

GAW Report No. 189

Report of the MACC/GAW Session on the
Near-Real-Time Delivery of the GAW Observations of
Reactive Gases

(Garmisch-Partenkirchen, Germany, 6-8 October 2009)

For more information, please contact:

World Meteorological Organization

Research Department

Atmospheric Research and Environment Branch

7 bis, avenue de la Paix – P.O. Box 2300 – CH 1211 Geneva 2 – Switzerland

Tel.: +41 (0) 22 730 81 11 – Fax: +41 (0) 22 730 81 81

E-mail: AREP-MAIL@wmo.int – Website: http://www.wmo.int/pages/prog/arep/index_en.html



**World
Meteorological
Organization**
Weather • Climate • Water

WMO/TD - No. 1527



© World Meteorological Organization, 2009

The right of publication in print, electronic and any other form and in any language is reserved by WMO. Short extracts from WMO publications may be reproduced without authorization, provided that the complete source is clearly indicated. Editorial correspondence and requests to publish, reproduce or translate these publication in part or in whole should be addressed to:

Chairperson, Publications Board
World Meteorological Organization (WMO)
7 bis, avenue de la Paix
P.O. Box 2300
CH-1211 Geneva 2, Switzerland

Tel.: +41 (0) 22 730 84 03
Fax: +41 (0) 22 730 80 40
E-mail: Publications@wmo.int

NOTE

The designations employed in WMO publications and the presentation of material in this publication do not imply the expression of any opinion whatsoever on the part of the Secretariat of WMO concerning the legal status of any country, territory, city or area, or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Opinions expressed in WMO publications are those of the authors and do not necessarily reflect those of WMO. The mention of specific companies or products does not imply that they are endorsed or recommended by WMO in preference to others of a similar nature which are not mentioned or advertised.

This document (or report) is not an official publication of WMO and has not been subjected to its standard editorial procedures. The views expressed herein do not necessarily have the endorsement of the Organization.

WORLD METEOROLOGICAL ORGANIZATION GLOBAL ATMOSPHERE WATCH



GAW Report No. 189

REPORT OF THE MACC/GAW SESSION ON THE NEAR-REAL-TIME DELIVERY OF THE GAW OBSERVATIONS OF REACTIVE GASES

(Garmisch-Partenkirchen, Germany, 6-8 October 2009)

Contributing authors

Harald Flentje, Stuart Penkett, Martin Schultz, Oksana Tarasova and Anja Werner



WMO/TD-No. 1527
August 2010

Table of Contents

1.	GENERAL INTRODUCTION	1
2.	OVERVIEW OF THE GEMS/MACC PROJECT	3
2.1	Introduction	3
2.2	The MACC Project- Objectives	4
2.3	The MACC forecast system	4
2.4	Global Structure of MACC.....	4
2.5	THE GRG – Global Reactive Gases work package	5
3.	MODEL VALIDATION WITH GAW MEASUREMENTS	6
3.1	Participating stations	6
3.2	Selected results	7
3.3	Recommendations	9
4.	RECOMMENDATIONS ON RAPID DATA DELIVERY	10
4.1	Rapid delivery strategy.....	10
4.2	Recommendations	11
5.	OUTLOOK AND FUTURE ACTIVITIES	13
	References	14
	Annex I - Acronyms	15
	Annex II Meeting agenda	16
	Annex III List of participants	18

1. GENERAL INTRODUCTION

The Global Atmosphere Watch (GAW) programme of the World Meteorological Organization (WMO) aims to provide reliable long-term observations and analysis of the chemical composition and physical properties of the atmosphere and works on issues connected with atmospheric chemistry and climate change. The mandate of the GAW programme as described in the GAW Strategic Plan for 2008-2015 (GAW Report No.172) includes the integration of satellite and aircraft observations with surface measurements through the use of numerical models and analysis. The ultimate aim of the programme is to realize an end-to-end system that includes data collection and quality control right through to the end products and services. Comparability of data from different observational platforms and sites is of crucial importance in realizing the full potential of global observations for the early detection of global trends and many other applications. If models are validated against available sets of measurements, they can be used to assimilate observations, fill spatial or temporal gaps and to optimize the whole observing system for a particular chemical variable.

To meet its mission and long-term objectives, the next generation WMO-GAW programme (2008- 2015) builds on a framework strategy, namely, on Integrated Global Atmospheric Chemistry Observations Strategy [IGACO, 2004]. GAW is implementing the recommendations of IGACO. The integrated system (Figure 1) deals with measurements throughout the atmosphere including observations, quality assurance and calibration/validation (cal/val), and data delivery—partly in near-real-time, but also after careful quality assurance to World Data Centres.

In leading the implementation of IGACO, GAW follows the mandate from WMO Members. It also responds to the needs and clear links to the plans of national, regional, and international observing projects, programmes, systems and strategies (e.g. GCOS, GEO, IGAC, see Annex I for Acronyms).

The key implementation principle of the end-to-end integration supposes combination in GAW modelling activities with atmospheric composition observations, quality assurance, data management, and outreach to enable data assimilation in forecasting systems and reanalysis of past atmospheric composition.

There are several different ways to integrate observations and models driven by particular user needs such as chemical weather prediction, reanalysis of atmospheric composition and inverse modelling to estimate sources/sinks of atmospheric chemicals. While chemical weather prediction requires real-time delivery of data, which limits the availability of some observations, chemical reanalysis focusing on the most complete analysis of the past atmospheric composition states utilizes all observations.

In response to requests to integrate chemistry and meteorology data and models, several projects have recently been initiated in the World (USA, Canada, Japan, and Europe). For example, the European GEMS¹ project and its successor project MACC², involve numeric weather prediction research that will eventually utilize chemical observations in forecast models and in atmospheric reanalyses. WMO is advancing regional scale air quality forecasts through the GURME project, Air Now (USA), INFO-SMOG (Environment Canada). Japan is building similar systems based on "research-base" forecast by JAMSTEC, Kyushu University, NIES and MRI, which can be seen from an integrated portal site <<http://www.data.kishou.go.jp/obs-env/oxidant/index.html>> (Japanese only).

¹ Global and regional Earth-system (Atmosphere) Monitoring using Satellite and in-situ data: *European Union framework 6 integrated research project, 2005-2009, web site: <http://gems.ecmwf.int>*

² *Monitoring of Atmospheric Composition and Climate: European Union framework 7 integrated research project, 2009-2011, web site: <http://www.gmes-atmosphere.eu>*

Components: Integrated Atmospheric Observations System

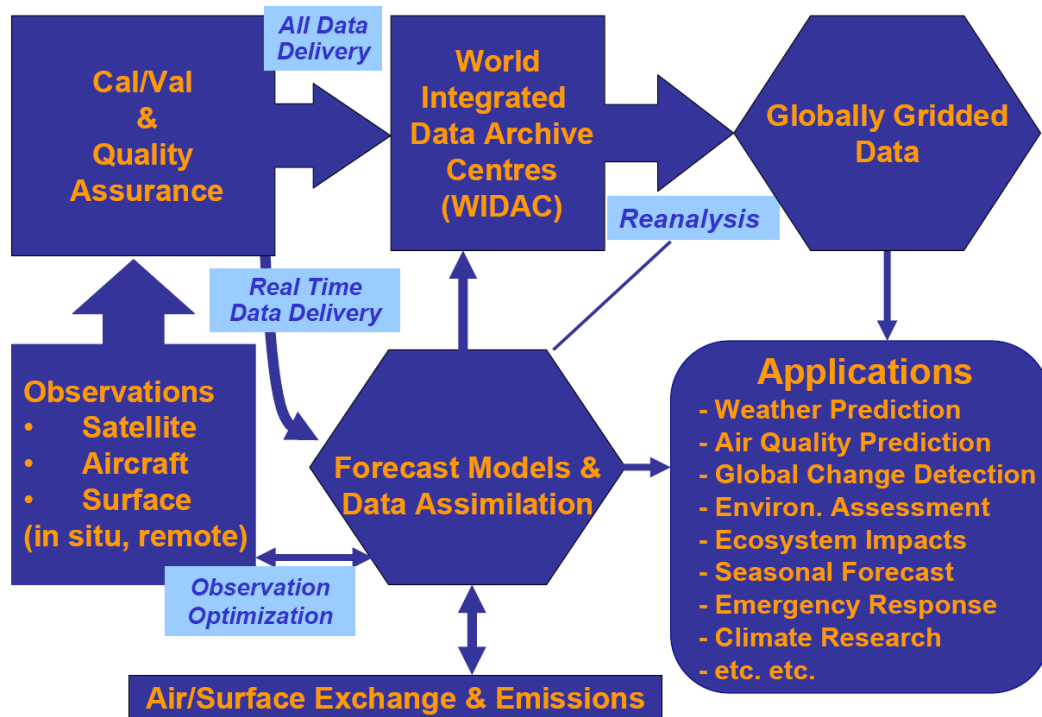


Figure 1 - Framework of a global integrated atmospheric observations system [IGACO, 2004]

These initiatives and services are critically dependent on in situ data. They impose strict criteria for timely delivery of these data which go far beyond the established criteria applicable to long-term monitoring data sets. Consensus has been reached by modelling community on the following requirements and hence classification of delivery times:

NRT (near-real-time): data suitable for assimilation in analysis and forecast models. Delivery time is less than 12 hours. Such data could also be used directly in decision processes, for example in extreme pollution episodes where public health is at stake.

RD (rapid delivery): data suitable for fast-response evaluation of near-real-time analyses and forecasts. No strict deadline, but no more than 1 week delay. Continuously measured species where data processing can be almost completely automated should become available 1-2 days after observation.

