The New Initiative on Past Changes in the Vertical Distribution of Ozone

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Introduction

Over three and a half decades have passed since Molina and Rowland postulated that anthropogenic chlorofluorocarbons could deplete the ozone layer (Molina and Rowland, 1975), and over two and a half decades have passed since the discovery of the ozone hole (Farman *et al*., 1985). In this time, the countries of the world have produced and signed the Montreal Protocol limiting the production of ozone-depleting substances (ODSs), and leading to reductions in their atmospheric concentrations (WMO, 2011). As we proceed towards the expected ozone recovery from the influences of ODSs, scientific questions concerning the detection and attribution of that recovery have come to the fore. Answering many of these questions will require a critical examination of the pattern and time sequence of ozone change.

These questions can be split into two main categories:

(i) long-term ozone changes associated with the declining concentration of ODSs and from the increases in greenhouse gases; and

(ii) short-term ozone changes (related to, *e.g*., volcanic eruptions, QBO or ENSO), which will moderate the longer-term changes.

Within each category a number of important questions can be identified. The questions associated with the long-term changes are often relevant for both science and policy. Can we identify the effects of the reduction of ODS concentrations on ozone amounts? Is ozone increasing? If so, is the increase statistically significant? Where is it increasing? Can we separate the causes of the ozone changes over the recent decades? How much of the ozone depletion was and how much of the stabilisation/recovery is due to ODS changes? What was the peak ozone depletion resulting from ODSs and how well is that modelled? What are the impacts of climate variability and of climate change? In particular, is there a significant ozone trend in the tropical lower stratosphere as a result of an acceleration in the residual circulation (*e.g*., Ray *et al*., 2010)?

The questions associated with the shorter-term ozone changes are primarily scientific in nature and are associated with improving our understanding of atmospheric processes (*e.g.,* by testing current models). These can be related to the various modes of internal variability (QBO, ENSO, *etc*.), or to external forcings such as volcanic eruptions, or the 27-day or 11-year cycles in solar variability (*e.g.,* Fioletov, 2009).

For all of these, accurate knowledge of the altitude, latitude, and seasonal structure of the ozone response is required. To address the long-term questions, it is important to have a set of stable measurements extending over decades. For the short-term questions, it is as important to have good spatial and temporal coverage. For both issues, it is critical that the quality of the measurements used is as high as possible, and that the quality is known. To this end, a workshop was convened in January 2011 with the support of SPARC, the International Ozone Commission (IOC) and the ozone focus area of the Integrated Global Atmospheric Chemistry Observations (IGACO-O3) programme. Over 50 experts attended who are familiar with satellite, ground-based and airborne measurements, as well as in methods of preparing combined data sets. These experts agreed to set up a joint initiative to assess the current knowledge and understanding about the measurements of the vertical distribution of ozone, with the aim of providing input to the next WMO Scientific Assessment of Ozone Depletion anticipated for 2014. This article describes the current state of the measurements, the on-going projects in this area and the structure and plans for the initiative. The initiative is being organised under the auspices of SPARC, IOC, IGACO-O3 and the Network for the Detection of Atmospheric Composition Change (NDACC).

Ozone Measurements

High quality measurements of total ozone are now made routinely by several systems which are stable to ~1% per decade. These systems all show the same regional patterns in the total ozone evolution over the last 30 years, most notably the lack of a long–term trend in the tropics, and different evolutions of total ozone in the Northern and Southern hemispheres (see **Figure 1**). Once identified, such patterns need to be explained in terms of the halogen loading, the volcanic signals, polar ozone depletion and the influence of dynamical forcing from the troposphere (*e.g*., Harris *et al.*, 2008). However, it is hard to be completely sure about these explanations using only total ozone measurements. Information about changes in the 3-dimensional spatial nature of the ozone concentrations would place significantly tighter constraints on the possible explanations.

