GERMANY

Ozone-monitoring and ozone-research in Germany is distributed over numerous institutions. Generally, research is carried out at university institutes or research centers (MPI, DLR, FZ-Karlsruhe, FZ-Jülich). Many institutes are deeply involved in the regular monitoring of ozone by several satellite instruments. Ground based long-term observations are provided by DWD and AWI, UV-monitoring by BfS, UBA and DWD. Table 1 gives an overview of the institutes and their activities.

Table 1: Institutes involved in ozone/UV research (R), development (D), modeling (MD), monitoring (MT), quality assessment /quality control (QA/QC).

Institute	Location	Field	Keywords
Deutscher Wetterdienst, www.dwd.de/	Hohenpeissenberg, Lindenberg	MT, R, QA/QC	RDCC, NDACC, GAW
Alfred Wegener Institut für Polar u. Meeresforschung, www.awi-potsdam.de/ www.awi-bremerhaven.de/	Potsdam, Bremerhaven	R, MT, D	Neumayer, Ny Ålesund, MATCH
Forschungszentrum Jülich, www.fz-juelich.de/	Jülich	R, QA/QC, MD	Calibration O_3-Sonde, JOSIE, ClaMS
MPI f. Meteorologie (DKRZ), www.dkrz.de/	Hamburg	R, MD	ECHAM
DLR, DLR/DFD, www.dlr.de/pa/ www.wdc.dlr.de/index.html	Oberpfaffenhofen	R, MD, MT, QA/QC	GOME, ECHAM, Air-Traffic
IAP Kühlungsborn, www.iap-kborn.de/	Kühlungsborn	R, D, MT	Middle Atmosphere, Alomar,
Bundesamt f. Strahlenschutz (BfS) www.bfs.de/	Salzgitter	MT	UV
Umweltbundesamt (UBA), www.umweltbundesamt.de/	Berlin	MT,	Air quality
Uni Bremen, IUP, IFE, www-iup.physik.uni-bremen.de/index.html	Bremen	R, D	GOME, SCIAMACHY, MICROWAVE
Uni Köln, Inst. f. Meteorologie, www.uni-koeln.de/math-nat-fak/geomet/	Köln	R, MD	EURAD,
FU Berlin, Inst. f. Meteorologie , strat-www.met.fu-berlin.de/	Berlin	R, MT	Stratosphere
Uni Frankfurt, Inst. f. Meteorologie, http://www.geo.uni-frankfurt.de/iau/PhysAtm/index.html	Frankfurt	R, MT	CFC's
Uni Mainz, MPI f. Chemie , www.atmosphere.mpg.de/enid/2_html	Mainz	R, MD	ECHAM/CHEM
Uni Heidelberg, www.physik.uni-heidelberg.de	Heidelberg	R, QA/QC	DOAS
IMK, Forschungszentrum and University Karlsruhe www-imk.fzk.de	Karlsruhe, Garmisch-Partenkirchen (IfU)	R, D, MD, MT, QA/QC	FTIR, MIPAS, ENVISAT, LIDAR, CARIBIC
Uni München (LMU) www.meteo.physik.uni-muenchen.de/	München	R, MD	UV, STAR
Uni Hannover, Inst. f. Meteorologie www.muk.uni-hannover.de	Hannover	R	UV

OBSERVATIONAL ACTIVITIES

German agencies are heavily involved at various levels in ongoing satellite measurements of ozone. IMK has co-developed the MIPAS instrument onboard ENVISAT, and is routinely deriving atmospheric profiles of ozone, temperature and many chemical compounds from the MIPAS data. IUP Bremen is a leading partner for the SCIAMACHY instrument on ENVISAT, and for GOME and GOME-2, both for instrument and algorithm development and advanced data processing. DLR is providing much of the ground-processing for several satellite missions and also hosts the World Data Centre for Remote Sensing of the Atmosphere (WDC-RSAT).

Germany's Meteorological Service (DWD) is running a comprehensive ground-based measurement program at the Observatories Hohenpeissenberg and Lindenberg, monitoring the ozone vertical distribution and total ozone columns on a regular and long-term basis (Table 2). Special efforts are put into high quality and long-term consistency. The time series cover up to 41 years for column measurements of ozone (Dobson since 1967 and Brewer since 1981) and ozone profile measurements (balloon-sonde since 1967) and 21 years for stratospheric LIDAR observations up to 48km. Data are regularly submitted to the data centers at Toronto, Thessaloniki, NILU, and NDSC. In addition to the observational UV-network of the BfS (Table 2), DWD continues to measure UV-B radiation for research and development purposes.

Table 2: Operational network for long-term measurements of ozone and UV.