DM (delayed mode): data suitable for long-term “trend” analysis and detailed evaluation of model systems and reanalysis simulations. This comprises the current way of data delivery from GAW to its World Data Centres. However, it would be desirable to shorten delivery times from currently 1 year or more to a maximum delay of 6 months.

Definitions similar to the above have been formulated already in “Global Monitoring for Environment and Security Atmosphere Core Service (GACS), Implementation Group – Final Report (Annex 4) (<http://www.gmes.info/pages-principales/library/implementation-groups/gmes-atmosphere-core-service/>), published in April 2009.

In many cases, integration of satellite, aircraft and ground-based data needs data in near-real-time (NRT). Majority of ground-based observations are too sparse to be directly assimilated into models, but such data are important for model validation and their delivery in rapid mode is critical for model validation and data diagnostics. Projects that integrate meteorological and

atmospheric chemistry data, such as GEMS and MACC, need data on the chemical composition of the atmosphere in NRT. Forecasts and monitoring of air quality and UV radiation are examples where public health is at stake and where data is needed for rapid decision making (exposure limitation, traffic reduction etc.). Models used for such purposes need both input data and validation data in NRT. The GAW programme set up the Expert Team on Near-real-time Chemical Data Transfer (ET-NRT CDT) to respond to an increasing need in NRT data delivery from a modelling community, as this collaboration is important in the implementation of the integrated observing systems. This expert group revises definitions of data delivery time frame, given above.

Delivery of data in NRT is not an entirely new exercise in GAW. Total ozone from many stations are communicated to the WMO World Ozone and Ultraviolet Radiation Data Centre (WOUDC) in Toronto and to the WMO Ozone Mapping Centre hosted by the University of Thessaloniki within a day or faster after the measurement has been performed. This is an activity that has been ongoing since the 1990s. Ozone data are also communicated directly from a number of Antarctic stations to the WMO secretariat in Geneva for use in the WMO Antarctic Ozone Bulletins that are issued during the ozone hole season. It should be pointed out that this kind of data delivery is ad hoc and not carried out in a systematic and standardized way. An example of a more standardized and systematic NRT data delivery is the ozonesonde service run by the Norwegian Institute for Air Research (NILU). This routine is a natural continuation of the NRT data services put in place by NILU for European Commission funded ozone research projects since 1991.

Under the GAW umbrella there are now two pilot projects under way that aim at improving and extending NRT data delivery through the WMO Information System (WIS). One of these projects aims at improving NRT delivery of ozone and aerosol data through WIS.

Specific requirements for near-real-time delivery of chemical data, and in particular reactive gases concentrations, led to the organization of the workshop by MACC subproject on reactive gases with involvement of the GAW programme (station operators and secretariat). This workshop was held at UFS Schneefernerhaus, which is a part of the Global GAW station Zugspitze/Hohenpeissenberg, in Germany from 6 to 8 October 2009. The aim of the workshop was to foster further collaboration between the GAW observing system (stations) and modelling groups, to formulate the concept of such collaboration and to establish the Data Quality Objectives for the reactive gases data delivery in NRT or rapid delivery mode.

Recommendations formulated at the workshop will serve as a basis for the Agreements between GAW stations and MACC project on rapid data delivery.

The GAW programme would like to thank Deutscher Wetterdienst (DWD) for their efforts in the organization and support of the facilities necessary for rapid data delivery.

2. OVERVIEW OF THE GEMS/MACC PROJECT

2.1 Introduction

Operational atmospheric composition monitoring and forecasting is emerging rapidly as a key element for the verification of environmental treaties and protocols (e.g. UNFCCC, post-Montreal protocols, CLRTAP) and as a warning system to help in limiting the impacts of health and ecosystem disasters related to extreme air pollution episodes. Such systems contain both global and regional elements and must rely on the timely availability of observational data for analyses and verification of the atmospheric state. In Europe, these operational monitoring and forecasting activities are organized in the context of the Global Monitoring for Environment and Security (GMES) initiative, jointly funded by the European Space Agency and the European Union. GMES has defined a target to implement a fully operational Atmosphere Service by 2014. In preparation for this, two EU funded large-scale integrated projects (GEMS and MACC) have built comprehensive data analysis and modelling systems for monitoring the **global** distributions of atmospheric constituents important for climate, air quality, stratospheric ozone and UV radiation.

The MACC system is based at the European Centre for Medium-Range Weather Forecasts (ECMWF) and is running quasi-operationally since May 2007. The main goal of MACC is the consolidation and improvement of the comprehensive global and regional data assimilation and modelling systems developed within GMES and the evolution of data products into actual services which take into account the needs of specific user groups.

2.2 The MACC Project - Objectives

The MACC Project and its precursor GEMS constitute the main core service of the EU initiative GMES. While in GEMS comprehensive monitoring and forecasting systems for atmospheric constituents important for climate and air quality have been developed, MACC focuses on the integration and validation of the improved and extended GEMS systems as an operational forecast – the operational GMES Atmospheric Core Service. MACC includes also the PROMOTE (Protocol Monitoring for the GMES Service Element: Atmosphere) services, which provide an operational service to support informed decisions on the atmospheric policy issues of stratospheric ozone depletion, surface UV exposure, air quality and climate change.

By providing daily forecasts on the atmospheric distribution of the major greenhouse and chemically reactive gases, as well as aerosols, the MACC services aim to [MACC, Description of Work, 2009]:

- Provide global data in support of conventions and protocols on climate change, depletion of stratospheric ozone and long-range transport of atmospheric pollution.
- Provide information in support of development and implementation of European environmental policy.
- Address areas of key uncertainty in climate forcing identified by the Intergovernmental Panel on Climate Change (IPCC).
- Provide improved operational air-quality forecasts and a means for assessing the impact of climate variability and change on regional air quality.
- Provide improved monitoring and forecasting of UV radiation and solar-energy resources;
- Support downstream services for end-users.
- Complement the weather and climate services provided by the European Meteorological Infrastructure.

2.3 The MACC forecast system

The MACC forecast system is based on the global weather forecasting system operated by ECMWF coupled with a chemistry transport model (e.g. MOZART, TM5 or MOCAGE). The integrated forecast system (IFS) is capable of analysing, modelling and forecasting the atmospheric distribution of major greenhouse and chemically reactive gases, as well as aerosols. In a further development step this coupled system will be replaced by the IFS, a fully integrated chemistry transport model in the ECMWF forecasting system.

The forecast systems are capable of assimilating observational meteorological data, associated ocean-wave and land-surface data as well as data on atmospheric trace constituents that have been provided by in-situ (e.g. ozone sonde) or remotely sensed measurements (satellites).

2.4 Global Structure of MACC

To realize the above set objectives, the MACC project is divided into work package clusters as displayed in Figure 2.

Pre-existing GEMS and PROMOTE services together with ECMWF infrastructure from meteorological operations and climate reanalysis were the basis for the global component of MACC. The global component incorporates 4 sub-projects: G-GHG, G-RG, G-AER and G-IDAS. The first three sub-projects deal with aspects of observations, modelling, model and forecast validation, flux inversion and improvement of the integrated forecast system for greenhouse gases (G-GHG), reactive gases (G-RG) and Aerosols (G-AER). Data assimilation and the production of forecast and reanalysis products for these constituents as well as their monitoring and validation

are incorporated in G-IDAS, Global integrated data assimilation, production and services.

Input from satellite and in-situ data and emission inventories and estimates are provided by the sub projects D-SAT, D-INSITU, D-EMIS and D-FIRE.

Associated with the validation of reactive gas products with observational data from the GAW network, the G-RG work package will be illuminated further.

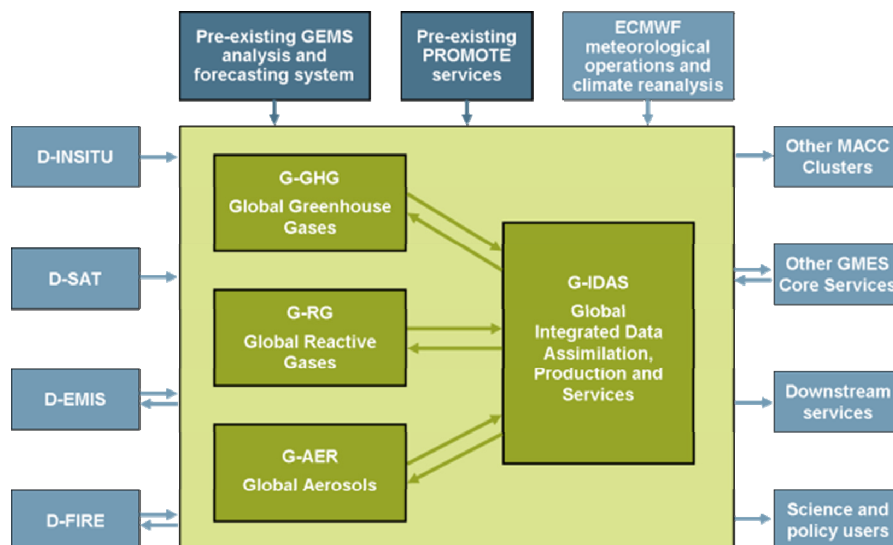


Figure 2 - Schematic of MACC sub projects. Taken from [MACC, Description of Work, 2009]

2.5 The G-RG – Global Reactive Gases work package

G-RG represents the largest work package group within the MACC project and is strongly based on the achievements of GEMS and PROMOTE. Among its major objectives are the consolidation, operation and improvement of the integrated forecast system for stratospheric and tropospheric ozone and some reactive gases (such as NO_x, CO, CH₂O, SO₂, non-methane VOCs) with an emphasis on the validation tasks. The development of a fully integrated chemistry transport model in the ECMWF integrated forecast system will be initiated, allowing inverse modelling applications, optional (simplified) chemistry schemes and thus being capable of performing source and process inversions in future applications.