During the 1990s, ozone profile trends deduced from different instruments (satellite instruments SAGE I and II, SBUV, and ground-based instruments) showed substantial discrepancies. A cooperative effort was organised to resolve the differences which resulted in the first SPARC Assessment Report (SPARC/IOC/GAW, 1998). The core of the report was the recognition that the SAGE record was the only one that could provide global coverage of ozone changes in the lower stratosphere, while both SAGE and SBUV could provide global coverage in the upper stratosphere. Ground-based measurements with longer records (ozonesondes, Umkehr) were assessed for consistency where sufficiently long records existed (principally northern mid-latitudes). Shorter records (*e.g*., HALOE, lidar and other newer techniques used at NDACC stations) were used for validation. Trends based on a combined SAGE, SBUV, Umkehr and ozonesonde record at northern mid-latitudes showed that (a) most of the total ozone trend at northern mid-latitudes resulted from trends in the lower stratosphere; and (b) a secondary trend maximum occurred at 40 km where gas phase chemistry was expected to dominate. Elsewhere, it was hard to say much categorically about the trends as a result of the larger uncertainties.

It is now 15 years since that assessment took place. In that time, the stratospheric halogen loading has started to decrease, the impact of Mt Pinatubo has decreased and the importance of dynamical effects in determining lower stratospheric ozone over decades is more clearly recognised. All three factors make analysis of the ozone record trickier. On the measurement side, SAGE II continued until 2005, giving a 21-year record. While there has been no global follow-up to the first two SAGE instruments, many new satellite instruments have been launched since 2000. To date there has been no thorough assessment of how well these new measurements agree with each other or – most importantly for studies of long-term changes – the SAGE record. The ground-based records are also 15 years longer, and with their improved geographic coverage have the potential to provide a global view about ozone changes in their own right (Steinbrecht *et al*., 2009). However, due to the lack of rigorous evaluation between satellite instruments, few trend analyses using satellite ozone profile data have been performed since the WMO (2007) report, *i.e*., the satellite records did not provide significant updates of the long-term changes for the WMO (2011) report. The SBUV (/2) instrument series now provides the only internally consistent satellite record, and even that has issues associated with the orbits of the different instruments. Biases between some of these instruments are comparable with long-term ozone changes (*e.g*., Terao and Logan, 2007; Fioletov *et al*., 2008) and make the combined record difficult to use for the trend estimates. **Figure 2** shows the time periods each instrument type has operated over. It is clear that the key to having a continuous record for both ground-based and satellite instrument types is now ensuring that measurements from individual instruments are comparable.

Workshop Outcome: the Second Ozone Initiative

There is thus limited knowledge of the changes in the vertical distribution of ozone that have occurred globally since 2005, a situation which is unsatisfactory given the importance of the scientific issues discussed above and the size of the investment in the ozone monitoring systems. The workshop in Geneva was held to discuss how to improve our knowledge and understanding of the past changes in the vertical distribution of ozone, and covered the following topics:

- satellite data retrieval, quality and records;
- ground-based measurements retrieval, quality and records;
- procedures for merging ozone measurements from different sources; and
- definition of a new ozone initiative.

From the workshop it become clear that real opportunities exist to make progress in improving our understanding of the existing measurement record, and that a new ozone initiative would provide valuable information for the next WMO Ozone Assessment, anticipated in 2014. A number of formats for the initiative ranging from a full SPARC assessment (as with the first ozone report) to a set of coordinated papers or technical reports (shorter, more focused on single issues) were discussed. The work required is heterogeneous and it was decided to pursue the latter option for a year or so, before discussing the outcomes and the way ahead at a second workshop in the first half of 2012. The preferred option is to write a summary assessment based on the work in the six working groups described below, which should be published separately either as papers or technical reports, published under the auspices of the space agencies, IGACO-O3 or SPARC, for example. The working groups are shown in **Figure 3,** and the timetable is shown in **Figure 4**.

There is a lot of work already going on within existing projects and programmes, which could be enhanced by a degree of international coordination. The major space agencies involved (US National Aeronautics and Space Administration (NASA), Canadian Space Agency (CSA), European Space Agency (ESA) and the national space agencies in Europe) all have projects aimed principally at improving the measurement record over the last decade. These projects are focusing on the measurements (including ozone among a range of species) made by instruments on the ENVISAT, AURA, ODIN and SCISAT satellites, and are already contributing to the SPARC Data Initiative. They will also work closely together in the new ozone initiative, largely sticking to their existing work-plans but also developing a few collaborative initiatives to ensure that the quality of the data over the last decade is well understood and that the strengths and weaknesses of each ozone data set for studies of climate variability (*e.g.,* spatial and temporal coverage and resolution) are well characterized and documented. M. van Roozendael and L. Froidevaux are coordinating this working group.

