison of measurement data, the instrument has demonstrated high quality of measurements for nitrogen dioxide (NO_2), ozone (O_3), formaldehyde (HCHO) and oxygen dimer (O_4) in a UV wavelength range of 320÷390 nm.

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

2.1 State of the ozone layer

The analysis of long-term changes in the state of the ozone layer over the territory of Belarus has been in progress based on the results of ground-based monitoring and satellite data of total ozone in the vertical atmospheric column (TO) for the city of Minsk (53.83 °N, 27.47 °E). Series of average daily, monthly and annual TO values for the periods of 1979-1992 and 1997-2016 have been analyzed.
In the period from 1979 to the end of the 90's, trend magnitude was ~1.5 units/year. Since 2000, the negative trend has remained but its value has decreased, and for the period of 2000-2016 it amounts to ~0.3 units/year. Registered variations of the average annual TO values are presented in Figure 2.1.

Analysis of long-term trends of TO average monthly values for the considered time periods have shown that in 1980s and 1990s TO negative trend occurred in some way in all seasons, but the strongest decrease in TO was observed in winter and early spring. After 2000, the magnitude of the negative trend for all months except June and September has decreased significantly. In January and to a lesser extent in February, a positive trend of TO average monthly values has been observed.

Joint analysis of variations in TO average monthly values and variations of general circulation processes in the troposphere of the Northern Hemisphere has revealed their relationship (wherein variations in tropospheric general circulation are analyzed on the basis of a circulation link between high latitudes and middle latitudes expressed by the amount of Arctic intrusions and their area, thereby allowing to identify repetitive circulation patterns in the Northern Hemisphere).

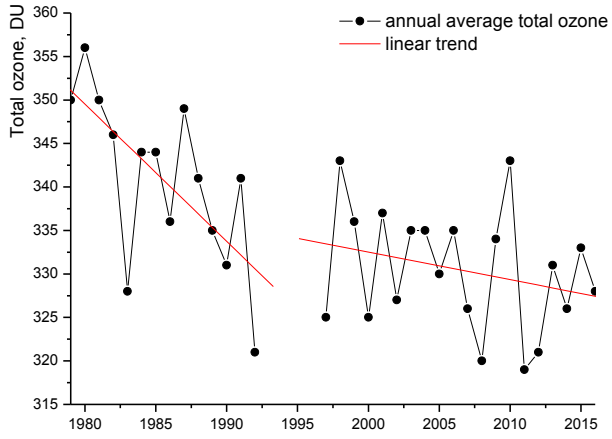


Figure 2.1. The average value of TO and linear trend for the periods of 1979-1992 and 2000-2016.

Figure 2.2 presents results of observations in 2011-2016 compared to the TO climate norm and its monthly average values. Also, the most pronounced ozone anomalies are marked. These are the ones falling beyond the 95% confidence interval of the variation of the daily average values that have been used to determine the climatic norm.

As can be seen from Figure 2.2, the frequency of positive anomalies detected over the territory of Belarus has been growing since 2013. The maximum of positive anomalies was registered in 2015. The TO average monthly values are close to the climatic norm, which is currently experiencing slow growth with the addition of the data for each subsequent year.

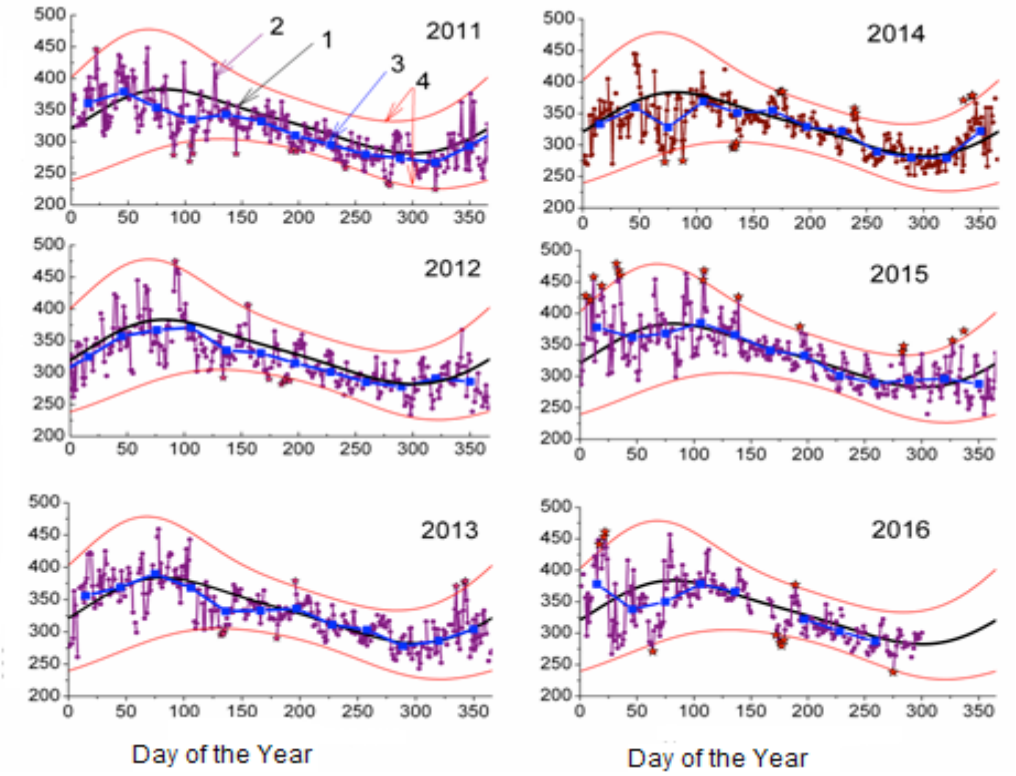


Figure 2.2. The TO average daily values over the territory of Belarus in 2011 - 2016. 1 – the annual variation of the climatic norm, 2 – observations data, 3 – monthly average values, 4 – 95% confidence interval. Asterisks denote the most significant ozone anomalies.

2.2 Stratospheric nitrogen dioxide

While it is known that high concentrations of NO_2 in the surface atmospheric layer pose a significant challenge for ground-based passive remote sensing of stratospheric NO_2, certain design features of the MARS-B instrument make it possible to partially overcome this problem. On the other hand, measurements in Antarctica provide a unique opportunity for stratospheric NO_2 observations due to almost complete absence of near-surface NO_2.

In 2014, measurements with the MARS-B instrument were conducted in Eastern Antarctica near the Russian Station “Progress” during the 6th Belarusian Antarctic Expedition. A detailed study of NO_2 and ozone DSCDs series registered in Antarctica shows that information about altitudinal distribution of stratospheric trace gases can be obtained by studying functional dependence of trace gases DSCDs on time. From day to day, the diurnal variation of ozone DSCD changes its shape, which may indicate changes in the height of the ozone layer. In cases when NO_2 DSCD diurnal variations have the same shape as ozone DSCD variations, it leads to the conclusion that maximal concentrations of ozone and NO_2 are on the same altitude on these days.

Measurement results are in good agreement with reanalysis data, which also indicate that higher concentrations of NO_2 in the upper stratosphere lead to decreases in ozone and vice a versa when NO_2 concentrations are lower, ozone concentrations increase, and the ozone layer ascends. This suggests a possible negative correlation in the behaviour of these trace gases, which can be seen as a manifestation of their interaction in the stratosphere.

2.3 Surface ozone

Figure 2.3 shows results of observations of surface ozone concentrations taken at the NOMREC BSU Minsk Ozone Station in 2013-2016. Individual measurements performed at local noon (about 13.00 local time) are shown along with monthly average values of noon concentrations.

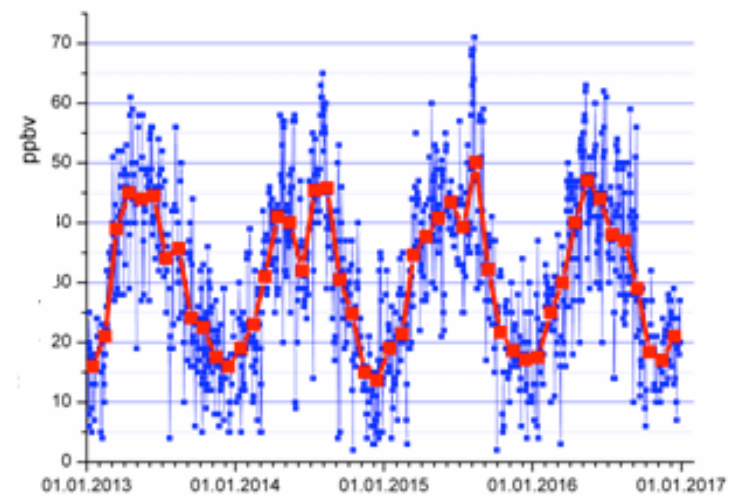


Figure 2.3 Surface ozone at NOMREC BSU Minsk Ozone Station for 2013-2016. Blue: noon concentrations. Red: monthly averages of noon values.

Analysis of surface ozone observational data demonstrates a high correlation between its noon concentrations and maximum diurnal ones (correlation coefficient is around 0.9).

3. THEORY, MODELLING, AND OTHER OZONE RELATED RESEARCH

Stratosphere-troposphere interactions research and studies of the interactions between the stratospheric ozone layer dynamics and circulation in the troposphere are continued in NOMREC BSU utilizing both processing of observational data and reanalyses and numerical atmospheric modelling.

At present, two numerical atmospheric models are used. High-resolution regional simulations for fine-scale stratosphere-troposphere interactions studies are carried out in a modified WRF modelling system. Furthermore, since June 2014 NOMREC BSU has been also a registered user of the ECMWF OpenIFS general circulation model, utilizing it for global-scale simulations.

Atmospheric modelling activities are primarily aimed at investigation of the dynamical processes of local ozone anomalies formation, analysis of interactions between the stratospheric ozone dynamics and features of circulation and global-scale air masses in the troposphere, and also at estimation of time lags and causal relationships between these categories of processes on different spatial and temporal scales.

4. DISSEMINATION OF RESULTS

NOMREC BSU data along with the data from B.I. Stepanov Institute of Physics are submitted to and archived in the database of the National Environmental Monitoring System (NEMS).

In accordance with the recommendations of the 9th ORM, special data banks have been formed containing observations conducted in Belarus and Antarctica in 2014-2016. Monitoring results are submitted to the MIAC of NEMS and are regularly published in

annual collections: “Results of Monitoring of NEMS”, “NEMS Bulletin”, “Bulletin of the Ecological State of the Naroch Lake”.

UV mapping and UV Index forecasts generated specifically for different regions of Belarus are continuously provided by NOMREC BSU since 2006. The data are available online on the NOMREC Web-site http://ozone.bsu.by and also on the Web-site of the Hydrometeorogical Center of Belarus http://www.pogoda.by.

5. PROJECTS, COLLABORATION, TWINNING AND CAPACITY BUILDING

According to the recommendations of the 9th ORM, studies of ozone-climate relations are implemented in Belarus as a research project within the framework of the National Programme “Informatics, Space and Security”. The project has already been active for more than five years and has been prolonged further.

There are some relevant international research collaborations currently underway in NOMREC BSU. These are as follows:

1. A.M. Obukhov Institute of Atmospheric Physics (Russia) – study of atmospheric trace gases.
2. A.I. Voeikov Main Geophysical Observatory (Russia) – TO monitoring, instruments design, research in the area of stratosphere-troposphere interactions and impact of ozone on climate and atmospheric processes.
3. Institute of Arctic and Antarctic (Russia) – research in the Antarctic region.
4. Max Planck Institute for Chemistry (Germany) – MAX-DOAS observations of atmospheric trace gases, processing of observations, algorithms.
5. European Centre for Medium-range Weather Forecasts, ECMWF (UK) – using OpenIFS model in current research activities in contact with ECMWF.

6. FUTURE PLANS

Participation in international intercomparison and calibration campaigns is important to ensure that ozone monitoring instruments meet international requirements, so Belarus has requested support for this activity and is ready to implement it in the nearest future. This will provide some additional confidence for submission of observational data to WOUDC and GAW SIS.

BELGIUM

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FOREWORD

This report is a synthesis of the contributions provided by four Belgian research institutes, whose contact details will be found in ANNEX F:

- the Institute of Astrophysics and Geophysics of the University of Liège (ULg),
- the Service de Chimie Quantique et Photophysique of the Université Libre de Bruxelles (ULB),
- the Royal Meteorological Institute (RMI) and
- the Royal Belgian Institute for Space Aeronomy (BIRA-IASB).

1 OBSERVATIONAL ACTIVITIES

All four institutes are actively involved in the long-term monitoring of atmospheric ozone, gaseous species important for the ozone chemical budget, e.g. catalyst reservoirs and ozone-depleting substances (ODS), aerosol properties or ultra-violet radiation. Measurements of chemical species include vertical profiles as well as partial and total columns and use both IR and UV-Visible spectrometry. Measurements are performed at or from ground-based stations and from satellites. Data are exploited by the four institutions for budget, process, validation and long-term trend studies.

The list of the eighteen stations hosting instruments operated and exploited by the four Belgian scientific institutes is displayed in ANNEX A (Table A 1). The table provides the station geolocation and the type of data collected. Details on the instruments, the retrieved physical quantities, the time record duration, the data usage and other observational information is also provided in ANNEX A (Table A 2, Table A 3 and footnotes). Fifteen of these stations belong to international networks and report data to shared central databases.

ULg, ULB and BIRA are involved in several satellite missions measuring ozone and ozone relevant species (halogens, NOy, BrO, HCFC, CFC…). The detail of the satellite missions with which the institutes are associated is provided in ANNEX B.

1.1 Column measurements of ozone and other gases/variables relevant to ozone loss

The vertical column of ozone and other species is monitored at ten of the ground-based stations (ANNEX A, Table A 1) by ULg, BIRA-IASB and RMI (see ANNEX A,Table A 2 and Table A 3). ULg, ULB and BIRA-IASB are involved in several satellite missions measuring the total column of ozone and of ozone relevant species – see detail in ANNEX B.

1.2 Profile measurements of ozone and other gases/variables relevant to ozone loss

The vertical profile of ozone and other species is monitored from the ground or from balloons at seven of the stations (ANNEX A, Table A 1) by ULg, BIRA-IASB and RMI (see ANNEX A, Table A 2 and Table A 3). Some of the instruments also provide aerosol optical depth (AOD) data or aerosol backscatter profiles (see ANNEX A,Table A 2). ULB and BIRA-IASB are involved in satellite missions measuring the vertical distribution of ozone, ozone depleting substances (ODS) and other species relevant to ozone chemistry – see detail in ANNEX B.

1.3 UV measurements

RMI and BIRA-IASB monitor the UV irradiance and ancillary parameters by spectroradiometers in Belgium and in Antarctica (see detail in ANNEX A,Table A 2).

1.4 Calibration / Validation activities

Calibration / validation activities of the four institutes are enumerated in detail in ANNEX C. In summary, they can be divided in three types of activities:

- In compliance with the international network requirements, ULg, BIRA-IASB and RMI regularly calibrate the ground-based and balloon-borne instruments they operate (listed in ANNEX A, Table A 2), and perform uncertainty analyses and budgets

- ULB and BIRA-IASB are actively involved in Cal/Val activities in the context of satellite missions and data retrieval.
- BIRA-IASB is involved in several initiatives and projects to harmonise validation procedures and define data and service quality standards in compliance with the Quality Assurance Framework for Earth Observation (QA4EO).

2 RESULTS FROM OBSERVATIONS AND ANALYSIS

2.1 The Royal Meteorological Institute (RMI)

Research on the evolution of total atmospheric ozone and its distribution versus altitude at northern mid-latitudes, in particular above Belgium revealed a mean temporal decrease in 'good' ozone in the stratosphere and an increase in 'bad' ozone in the troposphere. With the help of model calculations it was shown that both changes are primarily of anthropogenic origin. Further observations in Uccle (Brussels) showed that observed levels of harmful UV-B irradiance at ground level anti-correlate with levels of stratospheric ozone. Initiatives have been taken to warn the general public about health risks resulting from excessive exposure to the sun in summertime.

Figure 1 shows the time evolution of the ozone column over Uccle based on the combined data of the Dobson (1971-1989) and the Brewer Instruments (1990-now). The ozone column decreased with 3% per decade in the period 1980-1997 and then there is possible sign of recovery afterwards, although the period is too short to draw firm conclusions. The ozone soundings have shown us that the decrease occurs in the lower stratosphere, especially during winter and early spring. In the troposphere, on the contrary, the ozone concentrations tend to increase due to photochemical reactions in polluted air.

The ozone measurements at the Antarctic Station princess Elisabeth are reported to the WOUDC as they become available.

The ozonesonde stations at Uccle (Belgium) and De Bilt (the Netherlands) are separated by only 175 km but use different ozonesonde types (or different manufacturers for the same electrochemical concentration cell (ECC) type), operating procedures, and correction strategies. As such, these stations form a unique test bed for the Ozonesonde Data Quality Assessment (O3S-DQA) activity, which aims at providing a revised, homogeneous, consistent dataset with an altitude-dependent estimated uncertainty for each revised profile. For the ECC ozonesondes at Uccle mean relative uncertainties in the 4–6 % range are obtained. To study the impact of the corrections on the ozone profiles and trends, we compared the Uccle and De Bilt average ozone profiles and vertical ozone trends, calculated from the operational corrections at both stations and the O3S-DQA corrected profiles.

In the common ECC 1997–2014 period, the O3S-DQA corrections effectively reduce the differences between the Uccle and De Bilt ozone partial pressure values with respect to the operational corrections only for the stratospheric layers below the ozone maximum. The upper-stratospheric ozone measurements at both sites are substantially different, regardless of the correction methodology used. The origin of this difference is not clear. The discrepancies in the tropospheric ozone concentrations between both sites can be ascribed to the problematic background measurement and correction at De Bilt, especially in the period before November 1998. The Uccle operational correction method, applicable to both ozonesonde types used, diminishes the relative stratospheric ozone differences of the Brewer–Mast sondes in the 1993–1996 period with De Bilt to less than 5 % and to less than 6 % in the free troposphere for the De Bilt operational corrections.

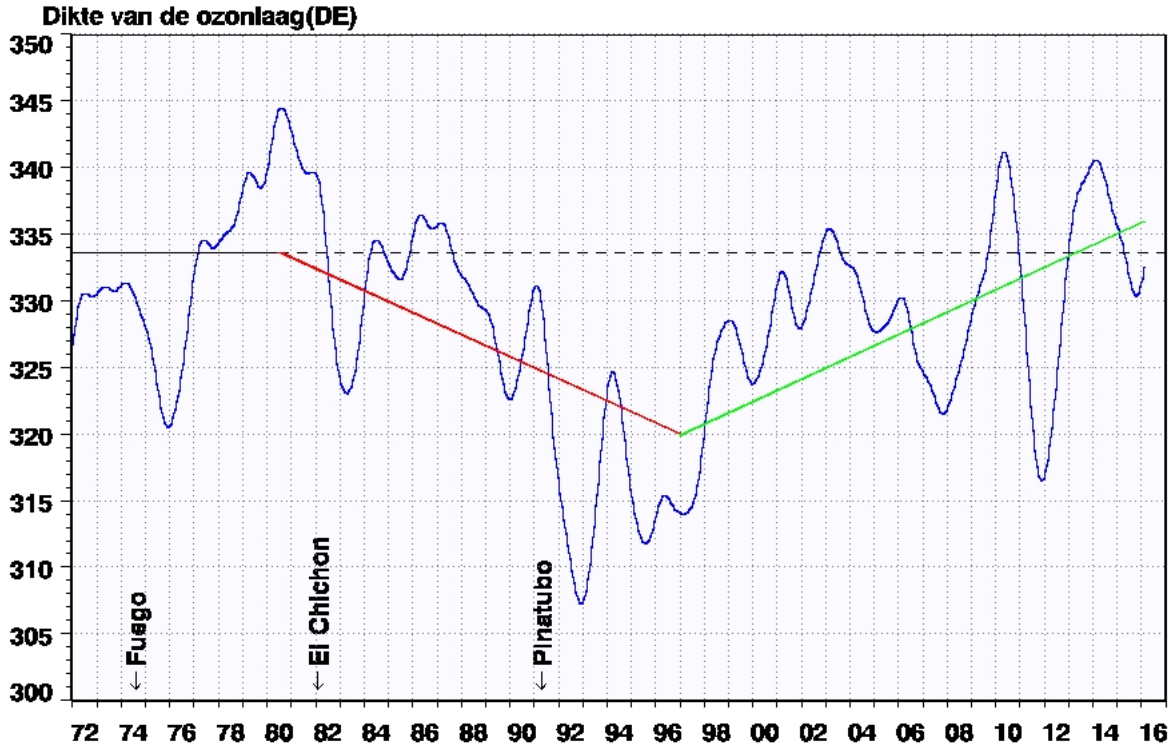


Figure 1. Running annual mean of total ozone (in Dobson Units) from Dobson and Brewer spectrophotometers at Uccle, together with a stepwise regression. The times of major volcanic eruptions, affecting the ozone layer are also indicated.

Despite their large impact on the average ozone profiles, the different (sensible) correction strategies do not change the ozone trends significantly, usually only within their statistical uncertainty due to atmospheric noise. The O3S-DQA corrections bring the Uccle and De Bilt ozone trend estimates for 1997–2014 closer to each other in the lower stratosphere and lower troposphere. Throughout the whole vertical profile, these trend estimates are, however, not significantly different from each other, and only in the troposphere significantly positive. For the entire Uccle observation period (1969–2014), the operational corrections lead to height-independent and consistent ozone trends for both the troposphere and the stratosphere, with rates of +2 to +3 % decade^{-1} and −1 to −2 % decade^{-1}, respectively.

2.2 Results from trend studies by the Royal Belgian Institute for Space Aeronomy (BIRA-IASB)

BIRA-IASB has contributed significantly to different activities of the SPARC/IO3C/WMO-IGACO/NDACC (SI2N) initiative, which itself has contributed significantly to the 2014 WMO Scientific Assessment of Ozone Depletion (WMO 2014): as co-author of the coordinated SI2N papers (*Hassler et al., 2014; Harris et al., 2015*), as coordinator of ozone trend studies based on NDACC FTIR network data records (*Vigouroux et al., 2015*), as principal investigator of the long-term stability of 14 limb and occultation ozone data records (*Hubert et al., 2016*), as principal investigator of the uncertainties associated on long-term trends derivation (*Harris et al., 2015, Hubert et al., 2016*), as investigator of the quality of several ozone data records (*Laeng et al., 2014; Adams et al., 2014; Keppens et al., 2015*), and as investigator of metrology aspects of ozone data use (*Verhoelst et al., 2015*).

BIRA-IASB is now coordinator of the LOTUS SPARC activity (Long-term Ozone Trends and Uncertainties in the Stratosphere, http://igaco-o3.fmi.fi/LOTUS/) which is a follow-on of the SI2N Initiative, and whose aim is to provide updated trends and improve accuracy of the uncertainties on the trends. The results of this project will be published in the next WMO 2018 report.

BIRA-IASB extended the past study on ozone trends (total columns and vertical distribution) at European stations (*Vigouroux et al., 2008*) to 8 FTIR NDACC stations, including Groenland, Australia and New Zealand (*Vigouroux et al., 2015*). The harmonization of the retrievals settings among the 8 stations was improved, the time-series were extended to 2012, and the simple regression model used in the first study was replaced by a multiple linear regression model including explanatory variables such as QBO, tropopause heigths,… This work was used for the 2014 WMO Scientific Assessment of Ozone Depletion (*WMO 2014, Chapter 2*) and was published in the papers resulting from the overview carried out within the SPARC/IO3C/WMO-IGACO/NDACC (SI^2N) initiative (*Hassler et al., 2014; Harris et al., 2015*).

The FTIR ozone data sets have then be extended up to end of 2015, and the tropospheric columns have been used in the Tropospheric Ozone Assessment Report (TOAR), Chapter 2 and 6 (*in preparation*).

BIRA-IASB succeeded in retrieving CFC-11 (CCl_3F), CFC-12 (CCl_2F_2) and HCFC-22 (CHF_2Cl) from the Saint-Denis and Maïdo FTIR measurements at Réunion Island (*Zhou et al., 2016*).

BIRA-IASB coordinates ESA's CCI Ozone Phase II project, in which it contributes to the refinement of total ozone retrieval algorithms in view of producing homogenised total ozone data records from all European UV-visible nadir satellites: GOME, SCIAMACHY, GOME-2A, OMI, GOME-2B…

BIRA-IASB coordinates ECMWF's C3S Ozone project (2016-2019), which is to feed the Copernicus Climate Data Store (CDS) with ozone profile and column data records suitable for climate change research and monitoring and for long-term trend studies.

BIRA-IASB has developed a new GOMOS retrieval algorithm in the framework of the ESA AerGOM project improving the aerosol extinction retrieval and providing a vertical profile for ozone and other trace gases (*Vanhellemont et al, 2016; Robert et al, 2016*).

BIRA-IASB has been responsible for the development of the stratospheric aerosol dataset in the framework of ESA's Aerosol CCI project, which consists of a 10-year time series of aerosol measurements carried out by the GOMOS instrument (*Popp et al, 2016; Bingen et al, 2017*).

2.3 University of Liège (ULg)

The Jungfraujoch FTIR observational data set from ULg now covers more than 30 years. It is the longest available worldwide and hence is particularly appropriate for trend determination investigations. We summarize here below a selection of relevant and recent results.

Since the mid-1980s, ULg has maintained the consistent monitoring of the vertical column abundances of HCl and $ClONO_2$, which are the main inorganic Cl_y reservoirs in the stratosphere. Their sum shows that the rate of increase of Cl_y has progressively slowed down during the early-1990s, and stabilised in 1996-1997, in response to the amended production regulations on O_3-depleting substances by the Montreal Protocol. Since then, the Cl_y loading has shown an overall decrease (-0.5%/yr.) over the 1997-2012 time period. More careful analyses reveal that the evolution of stratospheric chlorine has undergone significant deviations from a smooth decline, with in particular a significant increase of HCl over 2007-2011. The combination of ground-based FTIR data from eight NDACC sites, from satellites measurements by HALOE, AURA and ACE-FTS, supported by two reference 3-D Chemical Transport Models (KASIMA and SLIMCAT) has revealed that a prolonged slowing down of the stratospheric circulation has caused this unexpected HCl trend upturn. This study, coordinated by ULg, has been published in *Nature* (*Mahieu et al., 2014a*).

The CCl_4 time series produced by (*Rinsland et al., 2012*) has been updated, allowing contributing to the "SPARC report on the Mystery of Carbon Tetrachloride, 2016" as well as to a recent study modelling the CCl_4 decrease (*Chipperfield et al., 2016*), which is known to be slower than expected when accounting for the reported emissions and its atmospheric lifetime.

Measured rates of increase of the major radiatively active gases are: for CO_2, a recent study involving *in situ* surface and column measurements performed at Jungfraujoch indicated very consistent trends of 2 ppm/yr. over the 2005-2013 period (*Schibig et al., 2016*); for CH_4, a study involving FTIR measurements at ten NDACC stations and model simulations investigated the recent changed in methane, a global trend of 0.3 %/yr. has been determined. Causes for the observed increases are attributed to anthopogenic emissions (coal mining, gas and oil transport

and exploration (*Bader et al., 2016*); for N_2O, an average of 0.23%/year from 1996 to 2014; for SF_6, a substantial increase of still more than 4 %/yr. over 2004-2010; for CF_4, a continuous accumulation close to 1%/yr. since the early 2000s (*Mahieu et al., 2014b*).

2.4 Université Libre de Bruxelles (ULB)

In the last years, the ULB has been involved in the monitoring of global ozone distributions using IASI, both in terms of columns and vertical profiles. Time series are available from 2008 onwards.

2.4.1 Validation results

The ozone products – columns and profiles – were first mostly validated against ozonesondes and UV satellite instrument (for total columns see *Anton et al. 2011* and for profiles e.g. *Dufour et al., 2012*). The comparisons were extended to the study of the Polar Regions, for the stratosphere and the troposphere (*Scannell et al., 2012, Gazeaux et al., 2013, Pommier et al., 2012*). Generally, the results show good agreement between FORLI-O_3 and independent measurements with a low positive bias (<10%) in the total column and in the vertical profile, but a positive bias of 10-15% was identified in the UTLS (*Dufour et al., 2012; Gazeaux et al., 2012; Oetjen et al., 2014*) which required further investigations. Recently, *Boynard et al. (2016)* extended the validation of the FORLI-O_3 product on the global scale for the two IASI instruments against a series of independent observations (GOME-2, Dobson, Brewer, SAOZ and ozonesondes data) during the period 2008-2014. The comparison results indicate that the IASI total column overestimates the UV measurements by 4-6.5% and that the vertical profiles underestimate the ozonesondes data by ~5-15% in the troposphere and overestimate them by ~10-40% in the stratosphere. A large bias is still observed in the UTLS region around 10-15 km altitude, which could be explained by the large total retrieval errors associated with the low O_3 amounts which characterize the UTLS region (*Wespes et al., 2016*). The high positive bias observed in the stratosphere largely explains the systematic positive bias in the total columns. The overcoming issues observed in the stratosphere and in the UTLS could be explained by biases between UV–Vis and infrared spectroscopy, as well as uncertainties in the spectroscopic parameters.

Based upon these validation exercises, we developed an improved version of the FORLI algorithm (v20151001). Several corrections (e.g. to emissivity integration, continua region, look-up-table – LUT- construction) have been brought. A bigger LUT range for O_3 and an updated version of the HITRAN spectroscopic database have also been used. That new FORLI brings considerable improvements for the O_3 retrievals. It mainly improves the results in the stratosphere above 20 km, reducing the bias for the total ozone by ~4-5%, on average.

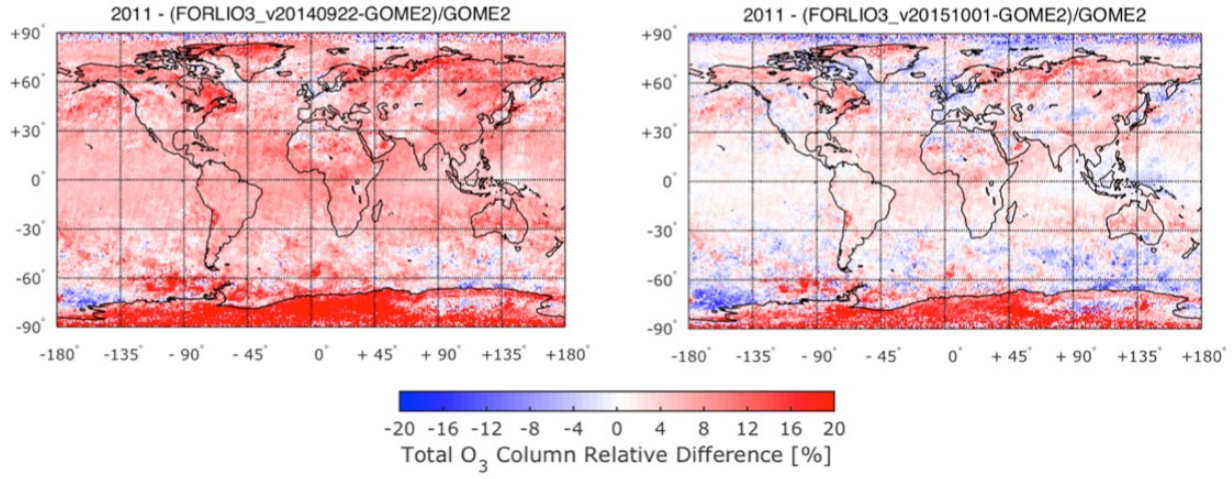


Figure 2. Global distribution of the relative differences (in %) between FORLI v20140922 (left panel) and FORLI v20151001 (right panel) against GOME-2A O3M-SAF TOCs averaged over 12 days of 2011 (on the 15th of each month) and over a 1° x 1° grid. The relative difference is calculated as: 100 x (FORLI-O3 – GOME-2) / GOME-2 (Boynard et al., 2016).

The differences between the two versions of FORLI have also been evaluated for CO. They are, however, shown to be negligible for the total CO columns. Inter-satellite comparisons of the FORLI-CO product is reported in *George et al. (2015)*.

The first characterization and validation of the FORLI-HNO_3 vertical profile product with FITR instruments at 6 stations has been recently published (*Ronsmans et al., 2016*). For all stations and for the total column or the vertical profile measurements, an overall good agreement is found with the measurements of both datasets within the error range of each other.

The validation results showed a positive bias of IASI in the UTLS (between 300 and 50 hPa), where the IASI sensitivity is the largest, varying with latitude from ~5% at Arrival Height to ~45% at Lauder. An overall positive bias (considering all stations together) of ~10% is reported for the HNO_3 total column, with bias values varying between ~4% in Thule and ~16.5% in Lauder.

2.4.2 Results from trend studies

The first trends of the Antarctic ozone hole have been obtained and the ability of IASI to capture the vertical structure of the ozone hole has been looked at (*Scannell et al., 2012*).

The daily time series of O_3 at various altitudes over the stratosphere and the troposphere in 20° zonal bands have been investigated over 6 years by fitting constant, annual and semi-annual terms along with important geophysical drivers of O_3 variation (e.g. solar flux, quasi biennial oscillations to the IASI time series (*Wespes et al., 2016*). The ozone time development estimation ("trends") has been quantified based on the six full years of the IASI observation in four selected layers. The results suggest interestingly a significant positive trend in the upper stratosphere possibly pointing out a recovery of upper stratospheric ozone while a significant negative trend is observed in the troposphere in the mid-latitudes of the N.H. during the summer, probably linked to decreased emissions of ozone precursor. The added value of the exceptional frequency sampling of IASI for monitoring medium to long-term changes in O_3 concentrations at a global scale has also been demonstrated by performing the multivariate regressions on IASI monthly averages and on ground-based FTIR measurements.

Preliminary global patterns of O_3 stratospheric trends have been obtained and reveal significant positive trends in the upper stratosphere almost everywhere, especially in the polar regions.

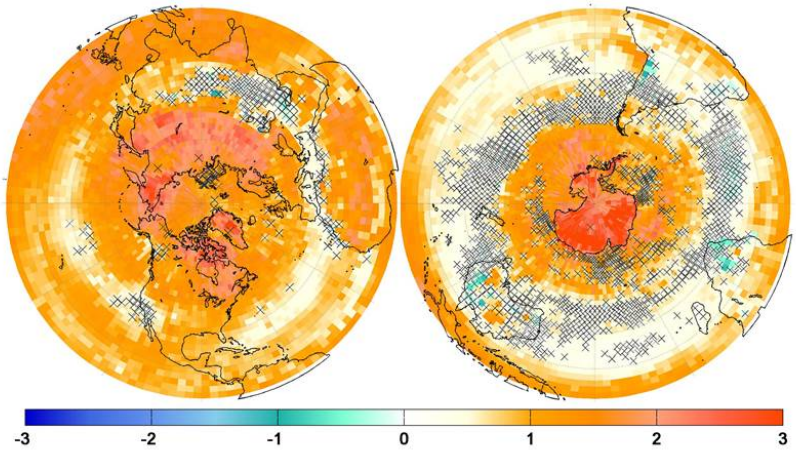


Figure 3. Global distribution of the trend values (given in DU/year) estimated by applying a multivariate regression model on daily IASI time series over the period 2008-2015. The crosses indicate that the trend in the grid cell is non-significant in the 95% confidence limits (2σ level) when accounting for the autocorrelation in the noise residual.

Many efforts were devoted to tropospheric O_3, including the study of transport, of relation with precursor emissions and of the East Asian summer monsoon effect ((*Wespes et al., 2012, Parrington et al., 2013; Safieddine et al., 2013; Safieddine et al., 2016*). Recently, eight years (January 2008 – March 2016) of daily O_3 observations in the troposphere (from ground to 300hPa) from IASI have been analyzed using dedicated multivariate regression models to identify the

geophysical mechanisms conducting the O_3 variability (*Wespes et al., JGR, in review*). Global patterns of the main geophysical parameters (including NAO, QBO and ENSO) adjusted by the regression model are obtained. They provide a meaningful view of the chemical and dynamical mechanisms driving the tropospheric O_3 variations in line with the current knowledge of these mechanisms.

Global patterns of tropospheric trends have been obtained and allowed us to identify negative trends in the Northern mid-latitudes (45°N-75°N) in summer which could be possibly associated with the decline of ozone precursor emissions.

Preliminary analysis of daily HNO_3 time series in the total column have been performed by using multivariate regression models.

Progress on the FORLI-O_3 and –HNO_3 time series analysis is ongoing using complex fitting procedures, as a function of the sounded layers and latitudes, and the last version of the FORLI products.

Time series of SO_2 and volcanic ash from volcanic eruptions have been obtained (*Clarisse et al., 2012)*.

First time series for CO columns from IASI and contribution to a decadal record by combination to MOPITT data (*Worden et al., 2013*). These activities will be strengthened in the frame of the EU-FP7 QA4ECV project.

3 THEORY, MODELLING AND OTHER RESEARCH

3.1 The Royal Meteorological Institute (RMI)

The Brewer data have been analysed for aerosol information in the UV. These AOD data at 320 nm are available now (*Cheymol and De Backer, 2003*). Special measurements with Brewer 178 (and later also with Brewer 100 in Antarctica) were started to measure also the AOD at 340 nm (De Bock et al, 2010).

3.1.1 Satellite data validation and characterisation

RMI is partner in the Ozone SAF (Science application facility) of EUMETSAT. The main task here is the validation of the ozone profiles retrieved from satellite observations.

3.1.2 Trend studies

A study on the effect of trends in ozone and aerosol content of the atmosphere on the trend of UV radiation received at the Earth's surface was undertaken in the frame of the BELSPO project AGACC-II.

3.2 The Royal Belgian Institute for Space Aeronomy (BIRA-IASB)

3.2.1 Modelling

Complete 3D modelling of the stratosphere, including transport, chemistry, aerosol microphysics and a heterogeneous chemistry module.

Chemical 4D variational and Ensemble Kalman Filter data assimilation (BASCOE), in particular of stratospheric O_3 and related species (http://bascoe.oma.be) (*Errera and Ménard, ACP, 2012, Skachko et al., GMD, 2014, 2016*). Production of a reanalysis of Aura MLS chemical observations from August 2004 (i.e. the beginning of the Aura MLS mission) and the present (October 2016 at the time of writing).

Validation of CAMS Stratospheric Ozone (http://copernicus-stratosphere.eu/), delivering in NRT global analyses of stratospheric ozone and related key species (*Eskes et al., GMD, 2015; Lefever et al., ACP, 2015*) and reanalysis for 2002-2014 (*Inness et al., ACP, 2013*).

Developpment of C-IFS-TS, i.e. the CAMS forcast model including the stratospheric chemistry of BASCOE (*Inness et al., GMD, 2015; Huijnen et al., GMD, 2016*).

1D box model for process studies, and for interpretation of UV-Visible DOAS observations.

Studies based on biogenic emission models and on the 3D model IMAGES for the troposphere

Development of inverse tropospheric modelling methods, to identify emissions (e.g., for the tropospheric ozone precursors CO, NOx, hydrocarbons, …)

3.2.2 Laboratory experiments

Spectroscopic studies in support of remote sensing experiments (optical spectroscopy, ion chemistry for mass spectrometry applications…)

Spectroscopic studies in support of investigations concerning global warming issues.

Radiometric calibration for UV monitoring instruments (see Section 1.4).

Studies of reaction pathways and kinetics of atmospheric species, using mass spectrometry.

3.2.3 Instrument developments

Atmospheric Limb Tracker for the Investigation of the Upcoming Stratosphere (ALTIUS): national development of a limb viewing satellite instrument responding to the requirements resulting from the three last ORM Meetings in 2008, 2011 and 2014, respectively (*WMO GORMP Report No. 51, No. 53 and No. 54*): "Satellite observations of high vertical resolution profiles using limb viewing for O_3 and key molecules are required in order to more accurately understand the changes in O_3 as CFCs decline and climate change occurs." – see ANNEX B.

MAXDOAS instruments and associated data analysis algorithms. The MAXDOAS technique has the capability of determining vertical distributions in the troposphere and low stratosphere.

Optimisation of the FTIR observations for achieving higher-quality measurements, in particular improved solar tracking technique; adaptation to combined NDACC and TCCON measurements.

3.2.4 Ground-based data retrieval algorithm developments

Use of inversion algorithms (using the Optimal Estimation Method) for ground-based DOAS and FTIR remote sensing spectral data, for the retrieval of the vertical distribution of absorbing atmospheric constituents. The algorithms allow the retrieval of vertical profile information from the ground-based DOAS and FTIR spectra, at low vertical resolution (worse than 5 km), for e.g., NO_2, O_3, HNO_3, HCl, ... For the FTIR data this approach has been optimised for some target species in the EC projects UFTIR (Feb. 1, 2003 – July 31, 2005) coordinated by BIRA-IASB. Tikhonov regularisation and Information Operator Approach have also been implemented as alternative inversion algorithms for FTIR measurements; in some cases, these approaches improve the robustness of the retrievals.

In the frame of the NDACC Infrared Working Group (IRWG), in the period 2006-2013 when a BIRA-IASB member was Co-chair, work has been done to homogenize the retrieval strategies across the network. Similar harmonization work is being performed for UV-Vis measurements as part of the NDACC UV-Visible Working Group (UVVISWG) where a BIRA-IASB member is co-chair since 2004. These efforts including the development of a facility for MAXDOAS centralised processing and automated quality control are supported by ESA in the FRM4DOAS project (2016-2018).

In the frame of NORS and the NDACC IRWG, a large effort has been carried out to develop harmonised error budget evaluations for the FTIR data products and to implement tools for their evaluation in the standard FTIR processing code SFIT-4. SFIT-4 is now in its test version.

3.2.5 Satellite data retrieval algorithm developments

Development and implementation of satellite data retrieval algorithms and processors for ALTIUS.

Development, validation and implementation of satellite data retrieval algorithms for ERS-2 GOME, Envisat SCIAMACHY, MetOp-A GOME-2, MetOp-B GOME-2 and Copernicus Sentinels 4/5/5p total O_3, NO_2, BrO, HCHO, SO_2…; data processing and dissemination.

Development, validation and implementation of satellite data retrieval algorithms for aerosols and trace gases from GOMOS.

Development of retrieval algorithms for IASI/MetOp for aerosols and CH_4.

3.2.6 Satellite data validation and characterisation

Continuous contributions to the geophysical validation of satellite data for O_3, NO_y, CH_4, CO, N_2O… (GOME, SCIAMACHY, GOMOS, MIPAS, ACE-FTS…) using independent ground-based network data, collected from network data archives like NDACC, TCCON, WOUDC and SHADOZ. These activities will be extended to upcoming missions like the Copernicus Sentinel-4 and Sentinel-5 (UVN and IASI-NG instruments) and their precursor Sentinel-5p TROPOMI.

A multi-purpose simulator of global measurement systems for atmospheric composition with full metrology description has been built at BIRA-IASB (*Verhoelst et al., 2015*): *OSSSMOSE* (Observing System of Systems Simulator for Multi-mission Synergies Exploration). This versatile environment provides realistic simulations of the output of real and hypothetic global observing systems and of their data comparison. It combines various state-of-the-art components, such as multi-dimensional observation operators mapping in 2D/3D the real sensitivity of a measurement system to atmospheric gradients, cycles and trends. OSSSMOSE is used to investigate and quantify smoothing and sampling properties of ozone measurement systems and to close the error budget of data comparison (e.g., *Cortesi et al., 2007; Lambert et al., 2012; Verhoelst et al., 2012, 2015*). OSSSMOSE is currently being used for optimisation studies and gap analysis of measurement systems in the GAIA-CLIM project and implemented partly in the Virtual Observatory being built at EUMETSAT.

Development of climatologies of some stratospheric species like BrO and NO_2.

3.3 University of Liège (ULg)

Most of the research activities reported in the previous Ozone Research Managers Report (2002, 2005, 2011, 2014) are continuing.

3.3.1 Satellite data validation and characterisation

ULg has been involved in numerous satellite validation studies over recent years (e.g. IASI, SCIAMACHY, OMI, and MOPITT).

3.3.2 Instrument developments

Since the end of 2008, remote operation of the Jungfraujoch Bruker instrument is possible, allowing to complement the observations performed locally and to maximize the observation time. The system is perfectly working despite the challenging harsh meteorological conditions encountered at the Jungfraujoch; it has already undergone numerous evolutions to improve reliability and determination of the instrument status.

In parallel, we have been developing a new acquisition system that, along with total integration inside the remote control system, will provide improved signal to noise ratio and instrument throughput as well as the capacity to implement new digital processing methods, leading to enhanced spectrum quality, improved line shape and therefore better vertical distribution determinations.

3.3.3 Trend studies

Numerous relevant long-term trend studies have been performed over the period under review here, on the basis of ground-based data recorded at Jungfraujoch and at other FTIR sites (see e.g. section 2.3) or using satellite products (inorganic chlorine and fluorine, organic chlorine and fluorine, source gases relevant to ozone (N_2O, CH_4, OCS)…

3.3.4 Modelling

The 3-D Chemistry Transport Model GEOS-Chem, developed and maintained at Harvard University, has been implemented in 2013 at ULg, in order to ease the interpretation of FTIR time series acquired at the Jungfraujoch and elsewhere. Apart from the global methane study mentioned previously (*Bader et al., 2016*), it has already been used in several studies focusing on tropospheric ozone precursors such as CO, C_2H_6, HCHO (*Franco et al., 2015a; Franco et al., 2015b; Franco et al., 2016a; Franco et al., 2016b; Helmig et al., 2016; Té et al., 2016*).

3.4 Université Libre de Bruxelles (ULB)

3.4.1 Laboratory experiments

The "Service de Chimie Quantique et Photophysique" has established expertise in the measurement of accurate absorption line parameters (positions, intensities and widths) for atmospheric trace gases in the infrared (far-, mid- and near-) and visible ranges, using high-resolution Fourier transform spectroscopy. Analysis of spectra is carried out using software written in the laboratory. The contribution of ULB to international spectroscopic databases remains at the forefront.

3.4.2 Retrieval algorithm developments

The group has acquired a leading position for the atmospheric radiative transfer modelling in the thermal infrared and also for the development of atmospheric trace gases retrieval methods. It owns and maintains sophisticated algorithms, for research and operational applications in atmospheric chemistry and physics. They include:

- The *Atmosphit* line-by-line radiative transfer model, which allows simulation of spectra recorded under various geometries and/or with different instruments. Accurate and versatile, it has been used in most studies prior to IASI launch, and for IASI local analyses. A module using an advanced doubling-adding method to account for multiple scattering was coupled to *Atmosphit*, allowing simultaneous retrieval of gas and aerosol properties.
- The *FORLI* series of software specific to IASI (*Hurtmans et al., 2012*). These rely on fast radiative transfer calculations using look-up-table (LUT) approaches. The LUT compile absorbance spectra, pre-calculated on a given spectral range and on well-defined temperature/pressure/humidity grids. *FORLI* versions are currently in place for O_3, HNO_3 of particular for stratospheric sounding, and in addition NH_3 and CO. The *FORLI* series allow NRT processing of the huge IASI data flow to provide global distribution of concentrations twice daily. FORLI-CO, FORLI-O3 and FORLI-HNO3 will become the operational processor for IASI after their implementation at EUMETSAT-CAF following the agreement signed under the O3MSAF-CDOP2.
- Radiance indexing schemes for IASI, which are used to track a reactive species, among which SO_2, CH_3OH, HCOOH, and aerosols, including volcanic ash (e.g. *Clarisse et al., 2012 and 2013; Van Damme et al., 2014*).

3.4.3 Satellite data retrievals

Development, upgrade and maintenance of a NRT IASI processing chain. Processing starts with the receiving of the calibrated L1C radiances from Eumetcast, which are transformed in suitable format and quality-flagged using available ancillary information (e.g. cloud coverage). The retrievals are performed on a cluster of PCs, which currently has 190 CPU's and 24TB of storage capabilities. Retrieved products from FORLI include O_3, HNO_3, CO and NH_3 profiles on the global scale (cloud-free data). Every new FORLI algorithm development delivered to EUMETSAT is also validated with that implemented in the EUMETSAT Central Application Facility.

Additional products from the offline processing are based on the calculation of hyperspectral radiance indices for several reactive species, which are converted to columns using appropriate look-up-tables.

We also developed a new global IASI Climate Product (*Donikis et al., 2015*): the ozone longwave radiative effect (LWRE) (in W/m^2), i.e., the radiative impact in the outgoing longwave radiation

(OLR) flux due to absorption by ozone, for both tropospheric and total columns with respect to the retrieved FORLI-O_3 vertical distribution. This product opens perspectives for studying the impact of tropospheric O_3 changes on the radiative forcing of climate at local and global scales – Project in collaboration with other research teams: «Benchmarking climate model top-of-atmosphere radiance in the 9.6 µm ozone band compared to TES and IASI observations».

3.4.4 Satellite data validation and characterisation

Contribution to the validation activities of IASI chemistry products, in particular CO, O_3 and HNO_3 but also SO_2, NH_3, CH_3OH.

Continued cross-comparisons between satellites, in particular for CO and O_3.

4 DISSEMINATION OF RESULTS

4.1 Data reporting

The ozone data collected by RMI (columns and profiles) are regularly deposited in the WOUDC of WMO. Uccle is also affiliated to NDACC. Therefore the data are also made available in that network. In near real time the data are also distributed via NILU, where the data can be used for campaigns (e.g. Match campaigns to determine ozone losses in the polar and sub polar winter atmosphere, see Streibel et al, 2005). The data are also stored and used in databases for the validation of satellite data (EUMETSAT). Total ozone values are exchanged daily with the WMO ozone mapping centres in Canada and Greece for the production of daily ozone maps. The ozone profiles corrected according to the recommendations of the O3S-DQA activity are also distributed to this panel.

Data of the RMI ceilometers are exchanged via the data-hub of the EUMETNET programme E-profile.

NDACC FTIR and UV-visible (MAX)DOAS data are submitted on a regular basis by BIRA-IASB to the NDACC Data Host Facility (DHF) established at NOAA NCEP (http://ndacc.org). Key results have been reported in the WMO Scientific Assessment of Ozone Depletion: 2014, and peer-reviewed puiblications (*Vigouroux et al., 2015; Harris et al., 2015*). On going work will be reported in the newt WMO 2018 report. 8.

BIRA-IASB is deeply involved in the ESA CCI programme (Ozone, Aerosols, GHG), providing high quality datasets for climate modelling applications and available on the CCI open data portal (http://cci.esa.int). Satellite ozone data reprocessings carried out as part of the CCI Ozone project are also available publicly from the project site hosted at BIRA-IASB: http://www.esa-ozone-cci.org/

Satellite ozone data records processed at BIRA-IASB as part of the C3S procurement will be available soon on the Copernicus Climate Data Store hosted at ECMWF.

BIRA-IASB spectral UV data are available from http://uvindex.aeronomie.be and http://ulisse.busoc.be/

Time series of NDACC-relevant molecules (e.g., HCl, $ClONO_2$, HF, HNO_3, NO_2, O_3,) from 1989 onwards are being archived routinely by ULg at the NOAA Data Host Facility (Washington, DC, USA), with the ozone data mirrored to the WOUDC archive in Toronto. Pre-1989 data are available upon request. These data are available in the hdf format which provides the available vertical information on the retrieved products.

In addition, important results deduced by ULg from Jungfraujoch observations have been included in successive editions of the scientific assessment of ozone depletion (UNEP/WMO), with ULg scientists involved as co-author or contributors in all recent volumes. ULg has also contributed to the SPARC report on CCl_4 and to a review paper on stratospheric aerosols (*Kremser et al., 2016*).

Datasets produced by the ULB are documented in the scientific literature.

IASI CO distributions of profiles are distributed in NRT by ULB to ECMWF in the frame of the Copernicus Atmosphere Monitoring Service (CAMS). The data are also archived at the French AERIS datacentre (http://ether.ipsl.jussieu.fr) and available upon request. O_3 distributions have

been distributed for validation and research activities to a series of research groups. They are now similarly available from the AERIS database.

Future operational dissemination by ULB of the IASI CO, O_3, HNO_3 and SO_2 products from IASI will occur within the O3SAF (data to processed at EUMETSAT-CAF and disseminated through EUMETCAST system). This will start in 2017 with CO and SO_2, followed by O_3 and HNO_3.

Archives of O_3 profiles are generated by ULB in the frame of the O3-CCI and made available to the community.

Spectroscopic information obtained by the "Service de Chimie Quantique et Photophysique" at ULB is disseminated through various channels.

4.2 Information to the public

Daily UV forecasts are produced and disseminated by RMI with the weather forecasts. They are also available on the internet (www.meteo.be).

Ozone and UV data collected by RMI at Uccle have been used in yearly reports on the environment (successive MIRA reports).

Relevant information is available on different web pages hosted by BIRA-IASB:

- UV radiation and indexes monitoring: http://uvindex.aeronomie.be
- NORS leaflet: http://nors.aeronomie.be
- CCI Ozone website, including documentation and data: http://www.esa-ozone-cci.org/
- AGACC brochure: http://agacc.aeronomie.be
- NDACC Satellite Working Group website, with catalogues and relevant information on atmospheric composition satellites: http://accsatellites.aeronomie.be
- Ozone monitoring and research activities on the BIRA-IASB website: http://www.aeronomie.be/en/topics/naturalhazards/ozone-bira-iasb.htm
- Article on "BIRA-IASB monitors effect of Montreal Protocol": http://www.aeronomie.be/en/topics/globalchange/montrealprotocol.htm

BIRA-IASB publishes press releases on ozone related subjects and activities.

BIRA-IASB contributes to WMO Antarctic Ozone Bulletins and WMO Arctic Ozone Bulletins (http://www.wmo.int/pages/prog/arep/gaw/ozone).

BIRA-IASB disseminates relevant information to the public through lessons and seminars in most of the major Belgian universities, through large public events like the Annual Open Doors organised at BIRA-IASB premises, through participation in public exhibitions at the Planetarium in Brussels and the Euro Space Centre in Redu.

Lectures popularising scientific research on ozone were delivered to the public by BIRA-IASB scientists at the occasion of the Space Pole Open Doors on 11 and 12 October 2014 (S. Skachko, De ozonlaag; A. De Rudder, Sur les pas des chercheurs à la découverte de l'ozone atmosphérique : les grandes étapes d'une petite histoire ; A. Keppens, Hoe meten we de ozonlaag? Instrumenten van de grond tot de ruimte; Q. Errera, La couche d'ozone).

4.3 Relevant scientific papers

A list of relevant scientific papers published or submitted after the issue of the Belgian National Report for the 9th WMO/UNEP Ozone Research Managers Meeting is provided in ANNEX D.

Regarding ULg, the list only includes a selection of papers. A complete list of relevant papers co-authored by ULg scientists is available from the ULg electronic repository, e.g., via this link).

5 PROJECTS AND COLLABORATION

Projects and collaborations involving the four institutes are listed in ANNEX E.

6 IMPLEMENTATION OF THE RECOMMENDATIONS OF THE 9TH OZONE RESEARCH MANAGERS MEETING

6.1 Research Needs

(i) Chemistry-climate interactions and monitoring the Montreal Protocol

- *Key Recommendation (1) – Ozone in climate models*

  ULB has undertaken several studies focusing on the link between chemistry and climate .

  BIRA-IASB coordinates the Data Assimilation activity of the international programme Stratosphere/Troposphere Processes and their Role in Climate (SPARC).

  BIRA-IASB participates to the SPARC Reanalysis Intercomparison Project (S-RIP) with a focus on the use of chemical tracers to better understand how the past changes of stratospheric circulation are represented in modern reanalyses.

  BIRA-IASB participates to the validation and development of the models used for the Copernicus Atmospheric Monitoring Service (CAMS).

  BIRA-IASB continuously improves its 4D-variational data assimilation system BASCOE and the chemical transport model associated with it, which includes detailed microphysics description.The Near-Real-Time analyses of stratospheric composition generated by BASCOE are often used in the WMO Antarctic Ozone Bulletins and for validation of the ozone forecasts delivered by the CAMS.

  BIRA-IASB contributes to the ACSO effort on ozone absorption cross-sections.

- *Key Recommendation (3) – Constructing data records*

  BIRA-IASB coordinates ESA's CCI Ozone project Phase II (2014-2017), in which RMI is a partner, which aims at improving ozone data products from European satellites in order to provide harmonised ozone data records suitable for climate change studies. This project includes specific effort on the improvement of ozone profile data in the upper troposphere and lower stratosphere, to improve our evolving understanding of the coupling and exchange in this particular altitude region. BIRA-IASB is also responsible for the operational generation of ozone Climate Data Records (CDRs) in support of the Copernicus Climate Change Service (C3S), service developed in the C3S-312a_Lot4 project (2016-2018).

- *Key Recommendation (4) – Trends in ozone*

  RMI continues the measurement of ozone columns and profiles, and applies state-of-art statistics to the data sets to retrieve trends (cf. Section 2.1).

  BIRA-IASB and RMI participate in the SI2N initiative with systematic data quality studies of past records on vertical ozone trends. BIRA-IASB conducts studies of ozone variabilities and trends, using ground-based and satellite data. RMI is part of the Ozondesonde Data Quality Assessment Working Group and with conducts studies of ozone variabilities and trends, using those ozonesonde data.

  BIRA-IASB also actively contributes to other international ozone trend assessment initiatives, namely, LOTUS (a SPARC Activity coordinated by BIRA-IASB, aiming at improving confidence in trend estimates), the 2014 WMO Assessment of Ozone Depletion, the TOAR.

(ii) UV Changes and other impacts of ODS changes

- *Key Recommendation (1) – Factors affecting UV*

  RMI studies the effects of aerosol on UV radiation.

- *Key Recommendation (2) – UV change impacts*

  RMI contributed to a study of the University of Antwerp on the relation between melanoma and UV radiation.

- *Key Recommendation (3) – Stratospheric aerosols*

BIRA-IASB actively participates in the ESA Aerosol_cci project, in which it leads the stratospheric aspects of the project. This work focuses on the production of stratospheric aerosol time series based on the GOMOS experiment on ENVISAT. The extinction time series produced by the project are used to update volcanoes inventory used for climate studies. More particularly, it is used to constraint the EMAC Chemistry-Climate Model for the study of the stratospheric aerosol evolution after 2002, and for radiative forcing calculations. The stratospheric aerosol products also provide reference datasets to the climate modelling community to study many key-aspects of today's stratospheric aerosol research such as tropospheric-stratospheric exchanges including specific pathways such as the Asian summer monsoon, long-term evolution of the aerosol burden in the stratosphere, etc. These time series, as well as precursor work on the SAGE II experiment (1984-2005), also offer reference datasets for aerosol studies, e.g. in the framework of geoengineering.

6.2 Systematic Observations

- *Key Recommendation (1) – Continuation of limb emission and infrared occultation observations from space*

  ULB has improved its satellite retrieval techniques.

  RMI is a partner in the EUMETSAT O3SAF, and is responsible for the validation of the operational ozonesonde profiles and aerosol products of the GOME2 instruments on board of the meteorological satellites.

  The work performed at BIRA-IASB on GOME/SCIAMACHY/OMI/GOME-2 total ozone retrieval algorithms is a response to the requirement to continue the key baseline set of solar backscatter UV observations. In particular, the development of the GODFIT-3 direct fitting algorithm has led to improvements needed to expand capabilities at high latitudes and high solar-zenith angles (*Lerot et al., 2014*).

  In anticipation of the upcoming gap in limb viewing satellites, BIRA-IASB has proposed the new satellite mission ALTIUS, a limb scattering and occultation satellite instrument addressing directly the 7ORM requirements, reiterated at 8ORM and 9ORM, for limb viewing observations of high vertical resolution profiles of ozone and key ozone related parameters that are critical for understanding the science behind changes in ozone in the context of changing climate – see ANNEX B. This instrument concept combines the technique of limb scattering observation with an imaging capacity when operating on the day side. At the terminator and in the eclipse phase, the spectrometer would be used in solar and stellar occultation modes respectively. This instrument is designed to infer from UV-visible-NIR radiance measurements from the upper troposphere to the mesosphere the vertical distribution of ozone, NO_2, BrO, CH_4, H_2O, OClO, aerosols and PSCs… After a phase B1 completion, the mission concept and the instrument preliminary design were reviewed by ESA in 2015 as well as the operational/scientific objectives by an international panel of scientists. In 2016, the ALTIUS mission was accepted by the ESA-Earth Observation programme board as an element of the EarthWatch programme and definitely approved at the last ESA ministerial council in Dec 2016.

  A PICo-satellite for Atmospheric and Space Science Observations (PICASSO) is an ESA project led by BIRA-IASB, in collaboration with VTT Technical Research Centre of Finland Ltd, Clyde Space Ltd. (UK), Centre Spatial de Liège (BE) and the Royal Observatory of Belgium – see ANNEX B. PICASSO is a three-unit CubeSat, for which VTT will develop the main payload,Visible Spectral Imager for Occultation and Nightglow (VISION). VISION will primarily target the observation of the Earth's atmospheric limb during orbital Sun occultation. By assessing the radiation absorption in the Chappuis band for different tangent altitudes, the vertical profile of the ozone is retrieved. A secondary objective is to measure the deformation of the solar disk so that stratospheric and mesospheric temperature profiles are retrieved by inversion of the refractive ray-tracing problem. PICASSO has now passed the Critical Design Review and is on way toward a launch in 2018.

- *Key Recommendation (2) – Continuation of ground-based stations with long-term records*

  ULg's primary aim will be to maintain the operation of the FTIR instrumentation at the Jungfraujoch station.

RMI continues the observations of the ozone layer at Uccle and in Antarctica, providing direct observations of polar ozone processes during the manned period of the Princess Elisabeth station.

RMI continues the ozone observing program with spectroscopic ozone column and UV measurements and 3 times per week ozone profile measurements with balloons. Also the ceilometer measurements are continued.

RMI actively participates in the COST action ES1207 EUBREWNET, which aims at creating an homogenized network of Brewer instruments (both in operating procedures and data processing) at the European level, in response to the fact that there are multiple calibration sites around the world within the Global UV Monitoring System that are not tied together sufficiently (*WMO report of the 8th session No. 53, p 35*).

Efforts have been made by BIRA-IASB to maintain operation of existing instrumentation, and to increase the use of more sophisticated instrumentation, mainly FTIR spectrometers and (MAX)DOAS UV-visible instruments. BIRA-IASB has continued operation of its FTIR and (MAX)DOAS UV-visible instruments which contribute to the NDACC and TCCON global monitoring networks.

- *Key Recommendation (3) – Maintenance of regular, long-term monitoring in key regions for troposphere stratosphere exchange*

  BIRA-IASB has maintained the additional ground-based instruments previously deployed in the Tropics: NDACC/TCCON certified FTIR instruments on Reunion Island (Indian Ocean), and NDACC certified (MAX)DOAS UV-visible instruments on Reunion Island and in Bujumbura (Burundi). It has deployed a new FTIR instrument at Porto Velho (Brazilian Amazonian forest).

- *Key Recommendation (5) – Increased efforts to monitor source gases, especially N_2O, CH_4, and water vapour*

  BIRA-IASB is involved in the development of a N_2O data product from IASI (N_2O becoming one of the most important substances that can lead to ozone destruction).

- *Key Recommendation (7) – Monitoring of temperature and trace gas profiles especially of dynamical tracers like N_2O and SF_6, and of ozone and water vapour in the UTLS*

  The ozone and water vapour profiles obtained simultaneously with the RMI balloon-borne ozonesondes are archived and are available. RMI published a study based on the corrected upper-tropospheric humidity profiles gathered with sondes (*Van Malderen and De Backer, 2010*).

  BIRA-IASB has improved its retrieval algorithm for water vapour profile (a strong driver for decadal climate variability) from FTIR spectrometers.

- *Key Recommendation (8) – Continuation of measurements of surface UV radiation and related parameters*

  RMI continues the UV observations with Brewer spectrophotometers in Uccle and in Antarctica.

- *Key Recommendation (10) – Public information services need to be further implemented*

  ULB has expanded data dissemination to a variety of users.

- *Previous ORM recommendation – Consistency and complementarity of data sets and re-evaluation of data records*

  Work has been done at BIRA-IASB, in collaboration with ULg, about the consistency between data from different observational techniques, in particular for NO_2 and HCHO from FTIR and UV-visible DOAS instruments.

  ULB's efforts to harmonize datasets from various satellite sounders have continued.

6.3 Data Archiving and Stewardship

- *Key Recommendation (1) – Develop robust automated data submission with centralised processing and QA schemes*

In the frame of the CAMS-84 NDACC-based validation project for the Copernicus Atmosphere Monitoring Service (CAMS), the follower of the EU FP7 NORS project, data archiving of NDACC observations has been accelerated for a set of stations, data being now submitted within 1 day to 1 month after acquisition. Tools for the evaluation of the quality and consistency of NDACC data files have also been developed. Procedures and tools that have been developed for NORS and CAMS-84 are being extended to other NDACC key species.

BIRA-IASB has developed tools for the complete evaluation of the uncertainty budget associated with the atmospheric composition measurements. The uncertainty components are now systematically submitted in the HDF FTIR and UV-Vis ground-based data files and the satellite total ozone data files.

- *Key Recommendation (3) – Encourage data providers to submit to existing databases; responsibilities for data centres should be clearly established*

  ULg performs regular data archiving at NDACC.

  RMI archives the data regularly in the well-established network databases as WOUDC and NDACC. It also submitted homogenized ozonesonde data to the database set up within the O3SDQA Working Group. It submits Brewer data to the database created within the framework of the COST action ES1207 EUBREWNET.

  BIRA-IASB archives continuously the ground-based data acquired by its NDACC certified instruments into the NDACC Data Host facility (http://ndacc.org), and its reprocessed satellite total ozone data into its in-house CCI-ozone data archive (http//www.esa-ozone-cci.org).

- *Key Recommendation (6) – Enhanced linkage among data centres; open and user-friendly formats and data access; free access to data; provision of different data levels adapted to different users*

  BIRA-IASB is ECMWF's prime contractor coordinating the collaborative project Production of Essential Climate Variable Datasets based on Earth Observations (Ozone), Ref. C3S_312a_Lot4, to populate the European Copernicus Climate Change Service (C3S) Data Store with Level 3 data products.

- *Other data archiving and stewardship activities*

  RMI stores raw data and metadata locally so that reprocessing of historical data is easily established.

  BIRA-IASB and RMI were partners in a national project aiming at setting up a metadata database which will be compliant with the EU INSPIRE Directive.

  BIRA-IASB has been the driver for the development, implementation and improvement of the GEOMS HDF formatting guidelines, in use in international data archives like the NDACC Data Host Facility and the Aura Validation Data Centre.

6.4 Capacity Building

- *Key Recommendation (1) – Provide training courses for station operators in developing countries*

  The NORS project coordinated by BIRA-IASB included a work package dedicated to capacity building, including exporting knowledge and expertise acquired in NORS to new and candidate NDACC stations outside of Europe (of the order of 10 stations outside of Europe were developed in this WP), and linking with the satellite community via representation at CEOS meetings. The non-European stations in this WP that are managed by BIRA-IASB are the stations at Xianghe (P.R. China) and Bujumbura (Burundi).

- *Key Recommendation (3) – Maintaining the quality of the WMO/GAW global ozone observing system through the continuation and expansion of regular calibrations and intercomparisons*

  RMI continues the ozone observing program with spectroscopic ozone column and UV measurements and 3 times per week ozone profile measurements with balloons. Also the ceilometer measurements are continued. Regular calibrations are performed (cf. Section 1.4.1).

- *Key Recommendation (4) – Ozonesonde intercomparisons and reprocessing of ozonesonde data*

  RMI participates in the efforts of homogenizing ozone profile data records.

- *Other capacity building activities*

  Relocation of the unused Dobson instrument from Uccle to Kyev (cf. WMO report of the 8th session, No. 53, p. 38).

  BIRA-IASB installed in 2015 a FTIR instrument at Porto Velho (Rondonia, Brazil) for NDACC and TCCON observations.

  In response to the need to further develop methods and tools for a better-integrated use of complementary data with different scale, resolution etc., BIRA-IASB has developed the multi-purpose simulator of global measurement systems for atmospheric composition with full metrology description (*Verhoelst et al., 2015*): OSSSMOSE (Observing System of Systems Simulator for Multi-mission Synergies Exploration). This versatile environment provides realistic simulations of the output of real and hypothetic global observing systems and of their data comparison. It combines various state-of-the-art components, such as multi-dimensional observation operators mapping in 2D/3D the real sensitivity of a measurement system to atmospheric gradients, cycles and trends. OSSSMOSE has been applied with success to the validation of Envisat and MetOp to close the error budget of data comparisons (e.g., *Cortesi et al., 2007; Lambert et al., 2012; Verhoelst et al., 2012, 2015*). OSSSMOSE is also being used for optimisation studies and gap analysis of measurement systems in the GAIA-CLIM project and implemented partly in the Virtual Observatory being built at EUMETSAT.

7 FUTURE PLANS

7.1 Royal Meteorological Institute (RMI)

Continuation of the observations at Uccle (ozone column, ozone profile, Spectral UVB, aerosol) and at the Antarctic station (Ozone column, Spectral UVB and aerosol).

Continuation of the automatic lidar ceilometer observations.

Analysis of the data obtained at the Belgian Antarctic station.

Participation in the validation and quality assurance of satellite observations (AC SAF CDOP-3 of EUMETSAT and Ozone CCI of ESA).

Comparison of ozone profile data obtained from ozonesondes and aircraft instruments at Brussels.

7.2 Royal Belgian Institute for Space Aeronomy (BIRA-IASB)

Contribution to a 1-year intercomparison campaign (2014-2015) aiming at filling gaps in the TCCON Network, through the demonstration of smaller and cheaper, portable, spectrometers.

Preparation of a large scale Sentinel-5 Precursor Cal/Val campaign to be organised in summer 2018. For this campaign, both ground-based and an aircraft experiments will be deployed in synergy. These will build upon the CINDI-2 UV-Vis Intercomparison exercise which took place in Cabauw, The Netherlands in later summer 2016, and on preparatory aircraft activities developed as part of the successive AROMAT, AROMAT-2, AROMAPEX and RAMOS campaigns, all coordinated by BIRA-IASB.

Development of a centralised and automated processing system for UV-visible MAXDOAS observations to be hosted at the ESA Cal/Val facilities, in support of multi-mission programmes (FRM4DOAS project, 2016-2018).

BIRA-IASB has developed the instrument concept of Atmospheric Limb Tracker for the Investigation of the Upcoming Stratosphere (ALTIUS) – see ANNEX B and Section 6.2. This instrument consists of a limb viewing atmospheric sounder designed to operate on board a micro-satellite like the PROBA platform. This instrument combines the technique of limb scattering observation with an imaging capacity when operating on the day side. At the terminator and in the eclipse phase, the spectrometer will be used in solar and stellar occultation modes

respectively. This instrument is designed to infer from UV-visible-NIR radiance measurements from the upper troposphere to the mesosphere the vertical distribution of ozone, NO_2, BrO, CH_4, H_2O, OClO, aerosols and PSCs… BIRA-IASB is the PI of this instrument, which has now received definite approval as an element of the EarthWatch programme at the last ESA ministerial council in Dec 2016.

A PICo-satellite for Atmospheric and Space Science Observations (PICASSO) is an ESA project led by BIRA-IASB, in collaboration with VTT Technical Research Centre of Finland Ltd, Clyde Space Ltd. (UK), Centre Spatial de Liège (BE) and the Royal Observatory of Belgium – see ANNEX B and Section 6.2. PICASSO is a three-unit CubeSat, for which VTT will develop the main payload,Visible Spectral Imager for Occultation and Nightglow (VISION). VISION will primarily target the observation of the Earth's atmospheric limb during orbital Sun occultation. By assessing the radiation absorption in the Chappuis band for different tangent altitudes, the vertical profile of the ozone is retrieved. A secondary objective is to measure the deformation of the solar disk so that stratospheric and mesospheric temperature profiles are retrieved by inversion of the refractive ray-tracing problem. PICASSO has now passed the Critical Design Review and is on way toward a launch in 2018.

The Tropospheric Monitoring Instrument (TROPOMI) aboard ESA's Copernicus Sentinel-5 Precursor satellite to be launched in 2017 will provide measurements of the troposphere down to the boundary layer and quantify emissions and transport of anthropogenic and natural trace gases and aerosols, which impact air quality and climate. BIRA-IASB is one of the key TROPOMI level-2 algorithm developers, being responsible for the prototyping of three important products: ozone, SO_2 and HCHO.

Continued participation and/or coordination of validation and quality assurance of satellite observations in the context of the EUMETSAT O3MSAF CDOP-2/3, ESA Multi-TASTE Phase F, ESA Ozone_cci, C3S_312a_Lot4, ESA Aerosol_cci, EXPANSION (ESA Living Planet Fellowship), SCIAMACHY Quality Working Group Phase-F and EU FP7 QA4ECV.

7.3 University of Liège (ULg)

Given the vanishing support of the Belgian authorities to the operation of the FTIR instrumentation at the Jungfraujoch station and to the scientific exploitation and valorization of our observational database, the focus of the team will be at 100% on the continuation of the NDACC observations at that site. It is currently not warranted that this will be possible, given the dissolution of BELSPO and the chronic underfunding of the F.R.S. – FNRS.

7.4 Université Libre de Bruxelles (ULB)

On the remote sensing side, IASI-related activities will be strengthened. The NRT FORLI processing chain will be upgraded and is planned to be implemented shortly at the EUMETSAT CAF (Central Application Facility) for wider dissemination of the L2 products to the community. This should be done within the O3M-SAF. The group will pursue its activities around the preparation of future sounders, including the IAS on EPS-SG and IRS on MTG.

The group will foster activities with IASI in the context of chemistry and climate, including O_3-HNO_3 correlations in the troposphere; link to O_3 and precursor emissions in the troposphere, STE, O_3 long-wave radiative effect. The group will contribute to various international efforts for providing long-term quality-assured information on essential climate variables, e.g. in the frame of the O_3-CCI and QA4ECV projects.

8 NEEDS AND RECOMMENDATIONS

There is an urgent need to secure financial support for laboratory spectroscopic activities supporting investigations of the terrestrial atmosphere.

There is a reccurring need for structural financial support of the Belgian observational activities at several NDACC sites.

There is also a need for structural logistical, technical and financial support of the activities at the Antarctic station Princess Elisabeth.

ANNEX A. LONG-TERM TIME SERIES OF GROUND-BASED MEASUREMENTS

ULg, BIRA and RMI are involved in instrument operation at eighteen stations located in various parts of the world and at different altitudes (**Table A 1**). Detail of the station networks, of the instruments and platforms, of the observation record duration, of the nature of the species observed and physical quantity retrieved, and of which institute is involved is provided in **Table A 2** while **Table A 3** provides the complete list of species monitored with the FTIR instrument operated by ULg at the Jungfraujoch.

Table A 1. Geolocation of ground-based stations and type of data collected. Col = column(s); Prof = profile(s); Aer = aerosol properties; UV = UV radiation.

Station	Country / Continent	Latitude	Longitude	Altitude a.s.l.	Type of data
Bujumbura	Burundi	3°S	21°E	774m	Col
Diepenbeek	Belgium	50.9°N	5.4°E	42m	Aer
Harestua	Norway	60.2°N	10.8°E	596 m	Col Prof
Humain	Belgium	50.2°N	5.25°E	240m	Aer
Jungfraujoch	Switzerland	46.55ºN	7.98ºE	3580 m	Col Prof Aer
La Réunion	France DOM/TOM	20.9°S	55.5°E	10 m	Col Prof
Le Port, La Réunion	France DOM/TOM	20.56°S	55.17°E		Col
Mol	Belgium	51.19°N	5.11°E	27m	UV
Mount Maïdo, La Réunion	France DOM/TOM	21°S	55.3°E	2200 m	Col
Mount Rigi	Belgium	50.5°N	6.1°E	674m	UV
Observatoire de Haute Provence (OHP)	France	43.94°N	5.71°E	650 m	Col Prof
Oostende	Belgium	51.22°N	2.9°E	6m	UV
Princess Elisabeth	Antarctica	71°S	23°E	1397m	Col UV
Redu	Belgium	50°N	5.15°E	325m	UV
Uccle	Belgium	50.8°N	4.35°E	100 m	Col Prof Aer UV
Virton	Belgium	49.57°N	5.53°E	226m	UV
Xianghe[1]	PR of China	40°N	115°E	166m	Col Prof Aer
Zeebrugge	Belgium	51.3°N	3.2°E	3m	Aer

Table A 2. Long-term time series of measurements at ground-based stations.

Station	Network	Technique	Start	End	Species	Physical quantity	Belgian institutes involved
Jungfraujoch	NDACC Alpine	FTIR	Early '80	/	*Detail in* Table A 3	total & partial columns, vertical profile	ULg BIRA
		SAOZ UV-Vis DOAS	1990	/	O_3, NO_2	column	BIRA
		MAXDOAS	2010	/	BrO, NO_2, O_3	stratos. vertic. profile	BIRA
					NO_2, H_2O, O_3, H_2CO	tropospheric abundance	
					aerosol	tropospheric AOD	
Harestua	NDACC Arctic	UV-Vis DOAS	1994	/	O_3, NO_2, OClO, BrO	column	BIRA
					NO_2, BrO	stratos. vertic. profile	

[1] Approximately 50 km East of Beijing. This area is not strongly affected by local emissions but still largely under the influence of pollutants transported from three surrounding major cities: Beijing, Tianjin and Tangshan.

Station	Network	Technique	Start	End	Species	Physical quantity	Belgian institutes involved
Observatoire de Haute Provence (OHP)	NDACC Alpine	UV-Vis MAXDOAS[2]	Summer 1998	/	O_3, NO_2, BrO	column	BIRA
					NO_2, BrO	stratos. vertic. profile	
			2000	/	NO_2, H_2CO	tropospheric abundance	
La Réunion	NDACC SH tropical	FTIR (Bruker 120M)	May 2009[3]	Dec 2011	O_3, halogenated and nitrogenated source and reservoir gases, …	total column, vertical profile	BIRA
	TCCON & NDACC[4]	FTIR (Bruker 125HR)	Sep 2011	/	As above + CO_2, CH_4	column	BIRA
					O_3	partial columns[5]	
	/	UV-Vis MAXDOAS	Aug 2004	Jul 2005	O_3, NO_2, BrO, H_2CO, CHOCHO	column, tropospheric abundance	BIRA
Mount Maïdo	NDACC SH tropical	FTIR (Bruker 125HR)[6]	Feb 2013	/	O_3, O_3-related key species	column	BIRA
Le Port	/	MAXDOAS/ direct-sun	Apr 2016	/	O_3, O_3-related key species	column, tropospheric abundance[7]	BIRA
Xianghe	/	UV-Vis MAXDOAS	Feb 2010[8]	/	NO_2, O_3, H_2CO, SO_2, HONO, BrO, CHOCHO, H_2O	tropospheric and/or stratospheric column	BIRA[9]
					NO_2, H_2CO, SO_2, CHOCHO	tropospheric vertical profile	BIRA
					NO_2, BrO	stratos. vertic. profile	BIRA
					aerosol	AOD	BIRA
Bujumbura	/	UV-Vis MAXDOAS	Nov 2013	/	O_3, NO_2, HCHO, CHOCHO, SO_2, BrO, H_2O	column	BIRA
					NO_2, BrO	stratos. vertic. profile	BIRA

[2] Initially a standard UV-Visible DOAS instrument, upgraded with off-axis capability (MAXDOAS) in 2000.

[3] Initially FTIR observations were made during campaigns in Sept.-Oct. 2002, Aug.-Nov. 2004 and May-Nov. 2007. During the first FTIR campaign in 2002, simultaneous measurements at sea level and at high altitude (2200 m asl) were performed, allowing inferring columns in the boundary layer/low troposphere, via a differential approach.

[4] The instrument is switched regularly between the TCCON Mode (greenhouse gas measurements in the near-IR) and the NDACC mode (measurements of O_3 and related key species). The instrument got the official certification of being affiliated to the Total carbon Column Observing Network (TCCON) in summer 2012. As the evolution of the stratospheric ozone layer is influenced by climate changes, these measurements are relevant indirectly for understanding ozone in the future.

[5] From the FTIR observations at high spectral resolution, one can derive some limited information about the vertical distribution of the observed species. In particular, for ozone, one can derive 5 independent partial columns between the ground and the upper stratosphere.

[6] Solar absorption in the mid-IR.

[7] These observations will be exploited in cooperation with the Univerity of Colorado which will install another MAXDOAS system at the Maido site (2200 m asl) in January 2017. The combination of both systems will allow for better separation of the boundary layer, free-troposphere and stratospheric composition.

[8] Following a campaign based in Beijing (July 2008 to April 2009).

[9] Six years of observations are now available allowing for the study of a number of trace gases (NO_2, O_3, H_2CO, SO_2, HONO, BrO, CHOCHO, and H_2O) and aerosols in the troposphere and/or the stratosphere. These measurements are being exploited in support of various projects, serving in particular the validation of tropospheric measurements from recent satellite sensors (GOME-2, OMI and SCIAMACHY) and various modelling projects dealing with the determination of trace gas emissions in China.

Station	Network	Technique	Start	End	Species	Physical quantity	Belgian institutes involved
	/	CIMEL sun photometer	Nov 2013	/	aerosol	AOD	BIRA
Uccle	NDACC NH Mid-lat.	Mini-MAXDOAS [10]	Apr 2011	/	NO_2	tropospheric column	BIRA[11]
					aerosol	AOD	
	WOUDC Station 053	Brewer n°16 [12]	1983	/	O_3	column[13]	RMI
					UV	spectral irradiance[14]	
		Brewer n°178 [15]	2001	/	O_3	column	RMI
					UV	spectral irradiance	
		Dobson n°40 [16]	1971	May 2009	O_3	column	RMI
		Balloon-borne ozone-sondes[17]	1969 [18]	/	O_3	vertical profile[19]	RMI
Uccle	EUMETNET E-Profile	Automatic Lidar Ceilometers		/	aerosol	backscatter profile (0-14 km)	RMI
Zeebrugge							
Diepenbeek							
Humain							
Princess Elisabeth[20]	WOUDC Station 499	Brewer n°100 [21]	Jan 2011	/	O_3	column	RMI
					UV	spectral irradiance	
	EUVDB	UV-B, UV-A sensors, pyranometer	2012	/	UV	global solar spectral irradiance, broadband data, filter radiometer data, sunshine duration	BIRA
Mol	EUVDB	UV-B, UV-A sensors, pyranometer	1995	/	UV	global solar spectral irradiance, broadband data, filter radiometer data, sunshine duration[22]	BIRA
Mount Rigi							
Oostende							
Redu							
Uccle							
Virton							

[10] Time resolution : approximately 20 minutes.

[11] In support of the Copernicus Atmosphere Monitoring Service (CAMS) and for satellite validation purposes.

[12] Single monochromator.

[13] Daily.

[14] Several scans per day, number depending on the time the sun is above the horizon

[15] Double monochromator.

[16] In agreement with WMO-GAW the instrument is now loaned to the University of Kiev (Ukraine) and is operational there.

[17] Three times per week.

[18] Ozone profile data in the period 1969-1997 were obtained with Brewer-Mast sensors. ECC ozone sensors have been used since 1997. Special care is taken to ensure the homogeneity of the time series, not only between the two types of ozone sensors, but also between soundings using one single type of sensor.

[19] Resolution: a few hundred metres.

[20] The Antarctic station is operational during the manned periods in the austral summer

[21] Put at RMI's disposal by KNMI (The Netherlands).

[22] Plus associated cloud and meteorological parameters.

Table A 3. Molecules currently studied in FTIR solar spectra recorded at the Jungfraujoch [23]

Reference gas:		N_2
Minor constituents:		CO_2, N_2O, CH_4, CO, *O_3*
Trace constituents:	Halogenated species:	*HCl*, *$ClONO_2$*, *HF*, *COF_2*,
		CCl_2F_2, $CHClF_2$, CCl_3F, CH_3CClF_2, CCl_4, CF_4, SF_6, CH_3Cl
	Nitrogenated species:	*NO*, *NO_2*, *HNO_3*, *$ClONO_2$*, NH_3
	Others:	H_2O, C_2H_6, C_2H_2, C_2H_4, HCN, OCS, H_2CO, H_2CO_2, CH_3OH
		Isotopologues of CO, CH_4, H_2O, *O_3*

[23] Species typed *in italic* are primarily present in the stratosphere, while the other ones are tropospheric source gases.

ANNEX B. SATELLITE OBSERVATIONS

ULg, ULB and BIRA-IASB are involved in several satellite missions relevant to atmospheric ozone and connected issues, the detail of which is provided below

B.1 Column measurements of ozone and other gases/variables relevant to ozone loss

ULg, ULB and BIRA-IASB are involved in several satellite missions measuring the total column of ozone and of ozone relevant species (halogens, NOy, BrO, HCFC, CFC…).

- ***Royal Belgian Institute for Space Aeronomy (BIRA-IASB)***

- Global Ozone Monitoring Experiment (GOME), aboard ESA's ERS-2 platform, measured the column of O_3, NO_2, BrO and OClO from July 1995 till the switch-off of the platform in June 2011. BIRA-IASB is a co-proposer of the instrument, plays a key role in scientific developments, evolution and geophysical validation of the operational GOME Data Processor for total ozone and NO_2 established at DLR (Germany) on behalf of ESA and has developed his own operational algorithm based on the Direct Fitting Method, which is used in CCI-ozone reprocessing of Fundamental Climate Data Records on ozone *(Lambert et al. 1999, 2000; Spurr et al. 2004; Van Roozendael et al. 2007; Balis et al. 2007; Loyola et al. 2009; Lerot et al. 2010; Van Roozendael et al. 2012; Lerot et al. 2014; Koukouli et al. 2014)*. OIP Sensor Systems, a Belgian company specialised in defence, security and space, built the GOME Polarization Monitoring Devices (PMDs).
- Scanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY), a tri-national contribution to ESA's Envisat satellite by Belgium, Germany and The Netherlands, measured the column of O_3, NO_2, BrO, SO_2, OClO and other trace gases from August 2002 till the loss of contact with Envisat in April 2012. BIRA-IASB is a Co-PI of the instrument, has followed the technical development of the instrument, is involved in the development and evolution of retrieval algorithms, and is a Co-chair of the SCIAMACHY Validation and Interpretation Group (SCIAVALIG). OIP Sensor Systems, a Belgian company specialised in defence, security and space, built the SCIAMACHY Polarization Monitoring Devices (PMDs).
- Global Ozone Monitoring by Occultation of Stars (GOMOS), on board of ESA's Envisat, measured the vertical profile of O_3, NO_2, NO_3, aerosols, OClO and other trace gases from August 2002 till the loss of contact with Envisat in April 2012. BIRA-IASB is a co-proposer of the instrument, an expert support laboratory (ESL) certified by ESA, and has been active in the development and validation of O_3, NO_2, aerosols, OClO and temperature data products.
- Ozone Monitoring Instrument (OMI), aboard NASA's EOS-Aura polar platform, measures since 2004 the column of O_3, NO_2, BrO, SO_2, OClO and other trace gases. BIRA-IASB has been active in the development and geophysical validation of ozone, NO_2 and BrO data products from OMI.
- Global Ozone Monitoring Experiment-2 (EUMETSAT GOME-2), aboard EUMETSAT MetOp-A platform since October 2006 and MetOp-B platform since September 2012, measures the column of O_3, NO_2, BrO, SO_2, OClO and other trace gases. Partner of the EUMETSAT Satellite Application Facility on Ozone and Atmospheric Chemistry Monitoring (O3M-SAF), BIRA-IASB plays a key role in scientific developments, evolution and geophysical validation of the operational GOME-2 Data Processor for the column of ozone, NO_2, BrO, H_2CO and SO_2 established at DLR (Germany) as part of the O3M-SAF *(Loyola et al. 2011; Lerot et al. 2010b; Lerot et al. 2014; Koukouli et al. 2014)*.
- Infrared Atmospheric Sounding Interferometer (IASI), on board of EUMETSAT MetOp-A (since 2006) and MetOp-B (since 2012) platforms. BIRA-IASB is involved in the development of a N_2O data product. N_2O releases NO_x in the stratosphere, which is an Ozone Depleting Substance (ODS). The steady growth of N_2O makes it a threat to the stratospheric ozone layer in the future. In addition, BIRA-IASB is developing a methane product from IASI.
- Tropospheric Moniroting Instrument (TROPOMI), to be launched in 2017 on board of the Copernicus Sentinel-5 Precursor mission (S-5p). Member of the S-5p Mission Advisory Group, BIRA-IASB is involved in scientific developments, evolution and geophysical validation of the operational algorithms for the column of ozone, NO_2, H_2CO, CO, CH_4 and

SO_2. BIRA-IASB will host and operate parts of the ground-segment for data processing, as well as the Validation Data Analysis Facility (VDAF) of the S-5p Mission Performance Centre (MPC).

- Copernicus Sentinel-4 and Sentinel-5, planned by the turn of the decade. Member of the Sentinel-4/5 Mission Advisory Group, BIRA-IASB is involved in scientific developments, evolution and geophysical validation of the operational algorithms for the column of ozone, NO_2, H_2CO, CO, CH_4 and SO_2.

➢ ***Université Libre de Bruxelles (ULB)***

The Atmospheric Spectroscopy group (Service de Chimie Quantique et Photophysique) at ULB is heavily involved in the IASI/MetOp satellite mission, being member of its Science Working Group (ISSWG-2), under auspice of CNES and EUMETSAT. IASI is a sounder that measures the thermal infrared radiation of the Earth/atmosphere in nadir geometry (*Hilton et al., 2012*), at fairly high spatial (12 km diameter circular pixel on-ground) and spectral (0.5 cm^{-1}) resolutions (*Clerbaux et al 2009*). IASI is part of the EPS system, and is scheduled to operate up to 2020 at least. The first IASI instrument onboard the European MetOp-A was launched platform in late 2006 and declared operational in July 2007. The second instrument was launched in 2012. Both are currently in operation. As compared to UV sounders but also precursor infrared sounders (IMG and TES), IASI has the advantage of high spatial and temporal sampling, providing global measurements twice daily, once in the morning and once in the evening. The small pixel allows capturing fine concentration variations of several trace gases (*Clarisse et al., 2011*). The ULB group has set-up, in collaboration with the French LATMOS, a near-real time processing chain for IASI. Of particular relevance here are

- Ozone total columns distributions, which are retrieved global twice a day, in near-real time using FORLI-O_3. The product has undergone validation against a series of independent observations (GOME-2, Dobson, Brewer, SAOZ and ozonesondes data) on the global scale for the two IASI instruments (Boynard et al., 2016). The added value of IASI exceptional frequency sampling has been demonstrated to be of particular importance for monitoring medium to long-term changes in global ozone concentrations (Wespes et al., 2016). FORLI-O_3 is being implemented in the EUMETSAT Central Application Facility and is expected to become the operational processing chain for IASI O_3 during this year. FORLI-O_3 is also the reference algorithm for the work performed under the O_3-CCI and the IGAC's Tropospheric Ozone Assessment Report (TOAR) projects.
- Nitric acid total columns distributions, which have an important role in regulating the ozone hole, and a sensitive species to monitor its development. The first characterization and validation of the FORLI-HNO_3 vertical profile product with FITR instruments at 6 stations has been recently published (Ronsmans et al., 2016). The implementation of IASI-HNO_3 is ongoing and the product is expected to be declared operational in 2017.
- Aerosols from various types, including volcanic ash and sulfuric acid droplets *(Clarisse et al., 2013).*
- In addition a series of column measurements for tropospheric species, strongly involved in the ozone budget by being ozone precursors, are provided. These include in particular CO (*e.g. Worden et al., 2013*) and volatile organic compounds (*Duflot et al., 2013 and 2015; Razavi et al. 2011; Stavrakou et al., 2011 and 2012*). FORLI-CO is also being implemented in the EUMETSAT Central Application Facility and is expected to be declared operational in the next few weeks.

➢ ***University of Liège (ULg)***

ULg is further involved in the Canadian ACE satellite mission (Bernath et al., 2005), which includes an FTIR instrument on operation from space since early 2004. ULg actively contributes to the scientific exploitation of the ACE-FTS data.

B.2 Profile measurements of ozone and other gases/variables relevant to ozone loss

ULB and BIRA are involved in several satellite missions measuring the vertical distribution of ozone and of ozone relevant species (halogens, NOy, BrO, HCFC, CFC…).

- ***Royal Belgian Institute for Space Aeronomy (BIRA-IASB)***

BIRA-IASB is involved in several **satellite** missions measuring the vertical distribution of ozone, of ozone depleting substances and of other ozone relevant species (halogens, NOy, BrO, HCFC, CFC…) for budget, process and long-term trend studies:

- Global Ozone Monitoring Experiment (GOME), aboard ESA's ERS-2 platform, measured solar backscattered ultraviolet radiances from 1996 till the switch-off of the platform in June 2011. Form these radiance measurements several institutes retrieve the vertical distribution of ozone in the stratosphere and troposphere. BIRA-IASB is a co-proposer of the instrument, contributes to the evolution of several ozone profile retrieval algorithms through Round-Robin audits and plays a key role in their geophysical validation. OIP Sensor Systems, a Belgian company specialised in defence, security and space, built the GOME Polarization Monitoring Devices (PMDs).
- Scanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY), a tri-national contribution to ESA's Envisat satellite by Belgium, Germany and The Netherlands, measured the vertical profile of O_3, NO_2, BrO and other trace gases from August 2002 till the loss of contact with Envisat in April 2012. BIRA-IASB is a Co-PI of the instrument, has followed the technical development of the instrument, is involved in the development and evolution of retrieval algorithms, and is a Co-chair of the SCIAMACHY Validation and Interpretation Group (SCIAVALIG). OIP Sensor Systems, a Belgian company specialised in defence, security and space, built the SCIAMACHY Polarization Monitoring Devices (PMDs).
- Global Ozone Monitoring by Occultation of Stars (GOMOS), on board of ESA's Envisat, measured the vertical profile of O_3, NO_2, NO_3, aerosols, OClO and other trace gases from August 2002 till the loss of contact with Envisat in April 2012. BIRA-IASB is a co-proposer of the instrument, an expert support laboratory (ESL) certified by ESA, and has been active in the development and validation of O_3, NO_2, aerosols, OClO and temperature data products.
- Michelson Interferometer for Passive Atmospheric Sounding (MIPAS), on board of ESA's Envisat, measured the vertical profile of O_3, NO_2, HNO_3, N_2O, CO, CH_4, H_2O, CFCs, HCFCs and other trace gases from August 2002 till the loss of contact with Envisat in April 2012. BIRA-IASB has been active in the geophysical validation of O_3, temperature, NO_y, N_2O, CO, CH_4, HCFC and CFC data products.
- Atmospheric Chemistry Experiment – Fourier Transform Spectrometer (ACE-FTS) on board of CSA's SCISAT-1 launched in 2003, measures via the solar occultation technique the vertical distribution of many ozone related trace gases and parameters. BIRA-IASB has been active in the development and geophysical validation of ozone, CH_4, CO, N_2O, NO_y, HCl, HCFCs and CFCs and temperature data products. Inside the ACE-FTS instrument is a visible/near infrared imager with two filtered channels at 0.525 and 1.02 μm, chosen to match two of the wavelengths monitored by the SAGE II satellite instrument. Made by the Belgian company Fill Factory of Mechelen, the imagers provide an important diagnostic for pointing and for detecting the presence of clouds in the field of view of the instrument.
- Global Ozone Monitoring Experiment-2 (EUMETSAT GOME-2), aboard EUMETSAT MetOp-A platform since October 2006 and MetOp-B platform since September 2012, measures solar backscattered ultraviolet radiances, from which several institutes retrieve the vertical distribution of ozone in the stratosphere and troposphere. BIRA-IASB contributes to the evolution of several ozone profile retrieval algorithms through Round-Robin audits and plays a key role in their geophysical validation.
- Infrared Atmospheric Sounding Interferometer (IASI) operating on board of MetOp-A since 2006 and MetOp-B since 2012. BIRA-IASB has contributed to the validation of the CO and HNO_3 vertical profile data. It has developed an algorithm for retrieving vertical profiles of the mineral dust aerosol. It is working on a CH_4 vertical profile product. To improve the sensitivity at the surface, it is working on synergetic SWIR/TIR retrievals of CH_4 – with GOSAT data as test case.
- Tropospheric Moniroting Instrument (TROPOMI), to be launched in 2017 on board of the Copernicus Sentinel-5 Precursor mission (S-5p). Member of the S-5p Mission Advisory Group, BIRA-IASB is involved in scientific developments, evolution and geophysical validation of the operational algorithms for the vertical distribution of ozone. BIRA-IASB will

host and operate the Validation Data Analysis Facility (VDAF) of the S-5p Mission Performance Centre (MPC).

- Copernicus Sentinel-4 and Sentinel-5, planned by the turn of the decade. Member of the Sentinel-4/5 Mission Advisory Group, BIRA-IASB is involved in planning the geophysical validation of the operational algorithms for the vertical distribution of ozone.
- Atmospheric Limb Tracker for the Investigation of the Upcoming Stratosphere (ALTIUS): national development of a limb viewing satellite instrument responding to the requirements resulting from the 7th, 8th and 9th ORM Meetings in 2008, 2011 and 2014, respectively (*WMO GORMP Report N° 51, N° 53 and N° 54*): "Satellite observations of high vertical resolution profiles using limb viewing for O_3 and key molecules are required in order to more accurately understand the changes in O_3 as CFCs decline and climate change occurs." After a phase B1 completion, the mission concept and the instrument preliminary design were reviewed by ESA in 2015 as well as the operational/scientific objectives by an international panel of scientists. In 2016, the ALTIUS mission was accepted by the ESA-Earth Observation programme board as an element of the EarthWatch programme and definitely approved at the last ESA ministerial council in Dec 2016.
- PICASSO - A PICo-satellite for Atmospheric and Space Science Observations is an ESA project led by BIRA-IASB, in collaboration with VTT Technical Research Centre of Finland Ltd, Clyde Space Ltd. (UK), Centre Spatial de Liège (BE) and the Royal Observatory of Belgium. PICASSO is a three-unit CubeSat, for which VTT will develop the main payload,Visible Spectral Imager for Occultation and Nightglow (VISION). VISION will primarily target the observation of the Earth's atmospheric limb during orbital Sun occultation. By assessing the radiation absorption in the Chappuis band for different tangent altitudes, the vertical profile of the ozone is retrieved. A secondary objective is to measure the deformation of the solar disk so that stratospheric and mesospheric temperature profiles are retrieved by inversion of the refractive ray-tracing problem. PICASSO has now passed the Critical Design Review and is on way toward a launch in 2018.

➢ ***Université Libre de Bruxelles (ULB)***

- The Atmospheric Spectroscopy group (Service de Chimie Quantique et Photophysique) at ULB tackles several chemistry-related activities around the IASI/MetOp satellite mission. The researchers take active part in the IASI Sounder Science Working Group (ISSWG-2), under auspice of CNES and EUMETSAT, for IASI and preparation of IASI on EPS-SG. In addition to providing information on total columns (see above), IASI has also profiling capabilities at least equal if not superior to most instrument currently in operation. With the FORLI processing chain set-up at ULB, the following products are available in near-real-time:
    - Ozone vertical profiles, which are retrieved in 40 layers of 1km thickness starting from the ground, with 3-4 independent pieces of information. Upper stratospheric, middle-low stratospheric and tropospheric contributions are well decorrelated. The maximum sensitivity of IASI to the ozone profile extends from the mid-troposphere to the lower stratosphere, and the product is thus of high relevance for monitoring the vertical structure of the ozone hole, the contribution of tropospheric ozone to climate, as well as the impact of ozone in the lowest layers on air quality.
    - Nitric acid vertical profiles. The vertical information is low with only one level of information on the vertical profile and negligible sensitivity near the surface in most cases but the retrieval of vertical profiles improves on the columns measurements by accounting for changes in tropopause height. Vertical profiles are available in NRT. The maximum sensitivity is in the upper troposphere/lower stratosphere (10-20km). A partial de-correlation between tropospheric and stratospheric HNO_3 is possible in the best cases.
- In addition to IASI, the ULB researchers are involved SCISAT-1 ACE-FTS Science Team, although their active contribution has decreased in the last years due to their large involvement in IASI. They have contributed to several profile studies with ACE-FTS.

ANNEX C. CALIBRATION / VALIDATION ACTIVITIES

C.1 Ground-based and balloon-borne instrument calibration

The RMI Brewer instruments 016 and 178 were compared with the travelling reference instrument nr 017 in 2006 and 2008. In 2010 the instruments were calibrated in Uccle together with Brewer #100 (before it was sent to Antarctica) against Brewer reference instrument 158. The cosine response of Brewer 178 was measured in co-operation with BIRA in 2011. In 2012 Brewers 016 and 178 were calibrated against reference instrument 158. In 2014 a new calibration campaign is planned (this time also including the instrument operated in Antarctica). The results of these calibrations were taken into account for the new ozone observations and also the older data were recalculated. Next calibrations took place in 2012, 2014, 2016. The results of the calibrations are always immediately implemented, and recalculation of ozone values are done if needed.

The UV-B calibration of the RMI Brewer instruments was checked with 1000W lamps in 2006, 2008, 2010, 2012, 2014 and 2016 during the calibration visits. In 2004 the special comparative observations were performed with a travelling reference UV instrument of the Joint Research Centre (JRC in Ispra) in the frame of the Qasume project (Gröbner et al, 2004). All the 1000W calibrations were consistent with the calibrations based on the monthly tests with 50W lamps within the expected errors.

Different calibration facilities are available at the BIRA-IASB for the radiometric characterization (for example: angular response, relative spectral response, wavelength scales, ...) and absolute calibration (using standard of spectral irradiance) of pyranometers, filter radiometer and spectroradiometer.

The RMI ozone sondes are carefully prepared and calibrated with a reference instrument in the laboratory before launch. A correction procedure is applied to minimise the inhomogeneity that could have been introduced at the change of the sonde type in 1997. We also took part in the Ozone Sonde Data Quality Assessment (O3S-DQA) activity, a part of the SPARC-IGACO-IOC (SI2N) Assessment on "Past Changes in the Vertical Distribution of Ozone". The goal of the O3S-DQA activity is to create a world-wide, homogenized set of ozone sonde data which includes an uncertainty estimate for every single measurement. The idea is to define Standard Operating Procedures and corrections for the ozone sonde measurements and to convert all measurements to these by means of transfer functions. The Uccle dataset (from 1997 onwards) was corrected according to those standard operating procedures and algorithms and an uncertainty analysis have been applied to those data.

The BIRA-IASB ground-based FTIR, zenith-sky DOAS and MAXDOAS UV-visible instruments are all contributing to the NDACC. As such, they have to comply with the various NDACC protocols for instrument certification, measurement, data intercomparisons, data submission and data use, as well as guidelines and rules peculiar to the networks to which NDACC contributes, e.g., the GCOS Monitoring Principles.

The BIRA-IASB MAXDOAS instruments have participated to several calibration/intercomparison campaigns, e.g., the recent CINDI-2 campaign in Cabauw (NL) in September 2016 *(papers in preparation)*.

The calibration of the BIRA-IASB FTIR instruments at La Réunion is verified on a daily basis by doing HBr (for NDACC) and HCl (for TCCON) cell measurements. BIRA-IASB also participates in the data processing standardisation procedures that are on-going in the frame of the NDACC Infrared Working Group and the TCCON network.

Calibration by ULg of the Jungfraujoch FTIRs is performed according to NDACC recommendations, in order to characterize the instrument performance and stability. This is done by regularly recording HBr cell measurements. Also, N_2 (whose vertical distribution and concentration are well known) absorption features are further used to check the instrumental consistency, in particular for time periods for which regular cell measurements are unavailable.

C.2 Calibration / validation activities in the context of satellite missions and data retrieval

BIRA-IASB coordinates research and/or operational cal/val activities for a list of satellite missions, including GOME, Envisat (GOMOS, MIPAS, SCIAMACHY), ACE-FTS, Odin (OSIRIS and SMR), OMI, and MetOp-A/B (GOME-2 and IASI). In the near future BIRA-IASB will host operational validations facilities for its ALTIUS limb mission and for the Copernicus Sentinels 5-p, 4 and 5.

ULB has become a participant in the O3MSAF activities in CDOP2, from 2012. In this framework, it plays a key role in the implementation of algorithms (including for ozone, nitric acid and CO) at the EUMETSAT Central Application Facility, and on the quality assurance of the retrieved products. Based upon previous validation exercises using independent measurements (cf. Section 2.4.1 and Annex B), an updated version of FORLI retrievals has been developed and tested. The IASI dataset using the updated FORLI algorithm is now processing forward and backward at ULB.

The IASI-CO product produced at ULB/LATMOS (offline product) has already been validated with that operated at EUMETSAT.

For ozone retrieval, comparison between the processing chains operating in parallel at ULB and at EUMETSAT has been performed in 2014.

ULB is strengthening its calibration/validation activities within the O3-CCI project for which constructing long-term data records of stratospheric and tropospheric ozone profiles is the major requirement. This is also further reinforced by dedicated calibration activities in the frame of the EU-QA4ECV and TOAR projects.

C.3 Validation harmonisation and quality standards

BIRA-IASB contributes to the international implementation of the global Quality Assurance framework for Earth Observation (QA4EO, http://qa4eo.org/) for the GEOSS, an effort coordinated by the CEOS WGCV. At European level it is active in the system engineering for the Copernicus Atmospheric Monitoring Service (CAMS) and the Copernicus Climate Change Service (C3S), where it ensures coordination and harmonisation of the data quality strategy between, on one hand, Copernicus pioneering projects of the EC (MACC-II/III, PASODOBLE, EVOSS, QA4ECV, GAIA-CLIM) and ESA (CCI-ozone, CCI-GHG), and on the other hand, ECMWF sponsored procurement of CAMS (CAMS-84) and C3S (C3S-ozone). In particular, BIRA-IASB coordinates validation activities in the CAMS-84 and C3S-ozone procurement projects, including organisation of NDACC data provision on a rapid delivery basis (less than 1 month after acquisition) for the validation of the CAMS and C3S products.

In the EU projects FP7 QA4ECV (2014-2018) and H2020 GAIA-CLIM (2015-2018), BIRA-IASB coordinates the development, implementation and application of a Quality Assurance system for atmospheric Essential Climate Variables (ECVs). This project aims at developing a robust generic system for the QA of satellite and in-situ retrieval algorithms and multi-decadal data records that can be applied virtually to all ECVs in a prototype for future sustainable services in the frame of the Copernicus Climate Change Service (C3S). Multi-use tools and SI/community reference standards are being developed. More details on http://www.qa4ecv.eu/ and http://www.gaia-clim.eu

ANNEX D. LIST OF RELEVANT SCIENTIFIC PAPERS

Only publications issued or submitted after the Belgian Report for the 9th WMO/UNEP Ozone Research Managers Meeting (ORM9) are listed below.

D.1 Peer reviewed papers and books:

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Bingen, C., C. E. Robert, K. Stebel, C. Brühl, J. Schallock, F. Vanhellemont, N. Mateshvili, M. Höpfner, T. Trickl, J.E. Barnes, J. Jumelet, J.-P. Vernier, T. Popp, G. de Leeuw, and S. Pinnock, Stratospheric aerosol data records for the Climate Change Initiative: development, validation and application to Chemistry-Climate Modelling, under review for Remote Sensing of Environment.

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ANNEX E. PROJECTS AND COLLABORATION

Only projects and collaborations that are ongoing or have been running after the issue of the Belgian National Report for the 9th WMO/UNEP Ozone Research Managers Meeting are listed in the top three tables below. A list of agency and programme acronyms is provided in Table E 4.

Table E 1. Projects in partnership.

Table E 2. Participation to working groups and collaborative initiatives.

Table E 3. Membership of international organisations and committees.

Table E 4. Acronyms of agencies, programmes, working groups.

Table E 1. Projects in partnership.

Acronym / Title / Objective / URL	Agency / Programme	Start	End	Belgian partners
ACCROSS - Atmospheric Composition and Circulation investigated with meteorological Reanalyses, Observational datasets and models for the Study of the Stratosphere and its changes	F.R.S. - FNRS	2016	2019	ULg
ACROSAT - Atmospheric Composition Research using Observations from SATellites	BELSPO PRODEX	2014	2015	BIRA ULg
Aerosol_CCI Phase II http://www.esa-aerosol-cci.org/	ESA CCI	Spring 2014		BIRA
AGACC-II - Advanced exploitation of ground based measurements for atmospheric chemistry and climate applications http://www.oma.be/AGACC/Home.html	BELSPO SSD	Dec 2010	Sep 2015	BIRA (coordinator) RMI ULg
BACCHUS - Impact of Biogenic versus Anthropogenic emissions on Clouds and Climate: towards a Holistic UnderStanding http://www.bacchus-env.eu/	EU FP7	2013	2017	BIRA (PI)
B-O3MSAF - Belgian Contribution to the O3MSAF activities (see O3MSAF below)	ESA, BELSPO PRODEX	2014	2015	BIRA ULB
C3S_Ozone (C3S_312a_Lot4) - Production of Essential Climate Variable Datasets based on Earth Observations (Ozone) – to feed the C3S Data Store (CDS) with Level 3 data	ECMWF C3S	2016	2018	BIRA (prime contractor)
CDOP-2 - Continuous Development and Operation 2	EUMETSAT	2012	2017	BIRA
CDOP-3 - Continuous Development and Operation 3	EUMETSAT	2017	2022	BIRA
ECLAIRE - Effects of Climate Change on Air Pollution and Response Strategies for European Ecosystems	EU FP7	2011	2015	ULB
GAIA-CLIM - Gap Analysis for Integrated Atmospheric ECV CLImate Monitoring http://www.gaia-clim.eu/	EU H2020	Mar 2015	Feb 2018	BIRA
GAW-CH 3 - FTIR measurements at the Jungfraujoch	WMO GAW	2014	2017	ULg
IASI-Flow - Infrared Atmospheric Sounding with IASI and Follow-on missions	ESA, BELSPO PRODEX	2014	2015	BIRA ULB
Improvement of the FTIR spectroscopy instrumental technique in the framework of continued observations and characterization of the Earth atmosphere from the Jungfraujoch	F.R.S. - FNRS	2013	2016	ULg
ISOMET - Atmospheric content of the most abundant $^{12}CH_4$ isotopologues from ground-based and satellite infrared solar observations and development of a methane isotopic GEOS-Chem module (Marie Sklodowska-Curie grant agreement n° 704951)	EU H2020	2016	2017	ULg
MACC-II - Monitoring Atmospheric Composition and Climate - Interim Implementation	EU FP7	Nov 2011	Jul 2014	BIRA

Acronym / Title / Objective / URL	Agency / Programme	Start	End	Belgian partners
MACC-III - Monitoring Atmospheric Composition and Climate	EU H2020	2014	2015	BIRA
Multi-TASTE Phase F - Validation support to Envisat atmospheric data evolution	ESA	2014	2014	BIRA
NORS - Demonstration Network of Ground-based remote sensing observations in support to GMES atmospheric service	EU FP7	2011	2014	BIRA ULg
O3MSAF - Satellite Application Facility on Ozone and Atmospheric Chemistry Monitoring	EUMETSAT	2012	2017	RMI (validation) ULB
Ozone_CCI Phase II http://www.esa-ozone-cci.org/	ESA CCI	2014	2017	BIRA (coordinator) RMI
PANDA - PArtnership with chiNa on space DAta	EU FP7	2014	2017	ULB
QA4ECV - Quality Assurance system for Essential Climate Variables http://www.qa4ecv.eu/	EU FP7	2014	2018	BIRA ULB
Sentinel-5 Precursor Level 2 Processor Component Development project	ESA	2012	2015	BIRA
Sentinel-5p Mission Performance Centre (MPC) project	ESA			BIRA
S5L2PP	ESA			BIRA
TRACE-S5P	BELSPO PRODEX	2014	2015	BIRA
TROVA	BELSPO PRODEX	2016	2018	BIRA

Table E 2. Participation to working groups and collaborative initiatives.

Working group / Initiative	Belgian partners
ESA Envisat Atmospheric Chemistry Validation Team (ACVT)	BIRA
ESA Quality Working Groups	BIRA
ESA S-5p Validation Team (S5PVT)	BIRA
ESA Satellite validation projects	RMI
EUBREWNET - A European Brewer Network – ESSEM COST Action ES1207 http://www.eubrewnet.org/cost1207/	RMI
EUMETNET E-profile programme to exchange data from lidar-ceilometers	RMI
EUMETSAT Chemistry and climate related studies using the IASI remote sensor to prepare the scientific research aspects of the IASI mission on board METOP-A	BIRA
EUMETSAT Satellite validation projects	RMI
IPCC assessments	BIRA
LOTUS - Long-term Ozone Trends and Uncertainties in the Stratosphere – SPARC Activity http://www.sparc-climate.org/activities/ozone-trends/	BIRA
Science and processing teams of satellite missions, e.g. SCIAMACHY SSAG, SCIAVALIG and SADDU	BIRA
SPARC / IO3C / IGACO / NDACC (SI2N) assessment of trends in the vertical distribution of ozone	BIRA, RMI
STCE Support of the ozone research programme	RMI
TOAR - Tropospheric Ozone Assessment Report – IGAC Activity http://www.igacproject.org/TOAR	BIRA, ULB
TOPROF – COST Action to use aerosol profile information from lidar-ceilometers	RMI
WMO/UNEP ORM Reports	BIRA
WMO/UNEP Scientific Assessments of Ozone Depletion	BIRA

Table E 3. Membership of international organisations and committees.

International organisation / International committee	Belgian members
Advanced Composition Explorer (ACE) Science Team	ULg, ULB
Canadian ACE/SciSAT mission Science Team	BIRA
Centre Spatial de Liège (CSL) scientific committee	ULg
Committee on Earth Observation Satellites (CEOS): Participation in Working Group on Cal/Val (WGCV) and in Atmospheric Composition Constellation (ACC)	BIRA
EOS-Aura OMI International Science Team	BIRA
ESA Council	BIRA
EUBREWNET Management Committee (COST ES1207 - A European Brewer Network)	RMI
EUMETNET Scientific and Technical Advisory Committee (STAC)	RMI
EUMETSAT Council	BIRA, RMI
EUMETSAT O3MSAF project team	BIRA, RMI
EUMETSAT O3MSAF Steering Group	RMI
EUMETSAT Policy Advisory Committee	RMI
EUMETSAT Scientific and Technical Group	RMI
GAIA-CLIM Management Board	BIRA
GEOS-Chem Carbon Gases & Organics working group	ULg
IAMAS-IUGG International Ozone Commission (IO3C)	BIRA
IASI Conference Scientific Committees	ULB
IASI Sounder Science Working Group–II	ULB
International Committee on Space Research (COSPAR)	BIRA
International Scientific Station Jungfraujoch and Gornergrat (ISSJG) Astronomic Commission	ULg
MACC-II and MACC-III Management Boards	BIRA
NDACC-Infrared working group	ULg
NDACC steering committee	BIRA (co-chair (since Nov. 2013) ULg
NORS Management Board	BIRA
QA4ECV Management Board	BIRA
Science Advisory Groups of GOME and GOME-2, GOMOS, SCIAMACHY, OMI	BIRA
Sentinel-5p TROPOMI, Sentinel 4 and Sentinel 5 Mission Advisory Groups	BIRA
WCRP SPARC	BIRA
WMO GAW Brewer sub-committee	RMI
WMO GAW Satellite WG (co-chair since 1999), UV-Visible WG (co-chair since 2003)	BIRA
WMO GAW Scientific Advisory Group on UV Solar Radiation (UV-SAG)	BIRA
Working Group on Cal/Val Infrastructure	BIRA

Table E 4. Acronyms of agencies, programmes, working groups.

BELSPO	Belgian Science Policy
BELSPO PRODEX	BELSPO's PROgramme de Développement d'EXpériences scientifiques
BELSPO SSD	BELSPO's Science for a Sustainable Development programme
COST	European Cooperation in Science and Technology
ECMWF	European Centre for Medium-Range Weather Forecasts

C3S	European Union's Copernicus Climate Change Service
ESA	European Space Agency
ESA CCI	ESA's Climate Change Initiative
EU FP7	European Union's Seventh Framework Programme
EU H2020	European Union's Horizon 2020 research and innovation programme
F.R.S. - FNRS	Fonds National de la Recherche Scientifique, entité francophone
IAMAS	International Association of Meteorology and Atmospheric Sciences
IGAC	International Global Atmospheric Chemistry
IGACO	Integrated Global Atmospheric Chemistry Observations
IO3C	International Ozone Commission
IPCC	Intergovernmental Panel on Climate Change
IUGG	International Union of Geodesy and Geophysics
O3MSAF	EUMETSAT Satellite Application Facility on Ozone and Atmospheric Chemistry Monitoring
SADDU	SCIAMACHY Algorithm Development and Data Usage
SCIAVALIG	SCIAMACHY Validation and Interpretation Group
SPARC	Stratosphere-troposphere Processes And their Role in Climate (WCRP's core project)
SSAG	SCIAMACHY Science Advisory Group
STE	Solar Terrestrial Centre of Excellence
UNEP	United Nations Environment Programme
WCRP	World Climate Research Programme
WMO	World Meteorological Organisation
WMO GAW	WMO's Global Atmosphere Watch

ANNEX F. CONTACT DETAILS OF BELGIAN INSTITUTES AND SCIENTISTS INVOLVED IN OZONE RELATED RESEARCH

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Dr. C. Servais - Christian.Servais@ulg.ac.be (FTIR Instrumentation development and improvement (electronic, optic, remote control…), maintenance and observations)

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Dr. ir. Andy Delcloo - Andy.Delcloo@meteo.be (Validation of satellite ozone data, Member of project team of O3M SAF/AC SAF of EUMETSAT, member of the ESA-CCI and CHEOPS-5P teams, contributor to the Ozone assessment report nr 56 - WMO global Ozone and Monitoring Project)

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Dr. Jean-Christopher Lambert - J-C.Lambert@aeronomie.be (Member of the International Ozone Commission (2008-2016), satellite and ground-based remote sensing of the atmospheric composition, synergistic exploitation of atmospheric composition data, data quality strategy, multi-mission satellite validation, member of EUMETSAT O3M-SAF project team, Co-chair of the NDACC Satellite Working Group, Vice-chair of the CEOS Working Group on Cal/Val / Atmospheric Composition Subgroup, member of several satellite Mission/Science Advisory Groups).

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BRAZIL

THE BRAZILIAN NETWORK OF OZONE AND UV RADIATION MEASUREMENTS

The human activities have disturbed the natural balance of atmosphere composition (WMO, 2014). This fact has produced global scale issues like ozone layer depletion and climate change around the world. The scientific researches are very important to follow the changes of the environment and expand the knowledge. But the most important is to stop the liberation of ODS (Ozone Depletion Substances) and the GHG (Green House Gases), through activities that are sustainable and not harmful to the environment. Brazil acceded to the Montreal Protocol through Decree No. 99,280 on June 6yh, 1990, becoming a Party. The ODS were banned in 2010, but the GHG emissions continue happening, in urban areas and mainly in the Amazon rainforest. That is the biggest environmental crime that our politicians are committing against the Earth. The international commissions should urgently interfere in order to change this scenario. There is no emissions inventory of ODS in Brazil, but yes for GHG in the main cities.

1- OBSERVATIONAL ACTIVITIES

1.1 Column measurements of ozone and other gases/variables relevant to ozone loss:

Ozone research in Brazil is 42 years old. The first Dobson Spectrophotometer was installed in the city of Cachoeira Paulista – SP in 1974 and the second one in Natal - RN in 1978. Since then was established the first site for ozone monitoring in the tropics to provide continuous data for national and international researchs. Also in Natal was installed in 1994 a spectrophotometer Brewer and in 2009 a GUV radiometer to study the ozone layer, ultraviolet radiation and photosynthetically active radiation. In 2006, was created the LAVAT - Laboratory of Tropical Environmental Variables, where the ozone activities are conducted. From then on, a meteorological station (2006) and a solarimetric station (2007) were installed in INPE-Natal-RN. Besides that there are Brewer spectrophotometers in Cuiabá, Santa Maria and La Paz (Bolívia). The Brazilian Antarctic Station Comte. Ferraz has not been operating since 2012 due to a fire. The GHG measurements are made in Farol de Mãe Luiza, Natal since 11/25/2015.

Table1 – INPE's network spectrophotometers Dobson and Brewer.

SITE	LAT. (SOUTH)	LONG. (WEST)	DOBSON NUMBER	BREWER NUMBER	PERIOD and TYPE
NATAL BRAZIL	5.84º	35.21º	093 since 1978 - today	110 073	1994-1996 MARK IV 1996 - today MARK IV
CUIABÁ BRAZIL	15.3º	56.1º	-	056 081	1991-1997 MARK II 2002-today MARK IV
LA PAZ, BOLÍVIA	16.54º	68.06º	-	110	1996-2004 MARK IV
CACHOEIRA PAULISTA BRAZIL	22,68º	45,00º	114 since 1976 - today	124	1997- today MARK IV
SAO JOSE DOS CAMPOS BRAZIL	23,2º	45,86º	-	056	2000 - 2006 MARK II
SANTA MARIA BRAZIL	29,26º	53,48º	-	081 056 167	1992-1998 MARKIV 2000-2002 MARK II 2003 - today Mark III

1.2 Profile measurements of ozone and other gases/variables relevant to ozone loss:

The ozonesondes began to be launched in 1995 at INPE / CRN. In 2001, with the construction of the laboratory in Barra de Maxaranguape / RN, the launches were relocated to there due to the urban growth of Natal and the need to obtain samples of unpolluted air. In September 2013, the balloons were launched again at INPE / CRN The profile ozone concentrations measured by the ECC sounding technique on balloons is made by the participation in the SHADOZ Project (The Southern Hemisphere Additional Ozonesonde Network - http://croc.gsfc.nasa.gov/shadoz).

1.3 UV measurements:

The UV is monitored by INPE in São José dos Campos, Cachoeira Paulista, Cuiabá, Santa Maria, Natal, Angicos, Caicó and Currais Novos. The UV measurements in Rio Grande do Norte are made by Davis meteorological stations located in the followed sites: Natal (since 01/25/2016), Angicos (since 02/14/2015), Caicó (since 02/06/2014) and Currais Novos (12/09/2016).

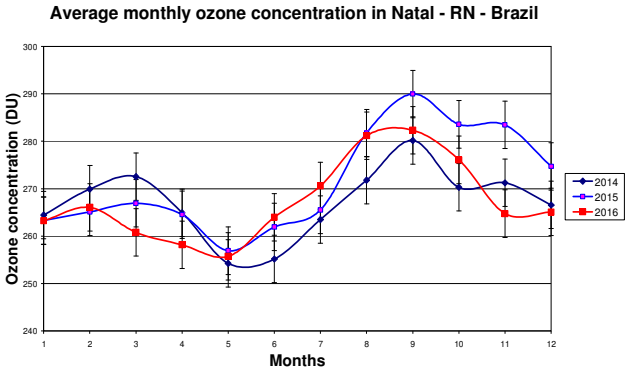
1.4 Calibration activities:

Five Brewer spectrophotometers were calibrated by International Ozone Services Inc. (IOS) in 2004, 2007 and 2009. INPE participated in the international calibration in 1994, in Spain, where the Natal Dobson (093) was shipped with our expert. In 1997, the expert Bob Evans, from NOAA, checked the Natal Dobson, on a visit to Natal, but did no adjustments in the instrument. Buenos Aires WMO Intercomparison was made in 2001, 2003, 2006 and 2010 with the participation of our two Dobson instruments.
Three GUV was calibrated in 2001, in São José dos Campos, Brazil, using standard instrument of Biospherical Instruments Inc. The GUV 9285 is operating in Natal, the GUV 9255, in Cachoeira Paulista and the GUV 9285, in Brazilian Antarctic Station. Nowadays, only one GUV is operational in São José dos Campos.

2- RESULTS FROM OBSERVATIONS AND ANALYSIS

2.1 Dobson spectrophotometers

Ground based ozone total column has been measured continuously at low latitude sites, using Dobson spectrophotometer at Natal (6º S, 35º W) and Cachoeira Paulista (23º S, 38º W). The ozone data from 2014 to 2016 for the two Dobson spectrophotometers are presented in the Figure 1.
In Natal, the total ozone column varies between 255 and 290 DU and shows seazonal variability, with two maximum in the equinox. In Cachoeira Paulista the total ozone Concentrations varies from 250 and 295 DU with one maximum in spring.



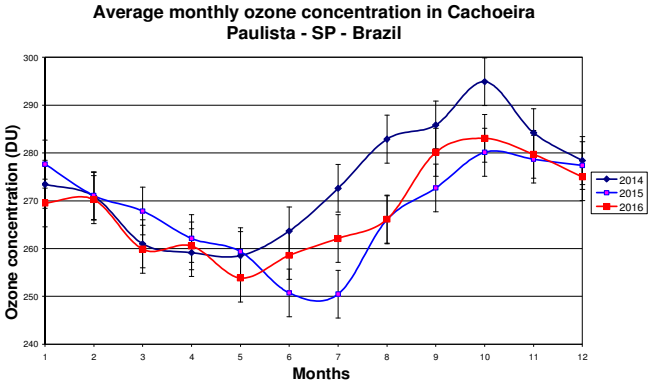


Figure 1: Average monthly ozone concentration in Natal and Cachoeira Paulista, Brazil.

2.2 Brewer spectrophotometer

The Brewers operating in Brazil need calibration.

2.3 Ozonesonde

From 1978 to 2002, weekly ozonesondes were launched in Natal, Rio Grande do Norte, Brazil and, from 2002 to 2015, in Maxaranguape, a city near Natal. In 07/23/2015 the laboratory in Maxaranguape was closed and the launches returned to Natal. The last launching was in 11/08/2016. The new ozonesondes are expected to arrive in one or two months in Natal.

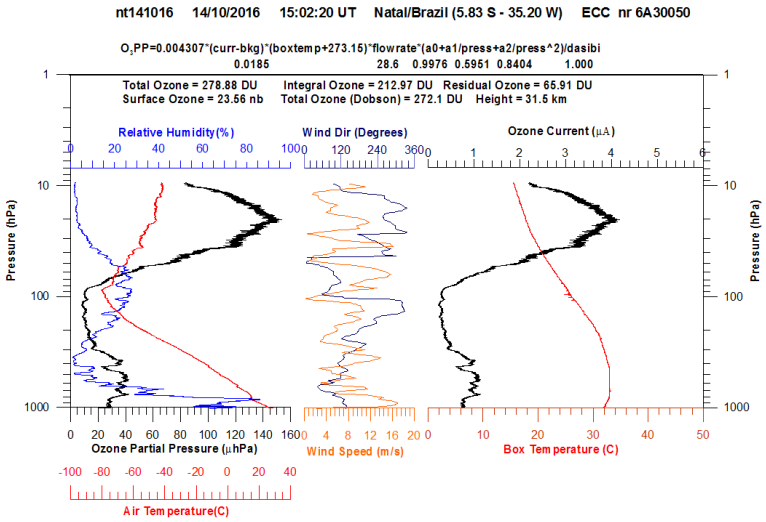


Figure 2: The ozone concentration profile measured in Natal with the ozonesonde, for 10/14/2016.

2.4 GHG monitoring

The CO_2 concentration in Natal shows a good agreement with the global average increasing.

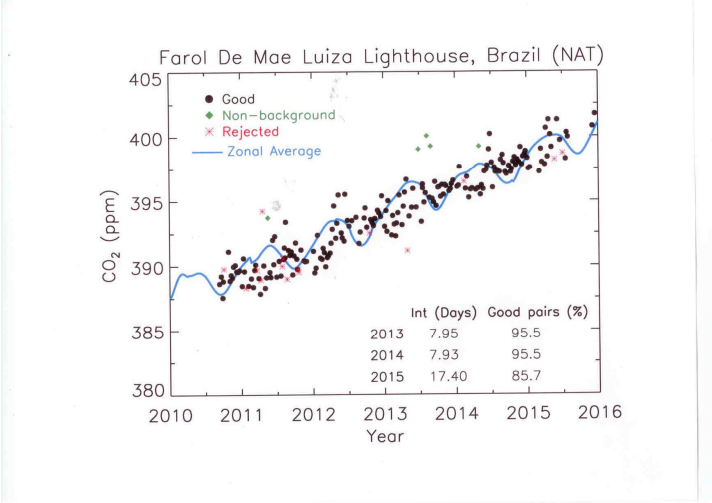


Figure 3: The CO_2 concentration measured in Natal from 2010 to 2016 (NOAA, 2016).

2.5 UV monitoring

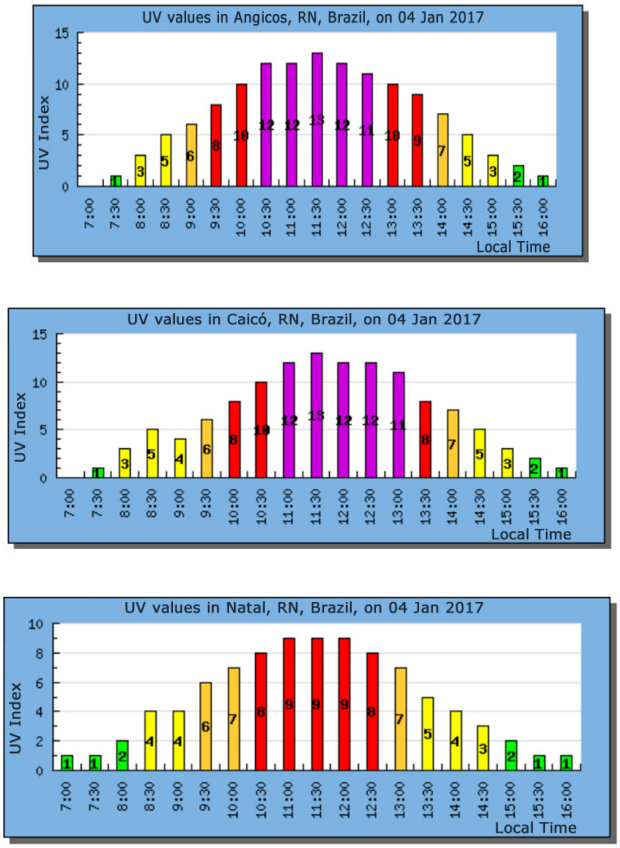


Figure 4:The UV index for Angicos, Caicó and Natal for 01/04/2017.

The figure 5 shows the diurnal UV variation measured in Natal by Brewer spectrophotometer.

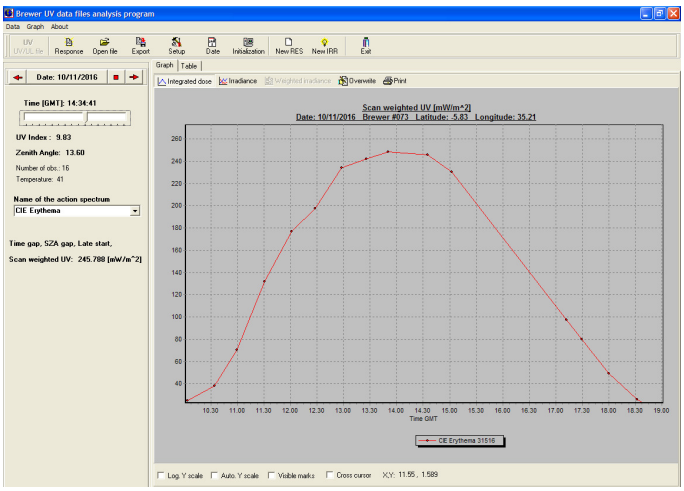


Figure 5: Diurnal UV variation measured in Natal with the Brewer, for 10/11/2016.

3- THEORY, MODELLING AND OTHER OZONE RELATED RESEARCH

The forecast of Ozone Layer Concentration and UV radiation can be obtained from INPE/CPTEC site (http://satelite.cptec.inpe.br/uv), which used satellite data NOAA 16, sensor SBUV/2.

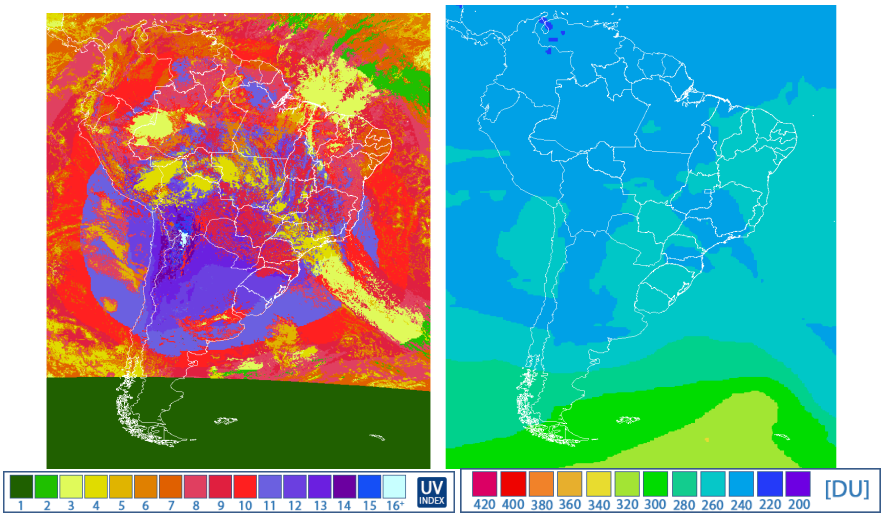


Figure 6. Example of UV index and Ozone forecast by INPE/CPTEC for 01/19/2017.

4- DISSEMINATION OF RESULTS

4.1 Data reporting

The Brewer data have been submitted to WOUDC since 2004 and Dobson data since 1978.

4.2 Information to the public

The Ozone e UV monitoring and forecasts are in web sites: **www.crn2.inpe.br/lavat** and **http://satelite.cptec.inpe.br/uv.**

4.3 Relevant scientific papers

Jaime Rodrigues Coariti, Solar Ultraviolet Radiation and human health in the cities of La Paz - Bolivia and Natal – Brazil. PhD thesis at Universidade Federal do Rio Grande do Norte and CRN/INPE, Natal, 2017.

Lucas Vaz Peres, Hassan Bencherif, Nkanyiso Mbatha, André Passaglia Schuch, Abdoulwahab Mohamed Toihir, Nelson Bègue, Thierry Portafaix, Vagner Anabor, Damaris Kirsch Pinheiro, Neusa Maria Paes Leme, José Valentin Bageston and Nelson Jorge Schuch. Ann. Geophys., 35, 25–37, 2017.

Paes Leme, Neusa M., Silva, Francisco R., Penha, Tércio L.B., Rodrigues, Nilson L., Silva, Edmilson L, Rae, Cristina T. S., Aleixo, Tiago,Total ozone trends in the tropics 1974-2013**,** IGAC 2014.

5- PROJECTS, COLLABORATIONS, TWINNING AND CAPACITY BUILDING

INPE / NOAA project with air sample collection in order to measure gases: CO_2, CH_4, H_2, CO, N_2O and SF_6 (May / 2010 in Maxaranguape - RN and November / 2015 in the Lighthouse of Mãe Luiza - Natal- RN).

INPE/NASA Southern Hemisphere Additional Ozonesondes Project (SHADOZ), PI Anne M. Thompson.

6- IMPLEMENTATION OF THE RECOMMENDATIONS OF THE 9TH ORM

The observations of ozone and climate variables were maintained. The scientific expertise are expanded by PhD thesis and master degree students. The linkage between climate changes and ozone depletion is part of the main researches in Brazil.

7- FUTURE PLANS

The current monitoring networks should be maintained operational. However, there is no special plan or project for building new capacities to conduct ozone or UV radiation. Projects focusing on climate change may include instruments installation and research related to ozone and UV.

8- NEEDS AND RECOMMENDATIONS

It is very important the support for the annual calibrations and maintenance of the Brewer. The last calibration of the Brazilian Brewers was in 2009. All instruments need calibrations as soon as possible. Financial support for trips techniques and participation in Ozone and UV Meetings, Congresses and Symposium are also needed.

9- REFERENCES

NOAA Earth System Research Laboratory, Global Monitoring Division, Issue 9: October 2016.

Thompson, A. M., et al. (2012), Southern Hemisphere Additional Ozonesondes (SHADOZ) ozone climatology (2005–2009): Tropospheric and tropical tropopause layer (TTL) profiles with comparisons to OMI-based ozone products, J. Geophys. Res., 117, D23301, doi:10.1029/2011JD01691.

WMO (World Meteorological Organization), Assessment for Decision-Makers: Scientific Assessment of Ozone Depletion: 2014, 88 pp., Global Ozone Research and Monitoring Project—Report No. 56, Geneva, Switzerland, 2014.

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BURKINA FASO

1. OBSERVATIONAL ACTIVITIES

1.1 Column measurements of ozone and other gases/variables relevant to ozone loss.

Observation of ozone layer by Satellite (Meteosat 8)

1.2 Profile measurements of ozone and other gases/variables relevant to ozone loss

Observation of ozone layer by Satellite (Meteosat 8) no other gases were measured

1.3 UV measurements

No UV measurement was done

1.4 Calibration activities

Calibration concern only Basic sensors (Temperature, humidity, Rain, Wind speed and Direction, Pressure)

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

No result concerning UV radiation

3. THEORY, MODELLING, AND OTHER OZONE RELATED RESEARCH

(e.g., 3-D CTM modelling, data assimilation, use of satellite data, UV effect studies)

Using WRF for Modelling. But only weather data are concerned (Temperature, rain, humidity, pressure, wind). Due to lack of ozone data collection to validate the model, WRF-Chem is not yet run.

4. DISSEMINATION OF RESULTS

4.1 Data reporting

(e.g., submission of data to the WOUDC and other data centres)

No Data reporting yet

4.2 Information to the public

(e.g., UV forecasts)

Public receive information about:

- Traditional weather forecast which includes temperature (mean, minimum and maximum), rainfall (only during rainy season), humidity, potential evapotranspiration and wind.
- Dust suspension provided though visibility estimate.
- Fumes from vehicles
- Bio-meteorological information related to health (meningitis-related and malaria related meteorological parameters)

4.3 Relevant scientific papers

No scientific Paper yet

5. PROJECTS, COLLABORATION, TWINNING AND CAPACITY BUILDING

(e.g., national projects, international projects, other collaboration (nationally, internationally))

All projects and collaboration concern:

- Agro meteorological sector
- Climate change
- Health sector

6. IMPLEMENTATION OF THE RECOMMENDATIONS OF THE 9th OZONE RESEARCH MANAGERS MEETING

We didn't participate to the 9th Ozone research Managers meeting

7. FUTURE PLANS

With the support of the WMO and the Ozone Secretariat, we aimed to received a deployment of an instrument, such as Dobson, for Ozone and UV measurement.

8. NEEDS AND RECOMMENDATIONS

Need more cooperation and training to implement Ozone monitoring in Burkina Faso.
Need equipment and training for measurement and ozone forecasting, and UV.

CABO VERDE

Ozone Monitoring and others Gas in Cabo Verde

The Cape Verde Atmospheric Observatory (CVAO) is part of a bilateral German-UK initiative to undertake long-term ground- and ocean-based observations in the tropical Eastern North Atlantic Ocean region. It links with the international programme SOLAS, the EU-funded TENATSO (Tropical Eastern North Atlantic Time-Series Observatory) project, and with the German SOPRAN (Surface Ocean Processes in the Anthropocene) project.

The CVAO (16° 51' 49 N, 24° 52' 02 W), exists to advance understanding of climatically-significant interactions between the atmosphere and ocean and to provide a regional focal point and long-term data context for field campaigns. Measurements of O3, CO, NO, NO2, NOy and VOCs began at the site in October 2006. Chemical characterisation of aerosol measurements and flask sampling of greenhouse gases began in November 2006, halocarbon measurements in May 2007, and physical measurements of aerosol in June 2008. On-line measurements of greenhouse gases began in October 2008.

But the most important is to stop the liberation of ODS (Ozone Depletion Substances) and the GHG (Green House Gases), through activities that are sustainable and not harmful to the environment. Cabo Verde acceded to the Montreal Protocol and Vienna Convention through Decree No. 5/97 and 6/97 on March 31st, 1997, becoming a Party.

The ODS (CFC 11, CFC 12) were banned in 2010, but the GHG emissions continue happening, in urban areas.

We have an inventory of ODS in Cape Verde and alternatives from years 2012 to 2015.

According to the Third National GHG Communication, the estimated emission of ODS (R134a) is 0.6 t CO2 eq, for the reference year 2005, and 1,9 t CO2 eq, for the reference year 2010.

1. OBSERVATIONAL ACTIVITIES

1.1 Column measurements of ozone and other gases/variables relevant to ozone loss.

Measures of Ozone Tropospheric at sea level are made. We do not use satellites, nor do we make observations of stratospheric ozone, ie the ozone layer. For measurements, we use the Ozone Analyzer, Model 49i from manufacturer THERMO Electron Corporation

1.2 Profile measurements of ozone and other gases/variables relevant to ozone loss

Observation of ozone layer and CO with Ozone Analyzer, Model 49i from manufacturer THERMO Electron Corporation

1.3 UV measurements

No UV measurement was done

1.4 Calibration activities

Calibration concern only Basic sensors (Temperature, humidity, Rain, Wind speed and Direction, Pressure)

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

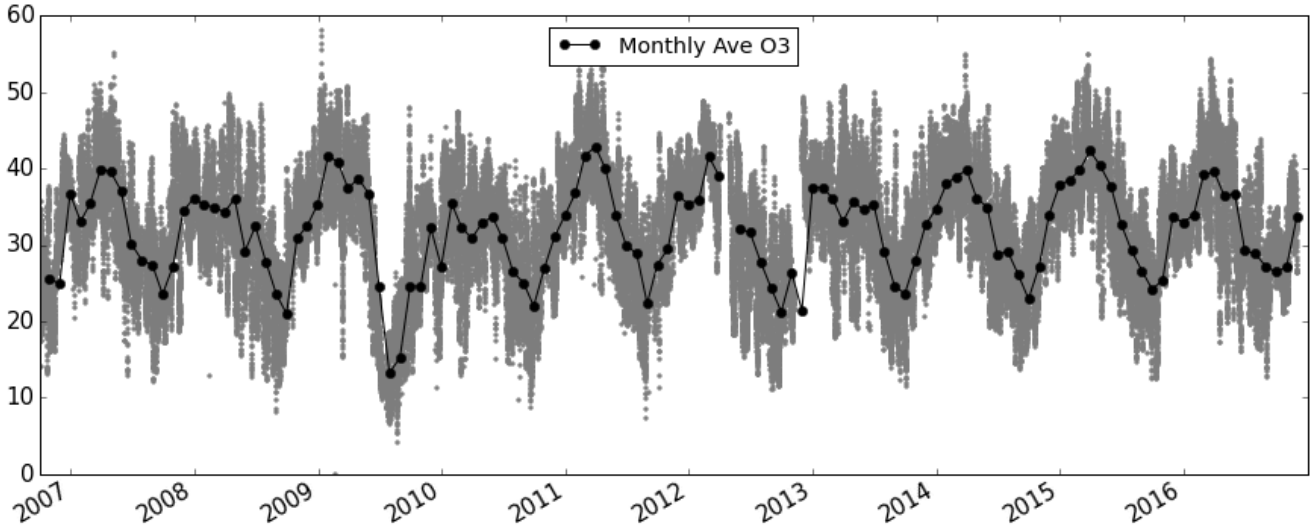
2.1 UV Monitoring

No result concerning UV radiation

2.2 Ozone and CO Monitoring

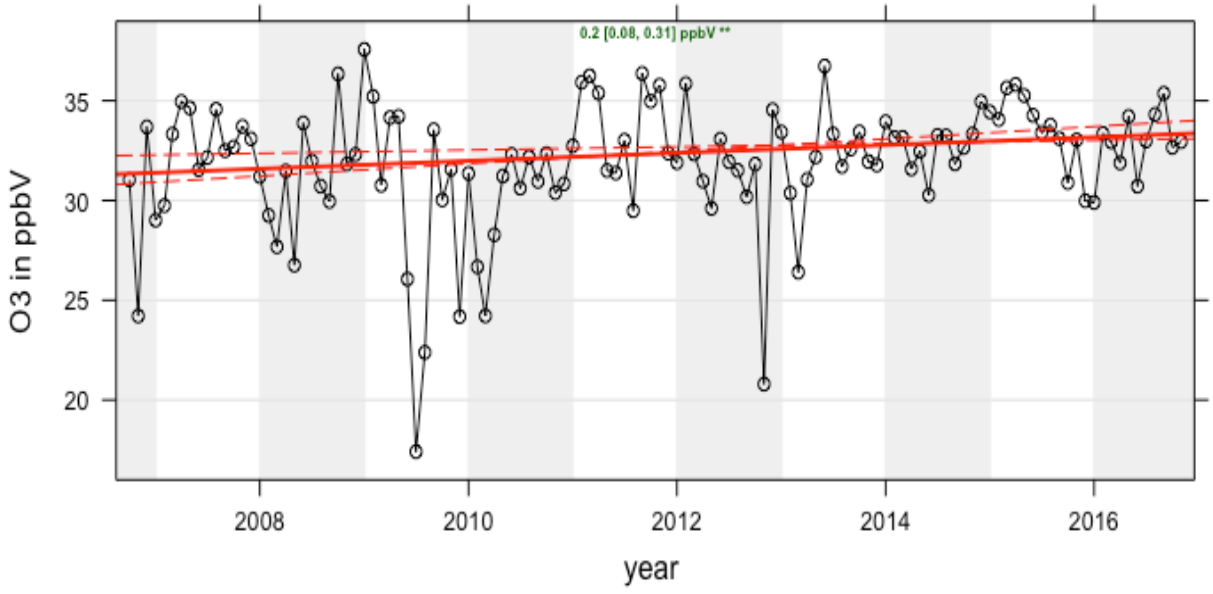
Note that the Observatory is located on the coast, and the measured gases come from the open ocean (NE), with no local contribution, so the concentrations are different from those that would be measured in urban centers.

