German National Report for the 8th meeting of WMO/UNEP Ozone Research Managers, Geneva, 2-4 May 2011

A number of institutions in Germany are very active in ozone and UV research and monitoring. See Table 1 for a summary. Generally, universities and research centers (MPI, DLR, KIT, FZ-Jülich, …) are more research oriented, government agencies are more monitoring oriented. Germany is a key player for several satellite instruments (GOME, SCIAMACHY, MIPAS). Ground based long-term observations in Germany are provided primarily by DWD (Hohenpeissenberg and Lindenberg stations) and by AWI in the Arctic and Antarctic (Ny-Ålesund/Koldewey and Neumayer stations). UV-monitoring is carried out by BfS, UBA and DWD. By hosting the World Calibration Centre for Ozone Sondes (WCCOS) and the RA VI regional Dobson Calibration Center (RDCC, in cooperation with the Czech Republic), Germany is supporting important international quality-assurance and quality-control activities. Table 1 gives an overview of institutes and their fields.

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

Institute	Location	Fields	Keywords
Deutscher Wetterdienst (DWD) www.dwd.de	Hohenpeissenberg, Lindenberg	MT, R, QA/QC	RDCC, NDACC, GAW
Alfred Wegener Institut für Polar u. Meeresforschung (AWI) www.awi.de	Potsdam, Bremerhaven	R, MT, D	Neumayer, Ny Ålesund, MATCH
Forschungszentrum Jülich (FZJ) 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, climate
DLR, DLR/DFD, www.dlr.de/pa www.wdc.dlr.de	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	Bremen	R, D, MT	GOME, SCIAMACHY, MICROWAVE
Uni Köln, Inst. f. Meteorologie, http://www.geomet.uni-koeln.de	Köln	R, MD	EURAD,
FU Berlin, Inst. f. Meteorologie , http://www.geo.fu-berlin.de/met	Berlin	R, MD	Stratosphere
Uni Frankfurt, Inst. f. Meteorologie, http://www.geo.uni-frankfurt.de/iau	Frankfurt	R, MT	CFC's
Uni Mainz, MPI f. Chemie (MPIC) www.atmosphere.mpg.de	Mainz	R, MD	ECHAM/CHEM
Uni Heidelberg, IUP www.physik.uni-heidelberg.de	Heidelberg	R, QA/QC	DOAS, Bromine, Iodine
Uni Kiel, IFM-GEOMAR http://www.ifm-geomar.de/index.php?id=me	Kiel	R, MD	Middle Atmosphere, Bromine
Institut für Meteorologie und Klimaforschung (IMK-KIT) www.imk.kit.edu	Karlsruhe, Garmisch-Partenkirchen (IfU)	R, D, MD, MT, QA/QC	MIPAS, FTIR, 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

1. OBSERVATIONAL ACTIVITIES

German agencies are major players in ongoing satellite measurements of ozone and related trace gases. The Institute für Meteorologie und Klimaforschung (IMK) of the Karlsruhe Institute for Technology (KIT) 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 lead partner for the SCIAMACHY instrument on ENVISAT, as well as for GOME and GOME-2, both for instrument and algorithm development, as well as 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. Special efforts are put into high quality and long-term consistency. The time series cover more than 40 years for column ozone and ozone profiles (Dobson since 1967 and Brewer since 1981, balloon-sonde since 1967), and more than 20 years for stratospheric LIDAR observations up to 48km (since 1987). Data are regularly submitted to the data centers at Toronto (WOUDC), NDACC, NILU and Thessaloniki. In addition to the operational UV-network of the BfS, DWD continues to measure UV-B radiation for research and development purposes.

Table 2. Operational ground-based 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
	Garmisch, Karlsruhe Izana, Kiruna	IMK, IfU	FTIR		2002
Calibration	Hohenpeissenberg	DWD	Dobson RDCC	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
	Ny Alesund(Svalbard)	IUP	µWaveRadiometer		2002
	Forster + Neumayer (Antarctica)	AWI	Ozonsonde	ECC (since 1992)	1985
	Garmisch	KIT	LIDAR (Troposphere)	DIAL	1988
	Merida(Venezuela)	KIT	µWaveRadiometer		2004
Calibration	Jülich	FZJ	Ozonsonde		
UV	Garmisch	IfU	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 temporarily onboard RV POLARSTERN. Regular vertical ozone balloon soundings at Neumayer continue the very long Antarctic sounding record that started at the former Georg Forster station in 1985 (see Fig. 1). The full suite of NDACC measurements is also running at the primary station