Currently, the coupled IFS-MOZART model is the selected system for the implementation of a routine forecast; however, individual case studies will be performed by IFS-MOCAGE and IFS-TM5. It is the aim of MACC G-RG to improve the existing model versions and to incorporate new data sets from D-SAT, D-INSITU, D-EMIS and D-FIRE.

Of course the simulation or forecast product has to be subject to a quality control process. An essential element for the evaluation of model simulations is validation with observational data, the quantification and description of model errors and biases. Methodologies, which have been developed in GEMS, will be further improved, adapted and tested for routine semi-operational use. Additionally, specific case studies will be run which will be based on retrospective analyses of extreme events and include improved retrievals from satellite instruments.

Validation and quality control of the reanalysis and forecast products from operational atmospheric composition monitoring is an essential element of these services. In-situ observations from ground-based stations as well as aircraft measurements or independent satellite retrievals (i.e. not used in the data assimilation) are therefore indispensable. GAW global observations provide calibrated and quality controlled measurements of many atmospheric constituents which are of high value for the MACC validation activities. However, the procedures presently established at most of the GAW sites do not account for rapid delivery of observational data and some GAW

stations have accumulated a multi-year lag of data delivery to WDCGG³. The G-RG consortium is therefore keen to stimulate a co-operation with GAW stations in order to establish rapid data transfer.

3. MODEL VALIDATION WITH GAW MEASUREMENTS

This chapter describes the procedure of model validation with GAW observations as it was established by the end of the GEMS project. The idea is to build a fast validation system within MACC based on the lessons learned in the preceding project and making use of the existing and further possible collaboration with the GAW stations.

Within GEMS volume mixing ratios of O₃ and CO were delivered on a monthly basis from eight GAW stations. Part of the data sets were basically quality-checked but uncertainties/errors were not provided. Quality issues seem to be related to model representativeness (resolution) – particularly in complex terrain – rather than related to the observations themselves.

3.1 Participating stations

The following GAW stations provided observational data for the validation process in GEMS: Cape Point (South Africa), Assekrem (Algeria), Monte Cimone (Italy), Hohenpeissenberg (Germany), Neumayer (Antactica, Germany), BEO Moussala (Bulgaria), Izana and Santa Cruz (both Tenerife, Spain). Volume mixing ratios O₃ and CO were delivered on a monthly basis with a delay between 6 and 8 weeks, which is much faster than a standard submission to the data centre. Data were either transferred as e-mail attachment or via ftp to the DWD server. In Table 1, the stations are summarized. It is important to note that more than a half of these stations are located at high altitude, which creates some difficulties in the interpretation of the observations/simulations comparison. Hence it is very important to increase the participation of the GAW stations in this initiative to cover a wider spectrum of possible observation conditions.

Observations from the GAW network were used to evaluate global model simulations (1.125°- 2° lat x 1.125°- 3° lon, 60 vertical levels) from October 2007 onward (as a part of MACC project now). Model values at the station's locations in the horizontal were interpolated linearly from the model gridded data. In the vertical they were extracted at the model level which matches the GAW stations' real altitude (geopotential) which is equivalent to matching the mean pressure of the model level and station. As upper levels lack ground effects, this approach is not really satisfactory for mountain stations - thus the sensitivity to the chosen model level is used to estimate the uncertainty.

Table 1 - GAW sites participating in the GEMS models validation

Station	ID	Lat [°]	Lon [°]	alt [m a.s.l.]	O ₃	CO	NOx	SO ₂	VOCs
Hohenpeissenberg	HPB	47.8	11.02	985	X	X	X	X	X
Monte Cimone	MCI	44.18	10.7	2165	X	X			
BEO Moussala	BEO	42.2	25.4	2925	X	X			
Santa Cruz (Tenerife)	STC	28.5	-16.3	50	X	X	X	X	
Izana (Tenerife)	IZO	28.3	-16.5	2367	X	X	X	X	
Assekrem	ASK	23.17	5.42	2728	X	X			
Cape Point	CPT	-34.35	18.48	230	X	X			
Neumayer	NEU	-70.65	-8.25	42	X				

³ The World Data Centre for Greenhouse Gases (WDCGG) is one of the WDCs under the GAW programme. It serves to gather, archive and provide data on greenhouse gases (CO₂, CH₄, CFCs, N₂O, surface ozone, etc.) and related gases (CO, NOx, SO₂, VOC, etc.) in the atmosphere and ocean, as observed under GAW and other programmes. <http://gaw.kishou.go.jp/wdcgg/>

The comparison of surface in-situ data with global model output is rather complicated due to the issues of representativity (how model conditions in a particular model grid box fit observational conditions). In the horizontal, this is relatively uncritical in the sense that errors can be estimated. The vertical matching remains critical. The relevant model level must be selected for each station individually, depending on the deviation of its real altitude/pressure from that of the smoothed model surface layer. Generally stations in flat terrain are more favourable for comparison as being less sensitive to unresolved variability in vertical dimension.

3.2 Selected results

GEMS model simulations were intensively validated (Cammass et al., 2009). Some results from the forecast validation are presented in Figures 3 and 4. Displayed is the relative bias of the IFS-forecasts with reference to the GAW observations delivered in rapid mode (model minus observations). Red colours mark a positive model bias, blue colours show a negative bias. Relatively small biases, -20 % to 20 %, are illustrated in green to yellow colours respectively.

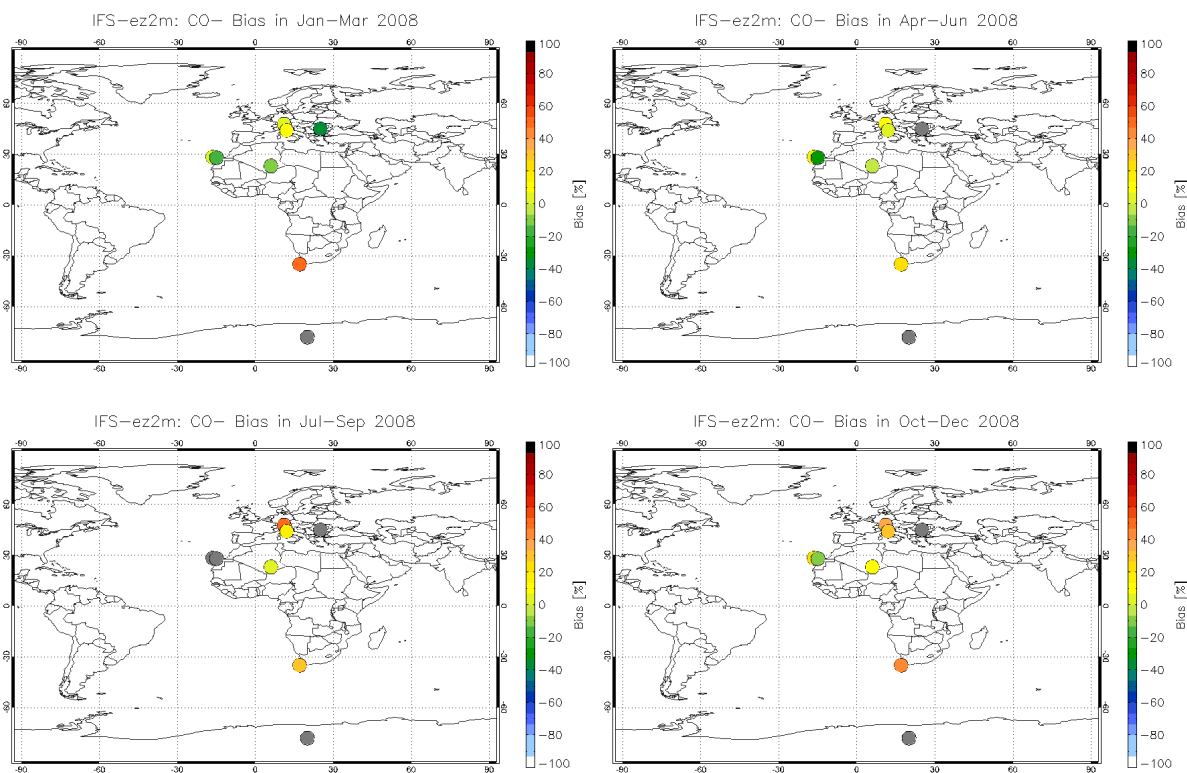


Figure 3 - Relative bias of CO simulations from run ez2m with respect to the GAW surface station observations for the four quarters of 2008. Grey colour indicates no data

Simulated CO is always too high (positive bias) over the SH maritime mid-latitudes. At Cape Point (CPT) station (marine southern hemisphere) the CO background is too high and regional sources (fires, industrial areas) are captured but not resolved by the model. At the Central European mountain stations Hohenpeissenberg (HPB) and Monte Cimone (MCI) CO is overestimated probably due to the fact that emissions are overestimated or not representative for these mountain sites. In Europe during the summer it appears that CO formation from organic compounds may be too high while depletion by OH may be too low. At the Saharan station Assekrem (ASK), the bias changes from small negative to small positive values throughout the year 2008. The high CO levels at Santa Cruz (STC - Tenerife) are not captured (underestimated) by the model but at the regionally more representative station Izana (IZO - Tenerife) only a small positive model bias is found in all seasons. Based on intensive comparison (Cammass et al., 2009) it was concluded that CO generally tends to be higher in the model than in observations and model is better at reproducing CO levels at lower latitudes.

