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World Meteorological Organization
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GAW Report No. 182

IGACO-Ozone and UV Radiation Implementation Plan

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WORLD METEOROLOGICAL ORGANIZATION

GLOBAL ATMOSPHERE WATCH

IGACO-Ozone and UV Radiation Implementation Plan

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TABLE OF CONTENTS

FOREWORD

The stratospheric ozone layer has gained widespread recognition in the last 30 years of the 20th century for its importance in protecting humans and the biosphere from harmful ultraviolet radiation. This is embodied in the Vienna Convention for the Protection of the Ozone Layer signed in 1985 and the Montreal Protocol on Substances That Deplete the Ozone Layer of 1987 and its subsequent adjustments and amendments. Closer to the ground, in the air we breathe, photochemically produced “smog” ozone is of concern for its damaging effects on human health and vegetation. In most developed countries, there are regulations controlling the levels of ozone in ground level air. Since the 2001 report of the Intergovernmental Panel on Climate Change (IPCC), it has been widely recognized that ozone which lies in between the surface air layer and the stratosphere acts as a greenhouse gas. Finally, ozone throughout the atmosphere is a major source of atmospheric oxidants that regulate atmospheric composition and thereby, maintain a more habitable atmosphere.

The Atmospheric Chemistry Theme Report on Integrated Global Atmospheric Chemistry Observations (IGACO) was published in 2004. The World Meteorological Organization (WMO), which together with the European Space Agency (ESA) led the production of the IGACO report (available as WMO GAW Report # 159), has been designated by international partners including GEO as the lead in developing an implementation plan for the IGACO. The WMO Global Atmosphere Watch Programme (GAW) continues as the lead in a partnership with other WMO programmes and international research organizations. Figure 1 shows the framework of a global integrated atmospheric observations system.

The IGACO report provides: a rationale for integrated global air chemistry observations; an assessment of observational capacity; and, in chapter 5, recommendations that highlight what is needed to build an integrated atmospheric chemistry observational system. It emphasizes the role of ozone (O_3) as a key component of the atmosphere and the Earth system. The plan for implementing IGACO involves four theme foci for ozone, aerosol-climate, air quality/long range transport of air pollution and carbon-based greenhouse gases. The Finnish Meteorological Institute hosts the IGACO-O_3/UV Office which supports the GAW Scientific Advisory Groups for Ozone and for UV in developing and carrying out this implementation plan and facilitating activities that serve to integrate observations and yield useful services and products. It involved also a strong consultative process between WMO-GAW and the International Ozone Commission of the International Association for Meteorology and Atmospheric Science (IAMAS).

On behalf of the Global Atmosphere Watch Programme of the World Meteorological Organization that supports atmospheric chemistry research, we are very pleased to introduce this plan and are confident that its implementation will lead to more effective utilization and application of resources for weather, climate and environmental decision making. We urge appropriate organizations at all levels in the hierarchy of global atmospheric observations to support the research as well as the methodological and technological advances required.

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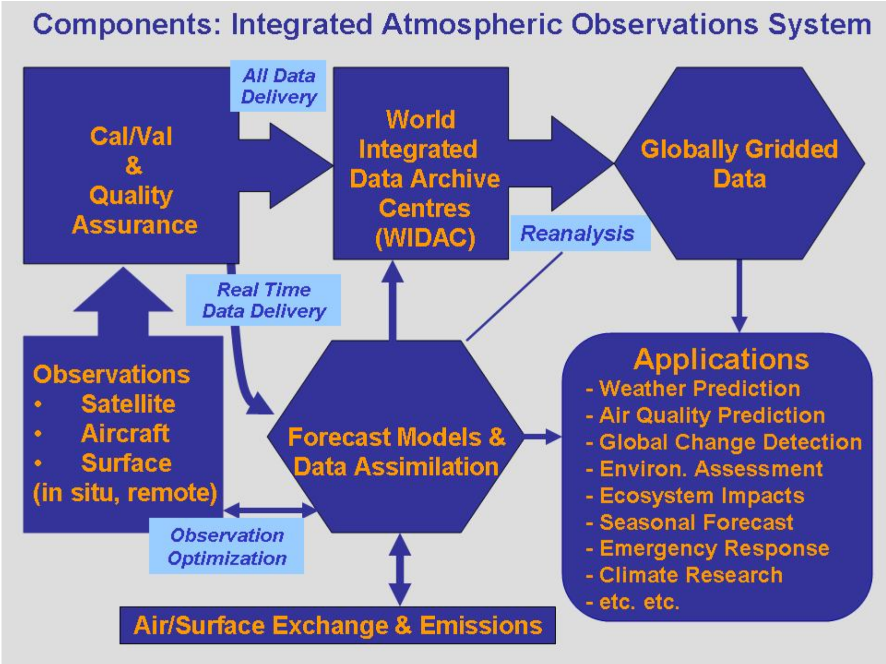


Figure 1. Framework of a global integrated atmospheric observations system [IGACO, 2004] (GAW Strategic Plan 2008-2015, GAW Report No. 172).

SUMMARY

The approach for implementing IGACO within WMO's GAW programme is organized with thematic foci (Ozone and UV, Aerosols, long range transport of air pollution and air quality, and climate forcing related to greenhouse gases) and cross-cutting activities. This document describes the plan for implementation activities related to ozone and UV.

The implementation will be facilitated by the WMO Secretariat and the Finnish Meteorological Institute, which - through a memorandum of understanding with WMO - hosts the Theme Office for IGACO-O_3/UV. Oversight of the implementation will be to the SAG Ozone and SAG UV of the GAW programme and reporting to the JSC OPAG EPAC.

The IGACO theme is planned to be implemented by working on activities with given goals, tasks, and schedules. Those activities will mainly be financially supported by participating organizations and institutions through their funding sources. For each activity, one participant will act as lead, advising the IGACO-O_3/UV Office and WMO Secretariat on coordination, progress tracking and reporting.

The envisaged activities are divided into clusters according to the scope of the activity: Stratospheric ozone, Ozone in the upper troposphere/lower stratosphere, UV radiation, and Services. As a result of User Consultation Workshops held in 2006 and 2007, 32 activities have been defined. This initial set of activities consists of tasks that have been considered urgent and/or where work relevant to the goals of IGACO has already been initiated. These activities concern – based on the consultation outcomes – observations and data, while activities on modelling and integration will be emphasized in the future. Since funding will need to be obtained through different sources, work will be done on a best effort and availability of funds basis. In the long run it is foreseen that the global importance of activities agreed for IGACO will help in obtaining the necessary resources to continue these and forthcoming tasks.

The current activities discussed in this report do not evenly cover all of the recommendations in the IGACO Theme Report (IGACO, 2004). The scope of the first phase of IGACO Implementation by GAW (GAW, 2007) is five years and this report covers the same timeframe with an initial set of activities. More activities for this as well as the second phase (5-10 years) and beyond are to be defined as described later in this document. Up-to-date information and progress tracking of IGACO-O_3/UV will be maintained on the IGACO-O_3/UV website.

1. IGACO FOR OZONE AND UV

The IGACO theme report (2004) aims at developing an Integrated and Global system for Atmospheric Chemistry Observations and derives 12 general and 7 specific recommendations (GR and SR hereinafter). The World Meteorological Organization (WMO) agreed to take the responsibility of implementing the IGACO Theme as a strategic component of its Global Atmosphere Watch (GAW) programme (GAW Report No. 172). The implementation is planned to be proceeding in four focus areas: Ozone and UV, Aerosols, Greenhouse gases, and Air quality and long-range transport. Each of the focus areas will be coupled with the corresponding Scientific Advisory Group (or groups) of the GAW programme, providing oversight and scientific guidance to the implementation.

In the practical coordination of the implementation, such as organising meetings etc., the WMO Secretariat in Geneva will be supported by an IGACO Theme Office, hosted by a research institution in the field. This Office reports to the corresponding SAG (for IGACO-O_3/UV to the SAG Ozone and SAG UV) in order to coordinate with other GAW activities. For IGACO-O_3/UV the Office is hosted by the Finnish Meteorological Institute (FMI). For activities that are foreseen to be common over focus areas ad-hoc working groups will be formed.

This document is the first issue of an Implementation Plan for IGACO-O_3/UV. Revised issues of the plan will be written as appropriate.

1.1 Scope of IGACO-O_3/UV

IGACO-O_3/UV covers ozone in the stratosphere, UV, ozone in the lower stratosphere and upper troposphere and constituents/parameters that are important for ozone chemistry as well as UV radiation. A summary of target variables for IGACO-O_3/UV is given in Table 1 (GAW Report No. 159).

Table 1. Target variables of IGACO.

IGACO-O_3/UV target variables are indicated in boldface

Chemical species/parameters	Air Quality	Oxidation Capacity	Climate	Stratospheric Ozone Depletion	Note
O_3	✓	✓	✓	✓	
H_2O (water vapour)	✓	✓	✓	✓	Stratosphere
CO	✓	✓	✓		
CO_2			✓		
CH_4		✓	✓	✓	Stratosphere
HCHO	✓	✓			
VOCs	✓	✓			
N_2O			✓	✓	Stratosphere
$NO_x = NO+NO_2$ **HNO_3**	✓ ✓	✓ ✓	(✓)	✓ ✓	Stratosphere
SO_2	✓	✓	✓	✓	
BrO, ClO, OClO **HCl, $ClONO_2$** **CH_3Br, CF_3Br,** **CFC-11, CFC-12,** **HCFC-22**			 ✓ ✓	✓ ✓ ✓ ✓ ✓	Stratosphere
Aerosol optical properties	✓		✓	✓	Needed for UV
Spectral actinic flux	✓	✓			

The list in Table 1 contains important species other than ozone. Those that are deemed important for stratospheric ozone chemistry have been highlighted, yet the activities for implementation later described do not necessarily at this moment involve any of these (See Annex

A for a full list of IGACO target variables). Some of those variables also fall in the scope of other IGACO Themes, and they are expected to be included in or linked to IGACO-O_3/UV activities in a later stage.

The goal is an integrated system providing all the functionality presented in Figure 2. In the first step, coherent and integrated availability, quality and coverage for ozone and UV observations has priority, with downstream services such as modelling to be detailed later. IGACO aims to work on activities that otherwise might not fall into the scope of any of the other elements, and at the same time, acting as an umbrella to different networks and programmes, encouraging and improving communication and supporting the individual observing systems.

In practice the IGACO work means:

- Coordinating implementation of planned activities. A first list of activities is included in section 2 of this document.
- Organization of meetings that are of interest to the scientists.

In summary, one could describe the roles between the SAG activities of GAW and IGACO as follows: IGACO-O_3/UV will be more strongly focusing on the synergy between satellites, aircraft and ground based data, on one side and between data centres and modelling on the other hand, while O_3 and UV SAGs have a somewhat stronger focus on populating the data centres with quality assured ground-based measurements (including ozonesondes). IGACO-O_3/UV with its synergistic scope should also strongly interact with the WMO Ozone Assessment teams.

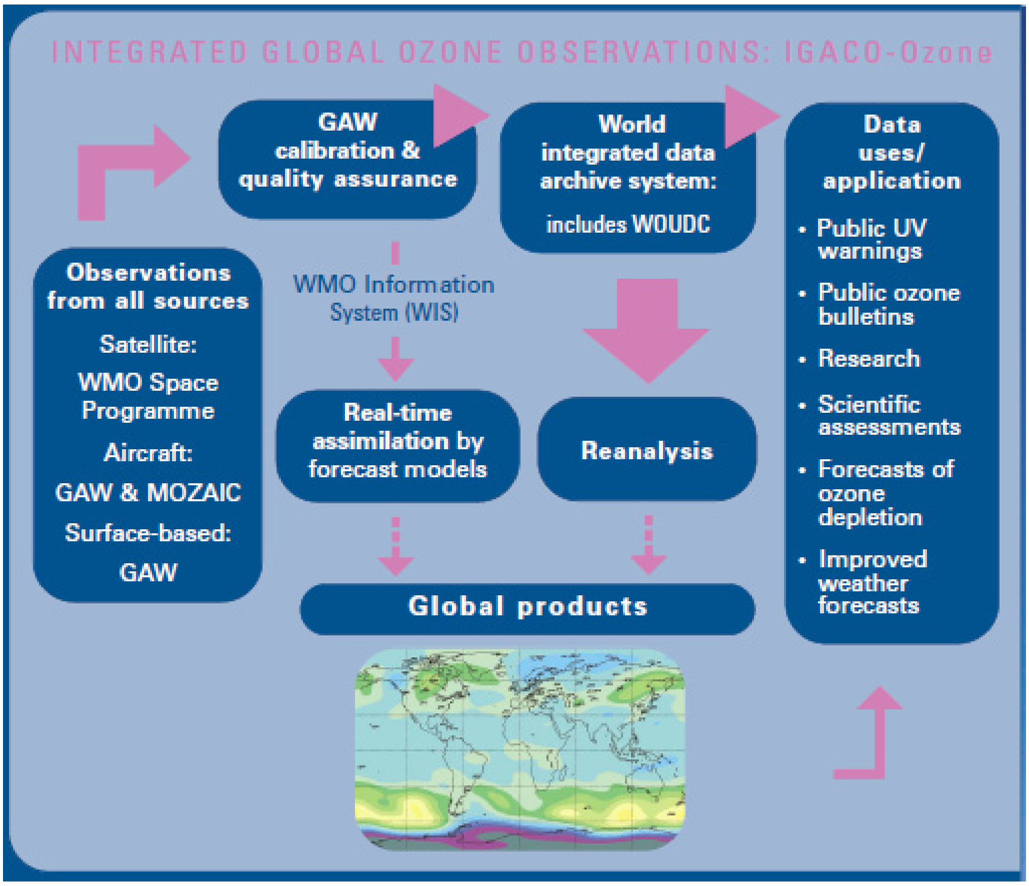


Figure 2. Goal of IGACO-O_3/UV. The aim is an integrated system, where all the existing and missing elements are linked.