Ozone time-series

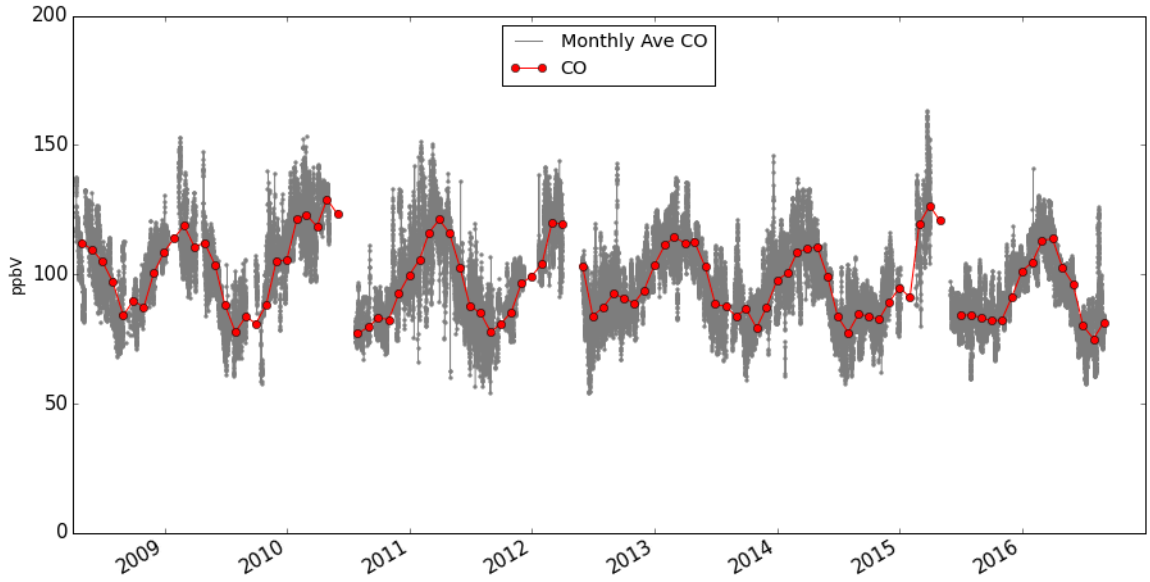


O_3 deseasonalised trend

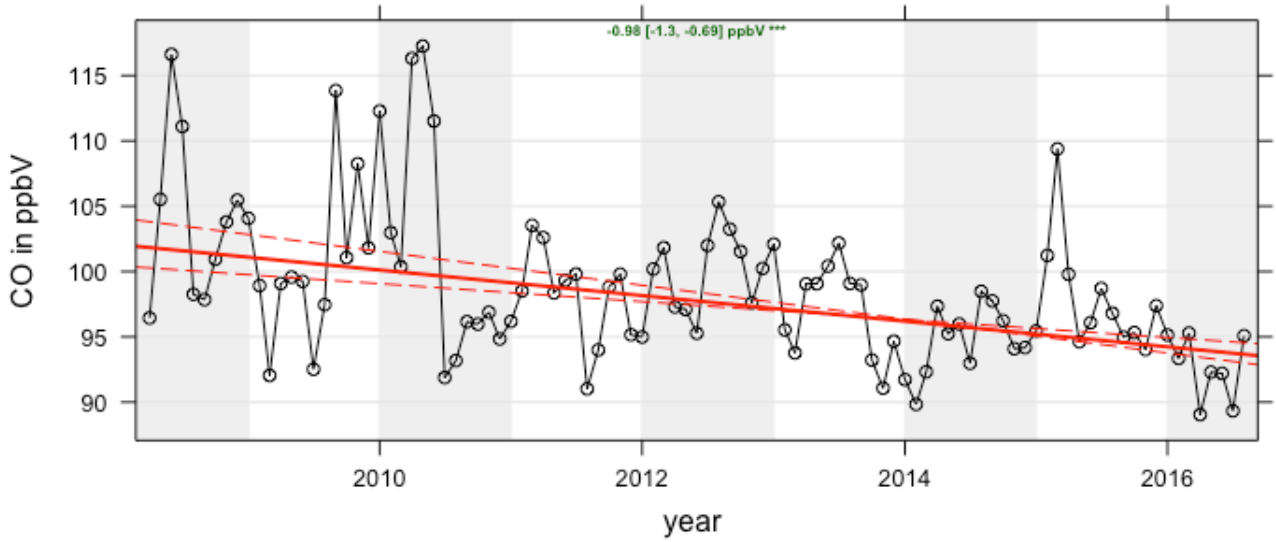
Increase in ozone concentrations of 0.2 ppbV/year.



Carbon Monoxide time-series



CO deseasonalised trend
Decrease in carbon monoxide of 0.98 ppbV/year



3. THEORY, MODELLING, AND OTHER OZONE RELATED RESEARCH

(e.g., 3-D CTM modelling, data assimilation, use of satellite data, UV effect studies)

We use the "Model 49i UV Photometric Ozone Analyzer"

4. DISSEMINATION OF RESULTS

4.1 Data reporting

(e.g., submission of data to the WOUDC and other data centres)

- We make the data report through World Data Centre for Reactive Gases (WDCRG),

- WMO-GAW e British Atmospheric Data Centre (BADC)

4.2 Information to the public
(e.g., UV forecasts)

Public receive information about:

- Traditional weather forecast which includes temperature (mean, minimum and maximum), rainfall (only during rainy season), humidity, data on the sea (size of waves) and wind.
- weather data is disseminated to the public through print and electronic media and Radio.
- Dust suspension provided though visibility estimate.
- UV forecasts are not done and therefore not disseminated to the public.

4.3 Relevant scientific papers
In fact, many publications have been made during these 10 Years of observation, including one on Ozone in NATURE magazine.

Link - http://www.nature.com/nature/journal/v453/n7199/abs/nature07035.html

5. PROJECTS, COLLABORATION, TWINNING AND CAPACITY BUILDING
(e.g., national projects, international projects, other collaboration (nationally, internationally))

All projects and collaboration concern:
- Meteorological sector
- Climate change
- National Adaptation Programme of Action on Climate Change (NAPA)
- Health sector

6. IMPLEMENTATION OF THE RECOMMENDATIONS OF THE 9th OZONE RESEARCH MANAGERS MEETING

We didn't participate to the 9th Ozone research Managers meeting

7. FUTURE PLANS
With the support of the WMO and the Ozone Secretariat, we aimed to received a deployment of an instrument, such as Dobson, for Ozone and UV measurement.

8. NEEDS AND RECOMMENDATIONS
Need more cooperation and training to implement Ozone monitoring in Cabo Verde.
Need equipment and training for measurement and ozone forecasting, and UV.

Financial support for trips techniques and participation in Ozone and UV Meetings, Congresses and Symposium are also needed.

Eng.º Adilson Fragoso
Eng.º Luis Neves

NATIONAL DIRECTION OF THE ENVIRONMENT – DNE
NATIONAL INSTITUTE OF METEOROLOGY AND GEOPHYSICS - INMG
NATIONAL CENTRE FOR ATMOSPHERIC SCIENCE (NCAS), UNIVERSITY OF YORK, UK

CANADA

1. OBSERVATIONAL ACTIVITIES

1.1 Column measurements of ozone

Both the Canadian Brewer Spectrophotometer Network and the Canadian Ozonesonde Network are operational with no major changes to the two programs.

The Canadian Brewer Spectrophotometer Network consists of eight main observing sites, monitoring total column ozone and spectral ultraviolet radiation (UV). Each of the network's mid-latitude stations (Saturna Island, British Columbia; Stony Plain, Alberta; Churchill, Manitoba; Toronto, Ontario; and Goose Bay, Newfoundland and Labrador) operate two Brewer spectrophotometers, and each Arctic station (Resolute, Eureka and Alert in Nunavut) have three instruments on-site. The additional instruments provide redundancy; minimize operational downtime, and thus, reduce likelihood of long gaps in the data due to logistical difficulties (transportation of goods, and technician travel time for repairs) associated with monitoring in the Canadian Arctic. They also provide means of optimizing the observations of both column ozone and UV spectral irradiance; and are for quality assurance purposes. Since the 1990s, Environment and Climate Change Canada has been replacing the single monochromator spectrophotometers with double monochromator instruments through network lifecycle management. Currently, one double monochromator Brewer spectrophotometer is operating per station. The advantage of using double monochromator Brewers is the expansion of the daily hours of data collection by also including low sun conditions, particularly important for the winter, spring and autumn observations from the Canadian Arctic. All Canadian stations have been visited for service, upgrade and calibration in the 2014-2017 time period, meeting a two-year cycle maintenance target. Two new double Mark III Brewers were acquired in 2017 as part of the formal lifecycle management program, and their performance is currently under evaluation.

Canada, in collaboration with the U.S. National Oceanic and Atmospheric Administration (NOAA), maintains two Brewer spectrophotometers (one single and one double) at the Mauna Loa Observatory in Hawaii and one instrument at South Pole station in the Antarctic. Data from the South Pole Brewer are submitted to the WMO and are used in the WMO Antarctic Ozone Bulletins. There is a continuous record for the South Pole station since 2008. In 2015, the Brewer instrument at the station was replaced with a newly calibrated one. Other Brewers have been operated by Canadian universities for research purposes in collaboration with Environment and Climate Change Canada, for which data were not reported on a regular basis.

Total column ozone and UV data are made available through the World Meteorological Organization (WMO) World Ozone and Ultraviolet Radiation Data Centre (WOUDC).

Since 2013, Environment and Climate Change Canada has acquired six Pandora spectral sunphotometers. The instrument not only measures nitrogen dioxide (NO_2) and sulphur dioxide (SO_2), but also is capable of producing high quality total column ozone data. A Pandora

instrument was compared with the Brewer Triads (single and double monochromator instruments) to assess its suitability for long-term ozone monitoring (Zhao et al. 2016).

1.2 Profile measurements of ozone

Environment and Climate Change Canada launches ozonesondes at eight locations across Canada (Kelowna, British Columbia; Stony Plain, Alberta; Churchill, Manitoba; Goose Bay, Newfoundland and Labrador; Yarmouth, Nova Scotia; and Resolute, Eureka and Alert in Nunavut) on a weekly basis using electrochemical concentration cell ozonesondes. A limited number of higher frequency launches were carried out during Match campaigns (in collaboration with the Alfred Wagner Institute in Bremerhaven, Germany) and Atmospheric Chemistry Experiment (ACE) validation campaigns.

Ozonesonde data are archived in the WMO WOUDC.

1.3 UV measurements

1.3.1 Broadband measurements and narrowband filter instruments

Currently, broadband observations are not made by Environment and Climate Change Canada; however, commercial forecasting companies have developed their own broadband UV network for observing erythemal-weighted UV at major Canadian cities. Also, the United States Department of Agriculture (USDA)'s UV-B Monitoring and Research Program (UVMRP) is co-located with the Canadian Brewer spectrophotometers at the monitoring site in Toronto. As part of their measurement program, the UVMRP obtains erythemal-weighted UV-B irradiance using a Yankee Environmental Systems UVB-1 pyranometer. Further information on UVMRP can be found at: http://uvb.nrel.colostate.edu/UVB/index.jsf.

In summer 2015, Environment and Climate Change Canada conducted a project associated with the 2015 Toronto Pan American and Para-Pan American Games. As part of this project, four Kipp and Zonen broadband instruments that measure erythemal UV provided diurnal monitoring during the Games in addition to the measurements from the Brewer instruments in Toronto.

1.3.2 Spectroradiometers

Observations of spectral UV-irradiance are made using Brewer spectrophotometers. Approximately five UV spectra are obtained each hour. All eight Brewer sites are equipped with double Brewer spectrophotometers that measure UV in the 286-363 nm spectral range (the older Mark II Brewer instruments take measurements in the 290-325 nm range). Collected data are used for UV index forecast validation purposes.

1.4 Calibration activities

The Triad of absolutely calibrated double monochromator Brewer instruments (#145, #187 and #191) was established in addition to the existing Triad of single monochromator Brewer spectrophotometers (#008, #014 and #015). As part of the Brewer World Calibration Centre (WCC) activities, three Brewer Triad instruments (#008, #145 and #187) were absolutely calibrated at Mauna Loa Observatory in October 2015. The next calibration of Triad instruments at the Mauna Loa Observatory will be carried out in August 2017.

Following the WMO Ozone SAG recommendation, Toronto Brewer #145 was sent to Izana, Spain to compare the Triad of the Brewer World Calibration Centre (WCC) situated in Toronto with the Triad of the Regional Brewer Calibration Center for Europe (RBCC-E) in Spain in March 2014. The intercomparison between the reference instruments of the two calibration centres was completed by the end of May 2014.

Environment and Climate Change Canada's Brewer #017 is recognized by WMO as the global traveling standard instrument. It has been used for more than 30 years and is directly linked to the global stratospheric monitoring program coordinated by WMO. Ozone calibrations have been transferred from the WCC Triad in Toronto to instruments in various countries with the travelling standard instrument. Also, calibration of the RBCC-E Triad to the WCC Triad has been established by yearly comparison with the travelling standard Brewer #017.

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

2.1 Ozonesonde records re-evaluation

The Canadian ozonesonde record was re-evaluated for measurements of the vertical distribution of ozone over Canada from 1966 to 2013, and the results was published in 2016 (Tarasick et al. 2016). The re-evaluation corrected a number of minor systematic errors, resulting in reduced scatter and drift in the comparison with total ozone measurements. A new error analysis finds that Canadian ozonesondes are now close to 5% overall error.

2.2 Pandora spectrometers and Brewer Triad

Environment and Climate Change Canada is testing and evaluating a new instrumentation, the Pandora spectrometer. The instrument measures the ultraviolet-visible solar spectra used to retrieve total columns of atmospheric trace gases. From the spectral measurements, total column of NO_2, SO_2, ozone and other species can be obtained. The measurement modes are Direct Sun, sky (scattered) light, and Direct Moon. It is designed for satellite validation and pollution monitoring. Since 2013, two Pandora instruments are deployed at monitoring sites, one in Toronto and the other in Fort McKay within the oil sands region. There are plans to deploy more instruments across Canada.

The performance of the Pandora spectrometer was evaluated for total ozone column from a comparison with the Brewer Triads in Toronto. The goal was to evaluate the instrument for its suitability for long-term monitoring of total ozone column. The results show the Pandora instrument's accuracy and precision of total ozone column measurements are comparable with those for the Brewer Triad in Toronto (Zhao et al. 2016). Its precision is similar or even better than that for the Brewer instrument; however, there is a large dependence on stratospheric temperature for which has to be accounted.

2.3 Satellites (space-based monitoring and research)

The OSIRIS (Optical Spectrograph and Infrared Imager System), a Canadian instrument on Odin satellite since 2001, measures spectra of limb scattered sunlight from the ultraviolet to the

near-infrared that are primarily used to retrieve ozone, NO_2 and aerosol extinction. The instrument has 2-km vertical resolution and good accuracy and long-term stability with respect to altitude registration. The instrument continues to operate in 2017.

Launched in August 2003 for a two-year mission, the SCISAT/ACE (Atmospheric Chemistry Experiment) satellite continues to perform very well. The instruments and satellites are functioning nominally with only minor degradation in performance, which will not limit continued operations. There are two instruments: the infrared ACE- Fourier Transform Spectrometer (FTS) produces profiles of nearly 60 different species and isotopologues, and the MAESTRO focuses in visible-near infrared for ozone, NO_2 and water vapour. The SCISAT/ACE is in a highly-inclined orbit that was chosen as the initial focus of the mission was on polar ozone chemistry. This mission has expanded and currently SCISAT/ACE contributes to studies related to ozone recovery and chemistry, climate science and air pollutants. The broad range of species from the ACE-FTS allows a more complete picture of ozone loss, and provides attribution of changes with measurements of a wide range of chlorine species (sources, breakdown products and reservoirs). The vertical resolution of ACE-FTS is approximately 3 km (from field-of-view), and of MAESTRO is about 1.5 km. One example of results is from recent validation comparisons for ozone (and other species), which show excellent performance of ACE-FTS compared to MLS on the National Aeronautics and Space Administration (NASA)'s Aura satellite and MIPAS on European Space Agency (ESA)'s Envisat satellite.

The on-going validation of ozone profiles from the ACE-FTS and OSIRIS satellite instruments is being performed using measurements from PEARL.

Environment and Climate Change Canada is making use of SCISAT/ACE measurements to assess the quality of stratospheric ozone model predictions, which is a central component of the next version of Canada's UV forecasting system.

2.4 Polar Environment Atmospheric Research Laboratory (PEARL)

The Polar Environment Atmospheric Research Laboratory (PEARL) is a Canadian Network for the Detection of Atmospheric Change (CANDAC) facility for atmospheric research in the Arctic. It began measurements in 2005-2006 and continues to carry out research on large range of atmospheric constituents including the partial and total column measurements of trace gases. The PEARL instrument suite is being used to examine trends in halogen containing species and other atmospheric constituents / parameters that control the ozone budget. These measurements are being used to quantify the contributions from dynamics, chemistry, and climate change to stratospheric ozone depletion and recovery, and to study the tropospheric ozone budget. PEARL-based observations have been used to validate SCISAT/ACE and Odin/OSIRIS data. Over the past few years, the Ozone Differential Adsorption Lidar (DIAL) at PEARL was refurbished, and made measurements in winter/spring 2017 as part of the Canadian Arctic ACE/OSIRIS Validation Campaign. Other instrumentation includes UV-visible and Fourier transform infrared (FTIR) spectrometers that measure ozone and related species (e.g., hydrochloric acid, hydrofluoric acid, chlorofluorocarbons, bromine oxide). The UV-VIS and FTIR data are contributed to the Network for the Detection of Atmospheric Composition Change (NDACC – see ftp://ftp.cpc.ncep.noaa.gov/ndacc/station/eureka/hdf/ftir/ and ftp://ftp.cpc.ncep.noaa.gov/ndacc/station/eureka/ames/uvvis/). Bromine explosions and tropospheric ozone depletion events are regularly observed at PEARL in the springtime, most

recently in March 2017 (K. Walker and K .Strong, private communication 2017). A combination of surface ozone analyzer and UV-spectrometer data is being used to characterize this event as well as using ozonesondes and complementary measurements by other instruments. PEARL data are being utilized for validation, scientific studies, instrument development and demonstration. PEARL is a very well used and equipped facility, and will be part of the validation program for the upcoming TROPOMI (TROPOspheric Monitoring Instrument) mission on ESA's Sentinel-5 Precursor.

2.5 The University of Toronto Atmospheric Observatory (TAO)

The University of Toronto Atmospheric Observatory (TAO) houses a Bomem DA8 high-resolution Fourier transform infrared spectrometer that has been operational since 2002. This instrument acquires solar infrared absorption spectra for long-term measurements of stratospheric and tropospheric trace gases. The TAO FTIR is an NDACC instrument and regularly measures ozone (see ftp://ftp.cpc.ncep.noaa.gov/ndacc/station/toronto/hdf/ftir/). TAO data have contributed to validation of ACE-FTS, SCIAMACHY, and OSIRIS, the first detection of NO in the mesosphere and lower thermosphere using ground-based FTIR spectroscopy, and studies of chlorine trends, polar intrusions, and tropospheric transport of pollutants over Toronto. TAO will be part of the validation program for TROPOMI.

3. THEORY, MODELLING, AND OTHER OZONE RELATED RESEARCH

3.1 Stratospheric ozone related modelling

The Canadian Middle Atmosphere Model (CMAM) is a chemistry-climate model that has been developed jointly by Environment and Climate Change Canada and university-based collaborators over almost two decades. The latest version of CMAM, with an improved representation of tropospheric chemistry, will be used to provide simulations requested for the Chemistry Climate Model Initiative (CCMI), which is providing new CCM simulations for the 2018 Scientific Assessment of Ozone Depletion.

3.2 Chemical data assimilation

Chemical data assimilation consists of improving chemical model forecasts by incorporation of information from constituent observations, including ozone measurements. Global stratospheric and column ozone data assimilation is being conducted at Environment and Climate Change Canada as a means to investigate different aspects for improving or inquiring insight in chemical data assimilation, to investigate feedback effects on weather, and to providing lateral boundary conditions for regional chemical data assimilation and improving ultraviolet (UV) index forecasts. Some of these activities involve international collaborations such as undergoing activities with the Belgium Institute for Space Aeronomy (BIRA). With the assimilation system, stratospheric ozone forecasts are generated from the LINearized stratospheric OZone chemistry model (LINOZ) of McLinden et al. (2000) which has been incorporated in the Global Environmental Multiscale (GEM) weather prediction model. These efforts are contributing to the development of a comprehensive system for assimilating air quality measurements (including stratospheric ozone) into Environment and Climate Change Canada's air quality model prediction systems

3.3 New UV index prediction project

The original UV index forecast was developed 25 years ago by scientists at Environment and Climate Change Canada. It is being updated. The new UV index forecasts make direct use of:

- Ozone model forecasts at Numerical Weather Prediction (NWP) resolution.
- Satellite measurements of ozone through data assimilation.
- Solar UV fluxes at the surface provided by the Environment and Climate Change Canada's Global Environmental Multiscale (GEM) model to calculate clear-sky and all-sky UV indices.

There will allow for new products such as daytime variation (e.g., hourly); longer forecasts (e.g., four days or more); and global, continental and regional maps. This new UV index forecasting system is integrated tightly to the current weather forecasting system. Also, the system is to automatically take advantage of improvements in global and regional cloud/precipitation forecasts using GEM irradiances. The goal is for operational implementation of the new UV index forecasting system in 2018-19.

As part of a new UV index forecasting and interactive ozone-radiation project, a multi-sensor ozone assimilation project with total column bias correction was undertaken. The assimilated data sets include OMI, GOME2 of MetOp A&B, and OMPS-NM total column ozone retrieved from the TOMS algorithm and OMPS-NP and SBUV/2 partial column profiles. The selected standard is the OMI with validation using Brewer data. The project will be completed in 2017.

The Toronto 2015 Pan American and Para-Pan American Games were used to demonstrate the new UV Index forecast. New Kipp and Zonen UV sensors were installed at four locations across the Games footprint in southern Ontario's Greater Golden Horseshoe Area. They are in addition to the Brewer instruments in Toronto. UV index model forecasts provided 4-day hourly forecast maps updated twice a day. The evaluation study of UV index forecasts is expected to be completed in 2017.

4. DISSEMINATION OF RESULTS

4.1 Data reporting

Brewer ozone and UV data are available in near real-time, and used for various applications. They are produced as hourly bulletins for UV index forecasts, and used for satellite data validation. Brewer data also are used in WMO Arctic and Antarctic Ozone Bulletins, NOAA Arctic Report Cards, the Bulletin American Meteorological (BAMS) State of the Climate reports and other publications.

Total column ozone and ozonesondes data from the Canadian measurement programs are submitted to the WMO WOUDC.

The WOUDC (woudc.org) is operated by the Meteorological Service of Canada at Environment and Climate Change Canada. It has been renewed to create a new foundation to meet growing requirements. The system renewal has been operational since March 2015. The ultimate goal of

the renewal is to enhance the data submission mechanism and infrastructure; to provide effective and efficient data management; to modernize data access mechanisms and improve accessibility and usability of the website. In addition, focus on standards and interoperability has been a key driver of the renewal.

Key enhancements to the WOUDC are as follows:

- Near-real time data (OzoneSonde, TotalOzone) – They are of known quality, but not fully quality-controlled. The paradigm is to 'Release early, release often'.
- Validation services – Format validation and quality assessment tools are available for online use.
- Self-serve metrics/reporting. They are available to the Ozone and UV Scientific Advisory Groups (password protected).
- New dataset – RocketSonde datasets were added in 2016.
- NetCDF data delivery – It is available to address modelling community requirements, thus lowering the barrier to integration/workflows.
- Integrated distributed Data Centre search (NDACC, Eubrewnet) – It is for searching remote data centres directly from WOUDC, and downloading from an authoritative data centre.
- Level 0 data archive
- Standards (ISO, OGC) – Interoperability is a key driver of WMO, Open Data, GEOSS (Global Earth Observation System of Systems) and beyond. Standards lower the barrier and extend the reach and usability of the data for existing and new communities.
- Geospatial capabilities – Online maps and data is now GIS capable.
- WMO alignment (WIS, GAW, WIGOS) – WMO provides a next generation system aligned with key WMO drivers

UV-VIS and FTIR data from PEARL, and FTIR data from TAO are archived on the NDACC database (http://www.ndsc.ncep.noaa.gov/).

4.2 Information to the public

Canada provides daily UV index forecasts through the Meteorological Service of Canada regular weather reports on http://weather.gc.ca/canada_e.html, and daily UV Index Forecast public text bulletins https://weather.gc.ca/forecast/public_bulletins_e.html/. The 1-day forecast, provided when the UV index value is 3 or higher, consists of the midday UV index accounting for average cloud conditions from 10 am to 4 pm over 900 locations in Canada.

Each year, based on springtime ozone levels, a summer seasonal forecast is provided to the public through the Environment and Climate Change Canada website: https://www.ec.gc.ca/uv/default.asp?lang=En&n=396B9A58-1#X-201701131108212. The forecast normally comes out before Canada's Victoria Day long weekend as this is the 'first' long weekend of summer in Canada and many individuals are prone to extended hours outdoors for the first time since winter.

Private sector forecasts of the UV index are also provided by organizations such as the Weather Network:
http://www.theweathernetwork.com/uvreport/canuv_en/?ref=topnav_homepage_uvrepo

4.3 Relevant scientific papers

Environment and Climate Change Canada will contribute to the upcoming 2018 WMO/UNEP Scientific Assessment of Ozone Depletion.

Ozone and UV-related reports are as follows:

- 2014 WMO/UNEP Scientific Assessment of Ozone Depletion
- NOAA Arctic Report Cards
- BAMS State of Climate reports

Scientific publications from 2014-2017 are as follows:

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5. PROJECTS, COLLABORATION, TWINNING AND CAPACITY BUILDING

The following are selected collaborative projects:

- CAFTON - the Canadian FTIR Observing Network, a Canadian Space Agency-funded project http://www.atmosp.physics.utoronto.ca/CAFTON/.

- PAHA (Probing the Atmosphere of the High Arctic) project with three themes, one of which is Composition Measurements (CM), which includes a project on Ozone and Related Species (CM-O3) , which is funded by the National Science Research Council of Canada. http://www.candac.ca/candacweb/content/paha.

- Collaboration in the development of the 4DVar/EnsKF systems at the Belgium Institute for Space Aeronomy (BIRA, Belgium; on-going).

- Contribution to “Study group on the added-value of chemical data assimilation in the stratosphere and upper-troposphere” in collaboration with BIRA and other institutions. This study (2013-2015) was supported by the International Space Science Institute (ISSI), Switzerland, through the International Teams in Space and Earth Sciences program. http://www.issibern.ch/teams/dataassimsphere/.

6. IMPLEMENTATION OF THE RECOMMENDATIONS OF THE 9th OZONE RESEARCH MANAGERS MEETING

Systematic observations are ongoing, especially ground-based sites with long records and in the Arctic region. All Dobson/Brewer and ozonesondes sites open in the 1950s and 1960s are operational. Environment and Climate Change Canada, within its resources, continues to work on improving the measurements of ozone and UV radiation, which includes any technical issues related to instrument performance and analysis of data collected in the Brewer network. The testing and evaluation of the Pandora spectrometer continue for remote sensing of atmospheric composition.

The new UV index forecast system based on ozone data assimilation is being tested and evaluated, with its implementation in the near future. Modelling studies are ongoing to improve our understanding of the relationship between ozone and climate. Although Odin/OSIRIS and SCISAT/ACE are beyond their design life, they continue to operate successfully, and thus, research related to their measurements continue unabated.

In 2015, Canada renewed its commitment to the sponsorship of the WMO Brewer Trust Fund for another five years from April 1, 2015 to March 31, 2020. This fund provides $37,500 CAN per year to support the development of Brewer observations through instrument calibrations and capacity building.

7. FUTURE PLANS

One of the main future applications of Environment and Climate Change Canada's ground-based remote sensing network, which includes ozone monitoring, is validation of satellite measurements of atmospheric composition related to air quality and stratospheric ozone. The satellite validation activities relate to TROPOMI and NASA's TEMPO (Tropospheric Emissions: Monitoring Pollution) mission as follows:

- Validation of NO_2, SO_2, formaldehyde, and perhaps other species using new Pandora instruments, which assures the quality of satellite data over Canada.
- Validation of ozone and UV index products using the Canadian Brewer Spectrophotometer Network as well as Environment and Climate Change Canada's ozone data assimilation output and UV index forecasts.
- Validation of ozone profiles using ozonesonde measurements from Canadian stations to ensure satellite tropospheric ozone measurements are suitable for Environment and Climate Change Canada's Air Quality Health Index (AQHI) applications (assimilation, validation, research, trend studies, etc.)
- Validation of aerosol optical depth (AOD) data products using Canadian AERONET measurements and possibly Environment and Climate Change Canada aerosol data assimilation output from the AQHI forecasting system.

CHILE

INTRODUCTION

Chile is located in Southern South America, from 17°30′ S in the north to 56º30′ S (Cape Horn), bordering the South Pacific Ocean. Chile stretches over 4,300 km (2,700 mi) along the southwestern coast of South America from north to south, Chile extends 4,270 km (2,653 mi), and yet it only averages 177 km (110 mi) east to west.

The most austral region of Chile is the nearest one to the continent Antarctic, therefore that during the activity of the Hole of Ozone Antarctic in every spring season is possible to measure events of depletion of the ozone column in the most austral region of Chile. In this way the activities of observation of ozone column and ultraviolet radiation are of great importance for the international scientific community.

1 ACCOMPLISHMENT OF THE 9TH ORM RECOMMENDATIONS

Many of the recommendations of the 9th meeting for developing countries during the period 2014-2016 have been accomplished or efforts have been made to develop research in stratospheric ozone and ultraviolet radiation. In this sense, the projects should be noted between Chile, Japan and Argentina in Patagonia.

2 OBSERVATIONAL ACTIVITIES

Continuous monitoring of UV radiation in major cities is mainly operated and maintained by the National Meteorological Service of Chile (DMC, Dirección de Meteorología de Chile). Observations of total column ozone from spectroradiometer Brewer are carry out only in one station, in southern Chile (Punta Arenas), operated and maintained by the University of Magallanes (Umag). Ozone profile measurements, two stations are operating: in Isla de Pascua (Eastern Island) since 1995 and in Punta Arenas during 2009-2012 and 2014-now periods were carried out continuous observations with ECC ozonesonde. Two new stations are carry out

observaions of solar spectrum and ozone column, this projects are maintained by the University of Santiago (USACh): Transportable Antarctic Research Platform (TARP-04) became operational in July 2016 on the Chajnantor plateau (located at 5,100 meters above sea level in the Atacama desert, nearby the ALMA Observatory). TARP-04 is a twin unit of TARP-02, deployed early 2015 on King George Island (62° 12' S; 58° 57' W, Antarctic Peninsula). TARP-04 is fitted with state-of-the-art instruments aimed at measurements of the solar spectrum.

The following tables are the detailed measurements activities according with specific variables.

2.1 Ozone Column Measurements

Station	Instruments	Institution	LAT.	LONG.	Period of observations	Calibrations
Punta Arenas	Brewer MKIV 068	University of Magallanes	53°18´S	70°54´W	1992-2000	
Punta Arenas	Brewer MKIII 180	University of Magallanes	53°18´S	70°54´W	2002 – Jun.2006	2003-2004
Punta Arenas	Brewer MKIV 124	University of Magallanes (Chile)- INPE (Brazil)	53°18´S	70°54´W	Aug.2007-Nov.2007	
Punta Arenas	Brewer MKIII 180	University of Magallanes	53°18´S	70°54´W	Nov.2007-today	2007-2009-2015

2.2 Ozone Profile Measurements

Station	Type	Institution	LAT.	LONG.	Period of observations
Punta Arenas	Umkehr	University of Magallanes	53°18´S	70°54´W	2002 – today
Punta Arenas	Ozone sondes -ECC-Z LMG6	University of Magallanes	53°18´S	70°54´W	2009 – today
Eastern Island	Ozone sondes ECC	DMC	27°09´S	109°27´W	1994- today

DMC: Dirección Meteorológica de Chile (National Meteorological Service)

2.3 UV Measurements

Broadband

Station	Instruments	Institution	LAT.	LONG.	Period of observations
Arica	Solar Light 501	University of Atacama	13º 28'S	70º 20'W	1998 - 2005
Santiago	Solar Light 501	University of Santiago	33º26'S	70º40'W	1999 - today

Puerto Natales	Solar Light 501	University of Magallanes	51° 43'S	72° 31'W	1997 - today
Punta Arenas	Solar Light 501	University of Magallanes	53°18´S	70°54´W	1997 - today
Puerto Porvenir	Solar Light 501	University of Magallanes	53° 17'S	70°22'W	1997- 2002
Puerto Williams	Solar Light 501	University of Magallanes	54° 55'S	67° 37'W	1997 - 2010
Bernardo O´Higgins Station (Antarctic)	Solar Light 501	University of Magallanes	63°19´S	56°54'W	2007 - 2014

DMC UV Network

STATION	TYPE	LAT	LONG	ELEV	PERIOD OF OBSERVATIONS
Arica	Pyranometer YES UV–B	18º 28' S	70º 19' W	23m	2006 – today
Iquique	Pyranometer YES UV–B	20º 33' S	70º 07' W	60m	1998 – today
María Elena	Pyranometer YES UV–B	22º 21' S	69º 40' W	1241m	2008 – 2010
San Pedro de Atacama	Pyranometer YES UV–B	22º 55' S	68º 12' W	2450m	2007 – today
Antofagasta	Pyranometer YES UV–B	23º 27'S	70º 26' W	145m	2006 – today
Isla de Pascua	Biometer Solar Light	27º 09' S	109° 26' W	47m	2009 – today
Desierto de Atacama	Pyranometer YES UV–B	27° 15' S	70° 46' W	204 m	Dec.2011- today
La Serena	Pyranometer YES UV–B	29º 54' S	71º 12' W	25m	2003 – today
El Tololo	Pyranometer YES UV–B Kip –Zonen /Li-Cor	30º 10' S	70º 48' W	2030m	1997 – today
Valparaíso	Biometer Solar Light	32º 56' S	71º 28' W	131 m	2002 – July 2012
	Pyranometer YES UV–B	33° 2' S	71° 37' W	28 m	July 2012- today
Farellones	Pyranometer YES UV–B	33º 21' S	70º 17' W	2746m	2011 – today
Valle Nevado	Pyranometer YES UV–B	33º 21' S	70º 15' W	3015m	2006 – 2009
Santiago- Pudahuel	Pyranometer YES UV–B	33º 23' S	70º 47' W	475m	1992 – 2006
Santiago- Quinta Normal	Pyranometer YES UV–B	33º 26' S	70º 40' W	520m	2002 – today
Rancagua	Pyranometer YES UV–B	34º 10' S	70º 46' W	491m	2010 – today
Talca	Pyranometer YES UV–B	35º 25' S	71º 40' W	100m	2010 – today

STATION	TYPE	LAT	LONG	ELEV	PERIOD OF OBSERVATIONS
Concepción	Pyranometer YES UV–B	36º 46′ S	73º 03′ W	8m	2002 – today
Termas Chillán	Pyranometer YES UV–B	36° 54' S	71° 24' W	1708m	DIC 2013- today
Temuco-Universidad Católica de Temuco	Pyranometer YES UV–B	38° 42' S	72° 32' W	153 m	2012-today
Valdivia – UACH	Spectroradiometer SUV 100	39º 48′ S	73º 14′ W	9m	1998 – 2007
Valdivia – Cecs	Pyranometer YES UV–B	39º 49′ S	73º 15′ W	18m	2010 – today
Puerto Montt	Pyranometer YES UV–B	41º 25′S	73º 05′ W	85m	2001 – today
Coyhaique	Pyranometer YES UV–B	45º 35′S	72º 07′ W	310m	2001 – today
Punta Arenas	Pyranometer YES UV–B	53º 00′ S	70º 51′ W	37m	2001 – today
Centro Meteorológico Antártico Presidente Eduardo Frei	Pyranometer YES UV–B	62º 25′ S	58º 53′ W	10m	1992 – today

Narrowband filter instruments

Station	Instruments	Institution	LAT.	LON.	Period of observations
Santiago	GUV 511	University of Chile	33º26'S	70º40'W	1995 – today
Valdivia	GUV 511	University Austral	39º48'S	73º14'W	1995 – 2007
Punta Arenas	GUV 511	University Magallanes	53º18´S	70º54´W	1993 – today
Punta Arenas	NILU UV	University of Magallanes	53º18´S	70º54´W	2010 – today
Base Prof. Julio Escudero	NILU UV	University Magallanes	62º12'S	58º57'W	2005 – 2009

Spectroradiometers

Station	Instruments	Institution	LAT.	LON.	Period of observations
Valdivia	SUV 100	DMC-Austral University	39º48'S	73º14'W	1997 – 2007
Punta Arenas	Brewer MKIII 180	University of Magallanes	53º18´S	70º54´W	2002–today

Radiometers

Station	Instruments	Institution	LAT.	LON.	Period of observations
Chajnantor Plateau Atacama Desert	Bentham Double Monochromator	University of Santiago (USACh)	23°1'S	67°5'W	2016-today
Santiago	Bentham Double Monochromator	University of Santiago (USACh)	32°27´S	70°41´W	2013-today
Escudero Antarctic Peninsula	Bentham Double Monochromator	University of Santiago (USACh)	62°1´S	58°6´W	2015-today

Contact: Dr. Raúl R. Cordero (raul.cordero@usach.cl)

3 Calibration activities

a) **DMC-network**: In collaboration with University of Santiago (USACh), had been developed calibration activities in following dates:
November 2013, one week
April 2014, one week
February-March 2015, one week
Reference instrument: Bentham Monochromator.

b) BREWER 180 (Punta Arenas): The last calibration carry out for International Ozone Services Inc. (IOS) did the ozone and UV calibration and service of Chilean Brewer Spectrophotometer #180 during November 2015 at Punta Arenas, Chile.

c) **Biometers network (University of Magallanes):** The Solar Light instruments of the group of the University of Magallanes are calibrated each two year using the Brewer 180 located in Punta Arenas.

4 RESULTS FROM OBSERVATIONS AND ANALYSIS

Results of Studies at Punta Arenas Chile (Lat. 53S, Long. 70W).

The Brewer observations have been operational at Punta Arenas from May 1992 until today. The Fig. 1

was constructed using TOMS data(1978-1992), Brewer #068 (1992-2000) and Brewer #180 (since year 2002). This Figure shows the variation of the ozone column with monthly mean. A polynominal fit (order 2) shows a slight increase in the total ozone column at Punta Arenas, and the recovery of the ozone column values to pre 80 should occur approximately between 2030-2040.

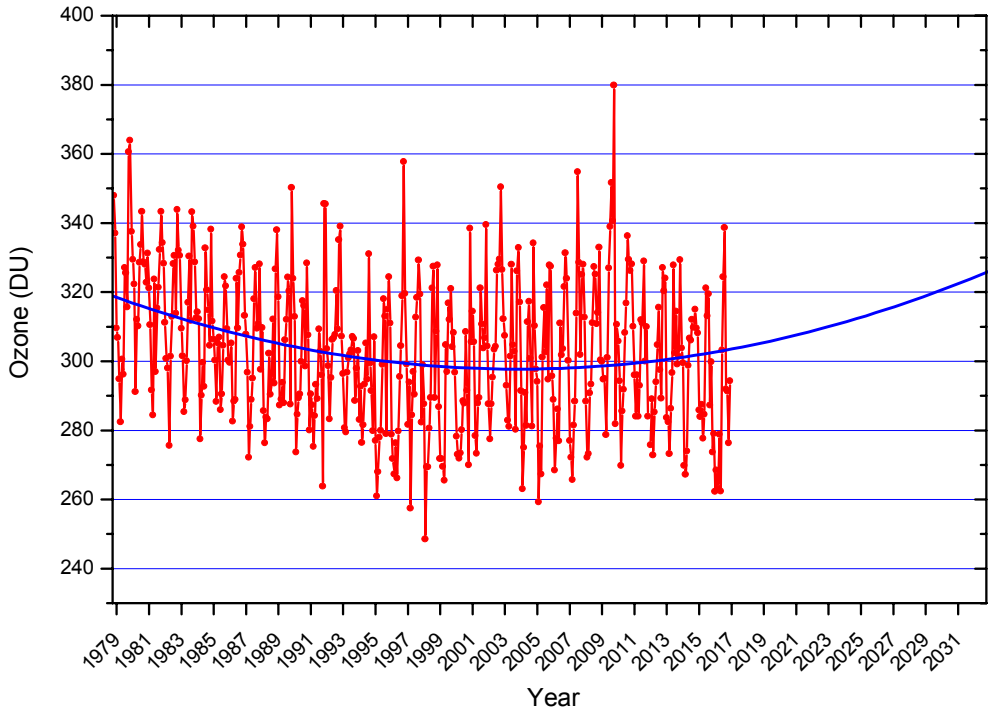


Fig.1 .- Ozone over Punta Arenas Chile 1978-2016 obtained with TOMS and Brewer spectroradiometer (# 068 and # 180).

The number of days in which the Antarctic Ozone Hole (AOH) has been over South cone region varies year to year. Figure 2 shows the number of events of low ozone to Punta Arenas. The criteria for defining an event of low ozone is that ozone column (daily average) must be lower than the reference (mean monthly climatological values for Punta Arenas from TOMS overpass data for the period 1978-1987), minus twice the standard deviation of the mean (mean monthly - 2σ). The number of days per year is shown in part (a), these data show a cyclical variability of about 10 years. Last three years shows significant minimum, if these values remain low during next years it would be a sign of recovery of total column ozone to pre-80 values.

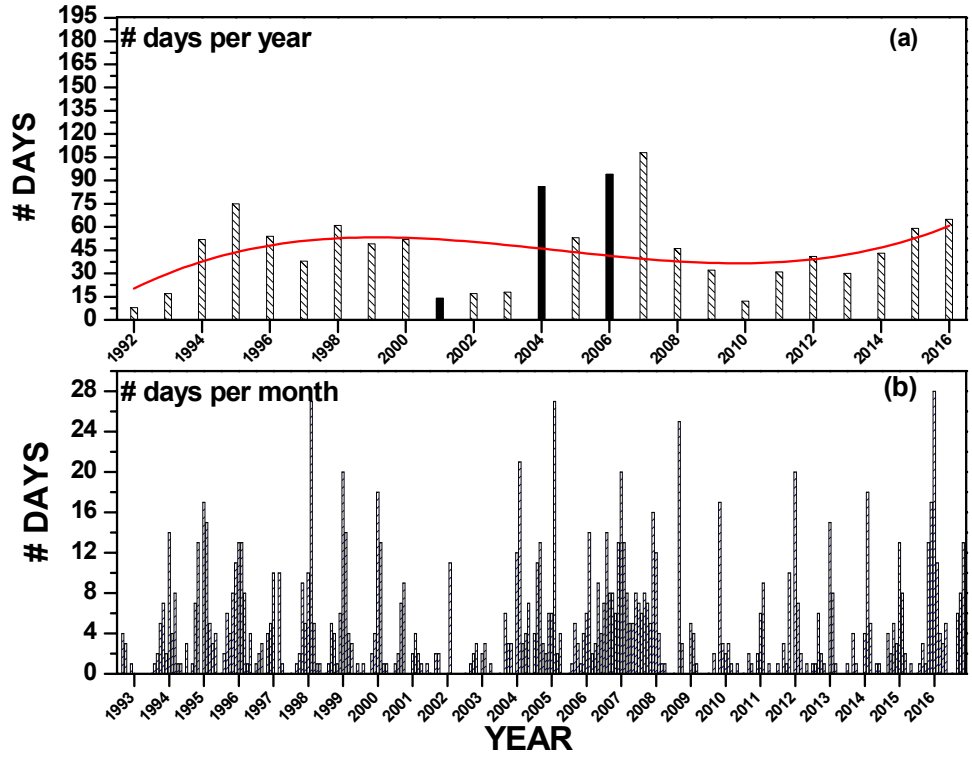


Fig. 2.- Number of days per year under the climatological (1978-1987) average minus two standard deviations, period 1992-2016.

5 DISSEMINATION OF RESULTS

Data reporting

University of Magallanes stations

- Data from Brewer 180 being sent to the WOUDC.
- Data of ozone profiles obtained in Punta Arenas being sent to the WOUDC.

DMC stations

- Submission of UVI data to the WOUDC in process.
- Submission of greenhouse gases data (CH4, CO, CO2, O3) from GAW station Tololo to WDCGG, on March 2016.

Information to the public

National Meteorological Service (DMC)

- UVI Hourly Monitoring online.
- UVI daily Forecast, by 24 hours, with Clouds.
- UVI daily forecast by three days. Without Clouds.
  University of Magallanes
- Since 1999 the Ozone Laboratory and RUV of the University of Magallanes provides a UV-Index daily forecast during spring and summer time (TEMIS).

6 RELEVANT SCIENTIFIC PAPERS 2014-2016

Cordero R.R., Damiani A., Seckmeyer G., Jorquera J., Caballero M., Rowe P., Ferrer J., Mubarak R., Carrasco J., Rondanelli R., Matus M., Laroze D., The Solar Spectrum in the Atacama Desert, Sci. Rep. (2016), **6**, 22457

Cordero R.R., Seckmeyer G, Damiani A, Jorquera J, Carrasco J, Muñoz R., Da Silva L., Labbe F, Laroze D, Aerosol Effect on the UV Irradiance in Santiago de Chile, Atmospheric Research 149 (2014) 282–291.

Damiani A, Funke B, López-Puertas M, Gardini A, von Clarmann T, Santee ML, Cordero RR, Changes in the composition of the northern polar upper stratosphere in February 2009 after a sudden stratospheric warming, Journal of Geophysical Research – Atmospheres (2014), **119**(19), 11-429.

Cordero, R.R., Damiani A., Carrasco J, Ferrer J., Rayas J., Jorquera J., Tobar M., Labbe F., Laroze D., "UV Irradiance and Albedo at Union Glacier Camp (Antarctica): a case study", Plos One (2014), **9**(3): e90705

Damiani A, Cordero RR, Laurenza M. Rafanelli C., "Cloud cover and UV index estimates in Chile from satellite-derived and ground-based data", Atmospheric Research, (2014) **138** 139–151.

Cordero RR, Seckmeyer G, Riechelmann S, Damiani A, Labbe F, D. Laroze, "The world's highest levels of surface UV", Photochem. Photobiol. Sci., (2014) **13** 70 - 81

7 FUTURE PLANS

The research group of the University of Magallanes will be continue ozone observations. Collaboration with other groups will be intensified, especially with the CEILAP group in Rio Gallegos.

DMC: 1) Capacity Building and Twinning for Climate Observing Systems, CATCOS Project. GAW station EL Tololo. Greenhouse Gases measurements.Instrument: PICARRO.

2)Project for development of the atmospheric environmental risk management system in South America. Japan (JICA, JST, NIES, Nagoya University), Argentina (SMNA, CITEDEF), Chile (DMC, UMAG). Includes measurements and studies of profile and column of ozone, volcanic ash, aerosols and ultraviolet

radiation. 2013-2018.

8 NEEDS AND RECOMMENDATIONS

- Financial support for supplies for ozonesonde of Punta Arenas is a priority, because the **"Project for development of the atmospheric environmental risk management system in South America"**, supported for **Science and Technology Research Partnership for Sustainable Development (SATREPS-Japan)** and the **Japan International Cooperation Agency (JICA)**, will be finished the help to buy ozonesondes.

  Recommendations 10- ORM

  Provide resources for sustainable, long-term operation and research in developing countries. Several regional centers for Dobson and Brewer instrument calibration have been established. It is of vital importance that these centers receive sufficient support to arrange regular calibration exercises for the instruments in their respective regions.
  It is necessary emphasize that the first priority at present for Chile is to maintain their current monitoring of ozone profile at Punta Arenas due Cone of South-America must be still for many years the best region to observe the recovery of Antarctic Ozone Hole

Claudio Casiccia S., PhD.
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CHINA

1. OBSERVATIONAL ACTIVITIES

1.1 Column measurements of ozone and other gases/variables relevant to ozone loss.

China Meteorological Administration (CMA) started operational ozone and UV monitoring since 1980s. There are seven ground-based ozone and UV observing stations and two additional UV observing stations in mainland China running by CMA. Taiwan and Hong Kong have been measuring the ozone and UV on the ground level even longer than mainland China. Chinese ground-based ozone and UV monitoring stations are listed in Table 1. Measurements have been shared through the WOUDC websites.

The first long-term in-situ measurement of Ozone Depletion Substances (ODS) in China was performed by GC-ECDs at the Shangdianzi (SDZ) station, and ODS have been measured since 2006. SDZ station is a part of the domain of the CMA and is also a regional station of World Meteorological Organization/Global Atmosphere Watch (GAW Regional Station), which is located about 100km northeast of urban Beijing. The station is linked to the Advanced Global Atmospheric Gases Experiment (AGAGE) network. There are 13 ODSs and solvents observed by the system, including ODS such as CFC-11, CFC-12, CFC-113, HCFC-22, HCFC-142b, Halon-1311, Halon-1201, CCl_4, CH_3CCl_3, CH_3Br, etc.

An art Medusa GC-MS system was installed at SDZ station and started operation in May 2010 to measure more than 40 ODSs and their substitutes. The scientifically defensible data from SDZ are produced with an approach consistent with SOGE/AGAGE guidelines and recognized QA/QC procedures. Most all of the global assessment reports related to China and Asian halogenated GHGs are supported by the SDZ observational data.

Besides, a network of five CMA stations which collect air samples was established in 2010. Of which, Mount Waliguan (WLG) in Qinghai Province is a high-altitude station that is the only global background station of the WMO/GAW on the Central Eurasia continent. The other four regional background stations are SDZ, Lin'an (LAN) in Zhejiang Province, Longfengshan (LFS) in Heilongjiang Province, and Shangri-La (XGL) in Yunnan Province, which are located in four additional different geographic areas and representing the background conditions of Northern China Plain, Northeastern China Plain, Yangtz River Delta, Yunnan-Guizhou Platue, respectively. The samples were collected weekly at the 5 stations and analyzed by a Medusa GC-MS in the central lab at CMA in Beijing for more than 40 ODSs and their substitutes. The spatial and temporal variations of atmospheric CFCs, HCFCs, Halons, HFCs, PFCs and other

solvents of five regions in China were achieved. Three more Chinese stations are planned to join the network in 2017.

Table 1. Operational Ground-based stations for measurements of Ozone and UV

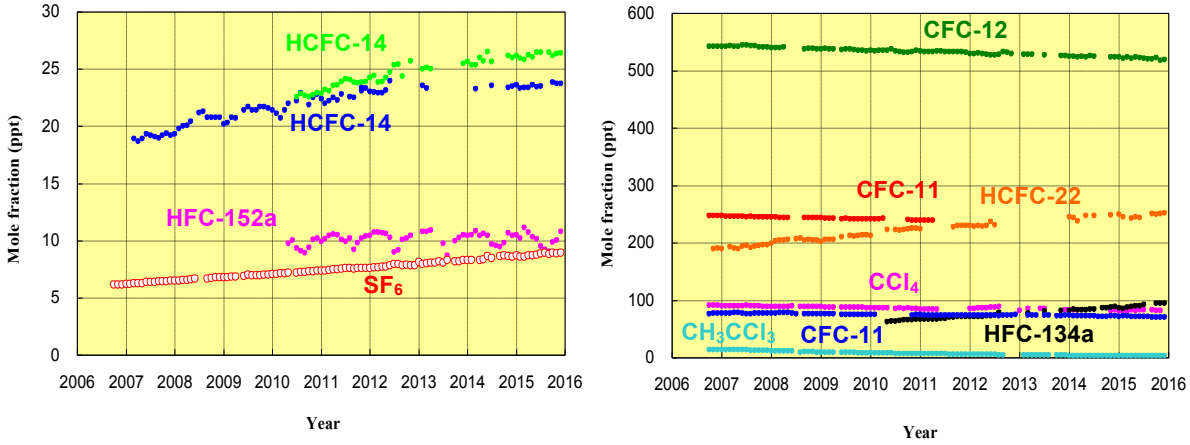
Type of observation	Station	Org.	Instrument	No.	Period
Total ozone	Xianghe	CMA	Dobson	#075 #216	1979- 2013-
Total ozone	Kunming	CMA	Dobson	#003 #198	1980- 2010-
Total ozone/ UV	Waliguan	CMA	Brower	#54	1991-
Total ozone/ UV	Longfengshan	CMA	Brower	#76	1993-
Total ozone/ UV	Linan	CMA	Brower	#77	1993-
Total ozone/ UV	Zhongshan	CMA	Brewer	#74 #193	1993-2010 2011-
Total ozone/ UV	Lhasa	CMA	Brewer	B#177	2008-
Total ozone/ UV	Hongkong	HK	Brewer	#115	1993-
Total ozone/ UV	Taipei	Taipei	Dobson Brewer Brewer	#065, #023 #129	1965- 1985-
Total ozone/ UV	ChengKung	Taipei	Brewer	#061	1991-
UV	Shangdianzi	CMA	KIPP & ZONEN		
UV	Dangxiong	CMA	UVB-1		2009-2011
Calibration standard	Beijing	CMA	Brewer	#197	2009-

1.2 Profile measurements of ozone and other gases/variables relevant to ozone loss

Global total ozone and ozone profile detection from space have been carried out since the launch of the polar orbit satellite FY-3A in 2008 and its successors FY-3B and FY-3C. There are two ozone monitoring instruments onboard the FY-3 satellites: TOU (Total Ozone Unite) and SBUS (Solar Backscatter Ultraviolet Sounder). The FY-3A, B and C were launched in 2008, 2010 and 2013 respectively. The daily ozone data have been shared for the world user from website.

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

The ozone-depleting substances (ODS), which were phased out in China, include CFCs, Halons, CH_3CCl_3 and CCl_4, have all begun to decline, while their replacements, e.g. HCFCs and HFCs are increasing rapidly in the atmosphere.



Monthly mean mole fractions of selected ODS and related substances at Shangdianzi[1]

3. DISSEMINATION OF RESULTS

As mentioned above in sections, measurements for ozone and UV in the Chinese stations are shared through the WOUDC websites; s some of measurements for ODS and other related substances are shared through scientific cooperation project, for example SOGE-A. The daily ozone data from the satellites have been shared for the world user from website at http://fy3.satellite.cma.gov.cn/portalsite/default.aspx?currentculture=en-US.

4. PROJECTS, COLLABORATION, TWINNING AND CAPACITY BUILDING

China will develop a high spectral ultraviolet/visible ozone instrument, a new generation of ozone instrument, onboard the FY-3E or F satellite which is scheduled launch in about 2020. The new generation ozone instrument is similar with OMPS on the SNPP and SCIAMACHY on the ENVISAT. The instrument consists of three main parts mounted on a baseplate: The Nadir instrument, the ozone profiler and the Limb instrument. The nadir instrument products include total ozone, NO_2, SO_2, HCHO, BrO, OClO, and aerosol. The ozone profiler will detect ozone profiles. The limb instrument will detect stratospheric profiles of atmospheric compositions such as O_3, NO_2, SO_2, HCHO, BrO, OClO and aerosol.

5. Relevant scientific papers

1. Climate Change Centre China Meteorological Administration, The State of Greenhouse Gases in the Atmosphere Based on Chinese and Global Observations before 2016, CHINA GREENHOUSE GAS BULLETIN, No. 5, 2016

2. Bo Yao ，Lingxi Zhou，Lingjun Xia，Gen Zhang，Lifeng Guo，Zhao Liu，Shuangxi Fang，Atmospheric sulfur hexafluoride in-situ measurements at the Shangdianzi regional background station in China，Journal of Environmental Sciences，2014，26（12）：2451-2458

3. Xingqin An, Bo Yao, Yan. Li, Nan Li and Lingxi Zhou. Tracking source area of Shangdianzi station using Lagrangian particle dispersion model of FLEXPART. Meteorol. Appl. 2014, 21(3): 466-473, DOI: 10.1002/met.1358

4. Shenshen Su, Xuekun Fang, Li Li, Jing Wu, Jianbo Zhang, Weiguang Xu, Jianxin Hu; HFC-134a emissions from mobile air conditioning in China from 1995 to 2030, Atmospheric Environment 102 (2015) 122-129

5. Xuekun Fang, Guus J. M. Velders, A. R. Ravishankara, Mario J. Molina, Jianxin Hu, and Ronald G. Prinn, Hydrofluorocarbon (HFC) Emissions in China: An Inventory for 2005− 2013 and Projections to 2050, Environ. Sci. Technol. 2016, 50, 2027−2034

COLOMBIA

1. OBSERVATIONAL ACTIVITIES

1.2 Profile measurements of ozone and and other variables relevant to ozone loss

- Ozone-sounding:

The Institute of Hydrology, Meteorology and Environmetal Studies (Instituto de Hidrología, Meteorología y Estudios Ambientales, IDEAM) began the measurements of vertical ozone column from November 1998 and finished in September 2011, in Eldorado synoptic station in Bogota, which is located at table 1:

Table 1. Bogota station location

Station	Latitud	Longitud	Altura
Bogota	04° 43'N	74° 03'W	2546 m

For the making was used Vaisala ozonesonde, OES - Model 6ª ECC, with electrochemical concentration cells (Iodide – Iode). The calibration was made with OZONESONDE OZONISER/TEST UNIT MODEL TSC-1 and reference conditions were 12 y 13 V voltage and current intensity below of 115 mA.

1.3 UV measurements

IDEAM has established a national network for the monitoring and monitoring of ultraviolet radiation, with five conventional surface stations. They are shown in Table 2.

Table 2. Location of UV radiation measuring network stations

Station	**Latitude**	**Longitude**	**Height (m)**
Riohacha	11° 32' N	72° 56' W	4
Bogotá	04° 42' N	74° 09' W	2546
Pasto	01° 11' N	77° 18' W	2580
Leticia	04° 33' S	69° 23' W	84
Isla de San Andrés	12° 35' N	81° 42' W	2

Calibration: Test of inter calibration of two spectroradiometers Biospherical GUV-511 of the IDEAM with referent spectroradiómeter Biospherical GUV-2511 (equipment calibrated for the manufacturer) Fundación Universitaria Los Libertadores..

2 RESULTS FROM OBSERVATIONS AND ANALYSIS

OZONE LAYER BASE HEIGHT

The height of the base of the ozone layer is presented about 15 to 17 kilometers above Bogota (see Illustration 1), but according to figure 14 this height varies throughout the year and has a

monomodal behavior, Which is characterized by the fact that in January the highest values (16730 meters) are presented and from February onwards there is a gradual decrease in the height up to July, which is when the minimum values are presented during the Year (about 14270 meters). Starting in August, the increase in height starts to the maximum that appears in January. (See **Illustration 2**)

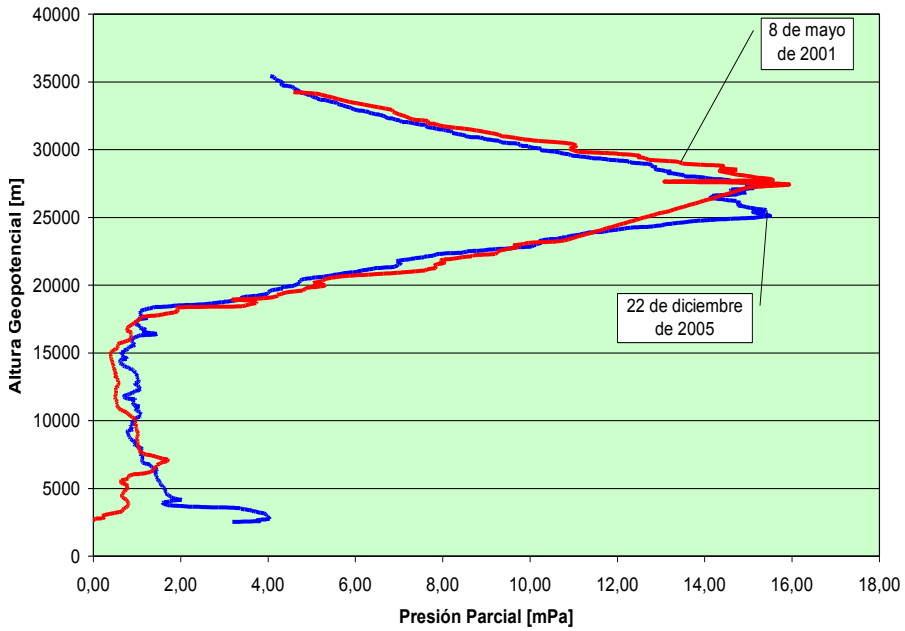


Illustration 1. Ozonesonde profiles of Bogota station which reached the higher height: one made on 22/12/2005 with 35424 m (blue) and second made on 08/05/2001 with 34247 m (red). (Source: IDEAM).

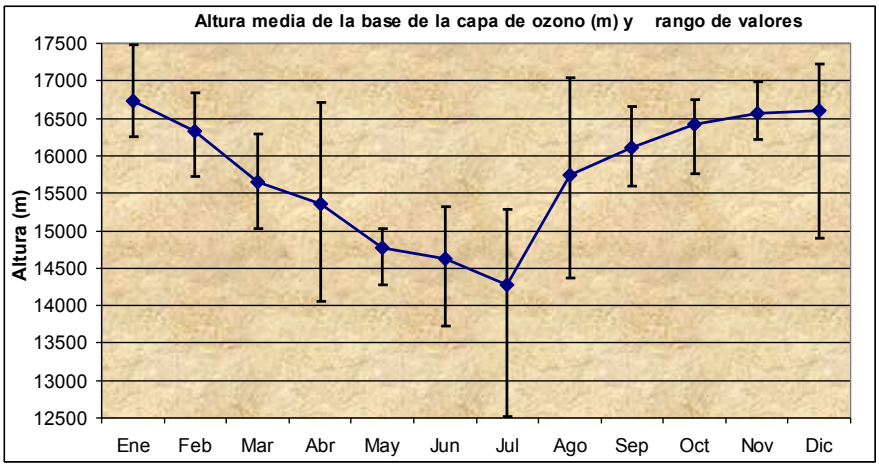


Illustration 2. Behavior of the monthly average height of ozone layer base. (Source: IDEAM).

The behavior of the height of the maximum concentration in the ozone layer is shown in Illustration 3. Its monomodal behavior is characterized by the fact that in February the highest values (27420 meters) are presented and from March a gradual decrease of the height is presented until the month of June, which is when the minimum values are presented during

the Year (about 24550 meters). From July begins the increase of the height to the maximum that appears in February.

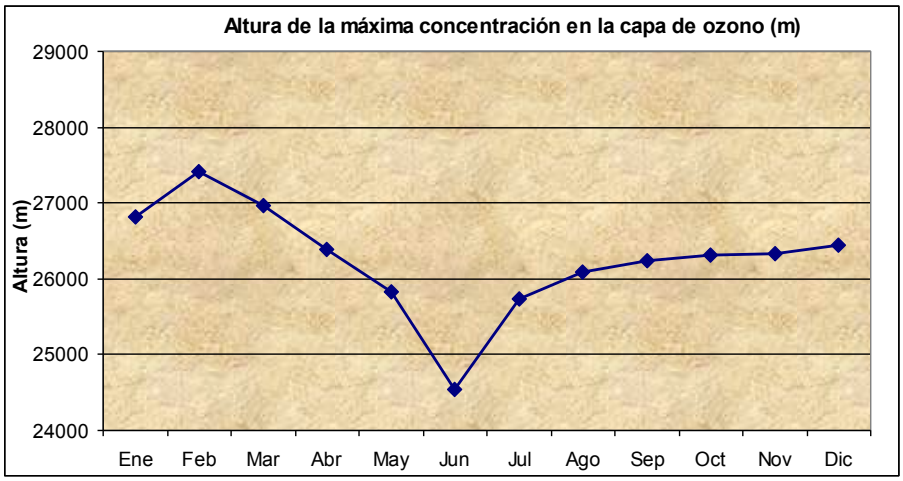


Illustration 3. Behavior of the height of the maximum concentration in the ozone layer, based on the ozone-soundings made in Bogotá. (Source: IDEAM).

The behavior of the value of the maximum concentration of ozone is showed in its layers. The maximum values of concentration presented in June (16.7 mPa, concentration expressed as partial pressure) and from July there is a gradual decrease of the concentration until the month of January, which is when the minimum values are presented during the year, around of the 13.2 mPa, (millipascals). From February begins the increase of the concentration until the maximum that appears in June.

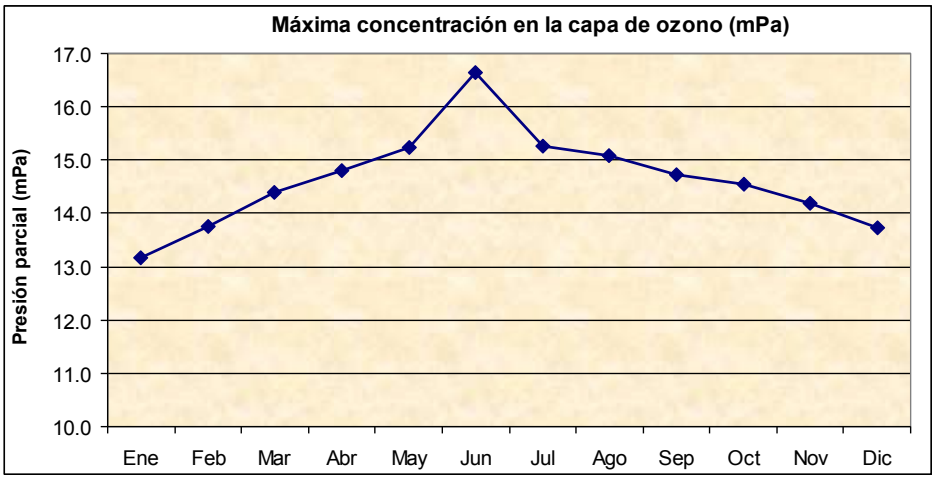


Illustration 4. Behavior of the maximum concentration in the ozone layer, based on the Ozonosondeos made in Bogotá. (Source: IDEAM).

The vertical distribution of the ozone concentration between the surface area (SFC) and 7 millibars (approximately 34 km) over Bogotá, shows that high concentrations of ozone are found in the stratosphere, between 30 mb (24 km of altitude) and 10 mb (31 km of altitude), with a maximum value of 13.70 mPa, below the typical global values for this level (see Table 3). Between 24 and 26 km altitude, is the highest average of the maximum concentration in the ozone layer (between May and July), with values between 15 mPa and 17 mPa.

Table 3. Valores medios de las concentraciones de ozono (mPa) para Bogotá.

Level (mb)	Height (m)	Ozone (mPa)
SFC	2.567	1.91
700	3.000	2.28
500	5.500	1.63
400	7.500	1.43
300	9.000	1.14
250	10.500	0.99
200	12.000	0.91
150	14.000	0.87

Level (mb)	Height (m)	Ozone (mPa)
100	16.000	1.14
70	19.000	3.31
50	21.000	6.76
30	24.000	11.92
20	27.000	13.70
10	31.000	9.70
7	33.500	6.15

Note: It corresponds to the averages of the data of the period between February of 1998 and May of 2008, obtained by the atmospheric probes realized monthly by the IDEAM. These averages include 73 ozone count data. (Source: IDEAM)..

The behavior of the monthly average of day-integrated UV-A radiation at the Eldorado station for the 340nm channels is presented in Figure 9, as well as the integrated average for the entire range of UV-A radiation obtained from these two channels. It is observed that the lower averages of UVA radiation, also occur between April and June and the months of highest average are January, February, July and August (months that are part of the two dry seasons in the center of the country).

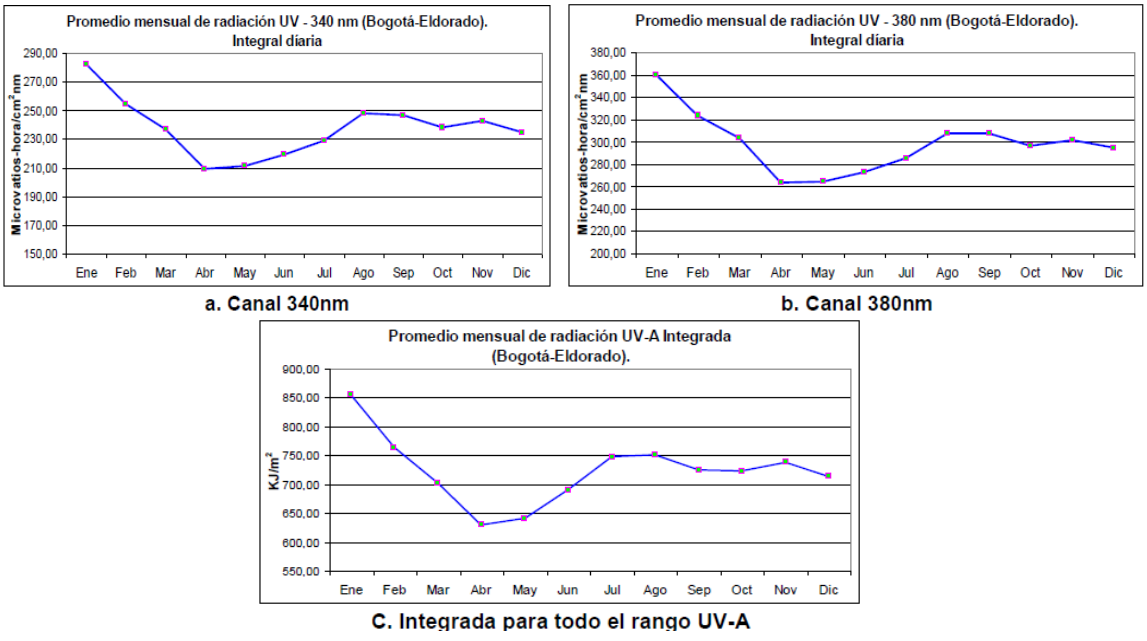


Illustration 5. Average monthly UV-A integrated day in the channel 340nm, 380nm and integrated for the UV-A range in Eldorado. (Source: IDEAM).

4 DISSEMINATION OF RESULTS

4.3 Information to the public

The IDEAM have institutional web, a page with information of basic concepts of ultraviolet radiation, ultraviolet index and presents forecasting of UVI and ozone concentration. The web

direction is: http://institucional.ideam.gov.co/jsp/273. And UVI and total ozone forecasting is: http://modelos.ideam.gov.co/atmosfera/indice-uv/mapas/. In Illustration 6 shows examples of this forecasts

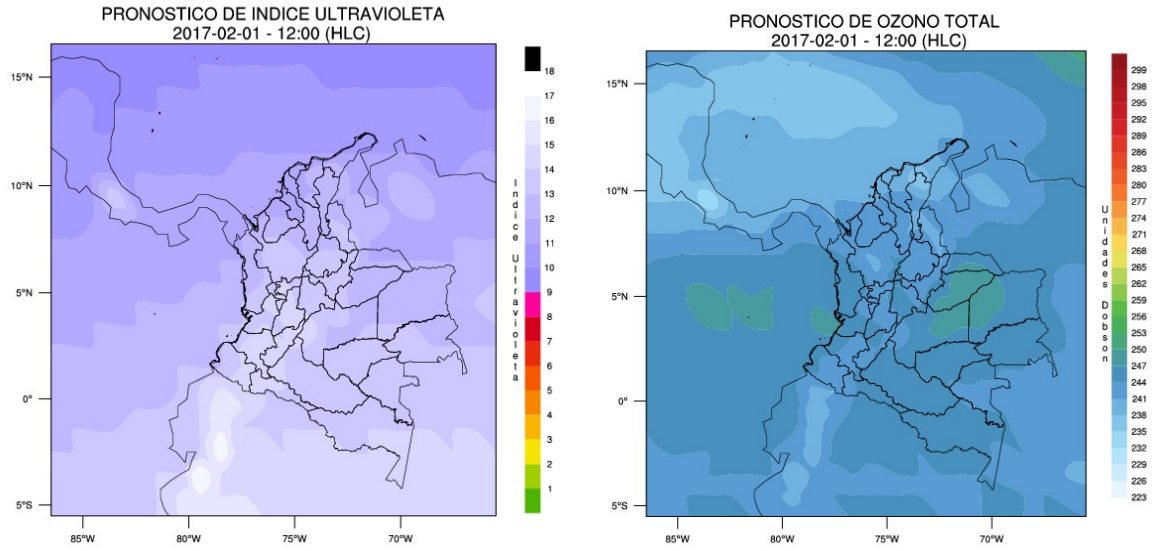


Illustration 6. Imagines of UVI and total ozone forecast. (Source: IDEAM).

7. FUTURE PLANS

The ozonesounding program should begin again in 2018.

Henry Benavides and Luis Barreto, Subdirection of Meteorology (IDEAM))

COMOROS

I INFORMATIONS GENERALES

1. Présentation du pays

L'Union des Comores est constituée d'un archipel de quatre îles situées dans le Canal de Mozambique **à environ 200 KM du Nord ouest** de Madagascar **et à 300 km à l'est du Mozambique** ; elles couvrent une superficie de 2236 km^2 : Grande Comore (Ngazidja : 1148 km), Anjouan (Ndzuani : 374 km), Moheli (Mwali : 290 km) et Mayotte (Maore : 424 km). Mayotte est toujours sous administration française malgré l'indépendance des Comores en 1975. Le relief est accidenté et volcanique et les sol et sous-sol sont dépourvus des ressources minières et énergétiques, mais ont beaucoup de potentialités agricoles.

Le climat tropical mais tempéré à la fois par l'altitude et par l'influence océanique est caractérisé par deux saisons : saison chaude et humide (**novembre à avril**) marquée par de fortes pluies et des vents violents (kashikasi) et une saison sèche et fraîche (**mai à octobre**) caractérisée par des vents (kusi) avec des températures oscillant entre 24 et 30° C, d'où l'utilité et la consommation du froid (climatisation, réfrigération, congélation, chambre froide etc…).

NB : Le présent document se réfère uniquement aux trois îles indépendantes regroupées au sein de l'Union des Comores. La superficie totale de ces trois îles est de 1862 km2.

Le recensement **général de la population et de l'habitat (RGPH)** de 200 **indique** 576 000 habitants. **La population urbaine à** 28% **et rural** 72%, **est en majorité concentrée sur la zone côtière**. Ainsi l'environnement subit une série d'agressions à cause de l'ignorance de la population ou tout simplement pour le désespoir de survie. Le taux d'accroissance annuel moyen étant de 2,1% entraînant un doublement projeté de la population en 33 ans ; les projections de ce recensement donnent une population de 716 000 en 2013 repartis inégalement dans les îles.

Le document de stratégie de croissance et de réduction de la pauvreté (DSCRP), adopté en 2005, constitue le cadre global de développement économique du pays. Ce document accorde une priorité centrale à la promotion du développement agricole, identifié comme moteur de croissance économique.

Le gouvernement a également élaboré un rapport sur les Objectifs du Millénaire pour le Développement qui renforce les actions du DSCRP dans le secteur agricole par la réduction de moitié entre 1990 et 2015, de la population qui souffre de la faim et l'inversion de la tendance actuelle à la déperdition des ressources environnementales

2. CADRE INSTITUTIONNEL ET JURIDIQUE

a) Cadre institutionnel

Le Bureau Ozone Comores (BOC) est crée au sein de la Direction Générale de l'Environnement au Ministère de la Production, de l'Environnement, de l'Energie, de l'Industrie et

de l'Artisanat (MPEEIA) qui est chargé de la tutelle institutionnelle de la protection de la couche d'ozone. Le Bureau Ozone a pour mission d'assurer la coordination et d'impulser toute la politique nationale pour la protection de la couche ozone.

Les personnes ressources y sont affectées pour la gestion quotidienne du programme et un Comité Ozone, impliquant tous les acteurs concernés renforce l'efficacité du Bureau Ozone Comores.

Pour plus d'efficacité le BNO s'appuie sur les associations ses frigoristes des trois iles et de l'Ecole Technique professionnelle d'Anjouan

b) Cadre juridique

Depuis 1993, les Comores sont dotées d'une Politique Nationale de l'Environnement :

- La loi cadre n° 94-018 relative à l'environnement stipule dans son article 38b : «un décret portant des mesures pour limiter et réduire l'importation, la production, la consommation et l'exploitation des substances de nature à détruire la couche d'ozone et encourager le recours à des substances et techniques de substitution »,
- La loi n° 94-011 autorise le Président de la République à ratifier la Convention de Vienne, le Protocole de Montréal et ses amendements

Les Comores, à l'instar de la communauté internationale soucieuse de préserver un environnement sain pour les générations présentes et futures, ont adhéré à la dynamique d'asseoir un cadre juridique international en ratifiant :

en 1994,
- la Convention de Vienne,
- le Protocole de Montréal,
- l'Amendement de Londres ;

et en 2002,
- l'Amendement de Copenhague,
- l'Amendement de Montréal,
- l'Amendement de Beijing.

La mise en application de ces instruments juridiques internationaux s'est traduite sur le plan local par :

- la signature d'un arrêté interministériel, en 2001, réglementant l'importation aux Comores, des SAO, des équipements et autres appareils utilisant ces substances.
- l'introduction d'un système des licences afin de pouvoir mieux gérer les quotas à l'importation des SAO jusqu'à leur élimination pure et simple en 2010.

3. Secteurs d'utilisation des HCFC

Le secteur du froid aux Comores est constitué principalement de la réfrigération et de la climatisation domestiques et industrielles, mais aussi de la réfrigération commerciale.

Tous ces sous-secteurs utilisent principalement des HCFC et dépendent majoritairement des ateliers de réparations et d'entretien dont les propriétaires constituent des partenaires privilégiés dans le processus d'élimination des substances nocives à l'ozone.

Ces acteurs constituent les principales cibles pour la sensibilisation et la formation pour la mise en œuvre des mesures d'élimination des SAO

4. Substances réglementées visées

Les résultats des enquêtes nationale sur la consommation des HCFC illustrée dans le tableau ci-après dans les sous secteurs d'utilisation et le parc d'équipements correspondant montre l'exclusivité du R22 dans le secteur de l'entretien.

Tableau 1 : Parc National des Equipements frigorifiques utilisant les HCFC 22

	Climatiseurs								
Installation	**9000 BTU**	**12 000 BTU**	**18 000 BTU**	**24000 BTU**	**48000 BTU**	**Climatisation Centrale**	**Chambre froide**	**Refroidisseur d'eau**	**Fabrique glace**
Total	3330	8650	8390	1480	153	4	55	110	20

Le parc national est dominé par la climatisation.

5. Projets réalisés pour élimination des CFC et des HCFC

Dans le cadre de la mise en œuvre du Protocole de Montréal d'une part, et d'autre part du partenariat avec le Secrétariat Exécutif de l'ozone, le Programme des Nations Unies pour l'Environnement, le Fonds Multilatéral ainsi que le PNUD, les Comores ont bénéficié d'une assistance technique et financière caractérisée par un ensemble de projets pour la Protection de la couche d'ozone. Cet ensemble de projets qui visait comme objectif, l'élimination des Substances Appauvrissant la couche d'Ozone (SAO) avant 2010, se présente comme suit :

a) Objectifs des projets

- Préparation du programme pays : réaliser un diagnostic de la consommation des SAO et projeter des mesures appropriées pour une gestion rationnelle des ces substances ;
- Renforcement institutionnel : renforcer les capacités institutionnelles nationales en vue de protéger la destruction de la couche d'Ozone par l'élimination progressive des SAO et par la promotion des produits de substitution ;
- Plan de gestion des fluides frigorigènes (PGFF) : planifier et gérer d'une manière dégressive les fluides frigorigènes nocives importées et existantes au niveau du pays en vue de leur élimination définitive programmée d'ici 2010 ;
- Projet régional de bromure de méthyle : mise en place d'une stratégie nationale pour prévenir l'introduction et la diffusion des utilisations du bromure de méthyle ;
- Préparation et mise en œuvre du programme d'élimination finale des fluides frigorigènes d'ici 2010 (TPMP) ;
- préparation et mise en œuvre du PGEH: planifier l'élimination progressive des FCFC d'ici 2030

b) Impact des projets réalisés

L'ensemble de projets et programmes a découlé de l'adhésion des Comores au Protocole de Montréal. Les activités réalisées ont concouru à un renforcement des capacités institutionnelles, à une amélioration du savoir faire des acteurs impliqués et leurs moyens logistiques, une prise de conscience d'une grande partie de la population sur la problématique de l'ozone ainsi qu'une compréhension et une implication effective des autorités politiques

L'impact se traduit aujourd'hui par :

- Une prise de conscience de la population et des acteurs (douaniers et frigoristes) sur les enjeux liés à la destruction de l'ozone ;
- Une prise de conscience des autorités et une intégration de la problématique de l'ozone dans la politique environnementale nationale ;
- Une maitrise par les frigoristes des techniques de manipulation des gaz prohibés et d'utilisation des gaz alternatifs ;
- Une maitrise par les douaniers des techniques de contrôle des SAO ;
- Une disponibilité d'équipements et outillages appropriés aux différents types de gaz (anciens et nouveaux)

- Une opérationnalisation du bureau ozone Comores et une reconnaissance au niveau international ;
- L'établissement d'un cadre de concertation opérationnel entre les institutions et partenaires nationaux (administrations, associations de frigoristes et douaniers ; écoles de formation technique et médias) ;
- La mise en place d'un cadre réglementaire opérationnel et accepté par tous ;
- Une conformité du pays par rapport aux exigences du protocole de Montréal à l'échéance 2010 (élimination totale des CFC) ;
- Le lancement d'un dispositif national pour garantir le respect futur des engagements liés au processus en cours d'élimination des HCFC ;
- Asseoir les bases d'une stratégie d'élimination des HCFC

Tableau 2 : consommation de CFCs aux Comores

Année	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
CFC-12	3.6	2.5	2.7	1.9	1.8	1.2	1.1	0.9	0.8	0.3	0.0	0.0	

6. Lessons learn from ODS phase-out

L'ensemble des dispositifs mis en place dans le processus d'élimination des CFC et la collaboration établie entre le Bureau ozone et ses partenaires nationaux et internationaux se sont averés efficaces, ce qui a permis une bonne compréhension de la problématique ozone par les acteurs, une adoption participative et une acceptation de la stratégie d'élimination des SAO, ce qui a conduit notre pays à une conformité avant la date arrêtée. Cette stratégie qui a apporté ses fruits mérite d'être capitalisée à travers son intégration dans les projets en cours de préparation notamment le PGEH

II Plan de Gestion et d'Elimination des HCFC (PGEH)

II.1 Stratégie d'élimination

L'Union des Comores étant Partie au Protocole de Montréal doit, conformément à la décision XIX/6 et à l'article 5, mettre en place le cadre réglementaire approprié et prendre les mesures nécessaires à la gestion rationnelle de l'importation et l'utilisation des HCFC ainsi que des équipements contenant ces substances.

Le but du PGEH est de réaliser des cibles de réduction des HCFC jusqu'à leur élimination :

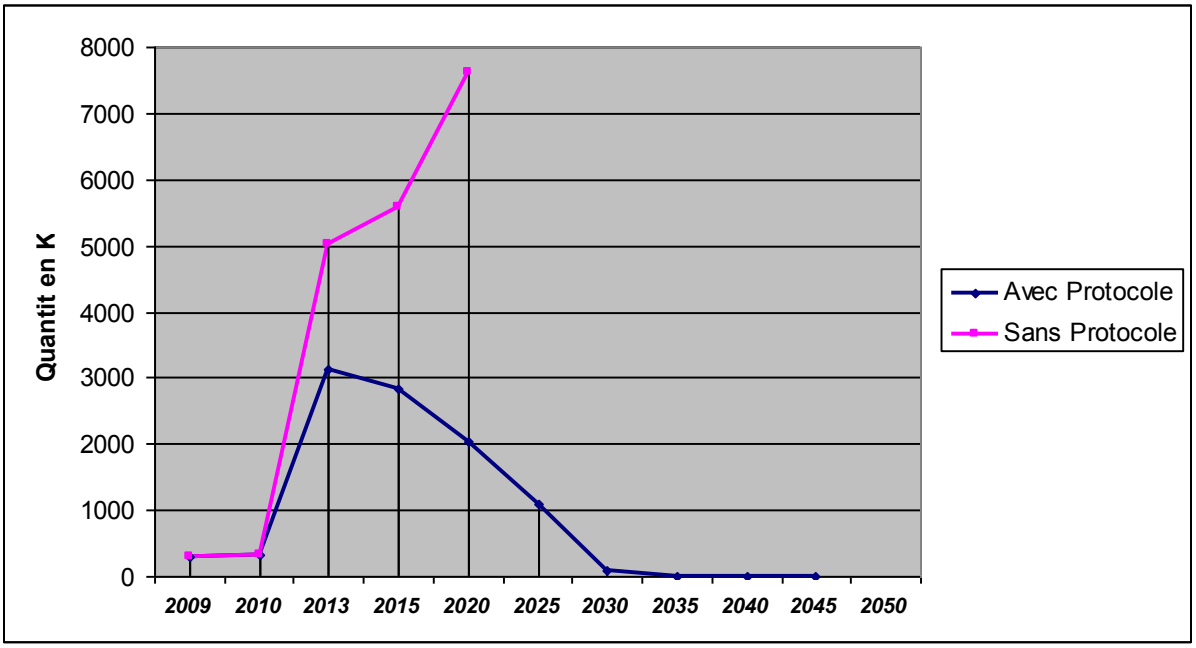
- Gel à partir de 2013 de la quantité des HCFC, suivi d'une réduction de 15% en 2015.
- Réduction progressive des HCFC par rapport à la valeur de 2013 (35% en 2020, 65% en 2025, 97,5% en 2030) puis, élimination totale entre 2016 et 2030.

Tableau 2 : Prévisions de la consommation en HCFCs, sans et avec le PM:

PHASE	PHASE 1											
ANNEE	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
PREVISIONS SANS PM	2,5	2,85			5,00		5,60					7,7
PREVISIONS AVEC PM	2,5	2,85			3,15		2,98					2,04
PHASE	PHASE 2											
ANNEE	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030		

PREVISIONS SANS PM												
PREVISIONS AVEC PM					1,09					0,078		

Graphique 1 : Évolution prévisionnelle de la consommation des HCFC de 2009 à 2040, Avec protocole et sans protocole



La prévision de la consommation en HCFC suit une progression croissante si l'on n'applique pas le protocole sur l'élimination progressive des HCFC comme l'indique le graphique 1. On atteindrait des niveaux de consommation très élevés à l'horizon 2050 contrairement aux recommandations du protocole sur l'élimination des HCFC

II.2 Resultats obtenus pour la mise en œuvre du PGEH

La mise en œuvre de la première phase du PGEH a permis de :

- capitaliser les acquis des projets antérieurs sur l'élimination des CFC ;
- former un nombre important de frigoristes et douaniers sur les nouveaux enjeux du protocole notamment sur les risques liés à l'utilisation des gaz alternatifs ;
- poursuivre l'approvisionnement des équipement appropriés (Kits et identificateurs) aux frigoristes et douaniers,
- préconiser une réadaptation-révision) du cadre règlementaire pour intégrer les nouveaux enjeux.

La 2eme phase du PGEH a porté sur la poursuite des mêmes activités que la phase I

Notamment la collecte des informations sur les HCFC, pour la période 2011-2015, qui s'est réalisée d'une manière facultative car les enquêtes en cette période portait sur les SAO règlementés ; ces enquêtes générales ont, néanmoins, permis d'obtenir les données estimatives consignées dans le tableau 3 ci-après.

Tableau 3 : Consommation de HCFC aux Comores (2011-2015, données au titre de l'Article 7)

HCFC-22	2011	2012	2013	2014	2015	Valeur de référence*
Tonnes métriques	2,10	1,98	2,11	1,91	1,62	2,48
Tonnes PAO	0,12	0,11	0,12	0,14	0,10	0,14

(*) La valeur de référence des HCFC aux fins de conformité est de 0,1 tonne PAO (sur la base d'une décimale après la virgule).

Pour ce même programme PGEH, Les Comores ont, en juin 2016, réalisé l'inventaire nationale pour la période 2012-2015 sur les alternatives aux substances appauvrissant la couche d'ozone (SAO) dans le cadre d'élimination future d'autres types de gaz qui, certes moins néfastes à la santé humaine, ont un impact certain dans le réchauffement climatique. Il s'agit des substances HFC.

Tableau 4 : consommation (en Tm) des HFC pur et des mélanges à HFC entre 2012-2015 dans la maintenance

	Air - conditionné				Réfrigération	
	HFC-134a	R-404A	R-410A	R-407C	HC-290	HC-600a
2012	3,14	0,75	0,50	1,21	0	0,98
2013	3,89	0,90	0,45	1,35	0	0,80
2014	2,99	0,79	0,51	1,35	0	1,00
2015	3,99	1,26	0,70	1,65	0	1,10
% (en 2015)	45,86	14,47	8,03	18,98	0	12,66

Comme l'Union des Comores ne dispose d'aucune unité de production de ces gaz, la majeure partie de la consommation des gaz HFC provient des importations de ces gaz utilisés dans les opérations d'entretiens et de maintenance dans les secteurs de la réfrigération et de la climatisation fixe et mobile comme l'indique le tableau 4 sur la consommation des HFC. Elle représente environ 65% de la consommation totale.

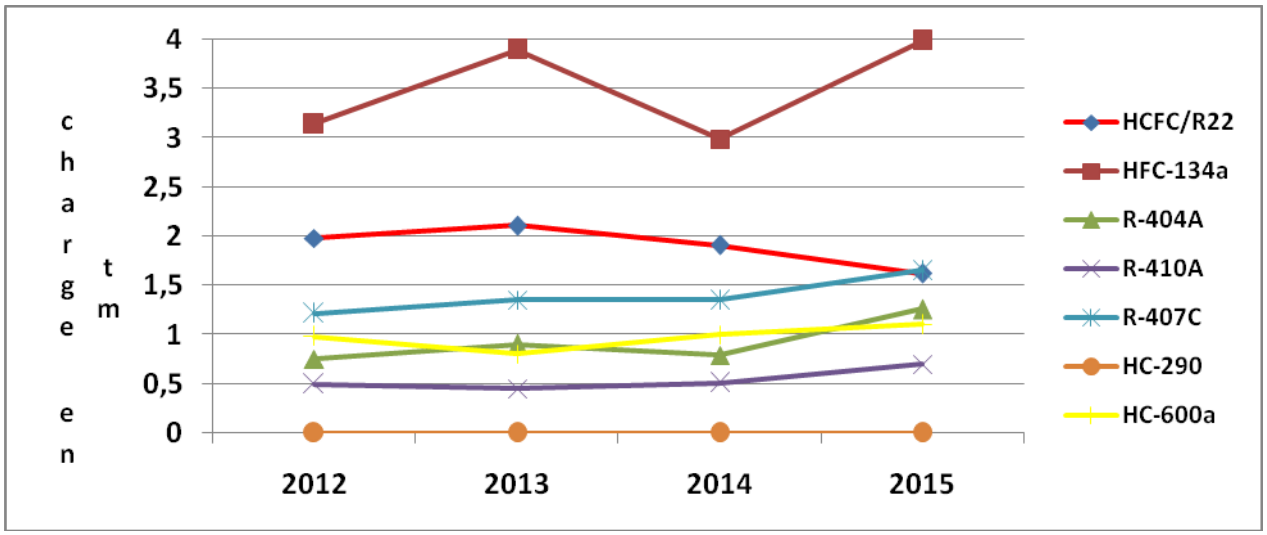
Comparaison de la consommation de HFC et HCFC/R2

Entre 2012 et 2015 l'enquête révèle une diminution de la consommation du HCFC/R22 en faveur de la consommation des alternatives. Ceci peut s'expliquer par la mise en œuvre des recommandations formulées dans le PGEH sur la réduction progressive des substances hydro chlorofluorocarbures. Cette tendance, si elle se poursuit normalement, comme l'indique le tableau 5 et le graphique 2, permettra à l'Union des Comores d'être conforme à la décision du Protocole de Montréal

Tableau 5 : consommation (en Tm) des HFC et mélanges et les HCFC entre 2012-2015

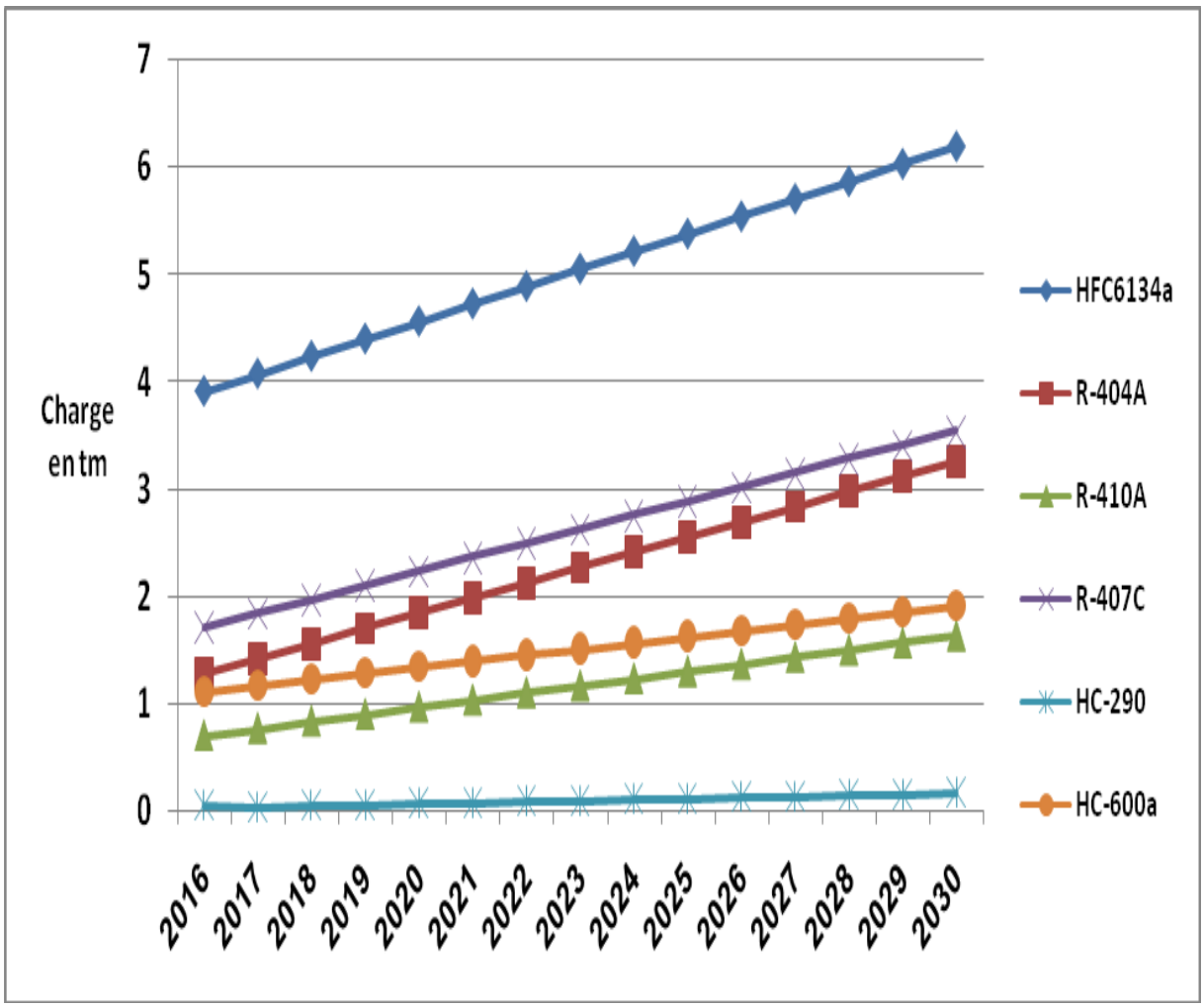
		Air - conditionné					Réfrigération
	HCFC/R22	HFC-134a	R-404A	R-410A	R-407C	HC-290	HC-600a
2015	1,62	3,99	1,26	0,70	1,65	0	1,10
Total en (Tm) en 2015	1,62	8,694					
% en 2015	15,71	84,29					

Graphique 2 : Evolution de la consommation entre le HCFC et les HFC entre 2012-2015



Graphique 3 : projection future de la consommation du HFC en 2016-2030

Selon les données collectées, la projection en termes de consommation de ces gaz dans les quatorze années à venir indique une augmentation aussi bien pour les HFC pur que pour les mélanges de ces gaz comme l'indique le graphique 3 ci-dessous



III ACTIVITES SUR L'OBSERVATION ET LA RECHERCHE EN OZONE

Malgré la faiblesse de l'industrie du froid aux Comores, la recherche constitue un maillon essentiel pour l'accompagnement du programme Ozone aux Comores. D'importants efforts ont été déployés pour la réduction de la consommation des SAO, CFC et des résultats significatifs ont été obtenus. Ces efforts méritent d'être soutenus par la mise en place d'une Unité d'observation et de recherche sur l'ozone, devant servir de base d'orientation dans la mise en œuvre du programme ozone aux Comores :

Dans le souci d'opérationnaliser l'Unité d'observation et de Recherche sur l'ozone, il y a donc lieu d'associer l'expertise locale dans les activités de recherche au niveau international et soutenir notre pays pour le financement de projet de recherche (annexe ci-joint) sur:

- l'implantation d'une station de contrôle de la pollution de l'air afin de déterminer les principaux polluants,
- l'équipement de ladite station en instruments pour les mesures (UV-B),
- le renforcement des capacités des cadres impliqués dans les activités d'observation et de recherche,
- l'archivage des données provenant de diverses sources d'observation

7. CONCLUSION

Notre pays participe au mieux de ses moyens à l'effort mondial de mise en œuvre des dispositions planétaires sur la protection de la couche d'ozone sur le plan politique, et juridique. Le plan technique et matériel mérite d'être renforcé et soutenu financièrement.

ANNEXE
TDR du Projet de Recherche de l'Union des Comores
sur la mise en place d'un observatoire de l'ozone

1. Contexte générale

Les Comores est un petit pays insulaire de l'hémisphère sud (12° 10'S, 44° 12'E) situé à l'entrée du canal de Mozambique entre la côte Est de l'Afrique et Madagascar dans le sud-ouest de l'océan indien. Localisé au cœur du tropique, le pays bénéficie d'un climat tropical généralement composé de deux grandes saisons :

- la saison d'été austral de novembre à avril est caractérisée par des fortes convections profondes, des précipitations et des températures au sol qui peuvent atteindre 34°C.
- la saison d'hiver austral entre mai et octobre est caractérisée généralement par un ciel bien dégagé et peu de faibles précipitations.

Ces caractéristiques du climat comorien font du pays un milieu très favorable à une production photochimique massive de l'ozone. Pourtant la complexité dynamique de cette région située dans le réservoir tropical fait en sorte que l'ozone formé subit, en fonction des saisons, un « transfert » vers les moyennes latitudes sous l'action de la circulation de Brewer-Dobson. Cette circulation implique aussi le transfert dans la basse stratosphère des masses d'air riches en ozone vers les latitudes supérieures. Ainsi, les tropiques représentent un réservoir de génération d'ozone. La stratosphère tropicale est un compartiment important dans le système climatique terrestre. Elle est le siège d'une forte activité dynamique impliquant

- des échanges verticaux, notamment avec les basses couches de l'atmosphère en interaction avec les activités anthropiques ;
- des échanges isentropiques (quasi-horizontaux) conduisant au transport des masses d'air riches ou pauvres en ozone selon les saisons et selon les niveaux d'altitude.

L'évaluation du bilan de l'ozone et l'impact des actions mises en œuvre pour protéger la couche d'ozone à différentes échelles, particulièrement à l'échelle nationale et régionale, nécessitent la connaissance d'une quantité importante d'information sur la variabilité et la distribution de l'ozone dans différentes couches de l'atmosphère. A ce jour, compte tenu de la faible densité des observations dans les tropiques sud, l'état de la couche d'ozone et son évolution sont peu documentés dans nos latitudes. D'où l'intérêt de renforcer l'observation de l'ozone dans cette région tropicale et d'effectuer des recherches sur son évolution, en synergie avec les observations existantes.

2. Justification du projet à l'échelle régionale et internationale

La réalisation des mesures et des recherches sur l'ozone aux Comores représente une contribution modeste, néanmoins utile et pertinente, à l'effort de la communauté internationale pour une meilleure compréhension de l'évolution du climat de la Terre, particulièrement dans les tropiques sud où la densité des mesures est faible, voire inexistante par endroit. Ce projet de recherche peut avoir des retombés positifs au niveau régional et international. En plus des émissions anthropiques notamment des émissions de composées halogénées, les concentrations d'ozone dans l'atmosphère dépendent des émissions de gaz et aérosols volcaniques, de la variabilité naturelle et des forçages dynamiques influant sur la variabilité de la stratosphère, comme la QBO (oscillation quasi-biennale), l'ENSO (anomalie El-Niño) et les cycles solaires.

2.1. *Analyse de la contribution des gaz et aérosol volcaniques sur la variabilité de l'ozone*

Il est à rappeler que l'océan indien abrite plusieurs îles volcaniques, avec des volcans actifs :

- le Piton de la Fournaise à la Réunion, qui est souvent en éruption et
- le Karthala aux Comores, dont la dernière éruption remonte à novembre 2005 a fait état d'éjection d'une masse importante d'aérosol ayant couvert l'archipel et les régions environnants.

Par ailleurs, les panaches d'aérosols émis par certains volcans, comme ceux d'Indonésie ou des Philippines peuvent atteindre facilement les Comores. De ce fait, la mise en place d'un système d'observations atmosphériques aux Comores permettra de surveiller de façon permanente la couche d'ozone et de réaliser des études pertinentes sur la contribution des gaz et aérosols volcaniques sur la variabilité de l'ozone et leurs impacts sur les tendances et changements à court, moyen et long termes.

2.2. *Analyse de l'influence de la QBO sur la variabilité et la tendance de l'ozone*

Il a été démontré que les oscillations quasi-biennales (QBO) du vent zonal équatorial influent de façon significative la variabilité de l'ozone aux tropiques et aux latitudes supérieures. Elles engendrent des anomalies de températures stratosphériques qui influencent la circulation de Brewer-Dobson. En effet, durant le régime d'est de la QBO, il y a une augmentation de la température des tropiques vers les subtropiques. Ce phénomène conduit à une accélération de la circulation de Brewer-Dobson durant laquelle la hauteur de la tropopause augmente, et le transport des masses d'air riches en ozone des tropiques vers les moyennes latitudes est renforcé conduisant par conséquent à des anomalies négatives d'ozone aux tropiques. Le phénomène opposé s'observe durant la phase d'ouest de la QBO. Des études ont montré que la contribution de la QBO à la variation de la concentration de l'ozone est importante au niveau des tropiques et elle diminue avec l'augmentation de la latitude. Le changement des régimes d'anomalies d'ozone induit par la QBO se produit entre 10° et 15° de latitude (Toihir et al., 2016). La mise en place d'une structure d'observation et de recherche sur l'ozone aux tropiques notamment aux Comores (12°10'S) permettra la mise en évidence de ces anomalies d'ozone induit par le forçage de la QBO, de quantifier sa contribution sur la variance totale de l'ozone, de déterminer et de suivre la variabilité de la zone de bordure entre les régimes négative et positive de l'ozone induit par le forçage de la QBO.

2.3. *Analyse de la contribution des forçages océaniques sur la variabilité de l'ozone*

Des recherches sur la variabilité de l'ozone aux Comores permettront de mieux quantifier des forçages d'origine océanique, comme celui

- du Dipôle Océan Indien (IOD)
- de l'oscillation ENSO (El-Niño Southern Oscillation)

et leurs contributions à la variabilité pour une meilleure estimation des tendances dans le bassin sud-ouest de l'océan indien particulièrement au niveau du canal de Mozambique.

Il a été expliqué qu'une période à forte activité El-Niño s'associe à une diminution d'ozone aux tropiques. Toutefois, nous avons montré que la part de contribution du forçage ENSO sur la variance totale de l'ozone varie d'une région océanique à un autre (Toihir et al, 2016). Nous soupçonnons que les événements El-Niño ont une influence significative sur la variabilité totale de

la couche d'ozone au niveau des Comores étant donnée l'interconnexion entre l'Océan Indien et l'Océan Pacifique (région où l'influence de l'ENSO est maximale). Pour examiner cette hypothèse, des analyses des distributions et de variabilité de l'ozone au-dessus de l'archipel des Comores sont nécessaires.

2.4. Renforcement du réseau d'observation de l'ozone dans l'hémisphère sud

L'observatoire de l'ozone aux Comores contribuera au renforcement du réseau d'observation de l'ozone à l'hémisphère sud, notamment en Afrique et dans l'océan indien où le nombre d'observatoire est très limité. Notons qu'il existait environs une douzaine des sites d'observations d'ozone en Afrique sub-saharienne et dans l'océan Indien (Irène, Springbok, Maun, Maputo, Nairobi, Malindi, Etosha Pan, Brazzaville, Lagos, Cotonou Réunion et Seychelles). Actuellement les instruments installés dans la plupart des sites ne sont pas opérationnels. D'où l'intérêt d'encourager la politique de relance des activités des sites reformés et la mise en place des nouveaux sites d'observation dans la région. Notons que la Réunion, l'Afrique du sud et le Kenya ont réussi à maintenir leurs activités. Un observatoire aux Comores renforcera le réseau d'observation Est Afrique et océan Indien.

3. Problématique du projet au niveau locale

Conscient de la nécessité de protéger la couche d'ozone pour un développement durable des écosystèmes, L'union des Comores a ratifié en octobre 1994 :

- la convention de Vienne sur la protection de la couche d'ozone
- Le protocole de Montréal relatif aux substances appauvrissant la couche d'ozone.

Notons que la convention de Vienne et le Protocole de Montréal sont entrés en vigueur pour les Comores le 31 Janvier 1995.

Depuis 1998, les Comores bénéficient d'une assistance technique et financière pour réaliser une série d'activités suivant un plan d'action prédéfini pour chaque pays conformément aux prérogatives et recommandations de la convention de Vienne et du protocole de Montréal. L'objectif principal des activités effectuées jusqu'à ce jour est de réduire la quantité des SAO (substances appauvrissant l'ozone) dans l'atmosphère locale d'ici 2020, selon le calendrier prédéfini par le fond Multilatéral. Ceci aura comme conséquence un rétablissement progressif de la couche d'ozone et un retour à l'état 1980 en 2050.

Par ailleurs, le rétablissement de la couche d'ozone ne peut être dissocié du changement climatique lié à l'augmentation de l'effet de serre, compte tenu du rôle joué par ce constituant dans l'atmosphère terrestre. Rappelons que le réchauffement de la planète est dû entre autres aux émissions anthropiques des gaz à effet de serre ayant pour conséquence le changement climatique. Pourtant ce changement climatique peut induire des modifications dans la stratosphère susceptibles de retarder ou bien d'accélérer le rétablissement de l'ozone, suivant les processus mis en jeu.

Sans une observation quotidienne de l'ozone à l'échelle locale, il est difficile d'évaluer l'impact des actions entrepris pour réduire les émissions des SAO (substances appauvrissant la couche d'ozone) à l'échelle nationale. D'où l'intérêt d'investir sur l'observation et la recherche sur l'évolution temporelle de l'ozone à l'échelle locale

4. Objectif globale du projet

Renforcement des capacités nationales en matière de surveillance de la qualité de l'air et de l'environnement.

5. Objectif spécifique

Acquisition d'un système permettant d'observer la colonne totale de l'ozone et d'entreprendre des recherches sur sa variabilité et sa tendance à moyenne et à long-terme.

6. Résultats attendus

- renforcement des capacités techniques et matérielles de l'Union des Comores, particulièrement l'Agence Nationale de l'Aviation Civile et de la Météorologie,
- renforcement des capacités d'entreprendre des recherches sur l'évolution du système climatique en générale et sur la couche d'ozone en particulier,
- constitution d'un réseau régional d'observation d'ozone et intégration de l'observatoire des Comores dans un réseau d'observation international (NDACC)
- évaluation des efforts entrepris sur la protection de la couche d'ozone au niveau national
- développement d'un model numérique d'analyse de l'évolution spatiale et temporelle de l'ozone à l'échelle nationale et régionale.

7. Ressources nécessaires

7.1. Ressources matérielles disponibles

La Direction de la météorologie possède du matériel suffisant pour réaliser les observations du temps et du climat :

- une antenne de réception des données satellite avec laquelle il est possible d'obtenir aussi des données sur plusieurs particules qui interagissent directement ou indirectement avec l'ozone. Bien que ces données soient de faible résolution elles peuvent servir pour la validation des travaux et des observations au sol dans le cas où besoin est,
- une connexion internet haut débit, permet de télécharger les données des forçages dynamiques et les paramètres auxiliaires nécessaires pour l'étude de la variabilité et la tendance de l'ozone et pour la conception du modèle numérique,
- un serveur avec une capacité suffisante pour la sauvegarde des données acquises,
- Un local pour abriter les instruments de mesures et de traitement des données.

7.2. Les besoins en équipement

Pour mener à terme ce projet la direction technique de la météorologie a besoin d'un supplément des matérielles notamment :

- un spectromètre de mesure de l'ozone notamment le SAOZ et les équipements annexes
- un bureau et un ordinateur performant dédié aux travaux liés à l'analyse des données
- un logiciel de traitement des données notamment le Matlab

7.3. Ressources humaines disponibles

La direction technique de la météorologie possède les ressources humaines nécessaires pour mener à bien ce projet. Les personnes qui seront impliqué directement à ce projet sont les agents affectés au service de la climatologie, observation et environnement. On note entre autres :

- Un Docteur, chargé de la surveillance de la qualité de l'air et spécialiste en ozone,
- Le chargé de la climatologie,
- Le chargé des études liées à la surveillance de l'environnement,
- Des techniciens en observation et maintenance des instruments d'observation météorologique.

Cette équipe sera appuyée par :

- Un expert national en matière de changement climatique,
- Le chargé de recherche au niveau de la direction de la météorologie,
- Un ingénieur prévisionniste,
- Le directeur technique de la météorologie,
- L'expert de recherche, Bureau -Ozone Comores

Les personnes citées travaillent déjà en synergie pour développer, cordonner et mettre en œuvre toute activité relative à la prévision du temps et du climat, à la surveillance de l'environnement et de la qualité de l'air.

7.4. Les besoins en ressources humaines

Pratiquement l'équipe présentement à la Direction de la météorologie est en mesure de lancer le projet une fois qu'elle aura acquis des formations spécialisées sur l'installation, l'opérationnalisation et la maintenance de l'équipement de mesure d'ozone. Par contre, une fois qu'il y'aura suffisamment des données exploitables, l'Agence Nationale de l'Aviation Civile et de la Météorologie va appuyer financièrement ce projet pour recruter des stagiaires et/ou d'un assistant de recherche sur l'ozone de profil géosciences (géosphère), pour l'exploitation des données.

8. Activités

Les principales activités du projet sont les suivantes :

8.1. Achat d'un mini-SAOZ en France

L'Achat du mini SAOZ se fera au près du concepteur de l'appareil à savoir : « Gordien Strato » en France. Le SAOZ a été développé au début des années 80 et elle est utilisée pour la première fois à Dumont d'Urville pour mesurer les colonnes totales de l'ozone dans le cadre de la surveillance du trou d'ozone en Antarctique. C'est un spectromètre UV –visible qui mesure la lumière solaire rétrodiffusée à partir du zénith. L'instrument est désigné pour les observations de la colonne verticale de l'O_3 et du NO_2 dans une bande spectrale de longueur d'onde comprise entre 300 et 600 nm suivant une résolution de 0.8 nm Les observations sont effectuées depuis la surface terrestre pendant le lever et le coucher du soleil. Les observations faites pendant le lever et le coucher du soleil permettent de maximiser le parcours optique dans la stratosphère (20 fois plus que le parcours optique dans la troposphère), ce qui permet d'examiner la stratosphère. La précision des mesures est de 4.7% pour l'O_3 et 10% pour le NO_2

8.2. Organisation d'une mission de transport et d'installation de l'équipement

Etant donné que l'équipement devrait être acheté en France, une mission de transfert de l'équipement de la France aux Comores doit être faite. Vu que le poids de l'instrument est inférieur à 30kg, celui-ci sera transféré par avion. Deux (2) techniciens doivent accompagner l'appareil pour son installation.

8.3. Organisation d'une formation sur l'opérationnalisation et la maintenance

Après installation, les techniciens doivent donner une formation sur l'opérationnalisation et la maintenance de l'appareil. Cette phase est très importante pour la pérennité du projet. La formation sera dispensée aux techniciens et aux observateurs de la direction de la météorologie

8.4. *Observation continue de l'ozone et des composées auxiliaires*

L'observation de l'ozone après installation de l'appareil constitue une des activités principales du projet. Cette activité sera maintenue aussi longtemps que possible et elle comprend 4 phases à savoir : l'acquisition, le traitement, la validation et la sauvegarde de la donnée journalière. Une autre activité prévue dans ce volet est la mise des données nationales sur un réseau d'observation régional et international

8.5. *Réalisation des recherches sur l'ozone au niveau local et régional*

Les études de recherche sur l'ozone seront axé sur :

- l'analyse de la distribution saisonnière et la variabilité interannuelle de l'ozone,
- l'étude des anomalies d'ozone et les principales sources,
- l'étude de l'impact des SAO et de la pollution locale sur la variabilité de l'ozone à l'échelle régionale
- l'étude des tendances de l'ozone à court, moyen et à long-terme
- la conception d'un model numérique servant à prévoir l'évolution spatio-temporelle de l'ozone.

9. Coût de réalisation des activités

Le coût estimé pour la réalisation des activités mentionnées est de **60 585€** reparti de la manière suivante

Désignation	**Description**	**Coût Totale en €**	**Période d'exécution**
Achat Mini-SAOZ	Prix d'Achat d'un Mini-SAOZ depuis le concessionnaire en France	45 000	6 mois
Achat d'un logiciel de traitement des données	Achat d'un ordinateur et d'un logiciel de traitement des données (MATLAB)	2 500	2 mois
Achat Matériel bureautique	Achat des fournitures pour aménager un bureau pour l'installation des matérielles annexes et le traitement des données	1 500	1 mois
Frais de transport et dédouanement des équipements	Frais alloué au transport du Mini-SAOZ par avion, à l'assurance et au dédouanement des équipements aux Comores	2 200	2 jours
Mission 2 technicien	2 billets d'avion et perdiem de deux (2) techniciens pour accompagner les matérielles, l'installer et dispenser les formations pour l'opérationnalisation et la maintenance des équipements	4 000	7 jours
Renforcement de Capacité	Frais alloué à l'assistance technique et aux ateliers de formation des techniciens	2 500	5 jours
Total	**Montant total alloué aux activités prévues**	**57 700**	
Marge de sécurité	57700 x 0.05	2 885€	
COUT-TOTAL		**60 585**	

10. Approche méthodologique de mise en œuvre

Une commission mixte Météo-Bureau Ozone sera mise en place pour l'administration et le suivie du projet. Le projet sera abrité par l'ANACM

11. Pétennisation du proj

Ce projet est inscrit dans le cadre des activités du bureau ozone-Comores et de la direction de la météorologie dans le programme sur l'observation de la terre et la surveillance de la qualité de l'air et l'environnement à partir des outils de télédétection. Dans ledit programme, un poste d'assistant de recherche sur la qualité de l'air est prévu. La personne à recruter aura comme principale mission, la valorisation et le traitement des données des composés atmosphériques y compris l'ozone. Donc le projet aura le soutien entier de la direction de la météorologie pour sa pérennisation.

12. Quelques bibliographies en rapport avec le projet

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CROATIA

1. OBSERVATIONAL ACTIVITIES

1.3 UV measurements
(e.g., broadband, narrowband, Spectroradiometers, etc)

UV-B measurements have been established at main meteorological mountain site Parg since November 2011, and at main meteorological station GMP Zagreb – Maksimir since March 2014.

1.4 Calibration activities

Last calibration of instruments took place in 2015, Innsbruck, Austria. Recommended control of sensitivity of instruments is performed every second year.

2. RESULTS FROM OBSERVATIONS AND ANALYSIS
(e.g., trend analyses, UV doses (annual, monthly etc.), UV maps)

Not yet. In preparation.

3. THEORY, MODELLING, AND OTHER OZONE RELATED RESEARCH
(e.g., 3-D CTM modelling, data assimilation, use of satellite data, UV effect studies)

Not yet. In preparation.

4. DISSEMINATION OF RESULTS

4.2 Information to the public

Forecasts of UV index are issued daily (with special attention during summer periods) and in connection with regular weather forecast provided for TV and radio broadcasting. Forecasts of UV index are also available at the web page od Meteorological and Hydrological service:
http://vrijeme.hr/aktpod.php?id=uvi&param=&code=opis

7. FUTURE PLANS
(e.g., new stations, upcoming projects, instrument development)

Within the project of modernisation of national meteorological infrastructure (METMONIC, 2019-2021) the new network of 20 UV-B measurement sites will be built. In addition, two Brewer instruments for column measurements of ozone will be purchased and installed within the same project.

8. NEEDS AND RECOMMENDATIONS

Severe financial restrictions since 2008 have limited developments in this area with respect to both, infrastructure upgrade and human resources. We expect this situation will be improved in the forthcoming years.

CUBA

OBSERVATIONAL ACTIVITIES

Program of measurements of the total amount of atmospheric ozone and ultraviolet solar radiation (UV-B)

Total Ozone

- The measurements of total amount of ozone at Havana Ozone Station continue from February 2011 until August 2015 when Havana Ozone measurements are interrupted due to difficulties with the transportation of the instrument.
- . The Dobson No.67 was calibrated last time in the IV Regional Dobson Intercomparison in Buenos Aires, Argentina between Nov and Dec 2010 where the instrument was subjected to a deep revision.
- We have assisted and supported the colleagues at the Solar Radiation Observatory of the National Autonomous University of Mexico to restart total ozone measurements with Dobson spectrophotometer #98 after being repaired at NOAA/ESRL/GMD in charge of Robert Evans. Currently the instrument is operational and the station of Mexico City is reporting daily to http://exp-studies.tor.ec.gc.ca/e/ozone/Curr_allmap_g.htm

UV Measurements

- Due to problems with the radiometer (Biometer 501 No.2853 No.2853 manufactured by Solar Light) for UV solar radiation measurements and UV index determination at Havana station these measurements are interrupted since April 2012.
- In any case, partly compensating the lack of ground measurements, an analysis was made of the behavior of the UV index for Havana based on information from OMI (aura_omil2ovp_omuvb_vO3_havana.txt). The statistical analysis of these data were the subject of a bachelor degree thesis at Havana University, no significant trend was found for UV solar radiation for the period 2004-2013 at Havana station.

Stratospheric Aerosol

Grupo de Optica Atmosferica de Camagüey (GOAC) from INSMET, Cuba From 1989 to 1994: Stratospheric aerosols lidar measurements for the Mt. Pinatubo eruption. (*Antuña et al.,* 2002). Measurements interrupted because of the lack of spare parts and instrument aging. This year the Max Plank Institute for Meteorology offered the equipment and parts to refurbish the lidar, pending approval of Cuban authorities.

2008 to the present: Aerosol spectral optical properties with sun photometer in Camagüey in cooperation with the University of Valladolid, Spain. Measurements have been contributed also to AERONET (*Antuña et al.,* 2016).

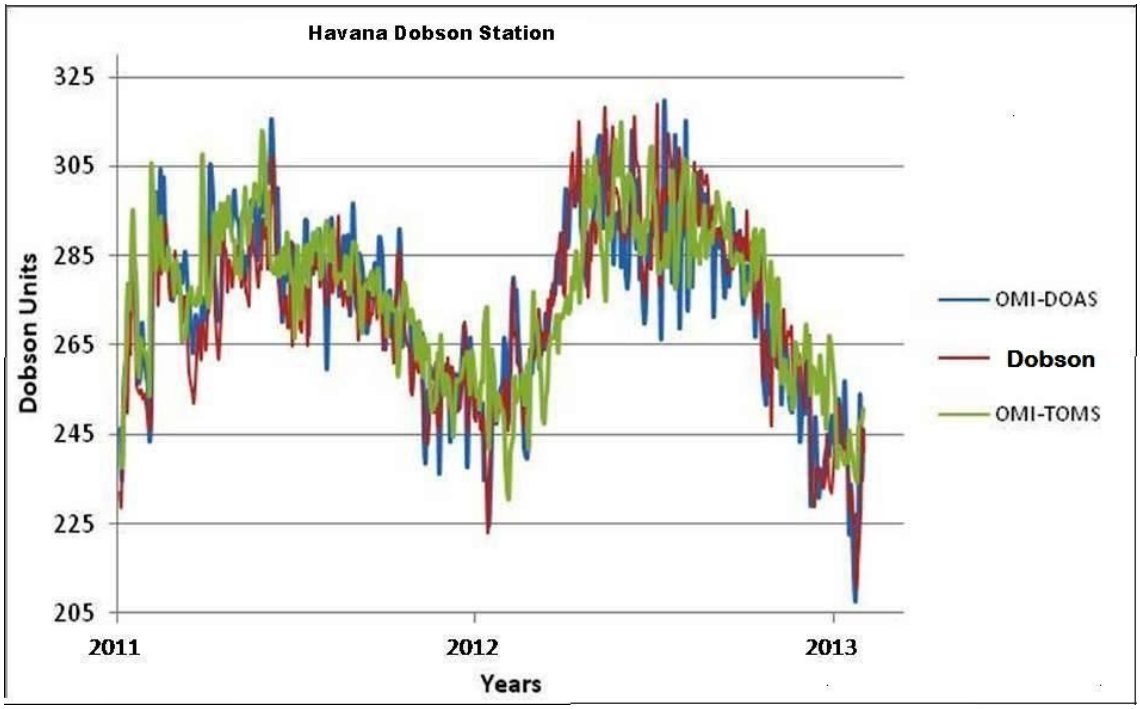
RESULTS FROM OBSERVATIONS AND ANALYSIS

The study of ground measurements at Havana station and those from the OMI instrument over the same location, and at Camaguey station, located Eastward on the National Territory show, in agreement with former reports, the following results.

The total ozone distribution over the National Territory is well defined by an annual cycle with maxima in the summer months and minima in the winter months. The amplitude of this cycle is of about 40 Dobson Units and its mean value is 275 Dobson Units

Regarding the spatial distribution over the National Territory, the total ozone content shows a small latitudinal gradient of about 2 DU between the Eastern and the Western regions in the winter season. In the summer this gradient turns bigger reaching 10 DU in May. The small values in latitude are explained by the disposition of our territory, which practically spans over a single latitude (rigorously just a range no larger than 3.5 degrees). As previously pointed out, the most relevant feature is the wide annual cycle of the TOC.

In addition to the annual cycle, TOC also shows two other seasonal cycles. It is known the variation of ozone following the quasi-biannual oscillation of stratospheric wind, with its greater value precisely over the Equatorial region. At our territory's location, this signal is less visible, but still existent (Bojkov and Fioletov, 1996).



Cuban scientist on lidar measurements from GOAC participated in the WMO panel in charge designing GAW Aerosols Lidar Observation Network (GALION):

J. Bösenberg,R. Hoff, A. Ansmann, D. Müller, **J. C. Antuña**, D. Whiteman, . Sugimoto, A. Apituley, M. Hardesty, J. Welton, E. Eloranta, Y. Arshinov, S. Kinne, V. Freudenthaler, (2008), Plan for the implementation of the GAW Aerosol Lidar Observation Network GALION. GAW Report No. 178, WMO TD No. 1443, 45 pag.

DISSEMINATION OF RESULTS

Data reporting

All data obtained so far has been sent to WODC, an can be consulted on http://esee.tor.ec.gc.ca/cgi-bin/total ozone/ until august 2015 when Havana Ozone measurements are interrupted due to difficulties with the transportation of the instrument

Relevant scientific papers

GOAC members promoted and facilitated the series of Workshops on Lidar Measurements in Latin America from 2001 to the present and the foundation of the Latin American Lidar Network (LALINET). LALINET is one of the regional lidar networks associated to GALION:

J. C. Antuña-Marrero, E. Landulfo, **R. Estevan, B.Barja**, A. Robock, E. Wolfram, P. Ristori, B. Clemesha, F. Zaratti, R. Forno, E. Armandillo, A. E. Bastidas, A. M. de FrutosBaraja, D. N. Whiteman, E. Quel, H. M. J. Barbosa, F. Lopes, E. Montilla-Rosero, J. L. Guerrero-Rascado, 2016, LALINET: The first Latin American-born regional atmospheric observational network. Bull. Amer. Meteor. Soc., http://journals.ametsoc.org/doi/pdf/10.1175/BAMS-D-15-00228.1

Antuña, J. C., A. Robock, G. L. Stenchikov, L. W. Thomason, and J. E. Barnes, (2002): Lidar validation of SAGE II aerosol measurements after the 1991 Mount Pinatubo eruption. *J. Geophys. Res.*, 107(D14), 4194, doi:10.1029/2001JD001441

PROJECTS, COLLABORATION, TWINNING AND CAPACITY BUILDING

- Currently we do not have collaboration any project with foreign institution.

Recommendations 10- ORM

- It would be helpful for technicians who perform measurements and processing of measurements with the Dobson spectrophotometer to be able to attend courses similar to those held at the Hradec Kralove Observatory (Czech Republic) in the same way as holding Dobson Data Quality Workshop which took place in Hradec Kralove in 2011.

- The Dobson Intercomparisons have been greatly extended and now are hardly ever performed every six years, at least for the III and IV WMO´s Regions. We consider that the Intercomparisons of the Dobson instruments should be realized at least every four years.

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CZECH REPUBLIC

In the Czech Republic (CR), the ozone and UV monitoring and research activities are mostly carried out at the facilities of the Czech Hydrometeorological Institute (CHMI). In the recent years, the scientists from the Institute of Atmospheric Physics of the Czech Academy of Sciences, Prague (IAP-CAS) were involved in investigation of the relation between ozone and the processes in the upper atmosphere.

1. OBSERVATIONAL ACTIVITIES

Long-term monitoring of the ozone layer started in CR more than five decades ago in 1961 as a contribution to the initiative of the International Geophysical Year and later to the GAW Programme of WMO. In 1994, measurements of UV spectral and erythemal radiation have been implemented at the Solar and Ozone Observatory (SOO-HK) to couple the monitoring of both important environmental parameters. Currently these activities become more integrated into the projects and in-situ infrastructure of the European Union. Significant attention is paid to the scientific presentation of the outputs and to the public information.

1.1 Column measurements of ozone and other gases/variables relevant to ozone loss.

Uninterrupted daily observations of total ozone column (TOC) by the Dobson D#074 (since 1961), Brewer MK-IV B#098 (since 1994) and MK-III B#184 (since 2004) spectrophotometers have been performed at SOO-HK in Hradec Kralove. The TOC measurements are regularly deposited into the World Ozone and UV Data Center (WOUDC) in Toronto as free available data sets and to the Total Ozone Mapping Center operated by Environment Canada for the daily mapping of the TOC geographical distribution.

The results of O3M-SAF for Central Europe were made available for the public at the CHMI web portal (http://portal.chmi.cz/files/portal/docs/meteo/sat/data_jso3msafview.html).

Since 2010, the Brewer MK-III spectrophotometer B#199 of CHMI has been operated at the station Marambio Base in Antarctic Peninsula, under the bilateral cooperation of CR and Argentina. All available functions of the Brewer spectrophotometer are implemented in the measurement schedule (TOC, UV, Umkehr). This international project is supported by the Ministry of the Environment of the Czech Republic and the State Environmental Fund of the Czech Republic as a contribution of CR to the monitoring of the ozone layer in the polar regions.

1.2 Profile measurements of ozone and other gases/variables relevant to ozone loss

The monitoring of ozone profiles by the electrochemical ozonesondes is carried out at the Upper Air Department (UAD-PR) of CHMI in Prague. Since 1992, the measurements have been performed using the ECC sondes and the VAISALA DigiCORA facility. The balloon-born sondes are launched three times a week from January to April. The observations are submitted to the WOUDC and also to the data bases of the Network for the Detection of Atmospheric Composition Change (NDACC).

Regular daily measurements of the vertical distribution of ozone to about 50 km by the Umkehr inverse technique are performed at SOO-HK by the Brewer spectrophotometers. A special software package was developed by the experts from SOO-HK and NOAA Boulder that is used for operation of the instruments and data processing.

Umkehr measurements continue at the Marambio Base, Antarctica, with the help of B#199 (MKIII).

1.3 UV measurements

1.3.1 Broadband measurements

The UV-Biometers are still operating at three CHMI stations (Hradec Králové, Košetice and Kuchařovice), which are located in three typical climate and geographical regions of CR.

The 10-minute erythemal irradiances (EUV) are collected in the near-real-time at SOO-HK, archived in the CHMI CLIDATA database and presented at the web Portal of CHMI (http://portal.chmi.cz//files/portal/docs/meteo/ozon/o3uvb.html) together with the actual TOC and UV-Index values.

1.3.2 Narrowband filter instruments

Since January 2013, the narrowband spectral measurements of the solar radiation have been carried out at SOO-HK using the 10-channel SPUV-10 filter sun photometer (Yankee Env. Systems, Inc, USA). The instrument measures irradiances at 10 selected wavelengths from UV to IR parts of the solar spectrum (316.6, 331.7, 367.3, 413.4, 495.8, 613.4, 672.0, 869.4, 938.3 and 1023.6 nm). This enables the calculation of atmospheric parameters related to ozone (AOD, NO_x, vertically integrated water vapor amount, SO_2).

1.3.3 Spectrophotometers

Spectral measurements of UV solar radiation are performed with both Brewer spectrophotometers at SOO-HK (B#098 MK-IV 290-325 nm, B#184 MK-III 290-363 nm) and with B199 MK-III at the Marambio Base. The high-quality and evaluated scans from B098 and B184 are submitted also to the European UV Data Base (EUVDB) at FMI, Helsinki. The Brewer MK-III operated at SOO-HK is used as the national reference for calibration of the operational UV-Biometers.

1.4 Calibration activities

The Dobson D#074 instrument is regularly compared towards the regional standard D064 at the Regional Dobson Calibration Center – Europe (RDCC-E), Hohenpeissenberg. The spectrophotometer is maintained as the secondary reference for Europe. D074 was calibrated within the framework of ATMOZ Total Ozone Measurements Intercomparison Campaign, Izana, September 12–30, 2016.

The Brewers at SOO Hradec Kralove (B#098 and B#184) are regularly calibrated every two years by the travel reference B#017 that represents the calibration scale of the World Triad maintained by EC, Canada. In 2015, the calibration was realized at SOO-HK, the calibration in 2017 is under preparation.

Brewer B#199, operating at the Marambio Base, Antarctica, was serviced every year and in 2016 it was calibrated with the help of the travel reference B#017.

The ozonesondes are properly calibrated in the pre-launch preparation procedures defined by the SOPs. Ozone tester Model TSC-1 Ozonizer from the Science Pump Corporation is being used at UAD-PR since 2012.

Calibration of all spectrophotometers and UV-Biometers may be now performed even by the UV calibration unit (dark box, precise power supply and sets of the PTB standard lamps) that is available at SOO-HK. In the future, the calibration activities are to expand, in cooperation with the Czech Metrological Institute within the framework of the European Metrology Research Programme EMRP that is currently underway.

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

One part of data processing was focused on the comparison between "concurrent" Direct Sun (DS) and Zenith Sky (ZS) Brewer MK-III measurements for B#199 (Marambio Base) and B#184 (SOO Hradec Kralove), especially for high MU values. Systematic ZS underestimation was found for MU>3. This underestimation may reach more than 10% for both instruments at extremely high MU values. There are several possible causes of this effect but it indicates lower reliability of ZS measurements at high MU values.

As for the differences between Brewer and Dobson TOC values at Marambio, Brewer TOC vaues were about 1% higher than Dobson ones, on average (based on daily representative values). The minimal mean Brewer/Dobson ratios were found in November (about 1.00), while the maximal ones in August (about 1.03), which indicates the influence of Solar Zenith Angle (SZA).

Erythemal UV (EUV) daily doses were reconstructed and analyzed for Hradec Kralove, Czech Republic, for the period 1964–2013. EUV time series was reconstructed with the help of the libRadTran radiative transfer model supplemented with non-linear regression models based

on observed values (EUV, global radiation, TOC, global and UV albedo, AOD320, AOD550, total column water vapor). An increasing trend of EUV daily doses (ca 3.5% / 10 years) was detected till the mid-90s and it was statistically significant, with the exception of late autumn and early winter. The slight increase in EUV daily doses since the mid-90s was not statistically significant.

3. THEORY, MODELLING, AND OTHER OZONE RELATED RESEARCH

The research activities of IAP-CAS were focused in two directions: (1) Ozone laminae and their long-term trends. (2) Meridional wind in the stratosphere and its longitudinal distribution (this is related to ozone via the Brewer-Dobson circulation). It was found that the positive laminae above Europe, Japan, North America and Arctic over 1970–2011 exhibit a negative trend till the mid-90s and a rather positive trend afterwards. Several factors play a role in the trend in laminae in Europe, namely NAO, EESC and the behavior of the winter polar stratospheric vortex represented by the 10 hPa polar temperature. As for longitudinal distribution of meridional wind, surprisingly large differences in both wind speed and wind direction were found in some periods between ERA reanalyses (ERA-40, ERA-Interim) and Prague soundings at 10 hPa level. With the help of NCEP/NCAR, MERRA and ERA-Interim reanalyses, two structures of stratospheric meridional winds were identified. The first one, a well-developed two-core structure of strong but opposite meridional winds with a core at each hemisphere in the higher northern mid-latitudes, was observed at the 10 hPa pressure level. At the 100 hPa pressure level, there was a less-pronounced four-core structure. Long-term trends in the meridional wind in the "core" areas were significant at the 99% level. The trends were negative during the period of ozone depletion development (1970–1995), while they were positive after the ozone trend turnaround (1996–2012). They were independent of the sudden stratospheric warming (SSW) occurrence and the Quasi-Biennial Oscillation (QBO) phase. The influence of the 11-year solar cycle on stratospheric winds has been identified only during the west phase of QBO. The well-developed two-core structure in the meridional wind illustrates the limitations of the application of the zonal mean concept in studying stratospheric circulation.

4. DISSEMINATION OF RESULTS

4.1 Data reporting

The CHMI facilities continue the deposition of the ozone observations mainly to the WOUDC Toronto and the high quality UV spectral irradiances into the European UV Data Base (EUVDB) at FMI, Helsinki. The daily representative values of TOC are submitted to the World Ozone Mapping Centre of the Environment Canada via the GTS/VIS telecommunication system using the CREX-BUFER codes. The ozone sonde observations are submitted to WOUDC via the NDSC data base and to the partners in the MATCH campaigns.

4.2 Information to the public

For a long time, the actual values of total ozone and the UV-Index at the territory of CR and their comparison with the long-term averages have been presented daily in mass media and at the CHMI web portal: http://portal.chmi.cz//files/portal/docs/meteo/ozon/o3uvb.html. In this way, the public has the access to the actual information related to the condition of the ozone layer and harmful UV irradiances at our territory. Since 2015, the actual data of total ozone from the Marambio station have been presented at the CHMI web portal (http://portal.chmi.cz/files/portal/docs/meteo/ozon/o3picMar.gif).

The results of O3M-SAF for Central Europe were also made available for the public at the CHMI web portal (http://portal.chmi.cz/files/portal/docs/meteo/sat/data_jso3msafview.html).

Public presentations of the complex information on the condition of the ozone layer in the global scale and over the territory of CR were given by the Czech research teams to the public, scientific community and students at joint meetings in the recent years. These were organized by the Ministry of the Environment of CR at universities and in the conference facilities usually in relation with celebration of the International Day for the Preservation of the Ozone Layer. The chief goals and the implementation of the Vienna Convention and the Montreal Protocol were also presented and discussed at the meetings.

4.3 Relevant scientific papers

Except from many oral and poster presentations given at the scientific meetings, including the Quadrennial Ozone Symposium 2016, the following peer-reviewed papers were published in the scientific journals.

- M. Kozubek, J. Laštovička, P. Križan: Differences in midlatitude stratospheric winds among reanalysis data and versus radiosonde observations in Prague. Ann. Geophysicae, 32 (4), 353-366, www.ann-geophys.net/32/353/2014/, 2014.
- M. Kozubek, P. Križan, J. Laštovička: Northern Hemisphere stratospheric winds in higher middle latitudes: longitudinal distribution and long-term trends. Atmos. Chem. Phys.., 15, 2203-2213, 2015, www.atmos-chem-phys.net/15/2203/2015/.
- P. Križan, J. Laštovička, M. Kozubek: Size dependence of ozone lamina characteristics and their correlations. J. Atmos. Sol.-Terr. Phys, 132, 116-123, 2015, http://dx.doi.org/10.1016/j.jastp.2015.06.017.
- J. Laštovička, P. Križan, M. Kozubek: Long-term trends in the northern extratropical ozone laminae. J. Atmos. Solar-Terr. Phys., 120, 88-95, http://dx.doi.org/10.1016/j.jastp.2014.09. 006, 2014.

5. PROJECTS, COLLABORATION, TWINNING AND CAPACITY BUILDING

In cooperation with RDCC-E Hohenpeissenberg, the training of Dobson operators took place in Hradec Kralove in May 2015. The Dobson ozone spectrophotometer D#014 has been lent by the IO3C to the IAO (Institute of Atmospheric Optics) to start the total ozone Dobson observation at Tomsk. Before the installation of the instrument at this ozone monitoring station, the spectrophotometer was refurbished at the MOHp, with the installation of new electronics and alignment, and then it was calibrated against the European regional standard D#064 at the MOHp. Two operators from IAO were trained in the operation of the D#014 spectrophotometer at the SOO-HK. At the same time, two operators from the Kenya Meteorological Department (KMD) Nairobi were trained in the operation of the Dobson spectrophotometer D#074 at the SOO-HK to improve their routine procedures of measurement, testing and reporting. The action was recommended by the SAG-Ozone and organized under the umbrella of the Global Atmosphere Watch Programme (GAW) of the WMO as the activity of the Regional Dobson Calibration Centre – Europe on the capacity building.

In the recent years, the researchers of the Czech institutions participated or still contribute to the following research and development projects and collaborations.

- "Contribution of CR to detection of the stage of the Ozone Layer and UV Radiation in Antarctica". Research project No. 034621022 funded by the State Environmental Fund of the Czech Republic. Measurements of total ozone, Umkehr ozone profiles and solar UV spectra by the Brewer spectrophotometer at the Marambio station. Co-operation of CHMI with the Direccion Nacional del Antartico / Instituto Antartico Argentino. Continued.
- MATCH: International ozonesonde campaigns for the quantification of polar chemical ozone loss since 1998. Participation in yearly campaigns by alert ozonesonde flights. Multinational funding. CHMI, UAD-PR. Continued.
- COST-ES1207 „A EUropean BREWer NETwork – EUBREWNET": Research and development project implemented by the European Union (2013-2017). The creation of a joint infrastructure for the operation of the Brewer spectrophotometers in Europe is the main goal of the project. Experts from CHMI-SOO-HK are involved mostly in creation and implementation of the operational software and calibration procedures of the instruments. Continued.
- NDACC: "The Network for the Detection of Atmospheric Composition Change". Monitoring of the vertical distribution of ozone by balloon flights. CHMI, UAD-PR. Continued.
- WMO/GAW/RDCC-E: "The Regional Dobson Calibration Centre – Europe". Bilateral cooperation between the German Weather Service, Meteorological Observatory Hohenpeissenberg, and the CHMI, SOO-HK on activities of RDCC-E, since 1999.

Calibration campaigns, re-location of instruments, training of operators, software for the GAW Dobson network. Continued.

- Sub-regional calibration campaigns of the Brewer spectrophotometers from Central Europe (CR, Hungary, Poland, Slovakia) towards the travel reference of the IOS, Hradec Kralove, 2015. Continued.

6. IMPLEMENTATION OF THE RECOMMENDATIONS OF THE 9th OZONE RESEARCH MANAGERS MEETING

In the recent years, the organizations in the Czech Republic were active in a number of areas in accordance with the recommendations 9.ORMM, namely:

- Capacity building: training of Dobson operators from Russia (related to D#014 relocation from Tromso to Tomsk) and of the operators from Kenya in 2015.
- Studies of factors affecting UV radiation: cooperation with Faculty of Science, Masaryk University, Brno (diploma and doctoral theses focused on this topic were entered and are being processed).
- Systematic observations: continuation in high-quality TOC and UV measurements in both Czech republic (SOO Hradec Kralove, UAD Prague) and Antarctica (Marambio Base).
- Continuation of measurements of vertical ozone profiles at UAD Prague.
- Active work on ATMOZ project in cooperation with CMI (Czech Metrological Institute).
- Research: activities of IAP-CAS on ozone laminae and stratospheric meridional wind research.

7. FUTURE PLANS

For upcoming years we plan

- to continue all the activities related to running projects and cooperations (see chapter 5), including RDCC-E and RBCC-E activities.
- to continue all running ozone and UV measurements (D#074, B#098, B#184, UV-Biometers, ozonesondes)
- to continue and expand our effort related to ozonesonde-Umkehr comparisons (Marambio base, SOO HK and UAD-PR of CHMI) and analyses of vertical ozone profiles
- to take active part in the implementation of new ozone absorption coefficients (Serdyuchenko) in Europe
- to expand UVI measurements by one mountain station
- to modernize the instruments for ozone and UV measurements

8. NEEDS AND RECOMMENDATIONS

WOUDC, as a key data facility of GAW, does not meet the expectations, especially in

- timely availability of contributed data (e.g. some datasets from past years are not available yet despite the fact that they were uploaded to WOUDC several times)
- almost no feedback from WOUDC (e.g. no feedback information if WOUDC detects some problem with the uploaded extCSV data files, it makes the correction of errors in uploaded files almost impossible).

An urgent attention should be paid to improvement of WOUDC functionality by WMO and Environment Canada.

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DENMARK

1. OBSERVATIONAL ACTIVITIES

The Danish Meteorological Institute (DMI), in collaboration with the Danish Environmental Protection Agency, has conducted continuous measurements of the stratospheric ozone layer. Daily ground-based measurements of the ozone layer thickness as well as weekly balloon based measurements of the vertical ozone profiles have been performed in Denmark and Greenland. The measurements have been reported to international databases. In addition, the measurements are incorporated in validation of satellite measurements. Balloon-based measurements of the ozone layer have often been conducted as part of larger international projects such as Match-campaigns.

1.1 Column measurements of ozone and other gases/variables relevant to ozone loss.

Daily observations of total ozone have been performed by the DMI in Denmark and Greenland:

Station	Location	Instrument	Start of observations
Copenhagen	56°N, 12°E	Brewer Mark IV Brewer Mark III	May 1992 January 2014
Sondre Stromfjord (Kangerlussuaq)	67°N, 51°W	Brewer Mark II Brewer Mark III	September 1990 February 2010
Thule Air Base (Pituffik)	77°, 69°W	SAOZ 1024 diode array	September 1990

1.2 Profile measurements of ozone and other gases/variables relevant to ozone loss

Weekly ozone soundings have been performed using balloon-borne EEC sensors from Scoresbysund (Illoqqortoormiut, 71°N, 22°W) since January 1993. Ozone soundings have also been performed on campaign basis from Thule Air Base each winter since January 1992 and occasionally from Copenhagen.

1.3 UV measurements

1.3.1 Broadband measurements

A Yankee Environmental Systems model UVB-1 radiometer has been operated by DMI in Copenhagen since 1996. A custom UV radiometer (erythemally weighted UV and total UV-A) has been in operation in Thule (Pituffik) since 1993 and owned by Public Health England (former Health Protection Agency and National Radiological Protection Board), the UV-B part of the instrument being very similar to the Solar Light model 500 UV-B radiometer.

1.3.2 Narrowband filter instruments

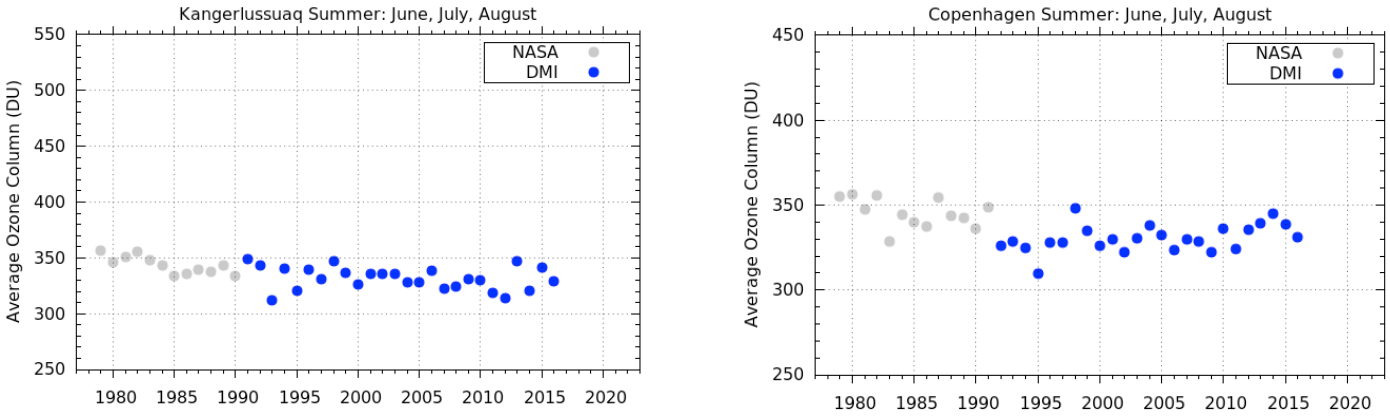
A narrowband filter instrument – Biospherical Inc., model GUV2511 – has been operated on the east coast of Greenland at Scoresbysund (Illoqqortoormiut) by DMI in the period 2008-2015.

1.3.3 Spectroradiometers

At Sondre Stromfjord (Kangerlussuaq) the Brewer MkII instrument has measured spectral UV-B (290-325nm) since late 1990 and the Brewer MkIII instrument since February 2010.

