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Vienna Convention issues: report of the tenth meeting of the Ozone Research Managers of the Parties to the Vienna Convention

Recommendations of the tenth meeting of the Ozone Research Managers of the Parties to the Vienna Convention

Note by the Secretariat

1. The tenth meeting of the Ozone Research Managers of the Parties to the Vienna Convention for the Protection of the Ozone Layer was held at the headquarters of the World Meteorological Organization in Geneva from 28 to 30 March 2017. At that meeting, the Ozone Research Managers made several recommendations, which are divided into the following five categories:

(a) Overarching goals;

(b) Research needs;

(c) Systematic observations;

(d) Data archiving and stewardship;

(e) Capacity-building.

2. Those recommendations are reproduced in the annex to the present note, without formal editing by the Secretariat. They are relevant to the discussions on the status of the General Trust Fund for Financing Activities on Research and Systematic Observations Relevant to the Vienna Convention, to be held at the eleventh meeting of the Conference of the Parties to the Vienna Convention under agenda item 5 (b). The full report of the Ozone Research Managers will also be available to the Conference of the Parties as a background document.

* UNEP/OzL.Conv.11/1-UNEP/OzL.Pro.29/1.

Annex

Recommendations

A. Overarching Goals

1. 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.

2. *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 ozone-depleting substances (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.

3. *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.

4. *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.

5. *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

6. 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 greenhouse gas (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.

7. 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.

8. From a climate change perspective, the effects of changing climate on stratospheric temperature and chemistry, and of increased greenhouse gas 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 Brewer-Dobson Circulation.

9. 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

10. 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.

11. 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.

12. 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 (CH3Br): 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.

13. 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

14. 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 hydrofluoro-olefins (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 (OSSE), 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 SO_2 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

15. 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

16. 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.

17. 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.

18. 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 (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 N2O, CH4, 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

19. 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 CCl4. 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 re-process 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

20. 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.

21. 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.

22. 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.

23. 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

24. 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.

25. 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 ultraviolet (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.