Type of observation	Location	Org.	Instrument	Type/No.	Start
Total Ozone Column	Hohenpeissenberg	DWD	Dobson	No. 104, No. 064	1967
	Hohenpeissenberg	DWD	Brewer	No. 010	1983
	Hohenpeissenberg	DWD	Microtops	No. 3128, No. 3785	1996
	Lindenberg	DWD	Dobson	No. 071	1964
	Lindenberg	DWD	Brewer	No. 030, No. 078	1987
Calibration	Hohenpeissenberg	DWD	Dobson	No. 064	1999
Ozone Vertical Profile	Hohenpeissenberg	DWD	Ozonsonde	Brewer-Mast	1967
	Hohenpeissenberg	DWD	LIDAR (Stratosphere)	DIAL	1987
	Lindenberg	DWD	Ozonsonde	ECC (since 1992)	1974
	Ny Alesund (Svalbard)	AWI	Ozonsonde	ECC	1990
	Ny Alesund(Svalbard)	AWI	LIDAR	DIAL	1991
	Neumayer (Antarctica)	AWI	Ozonsonde	ECC	1992
	Garmisch	FZK	LIDAR (Troposphere)	DIAL	1988
Calibration	Jülich	FZJ	Ozonsonde		
UV	Garmisch	FZK	Bentham DTM 300		1994
	Hohenpeissenberg	DWD	Brewer MK II	No. 010	1991
	Lindenberg	DWD	Brewer MK IV	No. 078	1995
	Lindenberg	DWD	Brewer MK III	No. 118	1996
	Lindenberg	DWD	Bentham DM 150		2000
	Lindenberg	DWD	Spectro 320D		2002
	Dortmund	BAuA	Bentham DM150		
	Kulmbach	LfU	Bentham DM150		
	München	BfS	Bentham DM150		1993
	Langen	BfS	Bentham DM150		1993
	Schauinsland	BfS	Bentham DM150		1993
	Sylt	CAU	Bentham DM300		1995
	Zingst	BfS	Bentham DM150		1993
	Zugspitze	FZK	Bentham DTM300		1995

The Alfred Wegener Institute for Polar and Marine Research (AWI) operates two fully equipped polar stations in the Arctic (Koldewey/Ny-Ålesund), and Antarctic (Neumayer) and temporary onboard of RV POLARSTERN. The Neumayer meteorological observatory is a radiation and climate monitoring station and an air chemistry observatory. The new station (Neumayer III) will replace Neumayer II to continue the long-term observations. Since 1992 vertical ozone balloon soundings are part of the regular observations. These measurements continue the sounding record from the former station Georg Forster, beginning in 1985. Measurements of surface radiation as part of a global observation network to detect long-term changes in the Earth's radiation budget and their impacts on climate (BSRN) are included.

The full suite of NDACC measurements are routinely performed at the primary station Koldewey/Spitsbergen. This includes ozone-soundings by ECC-sondes, Lidar, microwave, DOAS, FTIR and UV-spectrometers. In addition, the same radiation measurements as at Neumayer-Station are performed as part of the BSRN.

IMK (Forschungszentrum and University of Karlsruhe) contributes with ground based remote sensing observations by FTIR- and mm-wave spectrometers and LIDAR instruments. With the tropical mm-wave spectrometer station in Merida, Venezuela, 4700 m asl, FZK-sites cover tropical, sub-tropical, mid- and polar latitudes. Within the NDACC, FTIR spectrometers are operated by IMK at Kiruna (Sweden), at Izaña on Tenerife Island (Spain) and at the Zugspitze mountain. Several ozone- and climate-related species have been measured with this technique for about 15 years. The stratospheric aerosol content is monitored since 1976 with a LIDAR which is part of the NDACC at the Garmisch site.

Measurements of ozone and ozone relevant species by IMK have been performed for many years by ground-based, balloon and airborne observations. Since the successful launch of the ENVISAT satellite in 2002, the retrieval of MIPAS-ENVISAT data beyond ESA standard products with the KOPRA-RCP processor developed at IMK provides high quality data sets on a global scale for O3, HNO3, NO, NO2, N2O5, HNO4, ClONO2, ClO, HOCl, COCl2, CFCs, water vapour, atmospheric tracers as N2O, CH4, CO, and SF6, and cloud particle properties of PSCs relevant for the polar ozone loss.

A new container with many new instruments has been developed for measurements on board a passenger aircraft Airbus A340-600 of Deutsche Lufthansa AG. It measures regularly the distribution of ozone and other trace gases in the tropopause region within the CARIBIC project (Civil Aircraft for the Regular Investigation of the atmosphere Based on an Instrument Container) since 2005. This project with many European partners is co-ordinated by Max Planck Institute for Chemistry in Mainz. http://www.caribic-atmospheric.com/

Calibration activities
The World Calibration Center for Ozone Sondes (WCCOS) at FZ Jülich continues to improve and standardize the quality of ozone-soundings with balloon sondes. Under the auspices of WMO/GAW the Assessment of Standard Operating Procedures for Ozone Sondes (ASOPOS) has been preparing a final document in 2008 with recommendations for standardization of sonde operation.