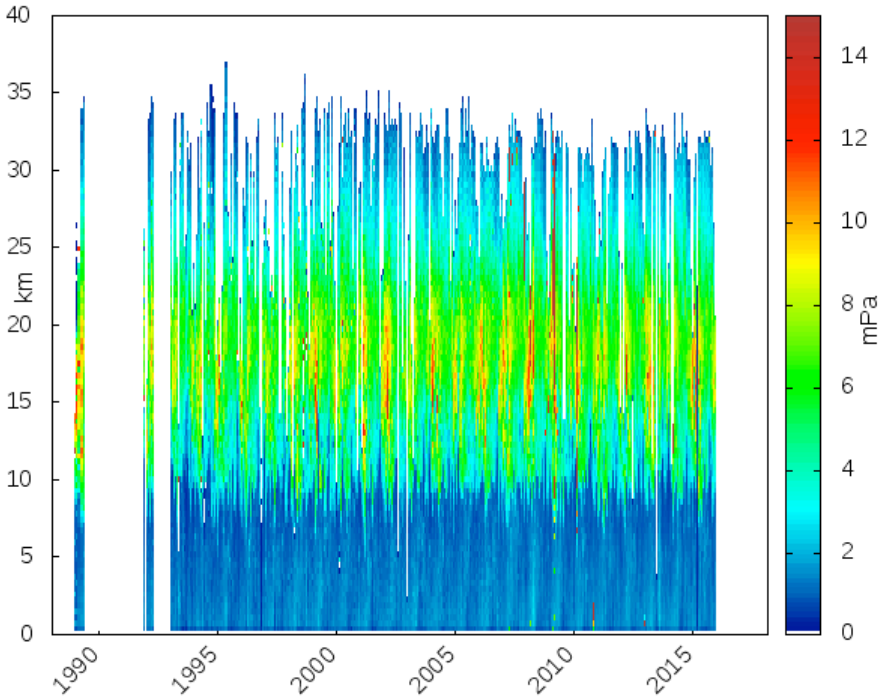
2. RESULTS FROM OBSERVATIONS AND ANALYSIS

Summer (June, July, August) average column ozone measurements, based on NASA TOMS Nimbus 7 version 8 (years 1979-1991) and DMI Brewer (years 1992-2016) from Sondre Stromfjord (Kangerlussuaq), Greenland, are shown in left-hand side in the figure below.



Likewise summer (June, July, August) average column ozone measurements, based on NASA TOMS Nimbus 7 version 8 (years 1979-1991) and DMI Brewer (years 1992-2016) from Copenhagen, Denmark, are shown in the right-hand side of the figure. Neither data set shows significant trends since 1994.

Below is shown the 23-year long record of weekly ozone soundings from Scoresbysund (Illoqqortoormiut). Shown are the vertical profiles of ozone partial pressure (mPa).



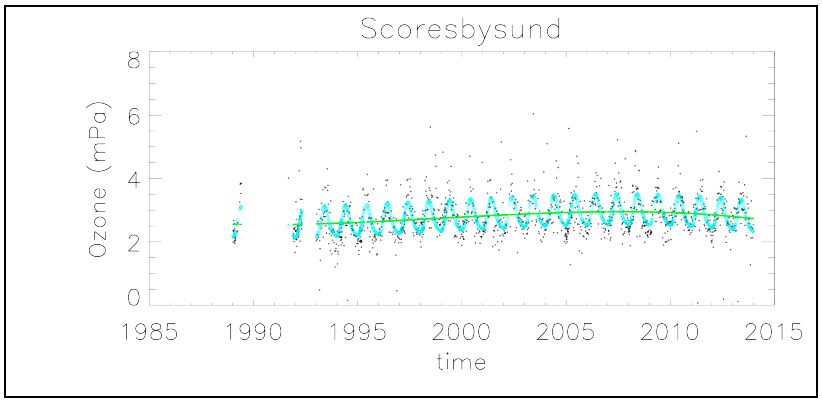
3. THEORY, MODELLING, AND OTHER RESEARCH

DMI has participated in major European Arctic and tropic campaigns since the beginning of the 1990's including EASOE, SESAME, THESEO, THESEO-2000-SOLVE, VINTERSOL, HIBISCUS, and Scout-AMMA, as well as a long series of EU-projects. The research was based on a broad spectrum of accessible observations and analyses of meteorological conditions in the stratosphere.

DMI participates in the EC-Earth climate model development, in particular regarding an improved representation of the stratosphere, and studies are performed on the downward influence from the stratosphere on tropospheric climate.

Using the personal exposure data combined with satellite and ground station data DMI has participated in the development of more accurate models to assess the impact of climate change on future UVR exposure to European populations.

Analysis of tropospheric ozone from selected Arctic stations has been conducted using funding from Nordic Council of Ministers. The work was done with Nordic partners from NILU and FMI. The model used contained a trend, an annual cycle and noise. Parameters were determined using a Metropolis-Hastings algorithm. A sample result is shown below for Scoresbysund at 500 hPa. Cyan curve is annual cycle and green curve is trend.



4. DISSEMINATION OF RESULTS

4.1 Data reporting

The measurements are reported to databases under Network for the Detection of Atmospheric Composition Change (NDACC) and World Ozone and UV-radiation Data Center (WOUDC) under the WMO-programme Global Atmosphere Watch (GAW), as well as to NILU. Brewer data has since 2016 been uploaded to the EUBrewnet database, a result from COST Action ES1207.

4.2 Information to the public

UV-index forecasts, based on Danish total ozone measurements, were initiated at DMI in summer 1992. This public service runs permanently, made public on the Internet and in several media. DMI is responsible for the Near Real Time UV-index processing as part of the EUMETSAT Satellite Application Facility on Ozone and Atmospheric Chemistry Monitoring and provides daily global maps of clear sky UV-indices. DMI has initiated a UV service for Greenland in collaboration with the Greenland Department for Health in 2008. DMI's ozone measurements are made available on the Internet (www.dmi.dk) together with a yearly updated status report (in Danish language).

4.3 Relevant scientific papers

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C. Di Biagio, A. di Sarra, P. Eriksen, S.E. Ascanius, G. Muscari and B. Holben: Effect of surface albedo, water vapour, and atmospheric aerosols on the cloud-free shortwave radiative budget in the Arctic. Climate Dynamics. DOI 10.1007/s00382-011-1280-1. 2012

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G. L. Manney, M. Santee, M. Rex, N.J. Livesey, M. C. Pitts, P. Veefkind, E. R. Nash, I. Wohltmann, R. Lehmann, L. Froidevaux, L. R. Poole, M. R. Schoeberl, D. P. Haffner, J. Davies, V. Dorokhov, H. Gernandt, B. Johnson, R. Kivi, E. Kyrö, N. Larsen, P. F. Levelt, A. Makshtas, C. T. McElroy, H. Nakajima, M. C. Parrondo, D. W. Tarasick, P. v. d. Gathen, K. A. Walker and N. S. Zinoviev,, Unprecedented Arctic ozone loss in 2011, Nature 478, 469–475, 2011, doi:10.1038/nature10556

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5. PROJECTS AND COLLABORATION

Thule (Pituffik), Sondre Stromfjord (Kangerlussuaq), and Scoresbysund (Ittoqqortoormiit) are Arctic stations within the Network for the Detection of Atmospheric Composition Change. In addition to the DMI instrumentation, aerosol lidars are operated at these stations by the University of Rome (Italy) and SRI International (USA), respectively, together with an FTIR spectrometer at Thule, operated by National Center for Atmospheric Research (USA). DMI also collaborates with Laboratoire Atmosphères, Milieux, Observations Spatiales (LATMOS) (France) for daily total ozone measurements by a SAOZ instrument at Scoresbysund. DMI participates from Thule and Scoresbysund in the yearly Match-campaigns, coordinated by the Alfred Wegener Institute in Germany, with ozone soundings in the Arctic to quantify the chemical ozone depletion. DMI ozone measurements have been used for validation of the Suomi-NPP.

Aerosol sun photometers (Aeronet) from NASA are installed in Thule, Sondre Stromfjord, Scoresbysund and Narsarsuaq in Greenland.

DMI has been involved in European projects on modelling aspects of the stratosphere-troposphere coupling, investigating the importance of a well-resolved stratospheric representation for modelling the tropospheric climate. DMI participated in European projects investigating the adverse and beneficial health effects of ultraviolet radiation (UVR) exposure and in Nordic projects, analysing time series of tropospheric ozone based on balloon borne ozone measurements from several Arctic locations. Lately DMI has also been involved in a COST project 1207, EUBREWNET.

The DMI participates in EUMETSAT's Satellite Application Facility on Ozone and Atmospheric Chemistry Monitoring, developing operational UV-index products, based on satellite measurements of the ozone layer.

6. IMPLEMENTATION OF THE RECOMMENDATIONS OF THE 9th OZONE RESEARCH MANAGERS MEETING

Denmark has contributed to the research recommendation to better quantify trends in vertically resolved ozone data records over the polar regions, in particular regarding tropospheric trends.

Denmark has contributed to the recommendation for continuation of ground-based stations with long-term records which is absolutely necessary to provide a reliable baseline for trend estimation as well as too maintain stewardship of long-term surface UV records.

Denmark has been active in public information services about the development of the ozone layer.

7. FUTURE PLANS

National funding for ozone and UV monitoring in Denmark and Greenland was secured until the end of 2016. In 2017 the funding situation will be renegotiated.

Research efforts will be directed towards improved understanding of the role of stratospheric changes for tropospheric climate including the dynamical coupling between the troposphere and the stratosphere. It is intended to include a stratospheric representation in new developments of the EC-Earth model complex.

8. NEEDS AND RECOMMENDATIONS

It is considered important to monitor the recovery of the ozone layer at high latitudes during changing stratospheric climatic conditions (decreasing temperatures, changes in chemical composition, changes in stratospheric dynamics). Maintaining and running stratospheric monitoring stations in the Arctic and elsewhere is becoming an increasingly heavy burden on national funding sources and possibilities for direct funding of ground-based monitoring activities and data provision should be considered to be included in major international programmes such as the European Copernicus and considered as part of validation efforts for satellite missions by major space agencies.

DOMINICAN REPUBLIC

REPORT OF THE DOMINICAN REPUBLIC ON THE PROGRAMS OF OZONE CONTROL MEASURES TROPOSPHERIC AND STRATOSPHERIC.

The Dominican Republic was recognized by the United Nations Environment Program (UNEP) and the World Meteorological Organization (WMO) for its progress in the Reduction of Substances that deplete the Ozone Layer through the National Ozone Program of the Ministry of Environment and Natural Resources. Through compliance with the Montreal Protocol, whose purpose is the conservation and protection of the Ozone Layer throughout the Caribbean zone.

At the Twenty-eighth Meeting of the Parties to the Montreal Protocol, an amendment on substances that deplete the ozone layer in the city of Kigali, Rwanda, which will substantially reduce the emission of the gases it generates, is being adopted at the Twenty-eighth Meeting of the Parties to the Montreal Protocol By lowering the production and use of hydrofluorocarbons (HFCs).

The HFCs, used mainly in air conditioning, refrigeration, insulation foams and emerged as a replacement for chlorofluorocarbons (CFCs), were found to be harmful to the ozone layer. Since then, it has been determined that HFCs have fostered global warming by trapping 23,000 times more heat than Carbon Dioxide.

The Multilateral Fund of the Montreal Protocol, approved financing to the Dominican Republic for the second stage of the hydrochlorofluorocarbon (HCFC) consumption reduction management plan, with the objective of reducing 40% of these substances, which are broad Use in the refrigeration and air conditioning sectors, these substances are exhausting the Ozone Layer and Global Warming Producer. The project will be implemented in the period 2017-2020 through the National Ozone Layer Protection Program (PRONAOZ).

The Dominican Republic it's in the status of compliance with the Montreal Protocol adopted the Vienna Convention and the Montreal Protocol on Substances that Deplete the Ozone Layer in 1992 and following the amendments of London 12/24/2001, Copenhagen 24/12/2001, the Montreal one 01/10/2009 and the Beijing amendment 01/10/2009.

It fulfilled its commitment to eliminate CFCs, Halon, CBT and Methyl Bromide by the year 2010. The HCFC phase-out schedule, achieving a 15% reduction of its baseline, greater than 10% required by the Protocol of Montreal by 2015.

In cooperation with the Multilateral Fund of the Montreal Protocol, had implemented more than 47 projects since 2000, including the Chlorofluorocarbon (CFC) phase-out plan and the Hydrochlorofluorocarbon Phase-out Plan (HCFC)), Which included the conversion of HCFC-based companies into the manufacture of rigid foams.

The Ministry of Environment and Natural Resources is working on the implementation of the HCFC management plan to eliminate 15.36 tons, which the country promised to reduce by 2020. With regard to tropospheric and stratospheric ozone.

The Dominican Republic has not carried out measurements of stratospheric ozone and ultraviolet radiation, there are no tropospheric ozone measurement programs at the surface level, it does not have the equipment or the technical preparation in this specific area in the ultraviolet UV, the National Office of Meteorology (ONAMET), only measures the sun hour.

The country is in the process of approving the criteria applied in other countries of the Caribbean region to participate in the network of countries that are carrying out these measurements of stratospheric ozone and ultraviolet radiation at a global level due to the large coastal extension of beaches That we already have the tourists that are, exposed to the sun.

The Spanish island is occupied by the Dominican Republic and the Republic of Haiti, two constitutionally separated governments, with different cultures and languages, the island covers an area of 76,420 km², and a coastal line that extends about 3,347 km of beaches and reefs. The Republic of Haiti occupies an area of 27,750 km² of territory and with a coastline of 1,771 km.

The Dominican Republic occupies an area of 48,670 km² of territory, with a coastline of 1,576 km, is one of the main tourist destinations in the Caribbean.

Tables of visits of foreigners to the Dominican Republic

2012	2013	2014	2015
5,047,021	5, 163,682	5, 648,743	6,151003

- **(According to data from the Dominican Economy Report of the Central Bank).**

The decrease in the ozone layer in recent years has a direct consequence on all humans, due to the increase in UV-B radiation (290-320 nm), which reaches the Earth's surface. Although these proportions are small relative to the solar spectrum represented by UV-B radiation, these photons are capable of altering human DNA and its biological effects are directly dependent on wavelength and are represented by biological responses.

According to the organisms being studied, from skin cancer in human, to its effect on the seedling. The effect of exposure to ultraviolet light is given by the concept of doses, so we speak of erythematous (redness of human skin), daily or monthly.

There are three types of rays (UV): UVA, UVB and UVC. UVA rays are of long wavelength and are also responsible for the immediate pigmentation of the skin and tan, which penetrate slowly into the deeper layers of the skin, and cause changes in blood vessels, stains, aging Cutaneous lesions and precancerous lesions, although they have often been considered harmless.

The UVB radiation, of medium wavelength, possesses greater energy but penetrates little in the skin. Its effects are cumulative and are responsible for burns, increased thickness of skin and skin cancer. The short UV rays, or UVC, are the most aggressive but do not cross the stratospheric ozone layer because they are absorbed into the atmosphere.

In this respect, Dr. Guzman a specialist in skin surgery, revealed that in a study conducted in the Dominican Republic, where 365 patients were evaluated, and that 90% of these individuals had tumors in the face, 95% in Nose, cheek and mouth from high exposure to the sun. This said that the cell cancer is caused by excessive exposure to the sun and said that this type of jail does not tend to metastasize nor does it require chemo therapy in most cases, but surgery with removal of the area Affected.

The Dominican Republic, located between the Tropic of Cancer and Ecuador; the tropic of cancer is one of the states of the planet that is located in the Northern Hemisphere. In the parallel at a latitude of 23˚26'50 "north of the equator, it travels south at a rate of 14.4 meters / year, in a half-second time (0.46s / y. Delimits the most northern points in That the sun, is placed in the Cenit (the vertical of the place), this phenomenon happens between the 20 and June 21 of each year.

For this reason it is termed as the solstice of June, where the solar rays fall vertically, on the ground, in the imaginary line of the northern hemisphere tropic (Tropic of Cancer). According to the Ecuadorean Civil Space Agency (EXA), quoted by the British Broadcasting Corporation: (BBC), the inhabitants of the equatorial strip and the Tropic of Cancer daily receive extreme ultraviolet radiation levels due to the deterioration of the ozone layer.

The study, says the British Broadcasting Corporation (BBC), World, bases its measurements made by the Ecuadorian Civil Space Agency (EXA) in the last six months and in the information provided by 10 satellites belonging to different space and environmental agencies around of the world. Data from satellite images and ultraviolet (UV) sensors indicate that this region is subjected most of the day to UV rates much higher than those recommended by the World Health Organization (WHO). The EXA warns that the short- and medium-term exposure of this phenomenon will be an increase in cases of skin cancer and other diseases related to excessive exposure to radiation.

The National Ozone Program of the Ministry of Environment and Natural Resources of the Dominican Republic requests the support of the United Nations Environment Program (UNEP) for its work to promote the cooperation of the member countries of which we are signatories. The Dominican Republic addressed the National Ozone Officers, where they undertook to establish coordination mechanisms with the countries of the region and their regional representatives before the Executive Committees and Implementation of the Montreal Protocol on issues relevant to the financing guidelines and fulfillment.

In addition, we wish to have the opportunity as a country to socialize our experiences, lessons learned and training opportunities in relation to ultraviolet radiation and motivate the National Ozone Officers who require such support, establish a bilateral dialogue or request that it be facilitated South-South cooperation and other regional mechanisms.

Finally, the Assistance Program for the implementation of the United Nations Environment Program (UNEP) for its work to promote the cooperation of member countries.

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ECUADOR

1. OBSERVATIONAL ACTIVITIES

1.3 UV measurements

Since 2013, The Meteorology and Hydrology National Institute (INAMHI) starts measuring UV radiation on nine weather automatic stations located around Ecuador country.

Table 1: Weather stations with UV sensors and date period of measuring

Weather Stations	Geographic location				Sensor/ equipment		Measuring	
	zone	Latitude (°)	Longitude(°)	Altitude (masl)	Brand	Model	Start	Last records
Cuenca	highland	-2.8972444	-79.0058611	2587	Kipp&Zonen	UV-S-AE-T	oct-13	dic-15
Izobamba (Quito DM)	highland	-0.3660889	-78.5550611	3085	Kipp&Zonen	UV-S-AE-T	oct-12	dic-16
					Kipp&Zonen	Brewer MKIII Nro. 218	ene-14	mar-16
Loja	highland	-4.0197222	-79.2011111	2160	Kipp&Zonen	UV-S-AE-T	jun-13	dic-16
Pedernales	coastland	0.0638056	-80.0502222	25	Kipp&Zonen	UV-S-AE-T	abr-13	dic-16
Pichilingue	highland	-1.0743056	-79.4929167	2	Kipp&Zonen	UV-S-AE-T	jun-13	dic-16
Puyo	jungle	-1.5075000	-77.9438889	960	Kipp&Zonen	UV-S-AE-T	jun-13	dic-16
Riobamba	highland	-1.6547222	-78.6811111	2850	Kipp&Zonen	UV-S-AE-T	abr-15	dic-16
San Gabriel	highland	0.5998333	-77.8219167	2846	Kipp&Zonen	UV-S-AE-T	jun-15	dic-16
Santa Elena	coastland	-2.2336056	-80.8751000	38	Kipp&Zonen	UV-S-AE-T	jun-13	dic-16

The UV data has been recorded every minute, and Brewer MKIII every 5 minutes. The data series are available since start date shows on the table 1. All this weather stations include also other meteorological parameters measurements.

1.4 Calibration activities

Previous to install UV-S-AE-T sensors in each weather station, they were tested by contrasting among all UV sensors during their acquisition process. After that, each sensor was verified annually in field by contrasting with other US-S-AE-T sensor selected as reference previously. Since September 2015, these sensors do not have maintenance.

The BREWER BR218 spectrophotometer has only one calibration until now. It was performed in November 2013, during its acquisition procedure, by field contrast with other BREWER BR158 (Kipp & Zonen´s won). This equipment shows troubles with orientation calibration because it was built to work at median latitudes locations and, it cannot work with an equatorial geographic location satisfactorily. It is necessary a full reinstallation of this spectrophotometer in order to reorient it to the north or south each

equinox and, the software got several jams during this procedure also. Nowadays, this equipment is out of order as consequence to electrical storm occurred in April 2016.

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

The main outputs from UV data set note that Ecuador country has actual very higher values of Ultraviolet Index (UVI). The Table 2 and 3 show a maximum UVI value in each month during 2014 and 2015.

Table 2: Maximum UVI values observed at six weather stations, at year 2014

2014	Cuenca	Izobamba	Loja	Pedernales	Pichilingue	Puyo	Santa Elena
January	17.77	17.18	-	-	-		-
February	18.26	16.83	-	-	-		-
March	-	17.05	-	-	-		-
April	-	17.09	-	-	12.88	15.08	14.8
May	15.28	15.65	15.52	-	11.72	13.8	14.48
June	13.81	13.96	13.24	-	10.88	13.08	12.04
July	14.32	14.61	14	-	10.04	12.72	11.16
August	15.03	15.04	14.68	11.71	10.6	12.52	12.16
September	14.78	15.94	16.08	12.44	12	12.76	11.84
October	16.41	17.2	17.32	11.69	12.48	12.48	14.64
November	15.9	17.12	-	10.35	11.12	11.12	-
December	16.56	17.09	-	10.06	11.48	13.6	-

Table 3: Maximum UVI values observed at nine weather stations, at year 2015

2015	Cuenca	Izobam-ba	Loja	Peder-nales	Pichilin-gue	Puyo	Riobam-ba	San Gabriel	Santa Elena
January	16.5	17.81	-	-	12.64	13.76	-	-	-
February	17.63	18.61	-	-	14.12	15.52	-	-	15.96
March	18.26	19.58	-	-	14.4	15.32	-	-	17.16
April	17.56	18.18	-	13.49	13.96	15.84	19.34	-	16.12
May	14.87	16.49	-	12.15	11.4	13.72	16.64	-	14.04
June	13.14	15.36	-	10.6	10.16	12.08	14.96	13.67	12.08
July	14.95	15.22	12.98	11.24	10.04	12.4	15.51	14.1	11.96
August	15.27	16.02	13.68	10.98	11.32	13.36	15.53	15.28	13.04
September	15.1	15.62	14.52	10.66	10.76	13.08	16.3	14.6	13
October	16.93	16.79	17.09	12.28	11.68	13.56	18.56	15.76	15.24
November	17.14	16.44	16.55	10.41	10.68	13.84	16.32	14.88	12.71
December	17.47	16.48	15.74	11.54	11.62	14.86	16.45	15.08	14.2

Figure 1. Cuenca weather station, maximum UV Index measurements by month and distribution of all available measurements in 2014 and 2015.

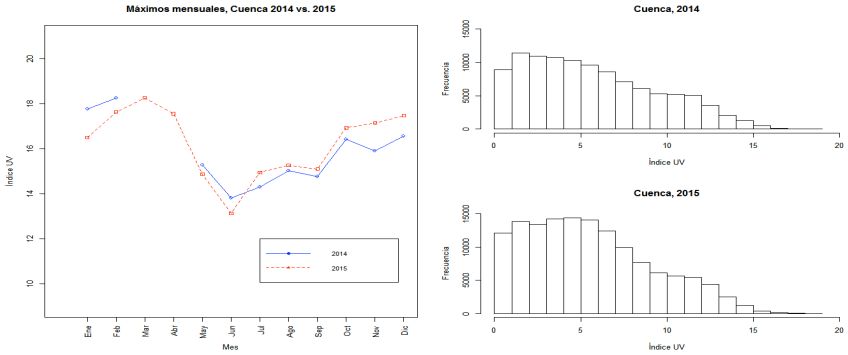


Figure 2. Izobamba weather station, maximum UV Index measurements by month and distribution of all available measurements in 2014 and 2015.

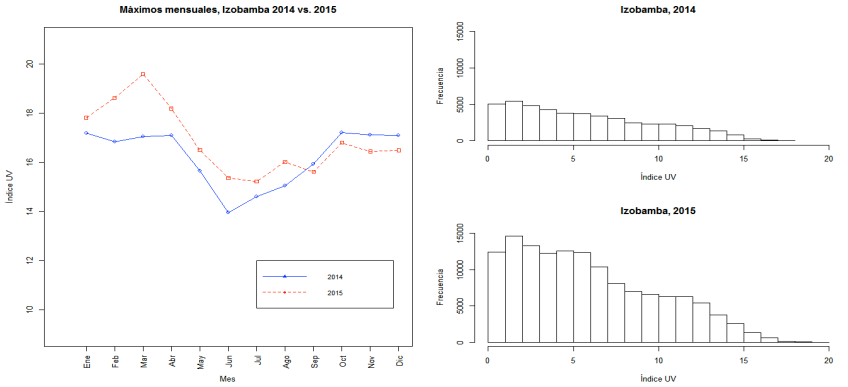
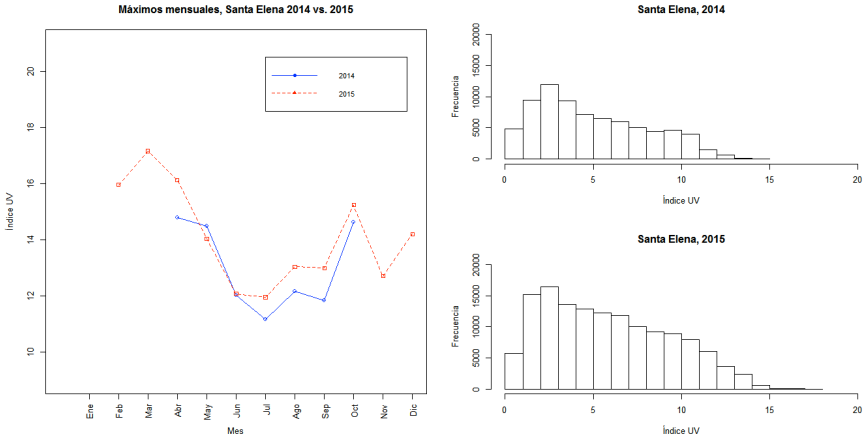
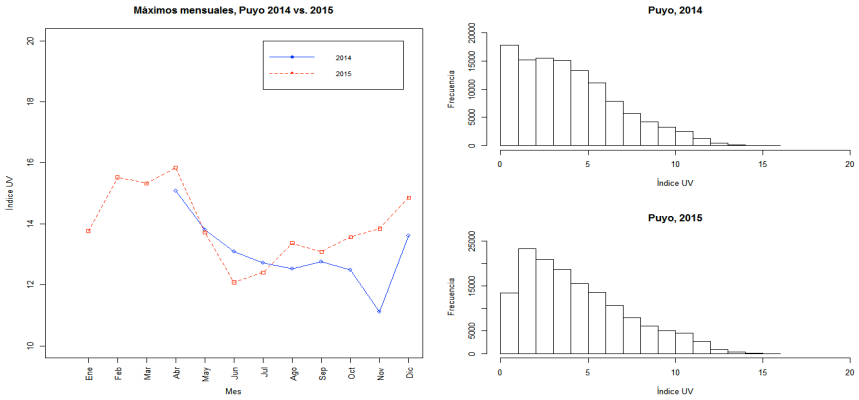


Figure 3. Santa Elena weather station, maximum UV Index measurements by month and distribution of all available measurements in 2014 and 2015.



Figures 1, 2, 3 and 4 show UVI values from selected weather stations as representative places to highland, coastal and jungle cities. In Cuenca (highland) weather station (Figure 1), its maximum UVI values follow similar patterns in 2014 and 2015. In 2014, the highest UVI value recorded was 18.256 (11th February) which was similar to the maximum obtained in 2015 (18.261; 11th March). In addition, its frequency distribution graphics of the measurements obtained in both years show slightly higher frequency of UVI measurements of 4-5 in 2015. In Izobamba (Quito DM) weather station (Figure 2); other highland city, the highest UVI value measured in 2014 was 17.2 (22nd of October) while the highest UVI value in 2015 was 19.6 (7th of March).

Figure 4. Puyo weather station, maximum UV Index measurements by month and distribution of all available measurements in 2014 and 2015.



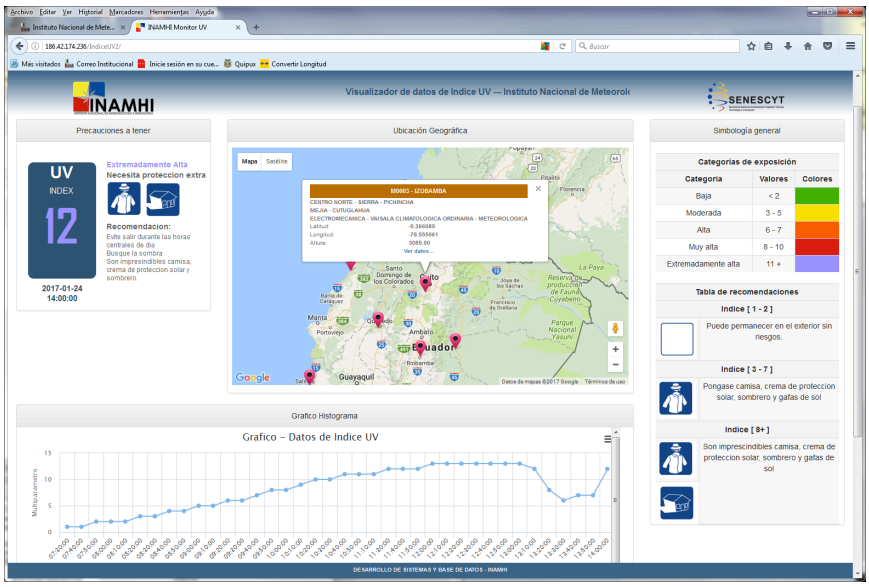
In Santa Elena weather station (Figure 3), a coastland one, the highest UVI value measured in 2014 was 14.80(27nd of April) while the highest UVI value in 2015 was 17.6 (20th of March). In Puyo weather station (Figure 4), placed at near a jungle city, the highest UVI value measured in 2014 was 15.08(16nd of April) while the highest UVI value in 2015 was 15.84 (21th of April).

4. DISSEMINATION OF RESULTS

4.2 Information to the public

Nowadays, eight weather stations are continuously measuring UVI, their data is available in quasi-real time at the INAMHI webpage (1).

Figure 6. Actual webpage screen of online data from UV weather station network



4.3 Relevant scientific papers

Harari Arjona R[1], Piñeiros J[2], Ayabaca M[2], Harari Freire F[3], Climate change and agricultural workers' health in Ecuador: occupational exposure to UV radiation and hot environments, Ann Ist Super Sanita. 2016 Jul-Sep;52(3):368-373. doi: 10.4415/ANN_16_03_08. (2)

María Carzola PhD, Ozone structure over the equatorial Andes from balloon-borne observations and zonal connection with two tropical sea level sites, Universidad San Francisco de Quito, Instituto de Investigaciones Atmosféricas, Colegio de Ciencias e Ingenierías Quito Ecuador, SprigenrLink, Journal of Atmospheric Chemistry, Volume 73/2016, Sprigenr Netherlads. (3)

5. PROJECTS, COLLABORATION, TWINNING AND CAPACITY BUILDING

INAMHI and the Research National Secretariat (SENESCYT) are working together in order to develop a Physics-Chemical Atmospheric laboratory, which is located at YACHAY city, at 80 kms north from Quito DM. In this case, Ecuador need advising support to develop his new research program.

In 2014, The San Francisco de Quito University has developed at Research Atmospheric Institute, and Maria del Carmen Cazorla, Phd, is the current head. (4).

6. IMPLEMENTATION OF THE RECOMMENDATIONS OF THE 9th OZONE RESEARCH MANAGERS MEETING

The deployment of Ultraviolet National network is the main contribution from Ecuador to Montreal protocol, in addition to compliance follow on reduction of SAO substances. Of course, the current economical restriction of Ecuador, has affected INAMHI budget, but, there is enough hope this situation will be overcome in short time.

7. FUTURE PLANS

INAMHI has a duty to maintain the de UV monitory national network permanently and plans to increase the number of weather automatic stations with a new UV sensors. In addition, INAMHI are working to deploy a new reference surface automatic solar station in order to be including into the Baseline Surface Radiation Network (BSRN).

8. NEEDS AND RECOMMENDATIONS

Ecuador needs an urgent advice to develop its Physic - Chemical National Laboratory, in order to prepare list equipment requirements and specifications, preparation of new researcher on these areas and to create a long time research partnership with other partner laboratories.

In the same way, INAMHI also needs an urgent advice about minimal equipment acquisition for its metrology laboratory about solar radiation and air quality, in order to guarantee the quality control of these parameter measurements.

INAMHI will need international financial assistance to maintain the operation of its national UV radiation-observing network, especially to calibrate the BREWER spectrophotometer (#218) and UV sensors, and; hardware and software upgrades for its spectrophotometer.

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EGYPT, ARAB REPUBLIC OF

1. INTRODUCTION

Egypt lies in the northern corner of Africa. It is bounded by the international frontiers of the Mediterranean Sea in the North, the Red Sea in the East, Libya in the west and Sudan in the south. The total area of Egypt is about 1.02 million Km^2 and the Capital is: Cairo. Egypt is geographically divided into four main divisions: The Nile Valley and Delta (approx. 33,000 Km^2) - The Western Desert (approx. 680,000 Km^2) - The Eastern Desert (approx. 325,000 Km^2) - Sinai Peninsula (approx. 61,000 Km^2).

2. CLIMATE

The Egyptian climate is influenced by the factors of location, topography, and general system for pressure and water surfaces. These aspects affect Egypt's climate dividing it into several regions. Egypt lies in the dry equatorial region except its northern areas located within the moderate warm region with a climate similar to that of the Mediterranean region. It is warm and dry in the summer and moderate with limited rainfall increasing at the coast in winter. The annual average day and nighttime temperatures in Lower and Upper Egypt is 20 and 25, and 7 and 17 respectively (1).

Table 1, summarizes monthly-average meteorological parameters for GC over the past 30 years. Through most of the year, wind speed is fairly consistent from the north (ENE to NNW) sector. However, during winter and spring (Nov. – Mar.), somewhat higher average winds are seen in the WSW sector. These often represent desert wind storms (Khamaseen winds) which transport dust from the deserts to the west and produce elevated PM concentrations in GC. Table 1, presents a quick and approximate data for the meteorological elements of the GC area.

Table (1): Monthly-average meteorological data in the greater Cairo (GC) area

Month	Relative Humidity (%)	Visual Distance (Km)	Cloud Cover		Temperature (°C)		Wind Speed (Knots) and Direction [a]			
			%	Cloud Base (m)	Max	Min	E-NE	N-NW	W-SW	S-SE
January	58	9	50	1845	18.1	8.6	9*	-	12**	-
February	56	9	50	1756	19.5	9.4	9*	-	11**	-
March	51	9	50	2164	23.4	11.2	9**	9*	12*	-
April	45	9	50	3068	28.1	14.5	10**	9*	-	-
May	45	9	50	3677	31.8	17.2	10*	9*	-	-
June	49	9	50	1454	34.3	19.9	10*	9**	-	-
July	57	9	50	875	34.2	21.5	8*	8**	-	-
August	61	9	50	731	33.6	21.8	8*	8**	-	-
September	61	9	38	827	32.3	20.2	9*	9**	-	-
October	60	9	38	1628	30.0	18.0	9**	8*	-	-
November	58	9	38	1663	24.4	14.0	9*	-	10*	-
December	59	8	38	2472	20.3	9.9	8*	-	10**	-

[a] A double asterisk (**) indicates a "most probable" value while a single asterisk indicates a less probable value.

Meteorological data (temperature, relative humidity, and wind speed and direction) from Cairo International Airport are available on an hourly basis from the U.S. NOAA National Climatic Data Center. Data from other locations may be obtained upon request to Egyptian agencies. Studies conducted by Lowenthal et al. (2001) and Abu-Allaban et al. (2007) showed that PM_{10} concentrations in GC were higher in fall than in winter, 1999 or during summer, 2002. Surface meteorological data were examined to try to explain differences between fall and winter of 1999 (2). Seasonal-average temperature and vector-averaged wind speed and direction were calculated for four sites in GC. The average winter temperature ranged from 13.7 to 15.4 ^{o}C while the average fall temperature ranged from 19.4 to 20.6 ^{o}C. Thus, the seasonal variation was approximately 5 ^{o}C. The vector-averaged wind direction ranged from 312 to 6 degrees, i.e., from the north, in both seasons at the four measurement locations. The seasonal variation in concentration was thus unrelated to wind direction. The seasonal vector-averaged wind speed ranged from 1.2 to 2.8 mph in winter and from 0.72 to 1.86 mph in fall. The average ratio of winter to fall wind speed was 1.8±0.8. The lower wind speeds during fall along with increased emissions from agricultural burning may explain the higher PM concentrations during that season because lower ventilation associated with low wind speeds may allow for buildup of pollutants in the vicinity of the sources in Cairo (3).

3. OZONE ACTIVITIES IN EGYPT

In Egypt, Systematic monitoring of atmospheric ozone, UV solar radiation and related research activities are conducted by Egyptian Meteorological Authority (EMA). All the observations data are performed by ozone and UV solar radiation experts at the regional ozone center in EMA to end up with high quality ozone and UV measurements. After that the data are stored in the central data base of EMA. The atmospheric ozone and UV solar radiation observations contribute to the regular monitoring of the atmosphere and climate in Egypt and to international activities and projects, mainly to the GAW Program. The World Ozone and Ultraviolet Radiation Data Centre (WOUDC) is one of six World Data Centers which are part of the Global Atmosphere Watch program of the World Meteorological Organization (WMO). The WOUDC data center is operated by the Meteorological Service of Canada, a branch of Environment and Climate Change Canada. Ozone data set categories include total column ozone and vertical profile data from lidar measurements, ozonesonde flights, and the Umkehr technique. Ultraviolet (UV) radiation data set categories include broadband, multiband, and high resolution spectral data types. There are over 500 registered stations in the archive from over 150 contributors. Metadata such as station lists with locations, are available from the WOUDC Website. Value added data products include total ozone time series graphs and near real-time ozone maps. All WOUDC data are made available by using the data search/ download, or web accessible folder (WAF) access. In addition, the Open Geospatial Consortium web services provide enhanced access to the archive, which provides standards-based-on-demand access to the archive.

4. OZONE NETWORK AND MEASUREMENTS

EMA has been involved in the long-term monitoring of the ozone layer for more than 40 years. Measurements of the total ozone amount and ozone vertical profile by the Umkehr method at Cairo (30.08°N, 31.28°E) by means of the Dobson spectrophotometer No.96 started in 1967, long before the depletion of the ozone layer became great challenge for research community and the policy makers. At 1973 Cairo became a Regional Ozone Center (ROC) for ozone stations at North Africa and Middle East. After discovering the ozone depletion, in 1984 EMA established another ozone observatory at Aswan (23.97°N, 32.78°E) measuring of the total ozone amount and ozone vertical profile closed to the tropics region by means of the Dobson spectrophotometer No.69. Since the ozone became an important subject for research community and the policy makers, EMA established another two ozone observatories in both Matrouh and Hurghada in 1998 and 2000 respectively to end up with ozone monitoring network cover the Egyptian sky. In Matrouh, measurements of total ozone and ozone vertical profile by means of Brewer spectrophotometer No.143 while in Hurghada by means of Dobson

spectrophotometer No.59. Table 2, presents the ozone monitoring network in Egypt, and Figure 1, presents the Egyptian ozone monitoring stations.

5. OZONE MONITORING AND ITS OBSERVATIONAL ACTIVITIES

Table (2): The ozone monitoring network in Egypt

	Cairo	Aswan	Matrouh	Hurghada
WMO No.	62371	62414	62306	62464
Ozone ID.	152	245	376	409
Latitude	30.08°N	23.97°N	31.33°N	27.28°N
Longitude	31.28°E	32.78°E	27.22°E	33.75°E
Height (m)	037	193	035	007
Instrument	Dobson # 096	Dobson # 069	Brewer # 143	Dobson # 059
Elements	O_3	O_3	O_3 , UV-B	O_3
Started at	October 1967	December 1984	November 1998	November 2000

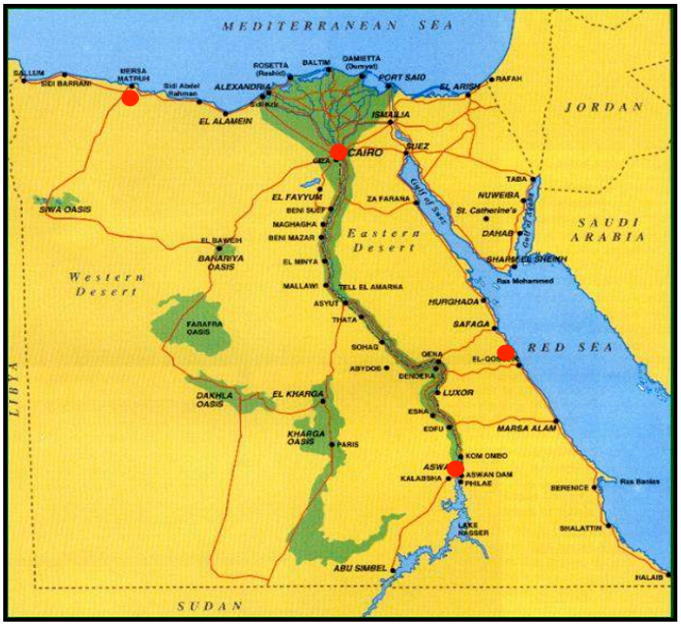


Fig (1): Egyptian Ozone Monitoring Stations

5. Cairo Regional Ozone Center (ROC) duties

- Responsible for all the data and instruments at all Egyptian ozone stations.
- Collecting ozone data form all stations at Egypt.
- Re-calculating the data of all ozone stations by "DOBSON" software package.
- Maintenance and Calibration all ozone instruments.
- Training Dobson and Brewer Operators.
- Re–processing of historical data sets and maintenance of total Ozone database.
- Updating the of zenith polynomials correction.

- All ozone data are regularly submitted to WOUDC (World Ozone and Ultraviolet Radiation Data Centre) in Toronto, Canada.
- ROC researchers promote the main activities of ozone research.

6. VERTICAL DISTRIBUTION OF OZONE

Vertical distribution of ozone in the atmosphere is measured by both Dobson and Brewer Spectrophotometers (Umkehr method) at Aswan, Matrouh and Hurghada. The N-values are stored in the ozone database at EMA and they are also deposited in the WOUDC, Toronto, Canada for final processes.

7. SURFACE OZONE

EMA measures surface ozone outside urban regions, at Hurghada which is an official WMO Global Atmospheric Watch (GAW) station. Also EMA measures surface ozone at Sidi Branni (31.37ºN, 25.53ºE). South Valley University (SVU) in cooperation with EMA has been measured surface ozone at Qena city.

8. CALIBRATION and Research ACTIVITIES

- The Dobson spectrophotometers have been regularly calibrated using Mercury and Standard lamps to adjust ETC, R-N tables and Q-table. In this way their intercomparisons stability can be checked and evaluated (4).
- Dobson spectrophotometers No.96 has been participated in different international intercomparisons which took place at Poland in 1974, at Boulder Colorado (USA) in1977, at Arosa Observatory (Swiss Meteorological Institute) in 1986, at Greece in 1997, at Germany 2001, at Dahab (Egypt) in 2004, and at Hohenpeissenberg Observatory (Germany) in 2011.
- Dobson spectrophotometers No.69 has been participated in different international intercomparisons which took place at Boulder Colorado (USA) in1984, at Hradec Kralove Observatory (Czech Republic) in 1993, at Arosa Observatory (Swiss Meteorological Institute) in 1999, at Dahab (Egypt) in 2004, and at Hohenpeissenberg Observatory (Germany) in 2010.
- Dobson spectrophotometers No.59 has been participated in different international intercomparisons which took place at Hohenpeissenberg Observatory (Germany) in 2010, at Dahab (Egypt) in 2004, and at Hohenpeissenberg Observatory (Germany) in 2009.
- The Brewer spectrophotometer mark II No.64 was calibrated against the reference instrument Brewer No.17 maintained by the International Ozone Corporation (Canada) at the Matrouh observatory in 2005 and 2008, 2015.
- At least one of 3 (Dobson)s will be calibrated the ElAreno2017 in Spain.
- EMA aims to strengthen the network of ozone with new device (Brewer spectrophotometer).

9. ULTRAVIOLET RADIATIOM

EMA measures the broadband UV solar radiation due to its biological effect at different sites. Also EMA in cooperation with University of South valley have been measured the broadband UV radiation at Qena since 2000. The present network for monitoring the UV and UVB radiation at Aswan, Qena, Cairo, Rafaah (31.22ºN, 34.20ºE) is presented in Table 3.

Table (3): The Egyptian UV and UV-B radiation Stations

	Aswan	Qena	Cairo	Rafaah	Matrouh
UV Instrument	Epply Radiometer	Epply Radiometer	Epply Radiometer	-	-
Started at	Aug. 1989	Apr. 2000	Mar. 1989	-	-
UV-B Instrument	UVB-1 Pyranometer	UVB-1 Pyranometer	UVB-1 Pyranometer	UVB-1 Pyranometer	Brewer MII
Started at	Sep. 1998	Apr. 2000	May 1996	Jun. 2000	Jan. 1998

10. COLLABORATION - NATIONAL AND INTERNATIONAL

Ozone and related research are conducted sporadically within the country, mostly at a few academic institutions such as Cairo University, EL Azhar Univesity and South Valley University.

- ROC researchers promote the main activities in ozone research.
- EMA in co-operation with WMO carries out a training program for operators of ozone Arab countries.
  Egyptian Meteorological Authority must also acknowledge its many international collaborators with specific references to international programs as:
- The World Meteorological Organization (WMO) for her support to attend international intercomparisons and training courses. Also for the financial support to organize the intercomparison of the Dobson ozone instruments operated in the Africa region at Dahab from 22/2-12/3/2004.n which 21 specialists and 11 instruments from 10 countries.
- USA NOAA ESRL, Boulder for maintenance the ozone instruments.
- WOUDC, Toronto, Canada for the scientific cooperation.
- Training assistance from the CZECH SOO-HK, in Hradec Kralove
- Germany also DWD (European Dobson Calibration facility).
- The state Meteorological Agency of Spain (AEMET) for offering the Brewer training course.

11. RESULTAS AND ANALYSIS

11.1 Variation of ozone over Egypt:

Figure 2, presents the Maximum values of total ozone amount appear at spring months over Matrouh and Cairo but appear at summer months over Aswan and Hurghada due to the photochemical effect (near to tropical region).

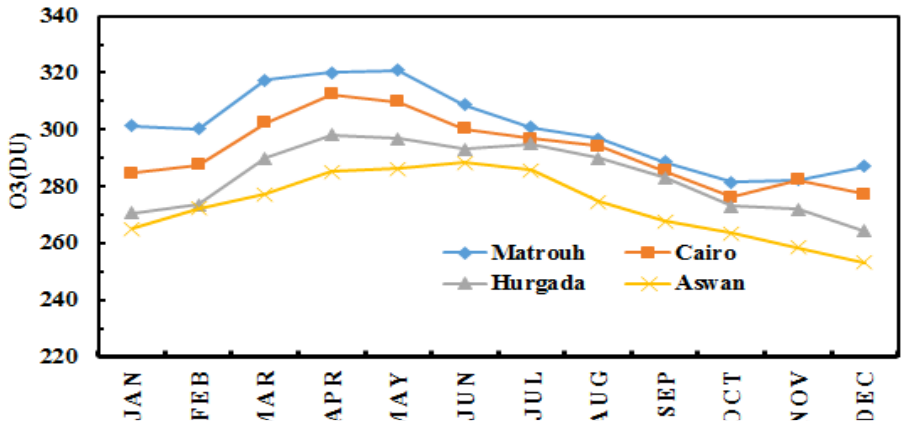


Fig.(2): Annual variation of ozone at Egyptian ozone observatories from 2010 to 2016

Monthly variation and trend of ozone for seven years over Egyptian ozone observatories are presented in Figure 3. The figure shows that the linear trend is negative at all station.

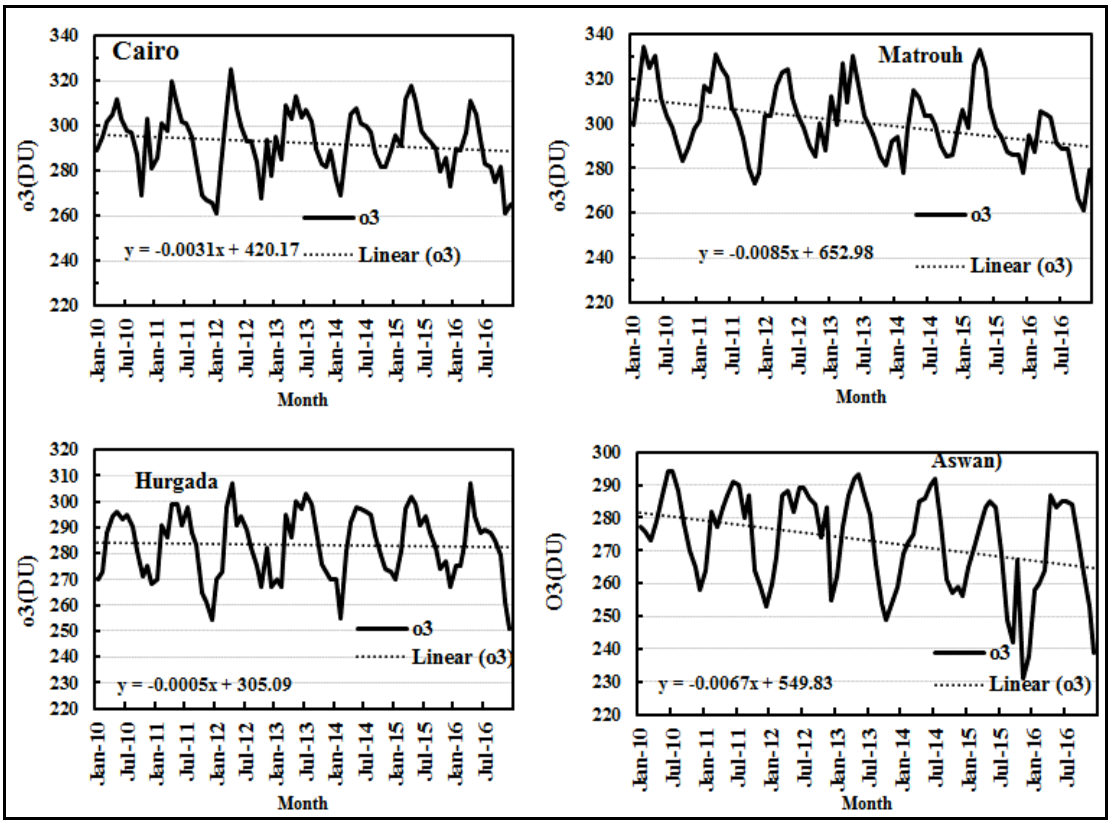


Fig.(3): Monthly variation and trend of ozone at Egyptian ozone stations

11.2 Variation of total column of sulfur dioxide (SO_2) and Aerosol Optical Depth (AOD) at northwest of Egypt

Monthly variations of Aerosol optical Depth (AOD) and total amount of sulfur dioxide to the ground level during the day (dose) at Matrouh [5] shown in Figure 4, and Figure 5 respectively. It shows that SO_2 varies seasonally with a maximum in spring and minimum in autumn and positive trend (+0.0018).

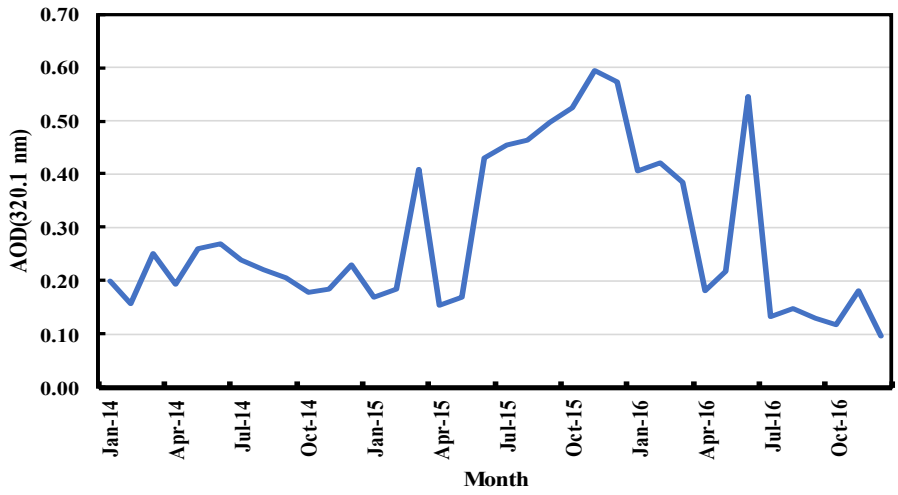


Fig. (4): Monthly variation of Aerosol optical Depth (AOD at 320.1 nm

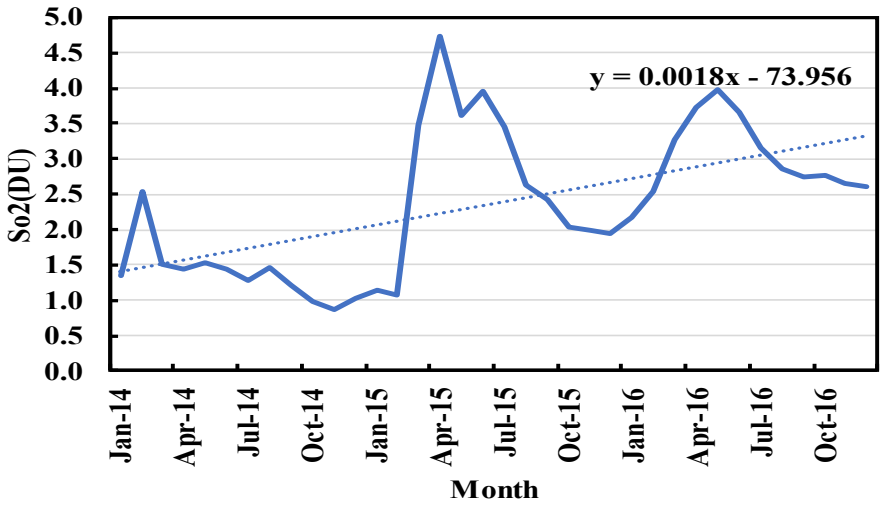


Fig. (5): Monthly variation of total column of sulfur dioxide (SO_2)

11.3 UV index at northwest of Egyptian:

Hourly UV radiation was determined for the entire period evaluated in this study. Figure 6, presents the hourly variation of dangerous UV with its Index over coastal northwest of Egypt (Matrouh). The amount of UVB light at ground level is determined by the solar elevation, the amount of ozone in the atmosphere and the cloudiness of the sky. When the sun raises higher in the sky the amount of atmosphere its rays have to pass through before striking the ground lessens. Therefore UVB protection is critical in the hours around solar noon. A person being out in the sun during midday hours more than ten minutes if you are without protection. A person should wear protective clothing and use a sunscreen, a hat with a brim and sunglasses (4).

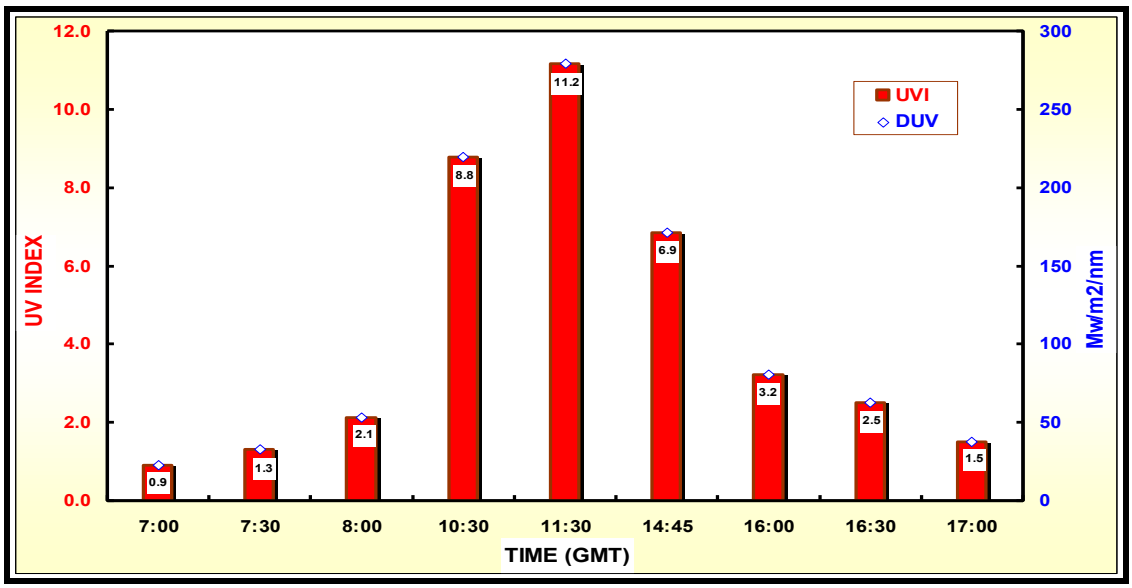


Fig.(6): Diurnal variation of Dangerous UV on a clear summer day over Matrouh

13. Global Warming Potentials (GWP) of ODS's

The global warming potential (GWP) represents how much a given mass of a chemical contributes to global warming over a given time period compared to the same mass of carbon dioxide. Carbon dioxide's GWP is defined as 1.0. A GWP is calculated over a specific time interval and the value of this must be stated whenever a GWP is quoted or else the value is meaningless.

14. Montreal Protocol Projects in Egypt

Montreal Protocol projects in Egypt can be summarized in different sectors. Different projects were conducted to minimize and stop using of these ODS [3]. The Ozone Depleting Potential ODP (Tons) and the Global Warming Potential (GWP) in CO_{2e} metric tons of these projects can be summarized in Figure 7, and Figure 8.

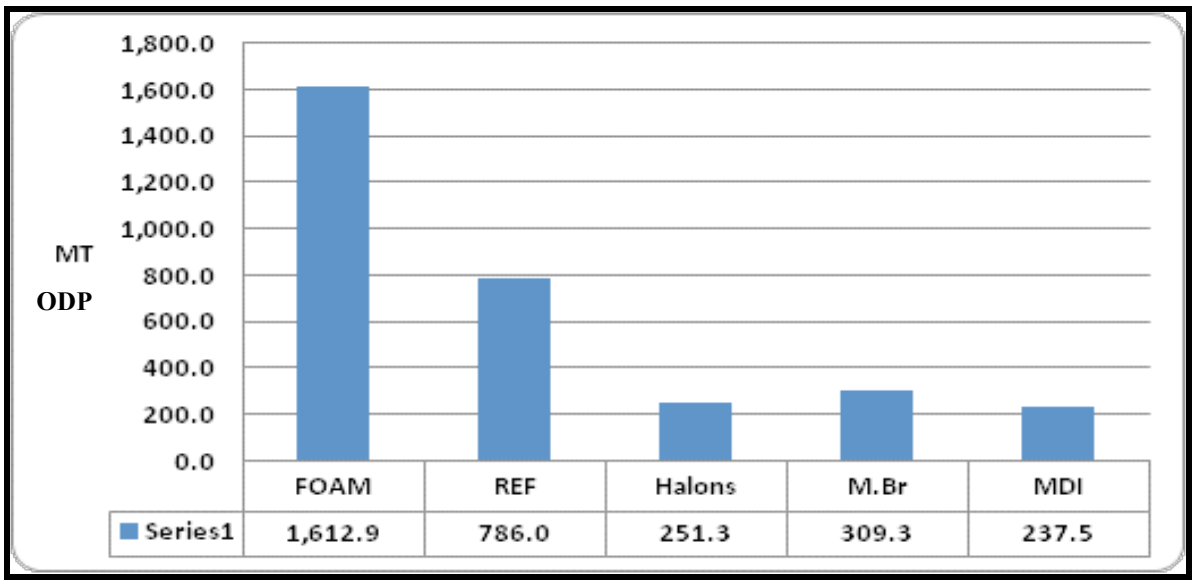


Figure (7): ODP Tons of all Montreal Projects in Egypt

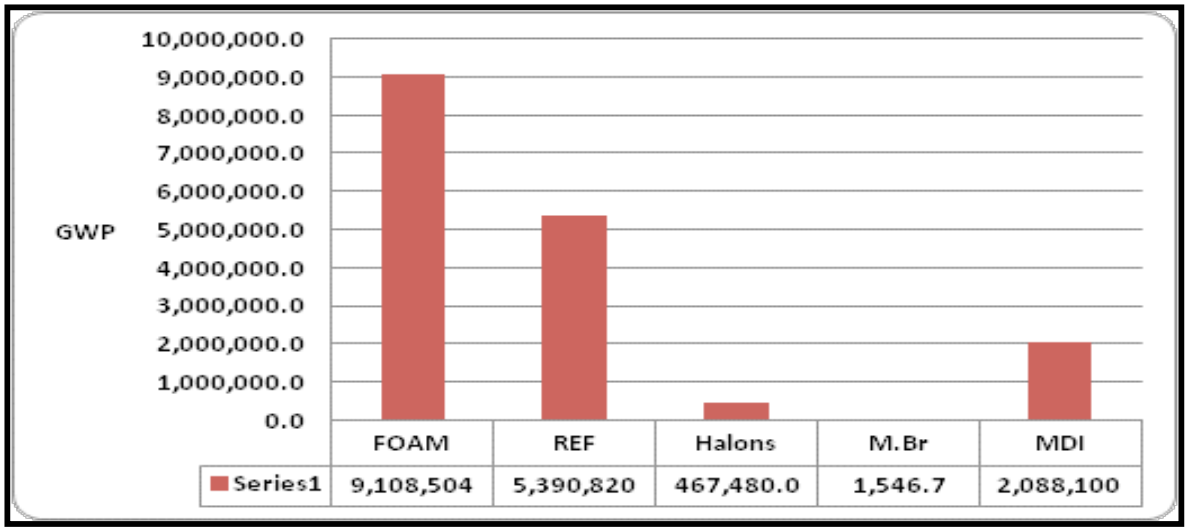


Figure (8): GWP of all Montreal Projects in Egypt (CO_{2e} metric tons)

15. CONCLUSIONS & RECOMMENDATIONS

- Providing a continued maintenance and calibration of instruments such as Dobson, Brewer spectrophotometers and UV sensor with the support of WMO is important.
- It is highly appreciated to get fanatical support to start measuring ozone vertical distribution by ozone node in both Aswan and Matrouh and Farafra upper air stations. Because it is very important to study the tropospheric ozone budget and its impact in climate change.
- It is recommended to take care of problems on operation of instruments and stability of data quality persist at some strategic ozone stations located mainly in developing countries in the tropics and in the Southern Hemisphere. To solve the situation the WMO/GAW and the UNEP Programs should reinforce their key role in the capacity building and in maintenance of the global ozone and UV monitoring infrastructure.
- We in need to involve and connect brewer No.143 by the south Europe Brewer net.
- Participate in a scientific research program for ozone and climate change modeling.
- It is recommended to support awareness programs to increase the use of ODS alternative substances with low or negligible global warming potential.

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3) Abu-Allaban, M. Lowenthal, D.H., Gertler, A.W., and Labib, M., 2007: "Sources of PM10 and PM2.5 in Cairo's ambient air". Environ. Monit. Assess. 133, 417-425.
4) Egyptian Environmental Affairs Agency – Ozone Unit: Website, http://www.eeaa.gov.eg/
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ESTONIA

1. OBSERVATIONAL ACTIVITIES

The monitoring of atmospheric ozone and solar UV radiation in Estonia is performed by the Estonian Environmental Agency and Tartu Observatory, a research institute specializing in astronomy, remote sensing and space technology.

The main instrumentation for ozone and UV related measurements are located in South Estonia, at Tõravere (58° 15' N, 26° 28' E, 70 m a. s. l.), the location of Tartu Observatory and the Tartu-Tõravere Meteorological Station. The landscape pattern around the Tartu-Tõravere monitoring station consist of arable fields, grassland areas and patches of coniferous forest. It may be considered typical to Estonia. Since 1999, the meteorological station has belonged to the Baseline Surface Radiation Network (BSRN) and is specialized in solar radiation measurements.

Scientific work on ozone and UV radiation is mostly performed at Tartu Observatory by the department of remote sensing. Different auxiliary regular measurements like aerosol and cloud data collection are taken at the same site.

The NASA AERONET sun photometer measuring column aerosol optical depth (AOD) has been operating there since 2002.

1.1 Column measurements of ozone and other gases/variables relevant to ozone loss

Column ozone data is received from satellite measurements. The Tartu-Tõravere meteorological station also has MICROTOPS-II instrument for direct sun column ozone measurements. The instrument is irregularly in use mainly for comparison to the satellite data.

1.2 Profile measurements of ozone and other gases/variables relevant to ozone loss

No profile measurements of ozone have been performed in Estonia.

1.3 UV measurements

1.3.1 Broadband instruments

Broadband measurements of UV radiation are performed by the Estonian Environmental Agency in cooperation with the research scientists from Tartu Observatory.

There are 5 meteorological stations (Tartu-Tõravere, Haapsalu, Pärnu-Sauga, Roomassare and Tallinn-Harku) measuring UV index (UVI) with erythemally weighted sensors UV-S-E-T in Estonia. At the Tartu-Tõravere station there are 2 sensors measuring simultaneously and there is another one for calibration.

Locally developed, manufactured and tested broadband UV-A and erythemal sensors on the basis of the solar blind phototube with caesium telluride photocatode were installed in 2002. Also, a Kipp & Zonen broadband UV-A sensor CUV3 is installed.

1.3.2 Narrowband filter instruments

The Kipp & Zonen narrowband filter instrument CUVB 1 with effective wavelength 306±0.2 nm and bandwidth 2±0.5 nm has been operating at the Tartu-Tõravere Meteorological Station since 2002.

1.3.3 Spectroradiometers

Spectral measurements of solar UV radiation have been performed by Tartu Observatory since 2004. In 2004 to 2009 UV spectra in spectral range 290-400 nm were recorded by Avantes

Inc. simple compact array spectrometer AvaSpeC-256. Using of this instrument was stopped in 2009 due to decrease of array sensitivity.

Since 2009 spectrometric system is based on Bentham Instruments Ltd DMc150F-U double monochromator. It is measuring from sunrise to sunset with 15 minute intervals in the wavelength range of 280-400 nm. Scanning of each spectrum takes approximately 40 seconds. All the spectra are recorded in a database.

In summer 2016, diffuse UV measurements were started at Tartu Observatory in addition to global UV radiation.

1.4 Calibration activities

The broadband instruments operated by the Tartu-Tõravere Meteorological Station of the Estonian Environment Agency need regular recalibration and intercomparison. During the period of UV measurements the Eppley Labor Inc. pyrheliometers and the Kipp & Zonen pyranometers were used as broadband solar radiation sensors. The intercalibration of sensors is regularly performed in the World Radiation Center (Davos, Switzerland) with the support of WMO. Between the campaigns, the absolute radiometer PMO-6 nr R850405 is used as a secondary standard for regular assurance of the calibration.

The Kipp & Zonen UV-S-E-T instruments are calibrated with a comparison instrument that is planned to be sent to Davos for intercomparison.

The CUVB1 narrowband instrument is calibrated at the optical laboratory of Tartu Observatory.

The spectroradiometric Solar UV system is calibrated in the measurement configuration, i.e. the fiber and measurement head attached, using the field calibrator CL6-V (S/N 9759/1) every 3 months. CL6-V is calibrated at the optical laboratory of Tartu Observatory against a NIST traceable 1000 W quartz tungsten halogen lamp (FEL) once per year.

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

The research presently done in Estonia using ozone data focuses on the studies of spectral composition of ground-level UV irradiance and doses as environmental, biospheric, and health effects as well as influence on atmospheric photochemistry depend on spectral composition of incoming solar radiation in the UV range.

At the site of Tartu Observatory the data set of weather condition data extends back to 1955 and allows using proxies like daily and hourly sums of global and direct incoming irradiance and sunshine duration. The auxiliary data are digitized and the files prepared for using in treatment and analysis of daily spectra. The work is addressed to potential collaboration with the researchers of UV effects.

At the study site the width of recorded UVA wavelengths is 85 nm (315–400 nm) in all cases, the range of recorded UVB varies significantly due to limits set by the instruments sensitivity. By definition it is 35 nm (280–315 nm), but the observed range can be even as short as 5 nm (310–315 nm) and generally doesn't exceed 20 (295–315 nm). The ratio UVA/UVB may reach about 500-600 just after sunrise of before sunset and decreases to less than 50 in summer noon hours. In cloudless conditions the major modulators of the ground-level UV irradiance are column ozone and spectral aerosol optical depth.

3. THEORY, MODELLING, AND OTHER RESEARCH

Models for calculating UVB and UVA daily doses have been developed on the basis of freely available software ARESLab and libRadtran. The models use measured daily global solar radiation, column ozone, noon SZA and calculated clear sky UV daily dose.

The models have been used for reconstruction of UVB and UVA daily doses back to 1955. Annual doses of UVB calculated in the data reconstruction are presented in Figure 1. The models are continuously in use for filling gaps in measured data series.

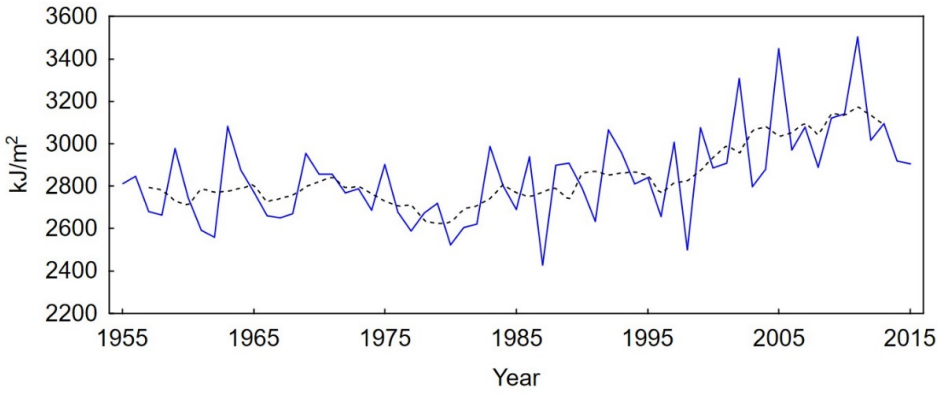


Figure 1. UVB annual doses (blue line) with 5-year moving average (black dotted line) from 1955 to 2015 at Tõravere, Estonia. Solely calculations have been used for the period 1955–2003 and measurements combined with calculations (in case of no available measurements) for the period 2004–2015.

Analysis of the data shows an increase in annual doses of UV radiation since the 1980s, UVB reaching maximum levels in 2011. This is supported by the broadband solar radiation measurements at Tartu-Tõravere meteorological station, showing similar increase in available solar radiation and extremely high radiation levels in 2011. The results are also supported by ozone data as the average ozone levels in Estonia have stayed at a lower level for the past decades but with high variability, e.g. in 2011 the annual average ozone was very low.

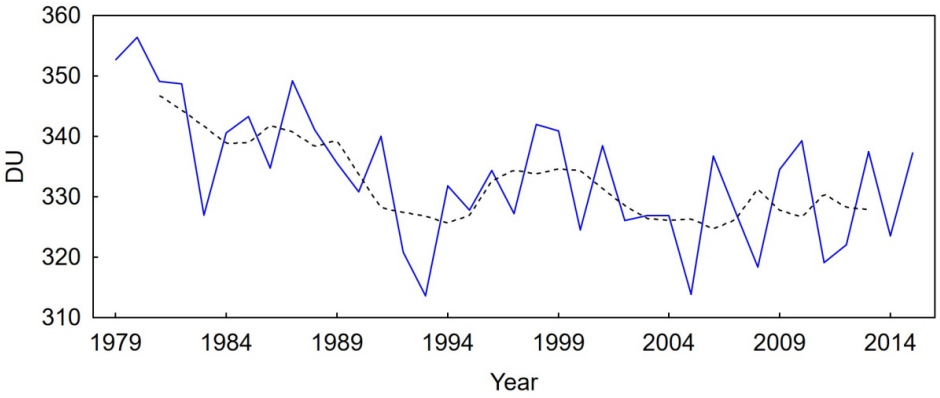


Figure 2. Annual average column ozone (blue line) in Estonia from 1979 to 2015 with 5-year moving average (black dotted line).

The modelling method enables to create new models for different action spectra weighed radiation, e.g. to investigate available radiation for vitamin D synthesis.

4. DISSEMINATION OF RESULTS

4.1 Data reporting

The databases of UV spectra in the range 280–400 nm recorded since 2004 together with daily and hourly broadband solar radiation data and basic meteorological information are collected at Tartu Observatory.

4.2 Information to the public

At the Estonian Weather Service web page (http://www.ilmateenistus.ee/ilm/ilmavaatlused/uv-indeks/) a graph showing the advance of UV-index at Tõravere as well as numerical values for 3 other stations during current day are available in real time for the public. Also, short general information on UV radiation is available at the Weather Service web page.

During the period May to August media often publish and display information on UV index, quality of sun-glasses, sun protection factor and on other sunbath related topics. UV radiation usually receives more attention during extremely sunny periods, like spring 2016. General information on the solar radiation, including UV, is also presented in the Yearbook of Meteorology by the Estonian Environment Agency.

Short texts containing necessary information about the research done in the field of atmospheric research (mainly UV radiation) is available on the web page of Tartu Observatory (https://www.to.ee/eng/research/research_topics/remote_sensing/remote_sensing_of_atmosphere) in Estonian and English.

4.3 Relevant scientific and popular papers in 2014-2016

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5. PROJECTS AND COLLABORATION

Currently, UV studies are financed by Tartu Observatory and the Weather Service of the Estonian Environment Agency. Tartu Observatory is an active member in Nordic Ozone and UV Group (NOG) presently chaired by K. Lakkala from FMI.

6. IMPLEMENTATION OF THE RECOMMENDATIONS OF THE 9th OZONE RESEARCH MANAGERS MEETING

Tartu Observatory has decided to continue the UV measurements with spectrometer Bentham DMc150F-U. Diffuse measurements have been added for more detailed data.
There is an ongoing collaboration with the Tartu-Tõravere meteorological station for data exchange.

Investigation and quantification of the effects of different factors (clouds, aerosols, ozone) on UV radiation have continued based on statistical methods and case studies.
The Estonian Environmental Agency has increased the number of stations transmitting online UV index data to the public.

7. FUTURE PLANS

The Estonian Environmental Agency is planning to install an UVS-B radiometer for UVB measurements at Tõravere. Also, calibration method for UV instruments outside Tõravere are planned to be updated. Further planned activities include:

- Development of methods for backward estimation of UV doses corresponding to different action spectra in all-weather conditions;
- Analysing collected data on diffuse UV-radiation;
- Development of Estonian internal cooperation in quantitative studies of environmental and biospheric effects of UV radiation.

8. NEEDS AND RECOMMENDATIONS

It would be useful if WMO/UNEP could provide official recommendations to the governments on the necessity to participate in intercomparisons of UV instruments like it is done in the case of pyranometers.

Also, it could be beneficial to emphasize the necessity of closer collaboration between the UV radiation measuring community and process biologists community to produce synergy on the influence of environmental factors on biospheric species and ecosystems.

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FINLAND

1. GROUND BASED OBSERVATIONS

1.1 Column measurements of ozone and other gases/variables relevant to ozone loss

In Finland, ozone column monitoring has been carried out by the Finnish Meteorological Institute (FMI) at Sodankylä (67.4°N, 26.6°E) since 1988, at Jokioinen (60.5°N, 23.3°E) during 1994—2015 and at Helsinki since 2016. At the stations an automated system based on Brewer spectrophotometer is continuously operated. Since November 2012 this monitoring programme has taken place in close cooperation with the COST Action ES1207: A EUropean BREWer NETwork – EUBREWNET. At Sodankylä Arctic research centre (FMI-ARC) wintertime ozone columns are also monitored with a SAOZ spectrophotometer which is operated in cooperation with CNRS-Paris already since 1990. The SAOZ measurements also provide NO_2 and OClO column amounts.

1.2 Profile measurements of ozone and other gases/variables relevant to ozone loss

Ozone soundings have been carried out since 1989 at Sodankylä on regular basis throughout the year, while in Jokioinen these measurements have been conducted during winter and spring when chemical ozone depletion is expected. Both sites have participated in the ozonesonde Match project, which is a coordinated effort to measure ozone loss in the Arctic vortex. Measurements of polar stratospheric cloud (PSC) properties have been carried out at Sodankylä since 1991/1992 by lidar and since 1994 by aerosol backscatter sondes. Stratospheric water vapor is measured at Sodankylä during all seasons using Cryogenically cooled Frost point Hygrometer (CFH). Sodankylä site is participating in GCOS Reference Upper-Air Network (GRUAN). The national meteorological institutes in Finland (FMI) and Argentina (SMN) jointly carry out regular ozonesonde measurements at Marambio (64.1°S, 56.4°W), Antarctica, since 1988.

1.3 UV measurements

1.3.1 Broadband measurements

FMI operates SL501 broadband instruments at seven sites in Finland. These instruments provide on-line information on the erythemal irradiance that is published through the internet along with the UV-Index forecast (http://en.ilmatieteenlaitos.fi/uv-index). To complete the network, new broadband measurements were started in November 2014 in Kuopio. FMI measures incoming and outgoing broadband SL501 UV radiation (UV albedo) in the GAW stations of Sodankylä (2008-) and Marambio (2013-).

1.3.2 Narrowband filter instruments

FMI has three narrowband NILU-UV filter instruments, from which two measures at the roof of the sounding station in Sodankylä and one is located in Helsinki and used for campaigns. In 2016, FMI invested in two GUV multifilter radiometers, which will be used for continuous UV measurements in the Antarctic in the research station of Marambio. They will rotate so that one is always measuring in Marambio, and the second one is recalibrated in Finland. The first one has been sent to Marambio in December 2016 and will be set up in February 2017. The GUV measurements will be made within the existing Antarctic research cooperation between FMI and SMN.

1.3.3 Spectroradiometers

FMI has monitored the spectral UV irradiance with Brewer instruments in Jokioinen (Mark III during 1995-2015), Helsinki (Mark III since 2016) and Sodankylä (Mark II since 1990, Mark III since 2013). The monitoring program conducted with the FMI Brewer spectroradiometers is described in Mäkelä et al. (2016). In addition, a Bentham DM150 spectroradiometer is maintained and used for campaigns. Furthermore, two CCD spectrometers (Flame, from Ocean

Optics Inc.) with wavelength range 348–1024 nm are employed, one in Mukteshwar, India, since 2015, and another in Kumpula, Finland, since 2016.

1.4 Calibration activities

FMI is operating dark room UV calibration facilities both in Helsinki and Sodankylä (Lakkala et al. 2016). FMI has participated in several UV measurement comparison campaigns, where it has been established that the quality of Finnish Brewer measurements is high and steady. The maintenance of the irradiance scale and the procedures ensuring the traceability of the scale is described by Heikkilä et al. (2016). The Brewer instrument of Helsinki serves as one of the core instruments of the QUASUME project (Quality Assurance of Spectral Ultraviolet Measurements in Europe). The European reference spectroradiometer developed in the project and now hosted by the WMO World Calibration Center for UV radiation in Davos is invited for auditing visits to both observatories on a regular basis. FMI is also responsible for the calibration of the Antarctic/Marambio GUV-multifilter radiometer and for its data quality assurance. Brewer total ozone measurements in Helsinki and Sodankylä are calibrated by annual visits of a travelling Brewer standard instrument or by visiting the Regional Brewer Calibration Center for Europe (RBCC-E) at Tenerife/Spain.

1.5. Measurement and validation campaigns

FMI stations at Sodankylä and Jokioinen have participated in ozonesonde Match campaigns during each Arctic winter, including winter 2015/2016.

FMI has actively participates in the EU COST1207 project EUBREWNET (2013-2017) with two MC members and one WG leader. FMI has led the work on stray-light correction of Brewer ozone measurements (Karppinen et al. 2015) and transferred routine UV data processing methods (Mäkelä et al. 2016, Lakkala et al. 2008) to the data processing of the EUBREWNET database. FMI has participated in the intercomparison campaign organized in Spain in 2015. A WG/MC meeting was organized in Sodankylä in November 2015. Research scientists from FMI gave 6 lectures in the EUBREWNET - WMO-GAW Brewer Ozone Spectrophotometer training school as side event of the Quadrennial Ozone Symposium 2016.

Validation and intercomparison of satellite ozone profiles studies have been performed (Rahpoe et al., 2015; Kauppi et al, 2016). The methods for validation of uncertainty estimates are presented in (Sofieva et al., 2014b). The influence of orbital sampling on averaged ozone distributions from satellite measurements is discussed in (Sofieva et al., 2014c)

2. SATELLITE OBSERVATIONS AND DATA PRODUCTS

FMI has a strong participation in several satellite instruments that are targeted for monitoring ozone in the atmosphere (GOMOS/Envisat, OSIRIS/Odin, OMI/EOS-Aura, GOME-2/METOP-A, METOP-B, Sentinel). FMI participates in ensuring the GOMOS data quality and in improving the data processing as a member of the ESA's GOMOS quality working group. In several international projects (Ozone-CCI, ALGOM, MesosphEO, SPARC DI) new GOMOS data sets have created and made available:

- GOMOS user friendly products: All Level 2 products. Vertically gridded nighttime products. Available from: https://earth.esa.int/web/sppa/activities/instrument-characterization-studies/algom and http://mesospheo.fmi.fi/index.html.
- GOMOS O_3, NO_2, NO_3 nighttime climatologies: http://mesospheo.fmi.fi/index.html
- GOMOS O_3, NO_2, aerosols nightime climatologies: http://www.sparc-climate.org/data-center/data-access/sparc-data-initiative/
- GOMOS daytime ozone: ftp.fmi.fi
- GOMOS UTLS-corrected ozone: https://earth.esa.int/web/sppa/activities/instrument-characterization-studies/algom

FMI is hosting the OMI UV surface irradiance processing and archiving facility which includes level 2 data, gridded level 2 data and level 3 data. The improvement and validation of the UV products are continued. In addition, local maps of total ozone columns and UV irradiance

together with other atmospheric constituents covering Central and Northern Europe are processed at FMI. These Very Fast Delivery (VFD) products exploit the Direct Broadcast antenna at the Satellite Data Centre of FMI-ARC in Sodankylä, Northern Finland. These products are available in the Internet (http://sampo.fmi.fi/) within 15 min after the overpass of the satellite. Presently similar real time ozone products are being developed for OMPS instrument on-board NASA/NOAA Suomi NPP satellite.

FMI is the Leading Institute for the EUMETSAT's Satellite Application Facility of ozone and atmospheric chemistry monitoring, O3M-SAF (http://o3msaf.fmi.fi), which focuses on algorithm development, data processing and product dissemination and archiving of atmospheric constituents (trace gases, aerosols, radiation products) of GOME-2 and IASI instruments. The project will continue as AC SAF (Atmospheric Composition Monitoring SAF) from 2017 until 2022. FMI is also responsible of developing, distributing and archiving of the UV-radiation products within this project.

3. RESULTS FROM OBSERVATIONS AND ANALYSIS

FMI has developed quality control (QC) and quality assurance (QA) practices that are suitable for many kinds of UV instruments. At FMI, at the moment, only Brewer UV measurements are considered to have a sufficient quality for assessment of long-term changes (e.g., Heikkilä et al. 2017b). The Sodankylä spectral time series is among the longest in the Arctic. No statistically significant spectral UV changes were found for the SZA interval 63°-65° at Sodankylä during 1990-2014. The effect of snow, enhancing the measured UVR due to high albedo, was important during late spring. Short-term variations were mostly due to changes in cloudiness, which was the dominant factor during summertime.

FMI's ground based and satellite UV and ozone measurements have been used to prepare the yearly published Ozone and UV chapter of the State of the Climate in the Bull. Amer. Meteor. Soc. (e.g. Bernhard et al. 2016). The UV and ozone time series of FMI have been used to assess the future UV levels (Eleftheratos et al. 2014). Recently, columnar amounts of atmospheric SO_2 measured by the FMI spectroradiometers was used in a study detecting volcanic SO_2 plumes (Zerefos et al. 2017).

FMI has participated in multidisciplinary research projects that aim at better understanding of the effects of increased UV exposures on human health, terrestrial and aquatic ecosystems, and materials. Research on the effects of UV radiation on materials has yielded new methods for the research on the effects of UV radiation on materials (Heikkilä 2014), new knowledge on the wavelength sensitivity of photo-degradation, especially photo-yellowing (Heikkilä & Kärhä 2014, Heikkilä et al. 2015) and novel instrumentation for the research thereon (Vaskuri et al. 2015, 2017).

4. THEORY, MODELLING, AND OTHER RESEARCH

The modelling activities related to middle atmospheric ozone includes the use of a global 3D chemistry transport model of the stratosphere and mesosphere (FinROSE-ctm), two climate models covering the middle atmosphere (MAECHAM, CESM/WACCM) and a model of the ionosphere (Sodankylä Ion and neutral Chemistry model). A model study using the FinROSE-ctm was made to evaluate the stratospheric water vapour distribution and variability in the Arctic. The calculations suggested that the variability in water vapour could mostly be explained by transport-related processes. An increase in water vapour in the presence of the low winter temperatures led to a more frequent occurrence of ice polar stratospheric clouds in the Arctic vortex. A study using MAECHAM model investigated possible impacts of Arctic ozone depletion 2011 on tropospheric circulation. It was found that both ozone depletion of observed magnitude and observed anomalies of sea surface temperature were needed to induce significant impacts on the troposphere.

We have continued work where atmospheric chemistry models are compared to satellite measurements. Measurements of O_3, NO_2 and NO_3 from the satellite instruments GOMOS on ENVISAT and OSIRIS on Odin are compared to the WACCM model. The results are being prepared for publication. Several studies have been dedicated to influence of energetic particle precipitation on the chemical composition of the middle atmosphere.

FMI measures UV albedo in the research projects A4 and NABCEA. The UV albedo of snow is high, for clean snow over 90 %. A high albedo increases the risk of the painful condition of snow-blindness and sunburn and causes an enhancement in the UV irradiance (UV-index) and in the air chemistry photolysis reaction rates, in comparison to snow-free surfaces. In addition, snow albedo can potentially be used to detect UV-absorbing impurities in snow, including climatically significant soot (Black Carbon) particles (Meinander 2016).

5. DISSEMINATION OF RESULTS

5.1 Data reporting

FMI has participated in the Global Atmospheric Watch (GAW) programme since 1994. Within the program, FMI maintains the Pallas-Sodankylä GAW station and conducts an extensive research programme related to atmospheric aerosols. Within this twin GAW station surface and boundary layer measurements are done in FMI clean air site of Pallas while upper air measurements, UV and Ozone monitoring takes place at Sodankylä (fmiarc.fmi.fi). In upper air research Sodankylä functions as an auxiliary station in the global Network of Detection of Atmospheric Composition Change (NDACC). The total ozone values are reported to the WOUDC.

FMI maintains the European UV Database (EUVDB) with a coherent QA system (Heikkilä et al. 2016). EUVDB is a database containing currently over 3.4 million UV spectra (uvdb.fmi.fi/uvdb/) from 49 measurement sites. For five stations, the stored data sets cover over 20 years of measurements. (uvdb.fmi.fi/uvdb/). The UV spectra of two Finnish Brewer instruments are submitted to EUVDB. The UV time series of FMI are used to yearly update the Ozone and UV chapter of the BAMS State of the Climate https://www.ncdc.noaa.gov/bams.

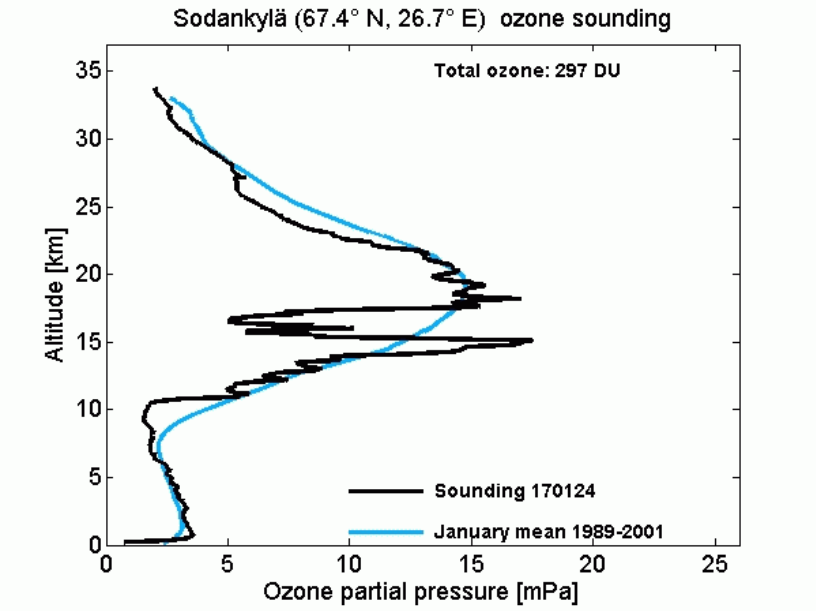


Figure 1. Ozone sounding at Sodankylä in January 2017. The ozone soundings have been made on regular basis in an effort to study Arctic stratospheric and tropospheric ozone changes. Results of the ozone soundings have been made publicly available through the FMI web site.

Regular ozone soundings have been performed at Marambio since 1988, the ozone data is sent to two international databases at the World Ozone and Ultraviolet Data Centre (WOUDC, Toronto, www.woudc.org) and the Norsk institutt for luftforskning (NILU, Oslo, www.nilu.no/nadir/). The ozone measurements are used in scientific publications, and form a significant contribution to the WMO ozone bulletins (www.wmo.ch).

5.2 Information to the public

FMI provides a 3-day global forecast of the UV Index (http://en.ilmatieteenlaitos.fi/uv-index). The forecast, which is published on the internet, includes contour maps of the local solar noon maximum clear sky maximum UV Index. Additionally, local clear sky UVI forecasts are provided for several sites in Finland and globally. The Finnish broadband UVI measurements are also incorporated in near-real-time on the web page. Several newspapers, radio channels and TV publish the forecasted or measured values during April to August. Warnings of high UV index are included in the general warning maps, and the global forecasted UV index is made available through a mobile phone application. FMI has actively participated in increasing the awareness of general public on the health effects of UV radiation, e.g. each year an UV info day is organized for the journalists as collaboration between FMI and other Finnish research institutes. Ozone depletion has a large public interest due to related health (UV) and environmental issues. Popularized information is distributed through press releases and interviews. Information about research activities, remote sensing projects as well as measurements and analysis results are available through FMI web pages, http://en.ilmatieteenlaitos.fi. FMI-ARC observations and analyses are available at http://fmiarc.fmi.fi.

5.3.1 Recent relevant scientific papers (2014–2017)

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6. PROJECTS AND COLLABORATION

The major national funding organisations are the Academy of Finland and Tekes, the Finnish Funding Agency for Innovation. Both of them have partially funded the ozone research in Finland in addition to FMI. FMI collaborates with Finnish universities and Research Institutes on atmospheric modelling and developing data retrieval methods, assimilation techniques for the satellite instruments and UV effect research. FMI has worked to enhance multidisciplinary UV research in Finland by organizing a national seminar on UV effects. The idea is to organize the seminar every second year in the future. FMI representative (Anu Heikkilä) has been nominated as a member in the UV-SAG (Scientific Advisory Group for Solar UV Radiation) of WMO (World Meteorological Organization). FMI representative (Anu Heikkilä) has been also invited as a full panel member in the UNEP-EEAP (United Nations Environmental Program – Environmental Effects Assessment Panel).FMI is chairing the Nordic Ozone and UV WG of the NORDMET since 2015.

A list of projects related to UV and ozone research during 2014-2017:

- ASTREX (Advanced Analyses of Stratosphere- Troposphere Exchange) (ended)
- A4 - Arctic Absorbing Aerosols and Albedo of Snow, 2012-2016, http://en.ilmatieteenlaitos.fi/a4-project
- UTLS WaVa (Arctic upper troposphere lower stratosphere water vapour) (ended)
- COOL (Aerosol intervention technologies to cool the climate: costs, benefits, side effects, and governance) (ended)
- Match: an international project, coordinated by AWI, to measure stratospheric ozone loss
- GRUAN (GCOS Reference Upper-Air Network)
- EMRP project ATMOZ - Traceability for atmospheric total column ozone
- ICASIF (Influence of Clouds and atmospheric Aerosols on Solar energy in India and Finland) – principal financier: Academy of Finland
- UVEMA (Effects of UV radiation on Materials, uvema.fmi.fi/)
- MACC-II (EU project, FMI participating in task related to UV-radiation)
- NABCEA - Novel Assessment of Black Carbon in the Eurasian Arctic: From Historical Concentrations and Sources to Future Climate Impacts, 2016-2020
- O3M-SAF (EUMETSAT's Satellite application facility on ozone and atmospheric chemistry): (http://o3msaf.fmi.fi)
- IGACO-O3/UV secretariat (WMO and GAW-ozone): IGACO (International Global Atmospheric Chemistry Observations) is a strategy which aims for bringing together ground-based, aircraft and satellite observations of 13 chemical species in the atmosphere. The implementation of IGACO-O3/UV has been organized through the Global Atmospheric Watch (GAW) programme of WMO. Everyday work during 2005 - 2015 has been coordinated by WMO jointly with a secretariat hosted by FMI with a Memorandum of Understanding with

the WMO. The implementation plan of IGACO-O3/UV was published in 2008 (http://www.igaco-o3.fi/linked/en/IGACO-O3_UV_Implementation_Plan.pdf). During the last years IGACO-O3/UV has concentrated on two activities: ACSO (Absorption Cross Sections of Ozone, http://igaco-o3.fmi.fi/ACSO) and SI2N (SPARC-IO3C-IGACO-O3-NDACC initiative on Past Changes on Vertical Distribution of Ozone, http://igaco-o3.fmi.fi/VDO/).

- ACSO (Absorption cross sections of ozone, IGACO-O3/UV activity): Review the presently available ozone absorption cross sections. Determine the impact of changing the reference ozone absorption cross sections for all of the commonly used (both ground-based and satellite) atmospheric ozone monitoring instruments. Recommend whether a change needs to bemade to the presently used WMO/IO_3C standard ozone absorption cross section data
- Ozone_cci (ESA Climate Change Initiative) aimed at the creation of homogenized and merged ozone profile datasets based on limb or occultation measurements from ESA and ESA Third Party Mission instruments. Six instruments that provide long-term measurements are involved in this project. Three of them are on board Envisat: GOMOS, MIPAS and SCIAMACHY; two of them are on board Odin: OSIRIS and SMR, and one is on board the SCISAT-1 satellite: ACE-FTS. FMI is responsible for creating Level 3 datasets.
- EUBREWNET (EUropean BREWer NETwork, COST Action ES1207 for the years 2012-2017 whose main objective is to establish a coherent network of European Brewer Spectrophotometer stations to harmonise and develop approaches, practices and protocols to achieve consistency in quality control, quality assurance and coordinated operations.)
- SI2N (Past changes in vertical distribution of ozone, SPARC, IO3C, IGACO-O3, NDACC initiative) (ended)
- PP-TROPOMI (Processor prototype studies for TROPOMI, Tekes funded)
- SPIN (ESA funded project, GOMOS ozone data and time series) (ended)
- MesosphEO (http://mesospheo.fmi.fi/index.html) is a project of European Space Agency (ESA) The aim is to provide the atmospheric science community a comprehensive data set of Level 2-4 mesospheric data products covering a time period of at least 10 years from the satellite instruments on ENVISAT (GOMOS, MIPAS, SCIAMACHY), on Odin (OSIRIS, SMR), and on SCISAT (ACE-FTS).
- The ESA ALGOM project (https://earth.esa.int/web/sppa/activities/instrument-characterization-studies/algom) consists of different Level 2 studies aimed at the improvement of the quality of the GOMOS products: Improvement of the algorithm for O_3 retrievals in the UTLS, improvements of the algorithms for H_2O and O_2 retrievals, design a new algorithm for minor species using averaged transmissions, user friendly GOMOS Level 2 data.
- SPARC Data Initiative (http://www.sparc-climate.org/data-center/data-access/sparc-data-initiative/) The goal of the SPARC Data Initiative is to improve our knowledge and understanding of the overall uncertainty in chemical trace gas and aerosol observations from limb-viewing satellite instruments. The SPARC Data Initiative Team, which consists of representatives from each instrument team and data analysts, has compiled zonal mean monthly mean time series of all available chemical trace gas and aerosol data in a common format (NetCDF). FMI has participated providing GOMOS data sets.
- ESA Climate Change Initiative project (Ozone_cci, http://www.esa-ozone-cci.org) aimed at the creation of homogenized and merged ozone profile datasets based on limb or occultation measurements from ESA and ESA Third Party Mission instruments. FMI is responsible for creating Level 3 datasets.

7. FUTURE PLANS

FMI aims to maintain its ongoing measurement programs and research activities in the Arctic and the Antarctic through nationally and internationally funded projects. The new GUV measurements in Marambio will continue the long-term UV time series. The continuation of the time series deals with two important topics: 1) long term stratospheric changes and 2) the atmospheric radiation budget in Polar Regions, specifically UV radiation. The work is in part dealing with the collection of key environmental datasets at Antarctica (ozone profiles, UV

radiation), but emphasis is also put on the data analysis and utilization of data in modelling studies. The long-term observational data sets of ozone and UV are important for monitoring purposes supporting the Montreal Protocol. Our research also fits the scientific topics given by the international Scientific Committee on Antarctic Research (SCAR) on Antarctica and Climate. The future work on Snow UV albedo can offer a new potentially significant application of UV radiation measurements to reveal UV-absorbing impurities in snow, including the climatically significant soot (Black Carbon, BC) particles.

8. NEEDS AND RECOMMENDATIONS

Although the basic processes related to stratospheric ozone are now believed to be fairly well understood, there remain important research topics related to ozone and UV, such as the interaction between ozone depletion/recovery and climate change and the effects of UV-irradiance on nature, human health, agriculture, and on materials. Also, future ozone recovery scenarios contain many uncertainties. Therefore it is important to ensure the continuity of long-term observational data sets of ozone and UV.

FRANCE

Research on the Stratospheric Ozone Layer in France (2014–2017)

The research on the stratospheric ozone layer in France is mainly performed by the following laboratories:

- LATMOS https://www.latmos.ipsl.fr/index.php/en/
- LACy http://lacy.univ-reunion.fr/home/
- Laboratoire d'Aérologie: http://www.aero.obs-mip.fr/
- CNRM http://www.cnrm.meteo.fr/
- LOA http://www-loa.univ-lille1.fr/
- GSMA http://www.univ-reims.fr/site/laboratoire-labellise/groupe-de-spectrometrie-moleculaire-et-atmospherique-umr-cnrs-7331/presentation,9558,17474.html

1. OBSERVATIONAL ACTIVITIES

The monitoring by French laboratories of the ozone layer and UV radiation is based on measurements performed within ground-based observation networks (e.g. NDACC – Network for the Detection of Atmospheric Composition Changes; SHADOZ Southern Hemisphere ADditional OZonesondes), on board aircrafts (e.g. IAGOS – In situ Aircraft for a Global Observing System) or satellite (e.g. IASI instrument aboard the European MetOp platform).

LATMOS, LACy, LOA and GSMA contribute to NDACC through:

- lidar and balloon sondes measurements of the ozone vertical distribution,
- lidar measurements of temperature and aerosols backscatter coefficient vertical distribution,
- Dobson spectrometer measurements of ozone total content,
- UV-Visible spectrometer measurements of ozone and nitrogen dioxide total contents,
- spectral UV radiation measurements.

Measurements are performed at several key NDACC stations: Observatoire de Haute Provence (OHP), Dumont d'Urville (Antarctica), Réunion Island, and within the SAOZ (Système d'Analyse par Observation Zénithale) network that includes 13 UV-Visible spectrometers implemented in stations located in France, Siberia, Brazil and Antarctica. Measurement time series of more than 30 years for some of them provide a detailed picture of the long term evolution of ozone and associated parameters.

1.1 Column measurements of ozone and other gases/variables relevant to ozone loss

The Dobson spectrophotometer based at OHP (D085) is working continuously since 1983. It provides daily measurements of the total ozone column and ozone profile (derived from the Umkehr technique). The instrument works semi-automatically for the total ozone column and automatically for Umkehr ozone profiles. The data are analyzed together by GSMA and by NOAA (National Oceanic and Atmospheric Administration). In 2014, the instrument was totally rebuilt thanks to CNRS funding. A collaboration between the DWD (MOHp, Germany), NOAA, the Japan Meteorological Agency (JMA) and the GSMA allowed us to replace the 30-year old electronic part of the instrument. The instrument calibration has been performed with the European MOHp's Dobson etalon (D064) and a new "WinDobson" interface has been implemented on the Dobson computer.

The SAOZ UV-Visible spectrometer has been developed by LATMOS. It contributes to NDACC since the start of the network in 1991. Nowadays more than 20 SAOZ owned by CNRS and other institutes are deployed at different latitudes, including the tropics. The first SAOZ was installed in 1988 at Dumont d'Urville in Antarctica to measure stratospheric ozone at high

latitudes during the polar winter. In contrast to UV measurements of ozone, the SAOZ, which measures in the visible, allows the continuous monitoring of ozone up to 91° Solar Zenith Angle (SZA) throughout the winter at the polar circle. In addition to the daily integrated ozone column, the SAOZ measures also the total column of NO_2, a key constituent in ozone destruction cycles, and detects the presence of polar stratospheric clouds from a color index[1]. The SAOZ data are available in Real Time at SAOZ webpage (http://saoz.obs.uvsq.fr/SAOZ-RT.html) and ESPRI French Data Centre (http://www.pole-ether.fr/NDACC/index.jsp).

LATMOS also monitors the total ozone column through measurements performed by the IASI (Infrared Atmospheric Sounding Interferometer) satellite instrument. IASI was designed for operational meteorology and monitoring of atmospheric chemistry and climate. It is a Fourier transform spectrometer, working in the infrared on board the MetOp-A and B satellites, launched in October 2006 and September 2012 respectively. As an example, Figure 1 shows the Antarctic ozone hole in 2016 as observed by IASI.

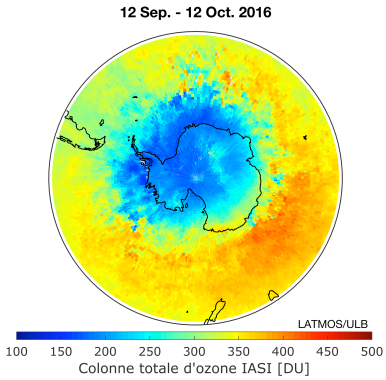


Figure 1. Total ozone column measured by IASI over the period 12/09–12/10/2016 over Antarctica

1.2 Profile measurements of ozone and other gases/variables relevant to ozone loss

Measurements of the ozone vertical distribution are performed using lidar and sondes instruments by LATMOS and LACy.

Differential Absorption lidar (DIAL) systems for measuring stratospheric ozone are implemented at OHP (since 1985) and at the Maido Observatory (Reunion Island) since 2013. These instruments provide long-term monitoring of ozone profiles in the Northern mid-latitudes and Southern tropics. At the Maido Observatory, the measured profiles were validated and the instrument re-labeled in the NDACC network during the international MORGANE campaign held in May 2015. The vertical profile of ozone is also monitored by LATMOS and LACy through regular ozone soundings performed at OHP, La Reunion Island and Dumont d'Urville (Antarctica). Around 50 profiles per year are obtained in the two former stations and 20 per year in Dumont d'Urville (mainly during the ozone hole period).

In addition, lidar measurements of the stratospheric vertical profile of aerosol backscatter coefficient and temperature are performed regularly by these laboratories in the above mentioned stations.

Laboratoire d'Aérologie, together with the Forschungszentrum Jülich (Germany), is responsible for the MOZAIC and IAGOS airborne observations of ozone in the upper troposphere and lower stratosphere (UTLS). MOZAIC/IAGOS observations (August 1994 - today) are airborne in-situ

[1] Sarkissian A., J. P. Pommereau, F. Goutail and E. Kyro, PSC and volcanic aerosol observations during EASOE by UV-visble ground-based spectrometry, Geophys. Res. Lett., 13, 1319-1322, 1994.

measurements for ozone, water vapor, carbon monoxide, and total nitrogen oxides (NO_y). Data acquisition is automatically performed during round-trip international flights (ascent, descent and cruise phases) from Europe to America, Africa, Middle East, and Asia. IAGOS observations (July 2011 - today) include ozone, water vapor, carbon monoxide, and cloud droplets (number and size). The time series of MOZAIC/IAGOS ozone measurements allow the quantification of ozone long-term trends in the critical Upper Troposphere - Lower Stratosphere (UTLS) region.

1.3 UV measurements

Monitoring of spectral UV radiation is carried out by LOA at three French sites with instruments affiliated with NDACC: Villeneuve d'Ascq (North of France) since 2000, OHP since 2009 and Saint-Denis (Reunion Island) since 2009. Calibration in laboratory is regularly conducted. Several assessments were carried out via comparisons with reference instruments (Quality Assurance of Spectral Ultraviolet Measurements in Europe (QASUME) and NDACC instruments, last campaign in 2014). Modeling of surface UV radiation is performed to analyze relationships to several parameters and assess the measurements.

Ground-based measurements have been used for validation of surface erythemal UV, UV-A and total ozone satellite-based estimates from TOMS, OMI and GOME-2. Indeed, despite their extensive geographical coverage, satellite data products are affected by measurement uncertainties and by modeling uncertainties, thus their accuracy must be evaluated. Our data products have also been used for studies related to health, especially for evaluating the risks due to high/low levels of UV radiation and develop the prevention via messages to the public. Trend analyses are inconclusive because the series are not long enough.

In addition, a broadband radiometer network (SECU-OI Network) is being deployed by LACy in the Indian Ocean to monitor the climatic evolution of surface UV radiation. Currently, measurements at Reunion Island (St Denis), Madagascar (Antananarivo) and Rodrigues Island have been established.

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

2.1 Satellite measurements validation

Only remote sensing observations from a satellite platform provide global ozone measurements. However, satellite instruments are subject to time-dependent drifts. Total ozone measurements by satellite instruments operating in the ultraviolet range are also limited to SZA lower than 83° preventing ozone evaluation studies over regions poleward of 60° in winter. High quality ground-based networks are thus necessary for independent calibration and validation of satellite experiments. It was shown[2] that systematic seasonal variation remaining in the difference satellite–SAOZ is mostly originating from a stratospheric temperature dependence. Since the visible ozone Chappuis bands used by SAOZ are little sensitive to temperature, and satellites measurements are in the spectral UV range, it is suggested that the seasonal variation of the difference between SAOZ and satellites observations in the UV is due to errors in ozone absorption cross sections in the UV or inadequate correction for temperature dependence in this wavelength region. After correction for temperature, the amplitude of the seasonal variation of the satellite-SAOZ differences decreases significantly.

The OHP ozone profile lidar observations have been used to evaluate the stability of various satellite measurements[3]. This study has demonstrated the good stability of the OHP time series, which is, together with similar lidar observations at Table Mountain (USA), Mauna Loa (USA), and Lauder (NZ), a reference time series for the evaluation of the drift of satellite instruments.

[2] Hendrick, F., et al., NDACC/SAOZ UV-visible total ozone measurements: improved retrieval and comparison with correlative ground-based and satellite observations. Atmos. Chem. Phys., 11, 5975–5995, doi:10.5194/acp-11-5975-2011, 2011.

[3] Hubert, D., et al., Ground-based assessment of the bias and long-term stability of 14 limb and occultation ozone profile data records, Atmos. Meas. Tech., 9, 2497-2534, doi:10.5194/amt-9-2497-2016, 2016.

2.2 Ozone long-term trends

2.2.1 Ozone trends at Northern mid-latitudes

Long-term measurements of ozone total content and vertical distribution enable the quantification of ozone decreasing trends up to the end of the 1990s and show its stabilization thereafter with some signs of increase. Total ozone trends were evaluated at OHP over the period 1983 – 2015. Results are presented in Figure 2 as a function of month, for the periods 1983 – 1996, corresponding to the increase of ozone depleting substances (ODSs), and 1997 – 2015 corresponding to ODS decrease, and for two methods of representation of the effects of ODS, based on the Equivalent Effective Stratospheric Chlorine (EESC) and two linear regressions, before and after the peak of ODSs[4].

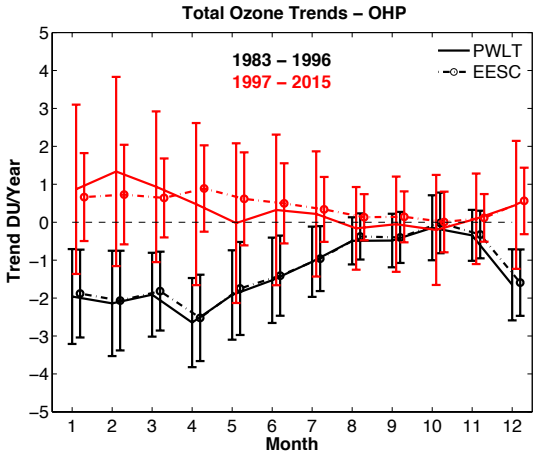


Figure 2. Total ozone trends during two periods (1983-1996 and 1997-2015) and for two methods: PWLT or EESC.

In annual average, ozone long-term trend since 1997 is equal to 0.36 ± 0.83 $DUyr^{-1}$, for the PWLT method. While positive, the recovery trend of ozone is still non-significant over the 1997-2015 period.

2.1.2 Ozone trends in the polar regions

Different analyses have shown that in Antarctica after a period of accelerated ozone depletion until 1999, a slow recovery is observed since 2000 but with strong inter-annual total ozone variability. No significant trend is detected during the period of important ozone destruction (mid-September-mid-October), but a significant positive trend is observed in September[5]. Figure 3 shows the evolution of polar ozone loss in the Arctic (blue) and in the Antarctic (red) as deduced from SAOZ measurements, through the passive ozone technique using simulation results from the Reprobus CTM model[6].

3. THEORY, MODELLING, AND OTHER OZONE RELATED RESEARCH

The analysis and prediction of the evolution of stratospheric ozone has to take into account the coupling between the chemical and dynamic processes. The LATMOS major activities concerning ozone simulation are linked to the contribution to international reports on the evaluation of chemistry-climate models (SPARC) and the state of the ozone layer (WMO). Over the past decade, our involvement in the CCMVal /SPARC and the WMO report enabled us to

[4] Nair, P. J., et al., Ozone trends derived from the total column and vertical profiles at a northern mid-latitude station, Atmos. Chem. Phys., 13 (20), 10373-10384, 2013, doi:10.5194/acp-13-10373-**2013**

[5] Pazmino, A., S. Godin-Beekmann, A. Hauchecorne, C. Claud, F. Lefèvre, S. Khaykin, F. Goutail, J. P. Pommereau, C. Boonne, E. Wolfram, J. Salvador, E. Quel, Evaluation of total ozone recovery inside the Antarctic vortex, Quad. Ozone Symp., 4-9 September, 2016

[6] Lefèvre, F., et al., Chemistry of the 1991–92 stratospheric winter: three dimensional model simulations, J. Geophys. Res., 99, 8183–8195, 1994.

improve and evaluate the different versions of the LMDZ-Reprobus CCM. We are involved in major international programs like CCMI (IGAC and SPARC, http: //www.met.reading.Ac.uk/ccmi/) focused on the evaluation of models of chemistry-climate and on the importance of chemistry for CMIP simulations of climate change. We also participate to the European project StratoClim (Stratospheric and upper Tropospheric processes for better Climate predictions) that focuses on the evolution of ozone at the global scale. We study the role of solar variability and volcanism in the variability and the climate predictability where stratospheric ozone plays a main role.

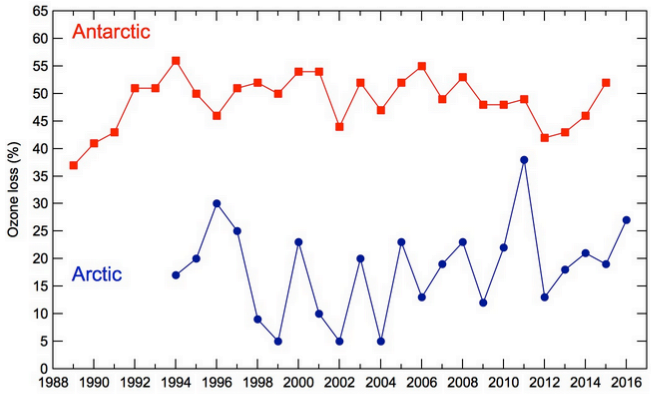


Figure 3. Ozone loss in Antarctica (red line) and Arctic (blue line) since 1989 and 1994, respectively.

4. DISSEMINATION OF RESULTS

4.1 Data reporting

Measurements performed within NDACC are submitted to the NDACC database (http://www.ndsc.ncep.noaa.gov/). Since the beginning of 2017, ozone profile lidar measurements obtained by LATMOS and LACy are delivered in near real time within the framework of the EU-CAMS program (Copernicus Atmosphere Monitoring Service) to the NDACC data base. Ozone sondes measurements obtained at La Reunion Island are also submitted to the SHADOZ database. SAOZ data are available at SAOZ webpage, ESPRIS/AERIS-France data centre, NDACC and WOUDC. Dobson total ozone data are available in the NDACC and WOUDC data bases. Spectral UV data are available in the NDACC data base. SAOZ data in the polar regions are used for the elaboration of the WMO bulletins related to Antarctic and Arctic ozone depletion.

4.2 Information to the public

In addition to various interviews in the media at the occasion of the International Ozone Day, a 13-minute movie in English and French was realized on the Maïdo Observatory and in particular on the measurements of stratospheric ozone. This film is aimed at the general public.

4.3 Relevant scientific papers published by French scientists

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5. PROJECTS, COLLABORATION, TWINNING AND CAPACITY BUILDING

International collaborations: IASB-BIRA (Belgium), FMI (Finland), IMC (Germany), Rome University (Italy), CSMEHRG-South Africa, Institute of Applied Physics, University of Bern, (Switzerland), Federal University of Santa Maria (Brazil), South African Weather Service (South Africa), U. of ZuluLand, Department of Geography (South Africa), U. of Antananarivo (Madagascar), BAS (UK), CAO (Russia), CEILAP-CITEFA (Argentina), DMI (Denmark), NASA (USA), NOAA ESRL (USA), NILU (Norway), SMHI (Sweden), U. of Bremen (Germany), U. of Leeds (UK), U. d'Itajuba (Brazil), and U. of Toronto (Canada).

6. IMPLEMENTATION OF THE RECOMMENDATIONS OF THE 9th ORM

France contributes to the following recommendations of the 9th ORM:

Research:

(i) Chemistry-climate interactions and monitoring the Montreal Protocol: The French scientific community has developed state of the art chemistry-climate models (CCMs) and several high quality data records of both the total content and vertical profile of ozone. Long term data records include also measurements of NO2 total content and vertical profile of stratospheric aerosols and temperature. Analyses of trends in ozone, temperature and aerosols are performed.
(ii) Processes influencing stratospheric evolution and links to climate: The long-term evolution of stratospheric aerosol and its link to the Asian monsoon are analyzed.
(iii) UV changes and other impacts of ODS changes: Long term data records of surface UV radiation are established. Studies include evolution of factors influencing UV radiation and UV changes impacts on health (including both erythemal and vitamin D doses).

Capacity building: French scientists collaborate with scientists from Argentina for the lidar and SAOZ measurements performed at the Rio Gallegos station.

7. FUTURE PLANS

Ozone total columns and profiles will continue to be monitored at the various NDACC stations and will be used for the validation of satellite ozone products and analyses of ozone recovery. Regarding UV radiation, the trends will continue to be monitored. LOA will participate to the validation of data products of future satellite instruments (TROPOMI on Sentinel-5P, OMPS on JPSS) and will establish and analyze climatologies of biological effects for public health use.

8. NEEDS AND RECOMMENDATIONS

For the continuation of ozone monitoring, funding for instruments' refurbishing need to be secured. In the coming years, after the end of some satellite missions (e.g. limb sounding instruments such as the Microwave Limb Sounder), the evaluation of highly resolved trends of ozone vertical distribution will mainly rely on ground based instruments such as ozone sondes and lidars.

Coordinated by Sophie Godin-Beekmann (LATMOS),
President of International Ozone Commission (IO_3C)

Coauthors: C. Clerbaux, M. Marchand, A. Pazmiño, J.P. Pommereau (LATMOS),
C. Brogniez (LOA), M.R. de Backer (GSMA)

GERMANY

German agencies and institutes remain active in ozone and UV monitoring and research. they regularly contribute to the WMO/UNEP Scientific Assessments, and to Scientific Working and Advisory Groups. Table 1 summarizes institutes and their activities. Generally, universities and research centers (MPI, DLR, KIT, FZ-Jülich, AWI) are more research and project oriented. Government agencies (DWD, BfS, UBA) are more focused on long-term measurements and monitoring. Germany is a key player for several satellite instruments (SCIAMACHY, MIPAS, GOME-2/MetOp-A,B,C). It is also supporting international quality-assurance and quality-control activities by hosting the World Calibration Centre for Ozone Sondes (WCCOS) and the WMO RA VI Regional Dobson Calibration Center (RDCC-E, in cooperation with the Czech Republic).

Table 1 German Institutes involved in ozone/UV research (R), development (D), modeling (MD), monitoring (MT), quality assessment /quality control (QA/QC)

Institute	Location	Fields	Keywords
Deutscher Wetterdienst (DWD) www.dwd.de	Hohenpeissenberg, Lindenberg	MT, R, QA/QC	RDCC-E, NDACC, GAW
Alfred Wegener Institut für Polar u. Meeresforschung (AWI) www.awi.de	Potsdam, Bremerhaven	R, MT, MD, D	Neumayer, Ny Ålesund, Polarstern, Palau, ATLAS, MATCH
Forschungszentrum Jülich (FZJ) www.fz-juelich.de	Jülich	R, QA/QC, MD	Calibration O_3-Sonde, JOSIE, CLaMS
MPI f. Meteorologie (DKRZ) www.mpimet.mpg.de	Hamburg	R, MD	MPI_ESM, EMAC, climate
DLR, DLR/IMF, DLR/DFD, DLR/PA atmos.eoc.dlr.de/gome2 www.dlr.de/pa www.wdc.dlr.de	Oberpfaffenhofen	R, MD, MT, QA/QC	GOME-2, EMAC, Air-Traffic
IAP Kühlungsborn, www.iap-kborn.de	Kühlungsborn	R, D, MT	Middle Atmosphere, lidar Alomar,
Bundesamt f. Strahlenschutz (BfS) www.bfs.de	Salzgitter	MT	UV
Umweltbundesamt (UBA), www.umweltbundesamt.de	Berlin	MT,	Air quality
Uni Bremen, IUP www.iup.uni-bremen.de	Bremen	R, D, MT	SCIAMACHY, GOME-2, MICROWAVE, DOAS, FTIR
Uni Köln, Inst. f. Meteorologie, www.geomet.uni-koeln.de	Köln	R, MD	EURAD,
FU Berlin, Inst. f. Meteorologie , www.geo.fu-berlin.de/met	Berlin	R, MD	EMAC, QBO, Stratosphere
Uni Frankfurt, Inst. f. Meteorologie, www.geo.uni-frankfurt.de/iau	Frankfurt	R, MT	CFC's, age-of-air, chemical composition
Uni Mainz, MPI f. Chemie (MPIC) www.atmosphere.mpg.de	Mainz	R, MD	EMAC/CCM
Uni Heidelberg, IUP www.physik.uni-heidelberg.de	Heidelberg	R, QA/QC	DOAS, Bromine, Iodine
GEOMAR, Kiel www.geomar.de	Kiel	R, MD	Middle Atmosphere, Bromine
Karlsruhe Institute of Technology (KIT) www.imk.kit.edu	Karlsruhe, Garmisch-Partenkirchen (IfU)	R, D, MD, MT, QA/QC	MIPAS, NDACC, LIDAR, IAGOS-CARIBIC, HALO, Balloon, Modelling
Uni München (LMU-MIM) www.meteo.physik.uni-muenchen.de	München	R, MD, MT	Radiation, UV
Uni Hannover, Inst. f. Meteorologie www.muk.uni-hannover.de	Hannover	R	UV

1. OBSERVATIONAL ACTIVITIES

German agencies are active in long-term ground-based monitoring and in ongoing satellite measurements of ozone and related trace gases. Regular ground-based measurements of ozone using Dobson and Brewer Spectrometers and/or ozone sondes are taken since the late 1960s at Lindenberg/Potsdam and Hohenpeißenberg, since the mid-1980s at the Antarctic Georg-Foster and Neumayer stations, and at the Arctic AWIPEV/Koldewey station on Spitsbergen. Within the framework of the Network for the Detection of Atmospheric Composition Change (NDACC) microwave radiometers, Fourier Transform InfraRed Spectrometers (FTIRs) and Lidars are deployed at the NDACC stations Hohenpeißenberg/Zugspitze, Kiruna, Izana, AWIPEV and Merida (Venezuela). Regular UV measurements are taken by BfS and other institutes at about 10 sites in Germany.

IUP Bremen is involved in satellite instrument and algorithm development, as well as advanced data processing, e.g. for upcoming new missions like Sentinel 5P (launch in 2017) and Sentinels 4 (geostationary platform) and 5 (launches in 2020). Scientific data processing for SCIAMACHY (2002-2012), OMI (since 2004) and GOME-2 (since 2006) are done as well by IUP. Several ground-based DOAS, microwave, and FTIR spectrometers at selected locations are run to monitor stratospheric species like O3, NO2, BrO, and OClO (stratosphere) as well as tropospheric species (MAXDOAS). All instruments are part of the NDACC (Network for the Detection of Atmospheric Change. The IUP combined ozone column dataset from European nadir viewing (downward looking) satellite UV/vis spectrometers now encompasses twenty years. It is used for detecting global long-term trends due to ozone depleting substances (ODS) and climate change within the international framework provided by the Vienna Convention, and the Montreal Protocol and its Amendments to protect the ozone layer. IUP regularly contributes to the WMO Scientific Assessments of Ozone Depletion (e.g. Pawson et al., 2014) and to the BAMS State of the Climate Report (Weber et al., 2016).

Karlsruhe Institute of Technology (KIT) coordinates the IAGOS-CARIBIC in-service aircraft observatory, ground-based FTIR measurements at four NDACC sites (Karlsruhe, Kiruna, Izana and Garmisch), infra-red remote sensing from balloon and airborne platforms and plays a leading role in retrieval, scientific analyses and quality control of MIPAS/ENVISAT satellite observations. KIT coordinated the Arctic aircraft campaign “The Polar Stratosphere in a Changing Climate” (POLSTRACC) using the German High Altitude and Long-Range Research Aircraft HALO in winter 2015/16. IAGOS-CARIBIC (www.iagos.org) is a long-term European Research Infrastructure with a well-equipped laboratory (19 instruments) deployed for ~500 flight hours per year onboard a Lufthansa passenger aircraft.

Germany's Meteorological Service (DWD) is running a comprehensive ground-based measurement program at the Observatories Hohenpeissenberg and Lindenberg, monitoring the ozone vertical distribution and total ozone columns on a regular and long-term basis. Special efforts are put into high quality and long-term consistency. The time series now cover 50 years for column ozone and ozone profiles, and almost 30 years for stratospheric LIDAR observations. Data are regularly submitted to the data centers at Toronto (WOUDC), NDACC, NILU and Thessaloniki. In addition to the operational UV-network of the BfS, DWD continues to measure UV-B radiation for research and development purposes.

The **German Aerospace Centre (DLR)** provides operational processing for satellite measurements of ozone and other trace gases (total NO2, tropospheric NO2, SO2, BrO, H2O, HCHO), as well as cloud information from GOME-2/MetOp-A, and B. DLR-EOC is also leading the development of the operational systems for the TROPOMI/Sentinel-5-Precursor mission. DLR also hosts the World Data Center for Remote Sensing of the Atmosphere WDC-RSAT (www.wdc.dlr.de), and operates the German high altitude research aircraft (HALO).

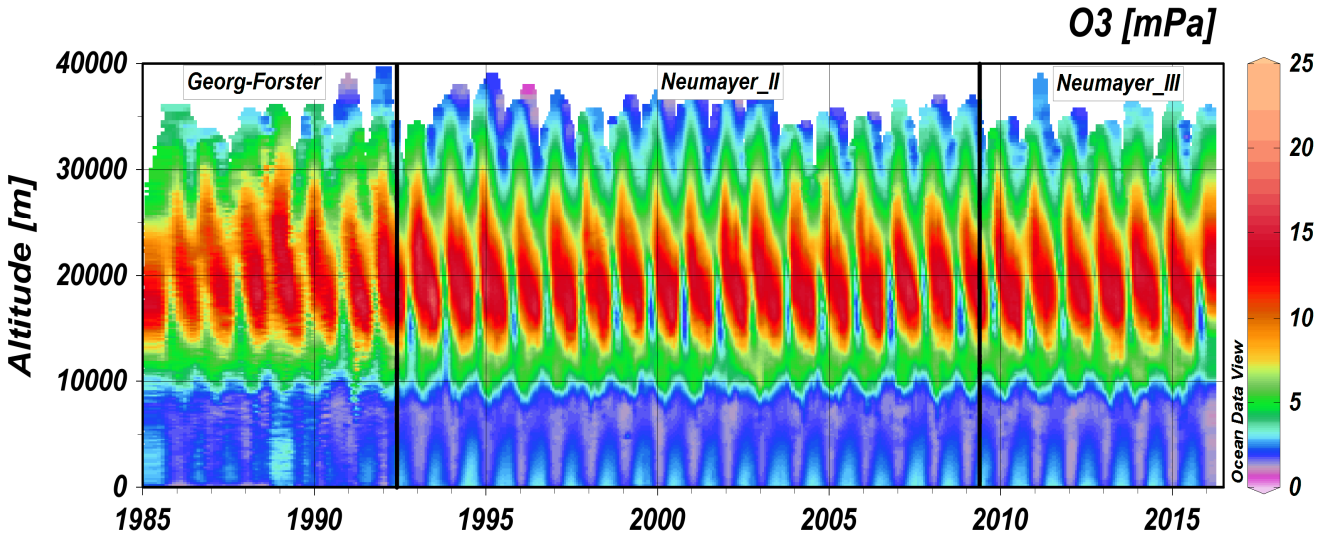


Fig. 1: Time and altitude plot of ozone partial pressure from German ozone soundings over Antarctica. Plot by G. König-Langlo, AWI Bremerhaven.

The **Alfred Wegener Institute for Polar and Marine Research (AWI)** operates two fully equipped polar stations in the Arctic (AWIPEV/Ny-Ålesund), and Antarctic (Neumayer) and temporarily onboard RV POLARSTERN. Regular vertical ozone balloon soundings at Neumayer continue the very long Antarctic sounding record that started at the former Georg Forster station in 1985 (see Fig. 1). A full suite of NDACC measurements is running at AWIPEV/Spitsbergen, in cooperation with Uni Bremen. This includes ozone-soundings by ECC-sondes, Lidar, microwave, DOAS, FTIR and UV-spectrometers. In addition, the same radiation measurements as at Neumayer-Station are performed as part of the BSRN. Currently ozone soundings are also done in the tropics, at Palau, Micronesia.

A number of **dedicated aircraft campaigns** with research aircrafts Geophysica and HALO with the focus on ozone research have been carried out with an extensive set of instruments determining the chemical composition of the air. In the winter 2015/2016, the project POLSTRACC with the German research aircraft HALO took place successfully. At the focus of this large campaign were observations of ozone and ozone-related chemical compounds in the lowest stratosphere.

1.1. Calibration activities

Forschungszentrum Jülich hosts the World Calibration Centre for Ozone Sondes (WCCOS). WCCOS is part of the quality assurance plan for balloon borne ozone sondes that are in routine use in the GAW observation network of the WMO. Since its inception in 1995, WCCOS provides an experimental chamber that simulates conditions in the atmosphere as a balloon ascends from the surface to the stratosphere. The Jülich Ozone Sonde Intercomparison Experiments (JOSIE) have evaluated and improved the performance of the ozone sondes substantially.

Previous JOSIE-intercomparisons have clearly demonstrated that even small differences of sensing techniques, sensor types or operating procedures can introduce significant inhomogeneities in the long term ozone sounding records between different sounding stations or within each station individually. To resolve these artifacts the WCCOS presently leads the “Ozone Sonde Data Quality Assessment (O3S-DQA)” activity with the primary goal of homogenizing selected long term ozone sonde data sets of the global ozone sounding networks. In addition, in 2016 the WCCOS started in collaboration with SHADOZ, with the preparation of a new JOSIE-campaign that is planned to take place in Fall 2017 at the WCCOS. From both activities we expect a new set of recommendations for ozone sonde procedures and data processing to reduce uncertainties between long term sounding records from 10-20 % down to the 5 % level.

The **Regional Dobson Calibration Centre for WMO RA VI Europe (RDCC-E) at the Meteorological Observatory Hohenpeissenberg (MOHp)** is closely co-operating with the Solar and Ozone Observatory at Hradec Kralove (SOO-HK, Czech Republic). It has been responsible for

second level calibration and maintenance service of approximately 20 operational Dobson spectrophotometers in Europe since 1999, including the Antarctic Dobsons at Halley Bay (British Antarctic Survey BAS) and Vernadsky (Ukraine). Refurbishment of European Dobsons that have been out of operation and their relocation, mostly outside of RA VI, has become more and more important.

The success of the global Dobson calibration system can be seen in Fig. 2. The majority of Dobson spectrometers coming in from years of field work now match the reference instrument within 1%, already in the initial comparison.

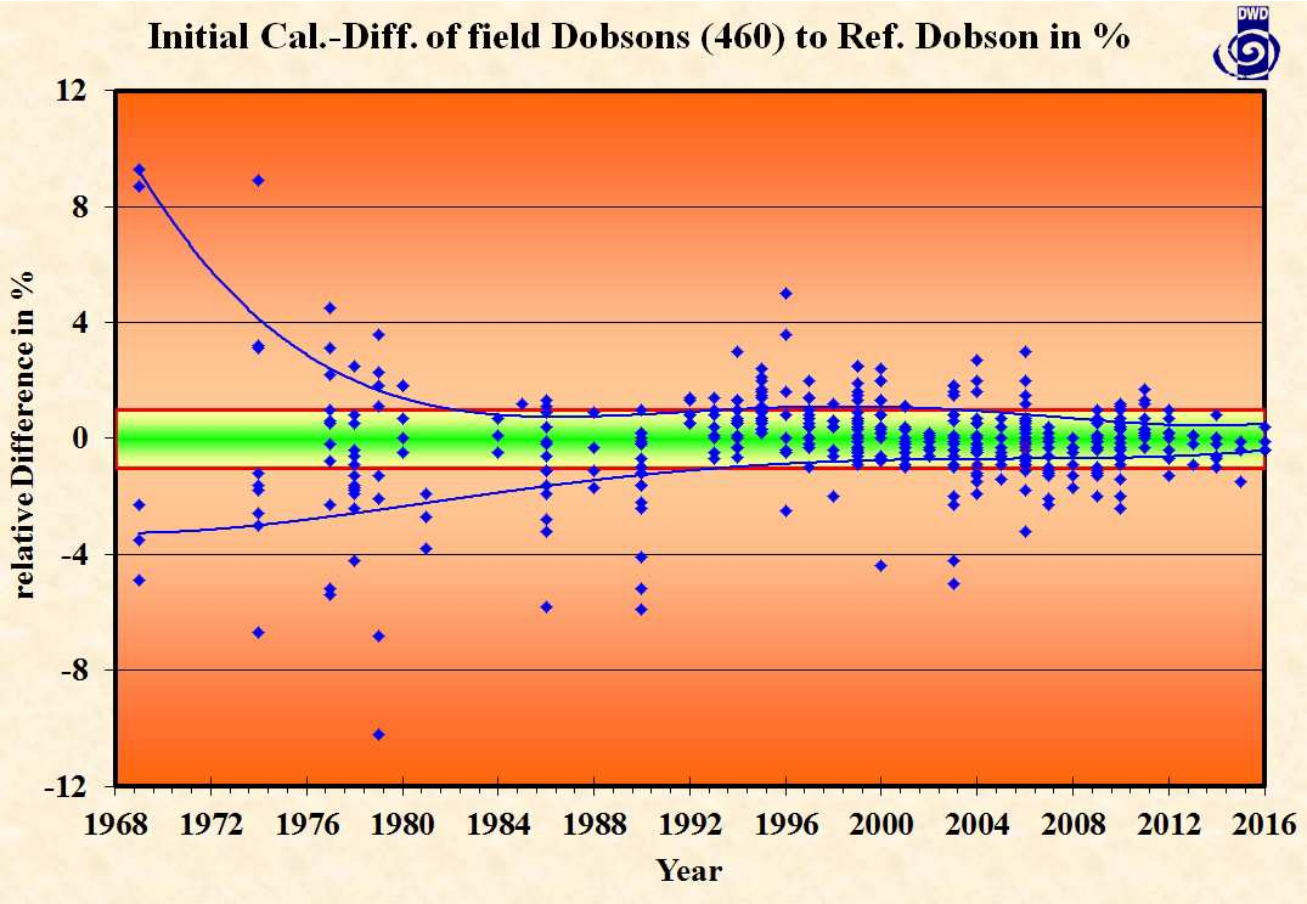


Fig. 2: Relative difference between field Dobson and reference instrument during initial calibration. Plot by U. Köhler, DWD Hohenpeissenberg.

Large progress in the standardization of ozone absorption cross-section was made in recent years by the ACSO initiative (Orphal et al., 2016). German researches were closely involved and **IUP Bremen** has already provided new and improved ozone absorption cross-sections at high spectral resolution (~0.03nm) and covering atmospheric temperatures between 193 and 293 K and the wavelength range 230-1050 nm (Serdyuchenko et al., 2013, Gorshelev et al., 2013, Orphal et al., 2016). Currently ozone cross-sections are measured again at **IUP** to improve in particular the ozone Huggins band region (300-340 nm) using improved and more stable light sources and more sensitive detectors as part of a metrological project to improve traceability of ozone measurements.

1.2. UV-measurements

The working group of **G. Seckmeyer at the Institute of Meteorology and Climatology of Leibniz University Hannover** continued their development of novel non-scanning multidirectional spectroradiometers for simultaneous measurements of spectral sky radiance (Riechelmann et.al. 2013). These MultiDIrectional Spectroradiometers (MUDIS) can measure the spectral sky radiance as a function of zenith and azimuth angle with high spectral and temporal resolution. A new instrument – called AMUDIS (advanced multidirectional spectroradiometer) - now covers the wavelength range of 250–1700 nm at 150 different directions simultaneously. Compared to the MUDIS instrument, the spectral resolution is much better (< 1 nm). The newly developed spectroradiometers are versatile instruments with a wide range of application possibilities, including vitamin D weighted exposure determination, solar energy applications, derivation of trace gases, investigation of material aging (e.g. on facades), radiance and plant growth applications and more.

For the determination of vitamin D weighted exposure and the explanation of the height dependence of skin cancer incidence, a novel method has been applied by integrating the incident solar spectral radiance over all relevant parts of the human body (Schrempf et al., 2016). Earlier investigations are based on the irradiance on surfaces, whereas the new method takes into account the complex geometry of the radiation field and the geometry of the human body (Fig. 3).

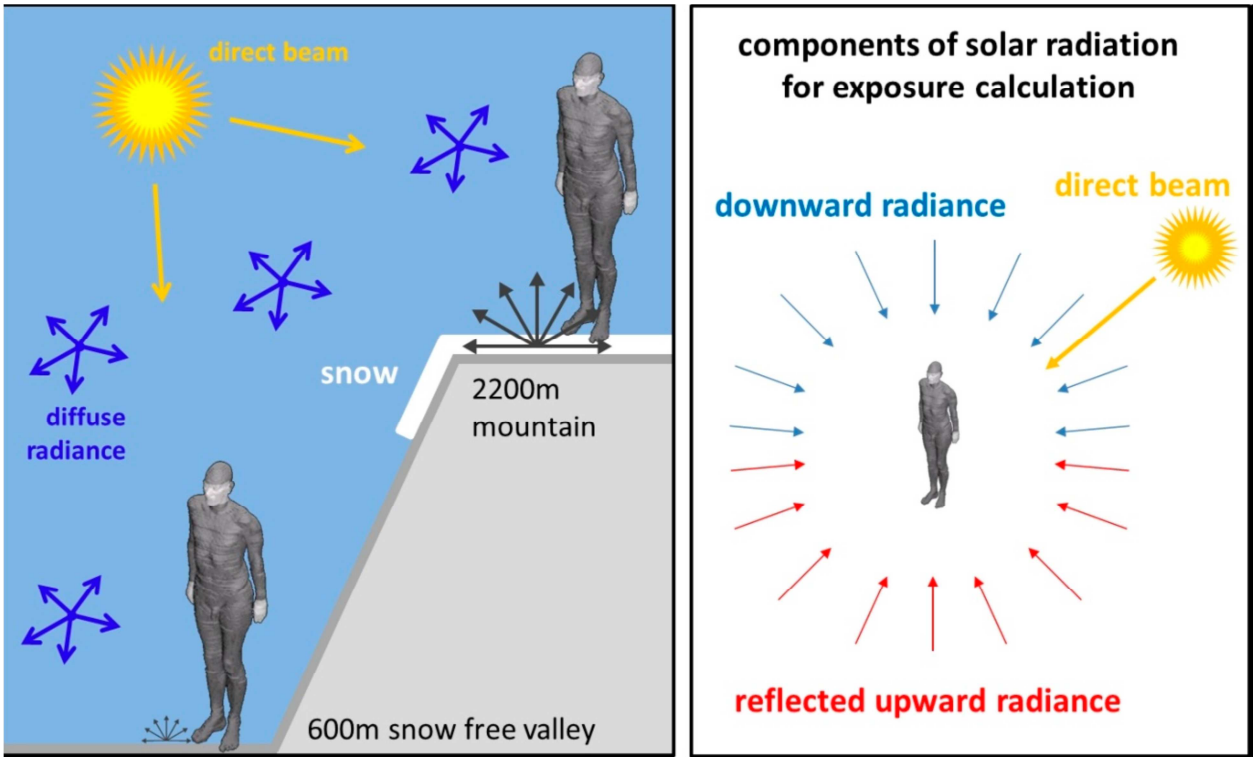


Fig. 3: Schematics of radiance components contributing to exposure of the human body (right), and their change with altitude and surface cover (left). By G. Seckmayer, U. Hannover.

These new investigations explain why melanoma incidence rates for Austrian inhabitants living at higher altitude increase by as much as 30% per 100 m altitude. This strong increase cannot simply be explained by the known increase of erythemally-weighted irradiance with altitude, which ranges between 0.5% and 4% per 100 m. Rather, a good part of the discrepancy is explained by upwelling UV radiation; e.g., reflected by snow-covered surfaces. These new results imply that upwelling radiation plays a significant role in the increase of melanoma incidence with altitude.

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

AWI has been instrumental in coordinating Match balloon-sonde campaigns for the observation of polar ozone losses. Whenever meteorological conditions were suitable for Arctic ozone loss, Match campaigns have been carried out for more than 20 years. They are a major component of European and world-wide ozone research, documenting the long-term evolution of polar ozone loss over the Arctic. The Arctic stratospheric winter 2015/16 was the coldest ever observed, resulting in high chlorine activation and large ozone loss. The observed ozone loss was comparable to, or even larger than the loss in the former record winter 2010/11 (Fig. 4).

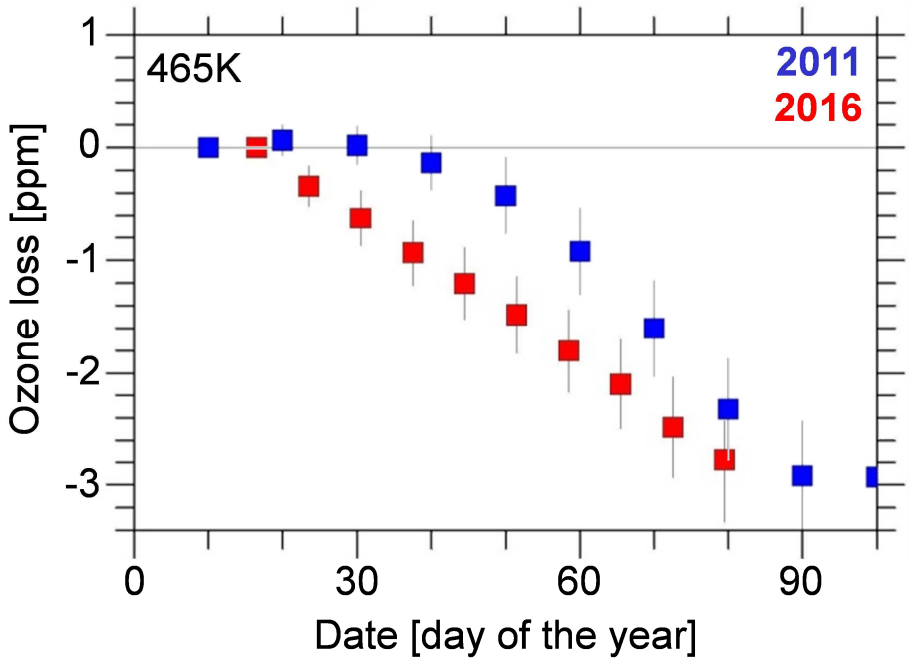


Fig. 4: "Accumulated ozone losses in the Arctic winters 2011 and 2016 at approx. 19 km altitude (465 K potential temperature) as determined with Match. No analysis beyond day 80 (2016) was possible because of the disturbed vortex in 2016.

Graphic: Peter von der Gathen, Alfred Wegener Institute.

The **Arctic aircraft campaign POLSTRACC** (The Polar Stratosphere in a Changing Climate) was successfully performed in winter 2015/16, coordinated by KIT and in cooperation with partners from Research Centre Jülich, German Aerospace Centre (DLR) and the Universities of Frankfurt, Mainz, Heidelberg and Wuppertal. The German High Altitude and Long-Range Research Aircraft HALO was equipped with a large number of in-situ and remote sensing instruments, including the imaging infra-red limb sounding instrument GLORIA. More than 150 flight hours were performed in the Arctic stratosphere between December 2015 and March 2016. The Arctic winter 2015/16 was exceptionally cold with widespread occurrence of polar stratospheric clouds. Substantial Arctic ozone depletion in the lower stratosphere was observed and the relevant processes investigated by the POLSTRACC campaign.

Stratospheric chlorine and bromine trend measurements at the **IMK and IfU** sites (ground-based), as well as air-craft and balloon-borne measurements from **Frankfurt and Heidelberg Universities**, indicate declining chlorine and bromine since the mid to late 1990ies, confirming success of the Montreal protocol. Data from University of Heidelberg and collaborating laboratories (NOAA and BIRA) show that the contribution of CH_3Br and the halons to total stratospheric bromine bromine has also started to decline in recent years, but the variable contribution of mainly naturally emitted very short lived brominated source gases (VSLS) and the measurement precision still obscures the trend (see Fig. 5). To better quantify the input of bromine from VSLS, University Frankfurt has measured the complete suite of short lived bromine source gases which are thought to be relevant to the stratosphere. These include CH_2Br_2, $CHBr_3$ and three mixed bromochlorocarbons. Their mixing ratios in the upper tropical troposphere have been quantified from Borneo/Malaysia. From these results a total input of bromine from VLSL of 2.9±0.3 ppt (Sala et al., 2014) was derived, well in line with current estimates from WMO 2014, or results in Fig. 6.

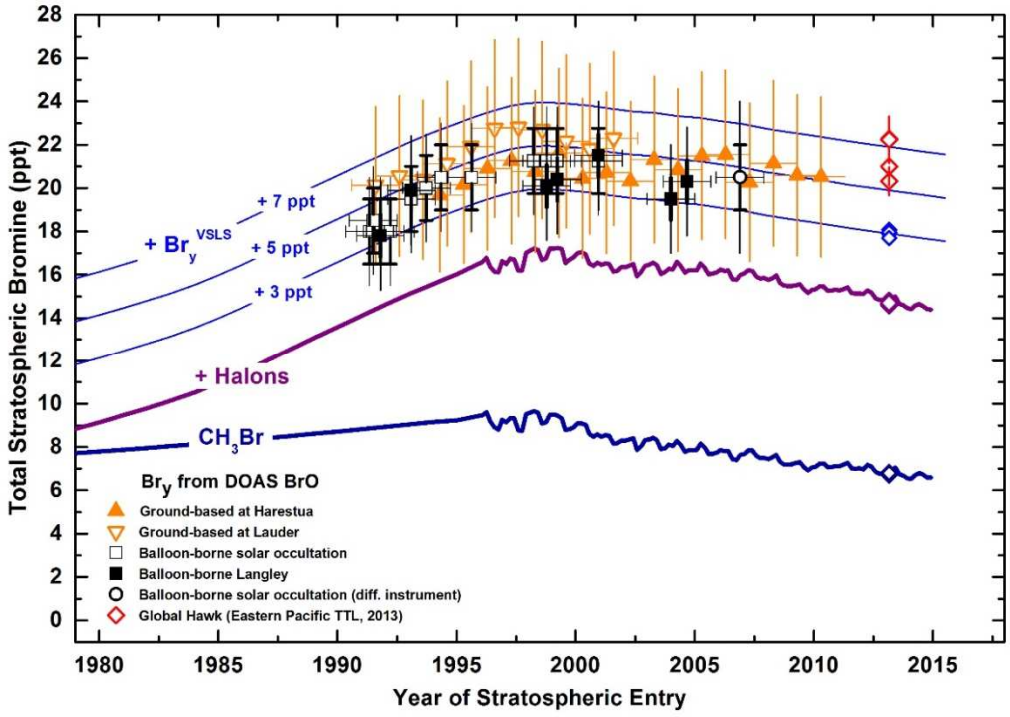


Fig. 5: Total stratospheric bromine (Bry) from balloon-borne BrO observations (squares), airborne observations onboard the Global Hawk, (diamonds), and annual means from ground-based measurements (orange triangles) at Harestua (60°N) and Lauder (45°S). The stratospheric data are compared to bromine at the Earth's surface, with varying amounts of very short lived bromine species added (blue lines). By K. Pfeilsticker IUP Heidelberg.