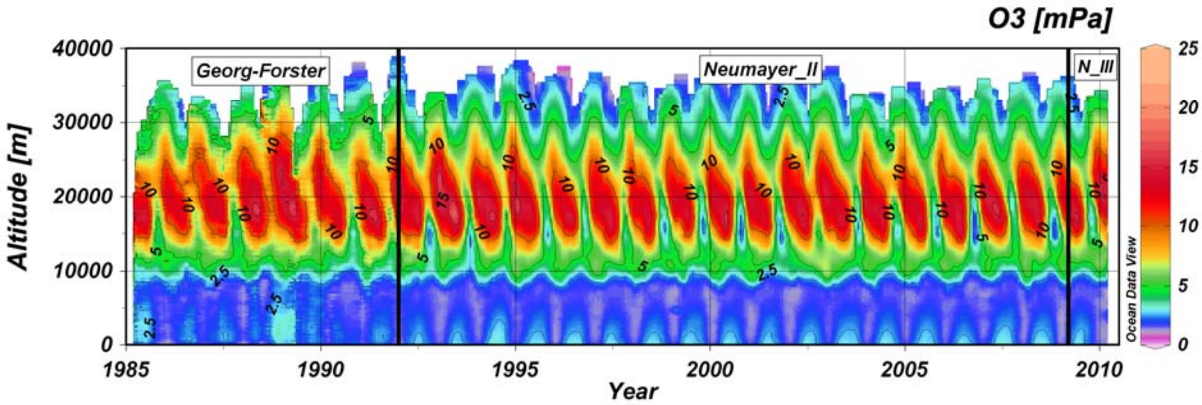

Fig. 1: Time and altitude plot of ozone partial pressure from German ozone soundings over Antarctica. Plot by G. König-Langlo, AWI Potsdam.

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.

Both IUP Bremen and IMK Karlsruhe are running microwave radiometers for ozone profiles (at Ny-Ålesund and Merida, Venezuela). IMK and IFU (both parts of KIT) operate FTIR spectrometers and routinely measure ozone columns (and many other trace gases) at sites in Germany (Karlsruhe, Zugspitze), as well as Kiruna (Sweden), and Izana (Spain). The stratospheric aerosol content is monitored by IFU-KIT 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 at IMK provides high quality data sets on a global scale for ozone, temperature, tropospheric source gases and their decomposition products (e.g. H2O, CH4, N2O, CFC-11, CFC-12, HCFC-22, COCl, SF6), chlorine radicals and reservoirs (ClO, ClONO2, HOCl), nitrogen reactants and reservoirs (NO, NO2, HNO3, N2O5, ClONO2, HNO4, BrONO2), odd hydrogen reservoirs (HOCl, H2O2), pollutants relevant to upper tropospheric ozone chemistry (CO, C2H6, C2H2, HCN, formic acid, acetone, PAN), and cloud particle properties of PSCs relevant for the polar ozone loss.

A new container with many new instruments is deployed from Airbus A340-600 passenger aircraft of Deutsche Lufthansa AG. It regularly measures 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/

1.1. Calibration activities

The Forschungszentrum Jülich hosts the World Calibration Centre for Ozone Sondes (WCCOS). WCCOS is part of the quality assurance plan for balloon borne ozone sondes that are in routine use in the GAW observation network of the WMO. Since its inception in 1995, WCCOS provides an experimental chamber that simulates conditions in the atmosphere as a balloon ascends from the surface to the stratosphere. The Jülich Ozone Sonde Intercomparison Experiments (JOSIE) have evaluated and improved the performance of the ozone sondes. In 2009 and 2010, JOSIE experiments were conducted to derive transfer functions for different types of sondes to homogenize long term ozone sounding records. The results will be integrated in the new SPARC/IGACO-O3/IOC initiative on "Understanding past changes in the vertical distribution of ozone"

The Regional Dobson Calibration Centre for WMO RA VI Europe (RDCC-E) at the Meteorological Observatory Hohenpeissenberg (MOHp) is closely co-operating with the Solar and Ozone Observatory at Hradec Kralove (SOO-HK, Czech Republic). It has been responsible for second level calibration and maintenance service of approximately 25 operational Dobson spectrophotometers in Europe since 1999, including the Antarctic Dobsons at Halley Bay (British Antarctic Survey BAS) and Vernadsky (Ukraine). In October 2009, RDCC further supported the establishment of the Regional Dobson Calibration Centre for WMO RA I Africa, to be run by the South African Weather Service. Increasingly, RDCC has been helping to refurbish RA VI Dobson Instruments and to move them to developing countries outside of RA VI.