The Regional Dobson Calibration Centre for WMO RA VI Europe (RDCC-E) at the Meteorological Observatory Hohenpeissenberg (MOHp) in close co-operation with the Solar and Ozone Observatory at Hradec Kralove (SOO-HK, Czech Republic) has been responsible for second level calibration and maintenance service of approximately 30 operational Dobson spectrophotometers in Europe since 1999. Included are the two Dobsons, at the Antarctic stations Halley Bay (British Antarctic Survey BAS) and Vernadsky (Ukraine).

In the past 9 years 18 intercomparisons (15 at MOHp, 2 at LKO, Arosa in Switzerland, and 1 at INTA, El Arenosillo in Spain) were organized, performed and evaluated under the lead management of RDCC-E. Altogether 57 Dobsons, some of them 2 or 3 times, from 21 countries got a complete calibration service. 15 instruments were completely upgraded. RDCC supports the establishment of the Regional Dobson Calibration Centre for WMO RA I Africa, run by the South African Weather Service. SOO-HK provided valuable contributions to the comprehensive RDCC-E tasks like training courses for operators, technical support during campaigns, soft- and hardware developments and free distribution.

RESULTS FROM OBSERVATIONS AND ANALYSIS

The trend measurements at the IMK sites exhibit declining trends of the chlorine reservoirs in the stratosphere since the mid 90ies as a response to the Montréal protocol. In addition, the long-term record of the stratospheric aerosol loading shows that current background levels are still at

historical low values. Trend analyses of the long ozone records at Hohenpeissenberg (Dobson, sonde, lidar) reveal increasing stratospheric ozone since the late nineties of the last century. While the ozone increase in the upper stratosphere can be taken as a first sign of a beginning ozone recovery from man-made chlorine, this is not the case for the total ozone column and for ozone in the lower stratosphere where dynamical factors play a major role in the recently enhanced levels. The strongest recent increase is found at about 14 km (+7.0% per decade for the period 1994-2007).

THEORY, MODELLING, AND OTHER RESEARCH

State of the art chemistry climate models are used in Germany to simulate and understand the past evolution of the ozone layer, and to predict the future. German activities are well interfaced to international programmes like the SPARC-CCMVAL activity. ECHAM related model development takes place at MPI-Mainz, MPI-Hamburg, FU Berlin, and at DLR. Models have been used to simulate the decadal trends from 1960 to 2020 and have contributed significant results to the IPCC/TEAP report (2005), the WMO Scientific Assessment of Ozone Depletion (2006), Germany was involved in the preparation of the Fourth Assessment Report of IPCC (2007). Beyond a reasonable reproduction of mean parameters and long-term variability characteristics there are many apparent features of episodic similarities between simulation and observation.

Downward-transport of NOx-rich mesospheric air into the polar winter stratosphere and its effect on the stratospheric ozone budget was one of the foci of the MIPAS-Envisat related IMK work. Scientific studies based on the observations of the Arctic and Antarctic winters 2002 to 2004 and the results of several CTMs and CCMs showed that NOx transport from the higher atmosphere, from high latitudes, or locally produced NOx due to solar proton events reduces considerably the stratospheric polar winter ozone which can, under certain circumstances, outweigh the impact of heterogeneous chemistry. One of the major results of MIPAS-ENVISAT with respect to polar ozone loss has been the retrieval of a global picture of PSC occurrence in the Antarctic during the last polar winters and comparison with chemistry-climate model simulations. Balloon-borne observations allowed further analysis of the composition of PSC particles, ground based studies analyzed ozone loss in several winters.

At Forschungszentrum Jülich (FZJ) various research activities related to stratospheric ozone are carried out with special emphasis on model simulations. All these studies significantly improved the knowledge on chemical ozone loss processes especially in the arctic (see 4.3 relevant scientific papers).

A number of studies on the chemistry of the ClO/Cl2 O2 were conducted, based on both laboratory and field observations. Further, the potential impact of ClOx radical complexes on polar stratospheric ozone loss processes was investigated.

Chemical ozone loss was analysed by simulation in chemistry climate models. Observed chemical ozone loss in the Arctic is still not fully reproduced by models, and towards the vortex edge still tends to be underestimated in the Antarctic.

Chemical ozone loss and related processes were deduced from observations for the first time in the Antarctic winter 2003 based on Improved Limb Atmospheric Spectrometer (ILAS)-II observations; both the setup phase of the polar vortex and the conditions in the established vortex were analysed.