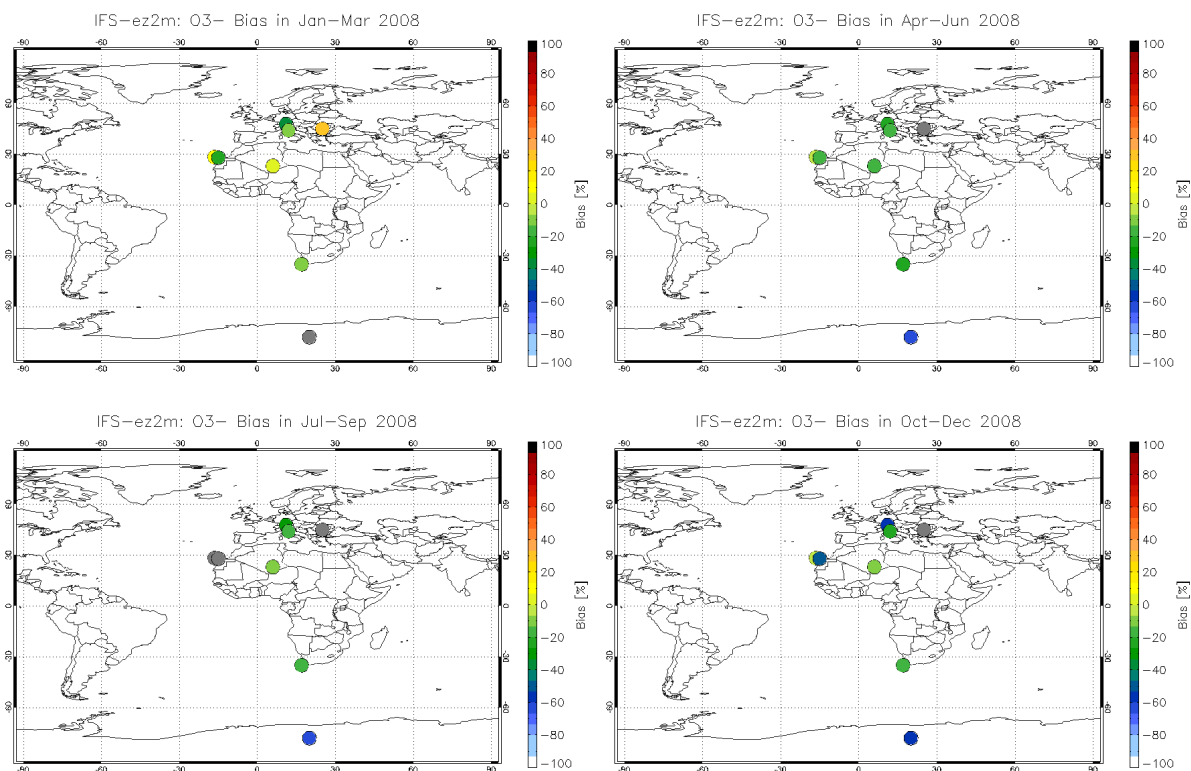


Figure 4 - Relative bias of O₃ simulations from run ez2m with respect to the GAW surface station observations for the four quarters of 2008. Grey colour indicates no data

Figure 4 shows that simulated ozone levels are too low (negative bias) except for the beginning of year 2008. The O₃-bias is comparable at all stations except for the Antarctic, where it is most severely underestimated, e.g. ozone is strongly underestimated at Neumayer station indicating that relevant processes are not yet captured there. This may be due to insufficient ozone column assimilation information (vertical transport) or incorrect precursor emissions (too strong chemical destruction). It must be noted however, that small scale transport in the steep terrain of the mountain stations may ventilate air-masses to the station which are not representative for the model level chosen on the basis of the station altitude. The negative biases at STC and HPB during the winter periods may be enhanced by regional traffic emissions. At CPT wildfires occurred whose impact on surface ozone cannot be captured as the biomass burning emissions are based on a ten-year averaged (1997-2006) inventory (Cammass et al., 2009). Generally low ozone bias is observed at ASK.

Based on more detailed validation (Cammass et al., 2009) it was concluded that ozone is mostly underestimated, particularly at night and in winter, partly due to low concentrations (emission/formation) of precursor gases and partly due to NO titration. The low nocturnal values indicate a strong surface (dry deposition) sink in the model. The model is capable in reproducing the day-to-day variability of CO in most cases, while for O₃ occasional significant deviations occur particularly during photochemical smog periods (see the complete GEMS report for details).

However, there is a considerable uncertainty imposed by the selection of the appropriate model level which represents the local conditions of the surface station, in particular for mountain sites. This is certainly an issue for future evaluation in MACC.

Systematic comparison can help to identify and fix the processes in the model, which are responsible for the highest uncertainty/bias.

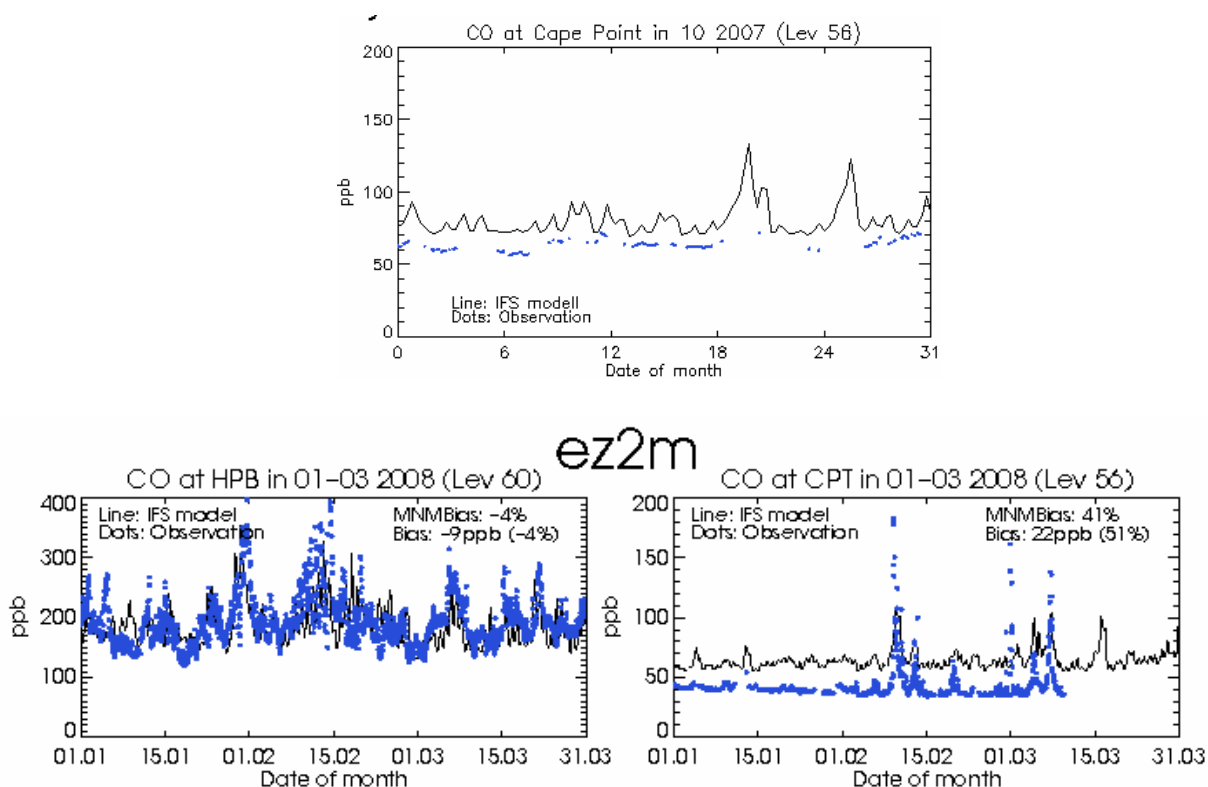


Figure 5 - Carbon Monoxide (CO) simulations from model runs 'eyr0' from October 2007 (top panel), 'ez2m' from Jan-March 2008 (bottom panel) and corresponding GAW near-real-time observations

3.3 Recommendations

Based on intensive validations (Cammass et al., 2009), potential for improvements can be identified both in the model design as well as in evaluation strategy/infrastructure:

- The assimilation of ozone columns has not lead to noticeable improvements in the lower troposphere due to missing measurements at the lower levels. More detailed ozone profile measurements in the lower troposphere are needed to resolve this issue.
- Interaction between aerosol/radiation and chemical parameters should be improved in the model. An interpretation of the aerosol related parameters is not yet feasible due to lack of necessary observations (e.g. resolved spatial fields of particle extinction, vertical profiles).
- Evaluations need to be extended to other gases like NO, NO₂, SO₂ but these are routinely reported only by a few stations (mostly European).
- 'Near-real-time' evaluation strategy of the operational forecasts must include more GAW stations, particularly in flat terrain (avoiding level sensitivity) and should cover diverse observational conditions (regions). Within the GAW programme some efforts are done to encourage more stations to provide observations in rapid mode.
- The format, pre-processing and archiving/retrieval of model data should be harmonized as an overarching standard between all model runs as already done for the sub-set of G-RG IFS runs.
- The information content of the different evaluation metrics with respect to climatological (monitoring) or case-related (forecasting) application need to be fully exploited.
- In order to improve the collaboration between the GEMS/MACC project and the GAW-NRT sites it is recommended to develop a feedback mechanism to make a NRT submission of data profitable for the data provider. Such a feedback mechanism could be a simple quality management (e.g. running outlier checks, flagging of data, long-term stability check), access to inter-comparison results (e.g. validation plots and online visualisation of the observations) and forecasts, thus offering additional information for the interpretation of observations.