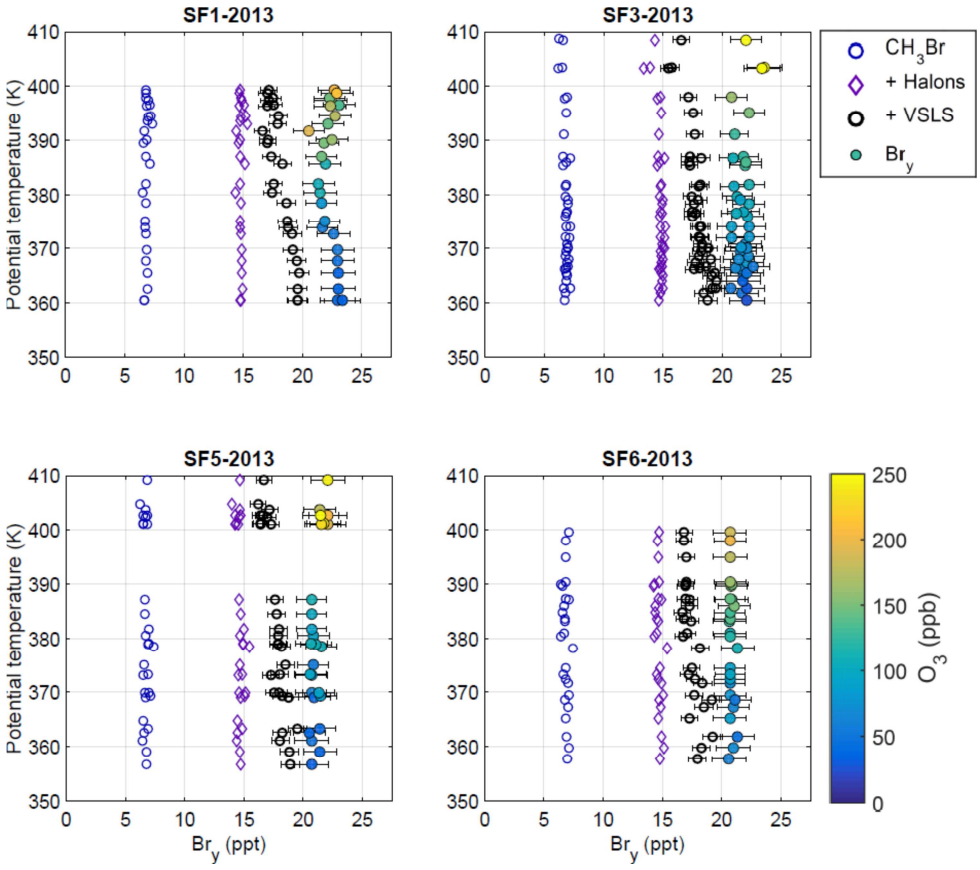


Fig. 6: Total bromine as a function of potential temperature (Θ) for all dives during the 2013 NASA-ATTREX flights (SF1 to SF6) across the tropical tropopause layer (TTL) over the Eastern Pacific in 2013. The contributions from CH_3Br (blue circles), halons (purple), brominated VSLS (black) and the measured inorganic fraction (coloured circles) are summed. From Werner et al., 2017.

Ozone measurements at **Hohenpeissenberg** (see Fig. 7) now have reached their 50th anniversary. Total ozone has not declined since the late 1990s. Significant ozone increases are seen in the upper stratosphere only (not shown), a first sign of a beginning ozone recovery. However, for the total ozone column and the lower stratosphere increases are not that clear and transport related variations are large. Factors like the Arctic Oscillation (AO) contribute majorly. The wide range of ozone values observed in recent years, therefore, is still obscuring the slow and small recovery signal indicated by the red line in Fig. 10.

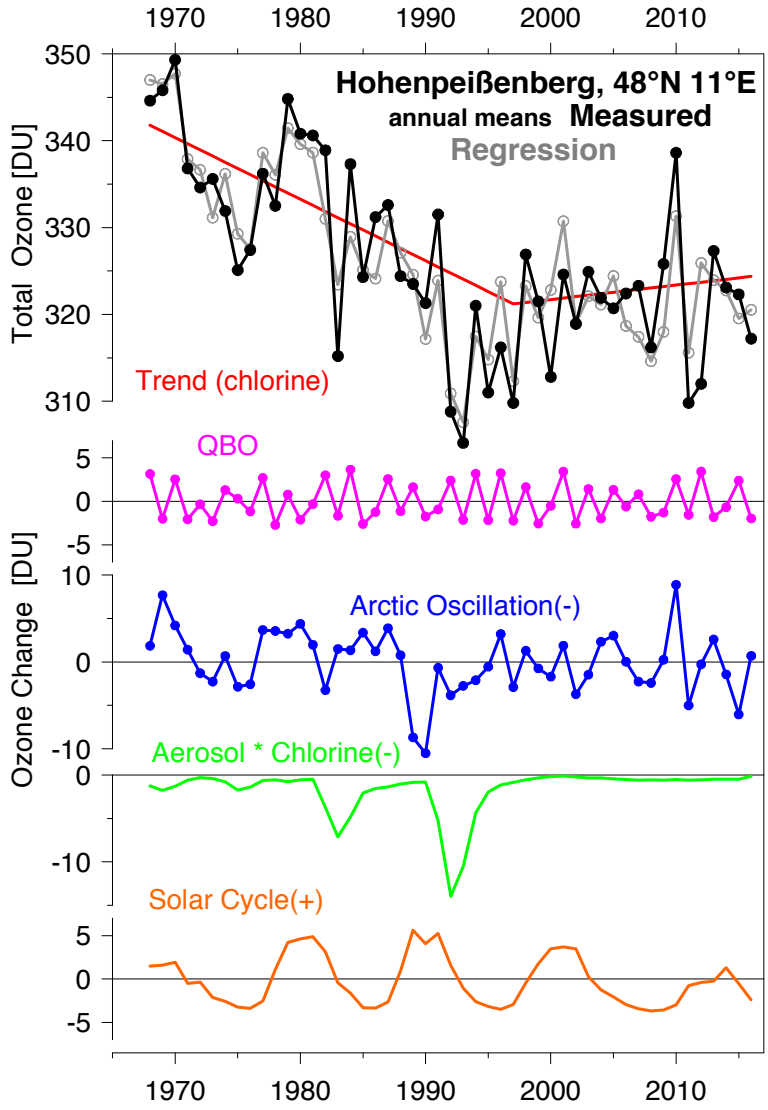


Fig. 7: Observed annual mean total ozone at Hohenpeissenberg, and multiple linear regression analysis of the magnitude of contributing factors. Top: Black: Observations at Hohenpeissenberg (47.8°N, 11°E). Gray: Multiple linear regression result. Red: Ozone variation attributed to Effective Equivalent Stratospheric Chlorine (EESC). Lower graphs: Ozone variation attributed to the QBO (magenta), to the Arctic Oscillation (AO, blue), to enhanced stratospheric aerosol (green), and to the 11-year solar cycle (orange). Plot by W. Steinbrecht, DWD.

World-wide total ozone columns from ground-based and satellite observations are regularly compiled by the **Institute for Umwelt-Physik (IUP) at Bremen University**. Results are given in Fig. 8. Also in this Figure, total ozone shows large inter-annual variability and no significant trends since 2000, following a brief but strong increase from the middle 1990. Nevertheless, the period of continuous decline of about 4%/decade observed since the late 1970s (Fig. 8) has clearly ended. The current observations are within the range of results from an ensemble of chemistry climate models (CCMVAL-2) that account for changing greenhouse gases as well as ozone depleting substances (ODS).

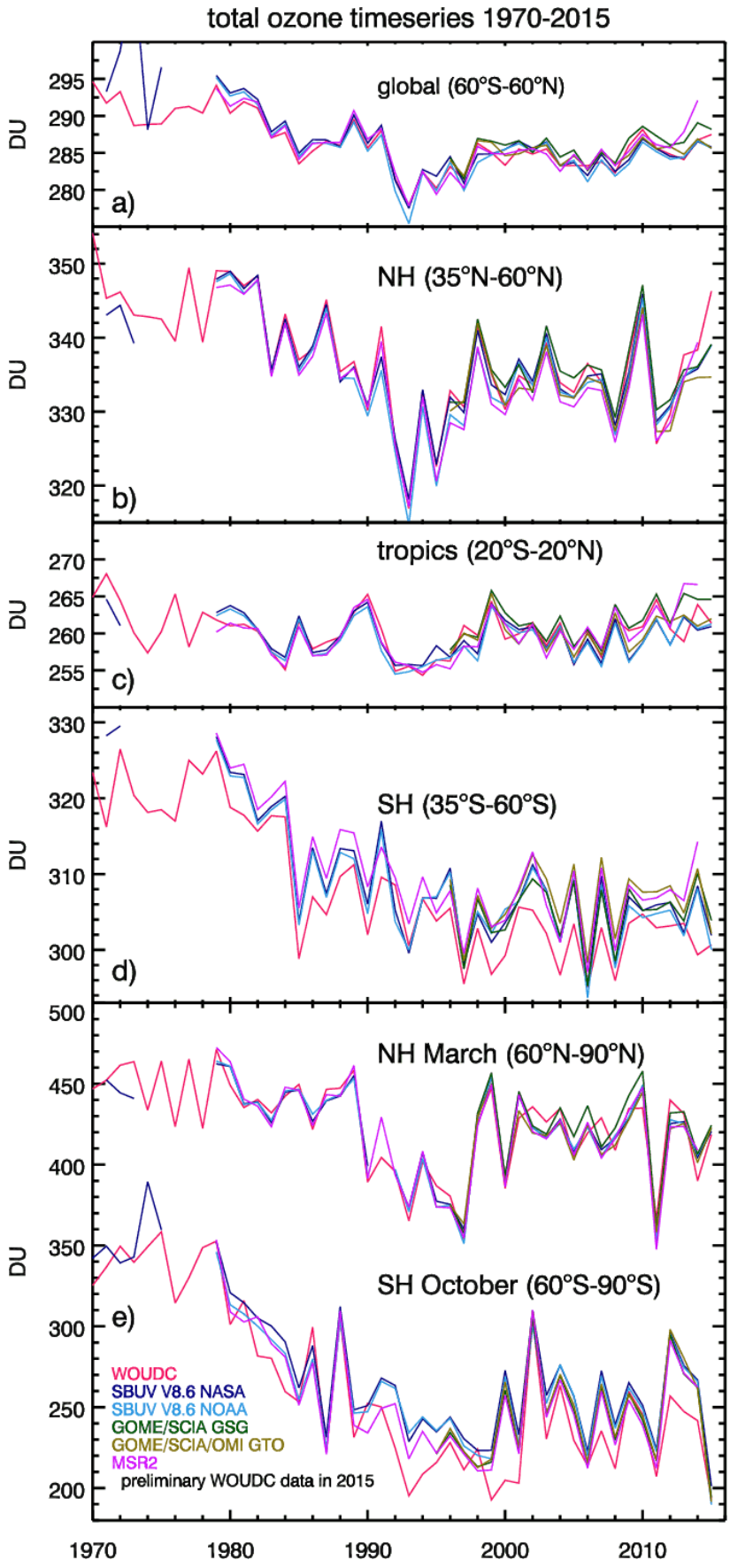


Fig. 8: Timeseries of annual mean total ozone in four zonal bands (a-d), as well as polar total ozone in March (NH) and October (SH) (e). Data are from WOUDC ground-based measurements combining Brewer, Dobson, SAOZ, and filter spectrometer data (red) the BUV/SBUV/SBUV2 V8.6 merged products from NASA (dark blue) and NOAA (light blue), the GOME/SCIAMACHY/GOME-2 products GSG from University of Bremen (dark green) and GTO from ESA/DLR (light green) and the MSR V2 assimilated dataset from KNMI extended with GOME-2 data. From Weber et al., 2016.

FTIR measurements from **KIT** together with ground-based FTIR data from eight NDACC sites where used to investigate trends in the ozone profile. While there is no significant trend in FTIR ozone column data there is a positive trend in the partial column of the upper stratosphere at most sites, in particular in the Arctic (Vigouroux et al., ACP, 2015).

Additional attention has been given to the evolution of tropospheric ozone. **IUP** implemented three different approaches that combine cloud information and ozone column from nadir viewing space measurements to derive tropospheric ozone columns. Both methods (Convective Cloud Differential (CCD) and Cloud Slicing (CS)) are statistical methods that derive mean quantities by averaging over sampled data in pre-defined grid boxes and their applicability is limited to the tropical region. Limb-nadir matching combines stratospheric columns (from limb observations) with collocated total columns (from nadir observations, Ebojie et al., 2014, 2016). Using these techniques, tropospheric ozone satellite data (GOME, SCIAMACHY, GOME-2) have been merged into a single long-term dataset (1995-present) for investigating trends and variability (Leventidou et al., 2016). MIPAS/ENVISAT was also used within a study to separate stratospheric from tropospheric ozone variation. This study showed that the halogen-induced stratospheric ozone loss is partly compensated by tropospheric ozone increase, particularly in the tropics (Shepherd et al., 2014, see Fig. 9)

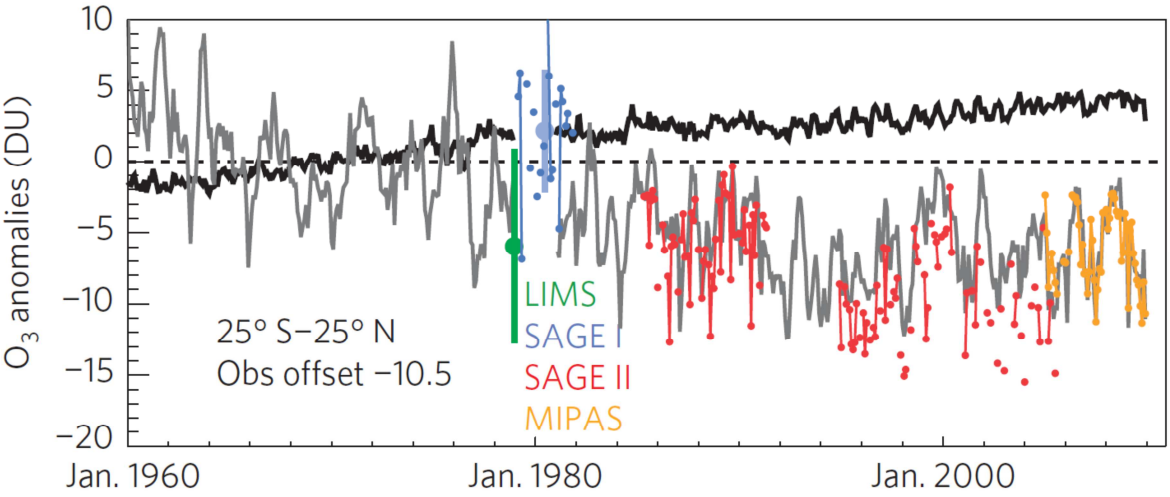


Fig. 9. Tropical ozone anomalies from model simulations (black: tropospheric partial column and gray: stratospheric column) together with satellite observations of stratospheric ozone anomalies. Halogen induced stratospheric ozone loss is partly masked by the increase in tropospheric ozone. From Shepherd et al., 2014.

Many groups work on improving and extending their data retrievals. IUP Bremen, e.g., has improved the quality of global vertical distributions of ozone and other atmospheric constituents (NO2, BrO, H2O, aerosols) retrieved from SCIAMACHY limb measurements. The main objective is to achieve quality and stability of the resulting time series, required for trend analyses. Supporting modelling studies are performed to explain the observed behaviour of the stratospheric species. Furthermore, the work on data from the recent limb sensor OMPS (on Suomi-NPP) is performed to extend long-term time series of stratospheric ozone and aerosol by merging with SCIAMACHY.

The agreement of SCIAMACHY ozone profiles with other satellite measurements, in particular MLS, shows large improvements. Ozone trends from 2004 to 2011 have been updated from Gebhardt et al. (2014) and are shown in Fig. 10. The increase in upper stratospheric ozone since 2002 is consistent with the decline in stratospheric halogen related to the Montreal Protocol phasing out ozone depleting substances. In certain regions of the atmosphere, however, a continuous decline in ozone is observed (~10 hPa in the tropics). This is likely related to changes in NOy and tropical upwelling. Continued efforts also go into improving data analysis for the MIPAS instrument. See e.g. Fig. 11 which demonstrates the improved quality of several current retrieval algorithms.

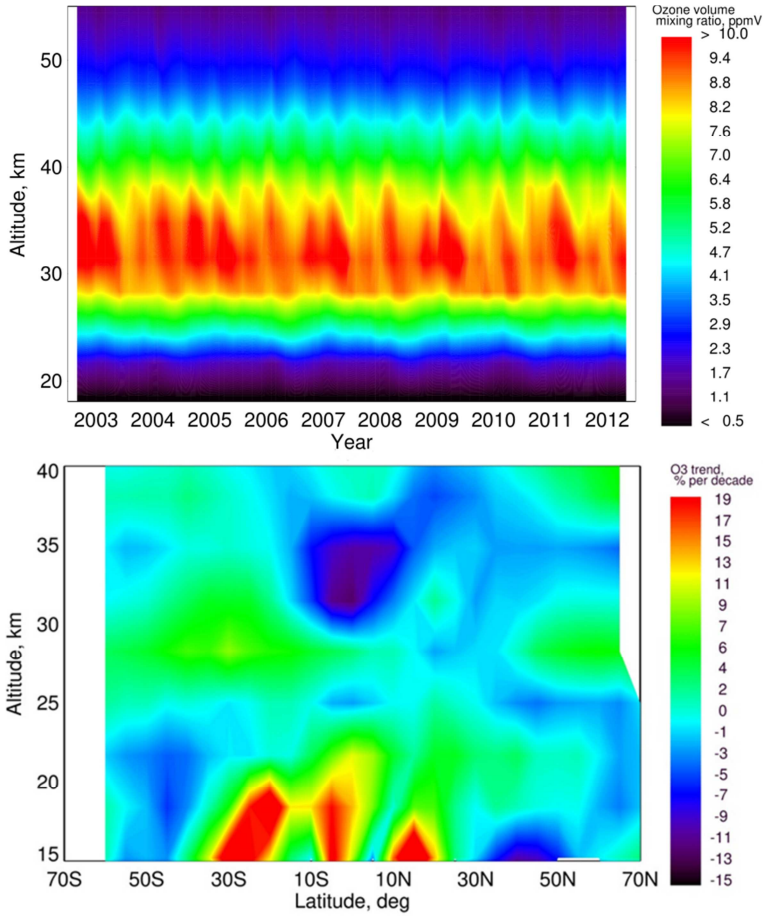


Fig. 10: Time series for the tropics between 10°S and 10°N (top) and linear change for zonal mean data from a linear regression (bottom) for the SCIAMACHY limb ozone data set V3.5 from 2004 to 2011. Plot by A. Rozanov, Univ. Bremen.

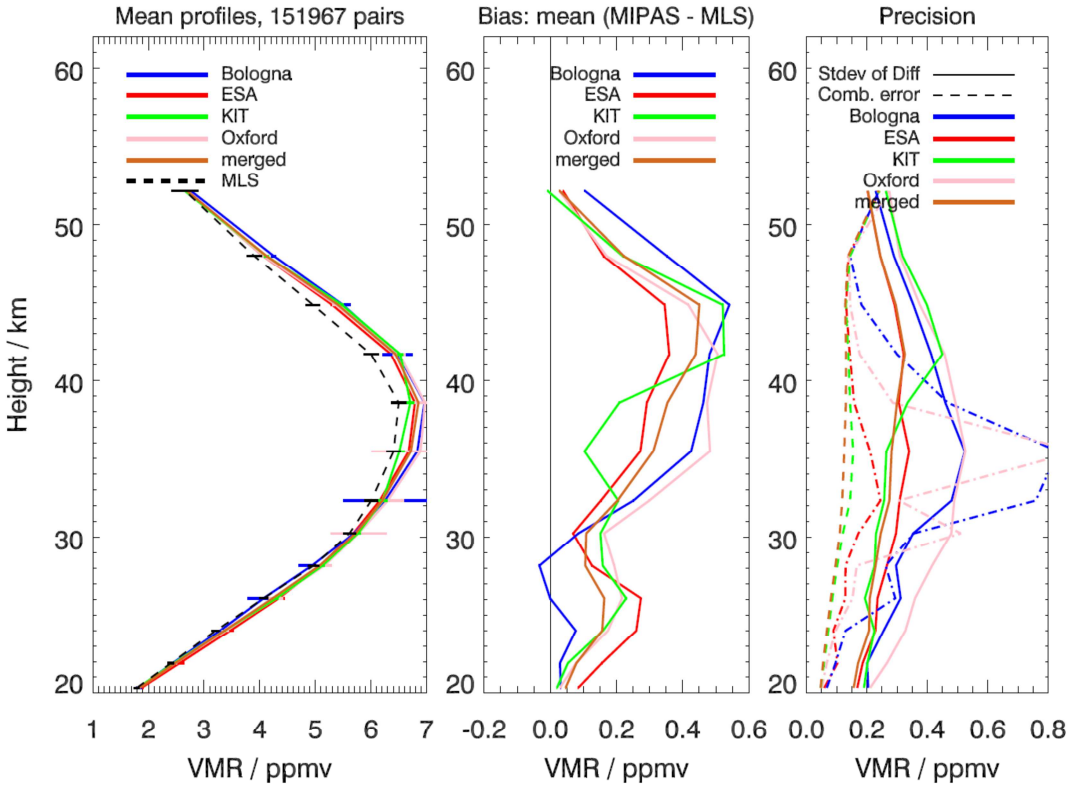


Fig. 11: Validation of the merged MIPAS/ENVISAT data set from four different processors with independent MLS data. From Laeng et al., 2016.

Routine ozone monitoring is also carried out by DLR (WDC-RSAT). Since the loss of ENVISAT in early 2012, only the AURA-MLS instrument is still providing ozone limb soundings. DLR has been assimilating MLS profile retrievals for O3, HCl, H2O, N2O and HNO3 into the 4Dvar chemical data assimilation system SACADA/DLR. Analyses are provided on a daily basis (wdc.dlr.de/sensors/mls). DLR also assimilates GOME-2 total column ozone using the ROSE/DLR model (wdc.dlr.de/sensors/gome2). In contrast to observations, analyses allow global mapping of the synoptic ozone and trace gas distribution, e.g. during the polar night.

These assimilated fields can be used to assess the trend of the ozone-hole size since 2007. Figure 12 shows this development of ozone-hole size (OHS) up to 2016. The latest year, 2016, is illustrated by the red line. Recent years saw a strong variation without a clear trend. During October and November, the strongest inter-annual variability can be found. While the OHS was especially large in September and October 2015 (among the largest in the last 10-years), the 2016 ozone hole showed average size with a rather early recovery. In 2015, in contrast, extremely low temperatures and a stable vortex prolonged stratospheric ozone depletion well into November (e.g., WMO ozone bulletins 2015).

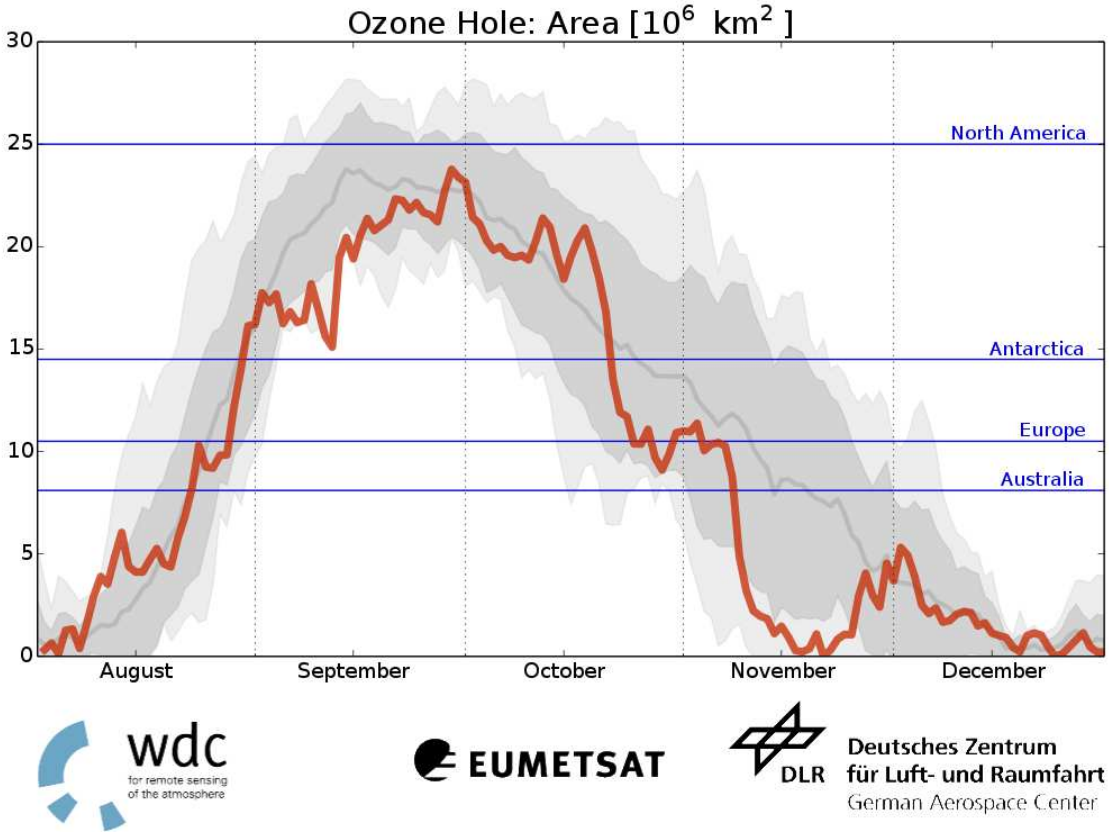


Fig. 12: Daily size of the Antarctic ozone hole from ROSE/DLR assimilation of GOME-2 data. Light grey area: Minimum to maximum range of daily data observed since 2007. Dark grey area: ±1 standard deviation around the mean (dark grey line). Red line: Evolution of the 2016 ozone hole. Plot by wdc.dlr.de.

Frankfurt University has continued investigations into the **trend in mean age of air** in the stratosphere. Age-of-air is an important diagnostic for changes in the strength of the Brewer-Dobson circulation. In the past, observations of a wide range of halocarbons, including the most important chlorine and bromine source gases were made by large and expensive stratospheric balloons carrying whole air samplers. These measurements have not been continued during the last years due to missing financial resources. University Frankfurt has instead focused on the Air-Core technique (Karion et al., 2010). It allows measurements of CO2 and Methane and thus derivation of mean age up to altitudes of about 30 km (Membrive et al., 2016). AirCore is light weight and can be flown on small balloons. U Frankfurt has used these observations to prolong their time series of mean age in the mid latitude stratosphere of the Northern Hemisphere (Engel et al., 2009). The trend derived from this new data set, shown in Fig. 13, and now spanning 40 years, is +0.15±0.18 years (Engel et al., in preparation, 2017). The positive trend is slightly smaller than the previous estimate but shows good agreement within the uncertainty range. These extended time series emphasize that a large negative trend in mean age of air in the middle stratosphere at Northern Hemisphere mid latitudes is difficult to reconcile with observations.

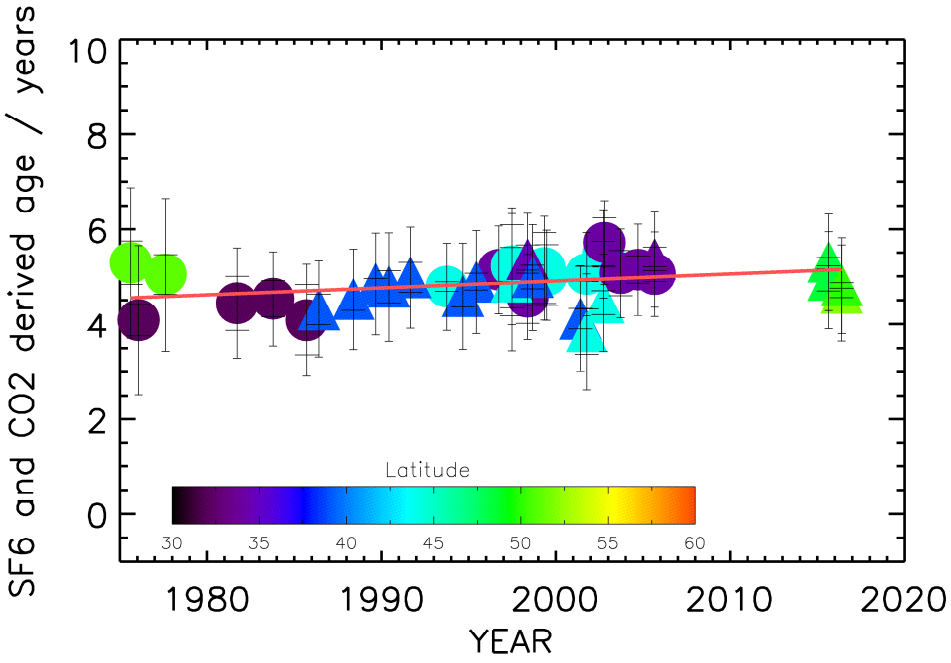


Fig. 13: Trend in mean age-of-air for the extratropical stratosphere derived from U Frankfurt air samples. The data points for 2015/16 are based on the AirCore technique. Update of Engel et al. 2009.

University Frankfurt has also developed new instrumentation for measurements of halocarbons. The classical measurement technique combines gas chromatographic separation with mass spectrometric detection using a quadrupole mass spectrometer. The use of a time-of-flight (TOF) mass spectrometer (MS), however, has significant advantages (Obersteiner et al., 2016; Hoker et al., 2015). The TOF-MS yields full-scan mass information, whereas the Quadrupole only measures certain pre-selected masses. The TOF-MS data thus constitute a full digital air archive, as all ions are recorded. Data can be later be evaluated for species not targeted at the time of measurements. Regular measurements with the new technique were started in 2013 at the Taunus Observatory near Frankfurt. They present the first long term measurements of halocarbons in Germany and they pioneer the new technique, allowing for future identification of interesting species. Since early 2014, similar measurements are performed on canisters sampled at the clean air station Mace Head in Ireland. The Taunus observatory is situated in the centre of Germany. It is well situated to provide observations for inverse modelling to derive emissions of halocarbons from Germany and parts of Central Europe.

3. THEORY, MODELLING, AND OTHER RESEARCH

A number of models, including chemistry-climate models (CCMs) are used in Germany to simulate and understand changes and trends of stratospheric ozone, and to predict the future evolution of the ozone layer. German activities are well interfaced to international programs like the SPARC/IGAC Chemistry-Climate-Modelling Initiative (CCMI), which has been co-led by DLR staff. ECHAM-MESSY (=EMAC), an improved CCM has been established by a consortium from **DLR, MPI for Chemistry, the University in Mainz, MPI for Meteorology in Hamburg, FU Berlin, and KIT** (Jöckel et al., 2016). Coordinated model simulations and analyses are being performed. EMAC has been used to simulate the decadal trends from the 1960s to 2100. These results have and will continue to contribute significantly to WMO/UNEP Scientific Assessments of Ozone including the upcoming one.

At **MPI for Chemistry** a version of EMAC with interactive stratospheric and tropospheric aerosol, including volcanic effects, was developed as contribution to the SPARC-Initiative SSIRC and the EU-project StratoClim (Brühl et al, 2015). SO2 data from MIPAS on ENVISAT provided by **KIT** were essential to attribute the volcanic injections into the UT/LS. MIPAS is also used for model validation. **AWI** is developing and employing the ATLAS CTM, which has been used for, e.g., modeling polar ozone depletion or transport pathways from the troposphere to the stratosphere. AWI is also developing SWIFT, a fast but accurate ozone chemistry scheme intended for use in Earth System and Climate Models, like the models used in the IPCC reports. So far these use prescribed ozone only. The fast new SWIFT enables the inclusion of interactions of ozone and climate in these models, which has not been feasible in the past due to computational constraints.

FZ-Jülich regularly performs simulations of polar ozone depletion and its interaction with other processes like vertical NOy redistribution using the Lagrangian CTM CLaMS (Grooß et al., 2014). CLaMS has been used extensively in the scientific flight planning for various aircraft measurements campaigns (e.g. POLSTRACC, StratoClim). Research on Polar Stratospheric Clouds (PSCs) has led to the development of a new PSC type classification from MIPAS observations (Spang et al., 2016) and to further insights into PSC nucleation (Engel et al., 2013; 2014, Hoyle et al, 2013). A simple measure for polar ozone loss is regularly derived from satellite total column observations and wind data (Müller et al., 2008). Figure 14 shows an update of this proxy for Arctic ozone depletion until the year 2016.

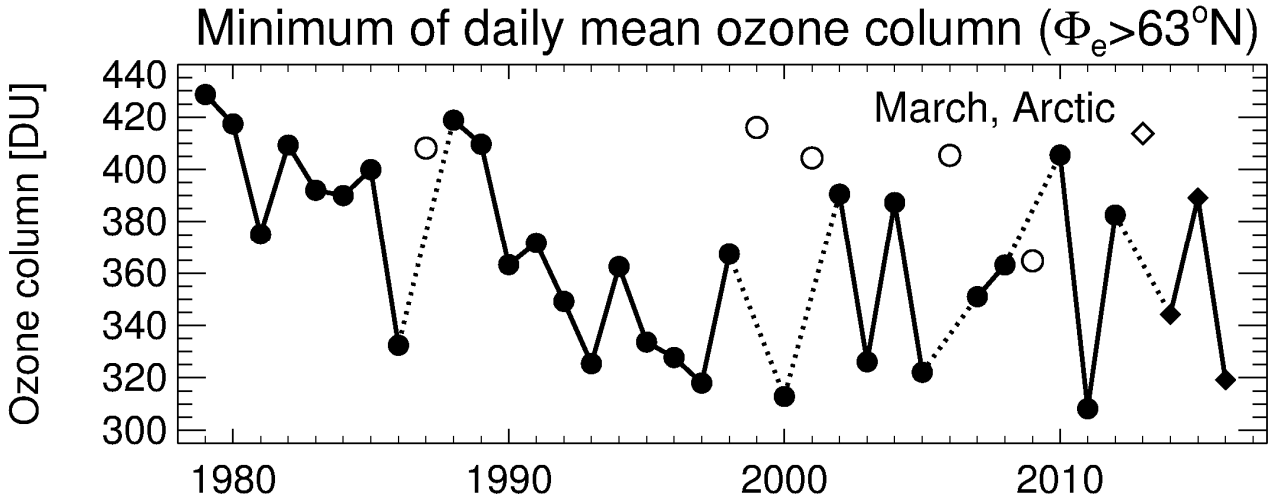


Fig. 14: Measure of Arctic ozone depletion given as the minimum of daily average column ozone poleward of 63° equivalent latitude in March. Open circles represent years in which the polar vortex broke up before March. Update from Müller et al. 2008, and WMO 2014.

KIT scientists have been involved in a number of ozone modelling activities with chemistry-climate, chemistry transport, and process models, as well as model development. Bednarz et al. (2016) investigated the importance of chemistry and dynamics for future Arctic ozone recovery. Sinnhuber and Meul (2015) investigated the impact of emissions of brominated very short-lived substances on past stratospheric ozone trends.

The working group **Atmospheric Dynamics at the Institut für Meteorologie of Freie Universität Berlin** (head: Prof. Dr. Ulrike Langematz) uses EMAC, as well as observations, to study the effects of changes in anthropogenic emissions of ozone depleting substances (ODSs) and greenhouse gases (GHGs) on stratospheric ozone. Using output from transient CCMVal-2 CCM simulations from 1960 to 2000 with prescribed changes of ozone depleting substance concentrations in conjunction with observations, Langematz et al (2016) examined the extent of anthropogenically-driven Antarctic ozone depletion prior to 1980. The year 1980 has often been used as a benchmark for the return of Antarctic ozone to conditions assumed to be unaffected by emissions of ozone depleting substances (ODSs), implying that anthropogenic ozone depletion in Antarctica started around 1980. A regression model was applied to attribute CCM modelled and observed changes in Antarctic total column ozone to halogen-driven chemistry prior to 1980. All models consistently show a long-term, halogen-induced negative trend in Antarctic ozone from 1960 to 1980 in response to rising ODSs (Figure 15). The anthropogenically-driven ozone loss from 1960 to 1980 of maximal 49.8 ± 6.2 % of the total anthropogenic ozone depletion from 1960 to 2000 in the CCMs is lower but consistent with the ozone decline of 56.4 ± 6.8 % estimated from ozone observations. This analysis clarified that while the return of Antarctic ozone to 1980 values remains a valid milestone, achieving that milestone is not indicative of full recovery of the Antarctic ozone layer from the effects of ODSs.

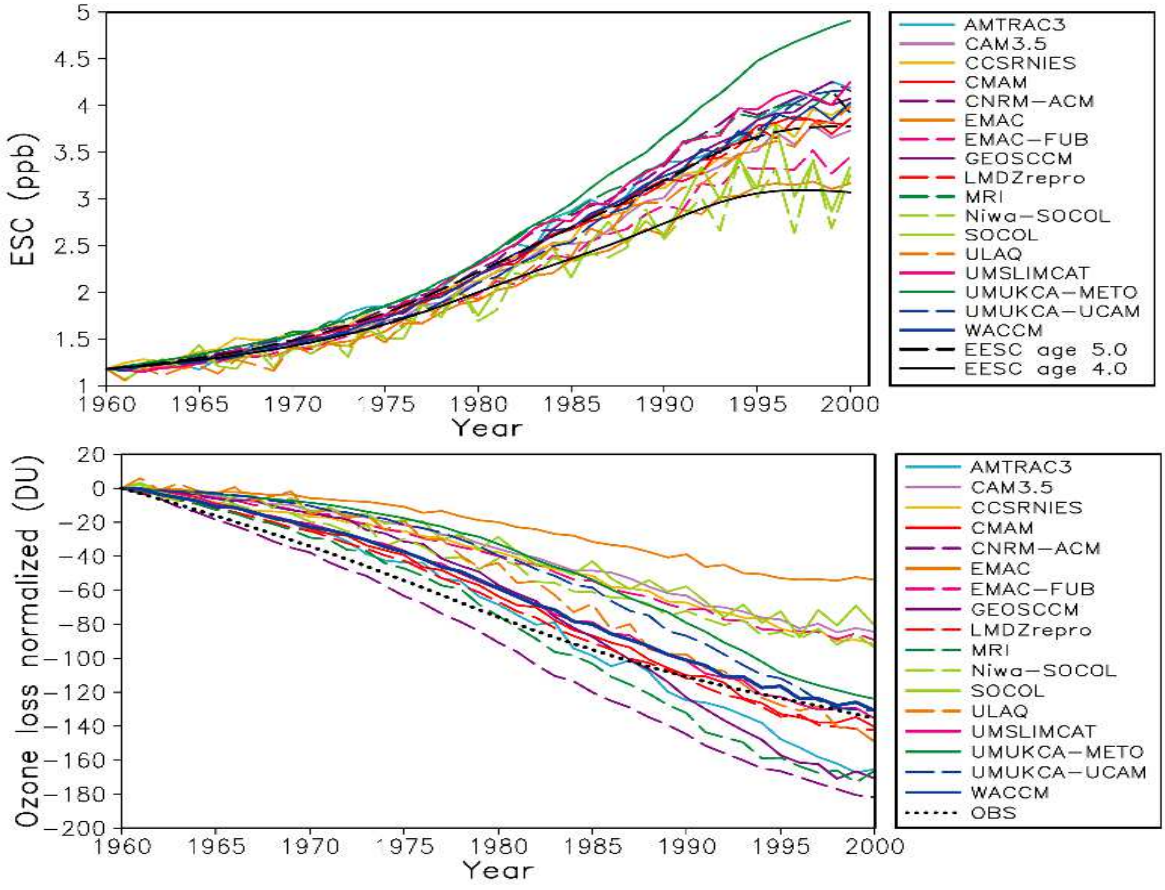


Fig. 15: top: Evolution of Antarctic September/October/November (SON) average ESC (in ppb) in the REF-B1 CCM simulations between 1960 and 2000, adjusted to a common baseline of 1960. Black lines show EESC (in ppb), provided by Newman et al. [2007] for mean transit times of 4 (solid) or 5 (dashed) years. Bottom: Antarctic total ozone column depletion (in DU, SON average) between 1960 and 2000 due to ESC in the CCMs and due to EESC in observations, adjusted to a common baseline (1960 mean of CCMs). From Langematz et al., 2016.

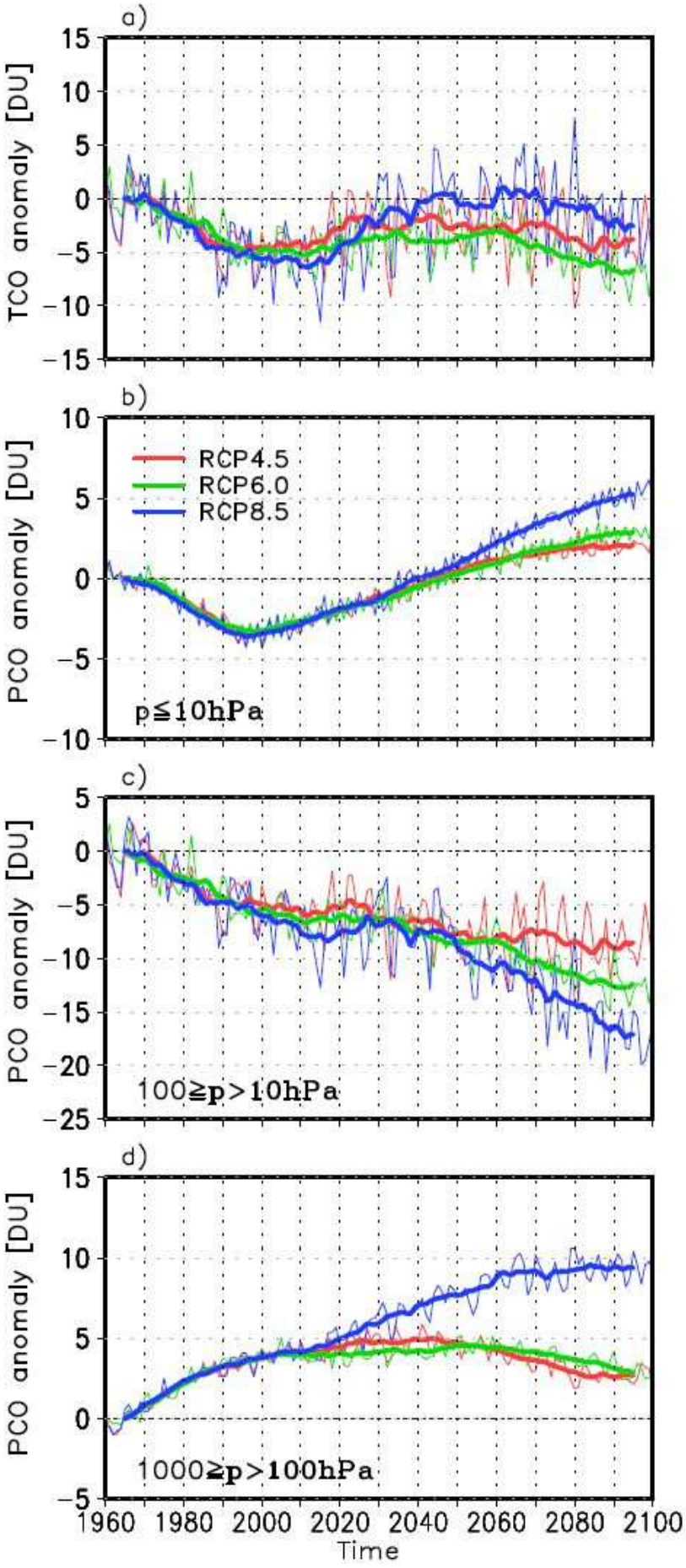


Fig. 16: (a) Time series of annual mean tropical (20°S–20°N) total column ozone anomaly to the 1960–1970 mean for the RCP4.5 (red), RCP6.0 (green), and RCP8.5 (blue) simulations, (b–d) same but for the partial columns in the upper stratosphere (pressure ≤ 10 hPa), middle stratosphere (100 hPa ≥ pressure > 10 hPa), and troposphere (1000 hPa ≥ pressure > 100 hPa). Thick solid lines give the smoothed time series. From Meul et al. 2016.

The future evolution of tropical total column ozone (TCO) is affected not only by the expected decline of ODSs but also by the uncertain increase of GHG emissions. Meul et al. (2016) assessed the range of tropical TCO projections in simulations with the EMAC CCM forced by three different GHG scenarios (Representative Concentration Pathway RCP4.5, RCP6.0, and RCP8.5). Figure 16 shows that tropical TCO will be lower by the end of the 21st century compared to the 1960s in all scenarios, with the largest decrease in the medium RCP6.0 scenario. Contributions for different atmospheric layers vary in magnitude and sign. This means that significant uncertainties for the projected TCO come from uncertain magnitude of stratospheric column decrease and tropospheric ozone increase, which vary significantly between scenarios. In all three scenario simulations, future stratospheric column decrease is not compensated by increases in tropospheric ozone. In Fig. 17, the concomitant increase in harmful ultraviolet irradiance is strongest in the medium RCP6.0 scenario and reaches up to 15% in specific regions, while in the extreme RCP8.5 scenario a strong increase in tropospheric ozone due to high future methane emissions mitigates stratospheric tropical ozone decreases and the increase in harmful surface irradiance.

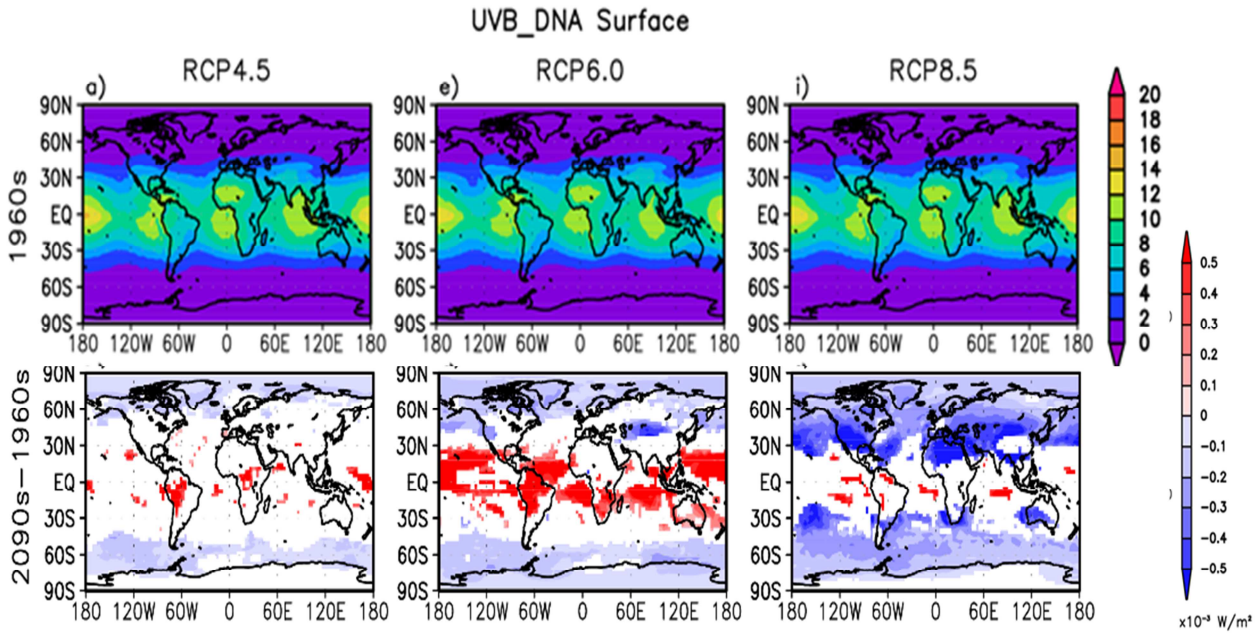


Fig. 17: Top row: Geographical distribution of the 21st century annual mean UV-index, i.e. UV-B radiation weighted with the DNA damage action spectrum (UVB-DNA) at the surface, for the RCP4.5 (left), RCP6.0 (middle) and RCP8.5 (right) simulations, Bottom row: Change in UVB-DNA from 1960 to 2100 for the three RCP scenarios (2100-1960, in 10-3 W/m2). Statistically significant changes at the 95% confidence level are colored. From Meul et al., 2016.

4. DISSEMINATION OF RESULTS

4.1 Data reporting and providing

German ozone and related data are regularly submitted to the World Ozone and UV Data Centers at Toronto (WOUDC), to NDACC and to rapid delivery data centers in Thessaloniki, and at NILU. In addition DLR hosts the World Data Center for Remote Sensing of the Atmosphere, WDC-RSAT, and provides operational processing and data delivery for GOME-2 Metop total ozone columns and other traces gases. See Fig. 18 for examples and URLs. In addition data and results are available from a number of institutes through the websites given in Table 1 at the beginning of this report. FZ Jülich, for example, provides information of chemical ozone loss in the Arctic within the Earth System Knowledge Platform (ESKP). The site iek-7.eskp.fz-juelich.de provides actual CLaMS model calculations of ozone depletion during the Arctic winter and its comparisons with previous years. Also the temperature-based proxy V_PSC and estimations of the UV Index increase due to ozone depletion are provided. General information sources for UV radiation, arguably most important for the general public, are detailed in the next sub-section.

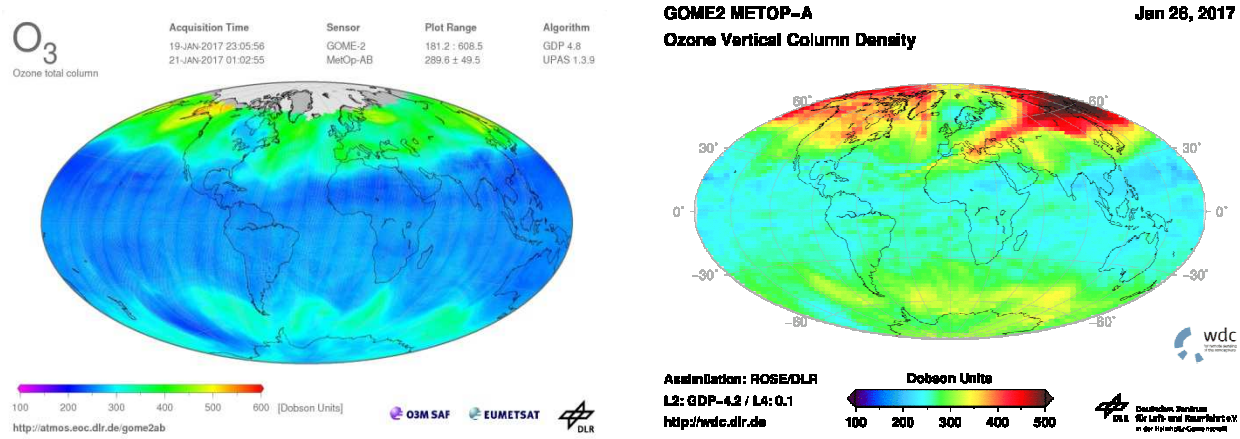


Fig. 18: Ozone total columns from MetOp-A,B/GOME-2 for January 2017. Left: Data product from DLR processing in the framework of EUMETSAT Ozone-SAF (atmos.eoc.dlr.de/gome2). ***Right: Assimilated data product from Chemistry Transport Model*** (wdc.dlr.de).

4.2 Information to the public

BfS and DWD provide the public with UV-information including daily forecasts of the UV-index and warnings. The daily UV-forecasts for clear sky and cloudy conditions are available for free on a global scale (kunden.dwd.de/uvi/) and nationally (www.uv-index.de, www.bfs.de/DE/themen/opt/uv/uv-index/prognose/prognose_node.html).

When necessary, press releases and dedicated warnings are published by the appropriate agencies and institutes. In addition, outreach activities include open houses, tours, events and internship programs.

4.3 Selected recent scientific papers

For a complete list of ozone related publications from Germany, the use of bibliographic search engines is recommended (e.g. scholar.google.com or isiknowledge.com/WOS)

Bednarz, E. M., A. C. Maycock, N. L. Abraham, P. Braesicke, O. Dessens, J. A. Pyle, Future Arctic ozone recovery: the importance of chemistry and dynamics, Atmos. Chem. Phys., 16, 12159-12176, 2016.

Brühl, C., J. Lelieveld, H. Tost, M.Höpfner, N. Glatthor ,2015: Stratospheric sulfur and its implications for radiative forcing simulated by the chemistry climate model EMAC, J. Geophys. Res., 120, 2103-2118, doi:10.1002/2014JD022430

Ebojie, F., von Savigny, C., Ladstätter-Weißenmayer, A., Rozanov, A., Weber, M., Eichmann, K.-U., Bötel, S., Rahpoe, N., Bovensmann, H., and Burrows, J. P., Tropospheric column amount of ozone retrieved from SCIAM-ACHY limb–nadir-matching observations, Atmos. Meas. Tech., 7, 2073-2096, doi:10.5194/amt-7-2073-2014, 2014.

Ebojie, F., Burrows, J. P., Gebhardt, C., von Savigny, C., Rozanov, A., Weber, M., and Bovensmann, H.: Global and zonal tropospheric ozone variations from 2003–2011 as seen by SCIAMACHY, Atmos. Chem. Phys., 16, 417-436, doi:10.5194/acp-16-417-2016, 2016.

Engel, A., Mobius, T., Bonisch, H., Schmidt, U., Heinz, R., Levin, I., Atlas, E., Aoki, S., Nakazawa, T., Sugawara, S., Moore, F., Hurst, D., Elkins, J., Schauffler, S., Andrews, A., and Boering, K.: Age of stratospheric air unchanged within uncertainties over the past 30 years, Nature Geosci., 2, 28-31, 10.1038/NGEO388, 2009.

Engel, I., B. P. Luo, M. C. Pitts, L. R. Poole, C. R. Hoyle,J.-U. Grooß, A. Dörnbrack, and T. Peter Heterogeneous formation of polar stratospheric clouds - Part 2: Nucleation of ice on synoptic scales, Atmos. Chem. Phys., 13, 10769-10785, 2013.

Engel, I., B. P. Luo, S. M. Khaykin, F. G. Wienhold, H. Vömel, R. Kivi, C. R. Hoyle, J.-U. Grooß, M. C. Pitts, and T. Peter, Arctic Stratospheric Dehydration - Part 2: Microphysical Modeling, Atmos. Chem. Phys., 14, 3231-3246, 2014.

Gorshelev, V., Serdyuchenko, A., Weber, M., Chehade, W., and Burrows, J. P., High spectral resolution ozone absorption cross-sections – Part 1: Measurements, data analysis and comparison with previous measurements around 293 K, Atmos. Meas. Tech., 7, 609-624, doi:10.5194/amt-7-609-2014, 2014.

Grooß, J.-U., I. Engel, S. Borrmann, W. Frey, G. Günther, C. R. Hoyle, R. Kivi, B. P. Luo, S. Molleker, T. Peter, M. C. Pitts, H. Schlager, G. Stiller, H. Vömel, K. A. Walker, and R. Müller, Nitric acid trihydrate nucleation and denitrification in the Arctic stratosphere, Atmos. Chem. Phys., 14, 1055-1073, 2014.

Heikkilä A., Kaurola J., Lakkala K., Karhu J.M., Kyrö E., Koskela T., Engelsen O., Slaper H., Seckmeyer G.: European UV DataBase (EUVDB) as a repository and quality analyzer for solar spectral UV irradiance monitored in Sodankylä, in Special issue: Multi-disciplinary research and integrated monitoring at the Sodankylä research station: from sub-surface to upper atmosphere processes, Geoscientific Instrumentation, Methods and Data Systems, 2016

Hoker, J., Obersteiner, F., Bönisch, H., and Engel, A.: Comparison of GC/time-of-flight MS with GC/quadrupole MS for halocarbon trace gas analysis, Atmos. Meas. Tech., 8, 2195-2206, 10.5194/amt-8-2195-2015, 2015.

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5. PROJECTS AND COLLABORATION

German institutions have participated in a number of national and EU funded research projects, special measurement campaigns and modeling studies, such as SHARP, ROMIC, CAWSES, MACC, CAMS, SHIVA, STRATOCLIM, RECONCILE, CCMVal, CCMI, SPARC and SSiRC. They also play an important role in EUMETSAT and ESA projects. DLR-EOC, for example, is responsible for the operational GOME-2 total and tropospheric ozone and trace gas processing (total NO2, tropospheric NO2, SO2, BrO, H2O, HCHO) in the framework of the EUMETSAT O3M-SAF. DLR, KIT, and IUP Bremen are key partners in the ESA CCI project to provide the Total Ozone Essential Climate Variable (GTO-ECV). 14 active Arctic and 2 Antarctic Match campaigns, coordinated by AWI, and additional 3 passive Arctic Match analyses, funded by the EU and national institutes, have been carried out since the winter 1991/92, most recently in the Northern Hemisphere winter 2016/2017. These campaigns have been instrumental for our current understanding of chemical ozone loss in the Arctic.

Since 1 December 2013 AWI coordinates the EU project StratoClim (budget ~12 million Euros, 28 partners from 11 European countries) which aims to strengthen our understanding of the role of stratospheric aerosols, ozone and water vapor on climate. Within that project an airborne campaign was carried out in the Bay of Bengal in 2016 and a station on the West Pacific Island Palau is taking measurements with ozone-sondes and a FTIR for at least 2 years.

KIT scientists are member of ESA's MIPAS Quality Working Group, the ACE-FTS Science team and various science teams of international space experiments. Further, they are involved and play a leading role in the Network for the Detection of Atmospheric Composition Change (NDACC), in a number of SPARC activities (WAVAS, SDI, Stratospheric Sulphur, CCMI, SI2N and LOTUS) and participate to ESA's Climate Change Initiative, where the KIT-IMK ozone product from MIPAS is preferred over the official ESA data product. KIT contributes to the STRATOCLIM EC project, the DFG Research Unit SHARP, and the BMBF research program ROMIC. J. Orphal is president of the ACSO committee of WMO/IO3C/IGACO (see also Orphal et al., 2016).

IUP Bremen scientists are members of ESA's SCIAMACHY Quality Working Group and are on the advisory boards of upcoming new missions (Sentinel 5P, 4, and 5). They are participating in several ESA/DLR projects (validation, verification algorithm development, Copernicus program) and part of various science teams of international space missions. IUP Bremen was involved in the DFG Research Unit SHARP and is involved in the BMBF Priority Program ROMIC.

German modelling groups are contributing to the International Chemistry-Climate-Model Intercomparison (CCMI), where key simulations for the prediction of the future evolution of the ozone layer under various scenarios for changing ODS and greenhouse gas concentrations are being done. CCMI will deliver key input for the next UNEP/WMO Scientific Assessment of Ozone Deple-

tion. It is expected that German scientists will contribute substantially again to the upcoming assessment.

Key Programs:

ROMIC – Role of the Middle Atmosphere in Climate – BMBF German Federal Ministry for Research

MiKlip I, II, - Mid-range Climate Prediction - – BMBF German Federal Ministry for Research

SHARP – Stratospheric Change and its Role for Climate Prediction – Deutsche Forschungsgemeinschaft.

IAGOS-D - In-service Aircraft for a Global Observing System – BMBF German Federal Ministry for Research

POLSTRACC - Polar Stratosphere in a Changing Climate – Helmholtz Gesellschaft and Deutsche Forschungsgemeinschaft.

SHIVA - Stratospheric Ozone: Halogen Impacts in a Varying Atmosphere- European Community, Framework 7

STRATOCLIM - Stratospheric and upper tropospheric processes for better climate predictions – European Community, Framework 7

MACC II / III - Monitoring Atmospheric Composition and Climate Interim Implementation - European Community, Framework 7, Horizon 2020

CAMS – Copernicus Atmospheric Monitoring Service – European Commission

ESA_CCI – ESA Climate Change Initiative – European Space Agency

6. FUTURE PLANS

Generally, German ozone observations and research activities are expected to continue along the indicated lines. Funding is expected to continue from national and European sources and projects, however, with a generally decreasing trend.

The German Aerospace Centre (DLR-EOC) is leading the development of the operational system for processing the TROPOMI/Sentinel-5-Precursor data (to be launched in 2017) in close collaboration with leading scientists from the institutes KNMI (The Netherlands) , SRON (The Netherlands). IUP Bremen, MPIC Mainz, BIRA (Belgium), and RAL (UK). In the same way, DLR-EOC will play a key role in the processing of the Sentinel 4 and Sentinel 5 data.

KIT, together with the Research Center Jülich, is Lead Investigator of the German satellite project AtmoSat, carrying a limb-2D-imaging infrared spectrometer, in order to observe the chemical composition and dynamics of the upper troposphere, the stratosphere and the lower thermosphere, at unprecedented spatial resolution and coverage. AtmoSat is currently being evaluated by the German Wissenschaftsrat. If accepted, AtmoSat will be launched in 2023 with a proposed lifetime of at least 5 years. During the POLSTRACC (The Polar Stratosphere in a Changing Climate) campaign in winter 2015/2016 a large number of trace gases were measured in the lower stratosphere and UTLS, by a number of instruments from different institutes onboard the German research aircraft HALO. Similar aircraft campaigns are envisioned for the future.

Within the EU project StratoClim AWI and Uni Bremen together with international collaborators will perform measurements with ozonesondes, FTIR and a multi-wavelength cloud/aerosol lidar for about 2 years on the West Pacific island Palau.

German modeling simulation activities will continue within the international framework of, e.g., CCMI, to clarify the expected evolution of ozone (recovery, super-recovery, tropical decline), but also to address the important links with climate change (tropospheric warming, stratospheric cooling, changes in wave driving, possible acceleration of the Brewer Dobson circulation).

7. NEEDS AND RECOMMENDATIONS

- Adequate tracking of the expected ozone layer recovery process requires continuing high-quality measurements of total ozone and ozone profiles by satellites and ground-based systems for the next decades. High-quality data and long-term records of ozone, temperature, and UV must have high priority.
- Quality Assurance/Quality Control activities like calibration centres are essential in order to achieve the required accuracy of the global ozone observing system. They lay the foundation for satellite validation, for ozone monitoring, and for trend analyses.
- Within this context, the finalization and implementation of new ozone cross-section/absorption coefficients across the various instruments, both ground-based and satellite-borne, with an accuracy reaching 1% or better, remains a high priority.
- The complex coupling of ozone, atmospheric chemistry, transports and climate changes is still not fully understood. High quality, long-term data sets and continued modelling efforts are key prerequisites to understand and track the underlying processes.
- Further model studies are required to better quantify the expected substantial changes in both ozone and temperature distributions, and for different emission scenarios.
- Critical stratospheric constituents that are relevant for ozone and green-house warming/ stratospheric cooling need to be monitored in the future as well. This monitoring program must include a limited number of high quality ground-based stations targeting the middle atmosphere, as well as direct sampling of stratospheric air from air-borne platforms such as high flying aircrafts and balloons.
- The lack of future limb sounding satellite instruments is of great concern. Vertically resolved profiles not only of ozone but also other key constituents are essential for monitoring and attribution of future ozone changes, resulting from recovery from man-made halogen loading, but also under the influence of a changing climate.

INDIA

The five IMD stations recording total ozone since 1957 with Dobson spectrometers/Brewer Ozone Spectrophotometers are spread out in a latitudinal belt ranging from 10° N to 35°N. The mean total ozone amounts over these station range from about 300 DU at the northern most stations to about 250 DU at the southern extreme. All the stations show marked seasonal variations in total ozone amounts. The amplitudes of the seasonal variations are higher over Srinagar (34°N), with 40 DU and are low over stations in the tropical belt where the amplitudes are about 20-25DU. A clear phase-shift in the occurrence of ozone maxima and minima is also observed as we move from higher to lower latitude tropics. The maxima and minima occur during spring (Feb-Apr) and autumn (Sept-Oct), respectively in Srinagar. This progressively shifts to summer (Jun-Aug) and winter (Dec-Jan) at Kodaikanal (10°N). Although one could be due to sun driven photochemistry and lower stratospheric dynamics.
Analysis of long-term total ozone data from the Indian stations has not shown any trends, however, there are inter-annual variations. Such variations are of scientific interest and not of any public concern at the present age. Measurements by different techniques and investigations also vary nominally, mostly within the limits of statistical fluctuations of the data.

The vertical distribution of ozone in the equatorial atmosphere has been shown to be generally same although small changes occur in both the lower stratosphere and the troposphere. One particularly interesting feature is smallest concentration of ozone found consistently, just below the Tropopause, in all seasons and at all places where sounding have been made in India. Over Delhi the maximum occurs at about 23-24 km with secondary maxima in the lower stratosphere particularly during winter and spring. The maximum ozone concentration of the order of 150μmb occurs at a height of 26-27 km over Thiruvananthapuram (8°N) and 25-26 km over Pune (8°N). During the summer monsoon months, the vertical distribution of ozone throughout India is very similar.

Based on Umkehr data, Ozone concentration in the lower troposphere has been observed to be slightly increasing over Delhi. Also the stratosphere shows a decreasing trend, especially after 1982.

From the study of Peshin et al 2003,2008,2011 , Chakrabraty and Peshin 1995,1998,2011,Sreedharan, C.R., et.al. 1989; Mani, A., 1993; Subbaraya,B.H., 1993; Rao, K. Nagbhusan, 1993; Sreedharan, C.R., et. al. 1993a; Sreedharan, C.R., et. al. 1993b; Koppar, A.L. and S.C. Nagrath, 1991; Kane, R.P., 1994 and Tiwari, V.S., 1992; the following conclusions may be drawn:

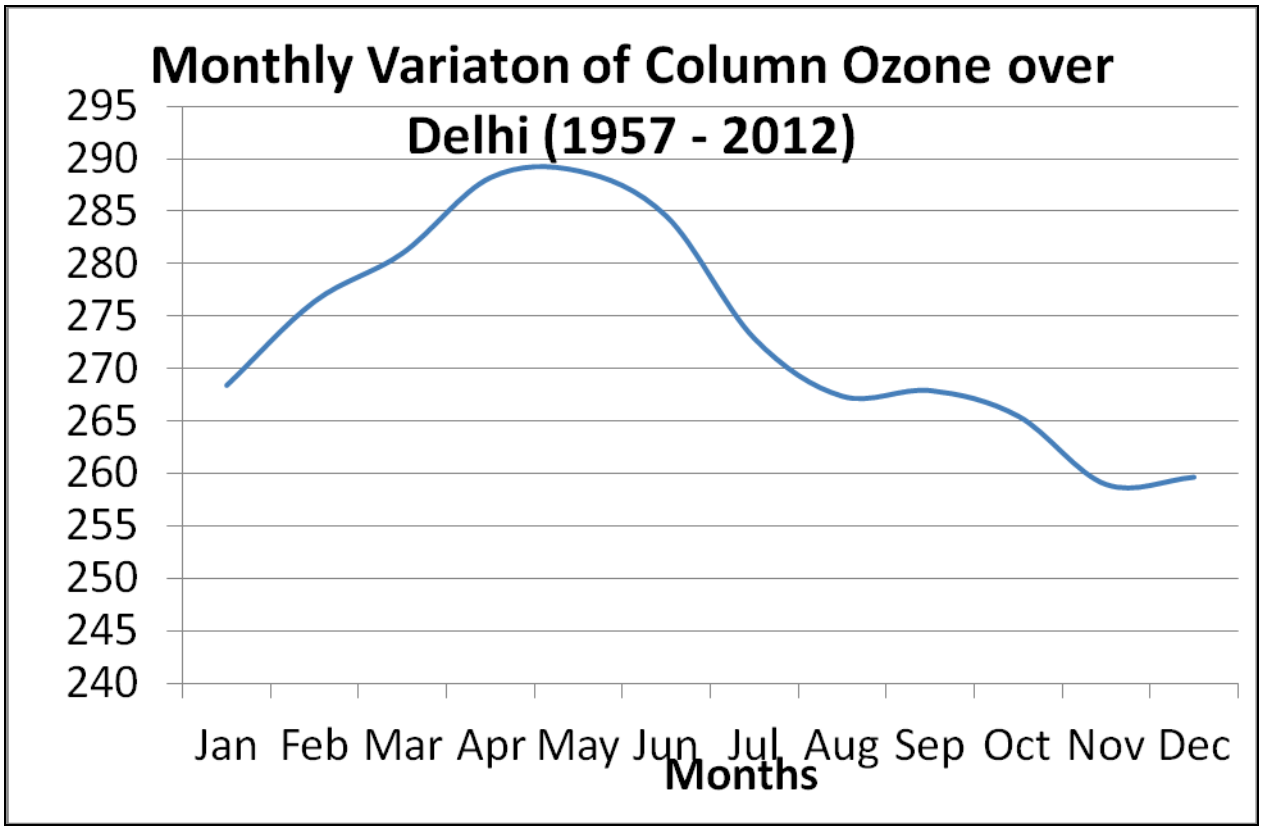
1. Analysis of the data available so far does not establish any clear trend in the variation of total ozone over India. However, stratospheric ozone shows little decreasing trend since the last few years over stations situated North of Lat.24-25°N. Tropospheric ozone shows an increasing trend but not statistically significant.

2. From the equator to about 20°N, the tropospheric ozone concentration remains practically the same throughout the year.

3. Significant changes occur in the vertical distribution of ozone associated with passing weather systems occur at New Delhi during the non-monsoon months.

4. Depletion of ozone over Antarctica is observed, confirming occurrence of Antarctic hole. The ozone hole phenomenon has also been observed over the Indian Antarctic Station at Maitri (70°S, 11°E) where IMD monitors ozone amounts throughout the year.

5. Surface ozone data over the Indian stations have not indicated any systematic variation. Presently ozone concentrations at surface level are within safe limits. Ambient surface concentrations prevailing over Indian cities are not more than 40 ppbv which is well within the prescribed limits of 50 ppbv as given by the MoES (SAFAR).



TOTAL OZONE:

S.No	Name of station	Lat.	Long.	Instrument Type & S.No	Frequency of obsn.	Since when
1	Srinagar	34° 05′ N	74° 50′ E	Dobson 10	6/day	Nov.1955
2	New Delhi	28° 35′ N	77° 12′ E	Dobson 36	6/day	Jan. 1955
3	New Delhi	28° 35′ N	77° 12′ E	Brewer 089/164	Cont.	Aug.1994
4	Varanasi	25° 18′ N	83° 01′ E	Dobson 55	6/day	Dec.1963
5	Pune Pune	18° 32′ N	73 °51′ E	Dobson 39 Brewer 170	6/day Cont.	Mar.1973 Oct. 2005
6	Kodaikanal	10° 14′ N	77° 28′ E	Dobson 45	6/day	July 1957
7	Kodaikanal	10° 14′ N	77° 28′ E	Brewer 094	Cont.	May 1994
8	Maitri (Antarctica)	70° 48′ S	11° 42′ E	Brewer 153	Cont.	July 1999
9	New Delhi	STANDARD		Dobson 112	Aprl.1969	

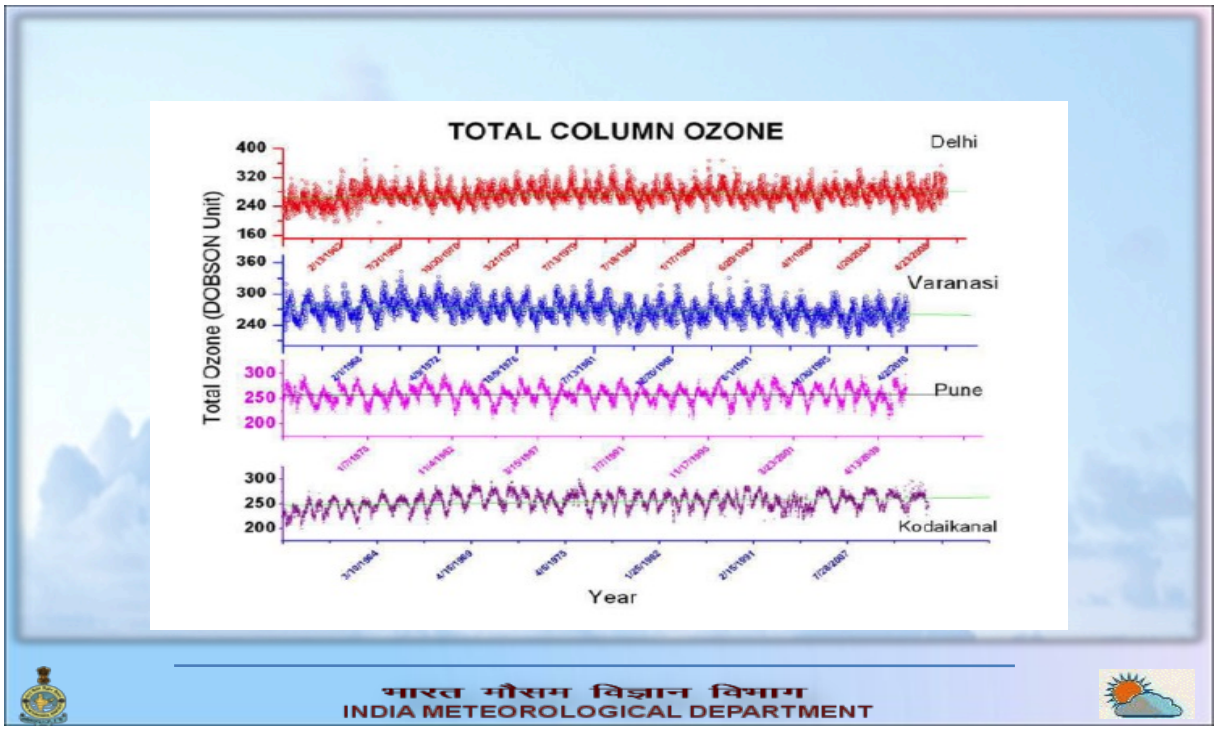


Figure : IMD's Network of Ozone Monitoring Stations in India

Vertical distribution of ozone

S.No	Name of station	Lat.	Long.	Frequency of observation	Since when
1	New Delhi	28º 35′ N	77º 12′E	Fortnightly	1971
2	Pune	18º 32′ N	73º51′ E	Fortnightly	1971
3	Thiruvananthapuram	08º 29′ N	76º 57′ E	Fortnightly	1971
4	Dakshin Gangotri	70º 03′ S	12ºE	Weekly	1986-89
5	Maitri (Antarctica)	70º 48′ S	11º 42′ E	Weekly	1990

Indian ozonesonde was intercompared in West Germany in 1970 and 1980,Canada in May 1991 and in Germany February 1996.



Calibration

- Network instruments standardized against the National Standard at regular intervals.
- National Standard, in turn intercompared with world standard in international intercomparisions/RA-II held in Japan .
- IMD participated in such comparisons held at Belsk (1974), Boulder (1977), Melbourne (1984) and Japan (1996,2006).

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NEEDS AND RECOMMENDATIONS

The WMO support is required for technical inspection of the Brewer spectrophotometers in Delhi, Kodaokanal and Pune, and calibration of all the 3 ones operating in India, and also Calibration of Dobson Spectrophotometer.

IRAN, ISLAMIC REPUBLIC OF

1. OBSERVATIONAL ACTIVITIES

This report contains the updated information on the ozone and UV observation and research activities which have been pursued in Iran during past two years since the 9th meeting of the WMO/UNEP Ozone Research Managers.

For the past three decades, the Meteorological Organization (MO), Geophysics Institute of the University of Tehran and Tarbiat Modares University of Tehran (the Department of Physical Geography) with the encouragement and support of Iran's NOU have been performing UV-B and ozone monitoring and research activities in Iran. However, there are some obstacles on this roadmap that have almost weakened the attainment of the specified goals.

Research and monitoring activities are based mainly on and through continuous cooperation and exchange of information between these centers and some other new research and executive entities. In addition, the Iran's NOU through the communications and correspondences with different organizations and organizing successive meetings between members have now involved them to solve the capacity building problem of Ozone/UV monitoring system and public awareness. For example the Ministry of Health and Atomic Energy Organization have lunched the UV index Monitoring System in 18 stations of Iran during three past years. As a consequence, the mentioned UVI network in Iran is being tested and calibrated with international standard to be used in academic researches and for informing the public. It should be also noted that these new measuring instruments are result of efforts of the Department of Environment and other Institutes to improve and develop regional environmental information and reduce data gaps in order to better understand the global environment concerning UV radiation especially in the Middle East region (mentioned in the last report of UNEP in 2014).

In spite of fairly long history of the ozone atmospheric observation and research, Iran still lacks a sufficient capacity to form national network in the field of ozone observation limited to only two points of the country's atmospheric research and monitoring platform.

1.1 Column measurements of ozone and other gases/variables relevant to ozone loss

There are two stations where the ozone measurement facilities have been installed and are in use. The following stations are operating under the supervision of the Meteorological Organization (MO) and the Geophysics Institute of the University of Tehran. As shown in table 1, names, situation and other relevant information of three stations in Iran i.e. types and facilities have been included.

Two considered ground based stations of Isfahan and Geophysics of Tehran use two different kinds of Brewer and Dobson equipment respectively. The Firooz-kooh station which had been mentioned in the last national report of Iran had measured the tropospheric ozone not the stratospheric ozone. In fact, there are only two stations in Iran that have responsibility for measuring the Total Ozone Column (TOC). Nevertheless, the two mentioned stations are not permitted to arrange datasheet based on the annual and monthly timescales without long gaps, because so far, they have measured TOC with consecutive intervals.

The information of the above stations is provided in the Table 1, and the spatial distribution of them is also shown in the Figure 1. As it can be inferred from Fig 1, distance and distribution between three stations don't well cover the all parts of country and there are many vacant and unknown areas from north-west to south –east and north east to south- west. Based on the last study performed by Iran's NOU, no stations have been allocated for the regions of Iran where extreme UV radiation seen by the modified data of satellite instrument.

Table 1. Stations active in the ozone and UV measurement and monitoring actives in Iran

Station	Type		Coordination			Measurement Facilities		
	Synoptic	Upper Atmospheric	Latitude	Longitude	Altitude (metric)	Surface	vertical	Total
Isfahan	Yes	Yes	32° 37′N	51° 40′ E	1550	Yes	Yes	Yes
Geophysics	Yes	No	35° 44′N	51° 33′ E	1419	Yes	No	Yes
Firooz-kooh	Yes	No	35° 43′N	52° 34′ E	2986	Yes	No	No

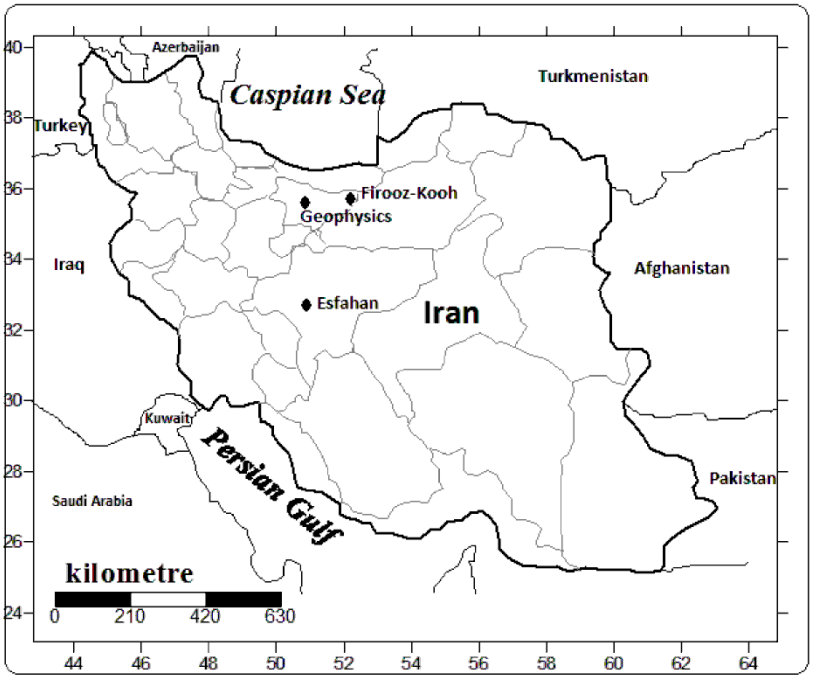


Figure 1. The spatial pattern of different stations in Iran with measurements of ozone column contents, (Isfahan measures UV and TOC, Geophysics measures TOC and Firooz-kooh measures surface Ozone).

Isfahan Ozone Station

This station is recognized by an international 336 code and is connected to the global networking system. Total ozone is being measured using Dobson system since January 2000. Since April 2000, Brewer equipment was installed and has been operating at Isfahan station. This system measures total ozone in vertical column in an area of 1 cm^2 by attracting solar and sky radiation. In addition, the system measures UV-B, SO2, and NO2.The Isfahan station is recognized by an OIFM code and measures on a daily basis the upper atmospheric conditions between 11 to 12 GMT. This station is also equipped with Radiosonde (RS80) and Hydrogen balloon (totex 600gr) in order to study the Upper Atmosphere. Unfortunately during recent years, due to the lack of calibration at its deadline (from May 2013), the Brewer spectrophotometer located in Isfahan station was stopped measuring the Total Ozone along with other parameters. So far, Iran's NOU and MO have frequently requested WMO/UNEP and other relevant universities and institutes to assist to solve this routine and simple problem (calibration) , but the Brewer instrument of Isfahan station has been still remained undecided

in the technical warehouse of MO and is waiting to receive permission of calibration in a reliable and responsible country.

Geophysics institute station

The institute is mainly responsible for total ozone monitoring, data recording and processing, networking with World Ozone and Ultraviolet Radiation Data Center (WOUDC) and conducts networking, training and public awareness campaigns on stratospheric and surface ozone. The center is equipped with a Dobson photo-spectrometer and ancillary data processing and analysis hardware and software systems. The institute has been cooperating with the Municipality of Tehran for the air pollution monitoring activities through the established network of pollutants monitoring stations. As of 2000, total ozone has been measured using Dobson system for 30 minutes (from 8am to 7pm). Results of the measurements are regularly calibrated using satellite data. The data recorded at the above stations is being reported to the WOUDC and are available through the center's web pages.

Dobson photo-spectrometer in Geophysics institute station had been idle up to September 2016. Iran's NOU has been following up this issue and coordinated so that Geophysics Institute could eventually calibrate Dobson instrument through an equipped center in Europe. The calibration of the equipment was delayed because they could hardly find a responsible organization to perform calibration. Finally, as of October 2016, after about 5 years delay in calibration, this instrument in Geophysics institute station has been operating while suffering from many technical issues.

Firooz Kooh Station

Of the above station, Firooz-kooh has not reportedly been active to measure stratospheric ozone for about past 10 years. Surface ozone outside urban area has been measured at Firooz- Kooh. The station is a reference station and official connected to the World Meteorological Organization's (WMO) Global Atmospheric Watch (GAW).

Isfahan and Geophysics stations are mainly involved in the ozone and UV observation in the world network measurement activities.

1.2 Profile measurements of ozone and other gases/variables relevant to ozone loss

Profile measurement of ozone needs employment of special equipment which are not available at the existing station. In order to study the Upper Atmosphere, radiosonde (RS80) and hydrogen balloon (Totex 600gr) were in use at Isfahan station. Data recorded by these instruments then is transmitted to the global telecommunication system using a switching system. Isfahan station is connected to the global network of ozone observation and reports the data back to the WOUDC on a regular basis.

1.3 UV measurements

Until a few years ago, the UV-B measurement in Iran was only being recorded at Isfahan by Brewer instrument at the wavelengths between 303.2 and 320.1 nm (which has been currently out of work) but with continuous effort by Iran's NOU and through cooperation with other organizations, the UV-B network was developed in 18 provinces of Iran. It is projected during next two years, the number of stations expand to 32 points. The solar UV radiation under this project measures the wavelengths between 280 and 400 nm including UV B-A.
There are several other locations reported as high risk spots in terms of exposure to UV. UV monitoring in these high risk spots are of utmost importance and need establishment and use of new UV measurement equipment and facilities beside the other native devices.

1.4 Calibration Activities

Data recorded by the stations was being regularly checked for their validation and consistency. In the case of data inconsistency the equipment were sent to the WMO for calibration. But during 5 years ago, Islamic Republic of Iran has encountered with many obstacles for calibrating their instruments which have had international codes in WOUDC. NOU of Iran wishes that International Organizations would carry out their professional duties and also consider a solution that every four years the Dobson and Brewer instruments in developing

countries are regularly calibrated regardless of the international political controversies. However, only the Dobson instrument was hardly calibrated by the intervention of Iran's NOU. But despite many efforts, Brewer spectrophotometer which is well known in the WOUDC and supported by WMO still has not been calibrated.
Equipment installed at the Firooz-kooh station was damaged and not in use since about 10 years ago. In order to maintain the continuity of ozone data series, the station will need to fix the damaged apparatus and to improve its measurement system. This station only records surface ozone data. A strategy was in place to change the station' systems to European standards.

As mentioned above, calibration of equipment in Geophysics station had been last made in February 2006 in Japan. In an agreement with the Japanese atmospheric research center, the Dobson apparatus at Geophysics station should be calibrated, which was refused for unknown reason during 5 years ago. Eventually, this Dobson spectrophotometer with many troubles has been calibrated through an equipped center in Europe and it has been operated from October 2016, after about 5 years delay in calibration. According to the previous information, the data collected by the Geophysics equipment had 3% deviation from the satellite data recorded for the same period which is considerably acceptable.

Regarding to previous statement of Brewer instrument, the ozone and UV-B radiation measurement equipment at Isfahan station has not been still calibrated**.** Since May 2013, the machine is not working and needs to be calibrated. Up to now, in spite of the correspondences with the respective international organizations, unfortunately no required movement or action has been performed for this instrument yet.

2. RESULTS FROM OBSERVATIONS AND ANALYSIS USING DATA OF ISFAHAN STATION

Figure 2 is shown variability of Ozone over Isfahan station with two measuring instruments of ground-based station and satellite data. As seen in this figure, the first half of year, the curve of satellite data has exceeded the ground-based data (until May) but in the second half of year it is approximately lower or equal than ground observation. In the following, figure 3 is shown that this proportion of difference between the ground based and satellite UV Index data is

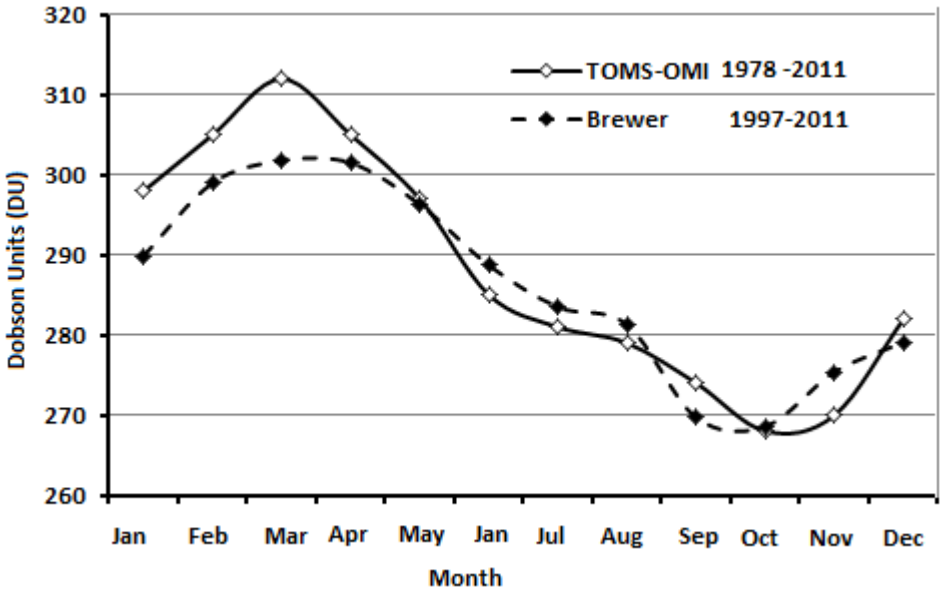


Figure 2. Monthly variation of total ozone for two periods of 1979-2011 (TOMS-OMI instrument) and 1997-2011 (Brewer spectrophotometer) over Isfahan station.

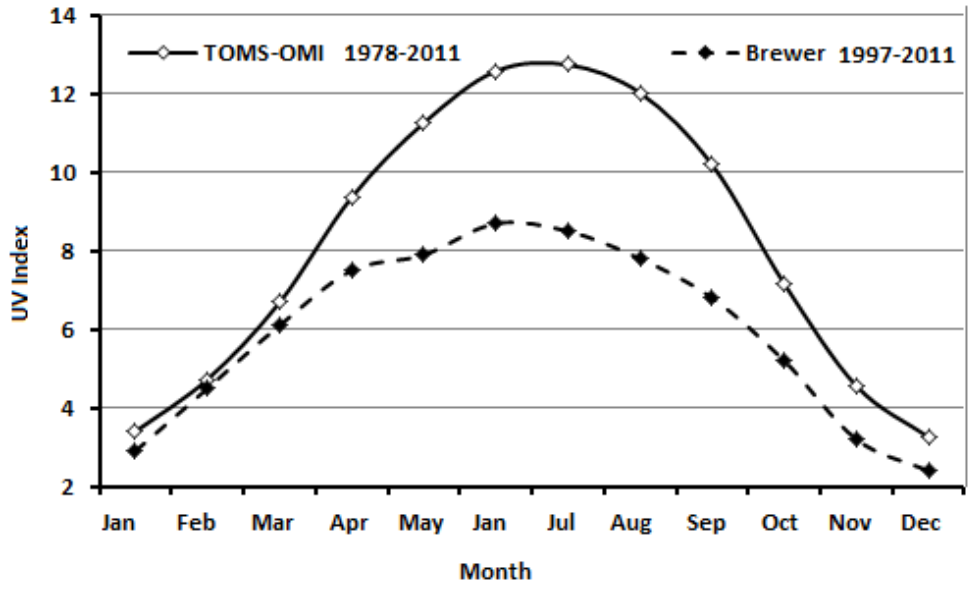


Figure 3. Monthly variation of UV-B radiation for two periods of 1979-2011 (TOMS-OMI instrument) and 1997-2011 (Brewer spectrophotometer) over Isfahan station.

significant especially during months with the high solar UV radiation (Apr- Sep). However, these two study periods do not completely overlap each other, but with balancing and assimilating the periods would not been seen significant difference between them again. For this reason, one of the importance issues which can consider for developing and expanding the ground based UV and ozone observational network in each country, is the reality of ground-based data in comparison with satellite data which does not well compute aerosol and cloudiness in lower atmosphere. As a consequence, however satellite data is providing the global coverage of Ozone and UV observation even with high resolution, because their instruments does not well calculate other atmospheric elements into the lower tropospheric, they could not been used for important and executive decisions.

Figure 4 shows the TOC time series in two separate periods of 1979–1994 and 1996–2011. This is because of negative trend in NH extratropical ozone existed up to the mid-1990s that corresponded with an increase in the concentration of the ozone depletion chemicals in the stratosphere. Afterwards, a kind of the ozone recovery has been observed. The annual mean of TOC reveals high inter variability as well as a decreasing trend in the first period. Although, the mean level of TOC over the 1996–2011 period (in comparison with the 1979-1994 period) reduced by about 8 DU, the anomaly amplitude and the downward linear trend have considerably weakened in this duration. It is reported that in the mid-latitude lower stratosphere (15–25 km) after long-term decreasing of TOC for the 1980–1995 period, the total ozone has approximately remained stable at this altitudes since 2000. On the longer time scale (1979–2011), the linear regression analysis of ozone mean levels indicated a decrease of 4 DU (1.4 %) per decade over central plateau of Iran, which strongly depends on the seasons with a maximum (minimum) decrease of about 2.2 % in spring/winter months (0.5 % per decade in the summer/ autumn months).

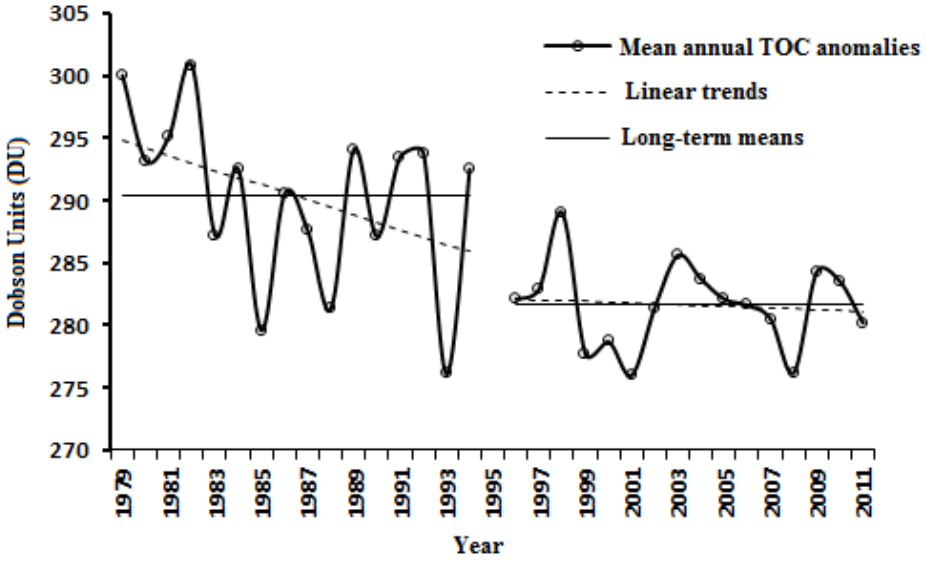


Figure 4. Time series of the annual mean ozone and linear regression lines for two separate periods 1978–1994 and 1996–2011 over Isfahan station (TOC data belongs to the TOMS-OMI instruments).

3. THEORY, MODELING AND OTHER RESEARCH

Affiliated with the Ministry of science and Meteorological Organization, Geophysics research Institute of Tehran University is active in the field of theoretical subjects, modeling and other relevant issues.

Computer software is available at the Iranian Geophysics Center for processing and modeling of the atmospheric ozone and photo-chemicals. These facilities have only been utilized for data processing and analysis. Models developed thus far have only for the simulation and analysis of air pollution in urban areas and so far no model has been developed especially applicable for ozone and UV analyses.

The first Iran- Korea joint workshop on climate modeling, Co-hosted by climatological Research Institute (CRI) and Meteorological Research Institute (MERI) was held on November 16- 17 2005. The program consisted of invited and contributed oral presentations from both countries and issues related to the subjects of the workshop were discussed in full. The workshop covered theoretical and applied topics of climate modeling as follows:

- Long- Term Forecasting
- Climate Change and Variability
- Extreme Events
- Application of climate Information
- Tele connections
- Paleoclimatology

4. DISSEMINATION OF RESULTS

4.1 Data reporting

Firooz-Kooh and Isfahan stations are reference reference stations connected to the global network of atmospheric watch. Total and vertical ozone data in WMO format were being regularly reported to the World Ozone and Ultraviolet Data Center in Canada (WOUDC). The data recorded by the stations also being archived at the related centers. Data on Ozone and UV recorded at Isfahan station was being reported to WOUDC in Canada every two months. The Firooz-kooh data was reported to the same center on a monthly basis.

The TOC time series have been recently extracted through the ozone and air quality of NASA site from the observation taken on central plateau of Iran (1978 on ward) especially over Isfahan. The ozone data using in the study related to TOMS-OMI instrument on board four satellites including Nimbus-7, Meteor-3, Earth Probe and Aura. These data are examined by statistical models to detect the ozone mini-hole events over central plateau of Iran for every month and their seasonal cycles along with their effects on increasing UV radiation. Iran's NOU in cooperation with Tarbiat Modares University of Tehran especially Physical Geography Department and Geophysics Institute of Tehran University have achieved new results concerning variability of TOC and its quantitative and qualitative effects on features of the UV radiation.

4.2 Information to the public

As its routine procedure, the Geophysics institute provides assistances to the graduate and post graduate students through their MSc and PhD research programs on air pollution and atmospheric research. These assistances are in the form of long term meteorological data series and processed information. Reports of the student's theses are normally available for use by other researchers. The Long- Term Ozone Observation Data are also available at the web-sites of the Geophysics Institute. Information is also provided at the above web-site for the public use. (URLs for the web-sites are: http:// geophysics.ut.ac.ir/En/ for Geophysics Institute).

Over the past few months, the Ministry of Healthy in cooperation with the Environmental Researcher Institute of Tehran Medical Science University has designed and built a comprehensive health information system that informs daily UV radiation to public plus other relevant information.
http://enhealth.health.gov.ir/map.aspx

5. PROJECTS AND COLLABORATION

The following research programs have been completed by the Geophysics research institute and other relative universities:

- The study of Stratospheric / Tropospheric exchange by means of ground Ozone measurement (1978)
- Total Ozone change analysis with respect to the periodic solar activities(1983)
- The correlation between Total Ozone and troposphere/Stratosphere parameters(1991)
- Analysis of interaction between the Total Ozone recorded at a random Meteorological station and regional weather systems (1999)
- Comparative analysis of Ozone change through an eleven- year period of activities(1994)
- Correlation between Total Ozone and ground-base UV(1999)
- Tropospheric ozone and reaching Ultra Violation radiation over the earth surface (1999)
- Effects of synoptic factors on daily TOC variability over Isfahan (2002)
- Investigation of Ozone pollution in the earth (2003)
- Trend analysis of Surface Ozone data collected at Geophysics Synoptic Station in 2002 (2007)
- Temporal and spatial variability of Total Ozone in Central plateau of Iran revealed by ground- based instruments(2007)
- Estimation of clear-sky effective erythema radiation from broadband solar radiation (300–3000 nm) data in an arid climate (2009)
- Analysis of correlation between total ozone and upper air meteorological parameters in the Middle East (2010)
- Investigation of total ozone seasonal distribution over Iran area for 2007-2008 (2013)
- Study of TOC variability and atmospheric upper pattern over Iran in correlation with the extreme condition of Antarctic holes (2013)
- Modified Model of the satellite UV Radiation Data in the warm seasons of Iran (2013)
- Study of atmospheric total ozone variations due to winter synoptic scale disturbances over Iran (2014)

- Assessment of the Solar UV-B Radiation Risk in Creating Skin Cancer Using TOMS Datasets (2016)
- Climatic variability of the column ozone over the Iranian plateau (2016)
- The synoptic analysis of ozone mini-hole events over central Iran (Isfahan), (2016)

The Geophysics Institute and Meteorological Organization are in continuous cooperation with other academic and non- academic research units for the study of atmospheric phenomena.

6. FUTURE PLANS

Department of Environment has recently provided a proposal to form a comprehensive UV-B network through cooperation with other institutes. In the mentioned proposal all the activities are predicted i.e. the data collection process, analysis, modelling and forecasting and informing. The In this proposal, Meteorological Organization and Geophysics Institute are also used for improvement of their research, Observation and data recording and reporting systems through regular UV Monitoring and analysis as well as public awareness campaigns.
There is a strong scientific research on environmental impacts of increased UV due to the ozone depletion in different parts of country covering effects of UV radiation on:

- Human health
- Terrestrial and aquatic ecosystems
- Biogeochemical cycle (i.e. disturbing in the flow of materials and energy between soil and plant)
- Air quality
- Materials (Plastic, Color, other artificial materials)

Development and improvement of "data networking system" is considered by the Department of Environment and Meteorological Organization as an important component of the existing Ozone/UV monitoring system. Atmospheric Modeling is another area of interest that requires professional training and advanced hardware and software facilities.

7. NEEDS AND RECOMMENDATIONS

- Development of National UV Observation and Monitoring Network
- Organization of regional and national training workshops for officials and experts from relevant UV/Ozone monitoring organizations and public seminars on Ozone /UV changes and its effects on terrestrial life;
- Thematic meetings on UV/Ozone Observation and monitoring will be needed to be included in the UNEP/ROAP networking system. This can be accomplished back to back to the annual network meetings;
- Capacity Building and provision of necessary advanced equipment and facilities to the existing stations including;

A) Equipping Geophysics station with the following instruments:
1) Sky Radiometer (POM-02)
2) Sky Radiometer (POM-01L)
3) Grating Sunphotometer(PGS-100)
4) Multichannel Data Logger (PMMS-100)
5) Brewer Spectrophotometer
6) Automation of existing Dobson Photo- Spectrometer for improved and precise measurements;

B) Renovation of Firooz-Kooh station;

C) Development of new UV monitoring stations in high risk UV spots;

D) Providing technical assistance and training to the centers for advanced atmospheric research and modeling;

- Systematic calibration of surface and upper –atmospheric Ozone measurement instruments at existing stations.

IRAQ

Introduction

Since Iraq joined the ozone celebration community and joined the five amendments joining Kigali amendment, Iraqi NOU completely phased out CFCs in 2010 and started phasing down HCFCs building capacities building awareness database regarding the ozone matters changing production lines in the Iraqi companies that uses ODSs, continuously training custom officers standardization and a wide spectrum of end users technicians, citizens and high level employees despite of the unstable political, economic and security situation Iraq implement all the activities assigned towards total phase out of ODSs and protect the ozone layer ,

Parties to the Montreal Protocol, at their 20th meeting, recognized the political, economical, security difficulties being faced by Iraq and adopted decision XX/15 urging all parties, secretariats, bilateral and implementing agencies to assist Iraq to meet its challenging obligations toward the protocol.

Observation and monitoring

Iraqi government is taking serious and ambitious steps about monitoring and research to all environmental issues, Iraqi NOU continuously since its establishment monitoring ODSs in all sections of manufacturing, servicing and import in coordination with customs and standardization, local importers, manufacturers and servicing sectors,
A wide range of database and knowledge created for ODSs and non-ODSs alternatives, historical and yearly basis information is reported and enhanced,

Ministry of health and environment so as many institutions have the laboratory and the portable instruments capacity to measure and observe a lot of contaminates especially relevant to ozone and global warming, having the great well and need to observe and measure ozone and UV measurements using available technologies of measurements,

At the present time there is no availability to measure atmospheric ozone and UV measurement.

Ministry of environment measures and monitors some components such as CH_4, CO, CO_2, NO_x , SO_2 and O_3 in the troposphere using monitoring station as shown in the picture below.

The data collected using monitoring stations established all around Baghdad; these stations established five years ago, not existed before in the ministry of health and environment,
Data of some contaminates is collected, archived and studied every month throw the years as in tables below, some of the data collected shows the variables in concentrations of this contaminates average for each month.

Some of these studies observing the tropospheric ozone and carbon dioxide, these contaminates effecting the ozone layer and global warming and noticing the relationship between them throw the different ambient temperatures all over the year seasons.

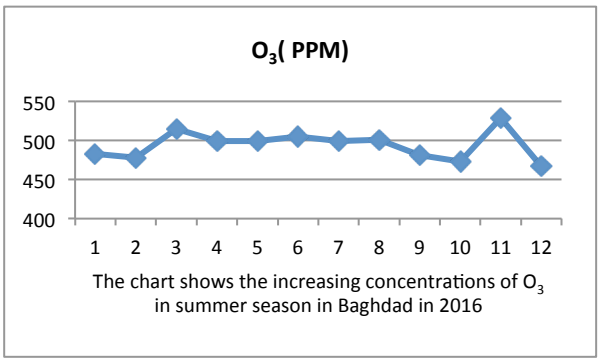
Research: relationship between O_3 & CO_2 contaminates

The data collected from the stations showing increasing in the tropospheric ozone concentrations especially in the summer in Baghdad which the temperature reaches 50 c

starting from April, after 3 or 4 months concentrations of O_3 start to decrease after July and August,

Tropospheric ozone formulate from the photochemical and chemical reactions of NO_x ,CO and CH_4 with the presence of sunlight,

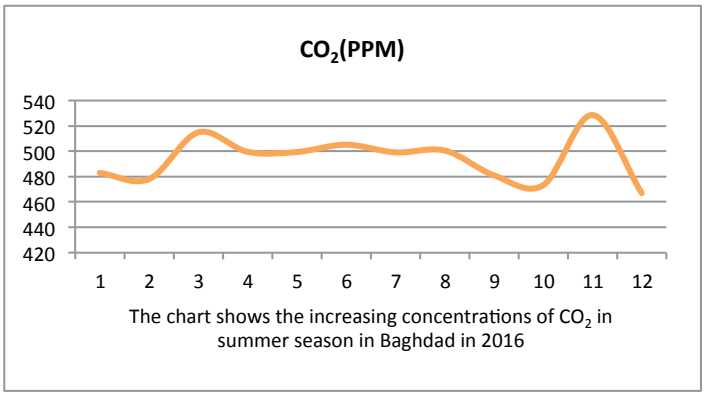
Researchers found that the concentration of O_3 depends also upon the speed of wind and the availability of NO_x , CO and CH_4 as additional to sunlight therefore high concentrations of O_3 is not consistent during the summer .



The chart shows the increasing concentrations of O_3 in summer season in Baghdad in 2016

TEMP (C°)	O_3(PPM)	2016
13.884	0.014	January
14.57	0.012	February
17.235	0.011	March
29.565	0.009	April
34.223	0.01	may
37.902	0.023	June
40.528	0.014	July
37.627	0.007	august
36.015	0.008	September
31.24	0.005	October
22.794	0.012	November
17.137	0.009	December

Carbon dioxide contaminant considerations on the other hand also increasing in the in the summer months because of high emissions from a lot of generators spread around the Baghdad city to generate power, emission of CO will be high with the sunlight CO_2 as well as O_3 is formulated.



The chart shows the increasing concentrations of CO_2 in summer season in Baghdad in 2016

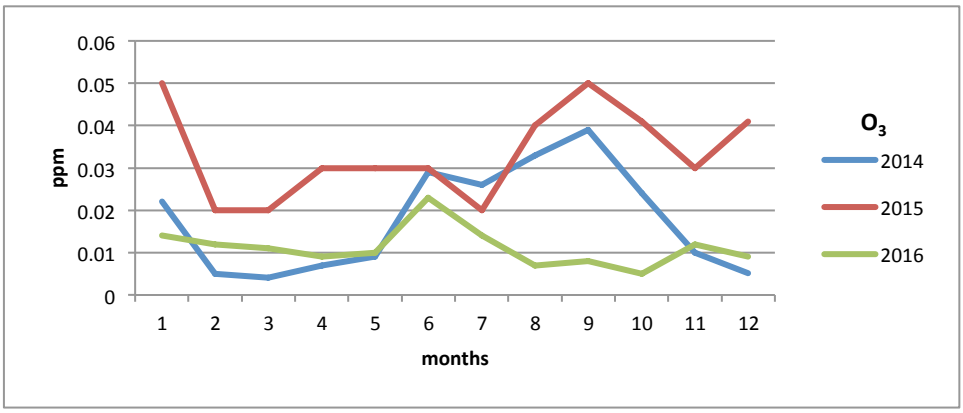
TEMP (C°)	CO_2(PPM)	2016
13.884	482.81	January
14.57	478.02	February
17.235	514.9	March
29.565	499.5	April
34.223	499.38	may
37.902	505.16	June
40.528	499.1	July
37.627	500.56	august
36.015	481	September
31.24	473.21	October
22.794	528.6	November
17.137	466.91	December

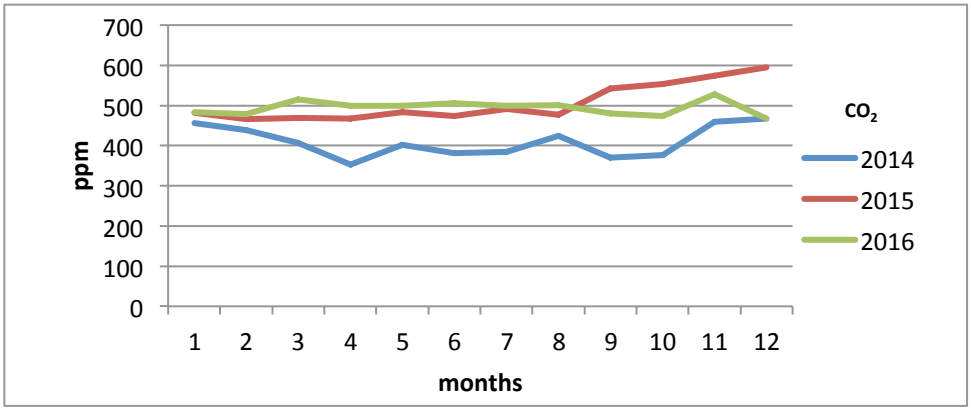


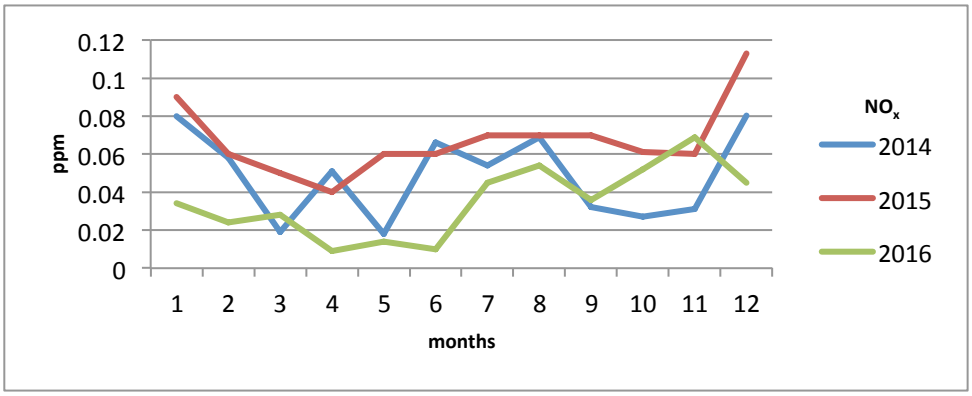
Average monthly data in 2014 in PPM							
	CH_4	CO	NO	NO_2	NO_x	O_3	CO_2
January	2.041	1.205	0.058	0.021	0.08	0.022	455.61
February	2.045	0.381	0.044	0.014	0.058	0.005	438.9
March	2.326	0.443	0.009	0.01	0.019	0.004	407.51
April	1.897	0.76	0.034	0.011	0.051	0.007	352.95
may	2.024	0.413	0.004	0.014	0.018	0.009	402.75
June	1.79	0.614	0.03	0.036	0.066	0.029	381.26
July	1.736	0.629	0.024	0.03	0.054	0.026	384.54
august	1.684	0.792	0.026	0.043	0.069	0.033	424.91
September	2.036	0.522	0.011	0.021	0.032	0.039	370.27
October	1.727	0.345	0.009	0.019	0.027	0.024	376.08
November	2.113	0.331	0.016	0.016	0.031	0.01	460.2
December	1.803	0.583	0.054	0.025	0.08	0.005	467.06

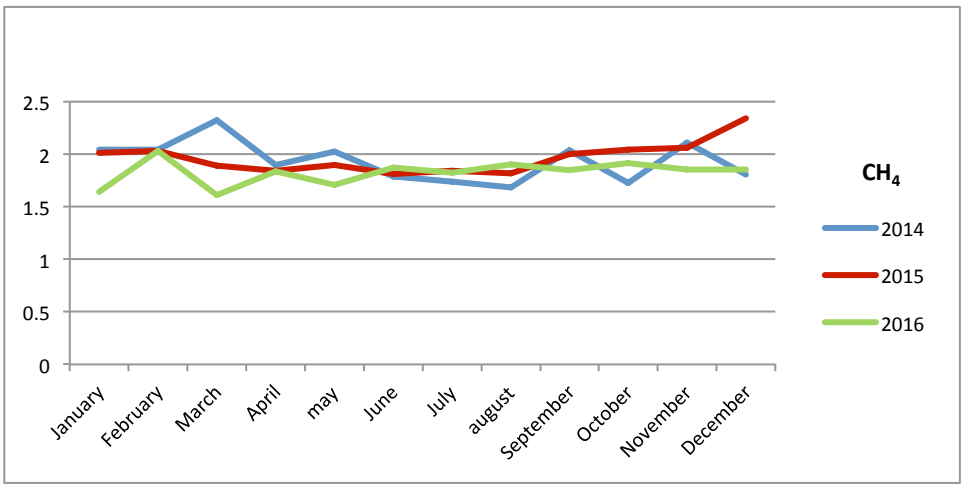
Average monthly data in 2015 in PPM							
	CH_4	CO	NO	NO_2	NO_x	O_3	CO_2
January	2.01	0.50	0.06	0.03	0.09	0.05	482.33
February	2.03	0.20	0.03	0.03	0.06	0.02	466.17
March	1.89	0.22	0.02	0.03	0.05	0.02	469.86
April	1.84	0.93	0.02	0.03	0.04	0.03	467.75
may	1.90	0.61	0.03	0.03	0.06	0.03	482.76
June	1.81	0.56	0.03	0.03	0.06	0.03	473.59
July	1.84	0.65	0.03	0.04	0.07	0.02	491.49
august	1.82	0.57	0.04	0.03	0.07	0.04	477.21
September	2.00	0.71	0.04	0.03	0.07	0.05	542.02
October	2.043	0.701	0.036	0.024	0.061	0.041	553.22
November	2.06	0.72	0.05	0.02	0.06	0.03	574.35
December	2.343	0.608	0.092	0.021	0.113	0.041	595.184

Average monthly data in 2016 in PPM							
	CH_4	CO	NO	NO_2	NO_x	O_3	CO_2
January	1.641	0.286	0.051	0.314	0.034	0.014	482.81
February	2.034	0.201	0.316	0.226	0.024	0.012	478.02
March	1.610	0.240	0.334	0.240	0.028	0.011	514.9
April	1.838	0.330	0.028	0.328	0.009	0.009	499.5
may	1.708	0.339	0.034	0.348	0.014	0.010	499.38
June	1.870	0.267	1.156	0.265	0.010	0.023	505.16
July	1.824	0.391	0.014	0.034	0.045	0.014	499.1
august	1.905	0.0325	0.014	0.039	0.054	0.007	500.56
September	1.851	0.375	0.009	0.027	0.036	0.008	481.0
October	1.915	0.045	0.012	0.038	0.052	0.005	473.21
November	1.856	0.049	0.063	0.031	0.069	0.012	528.60
December	1.855	0.271	0.014	0.42	0.045	0.009	466.91


0.06
0.05
0.04
0.03
0.02
0.01
0
ppm
1 2 3 4 5 6 7 8 9 10 11 12
months
O3
2014
2015
2016


700
600
500
400
300
200
100
0
ppm
1 2 3 4 5 6 7 8 9 10 11 12
months
CO2
2014
2015
2016


0.12
0.1
0.08
0.06
0.04
0.02
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ppm
1 2 3 4 5 6 7 8 9 10 11 12
months
NOx
2014
2015
2016


2.5
2
1.5
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0
January
February
March
April
may
June
July
august
September
October
November
December
CH4
2014
2015
2016

Iraq funded projects by MLF

Since Iraq totally phased out CFCs in 2010 by funding several projects and activities by MLF under NNP (national phase out plan of Iraq), a national survey launched for the HCFCs the results showed that Iraq's consumption in 2010 is mostly to HCFC-22 representing 99 per cent of the total HCFC consumption respectively. It also revealed that HCFC consumption increased from 1,735.8 metric tons (mt) (95.47 ODP tons) in 2006 to 1,923.63 mt (105.80 ODP tons) in 2010, the Executive Committee approved funding HPMP project of Iraq,

Since 2007, the yearly HCFC-22 consumption increase rate has ranged from 4 per cent to 14.6 per cent; the data collected during the survey was validated by the NOU. Data on HCFC-22 consumption from 2006 to 2015 reported under Article 7, a second survey will be launched for the second stage of HPMP of Iraq the information and data will be updated.

Ministry of Health and Environment Future Plans

-The overarching strategy of Iraq is based on consumption reductions in the servicing sector through the enforcement of regulatory measures, recovery/recycling, and better practices to reach the compliance target, and for future reductions, the assumption that new commercially viable refrigeration and, in particular, air-conditioning technologies that use zero ODP and low global warming potential (GWP) refrigerants in energy efficient equipment will become available in the coming decade as well as :

(a) Enforcement of policies and regulations;
(b) Development and production of booklets, training manuals and electronic references for different technical educational levels;
(c) Implementation of a national certification programme including development of the certification scheme, preparation of the certification admission and testing modules;
(d) Distribution of additional training equipment to upgrade training centers to conduct certification programme;
(e) Implementation of a pilot certification programme for 500 technicians in different servicing sub-sectors particularly HCFC consuming sectors;
(f) Development of terms of reference and work plan to prepare national standards and codes related to HCFC consuming sectors which could include equipment, refrigerants, refrigerants' containers and hazardous refrigerants;
(g) Implementation of specialized technical awareness programme for addressing large end-users, buildings owners, consultants and technical decision-makers at governmental level about alternatives to HCFC in different applications particularly zero/low GWP options;
(h) Monitoring of the three reclaim centers established under the NPP and provision of testing equipment for each centre;
(i) Supply of filter kits and two cylinders for each recovery and recycling machine provided under the NPP for onsite recovery/reuse;
(j) Supply of an additional 100 sets of recovery units including filter kits plus two cylinders for each machine; and
(k) Management, co-ordination and evaluation of the HPMP activities.

NEEDS AND RECOMMENDATIONS

- Iraqi ministry of environment looking forward from the participants in the 10th ORM such as parties, organizations and information centers to support Iraq and provide stations and information in research and monitoring of the atmospheric ozone and uv measurements, provide international training and visits for Iraqi experts to countries with such experience.

- Develop the available technologies and equipment in the Iraqi institutions and labs, benefit from all available resource to purchase and train on the available technologies and fund research projects to observe and measure contaminates in Iraq.

- Continue awareness urging all sectors using low GWP alternatives, phasing out ODSs and providing a good sufficient low (GWP) alternative for high ambient temperature countries.

- Assist Iraq to implement HPMP projects and activities since Iraq is an active member in protocol Montreal attending and interacting international ozone meetings and events.

ITALY

(PARTIAL) UPDATE 2013-2016

The contributing institutions are:

INSTITUTION	Contact persona	Short name
CETEMPS/Dipartimento di Scienze Fisiche e Chimiche, Università degli Studi dell'Aquila, L'Aquila, Italy.	**Vincenzo Rizi**	**CETEMPS/UNIAQ**
ENEA, Italian Energy, New Technology and Sustainable Development Agency.Department of Sustainability, Climate Modelling Laboratory (SSPT -MET CLIM), Roma, Italy.	**Irene Cionni**	**ENEA-MET CLIM**
Institute of Atmospheric Sciences and Climate of the Italian National Research Council (ISAC-CNR), Bologna, Italy.	**Vito Vitale, Boyan Petkov and Fabrizio Ravegnani**	**CNR-ISAC**

1. Ozone and ozone-related observation systems (column, profiles, UV, etc.):

CETEMPS/UNIVAQ: The ozone total columns observed on routine basis at L'Aquila (683 m a.s.l., 43.38°N, 13.31°E) are derived from the balloon ozone-sonde profiles. The ozone profiles (balloon-sonde) have been collected since 1994. From 2004 this activity has achieved a routine pace: about 2 ozone profiles (from ground up to 10hPa altitude) per month (This activity is also part of the commitments included in a Convention between University of L'Aquila/CETEMPS -*Centre of Excellence for the integration of remote sensing techniques and modelling for the forecast of severe weather*- and Italian Government/Ministry of Environment. The Italian Ministry of Environment (*Ministero dell'Ambiente e della tutela del Territorio e del Mare*) provides the needed resources for the acquisition of the ozone-sondes, and the maintenance of the radio-sonde system, as well as, of several other instruments (i.e., sunphotometer and UV sensors). The ozone profiles database has been available for several calibration/validation campaigns. UV-A and UV-B (Yankee Environmental Systems) instruments have been operating since 2004. Continuous monitoring of the aerosol radiative properties is performed with an AERONET sunphotometer (http://aeronet.gsfc.nasa.gov/), and water vapor mixing ratio and aerosol backscatter and extinction vertical profiles are measured with a EARLINET Raman lidar (https://www.earlinet.org/)

ENEA-MET CLIM: It uses data from: NASA TOMS, NOAA (SBUV), EOS Aura (OMI, MLS), Odin (Osiris, SMR), Envisage (SCIAMACHY, GOMOS, MIPAS), GOME, and ozone-sonde profiles from WOUDC, as well as, data by aircraft measurement campaigns like those ones included in http://clasp.engin.umich.edu/SASSarchive/.

CNR-ISAC: The CNR performs measurements of the ozone column and surface solar UV irradiance at Ny-Ålesund (Svalbard, Arctic), Bologna (Italy) and Concordia station (Antarctic) making use of a very-narrow-band filters radiometer UV-RAD designed and built at ISAC in the frame of the Italian Antarctic polar programme to perform accurate monitoring of the solar UV irradiance in remote regions with harsh environment. UV-RAD radiometer performs measurements in 7 very narrow bands from 290 and 400 nm. The reliability of the system has been proved in a couple of intercomparison campaign, the last made in Ny Alesund (79°N) with the reference spectroradiometer QUASUME realised at PMOD (Davos). ECC ballon sounding of vertical ozone profiles were carried at S. Pietro Capofiume, WODC #297 station.

2. Data storage and availability

CETEMPS/UNIVAQ: The extended ozone profile database (1994-2016 Electrochemical Concentration Cell balloon soundings, and 1991-1999 DIfferential Absorption Lidar measurements) has got the quality-standards for being used in analysis concerning the possible trends of the ozone content in the different atmospheric levels. Free access to the ozone data plots in:
http://cetemps.aquila.infn.it/osservatorio/Ozone_soundings_plots/.
UV-A and UV-B data as measured with full sky calibrated pyrometer, are also available (2004-2016). The Raman lidar data are in https://www.earlinet.org/).

CNR-ISAC: Corresponding data sets for periods from 2008 (Ny-Ålesund), 2005 (Bologna) and 2007 (Concordia) until now are collected by ISAC-CNR and are available on request. The balloon-borne ozone profiles taken in San Pietro Capofiume (1991-1997 period) are also available.

3. Key-words of related science (it can include theory and modelling):

CETEMPS/UNIVAQ: Stratospheric and tropospheric ozone monitoring, UV monitoring, aerosol and water vapour monitoring, research and assessment studies on stratospheric ozone using a global chemistry-transport model and a chemistry-climate coupled model.

ENEA-MET CLIM: Validation of Ozone in inter-comparison projects as Chemistry Climate Model Initiative (CCMI). Model study of interactions between climate and ozone.

CNR-ISAC: Atmospheric optics, ozone and UV climatology and modelling at high and low latitudes, surface UV fluxes, erythema and DNA damage doses, ozone in Antarctica and Arctic and influence at middle latitudes, effects of solar UV irradiance on human health and biological systems, radiative transfer in the atmosphere. ozone vertical profiles, troposphere, stratosphere, ECC, balloon borne.

4. Future plans:

CETEMPS/UNIVAQ: Keep going the observational activities: ozone balloon soundings, UV, photometric and lidar experiments.

ENEA-MET CLIM: Improving the database extension for the assessment studies (i.e., including ESA-CCI).

CNR-ISAC: Maintaining of the radiometers working at the three sites and integration of the available measurement stations and instruments at Svalbard in a local network. In Antarctica, to extend the measurements on the coast at Mario Zucchelli station (MZS) comparing them with those performed at Mendel station (MS, Antarctic Peninsula) by Czech colleagues (Kamil Láska, Masaryk University, Brno). Operate to create a regional network integrating the stations placed in the East Antarctica, Concordia, MZS, MS and the instruments used by other Italian groups in cooperation with Argentina.

5. Needs and recommendations:

CETEMPS/UNIVAQ: The interaction between climate change and ozone recovery is quite evident, and its understanding needs to continue the high quality observations of ozone column and vertical profiles. In general, a more efficient coordination among the different Italian Research Institutions and Universities involved in "ozone research" is advisable. The ORM could trigger a renewed interest of the parties, if suggesting that, on national basis, research infrastructures, including the different research entities, should be founded to keep going the ozone research activities, among others.

ENEA-MET CLIM: Expecting longer high-quality data time series for trends detection.

CNR-ISAC: More frequent quality control of the instruments that are placed at the polar areas is an important task that need to be regularly performed. In this regard, the development of the instruments and formation of structures at international (European) level that could perform regular quality control will give a great contribution to the ozone and UV irradiance monitoring at these remote sites.

This report has been compiled in March 2017.

Document compiled by Vincenzo Rizi, CETEMPS/Dipartimento di Scienze Fisiche e Chimiche, Università degli Studi dell'Aquila, L'Aquila.

JAPAN

1. OBSERVATIONAL ACTIVITIES

1.1 Column measurements of ozone and other gases/variables relevant to ozone loss

Total column ozone and Umkehr measurements are performed by the Japan Meteorological Agency (JMA) at four sites in Japan (Sapporo, Tsukuba, Naha, and Minamitorishima) and at Syowa Station in Antarctica (Table 1). A Brewer spectrophotometer is used for measurements at Minamitorishima, whereas Dobson spectrophotometers are used at the other observation sites.

Table 1. Locations of column ozone and Umkehr measurement sites operated by JMA

Observation site	Latitude	Longitude	Altitude (m)	WMO station number
Sapporo	43° 04′ N	141° 20′ E	26	47412
Tsukuba	36° 03′ N	140° 08′ E	31	47646
Naha	26° 12′ N	127° 41′ E	28	47936
Minamitorishima	24° 17′ N	153° 59′ E	9	47991
Syowa	69° 00′ S	39° 35′ E	22	89532

Concentrations of ozone-depleting substances and other atmospheric constituents are monitored by the Center for Global Environmental Research (CGER) of the National Institute for Environmental Studies (NIES) and by JMA. The monitoring sites are listed in Table 2. CGER/NIES monitors halocarbons (CFCs, CCl_4, CH_3CCl_3, and HCFCs), HFCs, surface ozone, CO_2, CH_4, CO, N_2O, SF_6, NO_x, H_2, the O_2/N_2 ratio, and aerosols at remote sites (Hateruma and Ochiishi). JMA measures surface concentrations of ozone-depleting substances (CFCs, CCl_4, and CH_3CCl_3) and other atmospheric constituents (surface ozone, CO_2, N_2O, CH_4, and CO) at Ryori, a Global Atmosphere Watch (GAW) Regional Station in northern Japan. The concentrations of surface ozone, CO_2, CH_4, and CO are also monitored at Minamitorishima (GAW Global Station) and Yonagunijima (GAW Regional Station).

The Japanese Ministry of the Environment (MOE) monitors concentrations of halocarbons (CFCs, CCl_4, CH_3CCl_3, halons, HCFCs, and CH_3Br) and HFCs at remote sites around Wakkanai and Nemuro, far from their emission source, and at an urban site (Kawasaki).

JMA also monitors CFCs, CO_2, N_2O, and CH_4 concentrations in both the atmosphere and seawater of the western Pacific on board the research vessels *Ryofu Maru* and *Keifu Maru*.

Table 2. Locations of monitoring sites for ozone-depleting substances and other minor atmospheric constituent

Monitoring site	Latitude	Longitude	Altitude (m)	Since	Organization
Ochiishi	43° 10′ N	145° 30′ E	45	Oct 1995	CGER/NIES
Hateruma	24° 03′ N	123° 49′ E	10	Oct 1993	CGER/NIES
Ryori	39° 02′ N	141° 49′ E	260	Jan 1987	JMA
Minamitorishima	24° 17′ N	153° 59′ E	8	Mar 1993	JMA
Yonagunijima	24° 28′ N	123° 01′ E	30	Jan 1997	JMA
Syowa	69° 00′ S	39° 35′ E	16	Jan 1997	JMA

1.2 Profile measurements of ozone and other gases/variables relevant to ozone loss

1.2.1 Ground-based and sonde measurements

From October 1990 to March 2011, CGER/NIES measured vertical profiles of stratospheric ozone at Tsukuba with an ozone laser radar (ozone lidar); these data were registered in the Network for the Detection of Atmospheric Composition Change (NDACC) database. CGER/NIES also measured vertical profiles of ozone with millimetre-wave radiometers from September 1995 to March 2011 at Tsukuba. The ozone measurements with millimetre-wave radiometers were conducted by CGER/NIES from March 1999 to March 2011 at Rikubetsu, and have been conducted by Nagoya University since April 2011 (Ohyama et al., 2016).
JMA has been monitoring vertical ozone distributions weekly by ozone sonde at three sites in Japan (Naha, Sapporo, and Tsukuba) and at Syowa Station in Antarctica. The KC sonde was developed by JMA and had been used in Japan since the 1960s. However, the ECC type ozone sonde succeeded the KC type in October 2008 at Naha, in November 2009 at Sapporo and Tsukuba, and in March 2010 at Syowa Station.

1.2.2 Airborne measurements

JMA has conducted monthly (approx.) airborne *in-situ* measurements (flask sampling) of CO_2, CH_4, CO and N_2O concentrations at an altitude of ~6 km along the flight path from mainland Japan to Minamitorishima since 2011.

Atmospheric greenhouse gases have been measured by commercial airliner with Continuous CO_2 Measuring Equipment (CME) and Automatic air Sampling Equipment (ASE) under the CONTRAIL project managed by NIES and the Meteorological Research Institute (MRI) since 2005.

1.2.3 Satellite measurements

The Superconducting Submillimeter-Wave Limb-Emission Sounder (SMILES) was developed for deployment in the Japanese Experiment Module (JEM) on the International Space Station (ISS) through cooperation of the Japan Aerospace Exploration Agency (JAXA) and the Japanese National Institute of Information and Communications Technology (NICT). SMILES began atmospheric observations on 12 October 2009, but unfortunately they have been suspended

since 21 April 2010 owing to a critical component failure of the submillimetre local oscillator. Until operations were suspended, SMILES measured concentrations of minor species in the stratosphere and mesosphere for about six months. Processing of SMILES data provided global and vertical distributions of atmospheric constituents related to ozone chemistry (e.g., O3, HCl, ClO, HO2, HOCl, BrO, O3 isotopes, HNO3, and CH3CN); these data have been distributed by ISAS/JAXA from DARTS (Data ARchives and Transmission System; http://darts.isas.jaxa.jp/iss/smiles/) for use by the scientific community.

Several important outcomes of SMILES observations are as follows. (1) They have revealed the global pattern of diurnal ozone variations throughout the stratosphere. The peak-to-peak difference in stratospheric ozone mixing ratio reaches 8% over the course of a day, suggesting care is needed when merging ozone data from satellite measurements made at different local times (Sakazaki et al., 2013). (2) SMILES successfully observed vertical distributions of ozone concentration in the middle atmosphere during the annular solar eclipse that occurred on 15 January 2010. This observation provided the first vertical distributions of mesospheric ozone during a solar eclipse event, and analyzed the theoretical eclipse-induced changes in ozone (Imai et al., 2015). (3) SMILES observations have also been used as good reference data for chemistry-climate models (e.g. Akiyoshi et al., 2016) and basic validation data for the international modelling community, such as the Chemistry-Climate Model Initiative (CCMI).

1.3 UV measurements

1.3.1 Broadband measurements

CGER/NIES has used broadband radiometers to monitor surface UV-A and UV-B radiation at five observation sites in Japan since 2000. CGER/NIES calculates the UV Index from observed data and makes it available to the public hourly via the Internet.

1.3.2 Spectroradiometers

JMA monitors surface UV-B radiation with Brewer spectrophotometers at Sapporo, Tsukuba, and Naha in Japan and at Syowa Station in Antarctica. Observations commenced in 1990 at Tsukuba and in 1991 at the other sites.

1.4 Calibration activities

JMA has operated the Quality Assurance/Science Activity Centre (QA/SAC) and the Regional Dobson Calibration Centre (RDCC) under the GAW programme of the World Meteorological Organization (WMO) to ensure the quality of ozone observations in WMO Regional Associations (RA) II (Asia) and V (South-west Pacific). The WMO/GAW Regional Intercomparison of Dobson Spectrophotometer for Asia, 2016 (DIC-T2016), was performed as an activity of the WMO RDCC in RA II, operated by JMA. This campaign was supported by the budget of "General Trust Fund for Financing Activities on Research and systematic Observations Relevant to the Vienna Convention". The U.S. National Oceanic and Atmospheric Administration (NOAA) also provided additional support by dispatching an expert specialist. In the intercomparison, instruments and personnel from China (Xianghe: D075), Pakistan (Quetta: D100), and Thailand (Bangkok: D090) attended. Their instruments were compared and calibrated with the Regional Standard Dobson instrument D116, maintained by JMA, which is calibrated against the World Standard instrument (D083) every three years. The most recent calibration was performed in February 2017 in Melbourne, Australia.

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

Trend analyses for total ozone concentrations at three sites (Sapporo, Tsukuba, and Naha), eliminating solar activity, QBO, ENSO and stratospheric aerosol variations, show an overall decrease in total ozone during the 1980s, but, in spite of large year-to-year variations, these analyses indicate either no significant change or slightly increasing trends since the mid-1990s. Vertical ozone profiles from Umkehr and sonde measurements in 2015 show reduced ozone levels at all layer altitudes at Sapporo and above 25 km at Tsukuba and Naha compared with those in 1979. In contrast, increasing trends of ozone levels from 2000 to 2015 have been

identified at altitudes between 30 and 35 km at Sapporo, 35 km at Tsukuba, 25 km at Naha, and below 24 km altitude at all three sites.

Erythemal UV measurements have been carried out at three sites in Japan (Tsukuba, Naha, and Sapporo) since the early 1990s. At Sapporo and Tsukuba, the increasing trends in erythemal irradiance have been observed since the early 1990s. On the other hand, no change in erythemal radiation has been observed at Naha since the 2000s. Because the decline in total ozone at Sapporo and Tsukuba ceased around the mid-1990s, the increase in erythemal UV radiation since 1990 cannot be attributed to ozone reduction.

The duration of solar exposure required for vitamin D_3 synthesis in the human body was estimated by using a radiative transfer calculation and UV-B and UV-A data taken at five locations in Japan, i.e., Cape Ochiishi, Rikubetsu, Tsukuba, Cape Hedo, and Hateruma (Miyauchi and Nakajima, 2016). The quasi-realtime data were provided from the Homepage of Center for Global Environmental Research, National Institute for Environmental Studies; titles "Information on Vitamin D Synthesis / Erythemal UV" at: http://db.cger.nies.go.jp/dataset/uv_vitaminD/en/index.html. In this page, exposure time for erythermal UV dose to reach 1 MED (Minimal Erythermal Dose) is also provided.

3. THEORY, MODELLING, AND OTHER OZONE RELATED RESEARCH

NIES, the Meteorological Research Institute (MRI), the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), and Nagoya University have been developing chemistry-climate models. These institutes in Japan provided their simulation results of recent past and future evolution of chemical species and climate to the Chemistry Climate Model Initiative (CCMI), an international project (Morgenstern et al., 2016). NIES primarily performed simulations of stratospheric process, JAMSTEC primarily performed those of tropospheric process, and MRI primarily performed those of both stratospheric and tropospheric process.

The latest version of the NIES model is CCSRNIES-MIROC3.2, which has been developed based on MIROC3.2 GCM by introducing stratospheric chemical process. An ocean coupled chemistry-climate model is in development at NIES based on MIROC5 GCM. In addition to the chemistry-climate interaction simulation recommended by CCMI, these models are also used as a chemical transport model. They assimilate meteorological data by a method of nudging for an analysis of chemical and dynamical ozone forcing inside/outside of the Arctic polar vortex during the 2009/2010 stratospheric sudden warming (Akiyoshi et al., 2016) and a simulation of low ozone air mass advection toward the South America continent in 2009.

JMA's MRI has developed both a CTM and CCM to study stratospheric and tropospheric ozone. The current version of the model, MRI-CCM Version 2 (MRI-CCM2), includes detailed tropospheric ozone chemistry as well as stratospheric chemistry. The model has been used at JMA to simulate ozone distributions by incorporating total ozone data from Ozone Monitoring Instruments (OMI) on board the NASA Aura or recently from the Ozone Mapping & Profiler Suite (OMPS) instruments on board the Suomi NPP, and has produced several-day ozone forecasts. These calculated ozone distributions can be used to monitor variations in stratospheric and tropospheric ozone as well as total column ozone, and to provide a UV forecast service. The MRI-CCM2 chemistry module is also an important component of the MRI earth-system model (MRI-ESM1), which participated in the fifth phase of the Coupled Model Intercomparison Project (CMIP). MRI-ESM1 has been developed as an extension of the atmosphere–ocean coupled general circulation model, MRI-CGCM3, by adding chemical and biogeochemical processes. This model has been used to perform some of the CCMI-recommended reference simulations. A new version of the model developed in 2016, MRI-ESM Version 2, will participate in the sixth phase of the CMIP.

Nagoya University, NIES, and JAMSTEC developed a CCM in 2011 (Watanabe et al., 2011), based on the climate model MIROC. The chemistry part of this CCM was developed by extending the upper boundary of the CHASER model from the lower stratosphere to the mesosphere and includes stratospheric chemistry and PSC processes. This CHASER model

(MIROC-ESM), also performs some of the CCMI-recommended simulations, focusing on chemistry–climate processes in the troposphere (Morgenstern et al., 2016), and Source-Receptor (S-R) simulations of the Hemispheric Transport of Atmospheric Pollutants Phase-II (HTAP2) experiment (Stjern et al., 2016; Huang et al., 2016). The data assimilation system based on the CHASER model was developed in 2012 (Miyazaki et al., 2012) and was used to infer recent changes in tropospheric ozone and emissions of its precursors, such as NOx (Miyazaki et al., 2015; 2016).

4. DISSEMINATION OF RESULTS

4.1 Data reporting

NIES and the Solar-Terrestrial Environment Laboratory (STEL) of Nagoya University have established stations at Tsukuba and Rikubetsu equipped with NDACC instruments, including lidar systems, millimetre-wave radiometers, and FTIR spectrometers. Some activities undertaken by organizations have been incorporated in NDACC measurements in Japan.

Observational data acquired at JMA's stations are submitted monthly to the World Ozone and UV Data Centre (WOUDC) in Toronto, Canada. Provisional total ozone data are also delivered daily on the Character Form for the Representation and Exchange of Data (CREX) through the WMO Global Telecommunication System (GTS), and used at the WMO Ozone Mapping Centre in Thessaloniki, Greece to map total ozone distribution over the Northern Hemisphere. Total ozone and ozone sonde data acquired at Syowa Station during the Antarctic winter and spring are submitted weekly to the WMO Secretariat for incorporation in Antarctic Ozone Bulletins.

4.2 Information to the public

The Japanese MOE publishes an annual report on the state of the ozone layer, surface UV-B radiation, and atmospheric concentrations of ozone-depleting substances.

JMA data summaries of total ozone, ozone sonde, and UV-B measurements are published monthly on the Internet. An annual report that includes detailed trend analyses of ozone over Japan and globally is also published for both government and public use. Since 2005, JMA has been providing an Internet-based UV forecast service (in the form of an hourly UV-index map) based on UV-B observations and ozone forecast modelling techniques. Analytical UV maps and quasi-real-time UV observations are also posted hourly on the website. MRI-CCM UV forecasts were replaced by MRI-CCM2 forecasts in 2014.

The MOE supports research on preserving the environment in Japan and around the world (including ozone layer depletion) through the Environment Research and Technology Development Fund (ERTDF); their results are published in Annual Summary Reports.

5. PROJECTS, COLLABORATION, TWINNING AND CAPACITY BUILDING

A research project, *Effects of Additional CFC Regulation on Fragility of Ozone Layer under Future Global Warming*, was undertaken as an ERTDF project by NIES during 2013-2015. This project investigates the possibility of large-scale ozone depletion in the Arctic, as observed in 2011, by performing 100-year CCM simulations in which concentrations of ozone-depleting substances and greenhouse gases are fixed to past or near-future concentrations.

An international project of the Science and Technology Research Partnership for Sustainable Development (SATREPS), *Development of the Atmospheric Environmental Risk Management System in South America*, has been conducted by Nagoya University and NIES since 2012. In this project, lidar for measuring aerosols and ozone, and millimetre-wave radiometers for measuring ozone and chlorine monoxide were deployed in Argentina and Chili. Advection of ozone-depleted airmasses from Antarctica have been observed by these instruments in the recent austral spring and simulated by the NIES CTM.

JMA's Aerological Observatory has developed an automated Dobson measuring system (described on the JMA web site: http://ds.data.jma.go.jp/wcc/dobson/windobson.html) that reduces the burden on equipment operators and improves data quality. JMA has provided technical support to some foreign organizations interested in using this system.

6. IMPLEMENTATION OF THE RECOMMENDATIONS OF THE 9th OZONE RESEARCH MANAGERS MEETING

Observational data acquired at all JMA's stations are submitted monthly to WOUDC.

JMA held the DIC-T2016 in March, 2016 to provide Asian countries with technical support to ensure the quality of ozone observation in the region, as a part of the RDCC activities. Representatives from China, Pakistan and Thailand with Dobson spectrophotometers took part in the intercomparison. Technical inspection and instrument adjustments were conducted and new calibration constants were determined for each instrument during the intercomparison. During DIC-T2016, training on ozone observation was also performed so that participants conduct proper instrument operations and process observation data, including submission to the WOUDC in their home countries. In addition, JMA provides technical support on ozone observation to Asian and South-West Pacific countries via email upon their request as a part of the QA/SAC activities.

A CCM coupled ocean is in development based on MIROC5 GCM for chemistry-climate interaction study. Development of a new CCM based on MIROC6 is also planned.

7. FUTURE PLANS

Ongoing monitoring of ozone, water vapor, and other species levels near the tropical tropopause will continue to improve our understanding of the role of the tropical transition layer in chemistry–climate interactions. Precise measurements of trace gas concentrations in the stratosphere will continue to provide key information on physical, chemical, and dynamical processes in the stratosphere. For example, precise monitoring of trace gases in the middle atmosphere enables identification of mean age of air variability and an evaluation of the ability of current models to reproduce changes in dynamical atmospheric processes.

Development and improvement of CCM and CTM numerical models will continue, which will allow better prediction of future changes to the ozone layer and improve our understanding of mechanisms of chemistry–climate interactions. A regular CCM update based on the newest global circulation model will be necessary for ongoing research on chemistry-climate interactions. For example, a new CCM has been constructed based on the MIROC 5 GCM used for climate projections for the IPCC Fifth Assessment Report. Because MIROC 5 GCM simulates sea-surface temperature distributions better than MIROC3.2 GCM, the new CCM may provide better chemistry-climate projections. A CCM based on MIROC 6 GCM is planned in the near future for further improvement of chemistry-climate interaction processes.

8. NEEDS AND RECOMMENDATIONS

Systematic observations to evaluate the changing state of the ozone layer, including detection of ozone layer recovery, should be continued in cooperation with international monitoring networks, such as NDACC and the WMO/GAW programme.

Reliable observation data for ozone and other chemicals in the upper middle atmosphere are needed, especially for HOx species such as OH and HO_2.

Ocean-coupled CCMs need to be developed and used for performing simulations recommended by CCMI. CCMs also need to be developed to accurately simulate solar variation effects.

Finally, a systematic calibration program and well-coordinated monitoring network should be established to detect variations and long-term trends in ground-level UV radiation.

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KAZAKHSTAN, REPUBLIC OF

1. OBSERVATIONAL ACTIVITIES

1.1 Measurements of ozone and data use

Ozone observations in the Republic of Kazakhstan are being carried out since 1957 with the M-124 ozonometer (filter). Ozonometric network of the Republic of Kazakhstan is composed from following stations: Almaty OHMS (since 1957), Aral Sea station (since 1976), Karaganda station (since 1963), Atyrau station (since 1965), and Semipalatinsk station (since 1964). Data from daily observations are recording on the logbook O-3. During the preliminary data processing corrections can be made, that reviews following factors: latitude, season and height above sea level etc., as well as instrumental corrections for each device. Digital observation data from Ozonometric network of Kazakhstan in the frameworks of WMO programs are sending to Main Geophysical Observatory named after Voeykova, St. Petersburg, where preliminary screening on credibility is making, and if necessary data can be amended. And then screened data is collecting in WOUDC for further analysis.

1.2 Basic regularities of spatio-temporal distribution of the ozone content in Kazakhstan for the period between 1974-2003 rr

In the frameworks of the 003 programme "Scientific researches are environment", report about the Scientific-research works on "Research on dynamics of the ozone layer under the Kazakhstan territory and development of confinements on spillovers of it" was provided in 2007 by RSE "Kazhydromet". The main aim of this research work was to obtain statistical estimation of the ozone content under the Kazakhstan territory. It can be concluded from the analysis that:

1.2.1 *Total ozone content (TOC) expansion observed from November to March, and its reduction is observed in the period between April and October;*
1.2.2 *Total ozone content's spatio-temporal distribution is quasi-latitudinal, as the latitude increases, so does TOC. Greatest horizontal gradient is observed in the period between April and May, and its measure is 5 e. D/100km, which is explained with atmospheric temperature contrast intensity between southern and northern parts;*
1.2.3 *Standard deviation of the average monthly ozone content is ranging from 8.0 e D to 29.6 e D; standard deviation of the average daily ozone content is ranging from 17.5 e D to 45.7 e D, depending on latitude and on seasons.*
1.2.4 *Monthly averages of ozone content are widely varied, the least minimal monthly averages of ozone content are observed at Almaty station, Aral Sea station, Karaganda station in November 1992 – 290 e.D., and the greatest minimal monthly averages of ozone content for 447 e.D. are observed at Semipalatinsk station in March 1979.*
1.2.5 *Monthly amplitude of ozone content is increasing with latitude, especially in winter and spring, maximal value in January on Semipalatinsk station (118 e.D.). In autumn amplitude is declining, till the minimal values in August on Semipalatinsk station (56 e.D.).*

1.3 Trends of total ozone content under the Kazakhstan territory

The main aim of this analysis was to define, if there were observations on changing of average level of ozone content for a specific period of time, if yes, the aim is to define direction and speed of changing. To achieve this objective characteristic of ozone content in time-series were analyzed: average for month, for season, for year.

The analysis revealed that total ozone content tendency in Kazakhstan is reducing, the pronounced reduction is observed in autumn and winter.