The work by this group is complemented by the work from the group on long-term satellite measurements. The main aim here is to improve our knowledge of processes in the lower stratosphere by extending the SAGE record from 2005. In the first instance, this will be tried using the measurements made by the GOMOS instrument because of the similarity in the measurement approach (solar occultation for SAGE and stellar occultation for GOMOS) and the three years of simultaneous measurements. It is very important to have confidence in this extension and so other instruments (*e.g*. OSIRIS, SCIAMACHY) will also be tried. It is possible that the SAGE II data will be reprocessed using recent reanalyses – more interestingly in terms of the length of the record, SAGE I (1979-1981) will be reprocessed in order to make it more consistent with the SAGE II measurements, and to remove the need for an altitude offset when considering the combined record. This work with SAGE will be performed in conjunction with further work on consolidating the SBUV(/2) record.

In between these two satellite-based groups are the ground-based working groups whose results will contribute to our understanding of the longer-term changes and to the variability in the last decade.

The geographic coverage of all the instrument types has improved significantly through the on-going efforts of WMO and NDACC, and while the longest records (over 40 years) are limited to northern mid-latitudes, the coverage now is quasi-global. The NDACC working groups are set up to continuously assess and assure the data quality of their ground-based measurements. The working groups (led by S. Godin-Beekman, T. Leblanc, N. Kämpfer, G. Neduloha, J. Hannigan and M. De Mazière) on lidar, microwave and FTIR instruments will take the lead within the new ozone initiative to ensure that the NDACC instruments contribute to the initiative on the requisite time scales. Full use will be made of existing working group meetings and the NDACC science meeting in La Réunion in November 2011.

In a similar manner, working groups on ozonesondes (led by S. Oltmans and H. Smit) and Umkehr (T. McElroy and I. Petropavlovskikh) measurements will work to produce improved measurement records. For ozonesondes, the aim is two-fold: first, to produce a fully homogenized data set for more than a decade, and hopefully quite a bit more, based on recent work characterizing differences between ozonesonde types. Secondly to provide or identify full, clear documentation about the homogenization process and about the quality of ozonesonde measurements generally to allow the recent record to be linked to the older records. The main thrust of the Umkehr working group is to provide a consistent set of ozone profiles from the Brewer instruments. The measurements from the sparser Dobson network are already of high quality, and there is a real opportunity to expand the spatial scale of the Umkehr network if the Brewer data can be worked up.

A common theme to all the working groups described above is that they entail combining the measurements from different instruments. In many cases these instruments are of the same basic design, but almost invariably improvements have been made over the years. While these improvements are generally a good thing, they do complicate matters when it comes to studying long-term changes. Matters are even more complicated when measurements from different instrument types are combined – and that is essential if the SAGE record is to be extended. Accordingly, a sixth working group (led by G. Bodeker and N. Harris) will assess the different approaches to producing multi-instrument ozone data, based on experience with ozone and other geophysical data sets.

Looking Ahead

The time is right for a second ozone initiative – there is a real need for better information about the long-term changes in ozone as well as in ozone's response to climate variability. A flexible plan was agreed upon in Geneva, which allows us to respond to the results from the first year's diverse activities and to re-define the priorities and the plans. The working groups described above will discuss their findings at a second workshop to be held in the first half of 2012. This discussion will lead to a clearly defined plan for the second half of the new ozone initiative so that the findings can be used in the preparation of the next WMO Ozone Assessment. Updated information about the initiative can be found at http://igaco-o3.fmi.fi/VDO/index.html.