An example of the user feedback is given in Fig. 5. Upper panel shows CO time series of Cape Point and the referring IFS model run for October 2007. It came up that the data filtering for unrepresentative local contaminations performed at CPT was even too restrictive as it removed CO peaks, which were actually reproduced by the global CTM. In the following evaluation from January-March 2008, this was handled differently and several large peaks were better caught by a global model.

4. RECOMMENDATIONS ON RAPID DATA DELIVERY

4.1 Rapid delivery strategy

The emphasis of the current GAW Programme is mainly on surface monitoring of atmospheric composition. However, the mandate of the GAW programme includes the integration of satellite and aircraft observations with profiles and surface measurements, as well as the integration of chemical data and numerical models. Chemical reanalysis and data assimilation in the chemical weather forecast models are among the methodologies that integrate observations and models. In response to requests to integrate chemical and meteorological data and models, several projects have recently been initiated, including the European MACC. The MACC consortium of about 40 partner institutes will further develop a global operational medium range forecast/assimilation capability for atmospheric dynamics and composition, using all available satellite and in-situ data.

Near-real-time data availability from GAW stations is a key element in validation of the model forecasts for reactive gases and aerosols and in the improvement of weather forecasts. As it has been shown within the GEMS project, intensive validation is very helpful for verifying geographical regions and also for process descriptions where the models need to be improved. Continuation and further enhancement of this service is therefore vital for making this task successful. A feedback mechanism proposed to the station operators from the modelling community in the case of NRT submission can include simple quality management (e.g. running outlier checks, flagging of data, long-term stability check), access to comparison results (e.g. validation plots and online visualisation of the observations) and forecasts results, thus offering additional information for the interpretation of observations.

The GAW observational network was important for the success of the GEMS project and will become a key element within MACC, provided that GAW data will be available in NRT or rapid delivery mode. Currently several GAW stations provide observations with several weeks delay after the measurements were performed, including Zugspitze/Hohenpeissenberg (Germany), Mt. Cimone (Italy), Izaña and Santa Cruz (Spain), Cape Point (South Africa), Assekrem (Algeria), Neumayer (Antarctica) and BEO Moussala (Bulgaria). Now, during MACC, Mt. Walliguan (China) and the Japanese stations Minamitorishima, Yonangunijima and Ryori joined the NRT evaluation activity. Participation of the other GAW stations in NRT or rapid mode data delivery will strongly enhance the effectiveness of GAW as an independent tool for a chemical forecast validation.

The G-RG coordinator and the team members confirmed the possibility to return a valuable service to the GAW station managers, which can help to motivate the stations to contribute to the validation of the MACC global reactive gases forecasting system.

An offer was made to set up a web site where the GAW members can see plots of their data in comparison to the MACC model results and in relation to other stations. Nevertheless, the main incentive for GAW station managers should be to have MACC and the future atmospheric service as a key user of their data and the better integration of the GAW stations into the global earth observing system.

It was pointed out that clear requirements and rules must be formulated from both sides. A more formal agreement or such as a memorandum of understanding can also help GAW station managers to secure national funding for the measurements if data provision in NRT or rapid delivery mode.

As an outcome of the discussion the following requirements and obligations were proposed. Chapter 4.2 can be used as a template for an official agreement letter between GAW stations and MACC-GRG coordinator.

4.2 Recommendations

A. Terminology

It was agreed within MACC that data submission of GAW station data on reactive gases should take place in the ideal case within 1 day (Rapid Delivery mode, RD), thus, immediate validation of forecasts would be possible. Data submitted within one week can be used for fast model validation and is also valuable.

Data submission later than 1 week should be done in the standard way to the World Data Centre for Greenhouse Gases.

RD has different requirements to the data quality and data flagging in comparison with a standard submission. Submissions in the regime of RD data are considered as *preliminary* while the data stored in the WDCGG are considered as high quality **final** data.

B. Substances of interest

As an initial step, surface O₃ and CO will be the substances of interest for RD. These substances are measured at many GAW stations and have a well established system of quality control. However, in the near to midterm future SO₂, NO_x and VOCs are desirable. These species are also very valuable but can initially be delivered with longer delays only (focus on the evaluation of reanalyses).

C. Sites of interest

All continuously operating GAW stations are recommended to submit data in RD mode to the MACC GAW validation group. It is desirable that the set of stations give global coverage. As a first step it is recommended that Global GAW and selected Regional stations participate in the initiative.

D. Data resolution and Data quality requirement

Only continuous measurements are considered for participation in the RD regime. Data are expected to be submitted as 1hr averages. No intensive data quality control has to be performed except the standard checks of the measuring equipment according to the Standard Operating Procedures (SOPs) or Measurements Guidelines (MGs) for the respective gases. Effectively, routine delivery of RD data will require some automated QC and data submission procedures that are presently available only at a few GAW stations.

For submission acceptable uncertainties are:

- Surface ozone uncertainty of 15% (± 5 ppb one sigma) is acceptable;
- CO uncertainty of 15% (± 10 ppb one sigma) is acceptable.

E. Flagging of data

A simple flagging system should be applied to the data. "Good" data are to be flagged with a "0" (zero) and possible questionable data (any problem) are flagged with a "1". Missing values are labelled with "-999.99".

F. Data format

For submission the data format of WDCGG is applied (GAW report No. 188).

G. Data Policy

The following main principles are applied to the access/use of the data submitted to the

data portal. These rules were formulated with the intent to protect ownership of the data by the station manager. The MACC project welcomes any relaxation of these rules towards free access. The exact terms of agreement can be negotiated with each participating station:

- I. Data are exclusively used for fast validation of MACC forecast products.
- II. The access to the data server is restricted. Data files are only accessible by the respective GAW site and the MACC GAW validation team (MGvt).
- III. One month after submission, the data can be deleted from the server by request of the respective site.
- IV. The MACC validation team will regularly check WDCGG for final or updated data sets. In case final or revised data sets are available, the “fast delivery” data set will be deleted in agreement with the respective GAW site. These fully calibrated and quality controlled data sets shall replace the “fast delivery” data sets for additional validation of archived forecast or reanalysis products.
- V. Validation products (plots) will be available for the GAW and MACC community.
- VI. In the case of data use for analysis of “interesting episodes” or any other scientific application, co-authorship on the respective publication should be offered to the data providers.

H. Data server

Submission is done by ftp transfer to the following controlled DWD ftp server:

ftp-gaw.dwd.de

A valid email address is necessary to register this FTP account; the registration procedure and terms of use are described at the below given link. Once registered, the upload of data is possible.

http://werdis-cbs.dwd.de/bvbw/bvbwDWD.portal?_nfpb=true&_pageLabel=bvbwDWD_page_6

I. Availability of data on WMO's GTS/WIS

The meta data on the data submitted to the DWD ftp site should also be made available on WMO's Global Telecommunication System (GTS) and in the future on the WMO Information System (WIS). It should be made available in such a way that the data is searchable and discoverable but not accessible, unless permission has been given by the data originator. This will be done by DWD, which will ensure translation of the submitted data files to a suitable WIS-compliant format such as CREX or BUFR and to get it posted on the GTS/WIS so that it can be discovered.

J. Tasks of MGvt and provided services

The main task of the MGvt is the use of GAW data for validation of MACC G-RG NRT forecasts produced with IFS – Mozart, IFS-TM5 or MOCAGE and later with the C-IFS system currently under development.

The data will be processed with some simple statistical filters to remove outliers. The results of this automated quality check (and the software tool to perform these checks) will be made available to the respective GAW site.

For the GAW station submitting data the following products will be provided:

- Global/regional forecasts;
- Validation products (plots);
- Model datasets for the GAW station location.

The details of the product layout and product delivery need to be discussed and should be iterated with interested GAW station managers.

K. Letter of agreement

A letter of agreement will be signed between a representative of each participating GAW site and the coordinator of the MACC project. With the signature both parties agree to follow these rules and the respective GAW site becomes a contributing partner of the MACC project.

Upon request the WMO Secretariat will provide a letter of support to the respective GAW station participating in this initiative.

5. OUTLOOK AND FUTURE ACTIVITIES

The topics and issues raised by the participants of this meeting are being discussed with the observation community, the WMO GAW SAGs (mainly the ones on reactive gases and aerosols) and WMO's ET-NRT CDT. Close collaboration will be set up with the corresponding activities within the EMEP NRT-initiative (see <http://tarantula.nilu.no/projects/ccc/nrt.html>), the EU ACTRIS project as well as with a number of other projects and networks (e.g. EUSAAR, EARLINET/GALION).

While the MACC project at present is a primary 'customer' of GAW NRT data, building a GAW NRT data stream will go well beyond MACC and will develop continuously over the next decade. Thus, rather general definitions of terms, objectives, technical/infrastructural and political needs are required and these issues will be addressed through the GAW in the next few years.