1.2 Connection to IGACO Theme Report

The report entitled IGACO: An integrated Global Atmospheric Chemistry Observations Theme for the IGOS Partnership, IGOS Atmospheric Chemistry Theme Report (ESA-SP1282/GAW Report No. 159 is called the IGACO Theme Report in this IGACO-O_3/UV Implementation Plan. It includes twelve General Recommendations which set the basic goals for all IGACO focus areas. The implementation of IGACO-O_3/UV should take into account both the General Recommendations (GR) and the Specific Requirements (SR). In the Theme Report, the recommendations have been grouped under the titles "Establishment" (corresponding to General Recommendations 1, 2, and 3), "Measurements" (GR 4), "Quality-assurance and data-handling protocols" (GR5, GR6, GR7, GR8), "World Integrated Data Archive Centres (WIDAC; GR8, GR9, GR10), and "Models and inputs needed for the IGACO system" (GR11, GR12). The recommendations, together with a brief summary of the status of the ozone observation system with respect to the recommendations (as discussed with involved scientists in User Consultation meetings) are given in Annex A.

The recommendations in the Theme Report form the basis for IGACO. However, in the current document, the grouping of the activities follows a different logic than that of the recommendations. It is important that the approach in this plan allows the scientific community, working on the implementation, and the policymakers and funding agencies, who need to agree on priorities, to find the links between the important scientific questions and the IGACO activities.

Thus, in this document we use the following grouping for activities:

1. Stratospheric ozone: Primarily observations, covering issues such as observation quality, coverage, comparability of measurement types and such.
2. Ozone at the upper troposphere/lower stratosphere.
3. UV radiation.
4. Services, including activities at data centres, tools, harmonisation of data protocols, etc.

The division of activities is not exactly defined, but it is intended that activities in categories 1-3 concentrate more on the provider end and the scientific activities, whereas in cluster 4 the emphasis is on access, availability and implementation of downstream services.

The initial set of activities concentrates on observations (data quality, accessibility), with more activity in modelling foreseen later. A separate summary of how the activities link to the Recommendations is included in section 2.5.

In this document we have not included a review of the major ground-based and satellite-based programmes providing the data for IGACO. This information can be found elsewhere (e.g., the IGACO Theme Report (IGACO, 2004), or the CAPACITY study report (CAPACITY, 2005)). We recognize the large body of existing work that is taking place, which forms the basis for our work on IGACO. The intention of the activities is to concentrate on what aspects are lacking or weak: For example, improving the flow and quality of data necessarily assumes that there will be data to flow and improve. A few actions have been agreed to assess and/or improve coverage and continuity (A6, B1, B2, D5).

1.3 Rules of the road for IGACO-O_3/UV

IGACO-O_3/UV aims to stimulate and coordinate activities in the respective fields of research, especially related to activities aimed at improving the availability and quality of world-wide observations. IGACO-O_3/UV also aims to strengthen connections between programmes, such as GAW and the Network for the Detection of Atmospheric Composition Changes (NDACC).

IGACO-O_3/UV activities might include a variety of different items falling within topics summarized in section 1.1. This might be workshops, reports, and resulting recommendations on:

- Strategies to solve particular practical problems (such as related to data transfer and data archiving).

- Specific topics in the IGACO-O_3/UV area, e.g., related to comparison of different instruments.
- Assimilation methods, analysis of particular measurements.
- Common interpretation of field measurements, etc.

The IGACO activities should complement work done by the SAGs, and close communication between the IGACO Office and the SAGs is thus important.

The WMO Secretariat and the IGACO Ozone/UV Office hosted by FMI coordinate the activities and organize or help to organize workshops. In order to follow the implementation, persons and organizations responsible for the activities need to report their progress to the WMO Secretariat and IGACO Office. The IGACO Office collects the results and the status of the activities within its annual report that is presented to the SAG O_3 and SAG UV to the WMO Secretariat. The report also includes planning for the following year, possibly proposing additional new activities as appropriate. The coordinator of IGACO-O_3/UV will be an ex-officio member of the appropriate SAG.

The Office takes the lead in organizing meetings to which all scientists contributing to IGACO-O_3/UV are invited, in order to review and discuss the progress of IGACO-O_3/UV, to inform the colleagues contributing to other activities and to plan new activities. Such IGACO- O_3/UV plenum meetings are envisaged to take place approximately every 3 years. The IGACO-O_3/UV plenum should preferably be arranged in connection with other major workshops or meetings like the Quadrennial Ozone Symposia or regular SAG meetings. Special sessions on core activities of IGACO could be proposed.

The progress of **running projects and their status**, as well as meetings, documentation and overall progress will be maintained at the IGACO-O_3/UV website, maintained by the FMI Office. The address is http://www.igaco-o3.fi/.

SAG O_3 and SAG UV will discuss the progress of IGACO-O_3/UV in their meetings based on the report, providing feedback and possible advice to the IGACO-O_3/UV Office.

Scientists of the respective communities are asked to carry out the implementation of individual activities. As IGACO does not have dedicated funds available for this work, the contributions are on a voluntary basis at the expense of these scientists and their (other) funding bodies. In order to allow the IGACO-O_3/UV Office to report to the SAGs, the coordinator of each activity is expected to provide a short report every year. Standard guidelines for activity leaders will be available.

Scientists are also encouraged to propose new activities. Such proposals should be sent to the IGACO-O_3/UV Office at FMI. A committee including the IGACO-O_3/UV Office, the representative of WMO and the chairs of SAG-Ozone and SAG-UV are in charge of approving new projects as IGACO activities.

The implementation of **over-arching and cross-cutting actions** needs to be agreed upon. Some of the activities described in this document already contain elements that will benefit other IGACO foci as they will be started. Such examples are any (high-level) approach for data access, which can be expected to be similar for constituents other than those related to ozone and UV.

2. ACTIVITIES FOR IMPLEMENTATION

In this section we present an overview of planned activity clusters, according to the grouping presented in section 1.2. A first set of activities has been proposed for implementation, based on discussions in ad-hoc User Consultation Meetings held in 2006 and 2007. These activities should be considered as a starting point. New activities will be adopted according to the rules described in section 1.3.

In the following subsections we introduce the initial activities agreed for implementation in early 2007. A short introduction is given before each cluster, with more details of status w.r.t. IGACO Recommendations given in Annex A.

2.1 Activity cluster A: Stratospheric Ozone

2.1.1 Scientific rationale and overview of stratospheric ozone

Stratospheric ozone depletion has been discussed since the 1970s (Molina and Rowland, 1974) and the Antarctic ozone hole was discovered in 1985 (Farman et al., 1985). A ground-based network for quality controlled measurements of the ozone layer by Dobson spectrophotometers was established in the 1970s under the auspices of WMO and a similar network was built for Brewer spectrophotometers, which have been commercially available since the middle of the 1980s. Measurements from satellite instruments providing almost continuous and near global monitoring of the ozone layer started in 1979.

Since the middle of the 1980s it became clear that the data quality of satellite observations needs to be controlled with high quality ground based total ozone observations in order to guarantee the long-term stability of satellite ozone series required for trend analysis. Satellite instruments have limited lifetimes and ozone series from different satellites need to be combined for long-term ozone trend analysis. This combining also requires high quality ground based measurements for monitoring the long-term stability of the composite satellite ozone series. Measurements of ozone profiles are important for documentation of the anthropogenic ozone depletion. Various instruments based on different principles (operated from ground and space and coordinated by different organizations such as WMO and NDACC) with complementary strengths and weaknesses are operationally used for ozone profile monitoring.

Based on the Vienna Convention (1985) the Montreal Protocol was signed in 1987 and strengthened several times in order to reduce the anthropogenic emissions of ozone depleting substances (ODS such as chlorofluorocarbons and halons). The state of the stratospheric ozone layer has been regularly reviewed by WMO and UNEP (WMO/UNEP, 2006) for the parties to the Montreal Protocol. Ground based measurements of concentrations of ODS performed at many sites in the troposphere demonstrate that the Montreal Protocol has been very successful to reduce the anthropogenic emissions of ODSs (see Figure 3). However, the demonstration of the beneficial effect of the reduction of ODSs on the ozone layer is still an issue, since it is unclear how and when the recovery will actually take place.

Numerical models of different degree of sophistication are used to describe the effect of anthropogenic ozone depletion. They have been continuously improved over the last decades. Some of the numerical simulations predict an increase of the ozone layer above the thickness of the pre-CFC era (e.g. before the early 1970s) which is attributed to the changes caused by climate change (see Figure 3, panel c), which was called “super recovery”. Increased ozone concentration in the lowermost stratosphere is not desirable, since a substantial fraction of the tropospheric ozone budget originates from the stratosphere and ozone in the upper troposphere/lower stratosphere is a particularly strong greenhouse gas and therefore the super-recovery of the stratosphere might add an additional burden to the radiative forcing in the future.

This leads to the following basic problems falling into the domain of interest of IGACO-O_3/UV: The turn around of stratospheric ozone and the expected recovery requires a comprehensive documentation of the change of the ozone layer. The long-term continuation is also required to detect possible “super-recovery”.

A particularly important region for detecting recovery, and eventually "super-recovery" is the upper stratosphere. This region is less variable than the lower stratosphere and ozone there is dominated by photochemical processes.

IGACO-O_3/UV is expected to contribute to solve these items by improving co-ordination of related activities and by providing a framework of collaboration of activities funded by other institutions.

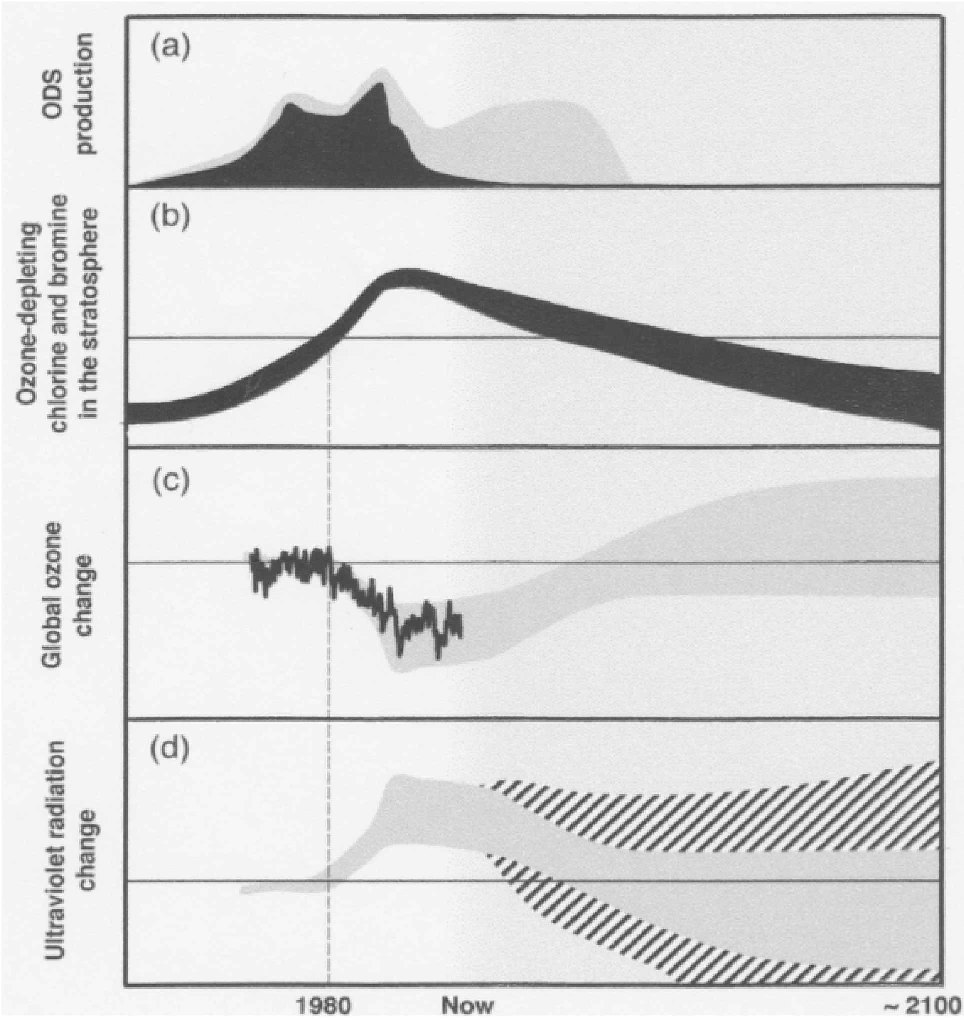


Figure 3. Illustration of predicted recovery of the Ozone hole, taking into account effects related to changing climate (From WMO/UNEP, 2006). (a) black: Production of Ozone Depleting Substances (e.g. chlorofluorocarbons (CFCs); grey: production of HCFCs (compounds that replace CFCs but their effect on ozone depletion is much smaller compared to CFCs; (b) Stratospheric ozone depletion by ODS; (c) black: Total ozone measurements (60oS - 60oN); grey: numerical simulations; (d) grey: UVB measurements at the surface; shaded: future evolution of surface UVB taking into account additional changes than stratospheric ozone.