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Figures:

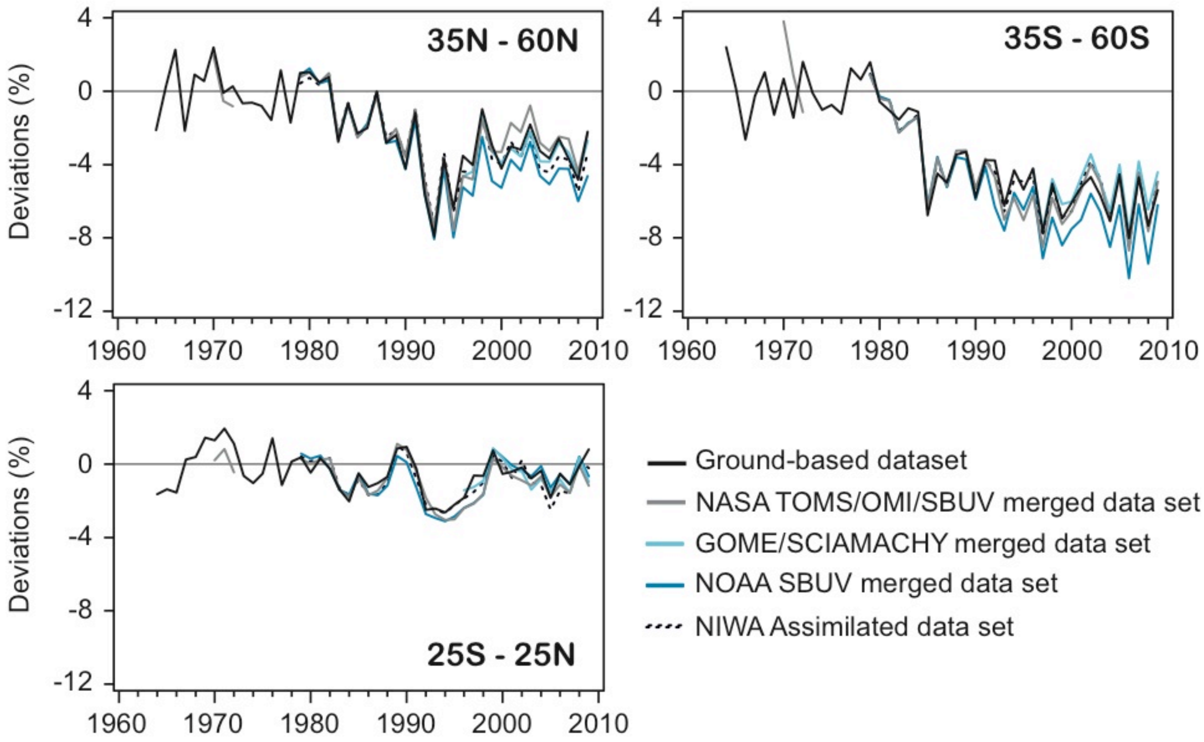

Figure 1. Annual mean area-weighted total ozone deviations from the 1964–1980 means for the latitude bands 25°S–25°N, 35°N–60°N, and 35°S–60°S, estimated from different global data sets: ground-based (black), NASA TOMS/OMI/SBUV(/2) merged satellite data set (gray), National Institute of Water and Atmospheric Research (NIWA) assimilated data set (cyan), NOAA SBUV(/2) (blue), and GOME/SCIAMACHY merged total ozone data (light blue). Each data set was deseasonalised with respect to the period 1979–1987. The average of the monthly-mean anomalies for 1964–1980 estimated from ground-based data was then subtracted from each anomaly time series. Deviations are expressed as percentages of the ground-based time average for the period 1964–1980. Adapted from Chapter 2 of WMO (2011).