References

- Cammas, J.-P., A. Gilles, S. Chabrilat, F. Daerden, N. Elguindi, J. Flemming, H. Flentje, C. Granier, V. Huijnen, A. Inness, L. Jones, E. Katragkou, F. Khokhar, L. Kins, K. Law, K. Lefever, J. Leitao, D. Melas, P. Moinat, C. Ordonez, V.-H. Peuch, G. Reich, M. Schultz, O. Stein, W. Thomas, V. Thouret, C. Zerefos, *GEMS GRG Comprehensive Validation Report*, Toulouse, 2009 (available at <http://gems.ecmwf.int/documents/index.jsp>).
- Flemming, J., A. Inness, H. Flentje, V. Huijnen, P. Moinat, M.G. Schultz, and O. Stein, *Coupling global chemistry transport models to ECMWF's integrated forecast system*, *Geosci. Model. Dev.*, 2, 253-265, 2009.
- IGACO (2004), *The Changing Atmosphere, An Integrated Global Atmospheric Chemistry Observation Theme for the IGOS Partnership*, ESA SP-1282, GAW Report No. 159 (WMO TD No. 1235), European Space Agency, ESA, Noordwijk, The Netherlands.
- Ordóñez, C., N. Elguindi, O. Stein, V. Huijnen, J. Flemming, A. Inness, H. Flentje, E. Katragkou, P. Moinat, V.-H. Peuch, A. Segers, V. Thouret, G. Athier, M. van Weele, C. S. Zerefos, J.-P. Cammas, and M. G. Schultz: *Global model simulations of air pollution during the 2003 European heat wave*, *Atmos. Chem. Phys.*, 10, 789–815, 2010.
- The MACC consortium, Monitoring Atmospheric Composition and Climate (MACC), Grand Agreement No. 218793, Annex I_v8, Description of Work, 2009.
- WMO, *Global Atmosphere Watch (GAW) Strategic Plan: 2008-2015*, GAW Report No. 172, WMO TD NO.1384 (2007).
- WMO, Global Atmosphere Watch, *Revision of the World Data Centre for Greenhouse Gases Data Submission and Dissemination Guide*, GAW Report No. 188, WMO TD NO. 1507(2009).
-

List of Acronyms

ACTRIS	Aerosols, Clouds, and Trace Gases Research Infrastructure Network (EU project)
CLRTAP	Convention on Long-Range Transboundary Air Pollution
DCPC	Data Collection or Production Centre
DM	Delayed mode (classification of data delivery time)
DWD	German Meteorological Service
EARLINET	European Aerosol Research Lidar Network to Establish an Aerosol Climatology
ECMWF	European Centre of Medium- Range Weather Forecasts
EMEP	Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe
ET-NRT CDT	Expert Team on Near-real-time Chemical Data Transfer
EUSAAR	European Supersites for Atmospheric Aerosol Research (EU project)
GALION	GAW Aerosol Lidar Observation Network
GAW	Global Atmosphere Watch programme of WMO
GCOS	Global Climate Observing System
GEMS	Global and regional Earth-system Monitoring using Satellite and <i>in situ</i> data
GEO	Group on Earth Observation
GMES	Global Monitoring for Environment and Security
G-RG	Global Reactive Gases (work package of MACC project)
GTS	Global Telecommunication System
GURME	GAW Urban Research Meteorology and Environment project
IFS	the integrated forecast system
IGAC	International Global Atmospheric Chemistry Project
IPCC	Intergovernmental Panel on Climate Change
MACC	Monitoring of Atmospheric Composition and Climate
MGvt	MACC GAW validation team
MGvt	MACC-GAW validation team
NILU	Norwegian Institute for Air Research
NRT	Near-real-time (classification of data delivery time)
PROMOTE	PROtocol MOniToring for the GMES Service Element: Atmosphere
QC	Quality control
RD	Rapid Delivery (of data)
SAG	WMO GAW Scientific Advisory Group
UNFCCC	United Nations Framework Convention on Climate Change
WDC	World Data Centre
WDCGG	World Data Centre for Greenhouse Gases
WIS	WMO Information System
WMO	World Meteorological Organization
WOUDC	World Ozone and Ultraviolet Radiation Data Centre

MACC GRG Subgroup Meeting

UFS Schneefernerhaus, Garmisch-Partenkirchen, Germany

6 - 8 October 2009

Meeting Agenda

Tuesday, 6th October

9:00	Departure from Eibsee-Hotel
9:10 – 10:30	Cable car to Zugspitze and to UFS
10:45 – 11:00	Welcome at UFS Schneefernerhaus, practical arrangements (W. Thomas)
11:00 – 11:15	The GAW station Schneefernerhaus (L. Ries)
11:15 – 11:45	GEMS achievements and plans for MACC Introduction of new groups (M. Schultz)
11:45 – 12:00	The role of in-situ data for the MACC project (W. Thomas)
12:00 – 13.30	<i>Lunch</i>
	MACC/GAW session on the Near-real time delivery of the GAW observations of reactive gases
13:30 – 14:00	WMO/GAW Intro/GTS and the GAW NRT approach (Tarasova)
14:00 – 14:15	A near-real-time capable QA/QM system for GAW stations (Ries)
14:15 – 14:30	MOZAIC: Validation using NRT and off-line data (Elguindi)
14:30 – 15:15	NRT implementation at the GAW sites (Cristofanelli, Flentje)
15:15 – 15:30	Planning of Wednesday discussion
15:30 – 16:30	Leaving UFS and travelling back by cable car to Eibsee Hotel
19:00	<i>Conference dinner at Eibsee Hotel</i>

Wednesday, 7th October

9:30 – 11:00	Parallel discussion sessions: 1) MACC system evaluation and GAW data format/transfer/standard issues, automatisisation/scripting -- discussion lead: O. Tarasova 2) satellite data in MACC / assimilation plans – PROMOTE -- discussion lead: W. Thomas
11:00 – 11:30	<i>Coffee Break</i>
11:30 – 12.30	Parallel sessions continued
12:30 – 13:30	<i>Lunch break</i>
13:30 – 15:00	Synopsis of morning discussions (all): 1) MACC-GAW linkages and synergies 2) PROMOTE service integration and links to MACC GRG system Planning of MACC GRG simulations (reanalysis, case studies)
15:00 – 15:30	<i>Coffee break</i>
15:30 – 17:00	MACC evaluation work (all): how to improve score factors
17:00	Adjourn
19:30	<i>Dinner</i>

Thursday, 8th October

9:00 – 10:00	MACC service roadmap (discussion lead M. Schultz)
10:00 – 11:00	MACC model integration: inline chemistry
11:00 – 11:30	<i>Coffee Break</i>
11:30 – 12.30	MACC GRG formalities, reporting, any other business
12:30	End of meeting
12:30 – 13:20	<i>Lunch break</i>
13:30 – 13:50	<i>Travel by Zahnradbahn from Eibsee station to Garmisch</i>

MACC/GAW session on the Near-real time delivery of the GAW observations of reactive gases

UFS Schneefernerhaus, Garmisch-Partenkirchen, Germany

6 - 7 October 2009

List of Participants

Paolo Cristofanelli
ISAC-CNR
Via Gobetti 101
40129 BOLOGNA
Italy
Email: p.cristofanelli@isac.cnr.it

Martin Schultz
Institute for Chemistry and Dynamics of the
Geosphere ICG-2: Troposphere
Forschungszentrum Jülich
D-52425 JÜLICH
Germany
Email: m.schultz@fz-juelich.de

Nellie Elguindi
CNRS
CNRM / AGT
42, avenue Gaspard Coriolis
31057 TOULOUSE
France
Email: nellie.elguindi@cnrm.meteo.fr

Oksana Tarasova
Scientific Officer
Research Department
World Meteorological Organization
P.O. Box 2300,
7 bis, Avenue de la Paix
CH-1211 GENEVA
Switzerland
Email: OTarasova@wmo.int

Harald Flentje
German Meteorological Service
Hohenpeissenberg Meteorological Observatory
Albin-Schwaiger-Weg 10
82383 HOHENPEISSENBERG
Germany
Email: harald.flentje@dwd.de

Werner Thomas
German Meteorological Service,
Hohenpeissenberg Meteorological Observatory,
Albin-Schwaiger-Weg 10
82383 HOHENPEISSENBERG
Germany
Email: Werner.Thomas@dwd.de

Claire Granier
LATMOS
LATMOS/UPMC; Tour 45-46; 3eme etage;
Boite 102; 4 Place Jussieu
75005 PARIS
France
Email: claire.granier@aero.jussieu.fr

Anja Werner
German Meteorological Service,
Hohenpeissenberg Meteorological Observatory
Albin-Schwaiger-Weg 10
82383 HOHENPEISSENBERG
Germany
Email: anja.werner@dwd.de

Ludwig Ries
Federal Environment Agency
Paul-Ehrlich-Strasse 29
63225 LANGEN
Germany
Email: ludwig.ries@uba.de