For successful documentation of the future evolution of the ozone layer the following problems concerning measurements need to be solved:

(a) Ozone monitoring from space needs to be continued with high quality of data and sufficient overlaps between different instruments. This is particularly true for the upper stratosphere where global coverage is not possible from the ground.

(b) Total ozone measurements at high latitude sites (>60 degree latitude) are made under difficult conditions. The instrumentation and analysis procedures need improvement.

(c) The network of ground based total ozone and ozone profile measurements (sondes and Umkehr) needs not only to be maintained, but the quality of the individual stations needs to be assessed in order to improve the data quality of the ground-based total ozone and ozonesonde monitoring networks, which is important for validation and continuity of ozone satellite measurements. Stations identified as having data or operational problems need to be assisted to improve the future data quality.

(d) Measurement of ozone and temperature profile by lidar, ozone profile by microwave radiometers and the Umkehr method need to be continued as the only ground truth connecting the series of satellite measurements for the upper stratosphere.

(e) In order to make best use of limited resources the co-operation between experts working on different aspects of stratospheric ozone measurements (both total and profile information) needs to be improved in order to obtain comprehensive high quality measurements of stratospheric ozone.

Numerical simulations with climate and chemical-transport models are needed to explain in a quantitative way (i) the past evolution of the ozone layer as a consequence of the release of ozone depleting substances (ODS) and (ii) for predictions, which will depend on the release of source gases such as N_2O and climate change.

(f) The progress of numerical simulations needs to be documented by evaluation with high quality measurements (model validation).

(g) Assimilated global ozone data are likely to be used in future stratosphere ozone trend analysis. This possibility has to be investigated carefully in view of differences between the assimilated and original data sets.

2.1.2 Present activities related to stratospheric ozone

2.1.2.1 Column ozone measurements

Stratospheric ozone is currently well covered by a combination of ground, airborne and space observations. For total ozone measurements at ground, the two most widely used instruments are the Dobson and Brewer spectrophotometers. Great success in improving data quality of the measurements has been achieved since the early 1980s through the activities carried out in the SAG Ozone of the GAW programme and several related scientific teams from WMO member institutions and supporting agencies. The current satellite fleet is providing good data on ozone and related chemical constituents. Especially, total ozone measurements from space are consistent and can be considered mature and they can be used as a homogeneous global dataset for quality control of the ground-based network.

However, even with the great progress achieved already, Dobson, Brewer and satellite measurements show distinct differences in seasonal variations of ozone. Therefore, this information needs to be further distributed in the community. Further comparisons and studies are needed that would address instrumental characteristics and spectral temperature dependences of the ozone cross sections in order to understand the remaining instrumental differences. This approach is essential for the creation of a homogeneous data set comprising of data from different instruments.

Activity A1: Measurement platform workshop

The global ozone measuring network consists of a suite of various platforms and instruments which perform similar measurements or, at least, measure the same quantities using different methods. Specialists in different measurement methods are not always aware of the differences between instruments (such as quantitative differences in precision and accuracy of the instruments in different atmospheric conditions and measurement geometries), especially when used in satellite validation campaigns. Interactions between satellite, aircraft, balloon and ground-based communities could and should also be improved. The goal is to provide an overview of the ongoing heterogeneous measurement activities.

Tasks:

- Workshop of 2-3 days and report.

Addresses recommendation(s): GR5, GR7

Activity A2: Dobson/Brewer absolute calibration comparison

The objective is to improve our understanding of the absolute differences between Brewer and Dobson spectrophotometers. An absolute calibration is thus an important task, improving understanding and coherence of the global measurement network, which includes instruments of both types.

Tasks:

- Perform an absolute calibration comparison at Izaña using the European secondary standard Dobson spectrophotometer and the European standard Brewer spectrophotometer.

Addresses recommendation(s): GR5, GR7

Activity A3: Clarify differences in UV/VIS measurements of ozone

Comparisons between satellite, Brewer, and Dobson show distinct seasonal variations in their differences. Instrument designs as well as retrieval algorithms and reference absorption spectra are different. Currently it is not clear which of these factors plays the most important role in the observed variations.

It is important to understand the absolute calibration differences of Dobson and Brewer instruments (see Activity A2 above). This could be improved by, e.g., bringing reference instruments to the laboratory and making measurements in a highly controlled environment. This activity should also include UV/Vis DOAS instruments for completeness. The final goal is to propose methods that would lead to a consistent instrument-independent “ground truth” ozone data set, with a follow-on activity of developing improved retrieval algorithms using the results of these investigations. This would also include characterization and standardization of DOAS ozone retrievals and comparisons to Brewers, Dobsons, and satellites.

Tasks:

- Measure instrument slit functions and then determine ozone cross-sections in a laboratory using reference Brewer and Dobson instruments.
- Process Brewer data with Dobson double pair algorithm and compare with Dobson results.
- Apply DOAS-type retrievals (GOME, SCIAMACHY, OMI) to Brewers.
- Identify and assess biases between satellite instruments.
- Repeat with different operational and lab measured cross-section datasets.
- Compare results and report.

Addresses recommendation(s): GR5, GR7

Activity A4: Improve ground-based and satellite measurements at high solar zenith angles and high latitudes

Validation of ground-based and satellite total ozone measurements are usually performed at mid latitudes where total ozone is near 300 DU. In general, the agreement between instruments is within 2%, which provides confidence in the methods and algorithms under these conditions. However total column ozone retrievals show persistent differences of 5–10% under conditions of low sun, high total column ozone and high column variability, especially at high latitudes where these conditions are very often met. Satellite and ground-based measurements must be compared under a greater variety of ozone column amounts and profile shapes if such differences are to be resolved.

Tasks:

- Measurement campaign.
- Analysis and report.

Addresses recommendation(s): GR5, GR7

Activity A5: Systematic comparison of total ozone measurements from ground and space

Ground-based measurements are needed and used to validate the quality of spacecraft total ozone observations. The ensemble of all ground-based measurements with composite series of satellite instruments confirm the good long-term stability of currently used satellite records (see, e.g. McPeters and Labow (1996)).

At the same time, it is also known that there are individual ground-based series deposited at WOUDC which are of questionable data quality, often related to particular periods. Especially the quality of the current tropical/sub-tropical total column ozone data set is considered to be quite heterogeneous, and thus the data set would require a thorough evaluation. Since the presently used total ozone satellite series have achieved high long-term stability they can be used to identify and assess those problems in individual station records.

The goal for this task is an improved homogeneous dataset with known and documented uncertainties, to be used in validation and trend studies. Additional task is to develop an operation method for performing quality assurance for tropical and subtropical ozone data remotely.

Tasks:

- Flagging of (periods) of suspicious ground-based measurements deposited at WOUDC by comparison with suitable satellite data.
- Communicate results of flagging to data providers, in order to allow improvement.
- Re-submit data to WOUDC.

Addresses recommendation(s): GR5, GR7

Activity A6: Brewer and Dobson network updates

More than 20 Brewer spectrophotometers have been decommissioned by the U.S. Environment Protection Agency (EPA). The equipment has been transferred to NOAA/ESRL/GMD. The goal of this activity is to upgrade the EPA decommissioned Brewers to enhance ozone measurement capability and to deploy the instruments to new sites across the NOAA network.

In order to improve the global coverage (filling gaps) of the Dobson network, some of existing instruments could also be relocated to either existing or new stations. This would also require Capacity building activities (e.g. training for spectrophotometer operators etc.).

Financial aspects of these activities should be addressed in corresponding discussions.

Tasks:

- Develop a plan of how to best use the existing equipment in order to have a homogeneous global coverage for Dobson/Brewer measurements.
- Upgrade decommissioned Brewers and deploy to new sites.
- Initiate necessary Capacity Building activities to ensure continuous operation of instruments.

Addresses recommendation(s): GR4

2.1.2.2 Stratospheric ozone profiles

Ozone profile measurements are available from ground using sondes, lidar, and microwave instruments, as well as from Brewer data using the Umkehr retrieval algorithm. Ozone profiles are also available from multiple satellite instruments, the best resolution and accuracy achieved with specific limb-viewing instruments. Ground based profile measurements provide an invaluable independent reference data set for continuous validation of satellite data.

The upper stratosphere is one of the key regions for the detection of ozone recovery and test of Montreal protocol. At present, there are only a few long term stations throughout the world which monitor ozone at this altitude range. After 2012, there is a possibility that satellite measurements stop monitoring this region, with the planned discontinuation of the limb-viewing solar and stellar occultation measurements. This issue should be discussed in connection with the global UT/LS monitoring approach (see Activity B1).All of the measurement systems have their advantages and limitations. When combining the data from these systems, this information must be considered.

Activity A7: Acquire Brewer Umkehr data

Over the Brewer network, more than 20 years of data have been collected, but not as yet processed with the Umkehr algorithm. Should this be done, a new ozone profile data set would be available for the scientific community.

Tasks:

- Acquire the Brewer raw Umkehr measurement data.
- Process and make the retrieved ozone profiles available in a consistent manner.
- Compare to correlative data sets (collocated Umkehr Brewer-Dobson measurements, satellites, sondes, etc.).

Addresses recommendation(s): GR6

Activity A8: Long-term ozone profile records and data harmonisation

Ozone profile measurements have been made using different methods for decades. However, different measurements have different characteristics, similarly to total ozone measurements (see, e.g., activities A3 and A5 above). The aim of this activity is to improve the knowledge of the properties of these data and thus improve the usability of the world-wide data set.

Tasks:

- Comparison of ozone profile measurements from ground (sondes, LIDAR, Umkehr, microwave) and space.
- Comparison and harmonisation of data taking into account for vertical resolution differences for trend assessment.
- Assessment of other trace gas profile observations (e.g. H_2O, NO_2) relevant for stratospheric chemistry.

Addresses recommendation(s): GR2, GR5, GR6, GR7

2.2 Activity cluster B: Ozone at the upper troposphere and the lower stratosphere (UT/LS)

2.2.1 Scientific rationale and overview of ozone at UT/LS

The upper troposphere/lower stratosphere (UT/LS) is an important altitude in the atmosphere where a variety of processes such as transport from the higher stratosphere, fast transport from the planetary boundary layer (such as by convection) and in-situ chemical production take place. Ozone is an important greenhouse gas and its effect on the radiation balance of our planet maximizes in the UT/LS altitude.

Chemical ozone production at the UT/LS depends on the ozone precursor concentrations mainly up-lifted from the planetary boundary layer and the emissions of the rapidly growing civil aircraft, released at their cruise altitude which is close to tropopause at mid-latitudes. Ozone at UT/LS is also a key parameter for data assimilation which is used to predict or forecast tropospheric chemical air composition and ozone data are used in the retrieval algorithms of tropospheric satellite measurements for other species such as nitrogen dioxide. Ozone concentrations at UT/LS also contain valuable information for weather forecast models.