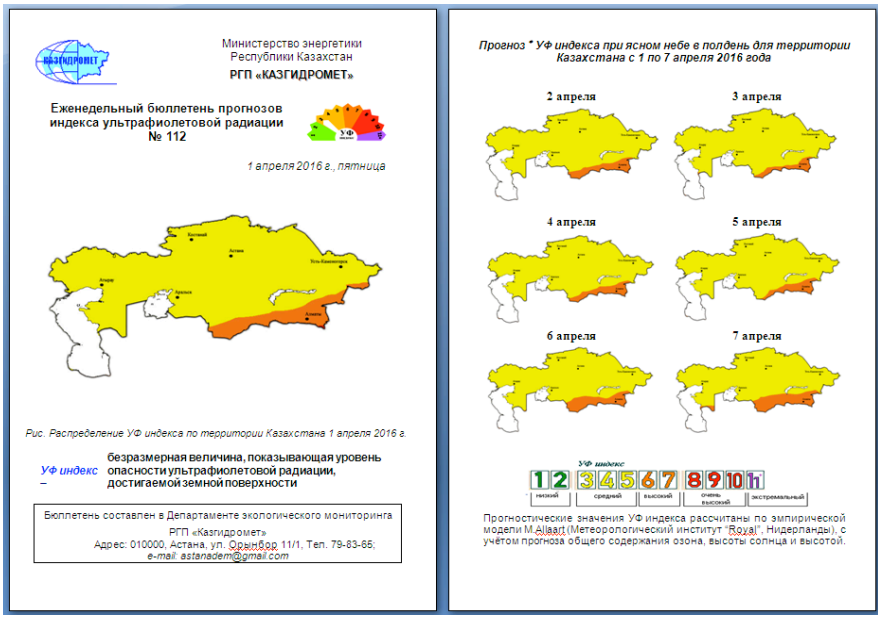
2. CALIBRATION OF INSTRUMENTS

Calibration interval for M-124 ozonometers is 2 years (once in two years ozonometers are calibrated in the Main geophysical observatory named after Voeykova, St. Petersburg). Each station should include three M-124 ozonometers: working ozonometer for daily measurements, spare ozonometer that will substitute working ozonometer in case of its failure, and backup ozonometer that is in MGO named after Voeykova for repair of calibration. Our stations have 2 ozonometers.

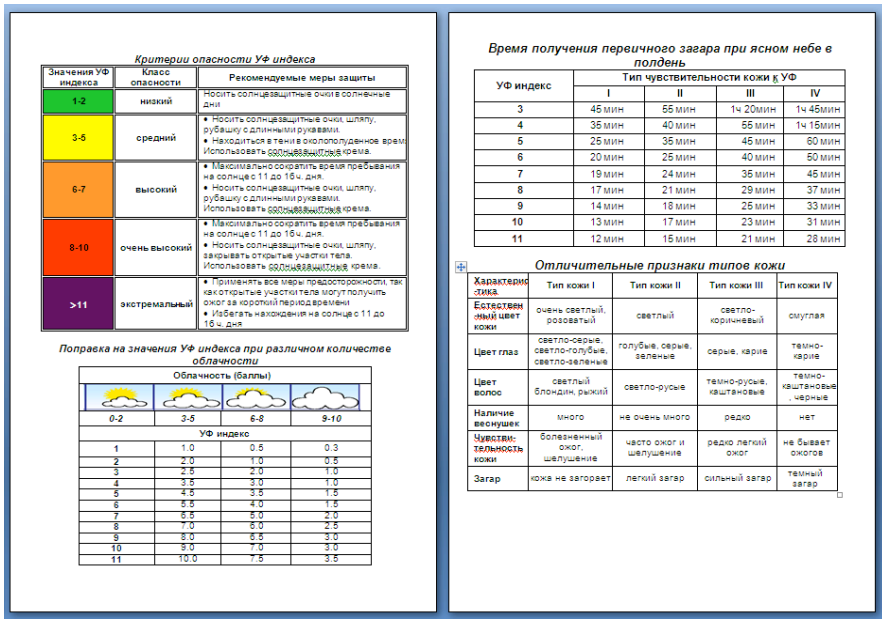
3. OBSERVATION DATA AND ITS ANALYSIS

3.1 Weekly bulletin of UV index forecasts is published annually in the period between April and September.
3.2 UV radiation index forecast values are received from ITCENTRA portal in pic. format, then processed in PHOTOSHOP, and then put on bulletin.
3.3 UV radiation index forecast values are calculated by M. Allaart empirical model ("ROYAL" Meteorological institute, Netherlands), considering total ozone content and angle of the sun.

Picture 1 below shows fragments from Weekly bulletin on UV radiation index.



Picture 1



Критерии опасности УФ индекса

Значения УФ индекса	Класс опасности	Рекомендуемые меры защиты
1-2	низкий	Носить солнцезащитные очки в солнечные дни
3-5	средний	• Носить солнцезащитные очки, шляпу, рубашку с длинными рукавами. • Находиться в тени в околополуденное время. Использовать солнцезащитные крема.
6-7	высокий	• Максимально сократить время пребывания на солнце с 11 до 16 ч. дня. • Носить солнцезащитные очки, шляпу, рубашку с длинными рукавами. Использовать солнцезащитные крема.
8-10	очень высокий	• Максимально сократить время пребывания на солнце с 11 до 16 ч. дня. • Носить солнцезащитные очки, шляпу, закрывать открытые участки тела. Использовать солнцезащитные крема.
>11	экстремальный	• Применять все меры предосторожности, так как открытые участки тела могут получить ожог за короткий период времени • Избегать нахождения на солнце с 11 до 16 ч. дня

Поправка на значения УФ индекса при различном количестве облачности

Облачность (баллы)			
0-2	3-5	6-8	9-10
УФ индекса			
1	1.0	0.5	0.3
2	2.0	1.0	0.5
3	2.5	2.0	1.0
4	3.5	3.0	1.0
5	4.5	3.5	1.5
6	5.5	4.0	1.5
7	6.5	5.0	2.0
8	7.0	6.0	2.5
9	8.0	6.5	3.0
10	9.0	7.0	3.0
11	10.0	7.5	3.5

Время получения первичного загара при ясном небе в полдень

УФ индекс	Тип чувствительности кожи к УФ			
	I	II	III	IV
3	45 мин	55 мин	1ч 20мин	1ч 45мин
4	35 мин	40 мин	55 мин	1ч 15мин
5	25 мин	35 мин	45 мин	60 мин
6	20 мин	25 мин	40 мин	50 мин
7	19 мин	24 мин	35 мин	45 мин
8	17 мин	21 мин	29 мин	37 мин
9	14 мин	18 мин	25 мин	33 мин
10	13 мин	17 мин	23 мин	31 мин
11	12 мин	15 мин	21 мин	28 мин

Отличительные признаки типов кожи

Характеристика	Тип кожи I	Тип кожи II	Тип кожи III	Тип кожи IV
Естественный цвет кожи	очень светлый, розоватый	светлый	светло-коричневый	смуглая
Цвет глаз	светло-серые, светло-голубые, светло-зеленые	голубые, серые, зеленые	серые, карие	темно-карие
Цвет волос	светлый блондин, рыжий	светло-русые	темно-русые, каштановые	темно-каштановые , черные
Наличие веснушек	много	не очень много	редко	нет
Чувствительность кожи	болезненный ожог, шелушение	часто ожог и шелушение	редко легкий ожог	не бывает ожогов
Загар	кожа не загорает	легкий загар	сильный загар	темный загар

Weekly bulletin on UV radiation index of the Ecological Monitoring Department is published on RSE "Kazhydromet" web-site.

4. DISSEMINATION OF OBSERVATION RESULTS

4.1 On 1st September 2013 "total ozone content in atmosphere measurements result transmission code" has entered into force.
4.2 RSE "Kazhydromet" produces observations, also provides monthly collection and adjustment of data in electronic form for further sending it to MGO named after Voeykova.
4.3 MGO verifies, makes adjustments, makes an analysis and culling of data, and then sends it to Canada for general use of all countries. UV radiation index is not defined on our stations; this index is defined only according to data from Russian Federation's stations.
4.4 Operational information, which received from ozonometric stations of Kazakhstan, Belarus and Russia, sends to MGO to Canada, to World Ozone UV Data Center (WOUDC) of WMO. World data center puts the data on ozone composition to the map.

5. FUTURE PLANS

M-124 ozonometers by which ozonometric network of RSE "Kazhydromet" conduct observations on TOC are established at 1957-1963. Update of ozonometric instruments to more advanced equipment are foreseen in the future.

KENYA, REPUBLIC OF

PREAMBLE

Kenya is a signatory to the international conventions and treaties on climate change and environmental protection. Consequently, the country is actively participating and contributing to the success of the World Meteorological Organization (WMO) programme through the Kenya Meteorological Department (KMD). The Department operates air pollution observation stations that monitor, among other pollutants, ozone at the surface, troposphere and the stratosphere.

It has been realized that developing countries in the tropics can play a major role in the global initiatives to achieve a better understanding of the atmospheric changes and the effects on the environment linked to ozone changes. Consequently, Kenya initiated its active involvement in the World Meteorological Organization (WMO) Global Ozone Observing System (GO3OS) with the launching of its total column ozone monitoring programme in 1984. The ozone monitoring programme has since expanded and is currently monitoring total column, vertical profile and surface of ozone.

1. KENYA'S OBSERVATIONAL ACTIVITIES

1.1 Column Measurements of Ozone

Nairobi regional GAW station (Altitude: 1795m asl, Latitude: 1.30 S, Longitude: 36.75 E) monitors the total column of ozone using Dobson spectrophotometer number 18 since 2005. However, these measurements commenced at the University of Nairobi in 1984 until 2005 when the instrument was transferred to Kenya Meteorological Department. The station is within Kenya Meteorological Departments and therefore all weather parameters are observed.

1.2 Profile Measurements of Ozone

The Nairobi regional Global Atmospheric Watch (GAW) station also monitors the vertical profile of ozone since 1996. It uses a Lightweight, balloon-borne instrument attached to a conventional meteorological radiosonde. It has an electrochemical concentration cell (ECC) that senses ozone as it reacts with a dilute solution of potassium iodide to produce a weak electrical current proportional to the ozone concentration of the sampled air. During its ascent through the atmosphere, the ozonesonde transmits readings of ozone and standard meteorological parameters (Ambient temperature, relative humidity, and wind speed and wind direction) to the ground receiving station. These measurements are performed once every week.

1.3 Ultra Violet (UV) Measurements

There are no UV measurements in the country

1.4 Calibration Activities

Since the inception of the Nairobi Ozonesonde Observatory Station, MeteoSwiss has supported the station with all the necessary equipment coupled with biannual instrument calibrations and audit missions.

However, for the international calibration mission, Dobson spectrophotometer number 18 was last calibrated in South Africa in 2010. The instrument therefore requires urgent calibration.

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

Figure 1 below shows annual total column ozone at Nairobi regional GAW station. Preliminary investigations indicate a decreasing trend of ozone from 1984 to 2016. The annual mean and standard deviation are 256.2 DU and 6.9 respectively.

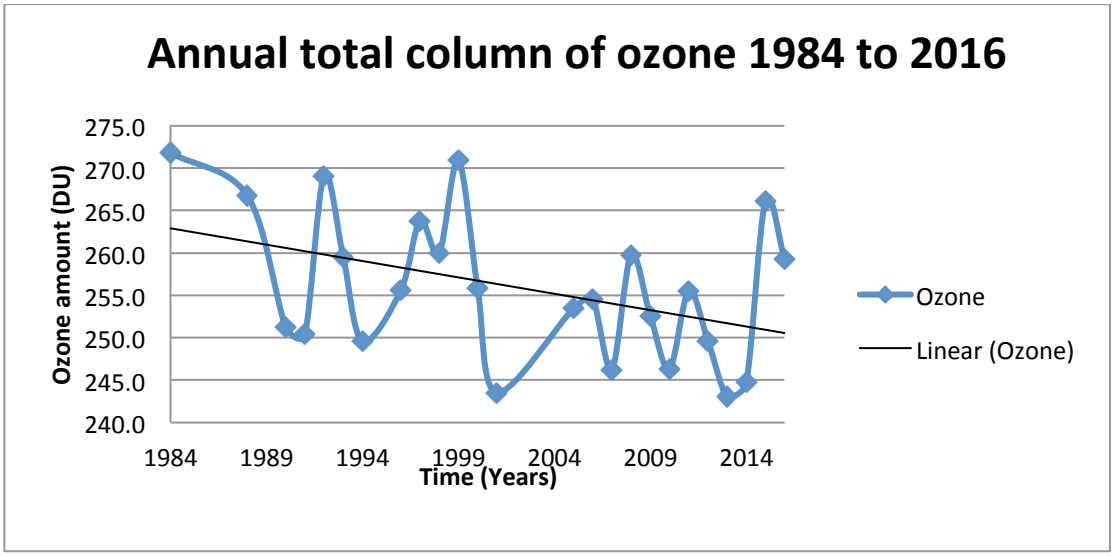


Fig: 1. Annual total column of ozone in Nairobi, Kenya

The mean monthly total column of ozone is indicated in figure 2. The figure shows a seasonal variation of ozone. There is a slight peak during the long rains in March-May and a major peak in August-October just before the commencement of the short rains. Minimum values are realized in December-February with corresponding maximum values in August-October. The difference in ozone amount is attributed to stratospheric ozone fluctuations due to the variation of the height of the tropopause (Muthama, 1989). The mean monthly standard deviation is 5.9.

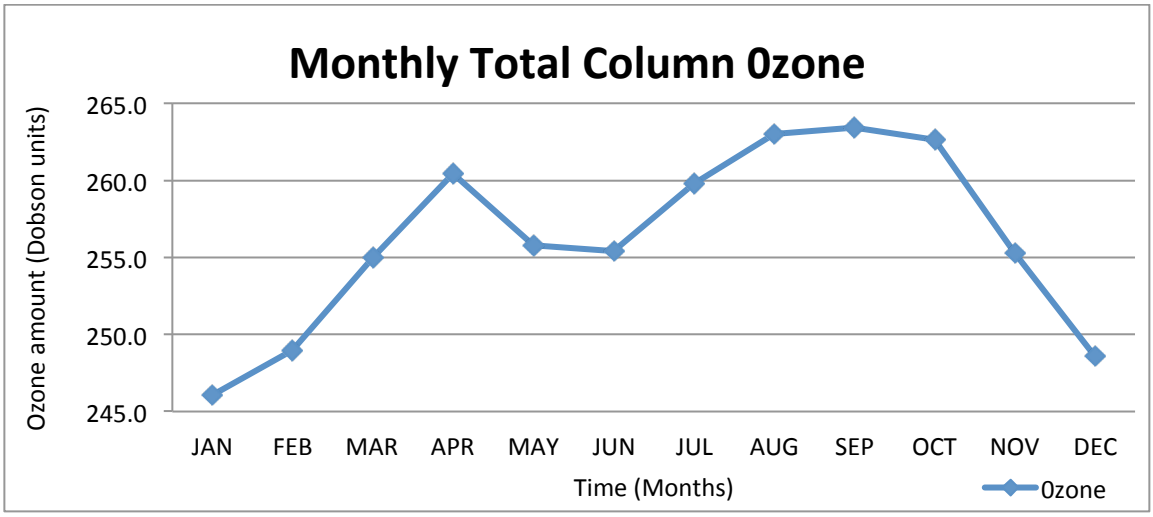


Fig: 2. Mean monthly total column of ozone

Statistical analysis of ozone profiles over Nairobi split into 3 layers reveals strong yearly variation in the free troposphere and the tropopause region, while ozone in the stratosphere appears to be relatively constant throughout the year. Total ozone measurements by Dobson instrument confirm maximum total ozone content during the short-rains season and a minimum in the warm-dry season (Ayoma et al, 2002).

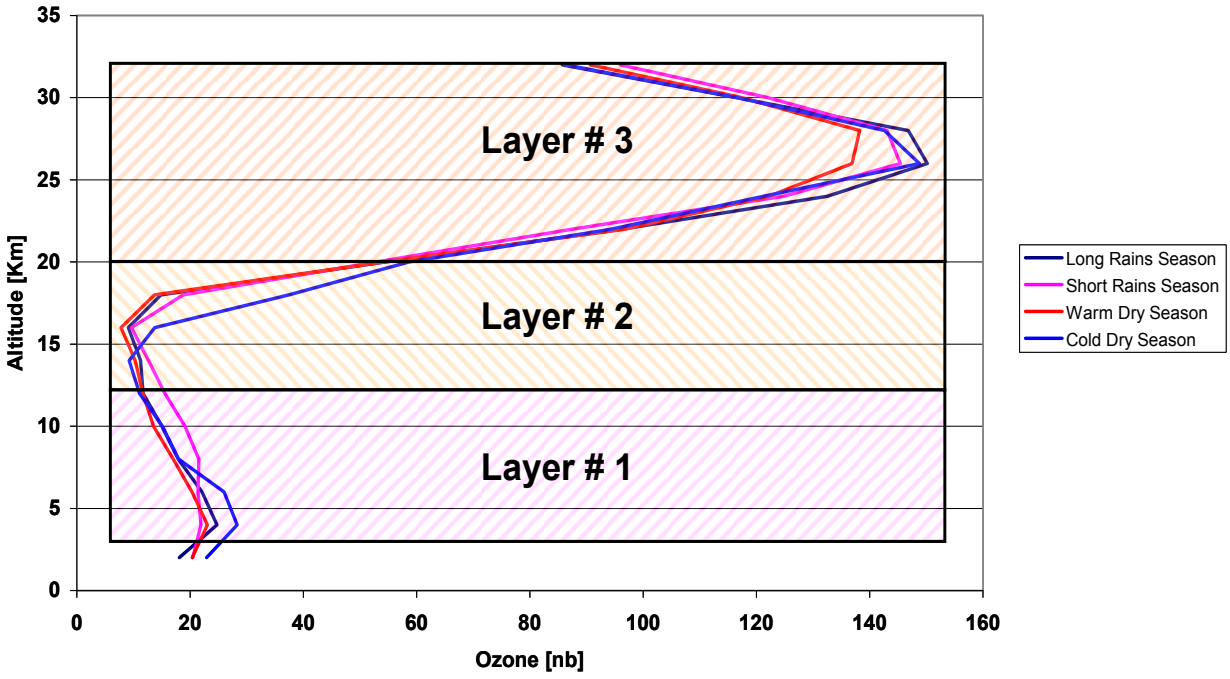


Fig: 3. Mean "Seasonally averaged" ozone profile over Nairobi based on 8 years of ozone sounding, for respectively long-rains, short-rains, warm-dry and cold-dry season.

As a first output of this analysis, there is indication that the relative ozone variability in the "stratosphere" is weak, thus indicative of small changes in the ozone concentration in the stratosphere over Nairobi during the last 8 years. On the contrary in the "free troposphere" and "tropopause" regions, observations have shown significant changes: up to 40% of peak to peak variation with a well-defined yearly cycle. This tropospheric ozone variability is higher than expected and may partially be attributed to turbulent air motions (Ilyas, 1991).

3. OZONE AND RELATED RESEARCH IN KENYA

Surface ozone measurements are conducted both in Nairobi (since 2012) and Mt. Kenya GAW station (since 2000). Several reports on the ozone levels including publications in refereed journals have been produced.

4. DATA AND INFORMATION DISSEMINATION

4.1 Data Reporting

Both column and profile ozone measurements are submitted to our twinning partners (Meteoswiss) on weekly basis for onward submission to the World Ozone and UV Data Centre (WOUDC).

Surface O3 and CO data (both from May 2002 – July 2010) have been submitted to the World Data Centre for Greenhouse Gases (WDCGG). No data was available after this period until January 2015 due to a major upgrade of the station.

4.2 Information to the Public

The country does not issue UV forecasts. However, Kenya Meteorological Department monitors surface ozone in Nairobi. The public, through the relevant government ministries is informed when the levels are high.

4.3 Relevant Scientific Papers

Ayoma, W., Gilbert, L., and Bertrand, C.,: Variability in the observed vertical Distribution of ozone over equatorial Eastern Africa: an analysis of NairobiOzonesonde data 2002

Henne, S., Klausen, J., Junkermann, W., Kariuki, J. M., and Aseyo, J.: Representativeness and climatology of carbon monoxide and ozone at the global GAWstation Mt. Kenya in equatorial Africa. J. of Atmos. Chem. Phys., 8, 3119-3139, 2008

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Llyas 1991: Ozone depletion implication for the tropics. Published University of Malaysia andUNEP, for international conference on tropical ozone change, Feb, 20-23 1990.

Muthama, N.J., 1989: Total atmospheric ozone characteristics over a tropical region. Msc. Thesis, University of Nairobi

5. COLLABORATION, TWINNING AND CAPACITY BUILDING

There is long standing and good collaboration between Kenya Meteorological Department and MeteoSwiss in the context of the WMO Global Atmosphere Watch (GAW) programme. MeteoSwiss proposes upgrades of the total ozone measurements in Nairobi and the meteorological surface measurements at Mount Kenya GAW station in January 2017. This will include;

- Commissioning an automatic ozone Brewer spectrophotometer in Nairobi
- Establishing an all-in-one meteorological station on Mt. Kenya; and
- Continue the MeteoSwiss support to KMD to consolidate the high quality ozone measurements in Nairobi.

6. STATUS OF IMPLEMENTATION OF THE RECOMMENDATIONS OF THE 9th OZONE RESEARCH MANAGERS MEETING

6.1 Research Needs

There has been minimum implementation of the recommendations of the 9th ORM on research. However, awareness to conduct research on ozone has been enhanced through seminars and workshops. This has led to publication of a few research reports on ozone.

6.2 Systematic Observation

Systematic observations are critical to understanding and monitoring long-term changes in atmospheric composition. Kenya has been monitoring, on long term basis both total column and vertical profile of ozone since 1984 and 1996 respectively. Kenya has been keen in maintenance of existing facilities and expansion of observing stations. These networks are maintained above a critical level of data quality.

The country has expanded Mt. Kenya GAW station by improving the infrastructure and introducing aerosols measurements through the Capacity building and Twinning for Climate Observing Systems (CATCOS) project.

6.3 Data Archving

The government provides funding for archiving all raw data from ozone monitoring stations. Raw data is submitted on a weekly basis to MeteoSwiss for onward submission to the WOUDC. However, development of a robust automated data submission with centralized processing and Quality Assurance (QA) schemes has not been realized.

6.4 Capacity Building

Kenya has established a regional and bilateral cooperation and collaboration (twinning) with Swiss Federal Laboratories for Material Testing and Research (EMPA).

EMPA provide resources and opportunities for scientific and technical training, at and beyond the instrument-operation level, thereby allowing instrument operators and other scientific personnel in Kenya to use their data, other available data, and models in both regional and international research areas. EMPA conducts a biennial system and performance audit of surface ozone and carbon monoxide at the global GAW station Mount Kenya.

The WMO-GAW Training and Education Centre (GAWTEC) established in Germany has been successful in providing training in measurements and instrument calibration to all our staff involved in ozone measurements.

7. FUTURE PLANS

Kenya plans to implement the National Flagship Programmes under Kenya's Vision 2030 which include establishment of climate monitoring stations for air pollution monitoring and climate change detection.

The country, through KMD plans to install an automatic ozone Brewer spectrophotometer in Nairobi and an automatic weather station on Mt. Kenya GAW station in January 2017. KMD proposes the establishment of new stations across the country that will monitor ozone amongst other pollutants. However, establishment of new station may take a long time to realize due to financial limitation. There is therefore need to secure the financial support from relevant institutions.

8. NEEDS AND RECOMMENDATIONS

8.1 Research

There are several factors that inhibit research activities in Kenya. These include:

- Lack of an establishment in Africa of a regional center for research on ozone-climate interactions.
- There are inadequate computing facilities especially for research that involve Global models. Twinning with more advanced research centers should be encouraged.

- Inadequate support of investigations to resolve the differences between tropical total-ozone column trend estimates, and those trends computed from satellite profiles.

8.2 Systematic Observation

Recommendations that will enhance systematic observation in the country are;

- There is poor spatial distribution of ozone observing stations in the tropics especially in Equatorial Africa. Governments in this region to be sensitized on the need to establish more ozone monitoring stations. This would require both infrastructure and equipment support in order to establish new stations.
- There is urgent need to start UV measurement in the country.
- Redistribution of instruments from instrument-rich sites to those areas that are poorly populated with instruments to be fast-tracked.

8.3 Data Archiving

- Participation in regular workshops that provide training on metadata collection and processes for archiving data may support the effort to improve these activities within the ozone and research community
- It is acknowledged that obtaining data of high quality is costly and time-consuming but is nonetheless an essential task and so data providers should be adequately funded and recognized for their efforts in providing this data to global archives for the furtherance of ozone and UV science.

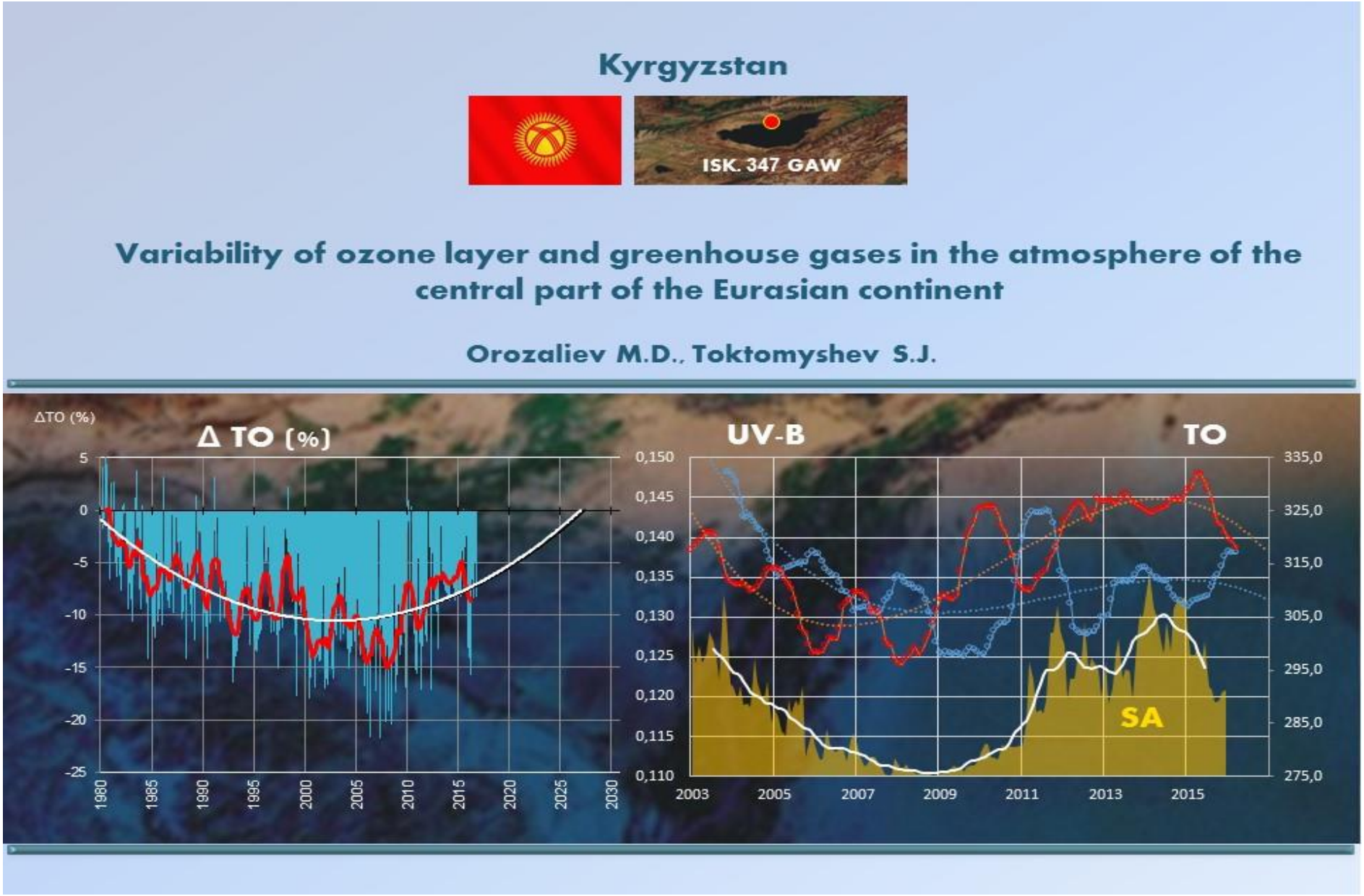
8.4 Capacity Building

- Establishment of regional centers for research, calibration, and validation in developing countries to be encouraged.
- Develop programs for the operators of ozone monitoring stations so that they can produce high quality, uniform data across the globe.
- Resources for the exchange programs and visits of personnel from monitoring stations from developed to developing countries should be increased in order to ensure technology and knowledge transfer and sustained measurement programs.

By

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KYRGYZSTAN


Kyrgyzstan
ISK. 347 GAW
Variability of ozone layer and greenhouse gases in the atmosphere of the central part of the Eurasian continent
Orozaliev M.D., Toktomyshev S.J.
ΔTO (%)
Δ TO (%)
5
0
-5
-10
-15
-20
-25
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
UV-B
TO
0,150
0,145
0,140
0,135
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0,125
0,120
0,115
0,110
335,0
325,0
315,0
305,0
295,0
285,0
275,0
2003
2005
2007
2009
2011
2013
2015
SA

Variability of ozone layer and greenhouse gases in the atmosphere of the central part of the Eurasian continent
(Kyrgyzstan, Issyk-Kul station)

INTRODUCTION

Monitoring of the atmospheric ozone and main greenhouse gases in Central part of the Eurasian continent has been conducted for more than 35 years at Issyk-Kul Station, located on the coast of the mountainous lake Issyk-Kul (lat. 42.62; long.76.98 a.s.l.; 1640 m.). There were received a unique number for the duration of TO and researched narrow impurities of the atmosphere, which significantly complimented the measurement results of the monitoring network managed by the World Meteorological Organization (WMO).

The selection of the station location on the northern shore of Issyk-Kul Lake (42.60 N, 77.00 E, 1650 m.a.s.l., Kyrgyzstan) was due to:

- by-way location in the central mountainous part of the Eurasian continent, in contrainiction to the vast majority of stations in oceanic and coastal regions of the world (Fig. 1);
- deficiency of industrial enterprises - sources of significant anthropogenic researched atmospheric components;
- climatic conditions and, in particular, the large number of sunny days (≈200 days), which increases the efficiency use of the solar-spectroscopic absorption method.

The uniqueness of the station location is defined, due to the fact, that this by-way studied intracontinental region has powerful mountain ecosystems Middle and Central Asia (the Himalayas, Tien Shan, Pamir-Alai, the Tibetan Plateau) which have a significant impact on the high-altitude streams, which play a significant role in spatial-temporal distribution of the general content of ozone and other climate active narrow impurities in the atmosphere.

The scientific station Issyk-Kul registered in the databases of the world's centers on:

- ozone, 1994 (Issyk-Kul № 347- WOUDC, www.woudc.org), Toronto, Canada;
- greenhouse gases, 1995 (ISK 242 NOOWDCGG, www.ds.data.jma.go.jp), Tokyo, Japan;
- nitrogen dioxide, (NDACC - Issyk-Kul, www.ndsc.ncep.noaa.gov), USA;

The Issyk-Kul station has been included in the network of international stations, Global Atmosphere Watch (GAW) since 2004 (Fig. 1). The station is the exclusive in the whole territory of the former USSR and Russia, regularly working since 1980, according to the full program of GAW.

The station has been included in an International network of AERONET www.aeronet.gsfc.nasa.gov (NASA, USA) of the automatic monitoring of atmospheric aerosol properties since 2007.

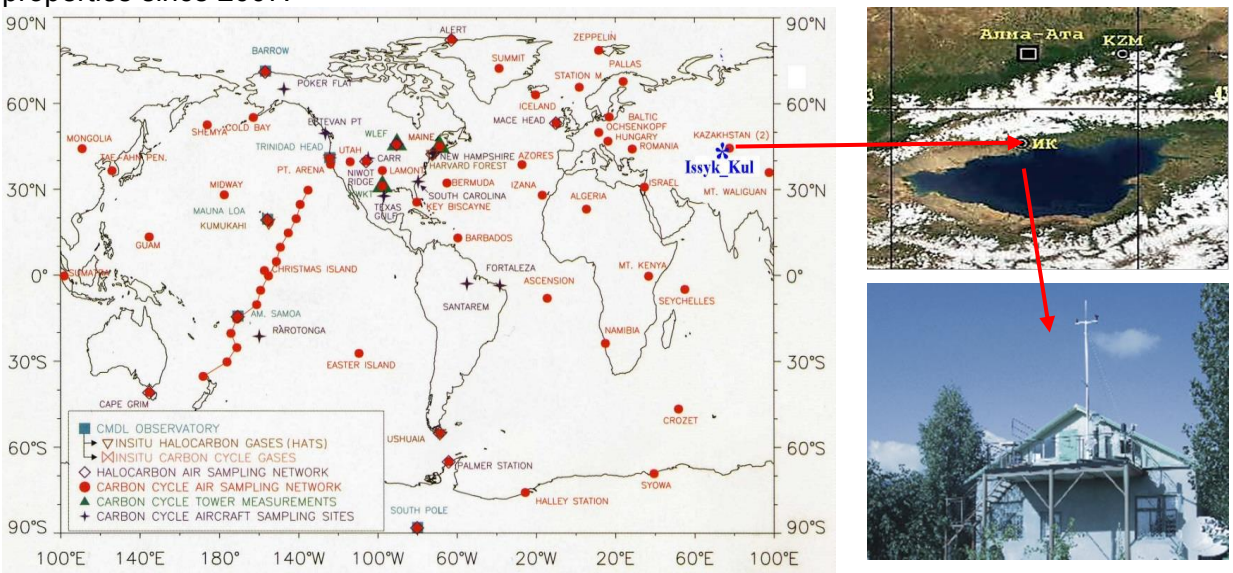


Figure 1. The location of Issyk-Kul Station relatively to other GAW monitoring stations

On the base station Issyk-Kul received a unique on duration (more than 35 years) and complexity a timing series database, on the base of which were researched features of changes in

ozone, greenhouse gases, ultraviolet (UV-B) radiation and aerosol characteristics in the atmosphere over the Central mountainous part of Eurasian Continent. The results of the research showed, that for mountainous conditions, the influence effect of solar and geophysical processes on the variability of the researched impurities was more significant than that of the ocean and the plains.

The data from Issyk-Kul Station are also used for validation and comparative analysis of satellite measurements, for development and specifications of models on forecasting of the ozone layer dynamics, greenhouse gases content and regional climate.

Detailed description of measurement methods, complex of measurement devices used at the research station Issyk-Kul, processing procedure and input-output analysis of measurements as well as detailed reference list on this subject are given in works [1-17].

Due to the large volume of material presented in the article informative and most significant results are shown in graphs

1. MONITORING OF TOTAL OZONE

The ozone content measurements are performed with the spectrophotometer scanning installation (SPS).

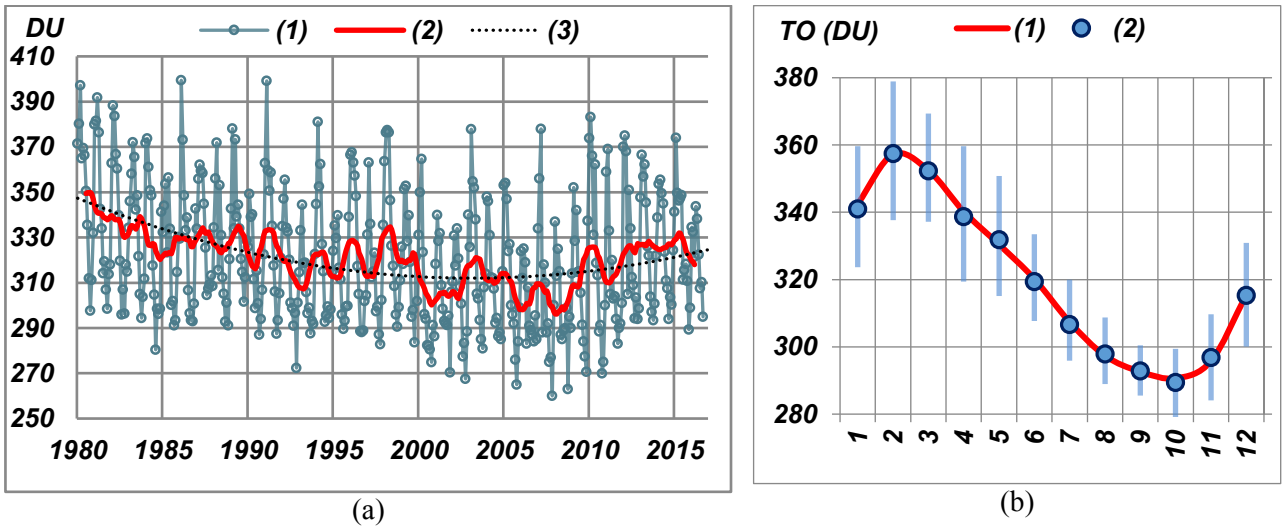
Results of TO monitoring, presented in Fig. 2, 3, 4, showed that TO changes is a complicated fluctuating process with distinct annual and quasi-biennial circularity.

Annually average TO numerical values for monitoring period (1980-2015) are presented in the Table1.

Table 1. Annually average TO values for monitoring period (1980-2015)

year	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
TO,DU	349	340	338	334	329	323	330	332	324	335	316	333
year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
TO,DU	315	310	323	315	325	315	332	320	305	306	307	320
year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
TO,DU	310	310	300	306	299	311	323	313	326	329	326	329

Fig. 3 shows, that ozone layer depletion and recovery occur at different rates (b): for 1980 - 1985, value of b = -0.4 DU/mon.; 1984 - 1990, b = 0.18 DU/mon.; 1989 - 1994, b = -0.26 DU /mon.; 1993 - 1998, b = 0.14 DU /mon.; 1997 - 2006, b = -0.16 DU/mon.; 2006 - 2015, b = 0.29 DU/mon. The amplitude of the oscillations of the rate of change of the TO (Fig. 4) varies within wide limits, and increase in magnitude of the amplitudes is observed at the beginning and its reduction at the end of the observation period (1980-2015) like the beating of amplitudes.



(a) (b)

Figure 2. Temporal variations of total ozone content according to data measured at Issyk-Kul station (ISK 347): (a). Variations of monthly average (1) and inter annual values of TO (2), parabolic trend (3); (b). Mean (1981-2013гг.) seasonal changes of TO (2) in comparison to model (curve 1), the correlation coefficient between (1) and (2) r=0.999.

Fig. 5 presents deviations of average monthly TO values (columns 1), expressed as a percentage to the average annual cycle of TO for year 1980. Curve “smooth” represents inter annual variations of the TO deviations, curve 3 is a polynomial trend of the second kind, showing the TO evolution during the monitoring and coming years. It shows that the impoverishment of ozone layer, according to parabolic trend, was 11% on average during 1980-2005, and in the last decade has been observed its recovery. According to the trend, the predictive recovery of the ozone layer to the level of 1980 over North Tien Shan is expected in 2025-2028, respectively.

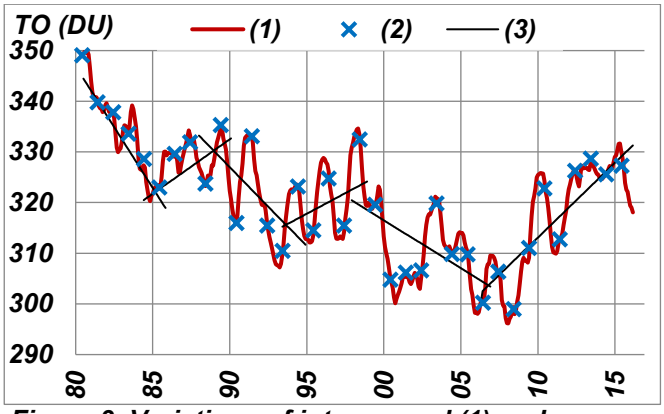


Figure 3. Variations of inter-annual (1) and average annual (2) TO values with linear trends (3).

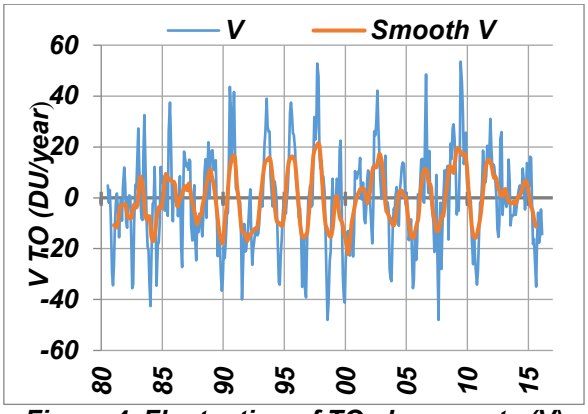


Figure 4. Fluctuation of TO change rate (V) and its smooth (smooth V) for 12 months.

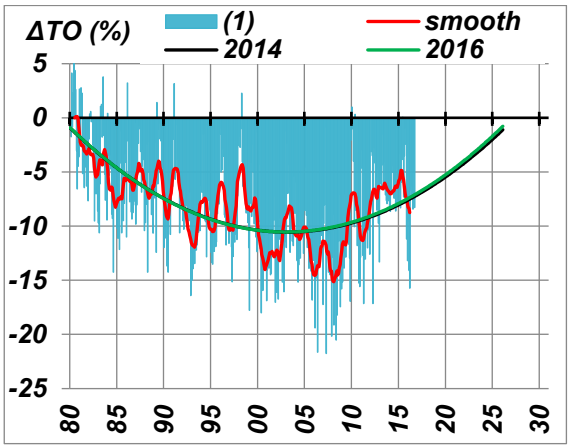


Figure 5.TO value deviations in % (1) relatively to TO values in 1980 and smooth (smooth) and parabolic trends (2014, 2016)

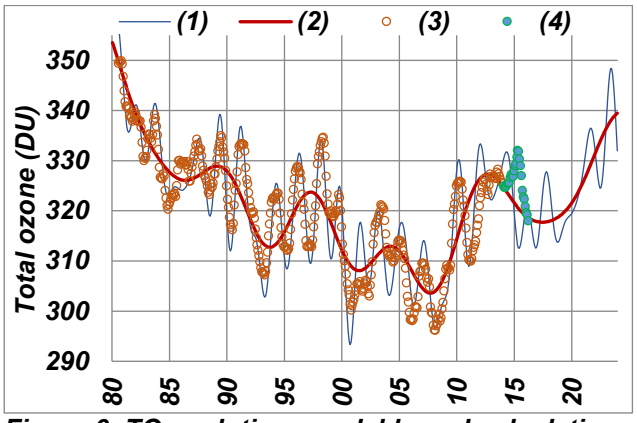


Figure 6. TO evolution: model based calculations with (1) and without (2) quasi-biennial contents in inter annual fluctuations of TO; experimental data for 1980-2013 (3) and for 2014-2016 (4)

Fig. 6 depicts comparison of inter annual changes of TO up to 2016 with model calculations of temporal variation of TO made in 2013 [6, 7]. According to estimated data in 2013 it was prognosticated, that observed recovery of the TO since 2008 should change to decrease in 2015 up to 2017-2018. Moreover, the scope of the oscillation amplitudes of the TO during the period (2014-2015) TO trend direction change was to decrease. Measured TO data in 2013-2016 (Fig. 2,3,4,5) proved prognosis about recession and decrease of amplitude excursion of fluctuations of TO. However, calculated and measured data differs with that fact that recession of quasi-biennial oscillation in TO takes place with delay, approximately, for 1 year. This delay is likely due to the fact that the beginning of 24th eleven years cycle of the solar activity occurred not in 2008 as previously predicted, but with a delay by one year in 2009.

To improve the model describing the observed experimental data and allowing prediction of TO changes for the coming years, more detailed study of solar and geophysical, astronomic and anthropogenic factors’ impact on inter annual fluctuations of TO are required.

It needs to note, that in ozone layer recovery on regional and global scales, there is undisputed contribution of world community, successfully realizing programs documents, accepted by Montreal Protocol in 1987, which is a supporting document of Vienna Convention, UNEP.

1.1 Regional specific features and temporal evolution of the quasi-biennial oscillation in total ozone (TO) in the atmosphere

Fig. 7 presents averaged (smoothed) values of TO for three and twelve months, received after subtraction of the annual cycle (norm) and non-linear trend (correspondingly curves 3 and 12) [8]. In the same figure, in order to demonstrate the features of interrelation between quasi-biennial oscillation in TO and in equatorial zonal wind, the diagrams of temporal TO variations, zonal wind velocities (V QBO) at the level of 20 hPa (www.fu-berlin.de), as well as temporal variation of solar activity index (F 10.7 – radio waves length 10,7 cm) were presented (http://www.ngds.noaa.gov).

In order to make analysis of regional features of QBO TO, the data of Xianghe (XIA 208), Kunming (KUN 209), Arosa (ARO 35), Mauna Loa (MLO 31) and Brisbane (BBN 27) stations (http://www.woudc.org), which are located at different latitudes and longitudes [9], were processed using above mentioned method.

Fig. 8 presents the comparison of relative norms of TO, that were determined for the monitoring stations: ISK 347, MLO 31, ARO 35, XIA 208, KUN209, BBN 27.

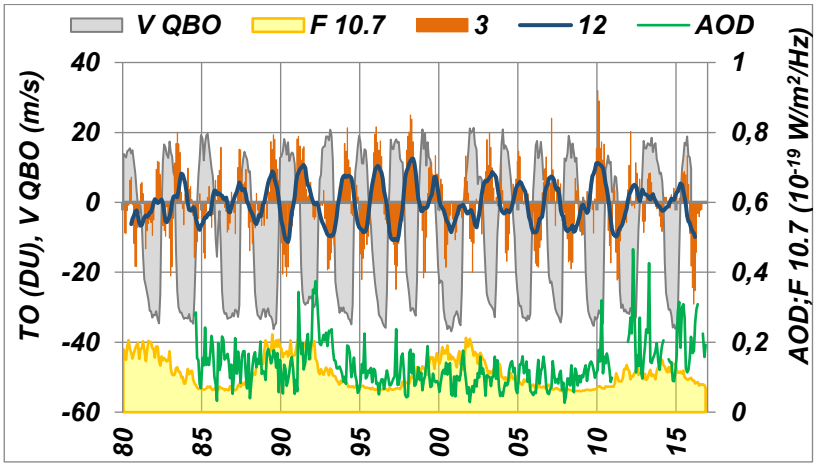


Figure 7.Comparison of quasi-biennial oscillation in TO (DU) (smoothed in three months - 3 and in twelve months - 12) with quasi-biennial oscillation in Equatorial Zonal Wind velocity (m/c) (V QBO) at the level of 20 hPa, with Solar Activity (Index F 10.7) and aerosol optical depth (AOD).

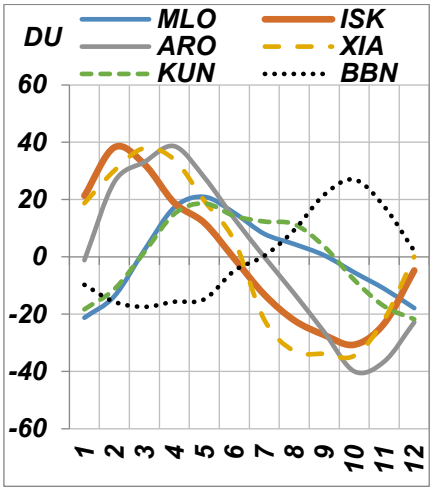


Figure 8. The relative norms of TO: ISK; MLO; ARO; XIA; KUN; BBN

Using Fourier and wavelet analysis of time series of TO and ZW have been identified parameters of significant harmonic QBO TO and QBO ZW components, as well as the period ratio, amplitude and phase of harmonics analyzed significant fluctuations.

Fig. 9 shows a good agreement between the experimental data ISK347 (2, 3 in Figure 9) to the mode

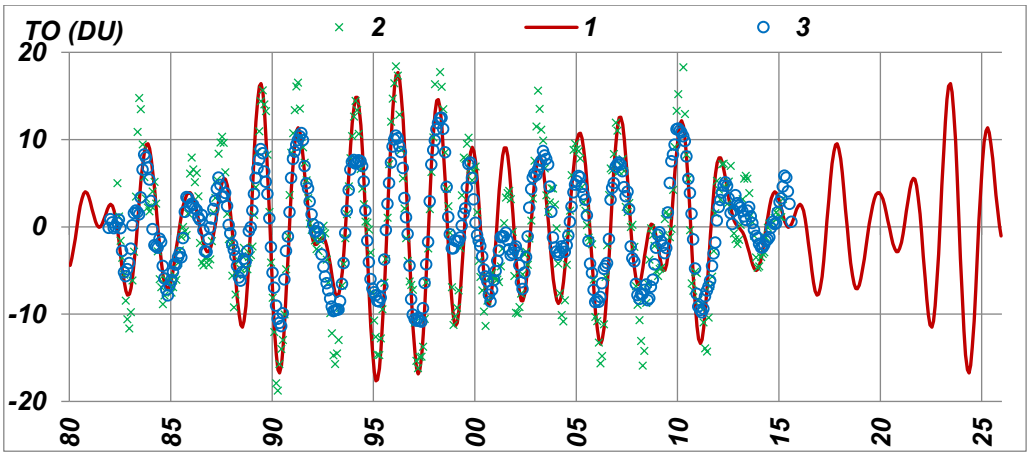


Figure 9. The comparison of model calculations (curve 1) with monitoring data of Issyk-Kul station (2 – smooth 6 month; 3- smooth 12 month).

Based on analysis of long-term (1980-2015) experimental data of Issyk-Kul station, in comparison with the data from other stations, there were defined specific features of quasi-biennial oscillation (QBO) in total ozone content over the North Tyan-Shan. It is established, that the regional specific feature and temporal evolution of QBO in total ozone, to a significant degree, are resulted by the synchronization of quasi-biennial and annual (seasonal) oscillations in TO. It was found, that experimentally observed QBO TO amplitude beats are based on superposition of harmonics of QBO TO, generated as a result of mutual-synchronization of quasi-biennial and annual (seasonal) oscillations in TO. Calculations revealed that the minimum in QBO TO amplitude excursion over North Tien-Shan was reached in 2015 and started new 34-years period in variations of ozone layer.

It is shown that the pattern of the relationship between TO and ZW is disrupted during the high values of the aerosol content in the atmosphere (volcanic activity), as well as during periods of change of magnetic polarity of the sun and its flare activity until r correlation coefficient sign is changed, the degree and duration of disturbances have regional features [6. 8]

1.2 Analysis of ground-based and satellite measurements of TO

Results of analysis of TO temporal variability in the region of mountainous zones of Middle Asia and Tibetian plateau obtained with traditional methods and the methods of spectral analysis, cross-wavelet and composite analyses are presented [15,17].

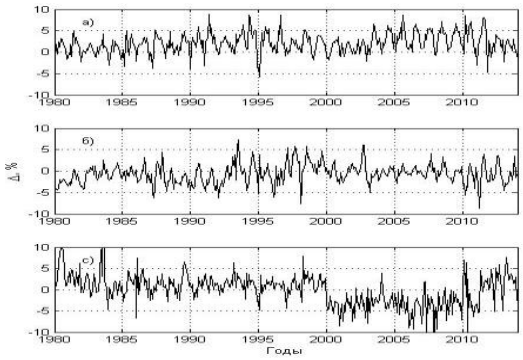


Figure 10. Relative deviation Δ (%) between ground-based and satellite (V86) measurement of TO 1980-2013. a) – Hianghe Station (No208), b) – Kunming Station (No 209), c) – Issyk-Kul Station (No 347).

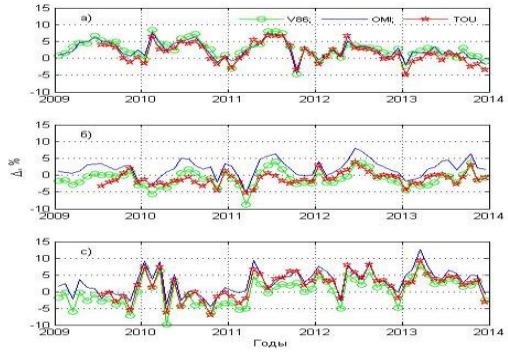


Figure 11. Relative deviation Δ (%) between ground-based and satellite (V86, OMI, TOU) measurement of TO 2009-2013. a) – Hianghe Station, b) – Kunming Station, c) – Issyk-Kul Station

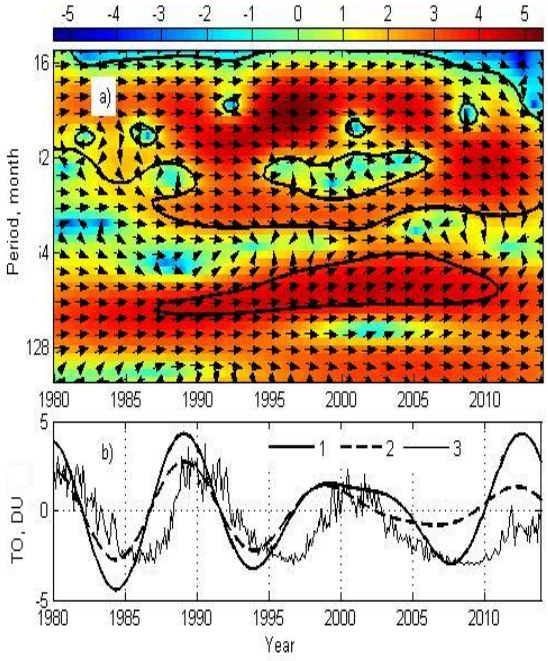


Figure 12. a) - Cross-correlation wavelet analysis of total ozone series based on ground-based and satellite data for the station 347, Issyk-Kul. Degree of correlation (color scale) is given in relative units. The thick black line marks the area with a confidence interval of 95%. Arrows show the relation between the phases of time series: the right - in phase, left - in the opposite, downward - G347 S347 variations ahead by 90 °, upwards - lagging by 90 °. b) - composite rows based on the ground (1) and satellite (2) data in 8-13 years and variations of solar activity (3).

The data of ground-based observation at stations located at Huanghe (№208), Kunming (№209) and Issyk-Kul (№347) along with the satellite data obtained at SBUV/SBUV2 (SBUV merged total and profile ozone data, Version 8.6) (ftp://toms.gsfc.nasa./_pub/sbuv/MERGED) during 1980-2013, OMI (Ozone Monitoring Instrument) (http://avdc.gsfc.nasa.gov) и TOU (Total

Ozone Unit) (http://satellite.cma.gov.cn) during 2009-2013 were used. A mean relative deviation from the data of SBUV/SBUV2 for the Kunming and Issyk-Kul for the period of 1980-2013 is less than 1%, for the Huanghe a typical excess of satellite data over the ground-based ones is registered at an average deviation of 2% (Fig. 10, 11).

The results of the Fourier analysis showed that the distribution of amplitudes and the periods of TO fluctuations within the range of over 14 months is similar for all the analyzed series. One of the reasons governing the general regularities of TO temporal variability in this region may be high mountainous systems of the Middle and Central Asia (Himalaya, Tien Shan, Pamir-Alai, Tibetan plateau) having a significant effect on the upper jets that, as it is known, determine in many cases both the TO spatial distribution and temporal variability. At the same time, according to the results of cross-wavelet and composite analyses, the phase relationships between the series may considerably differ, especially in the periods of 5-7 years. The phase of quasi-decennial oscillations for the Kunming station is close to the 11-year oscillations of the solar cycle, for the Huanghe and Issyk-Kul stations the TO variations go ahead the solar cycle (Fig. 12).

1.3 Monitoring of surface ultraviolet radiation (UV-B).

To monitor the total erythemal ultraviolet radiation in 2003 was purchased and installed an automatic UV 501modeli biometrics at the station "Issyk-Kul".

Fig. 13 shows the interannual variation in surface UV-B radiation (curve 2) and the CCA to order polynomial trend 3 (red and blue dashed line) and the average monthly value of solar activity index F10.7 (curve 3). Compare (Figure 13) interannual variations of UV-B (line 2) and TO (curve 1) and their rate of change (Figure 14) shows their high correlation [7, 9]

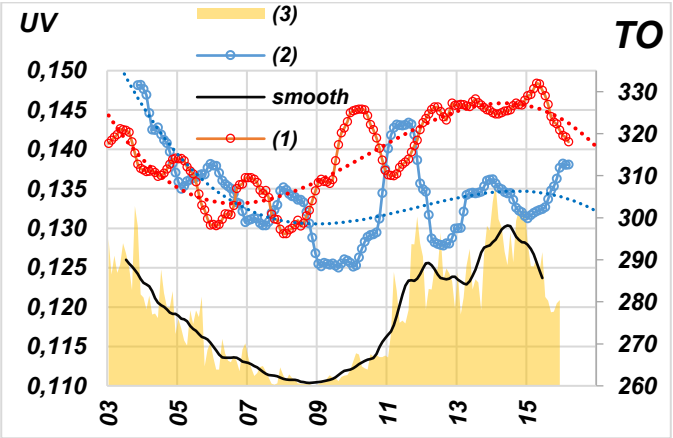


Figure 13. Inter annual variations of TO (1), surface UV-B radiation (2) with polynomial trends of 3rd order (dotted lines) and variations of monthly average solar activity index (F 10,7) values (3) and its smooth (smooth)

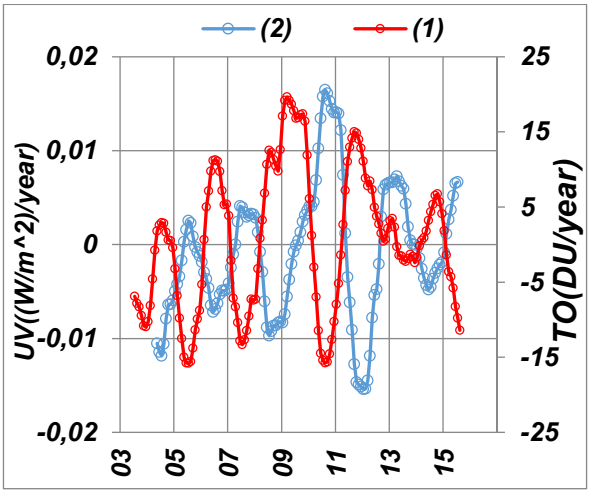


Figure 14. Inter annual variations of UV-B (2) and TO (1) changes rates

2. MONITORING OF VARIABILITY OF SMALL CONSTITUENTS IN THE ATMOSPHERE

2.1 Variability of total nitrogen dioxide (NO2).

For over 30 years (since 1983) measurements of NO2 total content are carried out at Issyk-Kul station, and the station in this part of the measurement is included to NDACC (www.ndsc.ncep.noaa.gov/sites/stat_reps/issykkul/). According to the continuous measurements, Issyk-Kul station is the longest in space in the former Soviet Union and the second longest for duration in the world.

The total NO2 content varies considerably throughout the day, especially during sunrise and sunset. NO_2 values dependence on time of a day is illustrated in Fig. 15.

Rapid and significant changes at sunrise and sunset, due to the rapid transformations between NO and NO2. Slower changes in NO2 content during the day and night are associated with slower photochemical processes involving N2O5 and NO3. Calculations using the three-dimensional transport and photochemical models of the atmosphere have shown that the values of NO2, corresponding to local noon time, exceed the value of the morning, but less than the value of the evening, appearing closest to half the sum of these two values (Figure 16).

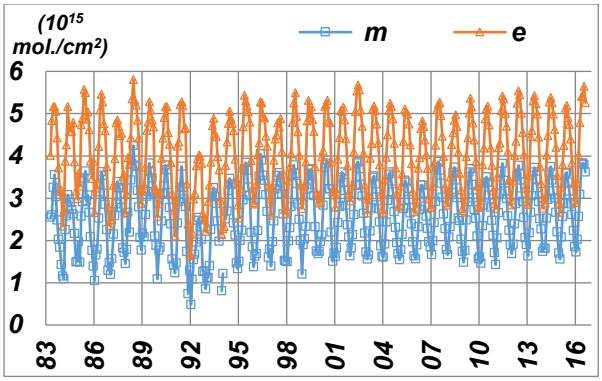


Figure 15. Variations of monthly average values of NO_2, obtained from morning (m) and evening (e) measurements

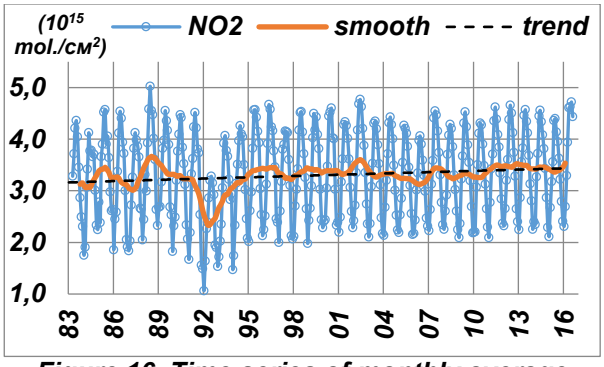


Figure 16. Time series of monthly average values of total NO_2, obtained from average daily data on NO2, it smooth (smooth) and linear trend (trend)

The growth rate (according to the linear trend), the total content of NO_2 in the atmospheric column for the observed period amounted to v = 8,8 * 1012 mol./cm2 or 0.28% per year. Total NO2 content for this period increased by 8.37%.

2.2 Variability of nitrous oxide (N2O).

As a result of nitrogen oxide N2O observations at the station Issyk-Kul are the lack of seasonal variation. During the observation period (2005-2015) N2O content increased by 3.54% in the atmosphere at a rate of 0.29% per year. It reported anomalously sharp increase in the content of the end of 2015. During the year, the content of N2O has increased by ~ 13%, i.e. about 5 times higher than the average N2O accumulation rate for the entire period 2005-2015. Increasing the content of nitrous oxide in the atmosphere represents a major threat from the point of view of climate change as well as the greenhouse effect of one molecule of N2O is about 300 times greater than the effect of a CO2 molecule. Furthermore, nitrous oxide is the main source of formation of nitrogen dioxide (NO2) in the stratosphere, which (NO2) is the main link in the catalytic cycle of stratospheric ozone.

2.3 Variability of water vapor (H2O).

The measurement results are integrated water vapor content in the atmospheric column at the station "Issyk-Kul" from January 1981 to September 2016 in the form of monthly mean (WM, g/cm2) values obtained by averaging the actually measured for the month average daily values of the water vapor content, presented at Fig. 17. It also shows the smoothed (averaged) curve 2 (smooth), obtained with the use of 12-month filter, which excludes seasonal variations H2O content. A positive linear trend was 0.18% per year.

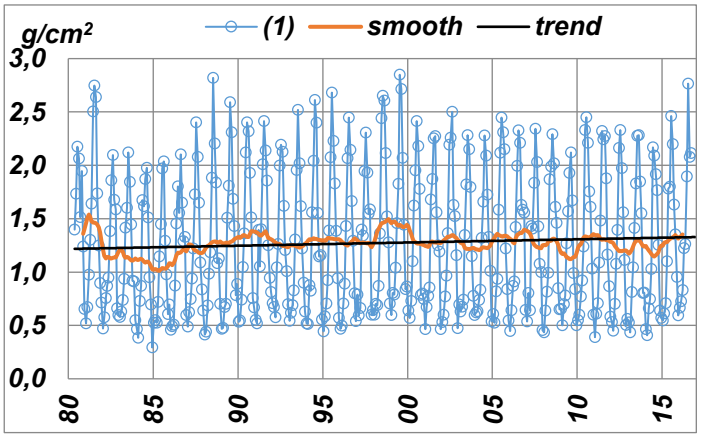


Figure 17. Variations of H2O: monthly average (1), inter annual (smooth), linear trend (trend)

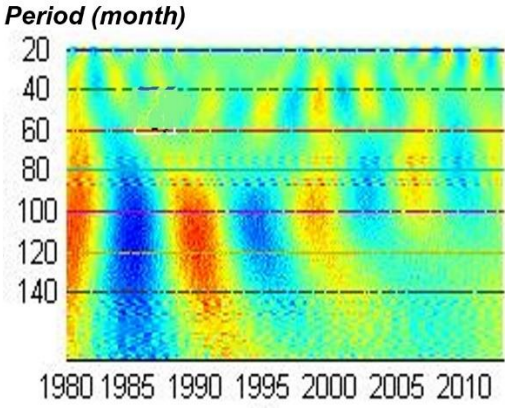


Figure 18. The results of wevelet analysis of time series of H2O (1980-2015).

From late of 2014 to 2016, the water vapor content has increased markedly. Most likely this is due to the El Niño phenomenon (2014-20150, which has a significant impact on the parameters of the atmosphere on a global scale.

2.4. Variability of carbon dioxide (CO2)

Fig. 19 represents a time series of monthly CO2 values, which demonstrates seasonal variation and the constant increase of CO2 in the atmosphere over the period 1980-2016 years. Since the end of 2013, there are abnormally high CO2 content in the atmosphere over the central part of Eurasia. This is most likely due to the volcanic activity of the Earth. Confirmation of this hypothesis are anomalously high values of Aerosol optical thickness (AOT) (Figure 21) and sulfur dioxide (of SO2) (Figure 23), which were received at the station "Issyk-Kul". These components of the atmosphere are products of volcanic eruptions. The growth rate (for linear trend) SO_2 concentration of the observed period amounted to v = 1.7 ppmv per year, or 0.49% per year. The total CO_2 concentration during this period increased by 16.3%.

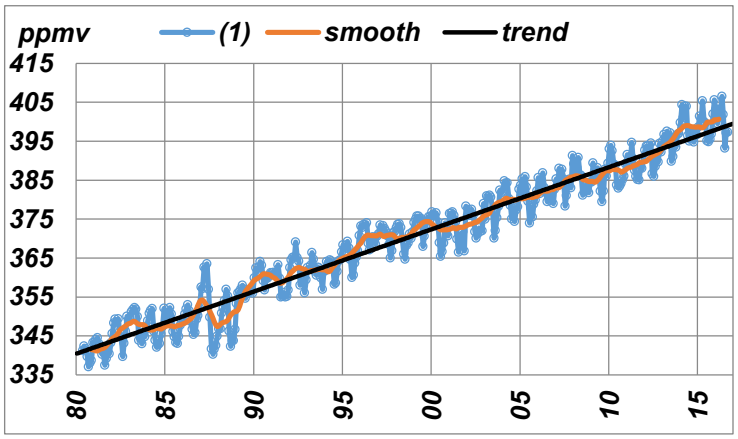


Figure 19. Variation of average monthly (1), inter annual (smooth) values of CO_2 and linear trend (trend).

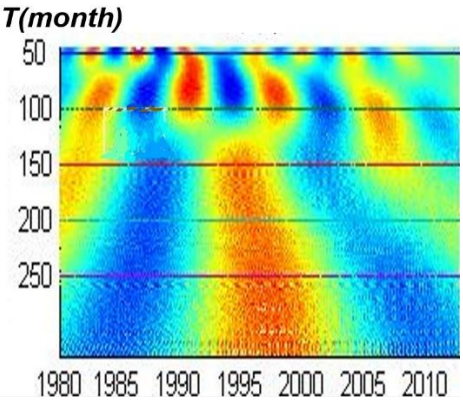


Figure 20. The results of wevelet analysis of time series of CO2 1980-2015 [3]

2.5 Variability of aerosol optical depth

From 1984 to 2009, the value of AOT (τa) was calculated from the measured value of the transparency of the atmosphere above the Issyk-Kul station.

At the station Issyk-Kul since August 2007 conducted the monitoring of the optical characteristics of aerosols modern automatic radiometer CIMEL model CE 318N-V8S5-M9, the results of which are published on the website [http://aeronet.gsfs.nasa.gov.] AERONET NASA.

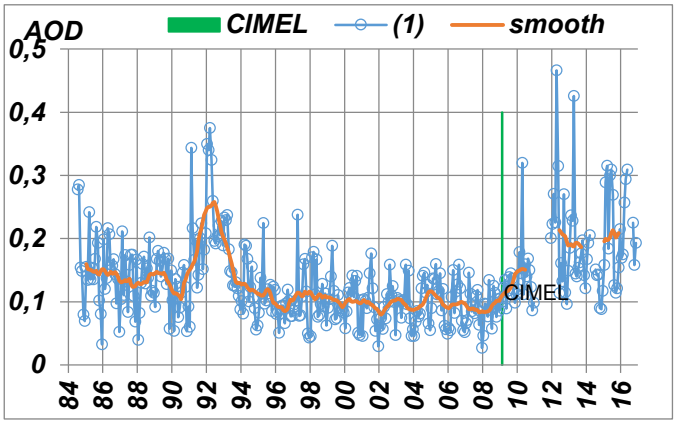


Figure 21. Variations of monthly average (1) and inter annual (smooth) values of AOD for 1984-2016

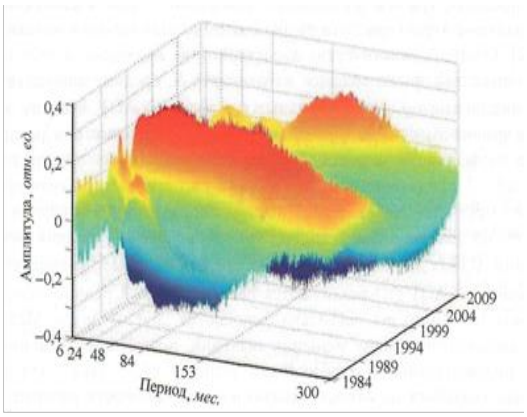


Figure 22. The results of wavelet transform of aerosol optical depth [12]

Fig. 21 shows the monthly variation (1) and interannual (smooth) AOD values for the period 1984-2016. Green dividing line (CIMEL) shows the border (2009), from which the AOD data starts only with the radiometer CIMEL. The lack of data in 2011, 2014 and 2016 is due to the passage of CIMEL Calibration Center Goddard Space Flight Center, NASA. One of the main reasons for an

abnormally highly AOD values in the intervals from 1991-1993 and for 2010-2016. It is a high volcanic and seismic activity of the Earth.

2.6 Variability of sulfur dioxide (SO2).

The results of the measurement of sulfur dioxide at the station Issyk-Kul in the period from 2000 to September 2016 are shown in Fig. 23. SO2 variability is dominated by seasonal changes, minimum SO2 content is observed in July and August, the maximum - in February (Fig. 24). It should be noted that in recent years (2013, 2014, 2015) according to the "Issyk-Kul" station, in the atmosphere of the Northern Tien Shan observed abnormally high content of SO2. For example, in 2013 the average annual value of SO2, approximately 1.7 times (66%) exceeded the long-term average (2000-2011gg.) SO2 value for the entire period of observation, in 2014 - 1.6 times (58%), and in 2015 - 1.9 times (85.5%). One of the most likely causes of such anomalies to change the SO2 is volcanic and seismic activity of the Earth observed since 2010. This increase in SO2 in the atmosphere poses a threat in terms of the formation of sulfuric acid aerosols and acid rain, have a negative impact on the environment of the region.

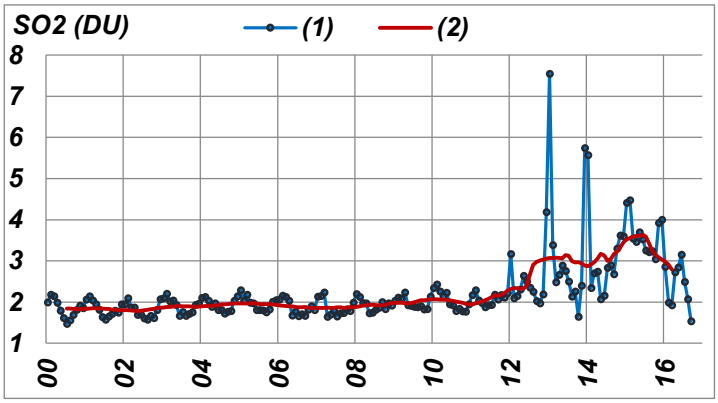


Figure 23. Monthly average values (1), inter annual (2) and linear trend (3) of SO2, according to data of Issyk-Kul Station.

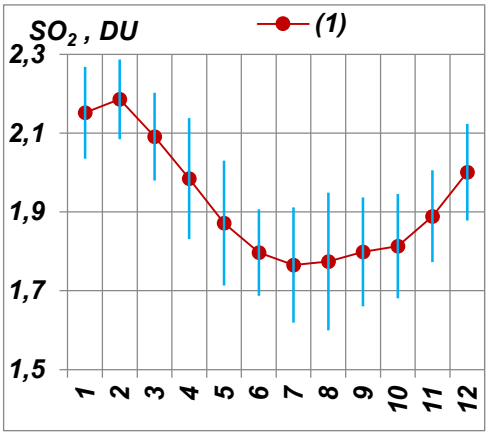


Figure 24. Mean for 2000-2011 seasonal rate of SO2 (1)

2.7 Variability if carbon monoxide (CO)

CO measurement results at the station Issyk-Kul in 2004 - 2016 years confirm the well-known facts of the presence of seasonal variations and the negative trend of CO. The highs and lows of seasonal variations often fall respectively in February and September, and in some years the extremes are shifted by one - two months. Over the entire period of observation (from 08 / 2004-09 / 2016) CO decreased by 27%. Linear trend indicator was -2.25% per year. The average annual value for the entire period of observation well (102,76 ± 8,36) ppb.

2.8 Variability of methane (CH4).

Based on the results of observations of CH4 at the station Issyk-Kul for the period 2004-2016 it can be noted the lack of seasonal variation, but there are more long-period fluctuations. During the entire observation period (2004-2016 years) was observed increase in CH4 content in the atmosphere at a rate of 5.13% from 0.43% a year.

3. DISSEMINATION OF RESULTS

3.1 Data reporting

The monitoring results (TO, H2O, CO2, CH4, NO2, aerosols and UV-B, etc.), received at the station «Issyk-Kul» are used:

- to expand the measurement results database world centers: Ozone (Issyk-Kul № 347-WOUDC, www.woudc.org); Greenhouse Gas (ISK 242 NOO WDCGG, www.ds.data.jma.go.jp); Nitrogen dioxide (NDACC - Issyk-Kul, www.ndsc.ncep.noaa.gov) Aerosol (NASA, Aeronet - Issyk-Kul, www.aeronet.gsfc.nasa.gov); for the development and adjustment of models forecast the state of the ozone layer and climate change;

- for comparative analysis and validation of satellite measurements [4, 5, 15, 17, etc.];

- for the development and adoption of international organizations (UNEP, WMO and others.) and government agencies (Kyrgyzstan, Russia, China and others) strategic plans and programs for the protection of the ozone layer and reduce the rate of climate change, as well as to address regional environmental and economic problems associated with abnormal changes in climatically active impurities in the atmosphere

4. IMPLEMENTATION OF THE RECOMMENDATIONS OF THE 9th OZONE RESEARCH MANAGERS MEETING

As a result of years of research in previous years created a database containing content measurements in the atmosphere of its trace gases (O3, CO2, NO2, H2O, CH4, CO, N2O, SO2, etc.) and related meteorological parameters. Analysis of the results obtained earlier revealed variability characteristics study of atmospheric gases, including variations in their content and long-term trends. These characteristics change with time under the influence of time-varying natural and anthropogenic factors, therefore, further experimental studies are needed to build predictive models refined temporal variability of the gas composition of the atmosphere.

The differentiation of natural and anthropogenic contributions to climate variability active impurities in the atmosphere is an urgent task that requires careful experimental studies based on modern, high-precision measuring equipment.

Unfortunately, in recent years, poor technical condition of obsolete equipment for 36 years to "Issyk-Kul" station poses significant difficulties in ensuring continuity of observations. Measuring instruments often comes from a working condition and it takes a long time to repair it due to the termination of the issue and the lack of spare parts. Such breaks in the observations significantly reduce the value and reliability of the data series of experimental studies at the patterns of change in the content of the measured pollutants in the atmosphere.

5. FUTURE PLANS

In connection with the above, there is an urgent need for a modernized station of the "Issyk-Kul OMD (Ozone Monitoring Development)», equipped with modern high-precision measuring equipment complex, which will generate a bank of high-quality experimental data, the value of which will increase with the increase of the observation period.

6. NEEDS AND RECOMMENDATIONS

Required equipment for modernization of the station:

Equipment that needs to be modernized:

- Brewer Spectrophotometer (latest modification) for monitoring of the TO;
- new Spectrometric Facility MP-32 manufactured by NGO “Typhoon” that allows to conduct the monitoring of greenhouse gases (H2O, CO2, CH4, CO, N2O) as in the depth of the atmosphere (at daily hours), as well as in air samples (at any time);
- device for measuring the concentration of ground-level ozone (GLO), TEI-49C;
- measuring device (latest modification) for an automatic control of intensity of the UV-B radiation reaching the Earth's surface;
- automatic photometer CIMEL for monitoring of the optical characteristics of aerosols;

For the modernization of the station in the Kyrgyz Republic prepared a new building to accommodate the instrumentation with a land about 0.5 hectares, and there are staff with many years of experience in monitoring and experimental studies of the variability of total ozone, greenhouse gases, ultraviolet radiation, aerosols and air pollutants.

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MADAGASCAR

Le présent rapport relate les grandes lignes des points saillants sur les programmes de recherche et de surveillance au niveau national en cours et ce de manière à assurer une bonne coordination desdits programmes et à relever les lacunes éventuelles.

Comme tous les pays en voie de développement, Madagascar a consacré beaucoup d'efforts à la mise en œuvre du programme sur la protection de la couche d'Ozone. En tant que Grande Ile au niveau de l'Océan indien, Madagascar a une importante responsabilité en termes de de contrôle, de vigilance et de surveillance sur l'importation de tous les produits venant de l'extérieur en général et des Substances Appauvrissant la couche d'Ozone(SAO) et de équipement pouvant contenir du gaz (SAO et non SAO) en particulier .

Beaucoup de chercheurs ont soutenu des mémoires et des thèses sur différents thèmes se rapportant à la protection de la couche d'Ozone.

A cet effet, ces efforts se repartissent en trois grands groupes:

A. L'ADMINISTRATION DU PROGRAMME AU NIVEAU NATIONAL

1. L'ancrage institutionnel du Bureau National Ozone (BNO) et la collaboration avec les autres services du Ministère et services interministériels;
2. L'état de mise en œuvre des activités d'élimination et de la réduction de la consommation de SAO;
3. La collecte des données : inventaires ;
4. La célébration de la Journée Mondiale de la Protection de la couche d'Ozone.

B. L'ACTION DE VIGILANCE POUR LA GESTION DES SAO ET DES SUBSTANCES ALTERNATIVES AU NIVEAU NATIONAL

1. La mise en œuvre de la législation et de la règlementation sur les SAO pour règlementer la consommation de SAO dans le Pays, le système de licence pour l'importation des Gaz et équipements contenant du Gaz, les difficultés et éventuellement les leçons tirées et expériences à partager;

2. La collaboration avec les parties prenantes composées par les services des Douanes, le Ministère du Commerce, l'Union des Frigoristes de Madagascar notamment pour la collecte de données et le renforcement des capacités des Douaniers et des techniciens du froid;

3. La collaboration avec l'association des frigoristes, les industriels, les centres de formation;

C. PERSPECTIVES

A. L'ADMINISTRATION DU PROGRAMME AU NIVEAU NATIONAL;

1. L'ancrage institutionnel du Bureau National Ozone (BNO) et la collaboration avec les autres services du Ministère et services interministériels se dessine comme suit :

Le Bureau National Ozone (BNO/NOU) est placé sous l'autorité du Ministère en charge de de l'Environnement Le Point Focal National Ozone du Bureau National Ozone(BNO) a accès direct au niveau de la Direction Générale de l'Environnement (DGE) et au niveau du Secrétariat Général (SG) du Ministère chargé de l'Environnement.

Le Point Focal National Ozone du Bureau National Ozone est également Chef du Service de l'Intégration de la Dimension Environnementale au niveau du Secteur Etatique et des Collectivités Territoriales Décentralisées (SIDE SE CTD). De par sa fonction, il travaille en quasi permanence avec tous les Départements ministériels au sein du Gouvernement et avec les services déconcentrés et les différentes Régions de la Grande Ile.

Sur le plan institutionnel, le Ministère de l'Environnement, de l'Ecologie et des Forets (MEEF) par le biais de la Direction Générale de l'Environnement (DGE) qui chapote directement le BNO, constitue la structure nationale chargée de la mise en œuvre du Programme de Pays sur la protection de la couche d'Ozone.

Le Bureau National Ozone (BNO) et le Comité National Ozone (CNO) constituent les deux chevilles ouvrières de la mise en œuvre de la Convention de Vienne pour la protection de la couche d'Ozone du Protocole de Montréal à Madagascar. Dans le cadre de la mise en œuvre de la politique nationale en matière de gestion et d'élimination définitive des Substances qui Appauvrissent la couche d'Ozone(SAO), le Ministère de l'Environnement, de l'Ecologie et des Forets (MEEF) a adopté une démarche participative, impliquant ainsi un grand nombre d'acteurs publics et privés. En effet, les représentants de toutes les parties prenantes évoluent au sein du Comité National Ozone(CNO).

Le rattachement du Bureau National Ozone (BNO) à la Direction Générale de l'Environnement du Ministère de l'Environnement facilite la communication et les échanges d'informations avec l'ensemble des Directions Techniques, les Points Focaux des Conventions Internationales relatives à l'environnement, les responsables des projets et programmes, les organismes sous tutelle, les Organisations Non Gouvernementales (ONG), le secteur privé, les instituts d'enseignement et de la recherche, les syndicats, ainsi que les Associations de la société civile, œuvrant dans le domaine de la protection de l'Environnement en général et de la couche d'Ozone en particulier.

D'après l'Organigramme du Ministère en charge de l'environnement, les activités menées par le Bureau National Ozone et celles des autres Directions techniques font l'objet du suivi régulier par la Direction de la Programmation, de la Planification et du Suivi Evaluation (DPPSE) du Ministère de l'Environnement de l'Ecologie et des Forêts(MEEF) afin de s'assurer de la bonne exécution des projets et programmes. Ce suivi permet également aux autorités ministérielles compétentes (Secrétaire Général et au Ministre) d'être informés et préparés afin de mieux orienter la prise des décisions.

Le BNO a joué un rôle important dans l'élaboration des textes existant en matière de contrôle des SAO et ce avec le concours des parties prenantes.

2. L'état de mise en œuvre des activités d'élimination et de la réduction de la consommation de SAO;

Madagascar est en conformité par rapport aux dispositions du Protocole de Montréal.

Conformément au SSFA entre le PNUE et Madagascar sur la mise en œuvre de la 2éme tranche de la première phase du PGEH au titre des années 2014 et 2015, le tableau ci-après montre ce qui est prévu dans le cadre de la mise en œuvre du Plan de Gestion pour l'Elimination des Hydrocholofluorocarbones (HCFCs) en abrégé PGEH:

N° d'ordre	Activités	2014				2015			
		T1	T2	T3	T4	T1	T2	T3	T4
1.1	Six Ateliers de formation des Agents de contrôle et des inspecteurs de Douanes		X	X	X	X	X	X	
1.2	Formation sur la manipulation des équipements et matériels pour les techniciens du Froid			X					
2.1	Six ateliers de formation sur R&AC service et sur les bonnes pratiques en réfrigération		X	X	X	X	X	x	
2.2	Formation sur le matériel et publication		X	X	X	X	X		
3.1	Publication: IEC sur les gaz alternatif et sur le matériel: brochures, émission du quota annuel		X	X	X	X	X	X	X
3.2	Réunion annuelle avec les principaux importateurs et journalistes.				X				X
4.1	Soumission des rapports intermédiaires de mise en œuvre		X		X		X		X
4.2	Soumission du rapport final								X

Par rapport à ce programme pour deux ans, le tableau ci-après montre l'état d'avancement au niveau des réalisations :

Par rapport à cette programmation, le tableau suivant récapitule les activités de formations réellement réalisées au titre de l'année 2014, plus exactement pendant la 2éme semestre 2014 d'Aout à décembres 2014)

Formation des Techniciens frigoristes :

Numéro d'Ordre	THEME DE FORMATION	DATE	LIEUX	NOMBRES DES FORMES	PROJETS	AGENCE D'EXECUTION
01	Atelier régional de formation des Techniciens-frigoristes sur la récupération des Hydrochlorofluorocarbones (HCFCs) et la sécurité liée à l'utilisation des Hydrocarbures et sur la	Du mercredi 05 au vendredi 07 Novembre	Toamasina, Royal Hôtel	Vingt cinq (25) techniciens-frigoristes issus de l'UFM	PGEH/HPMP 2ème tranche 1érè PHASE	PNUE

	maitrise des équipements et matériels reçus	2014				
02	Atelier régional de formation des Techniciens-frigoristes sur la récupération des Hydrochlorofluorocarbones (HCFCs) et la sécurité liée à l'utilisation des Hydrocarbures et sur la maitrise des équipements et matériels reçus	Du mardi 16 au jeudi 18 Décembre 2014	Taolagnaro, Hôtel Mahavoky	Vingt et un (21) techniciens-frigoristes issus de l'UFM	PGEH/HPMP 2ème tranche 1érè PHASE	PNUE
03	Atelier régional de formation des Techniciens-frigoristes sur la récupération des Hydrochlorofluorocarbones (HCFCs) et la sécurité liée à l'utilisation des Hydrocarbures et sur la maitrise des équipements et matériels reçus	Du lundi 22 au mercredi 24 Décembre 2014	Antsirabe, au CAF	Vingt six (20) techniciens-frigoristes issus de l'UFM	PGEH/HPMP 2ème tranche 1érè PHASE	PNUE
	TOTAL GENERAL			Soixante six (66) techniciens-frigoristes formés		

En tout, le BNO a pu réaliser en 2014 trois(3) ateliers de formations des techniciens frigoristes sur les Six(6) prévus pour deux ans. A ce stade, on a enregistré 50 % comme taux de réalisation. .

La Formation sur la manipulation des équipements et matériels pour les techniciens du Froid a été menée à chaque fois que le BNO organise un atelier de formation technique pour les techniciens frigoristes.

Pour l'année 2015, les trois (03) ateliers de formation restant seront organisés.

Formation des douaniers et autres agents de contrôle :

Numéro d'Ordre	THEME DE FORMATION	DATE	LIEUX	NOMBRES DES FORMES	PROJETS	AGENCE D'EXECUTION
01	Atelier régional de formation des Douaniers et autres agents de contrôle sur le Contrôle de l'importation des Hydrochlorofluorocarbones , des équipements et matériels contenant du gaz et sur l'identification des Hydrochlorofluorocarbones (HCFCs),	Demi-journées du mercredi 05 et du jeudi 06 Novembre 2014	Toamasina, Tamatave Royal Hôtel	Dix sept (17) agents	PGEH/HPMP 2ème tranche, 1ére PHASE	PNUE
02	Atelier régional de formation des Douaniers et autres agents de contrôle sur le Contrôle de l'importation des Hydrochlorofluorocarbones	Demi-journées du mardi 16 et du mercredi 17 Décembre 2014	Taolagnaro Fort dauphin Hôtel Mahavoky	Treize (13) agents	PGEH/HPMP 2ème tranche, 1ére PHASE	PNUE

	, des équipements et matériels contenant du gaz et sur l'identification des Hydrochlorofluorocarbones (HCFCs),					
	TOTAL GENERAL			Trente (30) agents formés et certifiés		

Au total, le BNO a pu réaliser en 2014 deux ateliers de formations des Douaniers et autres agents de contrôle sur les Six prévus pour deux ans. A ce stade, jusqu'ici, on a enregistré 40 % comme taux de réalisation.

Pour l'année 2015, les quatre(04) ateliers de formation restant seront organisés.

Par rapport à cette programmation, le tableau suivant récapitule les activités de formations réellement réalisées au titre du 1èr semestre de l'année 2015 (de Janvier à Juin 2015)

<u>Formation des Techniciens frigoristes</u> :

Numéro d'Ordre	**THEME DE FORMATION**	**DATE**	**LIEUX**	**NOMBRES DES FORMES**	**PROJETS**	**AGENCE D'EXECUTION**
01	Atelier régional de formation des Techniciens-frigoristes sur la récupération des Hydrochlorofluorocarbones (HCFCs) et la sécurité liée à l'utilisation des Hydrocarbures et sur la maitrise des équipements et matériels reçus	Du mercredi 27 au vendredi 29 Mai 2015	Antananarivo, Centre de Formation CNEAGR à Nanisana	Vingt un (21) techniciens -frigoristes issus de l'UFM	PGEH/HPMP 2ème tranche 1érè PHASE	PNUE
	TOTAL GENERAL			Vingt un (21) techniciens -frigoristes formés et certifiés		

En tout, le BNO a pu réaliser pendant le 1èr semestre 2015 un (01) atelier de formation des techniciens frigoristes sur les Trois(3) prévus pour l'année 2015. Ceci est dû au fait que le BNO n'a reçu le budget y afférent que le mois d'Avril 2015

La Formation sur la manipulation des équipements et matériels pour les techniciens du Froid a été menée à chaque fois que le BNO organise un atelier de formation technique pour les techniciens frigoristes.

Il nous reste à organiser deux ateliers de formations des techniciens frigoristes pendant le 2ème semestre 2015 qui va suivre.

Formation des douaniers et autres agents de contrôle :

Numéro d'Ordre	THEME DE FORMATION	DATE	LIEUX	NOMBRES DES FORMES	PROJETS	AGENCE D'EXECUTION
01	Atelier régional de formation des Douaniers et autres agents de contrôle sur le Contrôle de l'importation des Hydrochlorofluorocarbones, des équipements et matériels contenant du gaz et sur l'identification des Hydrochlorofluorocarbones (HCFCs),	Deux - journées du mercredi 27 et du jeudi 28 Mai 2015	Antananarivo, Centre de Formation CNEAGR à Nanisana	Treize (13) Inspecteurs et contrôleurs de douanes	PGEH/HPMP 2ème tranche, 1ére PHASE	PNUE
	TOTAL GENERAL			Treize (13) Inspecteurs et contrôleurs de douanes forés et certifiés		

Au total, le BNO a pu réaliser un atelier de formation des Douaniers et autres agents de contrôle sur Trois prévus pour l'année 2015.

Pour le 2ème semestre 2015, trois (03) ateliers de formation restant seront organisés.

PHASE 1 DU PGEH												
PERIODE	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
PREVISIONS SANS MP (kg)	210,160	283,710	383,000	459,600	551,520	661,820	761,100	856,230	958,980	1,069,260	1,186,880	1,305,570
PREVISIONS AVEC MP (kg)	210,160	283,710	383,000	344,430	341,000	309,987	307,000	223,880	223,880	223,880	223,880	220,000
CONSOMMATION REELLE HCFC		208,000	301,000	291,000	290,000	278,000	255,000	-	-	-	-	-
QUOTA ANNUEL PREVU	-	-	-	300,000	300,000	280,000	260,000	220,000	200 ;000	190,000	188 ,000	186,500
CALENDRIER D'ELIMINATION DEGRESSIVE DE LA CONSOMMATION EN HCFCs					Année du Gel		Réduction de 10%					Réduction de 35%

En ce qui concerne le quota annuel pour l'importation des HCFCs, le tableau ci-dessus récapitule le volume annuel susceptible d'être importé par les importateurs professionnels :

La détermination du quota annuel tient compte, à la fois, du Calendrier d'élimination dégressive de la consommation en HCFCs pour les pays de l'article 5 du Protocole de Montréal et du volume de consommation annuelle de Madagascar à partir de l'année 2012

Ce tableau nous renseigne également sur le volume de consommation annuelle sans et avec la mise en œuvre du Protocole de Montréal relatif à des Substances qui Appauvrissent la couche d'Ozone(SAO) ainsi que sur la consommation réelle en HCFCs depuis 2010 jusqu'en 2014

3. La collecte des données : inventaires

Les Travaux de collecte des données de consommation à travers les différentes régions de Madagascar sont toujours menés chaque année. Il s'ensuit la compilation et la consolidation des données au niveau national avant leur transmission à qui de droit

Par ailleurs, depuis quelques années, l'accent est mis sur le renforcement de l'échange d'informations et de données avec les administrations et responsables touchés par la gestion des SAO (de la douane, du Ministère du Commerce, de l'Institut National de la Statistique-INSTAT, de l'Union des Frigoristes de Madagascar-UFM, et des Sites de Récupération et de Recyclage(R&R).

La quantité des gaz ayant fait l'objet d'importation figure dans le document fourni par l'importateur au niveau du module MIDAC. La consolidation périodique des données fait ressortir le volume de la consommation annuelle.

4. La célébration de la Journée Mondiale de la Protection de la couche d'Ozone

A l'instar des pays du monde entier, Parties contractantes au Protocole de Montréal, Madagascar célèbre le 16 Septembre de chaque année la Journée Mondiale de la Protection de la Couche d'Ozone.

Chaque année, un programme de célébration selon le thème de l'année est élaboré et mis en œuvre.

Cette opportunité est saisie pour renforcer le partage des informations relatives à la protection de la couche d'Ozone et pour intensifier la sensibilisation du public cible et de tout un chacun sur la l'importance de la préservation de cette couche protectrice de la vie sur terre.

En effet, afin de conscientiser le public en général sur les conséquences néfastes de la dégradation de la couche d'Ozone et sur les mesures qui s'imposent pour y faire face, une campagne de sensibilisation est annuellement programmée dans le cadre de la célébration de la Journée internationale de la protection de la couche d'Ozone.

Actuellement, le pays est en train d'élaborer le programme de célébration de la Journée Mondiale de la protection de la couche d'Ozone (16 septembre 2015) qui coïncide cette année avec le 30ème anniversaire de la Convention de Vienne pour la protection de la couche d'Ozone.

Le thème de célébration de cette année est **« 30 ans pour guérir la couche d'Ozone ensemble. L'Ozone, tout ce qu'il y a entre vous et les rayons Ultra Violet (UV) »**.

B. L'ACTION DE CONTROLE, DE VIGILANCE ET DE SURVEILLANCE POUR LA GESTION DES SAO AU NIVEAU NATIONAL:

1. La mise en œuvre de la législation et de la règlementation sur les SAO pour règlementer la consommation de SAO dans votre pays, le système de licence pour l'importation des Gaz et équipements contenant du Gaz, les difficultés et éventuellement les leçons tirées et expériences à partager;

Dans le cadre de la mise en œuvre de la politique de gestion et d'élimination des fluides frigorifiques et produits chimiques responsables de l'appauvrissement de la couche d'ozone, un ensemble de mesures réglementaires a été adopté à Madagascar.

En l'occurrence Il s'agit du :

- Décret n° 2004- 167 du 03 février 2004 relatif à la Mise en Compatibilité des Investissements avec l'Environnement (MECIE) qui oblige tout investisseur ou promoteur à mener des Etudes d'Impact Environnemental (EIE)

- Décret n° 2003-170 du 04 Mars 2003 sur la réglementation de l'importation et de l'utilisation des Substances Appauvrissant la couche Ozone

- Décret n° 2007-327 du 24 Avril 2007 portant abrogation du décret n° 2003-170 du 04 Mars 2003 sur la réglementation de l'importation et de l'utilisation des Substances Appauvrissant la couche Ozone ; et réglementant l'importation, la vente, la revente et l'utilisation des fluides frigorigènes, des appareils ou équipements frigorifiques et des halons.

Madagascar, partie au Protocole de Montréal relatif aux SAO et à la Convention de Vienne sur la Protection de la couche d'Ozone, s'est engagé vis-à-vis de la communauté internationale, à réduire progressivement sa consommation en SAO avant l'élimination totale de consommation en ChloroFluoroCarbures (CFCs) en 2010 et en Hydrochlorofluorocarbones (HCHCs) en 2030.

Pour atteindre les objectifs des deux traités sur la protection de la couche d'ozone, le Gouvernement malagasy a adopté, le 04 Mars 2003, le décret n° 2003/170 qui réglemente l'importation et l'utilisation des SAO dont les CFCs.

La réglementation nationale a prévu, d'une part l'interdiction de l'importation et de l'utilisation des CFCs, des Halons et du Bromure de méthyle en particulier, et d'autre part le contrôle strict de l'introduction dans le pays, la vente et la manipulation des gaz réfrigérants autres que les CFCs, ainsi que les appareils ou équipements frigorifiques, en général.

De ce fait, les Hydrochlorofluorocarbones (HCFCs) y figurent en tant que substances réglementées car leur importation est soumise à l'autorisation spéciale et leur utilisation est soumise au contrôle strict.

Dans le cadre de la mise en œuvre du Plan de Gestion de l'Elimination des Hydrochlorofluorocarbones ou PGEH, Madagascar s'attelle à réviser ou compléter le Décret n° 2007-327 du 24 Avril 2007 portant abrogation du décret n° 2003-170 du 04 Mars 2003 sur la réglementation de l'importation et de l'utilisation des Substances Appauvrissant la couche Ozone ; et réglementant l'importation, la vente, la revente et l'utilisation des fluides frigorigènes, des appareils ou équipements frigorifiques et des halons, en y introduisant des dispositions sur l'élimination progressive et effective des HCFCs.

Il est important de souligner l'application effective du Décret n° 2007-327 du 24 Avril 2007 portant abrogation du décret n° 2003-170 du 04 Mars 2003 sur la réglementation de

l'importation et de l'utilisation des Substances Appauvrissant la couche Ozone; et réglementant l'importation, la vente, la revente et l'utilisation des fluides frigorigènes, des appareils ou équipements frigorifiques et des halons.

L'année 2015 est marquée par l'intégration généralisée de l'autorisation spéciale d'importation des Substances Appauvrissant la couche d'Ozone(SAO) et d'équipement contenant du gaz dans le module MIDAC (Ministère, Département et Agence de Contrôle). (Cf. Lettre n° 021/2015/MCC/SG/DGCE/DPEE du 17 Mars 2015).

Conformément aux dispositions du Protocole d'accord conclu entre le Ministère du Commerce et de la Consommation, la Direction Générale des Douanes et la Société GasyNet, et suite aux différentes réunions techniques qui se sont déroulées entre le Ministère du Commerce et de la Consommation, le Ministère de l'Environnement, de l'Ecologie, de la Mer et des Forêts et la Société GasyNet de la Direction Générale des Douanes, il a été convenu d'intégrer l'autorisation spéciale d'importation de substances appauvrissant la couche d'Ozone (SAO) et d'équipement contenant du gaz dans le module MIDAC.

Ce module consiste au traitement en ligne de tous les dossiers relatifs à l'importation des Gaz et équipements contenant du gaz.

Cette dématérialisation a été effective pour tous les importateurs à partir de l'année 2015.

2. La collaboration avec les Parties prenantes composées par les services douaniers et le Ministère du Commerce, notamment pour la collecte de données;

Conformément aux avis techniques délivrés par le BNO, le Service des Importations au sein du Ministère du Commerce et de la Consommation (MCC) est chargé d'enregistrer et étudier les demandes d'importation des SAO et de délivrer les autorisations d'importation. Les formalités de départ des opérations d'importation des SAO s'effectuent au niveau du BNO qui travaille en étroite collaboration avec le Service des Importations du MCC.

Le contrôle de l'importation des fluides frigorigènes ne peut être limité aux documents d'accompagnement (facture, spécification technique de l'équipement ou matériel contenant de fluides frigorigènes ou SAO, autorisation préalable, ect…).

La Direction Générale des Douanes est chargée de l'application de la législation douanière et de la perception des droits et taxes douaniers au moment de l'importation des SAO. Son rôle est de vérifier que les titres de commerce émis par les autorités compétentes sont réguliers.

La quantité des gaz ayant fait l'objet d'importation figure dans le document fourni par l'importateur au niveau du module MIDAC. La consolidation périodique des données fait ressortir le volume de la consommation annuelle.

La vérification physique de la marchandise est nécessaire, le cas échéant. La Direction Générale des Douanes a été dotée en appareils portatifs identificateurs des gaz réfrigérants SAO et non SAO.

Le Service de la Lutte contre les Fraudes (SLF) et les Brigades Mobile de Surveillance (BMS), structures opérationnelles au sein de la Direction Générale des Douanes (DGD) malagasy en collaboration directe avec le BNO procèdent inopinément aux confiscations et aux saisies des SAO vendues et revendues dans le marché national.

3. La collaboration avec l'association des frigoristes, les industriels, les centres de formation;

La mise en œuvre du Plan de Gestion d'Elimination Finale des HCFC (PGEH/HPMP) relève de la compétence du Bureau National Ozone (BNO), sous la tutelle de la Direction Générale de l'Environnement du Ministère de l'Environnement et des Forêts. Le BNO supervise et coordonne les activités dudit projet. Il rend directement compte à la Direction Générale à qui il lui soumet pour approbation le Plan de Travail Annuel (PTA), ainsi que les rapports techniques et financiers pour les activités réalisées. A cet égard, le Bureau National Ozone entretient des relations fonctionnelles avec les institutions suivantes impliquées de près ou de loin dans la protection de la couche d'Ozone:

- La Direction Générale des Douanes;
- Le Ministère du Commerce et de la Consommation;
- Les Associations des Techniciens Frigoristes établies au niveau des Régions et l'Union des Frigoristes de Madagascar (UFM)
- Les ateliers de froid installés sur le territoire national ;
- Les opérateurs économiques (Commerçants importateurs et distributeurs des gaz) ;
- Le secteur privé (entreprises et industries) du secteur de la réfrigération et de la Climatisation ;
- Les quatre (04) sites de Récupération et de Recyclage(R&R) ;

Les ateliers de formation pour le renforcement des capacités techniques et matériels des techniciens frigoristes sont toujours préparés en collaboration étroite avec l'Union des Frigoristes de Madagascar (UFM) et les Associations Régionales des Techniciens frigoristes.

Les centres de formation en froid organisent périodiquement des visites sur terrain et des séances pratiques dans les sites de Récupération et de Recyclage(R&R) des Gaz.

Des conférences sur la protection de la couche d'Ozone sont périodiquement tenues à l'Université et aux Instituts privés

Depuis quelques années à Madagascar, des étudiants et des universitaires ont mené des travaux de recherches sur la problématique liée à la protection de la couche d'Ozone. Des mémoires et des thèses sur différents thèmes y afférents ont été publiquement soutenus.

C. LES PERSPECTIVES:

A court terme, la mise en œuvre des activités restantes prévues dans le cadre du PGEH et la poursuite de la mise en œuvre des activités contenues dans le projet d'appui institutionnel du BNO constituent les principaux éléments des perspectives.

Il faut noter également la réalisation, dans le courant De l'année 2016 des enquêtes sur les substances alternatives aux SAO qui existent au niveau national.

A moyen terme, l'élaboration et la mise en œuvre des composantes de la troisième tranche de la 1ère phase (de 2016 à 2020) du PGEH sont les grandes lignes à inclure dans les perspectives. L'objectif étant l'atteinte de la réduction de 35% en 2020 de la consommation en

HCFCs comme il est prévu dans le calendrier d'élimination progressive de la consommation en HCFCs des pays de l'article 5 du Protocole de Montréal.

A partir des enquêtes sur les fluides alternatifs aux substances appauvrissant la couche d'ozone, recommandée par Comité exécutif du Fonds Multilatéral effectuées en 2016 à Madagascar, des réorientations en termes de mise en œuvre du programme Ozone de Pays seront de mise.

Les données recueillies à travers ces enquêtes de grande envergure représentent une nouvelle base de données dans l'avenir pour Madagascar.

En conséquence, des perspectives de résolutions ont été préconisées comme :

- mener une formation spéciale des techniciens supérieurs et des ingénieurs sur la méthodologie de reconversion,
- l'application effective et le strict respect de système de quota pour les importateurs,
- L'intensification des campagnes de sensibilisation et d'informations sur les SAO (CFC, HCFC), sur les HFC, sur la reconversion et sur les solutions de remplacement au sein des entreprises de fabrication, des sociétés, des ateliers s'occupant du froid , des centres de formation et de recherche et des autres parties prenantes.

Fait à Antananarivo, le 30 janvier 2017
Par Monsieur RAKOTO Claude

MALAYSIA

Status Report on the Ozone Monitoring Network and Research Collaboration

The ozone monitoring activities in Malaysia has started since October 1992, after realizing the importance of developing countries in the tropics to play a more prominent role in the global initiative to achieve a better understanding of the significant atmospheric changes and their effects on the ecosystem and life on earth that links to the ozone depletion.

It started with the country's involvement in the WMO GO_3OS with the launching and establishment of Malaysian Meteorological Department (MetMalaysia) ozone monitoring programme that includes surface ozone, vertical ozone distribution as well as total column ozone monitoring. The ozone monitoring and analysis has been providing important information with regards to the trend of ozone composition in the atmosphere which is beneficial to the policy makers who are dealing with environmental issues.

The activities for the establishment of ozone monitoring network and research collaboration in Malaysia comprise the following components:

- Enhancement of Monitoring System
- Data Collection and Information Dissemination
- Research Activities and Data Analysis
- Capacity Building
- Local and International Collaboration
- Future Direction

(1) Enhancement of Monitoring System

To strengthen the monitoring capability of ozone in Malaysia, several efforts has been undertaken in which MetMalaysia has established the ozone monitoring activities in the western and central part of Peninsular and also in the eastern part of Sabah. The locations of these sites are as shown below:

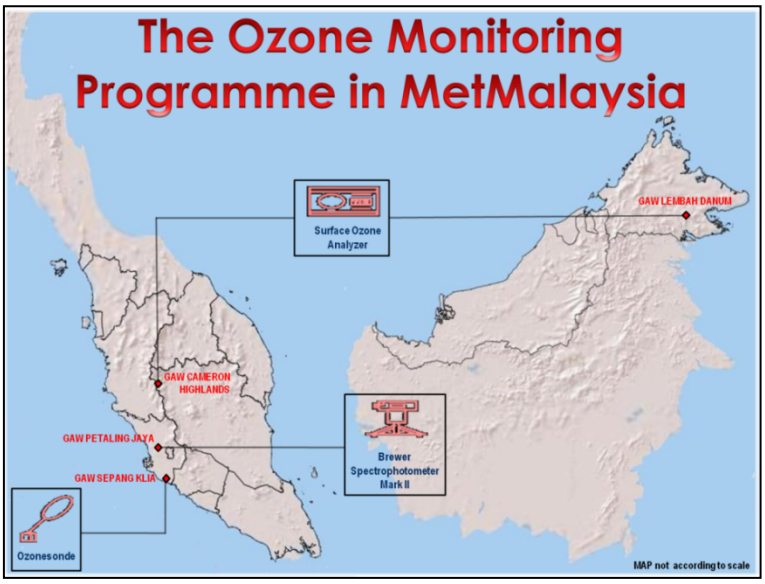


Figure 1. The Ozone Monitoring Programme in MetMalaysia

The locality of the monitoring sites represent the stations in the equatorial tropical region (Figure 1), where in general, the climate is influenced by drier period during the Southwest Monsoon (summer monsoon) and wetter period during Northeast Monsoon (winter Monsoon).

The surface ozone monitoring in Cameron Highlands GAW Regional station has started since 1997 using the Thermo Environmental Instrument Model 49C Ozone Analyzer, while in Danum Valley GAW Global Station, the monitoring using Thermo Scientific™ Model 49i Ozone Analyzer has been established since 2007. For this report, only the surface ozone analysis from Cameron Highlands is discussed.

The total amount of ozone in a vertical column from the surface to the edge of the atmosphere (total column) is observed using the Brewer Spectrophotometer MKII in Petaling Jaya GAW Regional Station since 1992. In addition, daily ultraviolet (UV) radiation is also measured using the same spectrophotometer as mentioned above.

Finally, the vertical ozone profile is recorded by releasing ECC type ozonesondes (Vaisala, Modem, Chang Feng and GRAW) twice a month in Petaling Jaya (1992 - 1997) and Sepang Meteorological Station (from 1998 onwards). For this report, only the vertical ozone profile from Sepang station is discussed.

Besides MetMalaysia, surface ozone monitoring network is also established under the Department of Environment Malaysia since 1995, focusing mainly in the residential urban areas. This monitoring is part of its Continuous Air Quality Monitoring (CAQM) network all over the country.

(2) Data Collection and Information Dissemination

Malaysia has established a linkage through the Southern Hemisphere ADditional OZonesonde (SHADOZ) network and World Ozone and Ultraviolet Radiation Data Centre (WOUDC) for disseminating, receiving and accessing ozone data from the global network. As part of the international obligation, the surface ozone, total column ozone (TCO) and vertical ozone profile data are submitted to the respective data centre on scheduled basis.

The TCO and UV radiation data are submitted once a month, while the surface ozone and vertical ozone profile are reported annually to WOUDC and SHADOZ network data centre respectively. Information of the current hourly solar UV index is posted on the MetMalaysia website and updated daily, whilst vertical ozone profile data is made available after every launch on SHADOZ website for scientific and research community.

By participating in this international network, MetMalaysia and other relevant research agencies in Malaysia will get access to these data centre for their research project and collaboration work concerning ozone matters.

(3) Research Activities and Data Analysis

A study was conducted to investigate the surface ozone distribution from 1995-2015 in Cameron Highlands which represents the baseline reading in the central part of Peninsula Malaysia. In general, the analysis shows that while there are no significant changes of the surface ozone trend over the 20 year period, it is also observed that the highest surface ozone concentration occurred during strong El Niño events, while during weak El Niño, La Niña and neutral phases, the values fluctuate within the monthly average range (Figure 2). Studies were also conducted by a group of researchers from The National University of Malaysia which focused on the ozone distribution in the Klang Valley region (1997-2011). The result shows that many industrial areas in Klang Valley recorded high level of ozone concentration, exceeding the Malaysia Ambient Air Quality Standard of 100 ppbv (Latif et al., 2012).

A study on TCO data from 1995-May 2016 for Petaling Jaya was also conducted. The analysis shows that in general, the TCO fluctuated in irregular cycle except during strong El Niño (1997 and 2015) where the changing patterns corresponded to the strength of El Niño (Figure 3). The study also shows that over the 20 years period, the TCO trend is slightly decreasing over the area. The study also concludes that TCO values increased during dry period (Southwest Monsoon) and decreased during wet period (Northeast Monsoon), significantly. During both periods of inter-monsoon, the TCO values were consistent.

The analysis for the vertical ozone profile was conducted using 18 years of observation data (1998-2015). In total there were 396 profiles collected with the average of 22 launches per year and the analysis focused on the significant effect of El Niño and La Niña to the profile recorded. The results show that the maximum stratospheric ozone in Sepang is ranged between 8.5-9.0 ppmv at the altitude of between 29-31 km (Figure 4). It is also important to note that the ozone concentration at the stratospheric layer is not so much influenced by the El Niño/La Niña events.

Results from Observation and Analysis

Surface Ozone

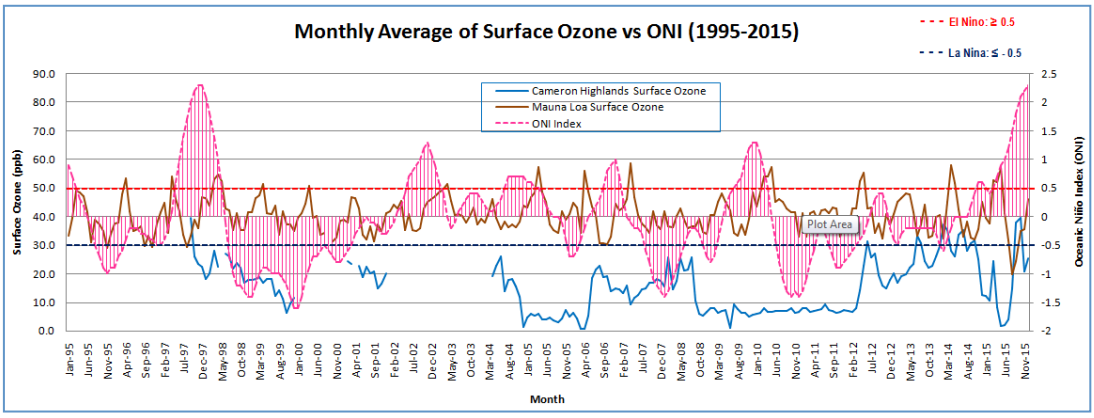


Figure 2. The monthly average of surface ozone and Ocean Niño Index (ONI) in Cameron Highlands and Mauna Loa (1995-2015).

Total Column Ozone

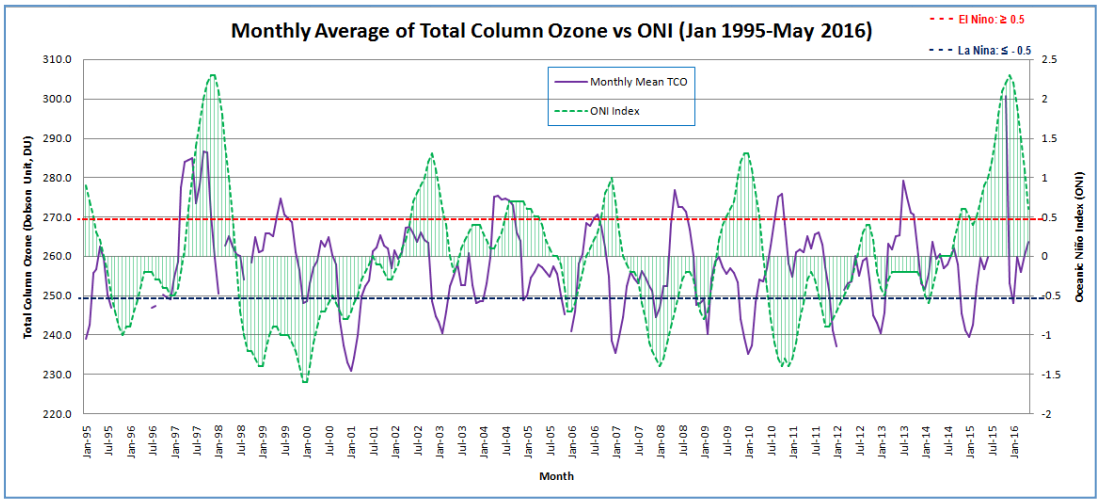


Figure 3. The monthly average of TCO and ONI in Petaling Jaya (1995-2016).

Ozone Vertical Profile Measurement

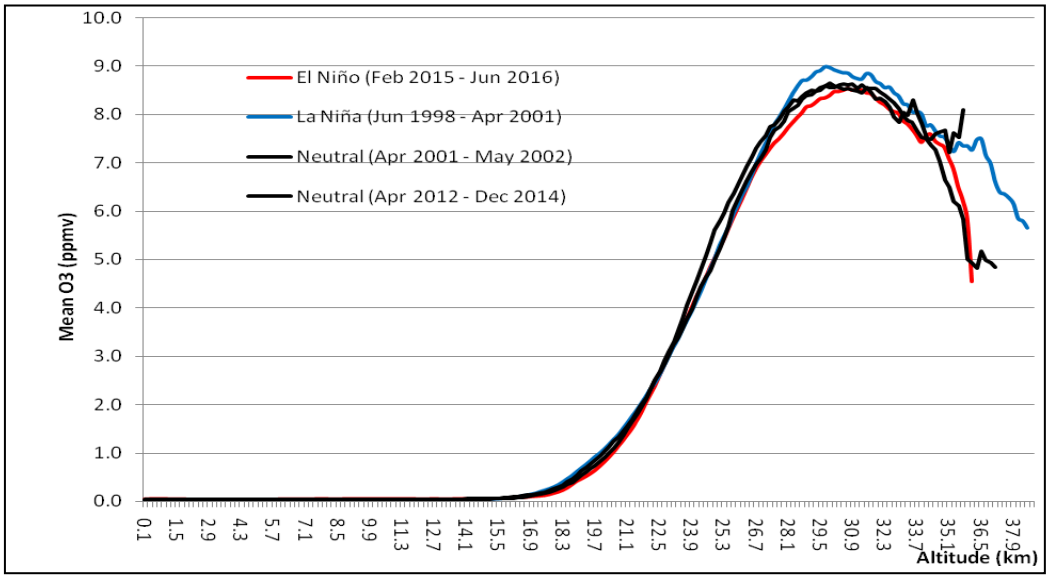


Figure 4. Vertical ozone profiles during strong El Niño (Feb. 2015-June 2016), moderate La Niña (June 1998-Apr. 2001) and two neutral periods (Apr. 2001-May 2002 & Apr. 2012-Dec. 2014).

There were several studies done by the Malaysian group of researchers, among those are;

i. Seasonal and Long Term Variation of Surface Ozone Concentration in Malaysia Borneo (Latif et al., 2012);

ii. Variation of Surface Ozone Concentration Across the Klang Valley, Malaysia (Latif et al., 2016);

iii. The ozone Monitoring activities and its trend analysis in Malaysia during El Nino and La Nina phenomena (Maznorizan et al., 2016);

iv. The Influence of Meteorological Factors and Biomass Burning on Surface Ozone Concentrations at Tanah Rata, Malaysia (Toh et al., 2013).

(4) Capacity Building

The enhancement of the ozone monitoring network and research activities in Malaysia also emphasize on the human resource development and capacity building. Three MetMalaysia officers are currently pursuing their doctoral degree in studies related to air quality modeling and climate research. Training activities in atmospheric chemistry including ozone is ongoing. Experts and scientists from international environmental agencies are invited to MetMalaysia to conduct training courses to MetMalaysia personnel. Besides that, some of MetMalaysia officers went for oversea technical training and workshop such as GAWTECH in Germany, WMO GAW Brewer Operator Course and Asia-Pacific GAW Workshop on Greenhouse Gases in Republic of Korea as well as participated in ozone related training courses and workshops within the country.

(5) Local and International Collaborations

MetMalaysia has embarked in several collaboration and cooperation with national and international research institutes and universities such as the following:-

i. Collaboration with National Institute of Environmental Studies, Japan to measure greenhouse gases and reactive gases using the flask sampling method;

ii. Contribution of monitoring data to international data centres such as WDCGG for the GHGs, WOUDC for UV and ozone;

iii. Participation in SHADOZ network since 1998 and contributing vertical ozone profiles data annually to the network. SHADOZ is submitting the data to WOUDC on behalf of MetMalaysia;

iv. Collaboration with The National University of Malaysia in research activities for greenhouse gases, ozone and reactive gases;

v. Collaboration with the University of Malaya to establish a Regional GAW station in the east coast of Peninsular Malaysia as part of the ongoing and future atmospheric research activities.

(6) Future Direction

With the establishment of the GAW Global station in Danum Valley, MetMalaysia will able to provide good infrastructure for research activities focusing on the environment, climate, atmospheric composition as well as ozone research. As such, MetMalaysia welcomes any institution to participate and collaborate together in extensive research works and subsequently produce research findings that will be beneficial to the country and the region.

MetMalaysia is also looking forward for future cooperation with other international research agencies especially in establishing partnership in areas such as data sharing, technical visit and subsequently establish a good partner in research project to investigate and understand the critical tropical processes and environmental issues that affect both countries as well as global atmosphere.

Since the government of Malaysia has acknowledged the importance of ozone monitoring activities, MetMalaysia is given enough allocation to acquire six units of total column ozone monitoring instrument this year. With the installation of Brewer Spectrophotometer MKIII by

early next year (Figure 5), Malaysia will be able to monitor near real time total column ozone as well as other parameters such as total column SO_2, UV radiation and AOD.

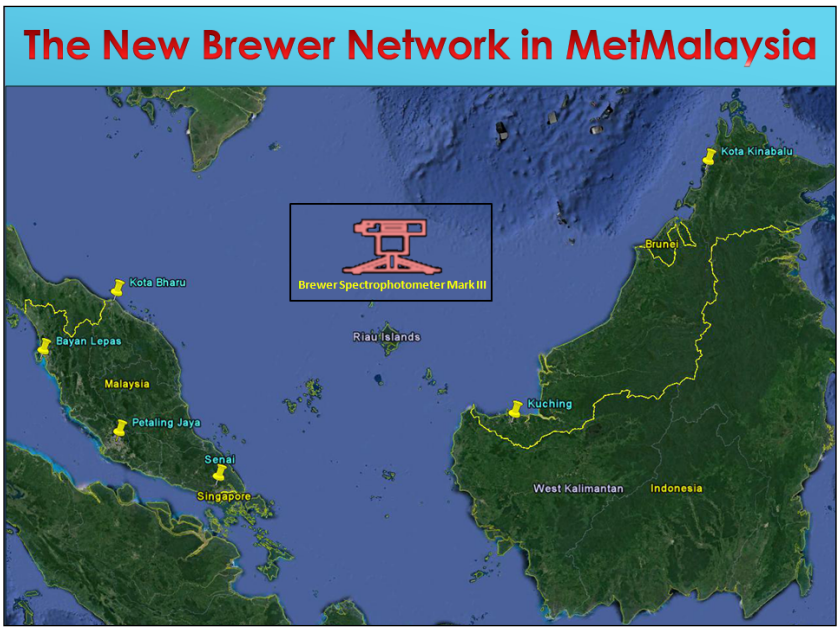


Figure 5. The new Brewer Spectrophotometer MKIII network in Malaysia.

MEXICO

OBSERVATIONAL ACTIVITIES

- **Column measurements of ozone**

Total ozone measurements at the Mexico City station were continued in 2014 to date, following a 10-year interruption due to changes in operating personnel of the Dobson spectrophotometer. Currently the management has been made to contribute to the measurements made to the World Ozone and Ultraviolet Radiation Data Center as well as the update of contact data.

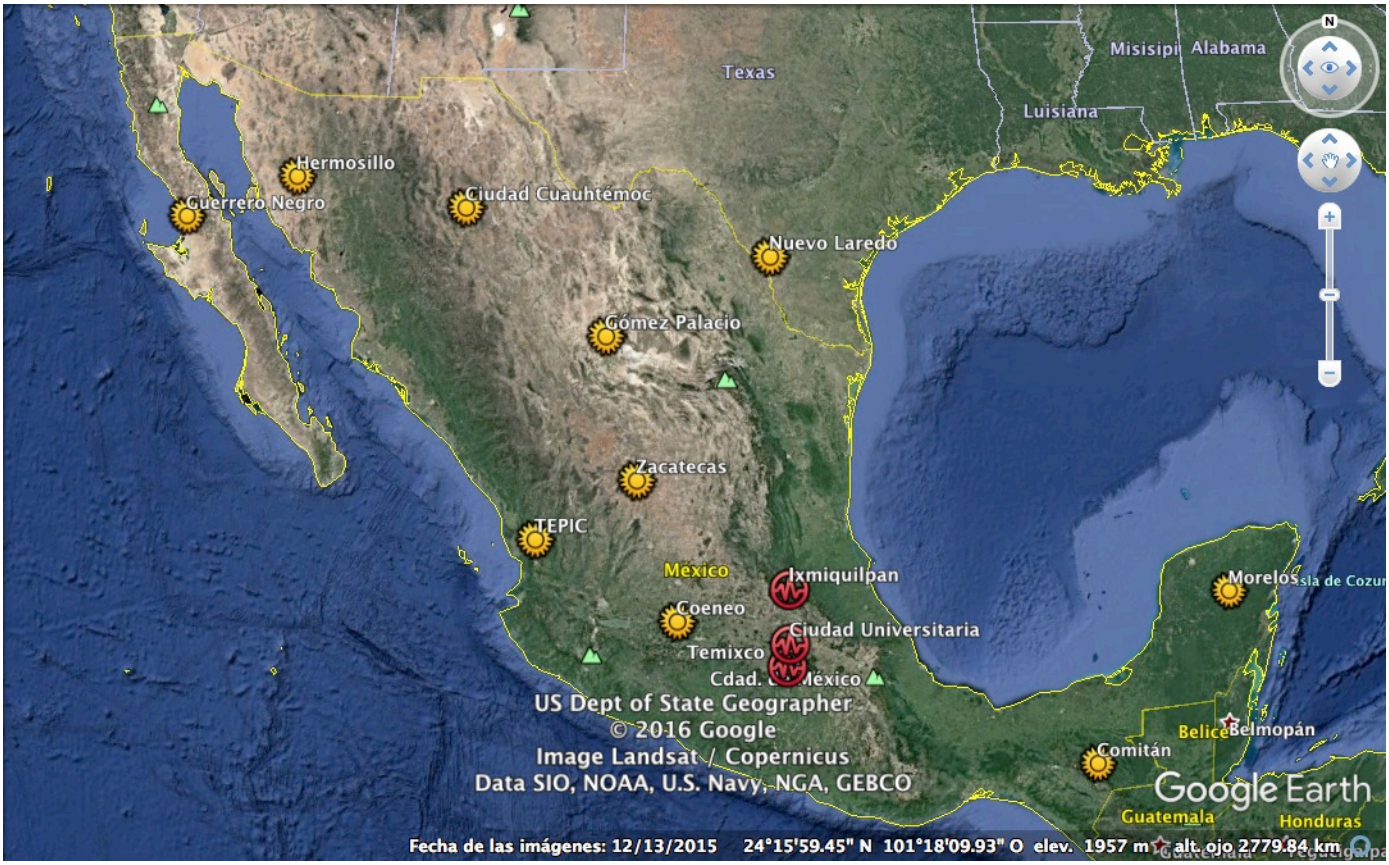
The Dobson 098 was calibrated last time in the IV Regional Dobson intercomparison in Buenos Aires Argentina between Nov and Dec 2010 obtaining the new measurement tables, The interval of 4 years without reporting data after the intecomparacion in the year 2010 was due to which the facilities of the building where the Dobson 098 was located were updated, besides that the rupture of the belle of the optical wedge was broken in two times.

A joint restoration work was carried out together with Juan Carlos Pelaez of the Cuban Meteorological Institute due to a rupture in the belt of the optical wedge which delayed the measurements, the measurements made are now reported to the address http://es-ee.tor. Ec.gc.ca/e/ozone/ozoneworld.htm

- **UV measurements**

For more than 15 years, the government of Mexico City has a variable number of UVB Biometer Model 501 Solar Light Radiometers (3 or 4 stations), which are used to inform the population of UV index levels. At the same time, an instrument of the same characteristics can be found at the facilities of the Solar Radiation Observatory of the National Autonomous University of Mexico for the purpose of climate research (Ultraviolet Solar Radiation Atlas for the National Center for Disaster Prevention of the Federal Government).

Recently (2016), 12 new photometers (Biometer Model 501) were installed in different locations in our country to try to achieve a latitudinal coverage of the country, these equipments are part of a solarimetric station equipped to measure more than 10 components of the radiation Solar, in addition to basic meteorology. The information is not public but transparent for research purposes.



- **Calibration activities**

For us as Regional Center IV, is important the calibration of our equipments, for this reason, the equipments are calibrated annually through intercomparison with instruments referenced in the factory; (UVA and UVB) in the "International Comparison of Radiometers with UV Filter" 2017 to be held at the World Solar Radiation Center in Davos, Switzerland to increase the control and certification of the information

RESULTS FROM OBSERVATIONS AND ANALYSIS

As a result of the work carried out at the Solar Radiation Observatory, monthly maps of UVB radiation have been published in the National Atlas of Risks of the National Center for Disaster Prevention of the Federal Government of our country.

http://www.atlasnacionalderiesgos.gob.mx/app/RadiacionUV/

DISSEMINATION OF RESULTS

- **Data reporting**

Currently, the access is being processed by ftp server to contribute information on total Ozone measurements to the WOUDC and is managing the entry of at least three stations to report measurements of UVB radiation.

Daily atmospheric thickness is reported to the AERONET project for Mexico City and Ciudad Juarez Chihuahua in the north of the country.

PROJECTS, COLLABORATION, TWINNING AND CAPACITY BUILDING

- The collaboration between the group of solar radiation of Mexico and the division of solar radiation of the Cuban meteorological service through the physicist Juan Carlos Pelaez is shown in the work of restoration of the Dobson 098, since as previously mentioned its operation was interrupted by About 10 years, his extensive knowledge in instrumentation allowed to resume the regimen of measurements to raise the station 192 again before the GAW.

FUTURE PLANS

- Currently under evaluation by the Federal Government of a project for the placement of UVB sensors in the main 30 cities of the country, in order to provide information to the general population of the UVB Index.

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MONGOLIA

1 OBSERVATIONAL ACTIVITIES

For this report, the current status of ozone observation and research in Mongolia is included.

1.1 Column measurements of ozone and other gases/variables relevant to ozone loss

There is no currently available ozone observation and research for total ozone and ozone profile measurement using any instruments in Mongolia. We get data from Aqua/MODIS satellites.

1.2 Profile measurements of ozone and other gases/variables relevant to ozone loss

In Mongolia, we get daily data from Aqua/MODIS satellites, and use them for weather forecasting and environmental researches. The only data of ozone profile measurements at 9.6 μm are archived. These data is not being analysed daily, and distribution of total ozone over Mongolia is not being assessed and studied. Because there are shortage of staff for ozone research and financial difficulties. There are some researchers (Adiyasuren Ts., Bujidmaa B., Oyunchimeg etc.) who analyze and study the archived data of ozone profile measurements.

1.3 UV measurements

In Mongolia, UV measurements have been done using CUV5 UV Radiometer and Kipp & Zonen Firm since 2013. But these data is not being analyzed daily and used due to shortage of staff. Some researchers use the data for their study. UV measurement index is being measured directly and archived.

1.4 Calibration activities

CUV5 calibration has not been done up to date.

2 RESULTS FROM OBSERVATIONS AND ANALYSIS

The instrument only measures 'total UV' irradiance. Some results from its measurement is shown in figures 1 to 3.

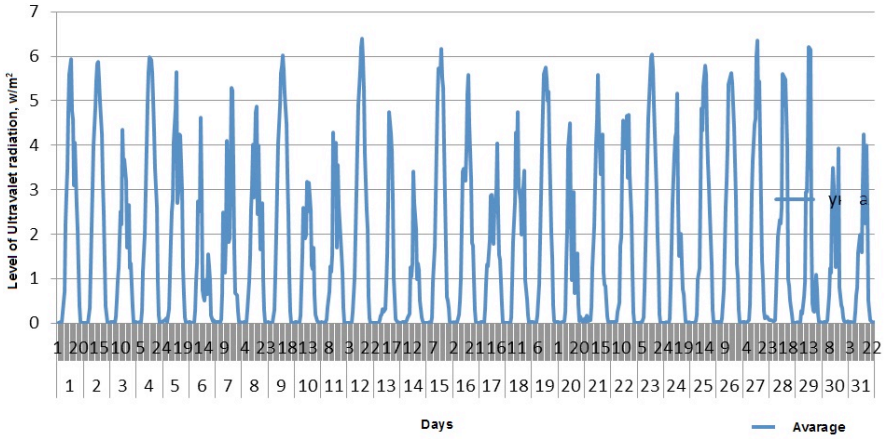


Figure 1. Level of UV radiation as of July 2013

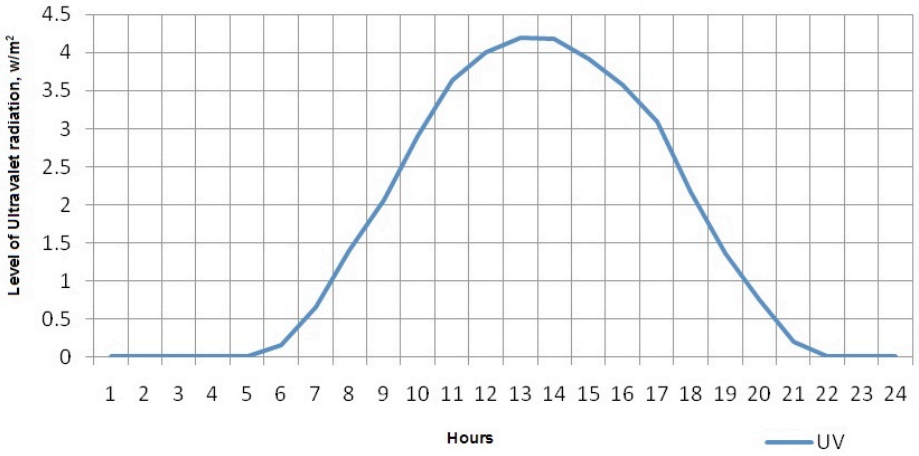


Figure 2. Daily trend of UV radiation

As shown in figure 2, level of UV radiation reaches its maximum at 13pm to 14pm.

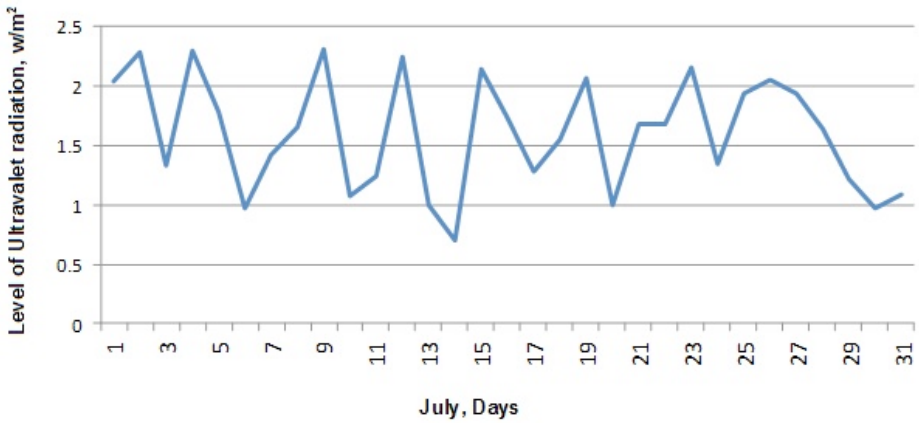


Figure 3. Daily average level of UV radiation

As shown in figures 1 to 3, daily level of UV radiation varies depending on cloudiness, surface albedo and components of air.

3 THEORY, MODELLING, AND OTHER OZONE RELATED RESEARCH

In this part, the results of analysis based on data obtained from Sainshand city, Dornogobi province, 1989 using M-124 Russian (former Soviet Union) instrument and data from Aqua Terra/MODIS satellites, 2014, and current research results of total ozone over Mongolia are included.

In cooperation with the Soviet Union, the Institute of Meteorology of Mongolia operated the weather rocket launch station located in Sainshand city, Dornogobi province from 1988 to 1992.

During that period, the total ozone was measured and analyzed by using M-124 ozonemeter, and the status of tropo pause by aerological data. Due to financial difficulties, measurements and observations of ozone and other researches had been stopped since 1992.

For the recent researches of ozone, daily data has been obtained from Aqua Terra/MODIS satellites since 2008. As a result of data analysis, the total ozone over Mongolia from 2008 to 2013 had been assessed.

The trend of total ozone over Mongolia and Sainshand city as of average levels in January, April, July and October from 2008 to 2013 is shown in figures 4 to 7.



Figure 4. January average total ozone

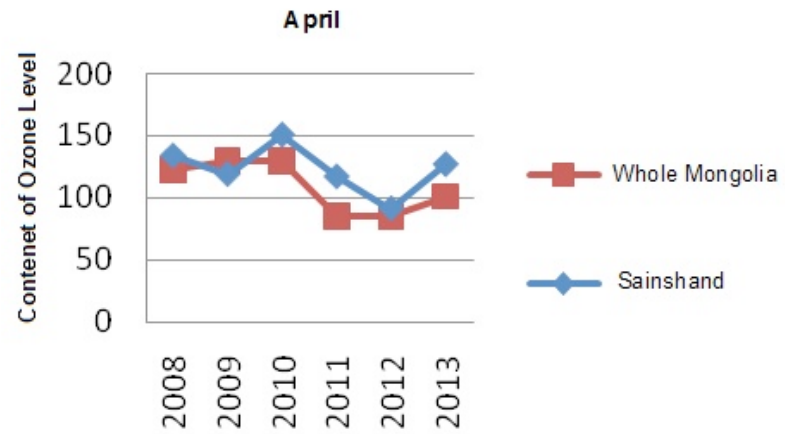


Figure 5. April average total ozone

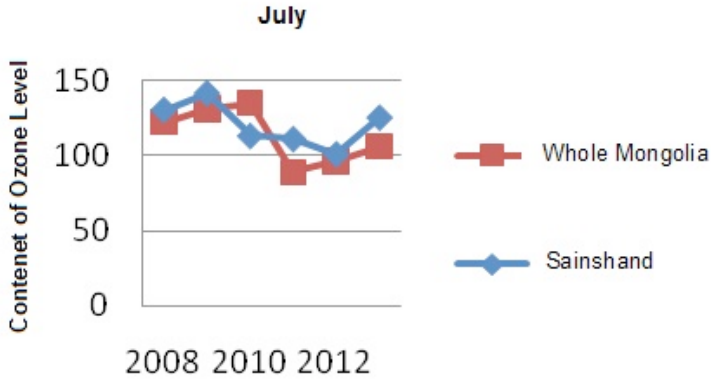


Figure 6. July average total ozone

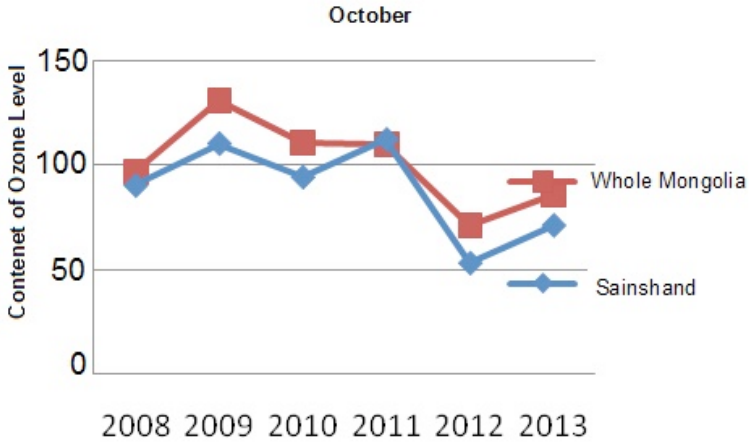


Figure 7. October average total ozone

As shown in figures 4 to 7, the trend of total ozone over Mongolia from 2008 to 2013 decreases in every season.

4 DISSEMINATION OF RESULTS

4.1 Data reporting

Currently, there is no submission of data to the WOUDC and other data centers.

4.2 Information to the public

There is no activities of information dissemination to the public regarding the levels of UV radiation and UV forecasts.

4.3 Relevant scientific papers

I have written several research papers for publication and delivered presentations to related research seminars held in Mongolia.

5 PROJECTS, COLLABORATION, TWINNING AND CAPACITY BUILDING

Currently, there is no implementation of major national and international projects.
There has been discussion over the implementation of small research project on the total ozone over Mongolia using Aqua Terra/MODIS satellite data starting from 2017 at the national level.

6 IMPLEMENTATION OF THE RECOMMENDATIONS OF THE 9th OZONE RESEARCH MANAGERS MEETING

According to the recommendations of the 9th Ozone Research Managers Meeting, it has been included in the Work Plan for 2017 to analyze data from Aqua Terra/MODIS satellites per season. There has been discussion over conducting data analysis of UV measurements at the Information and Research Institute of Meteorology, Hydrology and Environment of Mongolia starting from 2017. Furthermore, there has been submission of official letters and documents to NOAA/USA for transferring the Dobson Spectrophotometer provided by the World Meteorological Organization (WMO) to Mongolia in 2017.

7 FUTURE PLANS

The following activities have been planned at the national level.

1. To conduct measurements and observations for the distribution of surface ozone in Mongolia using Dobson Spectrophotometer
2. To measure UV radiation at the ground level in Ulaanbaatar city at regular basis using CUV5 instrument and to submit the results to the WMO, and to disseminate related information to the public
3. To archive data measurements of ozone obtained from Aqua Terra/MODIS satellites through channel 30 or at 9,6 μm, and to conduct basic analysis
4. To develop and implement projects from 2017 to 2018 on data analysis of ozone distribution and submission of the results to the WMO/WOUDC and other data centers, and dissemination of information to the public.

8 NEEDS AND RECOMMENDATIONS

1. To get support from WMO for transferring the Dobson Spectrophotometer provided by WMO from NOAA/USA to Mongolia in 2017
2. The Government of Mongolia should consider the issues of conducting measurements using CUV5 UV Radiometer and its data archiving, and dissemination of results to international organizations and the public
3. To conduct research for the total ozone distribution over Mongolia using Aqua Terra/MODIS satellite data, and to create annual database.

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NEPAL

Background

Upon the discovery that CFCs and other human-made substances are leading to a depletion of the ozone layer, the international community agreed upon the Vienna Convention for the Protection of the Ozone Layer in 1985. Following this, the Montreal Protocol on Substances that Deplete the Ozone Layer was adopted in 1987 with the objective of reducing and finally phasing out the production and consumption of ozone-depleting substances. Nepal ratified to the Vienna Convention and Montreal Protocol on 6 April 1990 and came into force on 4 October 1994.

Institutional Mechanism

Implementation of the Convention and Protocol in Nepal started with the following undertakings:

- Ministry of Population and Environment (MoPE) was designated as a focal ministry;
- MoPE and the then Ministry of Industries, Department of Customes, Bureau of Standard and Metrology started working in close coordination;
- MoPE established the coordination with the Convention Secretariat and necessary organizations;
- A National Ozone Unit (NOU) was established in NBSM with the responsibility of implementing and monitoring the ODS.
- Nepal Refrigeration and Electro Mechanical Association (NREMA) has been established in 2006; it cooperates very closely with the NOU and MOPE. NREMA has also attempted several activities regarding the awareness raising on ODS including training to the students and capacity building.

The Government formulated policies and enacted Acts and regulations such as Environment Protection Act, 1996, Environment Protection Rules, 1997 and Ozone Depleting Substances Consumption Rules (ODSCR), 2001 etc. Environment Impact Assessment (EIA) of development works was institutionalized and standards related to the industrial effluents air quality were implemented by MoE. Similarly, NBSM has also implemented activities as the major Implementing Agency of the Convention, Protocol and London Amendment.

Present Status

As the focal point of Convention, Protocol , the MoPE issued a public notice in the National Gazette on 25 September 2000 releasing the Government decision, on annual consumption, import quantity and phase-out rates of ODS. According to this notice, Nepal has already phased down the import of R-11 and R-12 refrigerant gas. In 2014 October 26, Government of Nepal published another notice on National Gazette with phase down plan of HCFC-22 as follows.

2011-2014	2015	2017	2020	2022	2025	2030
23.04 MT	20.736 MT	18.43 MT	11.52 MT	9.26 MT	0.576 MT	0

Nepal is strictly following this phase-down plan. Currently Ministry of Population and Environment grants permission for importing HCFC-22 and has allocated certain quotas for importers. The new importer is allowed to import only One Metric Ton annually and the old importer is allowed to import 2 Metric Ton annually. Before importing, the importers should bring lab test report of the refrigerant gas. With these all provisions, Nepal is committed for implementation of Vienna Convention and Montreal Protocol and protection of Ozone Layer.

Narayan Raj Timilsena
Joint Secretary
Ministry of Population and Environment
Singhdurbar, Kathmandu, Nepal.

The NETHERLANDS

Systematic observations:

Surface networks

- Brewer measurements in the Netherlands

The Brewer measurements at the station "De Bilt" by KNMI with Brewer #189 have been continued into 2017. Brewer #189 has been operated continuously since 1 October 2006. It replaced Brewer #100 which provided observations since 1 January 1994."De Bilt" had the longest record of ozone measured with an MKIII instrument in the WOUDC database. The Brewer ozone column data from 1994-2015 are presently available from WOUDC.

- Brewer measurements in Surinam

Measurements at the station "Paramaribo" with Brewer #159 have been continued into 2017. After careful cleaning, the ozone column dataset from1999-2013 has been submitted to WOUDC and NDACC. (The variability in de ozone data in this tropical station is low, and interference by clouds is a significant problem at this site.)

- Ozone soundings in the Netherlands

The ozone sounding program at station "De Bilt" by KNMI has been continued up to present, with at least one launch per week, and more when special events or campaigns occurred. The data from 1992-2015 are available from WOUDC.

- Ozone soundings in Surinam

The ozone sounding program in Paramaribo has been continued with one launch per week. Paramaribo station is part of the SHADOZ network. The observations at Paramaribo are performed by staff of the Meteorological Service of Surinam. All Paramaribo ozone soundings have been reprocessed in line with the "O3S-DQA-Guidelines Homogenization-V2-19November2012". However, the suggested background current correction does not work well for this site, hence the pressure dependent correction proposed by Newton and Vaughan (2016) has been used. Reprocessed data from 1999-2016 are available in the SHADOZ archive https://tropo.gsfc.nasa.gov/shadoz/Paramaribo.html.

- UV-monitoring in the Netherlands

RIVM continued the spectral UV-monitoring at Bilthoven in the Netherlands. The overall UV-data record in now spans 23 years (1994-2016). The solar UV-spectrum at the ground is recorded each 12 minutes from sunrise to sunset. More than 20000 spectra are recorded each year. The spectral data are automatically processed with the QC (quality control) and data-analysis software package SHICrivm and the calculated solar UV-index (or zonkracht in Dutch) is presented in real time on the RIVM website (www.rivm.nl/zonkracht (in Dutch) and www.rivm.nl/UVindex (in English)).

- Ozone lidar measurements Lauder, New-Zealand

RIVM has continued the operation of the stratospheric ozone lidar at the NDACC station in Lauder, New-Zealand where first measurements started in 1994. Procedures for lidar ozone profiling have been standardized with contributions by Van Gijsel and Swart from the Netherlands (Leblanc, 2016a,b). On a single measurement night, usually various measurements are done at Lauder. Profiles up to December 2016 have been submitted to international databases, including NDACC (ftp://ftp.cpc.ncep.noaa.gov/ndacc/station/lauder/ames/lidar/).

Concerns:

Driven by the need for budget-reduction, the operational strategy of the lidar was altered in July 2011. Given the limited budget, necessary software (and possibly hardware) adjustments take considerable time to implement. A second worry comes from the aging of the system. The lidar has been in operation in Lauder for more than 20 years. While laser and computer have been replaced once since, most parts are close to 25 years old. Many electronic parts are no longer replaceable (no longer built) and failure of those would require a large system update. This is not feasible with the current funding status. Continuity of the measurements is therefore at stake, and measurements may stop abruptly on a failure. To address these issues, RIVM and NIWA are working towards a transfer of the instrument from RIVM to NIWA. A smooth transfer of knowledge and PI-ship is anticipated.

Satellite networks

The Netherlands was and is involved in satellite ozone measurements from several instruments: GOME, SCIAMACHY, OMI, GOME-2 and TROPOMI. These are UV-visible satellite spectrometers, from which ozone and several other trace gases, like NO2, SO2, HCHO, are determined. The OMI and GOME-2 instruments are operational. The TROPOMI instrument is presently being prepared for launch in 2017.