GLOBAL ATMOSPHERE WATCH REPORT SERIES

1. Final Report of the Expert Meeting on the Operation of Integrated Monitoring Programmes, Geneva, 2 -5 September 1980.
2. Report of the Third Session of the GESAMP Working Group on the Interchange of Pollutants Between the Atmosphere and the Oceans (INTERPOLL-III), Miami, USA, 27-31 October 1980.
3. Report of the Expert Meeting on the Assessment of the Meteorological Aspects of the First Phase of EMEP, Shinfield Park, U.K., 30 March - 2 April 1981.
4. Summary Report on the Status of the WMO Background Air Pollution Monitoring Network as at April 1981.
5. Report of the WMO/UNEP/ICSU Meeting on Instruments, Standardization and Measurements Techniques for Atmospheric CO₂, Geneva, 8-11; September 1981.
6. Report of the Meeting of Experts on BAPMoN Station Operation, Geneva, 23–26 November 1981.
7. Fourth Analysis on Reference Precipitation Samples by the Participating World Meteorological Organization Laboratories by Robert L. Lampe and John C. Puzak, December 1981.
8. Review of the Chemical Composition of Precipitation as Measured by the WMO BAPMoN by Prof. Dr. Hans-Walter Georgii, February 1982.
9. An Assessment of BAPMoN Data Currently Available on the Concentration of CO₂ in the Atmosphere by M.R. Manning, February 1982.
10. Report of the Meeting of Experts on Meteorological Aspects of Long-range Transport of Pollutants, Toronto, Canada, 30 November - 4 December 1981.
11. Summary Report on the Status of the WMO Background Air Pollution Monitoring Network as at May 1982.
12. Report on the Mount Kenya Baseline Station Feasibility Study edited by Dr. Russell C. Schnell.
13. Report of the Executive Committee Panel of Experts on Environmental Pollution, Fourth Session, Geneva, 27 September - 1 October 1982.
14. Effects of Sulphur Compounds and Other Pollutants on Visibility by Dr. R.F. Pueschel, April 1983.
15. Provisional Daily Atmospheric Carbon Dioxide Concentrations as Measured at BAPMoN Sites for the Year 1981, May 1983.
16. Report of the Expert Meeting on Quality Assurance in BAPMoN, Research Triangle Park, North Carolina, USA, 17-21 January 1983.
17. General Consideration and Examples of Data Evaluation and Quality Assurance Procedures Applicable to BAPMoN Precipitation Chemistry Observations by Dr. Charles Hakkarinen, July 1983.
18. Summary Report on the Status of the WMO Background Air Pollution Monitoring Network as at May 1983.
19. Forecasting of Air Pollution with Emphasis on Research in the USSR by M.E. Berlyand, August 1983.
20. Extended Abstracts of Papers to be Presented at the WMO Technical Conference on Observation and Measurement of Atmospheric Contaminants (TECOMAC), Vienna, 17-21 October 1983.
21. Fifth Analysis on Reference Precipitation Samples by the Participating World Meteorological Organization Laboratories by Robert L. Lampe and William J. Mitchell, November 1983.
22. Report of the Fifth Session of the WMO Executive Council Panel of Experts on Environmental Pollution, Garmisch-Partenkirchen, Federal Republic of Germany, 30 April - 4 May 1984 (WMO TD No. 10).

23. Provisional Daily Atmospheric Carbon Dioxide Concentrations as Measured at BAPMoN Sites for the Year 1982. November 1984 (WMO TD No. 12).
24. Final Report of the Expert Meeting on the Assessment of the Meteorological Aspects of the Second Phase of EMEP, Friedrichshafen, Federal Republic of Germany, 7-10 December 1983. October 1984 (WMO TD No. 11).
25. Summary Report on the Status of the WMO Background Air Pollution Monitoring Network as at May 1984. November 1984 (WMO TD No. 13).
26. Sulphur and Nitrogen in Precipitation: An Attempt to Use BAPMoN and Other Data to Show Regional and Global Distribution by Dr. C.C. Wallén. April 1986 (WMO TD No. 103).
27. Report on a Study of the Transport of Sahelian Particulate Matter Using Sunphotometer Observations by Dr. Guillaume A. d'Almeida. July 1985 (WMO TD No. 45).
28. Report of the Meeting of Experts on the Eastern Atlantic and Mediterranean Transport Experiment ("EAMTEX"), Madrid and Salamanca, Spain, 6-8 November 1984.
29. Recommendations on Sunphotometer Measurements in BAPMoN Based on the Experience of a Dust Transport Study in Africa by Dr. Guillaume A. d'Almeida. September 1985 (WMO TD No. 67).
30. Report of the Ad-hoc Consultation on Quality Assurance Procedures for Inclusion in the BAPMoN Manual, Geneva, 29-31 May 1985.
31. Implications of Visibility Reduction by Man-Made Aerosols (Annex to No. 14) by R.M. Hoff and L.A. Barrie. October 1985 (WMO TD No. 59).
32. Manual for BAPMoN Station Operators by E. Meszaros and D.M. Whelpdale. October 1985 (WMO TD No. 66).
33. Man and the Composition of the Atmosphere: BAPMoN - An international programme of national needs, responsibility and benefits by R.F. Pueschel, 1986.
34. Practical Guide for Estimating Atmospheric Pollution Potential by Dr. L.E. Niemeyer. August 1986 (WMO TD No. 134).
35. Provisional Daily Atmospheric CO₂ Concentrations as Measured at BAPMoN Sites for the Year 1983. December 1985 (WMO TD No. 77).
36. Global Atmospheric Background Monitoring for Selected Environmental Parameters. BAPMoN Data for 1984. Volume I: Atmospheric Aerosol Optical Depth. October 1985 (WMO TD No. 96).
37. Air-Sea Interchange of Pollutants by R.A. Duce. September 1986 (WMO TD No. 126).
38. Summary Report on the Status of the WMO Background Air Pollution Monitoring Network as at 31 December 1985. September 1986 (WMO TD No. 136).
39. Report of the Third WMO Expert Meeting on Atmospheric Carbon Dioxide Measurement Techniques, Lake Arrowhead, California, USA, 4-8 November 1985. October 1986.
40. Report of the Fourth Session of the CAS Working Group on Atmospheric Chemistry and Air Pollution, Helsinki, Finland, 18-22 November 1985. January 1987.
41. Global Atmospheric Background Monitoring for Selected Environmental Parameters. BAPMoN Data for 1982, Volume II: Precipitation chemistry, continuous atmospheric carbon dioxide and suspended particulate matter. June 1986 (WMO TD No. 116).
42. Scripps reference gas calibration system for carbon dioxide-in-air standards: revision of 1985 by C.D. Keeling, P.R. Guenther and D.J. Moss. September 1986 (WMO TD No. 125).
43. Recent progress in sunphotometry (determination of the aerosol optical depth). November 1986.
44. Report of the Sixth Session of the WMO Executive Council Panel of Experts on Environmental Pollution, Geneva, 5-9 May 1986. March 1987.

45. Proceedings of the International Symposium on Integrated Global Monitoring of the State of the Biosphere (Volumes I-IV), Tashkent, USSR, 14-19 October 1985. December 1986 (WMO TD No. 151).
46. Provisional Daily Atmospheric Carbon Dioxide Concentrations as Measured at BAPMoN Sites for the Year 1984. December 1986 (WMO TD No. 158).
47. Procedures and Methods for Integrated Global Background Monitoring of Environmental Pollution by F.Ya. Rovinsky, USSR and G.B. Wiersma, USA. August 1987 (WMO TD No. 178).
48. Meeting on the Assessment of the Meteorological Aspects of the Third Phase of EMEP IIASA, Laxenburg, Austria, 30 March - 2 April 1987. February 1988.
49. Proceedings of the WMO Conference on Air Pollution Modelling and its Application (Volumes I-III), Leningrad, USSR, 19-24 May 1986. November 1987 (WMO TD No. 187).
50. Provisional Daily Atmospheric Carbon Dioxide Concentrations as Measured at BAPMoN Sites for the Year 1985. December 1987 (WMO TD No. 198).
51. Report of the NBS/WMO Expert Meeting on Atmospheric CO₂ Measurement Techniques, Gaithersburg, USA, 15-17 June 1987. December 1987.
52. Global Atmospheric Background Monitoring for Selected Environmental Parameters. BAPMoN Data for 1985. Volume I: Atmospheric Aerosol Optical Depth. September 1987.
53. WMO Meeting of Experts on Strategy for the Monitoring of Suspended Particulate Matter in BAPMoN - Reports and papers presented at the meeting, Xiamen, China, 13-17 October 1986. October 1988.
54. Global Atmospheric Background Monitoring for Selected Environmental Parameters. BAPMoN Data for 1983, Volume II: Precipitation chemistry, continuous atmospheric carbon dioxide and suspended particulate matter (WMO TD No. 283).
55. Summary Report on the Status of the WMO Background Air Pollution Monitoring Network as at 31 December 1987 (WMO TD No. 284).
56. Report of the First Session of the Executive Council Panel of Experts/CAS Working Group on Environmental Pollution and Atmospheric Chemistry, Hilo, Hawaii, 27-31 March 1988. June 1988.
57. Global Atmospheric Background Monitoring for Selected Environmental Parameters. BAPMoN Data for 1986, Volume I: Atmospheric Aerosol Optical Depth. July 1988.
58. Provisional Daily Atmospheric Carbon Dioxide Concentrations as measured at BAPMoN sites for the years 1986 and 1987 (WMO TD No. 306).
59. Extended Abstracts of Papers Presented at the Third International Conference on Analysis and Evaluation of Atmospheric CO₂ Data - Present and Past, Hinterzarten, Federal Republic of Germany, 16-20 October 1989 (WMO TD No. 340).
60. Global Atmospheric Background Monitoring for Selected Environmental Parameters. BAPMoN Data for 1984 and 1985, Volume II: Precipitation chemistry, continuous atmospheric carbon dioxide and suspended particulate matter.
61. Global Atmospheric Background Monitoring for Selected Environmental Parameters. BAPMoN Data for 1987 and 1988, Volume I: Atmospheric Aerosol Optical Depth.
62. Provisional Daily Atmospheric Carbon Dioxide Concentrations as measured at BAPMoN sites for the year 1988 (WMO TD No. 355).
63. Report of the Informal Session of the Executive Council Panel of Experts/CAS Working Group on Environmental Pollution and Atmospheric Chemistry, Sofia, Bulgaria, 26 and 28 October 1989.
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.