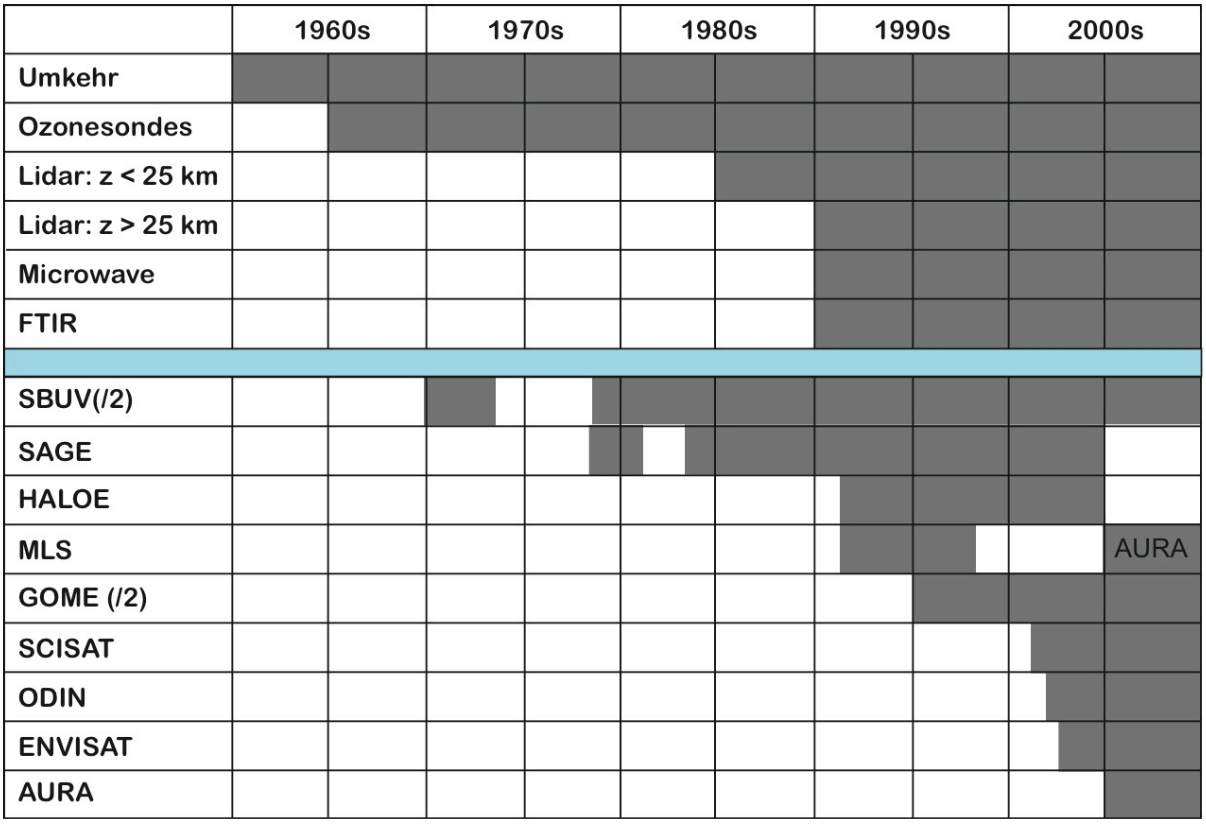

Figure 2. Periods of operation of the main instrument systems that measure the vertical distribution of ozone. Ground-based measurement systems are shown in the top part of the figure; satellite-based instruments in the bottom half. The geographic coverage and numbers of the ground-based instruments has increased over the years.