Obtaining reliable ozone observations at the UT/LS is a challenging task, because ozone concentrations tend to be very low close to the tropopause. The only continuous information on the long-term changes of ozone at UT/LS originates from a very few ozone sonde stations operated at northern mid-latitudes since the late 1960s but the data quality of these measurements is difficult to assess. Measurements performed by ground-based LIDAR instruments have limited vertical resolution at the tropopause and satellite measurements are restricted by vertical resolution and large ozone variability in the UT/LS, the best resolution and accuracy achieved with specific limb-viewing instruments. Measurements from civil aircraft can provide reliable ozone measurements close to tropopause. Such continuous series are available since 1994 from the project MOZAIC (see Figure 4), but presently the data coverage is not global and important parts of the northern mid-latitudes, namely the Pacific region, is missing.

In order to reach the goals of IGACO for ozone at UT/LS the following problems need to be solved:

(a) A long-term data set with global coverage of quality controlled ozone measurements at UT/LS needs to be obtained. This data set should make use of all suitable measurement platforms such as civil aircraft, satellite, ozone sonde and LIDAR measurements.
(b) The long-term continuity of the key measurements of ozone at UT/LS needs to be ensured.
(c) Numerical simulations for UT/LS ozone need to be developed further in order to predict what the impact of changes in emissions of ozone precursors and changes in climate on UT/LS ozone are.
(d) Assimilation of data into weather and climate models including a full chemical scheme might help in future for predictions of many compounds in the IGACO target list.

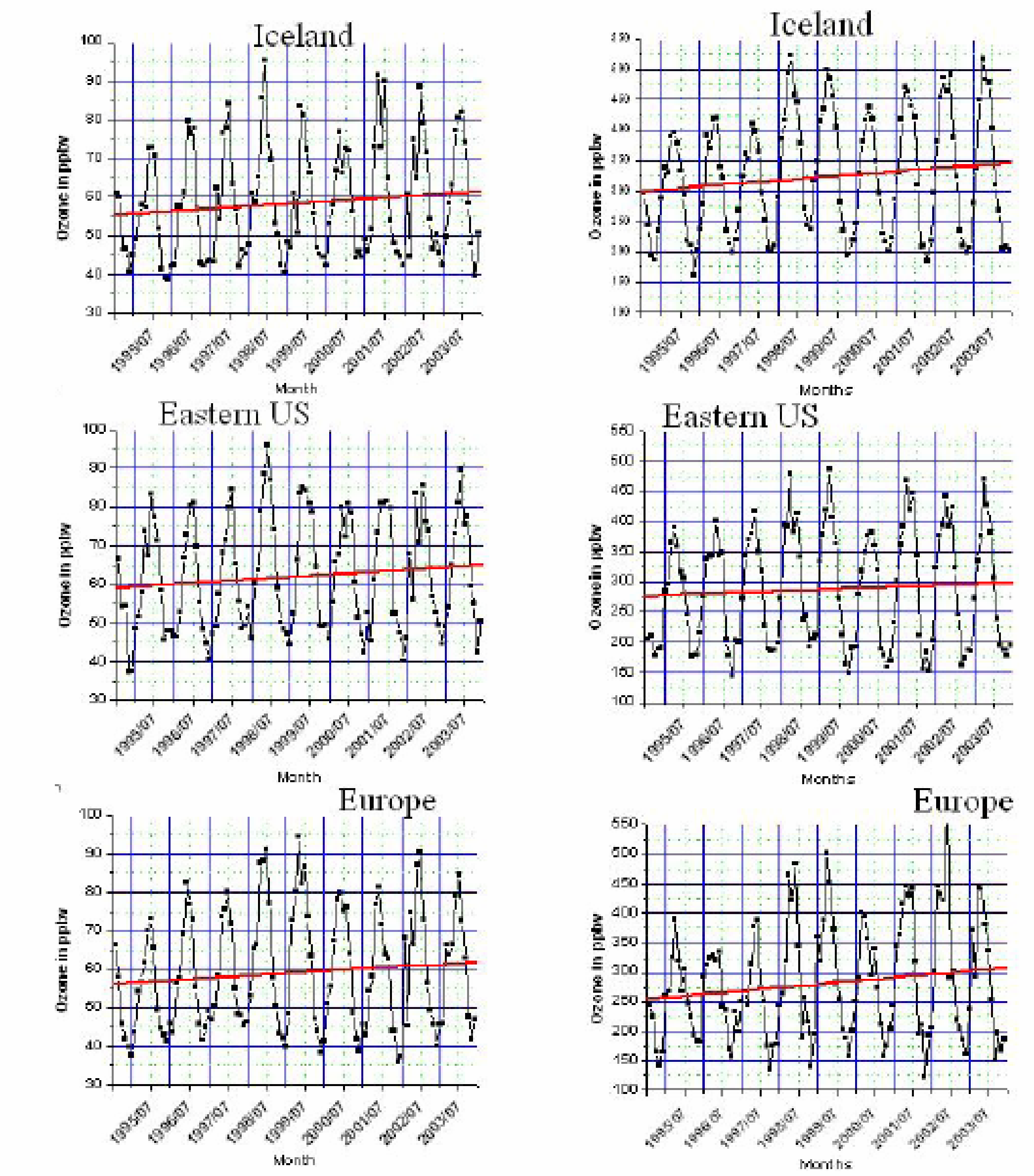


Figure 4. Time series of ozone monthly means for the UT (left panels) and the LS (right panels) from ozone measurements of MOZAIC (from Thouret et al., 2006).

2.2.2 Activities related to ozone at the UT/LS

Activity B1: Global UTLS monitoring approach

For global coverage for long-term UT/LS ozone monitoring, a coherent approach is needed. This can be accomplished by designing a network integrating current and planned civil aircraft, ground-based (ozone sondes and LIDAR) and UT/LS satellite measurements. Current commitments for space-based missions do not include instruments to continue the ozone profile estimates from occultation measurements. This is a potential major GR4 issue that needs action. In addition, a concept for data quality should be developed making use of the different measurement platforms.

Tasks:

- Organize a workshop to discuss current capabilities and identify gaps.
- Aim at developing a strategy to solve the problems.
- Prepare assessment report with recommendations.

Addresses recommendation(s): GR2, GR4, GR6

Activity B2: Continue/augment ozonesonde network

High-resolution vertical profiles of ozone measured with ozonesondes support climate change studies (UT/LS), development of environmental forecast models, satellite validation and ozone trend assessment. The goal of this task is increased knowledge of the magnitude of climate forcing from tropospheric ozone, improved performance of environmental prediction (pollution) models and accurate satellite-based ozone measurements by working on ensuring continuity of high-quality ozonesonde measurements.

Tasks:

- Prepare a briefing note for the WMO Executive Council on the importance of ozonesonde flights and secure co-operation of the Permanent Representatives of meteorological services to continue existing operations or restore operations discontinued.
- Maintain and improve quality assurance procedures at all stations.
- Identify sites that would add significant new information to the global community (e.g. tropical and southern hemisphere sites).

Addresses recommendation(s): GR2, GR4, GR5, GR6

Activity B3: Assimilation of ground-based ozone measurements

For the time being, only satellite-based ozone data are routinely used in data assimilation studies. The goal of this activity is to assess the added value and stand-alone value of ground-based vis-à-vis satellite ozone data for producing regularly gridded global ozone fields, and provide conclusions.

Tasks:

- Assimilation study using satellite AND Brewers & Dobsons.
- Assimilation study using satellite AND lidar/sonde/mwr data.
- Assimilation study using Brewers & Dobsons only.
- Assimilation study using lidar/sonde/mwr data only.
- Report.

Addresses recommendation(s): GR11

Activity B4: Assimilation of tropospheric ozone measurements

The goal of this task is to assess the contribution of assimilation of tropospheric ozone measurements with air quality models to the accuracy of forecast and analysis. We also aim at augmenting surface ozone measurements with data assimilation in order to produce consistent surface ozone fields. As an additional activity, contribution of satellite-based tropospheric ozone data (as available) to air quality fields should be assessed.

Tasks:
- Set up data assimilation system for tropospheric ozone in air quality model.
- Assess added value of observations.

Addresses recommendation(s): GR11

2.3 Activity cluster C: UV radiation

UV radiation at the Earth's surface is a function of wavelength, solar zenith angle, ozone (and some other trace gases), cloud, aerosol, albedo, altitude and Earth-Sun distance. It is thus more variable than ozone and any change or trend in UV can result from changes in any or several of the influencing atmospheric variables. Changes in ozone produce a spectral signature in the resulting UV changes, with greatest change at the shortest wavelengths, whilst other atmospheric changes have a less wavelength dependent influence on the UV. In terms of potential climate change, possible changes in, for example, cloudiness may have an equal or more significant influence on UV than changes in ozone.

Standard instruments for UV measurement have been defined by the WMO-SAG UV instrumentation group and recommendations for their characterization and operation have been given. Spectroradiometers provide spectrally resolved data and multifilter radiometers provide data from several wavebands, while broadband radiometers produce a measure of the integrated total irradiance, weighted with an instrument response. The most common instrument response is one similar to the erythemal action spectrum. Nonetheless, the erythemally effective UV, and hence the UV index can be derived from the great majority of UV instruments. The UV index is therefore taken as the single common factor that should be obtained from the data at every site. However, time and wavelength resolved data from a site is of much greater value for most applications and it is recommended that complete datasets rather than derived products should be submitted to any data centre.

Activity C1: Explore use of small, inexpensive diode array spectrometers

There are now several small, relatively inexpensive spectrometers on the market that use diode array or CCD detectors, permitting instantaneous measurement of a large spectral range. At present these instruments cannot provide the same performance in the UVB region as the scanning spectroradiometers, but with technical and data processing improvements they are becoming increasingly viable as UV monitoring instruments. In principle they allow full spectral data to be gathered at similar capital cost to current broadband radiometers.

Tasks:
- Preparation of a document with recommendation on instrument specifications, instrument characterization and calibration.
- Workshop to explore current state of the art in CCD spectrometer technology and application to UV measurements.

Addresses recommendation(s): GR4

Activity C2: Improve access to UV instrument calibration centres

GAW Regional UV calibration centres exist in NOAA, Boulder, Colorado, USA and in PMOD/WRC, Davos, Switzerland. There is no world calibration centre for UV measurements. The lack of facilities, and cost of using those available, is detrimental to data quality and the stability of long-term monitoring.

Tasks:
- Identify potential regional calibration centres in under-represented areas.
- Intercomparisons between existing and new calibration centres.
- Identify potential world calibration centre (could be an existing regional centre).

Addresses recommendation(s): GR5, GR7

Activity C3: Further develop and validate satellite UV algorithms

Different satellites / satellite products require more extensive validation for a wider range of sites and climatic conditions.

Tasks:

- Extend satellite validations to more sites with extensive UV records.
- Improve the treatment of aerosols in satellite retrieval algorithms.
- Improve the treatment of clouds in satellite retrievals, especially for the short-term data products such as daily doses where actuals can be very different to statistics and climatology.
- Improve the treatment of snow cover.

Addresses recommendation(s): GR5

Activity C4: Improve the knowledge base of the UV effects in relation to UV monitoring

Currently there is widespread use of the CIE erythema weighting function to represent biological effects. However, there are severe differences between published spectra for erythema. Even if the weighting function is appropriate, there are many other UV effects on humans (e.g. skin cancer, eye diseases, immune suppression…) and on plants (reduced growth, DNA damages…) that need to be considered as well. Often the threshold values for these other effects are not known. The present knowledge is assessed every four years by the UNEP effects assessment panel.

Tasks:

- Organize a joint conference for information exchange between the UV monitoring and the UV effects community.
- Identify action spectra to be reported in addition to CIE erythema.

Addresses recommendation(s): GR7

Activity C5: Extend the knowledge of UV for other receiving geometries

UV irradiance on a horizontal surface is a widely accepted geometry for studying the UV impact (e.g. for UV index). However, it is not the only relevant geometry to be considered. Depending on the application actinic flux, spectral radiance, or irradiance on tilted surfaces may be the more appropriate measure. In addition, polarization effects may be important in some applications.

Tasks:

- Assessment of the natural variability of UV radiance under various meteorological conditions.

Addresses recommendation(s): GR7

Activity C6: Improve the understanding of the factors affecting UV

The impact of total ozone on UV irradiance has been studied quite extensively in the past. While there has been progress in recent years, the influence of other factors determining UV irradiance such as clouds, aerosols and albedo, are less well understood. The importance of such studies is highlighted by the fact that these other factors will probably be affected by climate change. These changes may have a higher impact on UV than changes in ozone. The analysis might include statistical investigations on future UV irradiance changes, with time and location dependency.