66. Summary Report on the Status of the WMO Global Atmosphere Watch Stations as at 31 December 1990 (WMO TD No. 419).
67. Report of the Meeting of Experts on Modelling of Continental, Hemispheric and Global Range Transport, Transformation and Exchange Processes, Geneva, 5-7 November 1990.
68. Global Atmospheric Background Monitoring for Selected Environmental Parameters. BAPMoN Data For 1989, Volume I: Atmospheric Aerosol Optical Depth.
69. Provisional Daily Atmospheric Carbon Dioxide Concentrations as measured at Global Atmosphere Watch (GAW)-BAPMoN sites for the year 1989 (WMO TD No. 400).
70. Report of the Second Session of EC Panel of Experts/CAS Working Group on Environmental Pollution and Atmospheric Chemistry, Santiago, Chile, 9-15 January 1991 (WMO TD No. 633).
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).
72. Integrated Background Monitoring of Environmental Pollution in Mid-Latitude Eurasia by Yu.A. Izrael and F.Ya. Rovinsky, USSR (WMO TD No. 434).
73. Report of the Experts Meeting on Global Aerosol Data System (GADS), Hampton, Virginia, 11 to 12 September 1990 (WMO TD No. 438).
74. Report of the Experts Meeting on Aerosol Physics and Chemistry, Hampton, Virginia, 30 to 31 May 1991 (WMO TD No. 439).
75. Provisional Daily Atmospheric Carbon Dioxide Concentrations as measured at Global Atmosphere Watch (GAW)-BAPMoN sites for the year 1990 (WMO TD No. 447).
76. The International Global Aerosol Programme (IGAP) Plan: Overview (WMO TD No. 445).
77. Report of the WMO Meeting of Experts on Carbon Dioxide Concentration and Isotopic Measurement Techniques, Lake Arrowhead, California, 14-19 October 1990.
78. Global Atmospheric Background Monitoring for Selected Environmental Parameters BAPMoN Data for 1990, Volume I: Atmospheric Aerosol Optical Depth (WMO TD No. 446).
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).
82. Global Atmospheric Background Monitoring for Selected Environmental Parameters BAPMoN Data for 1991, Volume I: Atmospheric Aerosol Optical Depth (WMO TD No. 518).
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).
89. 4th International Conference on CO₂ (Carqueiranne, France, 13-17 September 1993) (WMO TD No. 561).
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).
93. Report of the Third WMO Meeting of Experts on the Quality Assurance/Science Activity Centres of the Global Atmosphere Watch, Garmisch-Partenkirchen, 5-9 July 1993 (WMO TD No. 581).
94. Report on the Measurements of Atmospheric Turbidity in BAPMoN (WMO TD No. 603).
95. Report of the WMO Meeting of Experts on UV-B Measurements, Data Quality and Standardization of UV Indices, Les Diablerets, Switzerland, 25-28 July 1994 (WMO TD No. 625).
96. Global Atmospheric Background Monitoring for Selected Environmental Parameters WMO GAW Data for 1993, Volume I: Atmospheric Aerosol Optical Depth.
97. Quality Assurance Project Plan (QAPjP) for Continuous Ground Based Ozone Measurements (WMO TD No. 634).
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).
- 112A. Report of the WMO/STUK '95 Intercomparison of broadband UV radiometers: a small-scale follow-up study in 1999, Helsinki, 2001, Addendum to GAW Report No. 112.
113. The Strategic Plan of the Global Atmosphere Watch (GAW) (WMO TD No. 802).
114. Report of the Fifth WMO Meeting of Experts on the Quality Assurance/Science Activity Centres (QA/SACs) of the Global Atmosphere Watch, jointly held with the Second Meeting of the Coordinating Committees of IGAC-GLONET and IGAC-ACE^{Ed}, Garmisch-Partenkirchen, Germany, 15-19 July 1996 (WMO TD No. 787).
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), 2001.
126. Guidelines for Site Quality Control of UV Monitoring (lead author A.R. Webb) (WMO TD No. 884), 1998.
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).

131. WMO Workshop on Regional Transboundary Smoke and Haze in Southeast Asia (Singapore, 2 to 5 June 1998) (Gregory R. Carmichael). Two volumes.
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).
139. The Fifth Biennial WMO Consultation on Brewer Ozone and UV Spectrophotometer Operation, Calibration and Data Reporting (Halkidiki, Greece, September 1998)(WMO TD No. 1019).
140. WMO/CEOS Report on a Strategy for Integrating Satellite and Ground-based Observations of Ozone (WMO TD No. 1046).
141. Report of the LAP/COST/WMO Intercomparison of Erythral Radiometers Thessaloniki, Greece, 13-23 September 1999) (WMO TD No. 1051).
142. Strategy for the Implementation of the Global Atmosphere Watch Programme (2001-2007), A Contribution to the Implementation of the Long-Term Plan (WMO TD No.1077).
143. Global Atmosphere Watch Measurements Guide (WMO TD No. 1073).
144. Report of the Seventh Session of the EC Panel of Experts/CAS Working Group on Environmental Pollution and Atmospheric Chemistry and the GAW 2001 Workshop (Geneva, Switzerland, 2 to 5 April 2001) (WMO TD No. 1104).
145. WMO GAW International Comparisons of Dobson Spectrophotometers at the Meteorological Observatory Hohenpeissenberg, Germany (21 May – 10 June 2000, MOHp2000-1), 23 July – 5 August 2000, MOHp2000-2), (10 – 23 June 2001, MOHp2001-1) and (8 to 21 July 2001, MOHp2001-2). Prepared by Ulf Köhler (WMO TD No. 1114).
146. Quality Assurance in monitoring solar ultraviolet radiation: the state of the art. (WMO TD No. 1180), 2003.
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).
149. Comparison of Total Ozone Measurements of Dobson and Brewer Spectrophotometers and Recommended Transfer Functions (prepared by J. Staehelin, J. Kerr, R. Evans and K. Vanicek) (WMO TD No. 1147).
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).

153. WMO/GAW Aerosol Measurement Procedures: Guidelines and Recommendations. (WMO TD No. 1178).
154. WMO/IMEP-15 Trace Elements in Water Laboratory Intercomparison. (WMO TD No. 1195).
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).
157. JOSIE-1998 Performance of EEC Ozone Sondes of SPC-6A and ENSCI-Z Type (Prepared by Herman G.J. Smit and Wolfgang Straeter) (WMO TD No. 1218).
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), 68 pgs, September 2004.
160. Manual for the GAW Precipitation Chemistry Programme (Guidelines, Data Quality Objectives and Standard Operating Procedures) (WMO TD No. 1251), 186 pgs, November 2004.
161. 12th WMO/IAEA Meeting of Experts on Carbon Dioxide Concentration and Related Tracers Measurement Techniques (Toronto, Canada, 15-18 September 2003), 274 pgs, May 2005.
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. Wehli) (WMO TD No. 1287), 153 pgs, November 2005.
163. World Meteorological Organization Activities in Support of the Vienna Convention on Protection of the Ozone Layer (WMO No. 974), 4 pgs, September 2005.
164. Instruments to Measure Solar Ultraviolet Radiation: Part 2: Broadband Instruments Measuring Erythemally Weighted Solar Irradiance (WMO TD No. 1289), 55 pgs, July 2008, electronic version 2006.
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), 189 pgs, March 2005.
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), 36 pgs, September 2006.
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), 124 pgs, December 2006.
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), 40 pgs, December 2006.
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), 196 pgs, December 2006.
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), 36 pgs, February 2007.
172. WMO Global Atmosphere Watch (GAW) Strategic Plan: 2008 – 2015 (WMO TD No. 1384), 108 pgs, August 2008.
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), 33 pgs, June 2008.

174. World Data Centre for Greenhouse Gases Data Submission and Dissemination Guide (WMO TD No. 1416), 50 pgs, January 2008.
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), 69 pgs, March 2008.
176. The Tenth Biennial WMO Consultation on Brewer Ozone and UV Spectrophotometer Operation, Calibration and Data Reporting (Northwich, United Kingdom, 4-8 June 2007) (WMO TD No. 1420), 61 pgs, March 2008.
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), 106 pgs, May 2008.
178. Plan for the implementation of the GAW Aerosol Lidar Observation Network GALION, (Hamburg, Germany, 27 - 29 March 2007) (WMO TD No. 1443), 52 pgs, November 2008.
179. Intercomparison of Global UV Index from Multiband Radiometers: Harmonization of Global UVI and Spectral Irradiance (WMO TD No. 1454), 61 pgs, March 2009.
180. Towards a Better Knowledge of Umkehr Measurements: A Detailed Study of Data from Thirteen Dobson Intercomparisons (WMO TD No. 1456), 50 pgs, December 2008.
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), 121 pgs, November 2008.
182. IGACO-Ozone and UV Radiation Implementation Plan (WMO TD No. 1465), 49 pgs, April 2009.
183. Operations Handbook – Ozone Observations with a Dobson Spectrophotometer (WMO TD No. 1469), 91 pgs, March 2009.
184. Technical Report of Global Analysis Method for Major Greenhouse Gases by the World Data Center for Greenhouse Gases (WMO TD No. 1473), 29 pgs, June 2009.
185. Guidelines for the Measurement of Methane and Nitrous Oxide and their Quality Assurance (WMO TD No. 1478), 49 pgs, September 2009.
186. 14th WMO/IAEA Meeting of Experts on Carbon Dioxide Concentration and Related Tracers Measurement Techniques (Helsinki, Finland, 10-13 September 2007) (WMO TD No. 1487), 31 pgs, April 2009.
187. Joint Report of COST Action 728 and GURME – Review of the Capabilities of Meteorological and Chemistry-Transport Models for Describing and Predicting Air Pollution Episodes (ISBN 978-1-905313-77-8) (WMO TD No. 1502), 69 pgs, December 2009, electronic version -July 2009.
188. Revision of the World Data Centre for Greenhouse Gases Data Submission and Dissemination Guide (WMO TD No.1507), 55 pgs, November 2009.