SCIAMACHY (July 2002-8 April 2012) was contributed by Germany, the Netherlands, and Belgium to ESA's Envisat satellite. OMI (1 October 2004 onward) is a contribution from the Netherlands and Finland to NASA's EOS-Aura satellite. TROPOMI is the successor instrument of OMI and SCIAMACHY. TROPOMI was developed by the Netherlands and ESA, and will fly on the ESA Sentinel-5 Precursor mission, to be launched in 2017. KNMI has the PI-role of OMI as well as TROPOMI.

Ozone data processing and users

At KNMI near-real time and off-line data processing of satellite ozone columns and ozone profiles is taking place; see Table 1. Also data assimilated products are made. Most of the products are being delivered to users via the web portal www.temis.nl. The multi-sensor reanalysis 1 (MSR1) which covered 1978-2008) has recently been extended to 1970-2012 and refined (Van der A, 2015). This version 2 (MSR2) is available at http://www.temis.nl/protocols/O3global.html

The OMI ozone products are being delivered via the GSFC Data and Information Services Center (DISC). GOME-2 data processing at KNMI (January 2007 onward) is performed in the framework of the Ozone and Atmospheric Chemistry Monitoring Satellite Application Facility (O3MSAF) of EUMETSAT. Data delivery of near-real-time ozone profile products is done via EUMETCast broadcasting**.**

There are many users of the satellite ozone data; for example, OMI ozone column data is being delivered in near-real-time to ECMWF for assimilation in the model, amongst others for the Copernicus Atmosphere Monitoring Service (CAMS) forecasts and reanalyses.

Table 1: Near-real-time and offline satellite ozone products made by KNMI.

Instrument	**Product**	**Period**	**Data delivery**
GOME	Ozone column	1995 – 2011 (global until 2003)	http://www.temis.nl
SCIAMACHY	Ozone column	2002 – 2012	http://www.temis.nl
OMI	Ozone column, Ozone profile, Assimilated ozone column	2004 – now	http://www.temis.nl http://disc.sci.gsfc.nasa.gov/Aura
GOME-2	Ozone profile, Assimilated ozone column	2007 – now	http://www.temis.nl http://o3msaf.fmi.fi http://wdc.dlr.de/data_products/SERVICES/GOME2NRT/o3.php EUMETCast
Multi-Sensor Reanalysis2 (MSR2)	Assimilated ozone column	1970-2012	http://www.temis.nl

Assessment contributions, input to negotiations on the amendment of the Montreal protocol, and outreach

Netherlands scientists (Jos de Laat and Ronald van der A from KNMI and Guus Velders from RIVM) have contributed to several chapters of the last UNEP/WMO Scientific assessment report.

Guus Velders has for many years provided important information on the future atmospheric abundances and climate forcings from scenarios of global and regional HFC emissions. The Montreal Protocol has been very successful in phasing out the global production and consumption of ozone-depleting substances (ODSs). In response, the use of HFCs as ODS replacements has increased strongly since the mid-1990s for refrigerants and foam blowing agents, medical aerosol propellants and miscellaneous products. HFCs do not deplete the ozone layer, but are greenhouse gases and therefore contribute to the radiative forcing of climate. Almost all HFCs currently used as CFC and HCFC replacements have high (100-yr time horizon) global warming potentials (GWPs) ranging from about 150 to 8000. Observations show that the abundances of many HFCs are increasing in the atmosphere. Therefore without regulations, HFCs may contribute significantly to future climate forcing.

In 2015 Velders et al. formulated baseline (or business-as-usual) scenarios for 10 HFC compounds, 11 geographic regions, and 13 use categories. The scenarios rely on detailed data reported by countries to the United Nations; projections of gross domestic product and population; and recent observations of HFC atmospheric abundances. In the baseline scenarios, by 2050 China (31%), India and the rest of Asia (23%), Middle East and northern Africa (11%), and USA (10%) are the principal source regions for global HFC emissions; and refrigeration (40-58%) and stationary air conditioning (21-40%) are the major use sectors. The corresponding radiative forcing could reach 0.22-0.25 W m^{-2} in 2050, which would be 12-24% of the increase from business-as-usual CO_2 emissions from 2015 to 2050. Using the climate model MAGICC6 it was calculated that under the baseline scenario HFCs would contribute 0.35 to 0.5 ^{o}C to global surface temperatures in 2100 (Figure 1).

In 2014 and 2015, regional (EU) and national (Japan, USA) regulations have been implemented to limit the use of high-GWP HFCs. In Oct. 2016 an amendment of the Montreal Protocol has been agreed by all Parties to the protocol. With the amendment HFCs are included in the Protocol and their use will be reduced globally by 80-85% from baseline levels before 2050. The contribution from HFCs to global surface temperatures is now expected to be reduced from 0.35-0.50 ^{o}C to about 0.06 ^{o}C in 2100.

The Netherlands satellite ozone observations are regularly used in the Antarctic and Arctic Ozone Bulletins given out by WMO. Each year for World Ozone Day a national news item is published about the evolution of stratospheric ozone and UV, e.g.:

- in 2014: https://www.knmi.nl/over-het-knmi/nieuws/wereldozondag-begin-herstel-ozonlaag

- in 2015: https://www.knmi.nl/over-het-knmi/nieuws/ozon-meten-nodig-ondanks-stagnatie-ozonafbraak
- in 2016: https://www.knmi.nl/over-het-knmi/nieuws/het-gaat-langzaam-beter-met-de-ozonlaag

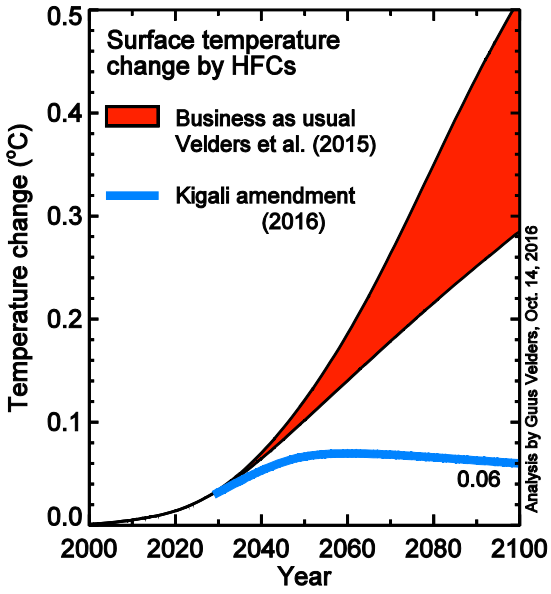


Figure 1. Global surface temperature contribution from HFCs under business-as-usual scenarios and with implementation of the Kigali amendment of 2016.

Selected other contributions

De Laat et al., 2015 performed a sensitivity analysis of multivariate regressions of recent springtime Antarctic vortex ozone trends using a "big data" ensemble approach. The results indicated that the poleward heat flux and the effective chlorine loading respectively explain most of the short-term and long-term variability in different Antarctic springtime total ozone records. The inclusion in the regression of stratospheric volcanic aerosols, solar variability and the quasi-biennial oscillation was shown to increase rather than decrease the overall uncertainty in the attribution of Antarctic springtime ozone because of large uncertainties in their respective records.
When taking fit residuals into account in a piecewise linear trend (PWLT) fit, they found that approximately 30–60% of the regressions in the full ensemble result in a statistically significant positive springtime ozone trend over Antarctica from the late 1990s onwards (Figure 2). De Laat et al. concluded that "Although the results indicate that the use of multivariate regressions is a valid approach for assessing the state of Antarctic ozone hole recovery, and it can be expected that results will move towards more confidence in recovery with increasing record length, uncertainties in choices currently do not yet support formal identification of recovery of the Antarctic ozone hole."

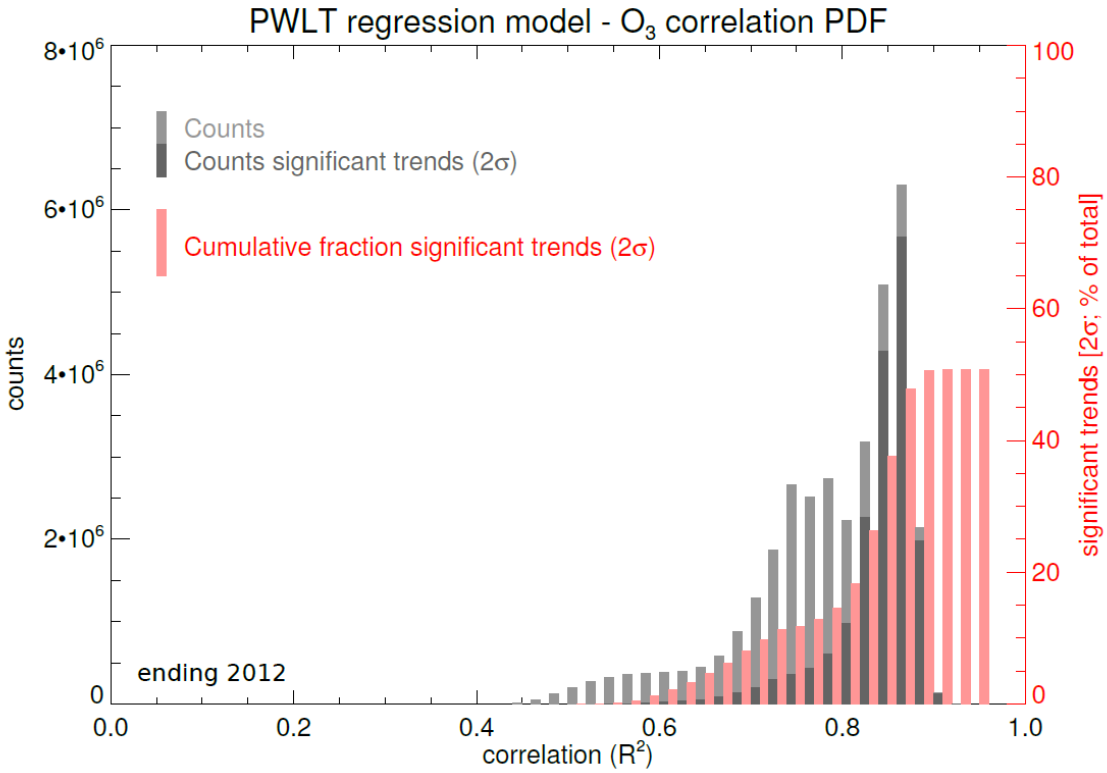


Figure 2
The probability distribution of regression-model–ozone-record-scenario correlations (R^2) for regressions ending in 2012 and the cumulative fraction of statistically significant (2σ) ozone trends for each correlation interval (red, right axis).

Van Peet et al. (2014) have further developed and documented the Ozone ProfilE Retrieval Algorithm (OPERA) version 1.26. This is used for retrieving ozone profiles from UV–VIS observations of most nadir-looking satellite instruments like GOME, SCIAMACHY, OMI and GOME-2.

Van der A et al. (2015) extended the total record of their first version (MSR1) in a second version of the multi sensor reanalysis of total ozone (MSR2) by 13 years. This resulted in an ozone record for the 43-year period 1970–2012.
The chemistry transport model and data assimilation system used in the reanalysis, TMDAM, have been adapted to improve the resolution, error modelling and processing speed. The resolution of the TMDAM model runs, assimilation and output was increased from 2x3 to 1x1 degrees from MSR1 to MSR2. The reanalysis was driven by 3-hourly meteorology from the ERA-Interim reanalysis of the European Centre for Medium-Range Weather Forecasts (ECMWF) starting from 1979, and from ERA-40 before that date. As observations the reanalysis included total ozone retrievals of 15 satellite instruments: BUV-Nimbus4, TOMS- Nimbus7, TOMS-EP, SBUV-7, -9, -11, -14, -16, -17, -18, -19, GOME, SCIAMACHY, OMI and GOME-2. The

performance of the MSR2 analysis was quantified with the help of observation-minus-forecast (OmF) departures from the data assimilation, by comparisons with the individual station observations and with ozone soundings (Figure 3). The OmF statistics show that the mean bias of the MSR2 analyses is less than 1 % with respect to de-biased satellite observations after 1979.

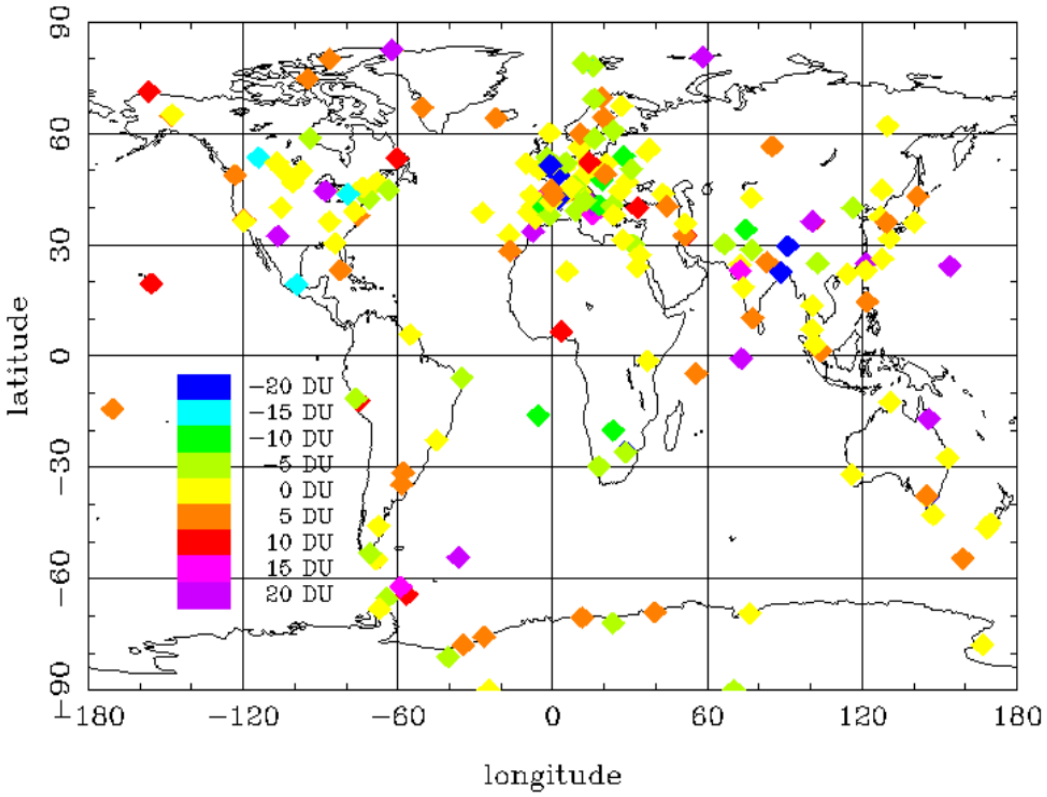


Figure 3
Mean offset (MSR2 minus observations) between the MSR2 reanalysis data and all selected Dobson and Brewer ground-based measurements during the period 1970–2012

As mentioned above, RIVM/VLH (Harry Slaper, Peter den Outer, and Arjan van Dijk) continued the spectral UV-monitoring in Bilthoven in the Netherlands. All measured data are used to calculate yearly sums of UV-radiation, skin cancer weighted doses, received on a horizontal plane. A standard procedure is used to correct for differences in cloud effects. Thus, one obtains the measured yearly sum of UV-radiation received at ground level and in addition derive a cloud-corrected yearly sum (see Figure 4 lower and upper panel) for the observed trends. The procedure enables a separation of trends caused by ozone, and trends and changes caused by combined effects of ozone and clouds.

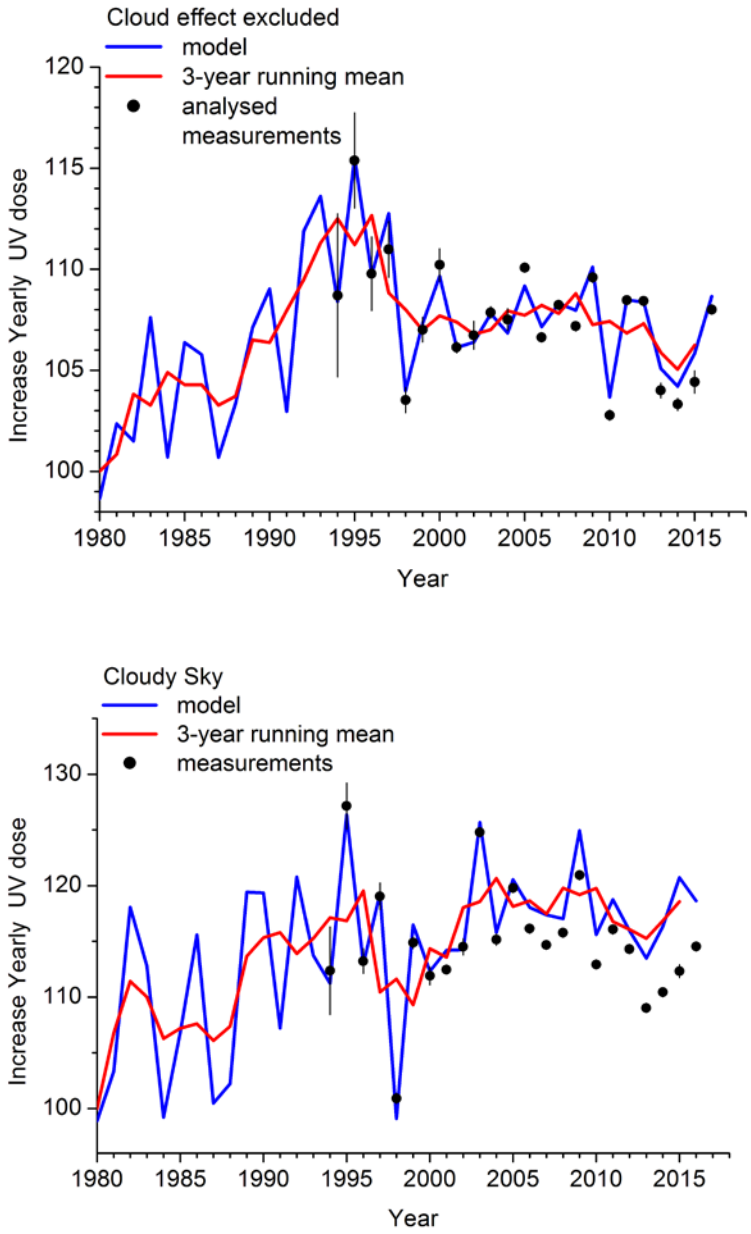


Figure 4.
Observed UV-trends and variations in the Netherlands (Bilthoven) in the past decades. The values are compared to the average over the periode 1979-1981 and thus 100% is given as the yearly dose in 1980. Trends are based on RIVM's UV-monitoring data (circles) and a comparison with modelled UV-radiation levels using a combination of ozone sources (techniques described by Den Outer et al., 2010). The upper panel is corrected for cloud effects and thus shows the ozone related changes in UV at ground level and the lower panel shows the relative doses received at the ground including changes and variations caused by clouds and ozone. Data for the recent period are preliminary.

Maximum clear sky UV-sums are found in the mid-nineties of the last century, with the highest yearly sum in 1995 (see Figure 4). Since that period ozone values slightly increased and consequently clear sky UV-radiation levels decreased slightly. When looking at the yearly UV-sum received at the ground, including ozone and cloud variations (Figure 4 lower panel), the highest yearly sum was also found in 1995. However, 2003 and 2009 closely follow 1995, and we see that for these years a lower reduction by clouds compensated the slightly higher ozone values.
The red line in the upper panel indicate the three year running averages and follows the curve estimated for the amendments of the Montreal Protocol (not shown here) as was previously calculated using the AMOUR-model (van Dijk et al 2013). Thus, the ozone layer appears to follow the expected recovery and this is reflected in the cloud-corrected UV-dataset. However, the cloud effects partly compensate the decrease in UV due to increased ozone (figure 4 lower panel).
Looking at the skin cancer incidence in the Netherlands it is noted that the increase in the incidence is much stronger than expected based on ageing of the population and the increased UV-radiation levels shown here. This implies that behavioral increases in UV-exposure at present dominate the effects of ozone and clouds on the skin cancer risks. However, future risks might further increase due to the presently observed increases in UV-radiation levels. Furthermore, climate change might indirectly, through higher summer temperatures, add to behavioral changes that further increase UV-exposure and subsequent future skin cancer risks.

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NEW ZEALAND

Introduction

In New Zealand, ozone- and UV-related research is undertaken by the National Institute of Water and Atmospheric Research (NIWA), Bodeker Scientific, and several of our Universities. Many relevant observations are taken at the Lauder Atmospheric Research Station in Central Otago. Lauder station (45°S, 170°E, 370 meters above sea level), a rural and clean background-level site, is representative of Southern mid-latitudes. It is a "Global" station of the WMO's Global Atmosphere Watch Programme, and is also part of the Network for the Detection of Atmospheric Composition Change (NDACC). Ozone, as well as a number of parameters related to ozone depletion, is measured using a variety of techniques including Dobson spectrophotometry, UV-visible spectroscopy, infrared spectroscopy, microwave radiometry, electrochemical ozonesondes flown on balloons, ozone and aerosol LIDARs, and frost-point hygrometers. Solar UV radiation is measured at a number of sites across New Zealand. There also are measurement activities outside of New Zealand, such as in Antarctica and the Pacific Islands. Specific work in support of environmental conventions is also taking place. Due to its location in the Southern Hemisphere and proximity to Antarctica, New Zealand is particularly interested in the climate effects of stratospheric ozone depletion. The "Deep South" National Science Challenge is a 10-year research programme that aims to better our understanding of how changes in the Antarctic region affect New Zealand; the effect of ozone depletion and recovery on climate will form part of this programme.

1. OBSERVATIONAL ACTIVITIES

Ozone Research in New Zealand

Of the more than 70 active NDACC measurement sites in the world, only Lauder is equipped with a full complement of the five standard ground-based ozone profile measuring techniques, i.e. ozonesondes, Dobson Umkehr, LIDAR, FTIR, and microwave radiometry. Total column ozone is also measured at Lauder using UV/vis spectrometers and surface *in situ* observations are made using UV photometers. Other sites across New Zealand also have active surface ozone measurement programmes.

High quality, long time-series measurements are key to identifying trends; the Lauder measurement site hosts several on-going multi-decadal data sets relevant to ozone research.

1.1 Column measurements of ozone and other gases/variables relevant to ozone loss.

The following measurement programmes are all located at the Lauder research station:

- Stratospheric NO_2 since 1981 (36 years)
- Dobson Total Column Ozone since 1987 (30 years)
- UV Spectrometers since 1989 (28 years)
- TEI *in situ* ozone analyser since 2004 (13 years)

1.2 Profile measurements of ozone and other gases/variables relevant to ozone loss

The following measurement programmes are all located at the Lauder research station:

- Ozonesondes, weekly launches since 1986 (31 years) which included radiosonde measurements of pressure, temperature and humidity
- Dobson Umkehr since 1987 (30 years)
- Ozone LIDAR since 1994 (23 years)
- Microwave radiometers since 1994 (23 years)

- FTIR since 1990 (27 years)
- NOAA frost-point hygrometers since 2004 (13 years)

1.3 UV measurements

Activities from NIWA's UV radiation programme are summarized at **https://www.niwa.co.nz/our-services/online-services/uv-ozone**

Spectral: NIWA maintains spectral measurements at Lauder, as well as at Mauna Loa Observatory HI, Boulder CO, Alice Springs and Melbourne, Australia.
Summary data from the NDACC sites are archived at the NDACC database, and plans are underway to routinely archive spectral data from all five sites in the WOUDC database. Historical spectral data are also available from Tokyo, Japan, and Darwin, Australia.
Broadband: NIWA maintains 6 Yankee UVB-1 pyranometers (i.e., new generation Robertson Berger "RB-type" meters) in NZ and the South Pacific region. Data from these are archived in the NIWA climate database, and are used in regular reports by the New Zealand Ministry for the Environment (http://www.mfe.govt.nz/publications/environmental-reporting/environment-aotearoa-2015-atmosphere-and-climate/state-our). NIWA also assists Callaghan Innovation to process and archive data from their UVB-1 meters at 6 other sites in New Zealand.
Complementary Measurements:
In support of our UV measurement programme, the following are also available at Lauder:

- BSRN radiation suite (direct, diffuse, and global short wave radiation)
- Aerosol optical depth at several wavelengths, and from LIDAR (BSRN)
- All sky cameras
- Direct beam spectral irradiances
- Actinic flux measurements
- Sunshine recorders
- USDA radiation suite
- Meteorological data
- Trace gas measurements

Additionally, NIWA has been closely involved with the development and use of personal UV dosimeters.

1.4 Calibration activities

- The most recent inter-calibration against international standards (maintained at the Physikalisch-Metorologisches Observatorium Davos; PMOD) was at Lauder in February 2016. NIWA and PMOD spectra agreed within the PMOD standard error range.
- NIWA UV spectrometers have also been used to cross calibrate other spectrometers in Australasia
- Australian Radiation Laboratory (ARPANSA), at Melbourne Australia, in Dec.2015
- Callaghan Innovation (CI), at Lauder in Dec.2016
- Broadband meters are cross calibrated against spectroradiometers at Lauder
- Lauder Dobson (D072) NDACC calibration to the regional standard in Melbourne, Feb.2017
- NOAA travelling ozone standard was used with the TEIs at Lauder in 2016

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

Through numerous publications (see below), conference presentations, seminars, and web pages. Results are updated at quadrennial NIWA Workshops (UV). See https://www.niwa.co.nz/our-services/online-services/uv-and-ozone/workshops

3. THEORY, MODELLING, AND OTHER OZONE RELATED RESEARCH

Through research papers, UNEP EEAP Reports, and WMO Ozone Assessment Reports.
UNEP: http://ozone.unep.org/en/assessment-panels/environmental-effects-assessment-panel
WMO: http://ozone.unep.org/en/assessment-panels/scientific-assessment-panel

Bodeker Scientific is funded under the Deep South National Science Challenge to develop a long-term homogeneous total column ozone database. This database combines total column ozone measurements from 17 different satellite instruments, removing all offsets and drifts between the data sets, to create a seamless homogeneous database from November 1978 to the present. This data set is available from:
http://www.bodekerscientific.com/presentations/peer-reviewed-literature

With funding from the same source, Bodeker Scientific is also developing a new version of its vertically resolved monthly mean, zonal mean, global ozone database. This database extends from 1979 to the present and is provided on 70 vertical levels (both altitude and pressure). A gap filling technique is used to generate a database suitable for constraining global climate models that do not have a chemically interactive stratosphere, or to validate the ozone fields simulated by coupled chemistry-climate models. This data set is available from:
http://www.bodekerscientific.com/data/monthly-mean-global-vertically-resolved-ozone

NIWA is a major contributor to the Chemistry-Climate Model Initiative (CCMI), which i.a. is focusing on tropospheric and stratospheric ozone. In association with that, a research focus has been on linkages between Southern-Hemisphere climate change and ozone depletion, and related to that in the attribution of such change to ozone depletion and/or increasing long-lived greenhouse gases. The research is continued under the Deep South National Science Challenge, using the nascent New Zealand Earth System Model.
http://www.deepsouthchallenge.co.nz; http://blogs.reading.ac.uk

4. DISSEMINATION OF RESULTS

4.1 Data reporting

See above. NIWA UV data are archived at:

NDACC: http://www.ndsc.ncep.noaa.gov/data/ (spectral summaries)
WOUDC: http://woudc.org/ (not yet publically available)
NIWA: https://cliflo.niwa.co.nz/ (broad band)

Scientific papers, etc. (see below)

NDACC, WOUDC: Dobson total column ozone and Umkehr profiles
NDACC, WOUDC: Stratospheric microwave radiometer profiles
NDACC, WOUDC, GRUAN: Ozonesonde profiles
NDACC, GRUAN: Frost-point water vapour profiles
NDACC: FTIR ozone, total column and profiles
NDACC: LIDAR ozone profiles

4.2 Information to the public

NIWA web pages include UV forecasts, maps of ozone and UV, time series of ozone.
UV Index displays in public places, along with behavioural advice
Smartphone Apps that include variation over the day including cloud effects and corresponding behavioural advice. (https://www.niwa.co.nz/node/111461).

The uv2Day app (NZ – Australia – South Pacific – Antarctica only)
The GlobalUV app (Global, but with daily noon cloud cover only)

Interaction with NZ health providers regarding both positive and negative effects of UV. For example,
https://www.health.govt.nz/system/files/documents/publications/vitamind-sun-exposure.pdf
http://www.sunsmartschools.co.nz/PS_RisksBenefits_SunExposureSept08.pdf

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5. PROJECTS, COLLABORATION, TWINNING AND CAPACITY BUILDING

National Projects

Ozone and related research in New Zealand are undertaken primarily through the Understanding Atmospheric Composition and Change programme, which includes various measurement activities of ozone and associated species, primarily at Lauder, New Zealand, and Arrival Heights, Antarctica, measurement of physical variables such as UV, as well as

global chemistry-climate modelling. UV measurements at Lauder are part of a larger research effort, spanning the physical and medical sciences communities, on the impact of UV on human health (both positive and negative effects), materials, and the biosphere. This research is informing health organizations such as the New Zealand Cancer Society.

International Projects

Ozone research in New Zealand is undertaken in close collaboration with many international partners and contributes to a wide range of international projects. Selected current international projects are:

- NDACC (Network for the Detection of Atmospheric Composition Change), for which Lauder is the primary southern mid-latitude site, has been the principal focus of ozone-related work by NIWA at Lauder for more than three decades. NIWA reports a variety of profile, total column, and surface *in situ* measurements of ozone and associated species to NDACC, taken at its primary locations at Lauder, NZ, and Arrival Heights, Antarctica, and also UV/Vis measurements of total-column NO_2 from Macquarie Island, Australia, taken in collaboration with the Bureau of Meteorology, and Mauna Loa, Hawaii, in collaboration with NOAA.
- IGAC/SPARC CCMI-1 (Chemistry Climate Modelling Initiative phase 1): Contributing CCM simulations to the CCMI archive and participating in process-oriented validation of CCMs. CCMI is the latest in a series of chemistry-climate modelling activities involving NIWA; previously, NIWA contributed to CCMVal-1 (informing the 2006 WMO Ozone Assessment), CCMVal-2 (informing the 2010 Ozone Assessment), and ACCMIP (informing the 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) on tropospheric composition change). Unlike these predecessor activities, the aim of CCMI is to perform and assess whole-atmosphere chemistry-climate model simulations that will inform upcoming ozone, tropospheric air quality, and climate assessments, all with the same class of model. NIWA is participating in the development of the MetOffice Unified Model which, in different versions, has been used for all of these purposes, and is also working with Australian partners on their contribution to CCMI, using the ACCESS model. Through a sub-contract with ETH Zurich (Switzerland), Bodeker Scientific has also contributed simulations to CCMI with the SOCOLv3 (Solar Climate Ozone Links version 3) chemistry-climate model.
- GRUAN (GCOS Reference Upper Air Network): Measurements of ozone, water vapour and meteorological parameters using ozonesondes and high-quality radiosondes are made at Lauder, a site hosting a GRUAN-certified measurement programme. Radiosonde measurements at Invercargill are submitted to GRUAN as a collaboration between NIWA and the New Zealand Metservice. In support of GRUAN activities, NIWA has introduced additional quality checks to radiosonde preparations and has installed a GPS/GNSS receiver used for measuring total water vapour column abundance.
- BSRN (Baseline Surface Radiation Network): Various measurements of radiation, particularly of UV, are supplied to this international network.
- SAGE-III-ISS Validation: Validation campaign, planned for 2017, of ozone and aerosol soundings, to validate the SAGE-III instrument on board the International Space Station, on contract with NASA.

National collaborators

NIWA

Richard Querel, Lauder: Ozone measurements project manager; GRUAN

Ben Liley, Lauder: UV, clouds, aerosols

Richard McKenzie (Emeritus), Lauder: UV

Olaf Morgenstern, Wellington: Programme Leader – New Zealand Regional Atmosphere (until Sep. 2016); Chemistry-climate modelling

Guang Zeng, Wellington: Chemistry-climate modelling

Mike Harvey, Wellington: Programme Leader – Measuring Atmospheric Composition (since Sep. 2016)

Wills Dobson, Lauder: Ozonesonde project, Dobson measurements

Dan Smale, Lauder: TEI and FTIR *in situ* ozone measurements

Sylvia Nichol, Wellington: Dobson measurements

Hisako Shiona, Christchurch: Dobson measurements, ozonesonde project, chemistry-climate modelling.

Adrian McDonald, University of Canterbury: Stratospheric ozone and dynamics, model analysis.

Tony Reeder, University of Otago: Effects of UV overexposure in humans.

Martin Allen, Univ Canterbury: UV dosimetry

Barbara Hegan, Cancer Society: UV Public health advisory

Karin Kreher, Bodeker Scientific: UV/Vis measurements of atmospheric composition

Greg Bodeker, Bodeker Scientific: GRUAN, simplified ozone chemistry

Stefanie Kremser, Bodeker Scientific

Birgit Hassler, Bodeker Scientific

Laura Revell, Bodeker Scientific and ETH Zurich: Chemistry-climate modelling, stratospheric ozone chemistry.

Robert Scragg & Alistair Stewart, Univ Auckland: UV, vitamin D and Health

Kathy Nield & Neil Swift, Callaghan Institute/MSL: Irradiance calibration issues, RB meters

Martin Allen, Univ Canterbury: Dosimeters

Zim Sherman, Scienterra, Timaru: Dosimeters

Health agencies including HPA and Cancer Society, Melnet, NZ Dermatological Association
NZ Meteorological Service (provision of UVI forecasts)

Australian collaborations

Peter Gies, Australian Radiation Protection and Nuclear Safety Authority: UV and behavioural studies

David Griffith & Nicholas Jones, University of Wollongong: Collaboration on FTS measurements, especially related to biomass burning

Bruce Forgan, Bureau of Meteorology: Spectral and broadband radiation and aerosols

David Karoly, U Melbourne: Collaboration on coupled chemistry climate modelling

Andrew Klekociuk, Australian Antarctic Division: Collaboration on coupled chemistry-climate modelling.

Janet Bornman (Curtin, Australia), United Nations UNEP: Environmental Effects of UV radiation

Robyn Lucas (ANU): UNEP also UV Workshop

Peter Gies (ARPANSA), Michael Kimlin (QUT): UV Workshop

USA and Canada collaborations

NOAA

Dale Hurst, GMD: Funder and co-investigator on frost point hygrometer flights at Lauder, provision of surface ozone instruments, data sharing and interpretation

Patrick Disterhoft, CSD, CUCF: Global variability of UV (Mauna Loa and Boulder), Calibration of spectroradiometers

Robert Evans & Irina Petropavlovskikh, GMD: Dobson total-column ozone measurements

GMD = Global Monitoring Division (was CMDL); CSD = Chemical Sciences Division (was aeronomy laboratory); CUCF = Colorado Ultraviolet Calibration Facility
NOAA, Maryland USA. Data for UVI Apps (uv2Day and GlobalUV)

NASA

Richard McPeters, GSFC: Provision of Total Ozone Mapping Spectrometer (TOMS) satellite-based total column ozone measurements

Jay Herman, GSFC: Validation of satellite derived UV, UV units

Larry Thomason, LaRC: Provision of Stratospheric Aerosol and Gas Experiment (SAGE) satellite-based measurements of trace gases and aerosols. Lead investigator of the SAGE-III campaign.

Michael Kurylo, NDACC: NDACC data archival, meta data

Qing Liang, Margaret Hurwitz, Paul Newman, GSFC: Chemistry-climate modelling

GSFC = Goddard Space Flight Center; LaRC = Langley Research Center; NDACC = Network for the Detection of Atmospheric Composition Change

USA Universities

Wei Gao & Marek Uliasz, Colorado State University/USDA: Global variability of UV, USDA radiation suite; collaboration on dispersion modelling

Alan Parrish, University of Massachusetts: Co-investigator on microwave radiometers for ozone profiling

Darryn Waugh, Johns Hopkins University: Collaboration on chemistry-climate modelling

USDA = United States Department of Agriculture

Other USA and Canada

Gerald Nedoluha, Naval Research Laboratories (NRL): Co-investigator on microwave radiometers

R Booth & G Bernhard, Biospherical Instruments: Validation of UV from spectrometers

Sasha Madronich, NCAR: TUV Radiative transfer model, aerosol studies, UNEP

Sancy Leachman, Utah: UV dosimeters and health

Tracy Petrie, Oregon: UV dosimeters and health

Charles N. Long, Pacific Northwest National Laboratory (PNNL): Radiation Studies

Vitali Filetov, Environment Canada: UVI

NCAR = National Center for Atmospheric Research

Collaborations with Europe

Neal Butchart & Fiona O'Connor, UK Met Office: Collaboration on chemistry-climate modelling

John Pyle, Alex Archibald, Luke Abraham, University of Cambridge: Chemistry-climate modelling

Ann Webb (and several others), Univ Manchester: Rationalising UV units for CIE

Jordi Badosa, Laboratoire de Meteorologie Dynamique (LMD), Ecole Polytechnique, Palaiseau, France: Radiation Studies

Josep Calbo, Departament de Fısica, Universitat de Girona (UdG), Girona, Spain: Radiation Studies

Daan Swart: National Institute for Public Health and Environmental Protection, The Netherlands: Ozone LIDAR measurements of vertical ozone profiles at Lauder

Ulrich Platt, University of Heidelberg, Germany: Development of instruments and techniques, data sharing and interpretation

Martin Dameris & Hella Garny: DLR-Institut für Physik der Atmosphäre, Germany: Collaboration on chemistry-climate modelling

Mario Blumthaler: Medical University of Innsbruck, Austria: Inter-comparisons and sky radiances

Dietrich Häder: University of Erlangen, Germany: Global variability of UV Eldonet instrument network

Günther Seckmeyer: University of Hannover, Germany: Sky imagery and pollution effects

Michiel van Roozendael, Belgium Institute of Space Aeronomy: Maintain UV/Visible trace gas standards and development of new techniques (NDACC)

Martine de Mazière, BIRA, Belgium: Interpretation of FTS measurements and validation of satellite data

Alkis Bais (Thessaloniki, Greece): UNEP

Lars Olof Bjørn, Lund Univ, Sweden: UNEP FAQs

FMI, Finland. Data for UVI Apps (uv2Day and GlobalUV)

Thomas Peter, Andrea Stenke, Fiona Tummon, Will Ball (ETH Zurich) and Eugene Rozanov (ETH/PMOD), Switzerland: Collaboration on chemistry-climate modelling.

Collaborations with Africa

Piet Aucamp (Private consultant, South Africa): UNEP FAQs

Caradee Wright, South African Medical Research Council: UV dosimeters

Collaborations with Southeast Asia and Japan

Hideaki Nakajima, National Institute for Environmental Studies, Japan: Provision of Improved Limb Atmospheric Spectrometer (ILAS) satellite-based measurements of trace gases

Tetsu Nagai, Meteorological Research Institute of Japan: Aerosol LIDAR

Osamu Uchino, National Institute of Environmental Studies, Japan: Aerosol LIDAR

Yoshihiro Kondo: University of Tokyo, Japan: Spectral irradiance & actinic flux in polluted sites, aerosol studies

Collaborations with South America

Francesco Zaratti, Univ San Andreas, La Paz, Bolivia: Dissemination of UVI information

Sergio Cabrera, Univ de Chile, Santiago, Chile: Dissemination of UVI information

Ruben Piacentini, CONICET, Rosario, Argentina: Dissemination of UVI information

Hector Guillen, Soc Photobiology, Arequipa, Peru: Dissemination of UVI information

Susana Diaz, CONECIT, Buenos Aires, Argentina: UVI/WMO

6. IMPLEMENTATION OF THE RECOMMENDATIONS OF THE 9th OZONE RESEARCH MANAGERS MEETING

In line with the recommendations of the 9th ORM, New Zealand is continuing to fund the high-quality trace gas measurements being made at its atmospheric research facilities. There is an effort underway to homogenise Lauder's historical ozonesonde data set (1987 to present). As mentioned above in item 3 there are also new developments in the areas of chemistry-climate modelling and satellite-based data assimilation products. A new version of the National Institute of Water and Atmospheric Research - Bodeker Scientific (NIWA-BS) total column ozone database has been generated, incorporating updated corrections and new satellite data sets (http://www.bodekerscientific.com/data/total-column-ozone). This assimilated ozone data set has previously featured in the WMO/UNEP report, Scientific Assessment of Ozone Depletion Ozone.

7. FUTURE PLANS

- Future-proof NIWA UV spectrometer systems at Lauder, including conversion of the legacy Visual Basic operating and processing software.
- Maintain and continue operation of all ozone measuring instrumentation at Lauder, Baring Head, and Arrival Heights.
- Continue ozonesonde launches at Lauder under the current 1 per week schedule.
- Work with RIVM to assure continued operation of ozone LIDAR at Lauder
- An intercomparison study of Lauder ozone instrumentation is underway.

8. NEEDS AND RECOMMENDATIONS

The following needs and recommendations require attention:

- Particularly in the tropics, there is some disagreement between different datasets and model results, regarding the trends since 2000 of total column ozone. Detection of ozone recovery in this region would benefit from resolving these discrepancies.
- The effects of stratospheric change on surface climate change, and the mechanisms involved, need to be better quantified. There is now largely a consensus in the literature that seasonally past ozone depletion has been the dominant driver of climate change in the Southern Hemisphere, and future ozone recovery will remain an important driver of climate change, but large uncertainties remain about the regional impacts of both.
- In particular, the links, if any, between ozone depletion and expanding sea ice around Antarctica remain poorly understood and are generally not captured by general circulation models. This casts doubt on climate projections of the Southern Hemisphere.
- Changes in ozone in the upper troposphere and lower stratosphere, especially in the tropics, need to be better quantified and the effects of changes in ozone in this region of

the atmosphere on the temperature structure of the atmosphere need to be better quantified.

- An ongoing debate about ‘optimal’ levels of UV exposure indicates that further research on vitamin D production and its health effects would be useful.
- A better quantification of natural sources of bromine in the troposphere is needed. Particularly, a possible intensification of the aquaculture of kelp, either for food production and carbon capture, would cause a potentially significant increase in the production of bromocarbons, which can affect the stratospheric ozone layer. This risk needs to be understood.
- Continuing support for long-term, high quality measurement sites.

NIGERIA

1. OBSERVATIONAL ACTIVITIES

Monitoring and research on ozone, UV radiation and related atmospheric constituents are carried out by different institutions and government agencies in Nigeria. The aim is to support government policies on environment and thereby contribute positively to the implementation of the Vienna Convention for the protection of the ozone layer and it's Montreal Protocol. The increasing involvement of these institutions has greatly enhanced the development of the national programme on ozone monitoring and research in Nigeria.
The monitoring of total column ozone and other atmospheric constituents under the auspices of Global Atmosphere Watch (GAW) programme of WMO started in Nigeria in 1993 with the establishment of a GAW station each in Lagos (Latitude06°36'N; Longitude 03°26'E; Elevation 10m) and Oshogbo (Lat.07° 47'N; Long.04° 29'E; Elevation 304.5m) by the Nigerian Meteorological Agency (NIMET) which was then known as Department of Meteorological Services in the Ministry of Aviation.

1.1 Column Measurements of Ozone and other Gases/Variables relevant to Ozone Loss

Total Column Ozone is measured at the GAW stations in Oshodi, Lagos and Oshogbo. Subject to the state of the atmosphere, daily routine measurements up to a maximum of ten observations are made with the Dobson spectrophotometer #5703 (Shimatzu type). Total ozone measurements are archived in the database of the Nigerian Meteorological Agency (NIMET).

1.2 Profile Measurements of Ozone and other Gases/Variables relevant to Ozone Loss

Field and model studies have found elevated surface O_3 concentrations in Nigeria in December to February due to seasonal open fires (Helas et al., 1995; Marufu et al., 2000; Sauvage et al., 2005; Aghedo et al., 2007). Following testing of the GEOS-Chem simulation of O_3 with aircraft observations from MOZAIC (Thouret et al., 1998) and satellite observations from TES, a thermal IR instrument with sensitivity to O_3 in the lower free troposphere and examine the implications for O_3 pollution over Nigeria now and in the future. MOZAIC observations of vertical O_3 profiles from commercial flights are available for Lagos and Abuja in January to February, 2003 - 2004 at 18 - 21 and 18 - 19 local time, respectively. These are shown in Fig. 1 together with the corresponding mean model profiles for January to February 2006 sampled at the same local time.

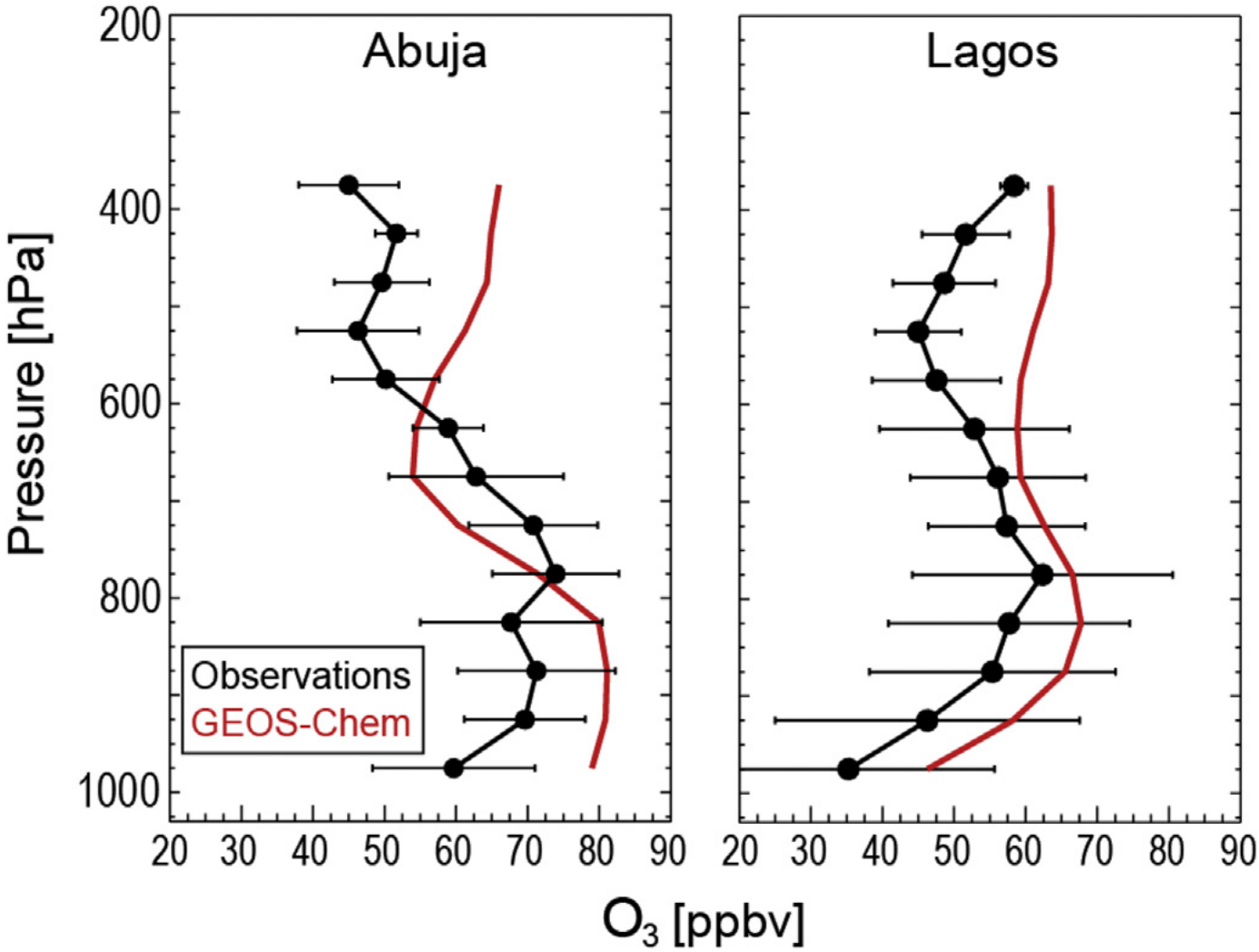


Fig. 1: Mean vertical profiles of O3 concentrations over Abuja and Lagos in January to February

MOZAIC observations are for 3 descent flights over Abuja and 16 over Lagos at 18 - 19 and 18 - 21 local time, respectively, in 2003 - 2004. Horizontal lines are 1s standard deviations. Corresponding GEOS-Chem profiles are means for January – February 2006 at the same local time.

The observations at Abuja show mean concentrations of 60 - 75 ppbv from the surface to 700 hPa. Such high values are due to a combination of fires and anthropogenic emissions. It does not capture the drop at the surface, which could be due to poor model representation of stratified conditions near the surface after sunset (Jacob et al., 1993). Lower O_3 concentrations in the Abuja profile above 700 hPa are associated with the African Easterly Jet (AEJ) (Sauvage et al., 2007). Concentrations over Lagos differ from those over Abuja mostly below 900 hPa, reflecting the influx of clean oceanic air

1.3 UV Measurements

NIMET has since commenced measurements of surface UVB and Solar radiation at several locations in Nigeria in addition to the GAW stations in Lagos and Oshogbo. The automatic weather stations that measure these parameters and some meteorological variables were set up as part of the implementation of the Agency’s programme on studies relating to the effects

of UV-B on human health and the ecosystems. The UV is measured with silicon photodiode sensor.

1.4 Calibration Activities

The Dobson spectrophotometer at NIMET is calibrated (mercury lamp and standard lamp tests) every month and the calibration data are documented. The instrument has also successfully participated in two international intercomparions organized by WMO for all the Dobson instruments
operated in Africa. These took place in Pretoria, South Africa in 2000 and Dahab in Egypt in 2004

2. THEORY, MODELLING, AND OTHER OZONE RELATED RESEARCH

(e.g., 3-D CTM modelling, data assimilation, use of satellite data, UV effect studies)
Comparative analysis of total ozone data from the ground-based Dobson spectrophotometer and the overpass data from satellite instrument EPTOMS in Lagos-Nigeria (Lat.6.6°N, Long 3.3°E) for the year 1997-2002 indicated that EPTOMS ozone series overestimated those of the Dobson's maximally between July-September with an average difference of 11%, while the Dobson ozone profile exceeded the EPTOMS by 6% in the month December-January(Akinyemi M.L., 2011). A strong anti-correlation of -0.88 was observed between the Dobson's ozone profile and the EPTOMS in the month July-September. The Dobson data showed considerable high frequency fluctuations with no clear seasonal trend. Maximum inter-annual differences for both instruments fell within the period of low precipitation in the West Africa region. Despite the monthly differences in the two set of data, their seasonal and annual component showed significant positive correlation of 0.53 with each other

3. DISSEMINATION OF RESULTS

3.1 Data Reporting

Total ozone data measured in Lagos are transmitted monthly to the World Ozone and Ultra-Violet Data Centre (WOUDC) in Toronto, Canada

3.2 Information to the public

In Nigeria, priority attention is given to public awareness campaign on the consequences of ozone layer depletion. The National Ozone Office (NOO) of the Federal Ministry of Environment, the Designated National Authority for the implementation of the Montreal Protocol in Nigeria anually commemorates the International Day for the preservation of the Ozone Layer. This usually include press release by the Honorable Minister of Environment on the importance of the ozone layer, the need to preserve it, national and international efforts in the preservation of the ozone layer and implementation of the Montreal Protocol in Nigeria. The NOO also carries out secondary schools outreach programme and give lectures with the aim of raising awareness among secondary school children on the importance of the ozone layer and its preservation. Awareness and promotional materials are distributed to the children on the importance of the ozone layer. The public awareness efforts of the NOO is yielding results as more Nigerians are getting aware of the importance of the ozone layer and need to preserve it as it can be shown in the country's achievements of meeting the Montreal Protocol's phase targets for HCFCs.

3.3 Relevant scientific papers

Akinyemi M.L. (2011): Comparative Analysis of Total Ozone Data from Satellite EPTOMS and Ground-Based Dobson Instrument at Lagos-Nigeria. Journal of Innovative Research in Engineering and Science.
PP*.162-172*

Akinyemi M.L. (2012): Wind Convolution and Ozone Distribution over Nigeria. Archives of Physics Research. PP 138 - 145

Marais et al (2014): Anthropogenic emissions in Nigeria and implications for atmospheric ozone pollution: A view from space. Atmospheric Environment Journal.PP.32 – 37

Olumayede E.G. (2014): Atmospheric Volatile Organic Compounds and Ozone Creation Potential in an Urban Center of Southern Nigeria. International Journal of Atmospheric Sciences
Volume 2014, Article ID 764948, 7 pages

4. PROJECTS, COLLABORATION, TWINNING AND CAPACITY BUILDING

A number of institutions are engaged in the monitoring and research needed to improve the understanding of ozone issue and other trace gases in Nigeria.
NIMET collaborates with OAU and some other institutions on issues relating to the protection of the ozone layer, impact of UV-B on human health and the environment in general.
The National Ozone Office (NOO) of the Federal Ministry of Environment is playing its statutory role as the Designated National Authority for the implementation of the Montreal Protocol in Nigeria. The NOO also collaborates with relevant government agencies and stakeholders in the implementation of the Protocol. Presently, the NOO is implementing the Hydrochlorofluorocarbons (an ODS) Phase out Management Plan (HPMP) project in Nigeria. The aim is totally phase out the use of HCFCs in Nigeria by 2040. The NOO has achieved its 10% reduction of HCFC consumption in 2015 and is prepared to achieving further reductions of HCFC consumption over the years. The following are critical achievements of the NOO in the phase out of ozone depleting substances:

i. **Completion and Commissioning of the Pilot Hydrocarbon (HC) Plant**: The Pilot HC Plant is a demonstration project for the feasibility of production of high grade HCs (R-290, R-600a) to be used in the Refrigeration & Air-conditioning sector (RAC). UNDP is the Implementing Agency for the project. The project was commissioned in November, 2015. The next step of the project is the up-scaling of the plant for commercial production of high grade HCs. This will assist the country and the West African region with much needed HC refrigerants when eventually the ban on HCFCs comes in to place. The project will also assist in the promotion of indigenous expertise in HC Refrigerants production.

ii. **Building of local capacity for the formulation and production of Methyl Formate-based pre-blended polyols in the foam sector**: The system house at Vitapur Nig. Ltd is being upgraded to produce Methyl formate based pre-blended polyols in the foam sector. UNDP is the Implementing Agency for the project. The project is at advanced stage of completion and if completed and operational will assist Nigeria in the implementation of the MP's ODS phase out project by phasing out the use of HCFC-141b in the foam sector.

iii. **Distribution of 75 low pressure foaming machines to manufacturers of ice block making machines**: 75 low pressure foaming machines were distributed to beneficiary ice block making machine manufacturers for the production of rigid foam for thermal insulation purposes in the ice block machines. This project is under the UNIDO component of the HPMP project. About 30 of the machines have been installed and the installation of the remaining 45 is ongoing. The machines are designed to use Methyl formate as the foam blowing agent, thereby assisting us to phase out of the use of HCFC-141b in the Refrigeration & Air-conditioning Manufacturing Sector. The machines will also assist the beneficiary technicians to retain their jobs since they will be using the machine with ozone friendly substances.

5. FUTURE PLANS

There is a deliberate plan by the government of Nigeria to continue to encourage and carry out monitoring and research that will improve the understanding of ozone issue and thereby contribute positively to the regional and global efforts towards the protection of the ozone layer and sustainability of the environment. The Nigerian Meteorological Agency is spearheading this course. The National Ozone Office is committed to further raising awareness on the importance of the ozone layer and the need to preserve it. The NOO is also committed to meeting the MP's ODS phase out targets for ozone depleting substances (HCFCs).
The following are the plans on ozone research and monitoring in Nigeria:
• Continuation of Total Ozone and UV-B radiation measurements.
• Increase in network of GAW stations for the monitoring of total ozone, surface ozone, greenhouse gases, UV-B radiation, solar radiation, acid rain, etc.
• Measurement of ozone profile with Dobson spectrophotometer and other methods.
• Daily UV-B radiation forecast for Nigeria.
• Effects of increased UV-B on human and animal health, as well as the ecosystems.
• Continuation of awareness campaign on ozone and related issues.
• Increased collaboration with local and international organizations on ozone and related issues.

6. NEEDS AND RECOMMENDATIONS

In order to facilitate the ongoing and planned ozone, UV radiation monitoring and research programmes in Nigeria, assistance will be needed in the following areas:

• Expansion of total column ozone measurements. This will involve among other things, acquisition of Brewer spectrophotometer and other modern instruments.

• Acquisition of instruments for ozone profile measurement.

• Expansion of our UV-B and solar radiation monitoring network.

• Regular calibration of instruments especially in the developing countries to ensure high quality data for research and other purposes.

• Training of personnel to enhance professional competence in monitoring, data processing and research especially in the developing countries.

• Provision of spare parts and essential consumables.

NORWAY

Ozone/UV monitoring and research

Ozone monitoring and related research activities in Norway involve several institutions and there is no distinct separation between research, development, monitoring and quality control. This report presents Norwegian ozone & UV related activities that have been carried out the last years.

1. OBSERVATIONAL ACTIVITIES

In 1990 the Norwegian Environment Agency (the former Norwegian Pollution Control Authority) established the programme *"Monitoring of the atmospheric ozone layer"*, which included measurements of total ozone at selected sites in Norway. Some years later, in 1994/95, the network was expanded and "*The Norwegian UV network*" was established. It consists of nine 5-channel GUV instruments located at sites between 58°N and 79°N. In addition the network included ozone lidar measurements until 2011. The measurements are undertaken by the Norwegian Radiation Protection Authority, and the Norwegian Institute for Air Research on behalf of the Norwegian Environment Agency. NRPA is responsible for the quality assurance program of the UV-network and for reporting relevant health effects of natural UV radiation. Table 1 gives an overview of the location of the various stations, the type of measurements, and the institutions/institutes responsible for the daily operation of the instruments. The measurement sites are marked in Figure 1: Blue circles represent sites where both quality assured total ozone and UV measurements are performed, whereas green circles represent sites with UV measurements only.

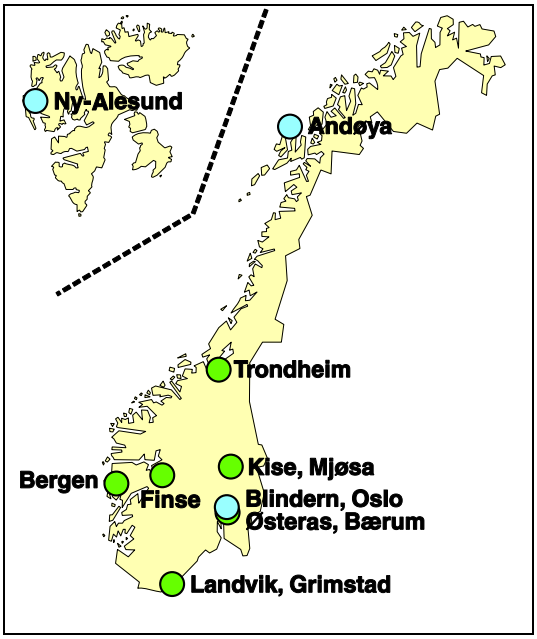


Figure 1: Map of Norwegian ozone and UV sites

Table 1: Overview of the locations and institutes involved in ozone and UV monitoring activities in Norway

Station	Location	UV	Total ozone	Ozone lidar	Institute
Landvik (Grimstad)	58ºN, 08ºE	GUV			Norwegian Radiation Protection Authority
Oslo	60ºN, 10ºE	GUV	Brewer, GUV		University of Oslo/ Norwegian Institute for Air Research
Østerås	60ºN, 10ºE	GUV, Bentham			Norwegian Radiation Protection Authority
Bergen	60ºN, 05ºE	GUV			Norwegian Radiation Protection Authority
Finse	60ºN, 07ºE	GUV			Norwegian Radiation Protection Authority
Kise	60ºN, 10ºE	GUV			Norwegian Radiation Protection Authority
Trondheim	63ºN, 10ºE	GUV			Norwegian Radiation Protection Authority
Andøya	69ºN, 16ºE	GUV	Brewer, GUV	x	Norwegian Institute for Air Research /Andøya Space Center
Ny-Ålesund	79ºN, 12ºE	GUV	SAOZ, GUV		Norwegian Institute for Air Research
Antarctica	72ºS, 02ºE	NILU-UV	NILU-UV		Norwegian Institute for Air Research

1.1 Column measurements of ozone

Total ozone measurements using the Dobson spectrophotometer D56 were performed on a regular basis in Oslo from 1978 to 1998. In Tromsø, Dobson measurements with D14 started back in 1939 and systematic measurements were performed until 1972. After a break of 12 years, the Tromsø

Dobson measurements started up again in 1985 and lasted until 1999. Quality-assured Dobson D8 measurements were also performed in Ny-Ålesund, Svalbard, from 1995 to 2007. In 2007 the measurements terminated due to technical failure.

Since the summer 1990 Brewer instrument no. 42 has been in operation at the University of Oslo (Blindern). In 1994 Brewer measurements (with B104) started up in Tromsø, but after the termination of other ozone-related activities at the Auroral Observatory in Tromsø in 1999, the instrument was moved to Andøya, 130 km southwest of Tromsø. Today daily total ozone values from Oslo and Andøya are primarily based on measurements with these Brewer spectrometers. The ozone values are derived from direct sun measurements when available. On overcast days and days where the solar zenith angle is large, the ozone values are calculated from the global irradiance (GI) method (Stamnes et al., 1991). Except for the period from 1973 to 1984, total ozone has been measured on a regular basis in Tromsø/Andøya since 1939, which makes this time series the second longest in the world. The Andøya site is no longer included in the national ozone monitoring programme, but financial funding from the Norwegian Ministry of Climate and Environment will ensure measurements in the future.

NILU - The Norwegian Institute for Air Research is also measuring total ozone in Svalbard. Since 1991 there has been a DOAS instrument (type SAOZ) in Ny-Ålesund measuring total columns of ozone and NO_2. These NO_2 and ozone measurements are a part of the Network for the Detection of Atmospheric Composition Change (NDACC). As SAOZ measurements only can provide ozone values at solar zenith angles > 85º, a GUV instrument is used to derive total ozone in Ny-Ålesund during summer. Recently, NILU has started a cooperation with CNR, Italy, to operate and quality-control common measurements with a Brewer instrument owned by CNR in Ny-Ålesund.

Since 2007, total ozone has also been measured by NILU at the Norwegian station Troll in Antarctica. This is done with the NILU-UV radiometer (see section 1.3). Currently, the complete data series is under re-evaluation.

1.2 Ozone profile measurements

An ozone lidar has been operated at ALOMAR (Andøya) since 1995. Initially, this was a cooperation project of the Norwegian Defence Research Establishment (FFI), NILU, and Andøya Rocket Range, from which FFI withdrew in 2006. Unfortunately the ozone lidar measurements were excluded from the national monitoring programme in 2011 due to lack of financial support with the consequence that also NILU had to withdraw from the cooperation. The lidar is still operational, but only operated occasionally by Andøya Rocket Range (now Andøya Space Center), and there is currently no funding for data analysis.

The lidar instrument was approved as a complementary site of the NDACC in 1997, and data were submitted to the NDACC database until 2011. The ozone lidar was also used to measure polar stratospheric clouds and stratospheric temperature profiles. Recently, all PSC observations have been re-evaluated systematically, both from ozone lidar measurements and measurements with the co-located Rayleigh-Mie-Raman lidar owned by the Leibniz Institute of Atmospheric Physics, Kühlungsborn, Germany. These data are available on request.

Ozonesonde measurements were performed from 4 sites on Norwegian territory in the 1990s and 2000s, but since 2007 only ozonesonde launches at Ny-Ålesund by Alfred-Wegener Institute, Germany, have continued. These are not part of the Norwegian ozone monitoring activities.

1.3 UV measurements

In total, nine sites are included in the Norwegian UV network. The instruments, GUV from Biospherical Instruments Inc, are designed to measure UV irradiances in 5 channels (except one instrument, which only has 4 channels). Using a technique developed by Dahlback (1996), it is possible to derive 9 different irradiance parameters, including complete UV spectra from 290 to 400 nm, biologically weighted UV doses for any action spectrum in the UV wavelength region, as well as total ozone column and cloud cover information.

Spectral UV irradiances (global scans) are measured regularly with the Brewer instruments at the Department of Physics, University of Oslo, and at Andøya (ALOMAR).

In January 2007 NILU started measurements with a filter instrument (the NILU-UV radiometer) at the Norwegian research station Troll in Antarctica, financed by the Norwegian Research Council. The instrument is calibrated every month against relative calibration lamps in order to keep track of instrument drift. In 2016, the instrument had to be replaced due to technical problems.

1.3 Measurements of Ozone-Depleting Substances (ODSs)

NILU is running an ADS-GCMS and a Medusa-GCMS at the Zeppelin Observatory, Svalbard, which provides high quality measurements of more than 20 ODSs regulated through the Montreal Protocol (Myhre et al, 2015). This is a part of the national programme for monitoring of greenhouse gases, financed by the Norwegian Environment Agency. Several CFCs are also measured at the Troll Observatory in Antarctica (www.nilu.no/Miljøovervåkning/Trollobservatoriet/tabid/213/Default.aspx).

1.4 Calibration activities

1.4.2 The Brewer instruments

The Brewer instruments in Oslo and at Andøya have been in operation for more than 20 years. Every year International Ozone Services, Canada, calibrates the Brewer instruments at both sites, and the instruments are also regularly calibrated against standard lamps in order to check their stability. The calibrations show that the Brewer instruments have been stable for most of the years of observations. The Andøya Brewer instrument has shown increased calibration instabilities since 2013, and especially in 2015 and early 2016. The issue is currently under discussion at IOS. Total ozone measurements from the Oslo Brewer instrument agreed well with the Dobson measurements performed during the period of overlapping measurements from 1991 to 1998.

1.4.3 The GUV instruments

As a part of the Norwegian FARIN project a major international UV instrument intercomparison was arranged back in 2005. Altogether 51 UV radiometers from various nations participated, among them 39 multiband filter radiometers (MBFR's). The instruments were also characterized on site. In addition to measurements of spectral responses, measurements against QTH lamps and cosine responses were performed for a selection of instruments. The main results have been published by Johnsen et al. (2008).

NRPA houses an optical calibration laboratory and facilities for outdoor calibrations. All the 13 GUV instruments in the Norwegian UV network are yearly calibrated on site against a travelling reference GUV, managed by NRPA. The travelling reference is traceable to the European travelling reference spectroradiometer QASUME, and regularly operated side by side a Bentham spectroradiometer operating at the roof of the NRPA building. Either reference instruments are regularly participating in blind test intercomparisons. Annual calibration factors are calculated for the GUV instruments prior to final publications of ozone and UVI. Currently, efforts are made to finance new instrumentation at the network locations, in order to ensure still continuous, high quality measurements, and to provide a wider spectral range and versatility of use of monitoring data.

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

Results from the national programme *"Monitoring of the atmospheric ozone layer and natural ultraviolet radiation"* are published by the Norwegian Environment Agency and NILU every year. Below are trend results from the last report (Svendby et al., 2016).

2.1 Ozone observations in Oslo

In order to detect possible ozone reductions and trends over Oslo, total ozone values from 1979 to 2015 have been investigated. For the period 1979 to 1998 data from the Dobson instrument has been applied, whereas for the period 1998 to 2015 the Brewer measurements have been used. The results of the trend analysis are summarized in Table 2. The second column indicates that a large ozone

decrease occurred during the 1980s and first half of the 1990s. For the period 1979-1997 there was a significant decline in total ozone for all seasons. For the winter and spring the decrease was as large as -6.2 %/decade and -8.4 %/decade, respectively. The negative ozone trend was less evident for the summer, but nevertheless it was significant to a 2σ level.

Table 2: Percentage changes in total ozone over Oslo for the period 1.1.1979 to 31.12.2015. The numbers in parenthesis represent uncertainty (1σ)

Time period	Trend (%/decade) 1979-1997	Trend (%/decade) 1998-2015
Winter (Dec – Feb)	-6.2 (2.4)	2.2 (2.3)
Spring (Mar– May	-8.4 (1.4)	0.0 (1.9)
Summer (Jun – Aug)	-3.4 (1.1)	0.1 (1.0)
Fall (Sep – Nov)	-4.3 (1.0)	1.8 (1.2)
Annual (Jan-Dec)	-5.8 (1.0)	0.9 (1.1)

For the period 1998-2015 the picture is very different. All seasonal trends as well as the annual trend are either zero or positive. However, none of the trend values are significant on a 2σ level. The largest positive trend (2.2%/decade) occurs in winter, while it is zero in summer. Although the trends are not significant on a 2σ level, they manifest a marked change compared to the trends in the previous report, which only included data until 2012 and which were still negative in 3 out of 4 seasons.

2.2 Ozone observations at Andøya

As mentioned above, ozone measurements in Northern Norway were performed in Tromsø until 1999 and at ALOMAR/Andøya from 2000. Correlation studies have shown that the ozone climatology is very similar at the two locations and that the two datasets are considered as equivalent representing one site.

Table 3: Percentage changes in total ozone over Andøya/Tromsø for the period 1979 to 2015. The numbers in parenthesis represent uncertainty (1σ).

Time period	Trend (%/decade) 1979-1997	Trend (%/decade) 1998-2015
Spring (Mar – May):	-8.4 (1.5)	0.7 (1.8)
Summer (Jun – Aug):	-2.8 (0.9)	0.5 (1.0)
Autumn (Sept – Oct):	-4.2 (1.1)	3.1 (0.7)
Annual (Mar – Oct):	-5.5 (0.9)	1.1 (1.0)

During the years with absent Dobson total ozone measurements in Tromsø in 1979 and the 1980s, total ozone values from the satellite instrument TOMS (Total ozone Mapping Spectrometer) over Andøya were used in the trend studies. The results of the analyses are summarized in Table 3.

Similar to Oslo, the ozone layer above Andøya declined significantly from 1979 to 1997. This decline was evident for all seasons. The negative trend for the spring season was as large as -8.4%/decade, whereas the negative trend for the summer months was -2.8%/decade and for autumn (September/October only) -4.2%/decade. The trend in annual (March – October) total ozone was -5.5%/decade. In contrast, all trends were positive in the period 1998 – 2015, but only the autumn value (+3.1%/decade) is significant at a 2σ level. Both trends in the autumn months are probably not caused by ozone depletion, but, as pointed out in Hansen and Svenøe (2005), due to long-term atmospheric changes (stratospheric temperature, tele-connection patterns).

2.3 Ozone observations in Ny-Ålesund

The first Arctic ozone measure-ments started in Svalbard almost 65 years ago. In 1950 a recalibrated and upgraded Dobson instrument (D8) was sent to Longyearbyen, and Søren H.H. Larsen was the first person who performed systematic ozone measurements in polar region (Henriksen and Svendby, 1997).

Regular Dobson ozone measure-ments were performed in Svalbard until 1962. The data have been reanalyzed and published by Vogler et al. (2006). After 1962 only sporadic measurements were performed in Longyearbyen, but after the instrument was moved to Ny-Ålesund in 1994 more systematic measurements took place. However, the Dobson instruments require manual operation

and it soon became more convenient to replace the Dobson instrument with the more automatic SAOZ and GUV instruments.

Table 4: Percentage changes in total ozone over Ny-Ålesund for the period 1979 to 2015. The numbers in parenthesis represent uncertainty (1σ).

Time period	Trend (%/decade) 1979-1997	Trend (%/decade) 1998-2015
Spring (Mar – May):	-11.8 (1.9)	0.1 (2.4)
Summer (Jun – Aug):	-2.2 (1.6)	-1.6 (1.0)
Autumn (Sept - Oct):	-3.8 (1.9)	0.6 (1.4)
Annual (Mar – Sep):	-6.2 (1.2)	-0.4 (1.4)

The ozone trend studies presented in Table 4 are based on a combination of Dobson, SAOZ, GUV and satellite measurements. For the years 1979 to 1994 the monthly mean ozone values have been based on TOMS Nimbus 7 and Meteor-3 overpass data. For the latest 22 years only ground based measurements have been used in the trend studies: Dobson data have been included when available, SAOZ data have been 2nd priority, whereas GUV data have been used when no other ground-based measurements have been available. Autumn observations have been made possible by the SAOZ instrument, which yields reliable data even at solar elevations close to zero.

As seen from Table 4 the ozone trend pattern in Ny-Ålesund has many similarities to the Oslo and Andøya trend series. A massive ozone decline was observed from 1979 to 1997, especially during winter and spring. The trend for the spring season was as large as -11.8%/decade, whereas the negative trend for the summer months was only -2.2%/decade. The annual trend in total ozone was -6.2%/decade during these years. In contrast, no significant trends were observed for the second period from 1998 to 2015. During this period virtually no change in total ozone was observed for the spring months, whereas a trend of -1.6%/decade was found for the summer months and a positive trend of 0.6%/decade in autumn. The annual trend for the period 1998-2015 was -0.4% /decade. None of these results are significant at a 2σ significance level.

2.4 UV observations

The Norwegian UV network, established in 1994/95, consists of nine 5-channel GUV instruments located from 58°N to 79°N (see Figure 1). NILU is responsible for the daily operation of three of the instruments, located at Oslo (60°N), Andøya (69°N) and Ny-Ålesund (79°N). The Norwegian Radiation Protection Authority (NRPA) is responsible for the operation of the measurements performed at Trondheim, Bergen, Kise, Landvik, Finse and Østerås.

Table 5: Annual integrated UV doses (kJ/m^2) at three stations during the period 1995 - 2015.

Year	Oslo	Andøya	Tromsø*	Ny-Ålesund
1995	387.6			
1996	387.4		253.6	218.5
1997	415.0		267.0	206.5
1998	321.5		248.4	217.7
1999	370.5		228.0	186.1
2000	363.0	239.7		231.0
2001	371.0	237.0		208.6
2002	382.5	260.0		201.8
2003	373.2	243.4		No measurements
2004	373.2	243.7		190.5
2005	*No annual UV doses due to calibration campaign*			
2006	372.4	219.4		No measurements
2007	351.8	253.3		No measurements
2008	375.3	266.5		No measurements

2009	278.6	254.1		No measurements
2010	360.5	225.6		201.6
2011	365.2	254.8		200.8
2012	352.6	227.5		211.6
2013	362.4	247.0		178.9
2014	396.4	249.7		215.0
2015	358.9	219.2		213.6
*The GUV instrument at Andøya was operating in Tromsø for the period 1996 – 1999				

Annual UV doses for the period 1995 - 2015 at the three GUV instruments in Oslo, Andøya and Ny-Ålesund are shown in Table 5.. For days with missing data daily UV doses are calculated from a radiative transfer model, FastRt, *http://nadir.nilu.no/~olaeng/fastrt/fastrt.html*. UV measurements in Ny-Ålesund were excluded from the national monitoring programme from 2006 to 2009 due to lack of financial support, but the GUV instrument is now back in daily operation.

At all three stations the annual integrated UV dose reveals a negative trend in the order of -2.5%/decade, being largest in Oslo (-3.2%/decade) and smallest in Ny-Ålesund (-2.0%/decade). However, none of the UV trends derived is significant at a 2-σ confidence level. It is also worth noting that although the three stations are rather evenly spaced geographically, UV levels at Tromsø/Andøya are much closer the Ny-Ålesund values than to Oslo values.

3 THEORY, MODELLING, AND OTHER RESEARCH

3.1 University of Oslo

Department of Physics is operating the Brewer instrument and a GUV instrument at the roof of the Chemistry building at the University of Oslo. The institute has also been involved in ground-based measurements of solar UV radiation in developed countries with extreme UV levels, e.g. at the Tibetan Plateau (Norsang et al., 2014). The University of Bergen and NTNU have also participated in these studies.

At the Physics department there has been a focus on developing tools for deriving total ozone and cloud parameters from filter instruments and global irradiance UV measurements (Dahlback et al., 2005). Radiative transfer models are used for many purposes, including UV effect studies related to various cancer types and Vitamin D production (e.g. Moan at al., 2012).

3.2 NILU - Norwegian Institute for Air Research

At NILU there has been a main research focus on understanding the dynamical influence on the variability in total ozone, especially at the northern hemisphere at mid and high latitudes. Several studies and research activities are done in collaboration with Birkeland Center for Space Research (University of Bergen), the University of Oslo, CICERO and the Norwegian Radiation Protection Authority. Some of the more recent activities and results are listed below:

- Using a data assimilation technique and satellite observations by the SMR instrument aboard the Odin satellite, the inter-annual variability in ozone depletion over the Arctic has been quantified homogenously between 2002 and 2013. The two ozone destruction mechanisms involving halogen and nitrogen chemical families play differently between cold and warm winters in the stratosphere. In cold winters, like in 2010/2011, characterized by a very stable vortex associated with particularly low temperatures, there is an important halogen-induced loss occurring inside the vortex in the lower stratosphere. We found a loss of 2.1 ppmv at an altitude of 450K in the end of March 2011, which corresponds to the largest ozone depletion in the northern hemisphere observed during the last decade. In warm winters affected by major sudden stratospheric warmings, such as 2003/2004,

2005/2006, 2008/2009 and 2012/2013, the ozone loss occurring in the middle stratosphere, driven by nitrogen oxides can outweigh the effects of halogens (Sagi et al., 2016)

- Transient increases in mesospheric ozone following stratospheric sudden warmings in the northern hemisphere and southern hemisphere (in 2002) have been studied (Tweedy et al., 2013; Smith-Johnsen et al., 2016) using simulations with the Whole Atmosphere Community Climate Model (WACCM), and also the Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) observations aboard the NASA TIMED satellite.
- The role of planetary, gravity and tidal waves in driving the transport of the nitrogen oxides produced by energetic particle precipitation from the lower thermosphere to the stratosphere has been studied with WACCM including detailed comparisons with Odin SMR observations during elevated stratopause events (Orsolini et al., 2016). Noticeably, change in low-latitude ozone drives anomalously strong excitation of semi-diurnal tide (Limpasuvan et al., 2016), as observed by radar measurements in Trondheim (64° N).

3.3 NRPA – the Norwegian Radiation Protection Authority

A continuous focus is kept on ensuring well calibrated UV monitoring data and developing data products relevant to health and environmental assessments. QA involves participation and arrangement of solar intercomparisons, and administration of annual calibrations with the travelling reference. The methodology involves corrections for spectral and angular characteristics of individual instruments, in combination with spectroradiometer operation and RT modelling. Time series of measurements for the UV stations are compared with RT modelling results, applying ancillary observation data to include the impact of variations in total ozone, surface albedo and cloud optical depth. Gaps in measurements series are substituted with modelled data in order to get continuous series of station data. NRPA is participating in the CERAD CoE, a research programme dedicated to environmental impacts of ionizing radiation in combination with UV radiation and other environmental stressors.

4. DISSEMINATION OF RESULTS

4.1 Data reporting and storage

The complete set of revised Dobson total ozone values from Oslo is available at The World Ozone and Ultraviolet radiation Data Centre (WOUDC), http://www.woudc.org/. Also, Brewer DS measurements are regularly submitted to WOUDC.

Submission of Brewer data from Andøya was set on halt after problems with instrument drift stability were detected. It is envisaged that they will be resumed after re-calculation of all measurements since. This may, however, be delayed because of the severe funding reduction for this site.

The total ozone and NO_2 measured from the SAOZ instrument at Ny-Ålesund are submitted to the Network for the Detection of Atmospheric Composition Change (NDACC).

An sql database at NRPA holds GUV measurements data for the whole period since 1995. A library of station data are stored as structured Matlab binary files, containing a complete archive of measurement data, meta data, and reconstructed data, as well as a number of data products to be disseminated in the near future. UVI measurements for the nine stations in the network are regularly disseminated for use in the annual State of the Climate report series, issued by BAMS.

4.2 Information to the public

Real-time values of total ozone, UV indices and cloud thickness (CMF) for Oslo are available at http://tid.uio.no/ozone/. Also, near real time data and historical ozone time series from the SAOZ instrument in Ny-Ålesund can be found at http://saoz.obs.uvsq.fr.

NILU operates a web portal for dissemination of UV observations and UV forecasts for Norway and common global tourist destinations, available at http://uv.nilu.no. The content of the UV web pages are:

- UV forecast for three days for user-selected locations in Norway. The UV forecast is given for clear-sky, partly cloudy and cloudy conditions. Snow cover is also taken into account.
- Global UV forecast for common tourist destinations
- Measured UV doses and total ozone values measured at the Norwegian stations
- Facts on UV radiation and the ozone layer
- Information about sun protection for different locations and situations
- Preliminary total ozone values derived from the GUV instruments.

The public may receive ozone and UV forecasts at user-selected locations by e-mail. The web application has been developed by NILU in co-operation with the Norwegian Radiation Protection Authority, Storm Weather Center, and the Norwegian Environment Agency. The Norwegian Meteorological Institute has developed an additional UV forecast service, where the weather forecast is an integrated part of the forecasted UV index.

Observations performed by the Norwegian Radiation Protection Authority and NILU are also available at the web portal http://www.nrpa.no/uvnett/ together with annual doses and information on sun protection.

In 2013 the Norwegian Environment Agency co-funded the production of a UNEP movie "The Arctic & the Ozone Layer: Stabilizing our Environment and Climate". Several Norwegian key researchers participated in the movie, together with the personnel operating the monitoring stations.

4.3 Relevant scientific papers

The ozone and UV monitoring and model studies in Norway give rise to research collaboration with national and international partners. In chapters 3 and 8 some of the most relevant publications are referred and listed. They give an impression of international collaboration and ongoing research in the Norwegian ozone and UV scientific community the last few years.

5. PROJECTS AND COLLABORATION

Norwegian institutions and scientists are participating in some international and national projects related to ozone and UV. However, the number of projects have decreased significantly the last years due to reduced funding and little focus on stratospheric ozone. Below is an overview of some of the most important projects related to ozone and UV research in Norway:

International projects

NDACC: *The Network for the Detection of Atmospheric Composition Change (1991-> present)* is a set of high-quality remote-sounding research stations for observing and understanding the physical and chemical state of the stratosphere. Ozone and key ozone-related chemical compounds and parameters are targeted for measurement. The NDAAC is a major component of the international middle atmosphere research effort and has been endorsed by national and international scientific agencies, including the International Ozone Commission, the United Nations Environment Programme, and the World Meteorological Organization. Web-site: http://www.ndsc.ncep.noaa.gov/

HEPPA-SOLARIS: This is an international cooperation including SPARC focusing on observational and modelling studies of the influences of solar radiation and energetic particle precipitation (EPP) on the atmosphere and climate. Topics covered include the causes and phenomenology of solar radiation and energetic particle variability, mechanisms by which radiative and particle forcing affect atmospheric chemistry and dynamics, contributions of solar and EPP forcing to climate variability and space weather.

Annual contributions to the 'State of the Climate' report serie of BAMS.

National projects

***Solar-Terrestrial Coupling through High Energy Particle Precipitation in the Atmosphere: a Norwegian contribution (HEPPA-Norway)*:** see HEPPA-SOLARIS.

Solar effects on natural climate variability in the North Atlantic and Arctic (SOLENA): This project will investigate possible effects of the solar cycle on atmospheric dynamics, especially on tele-connection patterns such as the NAO/AO. This may happen through a modulation of atmospheric chemistry in the upper stratosphere and the mesosphere. The project will apply coupled atmosphere-ocean models including relevant atmospheric chemistry in the 50-100 km altitude range.

Atmo-TROLL: *Atmospheric research and monitoring at Troll – a long-term observational program (2007->).* This program intends to establish new knowledge on annual and short-term variability as well as long-term changes of climate and pollution parameters. The list of parameters comprises physical, optical and chemical properties of aerosols, ozone and UV, organic and inorganic pollution including Hg, CO and NMHC and surface ozone. The project is coordinated by NILU and funded by The Research Council of Norway.

NRPA is involved in two **community medicine projects**, utilizing UV network data: A melanoma project in co-operation with the Norwegian Cancer Registry and University of Oslo, and a project on porphyriae patients, in co-operation with NAPOS (Haukeland University Hospital).

6. FUTURE PLANS

A short presentation of future plans are summarised below:

- The existing ozone and UV monitoring activity will continue, with a focus on long-term continuity and high-level quality assurance
- The cooperation with CNRS, France, regarding long-term series of O_3 and NO_2 measurements with the SAOZ instrument in Ny-Ålesund will continue.
- Cooperation has been established with CNR, Italy, regarding ozone and UV research in Ny-Ålesund in the frame of the Ny-Ålesund Atmospheric Flagship programme. In particular, it is envisaged to re-start Brewer operations and thus complement ozone monitoring with this instrument.
- The University of Oslo and NILU are already involved in community medicine activities related to ozone/UV and health and will continue to establish cooperation with the community medicine institutions.
- Efforts on improving measurement accuracy will continue at NRPA, implementing a newly designed instrument for monitoring long term drift in QTH secondary standard lamps for network instrument calibrations.
- NILU has deployed a NILU-UV instrument that is installed at the Norwegian Antarctic Troll Station (71º S). Analysis of the data and a publication are in progress.
-

Apart from the activities listed above, there are no immediate plans for changes in the ozone monitoring programs in Norway.

7. NEEDS AND RECOMMENDATIONS

While Ny-Ålesund ozone and UV monitoring has been included in the monitoring programme, total ozone and UV monitoring at Andøya is no longer covered by funding from the Norwegian Environment Agency. Instead, NILU receives direct support from the Ministry of Climate and Environment to continue this longest Norwegian ozone measurement series as well as UV measurements. The only ozone profiling measurements on Norwegian territory are weekly ozonesonde launches performed by Alfred Wegener Institute, Germany, at Ny-Ålesund, Svalbard. A long-term commitment to perform such measurements again at Ørlandet (the programme was stopped in 2007) would be highly welcome, as it fills a latitudinal gap between the closest remaining ozonesonde stations, Sodankylä, Finland (68º), and Lerwick (60º), UK.

The UV-monitoring programme in Norway is a split cooperation between the Norwegian Radiation Protection Authority (NRPA) and NILU, but is funded from different state agencies/ministries. This situation is untenable, as the funding to NRPA is on a long-term basis, and the funding to NILU relies more on short-to medium-term decisions.

In general there is a need for predictable multi-annual funding schedules in order to free operations from additional funding sources, which become ever fewer. In order to manage surveillance programmes and run instruments properly and continuously, stable long-term economic support is indispensible. The trend over the last decade has been that long-term monitoring programmes have been supported through other channels, like satellite validation or short-term research projects of typically 3 years duration. In recent years, also this source has become very small, so that the need for a genuine and stable long-term solution is even more urgent.

The UV-network has been operating since 1995. Spare parts are limited, and in order to continue high quality measurements, the instrumentation has to be replaced in the near future.

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POLAND

Ozone and UV monitoring and related research activities are conducted by the Institute of Meteorology and Water Management - National Research Institute (IMWM), and the Institute of Geophysics, Polish Academy of Sciences (IG PAS). The ozone, UV-B monitoring, and research, carried on at both Institutes, are supported the Chief Inspectorate for Environmental Protection; National Fund for Environmental Protection and Water Management; Ministry of the Environment, and the National Science Centre.

1. OBSERVATIONAL ACTIVITIES

1.1 Column ozone measurements and other gases and variables relevant to ozone loss

1.1.1 Institute of Geophysics, Polish Academy of Sciences

IG PAS has been involved in the long-term monitoring of the ozone layer for over 50 years. Measurements of the total ozone content and ozone vertical profile by the Umkehr method at Belsk (51°50'N, 20°47'E) by means of the Dobson spectrophotometer No.84 started in 1963, long before the depletion of the ozone layer became the great challenge for research community and the policy makers. In 1991 the Brewer spectrophotometer No.64 (single monochromator) with a UV-B monitor was installed. The Brewer spectrophotometer No. 207 (double monochromator) was put into operation in 2010. The column ozone and ozone content in the Umkehr layers are measured simultaneously by 3 instruments that helps to determine precision of the ozone observations by each spectrophotometer. The surface ozone measurements with Monitor Labs, ML8810 meter started in 1991 (replaced by ML9811 in 2004) and since 1992 NOx measurements have been done with Monitor Labs ML8841 meter (replaced by API200AV in 2004). The extended duration of the measurements and the high quality of the ozone data were essential for trend detection. Because the high quality of the ozone data is crucial subject in the analysis of the ozone variability the quality control and quality assurance of the ozone measurements is the major concern of the ozone research group. The Belsk ozone data were revaluated in 1983 and 1987 on a reading-by-reading basis, taking into account the calibration history of the instrument. The performance of the Belsk's ozone instruments was compared several times with the ground-based reference instruments (during international intercomparisons campaigns) and the satellite spectrophotometers (TOMS, OMI).

1.1.2 Institute of Meteorology and Water Management - National Research Institute

Surface ozone measurements with Thermo Scientific™ Model 49i Ozone Analyzer are performed at 4 stations: Leba (54.75N, 17.53E) on the Baltic Coast, Warsaw (52.28N, 20.96E) and Jarczew (51.81N, 21.98E) located in the central Poland, Sniezka (50.73N, 15.73E) in Sudety Mountains.

1.2 Profile measurements of ozone

1.2.1 Institute of Geophysics, Polish Academy of Sciences

The ozone content in selected layers in the stratosphere over Belsk is calculated using the Umkehr measurements by the Dobson spectrophotometer (since 1963) and the Brewer spectrophotometers (the Brewer No.64 since 1992 and Brewer No.207 since 2010). UMK04 algorithm is used for both the Dobson and Brewer Umkehr data.

1.2.2 Institute of Meteorology and Water Management - National Research Institute

The ozone soundings have been performed at Legionowo (52.40N, 20.97E) upper-air station since 1979. Up to May 1993 the OSE ozone sensor with the METEORIT/MARZ radio sounding system was used. Later on the ECC ozone sensor with Vaisala DigiCora radio sounding system and Vaisala radiosondes are in use. The upgrade of Vaisala system (MW41) with the Vaisala's

RS41/RS92 has been used since August 2015. The ozone soundings are launched regularly on each Wednesday. Additional ozone soundings were performed for the purpose of the MATCH campaign (statistical evaluation of ozone chemical destruction in Polar Vortex). The Legionowo ozone profiles were also used in the validation procedures of ozone profiles derived from satellite projects: MIPAS, SCIAMACHY and OMI. Legionowo is a complimentary station of the global NDACC/NDSC ozone sounding network. Ozone sounding data from Legionowo are submitted to the NDACC database. Since 1993, on the base of the NOAA/TOVS/ATOVS satellite data, total ozone maps over Poland and surroundings have operationally been performed at the Satellite Remote Sensing Center of IMWM in Krakow.

1.3 UV measurements

1.3.1 Broadband measurements

1.3.1.1 Institute of Meteorology and Water Management - National Research Institute

Broadband UV Biometers model SL 501 vers. 3 have been used for UV measurements at three IMWM stations: Leba (54.75N, 17.53E), on the Baltic Coast, Legionowo (52.40N, 20.97E), in central Poland, Zakopane 857m, in Tatra Mountains (49.30N, 19.97E). Since 2006, broadband OPTIX UVEM-6C have been used for nowcasting purposes at four IMWM stations in Poland: Leba (54.75N, 17.53E), Legionowo (52.40N, 20.97E), Katowice (50.23N, 19.03E) in the southern Poland, Zakopane 857m, in Tatra Mountains (49.30N, 19.97E).

1.3.1.2 Institute of Geophysics, Polish Academy of Sciences

Systematic measurements of ground level ultraviolet solar radiation (UV-B) with the Robertson- Berger meter were carried out at Belsk station in the period May 1975 – December 1993. In 1992 UV Biometer SL501A (replaced by the same type of the instrument in 1996), and in 2005 Kipp and Zonen UVS-AE-T broadband radiometer were installed. The instruments have been operated continuously up to now. The UV monitoring was conducted at the Polish Polar Station at Hornsund, Svalbard (77°00'N, 15°33') in the period 1996-1997 by UV Biometer SL501A, and starting in spring 2006 by Kipp and Zonen UVS-AE-T.

1.3.2 Spectroradiometers

The spectral distribution of UV radiation has also been monitored with the Brewer spectrophotometers at Belsk since 1992 (Brewer No.64) and in addition since 2010 (Brewer No.207). The spectra with 0.5 nm resolution for the range 290-325 nm and 286-363 nm have been calculated by the Brewer (No.64) and Brewer (No.207), respectively. Several spectra per hour are usually obtained for the solar zenith angles less than 85^0.

1.4 Calibration activities

1.4.1 Institute of Meteorology and Water Management - National Research Institute

The UV Biometers model SL 501 have been regularly calibrated at PMOD/WRC in Davos. The next calibration of the instrument is planned in 2017. The Thermo Scientific™ Model 49*i* Ozone Analyzers are regularly (twice per year) compared against to Model 49i-PS Ozone Primary Standard. Ozone Primary Standard is calibrated every year at Czech Hydrometeorological Institute, Calibration Laboratory of Immission in Prague.

1.4.2 Institute of Geophysics, Polish Academy of Sciences

The Dobson and Brewer spectrophotometers are regularly calibrated. The recent calibrations of the Dobson instrument took place at the Hohenpeissenberg Observatory of DWD in June 2014, and the next calibration is planned in 2019. The intercomparisons were carried out against the European substandard Dobson No.64. The Brewer spectrophotometer No.64 was calibrated against the reference instrument Brewer No.17 maintained by the International Ozone Corporation (Canada) at the Belsk observatory in 2014 and 2016, and in the Poprad-Ganovce Observatory (Slovak Hydrometeorological Institute) in 2015, and the next calibration is planned at Belsk in 2017. During the Brewer intercomparison campaigns both the total ozone and UV spectra were calibrated. Since 2010 the output of the Belsk's broad band UV meters is compared against the Belsk's Brewer No.207 (double monochromator).

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

The following phases of the long-term variability over Poland are derived from the Dobson spectrophotometer observations at Belsk in the period 1963-2016, Fig.1(left): levelling off (1963-1980), decline (20 DU decrease in the period 1980-1997), recovery (3 DU increase in the period 1997-2005), levelling off (2005-2016). This pattern of the ozone variability is partially related to the changes of the stratosphere contamination by the ozone depleting substances. Using the value of the NOAA ozone depleting gas index (http://www.esrl.noaa.gov/gmd/odgi/) of 57.7 for the year 2016 it could be estimated that the Belsk's total ozone should be ~10 DU larger than that found in the 1997 minimum if the ozone long-term changes follow changes in the concentration of the ozone depleting substances controlled by the Montreal Protocol (MP) 1987 and its further amendments. However, only 3 DU increase is retrieved from the ozone long-term pattern in the period 1997-2016) but the recovery was continuing in the upper stratospheric ozone in the whole 1997-2016 period, Fig.1(right). Thus, it should be hypothesized that 7 DU decline from the expected ozone level is due to specific regional dynamical effects or chemical depletion in the lower-mid stratosphere by substances non-controlled by MP 1987 and its further amendments. Such the ozone behaviour will trigger further studies concerning partitioning between the dynamical and chemical drivers of the total ozone recent changes.

The pattern of the long-term changes of surface ozone at Belsk shows an increase in the period 1990-2004 and decrease afterwards, Fig.2 (left). Two "heat waves" in 2003 and 2006 caused a strong increase of surface ozone in these years. Thus the declining tendency after the 2004 maximum should be less evident if we remove these two extreme years.
Surface erythemal UV radiation increase of 14% is found in the period 1976-2004. Ozone and cloudiness/aerosols trends contributed almost equally to this change. A slight declining tendency appearing after 2004 is not statistically significant, Fig2 (right).

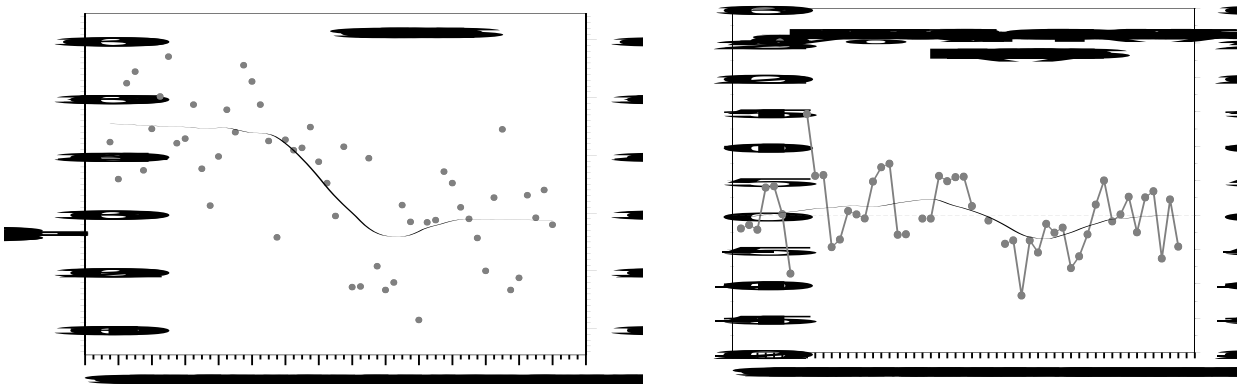


Figure 1. (left) Annual means (1963-2016) of total ozone at Belsk, Poland, from the Dobson spectrophotometer measurements. (right) Fractional deviations of the annual mean of ozone content in the upper stratosphere (32.5km - 37.5km) from the long-term (1963-2016) annual mean in percent of the long-term mean. The ozone vertical profile is calculated using UMK04 retrieval applied to the Umkehr observations by the Dobson spectrophotometer.

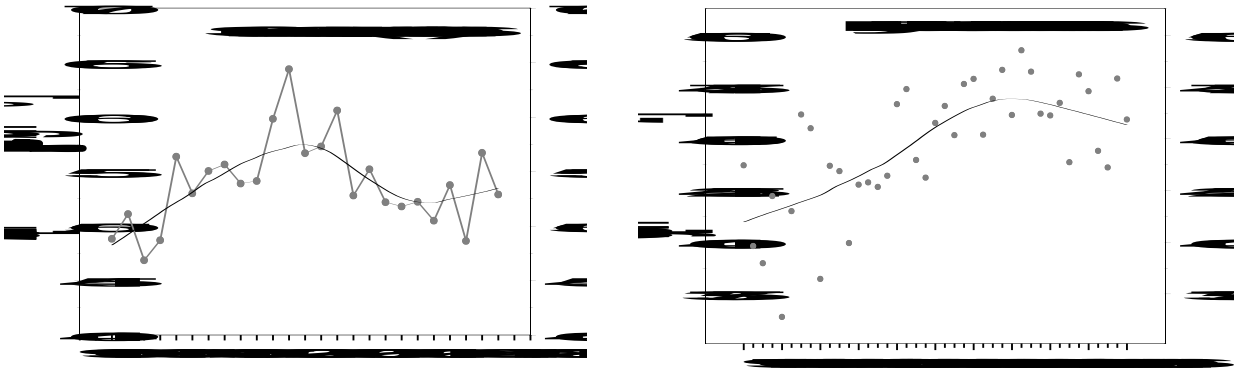


Figure 2. (left) Annual means (1992-2016) of surface ozone concentration. (right) Annual means of the erythemaly weighted doses (1976-2016) at Belsk, Poland .

3. THEORY, MODELLING, AND OTHER OZONE RELATED RESEARCH

3.1 Institute of Meteorology and Water Management - National Research Institute

Long-term changes in ozone profile at Legionowo, Poland, have been studied. Significant downward trends of ozone concentration in winter and spring months in the lower stratosphere have been found during the period of acceleration of ozone depletion processes on global scale (1979-1993). In recent years signs of ozone recovery in the middle stratosphere have been detected. The observed differences in stratospheric ozone destruction from year to year are the result of changing meteorological conditions in the NH stratosphere. Legionowo is often located at the edge of the polar vortex and since 1995 participates in MATCH campaigns (statistical evaluation of ozone chemical destruction in Polar Vortex). Episodes of serious ozone deficiencies, during the displacements of the cold polar vortex in the winter/spring seasons, have been observed.

3.2 Institute of Geophysics, Polish Academy of Sciences

The ozone time series (from observations taken at Belsk and from the global ozone data bases) were examined by statistical models developed at IG PAS to determine factors responsible for ozone changes. Ozone variability and quantification of the impact of human activities on the ozone layer is essential because of the coupling of the ozone layer and the global climate system. Changes in the ozone layer were examined in connection with changes in the dynamic factors characterizing the atmospheric circulation in the stratosphere. Various studies were carried out in the Institute focusing on the role played by dynamical factors of the ozone variability. Natural dynamical processes in the Earth’s atmosphere could perturb the recovery of the ozone layer.

Variability of solar UV radiation over Belsk since 1976 up to now, based on the world longest series of the erythemal observations, was analyzed after homogenization of the whole series of the broadband UV measurements. Biological effects of solar UV (synthesis of vitamin D, antipsoriatic heliotherapy) were analyzed using the modelled and observed data. The differences between erythemal and UV-A doses measured by the Brewer spectrophotometers in urban (Warsaw) and background (Belsk) site allow to discuss an anthropogenic component of the surface UV variability related to specific cloud and aerosols variability over the large agglomeration.

The research achievements since the previous Report (2014) could be summarized as follow:

Development a novel trend model to disclose the temporal variability of the long-term component of the ozone variability and to discuss the effectiveness of the Montreal Protocol (MP) 1987 and its subsequent Amendments regulations to save the ozone layer. The model has been used for the trend detection based on the NOAA SBUV merged data set. The trend errors are derived from the bootstrap resampling.

- Determination of anomalous recovery rate of total ozone in Central Europe in spring and summer seasons.
- Analysis of life style of human ancestors living in northern Tanzania supporting optimal daily intake of vitamin D equivalent to 2000 IU taken orally.
- Quantification of urban agglomeration effects on surface-UV doses based on a comparison of the Brewer measurements in Warsaw and Belsk, Poland, for the period 2013-2015.
- Development of scenarios of the antipsoriatic heliotherapy and cutaneous synthesis of vitamin D (for a person using UV transparent clothing) taking into account atmospheric conditions over Poland

4. DISSEMINATION OF RESULTS

4.1 Data reporting

The ozone data taken at Belsk are regularly submitted to the World Ozone and Ultraviolet Radiation Data Centre in Toronto. The mean daily values of total ozone are also submitted operationally to the Laboratory of Atmospheric Physics, Aristotle University of Thessaloniki, Greece. The ozone sounding data from Legionowo are submitted to the World Ozone and Ultraviolet Radiation Data Centre in Toronto regularly on a monthly schedule, and operationally to the data base at NILU (Norway).

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4.2 Information to the public

Since 2006, an operational monitoring of UV Index from the IMWM network has been published on IMWM web pages.
Since 2000, the UV Index forecast for Poland has been available from May to September on IMWM web pages.
Since 2001, the daily means of total ozone from the Dobson measurements at Belsk and UV Index from the SL501A measurements are displayed in almost real time on web pages http://ozon.igf.edu.pl and http://uvb.igf.edu.pl, respectively.)

4.3 Relevant scientific papers

4.3.1 Institute of Geophysics, Polish Academy of Sciences

1. Krzyścin, J.W., The ozone recovery in the NH extratropics:The trend analyses of the SBUV/SBUV-2 merged ozone data in the 1979-2012 period, 98, 17-24, doi: 10.1016/j.atmosenv.2014.08.029.12.2014, 2014.

2. Sobolewski, P.S., Krzyścin J.W.,Jarosławski J.,Wink J., Lesiak A., Narbutt J., Controlling adverse and beneficial effects of solar UV radiation by wearing suitable clothes - Spectral transmission of different kinds of fabrics, J. Photochem. Photobiol B 140, 105-110, 2014, doi: 10.1016/j.jphotobiol.2014.07.009, 2014

3. Krzyścin, J.W., Narbutt, J., Lesiak, A., Jarosławski, J., Sobolewski, P.S., Rajewska-Wiech, B., Szkop, A., Wink, J., Czerwińska, A., Perspectives of the antipsoriatic heliotherapy in Poland, J. Photochem. Photobiol. B., 140, 111-119, 10.1016/j.jphotobiol.2014.07.017, 2014.

4. Krzyścin J.W., Guzikowski J., Czerwińska A., Lesiak A., Narbutt J., Jarosławski J.,Sobolewski P.S.,Rajewska-Wiech B., Wink J., 24 hour forecast of the surface UV for the antipsoriatic heliotherapy in Poland, J. Photochem. Photobiol. B., 148, 136-144, doi:10.1016/j.jphotobiol.2015.04.002, 2015.

5. Krzyścin J.W.,Rajewska Wiech B., Specific variability of total ozone over Central Europe during spring and summer Int. J. Climatol., 36, 3539-3549, doi: 10.1002/joc.4574. 2016.

6. Krzyścin J.W., Guzikowski J., Rajewska-Wiech B., Optimal vitamin D3 daily intake of 2000 IU derived from modelled exposure of ancestral humans in Northern Tanzania, J. Photochem. Photobiol. B., 159,101-105, doi:10.1016/j.jphotobiol.2016.03.029, 2016.

7. Czerwińska A., Krzyścin, J.W., Jarosławski, J., Posyniak, M., Effects of urban agglomeration on surface-UV doses: A comparison of Brewer measurements in Warsaw and Belsk, Poland, for the period 2013-2015, Atmos. Chem. Phys., 16, 13641-13651, doi: 10.5194/acp-16-13641-2016. 2016

8. Posyniak Szkop, A., Pietruczuk, A., Podgórski, J., Krzyścin, J.,. The Long-term (1964-2014) Variability of Aerosol Optical Thickness and its Impact on Solar Irradiance Based on the Data Taken at Belsk, Poland, Acta Geophysica, 64, 1858-1874, doi:. 10.1515/acgeo-2016-0026. 2016

5. PROJECTS AND COLLABORATION

2011-2014 National Science Centre (Poland) grant No. 2011/01/B/ST10/06892 " Effect of the Montreal Protocol (1987) on atmospheric ozone" (IG PAS)
2013-2015 National Science Centre (Poland) grant No. 2012/05/B/ST10/00495 " Modelling of ground level solar UV radiation for assessment of antipsoriatic heliotherapy in Poland" (IG PAS)
2013-2017
Earth System Science and Environmental Management COST Action ES1207, EUropean BREWer NETwork - EUBREWNET (IG PAS)

6. IMPLEMENTATION OF THE RECOMMENDATIONS OF THE 9TH ORMM

In the recommendations of the 9thORM it was suggested that research is required to better quantify trends in ozone data. This issue has been subject of the study conducted in the IG PAS (*Krzyścin, J.W., The ozone recovery in the NH extratropics:The trend analyses of the SBUV/SBUV-2 merged ozone data in the 1979-2012 period, 98, 17-24, doi: 10.1016/j.atmosenv.2014.08.029.12.2014, 2014*).

Concerning the UV and vitamin D issue, in the study made in IG PAS it was found that the adequate solar UV exposure should be equivalent to to 2000 IU taken orally (*Krzyścin J.W., Guzikowski J., RajewskaWiech B., Optimal vitamin D3 daily intake of 2000 IU derived from modelled exposure of ancestral humans in Northern Tanzania,J. Photochem. Photobiol. B., 159,101-105, doi:10.1016/j.jphotobiol.2016.03.029, 2016).*

According to the recommendations monitoring of the ozone layer has to continue, and particularly continuation of ground-based stations with long-term records is absolutely necessary to provide a reliable baseline for trend estimation. The ozone measurements at Belsk station has been performed for over fifty years and every effort has been made by IG PAS to have continuous reliable ozone series (see section 1.1.1).

7. FUTURE PLANS

- continuation of the current monitoring and research:
- trend analyses of updated time series of the ground-based and satellite ozone and biologically weighted solar UV
- continuation of the ozone soundings at the upper-air station at Legionowo
- continuation of UV monitoring at IMWM network

8. NEEDS AND RECOMMENDATIONS

IMWM and IGF PAS recommend closer international collaboration on interactions between the ozone and climate changes to determine the ozone recovery date and evolution of policy instruments to reduce greenhouse gases.

RUSSIAN FEDERATION

1. OBSERVATIONAL ACTIVITIES

1.1 Column measurements of ozone and other gases/constituents responsible for ozone loss

In the Russian Federation, responsibility for regular total ozone measurements and interaction with the corresponding WMO bodies lies with the Federal Service for Hydrometeorology and Environmental Monitoring (Roshydromet). Daily total ozone (TO) measurements are being made with filter ozonometers M-124 on the network of 28 ozone measuring stations. Operating, technical, and metrological support of TO and UV radiation (UVR) monitoring is provided by A.I. Voeykov Main Geophysical Observatory (MGO).

Since 2009, a network of high-precision total ozone (and total NO_2) measurements has been developed under the direction of CAO specialists within the framework of the Federal Roshydromet special program, with the measurements fulfilled with automated spectrophotometers Mini-SAOZ (developed and manufactured in France) deployed in regions where total ozone (TO) anomalies frequently occur in winter and spring. Presently, 6 stations (Anadyr', Zhigansk, Salekhard, Murmansk, Irkutsk, and Dolgoprudny) equipped with such instruments are conducting network observations. Mini-SAOZ measurement data from Salekhard station (67° N, 67° E) is available at (http://saoz.obs.uvsq.fr/). Measurements from the other stations are periodically available at (http://www.cao-rhms.ru/saoz/).

Apart from that, TO measurements are performed at reference stations by institutions of Roshydromet and the Russian Academy of Sciences using ozonometers M-124, Brewer and Dobson spectrophotometers as well as SAOZ instruments. Brewer spectrophotometers measure TO in Kislovodsk (MKII № 043; the high-mountain station of Obukhov Institute of Atmospheric Physics of the Russian Academy of Sciences (IAP RAS KHMS)), Obninsk (MKII № 044; SI RPA "Typhoon"),Tomsk (MKIV № 049; Zuev Institute of Atmospheric Optics, RAS Siberian Branch), and Dolgoprudny (Mark III № 222; Central AerologicaL Observatory (CAO)), with the measurement data transmitted to WOUDC (http://woudc.org).

Regular measurements of NO_2 content in the vertical atmospheric column have been conducted at Zvenigorod research station (ZRS) of A.M. Obukhov Institute of Atmospheric Physics (IAP), RAS, since 1990. The measurements have been made with a spectrophotometer based on a domestically manufactured monochromator MDR-23, by an original technique which builds upon the reconstruction of NO_2 vertical distribution. The station is included in the International Network for the Detection of Atmospheric Composition Change (NDACC); its measurement data is readily available at the NDACC server (http://www.ndacc.org/).

Regular ground spectroscopic measurements of ozone and ozone-depleting gases have been conducted since 2009 at St. Petersburg State University (http://troll.phys.spbu.ru/science/measurements.html). They are conducted on sunny days using Fourier spectrometer with high spectral resolution (up to 0.005 cm^{-1}). Such measurements of solar radiation absorption spectra in the IR range make it possible to determine total content of 15-20 greenhouse, ozone-depleting and polluting atmospheric gases as well as elements of their vertical distribution.

1.2 Profile measurements of ozone and other gases / constituents responsible for ozone loss

In Obninsk and St. Petersburg, lidar measurements of the vertical ozone concentration within an altitudinal range of 12-35 km are made with the lidar AK-3 developed at SI RPA "Typhoon", by a method of differential absorption at 355-nm (outside an absorption band) and 308-nm (within an absorption band) wavelengths [Korshunov et al., 2014]. The same lidar is used to measure the vertical profiles of temperature (within an altitude range 30 - 70 km) and aerosol (10 - 65 km) – parameters important for the interpretation of ozone measurement data.

Measurements of ozone profiles in the stratosphere and mesosphere with a microwave radiometer (142.2 GHz) are conducted on a regular basis at Lebedev Physical Institute of RAS in Moscow [Solomonov et al., 2016].

Data on ozone content in different atmospheric layers has been obtained from ground measurements of direct solar infrared radiation (Fourier spectrometry) in the environs of St. Petersburg [Virolainen et al., 2015]. The measurements agree satisfactorily with satellite ozone measurements in the troposphere (IASI) and stratosphere (MLS).

1.3 UV measurements

Pilot measurements of UVB-radiation have been carried out at 14 ozone measuring stations of Roshydromet since 2006. The UV radiation (UVR) measurements follow the technique developed by the MGO and use ozonometers M-124 with correction attachments (Larche sphere).

Long-term regular measurements of UV-irradiation in an UV-B spectral range, using an UVB-1 YES pyranometer, have been conducted at Lomonosov Moscow State University (MSU) since 1999, and in a 300-380-nm range since 1968.

Measurements of UV-irradiance using Brewer spectrophotometer have been conducted in Kislovodsk (since 1989), Obninsk (since 1994), Tomsk (since 206), and Dolgoprudny (since 2014).

1.4 Calibration activities

The MGO is the center of calibration and control of the measurement quality of filter ozonometers M-124 in Russia. The calibration is performed once in 2 or 3 years. The unified measurement scale on the Roshydromet network is supported by regular calibration of allthe ozonometers against the domestic standard – Dobson spectro-photomer № 108. Over the last 30 years, the discrepancy between the domestic and the WMO standards has not exceeded 1%. The last comparison was made in Germany in 2014.

In 2010, a Category 1 operational reference sample of irradiation spectral density in a 250-800 nm range, based on a halogen bulb, certified by the Russian Federation State Agency for Standardization, Gosstandard, was introduced to practice. Absolute-scale calibration of UV radiation measurements has been fulfilled at the MGO since 2011. The UV radiation measurement scale is maintained using a Category 1 operational reference - a halogen lamp KGM 120-1000 W, which is annually verified at the All-Russia Research Institute of Optico-Physical Measurements.

Brewer spectrophotometer MKII № 044 (Obninsk) underwent calibration in Spain. The Brewer spectrophotometers operated in Kislovodsk and Tomsk were last calibrated in 2012. Calibration of Brewer spectrophotometers from Kislovodsk, Tomsk, and Dolgoprudny stations is expected to be fulfilled in Russia in 2017 with foreign specialists involved.

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

Observation analysis is primarily aimed at understanding the reasons for occasional ozone anomalies and long-term ozone layer changes. In late January, 2016, over the north of the Urals and Siberia, an ozone mini-hole (< 220 DU) was first detected; it was caused by an extremely intensive circumpolar vortex< which also resulted in temperature decrease in the stratosphere characteristic of winter period over the South Pole [Nikiforova et al., 2017]. Based on satellite data analysis and reanalysis it has been established that TO had practically stopped to decrease at all latitudes by 1997, and within 1997-2014 the ozone layer stabilized [Zvyagintsev et al., 2015].

As suggested in [Kashkin, 2016], based on OMI data, at middle latitudes of both hemispheres a statistically significant positive TO trend of 1.5-2% per decade occurred in 2005-2015. Unobvious phase correlations between the variations of total ozone, solar activity, quasi-

biennial oscillations, and some other weather parameters, are described in [Visheratin et al., 2016, 2017], using the methods of Fourier-composite and cross-wavelet analysis.
A new method of evaluating different types of biologically active UV radiation (erythema -, vitamin D - and cataract – weighted) [Chubarova et al., 2016] has been proposed. It is shown that for the above UV types, the altitudinal dependence of the coefficient of UV radiation increase can be represented as a composition of independent contributions from different factors within a wide range of their changes with 1% mean error and 3% standard deviation compared with precise results of modeling using the same input parameters. Parameterization takes into account altitudinal dependences of molecule number density, total ozone and aerosol content as well as spatial surface albedo.

Measurements of the Russian "Meteor-2" satellite-borne Fourier-spectrometer (IKFS-2) is carried out at St.Petersburg State University, and information about total ozone space-time variations is obtained [Garkusha et al., 2017].

3. THEORY, MODELLING AND OTHER RESEARCH

A numerical global photochemical model CHARM (CHemical Atmospheric Research Model) and the results of three-dimensional numerical modeling of the climatic distribution of ozone and other minor gaseous constituents of the earth atmosphere within a 0-90 km altitude range is presented by Krivolutsky et al. [2015]. The data from global numerical model series are compared with the data from ground spectrometer measurements of total ozone and some other ozone-depleting compounds as well as of ozone content in separate layers in [Virolainen et al., 2016, 2017]. Modeling of the influence of planetary waves on circumpolar vortex stability, polar stratospheric temperature, the content of ozone and other gases is fulfilled using the global chemical-climatic model of the lower and middle atmosphere [Smyshlyaev et al., 2016]. Inter-annual and seasonal variations of the integral ozone content in different high-altitude layers over St. Petersburg area as obtained from observations and numerical modeling are compared in [Smyshlyaev et al., 2017].

Scientists from St.Petersburg State University and the Russian State Hydrometeorological University have compared the results of 3D numerical modeling of ozone time variations with ground-based and satellite measurements made in St.Petersburg and at some other NDACCC stations to analyze the modeling quality.

The kinetics of ozone layer recovery in different latitudinal zones of the Northern Hemisphere in XXI century has been estimated using the interactive two-dimensional chemical-dynamic-radiative model of the middle atmosphere SOCRATES and prognostic scenarios IPCC. It is shown that upon its recovery the ozone layer will continue to increase to reach by late XXI century a stationary level exceeding "undisturbed" pre-Freon one, which, according to [Larin, 2015], poses no less ecological threat than the ozone layer depletion in late XX century. The algorithm and results of calculating the dynamics of stratospheric ozone destruction at middle latitudes is described based on the numerical modeling of the dynamics of gas and heterophase reactions involving Junge layer particles. The contribution of gas and heterophase reactions to ozone layer depletion is estimated, and the necessity of taking these reactions into account in developing forecasts of ozone layer recovery in XXI century [Larin, 2016].

A number of papers are devoted to the nature of abrupt stratospheric warmings and their considerable impact on the ozone layer, primarily at high latitudes of both hemispheres in winter and spring [Kochetkova et al., 2014; Marichev et al., 2014; Pogoreltsev et al., 2014; Solomonov et al., 2014; Vargin and Medvedeva, 2015].

A new numerical model of the global transport of multicomponent minor gases and aerosols in the atmosphere and polar stratospheric cloud formation in the Arctic and Antarctica has been developed (Aloyan et al., 2015).

In the references are also presented some other recent results obtained by Russian scientists.

4. DISSEMINATION OF RESULTS

4.1 Data Reporting

The data from the network observations using M-124 ozonometers is transmitted to CAO, MGO and Hydrometcenter of Russia on-line. CAO performs primary quality control of the data received on-line, archives and transmits it to WOUDC of the Environment Service of Canada. This data, together with that from other countries, is employed by WOUDC for daily imaging of TO fields (http://woudc.org/). Also, CAO performs on-line mapping of TO distribution over Russia and the neighboring countries, reveals anomalies and analyzes the reasons for their origination. In the case of the occurrence of substantial anomalies in TO and UV radiation fields, CAO swiftly informs the authority about it. At the MGO, the data undergoes more thorough quality control, which enables assessing the performance of separate instruments and stations, the data is corrected and then transmitted to WOUDC archives.
Also, WOUDC regularly receives TO and UV radiation data obtained with Brewer spectrophotometers at Kislovodsk, Obninsk, and Tomsk stations.

Data of regular measurements of total ozone and NO_2 in vertical column in St.-Petersburg, obtained by spectrometer, developed on the basis of Russian scanning monochromator MDR-12 (LOMO) since 2004 are available on the web page http://troll.phys.spbu.ru/Personal_pages/Ionov/welcome.html
Measurements of NO_2 content in the stratospheric column and atmospheric boundary layer are regularly transmitted from Zvenigorod research station of the Institute of Atmospheric Optics, RAS, to the NDACC, and are readily available at (http://www.ndacc.org).

In 2016, the research station of St.Petersburg State University in Peterhof near St.Petersburg was included in the NDACC network (IR Fourier measurements), and in the near future its measurement results will be presented on the NDACC webpage (http://www.ndacc.org/).

4.2 Information to the public

Reviews with the current analyses of the ozone layer state are published by CAO in the quarterly journal "Russian Meteorology and Hydrology" (with the English version disseminated by Springer Publishing House). The same data is also published in the annual "Reports on the features of climate on the territory of the Russian Federation" and "Reviews of the environment state and pollution in the Russian Federation" prepared by Roshydromet.

Forecasts of high UV index values for the current and the next day with indication of vulnerable territories and recommendation for protective measures to be taken by different groups of the population are given. The methodology for predicting TO and UV-index is available at the site of the Russian Hydrometeorological Center (http://meteoinfo.ru/).

4.3 Relevant scientific papers

Reviews of scientific publications:

1. Elansky N.F. Russian studies of atmospheric ozone in 2011–2014. // Izv. Atmos. Ocean. Phys. 2016. V. 52. No. 2. P. 132-146.

2. Krivolutsky A.A., Kukoleva A.A. Results of Russian investigations into the middle atmosphere (2011–2014). // Izv. Atmos. Ocean. Phys. 2016. V. 52. No. 5. P. 497-511.

3. Larin I.K. Russian investigations in atmospheric chemistry for 2011–2014. // Izv. Atmos. Ocean. Phys. 2016. V. 52. No. 2. P. 147-153.

4. Timofeev Y.M., Shul'gina E.M. Russian investigations in the field of atmospheric radiation in 2011–2014. // Izv. Atmos. Ocean. Phys. 2016. V. 52. No. 5. P. 467-482

5. Vargin, P.N., Volodin, E.M., Karpechko A.Y. et al. Stratosphere-troposphere interactions. // Herald of Russ. Acad. Sci. 2015. V. 85. No. 1. P. 56-63.

Original papers:

1. Ageyeva V.Yu., Grishaev M.V., Gruzdev A.N. et al. Anomalies of stratospheric NO2 content over Siberia related to the Arctic ozone hole 2011. // Atmos. Ocean. Optics. 2014. V. 27. No. 1. P. 40-45.
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5. PROJECTS, COLLABORATION, TWINNING AND CAPACITY BUILDING (e.g., national projects, international projects, other collaboration (nationally, internationally))

CAO specialists launched ozonesondes at Salekhard station (67°N, 67°E) during the recent winter-spring season within the framework of the international project "Match". The measurements obtained are available in the project's database. Measured vertical total ozone profiles were used to calculate chemical ozone loss in the Arctic stratosphere during 2014-2016 winter-spring seasons.

6. FUTURE PLANS

As far as ozonometers M-124 operated at the network stations for over 30 years, the MGO have developed an automated UV ozone spectrometer, UVOS, to replace them (more about UVOS http://www.voeikovmgo.ru/index.php/ru/struktura/otdel-monitoringa-i-issledovanij-khimicheskogo-sostava-atmosfery/laboratoriya-kontrolya-ozonnogo-sloya-atmosfery/31-resources/672-spektrometr-ozonnyj-ultrafioletovyj-ufos). It measures within a 290-400 nm range with resolution of not more than 1.0 nm the spectral composition of the UV radiation incident from the sky hemisphere and determines TO by the light scattered from the sky zenith. Automated measurements of TO and UV radiation spectrum are made at any cloudiness.

The first batch of UVOS instruments was manufactured in 2014 and underwent tests by the Russian agency for standardization (Gosstandart). The instruments were first supplied to the network stations in autumn 2015. By the end of 2016, 18 instruments were installed, with 4 more ones to be installed in 2017. It is suggested that during 1.5-2 years concurrent TO observations be fulfilled with UVOS instruments and ozonometer M-124 which thereafter will remain as a reserve instrument for TO measurements.

3 Roshydromet stations equipped with spectrophotometers Mini-SAOZ are planned to be put in operation in addition to the 6 stations already run.

At present, 7 lidar sounding stations of Roshydromet are equipped with lidars AK-3 to measure vertical ozone distribution. It is planned to conduct their test operations and thereafter make regular measurements.

7. NEEDS AND RECOMMENDATIONS

Russian research institutes presently facing financial difficulties, the WMO support is required for technical inspection of the Brewer spectrophotometers in Obninsk and Tomsk, and calibration of all the 4 ones operating in Russia, in 2017, with participation of foreign specialists.

SAMOA

1. OBSERVATIONAL ACTIVITIES

Samoa currently does not have the capacity and the resources to undertake ozone monitoring and observational activities. Samoa depends highly on monitoring conducted by other Countries and Scientific Institutes such as NOAA. In particular the data provided through American Samoa at the NOAA Station at Cape Matatula is the closest applicable situation to Samoa accessible through the below link:
http://www.esrl.noaa.gov/gmd/obop/smo/

2. DESSEMINATION OF OZONE INFORMATION

The Government of Samoa through the Ozone Section under the Meteorology Division of the Ministry of Natural Resources and Environment provide information on Stratospheric Ozone Layer Protection through many mediums. The http://www.samet.gov.ws/index.php/sections/section5 website provides background information on the implementation of Ozone Protection Projects in Samoa, including the legal framework, ODS licensing system, ozone publications and so forth. The inclusion of links to relevant Research Institutes and resources on ozone monitoring and research is also under development for easy public access.

The Ozone Section also distributes awareness information, reports on new technologies relating to Ozone depleting substances and alternatives through email, newspaper, online social media and awareness programs such as Refrigeration and Air Conditioning Association Trade Night. Most of these activities are funded under the Institutional Strengthening Project and HCFC Phase out Management Plan with assistance provided by UNEP.

3. PROJECTS, COLLABORATION TWINNING AND CAPACITY BUILDING

Since 2015 the Ozone Section joined the Two Samoa Meteorological Offices annual Meeting to allow for capacity building at the NOAA Global Monitoring Division. The Baseline Observatory located at the Cape Matatula American Samoa is one of the six observatories and the only Southern Hemisphere Station established in 1974. The Ozone Section comprised of two staff were able to witness monitoring on five research groups namely, Carbon Cycle, Ozone, Aerosols, Halocarbons and Atmospheric Trace Species and Solar Radiation. The Ozone team was also introduced to operations of equipment on site for taking measurements of stratospheric ozone as well as surface ozone.

4. FUTURE PLANS

The Government of Samoa has long anticipated a system for air quality monitoring. Climate change and its impacts is inevitably the major environmental problem facing the globe, and the national level is no exception. Trends and assessment of Samoa's Climate Risk Profile (CRP). Young. W.: 2007 best estimates of long term, systematic changes in the average climate for Samoa indicate that by 2050 sea level is likely to have increased by 36 cm;

rainfall shall increase by 1.2%; extreme wind gusts by 7%, and maximum temperatures by 0.7° C. However, there are no significant long term trends in the observed daily, monthly, annual or maximum daily rainfall.

Therefore Samoa submitted a proposal under the Global Climate Fund to establish an infrastructural network to collect information, quality control, analyse and produce products to help assess the impacts of climate change, variability and anthropogenic on the air (atmosphere). Part of this proposal requested for ozone monitoring to assess the links to climate change impacts on air quality in Samoa. Climate change impacts on air quality in Samoa are not very well-known as it does not have the air quality monitoring equipment (AQME). Needless to say, global warming changes the trends of ozone (O3 and pollutants (Carbon Monoxide, NOx, particulate matter,)

5. NEEDS AND RECOMMENDATIONS

In collaboration with American Samoa, there is hope to trial measurements of stratospheric and ground level ozone in Apia at the Meteorology Division where the Ozone Section is based. The Meteorology Division's functionality encompass a vast extend of climatic, weather, seismic data collection and it is Samoa's long term goal to establish a facility and build staff capacity to undertake ozone monitoring as well.

Samoa also wishes to seek assistance in acquiring appropriate equipment to carry out monitoring on Ozone and currently working with various government departments to find possible partnerships and assistance.

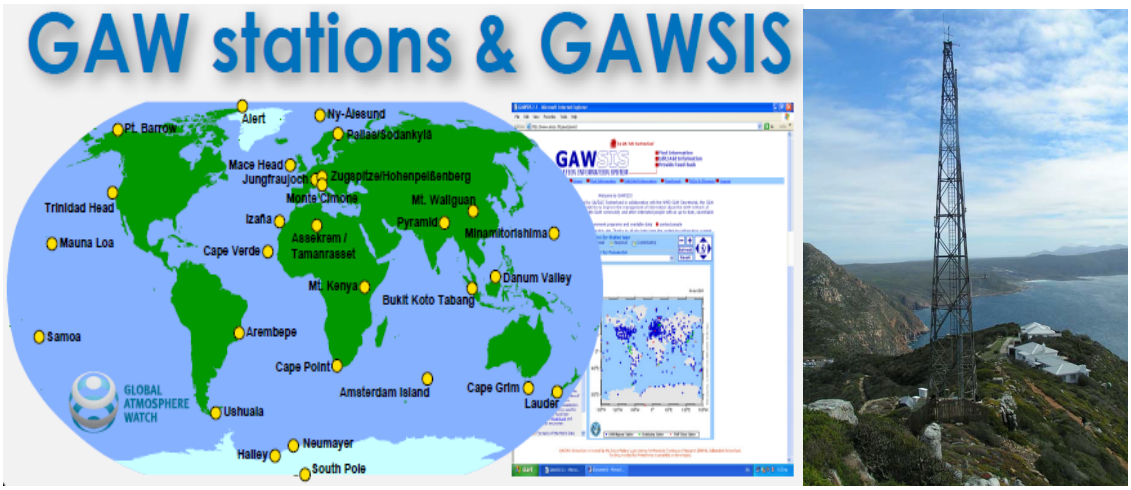
SOUTH AFRICA

The South African Department of Environmental Affairs (DEA) as the focal point for the implementation of the Montreal Protocol on substances that deplete the ozone layer has a responsibility to protect the environment and the well-being of people according to the Constitution of the Country. The South African Weather Service (SAWS) is an agency of the Department and is tasked with the responsibility which is focused on research and monitoring of atmospheric ozone.

1. OBSERVATIONAL ACTIVITIES

Ozone-Atmospheric Research and Monitoring Activities

Most of the sustained systematic atmospheric monitoring is conducted by the South African Weather Service. In particularly this is done by the research and monitoring program work of the WMO Global Atmosphere Watch Station (GAW) at Cape Point and its Regional Network of stations. Figure below shows WMO global stations and the Cape Point GAW laboratory.



1.1 Column measurements of ozone and other gases/variables relevant to ozone loss

The first South African column ozone measurements were made during 1964 until 1972 with Dobson #089 operating from Pretoria. This has been as a result of the IGY initiatives around the world. Due to skills capacity and instrument challenges Dobson 089 was decommissioned in 1972. After that, reinstating South Africa's commitment to the Vienna Convention, the Weather Service now operates two Dobson ozone spectrophotometers, #089 at Irene near Pretoria (25.9 S, 28.2 E) since 1989, and #132 at Springbok (29.7 S, 17.9 E) since 1995. Both these instruments have been regularly calibrated with reference to the world standard. A modest program of Dobson (#035) observations has started at the Stellenbosch Offices, under the auspices of the Cape Point GAW activities.

The Dobson Ozone Spectrophotometers at Springbok D132 has been operating well during this period conducting daily Total Ozone (TO3) column observations. Dobson 089 from Irene experienced optical wedge belt problems in 2014 and again some rain damage in 2015, but was repaired and placed back in operation. Dobson 035, on "permanent" loan from the UK Met. Office, has most unfortunately not been operating continuously at Cape Point since we still need to do some building construction changes to the GAW laboratory. Therefore, the observation program at

Stellenbosch has been undertaken. The value of the WMO/UNEP Dobson inter-calibrations also proves that the data sets can be made totally compatible and sustain a consistent long-term station record.

The South African Dobson data sets are maturing towards long-term climatic data sets. Over this period some 250 000 daily total ozone observations has been made. Since 2002 the Irene Dobson Total Column ozone shows a slight positive trend, but whether this is an indication of Stratospheric Ozone Recovery (90 percent of the atmosphere's ozone concentration resides in the Stratosphere) we still are not sure. Together with the data from the Irene balloon ozonesoundings, we are also investigating the questions whether pollution is also a contributing to enhanced "bad" ozone levels in the troposphere and near surface.

1.2 Profile measurements of ozone and other gases/variables relevant to ozone loss

1.2.1 Ozone Soundings

After a three year break the Weather Service has been fortunate to reinstate its Vaisala ECC RS92 Ozonesonde sounding program from Irene, a GAW regional station, in September 2012. The soundings are conducted with the Vaisala MW31 Digicora and RS92 GPS sondes and 1200g totex balloons. Thus we can state that we have been using the same system since 1990 when we started, which implies the data sets is much more compatible. Irene operated weekly ozone sounding since 1990 until early 2007 with a few data gaps. We joined the Southern **H**emisphere **Ad**ditional **OZ**onesondes (SHADOZ) program under leadership of the principle investigator Dr. Anne Thompson in 1997. This is a program from NASA, USA, and all data is submitted to WOUDC and NDACC as well. http://croc.gsfc.nasa.gov/shadoz/). The Irene ozone sounding program continues with ascents every two weeks.

1.2.2 LIDAR

Light Detection and Ranging (LiDAR) equipment at the School of Chemistry and Physics (SCP) from the University KwaZulu Natal University (UKZN) – Durban Westville campus was recently calibrated as part of an experiment to operate three LiDARs simultaneously and interpret their performance. The LiDARs were the fixed and portable UKZN ones as well as the Council for Scientific and Industrial Research (CSIR) National Laser Centre (NLC) mobile LiDAR.

The equipment, one of only two LiDAR systems in the country, assists research into remote sensing techniques and atmospheric pollution measurements conducted by the Atmospheric Research Group in the SCP, and is calibrated when necessary. The latest calibration came after refurbishment of the equipment, which was moved to the Westville campus from Howard College eight years ago.

Running of the equipment is facilitated by National Research Foundation (NRF) research grants, UKZN funding and the Rental Pool Project (RPP) of the Department of Science and Technology-funded (DST) CSIR-NLC. One LiDAR system was donated to UKZN from the Université de la Réunion through a Memorandum of Understanding.

UKZN's fixed LiDAR conducts daily observations for understanding the aerosol and cloud structure over Durban. Aerosol measurements indicate atmospheric pollution levels. UKZN's portable LiDAR has scanning capability and is used for studying pollution dispersion and bio-mass burning evolutions in the atmosphere (e.g. farmers' burning of agricultural land for re-cultivation). The group is also involved in joint collaborative research with Algeria, which involves the building of a system for forest fire detection, with two masters and three PhD students conducting research on this subject.

1.2.3 Air-Quality

The South African Air Quality Information System (SAAQIS) is a DEA/SAWS collaborative project which provides an online platform for managing air quality information in South Africa. It makes data available to stakeholders including the public and provides a mechanism to ensure uniformity in the way air quality data is managed i.e. captured, stored, validated, analysed and reported on in South Africa. The website is a mechanism for ensuring uniformity in the way air quality data is captured, validated, analysed and reported. Data is gathered via an established National Ambient Air Quality Monitoring Network (NAAQMN). The SAAQIS Ambient Air Quality Monitoring Module is an online platform that houses and provides access to ambient air quality data and reports from a number of registered air quality monitoring stations across the country. The objective is to provide all stakeholders with relevant, up-to-date and accurate information on ambient air quality in South Africa to support informed decision making. One hundred and forty five air quality monitoring stations are currently registered as data providers to SAAQIS (116 are government owned, 29 are industry owned). - **http://www.saaqis.org.za/** **.** The station parameters being monitored include PM 2.5 and 10.0, SO_2, NOx, CO, O_3, BTEX, and the normal meteorology including global radiation. Air quality forecasting is undertaken with the Unified Model from the UK Met office NAME III model at the South African Weather Service.

1.2.4 Cape Point Global GAW Station

The pristine location of the Cape Point Global Atmosphere Watch GAW station (34.3S, 18.5E) enables measurements to be made in air that has passed over the vast clean Southern Ocean. Such long-term observations are representative of background conditions, making it possible to detect changes in the atmosphere's composition.

Measurements include a wide range of parameters namely: - surface O_3, gases which lead to stratospheric ozone depletion such as: $CFCl_3$, CCI_2F_2, CCI_2F-$CClF_2$, CH_3CCl_3, CCl_4 , SO_2 and N_2O greenhouse gases in the troposphere such as CO_2 (22 years), CH_4 (30 years) and reactive gases such as CO with a 37 year record. The measurement of atmosphere total gaseous mercury (Hg) concentrations also has a long standing record and forms part of the international GEMS project. Wet chemistry ad passive sampling is conducted on the parameters, NO_2, NH_3, SO_2 and O_3. This all is complemented with traditional meteorological and climate parameters being monitored.

Furthermore, UV-A, UV-B and global radiation (DNI, total and diffuse with a Solys2 tracking station), are also measured as well as the normal surface meteorological parameters. ^{222}Radon measurements to assist with the classification of air masses arriving at Cape Point have been successfully established. This is in collaboration with ANSTO, Australia.

Since 2005 a project was undertake for the continuous measurements of aerosols. This is now a well-established program at the Cape Point GAW station and includes physical, chemistry and optical properties being measured. The latest addition was the establishment of Aerosol Optical Depth (AOD) precision filter instrument, which is regularly calibrated or exchanged at PMOD, Switzerland.
GAW Precision Filter Radiometer Network (GAWNET) *http://www.pmodwrc.ch/worcc.*

1.3 UV measurements

Since January 1994 the South African Weather Service has maintained a routine program for monitoring erythemally weighted UV-B radiation at Cape Town (34.0S, 18.6E), Durban (30.0S, 31.0E) and Pretoria (25.7S, 28.2E), De Aar (30.7S, 24.0E) and Port Elizabeth (33.9S, 25.5E). The equipment used in this network is the Solar Light Model 501 Robertson-Berger UV-Biometer. The program was motivated by and in collaboration with the School of Pharmacy at

the Medical University of Southern Africa (MEDUNSA), near Pretoria. The main purpose of the UV-Biometer network is to make the public aware of the hazards of excessive exposure to biologically active UV-B radiation, and it contributes to the schools' awareness programs for education. Regular enquiries from scholars are dealt with to satisfy their need to acquire more ozone and ultraviolet radiation knowledge. Celebrations around 16 September, each year, usually focus on public awareness. At these events the ministerial appearance encourages and informs scholars on the issues and actions of government.

The main UV research is undertaken by the Council for Scientific and Industry Research (CSIR) under the leadership of Dr. C Wright now residing at the Medical Research Council of South Africa. Their research unit is conducting research and monitoring of UVB exposure amongst scholars and many other outdoor activities by means of tagged badge dosimeters. The SunSmart Schools Research Project, which was co-funded by the Cancer Association of South Africa (CANSA), the South African Medical Research Council and the CSIR. In one outcome of the research, CSIR environmental health researchers have drafted a sun protection policy for schools and a roadmap for future actions. http://www.ehrn.co.za/sunsmart/ . The SAWS UB-B network thus supports the research efforts into Health risk areas posed by UV intensity over the country.

Since 2014 the SAWS has revamped its Solar Radiation network with 12 SOLYS2 tracking stations. High quality DNI, GHI and DIFF are measured at twelve stations representing the different climate zones of the country. In addition UVB and UVA (for the first time) is included in these measured parameters. Instruments used for this is the CMP11 and UVS-AB-T UVB an UVA radiometers from Kipp&Zonen. This new network is a tremendous advantage for addressing our Ozone and UV issues in the country as well and displays cross uses of technology for covering energy project aims and atmospheric research. This includes the De Aar Base-Line Surface Radiation Network (BSRN) station which was in-active between 2008 until 2014, but now back in full operations.

The Southern African Universities Radiometric Network (SAURAN) is an initiative of the Centre for Renewable and Sustainable Energy Studies (CRSES) at Stellenbosch University and the Group for Solar Energy Thermodynamics (GSET) at the University of KwaZulu-Natal and others. SAURAN aims to make high-resolution, ground-based solar radiometric data available from stations located across the Southern African region, including South Africa, Namibia, Botswana and Reunion Island. Most of our stations provide direct normal irradiance (DNI), global horizontal irradiance (GHI) and diffuse horizontal irradiance (DHI) at 1-minute, hourly and daily time averaged intervals, using state of the art Kipp & Zonen radiometers. Their focus remains on the alternative energy sector and more detail can be found at. http://www.sauran.net/

1.4 Calibration activities

SAWS has hosted past Dobson Spectrophotometer Inter-calibrations for the African Dobson in 2000, and the last in 2009. South Africa also participated in the 2004 Dahab, Egypt Intercalibration event.

The Regional Standard Dobson instrument D089 has been calibrated against the World Standard instrument (D083), but the need exits for another Inter-calibration, which currently is only planned for the Southern African Dobson in 2018. It is hoped that most of the Northern African Dobson's and D089 from Irene may be accommodated in European IC events during 2017.

Ozonesonde standard operational procedures (SOP's) are carefully maintained. The ozonesonde Workshop coinciding with the Quadrennial Ozone Symposium was also attend in Edinburgh, Scotland during September 2016.

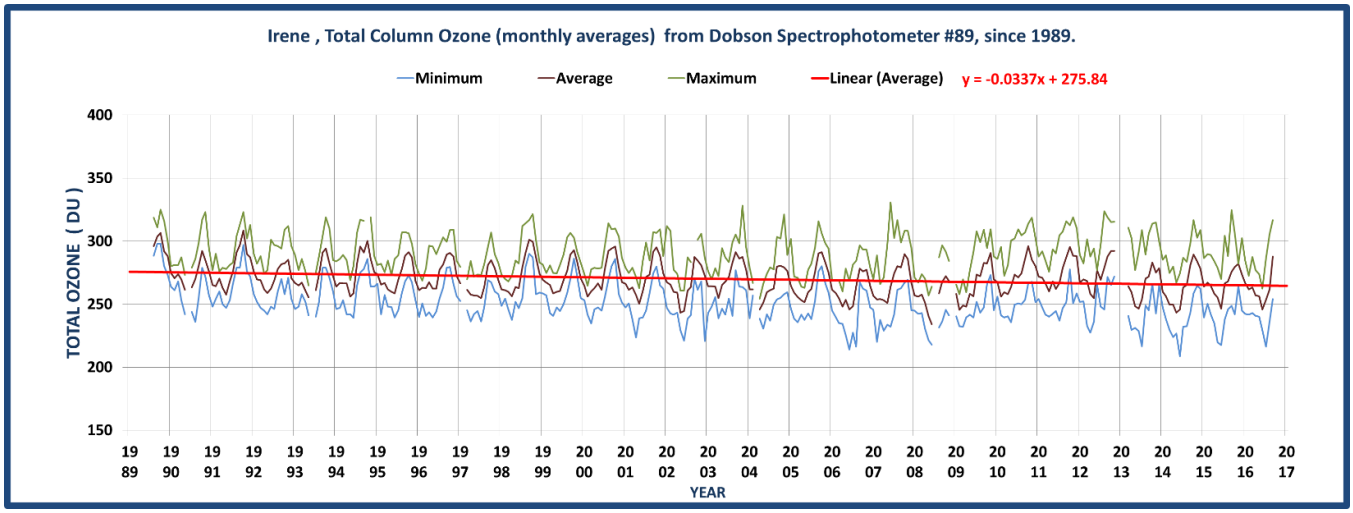
The Cape Point Global GAW station regularly takes part in schedule instrument and data audits under the auspices of the WMO GAW community.

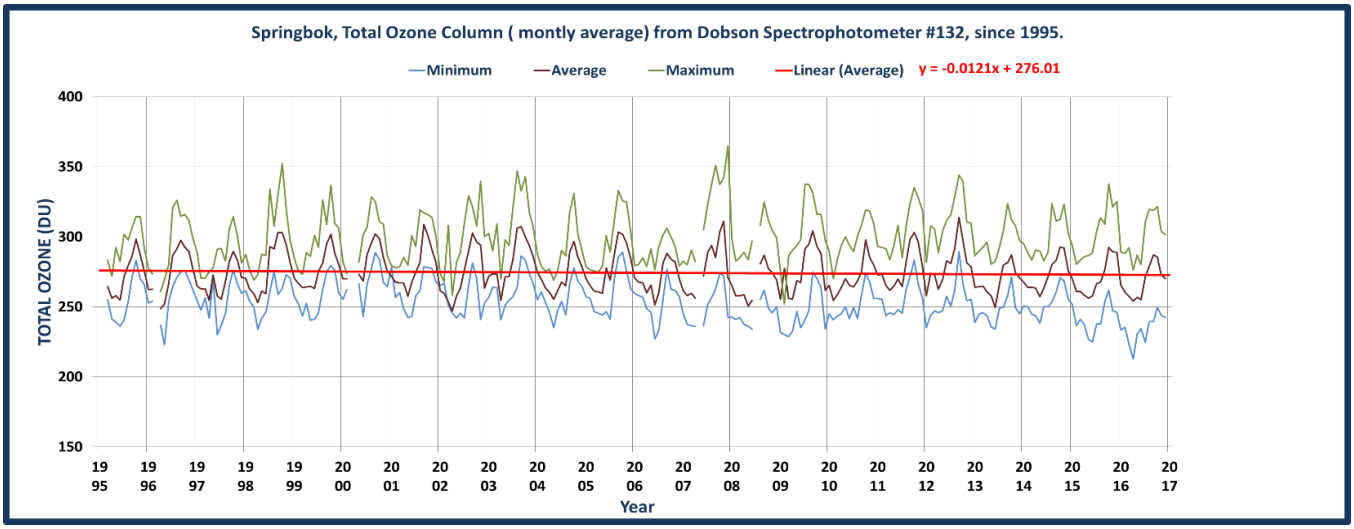
2. RESULTS FROM OBSERVATIONS AND ANALYSIS

Ozonesonde, Dobson and Cape Point GAW data sets are available through the World Data centers (and per direct request) and are frequently used in national and international research and publications projects.

Trend results from the UV Biometer network is inconclusive, due to the instruments inherent variability. However, South Africa remains one of the world's very high UV prone countries, especially in the summer months, spring and early autumn months.

Trend analysis of the Total Ozone Column from the Irene Dobson spectrophotometer (since 1989) continues to show a slight positive trend after 2002, and the overall trend since 1989 is less negative. The Springbok Dobson Ozone trend since 1995 remains slightly negative overall. See figures below:-





3. THEORY, MODELLING, AND OTHER OZONE RELATED RESEARCH

The country has limited capacity and actions in this regard. However, satellite data is used to keep check on the ground based Dobson observations and other data sets and vice versa. UV effects studies are also being conducted – note within the selected reference materials further below.

4. DISSEMINATION OF RESULTS

4.1 Data reporting

Measurements from the Dobson Spectrophotometer stations Irene and Springbok are submitted to the WOUDC on an annual basis. This includes the zero-level data files since 2014.The Cape Point Global GAW station data sets are also being deposited regularly at the World data centers, such as WDC- GHG-Japan and for the surface ozone. Ozonesonde data from Irene is taken up in the SHADOZ database, and thus also submitted to WMO WDC WOUDC, Toronto Canada.