Tasks:

- New process studies on the impact of clouds, aerosols and albedo.

- Analysis of existing data series to study the UV variability due to changes in clouds, aerosols and albedo.

Addresses recommendation(s): GR7

2.4 Activity cluster D: Services

Access to data with known quality is a key point for all users from research scientist to policymakers. New applications also are expected to emerge in forecasting ("chemical weather"), which sets new requirements on availability of data in near real time (NRT). NRT data also needs to be supported by ancillary data, such as meteorological observations.

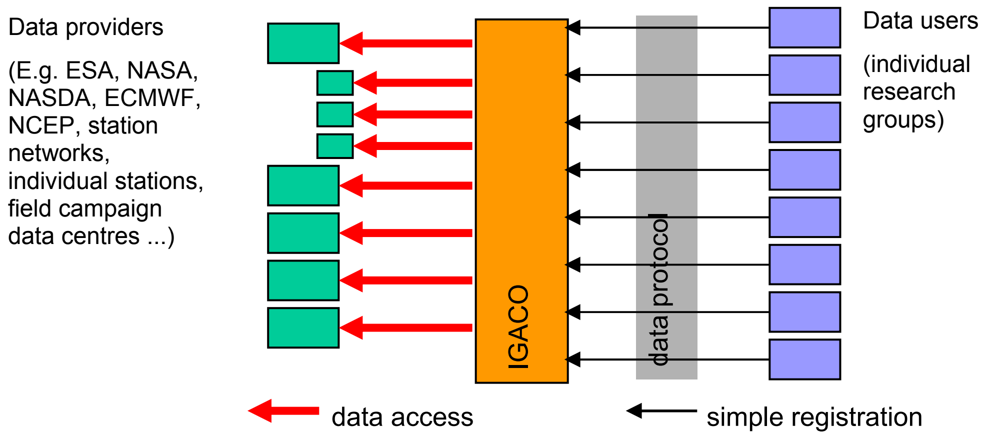
One of the key points discussed in the first consultation meeting in Anavyssos in May 2006 was access to data. Registration bureaucracy, varying protocols, and data scattered in all too numerous places around the world were seen as bottlenecks holding back success in science. As a result, it was agreed that a dedicated meeting should be held to discuss improvements over the existing system. This meeting was held in March 2007, hosted by EMPA in Dübendorf, Switzerland. The discussions in the meeting covered a wide scope of goals: access and submission, how to further improve the overall quality of the data (including ancillary data, metadata and error estimates on total ozone and profile data), as well improving homogeneity between data sets. Services for derived products were also discussed: data visualisation and data availability in long term were also on the agenda. Feedback from users to providers and, in general, open communication between data providers and users were considered extremely important.

Activities in this section form a starting point. Many of these activities also have much wider interest than only IGACO-Ozone/UV, and some of them, falling into the "cross-cutting activities" category presented in the Foreword, will probably in the long run be coordinated with other IGACO Foci and the World Data Centre for Remote Sensing of the Atmosphere (WDC-RSAT).

Activity D1: Better data access and archiving

The goal for this task is to develop a plan on how to work towards one-stop facilities for both data submission and retrieval. Despite attempts to integrate data sets of different types and from different sources at an accessible data centre (e.g. WOUDC), currently each scientist typically needs to contact all data sources and archives individually (and sign a multitude of agreements and protocols) in order to obtain data for a study. An alternative situation might look as shown in Figure 5.

A scientist's dream



Each user has to establish just one link to IGACO get access to all atmospheric data, including a complete overview over all data sets

Figure 5. "A Scientists Dream" for data access.

(Figure courtesy of M. Rex, AWI Potsdam).

Obviously this is a long-term goal, and the immediate activities aim to discuss how this goal can be achieved. The WOUDC has initiated activities towards this approach. The first step agreed is to organise a workshop, where data archive managers, data providers, users and data network experts can discuss aspects of this plan.

Tasks:

- Organise workshop to discuss the process, including user requirements.
- Develop tools for improving access to data that are routinely needed for Antarctic Ozone Bulletins.
- Develop tools for Scientist assigned to work on the forthcoming Ozone Assessments.
- Follow implementation.

Addresses recommendation(s): GR8, GR12

Activity D2: Make more total ozone, Umkehr profiles and sondes available in near-real time

For many applications, such as Antarctic Ozone Bulletins, prediction of chemical weather, and satellite validation campaigns, near real time (NRT) access to data is crucial. The GAW/IGACO goal for improving predictive capability and increased use of assimilation schemes will increase the need of NRT data in the future. Many stations already provide fast data access but more stations should be capable of providing data in near real-time. A possible solution is to use the WMO GTS/WIS data network, developed for worldwide distribution of meteorological data.

Tasks:

- Train station personnel on how to make data available in GTW/WIS.
- Discuss with World Weather Watch and National Meteorological Services how scientists worldwide would obtain easy access to GTS/WIS.

Addresses recommendation(s): GR8

Activity D3: Improve access to meteorological data

This task is linked to the previous one. Central repositories such as the European Centre for Medium-Range Weather Forecasts (ECMWF) retrieve and store meteorological data globally in near real time. For assimilation and modelling purposes, access to those data would be valuable. A contact with ECMWF will be established to discuss how those data could be used for non-meteorological applications and users not working at National Meteorological Services.

Tasks:

- Discuss with ECMWF how meteorological data could be made available for non-meteorological applications and users not working at National Meteorological Services.

Addresses recommendation(s): GR12

Activity D4: Streamlining accessibility of UV data in WOUDC and EUVDB

UV data from within GAW is submitted to the World Ozone and Ultraviolet Data Centre (WOUDC) in Toronto, operated by Environment Canada. At present, the WOUDC archive contains both broadband and multi-band data: spectral UV observations from 45 sites mostly located in North America and Asia; multi-band UV data from 35 sites, mostly from the US; and broadband UV data from 4 sites. Archives of the European UV Data Base (EUVDB) and NSF UV network contain measurements from European and the NSF network respectively. Most of these data are not currently available from the WOUDC, or vice versa.

Tasks:

- Harmonization of WOUDC and EUVDB databases.
- Generate pre-calculated products (at the database) from spectral data for users (various dose rates, daily and monthly doses etc.).

- Include of overpass satellite UV data to facilitate validation against ground-based data (one-stop service).
- In the next phase (follow-on activity), work also on NSF and NDACC data.

Addresses recommendation(s): GR8

Activity D5: Increase UV data in the WOUDC

Even if no formal requirements from the SAG UV exist for those data, both WOUDC and EUVDB initially concentrated on populating the database with spectral data. There is a need to extend the database(s) to include more multifilter and broadband data, and possibly also underwater measurements in the future. For some data types the submission (and retrieval) process might be simplified. The SAG UV has already begun to address this issue.

Tasks:

- Invite more existing stations to become GAW associated as regional or contributing stations (already under discussion in SAG UV).
- Discuss simplified data submission procedures to database(s), particularly for the under-represented broadband and multifilter instruments (see below).
- Results of (Activity B1) may lead to increased spectral monitoring at new sites, or replacing current broadband sites.
- There are 3 USDA decommissioned UV spectroradiometers that are available for re-assignment to other sites within GAW. Suitable sites with sufficient support will be selected by SAG UV.

Addresses recommendation(s): GR4, GR8

Activity D6: Mapping the current situation for data providers

The purpose of this activity is to have a quantitative understanding of how many different databases/formats the individual data providers need to support, in order to estimate the usefulness and feasibility of a ”one-stop portal” for data submission (see Activity D1 above).

Tasks:

- Approach data providers and ask which databases they are asked to support / supporting, with specific questions on data centres, frequency of submission, data types submitted.
- Check those databases for products: data formats, commonalities/differences, redundancies.
- *Not* checking consistency of data.

Addresses recommendation(s): GR8

Activity D7: Multiple versions of same data

The purpose of this activity to avoid the situation when apparently same data appears in different databases, but has different content (example: NDACC O_3 profile may have different content than WOUDC). There would be a need for a ”main database” for any given dataset. This is a long term goal, not immediate implementation for a wider system.

- Pilot project could be started between NDACC & WOUDC, and possibly SHADOZ.
- Follow-on Activity / pilot project: Consider the possibility of switching to “pick up“ system at specific sites (i.e., data centre “pulling” data from provider instead of provider “pushing” data to data centre).

Addresses recommendation(s): GR7

Activity D8: Review existing services and tools

A review on ozone, UV, greenhouse gases and air quality was performed within the GSE PROMOTE project (2005). ESA agrees to provide this documentation, precising the different segments and the corresponding needs.

- Obtain review results from ESA and make available on IGACO website. (Note: focus is on Europe, so this is a starting point. Needed as background information for developing services).

Addresses recommendation(s): GR8

Activity D9: Overview of existing data services – follow-on

- Send out a questionnaire on behalf of IGACO requesting for concise information on existing Ozone data services (web link; 2-3 sentences description; contact person; information on main users; original / main data source).
- Feed-back from service providers.
- A review phase to test the links, assess usefulness, lacks.
- WMO coordinates a report.

Addresses recommendation(s): GR8

Activity D10: Guidelines for tools to be included

Several databases offer web-based tools (either images or on-line graphical package); however those tools do not necessarily meet the needs of all users, who would want to, e.g., compare data and make their own tailor-made plots.

A recommendation is that, in a system for instance like WIS, a dataset that is requested will come with its metadata, data protocol, and also an « interface package ». At minimum, this interface package would include reading routines in FORTRAN and/or C. There could be supplement, such as graphical scripts **as long as** they are based on free software and that they are open-source. For graphics these scripts could rely on software like GMT, Grads, and Vis5d.

Tasks:

- Define guidelines for "mandatory" tools, based on description above. Read/write routines and data catalogue are probably the most useful tools.

Assesses recommendation(s): GR8

Activity D11: Identifying historical data

There exist quite a lot data that have been discontinued, and the originator does not (any more) support calibration/validation history. Specific campaign data can be included in this category. WOUDC (other data centres to be confirmed) will tag those data so that users clearly understand the difference with those data and currently supported data.

Addresses recommendation(s): GR7

Activity D12: Development of WIS

Follow the definition and development of the WMO Information System (WIS) proactively, so that the needs of IGACO are taken into account as much as possible. At the same time, IGACO-O_3/UV and WMO will keep the O_3/UV community informed of development status. WMO will work (on a best effort basis) to obtain a commitment from WIS for supporting non-WMO (science) communities.

Addresses recommendation(s): GR8, GR9, GR10

2.5 Summary of Activities vs. IGACO Recommendations

In the IGACO Theme Report, the recommendations are grouped in five groups. Below we summarise how the activities listed below fall within the scope of each group of recommendations, based on the "Assesses recommendation(s)" statements given above. A summary is also given in Table 2.

Table 2. Summary of IGACO Activities, including relation to General Recommendations from the Theme Report. (GR1, GR2 etc. are explained in Annex A)

IGACO Activity Status List

Unique ID	Document/meeting origin	Activity ID	Description	GR1	GR2	GR3	GR4	GR5	GR6	GR7	GR8	GR9	GR10	GR11	GR12
1	Anavyssos May 2006	A1	Measurement Platform Workshop					X		X					
2	Anavyssos May 2006	A2	Dobson/Brewer Absolute Calibration Comparison					X		X					
3	Anavyssos May 2006	A3	Clarify differences in UV/VIS measurements of ozone					X		X					
4	Anavyssos May 2006	A4	Improve Ground-based and Satellite Measurements at high Solar Zenith Angles and high latitudes					X		X					
5	Anavyssos May 2006	A5	Systematic comparison total ozone measurements from ground and space					X		X					
6	Anavyssos May 2006	A6	Brewer and Dobson network updates				X								
7	Anavyssos May 2006	A7	Acquire Brewer Umkehr Data						X						
8	Implementation Plan Review 2007	A8	Long-term ozone profile records and data harmonisation		X			X	X	X					
9	Implementation Plan Review 2007	B1	Global UTLS monitoring approach		X		X		X						
10	Anavyssos May 2006	B2	Continue/augment ozonesonde network		X		X	X	X						
11	Anavyssos May 2006	B3	Assimilation of groundbased ozone measurements											X	
12	Anavyssos May 2006	B4	Assimilation of tropospheric ozone measurements											X	
13	SAG UV May 2007	C1	Explore use of small, inexpensive diode array spectrometers for ground-based UV measurements				X								
14	SAG UV May 2007	C2	Improve access to UV instrument calibration centres					X		X					
15	SAG UV May 2007	C3	Further develop and validate satellite UV algorithms					X							
16	SAG UV May 2007	C4	Improve the knowledge base of the UV effects in relation to UV monitoring							X					
17	SAG UV May 2007	C5	Extend the knowledge of UV for other receiving geometries							X					
18	SAG UV May 2007	C6	Improve the understanding of the factors affecting UV							X					

Unique ID	Document/meeting origin	Activity ID	Description	GR1	GR2	GR3	GR4	GR5	GR6	GR7	GR8	GR9	GR10	GR11	GR12
19	Anavyssos May 2006	D1	Better data access and archiving								X				X
20	Anavyssos May 2006	D2	Make more total ozone, Umkehr profiles and sondes available in near-real time								X				
21	Anavyssos May 2006	D3	Improve access to meteorological data												X
22	SAG UV May 2007	D4	Streamlining accessibility of UV data in WOUDC and EUVDB								X				
23	SAG UV May 2007	D5	Increase UV data in the WOUDC					X			X				
24	Duebendorf March 2007	D6	Mapping the current situation for data providers								X				
25	Duebendorf March 2007	D7	Multiple versions of same data							X					
26	Duebendorf March 2007	D8	Review existing services and tools								X				
27	Duebendorf March 2007	D9	Overview of existing data services – follow-on								X				
28	Duebendorf March 2007	D10	Guidelines for tools to be included								X				
29	Duebendorf March 2007	D11	Identifying historical data							X					
30	Duebendorf March 2007	D12	Development of WIS								X	X	X		

- Establishment of a global system (GR 1, 2 and 3), dealing with the establishing and managing a System, as well as ensuring continuous provision of data for target variables.