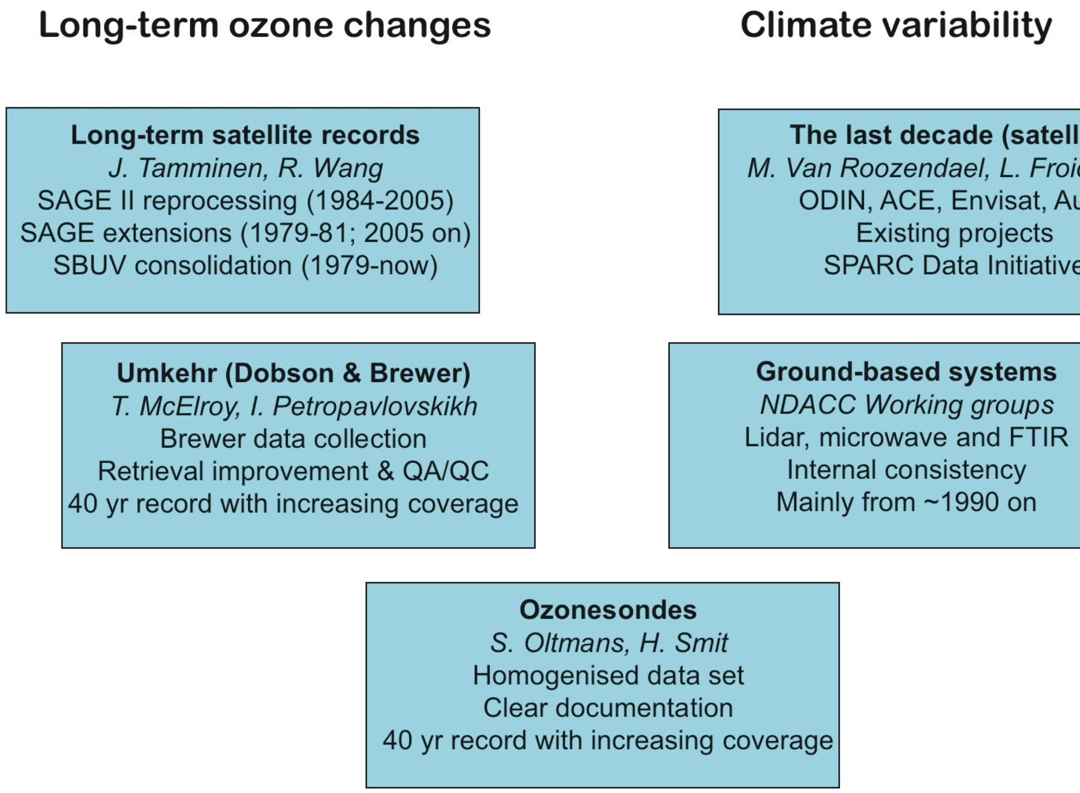

Figure 3. Schematic of the five main working groups in the second ozone initiative. The sixth working group looking at the different approaches to combining data sets is led by G. Bodeker and N. Harris. The remit in these six work packages will be re-assessed at the second workshop.

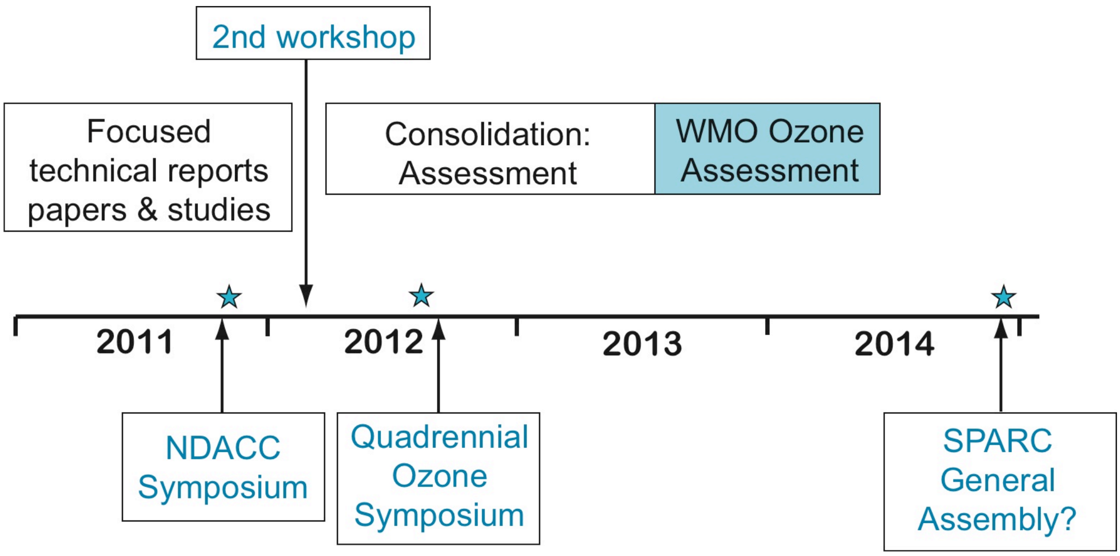

Figure 4. Timetable for the work organised within the second ozone initiative. Full use will be made of existing plans, projects and meetings particularly in the first year of the initiative. A consolidation of the results (most likely in a short assessment) will be produced in time for the anticipated WMO Ozone Assessment in 2014.