4.2 Information to the public

The SAWS disseminates UV- index forecasts with its daily weather bulletins for the greater Metropolitan areas. Data and information is also shared with the Department of Environmental Affairs and to other government institutes as requested. The Ozone Unit of the Department of Environmental Affairs also embarks each year on 16 September to celebrate "world ozone day ". Celebrations are alternatively arrange with events in the rural area of our provinces, to raise awareness and to disseminate information. Ministry Press Release are also prepared and local radio stations are supplied with information to their audiences.

4.3 Relevant scientific papers

- Adesina J., K.R. Kumar, V. Sivakumar and S.J. Piketh, Intercomparison and assessment of long-term (2004-2013) multiple satellite aerosol products over two contrasting sites in South Africa, J. Atmos. Solar. Terr.Phys, 148, 82-95, 2016.

- Cadet J.M., H. Bencherif, C.Y. Wright, T. Portafaix, K. Ncongwane and G.J.R. Coetzee, Comparison of ground-based and satellite derived solar ultraviolet radiation levels at six South Africa sites, Ann. Geophys. (2016 Submitted)

- Vaz Peres L., H. Bencherif, N. Mbatha, A.P. Schuch, A.M. Toihir, N. Bègue, T. Portafaix, V. Anabor, D.K. Pinheiro, N.M.P. Leme, J.V. Bageston, and N.J. Schuch, Measurements of the total ozone column using a Brewer spectrophotometer and TOMS and OMI satellite instruments over the Southern Space Observatory in Brazil, Ann. Geophys., 35, 25–37, 2017

- Tesfaye M., J. Botai, V. Sivakumar, G. Mengistu Tsidu, C.J.deW. Rautenbach and Shadung J. Moja , Simulation of bulk aerosol direct radiative effects and its climatic feedbacks in South Africa using RegCM4, Journal of Atmos. Solar Terr. Physics, 142, 1-19, 2016.

- Sivakumar V., H. Bencherif, C. Liousse, J.P. Beukes, P.G. van Zyl, P. Formenti, S. Piketh and C.Y. Wright, Atmospheric Research in Southern Africa and Indian Ocean: a South Africa – France bilateral collaborative programme, Clean Air Journal, Volume 25, No 2, 2015

- NYEKI, S., WEHRLI, C., GRÖBNER, J., KOUREMETI, N., WACKER, S., LABUSCHAGNE, C., MBATHA, N. and BRUNKE, E.-G. 2015. The GAW-PFR Aerosol Optical Depth Network: 2008 – 2013 Time-Series at Cape Point Station, South Africa. Journal of Geophysical Research Atmospheres, 120, pp. 5070-5084. http://dx.doi.org/10.1002/2014JD022954.

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- THOMPSON, A. M., BALASHOV, N. V., WITTE, J. C., COETZEE, J. G. R., THOURET, V. and POSNY, F. 2014. Tropospheric ozone increases over the southern Africa region: bellwether for rapid increases in Southern Hemisphere pollution? Atmospheric Chemistry and Physics, 14, pp. 9855-9869. http://dx.doi.org/10.5194/acp-14-9855-2014.

- STAUFFER, R. M., MORRIS, G. A., THOMPSON, A. M., JOSEPH, E., COETZEE, G. J. R., and NALLI, N. R. 2014. Propagation of radiosonde pressure sensor errors to ozonesonde measurements. Atmospheric Measurement Techniques, 7(1), pp. 65-79. http://dx.doi.org/10.5194/amt-7-65-2014.

- OLTMANS, S.J., LEFOHN, A.S., SHADWICK, D., HARRIS, J.M., SCHEEL, H.E., GALBALLY, I., TARASICK, D.W. JOHNSON, B.J., BRUNKE, E.-G, CLAUDE, H., ZENG, G., NICHOL, S., SCHMIDLIN, F., DAVIES, J., CUEVAS, E., REDONDAS, A., NAOE, H., NAKANO, T. and KAWASATO, T. 2013. Recent tropospheric ozone changes: a pattern dominated by slow or no growth. Atmospheric Environment, 67 (March), pp. 331-351. http://dx.doi.org/10.1016/j.atmosenv.2012.10.057.

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5. PROJECTS, COLLABORATION, TWINNING AND CAPACITY BUILDING

The French/South African GDRI ARSAIO project continues. The following institutions forms part of this initiative. South Africa – North West university, Potchefstroom, University of Kwa-Zulu natal, Durban, University of Pretoria, The Council for Industrial Research CSIR, the Medical Research council and some other. France- Laboratoire de l'Atmosphère et des Cyclones, Université de la Réunion, Réunion, and LISA, UMR 7583, Créteil, France.

The French and South African researcher's coordinate their particular actions/theme, such as;
- Action 1 Impact of anthropogenic pollution in Southern Africa on Climate Change and Health
- Action 2 Transport and deposition of mineral dust in western southern Africa
- Action 3 Stratosphere and troposphere interactions: ozone, water vapour, aerosols and UV radiations Variability and change

SAWS is also a collaborator in the NASA, USA - Southern Hemisphere Additional OZonesondes (SHADOZ) program under leadership of the principle investigator Dr. Anne Thompson since 1997. http://croc.gsfc.nasa.gov/shadoz/).

Collaboration with NOAA, Boulder, USA and DWD, Hohenpeissenberg, Germany continues in light of maintaining the Southern African Dobson responsibilities and operational work.

BSRN (Baseline Surface Radiation Network): With the De Aar site various solar measurements are shared and workshop are attended.

Global Mercury Observations System (GMOS) – Cape Point GAW station contributes to this international Program.

DEBITS Program - LSCE, CNRS, France. North West University has been actively taking part in this initiative over a very long period.

Training assistance from GAWTEC http://www.schneefernerhaus.de/e-gawtec.htm , Germany. Over the years many South African scientist have benefited from this successful initiative.

National Collaborating Institutions :- Ozone and related monitoring and research are conducted mostly at a few academic institutions such as the University of KwaZulu Natal in Durban, the University of Cape Town, The University of North West, Potchefstroom, University of Pretoria, CSIR-Council for Scientific and Industrial Research and the Medical Research Council.

6. IMPLEMENTATION OF THE RECOMMENDATIONS OF THE 9th OZONE RESEARCH MANAGERS MEETING

The main focus has been to maintain the existing ozone observations, monitoring and research activities, to enable for the quality long-term data sets to mature even further. Capacity building has also received good attention with students enrolling for post graduate studies, over a wide ozone related field. Additional staff members has also been recruited to assist with Dobson and Ozone soundings at the Irene Weather office. This to ensure sound continuity and skills transfer for the future uphold of current networks.

One difficult area that has been experienced in the adherence of especially the regular Dobson Spectrophotometer international calibrations. This remains a logistical challenge at times, and alternative arrangements (2017 and 2018) are being looked at, alongside our international collaborators and WMO.

Dobson 035, (on loan from UK Met Office to SAWS) has started with a modest observation total ozone program at the Stellenbosch weather office (about 40km west of Cape Town) to compliment Cape Point GAW program. Capacity for a substantial observation program is still hampered due to the small staffing compliment currently residing at the Cape Point Global station.

The establishment of mechanism to improver data turn-around, into near real time data dissemination still remains a large challenges as the quality assurances and final data checks remain to be a very hands-on process to deal with.

7. FUTURE PLANS

The main aim is to maintain the operability and quality of the current available monitoring infrastructure through the appropriate institutions. The frequent calibration of instruments and to avoid and rectify gaps of the past, to safeguard the primary long-term data sets of atmospheric parameters.

The focus will remain on capacity building enabling students with post- graduate studies in this important atmospheric field.

It still remains a goal to expand the SAWS GAW – ozone related monitoring activities in South Africa, towards the Southern Oceans and Antarctica. However plans seem to fail, due to the current unsatisfactory economic climate and the many other priorities we are being faced with. South Africa has access to Gough (UK) and Prince Edward Island Group (RSA) in the Southern oceans and the SANAE-IV Antarctic base. South Africa also has a new research vessel the Agulhas-II which could play a major role in the relevant atmospheric monitoring as it traverses the Southern Oceans on routine research and relief voyages.

8. NEEDS AND RECOMMENDATIONS

There is a continued need for maintaining systematic monitoring of the ozone layer, this in spite of what is perceived to be the success story of the Montreal Protocol. Full recovery is still a few decades away, and we need to account for all the atmosphere/climate feedback mechanisms and their uncertainties as the ozone layer enters the recovering phase.
Internationally, strong support for maintaining ground-based observation stations with long-term data records must continue, especially in the world's data sparse regions.
There is an existing need to monitor the ozone depleting substances (CFC's and HCF's) with more intensity and at more locations globally.

It is essential to continue with the provision and development of international data archive facilities and instrument calibration standards and inter-comparisons. Collaboration and assistance of the international community remains the cornerstone of these efforts.
For some instruments the software for data processing could be upgraded and be made more user friendly. Software such as Dobson tools could keep track with the IT technology advances, but this would mean specialised efforts and investment for some experts to develop, test and adopt as a global standard.

CONTACT INFORMATION

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SPAIN

1. OBSERVATIONAL ACTIVITIES

The monitoring and research of continuous long term ozone, UV radiation and related atmospheric compounds is mainly conducted by the Meteorological Agency of Spain (AEMET) and the Instituto Nacional de Técnica Aeroespacial (INTA). The Departments of Physics and Meteorology of several Spanish universities also perform long term observations to support their research. There is close cooperation between research and monitoring institutes (INTA/AEMET) and Universities on the field of ozone and UV research, participating together in most of the research (Table I).

Table 1: Spanish Institutes involved in ozone/UV research (R), development (D), modelling (MD), monitoring (MT), and quality assessment/quality control (QA/QC)

Institute	Fields	Research Proyects	Keywords
AEMET	R,D,MT,QA/QC,	ATMOZ,EGV-SVN	CRN,GAW; RBCC-E, NDACC
U. Extremadura (UEx)	R,D,MD,MT,QA/QC	ICARO	CCD
INTA	R,D,MT,QA/QC,	ICARO, COST-ES1207	MAXDOAS, OClO,BrO
U. Valladolid (UVA)	R,D,MT	VALIASI	FTIR.
U. La Laguna (ULL)	R,MT,MD	ATMOZ,EGV-SVN	Brewer, Pandora QA/QC

1.1 Column measurements of ozone and other gases/variables relevant to ozone loss

The longest total ozone record in Spain (since 1980) has been obtained with the Dobson spectrophotometer #120 installed at "El Arenosillo Atmospheric Sounding Station" (Huelva) and operated by INTA. In 1997 this station is complemented with a Brewer spectrophotometer. The AEMET operates a network of six Brewer spectrophotometers with observations since 1992 at Madrid and Izaña. The Brewer network is calibrated every two years at the RBCC-E campaigns at INTA/El Arenosillo Huelva.

Table 2: Total Ozone Column Operational Long Term measurements in Spain

Operational Long Term ozone and UV measurments SPAIN					
Total Ozone Column					
Location	**Org.**	**Instrument**	**type/No**	**Start**	**Database**
Izaña Observatory	AEMET	Brewer	#157,#183,#	1992	WOUDC/NDA
Izaña Observatory	AEMET	FTIR		2007	NDACC
Izaña Observatory	INTA	DOAS		1993	NDACC
Izaña Observatory	AEMET	Pandora	101/121	2011	Pandonia
A Coruña	AEMET	Brewer	#151	1999	WOUDC
Zaragoza	AEMET	Brewer	#166	2000	WOUDC
Madrid	AEMET	Brewer	#070, #186	1991	WOUDC
Murcia	AEMET	Brewer	#117	1995	WOUDC
Sta Cruz de Tenerife	AEMET	Brewer	#033	1995	WOUDC
El Arenosiilo	INTA	Dobson	#120	1980	WOUDC
El Arenosillo	INTA	Brewer	#150	1997	WOUDC
Huelva	UEx-INTA	NILU-UV	#119	2011	
Badajoz	UEx	NILU-UV	#145	2012	

The Izaña Observatory is one of the reference measurement stations worldwide gathering the most precise ozone measurement instruments: Brewer (since 1992), ozonesondes (since 1993), Pandora (2012), DOAS (1993) and FTIR (1999, the latter in cooperation with the National Institute of Aerospace Technology, INTA, and the Institute for Meteorology and Climate Research, IMK-Germany). These measurements belong to the Global Atmosphere Watch programme (GAW) of the World Meteorological Organization (WMO) and the network of excellence "Network for the Detection of Atmospheric Composition Change (NDACC).

Table 3: Ozone Profile operated by Spain

Ozone Vertical Profile					
Location	**Org.**	**Instrument**	**type/No**	**Start**	**Database**
Madrid	AEMET	OzoneSonde		1993	WOUDC
Izaña Observatory	AEMET	Ozone Sonde		1993	NDACC
Izaña Observatory	AEMET	FTIR		1999	NDACC
Belgrano (Antarctica	INTA	ozonesonde	Marwin 15	1999	WOUCD
Ushuaia	AEMET/INTA	ozonesonde	Marwin 13	2008	WOUDC

In the framework of INTA and Dirección Nacional del Antártico (DNA, Argentina) collaboration, three UV-VIS spectrometers were installed at the permanent Argentinean bases of Belgrano (77º 52' S 34º37' W), Marambio (64º 14' S 56º37' W) and Ushuaia (54º 48' S 68º19' W) in 1994. The selected stations are scientifically of interest for Polar atmosphere studies since they cover areas in the stratosphere dynamically and chemically differentiated. The main objective of this network is to provide both long term and near real-time observations of column O3 and NO2, in order to characterize the polar vortex and the O3 destruction. The instruments were updated with new MAXDOAS in the three stations. In Ushuaia, the new MAXDOAS was installed in the GAW station operates by Servicio Meteorológico Nacional (SMN). New instruments have expanded its capability to BrO, OClO, IO and O4.

Table 4: Relevant species related to ozone loss

Type of Observation	Location	Org.	Instrument	Start	Database
NO2 Total Column					
	Izaña Observ	INTA	MAXDOAS	1993	NDACC
	Marambio	INTA	MAXDOAS	1994	
	Belgrano	INTA	MAXDOAS	1995	
	Ushuaia	INTA	MAXDOAS	1994	
BrO Total column					
	Belgrano	INTA	MAXDOAS	2011	
	Marambio	INTA	MAXDOAS	2015	
OClO					
	Belgrano	INTA	MAXDOAS	2011	
	Marambio	INTA	MAXDOAS	2015	

1.2 Profile measurements of ozone and other gases/variables relevant to ozone loss

In November 1992, the ECC ozonesonde programme was initiated as part of the GAW activity at Izaña Observatory. The ozonesoundings have been launched from Puerto de la Cruz station (36 m.a.s.l.), at a distance of 28 Km from the Izaña Observatory, on a weekly basis and without any interruption since 1992. ECC ozonesondes have been launched on a weekly basis from Madrid by INM since 1992. A long-term ozonesounding programme between INTA and

DNA/IAA (Argentina) has been running at the Belgrano station (Argentina, 78oS, 35oW) since 1999. Ozonesondes have been regularly launched throughout the year providing ozone vertically resolved dataset for seasonal characterization of the Antarctic ozone layer. Belgrano ozonesounding station has recently been accepted as NDACC station. AEMET, the Argentinean Meteorological Service (SMN), INTA and the Government of the province of Tierra del Fuego (Argentina), initiated a programme on 2008 for total column atmospheric ozone monitoring from the Ushuaia GAW station. Data from both stations are used to develop the WMO Antarctic ozone bulletin.

FTIR: since February 1999 a ground-based FTIR (Fourier Transform InfraRed) spectrometer (Bruker IFS 120 M) is operated at the Izaña Observatory by the Institut fur Meteorologie und Klimaforschung (IMK) (Forschungszentrum Karlsruhe, Germany). Besides zenith column amounts and profile (ZCA) of trace gases such as O3, H2O, HDO, N2O, CH4, HF, HCl, ClONO2, NO, NO2, and HNO3, profiles of gases with narrow absorption lines such as O3, NO, HCl and HF can be retrieved. In March 2005 a new FTIR spectrometer was installed at Izaña Observatory.

Table 4 : Ozone Profile operated by Spain

Ozone Vertical Profile					
Location	**Org.**	**Instrument**	**type/No**	**Start**	**Database**
Madrid	AEMET	OzoneSonde		1993	WOUDC
Izaña Observatory	AEMET	Ozone Sonde		1993	NDACC
Izaña Observatory	AEMET	FTIR		1999	NDACC
Belgrano (Antarctica)	INTA	ozonesonde	Marwin 15	1999	WOUCD
Ushuaia	AEMET/INTA	ozonesonde	Marwin 13	2008	WOUDC

1.3 UV measurements

The Meteorological Agency of Spain (AEMET) is running a comprehensive ultraviolet ground-based measurement programme which covers all the country. In addition to the operational UV-network of AEMET, autonomous regions of Andalucia, Extremadura, Galicia and Valencia also provide continuous measurements of UVB radiation for research and development purposes (Table 3). These networks are calibrated at the laboratories of AEMET (Madrid Area of Atmospheric Observation Network), which perform a two-year calibration of Broadband detectors of AEMET, and INTA (Huelva, El Arenosillo Sounding Station), which performs the calibration of the INTA/Uex network.

1.4 Calibration activities

In November 2003 the WMO/GAW Regional Calibration Centre for RA-VI region (RBCC-E) was established at the Izaña Atmospheric Research Centre of AEMET, Canary Islands (IZO). RBCC-E owns a full set of calibration and reference-maintenance equipment composed of three Brewer spectroradiometers (The IZO Triad): a Regional Primary Reference (Brewer 157), a Regional Secondary Reference (Brewer 183) and a Regional Travelling Reference (Brewer 185), which can be transported for calibration campaigns outside IZO. The Regional Brewer Calibration Center transfers the calibration from the World Reference Triad in Toronto. Due to the doubts about the maintenance of the World Triad, the WMO Scientific Advisory Group for Ozone (WMO-SAG Ozone) authorized RBCC-E in 2011 to transfer its own absolute calibration obtained by Langley.

Table 5: Ultraviolet radiation monitoring network in Spain

Ulltraviolet Radiation					
Location	**Org.**	**Instrument**	**type/No**	**Start**	**Database**
Almeria Airport	AEMET	Broad B. Rad.	UVB-1, YES	2007	ww.aemet.es
Moguer (El Arenosillo)	AEMET	Broad B. Rad.	UVB-1, YES	2007	ww.aemet.es
Badajoz	AEMET	Broad B. Rad.	UVB-1, YES	1999	ww.aemet.es
Barcelona	AEMET	Broad B. Rad.	UVB-1, YES	2008	ww.aemet.es
Cáceres	AEMET	Broad B. Rad.	UVB-1, YES	2007	ww.aemet.es
Cádiz - Obs.	AEMET	Broad B. Rad.	UVB-1, YES	2007	ww.aemet.es
Ciudad Real	AEMET	Broad B. Rad.	UVB-1, YES	1999	ww.aemet.es
Córdoba - Airport	AEMET	Broad B. Rad.	UVB-1, YES	2009	ww.aemet.es
A Coruña	AEMET	Broad B. Rad.	UVB-1, YES	1999	ww.aemet.es
Granada Base Aérea	AEMET	Broad B. Rad.	UVB-1, YES	2003	ww.aemet.es
Izaña	AEMET	Broad B. Rad.	UVB-1, YES	2005	ww.aemet.es
León Airport	AEMET	Broad B. Rad.	UVB-1, YES	2007	ww.aemet.es
Madrid, Ciudad Universitaria	AEMET	Broad B. Rad.	UVB-1, YES	1995	ww.aemet.es
Málaga	AEMET	Broad B. Rad.	UVB-1, YES	1999	ww.aemet.es
as Palomas, C. Insular Turismo	AEMET	Broad B. Rad.	UVB-1, YES	2007	ww.aemet.es
Murcia	AEMET	Broad B. Rad.	UVB-1, YES	1997	ww.aemet.es
Puerto de Navacerrada	AEMET	Broad B. Rad.	UVB-1, YES	2012	ww.aemet.es
Palma de Mallorca, port	AEMET	Broad B. Rad.	UVB-1, YES	1999	ww.aemet.es
Tortosa	AEMET	Broad B. Rad.	UVB-1, YES	2007	ww.aemet.es
Salamanca, Matacan	AEMET	Broad B. Rad.	UVB-1, YES	2010	ww.aemet.es
Santander	AEMET	Broad B. Rad.	UVB-1, YES	1999	ww.aemet.es
San Sebastián, Igueldo	AEMET	Broad B. Rad.	UVB-1, YES	2005	ww.aemet.es
Sta Cruz de Tenerife	AEMET	Broad B. Rad.	UVB-1, YES	2009	ww.aemet.es
Valencia Airport	AEMET	Broad B. Rad.	UVB-1, YES	2007	ww.aemet.es
Valladolid	AEMET	Broad B. Rad.	UVB-1, YES	1999	ww.aemet.es
Zaragoza Base Aérea	AEMET	Broad B. Rad.	UVB-1, YES	1999	ww.aemet.es
Formigal	AEMET	Broad B. Rad.	UVS-E-T K&Z	2016	aire.unex.es/u
Badajoz	UEx	Broad B. Rad.	UVS-E-T K&Z	2001	aire.unex.es/u
Cáceres	UEx	Broad B. Rad.	UVS-E-T K&Z	2001	aire.unex.es/u
Plasencia	UEx	Broad B. Rad.	UVS-E-T K&Z	2002	aire.unex.es/u
Fuente de Cantos	UEx	Broad B. Rad.	UVS-E-T K&Z	2007	aire.unex.es/u
Orellana La Vieja	UEx	Broad B. Rad.	UVS-E-T K&Z	2007	aire.unex.es/u
La Covatilla	UEx	Broad B. Rad.	UVS-E-T K&Z	2008	aire.unex.es/u
El Arenosillo	INTA/CMAJA	Broad B. Rad.	UVB-1, YES	1999	aire.unex.es/u
Alcalá de Guadaira	INTA/CMAJA	Broad B. Rad.	UVS-E-T K&Z	2010	aire.unex.es/u
Cordoba	INTA/CMAJA	Broad B. Rad.	UVS-E-T K&Z	2010	aire.unex.es/u
Algeciras	INTA/CMAJA	Broad B. Rad.	UVS-E-T K&Z	2010	aire.unex.es/u
Marbella	INTA/CMAJA	Broad B. Rad.	UVS-E-T K&Z	2010	aire.unex.es/u
Ferrol	MeteoGalcia	Broad B. Rad.	-	-	/uv/observacio
Rivadeo	MeteoGalicia	Broad B. Rad.	-	-	/uv/observacio
Pontevedra	MeteoGalicia	Broad B. Rad.	-	-	/uv/observacio
Cervantes	MeteoGalicia	Broad B. Rad.	-	-	/uv/observacio
Granada Base Aérea	rsidad de Gra	Broad B. Rad.	-	2006	
UV Calibriation Facilities					
Madrid	AEMET	oration Laboratoy			
Huelva	INTA	oration Laboratoy			
Izaña	AEMET	ewer Calibration Center.			

Brewer inter-comparisons are held annually, alternating between Arosa in Switzerland and El Arenosillo Atmospheric Sounding Station (INTA) in Huelva, in the South of Spain. During these calibration campaigns a total of 45 Brewer ozone spectrometers were calibrated and reported in Huelva 10-20 Jun 2013 (17 instruments), Arosa 14-24 July 2014 (7 instruments) and El Arenosillo May 2015 (21 Instruments).

The calibration reports of the intercomparisons are regularly published as GAW publication series. During this reporting period the Arosa 2012 , Huelva 2013 and Arosa 2014, calibration reports were published (216. Seventh Intercomparison Campaign of the Regional Brewer

Calibration Center Europe (RBCC-E), Lichtklimatisches Observatorium, Arosa, Switzerland, 16-27 July 2012, 106 pp. March 2015, 224. Ninth Intercomparison Campaign of the Regional Brewer Calibration Center for Europe (RBCC-E), Lichtklimatisches Observatorium, Arosa, Switzerland, 14-26 July 2014, 40 pp. December 2015, 223. Eighth Intercomparison Campaign of the Regional Brewer Calibration Center for Europe (RBCC-E), El Arenosillo Sounding Station, Huelva, Spain, 10-20 June 2013, 79 pp. December 2015). The last campaign was the *XI Regional Brewer Calibration Center for Europe (RBCC-E) intercomparison* held at Arosa-Davos Lichtklimatisches Observatorium LKO of MeteoSwiss during the period June 24- July 05, 2016. In addition to the regular intercomparison campaigns, absolute calibrations were held at Izaña Atmospheric Observatory: the NORDIC campaign in December 2013 supported by ESA CalVal project, and the reference calibration of the Environmental Canada Brewer #145 in March 2014. The last absolute campaign was ATMOZ ozone instruments intercomparison, held at Izaña Atmospheric Observatory (Canary Islands, Tenerife, Spain) from 12-30 September 2016, organised by Izaña Atmospheric Research Centre of the Spanish Meteorological Agency (AEMET) and the World Radiation Center (PMOD-WRC). This campaign was supported by the European Union through the project EMRP 59 ATMOZ, "Traceability for Atmospheric Total Column Ozone." The objective of the campaign was to compare the Total Ozone measurements of the participating instruments and to obtain a ground-based high-resolution UV range extraterrestrial spectrum.

(More detailed information can be found in Chapter 17 of the Izaña Atmospheric Research Centre (IARC), from the State Meteorological Agency of Spain (AEMET) Activity Report (2012-2014) GAW report 219.)

The INTA ground-based MAXDOAS observations are all contributing to the NDACC and are being certified in this framework. The MAXDOAS instruments have participated to several calibration campaigns, e.g., the recent CINDI2 campaign in Cabaw (NL) in 2016

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

Several studies analyze the ozone evolution and trends of the ozone layer over Spain, (Román et al., 2014) use for the analysis satellites and ERA40, whereas (Mateos et al., 2015). analyse the evolution using ground based Brewer series. There are no significant differences in the trends over the Iberian Peninsula. From the 1970s to the mid-1990s stronger and significant negative trends were observed in the annual series of the averaged Iberian Peninsula: −3.9% per decade whereas the Iberian Peninsula shows a non significant increase from 1995 to 2011. This is in agreement with the ground bases analysis of the period 1991-2012 performed by (Mateos et al., 2015) who found TOC exhibits a positive significant trend in the period 1993–2012 of 9.3 DU per decade at Madrid station.

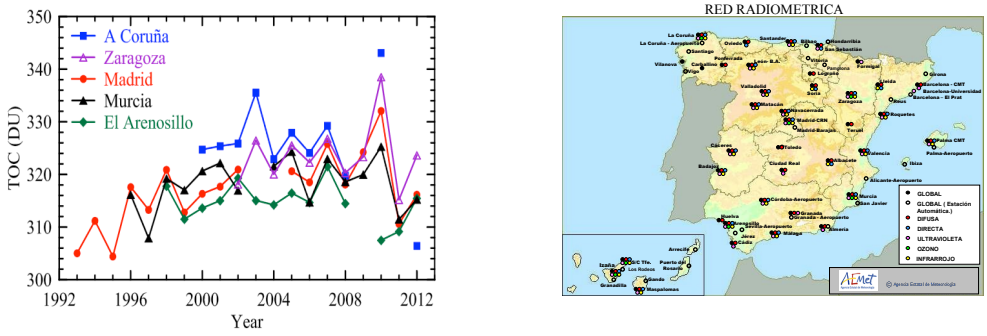


Figure 1: Temporal Evolution of yearly TOC values at five Spanish Stations (left),(Mateos et al., 2015) and the AEMET UV broadband network.

Thirteen years of ozone soundings at the Antarctic Belgrano II station (78_ S, 34.6_ W) have been analysed to establish a climatology of stratospheric ozone and temperature over the area (Parrondo et al., 2014). Decrease of the total ozone column over Belgrano during spring is highly dependent on the meteorological conditions. Largest depletions (up to 59 %) are reached in coldest years, while warm winters exhibit significantly lower ozone loss (20 %). It has been found that about 11% of the total O3 loss, in the layer where maximum depletion occurs, takes place before sunlight has arrived, as a result of transport to Belgrano of air from a somewhat lower latitude, near the edge of the polar vortex, providing evidence of mixing inside the vortex.

3. THEORY, MODELLING, AND OTHER OZONE RELATED RESEARCH

A relevant result for this reporting period is the study of the effect of the cross section (XS) on the ozone retrieval of Dobson and Brewer, the reference instruments for the measurement of total ozone. In 2009, the ozone community established the ACSO committee ("Absorption Cross Sections of Ozone") to review the presently available cross sections (XS) databases and to determine the impact of a change of the reference XS for the different instrument types (ground-based and satellite) used in the individual instrument retrieval algorithms. (http://igaco-o3.fmi.fi/ACSO/). This ACSO committee is a joint commission of Scientific Advisory Group (SAG) of the Global Atmosphere Watch (GAW) of the World Meteorological Organization (WMO) and the International Ozone Commission (IO3C) of the International Association of Meteorology and Atmospheric Sciences (IAMAS).

This study performed with the support of the ESA-CALVAL project was a joint effort of the weather services of Germany, Spain, Switzerland and United States of America with the participation of the Dobson and Brewer WMO calibration centres, which provide the high quality Brewer and Dobson ozone observations together with Bremen University, which

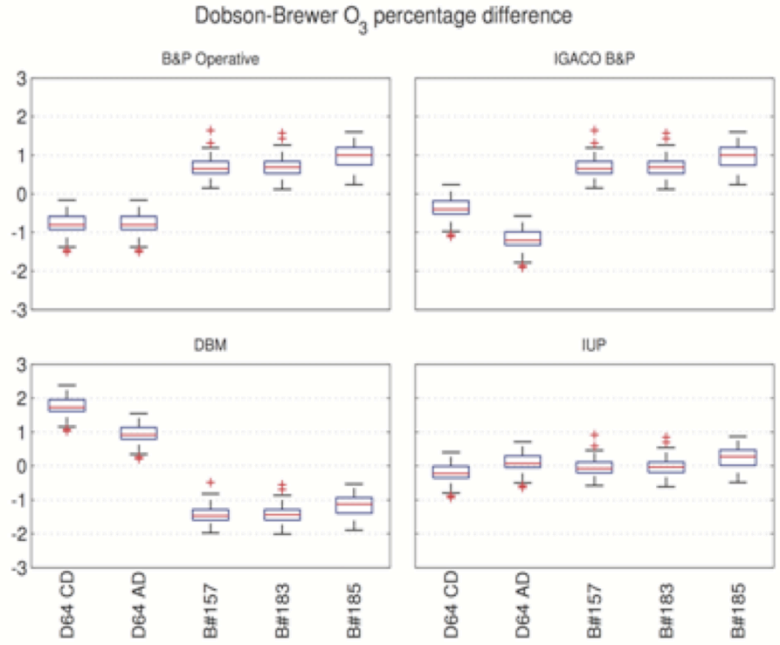


Figure 2: Percentage ratio between Dobson (Dobson 64 AD and CD pairs) and Brewer (B#157,B#183 and B#185) when apply the same Langley calibration and different cross section analysed (Bass & Paur, operative (B&P operative) and the temperature quadratic fit (IGACO B&P), the Daumont, Brion & Malicet (DBM) and the Serdyuchenko 2013 developed by the University of Bremen for the HARMONICS project. (Redondas et al., 2014)

provides the new proposed ozone cross section. It was published on ACP in a paper under the title: "Evaluation of the Use of Five Laboratory Determined Ozone Absorption Cross Sections in Brewer and Dobson Retrieval Algorithms". The paper demonstrates that the use of recently released Ozone Absorption Cross Section by Bremen University solves the historical differences between Dobson and Brewer spectrophotometers, the primary ground-based instruments to measure Total Ozone. The application of this new cross sections to the CEOS Calibration campaign data of reference instruments eliminates the bias between the Ozone measurements of these two instruments, moreover introducing the temperature dependence of the cross section on the retrieval algorithms. The seasonal differences of these instruments also disappear when we apply the Arosa, Switzerland, Dobson and Brewer simultaneous total ozone observations.

Another relevant study described the main features of the subtropical tropopause region over Tenerife (the Canary Islands, Spain; 28°N, 16°W), examined and characterised using 20-year (1992–2011) ozonesonde data and European Centre for Medium-Range Weather Forecasts ERA-Interim potential vorticity (PV) and zonal wind speed reanalysis.

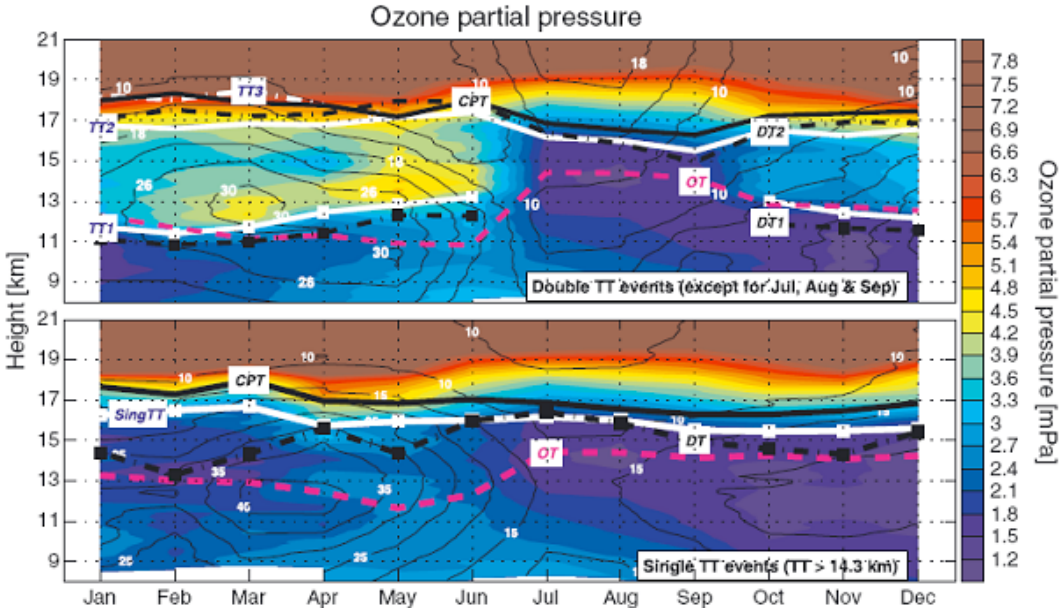


Figure 3: Time-height cross section of ozone partial pressure (mPa) and wind speed contours (ms−1) from 8 to 21 km height for (top) multiple and (bottom) single thermal tropopause events. The vertical coordinate is tropopause based. The different tropopause types are shown labeled with their corresponding acronym. TT1, TT2 and TT3 are the first, second and third thermal tropopauses, respectively; DT1 and DT2 are the first and second dynamical tropopause, respectively; OT is the ozone tropopause, and CPT is the Cold-Point tropopause.(Franco et al., 2013)

This study introduces new insights since high-resolution vertical profiles allowed a detailed description of the subtropical tropopause break and the associated subtropical jet stream (STJ), where models fail to properly simulate the upper troposphere–lower stratosphere (UTLS). The subtropical UTLS, which is a rather thick (~8 km) and complex region, is analysed by evaluating four different tropopause definitions: thermal (TT), Cold Point (CPT), ozone (OT), and dynamical (DT) tropopauses. A novel method to determine the DT based on the vertical gradient of Lait's modified PV is presented. This method represents an analytical improvement for DT determination from model reanalysis. The concept of a second DT and a second OT has been introduced for the first time, showing an excellent agreement with the second thermal

tropopause and the cold point tropopauses. The 14.3 km height level is used to differentiate between tropical and extratropical UTLS regimes, intimately linked to the position of the STJ. There is a fairly good consistency between all the defined tropopauses under the double tropopause scheme, except in spring, when the OT is observed at lower levels due to frequent baroclinic instabilities in the upper troposphere. In winter, altitude differences between OT, DT, and TT resulted from poleward STJ excursions forced by blocking systems over the North Atlantic. Analysis of the tropopause inversion layer showed distinctive features for tropical and midlatitude tropopauses.

3.2 Retrieval algorithm developments

Development of inversion algorithms (using the Optimal Estimation Method) for ground-based MAXDOAS remote sensing spectral data, for the retrieval of vertical distributions of the absorbing atmospheric constituents. INTA has recently developed algorithms to implement the Optimal Estimation Method, and therefore allow the retrieval of vertical profile information from the ground-based MAXDOAS spectra, at low vertical resolution for e.g., NO2, O3, BrO.

4. DISSEMINATION OF RESULTS

4.1 Information to the public: Database

Total ozone daily means are submitted on a daily basis to the WMO Northern Hemisphere Daily Ozone Mapping Centre run by the Laboratory of Atmospheric Physics at the Aristotle University of Thessaloniki (Greece) and to the WOUDC. Evaluated and refined total ozone data from Madrid, Murcia, El Arenosillo, Santa Cruz de Tenerife and Izaña stations are periodically submitted to the WOUDC database.

AEMET co-leads EBUREWNET European COST action, which aims to facilitate consistent and evenly measurements of ozone, spectral UV, and aerosol optical depth provided by Brewer spectrophotometers deployed in Europe. This project, in which 18 European countries are involved, has been joined by the United States, Canada and Australia. Scientists involved in EUBREWNET work together to increase the characterisation and calibration of instruments, as well as the process and quality control of observations. The database project is hosted by AEMET, where observations are received and processed in real time in a centralised manner.

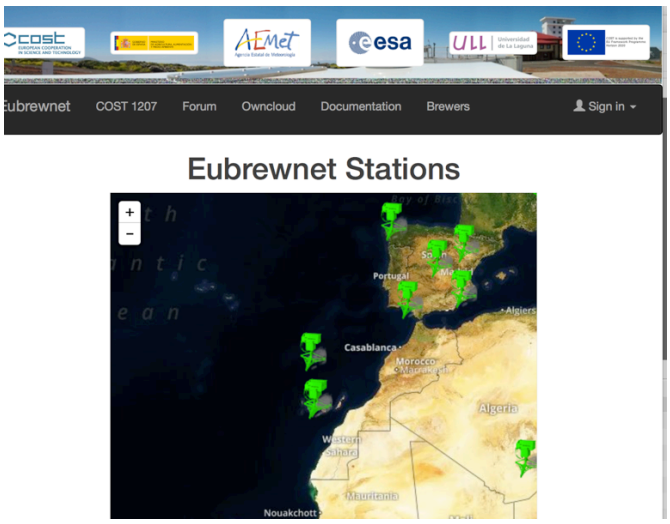


Figure 4: Spanish Eubrewnet Stations reporting real time ozone and UV observations

This database gives European response to the demand of organisations such as the World Meteorological Organization, the World Ozone and Ultraviolet Data Centre (WOUDC), the Intergovernmental Panel on Climate Change (IPCC), and the Global Monitoring for Environment and Security (GMES) of the European Union, for monitoring the Earth and atmosphere.

Ozone profiles data over Antarctica are sent to the WMO in almost real time as contribution to the reports on the evolution of the Ozone hole. Web page: (http://www.wmo.ch/pages/prog/arep/gaw/ozone/index.html#AntBull). Information of the INTA Antarctic project for the three stations and disseminated through www.spain.oracle-o3.org.

4.2 Information to the public: UV forecast

The real time ozone and uv observations are disseminated on the web (See Table 1) and the UV index forecast is also available at the AEMET webpage. The AEMET operational UV forecasting system is based on the libradtran software package for radiative transfer calculations [Emde et al., 2016]. The system provides the UVI at noon local time in clear sky conditions for the next five days for the main city of every Spanish province, every island and the cities of Ceuta and Melilla in North Africa. The TOC value is dynamically set from the ECMWF Integrated Forecasting System (IFS) forecasts. AEMET also produces UVI forecast based on the MOCAGE CTM . This model is used operationally at AEMET mainly in order to forecast surface parameters related to air quality, such as NOx, SO2 or O3. However, MOCAGE being a 3D global model, working with 47 vertical hybrid levels covering the PBL, free troposphere and stratosphere, can provide useful information on the evolution of the Total Ozone Column (TOC) distribution around the globe. Hourly forecasts for the Iberian Peninsula and Balearic Islands of NO, NO2, SO2 CO, O3 and TOC are disseminated through the AEMET public webpage. Additionally, MOCAGE provides UVI forecasts on clear sky conditions and considering cloudiness.

4.3 Relevant scientific papers

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5. PROJECTS, COLLABORATION, TWINNING AND CAPACITY BUILDING

5.1 Research Projects

Spanish institutions have participated is several research projects mainly focused on satellite validations, instrument development and trend analysis:

- ESA funded "CEOS Intercalibration of Ground-based Spectrometers and Lidars" (ESRIN contract 22202/09/I-EC) 2009-2015.
- ESA Funded EGB-SVN "EarthCare Ground-based Spectrometer Validation Network" 2014-2017, ESRIN/RFQ/3-14003/13/I–AM The objective of this project is building a homogenous ground-based remote sensing network measuring trace gas amounts and aerosol properties. 2014-2017
- EMRP (European Metrology Research Program) funded the project ATMOZ ("Traceability of Atmospheric Total Ozone") with the objective of reducing the uncertainty of the total ozone measurements below 1%, 2014-2017.
- EUBREWNET COST Action ES1207, 2013-2017. The RBCC-E has a leading role in this action, hosting the calibration service and the database of the action.
- AECI-WMO GAW-Sahara, which reinforces the "twinning" established between the Tamanrasset-Assekrem and the Izaña WMO Global Atmospheric Watch (GAW) stations of global importance initiated in 2006.
- VALIASI (Validation of the EUMETSAT products of atmospheric trace gases observed from IASI using ground-based Fourier Transform Infrared spectrometry; P.I.: Dr. Omaira García, EUMETSAT),
- NOVIA (Towards a Near Operational Validation of IASI level 2 trace gas products; www.novia.aemet.es, P.I.: Dr. Omaira García, MINECO). By means of these projects the validation of all of IASI operational atmospheric trace gases.
- Polar atmosphere studies are carried out through the NILU Antarctic Network, from Spanish-Argentinean-Finnish co-operation, and IARC is also involved in the database collection (http://polarvortex.aemet.es/).
- Sentinel-5 Precursor NO2 and HCHO validation using NDACC and complementary FTIR and UV-Vis DOAS systems (NODFORVal), ESA (S5PVT), 2016-2023

- Support to the Cabauw Intercomparison Campaign for Nitrogen Dioxide measuring Instruments 2016 CINDI-2. ESA Proposal in response to ESA RFQ/3-14594/16/I-SBo. 2016-2017
- Halógenos en la Atmósfera Antártica y su Implicación en la Distribución de Ozono (HELADO), MINECO, Plan Nacional de I+D+i. CTM2013-41311-P. 2014-2018.
- SOLARIUM. Space -temporal distribution of the ultraviolet solar radiation on Spanish south east: Funded by MINECO, Plan Nacional de I+D+I.: CGL2011-29921-C01-02/CLI. 2012-2015.
- ICARO. Remotely Piloted Aircrafts and CCD spectrradiometer: cutting-edge technology for ground-based measurements and vertical profiles of solar radiation. Funded: MINECO, Plan Nacional de I+D+I. Ref: CGL2014-56255-C2-2-R. 2015-2018.

Table 6: Research Projects summary

Reseacrh Proyects				
Institute	Proyect	Tiime Period	Funding	Keywords
Uex-INTA	ICARO	2015-2017	MINECO	RPAs, Spectrometer, CCD
AEMET-ULL	EGB-SVN	2014-2017	ESA	Spectrometer Validation
AEMET-ULL	ATMOZ	2014-2017	EMRP	Spectrometer O3 tracebility
AEMET-ULL	IDEAS	2015-2517	ESA	Spectrometer, Pandora
AEMET	CAL-VAL	2009-2016	ESA	Spectrometer O3 validation
AEMET-UVA	VALIASI	2016-2018	EUMETSAT	FTIR trace gas validation
AEMET	NOVIA	2012-2015	MINECO	IASI trace gas valitdation
AEMET	TOAR /LOTUS			Stratosphere Trend
AEMET-INTA-Uex	EUBREWET	2014-2017	COST	Brewer Spectrometer Netwc
INTA	NODFORVa	2016-2023	ESA	FTIR, DOAS
INTA	CINDI-2	2016-2017	ESA	DOAS
INTA	HELADO	2014-2018	MINECO	Antartca
INTA	SOLARIUM	2012-2015	MINECO	UV

5.2 Capacity building

AEMET has a close cooperation with North Africa (Morocco and Algeria). In Algeria, a Brewer spectrophotometer operates in the heart of the Sahara (Tamanrasset). Ozone related activities from CIAI also take place in Antarctica where, in collaboration with Spanish and Argentine institutions (National Antarctic -DNA- and -CADIC- Southern Research Center and the National Weather Service, INTA and AEMET), co-manages the ozonesonde station at Ushuaia (Patagonia Argentina). The RBCC-E supports ozone measurements of the Uruguayan Antarctic Institute in Artigas Base Station. In collaboration with the DNA and the FMI (Finnish Meteorological Institute) manages a multichannel radiometer at Antarctica for ozone and UV radiation measurements in Ushuaia, Belgrano and Marambio stations. At the moment this network, established in 2000, is under renovation.

Another important contribution is the membership of Alberto Redondas, Ozone and UV radiation Programme of the CIAI, to the WMO Scientific Advisory Group of Ozone (SAG-Ozone) and to the International Ozone Commission.

5.2.1 Brewer Training activities and Capacity Building

- GAW Sahara Brewer Training course (El Arenosillo, 10-21 June 2013). The GAW Sahara Brewer Training course funded by the Spanish International Cooperation Agency (AECI) and organised by the University of Extremadura, was held during the VIII RBCC-E campaign, 10-21 June 2013, El Arenosillo, Spain.

- EUBREWNET training school and Brewer Ozone Spectrophotometer open congress in conjunction with the 14th Biennial WMO-GAW Brewer Users Group Meeting (Tenerife, 24-28 March 2014). The event was a joint collaboration of EUBREWNET (COST Action ES1207) and WMO-GAW. The presentations are available at (as links on the programme): https://docs.google.com/document/d/1xaxWOkntotk7rB6PeRp0ZEYVJlWFPSnbJTrYQ_6DfrQ/edit

- Brewer Ozone Spectrophotometer Workshop (El Arenosillo, 25 May-5 June 2015) in collaboration with the EUBREWNET cost Action.

- EUBREWNET Brewer Ozone Spectrophotometer open workshop in conjunction with the EMRP ATMOZ project and the 15th Biennial WMO-GAW Brewer Users Group Meeting. The event was a joint collaboration of EUBREWNET (COST Action ES1207) and WMO-GAW. The event was hosted by the Instituto Português do Mar e da Atmosfera (IPMA) in Ponta Delgada 17-20 May 2016.

- EUBREWNET training school and Brewer Ozone Spectrophotometer open congress in conjunction with the Quadrennial Ozone Symposium in Edinburgh.

6. IMPLEMENTATION OF THE RECOMMENDATIONS OF THE 9th OZONE RESEARCH MANAGERS MEETING

Spain has maintained the observation network with significant advances in QA/QC, with the active role of RBCC-E, and capacity building, with the organisation of training courses and twinning activities with Argentina, Argelia, Egypt, Morocco and Uruguay.

AEMET participates in the evaluation of the Laboratory Measurements (Recommendation 2-2) through the ATMOZ project, evaluating how the new ozone cross sections on the ozone determination affect the Brewer Dobson and Pandora instrument.

7. FUTURE PLANS, NEEDS AND RECOMMENDATIONS

In the frame of EUBREWNET, a new updated algorithm of the total ozone retrieval by the Brewer spectrometer has been developed. This introduces the new cross section, the stray-light correction, updated Rayleigh constants and the introduction of climatology values for effective ozone height and temperature. The preliminary results show that the stray-light correction for single brewers has a significant impact on the total ozone series and an ongoing study for different EUBREWNET stations (from Tamaraset to Sodankyla) is planned.

On the evolution of the UV radiation other than the evolution of the ozone layer, there are different related factors that have an influence and must be closely studied, including quantity and characteristics of the clouds, which are parameters that are changing because of the

climate change scenario. Cloud monitoring is an area to be enhanced in later editions. Therefore, there is a need to measure the different weight that accounts for the different factors, other than the ozone in the UV radiation: clouds, aerosols and sun flux.

The best possible definition of the effect of the aerosols in the range of UV with new techniques and methods of measurement in the spectrophotometer networks that, at the moment, are usually dedicated to measuring UV spectral radiation and ozone. Besides, air quality networks should include UV radiation measurements. On the last report of the Environmental Effects of ozone depletion and its interactions with climate change assessment 2014, aerosols are considered the main effect on the increase/decrease in the UV radiation. There are different studies which correlate the increase in the UV radiation observed in different stations with the decrease in aerosols due to improvement of the air quality through environmental policies.

Most of the aerosols studies are not focused on the range of UV, because sunshine photometers (WRC-PFR, AERONET-Cimel, etc...) yield bad performance under 400 nm. But recently in Spain, AEMET, along with the World Radiation Centre (WRC) and EUBREWNET, are starting to measure aerosols in the UV range.

Improvement of the quantification/parameterisation and therefore measurement of the scattering simple (SSA) in the UV region.

Consideration of measurements of the integrated tropospheric ozone from the ground to the tropopause through ground-based and satellite teledetection.

Finally, there is a certain need to include studies on how would be the impact of a recovery of the ozone layer to values higher than those belonging to the pre-ozone depletion times. This over-recovery of the ozone layer is predicted by some models and the impact over human health and air quality should be known.

SRI LANKA

Introduction

Sri Lanka ratified both the Vienna Convention and Montreal Protocol on Ozone Depleting Substances on 15th of December 1989. Since annual calculated level of consumption of the controlled substances in Annex A is less than 0.3 kilograms per capita on the date of the entry into force of the Protocol, Sri Lanka is belongs to the category of Article 5 (developing) country and Sri Lanka has phase out CFCs, Halons in advance of the phase-out schedule prescribed by the Montreal Protocol. Sri Lanka has been able to achieve Montreal Protocol targets on time without any complications due to successful awareness creation and legislative processes.

HCFC Phase-out Management Plan of Sri Lanka for Stage I (HPMP of Sri Lanka-Stage I) is progressing from 2013 for achieving 1st targets phasing-out of HCFCs by 2020. The Government of Sri Lanka agreed to phase-out 4.93ODP tons constituting (35 % of baseline) by the year 2020.

The Government of Sri Lanka, through the efforts of the Ozone office, has implemented several regulatory measures to control import of ODS and ODS based equipment and from 01.01.2018, import, assemble of brand new equipment working on HCFCs.

Recognition of Sri Lanka contribution

In honor of the 20th Anniversary of the Montreal Protocol in 2007, the United Nations Ozone Secretariat awarded the Implementer's Award to Sri Lanka, recognizing extraordinary contributions of the National Ozone Units and people whose hard work on the country level over the years has helped to make the Protocol's phase-out goals a reality. Sri Lanka's effort in preserving Ozone layer has again been recognized and appreciated at the 25th Anniversary of Montreal Protocol in 2012.

Future aspects of Research

The government of Sri Lanka has embarked on an ambitious mission to make this island the education hub in South-East Asia. Action have been taken to enhance the facilities for local graduates by shifting them towards job oriented education system and also providing them with effective research & development, communication skills and literacy in Information Technology. This strategy will ultimately improve the net value of the Human Capital in Sri Lanka. Whilst improving the existing facilities in the public Universities, the government's aim is to encourage Private University Colleges affiliated foreign Universities to conduct more researches. Sri Lanka has 15 National Universities, 17 Higher Educational Institutes and 12 Advance Technological Institutes and several private educational institution to develop and implement as local and international research and training centers for knowledge. Research plays a critical role in the innovation process. It is essentially an investment in technology and future capabilities which is transformed into new discoveries.

For an example, the National Ozone Unit (NOU) has conducted a study survey in 2013 in collaboration with University of Peradeniya on health impacts of Ozone Layer Depletion in the North – Central Province in Sri Lanka. Accurate data related to UV radiation was unavailable not only in Sri Lanka but also within neighbouring countries in this sub-region and therefore the study had been done based on temperature data recorded by the

Meteorological Department of Sri Lanka. Establishing of research facility to collect reliable data was realized whenever conduct such scientific surveys.

Sri Lanka interest for Monitoring Station

Sri Lanka has no ozone monitoring stations and Sri Lanka continue with its interest to establish a monitoring station in order to gather crucial data on pollution linked with damage to the Earth's ozone layer. It is difficult to carry out proper researches concerned to ozone depletion and monitoring activities in Sri Lanka until monitoring station is established.

In response to Sri Lanka's request 9th ORM has made recommendation to relocate of Dobson No.8 (formerly deployed in Spitsbergen) to Sri Lanka in late 2014 and approved the cost of US$ 20,000 for this activity.

Therefore, Sri Lanka is very keen on this project and a leading State University and Meteorological Department are ready to provide facilities in whatsoever form.

Establishing a Monitoring station in Sri Lanka has many global advantages as follows.

- Sri Lanka is located at the southern most part of the continent of South Asia close to the equator
- Sri Lanka is a small island monitors or researchers can reach any part of the island conveniently within short period of time.
- Facilitating Scientists to conduct research over tropics to ascertain the prediction that the ozone layer might have fully recovered by somewhere around the 2060s as a result of past, current and future actions of Montreal Protocol.
- The climate of Sri Lanka can be described as tropical and warm. Its position between 5 and 10 north latitude endows the country with a warm climate moderated by ocean winds and considerable moisture. The mean temperature ranges from about 16 °C in the Central Highlands (2500 m above sea level), where frost may occur for several days in the December-January) to a maximum of approximately 37 °C.
- Ability to connect with regional and global atmosphere monitoring networks, since Sri Lanka has very advanced communication facilities
- Assistance from Department of Meteorology and state Universities is readily available for setting up an Ozone Monitoring Centre in Sri Lanka and maintain equipment.

Conclusion

Since the relocating Dobson measuring unit had not been materialized, Sri Lanka wishes to refresh the proposal again to establish a monitoring station, in Sri Lanka to gather crucial data on adverse effects linked with damage to the Earth's ozone layer and also to observe the recovery of damaged ozone layer is genuinely taking place.

In this endevour, Sri Lanka expects to enhance its cooperation with UNEP in order to obtain Research facilities which encourage Researchers to engage with more research works related to UV very effective manner.

G.M.J.K. Gunawardana
Director – Air Resource Management & National Ozone Unit
Ministry of Mahaweli Development & Environment

SWEDEN

OBSERVATIONAL ACTIVITIES

Column measurements of ozone and other compounds

Total ozone is monitored at two sites in Sweden by SMHI (Swedish Meteorological and Hydrological Institute) on behalf of the Swedish Environmental Protection Agency. Daily measurements started in Norrköping in 1988 using the Brewer #6, which was replaced by Brewer #128 in 1996. In Vindeln manual measurements started in 1991 using the refurbished old Dobson #30 and since 1996 the automatic Brewer #6 is also used.

The instruments are calibrated and served regularly. Efforts have been spent on improving algorithms and methods to retrieve good observations at low solar elevations since the 1990-ties. Data are submitted to WOUDC in Canada.

The measurement site Harestua (60°N, 11°E) operated by Chalmers is equipped with a high resolution infrared spectrometer (FTIR) that records solar spectra during approximately 50 days per year. From these spectra the atmospheric columns of hydrogen chloride, chlorine nitrate, ozone, HCFC-22 and other species are retrieved. The measurements are funded through the Swedish Environmental Protection Agency's program: "Protective Ozone Layer" and they are made in the context of the global network NDACC (Network for the detection of atmospheric composition change).

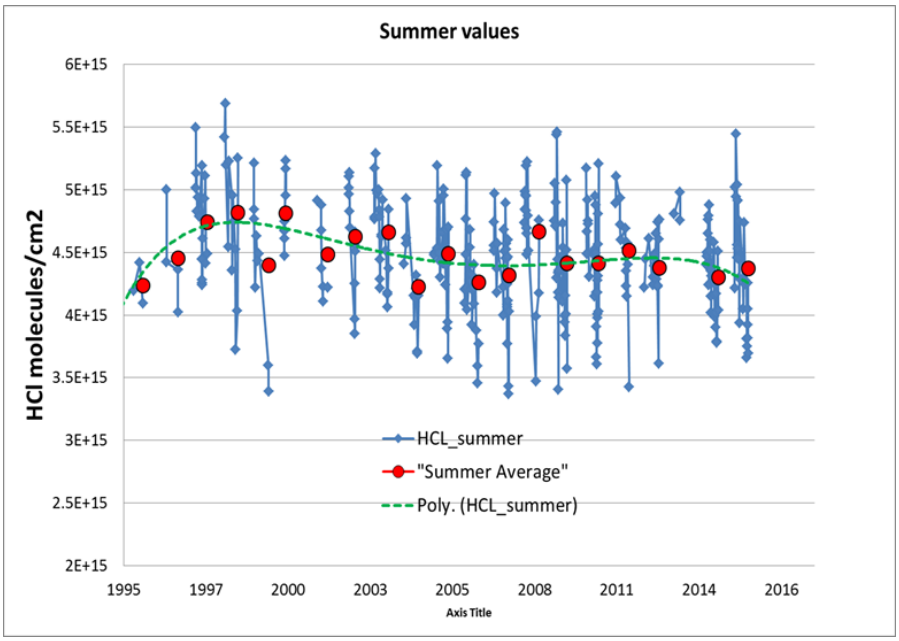


Figure 1. HCl column values from Harestua 1995 to 2015

For Harestua measuring station there is approximately 1050 measured days since 1994 stored in a database which allows studying the trends of the above topics. Column measurements over the last two decades show that the negative trend of HCl has leveled off the last few years while the ozone trend is insignificant, Figure 1. As for chlorine nitrate reduces this subject by about 1.5% per year. The atmospheric columns of HCFC-22 and N2O emissions are still increasing with each 3% and 0.4%. The results are consistent with similar measurements within NDACC network but differ in some cases for ground surveys.

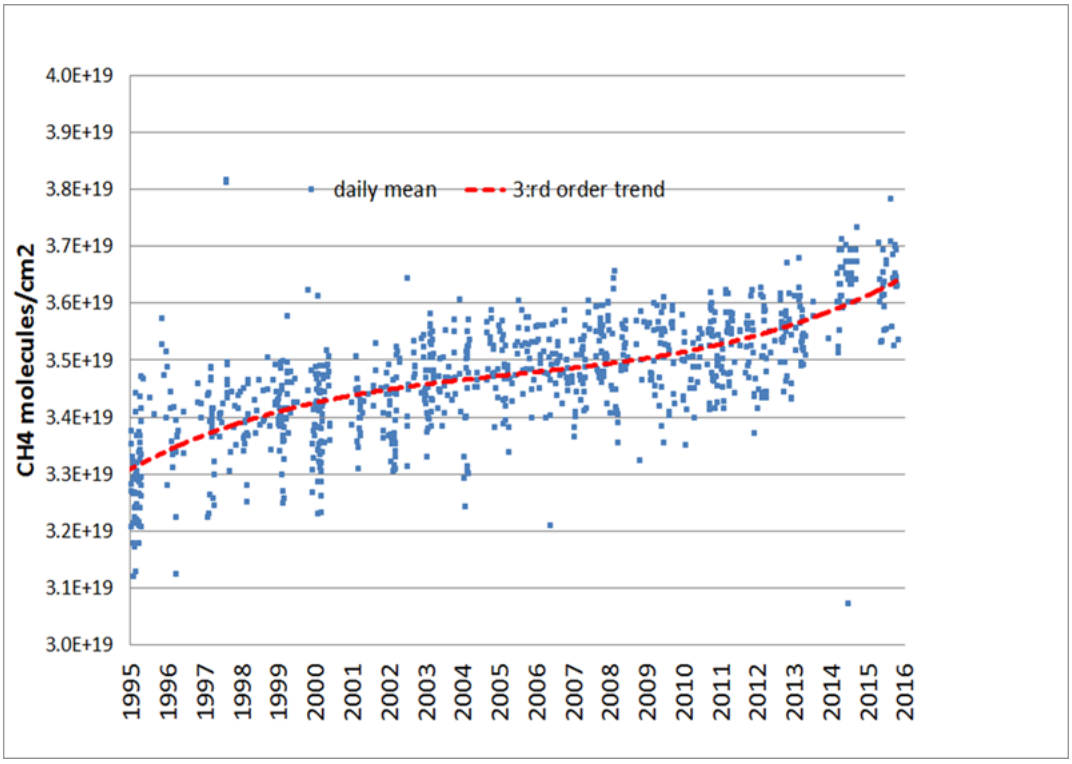


Figure 2. Column methane shows a positive trend at Harestua

An NDSC microwave station for ozone, CO and water vapour measurements is also run at the Onsala Space Observatory at Chalmers University of Technology.

Profile measurements of ozone and other gases

The Department of Meteorology at Stockholm University operates the Esrange lidar at Esrange Space Station in Northern Sweden. The focus of the Rayleigh/Mie /Raman lidar facility is on middle atmosphere research. During recent years, ozone-related studies have concerned the characterization of polar stratospheric clouds (PSC) and gravity wave activity in the vicinity of the winter polar vortex.

During January-February 2016, measurements with the Esrange lidar, radiosonde balloons and related ground-based instrumentation were carried out as part of the Swedish LEEWAVES project (Local Excitation and Effects of Waves on Atmospheric Vertical Structure). This project was a national complement to the German research programs POLSTRACC (The Polar Stratosphere in a Changing Climate) and GW-LCYCLE (Gravity Wave Life Cycle) with comprehensive aircraft measurements from Kiruna airport and related ground-based studies.

The Swedish Institute for Space Physics in Kiruna takes ozone profiles using a microwave radiometer, KIMRA. Data since 2002 will soon be available over the web. The KIMRA system has been compared to the German MIRA2 (Karlsruhe Institute of Technology) and with satellite observations from MLS on board the AURA-satellite; Ryan et al. 2016a.

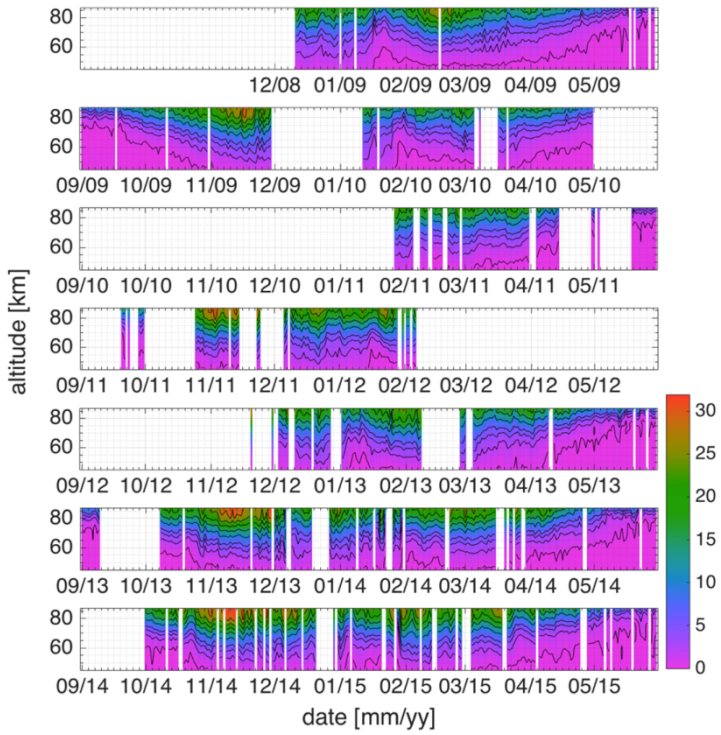


Figure 3. CO-profiles from KIMRA from Dec. 2008 to May 2015, Kiruna, Ryan et al. (2016b).

One of the longest series of CO profiles measured by a ground-based instrument (data since 2008) is also recorded by KIMRA, Ryan et al. 2016b, Figure 3. The observations of CO are used as tracers to track air inside the polar vortex to interpret the ozone chemistry and the observed ozone values. Also these observations will soon be available.

Satellite measurements

The Swedish led Odin satellite continues to deliver measurements of ozone and relevant compounds in the stratosphere. Odin is now 16 years old having been launched in Feb 2001. Together with MLS on Aura and Ace on Scisat, these are the only remaining limb measurements with no new missions yet decided. The Global environmental measurements and modelling group at Chalmers University of technology is responsible for the processing of the data from the Sub-millimetre Radiometer SMR while the University of Saskatchewan in Canada processes the data from the Optical instrument OSIRIS. Recent Chalmers results from Odin include observations of unusually strong descent of NO from the mesosphere in 2013 (Pérot et al 2014) and a study of the evolution on polar ozone over the lifetime of the mission Sagi et al (2016).

At the Department of Meteorology at Stockholm University, data from the Odin satellite and other satellite missions are used to study the effect on solar variability on the middle atmosphere. With better and longer time series of satellite data, it has become evident that changes in solar radiation and energetic particle fluxes affect all parts of the atmosphere, either directly or indirectly via coupling mechanisms. An important pathway is the production of nitric oxide (NO) in the lower thermosphere by solar energetic particles and radiation. In the winter NO is transported down to the stratosphere where it affects ozone chemistry, and thereby also heat budget and circulation patterns. Recent studies concern signatures of the 27-day solar cycle in this downward transport into the stratosphere.

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missions yet decided. Recent results from Odin include observations of defending NO from the mesosphere and a study of the evolution on polar ozone over the lifetime of the mission.

The Odin data are also part of the ESA Ozone-Climate Change Initiative and have been subject to various assessments in terms of agreement with other instruments and long-term drifts.

A complete reprocessing of the dataset is currently under way with the aim of including all new information to provide an improved product

UV Broadband measurements

Monitoring of broadband UV (CIE-erythema weighted) started relatively early in Sweden. Supported by SSM (the Swedish Radiation Safety Authority) SMHI has been measuring since 1983. There has also been a small network of five stations for a limited period. Presently, SMHI operates one station in Norrköping using two instruments; Solar Light Model 501, Figure 4.

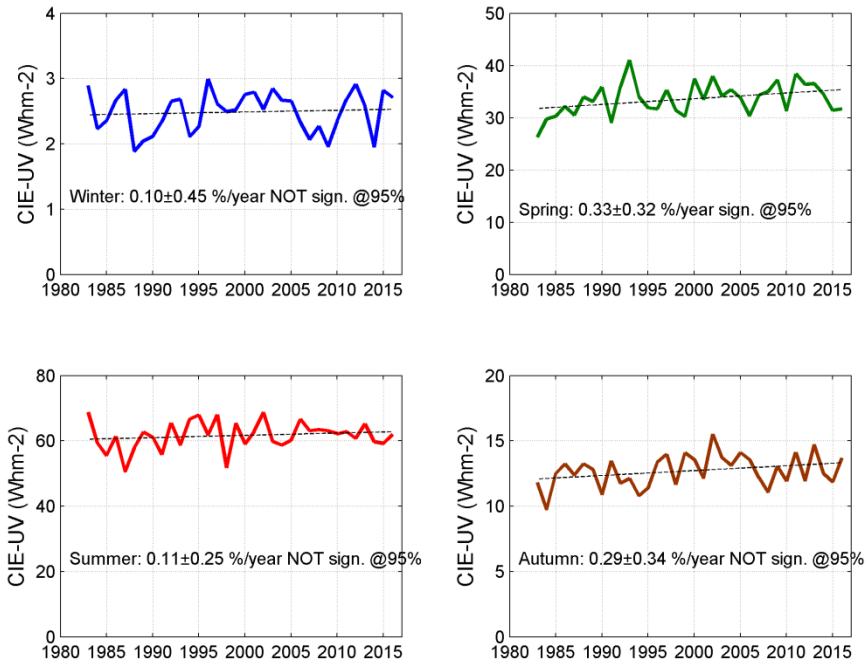


Figure 4. Seasonal CIE-weighted UV-radiation measured at Norrköping 1983-2016.

Modelling of UV

In early 2000 the STRÅNG-model system Landelius, Josefsson and Persson (2001) was launched, see http://strang.smhi.se/ as a co-operation between SMHI, the Swedish Environmental Protection Agency and the Swedish Radiation Safety Authority. Now, there is over 15 years of hourly data available for anyone to download, period 1999- up to yesterday.

The modelled variables are CIE-weighted UV, global radiation, direct solar radiation, sunshine duration and photosynthetic photon density (PAR). The geographical area covers a large part of northern Europe with a present spatial resolution of 11 km. In 2017 the model system will be updated.

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SWITZERLAND

1 OBSERVATIONAL ACTIVITIES

1.1 Column measurements of ozone

- Total ozone is measured regularly at Arosa since 1926. Presently, the measurements are performed with two computer-controlled Dobson spectrophotometers (D062 and D051) and two Brewer instruments B040 (Mark II) and B156 (Mark III). Additionally, a third automated Dobson (D101) and the Brewer (B072) instruments belonging to MeteoSwiss are operated at PMOD / WRC at Davos in parallel to the local Brewer B163 (MARK III) instrument.

1.2 Profile measurements of ozone

- Balloon ozone soundings are measured from the Payerne Aerological Station three times per week since 1968. Until August 2002, Brewer-Mast (BM) ozone sondes were used while since September 2002 ECC (ENSCI – 0.5%) sensors are the operational instruments.
- The Umkehr ozone profiles are recorded at sunrise and sunset at Arosa since 1956 in clear sky or partly cloudy conditions. Originally the measurements were performed manually but since 1989, the data acquisition of the Dobson Umkehr (D051) is computer-controlled. In 1988, the Brewer (B040) Umkehr series have started and presently the three Brewer are also simultaneously measuring the Umkehr profiles.
- Since 1995, ozone profiles (20 – 70 km) are retrieved from ground based microwave radiometry from Bern (GROMOS instr.) and since 2001 from Payerne (SOMORA instr.). Both instruments deliver hourly averaged ozone profiles independently of the weather conditions. The microwave radiometers have been updated to digital FFT spectrometers as a substitute to AOS devices. The SOMORA data processing software has also been changed adapting the widely used ARTS/Qpack package.

1.3 UV measurements

- The Swiss Atmospheric Radiation Monitoring programme (CHARM) consisting of 4 stations covering the altitude range of 366 to 3587m was build up between 1995 and 2000.
- The measurements programme consists of :
- - *Broadband measurements:* the direct, diffuse and global components of the broad-band erythemal UV-ERY radiation (Solar Light UV-Biometers) are measured,
  - *Narrowband filter instruments:* spectral direct irradiances are measured with Precision Filter Radiometers (PFR) at 16 wavelengths in the range 305 nm to 1024 nm,
- Besides the direct measurements, the UV index, the AOD at various wavelengths as well as the Integrated Water Vapor (IW) are calculated from those data,
- Spectral Brewer UV measurements: at Arosa, since 1994 spectral global UVB measurements are recorded with the Brewer instruments 072 on the range 290 nm – 325 nm. Since 1998, the Brewer Mark III 156 is in operation and it measures the range 286.5 - 363 nm,
- Solar Spectral irradiance from the Brewer B163 (MARK III),
- Operation of the QASUME portable world UV reference spectroradiometer (290-500 nm) since 2008 at the PMOD/WRC in Davos,
- Broadband radiometers: UVB, UVA, UV-ERYYTHEMAL at the PMOD/WRC in Davos.

1.4 Calibration activities

- At Arosa, regular calibrations and maintenances are organised for the Brewer (every 2 years) and for the Dobson instruments (every 5-6 years) traceable to the regional or world standards. The more recent calibration campaigns for the Brewer instruments have been organised in July 2014 and July 2016.
- Each ECC ozone sonde is calibrated prior to the flight again a reference UV photometer traceable to the national standard from the Federal Institute of Metrology (METAS).

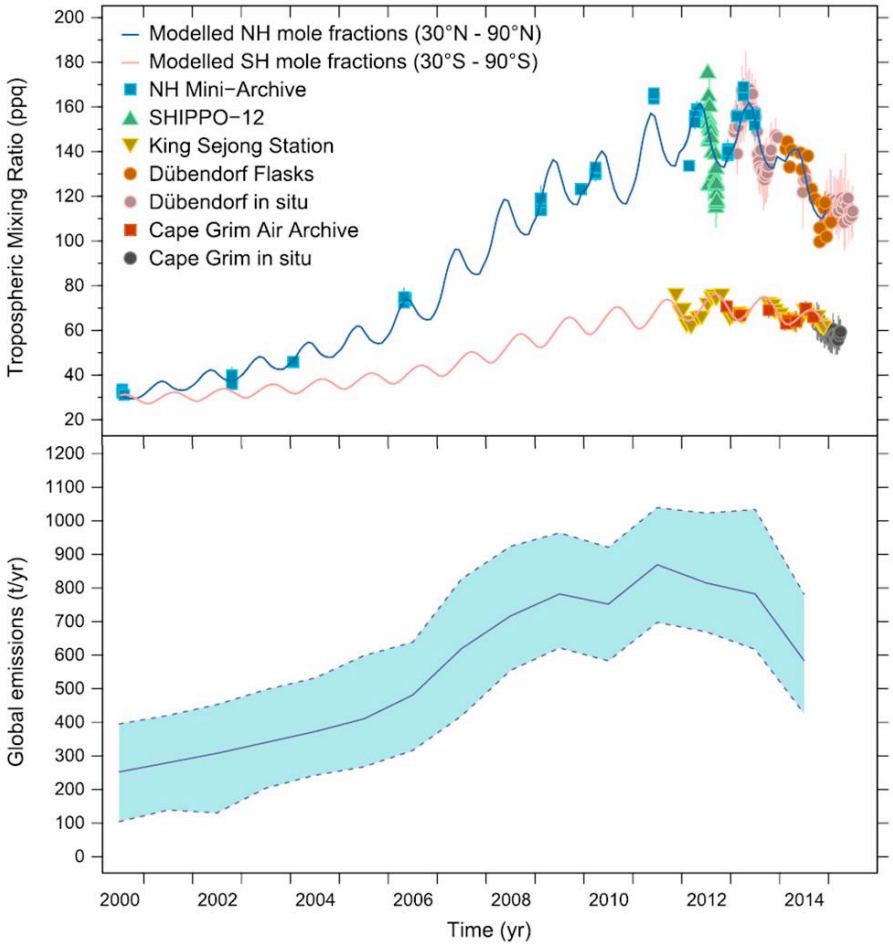
- The CHARM instruments are also compared to reference instruments traceable to the world standards.

2 RESULTS FROM OBSERVATIONS AND ANALYSIS

2.1 Halocarbon measurements at the global GAW station Jungfraujoch (Empa, Dr. S. Reimann, Dr. M.K. Vollmer)

- The high Alpine site of Jungfraujoch (3580 m asl) is one of a few stations covering the entire measurement programme of the GAW for greenhouse gases and reactive gases. The measurements of ozone depleting substances and halogenated greenhouse gases, such as HFCs, CFCs, HCFCs chlorinated solvents, and bromocarbons, are performed continuously at Jungfraujoch since the year 2000 in a joint project of Empa and FOEN (HALCLIM).

- A thorough description of the project (in German) is available at: https://www.empa.ch/documents/56101/190047/HALCLIM_6_Zwischenbericht/d2443424-b999-443a-a79e-e7ef806b6b66



- **Figure 1: Concentrations of HCFC-31 at global background sites and related global emissions (Schoenenberger et al., 2015).**

- In recent years Empa provides independent emission estimations for halogenated greenhouse gases from Switzerland by combining long-term measurements at Jungfraujoch with atmospheric transport models. For HFCs this is part of the Swiss National Inventory Report (NIR), which is annually submitted under the framework of UNFCCC.
- The measurements are part of the world-wide AGAGE network (Advanced Global Atmospheric Gases Experiment). Since February 2008, the sensitivity of the

measurements has been improved through the use of the preconcentration unit "Medusa", and several new halogenated organic compounds have since then been detected in the atmosphere. Most recently HCFC-31 (CH2ClF) was found to be present in the atmosphere, although it has never been produced in large quantities as a part of consumer products (Figure 1). In the related publication by Schoenenberger et al. (GRL, 2015) it was therefore concluded that emissions derive as a by-product of the production of HFC-32 (CH2F2). In a similar study on the newly-found HCFC-133a in the global atmosphere, Vollmer et al. (GRL, 2015) have suggested that the production of HFCs is the main source.

2.2 Ozone at MeteoSwiss: The automated Dobson instruments at Arosa (Dr. R. Stübi, H. Schill, W. Siegrist)

The Arosa ozone column time series are the longest continuous record worldwide based on sun spectrophotomer Dobson instruments. This type of instrument is originally operated by an operator which nowadays is not optimal in regards to more recent Brewer instruments. In order to continue the Dobson based Arosa data sets, an automated version of the Dobson instrument has been successfully developed at MeteoSwiss without changing the observation technique and the instruments characteristics. Figure 2 illustrate one of the three automated Dobson presently in operation at Arosa. The computer fully control the start-up and stop of the instruments as well as the positioning and the data acquisition. The switching to different operation modes like the Umkehr zenith measurements or the lamps tests still require the operator intervention to set up the lamps or to remove the sun director support.



Figure 2: The Dobson instrument is mounted on a rotating table (azimuth) and the entrance prism, protected by a quartz dome, follow the sun elevation (Solar Zenith Angle).

The benefit of the Dobson instrument automation are multiple, the main being:

- increased measurement frequency (dt ~ 140 sec / data),
- improved data reproducibility (± 1 DU in clear sky conditions),
- measure of the data quality with additional housekeeping parameters,
- decrease of the manpower necessary to run the station operation,
- flexibility of the measurement program by software adaptation.

However, the data quality control has to be adapted as well since the operator is no longer present to make the first data screening. The raw data sets contain outliers introduced by adverse measuring conditions which have to be eliminated in the post processing stage. Figure 3 illustrates Dobson data for a "clear sky" day with Umkehr measurements in the morning and in the afternoon and direct sun measurement between ~10:10 and ~13:20 UTC. In the lower panel, the comparison between two independent Dobson instruments data shows that the wiggling of the ozone column measurements ([DU]) are real fluctuations of the

atmospheric conditions and not noise of the data. A systematic offset of ~2 DU can be corrected by the ETC adjustments.

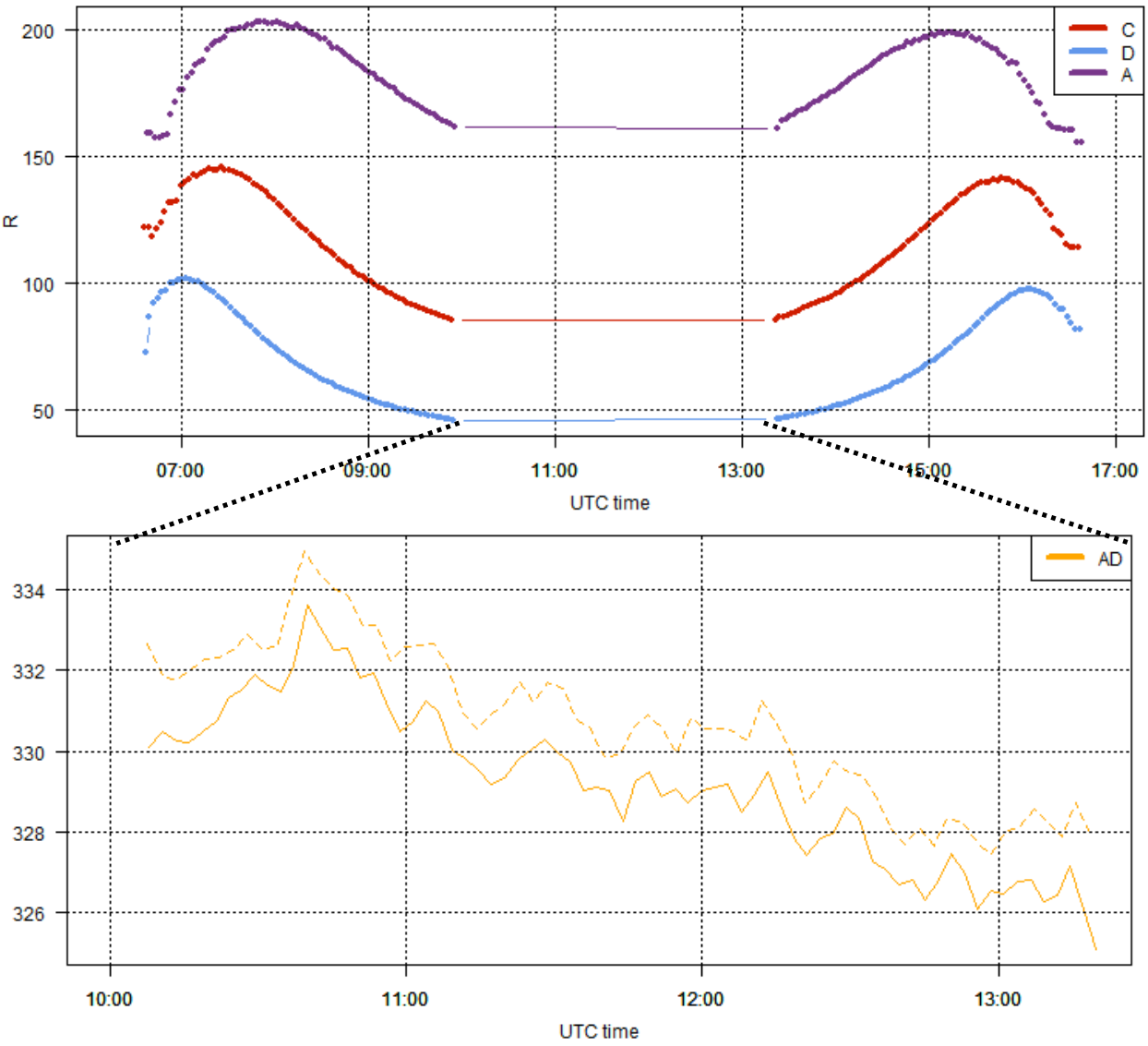


Figure 3: upper panel: Dobson (D051) Umkehr measurements for the 3 wavelengths pairs A,C and D; lower panel: direct sun ozone column measurements by to independent Dobson instruments (D062 and D051) at Arosa.

2.3 University of Bern / IAP (Prof N. Kämpfer, Dr. K. Hocke, Ms. L. Moreira)

Long-term monitoring of the vertical distribution of stratospheric ozone was continued with a 142-GHz microwave radiometer at Bern. The spectrometer was upgraded in 2009 from a digital filter bench to a FFT spectrometer. Both spectrometers were operated in parallel in order to get an overlap of coincident measurement for about 2 years. Ozone profiles with a time resolution of 30 min and a vertical resolution of about 10 km (Figure 4) were submitted to the Rapid Data Delivery System (RDDS, EU NORS project) which is part of the Network for the Detection of Atmospheric Composition Change (NDACC).

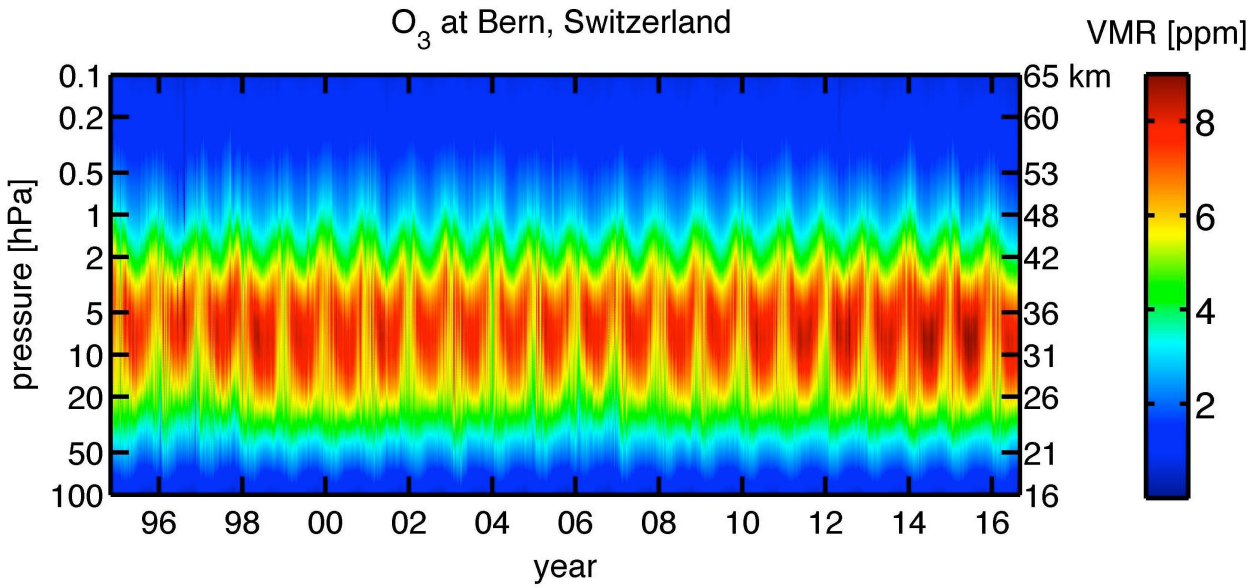


Figure 4: Ozone volume mixing ratio as function of time and pressure level above Bern. Observations were obtained by a 142-GHz microwave radiometer (IAP, Bern). Tick marks are on January, 1st of each year.

These ozone data were utilized for satellite validation, atmospheric modelling and ozone trend studies by the scientific community. The ozone data are regularly used for validation of ozone reanalysis data of the EU project MACC (Monitoring Atmospheric Composition and Climate) which belongs to the Copernicus Earth Observation programme. After an harmonization of the ozone time series above Bern, a trend study showed a statistically significant trend of mid-stratospheric ozone of about 3%/decade (Moreira et al., 2015). The natural stratospheric ozone oscillations (solar cycle, QBO, AO, SAO) were derived by Moreira et al. (2016) using the ozone time series at Bern.

In 2013, a compact version of an ozone microwave radiometer was constructed which is called GROMOS-C (Fernandez et al., 2015). Since October 2015, GROMOS-C is for a measurement campaign at Ny Alesund, Svalbard.

2.4 ETH Zurich / IAC (Prof J. Staehelin, Prof. T. Peter)

Swiss Ozone scientists of ETHZ, University of Bern and MeteoSwiss presented in an article the outstanding value of long-term Swiss ozone measurements for atmospheric science (Staehelin, J., S. Brönnimann, T. Peter, R. Stübi, P. Viatte and F. Tummon, The value of Swiss long-term ozone observations for international atmospheric research, in "From Weather Observations to Atmospheric and Climate Sciences in Switzerland - celebrating 100 years of the Swiss Society for Meteorology", S. Willemse and M. Furger (eds.), vdf Hochschulverlag AG an der ETH Zürich 2016, pp. 325-349 (Chapter 16)). Anthropogenic ozone depletion is the main motivation of continuation of long-term stratospheric ozone measurements to society since the discussion of anthropogenic ozone depletion started in the 1970s (comp. Figure 5).

The world longest series of total ozone measurements was performed (among other important ozone measurements) at the Light Climatic Observatory (LKO) at Arosa. The changeable history of LKO will be described in more details in a report by J. Staehelin and P. Viatte which will be published in 2018.

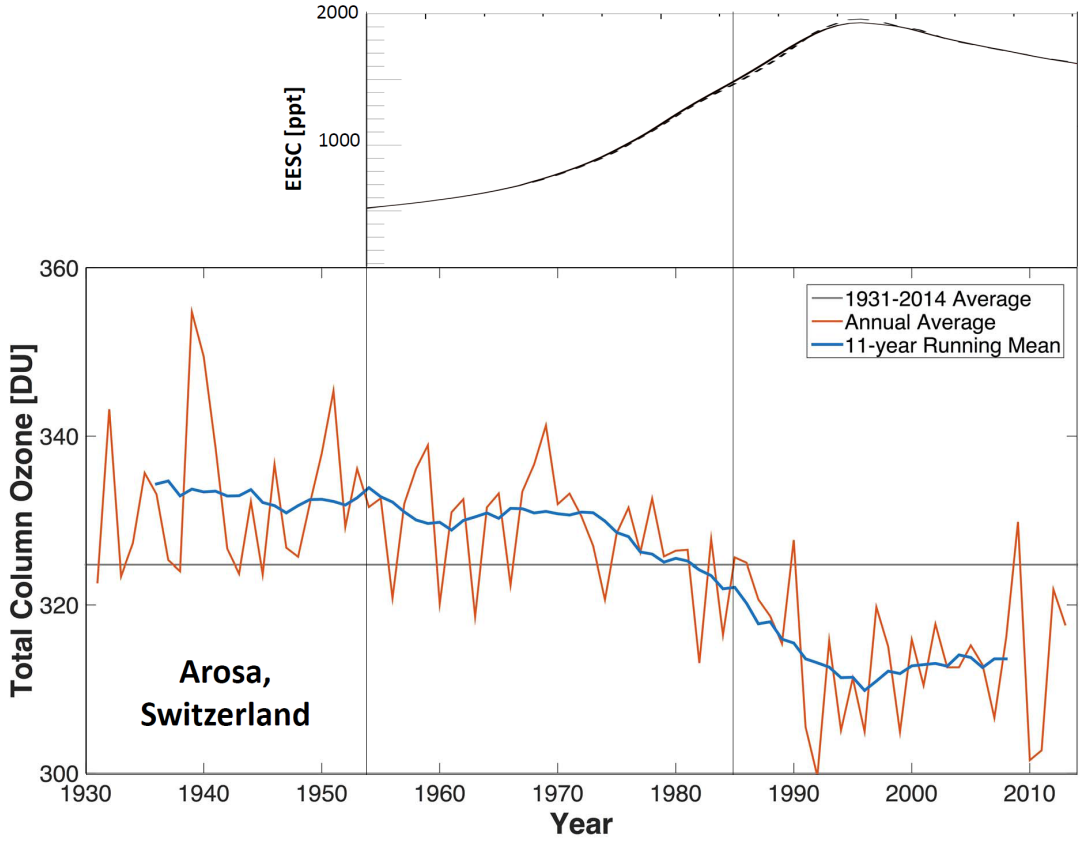


Figure 5: Total ozone time series from Arosa (annual mean values in Dobson Units [DU], lower panel) and effect of chemical ozone depletion as described by the Equivalent Effective Stratospheric Chlorine (EESC) for mid-latitudes (top panel), Fig. 4 of Staehelin et al., 2016).

3 DISSEMINATION OF RESULTS

3.1 Data reporting

- The ozone data from Arosa, respectively Payerne are regularly deposited at the WOUDC and at the NDACC data centers. They are also deposited at NILU data center for validation projects and measurements campaigns (Satellites, ECMWF, MATCH).
- The GROMOS and SOMORA radiometers data are deposited at NDACC and NILU (SOMORA only) data centres.
- The radiation data from the CHARM Payerne station are deposited at the WRM-BSRN data center.
- The data of the continuous halogenated greenhouse gas measurements at Jungfraujoch performed by Empa/BAFU are regularly reported to the WDCGG (World Data center for Greenhouse Gases) of WMO.

3.2 Information to the public

The UV forecasts are issued daily during the summer months in many newspapers, on different web sites (public media, national institutions) and at the TV weather presentations. The alerts for high ozone concentration at surface level are also announced when necessary in the same information channels.

3.3 Relevant scientific papers

Fernandez, S., Murk, A., and Kämpfer, N.: GROMOS-C, a novel ground-based microwave radiometer for ozone measurement campaigns, Atmos. Meas. Tech., 8, 2649-2662, doi:10.5194/amt-8-2649-2015, 2015.

Mahieu, E., R. Zander, G.C. Toon, M.K. Vollmer, S. Reimann, J. Mühle, W. Bader, B. Bovy, B. Lejeune, C. Servais, P. Demoulin, G. Roland, P.F. Bernath, C.D. Boone, K.A. Walker, and P. Duchatelet, Spectrometric monitoring of atmospheric carbon tetrafluoride (CF_4) above the Jungfraujoch station since 1989: evidence of its continued increase but at a slowing rate, *Atmos. Meas. Techn.,* 7, 333–344, 2014.

Moreira, L., Hocke, K., Eckert, E., von Clarmann, T., and Kämpfer, N.: Trend analysis of the 20-year time series of stratospheric ozone profiles observed by the GROMOS microwave radiometer at Bern, Atmos. Chem. Phys., 15, 10999-11009, doi:10.5194/acp-15-10999-2015, 2015.

Moreira, L., Hocke, K., Navas-Guzmán, F., Eckert, E., von Clarmann, T., and Kämpfer, N.: The natural oscillations in stratospheric ozone observed by the GROMOS microwave radiometer at the NDACC station Bern, Atmos. Chem. Phys., 16, 10455-10467, doi:10.5194/acp-16-10455-2016, 2016.

Schoenenberger, F., M.K. Vollmer, M. Rigby, M. Hill, P.J. Fraser, P.B. Krummel, R.L. Langenfelds, T.S. Rhee, T. Peter and S. Reimann, First observations, trends and emissions of HCFC-31 (CH2ClF) in the global atmosphere Geophys. Res. Lett., 42, 7817-7824, 2015.

Staufer, J., J. Staehelin, R. Stübi, T. Peter, F. Tummon, and V. Thouret: Trajectory matching of ozonesondes and MOZAIC measurements in the UTLS, Part II: Application to the global ozonesonde network, *Atmos. Meas. Techn.*, 7, 241-266, doi:10.5194/amt-7-241-2014 (2014).

Vollmer, M.K., M. Rigby, J.C. Laube, S. Henne,1 T.S. Rhee, L.J. Gooch, A. Wenger, D. Young, L..P. Steele, R.L. Langenfelds, C.A.M. Brenninkmeijer, J.L. Wang, C.F.O Yang, S. A. Wyss, M. Hill, D. E. Oram, P.B. Krummel, F. Schoenenberger, C. Zellweger, P.J. Fraser, W.T.Sturges, S. O'Doherty and S. Reimann, Abrupt reversal of HCFC-133a (CF3CH2Cl) in the atmosphere, Geophys. Res. Let., 42, 8702–8710, 2015.

4 PROJECTS AND COLLABORATION

Besides of the activities in the framework of the national and international monitoring and research programmes, Switzerland contributes to the international WMO/GAW programme through the following services and collaborations:

- Support to the ozone sounding station Nairobi of the Kenyan Meteorological Institute,
- World Optical Depth Research and Calibration Centre (WORCC) at Physikalisch-Meteorologisches Observatorium / World Radiation Centre (PMOD /WRC) in Davos
- World Calibration Centre for UV (WCC-UV) at Physikalisch-Meteorologisches Observatorium / World Radiation Centre (PMOD /WRC) in Davos
- World Calibration Centre (WCC) and Quality Assurance /Science Activity Centre (QA/SAC) for Surface Ozone, carbon monoxide and methane at the Swiss Federal Laboratories for Materials Testing and Research (EMPA) in Dübendorf.
- Support to the Jungfraujoch site which recently reached to the status of global GAW station

At the national level, there is an important cooperation between the Federal Office of Meteorology and Climatology (MeteoSwiss) and the academic and research institutions. This collaboration organised within a national GAW-CH programme allows to support research projects for the development and improvement of the monitoring programme as well as for the data analysis.

The continuous measurements of ozone-depleting substances (CFCs, HCFCs, halones) is part of the world-wide AGAGE program (Advanced Global Atmospheric Gases Experiment).

In October 2014 the European EMRP project ENV59 ATMOZ "Traceability for atmospheric total column ozone" (http://projects.pmodwrc.ch/atmoz/) started. The aim of the project is to significantly enhance the reliability total ozone column measured at the Earth surface with Dobson instruments, Brewer-Spectroradiometer and Array-Spectroradiometer.

New methods of observation (techniques, instruments and software) are developed to provide traceable total ozone column measurements with an uncertainty of less than 1%.

The project is coordinated by Julian Gröbner at the PMOD/WRC in Davos. Six partners from National Metrology Institutes and Industry, 3 Researcher excellent Grants from Universities and 10 collaborators (including MeteoSwiss) are working in different work packages to develop new instruments and devices, create software tools for uncertainty estimation of total ozone column and to characterize network instruments in the laboratory and the field.

The results of the project are disseminated at international conferences, in peer reviewed international journals, in two Newsletters and in trainings at two workshops and two measurement campaigns in Izaña and Huelva Spain.

The project will end in October 2017 and a publishable report will be available for the public.

THAILAND

1. OBSERVATIONAL ACTIVITIES

1.1 Column measurements of ozone and other gases/variables relevant to ozone loss

Since 1979, Thai Meteorological Department (TMD) has carried out ozone observation with Dobson spectrophotometer No.90 in Bangkok under WMO/GAW programme. In 1996, two Brewer spectrophotometer (MKIV) No.121 and Brewer spectrophotometer (MKIV) No. 120 were additionally installed to measure total ozone, umkehr ozone profile, ultraviolet radiation and aerosol optical depth in Bangkok (13.667812°N, 100.605289°E) and Songkhla (7.184520°N, 100.604701° E) respectively. In 2009, TMD solar network in Bangkok was implemented further for ground-based measurements such as global/diffuse/direct/broadband UVA/UVB radiation, sky images, and physical properties of aerosols.



Figure 1.1 Station map for Dobson 90, Brewer 121 and Brewer 120

Another laboratory by Department of Physics, Faculty of Science, Silpakorn University (SU) has studied total ozone using Microtop ozonometer at Nakhon Pathom since 2010.

1.2 Profile measurements of ozone and other gases/variables relevant to ozone loss

Umkehr ozone profiles have been measured with Dobson#90, Brewer #121 and Brewer #120. Recently, a campaign for ozonesonde observations has been initiated with collaboration between Silpakorn University and Thai Meteorological Department using ECC sensors during January 2014- May 2015.

1.3 UV measurements

UV measurements have been carried out by TMD in two GAW stations;

1.3.1. Bangkok, station number 216, Brewer #121,1996- present

A broadband UVA/UVB radiometer, during 2009-2015

1.3.2. Songkhla, station number 345, Brewer #120,1996- present

SU's laboratory has also studied UV radiation at Nakhon Pathom using a Bentham spectroradiometer and UV Biometers (since 1998) and GUV-2511 radiometers have been used to monitoring ultraviolet radiation at Chiang Mai, Ubon Ratchathani, Nakhon Pathom and Songkhla (since 2008).

1.4 Calibration activities

With supports from WMO and JMA, Dobson #90 was taken to participate the Inter-Comparison at Tsukuba in 1996, 2006 and 2016. The Brewers were calibrated at Bangkok and Songkhla with Brewer#017 by IOS in 2005, 2008, 2009, and 2014.

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

A figure show long term trend for total ozone measured in Bangkok during 1980-2016.

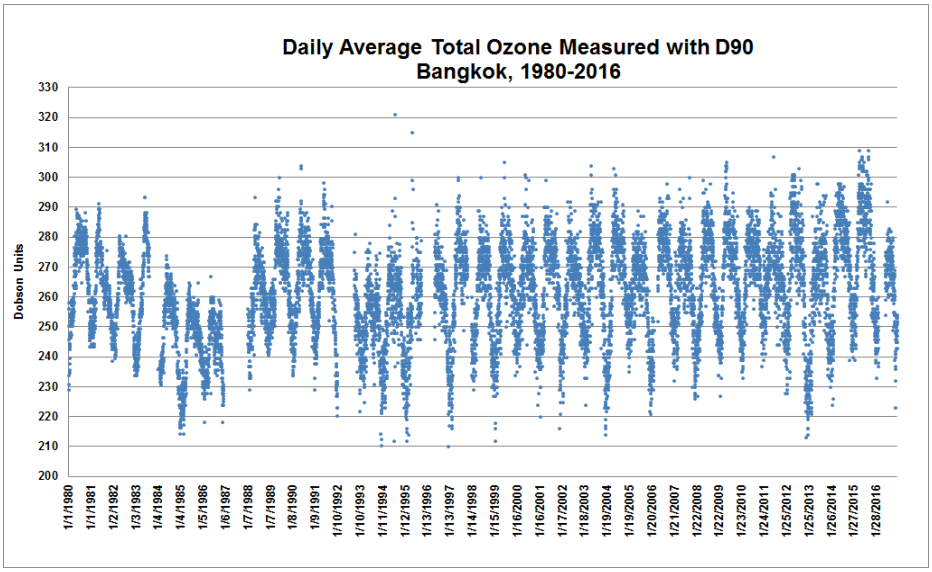


Figure 2.1. Daily average of total ozone measured with Dobson No.90 in Bangkok

A study has compared total ozone measurements with Dobson, Brewer OMI and ozonesonde and showed the result of seasonal variation and consistency as the figure below:

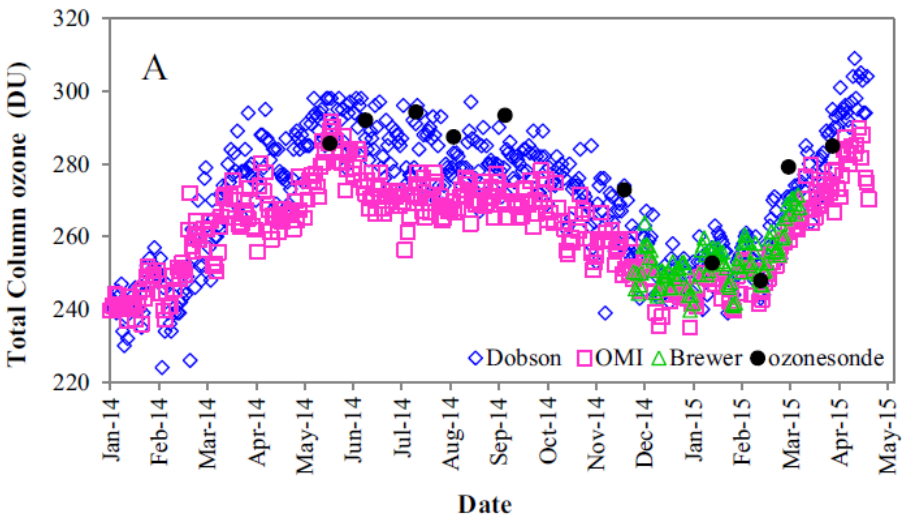


Figure 2.2. Seasonal daily variation of various quantities during the period 01/01/2014 to 31/05/2015 at the study site (13° 39′ 58.57″ N, 100° 36′ 21.44″ E): A) Daily column ozone obtained from Dobson spectrophotometer, Brewer spectrophotometer, ozonesonde and OMI/AURA satellite.

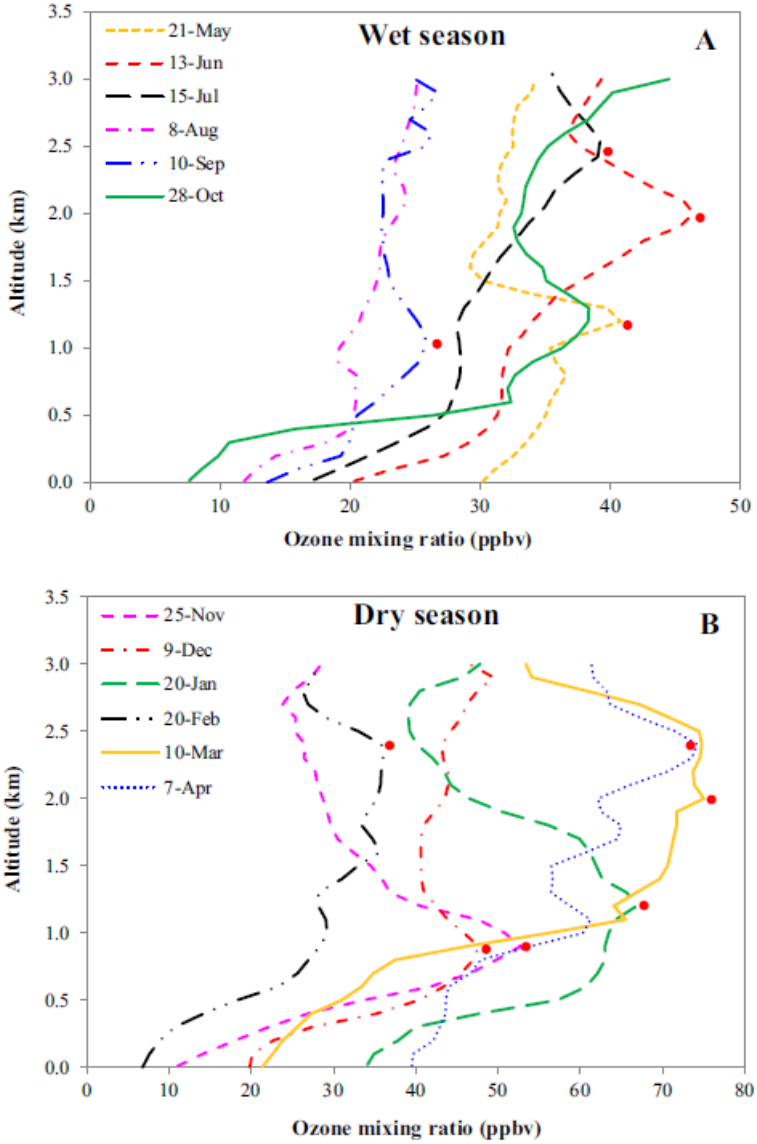


Figure 2.3. Ozone soundings showing mixing ratios in the bottom 3000 m of the atmosphere for A) the wet season from May-October, 2014 and B) the dry season from November 2014 to April 2015. Circles denote localised maxima.

3. THEORY, MODELLING, AND OTHER OZONE RELATED RESEARCH

There were investigating studies for total ozone and UV prediction. A study in 2004 were related to empirically erythemal UV models which using ground-based Dobson and/or Brewer spectrophotometer and TOMS/OMI ozone data, aerosol optical depth and other meteorological parameters as inputs for UV calculation. The empirical has been used coupled with radiative transfer (STAR) model in operational UV index forecasting.

4. DISSEMINATION OF RESULTS

Results of monitoring of ozone, solar UV radiation and others are disseminated to data centers, governmental and private sectors, educational institutes and public by documentary and in a website (http://ozone.tmd.go.th/)

4.1 Data reporting

Dobson and Brewer data are regularly submitted to World Ozone and Ultraviolet Data Centre by monthly. Solar radiation is submitted to World Radiation Data Centre. Sky radiometer raw data are submitted to SKYNET (http://atmos2.cr.chiba-u.jp/skynet/).

4.2 Information to the public

UV index forecasts are published in a website:

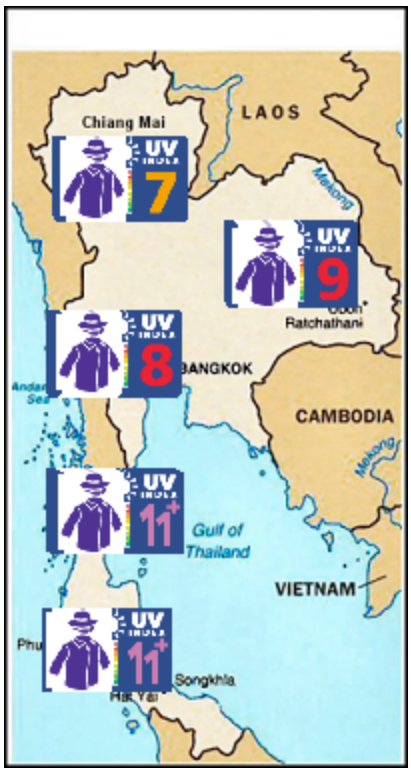


Figure 4.2. UV index forecast for Thailand (http://ozone.tmd.go.th/UV_index.htm)

4.3 Relevant scientific papers

4.3.1 Janjai et al. (2016) Meteorological factors affecting lower tropospheric ozone mixing ratios in Bangkok, Thailand Journal of Atmospheric and Solar-Terrestrial Physics 147, P. 76–89.

4.3.2 Sudhibrabha S, Exell RHB, Sukawat D (2006) Ultraviolet Forecasting in Thailand, ScienceAsia Vol. 32 No 2, pp. 107-114.

4.3.3 Sudhibrabha S, Exell RHB, Sukawat D (2004) Preliminary Forecast of Ozone and UV over Thailand, Proceedings of the XX Quadrennial Ozone Symposium, 1-8 June 2004, Kos, Greece, pp. 1157-1158.

4.3.4 Vanichnukroh P, Sukawat D, Sudhibrabha S (2004) Ozone Profile in the Climate of Thailand, Proceedings of the JGSEE and Kyoto University Joint International Conference on "Sustainable Energy and Environment (SEE)", 1-3 December 2004, Hua Hin, Thailand.

5. PROJECTS, COLLABORATION, TWINNING AND CAPACITY BUILDING

Mission in ozone monitoring and research in Thailand has been responsible by TMD. There is also collaboration with universities in particular projects.

For capacity building, some staffs from TMD received financial support from WMO in participating the 14th WMO-GAW Brewer User's Workshop, 24-28 March 2014 in Santa Cruz, Tenerife and and 15th EUBrewnet & WMO-GAW Brewer Operator Course,4-9 September 2016, Edinburgh. Some were supported in participating the 8th GAWTEC in 2004 and 10th GAWTEC in 2005.

6. IMPLEMENTATION OF THE RECOMMENDATIONS OF THE 9th OZONE RESEARCH MANAGERS MEETING

There were some difficulties that interrupted continuation or delay of ozone data submission to WOUDC due to instrumentation problems especially Brewer spectrophotometer. These problems are to be improved.

7. FUTURE PLANS

Public sectors have raised more questions and interests on ozone changing and UV levels. TMD has a strategy to strengthen public service relating to high level of solar UV, its impacts and health protection.

TMD will extend the Brewer network to be covered four regions of the country in the next few years.

There is a research project to improve ozone and UV forecasting and development a mobile App for users.

8. NEEDS AND RECOMMENDATIONS

Although the government has capability to support ozone and UV monitoring activities, implementation by the Trust Fund for Dobson/Brewer Inter-Comparison/calibrations and educational training would be highly appreciation. Additionally, TMD's working team should to join closer working with the ozone community. TMD would encourage and welcome external experts or partnership.

TURKEY

Turkish State Meteorological Service is responsible for observing and promoting research activities on measurements of ozone and UV radiation.

OBSERVATIONAL ACTIVITIES

Ozone measurements are made by Brewer Spectrophotometer in Ankara.

Ultraviolet radiation measurements are made in totally 15 stations with different specification instruments which of one is broad band and others are narrow band.

Column Measurements Of Ozone And Other Gases/Variables Relevant To Ozone Loss

Brewer Spectrophotometer

Station	Instrument	Institution	Latitude	Longitude	Start date of observation
Ankara	Brewer MKIII-188	TSMS	39° 57’ (N)	32° 53’ (E)	Sep.,2006 to present

Brewer spectrophotometer is deployed on a solar azimuth tracker which allows daily automatic measurements of total ozone, zenith sky and direct sun in Ankara station which is the component of WMO-Global Atmosphere Watch Programme.

Data is measured by Brewer MK III Spectrophotometer and the measured data are stored in the database of The Data Processing Department of TSMS and are also sent to the World Ozone and UV radiation Data Center (WOUDC) in Toronto, Canada and are archived in there. And since 2016 the data of Brewer 188 has started to share with data base of EUBrewnet Project that is the supported by WMO and GAW as a COST project.

Profile Measurement Of Ozone And Other Gases/Variables Relevant To Ozone Loss

Ozonesonde

Station	Instrument	Institution	Latitude	Longitude	Start date of observation
Ankara	Ozonesonde(ECC)	TSMS	39° 57’ (N)	32° 53’(E)	Sep.,2006 to Marc 2013

Ozone profile measurements were made by TSMS Research Department in the method of ozonesonde between January 1994 and March 2013 in Ankara for 19 years.

UV Measurements

Broad band measurements

Station	Instrument	Institution	Latitude	Longitude	Start date of observation
Ankara	Solar Light 501	TSMS	39° 57’ (N)	32° 53’ (E)	1997 to present
Antalya	Solar Light 501	TSMS	36° 42’ (N)	30° 44’ (E)	1997–2003

UV-Biometer Model 501 is used for broad band UV radiation measurements.

Narrow band filter instrument

Station	Instrument	Institution	Latitude	Longitude	Start date of observation
Akçaabat	Middleton Solar UVR1-B Radiometer	TSMS	41° 01’ (N)	39° 35’ (E)	2009 to present
Aksaray	Middleton Solar UVR1-B Radiometer	TSMS	38° 23’ (N)	34° 03’ (E)	2009 to present
Elazığ	Middleton Solar UVR1-B Radiometer	TSMS	38° 60’ (N)	39° 28’ (E)	2009 to present
Göksun	Middleton Solar UVR1-B Radiometer	TSMS	38° 01’ (N)	36° 30’ (E)	2009 to present
Mardin	Middleton Solar UVR1-B Radiometer	TSMS	37° 30’ (N)	40° 73’ (E)	2009 to present
Oltu	Middleton Solar UVR1-B Radiometer	TSMS	40° 33’ (N)	41° 59’ (E)	2009 to present
Sivas	Middleton Solar UVR1-B Radiometer	TSMS	39° 75’ (N)	37° 02’ (E)	2009 to present
Tarsus	Middleton Solar UVR1-B Radiometer	TSMS	36° 55’ (N)	34° 54’ (E)	2009 to present
Tokat	Middleton Solar UVR1-B Radiometer	TSMS	40° 30’ (N)	36° 57’ (E)	2009 to present
Van	Middleton Solar UVR1-B Radiometer	TSMS	38° 45’ (N)	43° 32’ (E)	2009 to present
İstanbul, Florya	PMA1102	MGM	40° 59 (N)	28° 45 (E)	2012 to present
İzmir, Güzelyalı	PMA1102	MGM	38° 43 (N)	27° 17 (E)	2012 to present
Antalya, Kale	PMA1102	MGM	36° 15 (N)	29° 57 (E)	2012 to present
Afyon, Çay	PMA1102	MGM	38° 35 (N)	31° 02 (E)	2012 to present

UVR1-B Global Spectral Radiometers and PMA1102 UV detector are used for narrow band UV radiation measurements.

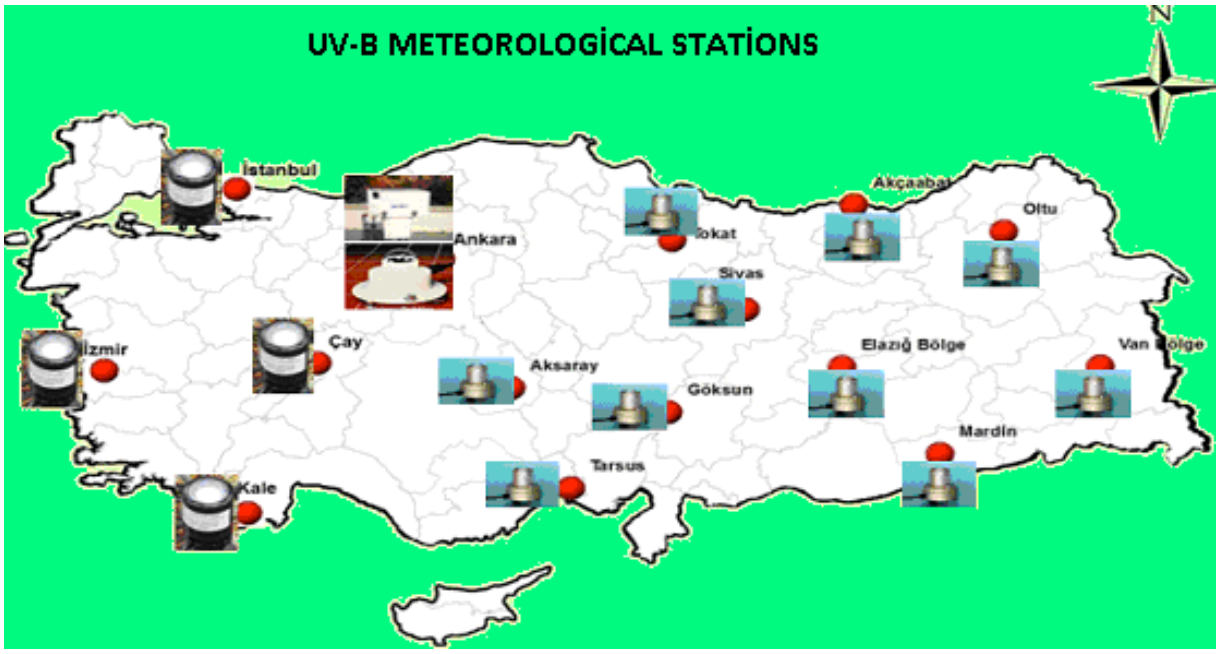


Figure 1. Turkey, UV-B Meteorological Stations

Spectroradiometers

Spectral UVB measurements (290-325 nm) by Brewer spectrophotometer #188 MK III have started from 09 September, 2006 in Ankara station.

Station	Instrument	Institution	Latitude	Longitude	Start date of observation
Ankara	Brewer MKIII–188	TSMS	39° 57’ (N)	32° 53’(E)	Sep.2006 to present

Calibration Activities

Calibration of Brewer Spectrophotometer #188 has performed since it was installed in 2006. First Brewer S. calibration was carried out by International Ozone Services Inc. (IOS) which provides worldwide ozone and UV calibration services to customers with Brewer Ozone Spectrophotometer instruments. IOS used Brewer Ozone Spectrophotometer #017 as a reference instrument on 07–12 October 2008 in Ankara station.



Figure 2. *First calibration of Brewer MKIII #188 with the reference Brewer MKIV #017 in Ankara station.*



Figure 3. *Second calibration of Brewer MKIII #188 with the reference Brewer MKIII #158 in Ankara station.*



Figure 4. *Third calibration of Brewer MKIII #188 with the reference Brewer MKIII #158 in Ankara station.*



Figure 5. *Fourth calibration of Brewer MKIII #188 with the reference Brewer MKIII #158 in Ankara station.*

Second calibration of Brewer S. #188 was carried out on 22 - 29 September in 2010 and Third calibration of Brewer S. #188 was carried out on 23 - 27 September in 2013 by Kipp& Zonen. Kipp& Zonen used Brewer Ozone Spectrophotometer #158 as a reference instrument during calibration in Ankara station. As well as the third calibration, the fourth calibration was also

made by Kipp& Zonen personel Mr. Oleksii Marianenko and used the same reference instrument #158 on 23-27 May 2016.

OBSERVATIONS AND ANALYSIS RESULTS

Brewer Ozone Variability Over Ankara, Comparison Between OMI and Brewer Ozone Measurements for Ankara (2007-2016)

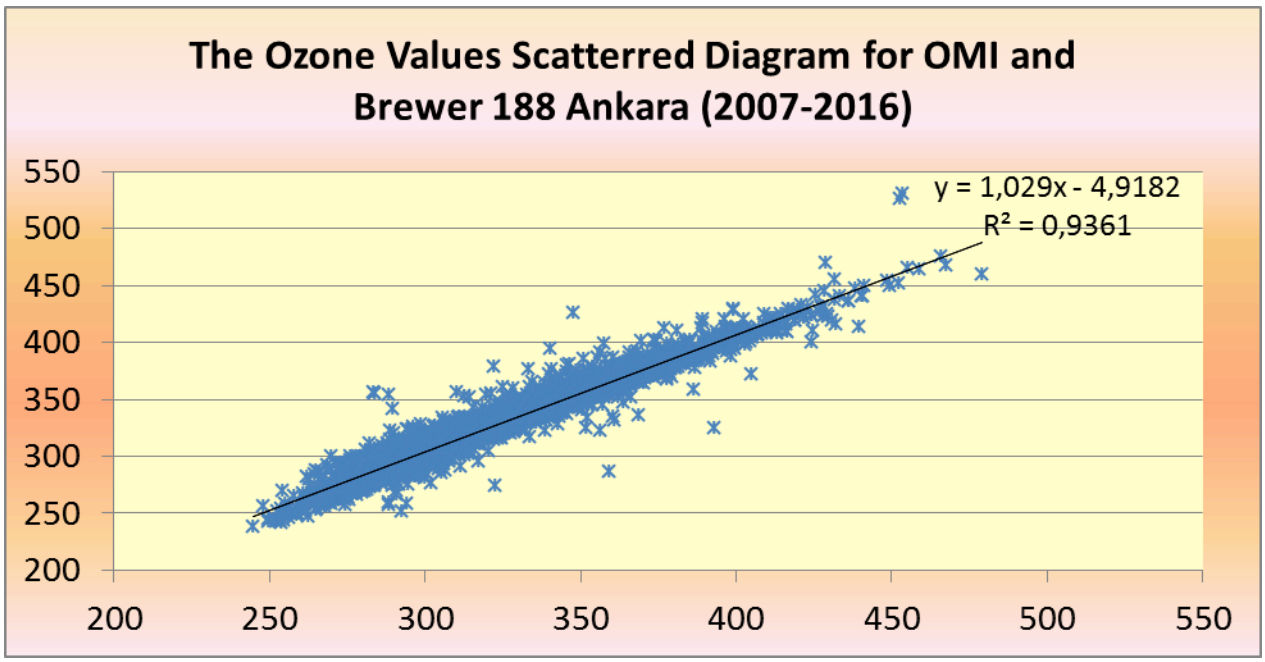


Figure 6: Comparison of OMI from NASA Aura Satellite with the total ozone measurements of Brewer S. #188 for 01 January 2007 and 31 December 2016 period.

In figure 6, relationship between total ozone measurements of Brewer #188 and OMI_TOMS observed total ozone data from satellite indicates high correlation. Correlation coefficient is R=0,96 and R^2=0,9361.

Turkey's Total Ozone Satellite (TOMS-OMI) Data Assessment for Long Period (1979-2016)

TOMS-OMI satellite ozone data used in this study is selected from the global data set which is in http://ozoneaq.gsfc.nasa.gov/ NASA's web address. Data is range Turkey's 25 ° - 45 ° East Longitude and 34 ° - 42 ° North Latitude, data resolution is 1°x1.25° and data grid consists of 82 points.

Data time range covers from 1979 to 2016 (37 years). The data set which is consist of total 3034 data and is belong to Turkey domain. 984 of data are used for monthly comparison and 328 of data are used for seasonal comparison.

Average total ozone value has been found in 316 DU from data set which is used in mapping. The lowest average value is 291 DU in point 37 °N and 44 °E in 1993. The highest average value is 351 DU in point 42°N and 28°E in 1991.

The average total ozone is approximately 305 DU at Turkey's southern latitudes and in northern latitudes is approximately 330 DU. The average total ozone difference is also 25 DU between the northern and southern latitudes in Turkey.

DISSEMINATION OF RESULTS

Data Reporting

Products of ozone and UVB radiation measurements are stored at the Research and Data Processing Section of TSMS and can be accessible through intranet to users.

All data measured by Brewer MK III Spectrophotometer #188 and ozonsonde are sent regularly to the World Ozone and UV radiation Data Center (WOUDC). They are archieved and published with the station number 348 in Toronto, Canada. At the same time, Ankara station is a part of the Global Atmosphere Watch Programme (GAW).

Eubrewnet; Descriptions are provided by the Actions directly via e-COST. This proposal will coordinate Brewer Spectrophotometer measurements of ozone, spectral UV and aerosol optical depth (AOD) in the UV within Europe. Around 50 Brewer Spectrophotometers are deployed in Europe, independently funded by national agencies. Brewer 188, Ankara is also included by the EuBrewnet Project since 2013 and the measurements of Brewer 188 are shared to EuBrewnet Data Base by TSMS.

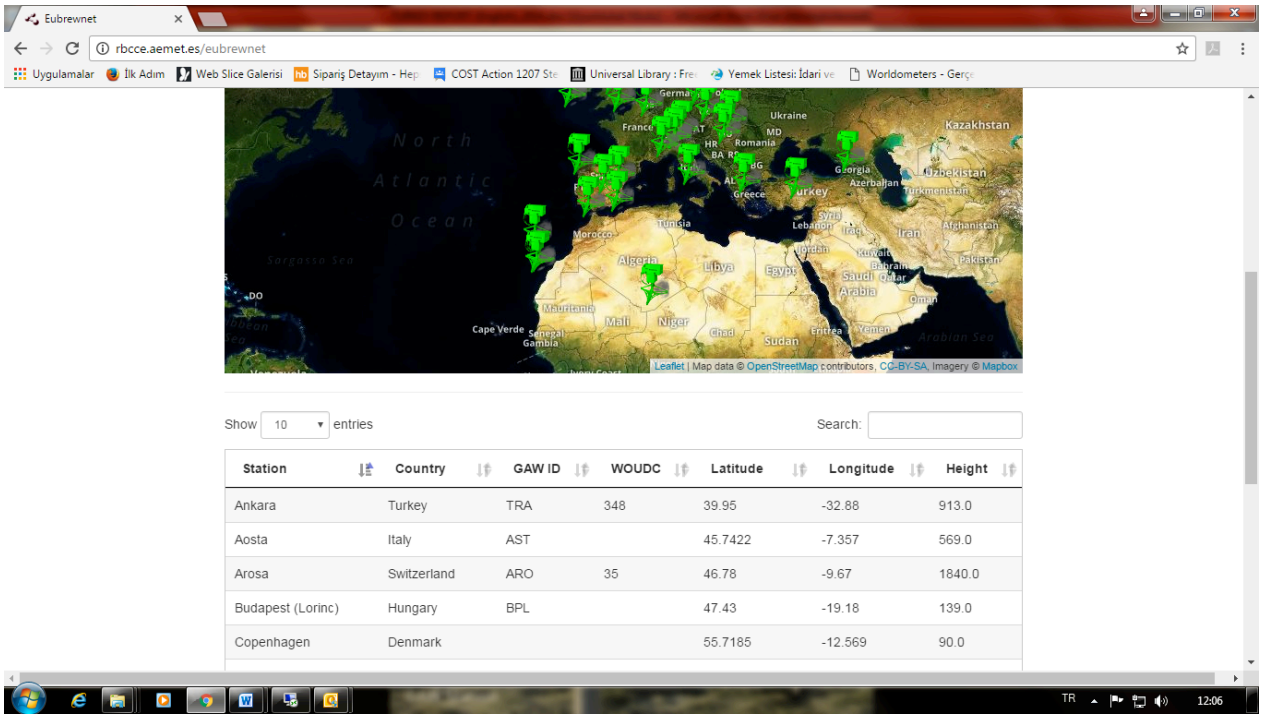


Figure 7: The European Brewer Stations in COST EuBrewnet Project.

Information for the Public

Since 2008, daily total ozone and ultraviolet index forecast information**,** which is derived by using a statistical model in Turkey's 125 points and Northern Cyprus Turkish Republic (TRNC)'s 5 points**,** are published through internet web site. http://www.mgm.gov.tr/kurumici/tahmin-ozon-mgm.aspx



T.C.
Orman ve Su İşleri Bakanlığı
Meteoroloji Genel Müdürlüğü

Günlük Toplam Ozon ve UV İndeks Tahmini - MGM

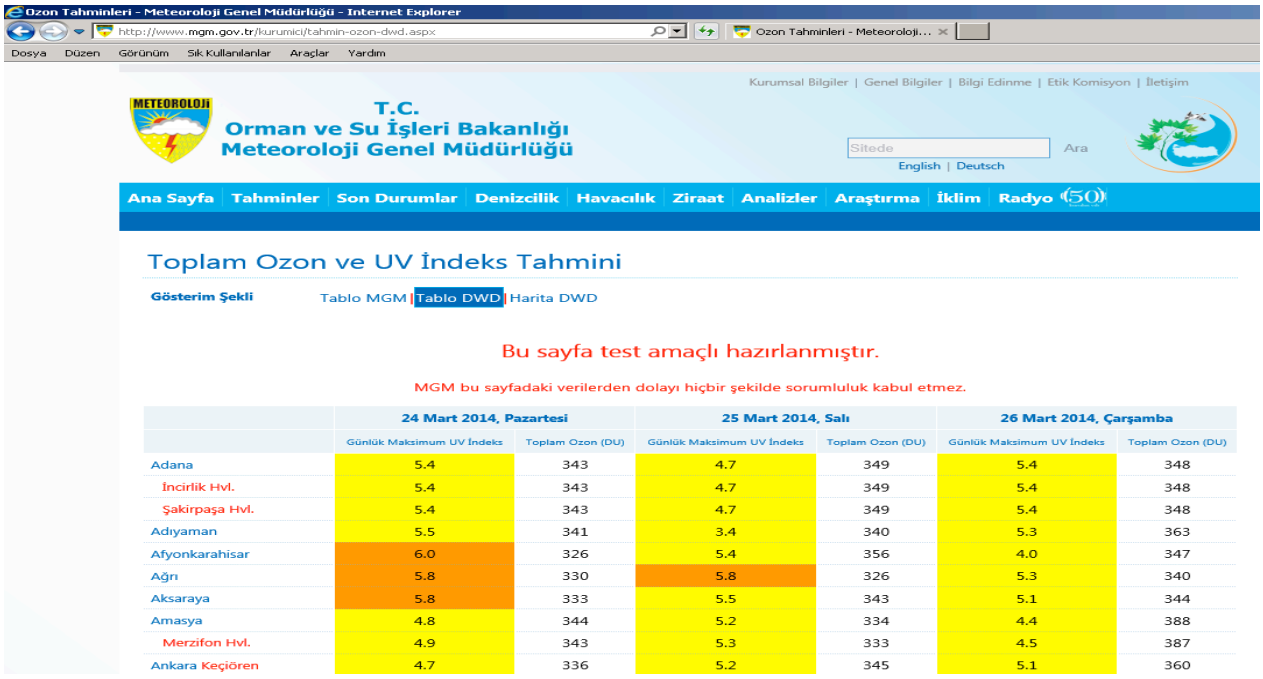
Gösterim Şekli: Tablo MGM | Tablo DWD | Harita DWD

Bu sayfa test amaçlı hazırlanmıştır.

Merkez	Toplam Ozon (DU)			Günlük Maksimum UV İndeks		
	24.03.2014 Pazartesi	25.03.2014 Salı	26.03.2014 Çarşamba	24.03.2014 Pazartesi	25.03.2014 Salı	26.03.2014 Çarşamba
Adana	408.1	411.0	400.5	4.6	4.6	4.6
İncirlik Hvl.	407.9	410.9	400.3	4.6	4.6	4.6
Şakirpaşa Hvl.	408.1	411.0	400.6	4.6	4.6	4.6
Adapazarı	380.7	391.3	392.6	4.3	4.1	4.1
Adıyaman	411.6	420.7	409.8	4.4	4.3	4.3
Afyonkarahisar	385.9	391.6	391.9	4.6	4.5	4.5
Ağrı	391.2	418.3	415.0	4.3	4.0	4.0
Aksaray	409.6	410.7	404.6	4.4	4.3	4.3
Amasya	405.8	412.3	409.8	4.0	3.9	3.9
Merzifon Hvl.	403.8	411.2	408.5	4.0	3.9	3.9

Figure 8: The TSMS Model outputs for daily forecasted total ozone and UV index in Turkey.

In Addition, TSMS and the German Meteorological Service (DWD) have been cooperation for ozone and ultraviolet index forecast. Daily total ozone and ultraviolet index forecast information, which is produced by DWD for Turkey's 125 points and Northern Cyprus Turkish Republic (TRNC)'s 5 points, are published through internet web site.
http://www.mgm.gov.tr/kurumici/tahmin-ozon-mgm.aspx



T.C.
Orman ve Su İşleri Bakanlığı
Meteoroloji Genel Müdürlüğü

Toplam Ozon ve UV İndeks Tahmini

Gösterim Şekli: Tablo MGM | Tablo DWD | Harita DWD

Bu sayfa test amaçlı hazırlanmıştır.

MGM bu sayfadaki verilerden dolayı hiçbir şekilde sorumluluk kabul etmez.

	24 Mart 2014, Pazartesi		25 Mart 2014, Salı		26 Mart 2014, Çarşamba	
	Günlük Maksimum UV İndeks	Toplam Ozon (DU)	Günlük Maksimum UV İndeks	Toplam Ozon (DU)	Günlük Maksimum UV İndeks	Toplam Ozon (DU)
Adana	5.4	343	4.7	349	5.4	348
İncirlik Hvl.	5.4	343	4.7	349	5.4	348
Şakirpaşa Hvl.	5.4	343	4.7	349	5.4	348
Adıyaman	5.5	341	3.4	340	5.3	363
Afyonkarahisar	6.0	326	5.4	356	4.0	347
Ağrı	5.8	330	5.8	326	5.3	340
Aksaraya	5.8	333	5.5	343	5.1	344
Amasya	4.8	344	5.2	334	4.4	388
Merzifon Hvl.	4.9	343	5.3	333	4.5	387
Ankara Keçiören	4.7	336	5.2	345	5.1	360

Figure 9: DWD model products showing information on daily forecasted total ozone and maximum UV index to the public at the TSMS web page for Turkey.

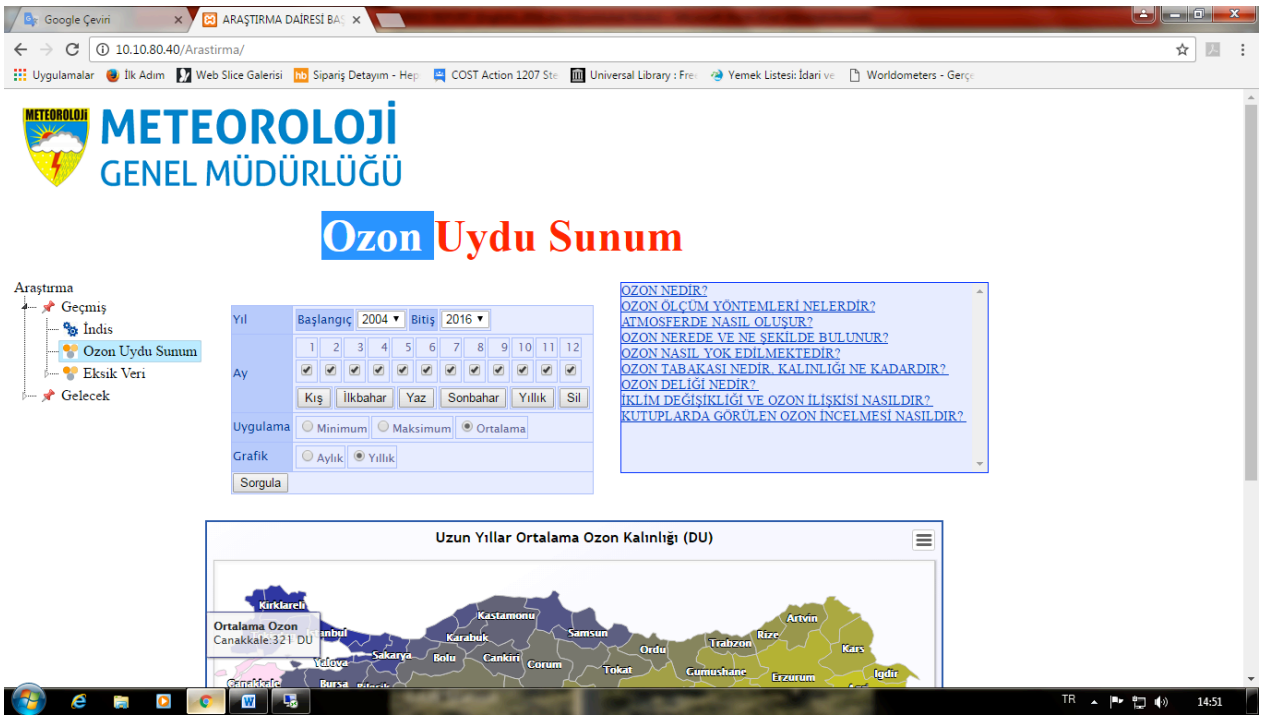


Figure 10: Information about general ozone and illustration of monthly, seasonal and annual ozone data

In Research Department Server, there is a new test page that is illustrated to last users the satellite ozone data for all Turkey as monthly, seasonal, annual and minimum, maximum and average values of the ozone as well. On the other hand, the last users could have informed about meta data, knowledge about general ozone information in this page (Figure 10).

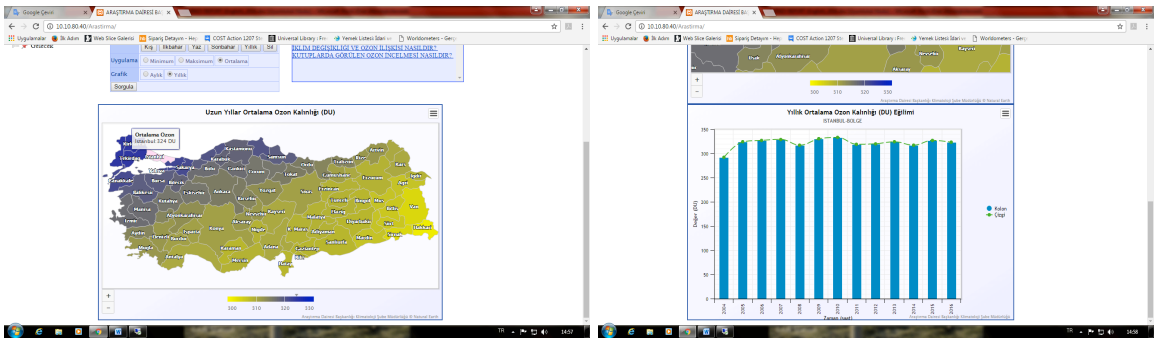


Figure 11: The İllustrations of satellite ozone data of all Turkey and a graphic of any province

In this page, any user could obtain the illustration of Turkey ozone map. In this map, any user could see the the ozone average of any province in Turkey and also if any user clicks on a province over the map, who can obtain the ozone graphic of that province (Figure 11).

FUTURE PLANS

- To establish a Brewer Spectrophotometer Network to cover and to represent whole Turkey for measuring total ozone and UV index by purchasing more Brewer Spectrophotometer.
- To study on interactions between stratospheric ozone and climate change.
- To examine variation in ozone and UV index in time.
- To evaluate interaction between ozone change and climate change.
- To contribute to ozone assessments by sharing information.

- To seek for research at the European level implemented through the Framework Programs for research and technological development (FPs)of European Commission.
- To attend seminars, conferences and meetings related with global ozone research and international monitoring program.
- To share all ozone and UV Radiation data and all products to the public. Would like to develop new test pages as soon as possible.

NEEDS AND RECOMMENDATIONS

Providing a continued maintenance and calibration of instruments such as Brewer S. and UV sensor with the support of WMO is important.

Relevant Scientific Papers

1- Barı D.D., Topcu S., Aksoy B., Kahya C., Incecik S., Acar Y., Ozunlu M., Ekici M., *"A Study Of Daily Total Column Ozone Forecasting Based On Toms Data And Meteorology*". Perugia, Italy. (IUGG), 2007.

2- B. Aksoy, S. Incecik, S. Topcu, D. Demirhan Bari, C. Kahya, Y. Acar, M.Ozunlu, M. *Ekinci "Total ozone over Ankara and its forecasting using regression models",* International Journal of Remote Sensing, Vol. 30, Issue 17, 2009, pages 4387-4400.

3- Topcu, S., D. Demirhan Bari, C. Kahya, S. Incecik, Y. Acar*, "Climatology of erythemal UV radiation in Ankara, Turkey",* Asia Oceania Geosciences Society (AOGS),6th Annual Meeting, Singapore, 11.08.2009-15.08.2009).

4- Topcu, S., D. Demirhan Barı, C. Kahya, S. İncecik, Y. Acar*, "Ankara'nın Erythemal UV radyasyon klimatolojisi",* Asya Okyanus Yerbilimleri Topluluğu (AOGS), Singapur, Ağustos, 10-15 2009.

5- Demirhan Bari D, Kahya C, Topcu S., İncecik S., Aksoy B, Acar Y., Ozunlu M., Ekici M, *"Estimating of Daily Erythemal UV Irradiation in Ankara, Turkey with an Empirical Model,",* 2009, Quadrennial Ozone Symposium (QOS),, Tromsø, Norway, 29.06.2009 - 05.07.2009.

6- Acar, Y., Ekici, M.*, "Ankara'nın Brewer Eritemal UV (EUV) Ölçüm Verileri İle Model Eritemal UV (EUV) Tahmin Verilerinin Karşılaştırması"* (Makale-1.Meteoroloji Sempozyumu), 2010.

7- Ekici, M., Acar, Y., *"Ankara İçin Brewer Spektrofotometre ve OMI Uydu Toplam Ozon Verilerinin Karşılaştırması*" (Makale,1.Meteoroloji Sempozyumu), 2010.

8- Acar, Y., Ekici, M, Yağan, S., Akçakaya, A., *"Brewer Spektrofotometresi (188) Ozon Profil Verilerine Göre Ankara Üzerindeki Ozonun Dikey Dağılımı",* MGM, Teknik Rapor, Şubat 2013, Ankara, Türkiye.

9- Mithat EKİCİ, Osman ESKİOĞLU, Yılmaz AÇAR, Mesut DEMİRCAN, Alper AKÇAKAYA, "Toms ve OMI Uydu Türkiye Ozon Verilerinin CBS Ürünleriyle Analizi (1979-2012)", III. İklim Değişikliği Kongresi, TİKDEK 2013, İstanbul, 3-5 Haziran 2013.

10- Yılmaz AÇAR, Serpil YAĞAN, Mithat EKİCİ, Salim ERSOY, Alper AKÇAKAYA, Osman ESKİOĞLU, "Türkiye Üzerine Gelen Hava Kütlelerinin Ankara'nın Toplam Ozon Kalınlığı Üzerine Etkisi", III. İklim Değişikliği Kongresi, TİKDEK 2013, İstanbul, 3-5 Haziran 2013.

11- Ekici, M., "*Brewer Ozone Variability Over Ankara And Comparison Between OMI And Brewer Ozone Measurements For Ankara (2007-2013)"* COST Action ES1207 EUBREWNET Open Congress/14TH WMO-GAW Brewer Users Group Meeting, Tenerife / SPAIN, 25-28 March 2014.

12 - Ekici,M., Eskioğlu, O., Acar, Y. *"Toms ve Omi Uydu Türkiye Ozon Verileri Analizi (1979-2015) ve Ankara Brewer Spektrofotometre Ozon Verileri (2006-2015) ile Karşılaştırması"* II. Meteorolojik Uzaktan Algılama Sempozyumu 3-5 Kasım 2015 Antalya.

TURKMENISTAN

Monitoring of atmospheric ozone

In Turkmenistan monitoring of atmospheric ozone is accomplished by a National Committee on Hydrometeorology at the Cabinet of Ministers of Turkmenistan (Turkmengidromet).

At present continue systematic daily observations of the total amount of the atmospheric ozone at one station:

Repetek (38.34° N, 63.11° E, 185 m, since 1983)

The measurements of total ozone amount are done by means of the ozonometer M-124, manufactured in Russia. The ozonometers physically became obsolete, already many years they were not calibrated. Spare and reserve ozonometers for replacement and control are absent. Nevertheless the carried out comparative analysis between the temporary changes in the total ozone amount, obtained using the ozonometers M-124 and by data of Central Aerological Observatory scientific report, gives satisfactory agreement.

Information

The daily averaged data of total ozone amount sent by telegram to Moscow 736 OZONE. Monthly schedules O-3 not later than 3 days of the following month are sent to the Main Geophysical Observatory named Voeikov. Further all data are transferred to the coordinated international network by data exchange of the World Meteorological Organization (WMO).

All primary data are stored in the archive of Turkmengidromet on the paper carrier. As it is known, the paper becomes yellow at long storage, records grow dull and there is a danger of important information loss received for a long time. Therefore in the near future it is necessary to transfer all information on ozone in the electronic format.

Studies

It is known that the ozone actively absorbs UV - radiation of the Sun and hereby influences on temperature distribution in the stratosphere, consequently on climate. By-turn climate changes, leading changes of temperature and composition of the atmosphere can influence on condition of ozonosphere. Depletion of the ozone layer will increase hard spectrum of UV - radiation which promote initiation of sun burnings, eye diseases, allergic reactions and skin diseases including cancer. Therefore studying of change of the total content of atmospheric ozone appears as actual task of the present.

Though obtained results of scientific analysis regarding influence of hard spectrum of UV - rays on condition of the ozonosphere in a phase of high solar activity, presently an opinion about role of anthropogenic factor becomes prevalent. In the last years an increase of the quantity of industrial objects in Turkmenistan can lead to the growth of the role of anthropogenic factor.

Turkmenistan having ratified the Vienna Convention and the Montreal Protocol, and also London Amendment to the Montreal Protocol undertook the corresponding obligations on the problem solution of the Ozone depleting substances (ODS). Plan of actions is developed on decrease of pollutants emission in the atmosphere and on ODS phase-out.

22nd of January 2008 the Medjlis (Parliament) of Turkmenistan has accepted a Decree about acceding to the Beijing, Montreal and Copenhagen Amendments of the Montreal Protocol on Substances that Deplete the Ozone Layer**.**

15th of September 1999 adopted the Law of Turkmenistan "On Hydro-meteorological activity" with introduction Amendments and additions to the Law of Turkmenistan on 18.04.2009 and 26.11.2010.

15th of August 2009 adopted the Law of Turkmenistan "On the Protection of the Ozone Layer" and 24th October 2015 was introduced Amendments and additions to the Law.

Problems and needs

The contemporary level of investigations requires the presence of new technical equipment, which will permit to carry out the regular control of the content of ozone both in the atmospheric surface layer and at the stratosphere heights. This is dictated by the fact that decrease of the total ozone amount in the stratosphere leads to an increase of the intensity of UV - rays dangerous for the life, and its increase in the atmospheric surface layer adversely affects on human health and it leads to a drop in the productivity of agricultural crops (wheat, rice, potato and etc.).

For obtaining more reliable information about the total ozone amount it is necessary to enlarge a network of regular daily observations. Also necessary to more widely use the data, obtained from the satellites. This can be carried out with the aid of the acting stations equipping by the contemporary instruments and opening of new stations with the technical support of international organizations.

Turkmenistan gained ozonometer device brand "SOLAR" and currently is working on the installation of this device.

In Turkmengidromet also there is necessity in training of young specialists with purpose of effective usage of contemporary instruments for measuring the total amount of atmospheric ozone and ultraviolet radiation.

Taking into consideration recommendations of the ninth meeting of the Ozone Research Managers of the Parties to the Vienna Convention, which was held in Geneva from 14 to 16 May 2014, Turkmenistan is in need of support, namely:

1. To get links to detailed technical description of modern devices or ozonometers.
2. If it is possible to receive financial support for travel and exchange of scientists and observation stations staff from the developing countries for their participation in conferences and seminars.