The sensitivity of Arctic ozone loss to enhanced stratospheric H_2O was investigated. Further, strongly enhanced Arctic ozone loss in the years following the eruption of Mt. Pinatubo was deduced; these results are important in view of proposed geo-engineering schemes.

In several studies, the chemical ozone depletion in the Arctic vortex has been reproduced rather successfully with the CLaMS model. Based on these studies CLaMS was also employed to investigate the strength and weaknesses of the Match method to deduce polar ozone loss; ozone

loss at lower altitudes seems to be overestimated. Further, a ClaMS study reveals that ozone loss driven by nitrogen oxides and triggered by stratospheric warmings can play a major role.

MATCH campaigns, coordinated by AWI, and funded by the EU and national institutes, have been carried out for more than ten successful years, most recently in the past winter 2007/2008. These campaigns have been instrumental for our current understanding of the chemical ozone loss in the Arctic.

The IUP at the university of Bremen is the PI institute for the SCIAMACHY instrument aboard the ENVISAT satellite. Research is made in the field of ozone and ozone relevant trace gas analysis using Fourier Transform Spectroscopy (FTS) and other methods, aerosol analysis, satellite data retrieval and scientific support including validation for the GOME and SCIAMACHY projects.

The Atmospheric Chemistry Department of the Max Planck Institute for Chemistry in Mainz has a research focus on ozone and the role of radicals in photo-oxidation mechanisms which play a central role in the self-cleansing capacity of the atmosphere. Computer models are developed to simulate the interactions of chemical and meteorological processes, and investigate the influences of atmospheric composition changes on climate.

DISSEMINATION OF RESULTS

The International Council for Science (ICSU) World Data Centre for Remote Sensing of the Atmosphere (WDC-RSAT) is hosted by the Cluster for Applied Remote Sensing at the German Aerospace Centre (DLR-CAF). The primary focus of WDC-RSAT is the provision of data which are primarily gathered from satellite based sensors. Higher level data and information products are also generated from the data through assimilation into numerical models of the atmosphere and of its interaction with the biosphere. Additionally offered is a service contributing to validation of atmospheric measurements through application, for example, of a 3D trajectory model such that satellite data can be better matched with correlative measurements. http://wdc.dlr.de/

Data reporting

Data from nearly all institutes mentioned above are regularly submitted to the data centers at Toronto, Thessaloniki, NILU and NDACC.

Information to the public

BfS and DWD provide the public with UV-information including daily forecasts of the UV-index and warnings. The daily UV-forecasts for clear sky and cloudy conditions are available for free on a global scale: http://orias.dwd.de/promote/index.jsp
Since 1994 DWD regularly distributes the *Ozonbulletin des Deutschen Wetterdienstes* on current ozone- and UV-issues: http://www.dwd.de/ozonbulletin.

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PROJECTS AND COLLABORATION

German institutions participate in a number of international and EU funded research projects, special measurement campaigns and modeling studies, such as CAWSES and SCOUT-O3. They also play a major role in ESA and EUMETSAT projects.

FUTURE PLANS

IMK develops new instruments for the German research aircraft HALO and co-ordinates the HALO demo mission POLESTRACC which concentrates on the polar ozone chemistry. In addition, IMK act as a capacity builder as a new FTIR ground-based station in Ethiopia will be build up in order to measure total ozone and other ozone relevant substances with high quality at a tropical station.

FZJ/ICG-1and IMK together with European partners take the initiative for a new ESA satellite mission PREMIER (PRocess Exploration through Measurements of Infrared and millimeter-wave Emitted Radiation) – to understand processes that link trace gases, radiation, chemistry and climate in the atmosphere.

GLORIA (GLObal Radiance Limb Imager for the Atmosphere) is an imaging Fourier-spectrometer under development for the German research aircraft HALO and for satellites. From 2009 onward it will provide a large number of atmospheric parameters with high resolution.

NEEDS AND RECOMMENDATIONS

- Continuing high-quality measurements of total ozone and ozone profiles by satellites on the global scale and by ground-based systems at selected stations have to insured for the next decades. Without such high-quality data it would become impossible to follow the expected recovery of the ozone layer from man-made halogens, and to understand the substantial cooling of the stratosphere and warming of the troposphere that are expected over the next decades from man-made climate change.
- The complex system of ozone, atmospheric chemistry and dynamics is still not fully understood. Continued research is needed to better understand the underlying processes and to explain the discrepancies between model predictions and observations.
- The release of observational data to the data centers should be accelerated.
- Quality Assurance/Quality Control activities like calibration centers should be supported to maintain the high quality standards of the ground stations, which is necessary for satellite validation and ozone monitoring incl. trend analyses.
- The release of observational data to the data centers should be accelerated.

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