The development of the IGACO system has been initiated by WMO, and is proceeding as a strategic element of its GAW programme. Thus this document as a whole corresponds to work towards completing recommendations GR1 and GR3. For GR2 (Continuity of measurements) there are 3 activities.

- Measurements (GR 4), spelling out the recommendation to fill any gaps (either spatial or temporal) in the existing measurements system(s).

There are 4 activities that assess GR4.

- Quality-assurance and data-handling protocols, long-term provision and validation as well as comparability of data from differing sources, (GR 5, 6, 7 and 8).

Total of 24 of the 30 activities introduced above address at least one of these recommendations. In the Services cluster, activities D1 to D5 originate from the first user consultation meeting, whereas activities D7 to D15 were agreed in the meeting arranged as activity D1.

- World integrated data archive centres (GR 9 and 10), spelling out the need for central archives for key variables.

In the initial plan there is one activity which assesses both recommendations GR9 and GR10.

- Models and model inputs for the IGACO system (GR 11 and 12), emphasizing the need for improved modelling capability in order to bring together data from different sources to applications that need global coverage.

Modelling is a field of activity that will need more emphasis in the future. There are two activities assessing GR11, and two assessing GR12.

3. CONCLUSIONS

In this document we have presented an Implementation Plan for IGACO Ozone and UV radiation for years 2008-2011. As discussed in the "IGACO for ozone and UV section", the IGACO activities are a strategic element of the GAW programme, and thus the Implementation Plan should also be seen as complementing the WMO Global Atmosphere Watch Strategic Plan: 2008-2015 (GAW, 2007), where the IGACO recommendations have also been taken into account.

The role of IGACO-O_3/UV is to complement GAW with satellite and modelling activities, as well as facilitate and coordinate activities leading to a complete IGACO system. This will be done by defining activities that step-by-step lead to the build-up of a full IGACO system. Each activity is started with an analysis of the starting situation, followed by a more detailed work plan. As an example we could take Activity D1, where the meeting that was organized in March 2007 could be taken as the definition of way ahead, and then leading to 9 new activities.

The activities in this plan have been grouped into three clusters with different scientific questions, with a fourth cluster corresponding to services and activities that serve all of the other three. The activities in the service cluster are providing building blocks to the user part of the IGACO system, whereas the first three account for ensuring the quality and availability of good observations. In the long run the activities in this service cluster will also benefit the other IGACO Focus Areas, many of them falling into the category of cross-cutting activities in the IGACO terminology. The activities in this document are necessarily a starting point, and need to be complemented with new activities.

Column ozone is currently well covered with measurements from ground and using satellite instruments. The improvements, which are also covered by activities in this document, mainly aim at improving the knowledge of documented differences between data from different measurements, both in the sense that the user community need to be better informed of those differences, and understanding of the theoretical background of what is the root cause of those differences needs to be investigated. This done, the homogeneity of the data sets will be improved.

For ozone profile measurements, Brewer measurements can be processed with the Umkehr algorithm, which provides a new independent data set. Similarly to total column data, the harmonisation and validation of different data between instruments is needed. Error estimates will also be added to ground-based profile data: this is important for eventual use of those data in data assimilation.

The upper troposphere/lower stratosphere (UT/LS) is foreseen to be increasingly in the focus of ozone-related research, because of its important role in chemical and physical processes causing ozone loss and generation. Data exist from profiling ground-based and airborne instruments, but they need to be collected and harmonised. For the process studies, modelling efforts also need to focus in this area specifically.

UV radiation is measured globally on ground-based sites and UV doses on ground are also calculated from satellite measurements. The ground-based network consists of a multitude of instruments. Many of them make measurements in multiple wavelengths, but currently the common data that is provided is erythemally weighed UV index. Factors affecting the measurement need to be further studied and access to local calibration centres improved so that homogeneity of data over the network can be ensured. It is also desirable that in addition to the UV index, the original data with more information content would be more widely available through the data centres. To improve the coverage of the network, new semiconductor devices which are both robust and less expensive than earlier designs could be used to fill gaps in the network.

In the service cluster, access, homogeneity, data quality and continuity are the keywords. Ancillary and metadata need to be defined and then included in all data, in order to ensure that the data are useful over longer timeframes. Error estimates are also necessary for data assimilation and modelling. Near-real-time access is important to chemical weather prediction, which is an emerging field of interest.

During the timeframe of this plan, new activities will certainly be initiated. In the first phase of the implementation of IGACO-O_3/UV, priority was given to activities devoted to the measurements, data quality, collaboration of different networks and strategy of network for UT/LS ozone.

In the next step we plan to focus more also on the integration of modelling activities. Current climate models cover altitudes up to 200 kilometres and include chemical modules. The development of those models typically takes place in large consortia, where expertise of ozone chemistry and availability of models and validation data comes through partners that also contribute to IGACO-O3/UV. For stratospheric ozone the dialogue needs to be opened with groups involved in model validation, and for UT/LS ozone groups involved in activities in projects such as those supported by the GMES Atmospheric Service (e.g. MACC), which are working towards producing products related to “chemical weather”. With the global nature of the models and the large variety of modules in them, modelling is also an obvious candidate for cross-cutting activities between IGACO focus areas.

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GLOSSARY OF ACRONYMS

AREP	Atmospheric Research and Environment Programme (of WMO)
BIRA	Belgisch Instituut voor Ruimte-Aërnomie
BIRA-IASB	Belgian Institute for Space Aeronomy, see also IASB
CAS	Commission for Atmospheric Sciences (of WMO)
CEOS	Committee for Earth Observing Satellites
CHMI	Czech Hydrometeorological Institute
DAHC	Dobson Ad-Hoc Committee
DLR	German Aerospace Agency
DU	Dobson Units (measure of amount of ozone in the atmosphere)
DWD	Deutsche Wetterdienst, German NMS
EC	Environment Canada
ECMWF	European Centre for Medium-range Weather Forecasts
EOS-Aura	Earth Observing System satellite of NASA
EPA	(U.S.) Environmental Protection Agency
ESA	European Space Agency
EUVDB	European UV Database
FMI	Finnish Meteorological Institute
FTE	Full-time equivalent (work)
GAW	Global Atmosphere Watch (Programme of WMO)
GEO	Group on Earth Observation
GEOSS	Global Earth Observation System of Systems
GMES	Global Monitoring for Environment and Security
GR	General Recommendation (in IGACO Theme Report)
GTS	Global Telecommunications System (of WMO)
IAGOS	Integration of Routine Aircraft Measurements into a Global Observing System
IASB	Institute d'Aeronomie Spatiale Belgique (see also BIRA)
IGACO	Integrated Global Atmospheric Chemistry Observations
KNMI	Royal Netherlands Meteorological Institute
LAP	Laboratory of Atmospheric Physics (University of Thessaloniki)
NASA	National Aeronautics and Space Administration
NDACC	Network for the Detection of Atmospheric Composition Changes
NMS	National Meteorological Service
NOAA	National Oceanographic and Atmospheric Administration
NRT	Near Real-Time
NSF	(U.S.) National Science Foundation
ODS	Ozone Depleting Substances
OMI	Ozone Monitoring Instrument (on EOS-Aura)
QA	Quality Assessment
QC	Quality Control

RBCC	Regional Brewer Calibration Centre
RBSG	Regional Brewer Scientific Group
RDCC	Regional Dobson Calibration Centre
SAG	Science Advisory Group
SOP	Standard Operating Procedure
SR	Specific Recommendation (in IGACO Theme Report)
USDA	U.S. Department of Agriculture.
UT/LS	Upper Troposphere / Lower Stratosphere
WDC-RSAT	World Data Centre for Remote Sensing of the Atmosphere
WDCC	World Dobson Calibration Centre
WIDAC	World Information Data Archive Centre
WIS	WMO Information System
WMO	World Meteorological Organization
WOUDC	World Ozone and UV Data Centre

ANNEX A

RECOMMENDATIONS OF THE IGACO THEME REPORT

The twelve General Recommendations from the IGACO Theme report (IGACO, 2004) set the basic goals for all IGACO focus areas. The implementation of IGACO-O_3/UV takes into account both the General Recommendations (GR) and the Specific Requirements (SR). In the Theme Report, the recommendations have been grouped under the titles "Establishment" (corresponding to General Recommendations 1, 2, and 3), "Measurements" (GR 4), "Quality-assurance and data-handling protocols" (GR5, GR6, GR7, GR8), "World Integrated Data Archive Centres (WIDAC; GR8, GR9, GR10), and "Models and inputs needed for the IGACO system" (GR11, GR12). The recommendations, together with a brief summary of the status of the ozone observation system with respect to the recommendations (as discussed with involved scientists in User Consultation meetings) are given below.

As for terminology, by Group 1 species are meant: H_2O, O_3, CH_4, CO_2, CO, NO_2, BrO, ClO, HCl and CFC-12.

Group 2 variables are: NO, HNO_3, C_2H_6, CH_3Br, Halons, HCFC-22, $ClONO_2$, HCHO, SO_2, UVA j(NO_2) and UVB j(O^1D).

In addition, aerosol properties needed are listed as Aerosol Optical Depth (VIS+IR), Aerosol Extinction Coefficient (VIS), Aerosol Absorption Optical Depth (VIS) and PM1, PM2.5 & PM1 properties.

Establishment of a global system (GR1, GR2, GR3)

GR1 *Establishment: An Integrated Global Atmospheric Chemistry Observation System (IGACO) should be established for a target list of atmospheric chemistry variables and ancillary meteorological data.*

IGACO has been established by WMO and ESA and it will be implemented through the GAW programme of WMO.

GR2 *Continuity: the data products from satellite and non-satellite instruments, which are to be integrated into a global picture by IGACO, must have assured long-term continuity.*

The responsibility of maintaining observational networks lies mostly on national research institutions and agencies, with limited support from international organizations. Consequently, the continuity of observations depends on continuing support from the funding agencies. In addition to maintenance of the existing network, continuity of observations requires monitoring of instrumentation and continuous development of new methods for observations, both ground-based, airborne and from space.

For O_3 observations the situation is quite satisfactory: critical measurements are operational and mostly guaranteed for the time being, except for the possible discontinuation of solar and stellar occultation measurements, which poses a threat to the availability of routine high-resolution profile O_3 data from satellites.

GR3 *Management of IGACO: The responsibility for the co-ordination and implementation of IGACO should rest with a single international body. International and national agencies responsible for aspects of IGACO should be committed partners and agree on their appropriate responsibilities.*

WMO has taken the leading role in implementing IGACO through its GAW programme. The Office hosted by FMI is sharing responsibility of practical programme coordination tasks for IGACO-O_3/UV activities. The implementation team will have responsibility on maintaining communication towards and between the agencies referred to in the recommendation.

SR1 *Establishment of an IGACO system for selected Group 1 species encompassing data collection, harmonisation, QA/QC, data archiving and model-based integration.*
Status: This document.

SR2 *Initiate immediately the planning and implementation of a network of satellite platforms to be launched in the long term, with consideration of geostationary as well as enhanced low-Earth-orbit capabilities.*

Status: See GR 2 and GR 3 above.