UNITED KINGDOM

1. OBSERVATIONAL ACTIVITIES

1.1 Column measurements of ozone and other gases/variables relevant to ozone loss

Column ozone measurements are taken at four locations spanning the length of the UK: a Dobson instrument, operated by the Met Office, has been used at Lerwick in the Shetland Islands (North of Scotland) since 1957; a Mark III Brewer instrument, operated by the University of Manchester, has been used at Manchester in northern England since 2000; a Mark IV Brewer has been operated by the University of Manchester at Reading in southern England since 2003; and a SAOZ (Systeme D'Analyse par Observations Zenithale) instrument in Aberystwyth has been in place since 1991 with data reprocessed by the University of Manchester. The Lerwick and Reading operations are funded by the UK Government (Department for Environment, Food and Rural Affairs). The Manchester instrument is unsupported but operated on a pro bono basis by the team at Manchester University. In addition to ozone column measurements the SAOZ measures the nitrogen dioxide column. The site operation itself at Aberystwyth is supported by the Natural Environment Research Council (NERC) via the National Centre for Atmospheric Science (NCAS).

In the case of Reading, Manchester and Lerwick, the spectrophotometers operating in the UV band sample the ozone column at frequent intervals throughout the day to produce daily mean values, except when weather conditions prevent recordings or during winter at Lerwick when the sun is too low. The data is submitted to the World Ozone and Ultraviolet Radiation Data Centre (WOUDC), WMO World Data Archive and University of Thessaloniki. The data from these measurements are available at: https://uk-air.defra.gov.uk/data/ozone-data. The instrument at Aberystwyth works on a different methodology, operating in the Chappuis visible band (450-570nm), acquiring slant columns during sunrise and sunset to produce two estimates per day. Data are submitted to WOUDC, the University of Thessaloniki WMO mapping centre and the Network for the Detection of Atmospheric Composition Change (NDACC).

The UK also carries out ozone and nitrogen dioxide measurements at locations in Antarctica through the British Antarctic Survey (BAS). This includes a Dobson spectrophotometer, operated since 1956, and a SAOZ spectrometer, operated since 2013, at the Halley station, and a SAOZ instrument at Rothera, operated since 1996, which was previously installed at Faraday from 1990 - 1995. A Dobson instrument at Ukraine's Vernadsky/Faraday station, operated since 1957, is on long-term loan to Vernadsky from BAS. Radiosonde measurements are also taken at Halley and Rothera.

1.2 Profile, surface and tropospheric measurements of gases/variables relevant to ozone loss

Brewer umkehr profile measurements of ozone are made routinely at the Manchester and Reading sites, processed by the University of Manchester, and also routinely submitted to WOUDC.

The Met Office has conducted ozonesonde launches from Lerwick regularly since 1995, currently for model verification purposes. Data is sent the same day to the Norwegian Institute for Air Research (NILU) database. Data is sent annually to the WOUDC.

Lerwick also takes part in the Northern European co-ordinated Match Program ozonesonde launches, when ozone depletion is expected. These ozonesondes are provided by the Alfred Wegener Institute for Polar and Maritime Research at Potsdam (AWI), who also run the program and analyse the data.

The UK Government funds six stations in the UK and Ireland monitoring ozone-depleting substances (ODS) and related gases. Two of these (Mace Head, in the west of Ireland, operated since 1987, and Tacolneston, a TV mast in England, since 2011) make high frequency, real time, *in situ* measurements of a comprehensive suite of ODS including halocarbons, methane, and nitrous oxide (N_2O) as well as related radiatively active trace gases such as HFCs, SF_6, NF_3, CO_2, etc. Four further sites in the east and west of England and central Scotland (the latter now replaced by a site in northern England) measure CH_4, N_2O, CO_2 and SF_6. The Mace Head site is well positioned to contrast clean westerly air entering Europe from the Atlantic with emissions leaving Europe towards the Atlantic. The site is, therefore, ideally situated to record trace gas concentrations associated with both the Northern Hemisphere background levels and the more polluted air arising from Europe. The other sites in England provide spatial measurement distribution to help determine emissions estimates for the UK. Analysis of the atmospheric observation data also identifies sources of and trends in ODS and related gas emissions from different areas, including comparison of observed data with expected trends from inventories. Work is also in progress to identify new substances with ozone depleting or radiative forcing properties, and a significant number of these have been identified, including "new" CFCs, HFCs, HCFCs and PFCs. Some of these measurements form a key part of the international Advanced Global Atmospheric Gases Experiment (AGAGE) measurement programme, another part of the Integrated Carbon Observing System (http://www.icos-uk.org/icos-and-uk). More information, including links to the data is available at: http://www.metoffice.gov.uk/research/monitoring/atmospheric-trends and http://weybourne.uea.ac.uk/data.php.

Summary of UK stations monitoring ozone-depleting substances (ODS) and related gases

Station	Surface or tall tower	Date ODS-related measurements started	ODS and related measurements	Network affiliated	Responsible organisation
Mace Head, Ireland	Surface	1987	Halocarbons, N_2O, CH_4, SF_6, CO_2	AGAGE	UBristol
Tacolneston, England	TV mast	2012	Halocarbons, N_2O, CH_4, SF_6, CO_2	AGAGE	UEA/UBristol
Weybourne, England	Surface	2013	N_2O, CH_4, SF_6, CO_2	ICOS	UEA
Bilsdale, England (replacing Angus, Scotland)	TV mast	2013	N_2O, CH_4, SF_6, CO_2	AGAGE	UBristol
Ridge Hill, England	TV mast	2013	N_2O, CH_4, SF_6, CO_2	AGAGE	UBristol
Heathfield, England	TV mast	2013	N_2O, CH_4, SF_6, CO_2	AGAGE	UBristol

The NCAS supports various long-term halocarbon measurement programmes at the University of East Anglia. These include the Cape Grim air archive measurements from Tasmania (dating back to 1978) and the CARIBIC flying observatory (www.caribic-atmospheric.com) which provide regular data from the upper troposphere/lower stratosphere (UTLS) region. UEA also have numerous other ODS-related projects which include surface measurements in East and SE Asia, aircraft measurements and measurements in air trapped in firn and ice. For many years UEA have pioneered the detection and identification of new ODS in the atmosphere and are currently developing a unique low-cost "AirCore" sampling programme for halocarbons in the stratosphere, which will provide data over the 30-40 km altitude range.

1.3 UV measurements

1.3.1 Broadband measurements

The solar UV index is measured at nine sites (from 50 to 60° N) across the UK by Public Health England (PHE), an executive agency sponsored by the UK Department of Health. PHE also operates sites in Gibraltar, Cyprus and Malin Head in the Republic of Ireland. Each site includes an erythemally weighted radiometer, UV-A and illuminance sensor with measurements averaged over 5 minutes, 24 hours a day. These monitoring sites provide information for the Global Solar UV Index in association with World Health Organisation (WHO), WMO, United Nations Environment Programme (UNEP) and the International Commission on Non-Ionizing Radiation Protection.

PHE also operates a Kipp and Zonen Solys 2 Sun tracker with two Kipp and Zonen UV-S-E-T broadband radiometers measuring erythemally weighhted UV radiation's global and diffuse component on the horizontal plane every 5 minutes, 24 hours a day at Chilton in Oxfordshire.

The University of Manchester operates a Kipp and Zonen UV-S-AE-T broadband radiometer which measures erythemal UV radiation at a location in Manchester.

1.3.2 Narrowband filter instruments

The University of Manchester operates a Biospherical GUV-541 multifilter instrument, located in central Manchester, which has been in operation since 1997. It has 5 channels of bandwidth ~ 10 nm, centred at 305, 313, 320, 340 and 380 nm. From this the erythemal / UV index is calculated every minute and is available on https://uk-air.defra.gov.uk/data/uv-index-graphs

1.3.3 Spectroradiometers

The UK Government funds measurements from a Bentham DM150 spectroradiometer which is co-located with the Brewer spectrophotometer at Reading in southern England. The data series is one of the longest in the World and extends back to 1991 with regular operation since 1993. The current instrument takes calibrated (NIST) measurements from 290nm to 500nm at 0.5nm resolution at half-hour periods during daylight hours, every day of the year.

The University of Manchester uses a Mark III Brewer (double monochromator) to measure spectral UV irradiance (290 to 363 nm) in Manchester. This instrument has been in operation since 2000 and forms the basis for studies requiring long term spectral data in the north of England.

Since 2003 Spectral UV measurements have been carried out at the PHE site at Chilton. The spectroradiometer is an ISA-Jobin Yvon-Spex D3 180 Series scanning spectroradiometer, manufactured by Horiba Jobin Yvon Inc. Edison, New Jersey. The instrument takes measurements from 280 nm to 400 nm at fifteen minute intervals from 03:00 to 22:00 every day of the year. Two portable spectral measurement systems (APSUS) have been developed for temporary deployment during extreme weather, atmospheric events or at locations where large numbers of people gather outside during the summer. They are able to measure spectral UV irradiance from 280 nm to 420 nm at a sampling rate of 1 minute. A customised Bentham

DMc150 double Monochromator, able to measure 280 – 600 nm and housed in an environmental housing, has been operated around the world and is available for deployment.

Most of the UV data described in the sections above is available at: https://uk-air.defra.gov.uk/research/ozone-uv/

1.4 Calibration activities

The Dobson #32 machine at Lerwick was last calibrated in 2011. The next calibration will take place in 2017 at the Regional Dobson Calibration Centre at Hohenpeissenberg, Germany. Dobson #41 at Lerwick was calibrated at Hohenpeissenberg in 2014 and the next calibration is due in 2019.

Brewer #075 at Reading was calibrated at El Arenosillo in 2015. The next calibration is due in 2017.

The Bentham DM150 UV spectroradiometer in Reading is regularly calibrated in situ with reference to the irradiance standards held at the University of Manchester calibration laboratory.

At least one of the BAS Dobson instruments in Antarctica is scheduled for recalibration at Hohenpeissenberg in 2017. It is planned to then exchange this with the Dobson currently at the Vernadsky station.

PHE's solar network (12 sites) and spectral systems at Chilton are regularly calibrated in situ.

In 2012 in situ calibrations were undertaken with Physikalisch-Meteorologisches Observatorium Davos World Radiation Center (pmod wrc) for the ISA-Jobin Yvon-Spex D3 180 Series scanning spectroradiometer, Bentham DMc150 double Monochromator and an APSUS.

In 2014 the APSUS visited pmod wrc in Davos to take part in an intercomparison as part of the traceability for surface spectral solar ultraviolet radiation (EMRP ENV03) project.

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

2.1 Column ozone

Data from the ozone column measurements at Lerwick, Manchester and Reading is published by the UK Government here: https://uk-air.defra.gov.uk/data/ozone-data.

UV data is viewable from the PHE solar network and from Manchester/Reading here: https://uk-air.defra.gov.uk/data/uv-index-graphs. Data is also available on request from PHE (solar@phe.gov.uk), while Reading and Manchester data is available here: https://uk-air.defra.gov.uk/data/uv-data.

Trends analysis of the measurements suggests that as of the start of 2015, the long-term decline in column ozone over the UK has not yet been reversed. The long-term (since 1978) autumn decline is significant for single and multiple regression. It is difficult to explain enhanced ozone loss prior to the cold season of polar stratospheric cloud formation. However, the principal component analysis confirms that the most likely cause of the autumn trend is tropospheric circulation changes. In Smedley et al (2010) (Int. J. Climatol., doi:10.1002/joc.2275) the Reading ozone series was homogenised with older records to create a southern UK time series extending back to 1979.

Site (ordered south to north)	Annual mean [DU]	1979-1994 annual linear trend [%/yr]	Significance of 1979-1994 annual linear trend [%]	Post-1994 annual linear trend [%/yr]	Significance of post-1994 annual linear trend [%]	Recent decadal trend
Southern UK / Reading	330.0	**-0.42**	**99.86**	+0.17	87.44	+0.26
Manchester	335.7	N/A	N/A	+0.05	0.00	+0.33
Lerwick	337.8	**-0.53**	**98.30**	+0.15	39.23	+0.00

Notes:

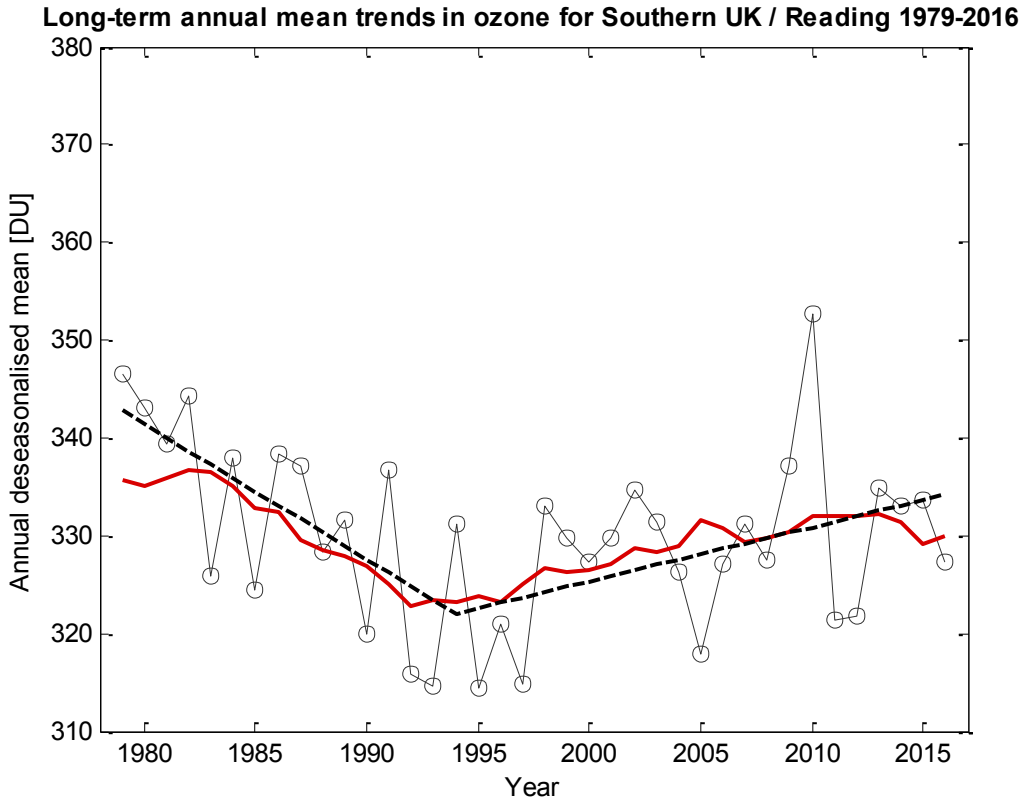
These trend analyses are updated versions of those described in Smedley et al (2010), Int. J. Clim.

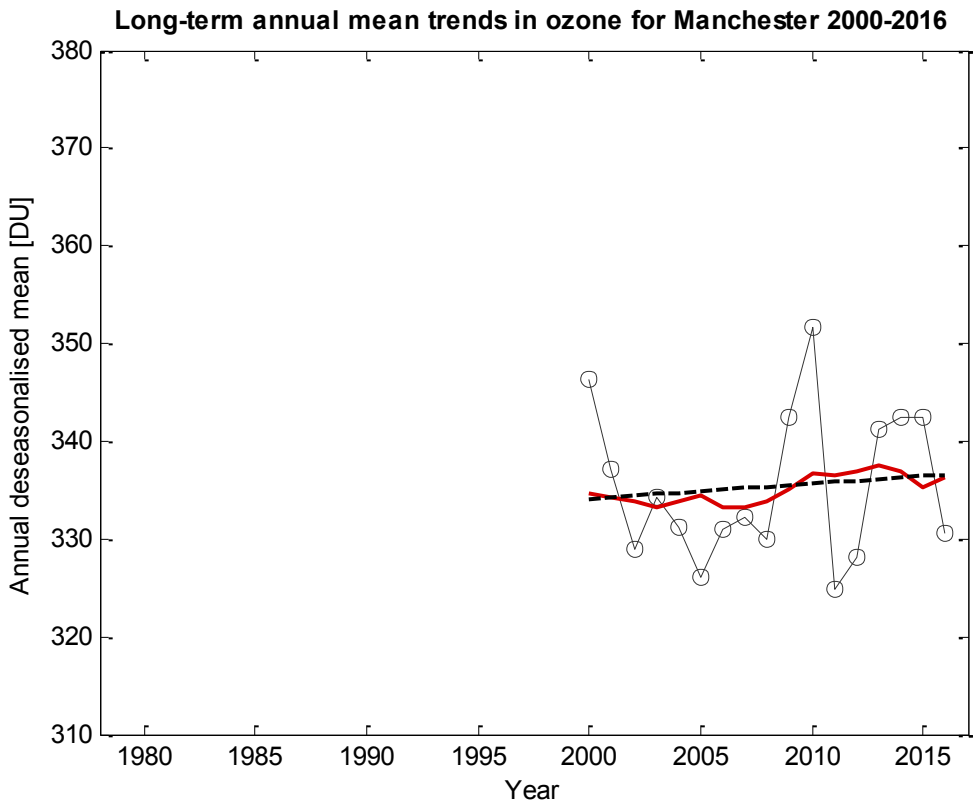
Annual means are annual deseasonalised values i.e. taking account of the observed climatology.

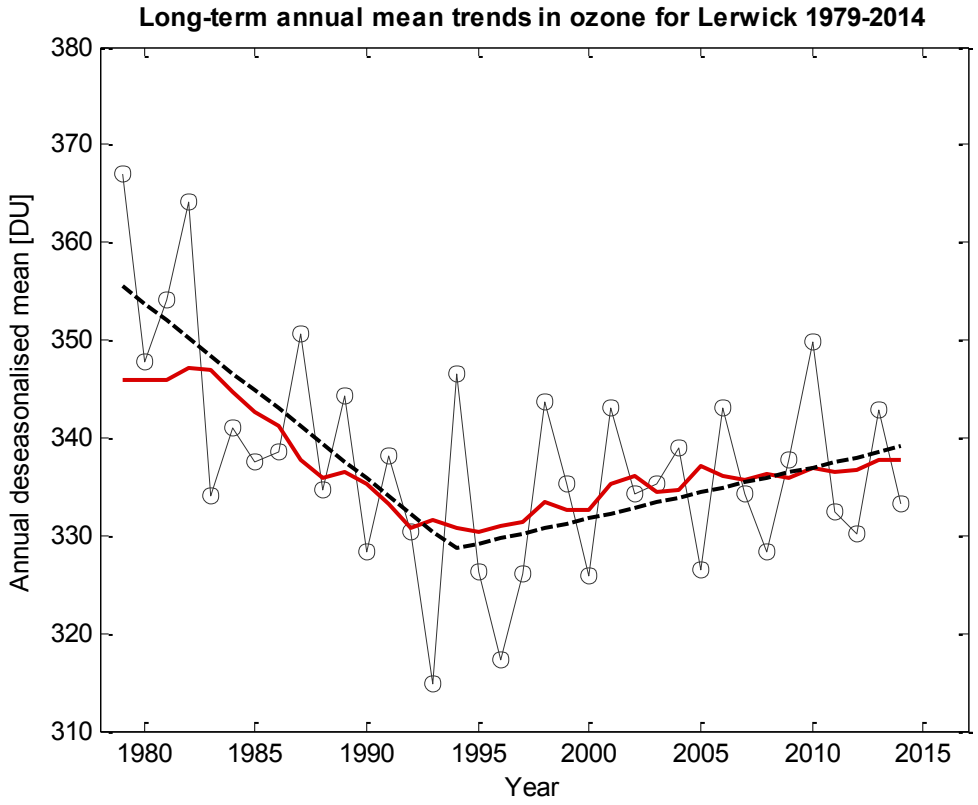
A breakpoint is assumed to occur at 1994, and two-part linear trends are calculated on this basis for the Southern UK / Reading and Lerwick data series.

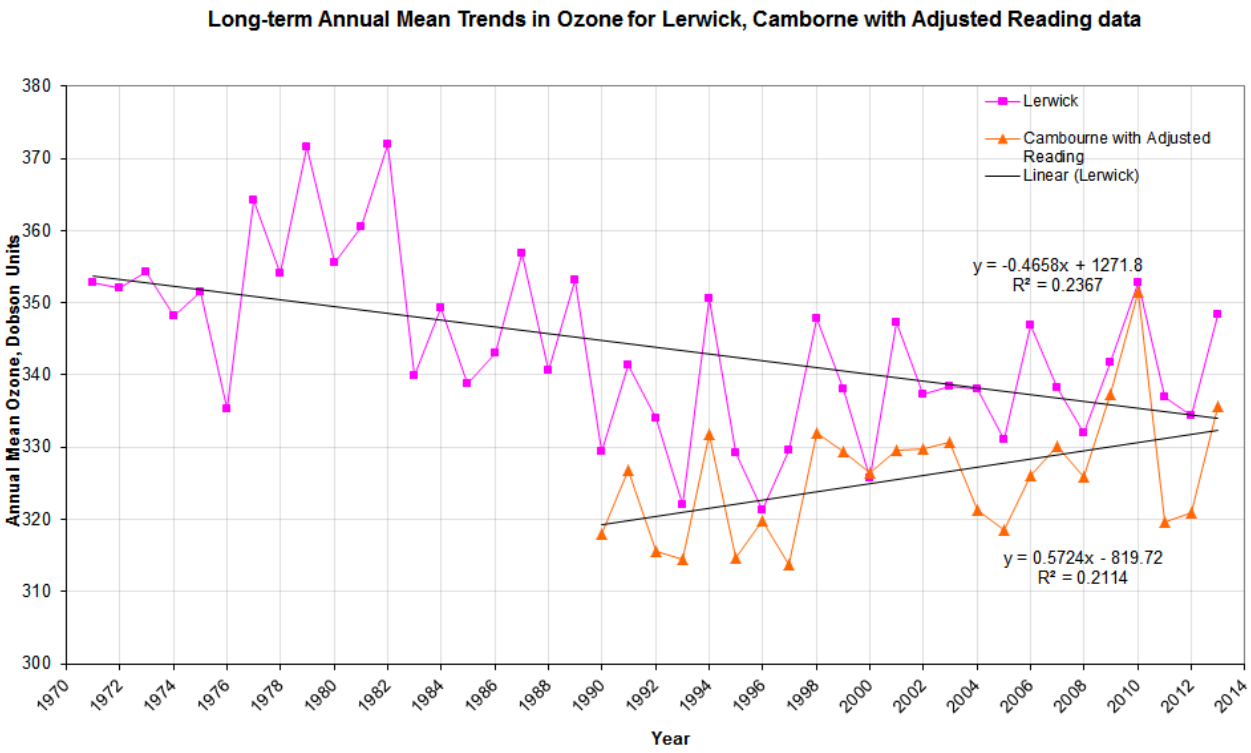
Lerwick data uses the most up to date showing on WOUDC at the time of writing (24 January 2017).

Significant trends at the 5% level are highlighted in bold. Only trends during ozone depletion are significant and none of the three sites yet shows statistical significant signs of recovery.




Long-term annual mean trends in ozone for Manchester 2000-2016
Annual deseasonalised mean [DU]
380
370
360
350
340
330
320
310
1980
1985
1990
1995
2000
2005
2010
2015
Year


Long-term annual mean trends in ozone for Lerwick 1979-2014
Annual deseasonalised mean [DU]
380
370
360
350
340
330
320
310
1980
1985
1990
1995
2000
2005
2010
2015
Year

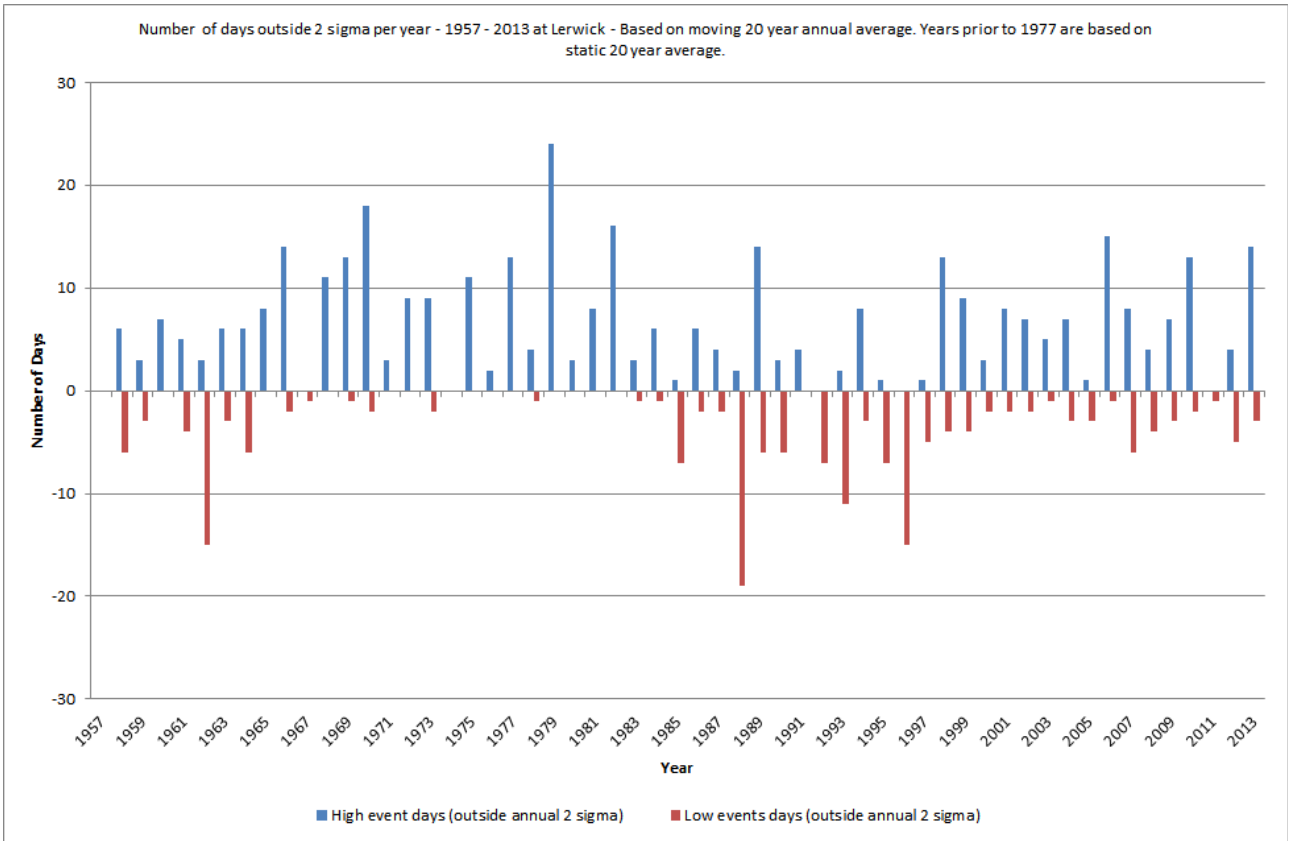


Column ozone trend in Dobson Unit (DU) per year with standard errors. Numbers in bold are significant at the 95% confidence level (P<0.05) SR: single regression; MR: multiple regression. Lerwick since 1978 and Reading since 2003.

Site	Annual[1] (to 2013)	Winter[2] (DJF) (to 2014)	Spring (MAM) (to 2014)	Summer (JJA) (to 2014)	Autumn (SON) (to 2013)
Lerwick -SR	**-0.51** +/- 0.18	-0.06 +/- 0.48	**-0.73** +/- 0.25	-0.14 +/- 0.13	**-0.47** +/- 0.18
Lerwick- MR	**-0.43** +/- 0.18	-0.05 +/- 0.48	**-0.52** +/- 0.22	-0.13 +/- 0.12	**-0.35+/-**0.16
Reading –SR	+0.79 +/- 0.95	+1.68 +/- 1.83	+0.24 +/- 1.08	+0.51 +/- 0.50	+0.85 +/- 1.03
Reading –MR	-0.17 +/- 0.97	**-**1.05 +/- 1.33	+0.28 +/- 0.93	+0.34 +/- 0.53	0.00 +/- 0.65

Low ozone events, defined as a departure of more than two standard deviations below the long-term monthly mean, are reported in near real-time. The graph below shows the number of high and low ozone events recorded at Lerwick between 1957 and 2013. Low ozone events from 2014 onwards for Lerwick, Manchester and Reading are recorded in the table below.

[1] Annual is to 2012 only
[2] Winter (DJF) season includes December of preceding year e.g. winter 2013 is December 2012 to February 2013.



Days that meet the Low Ozone Event criteria since Jan 2014

Lerwick	Manchester	Reading
	30-Nov-16	
		26-Nov-16
	28-Oct-16	28-Oct-16
	28-Sep-16	28-Sep-16
		16-Jul-16
01-Jun-16		
		13-Mar-16
		11-Mar-16
29-Feb-16		29-Feb-16
28-Feb-16		
27-Feb-16		
26-Feb-16		
		31-Jan-16
		04-Mar-15
		16-Mar-14
		06-Mar-14

Data from Halley in the Antarctic show that there is now a statistically significant increase in the springtime minimum amount of ozone seen at the station.

2.2 Ozone depleting substances

With respect to atmospheric quantities of ozone depleting substances (ODS), global measurements have notably focussed on 'new' halocarbon threats to stratospheric ozone. UEA scientists use a 2-D global model to reproduce the observed long term trends in global background concentrations of ODS and replacement compounds to determine "top-down" global emissions of these compounds. Together, these have shown non-zero emissions of CFC-112, -112a, -113a, -114, -114a, -216ba, -216ca and HCFCs-133a and -225ca. Some of

these are also increasing in abundance in the atmosphere, notably CFC-113a and HCFC-133a. Continued emissions of CFCs are not expected under the terms of the Montreal Protocol except where uses are exempted, or arise from banks, or are fugitive emissions of intermediate substances. The origins of the majority of these gases are poorly known. Few have published emissions estimates, and in most cases the "top-down" global estimates from modelling of observations do not agree with the inventory-based ("bottom-up") estimates. There are some surprising observations. For example, there are plainly separate sources for some of the isomers such that, for instance, emissions of CFC-113a are evidently continuing, while those of CFC-113 have largely ceased. Also notable are large swings in emissions of HCFC-133a over the space of just a few years.

UK monitoring of ODS in East and SE Asia (Taiwan and Malaysia) has revealed substantial emissions of halocarbons in the region, including some of the 'new' gases mentioned above. Of special note are very high abundances of chlorinated 'very short-lived substances' (VSL-Cl) emanating from East Asia, particularly dichloromethane (CH_2Cl_2), 1,2-dichloroethane (CH_2ClCH_2Cl), trichloromethane ($CHCl_3$) and tetrachloroethene (C_2Cl_4). These VSLS species are not controlled by the Montreal Protocol. Evidence has been found for a fast transport pathway between these source regions in mid latitudes and the upper tropical troposphere during 'cold-surge' conditions associated with the winter monsoon. Taken together with evidence from aircraft measurements made in the upper troposphere in SE Asia, this suggests that these (anthropogenic) VSL-Cl gases may contribute as much equivalent chlorine to the stratosphere as (largely natural) VSL-Br gases.

Measurements of global abundances of all significant ODS, as well as replacement species (HFCs) and related halocarbons continue at Cape Grim, Tasmania (and elsewhere) and will be reported as updates to the trends for publication in the next WMO Scientific Assessment of Ozone Depletion.

3. THEORY, MODELLING AND OTHER RESEARCH

Since the last report for the 9th Ozone Research Manager's meeting, the University of Manchester has undertaken a range of research on ozone and UV. Details are included in section 4.3 below.

PHE's current research includes: modelling of the estimation of sun exposure of children in day care nurseries; on-going research on personal dosimetry of recreational activities with a proportion of this work in collaboration with the "Institute for Occupational Safety and Health" (IFA), Germany; continued research into the UV exposure of commercial pilots in collaboration with the Civil Aviation Authority (CAA) and Monarch Airlines.

PHE is currently working in conjunction with SiHealth / FlyBy on the development of a smartphone app for personalised guidance on UV exposure using real-time satellite data.

4. DISSEMINATION OF RESULTS

4.1. Data reporting

The ozone monitoring data from Lerwick, Reading, Manchester and Aberystwyth is processed daily and quality checked by comparison with Ozone Monitoring Instrument (OMI) satellite measurements, the nearest ground-based measurements and previous ozone climatology. Results are supplied to the WOUDC Real-time mapping centre and University of Thessaloniki. The Brewer data from Manchester and Reading is also automatically transferred to the new EuBrewNet NRT database. The data is also published on the internet at http://uk-air.defra.gov.uk/research/ozone-uv for the wider research community.

Both total ozone, multi-filter UV data from the Manchester site and spectral UV data from Reading are submitted regularly to the WOUDC. Ozone data from Aberystwyth is additionally submitted to NDACC.

Level 0 and Level 1 Dobson ozone data from the Halley and Vernadsky stations in Antarctica are submitted to the WOUDC by the BAS. Observations are reported in real-time using CREX (Character form for the Representation and EXchange of data) on the Global Telecommunications System (GTS) from Halley, Rothera and Vernadsky. Quality controlled ozone observations are submitted by BAS to the WMO on a regular basis.

4.2 Information to the public

Ozone monitoring results from the Lerwick, Reading, Manchester and (no longer operational) Camborne sites are publically available at http://uk-air.defra.gov.uk/research/ozone-uv/. Real time broadband UV Index graphs are also published on that site at this address: https://uk-air.defra.gov.uk/data/uv-index-graphs. Public health messages continue to be issued in collaboration with Defra and the UK Met Office at times of higher than expected levels of UV Index. Data from the Antarctic stations, and assessments about the ozone hole are available at https://legacy.bas.ac.uk/met/jds/ozone/index.html

4.3 Relevant scientific papers

Below is a list of scientific papers led by or involving UK organisations, published since the last Ozone Research Managers meeting in 2014.

Klekociuk et al.. *Australian Meteorological and Oceanographic Journal* (2015) 65:2 The Antarctic Ozone Hole during 2013.

Klekociuk et al.. *Australian Meteorological and Oceanographic Journal* (2014) 64:4 The Antarctic Ozone Hole during 2012.

Klekociuk et al.. *Australian Meteorological and Oceanographic Journal* (2014) 64:4 The Antarctic Ozone Hole during 2011.

McKenzie R., Blumthaler M., Diaz S., Fioletov, V.E., Herman J.R., Seckmeyer G., Smedley A.R.D., Webb A.R. (2014) Rationalizing nomenclature for UV doses and effects on humans. *CIE 209:2014 and WMO-GAW Report No. 211 Joint Publication*

Russell A., Gohlan M., Smedley A.R.D., Densham M. (2014) The ultraviolet radiation environment during an expedition across the Drake Passage and on the Antarctic Peninsula. *Antarctic Science* 27(03), 307-316. doi:10.1017/S0954102014000790

- Polysulphone badges calibrated against University of Manchester instruments were used to assess UV doses during a British Services Antarctic Expedition to the Antarctic peninsula.

Walmsley L., Hanna L., Mouland J., Martial F., West A., Smedley A., Bechtold D., Webb A., Lucas R. and Brown T. (2015) *Colour As a Signal for Entraining the Mammalian Circadian Clock.* PLoS Biol 13(4), e1002127. doi: 10.1371/journal.pbio.1002127

- Here we relied on spectral UV and visible measurements at Manchester to reveal a new biological mechanism for entraining the circadian clock. In other words it is primarily the spectral balance of light, not the absolute level that the body uses to detect twilight and adjust the internal clock (feat. on BBC and other media outlets)

Kazantzidis A., Smedley A.R.D., Kift R.C., Rimmer J.S., Berry J.L., Rhodes L.E., Webb A.R. (2015) A modeling approach to determine how much UV radiation is available across the UK and Ireland for health risk and benefit studies. *Photochem. Photobiol. Sci.* 14(6), 1073-1081.

- This study produced a detailed map of the available spectral UV across the UK, which in turn is used to calculate weighted doses of erythema, DNA damage and vitamin D.

Manchester and Reading data from 2003 to 2012 is used to validate the model. The model has since been used for several UV effects studies across UK and Europe.

Smedley A. R. D., Kift R. C., Webb A. R. (2015) Assessment of a dual-channel array spectrometer for ground-based ozone retrievals. *J. Atmos. Ocean. Tech.* 32(8), 1464-1477.

- This paper describes the development of a new array-based instrument for measuring simultaneous direct and global spectral irradiance, with a focus on longer-term ozone retrievals. Relied upon data from the Brewer spectrophotometer at Manchester for validation of results.

Egli L., Gröbner J., Hülsen G., Bachmann L., Blumthaler M., Dubard J., Kahazova M., Kift R., Los A., Perez A.S., Smedley A.R.D. and Vilaplana J.-M. (2016) Quality assessment of solar UV irradiance measured with array spectroradiometers. *Atmos. Meas. Tech.* 9, 1553-1567. doi:10.5194/amt-9-1553-2016

- A related study to Smedley et al (2015) as part of the EMRP funded SolarUV project to assess independent measurements of UV irradiance produced by array spectroradiometers.

Zerefos C.,Eleftheratos K., Kapsomenakis J., Solomos S., Inness A., Balis D., Redondas A., Eskes H., Amiridis V., Repapis C., Allaart M., Engelmann R., Dahlback A., De Bock V., Diémoz H., Eriksen P., Gröbner J., Heikkilä A., Jarosławski J., Josefsson W., Karppinen T., Köhler U., Meleti C., Rimmer J., Savinykh V., Shirotov V., Siani A.M., Smedley A., Stanek M., and Stübi R. (2017) Detecting volcanic sulfur dioxide plumes in the Northern Hemisphere using the Brewer spectrophotometers, other networks, and satellite observations, *Atmos. Chem. Phys.*, 17, 551-574, doi:10.5194/acp-17-551-2017.

- Data from both UK Brewers was used as part of a European collaboration for detection of the sulphur dioxide plume from recent volcanic eruptions (which notably can diverge from the ash plume).
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Petkov B, Vitale V, Tomasi C, Siani AM, Seckmeyer G, Webb AR, Smedley ADR et al (2014) Response of the ozone column over Europe to the 2011 Arctic ozone depletion event according to ground-based observations and assessment of the consequent variations in surface UV irradiance. *Atmospheric Environment* 85; 1769-1778

- Data from Reading site used (with other ground based systems) to assess a low ozone event.

In progress: studies on improving the representativeness of reported daily ozone values from Brewer spectrophotometers and a second study looking at differences between low wintertime Vitamin D (UV induced) exposure in Europe vs New Zealand.

Hooke R., Pearson A., O'Hagan J., Autonomous portable solar ultraviolet spectroradiometer (APSUS) - a new CCD spectrometer system for localized, real-time solar ultraviolet (280-400 nm) radiation measurement. Photochem Photobiol. 2014 Jul-Aug; 90(4):903-10. doi: 10.1111/php.12251. Epub 2014 Mar 10.

Baczynska, K. A., Khazova, M., Methods of dark signal determination for CCD array spectroradiometers used in solar UVR measurements Radiat Prot Dosimetry (2015) 163 (3): 387-393 first published online June 10, 2014 doi:10.1093/rpd/ncu191

Chorley A1, Higlett M, Baczynska K, Hunter R, Khazova M., Measurements of pilots' occupational solar UV exposure. Photochem Photobiol. 2014 Jul-Aug;90(4):935-40. doi: 10.1111/php.12269.

Price, L. L. A., Hooke, R., Khazova M., Effects of ambient temperature on the performance of CCD array spectroradiometers and practical implications for field measurements. J Radiol Prot. 2014 Sep;34(3):655-73. doi: 10.1088/0952-4746/34/3/655. Epub 2014 Aug 13.

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5. PROJECTS, COLLABORATION, TWINNING AND CAPACITY BUILDING

In our report to the 9th Ozone Research Managers meeting, we reported on the following activities:

The UK Met Office

Assessments of polar ozone loss, low ozone events in the southern summer stratosphere and the impact of stratospheric ozone on extended range tropospheric forecasts.

Co-leadership of the World Climate Research Programme Stratospheric Processes and their Role in Climate WCRP SPARC Data Assimilation Working Group.

Modelling of stratospheric and tropospheric ozone and their relationship to long- and near-term climate change.

Participation in the WCRP's SPARC Chemistry-Climate Modelling Initiative (CCMI) which coordinates the evaluation of stratospheric ozone recovery and its interaction with climate-change.

Development of the whole-atmosphere chemistry and aerosol model which has enabled the role of ozone and aerosols in climate change to be more accurately assessed.

Loan of Dobson #35 to the South African Weather Service.

The Natural Environment Research Council

Screening the atmosphere for unknown halocarbons to determine their influence on ozone depletion.

Predictions of future climate change to take account of uncertainty in future ozone change, focussing on the southern hemisphere and the Antarctic ozone hole.

A study on the influences of solar variability on atmospheric composition and climate.

The Co-ordinated Airborne Studies in the Tropics (CAST) project to study the Tropical Tropopause Layer over the Pacific and South East Asia, to improve knowledge of the budgets of very short-lived halogen species and of their chemical transformation and transport in order to improve representation of these processes in global chemistry/climate models.

The impact of the representation of ozone on tropospheric weather forecasts.

Multi-scale modelling of mesospheric metals, and the impact of the mesosphere on stratospheric ozone and climate.

Interactions of the lower stratosphere with the tropospheric chemistry/climate system.

Producing a century-long record of trace gases in the northern hemisphere from the North Greenland EEMian ice core drilling project in Greenland.

Determining the impact of energetic electrons on polar stratospheric ozone.

The University of Cambridge

Co-chair of the Montreal Protocol's Scientific Assessment Panel and contribution to the SAP's reports.

Since the 9th ORM, the following additional activities have taken place:

University of Manchester

Chairing and managing the EUBREWNET project, funded by the European COST Office, to bring all the European Brewer Ozone Spectrophotometer stations together in a formal network. The project, which is due for completion in 2017, will integrate, automate and improve the consistency of Brewer ozone, UV and aerosol optical depth measurements by employing central data processing and QA/QC in a new NRT database, which will add significantly to the scientific value of the data and help cut the cost of future monitoring. EUBREWNET has expanded from its original scope of European sites and now includes stations in South America, Australia, North Africa, Alaska and will shortly include Antarctica, with discussions underway to include the NOAA network. This will lead to a fully functioning global network which will help to restore the capacity required for authentic satellite validations. More information is available at: http://www.eubrewnet.org/cost1207/

Development of an ozone monitoring training programme for analysts in Asia, building capacity in various A5 countries to monitor stratospheric ozone and climate interactions.

Participation in the EMRP funded SolarUV project, culminating in an international intercomparison in 2014. The focus of the project was spectral UV from array spectroradiometers, but the University of Manchester contribution was also directed towards deriving total ozone column from these measurements – in turn ozone measurements are a focus for the follow up European ATMOZ project.

Public Health England

PHE's current research includes personal dosimetry of recreational activities with a proportion of this work in collaboration with the "Institute for Occupational Safety and Health" (IFA), Germany.

Research into the UV exposure of commercial pilots in collaboration with the Civil Aviation Authority (CAA) and Monarch Airlines.

Working in conjunction with SiHealth/FlyBy on the development of a smartphone app for personalised guidance on UV exposure using real-time satellite.

University of Reading

Co-Chair of the IGAC/SPARC Chemistry-Climate Modelling Initiative (CCMI), which coordinates the evaluation of chemistry-climate models to foster our understanding of the interactions between climate change, air pollution, and stratospheric ozone depletion/recovery.

Co-Lead of the SPARC Data Initiative, which carried out a comprehensive assessment of ozone measurements (alongside other species involved in stratospheric ozone chemistry) from an international suite of satellite limb sounders. The results will be published in spring 2017 in a SPARC report, published as a WMO-WCRP technical report.

Steering Committee Member for the WMO/UNEP Scientific Assessment of Ozone Depletion 2014.

Lead Author (also design and print) of the WMO/UNEP 20 Questions and Answers about the Ozone Layer: 2014 Update: see http://www.esrl.noaa.gov/csd/assessments/ozone/2014/twentyquestions2014update.pdf

Co-author and contributing author to chapter 2 of the WMO /UNEP Scientific Assessment of Ozone Depletion 2014.

Reviewers for chapters 4 and 5 of the WMO /UNEP Scientific Assessment of Ozone Depletion 2014.

Development of a historical and future ozone forcing database in support of CMIP6/IPCC AR6. This work provides a model-based timeseries of stratospheric and tropospheric ozone between 1850 and 2100 for use in global climate models without interactive chemistry.

University of East Anglia

Measurement of a comprehensive suite of ODS and related gases at a tall tower in the south of England as part of a UK inventory validation activity led by the University of Bristol and the UKMO

UEA/CSIRO/NCAS Cape Grim sampling programme recording and modelling long term trends of ODS in the Southern Hemisphere

UEA/Max Planck Institute/NCAS CARIBIC ongoing aircraft programme of ODS measurement in the global upper troposphere

UEA/University of Malaya/NCAS/University of Cambridge: ODS and related gases transported across the South China Sea to the tropics

UEA/Academia Sinica/National Central University Taiwan: ODS and related gases monitoring in air flow out of eastern China

UEA/EU multi-party consortium: reconstruction of historic ODS trends from deep Greenland and Antarctic snow

UEA/NERC Advanced Research Fellowship on forensic innovations to constrain greenhouse trace gas budgets (including ODS).

UEA/ERC Starting Grant to explore stratospheric chemistry, composition and circulation over 4 decades using air archives and the first use of the novel AirCore technique to measure ODS

UEA investigators contributed to the writing and review of both the 2014 WMO Scientific Assessment of Ozone Depletion and also the WCRP/SPARC Lifetimes of Stratospheric Ozone-Depleting Substances, Their Replacements, and Related Species (SPARC Report No. 6, WCRP-15/2013) dated 2013 but available in 2014

British Antarctic Survey

Loan of Dobson #123 to the Ukrainian Antarctic Centre

6. IMPLEMENTATION OF THE RECOMMENDATIONS OF THE 9th OZONE RESEARCH MANAGERS MEETING

The recommendations from the 9th ORM are listed in bold below along with any relevant action undertaken by UK organisations.

6.1 Research needs

Joint observations of climate and ozone layer variables: The EuBrewNet project, managed by University of Manchester, includes AOD(UV) as well as ozone and UV. The AOD is an important factor in radiation budget.

Capacity building to expand scientific expertise in developing countries: The EuBrewNet project holds regular training courses for Brewer operators and managers. WMO support is arranged for participants from A5 countries. Courses so far: Tenerife 2014, Edinburgh 2016 and planned Sydney 2017.

Capacity building at a new monitoring observatory on the east coast of Malaysia (UN WMO is a partner) including training of a technician, provision and calibration of equipment and analysis of collected sample (UEA/NCAS/University of Cambridge/University of Malaya).

Capacity building at a new monitoring station in Taiwan (Cape Fugue): measurement of ODSs in collected samples (UEA/NERC/ Academia Sinica/National Central University Taiwan)

The coupling of ozone, atmospheric chemistry and transport, and climate changes: McLandress et al. (2015) used chemistry-climate model simulations with an interactive ocean to provide the first GCM estimate of the climate impact of ozone-depleting substances over the last 50 years. Halocarbons have an even greater climate role, relative to CO2, in the upper troposphere than they do for surface warming, and the feedback on tropical lower stratospheric ozone from strengthened tropical upwelling significantly reduces the stratospheric water vapour feedback from climate change.

Checa-Garcia et al. (2016) used a simple global-mean energy balance model to quantify the contributions of trends in different greenhouse gases and in particular in ozone-depleting substances to the recently observed hiatus in global mean surface temperature. The results highlight that the efforts of the Montreal Protocol to control ozone-depleting substances (which are also strong greenhouse gases) have not only protected the ozone layer but also led to a discernable contribution to the recent slowdown in global warming.

Simulations of future ozone changes using chemistry climate models (CCMs): The IGAC/SPARC CCMI activity (co-led by M. I. Hegglin at the University of Reading) has performed a coordinated set of chemistry-climate simulations at 20 international partner institutions around the world, in support of the next WMO/UNEP Scientific Assessment of Ozone Depletion 2018 and the next IPCC climate assessment 2020. The activity (see also short description above) aims at the evaluation of chemistry-climate models using observation-based, process-oriented diagnostics, with help of which model shortcomings can be identified and model development can be supported. A current overview of the participating models is given in Morgenstern et al. (2017).

Research, combining CCMs and reference quality, altitude-resolved data records in order to explain past changes: Shepherd et al. (2014) combined a nudged CCM with reference-quality, altitude-resolved stratospheric ozone records from the SPARC Data Initiative to explain past changes in total column ozone. In the SH, the halogen-induced loss after the Mt Pinatubo volcanic eruption was masked by transport, hence not evident in the column ozone record. Long-term stratospheric ozone depletion in the tropics is consistent with the very weak decline seen in tropical total column ozone, because of tropospheric ozone increases.

Resolving the apparent inconsistency between model projections of an increasing strength in the Brewer Dobson Circulation (BDC) and observations of long-lived trace gases in the stratosphere, which suggest a slowing of the BDC: Hegglin et al. (2014) introduce a new merging technique for climate data records using a model driven by observed meteorology as transfer function between satellite observations, highlighting the benefit of the synergistic use of observations and models. The new climate data record and its relation to physical drivers helped resolving a long-standing conundrum around stratospheric water

vapour trends. In addition, it reveals that past BDC changes show a distinct vertical structure and decadal variation, however, with a long-term slowing observed in the upper stratosphere and a fastening in the lower stratosphere, reconciling apparent inconsistencies between earlier observational results.

Development of the utility of long-lived halocarbon tracers (e.g. perfluorocarbons) with which to determine stratospheric age of air along with measurements from the Geophysica stratospheric aircraft (work on polar and mid-latutidinal flights already undertaken; flights in the subtropics planned as part of the EU Stratoclim project).

Improved, long-term data records of stratospheric ozone, other trace gases associated with ozone chemistry (e.g., HNO3, ClO, BrO, H2O, CH4, N2O) and other atmospheric state variables (e.g., temperature) to aid the interpretation of the causes of long-term changes in ozone: In progress is a UoM study looking into a more representative calculation of daily ozone column from existing Brewer datasets, which feeds into long-term data records and trend assessments.

The SPARC Data Initiative (co-led by Michaela I. Hegglin at the University of Reading) has conducted a comprehensive assessment of the quality and representativeness of stratospheric observations from a suite of 18 international limb satellite sounders (SPARC, 2017; also Tegtmeier et al., 2016). The evaluations encompassed 25 chemical trace gas species, including ozone and other long-lived greenhouse gases (such as N_2O, H_2O, methane, and CFCs) and shorter-lived species involved in stratospheric ozone depletion (NO_x, ClO, $ClONO_2$, and BrO). The results deliver key information on data quality needed for the production of climate data records, and also provide guidance for future measurements needs. An intercomparison of the datasets in the upper troposphere/lower stratosphere by Neu et al. (2014) thereby highlighted the large uncertainties in our knowledge of the atmospheric state of chemical variables in this region.

A temperature climate data record of the free troposphere and stratosphere to interpret the interactions between changes in the thermal structure of the atmosphere and changes in ozone and support the construction of ozone data records: McLandress et al. (2015) proposed a novel method of using vertically resolved temperature records from limb sounders to merge the global-mean temperature records of deep atmospheric layers provided by the nadir sounders. This allowed the merger of the historical SSU record with the more recent AMSU record, providing a 35-year time series which was shown to be consistent with simulations from CCMs. The impact of ozone recovery on the global-mean temperature record was also demonstrated.

Better quantification of trends in vertically resolved ozone data records in different regions of the atmosphere, particularly polar regions: Umkehr measurements are made routinely at Manchester and Reading. In time these will enable better quantification of vertically resolved ozone trends.

Detailed analysis of trends in ozone and associated trace gases to assess whether their observed evolution is consistent with our understanding of the process affecting trends and variability: Shepherd et al. (2014) used a nudged CCM to show that the observed evolution of both stratospheric and total column ozone over the observed record is consistent with observed meteorology and our understanding of ozone chemistry as reflected in atmospheric models. In particular, halogen-induced stratospheric ozone loss was shown to closely follow halogen loading, with pronounced enhancements following the El Chichon and Mt Pinatubo volcanic eruptions. A discernible recovery of global ozone is underway since halogen loading peaked in the late 1990s.

Continuing measurements of long term trends in ODSs and related gases, notably at Cape Grim, Tasmania and also from firn records, coupled with stratospheric profile measurements from the Geophysica aircraft. This combination is allowing Fractional Release Factors (FRF), stratospheric lifetimes, Ozone Depletion Potentials (ODPs), and Equivalent Effective

Stratospheric Chlorine (EESC) to be determined for a number of important known and newly-observed ODS.

Understanding of the surface emissions of very short-lived substances to the transport and transformation of species moving between the troposphere and stratosphere: UEA/University of Nottingham, Malaysia: modelling study using NAME to investigate the potential rapid transport of short-lived chlorocarbons from source regions in East Asia to the lower TTL (tropical tropopause layer)

Further investigation of the role played by gases not controlled under the Montreal Protocol (e.g., N2O, CH4 and biogenic bromocarbons), including improved emissions databases of CH4 and N2O: UEA have contributed data (CARIBIC/SHIVA) to several modelling studies looking at the budgets (sources) and atmospheric degradation of very short-lived bromocarbons (see publication list).

Several papers on Br-VSLS (see above)

Reconciling changes in atmospheric concentrations of ODS replacements with known emissions and atmospheric lifetimes: First global long-term trends and emissions of the fourth-most abundant CFC in the atmosphere (i.e. CFC-114) where the influence of its isomer CFC-114a has been separated

Disaggregation of the factors affecting UV radiation at the surface so that the influence of factors other than ozone (e.g., cloud cover, aerosol abundance, albedo, and temperature) can be better assessed: A manuscript is in preparation with colleagues from Germany and New Zealand looking at differences between low wintertime Vitamin D (UV induced) exposure in Europe vs New Zealand, the principal cause of which is the higher levels of cloudiness in Europe.

6.2 Systematic observations

Expanded monitoring to new species and parameters, including the upper troposphere and lower stratosphere, troposphere to stratosphere exchange in the tropics and monsoon circulations, the polar caps and the upper stratosphere. In particular, measurements of the vertical distribution, especially in the UTLS region and in the upper stratosphere: Expansion of monitoring of ODS in East and SE Asia has revealed substantial emissions of halocarbons in the region. This provides evidence for a fast transport pathway between source regions in mid latitudes and the upper tropical troposphere (stratospheric gateway). The monitoring has identified high levels (and increasing concentrations) of short-lived anthropogenic chlorocarbons not currently controlled by the Montreal Protocol.

Continuation of stratospheric aerosol measurements: Brewer AOD measurements continue with improved algorithms from EuBrewNet. There are ongoing measurements at Cambridge, Halley and Rothera with a POM

Increased monitoring of N2O, CH4 and water vapour to understand their changing fluxes, and better assess their impacts: Weybourne measurements of GHGs. Programme of long-term measurements of CH_4 on-going at Halley, and measurements on Falkland Islands and JCR, initiated by Royal Holloway University of London, are now being done by BAS. These observations are part of a much larger UK methane project led by Prof Euan Nisbet, RHUL.

Inclusion of emerging ODS substitutes in the baseline monitoring programmes and analysing existing archives for historic estimates of atmospheric burdens of such gases: Several papers on new halocarbons including CFC-112, -112a, -113a, HCFC-133a, HFC-227ea, etc. and a range of ultra-long-lived perfluorocarbons (age tracers and associated with ODS production in some cases).

Monitoring of temperature and trace-gas profiles, especially of dynamical tracers like N2O and SF6, and of ozone and water vapour in the UTLS to inform the connection between ozone and climate change, and the expected changes in the mean meridional Brewer-Dobson circulation. Measurements of SF_6, perfluorocarbons and ODSs in the stratosphere from the Geophysica.

Evaluation of new cost effective instruments for deployment in the networks: EMRP funded array-based instrument development for ozone retrievals in "SolarUV" campaign. Also Kipp and Zonen bv collaboration with University of Manchester for solid state instrument development (PhD studentship).]

3 year program of ODS measurements in the stratosphere using a cost-efficient weather balloon-based new platform (AirCore).

6.3 Data archiving and stewardship

Development of robust automated data submission with centralised processing and QA schemes to ensure timely submission: The EUBREWNET project will integrate, automate and improve the consistency of Brewer ozone, UV and aerosol optical depth measurements by employing central data processing and QA/QC in a new NRT database.

Long-term data archiving and preservation: The Dobson ozone observations from King Edward Point (South Georgia), Halley and Vernadsky back to 1972 are being re-evaluated, with individual ozone measurements now available on the BAS web page. Further re-evaluation is in progress.

6.4 Capacity-building

Provide training courses for station operators in developing countries: The EuBrewNet project holds regular training courses for Brewer operators and managers. WMO support is arranged for participants from A5 countries. Courses so far: Tenerife 2014, Edinburgh 2016 and planned Sydney 2017. The Sydney course is aimed specifically at the A5 countries in the Asia-Pacific region.

Establish fellowships for students from developing countries: UEA is currently hosting a PhD student funded by the Malaysian Government. The student is being training in the use of models to determine global emissions of long-lived ODS and regional sources of ODS, including VSL-Cl, in E and S.E. Asia.

Maintain the quality of the WMO/GAW global ozone observing system through the continuation and expansion of regular calibrations and intercomparisons: EuBrewNet is integrated with the Regional Brewer Calibration Centre – Europe (RBCC-E). Halley is now a GAW Global Station

6.5 General Trust Fund

UK experts have participated in the working group to develop a strategic plan for improving the effectiveness of monitoring and research under the Trust Fund.

7. FUTURE PLANS

Upgrade and commissioning of a new Spectral UV spectroradiometer at Chilton, UK

Development of prototype for next generation broadband detector to be used for the PHE solar network.

Development of prototype for a full range spectral system with the aim of potentially extending the solar network.

Upgrading of the Solys2 Sun Tracker at Chilton to measure the global and diffuse component on the horizontal plane with a full range spectral system.

Larger personal dosimetry studies of exposure to UV in recreational activities by members of the public as well as the exposure of pilots.

Analysis of long term UV variations for all solar network sites

Participation in the International UV Filter Radiometer comparison which is hosted by Physikalisch-Meteorologisches Observatorium Davos World Radiation Center (pmod wrc) in Davos in the summer of 2017.

Halley station is being shut down over the 2017 winter, and no observations of the 2017 ozone hole are likely to be made.

8. NEEDS AND RECOMMENDATIONS

As climate change intensifies, long-term measurement of both spectral UV and ozone is essential to track changes near population centres. The coincident measurements are essential for disaggregation of factors that affect UV with a prioritisation to stations where populations might be affected either negatively or beneficially. Recent studies have shown that high quality spectral UV data is required to separately calculate the available UV for Vitamin D production, DNA damage and erythema risk, which is not possible with broadband measurements.

As a general point there has been a worldwide reduction in ozone and UV monitoring, a trend which must be reversed to avoid further damage to our monitoring capabilities. In particular it is essential to ensure that there is sufficient high quality, geographically distributed ground station data in order to ensure adequate validation of satellite data. Equally important is the maintenance of technical and scientific expertise which is often lost by way of station closures.

The impact and future projected emissions of chlorinated 'very short-lived substances' should be investigated further to enable Montreal Protocol Parties to consider whether further action needs to be taken.

UNITED STATES OF AMERICA

OBSERVATIONAL ACTIVITIES

Column Measurements

Ozone

US Satellites

Long-term dataset of total column ozone continues to be produced from the SBUV/2 instruments on the NOAA polar orbiting environmental satellites (NOAA-16, 17, 18 & 19). The SBUV record extends back to April, 1970 with a data gap between 1974 and 1978. The TOMS total ozone series started in October 1978 and ended in December 2006. All TOMS data have been reprocessed by applying an empirical correction based on the SBUV/2 record. Hence the SBUV total ozone record is considered the primary record for trend analysis. (NASA, NOAA)

Total ozone data from the Ozone Monitoring Instrument (OMI) on the EOS Aura satellite is available beginning October, 2004. Two independent algorithms are used to produce OMI total ozone data, one developed by NASA the other by KNMI, NL. NASA now has reprocessed SBUV, TOMS and OMI data using a common (version 9) algorithm. Total Ozone is now also available from the two nadir instruments within the Ozone Mapping and Profiler Suite (OMPS) on the Suomi NPP satellite. These data are available since April 2013. The two OMPS nadir instruments are very similar to those on SBUV and TOMS. These OMPS nadir observations will continue under the US operational satellite JPSS program. (NASA, NOAA)

Ozone Estimates from Infrared Sensors

NOAA produces estimates of total ozone by using information in the 9.7 micron channel of HIRS. The retrieval products are combined with SBUV/2 information to generate global maps of column ozone. See http://www.osdpd.noaa.gov/PSB/OZONE/TOAST/. (NOAA)

Total ozone products from thermal emission spectrometers also exist from both the TES instrument on the EOS Aura satellite and the AIRS instrument on the EOS Aqua satellite. These data are available on the NASA GSFC DAAC at http://disc.gsfc.nasa.gov/. (NASA)

Dobson Network

Dobson total column ozone measurements in the U.S. are done through the NOAA Cooperative Network at 15 locations, including 6 continental U.S. sites and 5 sites in other US territories or states (Hawaii, Alaska (2 instruments), Samoa, and South Pole. Four other sites are collaborative international programs (BoM at Perth, Australia; Lauder, NIWA in New Zealand; Marseille-Provence Astronomical Observatory (OAMP) federation at Observatoire de Haute-Provence, France; and Meteorological and Hydrological National Service (SENAMHI) at Maracompoche, Peru). Data are used for satellite validation and determining ozone trends for the WMO/UNEP Ozone Assessments. NASA also supports Dobson measurements within the U.S. under the auspices of the Network for the Detection of Atmospheric Composition Change (NDACC). (NOAA, NASA)

Dobson and Brewer ozone data processing

Following recommendations from the ACSO (WMO GAW Ad Hoc Expert team on Absorption Cross-sections of Ozone - ACSO) analysis, SAG-Ozone (Activity A9 within the ICAGO-O3/UV implementation plan) recommended to implement changes to the Dobson and Brewer data processing. The change in the use of the ozone absorption cross-sections from Bass and Paur to Serdyuchenko et al (2014) (SER) will improve agreement between Brewer and Dobson data. The international ozone commission in 2016 made recommendation for the WMO/GAW ozone SAG to guide the process for the Dobson and Brewer networks to implement the SER ozone cross sections and temperature corrections for data processing and reporting to the archives. The impact of temperature corrections on the NOAA Dobson ozone network has been assessed in collaboration with NASA that provided the GMI/MERRA ozone and temperature profile

datasets. The NOAA Dobson and Brewer networks are in the process of developing the tools to implement recommended changes. Reprocessed data will be submitted to the WOUDC and NDACC. (NOAA)

UVB Monitoring and Research Programme (UVMRP)
Direct-sun column ozone is retrieved by UV Multi-Filter Rotating Shadowband Radiometers (UV-MFRSRs) at 34 U.S. sites, 2 Canadian sites, and 1 New Zealand site within the U. S. Department of Agriculture (USDA) UV-B Monitoring and Research Programme (UVMRP).

NOAA-Environmental Ultraviolet-ozone Brewer (NEUBrew) Network
NOAA, with cooperation from the EPA, has established a network of Brewer Mark IV UV spectrometers that were deployed at six U.S. locations. The six stations have been operating continuously since the fall of 2006 with instruments and initial funding from the EPA and operating funding from NOAA since then. The network Brewers http://esrl.noaa.gov/gmd/grad/neubrew/ are currently focused on taking spectral UV irradiance measurements in the 286-363 nm wavelength range 5 times per daylight hour and total column ozone measurements 2-3 times per hour of daylight. Absolute spectral UV irradiance, instantaneous UV index, and daily erythemal dose time series are available online with a latency of one day. (NOAA)

The near-real time total ozone column and Umkehr profile daily data are made available from the NOAA NEUBrew network. Six Brewer instruments were calibrated against the Canadian traveling standard in 2015. Brewer ozone data will be used in the validation activities of the total column and profile ozone data collected by the Suomi NPP OMPS satellite and the following Joint Polar Satellite System JPSS program. (NOAA)

Ozone-Relevant Gases and Variables
Ozone Monitoring Instrument (OMI) on the Aura Satellite
In addition to its primary focus on column ozone, OMI measures tropospheric columns of aerosols, nitrogen dioxide, and sulphur dioxide. (NASA)

Network for the Detection of Atmospheric Composition Change (NDACC)
This international ground-based remote-sensing network was formed to provide a consistent, standardized set of long-term measurements of atmospheric trace gases, particles, and physical parameters via a suite of globally distributed sites. While the NDACC maintains its original commitment to monitoring changes in the stratosphere, with an emphasis on the long-term evolution of the ozone layer its priorities have broadened considerably to encompass the detection of trends in overall atmospheric composition and understanding their impacts on the stratosphere and troposphere, establishing links between climate change and atmospheric composition, calibrating and validating space-based measurements of the atmosphere, supporting process-focused scientific field campaigns, and testing and improving theoretical models of the atmosphere. NDACC instruments that are particularly suited for column measurements include UV/Visible spectrometers for ozone, NO_2, BrO, and OClO; FTIR spectrometers for a wide variety of source and reservoir compounds; and Dobson and Brewer spectrometers for ozone. Additional information on the NDACC is available at http://www.ndacc.org. (NASA, NOAA)

Profile Measurements

Ozone
BUV Instrument Series (10 Instruments)
The SBUV/2 instruments on NOAA satellites continue to measure ozone vertical profiles in the upper stratosphere (1-30 hPa) with vertical resolution varying from 6 to 8 km. (This technique also provides accurate estimates of the partial column ozone between 30-700 hPa.) This data record extends back to April 1970, with a data gap between 1974 and 1978. Profile datasets are also being produced from the OMI instrument. OMI provides full daily coverage compared to SBUV which provides daily coverage in approximately two weeks. OMI profiles have similar information content as SBUV in the upper stratosphere (1-30hPa) but have higher vertical

resolution (~10 km) at lower altitudes. The long-term ozone profile record from the SBUV/2 instrument series has been significantly affected by drifting orbits. Analysis of these effects is currently in progress. NASA has reprocessed data from the entire BUV instrument series, including OMI, using a consistent algorithm (version 9). Current and archived Version 8 ozone profile data are being used in the NOAA/NCEP Climate Forecast System Reanalysis and Reforecast, a successor of the NCEP/DOE Reanalysis 2. This work continues using the OMPS nadir observations on Suomi NPP and the future JPSS series of satellites. (NOAA, NASA)

Stratospheric Aerosol Measurement (SAM) and Stratospheric Aerosol and Gas Experiment (SAGE) Instrument Series (4 Instruments)
The SAM/SAGE series of instruments has provided the longest data set on the vertical profile of ozone in the stratosphere. Near-global coverage has been provided on a near-monthly basis for the periods 1979 to 1981 and 1984 to 2005. This series is resuming now that the existing SAGE-III instrument is being deployed on the International Space Station. The launch was in February 2017 and will be operational by the end of April 2017. (NASA)

OMPS Limb Measurements
The OMPS Limb instrument within the OMPS suite has been producing vertically resolved ozone and aerosol concentrations since April 2013. These observations will also be a part of the JPSS-2 satellite to be launched in 5-6 years. (NASA, NOAA)

Aura Satellite Instruments
Ozone profiles from 0.5- 200 hPa with about 3 km vertical resolution have been produced by the Microwave Limb Sounder (MLS). The high resolution dynamic limb sounder (HIRDLS), which suffers from a partial obscuration of the field of view that occurred during launch, has recently reprocessed the ozone profile data. These data have 1 km or higher vertical resolution in the stratosphere. This data series ended in 2008. Two other instruments on Aura Tropospheric Emission Spectrometer (TES) and OMI produce lower vertical resolution ozone profiles but they measure lower into the troposphere than either HIRDLS or MLS. A new activity to combine the radiances from TES and OMI to obtain better profile information in the troposphere is ongoing. (NASA)

Balloonborne Measurements
NOAA routinely conducts ozonesonde measurements at nine locations (5 domestic, 4 international). NASA, in collaboration with NOAA and numerous international partners, supports the operations of the Southern Hemisphere Additional OZonesonde (SHADOZ) network of ozonesonde launches from several locations in the tropics and southern subtropics. NASA also flies ozonesondes and an ozone photometer as components of moderate-scale balloon campaigns that also utilize a submillimeter/millimeter-wave radiometer, an infrared spectrometer, and a far-infrared spectrometer. (NOAA, NASA)

Dobson Umkehr
Profiles are obtained from six automated Dobson instruments using the Umkehr technique (Lauder, Perth, Hawaii, Boulder, OHP, Fairbanks). Through collaboration between NASA and NOAA, a new ozone-profile algorithm was developed and deployed to process Dobson Umkehr data. This algorithm is similar to the SBUV V8 algorithm, and has been optimized for deriving trends. The algorithm is made available to the WMO ozone and UV Data (WOUVD) centers for routine Umkehr data processing. The working group is formed to update all Umkehr data at the WOUDC. (NOAA, NASA)

Brewer Umkehr
NOAA Environmental Brewer Spectrophotometer UV and Ozone Network
Total column ozone and ozone profiles using the Umkehr technique are regularly derived from the Brewer spectrometer around sunrise and sunset. All raw and processed data are posted on the open access NOAA/NEUBrew web-site: http://esrl.noaa.gov/gmd/grad/neubrew/. The Dobson Umkehr ozone profile retrieval algorithm has been modified to process Brewer Umkehr data on a selective basis. It is implemented at all NOAA operated sites. NOAA collaborates with the EUropean BREWer NETwork (EUBREWNET) network through partnership and shares its expertise in data network operations and data processing. The Brewer Umkehr algorithm has

been introduced to large group of Brewer operators at the recent COST Action ES1207 EUBREWNET open Congress, Santa Cruz de Tenerife, Spain- 24th – 28th March 2014. http://www.eubrewnet.org/cost1207/
In 2015 NOAA hosted a visitor from the EU Cost Action EUBREWNET program and provided training on processing of the Brewer Umkehr data collected at Thessaloniki, Greece. The software can be found at http://www.o3soft.eu/o3bumkehr.html. It was optimized in 2016 to incorporate instrumental parameters and stray light correction. Implementation of the algorithm to the entire EUBrew and other networks is pending on determination of instrumental parameters for individual instruments that is currently not performed on routine bases. The development of in-field calibration tools is in progress through collaboration between NOAA and EU COST action projects (NOAA)

Network for the Detection of Atmospheric Composition Change (NDACC)
NDACC lidars (whose retrievals are limited primarily to the stratosphere) and microwave radiometers (whose retrievals are limited primarily to the upper stratosphere) are providing long-term ozone profile measurements. Ozonesondes routinely launched at many NDACC stations and through the Southern Hemisphere ADditional OZonesondes (SHADOZ) collaboration also provide ozone-profile data. In addition, several of the high-resolution FTIR spectrometers are beginning to yield ozone-profile information. (NASA, NOAA)

Ozone-Relevant Gases and Variables
Stratospheric Aerosol Measurement (SAM) and Stratospheric Aerosol and Gas Experiment (SAGE) Instrument Series (4 Instruments)
The SAM/SAGE series of instruments has provided the longest data set on the vertical profile of aerosols in the stratosphere. Near-global coverage has been provided on a near-monthly basis for the periods 1979 to 1981 and 1984 to 2005. Water vapor profiles are also available. This series is resuming in 2017 with the ongoing deployment of the existing SAGE-III instrument on the International Space Station. (NASA)

Aura Satellite Instruments
The four Aura instruments provide profile measurements of numerous atmospheric constituents and parameters in the stratosphere and troposphere. MLS is delivering profiles of temperature, H_2O, ClO, BrO, HCl, OH, HO_2, HNO_3, HCN, N2O, and CO. TES provides limited profile information for O_3, CO, H_2O, and HDO from its nadir viewing owing to its high spectral resolution. (NASA)

Combined NASA Satellite Data
Past global space-based measurements of atmospheric composition (e.g., from SAGE, SBUV, UARS, and TOMS) are being extended via observations available from the Aura satellite and other A-Train satellites. These new measurements are providing an unprecedented global characterization of atmospheric composition and climate parameters. Merged data sets connecting these recent measurements to past satellite observations of the atmosphere now exist. (NASA)
Balloonborne Water Vapor Measurements
NOAA monitors upper tropospheric and stratospheric water vapor using cryogenic, chilled-mirror hygrometers that are flown with ozonesondes on a biweekly schedule in Boulder, CO, and at Lauder, New Zealand, in collaboration with NIWA, and monthly at Hilo, Hawaii starting in 2010. Water-vapor profiles also are obtained on a campaign basis in Indonesia and, the Galapagos. NASA supports the flights of several balloon instruments either through the TICOsonde activity in Costa Rica or on a campaign basis. (NOAA, NASA)

Airborne Measurements
NASA-sponsored airborne campaigns, using both medium- and high-altitude aircraft, have been conducted in collaboration with NOAA, NSF, and university partnerships, and a focus on satellite validation and scientific study of ozone and climate change. While designed more for process studies than for trend determinations, the airborne measurements have provided a unique view of changes in atmospheric composition at various altitudes. The most recent campaigns are ATTREX, POSIDON, Atom, KORUS-AQ.
(NASA, NOAA, NSF)

For more than a decade NOAA has supported an additional ongoing program to regularly measure vertical profiles of ozone-depleting substances and substitute gases (especially HFCs) from light aircraft at a suite of approximately 20 sites across North America and above Rarotonga. The program began in 2004 and involves sampling up to 12 flasks at altitudes ranging from ~100 m above ground to ≤ 8 km above sea level. The data from this program is used to provide measurement-based quantification of U.S. emissions for ozone-depleting substances, their substitutes, and long-lived greenhouse gases. (NOAA)

Network for the Detection of Atmospheric Composition Change (NDACC)
Several of the NDACC remote sensing instruments provide profile data for a variety of ozone- and climate-relevant gases and variables. These observations continue the long term trends for ozone, water vapor, CFCs, HCl, HF, CH_4, and N_2O. (NASA, NOAA, DoD/NRL)

Ground-Based In Situ Measurement Networks
Both NASA and NOAA support in situ sampling of ozone- and climate-related trace gases via networks of flask sampling and real time in situ measurements at sites distributed across the globe. These data provide the basis for determining global tropospheric trends and emissions of these gases, and for computing effective equivalent chlorine (EECl) in the lower atmosphere. The NASA Advanced Global Atmospheric Gases Experiment (AGAGE) network has the longest continuous observational record for some gases, extending back more than three decades for some CFCs, methyl chloroform, and carbon tetrachloride. Newer NASA and NOAA instrumentation permits the monitoring of many of the CFC replacements, thereby enabling a tracking of such chemicals from their first appearance in the atmosphere. Measurement and standards intercomparisons between the AGAGE and NOAA networks and with other international collaborators are leading to an improved long-term database for many ozone- and climate-related gases. (NOAA, NASA)

Both the ongoing NASA- and NOAA-based programs have been augmented over time to enable estimates of emission magnitudes on regional scales. The AGAGE effort relies on high-frequency measurements to provide information in surrounding regions, while the NOAA effort (regular aircraft profiling mentioned above, plus, since 2007, approximately daily flask sampling at 16 tower locations) is focused on providing measurement-based emission magnitudes for the United States.

UV Irradiance Measurements

Broadband Measurements

SURFRAD Network
Seven Surface Radiation Network (SURFRAD) sites operate Yankee Environmental Systems, Inc. (YES) UVB-1 broadband radiometers. The Integrated Solar Irradiance Study (ISIS) network of solar measurements includes broadband Solar Light 501 UVB biometers at each of seven sites. Other instrumentation (located at the Table Mountain test facility near Boulder, Colorado) includes a triad of calibration-reference YES UVB-1 broadband radiometers. A Solar Light 501 UVA biometer is also operated at the site. (NOAA)

NOAA *Network*
Supplemental measurements of UV-B using YES UVB-1 instruments continue at Boulder, Colorado and Mauna Loa, Hawaii, where high-resolution UV spectroradiometers also are operated and can be used to interpret accurately the broadband measurements. (NOAA)

NEUBrew network
Each NEUBrew station has a Yankee UVB-1 broadband radiometer collocated with the Brewer spectroradiometer. The UVB-1 provides measurements of Erythemal daily dose. The NEUBrew Mountain Research Station also includes a broadband Yankee UV-A instrument. (EPA,NOAA)

USDA UV-B Monitoring and Research Programme (UVMRP)
Thirty-eight YES UVB-1 radiometers are fielded under this programme. (USDA)

USDA UVB Monitoring and Research Programme (UVMRP)
UV-MFRSRs deployed within this 37 station network measure total and diffuse horizontal and direct normal irradiance at nominal 300, 305, 311, 317, 325, 332, and 368 nm with a 2.0 nm bandpass. In addition, vis-MFRSRs are deployed with nominal 415, 500, 610, 665, 862 and 940 nm wavelengths with 10.0 nm bandpass. These 13 measurements are used to create a continuous synthetic spectra model which can then be convolved with specific weighting functions to meet researcher's needs. Access to the synthetic spectra is found on the UVMRP web site at: (http://uvb.nrel.colostate.edu/UVB/uvb_dataaccess.jsf). Direct-sun column ozone is retrieved using the UV Multi-Filter Rotating Shadowband Radiometers (USDA, CSU)

NEUBrew Network
Five NEUBrew stations have a Yankee UV-MFRSR and all stations have a visible MFRSRs collocated with the Brewer spectrophotometer. (NOAA)

NOAA Antarctic UV Monitoring Network
NOAA/GMD has assumed operations of the Antarctic portion of the former NSF UV Monitoring Network. There are Biospherical Instruments (BSI) GUV-511 moderate bandwidth multi-channel radiometers deployed at two of the Antarctic stations, McMurdo and Palmer and a GUV-541 radiometer deployed at the South Pole. (NOAA)

Spectroradiometer Measurements

Central Ultraviolet Calibration Facility
A high-precision UV spectroradiometer and a UV spectrograph are located at the Table Mountain Test Facility in Colorado under the auspices of this programme. The UV spectrograph was removed from operation in August 2009 due to equipment failure. It had been in operation since June 2003 (NOAA)

Network for the Detection of Atmospheric Composition Change (NDACC)
State-of-the-art, high-resolution spectroradiometric UV observations are conducted as a part of the NDACC at several primary and complementary sites. In particular, U.S. collaboration with NIWA (New Zealand) enables such measurements at Mauna Loa, HI and Boulder, CO. The measurements at Mauna Loa were started in 1995, those in Boulder began in 1998, and they continue to the present. (NOAA)

NSF (AON Grant to the University of Chicago)UV Monitoring Network
BSI SUV-100 high-resolution scanning spectroradiometers have been deployed at three locations: San Diego, California (sub-tropical location); Barrow, Alaska through June 2016; and a BSI SUV-150B spectroradiometer was deployed at Summit, Greenland through the summer of 2017 ; and a BSI SUV-150B spectroradiometer deployed at Summit, Greenland. (NSF)

NOAA Antarctic UV Monitoring Network
NOAA has assumed operations of the NSF UV Antarctic Network. BSI SUV-100 scanning spectroradiometers are deployed at the three Antarctic stations, McMurdo, Palmer, and South Pole. The scanning range of these instruments is from 290-600 nm.

UV-Net Programme
Brewer Mark IV spectrometers that measure the spectrum between 290 and 325 nm are deployed at all 21 network sites located in 14 U.S. national parks and 7 urban areas around the U.S. This network ceased operation in 2004 and all 21 Brewers were removed from their network sites. (EPA)

NEUBrew Network
The NOAA Environmental Brewer Spectrophotometer Network (NEUBrew) consists of six stations located in the western, central and eastern United States. Brewer MKIV instruments provide UV irradiance over the range 286.5 nm to 363 nm with 0.5 nm resolution up to 20 times per day. Absolute spectral UV irradiance , instantaneous UV index, and daily erythemal dose time series are available online with a latency of one day.
http://esrl.noaa.gov/gmd/grad/neubrew/. (NOAA)

Satellite-based Estimation
Surface UV radiation can be estimated using satellite-measured total column ozone and top-of-the-atmosphere radiance at a non-ozone absorbing UV wavelength as input to a radiative transfer code. Such methods have been applied to estimate both the spectral irradiance as well as UVB from the TOMS instrument series. Similar data are being produced by the Finnish Meteorological Institute (FMI) using OMI data. Since the cloud effects vary at very short spatial and temporal scales, the satellite derived UVB data are most useful for making estimates of monthly average UVB and spectral irradiance at ~100 km grid scales. An outstanding problem in the estimation of UVB from satellites is the strong UV absorption of most aerosols, most notably dust and secondary organics. An aerosol absorption correction is applied to the TOMS UVB record (but not to the OMI record) using TOMS-derived aerosol index (AI). Though AI can correct for elevated plumes of dust and smoke, it is not sensitive to aerosols near the surface. As a result, the satellites can overestimate UVB by up to 30% in polluted areas. However, this error is largely localized to urban areas and shouldn't significantly affect regional averages. (NASA)

Calibration Activities

Satellite BUV instruments
The UV instruments have very high susceptibility to degradation in the space environment with unpredictable variability from one instrument to another. In addition, some instruments have had non-linear detector response as well as hysteresis and spectral stray light problems. The EP/TOMS instrument developed a complex cross-track dependent response after several years. NASA has for several decades supported the calibration of NOAA SBUV/2 instruments both before and after launch. The post launch activities include both hard calibration (by monitoring on-board calibration data and the solar irradiance), as well as soft calibration. Soft calibration techniques include analysis of spectral and spatial patterns in measured radiances to separate geophysical effects from instrumental effects. NASA flew the SSBUV instrument 8 times on the Space Shuttle to provide calibration of NOAA SBUV/2 instruments. Other satellite instruments such as SAGE, and currently the MLS instrument on Aura, are also providing useful calibration information. However, ground-based data have not been used for satellite calibration, except for the BUV instrument that operated on the Nimbus-4 satellite from 1970 to 1974. However, NASA uses Dobson/Brewer ozone network and ozone soundings to verify SBUV/2 and TOMS data after applying soft and hard calibrations. (NOAA)

Dobson Network
World Standard Dobson No. 83 is maintained at NOAA/ESRLGMD as part of the World Dobson Calibration Facility, and regularly participates in international intercomparisons of regional and national standards. Since 2014, intercomparisons have been held in Melbourne, Australia; Tsukuba, Japan; Hohenpeissenberg, Germany; and Izana, Spain. Investigations into the correct characterization of Dobson instruments were performed in collaboration with the PTB laboratory in Braunschwei, Germany, The laser equipment was used to test optical parameters of the spectral response of the Dobson band-pass. This work was done per agreement with the European Joint Research Project Consortium in line with the ATMOZ (Traceability for atmospheric total column ozone) project under the European Metrology Research Program that focuses on assessment of the accuracy in total column ozone measurements. Optical characterization of the instruments allows the development of schemes to compare and reconcile differences in ozone column data derived from different instruments, including applications related to satellite validation. NOAA conducts calibration verification of the Dobson 83 instrument by conducting campaigns every two years at the Manua Loa site, with the last campaign held in the summer of 2016. (NOAA)

Ozone Soundings
NOAA prepares ozonesonde instruments and follows pre-flight checks according to WMO standard operating procedures. It participates in international intercomparisons of ozonesonde measurements (environmental simulation chamber tests) and develops methods to resolve instrument related differences. The intercomparisons and dual ozonesonde flights at NOAA provide key information on developing a homogenized time series of balloon measurements at each NOAA site. WMO Global Atmospheric Watch sponsors the ozonesonde calibrations where various international groups are invited to the World Calibration Centre for Ozonesondes at the Juelich Research Centre. The Juelich OzoneSonde Intercomparison Experiments (JOSIE) were held in 1996 and 2000. The last calibration campaign was a field (balloon) project at Laramie Wyoming called BESOS in 2004: http://croc.gsfc.nasa.gov/besos/. The next JOSIE test will be held in October/November, 2017. (NASA, NOAA)

Network for the Detection of Atmospheric Composition Change (NDACC)
Several operational protocols have been developed to insure that NDACC data is of the highest long-term quality as possible within the constraints of measurement technology and retrieval theory at the time the data are taken and analyzed. Validation is a continuing process through which instruments and their associated data analysis methods must be validated before they are accepted in the NDACC and must be continuously monitored throughout their use. Several mobile intercomparators within the various NDACC instrument types exist to assist in such validation. (NASA, NOAA)

Ground-Based In Situ Measurement Networks
Both the NOAA and NASA/AGAGE networks independently develop and maintain highly accurate and precise calibration scales at ppt and ppb levels for the major and minor long-lived ozone-depleting gases. In addition, both networks are developing reliable calibration scales for the short-lived halogen-containing gases that have been introduced as CFC replacements. (NOAA, NASA)

Central Ultraviolet Calibration Facility
The Central Ultraviolet Calibration Facility (CUCF) is located in NOAA's David Skaggs Research Center in Boulder, Colorado. The CUCF calibrates UV instruments for several U.S. Government agencies and other UV research concerns, both national and international. The CUCF also measured spectral response and angular response (critical for direct beam retrieval) for broadband and narrowband instruments. In addition to laboratory calibrations, the CUCF has developed a portable UV field calibration system that allows laboratory-grade calibrations to be made at spectroradiometer field sites. The CUCF also produces secondary standards of spectral irradiance that are directly traceable to NIST primary transfer standards. The secondary standards can be calibrated for operation in either the vertical or horizontal orientation. (NOAA)

USDA UVB Monitoring and Research Programme (UVMRP)
NOAA CUCF lamp calibrations performed in horizontal and vertical position using NIST traceable 1000-W halogen lamps are used to calibrate 51 USDA UV-MFRSRs and 52 UVB-1 broadbands. A U-1000 1.0-m double Jobin Yvon with 0.1-nm resolution and 10^{-10} out-of-band rejection is used as a reference spectroradiometer to transfer lamp calibration to a broadband triad. The UV-MFRSR radiometer spectral response and its angular response (critical for direct beam retrieval) are measured. The Langley calibration method is employed to provide additional absolute calibration of UV-MFRSRs and to track radiometric stability *in situ*. (USDA)

NEUBrew network
The NOAA Environmental Brewer spectrophotometer network (NEUBrew) consists of six stations located in the western, central, and eastern United States. Each Brewer Mark IV spectrophotometer is calibrated for absolute spectral UV irradiance at least one per calendar year. (EPA, NOAA) All six of the network Brewers were originally calibrated by International Ozone Services by comparing to the WMO Brewer transfer standard #017. Brewer 017 is directly traceable to the WMO Brewer Ozone Triad located at Environment Canada in Toronto, Ontario, Canada. In 2015 Brewer 017 traveled to Boulder to calibrate several Brewers after

filter changes. Data quality evaluation with regards to measurement stability is ongoing after the filter changes.

In the summer of 2014 all NEUBrew Brewers were removed from their monitoring sites and returned to Boulder, Colorado for refurbishment and ozone calibration. For the refurbishment many of the NEUBrew Brewer's had a new solar-blind filter installed. The original NiSO4 filter was replaced by INRAD's new UVC-7 filter, a chemical variant of the original. The new filter is more thermally stable than the original and less hygroscopic. Eight out of 10 of the network Brewers received the new UVC-7 filter while two instruments kept the original NiSO4 filters. Two of the Brewers are operating side by side at Table Mountain, USA, one with the original $NiSO_4$ filter and the other with the UVC-7 filter. During October 2014 while all ten network Brewers were operating side by side they were calibrated against the WMO transfer standard, Brewer 017, by International Ozone Services.

Two methods of tracking any drift from those original calibrations are employed by NEUBrew. The first is to adjust the extra-terrestrial constant (ETC) calibration constant by using the internally generated R6 value and the second is by performing Langley regressions on the ozone data to derive the ETC. Data quality evaluation is ongoing after the filter changes regarding instrumental drift and measurement stability (NOAA)

RESULTS FROM OBSERVATIONS AND ANALYSIS

Ozone

Merged Satellite Datasets

Since there are often biases between different satellite instruments it is necessary to create consistent long-term data sets by cross-calibration of different records when they overlap and by using ground-based data (including NOAA ground based networks) when they do not. Such data sets have been produced using TOMS and SBUV total column ozone and profile records. Several new efforts to provide long term merged data sets of ozone columns and stratospheric profiles of ozone and other trace gases are ongoing. Many of these activities are part of the SI2N intercomparison efforts. (NASA, NOAA)

Ozone Depletion & Recovery

Statistical analysis of the Umkehr ground based data, FTIR, merged SBUV, SAGE, GOMOS, SAGE-MLS, and SAGE-OSIRIS profile ozone data from 1979 to June 1997 shows the largest negative trends in the upper stratosphere (35-45 km) at middle latitudes at -10 % per decade at both Southern and Northern Hemispheres. The middle stratosphere (20-25 km) trends are derived from ozonesonde, satellite and FTIR records indicate -7 % per decade decline at both Southern and Northern middle latitudes and less negative trends are found at lower stratosphere (12-15 km) at -9% per decade in the Northern Hemisphere (no information for Southern hemisphere)These trends are in general agreement with previous profile trend estimates from satellite and ground-based records. Since 1997, ozone between 12 and 15 km (lower stratosphere) in the Northern middle latitudes has increased at a larger rate than is expected based on the decline in the ODS abundances. The middle and upper stratospheric ozone has been increasing at the Northern middle latitudes, tropics, and Southern middle latitudes since 1997. Published analyses of Antarctic ozonesonde records at South Pole and Syowa stations show statistically significant increases in the middle- and lower-stratospheric ozone in September. Ground-based and satellite ozone measurements made in the upper stratosphere since 1997 also indicate positive trends that are consistent with a leveling off and initial decrease of stratospheric halogen concentrations. However, the derived ozone trends in the middle and lower stratosphere are not always statistically significant, since the natural ozone variability, stratospheric cooling and measurement uncertainties make analyses less certain.

Antarctic Ozone Hole

Since approximately 1997, the underlying trend of Antarctic ozone (i.e., the trend after removal of the effect of natural variability in vortex temperatures) has been showing slight

signs of improvement. The stratospheric ozone seasonal decline within the Polar vortex is measured by NOAA ozonesondes at South Pole since 1986. The loss rates in 14-21 km layer during the month of September in 2015 and 2016 were slightly less severe (at 3.2 and 2.9 Dobson Units per day respectively) as compared to the 1992-2011 average linear decline of 3.4 ± 0.03 DU/day (NOAA).

Antarctic ozone depletion is primarily controlled by inorganic chlorine and bromine concentrations (effective equivalent stratospheric chlorine, EESC), and secondarily controlled by Antarctic stratospheric temperatures and dynamics. Slightly warmer temperatures in 2016 lessened the severity of the ozone hole while it remains difficult to attribute ozone hole improvement with the slowly decreasing levels of stratospheric chlorine. Fits of various ozone hole diagnostics to temperature and chlorine and bromine levels suggest that the ozone hole is very slowly improving, and the observations in 2016 add confidence to this trend. However, detection of this slow improvement is masked by the large natural variability of the Antarctic stratosphere. (NASA)

Ozone Maps

Daily maps of total ozone and monthly total ozone anomalies are being produced, as well as routine updates of the SBUV-2 total ozone change utilizing a statistical model that includes the 1979 to 1996 trend, the trend-change in 1996, plus ancillary variables of solar variation (f10.7), QBO, and AO/AAO. In addition, twice-yearly (Northern and Southern Hemisphere) winter summaries of selected indicators of stratospheric climate are generated. Similar maps are created with the total column observations from the OMI instrument on Aura and the nadir looking OMPS instruments on Soumi-NPP. (NOAA/CPC, NASA)

Ozone depleting gases

Multiple global measurement networks continue to show that tropospheric concentrations of most long-lived ozone-depleting gases continue to decrease, and this has led to a fairly steady decline in total atmospheric chlorine, total atmospheric bromine, and EESC. Chlorine from some short-lived gases is increasing (from CH_2Cl_2), but not by an amount that offsets the overall chlorine decline from longer-lived gases. (NASA, NOAA)

UV

UV and Health

NOAA/GRAD and NOAA/NWS/NCEP/CPC in collaboration with Klein Buendel, Inc a health research company developed a prototype for a smart-phone application that utilizes NOAA's UV forecast. The application is a tool for managing and providing information on sun-burning potential and vitamin D production. The project was funded by the National institute of Health.

UV Trends

SURFRAD Network

Work by Colorado State University (CSU) UVB researchers continued for analyzing trends in solar UV irradiance at eight stations in the CSU-USDA network stations. Both positive and negative tendencies were detected ranging from –5% to +2% per decade. However, inter-annual variability was between 2 and 5%. (NOAA)

Scientists analyzing UV-B flux over the continental USA using NASA TOMS data and UVMRP network data found that "ground-based in-situ measurements, like those from the UVMRP network, are indispensible in monitoring atmospheric status and not totally replaceable by space-based remote sensing retrievals". The incorporation of these ground-based measurements with current satellite algorithms has improved UV retrievals for the latest satellite package (OMI). (Xu et al., 2010) (USDA)

UV Forecasts and Exposure

UV Forecasts and Alert System

NOAA/CPC is producing UV forecasts and has developed a UV Alert system with the EPA. The UV Index forecasts are on a gridded field covering the entire globe. Forecast fields are generated at one hour frequency out to five days. The UV Index forecasts include the effects

of Earth-Sun distance, total ozone, solar zenith angle, surface albedo (inclusive of snow/ice), cloud attenuation, and climatological aerosol conditions. The gridded fields are freely available on the NCEP ftp site. The UV Alert system is designed to advise the public when UV levels are unusually high and represent an elevated risk to human health. The UV Alert system consists of a graphical map displaying the daily UV Alert areas, as well as additional information included in the EPA's UV Index ZIP Code look-up web page and via the EPA's AIRNow EnviroFlash e-mail notification system. The criteria for a UV Alert are that the noontime UV Index must be at least a 6 and must be 2 standard deviations above the daily climatology. (NOAA/CPC, EPA)

Effects of UVB Exposure
A major limitation in predicting the impacts of UVB irradiance on humans, plant leaves and flowers, and aquatic organisms is the difficulty in estimating exposure. An analysis of the spatial variability in the daily exposure to narrowband 300- and 368-nm and broadband 290- to 315-nm (UVB) solar radiation between 12 paired locations in the USDA UV-B Climatological Network over two summer growing seasons has been completed. The spatial correlation of the UVB, 300- and 368- nm daily exposures between locations was approximately 0.7 to 0.8 for spacing distances of 100 km. The 300-nm daily exposure was typically more highly correlated between locations than the 368-nm daily exposure. (USDA)

THEORY, MODELING, AND OTHER RESEARCH

Ozone:

Antarctic and Arctic Ozone Loss
Recent analyses of Arctic and Antarctic ozone loss using observed concentrations of ozone and trace species in the stratosphere, in combination with advanced chemical/transport models show that much of the variability in ozone loss can be well explained by a combination of variations in transport that drive the distribution of ozone and the photochemical loss of ozone. (NASA)

Ozone-Related Gases and Variables

Environmental Properties of Atmospheric Gases

The abundance and atmospheric lifetime of carbon tetrachloride (CCl_4) is important to understanding stratospheric ozone recovery and climate change as well as the linkage between these issues. Laboratory work has determined updated values for the UV absorption cross sections and atmospheric lifetime for CCl_4. This information was used in a new international assessment of CCl_4 coordinated by the WCRP's SPARC program in 2016 with NOAA and NASA contributions (NOAA, NASA). This up-to-date analysis, closes the gap in the CCl_4 budget discrepancies, although imbalance remains in our understanding of CCl_4 sources and sinks that suggest additional sources of CCl_4 to the atmosphere of unknown origin. (NOAA, NASA)

Chemistry of Potential ODS Replacements

Laboratory and theoretical work has provided information about the ozone-layer friendliness and climate friendliness of candidate replacements for ozone-depleting substances used for a variety of societal applications such as refrigeration, air conditioning, electronics manufacture, and fire protections. Early information about the suitability of a proposed substance is needed by industry before costly development investments are made. These results provide important input parameters for model calculations of the future vulnerability of the ozone layer, and are used together with industrial production-and-use information to analyze the growth of such chemicals in the atmosphere. Recent studies have focused on reassessing the UV photolysis and $O(^1D)$ kinetics of several long-lived CFCs, HCFCs, and greenhouse gases. Model calculations of past and future ozone abundance and its trends rely on accurate measurements of the UV absorption spectra (and temperature dependence) and kinetic parameters to

minimize uncertainty. Laboratory measurements were made to reduce the model input uncertainty for key species to <5%, in some cases. Recent studies measured the UV absorption spectrum of NF_3 to better define its atmospheric lifetime, ~570 years. Kinetic studies were conducted for $CHF=CF_2$, HFO-1438ezy(E), and (E)-$CF_3CH=CHCF_3$. It was determined that these chemicals have short atmospheric lifetimes, 5-90 days and relatively low GWP_{100} values (<20). These studies have shown that there are substantially different lifetimes for fluoroinated stereoisomers. (NOAA)

Chemistry of Persistent Greenhouse Gases

Fundamental laboratory studies of the atmospheric formation and loss processes of persistent greenhouse gases, i.e., substances with atmospheric lifetimes greater than 500 years, are used to evaluate their environmental impact, e.g. global warming potential. Laboratory studies found that perfluoroamines, which are used as heat transfer compounds, are primarily removed in the upper atmosphere, which results in atmospheric lifetimes greater than 2000 years. Perfluoroamines were also found to have large radiative efficiencies (>0.6 W m^{-2} ppb^{-1}), which results in this class of compound having large global warming potentials (GWP_{100} values greater than 20,000). $CF_3C(O)F$ is formed in the atmosphere in the degradation of several HFCs currently present in the atmosphere. Laboratory studies showed that the short-wavelength UV photolysis of $CF_3C(O)F$ leads to a small yield (<1%) of CF_4, an extremely potent persistent greenhouse gas. (NOAA)

UV

UV Instrumentation
The temperature dependence of the Brewer UV spectrometer has been studied in order to improve the quality of data for UV trends. (NOAA)

UV Effects
The UVMRP supports research studying UVB effects on plants and ecosystems. Numerous publications document the results of these on-going studies, and are listed on the program's web site at (http://uvb.nrel.colostate.edu/UVB/uvb_pubs.jsf). (USDA)

UV Model Comparisons
The UVMRP's modeling group, "The Center of Remote Sensing and Modeling for Agricultural Sustainability" has published preliminary results of their coupled climate-crop modeling system. Validation and system refinement is underway and has shown promising results. Corn yields for the 16-state USA corn belt over the 27 year span (1979-2005) agree to within +/-10% of the actual yields. This modeling effort is being expanded to evaluate precipitation, temperature and UV effects on the yields, with the ultimate goal of developing a system that will be capable of both achieving credible and quantitative assessments of key stress factors, and evaluating alternative cultural practices for sustainable agriculture production. (USDA)

DISSEMINATION OF RESULTS

Data Reporting

Ozone
Ozone data from Aura instruments (OMI, MLS, and HIRDLS)), past TOMS instruments, the OMPS nadir and Limb instruments on Suomi-NPP, and the AIRS instrument are routinely distributed by the Goddard Earth Sciences (GES) Data and Information Services Center (DISC) at http://disc.sci.gsfc.nasa.gov/acdisc. Both level 2 (measured) data and level 3 (grid averaged) data are distributed in HDF format. OMI level 3 data are distributed in ASCII format via the TOMS web site (http://toms.gsfc.nasa.gov). Ozone data for the TES instrument on Aura can be found on the NASA Langley DAAC at http://eosweb.larc.nasa.gov/. (NASA)

Aura Validation Data Center (AVDC)
Preliminary and near real-time total ozone, ozonesondes, ozone profiles from LIDAR and microwave radiometers are archived from US Government Agencies and investigators worldwide. In addition, the AVDC (http://avdc.gsfc.nasa.gov/) also archives and distributes NASA and NOAA total column, profile and tropospheric satellite data subsets. The collected preliminary ozone data are restricted to participants in Aura validation teams, ESA OMI announcement of opportunity participants, and international validation contributors, while the satellite data is freely available (http://avdc.gsfc.nasa.gov/Data/). (NASA)

Umkehr Dobson Data
Dobson Umkehr data processed using UMK04 algorithm are available from the WOUDC archives. Dobson Umkehr data for six NOAA sites are also available at the web address: ftp://aftp.cmdl.noaa.gov/data/ozwv/Dobson/Umkehr/. Brewer Umkehr data are available for 6 NEUBrew sites at the web address: http://esrl.noaa.gov/gmd/grad/neubrew/. (NOAA, NASA)

World Ozone and Ultraviolet Radiation Data Center (WOUDC)
Total ozone, Umkehr, and ozonesonde data are reported to the WOUDC from U.S. Government agencies and institutions. Ozone data from sites that are part of the NDACC and the SHADOZ network are available from the programme web sites (http://www.ndacc.org/ and http://croc.gsfc.nasa.gov/shadoz/, respectively), and also are imported to WOUDC. (NOAA, NASA).

NEUBrew Data
UV spectra, total column ozone and Umkehr ozone profile data from the NOAA Environmental network are available at the web site http://esrl.noaa.gov/gmd/grad/neubrew/ (NOAA)

Maps
All daily SBUV/2 total ozone hemispheric analyses generated from NOAA-16, NOAA-17, and NOAA-18 observations are available on the Climate Prediction Center's stratospheric web pages at http://www.cpc.ncep.noaa.gov/products/stratosphere/sbuv2to/. The raw data from the SBUV/2 are available from NESDIS. Additionally, the NCEP/GFS total ozone analysis and forecast fields out to five days are available at http://www.cpc.ncep.noaa.gov/products/stratosphere/strat_a_f/. (NOAA/CPC)
Daily maps from the Version 8 total ozone algorithm processing of GOME-2 data are available from NOAA Operations at http://www.osdpd.noaa.gov/PSB/OZONE/gome.html (NOAA/CPC)

Assessments
NASA and NOAA scientists, along with other scientists from around the world, played key roles as editors, authors, contributors, and reviewers of the 2016 SPARC Report on the Mystery of Carbon Tetrachloride. NASA and NOAA scientists are involved in the planning and will be involved in the writing of the 2018 WMO/UNEP Scientific Assessment of Ozone Depletion, mandated under the provisions of the Montreal Protocol. Other scientists from the U.S. and around the world will contribute to the report, which will be given to the Parties to the Montreal Protocol in late 2018 and on the UNEP and NOAA websites in early 2018. (NOAA, NASA)

Stratospheric Winter Hemisphere Bulletins
Following each hemisphere's winter, an assessment of the stratospheric dynamics and chemistry are presented from a NOAA perspective. The southern hemisphere's winter bulletin focuses upon the ozone hole formation and longevity. Relevant thermal and dynamical attributions are presented. The northern hemisphere's winter bulletin will discuss ozone loss conditions and stratospheric warmings.
http://www.cpc.ncep.noaa.gov/products/stratosphere/winter_bulletins/ (NOAA/CPC)

NASA maintains the Ozone Watch web site at NASA GSFC (https://ozonewatch.gsfc.nasa.gov/) which contains daily updates on the satellite images of column ozone and polar stratospheric meteorological conditions, and near term forecasts. (NASA)

Ozone-Related Gases and Variables

Aura Data

Gas and Aerosol constituent data from Aura instruments (OMI, MLS and HIRDLS) are routinely distributed by the Goddard Earth Sciences (GES) Data and Information Services Center (DISC) at http://disc.sci.gsfc.nasa.gov/acdisc. Both level 2 (measured) data and level 3 (grid averaged) data are distributed in HDF format. OMI level 3 data are distributed in ASCII format via the TOMS web site (http://toms.gsfc.nasa.gov). Data for the TES instrument on Aura can be found on the NASA Langley DAAC at http://eosweb.larc.nasa.gov/ (NASA)

Ozone-Depleting Substance Data

Ongoing measurement data for ozone-depleting substances from the NOAA sampling network are updated at least every six months on the website (http://www.esrl.noaa.gov/gmd/) and are submitted annually to the World Data Centre and to the World Data Center for Atmospheric Trace Gases at the Carbon Dioxide Information Analysis Data Center (CDIAC). Data from field missions (*e.g.*, the Atmospheric Tomography Experiment Campaign), are posted shortly after mission completion. (NOAA)

Long-term data from the NASA/AGAGE network are reviewed on a semi-annual basis by the Science Team, and are archived every six months with Carbon Dioxide Information and Analysis Center (CDIAC) <http://cdiac.esd.ornl.gov/>. Data from the UCI flask sampling network are also archived at CDIAC. (NASA)

UV Data

SURFRAD Network Data

UV data from the SURFRAD Network are available on the NOAA/SRRB website (http://www.srrb.noaa.gov/). (NOAA)

NEUBrew Network UV Data

Spectral UV irradiances are available from the NEUBrew website http://esrl.noaa.gov/gmd/grad/neubrew/ (NOAA)

NOAA Antarctic UV Data

Spectral UV irradiances, derivative UV products, and GUV data will be available from NOAA's Antarctic UV website.
http://esrl/noaa.gov/gmd/grad/antuv (NOAA)

USDA UV-B Monitoring and Research Programme (UVMRP)

UV, visible and ancillary data from the UVMRP network is available next-day on the UVMRP website (http://uvb.nrel.colostate.edu/).

UVB-1 broadband data and UV-MFRSR data from this network are regularly submitted to the WOUDC. (USDA)

Information to the Public

Ozone

TOMS and OMI Data

Near-real-time ozone data from the OMI instrument on Aura is routinely distributed via the NASA web site (http://toms.gsfc.nasa.gov/). Data are usually available within 48 hours, though faster access can be arranged. The site provides online access to both TOMS (1978-2006) and OMI (2004-present) data. While used mostly by scientists, educators and students also use the site extensively. An Ozone Hole Watch web site, http://ozonewatch.gsfc.nasa.gov/ provides information for anyone interested in the Antarctic ozone hole. Near real time Ozone profile data from MLS now exist, and are available at http://disc.sci.gsfc.nasa.gov/Aura/data-holdings/MLS/ml2o3_nrt.002.shtml. (NASA)

Merged TOMS/SBUV Total and Profile Ozone Data
Merged TOMS/SBUV total and profile ozone data sets are available on the Internet (http://hyperion.gsfc.nasa.gov/Data_services/merged/index.html). (NASA)

UV
Forecasts
Noontime UV forecasts are made available to the public via several formats. One is a text bulletin for 58 cities in the U.S. The other is a map displaying the UV Index forecast at each of the 58 cities' locations. These can be found at http://www.cpc.ncep.noaa.gov/products/stratosphere/uv_index/. Additionally, gridded fields of the noontime forecast for the U.S. and Alaska are made available via the NOAA/CPC and NOAA/NCEP ftp sites. UV Index forecast gridded fields covering the entire globe at one hour increments out to five days are available on the NCEP ftp site: ftp.ncep.noaa.gov/pub/data/nccf/com/hourly/prod. (NOAA/CPC)

Advisories
The primary UVR advisory in the United States is the UV Index, operated jointly by NOAA and EPA. Currently, the UV Index computer model processes total global ozone satellite measurements, a rough cloud correction factor, and elevation to predict daily UVR levels on the ground and the resulting danger to human health. This model assumes zero pollution levels. UV Index reports are available in local newspapers and on television weather reports. The EPA also issues a UV Alert when the UV Index is predicted to have a high sun-exposure level and is unusually intense for the time of year. UV Alert notices can be found at EPA's SunWise web site (http://www.epa.gov/sunwise/uvindex.html), in local newspapers, and on television weather reports. (EPA)

Ozone-Depleting Gas Index
An ozone-depleting gas index (ODGI), based on Effective Equivalent Stratospheric Chlorine (EESC) derived from global surface measurements of ODSs in the NOAA network, has been implemented. The observation-derived EESC, along with WMO/UNEP ozone-depleting gas scenarios, are used to estimate the progress being made towards ozone recovery in the mid-latitude and Antarctic stratosphere (ODGI = 100 on January 1, 1994 when EESC reached its maximum value and 0 at 'recovery' (presumed to be 1980 EESC levels)). Values for the 2016 index range are approximately 80 for Antarctica and 58 for mid-latitudes, indicating substantial progress in ODS reductions. The index is updated annually and posted at http://www.esrl.noaa.gov/gmd/odgi. (NOAA)

PROJECTS AND COLLABORATION

NOAA
The Dobson and ozonesonde measurements are included in the WMO Global Atmosphere Watch (GAW) and in the NDACC. Significant collaboration with federal agencies (NASA, DoE) and universities (University of Colorado, Harvard, Princeton, Humboldt State University, etc.) is maintained through both global monitoring and field missions including support for satellite validations. The World standard Dobson instrument is maintained and calibrated by NOAA under the WMO GAW program. It provides calibration to regional Dobson standards at 6 centers. The NOAA Environmental Brewer spectrophotometer network (NEUBrew), initially established in collaboration with the EPA, consists of six stations located in the western, central, and eastern United States.

The CUCF is designated by a Memorandum of Understanding to be the national UV calibration facility by agreement among the following organizations: NOAA, USDA, EPA, NASA, National Institute of Standards and Technology (NIST), NSF, National Biological Service, and the Smithsonian Institution. The CUCF compared secondary standards of irradiance with the Joint Research Centre's European Union UV Calibration Centre's (ECUV) ultraviolet spectral irradiance scale in Ispra, Italy. The CUCF's irradiance scale is directly traceable to the NIST spectral irradiance scale, while the ECUV's irradiance scale is traceable to that of the German national standards laboratory, Physikalisch-Technische Bundesanstalt (PTB).

NOAA/CPC
Activities include participation in several initiatives of Stratospheric Processes and their Relation to Climate (SPARC), i.e., stratospheric temperatures, ozone, UV, climate change; collaboration with the EPA on the UV Index and the UV Alert system; collaboration with NASA in ozone monitoring, calibration of the SBUV/2 instruments, dynamical processes influencing ozone changes, and ozone assimilation; collaboration with the surface radiation monitoring efforts of NOAA/OAR and USDA-CSU for the validation of UV forecasts and NCEP/GFS surface radiation products, and the NDACC Data Host Facility.

NASA
NASA collaborates extensively with several NOAA laboratories in all areas of ozone and UV research, including space-based, airborne, balloon-borne, and ground-based measurements, as well as in various modeling and analysis activities. NASA often supports research activities within these laboratories, including support for NOAA groundbased measurements for satellite validation. The NDACC, which is championed by NASA and NOAA within the U.S., is a major contributor to WMO's Global Ozone Observing System (GO3OS) within the frame of its Global Atmosphere Watch (GAW) Programme. NASA is closely collaborating with KNMI (Netherlands) and FMI (Finland) on processing data from the Aura OMI instrument. NASA is assisting NOAA in the implementation of the OMPS nadir and limb instruments on the NPOESS Preparatory Satellite (NPP) by developing the limb operational algorithms and by performing assessments of the nadir operational products.

USDA
USDA is actively collaborating with the NASA TOMS and AERONET groups on aerosol absorption using UV-MFRSR and Cimel instruments.

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FUTURE PLANS

Ozone

Column Ozone from Dobson/ Brewer Zenith-Sky Measurements
The operational zenith-sky total ozone algorithm for Dobson and Brewer instruments is based on empirically derived tables. NASA has developed a TOMS-like algorithm to process these data, which has the potential to substantially improve data quality. There are plans to process all historical zenith-sky data using this algorithm.

In 2015-2016 NOAA performed a thorough assessment of all its historical Dobson datasets. Some inconsistencies were found in the total and Umkehr data submitted to the WOUDC and NDACC archives. NOAA is preparing to resubmit the revised dataset in 2017.

New algorithms to utilize multi-wavelength Brewer zenith sky measurements for improved ozone profile retrieval require detailed information on optical parameters of individual instruments (i.e., band-pass and stray light filters). The work on improvement of optical characterization of Dobson and Brewer instruments for stray light minimization will continue through in-lab and in-field characterization of the instruments in the WMO network.

NOAA will work to implement Serdyuchenko et al (2014) ozone cross-section datasets for its Dobson and Brewer ozone data processing. The future work will be focused on developing methods to incorporate daily and climatological variability in stratospheric temperature into the ozone data processing. (NOAA, NASA)

Ozone profiles from Dobson/ Brewer Zenith-Sky Measurements
NOAA GMD will continue to retrieve ozone profiles from the NOAA operated stations, and will submit results for Dobson stations to the WOUDC, and will make the amendment to the UMK04 algorithm to replace the look-up tables for the SER (2014) cross-section. Results from the NEUBrew instruments will be posted on the network website http://esrl.noaa.gov/gmd/grad/neubrew/. The set up for automatic submission of raw NEUBrew data (B-files) to the WOUDC Brewer archive depends on the future funding for the NEUBrew network.

A new multi-wavelength ozone profile retrieval algorithm for processing Brewer Umkehr measurements (similar to the SBUV retrieval) will be made available for the WOUDC and scientific communities after the optical characterization of instruments for stray light and polarization parameters becomes part of the recurrent calibration routine in the operations of the Brewer networks. The pass forward is through a NOAA collaboration with the European Joint Research Project Consortium. The future activity is in line with the ATMOZ (Traceability for atmospheric total column ozone) project under the European Metrology Research Program that focuses on assessing the accuracy in total column and profile ozone measurements. Optical characterization of instruments (in the lab and in the field) allows developing schemes to compare and reconcile differences in ozone column data derived from different instruments, including in applications for satellite validation projects.. The proposed multi-spectral Brewer algorithm is expected to significantly reduce operational time for the zenith sky measurements as compared to the established "Umkehr" measurements schedule in Brewer operations. It will also allow to process historical data that were not available for standardized processing due to shortness of the solar zenith range coverage. The data processed by the new algorithm will be archived at the WOUDC (NOAA).

The Brewer Umkehr data set series from NOAA and other international ground-based stations will be compared to other available co-incident ozone profile data from ozone-sondes, microwave, lidar and Dobson Umkehr profile data. Results will be reported at the LOTUS SPARC activity aimed at understanding of past changes in the vertical distribution of ozone, and will be made available for the next UNEP/WMO Scientific Assessment of Ozone Depletion. (NOAA)

Archiving of the "raw" data at the WOUDC
According to the SAG-Ozone recommendations NOAA will participate in the international effort at the finalization of formats for the storage and reporting of ECC ozonesonde measurements at WOUDC, archiving of R-values of Dobson measurements and related calibration information as well as B-files and relevant information for Brewer measurements. It will provide the updated and modified algorithms used to process these data. NOAA will assist WOUDC with changes of ozone absorption cross sections or other changes that may demand the reprocessing of data records. (NOAA)

Ozone in Climate Forecast Models
NCEP has modified and extended its synoptic forecast model (GFS) to time scales of three weeks to nine months. Ozone forecasts as well as stratospheric temperatures and heights have significant errors in these forecasts. Experiments modifying the model's physics and structure will need to be conducted in order to improve these forecasts. (NOAA/CPC)

Ozone in the NCEP/Climate Forecast System Reanalysis
NCEP is replacing the NCEP/DOE Reanalysis 2 (R2) with the Climate Forecast System Reanalysis (CFSR). The CFSR improves upon the R2 in many ways. One is by using ozone profile information from the SBUV/2. The CFSR is being rerun from 1979 to present and will continue as the model for NCEP's Climate Data Assimilation System (CDAS). The CFSR should be the reanalysis of choice to study ozone-dynamics interactions. (NOAA/CPC)

NOAA Antartic UV Network
Future plans are to deploy two NEUBrew Mark IV spectrophotometers to the McMurdo and Palmer stations to provide daily total column ozone and overlapping spectral UV measurements. The two Brewers will be temperature stabilizied and modified for Antarctic operation. Before deployment both Brewers will be converted to "red" Brewers to facilitate ozone retrievals in the Chappuis band. After conversion and before deploying they will be operated at the CUCF's Table Mtn Test Facility (Lat 40 N) over the boreal winter to determine the quality of ozone retrievals from this solar spectral region when compared to direct-sun retrievals from the Hartley-Huggins band.

NASA Ozone satellites
NASA will continue to operate the Aura satellite, assuming it continues to receive high science value through the NASA senior review process. NASA will also operate the SAGE-III satellite on the ISS through the three-year design lifetime of the instrument and will continue beyond that if the science value is determined to be high and no other instrument is scheduled to assume the location on the ISS that SAGE-III is occupying. (NASA)

Ozone-Relevant Gases/Variables:

OMPS and CrIS on NPP and JPSS
The Ozone Mapping and Profiler Suite is the operational US ozone monitoring instrument in the JPSS period. The suite consists of two nadir detectors; one with coverage in the 310 to 380 nm range to provide daily global total column ozone maps, and the other with coverage from 250 to 310 nm to provide nadir ozone profiles to continue the SBUV(/2) record. The first OMPS has been on the NASA Suomi-NPP since 2010. The Cross-track Infrared Sounder is a hyperspectral IR instrument with spectral coverage including the ozone lines around 9.7 microns. NOAA has implemented ozone retrieval algorithms with the AIRS instrument on EOS, and plans to use similar algorithms with the IASI on MetOp-A and the CrIS on NPP and JPSS. (NOAA, NASA)

Ground based networks
NASA and NOAA plan on continuing investment into the ground based networks supported by the NOAA Global Monitoring Division as well as the Network for Detection for Atmospheric Composition Change, SHADOZ ozone sondes, and AGAGE. (NOAA and NASA)

NASA Earth Venture (EV) Investigations and missions
NASA selected 5 investigations (EVI-2)that will last for 5 years to use suborbital platforms for sustained investigations of Earth System processes. 1 of these selected studies have direct

relevance to Ozone related science, the Atmospheric Tomography Mission These activities started in 2014 and will continue until 2018. One new competed space mission Announcements of Opportunities (AOs) was be released in 2016 for a cost constrained instrument for a mission of opportunity (EVI-4). (NASA)

UV

UV Index Forecast
Aerosols and clouds are the greatest cause of UV Index forecast errors. NCEP and NESDIS are working together to improve the skill of forecasting aerosols. When model generated forecasts of Aerosol Optical Depth and Single Scattering Albedo become available they will be included in the UV Index forecast system. (NOAA/CPC)

NEEDS AND RECOMMENDATIONS

Ozone

Column Ozone
Column ozone observations from ground stations and satellites provide the foundation for trend studies. Future levels of total ozone will be modulated by climate change effects. The current predictions of total ozone from state-of-the-art models suggest polar ozone recovery in the 2060-2070 period, and midlatitude recovery in the 2040-2050 period. It is a primary requirement to continue this data record and to enable retrieval improvements of the observations.

Column ozone data produced by satellite and ground-based instruments agree well in cloud-free conditions and at solar zenith angles less than 70º. However, the data quality of all measuring systems degrade under cloudy conditions and at large solar zenith angles, with differences of 10% or larger. Given the need for accurate ozone trends in the polar regions, it is important to improve the quality of ground-based data in these regions, and to focus future calibration and data intercomparison efforts accordingly. The work on improvement of optical characterization of Dobson and Brewer instruments for stray light minimization, and therefore improved accuracy at low sun and large total ozone conditions, are under development. In addition, the new ozone cross-section implementation in the Dobson and Umkehr data processing is underway. The improvement in Dobson daily ozone retrievals also depends on the stratospheric temperature variability. The methods to incorporate temperature corrections to the Dobson total ozone retrievals is of importance for reducing Dobson total ozone seasonal biases. The methods for the temperature correction applications (i.e. climatological vs. daily corrections) have yet to be validated. (NASA, NOAA)

Profile Ozone
Ozone profile information has critical importance for both ozone recovery and climate change. The vertical structure of ozone (~ 1 km resolution) near the tropopause is crucial to calculating the radiative forcing of ozone on climate. Furthermore, polar ozone recovery should first manifest itself in the 20-24 km region of the polar stratosphere. Models of ozone suggest that the cooling of the stratosphere will accelerate ozone recovery in the upper stratosphere leading to a "super-recovery". Hence, observations of the vertical structure of ozone have a bearing on two key scientific issues: ozone recovery and climate change. Some of these profile observations have been provided by MLS and OMI instruments aboard the AURA satellite since 2004 and, since 2013, by the OMPS Limb instrument on NPP. The OMPS ozone limb observations will be continued on the JPSS-2 platforms. OMPS-Limb is now joined by the SAGE-III on the International Space Station, which may provide useful data to about the end of the lifetime of ISS (~2023)

The SPARC activity "Observing Composition Trends and Variability in the UTLS" (OCTAV-UTLS) aims to develop unified, consistent, geophysically-based sampling metrics that can be applied to analyze data from different observation UTLS techniques. For the first time, the comprehensive data sets from different platforms will be consistently compared in the UTLS

using the same metrics (e.g. tropopause and jet relative coordinates referencing) derived from reanalysis data. This approach will help to assess the effect of platform dependent sampling on atmospheric composition (i.e. ozone and water vapor) and improve their trend estimates in the UTLS (NOAA, NASA)

A clear understanding of ozone trends and their significance as a function of altitude and latitude is still needed, nearly 20 years after the peak of ozone depleting substances in the stratosphere. A previous activity sponsored by SPARC, IO3C, IGACO-O3/UV and NDACC (SI2N) evaluated trends derived from long-term ozone profile records (ground-based and satellites, including merged satellite data records). The SPARC LOTUS (Long-term Ozone Trends and Uncertainties in the Stratosphere) activity goals are (a) to update and extend stratospheric ozone observations to recent years, (b) to improve our understanding of crucial yet poorly known sources of uncertainties in trend retrieval, (c) to investigate how uncertainties interact and propagate through the different stages of the analysis chain, and (d) to re-evaluate current best practice(s) and possibly establish more suitable alternatives. (NOAA, NASA).

There is a vast amount of unprocessed Brewer Umkehr data residing in the archives. A concerted effort should be made to process these data using a common Dobson/Brewer algorithm, which is necessary for trend studies. The new Brewer Umkehr algorithm to derive ozone profiles under low sun condition is also in works (NASA, NOAA)

NASA has two Earth Science Decadal Survey satellite missions recommended in the future. One (GEO-CAPE) is a geosynchronous orbit and designed to study North American air quality, but should also provide column ozone. The second (GACM) is described as a follow up to Aura with analogous instrumentation using more advanced technology. This will provide profiles for ozone and numerous trace gases in the stratosphere and troposphere. Though a portion of the GEO-CAPE mission science is being achieved by the competitively selected TEMPO mission of opportunity mission, neither full project has entered the formulation stage, and won't before the next Decadal Survey is released in late 2017. At that time, NASA is expected to reassess the priorities of missions that are programmatically directed. (NASA)

In order for ozone forecasts to improve in the NCEP/GFS, higher quality and greater numbers of ozone profiles need to be available for assimilation than what is available from the current nadir viewing SBUV/2. Ozone profiles from the Aura/MLS and OMI are promising as they provide ozone profiles of greater resolution (MLS) and of greater horizontal coverage (OMI). These products are now available in near-real-time, and are being assimilated into the NCEP/GFS. (NOAA/CPC)

Ozone-Relevant Gases and Variables

Ozone- and Climate-Related Trace-Gas Measurements
There is a need to maintain and expand the existing *in situ* networks, both geographically and with improved instrumentation. Current workforce limitations prevent the development and propagation of gas standards on as rapid a schedule as required by these networks to keep up with the increasing number of new chemicals of scientific interest. In addition, expanded efforts are needed for data analysis as more and more chemicals are being measured. An intercomparison study, IHALACE, for halocarbon standards between measurement groups that has examined differences in the individual gases was completed and a paper summarizing the results has been submitted for publication. The work found that most independent calibration groups agreed well for most compounds (<5%), but groups using the same calibration standards did not transfer the calibration. (NASA, NOAA)

Aerosol Absorption Optical Thickness (AAOT)
There are currently no operational ground-based instruments that provide AAOT in UV. AAOT from the AERONET network is limited to wavelengths longer than 440 nm. NASA has improved a long-standing technique to derive AAOT in UV by combining measurements from AERONET and UV Shadowband radiometers. Efforts to utilize this methodology for deriving AAOT in the UV should be implemented. (NASA)

NEUBrew Network
Future plans for the NEUBrew network are for algorithm development for aerosol optical thickness retrievals and direct-sun data processing to provide aerosol optical thickness estimates at the five direct-sun measured UV ozone and five visible NO_2 wavelengths.

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Field Campaigns
Aircraft, balloon, and ground-based measurement campaigns for satellite validation and science are expected to continue, but at a much lower level than in the past since Aura is in its Extended Mission phase now. These campaigns will provide important validation data for ozone and ozone- and climate-related trace gases and parameters for Aura and other satellite sensors. They also will address high-priority science questions associated with atmospheric ozone chemistry and transport. (NASA)

UV

USDA UV-B Monitoring and Research Programme (UVMRP)
A new site was installed at the University of Texas at El Paso (UTEP) in November 2008. (UDSA)

Geographical Measurement Coverage
UV monitoring in the tropics is very limited. Relatively inexpensive broadband UV instruments could be set up easily at installations launching ozonesondes (e.g., SHADOZ) in the tropical region. Such efforts should be coordinated with the NDACC. In this way, UV at the surface under aerosols/pollution can be linked with the ozone profiles measured by the ozonesondes and ground-based profiling instruments. (NOAA/CPC)

Only seven of the EPA Brewers are currently deployed in or near densely populated areas. Satellite-derived UVR is less reliable for urban locations, because satellite instruments do not adequately characterize pollutants at ground level. Because of the deficiency of current urban UVR data, health researchers conducting local studies are sometimes making their own UVR measurements as needed, with instruments that are often not easily compared with those from any of the existing UVR networks. Thus, better ground-level measurements collected in locations close to air-quality monitors are required. Finally, many sites have data gaps and inconsistencies. Only a limited number of ground-based sites provide historically continuous UV records. More analyses
of available data and improved calibration could fill gaps in coverage**.** (EPA)

Calibration and Validation
It is now well established that the ratio of UVB and UVA can be predicted accurately under clear conditions and to within a few percent in cloudy conditions wherever quality column ozone data exist. Absolute measurements of ozone amounts from satellites are accurate to 2% resulting in a 2% error in UV irradiance at 310 nm and an 8% error at 305 nm with larger errors at higher latitudes. UVA variability is known to correlate with variations in clouds, NO2, and aerosols, some of which are also measured by satellites. Ground based intercomparisons studies are using long time averages to simulate the spatial footprint of satellites. Further studies are required to determine the effectiveness of this approach. (NASA)

Effects Research
Although the effects of UV exposure drive UV monitoring activities, only limited resources historically have been targeted towards UVB effects research. Expansion of UVMRP activities in this critical area is needed at a multi-agency level. (USDA)

Acronyms and Abbreviations

AAOT aerosol absorption optical thickness
ACIA Arctic Climate Impacts Assessment
AERONET Aerosol Robotic Network
AGAGE Advanced Global Atmospheric Gases Experiment
AIRS Atmospheric Infrared Sounder
AO/AAO Arctic/Antarctic oscillation
BSI Biospherical Instruments
BUV Backscatter Ultraviolet
CAFS CCD Actinic Flux Spectroradiometer
CCD charge-coupled device
CDIAC Carbon Dioxide Information Analysis Data Center
CFC chlorofluorocarbon
COADS Comprehensive Ocean-Atmosphere Data Set
CPC Climate Prediction Center (NOAA, U.S.)
CrIS Cross-track Infrared Sounder
CSD Chemical Sciences Division (formerly the Aeronomy Lab, NOAA, U.S.)
CSD Chemical Sciences Division (NOAA,US)
CSU Colorado State University (United States)
CTMs chemical transport models
CUCF Central Ultraviolet Calibration Facility
DAAC Distributed Active Archive Center (NASA Langley, U.S.)
DISC Data and Information Services Center (NASA Goddard, U.S.)
DoD Department of Defense (United States)
DoE Department of Energy (United States)
DOAS Differential Optical Absorption Spectroscopy
ECD electron capture detector
ECMWF European Centre for Medium-Range Weather Forecasts (United Kingdom)
ECUV European UV Calibration Center
EECl effective equivalent chlorine
EESC effective equivalent stratospheric chlorine
EOS Earth Observing System
E EuMetSat European Organization for the Exploitation of Meteorological Satellites
P Earth Probe
EPA Environmental Protection Agency (United States)
ESRL Earth System Research Laboratory (NOAA, US)
FMI Finnish Meteorological Institute (Finland)
FTIR Fourier transform infrared
GAW Global Atmosphere Watch
GC Gas Chromatograph
GCM general circulation model
GCMS Gas Chromatography Mass Spectrometry
GES Goddard Earth Sciences
GFS Global Forecast System
GMAO Global Modeling Assimilation Office (NASA Goddard, U.S.)
GMD Global Monitoring Division (formerly CMDL – NOAA, U.S.)
GOES Geostationary Operational Environmental Satellite
GO3OS Global Ozone Observing System (WMO)
GOME Global Ozone Monitoring Experiment
GOMOS Global Ozone Monitoring by Occultation of Stars
GSFC Goddard Space Flight Center (NASA, U.S.)
HALOE Halogen Occultation Experiment
HIRDLS High-Resolution Dynamics Limb Sounder
HIRS High-resolution Infrared Radiation Sounder
IHALACE International Halocarbons in Air Comparison Experiment
IASI Infrared Advanced Sounding Interferometer
JPL Jet Propulsion Laboratory (United States)
JPSS Joint Polar Satellite System (United States)
KNMI Koninklijk Nederlands Meteorologisch Institut (The Netherlands)

MetOp Meteorological Operational Satellite
MFRSRs Multi-Filter Rotating Shadowband Radiometers
MIPAS Michelson Interferometer for Passive Atmospheric Sounding
MIRAGE Megacity Impacts on Regional and Global Environments
MLS Microwave Limb Sounder
NASA National Aeronautics and Space Administration (United States)
NAT nitric acid trihydrate
NCAR National Center for Atmospheric Research (United States)
NCEP National Centers for Environmental Prediction (NOAA, U.S.)
NDACC Network for the Detection of Atmospheric Composition Change
NDIR non-dispersive infrared
NESDIS National Environmental Satellite, Data, and Information Service (NOAA, U.S.)
NIST National Institute of Standards and Technology (United States)
NIWA National Institute of Water and Atmospheric Research (New Zealand)
NOAA National Oceanic and Atmospheric Administration (United States)
NOGAPS Navy Operational Global Atmospheric Prediction System
NRL Naval Research Laboratory (United States)
NSF National Science Foundation (United States)
NWS National Weather Service (NOAA, U.S.)
ODGI ozone-depleting gas index
ODSs ozone-depleting substances
OHP Observatoire de Haute-Provence (France)
OMI Ozone Monitoring Instrument
OMPS Ozone Mapping and Profiler Suite (NPOESS)
OMS Observations of the Middle Stratosphere
OSIRIS Optical Spectrograph and Infrared Imaging System
PEM Particle Environment Monitor
POAM Polar Ozone and Aerosol Measurement
POES Polar Orbiting Environmental Satellites
PSCs polar stratospheric clouds
PTB Physikalisch-Technische Bundesanstalt (Germany)
QBO quasi-biennial oscillation
SAGE Stratospheric Aerosol and Gas Experiment
SAM Stratospheric Aerosol Measurement
SBUV Solar Backscatter Ultraviolet
SCIAMACHY Scanning Imaging Absorption Spectrometer for Atmospheric Cartography
SHADOZ Southern Hemisphere Additional Ozonesonde (Network)
SOLSTICE Solar Stellar Irradiance Comparison Experiment
SPARC Stratospheric Processes and Their Role in Climate

ZIMBABWE

1. OBSERVATIONAL ACTIVITIES

1.1 Column measurements of ozone and other gases/variables relevant to ozone loss

(e.g., Dobson, Brewer, DOAS, FT-IR, Satellite; also include any measurements of meteorological parameters that are critical to the interpretation of your ozone and ozone-relevant data)

The Meteosat Secondary Generation (MSG) satellite is used for meteorological parameter observation. Ozone and other gases are not measured except for water vapour.

1.2 Profile measurements of ozone and other gases/variables relevant to ozone loss

(e.g., Satellite, OMI, aircraft, ozonesondes, ozone lidar etc; also include any measurements of meteorological parameters that are critical to the interpretation of your ozone and ozone-relevant data)

There are no measurements of ozone and other gases at the moment in Zimbabwe.

1.3 UV measurements

(e.g., broadband, narrowband, Spectroradiometers, etc)

Currently there are no measurements of UV in Zimbabwe as there are no instruments.

1.4 Calibration activities

There are no calibration activities in Zimbabwe at the moment**.**

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

(e.g., trend analyses, UV doses (annual, monthly etc.), UV maps)

These are not available but mostly weather and climate related data.

3. THEORY, MODELLING, AND OTHER OZONE RELATED RESEARCH

(e.g., 3-D CTM modelling, data assimilation, use of satellite data, UV effect studies)

There is ongoing research particularly by Zimbabwean students abroad but the research activities are not coordinated to give a true National profile of the parameters.

4. DISSEMINATION OF RESULTS

4.1 Data reporting

(e.g., submission of data to the WOUDC and other data centres)

Data reporting on ozone and UV measurements to the WOUDC and other data centres is currently not happening in Zimbabwe.

4.2 Information to the public
(e.g., UV forecasts)

UV forecasts are not done and therefore not disseminated to the public. Only weather data is disseminated to the public through print and electronic media.

4.3 Relevant scientific papers

Not available or very limited, if any.

5. PROJECTS, COLLABORATION, TWINNING AND CAPACITY BUILDING
(e.g., national projects, international projects, other collaboration (nationally, internationally))

These have not been happening but there is need for projects collaboration, twinning and capacity building through exchange and secondment to well established institutions Regionally and Internatioonally. The country will benefit immensely from such collaborative efforts.

6. IMPLEMENTATION OF THE RECOMMENDATIONS OF THE 9th OZONE RESEARCH MANAGERS MEETING
(e.g., specifics on progress towards such implementation, difficulties encountered,
near-term plans, etc.)

A. Overarching Goals – There has been close collaboration between the Ozone and Climate Change Offices in Zimbabwe. Most programs are jointly implemented but since the Country does not have capacity to monitor ozone and other gases, the activities have been confined to awareness raising, training and containment of emissions from ODS dependent appliances.

7. FUTURE PLANS
(e.g., new stations, upcoming projects, instrument development)

There is need for new set of ground based remote sensing equipment, stations and observation networks across the country including LIDARS, RADARS among others.

8. NEEDS AND RECOMMENDATIONS

Zimbabwe is planning to develop and submit a project proposal for developing a strategy on integrated observation and monitoring of ozone and other gases as well as UV measurements. The strategy will spell out the framework and institutional arrangements for monitoring activities**.**

ANNEX E

WMO/UNITED NATIONS ENVIRONMENT PROGRAMME TENTH MEETING OF THE OZONE RESEARCH MANAGERS OF THE PARTIES TO THE VIENNA CONVENTION FOR THE PROTECTION OF THE OZONE LAYER (Geneva, 28-30 March 2017)

ABBREVIATIONS AND CHEMICAL NOMENCLATURE

ABBREVIATIONS

3D	three-dimensional
ACE-FTS	Atmospheric Chemistry Experiment – Fourier Transform Spectrometer
ACP	*Atmospheric Chemistry and Physics* journal
ACT-America	Atmospheric Carbon and Transport – America
AEMET	Agencia Estatal de Meteorología – Meteorological State Agency, Spain
AERONET	Aerosol Robotic Network
AIRS	Atmospheric Infrared Sounder
ALTIUS	Atmospheric Limb Tracker for the Investigation of the Upcoming Stratosphere
AMT	*Atmospheric Measurement Techniques* journal
AOPC	Atmospheric Observation Panel for Climate
ASCENDS	Active Sensing of CO_2 Emissions over Nights, Days, and Seasons
ATom	Atmospheric Tomography Mission
AVDC	Aura Validation Data Centre
BDC	Brewer-Dobson Circulation
BIRA-IASB	Koninklijk Belgisch Instituut voor Ruimte-Aeronomie – Institut Royal d'Aeronomie Spatiale de Belgique - Royal Belgian Institute for Space Aeronomy
BoM	Australian Bureau of Meteorology
BUV	Backscatter Ultraviolet
CarbonSat / TanSat	Chinese Earth observation satellite dedicated to monitoring carbon dioxide in the Earth's atmosphere, also known as TanSat
CAS	Chinese Academy of Sciences
CCI	Climate Change Initiative
CCD	charge-coupled device
CCM	chemistry-climate model
CCMI	Chemistry-Climate Modelling Initiative
CDIAC	Carbon Dioxide Information Analysis Centre
CEOS	Committee on Earth Observation Satellites
CFC	chlorofluorocarbon
CMA	China Meteorological Administration
CMIP	Climate Modelling Intercomparison Project
CNES	Centre National d'Etudes Spatiales
CNR	Consiglio Nazionale delle Ricerche – National Research Council of Italy
CNRS	Centre National de la Recherche Scientifique – National Centre for Scientific Research, France
CONICET-CEPROCOR	Consejo Nacional de Investigaciones Científicas y Técnicas - Centro de Excelencia en Procesos y Productos de Córdoba - Argentinian National Scientific and Technical Research Council

CoP	Conference of the Parties to the Vienna Convention
COST	Cooperation in Science and Technology
CSA	Canadian Space Agency
CTM	chemistry-transport model
DAAC	Distributed Active Archive Centre (NASA)
DIAL	Ozone Differential Absorption Lidar
DLR	Deutsches Zentrum für Luft-und Raumfahrt – German Aerospace Centre
DOAS	differential optical absorption spectroscopy
DWD	Deutscher Wetterdienst – National Meteorological Service, Germany
EC	European Commission
ECHOZ	Ecuadorian Highlands Ozonesondes
ECMWF	European Centre for Medium-Range Weather Forecasts
ECV	Essential Climate Variable
EEAP	Environmental Effects Assessment Panel (Montreal Protocol)
EnvironSat	Environmental Satellite, India
EO	Earth Observation
EOS	Earth Observing System, U.S.
EPA	Environmental Protection Agency, USA
ERS-2	European Remote Sensing-2
ESA	European Space Agency
ESRIN	ESA Centre for Earth Observation
ESSD	*Earth System Science Data* journal
EU	European Union
EUBrewNet	European Brewer Network
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EVDC	ESA Validation Data Centre
FTS	Fourier transform spectrometer
FTIR	Fourier transform infrared
Gaofen-5 GMI	Gaofen-5 (GF, high-resolution) Greenhouse-gases Monitoring Instrument
GAW	Global Atmosphere Watch Programme
GAWTEC	GAW Training and Education Centre
GCOS	Global Climate Observing System
GCM	general circulation model
GEMS	Geostationary Environmental Monitoring Spectrometer
GEO-AQ	Geostationary Earth Orbit – Air Quality satellite constellation
Gg	gigagram (10^9 grams), a unit of mass
GHG	greenhouse gas
GOCI	GEO Ocean Colour Imager
GOME	Global Ozone Monitoring Experiment
GOMOS	Global Ozone Monitoring by Occultation of Stars
GOSAT	Greenhouse Gases Observing Satellite
GOZCARDS	Global Ozone Chemistry and Related Trace Gas Data Records for the Stratosphere
GRUAN	GCOS Reference Upper Air Network
GSN	GCOS Surface Network
GUAN	GCOS Upper Air Network
GURME	GAW Urban Research Meteorology and Environment project
GWP	global warming potential
HCFC	hydrochlorofluorocarbon
HFC	hydrofluorocarbon
HFO	hydrofluoroolefin

HRSS	High-Resolution SWIR Spectrometer
IAGOS	In-service Aircraft for a Global Observing System
IARC	Izaña Atmospheric Research Centre
IASI	Infrared Atmospheric Sounding Interferometer
IASI-NG	Infrared Atmospheric Sounding Interferometer – Next Generation
ICAO	International Civil Aviation Organization
IGAC	International Global Atmospheric Chemistry
IGACO-O_3	Integrated Global Atmospheric Chemistry Observations – Ozone
IG^3IS	Integrated Global Greenhouse Gas Information System
IKFS	Infrared Fourier Spectrometer
INSMET	Instituto de Meteorología de Cuba – Cuban Institute of Meteorology
INTA	Instituto Nacional de Técnica Aeroespacial
IO_3C	International Ozone Commission
IR	infrared
ISAC	Institute of Atmospheric Sciences and Climate
ISO	International Organization for Standardization
ISRO	Indian Space Research Organization
IUGG	International Union of Geodesy and Geophysics
JAXA	Japan Aerospace Exploration Agency
JMA	Japanese Meteorological Agency
JOSIE	Jűlich Ozone Sonde Intercomparison Experiment
JPSS	Joint Polar Satellite System
JPSS-2	Second Joint Polar Satellite System
KARI	Korea Aerospace Research Institute
KNMI	Koninklijk Nederlands Meteorologisch Instituut – Royal Netherlands Meteorological Institute
KORUS-AQ	Korea–United States Air Quality Study
LOTUS	Long-Term Ozone Trends and Uncertainties in the Stratosphere
LTDP	long-term data preservation
MAESTRO	Measurements of Aerosol Extinction in the Stratosphere and Troposphere Retrieved by Occultation
MAGICC6	Model for the Assessment of Greenhouse-gas-Induced Climate Change - 6
MAX-DOAS	Multi Axis Differential Optical Absorption Spectroscopy
MetMalaysia	Malaysian Meteorological Department
MetOp (A,B,C)	Meteorological Operational Satellite
MetOp-NG	Meteorological Operational Satellite – Next Generation
MEVBIS	Meteorological Data and Information System
MIPAS	Michelson Interferometer for Passive Atmospheric Sounding
MLS	Microwave Limb Sounder
MoP	Meeting of the Parties to the Montreal Protocol
MOPITT	Measurements Of Pollution In The Troposphere
MS	Mendel Station (Antarctic Peninsula)
MSG-IRS	Meteosat Second Generation InfraRed Sounder
MSR-2	Second Multisensor Reanalysis Set
MZS	Mario Zucchelli Station (Antarctica)
NASA	National Aeronautic and Space Agency, USA
NDACC	Network for the Detection of Atmospheric Composition Change
NERC	Natural Environment Research Council
NetCDF	Network Common Data Form
NIWA	National Institute of Water and Atmospheric Research, New Zealand (Taihoro Nukurangi)
NOAA	National Oceanic and Atmospheric Administration, USA

NRT	near-real-time
NSF	National Science Foundation, USA
NSMC	National Satellite Meteorological Centre, China
O_3S-DQA	Ozonesonde Data Quality Assessment
OCO-2, -3	Orbiting Carbon Observatory-2, -3
OCTAV-UTLS	Observed Composition Trends and Variability in the Upper Troposphere and Lower Stratosphere
ODA	official development assistance
ODS	ozone-depleting substance
OGC	Open Geospatial Consortium
OMI	Ozone Monitoring Instrument
OMPS	Ozone Mapping Profiler Suite
ORACLES	ObseRvations of Aerosols above CLouds and their intEractionS
ORM	Ozone Research Managers
OSSE	Observing System Simulation Experiment
OSIRIS	Optical Spectrograph and InfraRed Imager System
PAGASA	Philippine Atmospheric Geophysical and Astronomical Services Administration
POSIDON	Pacific Oxidants, Sulphur, Ice, Dehydration, and cONvection
RBCC-E	Regional Brewer Calibration Centre (for the RA/VI Region) Europe
RCP	Representative Concentration Pathway
RIVM	Rijksinstituut voor Volksgezondheid en Milieu – National Institute for Public Health and the Environment, Netherlands
QA	quality assurance
QA4EO	GEO Quality Assurance framework for Earth Observation
QBO	quasi-biennial oscillation
SAG	Scientific Advisory Group
SAGE	Stratospheric Aerosol and Gas Experiment
SAOZ	Système d'Analyse par Observation Zénithale
SAP	Scientific Assessment Panel (Montreal Protocol)
SBUV	Solar Backscatter Ultraviolet Instrument
SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Chartography
SCISAT-1	Science Satellite (Canada)
SHADOZ	Southern Hemisphere Additional Ozonesondes
SI^2N	SPARC/IO_3C/IGACO-O_3/NDACC initiative on past trends of the vertical distribution of ozone
SMHI	Swedish Meteorological and Hydrological Institute
SMR	Submillimetre-wave Radiometer
SPARC	Stratosphere-troposphere Processes And their Role in Climate
SRON	Netherlands Institute for Space Research
SSiRC	Stratospheric Sulphur and its Role in Climate
STE	stratosphere-troposphere exchange
Suomi-NPP	Suomi National Polar-orbiting Partnership
TanSat / CarbonSat	Chinese Earth observation satellite dedicated to monitoring carbon dioxide in the Earth's atmosphere, also known as CarbonSat
TCCON	Total Carbon Column Observing Network
TEAP	Technology and Economic Assessment Panel (Montreal Protocol)
TEMIS	Tropospheric Emission Monitoring Internet Service
TEMPO	Tropospheric Emissions: Monitoring Pollution
TES	Tropospheric Emission Spectrometer
TFA	trifluoroacetic acid
TOMS-EP	Total Ozone Mapping Spectrometer – Earth Probe

TOU/SBUS	Total Ozone Unit and Solar Backscatter Ultraviolet Sounder
TROPOMI	TROPOspheric Monitoring Instrument
TUNER	Towards Unified Error Reporting, a SPARC activity
UARS	Upper Atmosphere Research Satellite
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
U.S.	United States
USA	United States of America
USDA	United States Department of Agriculture
UTLS	upper troposphere / lower stratosphere
UV	ultraviolet
VCTF	Trust Fund for Financing Activities on Research and Systematic Observations Relevant to the Vienna Convention, also "Vienna Convention Trust Fund" or "Trust Fund"
VSLS	very short-lived substances
WCRP	World Climate Research Programme
WDC-RSAT	World Data Centre for Remote Sensing of the Atmosphere
WIGOS	WMO Integrated Global Observing System
WIS	WMO Information System
WMO	World Meteorological Organization
WMO RAVI	Regional Association VI (RAVI) of the World Meteorological Organization
WOUDC	World Ozone and Ultraviolet Data Centre

CHEMICAL NOMENCLATURE

BrO	bromine monoxide
CCl_4	carbon tetrachloride, also CTC
CH_4	methane
CH_3Br	methyl bromide
CH_2O	formaldehyde
ClO	chlorine monoxide
CO	carbon monoxide
CO_2	carbon dioxide
HCl	hydrogen chloride (hydrochloric acid)
HNO_3	nitric acid
H_2O	water
N_2O	nitrous oxide
NO_2	nitrogen dioxide
OClO	chlorine dioxide
OCS	carbonyl sulphide
OH	hydroxyl radical
SF_6	sulphur hexafluoride
SO_2	sulphur dioxide

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