Measurements (GR4)

GR4 *Gaps in observational coverage: for each target species and variable, the present gaps in the current spatial and temporal coverage should be filled by extending the existing measurement systems.*

The current coverage of the ground-based network is quite satisfactory. However, as discussed with GR2 above, continuity of funding is an issue that needs attention, and a specific activity (B2) has been agreed to assess these concerns.

In addition, some optimisation of the ground-based network by relocating Dobson/Brewer instruments to existing or new sites might result in more even global coverage. Financial aspects as well as necessary capacity building activities need to be included in the discussions.

SR3 *Develop the necessary data-harmonisation, quality/control and data-exchange protocols using the demonstration projects in SR1.*

SR4 *Upgrade the missing ground-based (in situ, total column, active and passive profiling, and balloon sondes) measurements to measure the Group 1 variables, and, where feasible, some of those from Group 2.*

SR5 *Develop a sustainable routine aircraft measurement programme based on the considerable experience obtained in ongoing projects.*

SR6 *Develop the necessary algorithms and associated calibration/validation procedures to retrieve operationally, total-column and vertical-profile concentrations from existing and planned satellites for as many of the Group 1 and 2 variables as possible.*

Status: Relatively mature for $O_{3;}$ Ongoing activities at individual research activities in institutions working on atmospheric chemistry.

Quality-assurance and data-handling protocols (GR5, GR6, GR7, GR8)

GR5 *Long-term validation of satellite observations: in order to ensure accuracy and consistency for satellite measurements, sustained quality assurance measures, over the entire lifetime of the observations, are essential.*

For most ground-based and routine aircraft observations of the gaseous species, the quality assurance of measurements is already achievable. However, in practice, the effectiveness of quality assurance in a measurement programme is highly variable. Validation and Quality Control standards for ground-based observations have been developed (WMO Report No. 143, and procedures mentioned therein). The Ozone and UV SAGs of the GAW programme are following and promoting the implementation of these standards.

For satellite-borne sensors the quality-assurance commonly referred to as calibration/validation is more complicated. It involves the evaluation of the retrieval algorithms used to extract geophysical quantities from calibrated and well-characterised basic data products. Satellite data products also require continuous validation to ensure that their quality is not deteriorated in time due to, e.g., instrument ageing. This requires that there is an independent high quality (ground-based) network providing reference data.

Calibration/validation is being addressed by the Working Group on Calibration and Validation of the CEOS subgroup on atmospheric composition. A policy for validating data for satellite ozone and chemistry missions was suggested in WMO/CEOS Report No. 140.

Since there are such a variety of instruments available for monitoring solar UV, the SAG-UV has produced a number of documents detailing the characteristics and operational requirements for the different categories: spectral, broadband and multifilter instruments. Another document on the use of diode array instruments is in preparation. However, many of the UV monitoring sites globally are not affiliated to GAW and operate independently, within national networks, or loose regional groupings. For example many European sites submit data to the European UV database (EUVDB), but there is no central funding agency willing to support the UV monitoring and its calibration within a formal European network.

While UV at the Earth's surface is not directly measured from satellites, it is derived using a number of other satellite products (ozone amount, aerosol optical depth and absorption, Rayleigh scattering, and cloud reflectivity) and radiative transfer theory. Satellite estimates of UV irradiance exist continuously for the entire globe since 1979 at a spatial resolution of 1^{o} x 1^{o}. These data have been compared with ground measurements of UV irradiance although detailed comparisons between ground-based measurement and satellite retrievals are limited to a few sites. In general, satellites tend to overestimate the amount of radiation reaching the ground by 10% to 40% compared to the best-calibrated ground instruments. The major source of this disagreement is still under debate and it is likely that absorbing atmospheric aerosols significantly contribute to the deviation between satellite derivations and ground based measurements. Snow covered regions are also problematical as the satellite retrievals struggle to distinguish between snow cover and cloud. Nonetheless, the great advantage of satellite information is its global coverage over land and oceans and its uniformity of calibration.

GR6 *Validation of vertical-profile data from satellite observations: a set of high performance scientific instruments using ground, aircraft and balloon platforms, possibly operated on campaign basis, must be maintained to provide the crucial validation data.*
See GR 4 (with related activity) and GR5 above.

GR7 *Comparability: the ability to merge observations of different types must be ensured by insisting that appropriate routine calibration and comparison activities linking diverse measurements together are part of an individual instrument measurement programme.*

Multiple satellite systems will be in orbit measuring the same constituent (e.g. O_3 from multiple instruments on Envisat and EOS-Aura). In the IGACO Theme Report it is recommended that every effort should be made to have a common or well-compared radiative transfer model and the same spectroscopic databases to ensure that these fundamental parameters do not cause biases. The respective algorithms for each system have a different heritage and physical basis. On the other hand, having different approaches is positive as long as comparisons are regularly made and differences are understood and well documented (c.f. differences between Dobson and Brewer measurements from ground). Knowledge is the keyword.

The UV community within GAW, and generally, lacks an acknowledged world reference centre for providing calibration sources to be used at the observation sites. Underlying all calibrations are standards of spectral irradiance available from national standards laboratories. The standards of different laboratories vary in the UV region and there is no accepted "truth". Even assuming that the national laboratories will converge to a universal standard, the standard still has to be maintained and transferred to the measurement instruments. It is not viable to have the facilities required for this task at every site. Since the instruments change their calibration when transported, central facilities are required to calibrate radiation sources to be calibrated on site. At present there are GAW calibration facilities for North America and Europe and it is hoped that a global facility will be supported in the near future.

GR8 *Distribution of data: universally recognised distribution protocols for exchange of data on atmospheric chemical constituents should be established.*

Distribution Protocols should be understood as covering formats, access, and policy. Easy, unbureaucratic access to data is an important goal for researchers. Protocols are discussed in several international forums, including WMO CAS, O_3 and UV SAGs, CEOS and GEO. Need for real or near-real time access to data is also foreseen to be increasing: Applications using data assimilation of stratospheric ozone have started to provide consistent distributions on a routine basis for some applications, i.e. for weather and UV forecasts.

SR3 *Develop the necessary data-harmonisation, quality/control and data-exchange protocols using the demonstration projects in SR1.*

Status: See activities below.

World Integrated Data Archive Centres (WIDAC; GR9, GR10)

GR9 *Multi-stake holder World Integrated Data Archive Centres (WIDAC) should be established for the targeted chemical variables.*

For ground-based O_3 and UV data, central archives are in place (WOUDC hosted by Environment Canada for both O_3 and UV data and European UV Database). It is not foreseen that additional central archives are needed for ground-based O_3 and UV data. However, since not all ground based data is archived in the WOUDC, operational links to other data bases such as NDACC and MOZAIC (aircraft data) should also established.

For satellite data, a distributed system with each operator maintaining their own archives has been the solution in the past. Access to data varies between different operators (policies, data portals etc. see http://idn.ceos.org for a collection of data services). These differences need to be discussed in order to potentially improve access and usability. An agreement was recently made between WMO/GAW and the German Aerospace Agency (DLR) on including the DLR-supported WDC-RSAT data centre (World Data Centre – Remote Sensing of the Atmosphere) as providing access to satellite data to the GAW programme. The further development of this facility will be coordinated with the needs of GAW/IGACO.

GR10 *Storage for raw data should be established so that they can be re-interpreted as models and understanding improves.*

As a general principle, the originator of data bears the responsibility of archiving (or storing) the raw data. The importance of this task is unfortunately often overtaken by reality: in order to store old data, archives need to be maintained actively by, e.g., transferring old data from old media to new systems regularly. This is a task that needs resources.

Except for satellite data the data volumes of O_3 and UV observations are relatively small, and a central archive could technically take this responsibility, providing sufficient resources are available. The WOUDC has started collecting original data from Brewer stations.

Models and model inputs needed for the IGACO system (GR11, GR12)

GR11 *The development of comprehensive chemical modules in weather and climate models should be an integral part of IGACO.*

Ozone plays an important part in all of the IGACO focus areas both through chemistry and radiative forcing. In addition to the effect on the atmospheric composition through chemistry, ozone influences the temperature profile in the atmosphere and functions as a driver for the stratospheric circulation. The development of comprehensive chemical modules for use in weather and climate models with appropriate data assimilation is therefore an integral part of IGACO. These same models can be used for re-analysis of observations (real time and non-real time) as the integrated observational system improves and delivers more data to a central archive (WIDAC).

For UV research several intercompared radiative transfer models are available. However, most of these models are one-dimensional models and are not able to handle horizontal dependencies like broken clouds. A central facility could hold information on the available models for the UV community.

GR12 *Strong coordination with meteorological services is essential so that the ancillary meteorological data required by IGACO is accessible.*

For National Meteorological Services ancillary data is usually available from their corresponding centres (NOAA, ECMWF…). For non-NMS users access to those data may be more complicated, especially for near-real-time applications.

SR7 *Develop chemical transport modelling and data assimilation so as to accommodate data from the various measurement components.*

Ongoing existing activities: ACCENT, SPARC, individual research activities. See also GR11 above.

GLOBAL ATMOSPHERE WATCH REPORT SERIES

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64. Report of the consultation to consider desirable locations and observational practices for BAPMoN stations of global importance, Bermuda Research Station, 27-30 November 1989.

65. Report of the Meeting on the Assessment of the Meteorological Aspects of the Fourth Phase of EMEP, Sofia, Bulgaria, 27 and 31 October 1989.

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71. Report of the Consultation of Experts to Consider Desirable Observational Practices and Distribution of GAW Regional Stations, Halkidiki, Greece, 9-13 April 1991 (WMO TD No. 433).

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73. Report of the Experts Meeting on Global Aerosol Data System (GADS), Hampton, Virginia, 11 to 12 September 1990 (WMO TD No. 438).

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79. Report of the Meeting of Experts to Consider the Aerosol Component of GAW, Boulder, 16 to 19 December 1991 (WMO TD No. 485).

80. Report of the WMO Meeting of Experts on the Quality Assurance Plan for the GAW, Garmisch-Partenkirchen, Germany, 26-30 March 1992 (WMO TD No. 513).

81. Report of the Second Meeting of Experts to Assess the Response to and Atmospheric Effects of the Kuwait Oil Fires, Geneva, Switzerland, 25-29 May 1992 (WMO TD No. 512).

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83. Report on the Global Precipitation Chemistry Programme of BAPMoN (WMO TD No. 526).

84. Provisional Daily Atmospheric Carbon Dioxide Concentrations as measured at GAW-BAPMoN sites for the year 1991 (WMO TD No. 543).

85. Chemical Analysis of Precipitation for GAW: Laboratory Analytical Methods and Sample Collection Standards by Dr Jaroslav Santroch (WMO TD No. 550).

86. The Global Atmosphere Watch Guide, 1993 (WMO TD No. 553).

87. Report of the Third Session of EC Panel/CAS Working Group on Environmental Pollution and Atmospheric Chemistry, Geneva, 8-11 March 1993 (WMO TD No. 555).

88. Report of the Seventh WMO Meeting of Experts on Carbon Dioxide Concentration and Isotopic Measurement Techniques, Rome, Italy, 7-10 September 1993, (edited by Graeme I. Pearman and James T. Peterson) (WMO TD No. 669).

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90. Global Atmospheric Background Monitoring for Selected Environmental Parameters GAW Data for 1992, Volume I: Atmospheric Aerosol Optical Depth (WMO TD No. 562).

91. Extended Abstracts of Papers Presented at the WMO Region VI Conference on the Measurement and Modelling of Atmospheric Composition Changes Including Pollution Transport, Sofia, 4 to 8 October 1993 (WMO TD No. 563).

92. Report of the Second WMO Meeting of Experts on the Quality Assurance/Science Activity Centres of the Global Atmosphere Watch, Garmisch-Partenkirchen, 7-11 December 1992 (WMO TD No. 580).

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98. Report of the WMO Meeting of Experts on Global Carbon Monoxide Measurements, Boulder, USA, 7-11 February 1994 (WMO TD No. 645).

99. Status of the WMO Global Atmosphere Watch Programme as at 31 December 1993 (WMO TD No. 636).

100. Report of the Workshop on UV-B for the Americas, Buenos Aires, Argentina, 22-26 August 1994.

101. Report of the WMO Workshop on the Measurement of Atmospheric Optical Depth and Turbidity, Silver Spring, USA, 6-10 December 1993, (edited by Bruce Hicks) (WMO TD No. 659).

102. Report of the Workshop on Precipitation Chemistry Laboratory Techniques, Hradec Kralove, Czech Republic, 17-21 October 1994 (WMO TD No. 658).

103. Report of the Meeting of Experts on the WMO World Data Centres, Toronto, Canada, 17 - 18 February 1995, (prepared by Edward Hare) (WMO TD No. 679).

104. Report of the Fourth WMO Meeting of Experts on the Quality Assurance/Science Activity Centres (QA/SACs) of the Global Atmosphere Watch, jointly held with the First Meeting of the Coordinating Committees of IGAC-GLONET and IGAC-ACE, Garmisch-Partenkirchen, Germany, 13 to 17 March 1995 (WMO TD No. 689).

105. Report of the Fourth Session of the EC Panel of Experts/CAS Working Group on Environmental Pollution and Atmospheric Chemistry (Garmisch, Germany, 6-11 March 1995) (WMO TD No. 718).

106. Report of the Global Acid Deposition Assessment (edited by D.M. Whelpdale and M-S. Kaiser) (WMO TD No. 777).

107. Extended Abstracts of Papers Presented at the WMO-IGAC Conference on the Measurement and Assessment of Atmospheric Composition Change (Beijing, China, 9-14 October 1995) (WMO TD No. 710).

108. Report of the Tenth WMO International Comparison of Dobson Spectrophotometers (Arosa, Switzerland, 24 July - 4 August 1995).

109. Report of an Expert Consultation on 85Kr and 222Rn: Measurements, Effects and Applications (Freiburg, Germany, 28-31 March 1995) (WMO TD No. 733).

110. Report of the WMO-NOAA Expert Meeting on GAW Data Acquisition and Archiving (Asheville, NC, USA, 4-8 November 1995) (WMO TD No. 755).

111. Report of the WMO-BMBF Workshop on VOC Establishment of a “World Calibration/Instrument Intercomparison Facility for VOC” to Serve the WMO Global Atmosphere Watch (GAW) Programme (Garmisch-Partenkirchen, Germany, 17-21 December 1995) (WMO TD No. 756).

112. Report of the WMO/STUK Intercomparison of Erythemally-Weighted Solar UV Radiometers, Spring/Summer 1995, Helsinki, Finland (WMO TD No. 781).

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113. The Strategic Plan of the Global Atmosphere Watch (GAW) (WMO TD No. 802).

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115. Report of the Meeting of Experts on Atmospheric Urban Pollution and the Role of NMSs (Geneva, 7-11 October 1996) (WMO TD No. 801).

116. Expert Meeting on Chemistry of Aerosols, Clouds and Atmospheric Precipitation in the Former USSR (Saint Petersburg, Russian Federation, 13-15 November 1995).

117. Report and Proceedings of the Workshop on the Assessment of EMEP Activities Concerning Heavy Metals and Persistent Organic Pollutants and their Further Development (Moscow, Russian Federation, 24-26 September 1996) (Volumes I and II) (WMO TD No. 806).

118. Report of the International Workshops on Ozone Observation in Asia and the Pacific Region (IWOAP, IWOAP-II), (IWOAP, 27 February-26 March 1996 and IWOAP-II, 20 August-18 September 1996) (WMO TD No. 827).

119. Report on BoM/NOAA/WMO International Comparison of the Dobson Spectrophotometers (Perth Airport, Perth, Australia, 3-14 February 1997), (prepared by Robert Evans and James Easson) (WMO TD No. 828).

120. WMO-UMAP Workshop on Broad-Band UV Radiometers (Garmisch-Partenkirchen, Germany, 22 to 23 April 1996) (WMO TD No. 894).

121. Report of the Eighth WMO Meeting of Experts on Carbon Dioxide Concentration and Isotopic Measurement Techniques (prepared by Thomas Conway) (Boulder, CO, 6-11 July 1995) (WMO TD No. 821).

122. Report of Passive Samplers for Atmospheric Chemistry Measurements and their Role in GAW (prepared by Greg Carmichael) (WMO TD No. 829).

123. Report of WMO Meeting of Experts on GAW Regional Network in RA VI, Budapest, Hungary, 5 to 9 May 1997.

124. Fifth Session of the EC Panel of Experts/CAS Working Group on Environmental Pollution and Atmospheric Chemistry, (Geneva, Switzerland, 7-10 April 1997) (WMO TD No. 898)

125. Instruments to Measure Solar Ultraviolet Radiation, Part 1: Spectral Instruments (lead author G. Seckmeyer) (WMO TD No. 1066)

126. Guidelines for Site Quality Control of UV Monitoring (lead author A.R. Webb) (WMO TD No. 884).

127. Report of the WMO-WHO Meeting of Experts on Standardization of UV Indices and their Dissemination to the Public (Les Diablerets, Switzerland, 21-25 July 1997) (WMO TD No. 921).

128. The Fourth Biennial WMO Consultation on Brewer Ozone and UV Spectrophotometer Operation, Calibration and Data Reporting, (Rome, Italy, 22-25 September 1996) (WMO TD No. 918).

129. Guidelines for Atmospheric Trace Gas Data Management (Ken Masarie and Pieter Tans), 1998 (WMO TD No. 907).

130. Jülich Ozone Sonde Intercomparison Experiment (JOSIE, 5 February to 8 March 1996), (H.G.J. Smit and D. Kley) (WMO TD No. 926).

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132. Report of the Ninth WMO Meeting of Experts on Carbon Dioxide Concentration and Related Tracer Measurement Techniques (Edited by Roger Francey), (Aspendale, Vic., Australia).

133. Workshop on Advanced Statistical Methods and their Application to Air Quality Data Sets (Helsinki, 14-18 September 1998) (WMO TD No. 956).

134. Guide on Sampling and Analysis Techniques for Chemical Constituents and Physical Properties in Air and Precipitation as Applied at Stations of the Global Atmosphere Watch. Carbon Dioxide (WMO TD No. 980).

135. Sixth Session of the EC Panel of Experts/CAS Working Group on Environmental Pollution and Atmospheric Chemistry (Zurich, Switzerland, 8-11 March 1999) (WMO TD No.1002).

136. WMO/EMEP/UNEP Workshop on Modelling of Atmospheric Transport and Deposition of Persistent Organic Pollutants and Heavy Metals (Geneva, Switzerland, 16-19 November 1999) (Volumes I and II) (WMO TD No. 1008).

137. Report and Proceedings of the WMO RA II/RA V GAW Workshop on Urban Environment (Beijing, China, 1-4 November 1999) (WMO-TD. 1014) (Prepared by Greg Carmichael).

138. Reports on WMO International Comparisons of Dobson Spectrophotometers, Parts I – Arosa, Switzerland, 19-31 July 1999, Part II – Buenos Aires, Argentina (29 Nov. – 12 Dec. 1999 and Part III – Pretoria, South Africa (18 March – 10 April 2000) (WMO TD No. 1016).

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140. WMO/CEOS Report on a Strategy for Integrating Satellite and Ground-based Observations of Ozone (WMO TD No. 1046).

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143. Global Atmosphere Watch Measurements Guide (WMO TD No. 1073).

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146. Quality Assurance in monitoring solar ultraviolet radiation: the state of the art. (WMO TD No. 1180).

147. Workshop on GAW in RA VI (Europe), Riga, Latvia, 27-30 May 2002. (WMO TD No. 1206).

148. Report of the Eleventh WMO/IAEA Meeting of Experts on Carbon Dioxide Concentration and Related Tracer Measurement Techniques (Tokyo, Japan, 25-28 September 2001) (WMO TD No 1138).

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150. Updated Guidelines for Atmospheric Trace Gas Data Management (Prepared by Ken Maserie and Pieter Tans (WMO TD No. 1149).

151. Report of the First CAS Working Group on Environmental Pollution and Atmospheric Chemistry (Geneva, Switzerland, 18-19 March 2003) (WMO TD No. 1181).

152. Current Activities of the Global Atmosphere Watch Programme (as presented at the 14th World Meteorological Congress, May 2003). (WMO TD No. 1168).

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155. 1st International Expert Meeting on Sources and Measurements of Natural Radionuclides Applied to Climate and Air Quality Studies (Gif sur Yvette, France, 3-5 June 2003) (WMO TD No. 1201).

156. Addendum for the Period 2005-2007 to the Strategy for the Implementation of the Global Atmosphere Watch Programme (2001-2007), GAW Report No. 142 (WMO TD No. 1209).

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158. JOSIE-2000 Jülich Ozone Sonde Intercomparison Experiment 2000. The 2000 WMO international intercomparison of operating procedures for ECC-ozone sondes at the environmental simulation facility at Jülich (Prepared by Herman G.J. Smit and Wolfgang Straeter) (WMO TD No. 1225).

159. IGOS-IGACO Report - September 2004 (WMO TD No. 1235)

160. Manual for the GAW Precipitation Chemistry Programme (Guidelines, Data Quality Objectives and Standard Operating Procedures) (WMO TD No. 1251).

161 12th WMO/IAEA Meeting of Experts on Carbon Dioxide Concentration and Related Tracers Measurement Techniques (Toronto, Canada, 15-18 September 2003).

162. WMO/GAW Experts Workshop on a Global Surface-Based Network for Long Term Observations of Column Aerosol Optical Properties, Davos, Switzerland, 8-10 March 2004 (edited by U. Baltensperger, L. Barrie and C. Wehrli) (WMO TD No. 1287).

163. World Meteorological Organization Activities in Support of the Vienna Convention on Protection of the Ozone Layer (WMO No. 974).

164. Instruments to Measure Solar Ultraviolet Radiation: Part 2: Broadband Instruments Measuring Erythemally Weighted Solar Irradiance (WMO TD No. 1289).

165. Report of the CAS Working Group on Environmental Pollution and Atmospheric Chemistry and the GAW 2005 Workshop, 14-18 March 2005, Geneva, Switzerland (WMO TD No. 1302).

166. Joint WMO-GAW/ACCENT Workshop on The Global Tropospheric Carbon Monoxide Observations System, Quality Assurance and Applications (EMPA, Dübendorf, Switzerland, 24 – 26 October 2005) (edited by J. Klausen) (WMO TD No. 1335).

167. The German Contribution to the WMO Global Atmosphere Watch Programme upon the 225th Anniversary of GAW Hohenpeissenberg Observatory (edited by L.A. Barrie, W. Fricke and R. Schleyer (WMO TD No. 1336).

168. 13th WMO/IAEA Meeting of Experts on Carbon Dioxide Concentration and Related Tracers Measurement Techniques (Boulder, Colorado, USA, 19-22 September 2005) (edited by J.B. Miller) (WMO TD No. 1359).

169. Chemical Data Assimilation for the Observation of the Earth's Atmosphere – ACCENT/WMO Expert Workshop in support of IGACO (edited by L.A. Barrie, J.P. Burrows, P. Monks and P. Borrell) (WMO TD No. 1360).

170. WMO/GAW Expert Workshop on the Quality and Applications of European GAW Measurements (Tutzing, Germany, 2-5 November 2004) (WMO TD No. 1367).

171. A WMO/GAW Expert Workshop on Global Long-Term Measurements of Volatile Organic Compounds (VOCs) (Geneva, Switzerland, 30 January – 1 February 2006) (WMO TD No. 1373).

172. WMO Global Atmosphere Watch (GAW) Strategic Plan: 2008 – 2015 (WMO TD No. 1384)

173. Report of the CAS Joint Scientific Steering Committee on Environmental Pollution and Atmospheric Chemistry (Geneva, Switzerland, 11-12 April 2007) (WMO TD No.1410).

174. World Data Centre for Greenhouse Gases Data Submission and Dissemination Guide (WMO TD No. 1416).

175. The Ninth Biennial WMO Consultation on Brewer Ozone and UV Spectrophotometer Operation, Calibration and Data Reporting (Delft, Netherlands, 31-May – 3 June 2005) (WMO TD No. 1419).

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177. Joint Report of COST Action 728 and GURME – Overview of Existing Integrated (off-line and on-line) Mesoscale Meteorological and Chemical Transport Modelling in Europe (ISBN 978-1-905313-56-3) (WMO TD No. 1427).

178. Plan for the implementation of the GAW Aerosol Lidar Observation Network GALION, (Hamburg, Germany, 27 - 29 March 2007) (WMO TD No. 1443).

179. Intercomparison of Global UV Index from Multiband Radiometers: Harmonization of Global UVI and Spectral Irradiance (WMO TD No. 1454).

180. Towards a Better Knowledge of Umkehr Measurements: A Detailed Study of Data from Thirteen Dobson Intercomparisons (WMO TD No. 1456).

181. Joint Report of COST Action 728 and GURME – Overview of Tools and Methods for Meteorological and Air Pollution Mesoscale Model Evaluation and User Training (WMO TD No. 1457).