1.2. UV-measurements

Apart from the routine UV monitoring activities given in Table 2, the University of Hannover (G. Seckmeyer) has also been involved in WMO activities for the description and standardization of UV measurement systems, most recently filter radiometers and the newly emerging UV array spectrometers. The resulting two WMO-GAW reports No. 190 and 191 are detailed in the reference list under 4.3.

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

Stratospheric chlorine trend measurements at the IMK and IfU sites (ground-based), as well as balloon-borne measurements from Frankfurt and Heidelberg Universities, indicate declining chlorine since the mid 1990ies. This shows the success of the Montréal protocol. The data from University of Heidelberg and University of Frankfort show that Bromine has also started to decline in recent years (see Fig. 2).

Ozone trend analyses from IUP Bremen (satellite records, see Fig. 3) and at Hohenpeissenberg (Dobson, see Fig. 4) reveal increasing stratospheric ozone since the late 1990s. Ozone increase in the upper stratosphere (not shown) is a first sign of a beginning ozone recovery, but this is not so clear for the total ozone column and the lower stratosphere. There, dynamical factors like the Arctic Oscillation (AO) contribute majorly to the recently enhanced levels. As Figs. 3 and 4 indicate, 2010 was a year with much higher total ozone than observed in the last 15 to 20 years. This substantial increase in just one year can be attributed to the phase of the QBO in early 2010, and to the extreme negative phase of the AO in much of 2010 (compare Fig. 4).

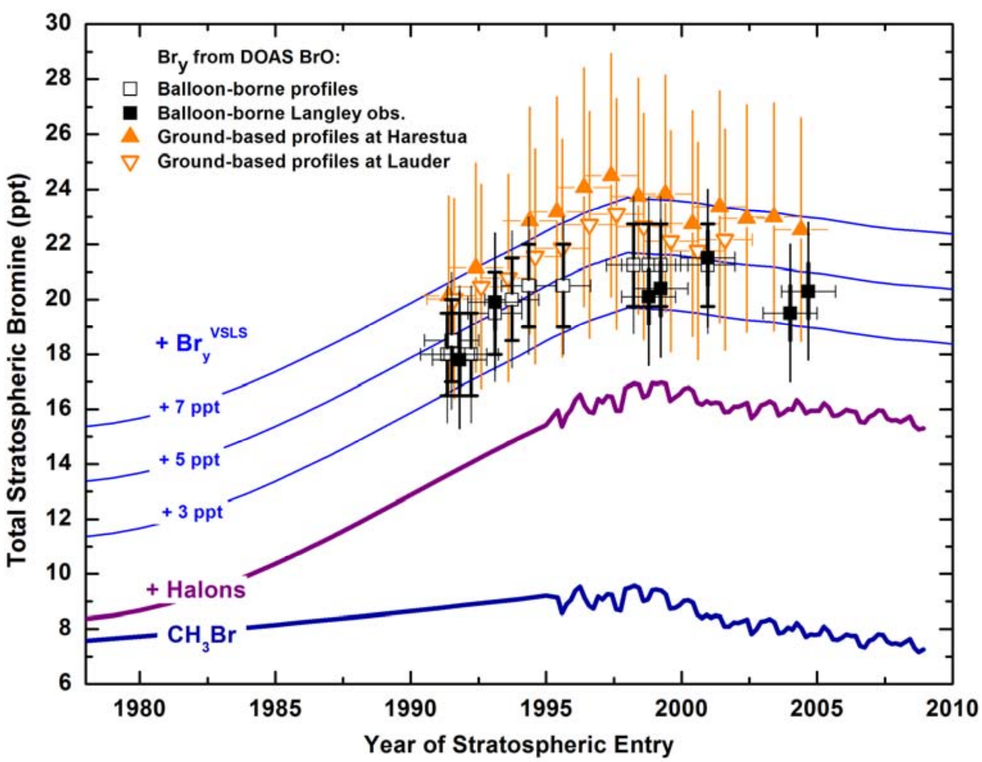

Fig. 2: Total stratospheric Bry from balloon-borne BrO observations (squares) and annual means calculated from ground-based measurements at Harestua (60°N) and Lauder (45°S). The stratospheric data are compared to bromine (ppt) measured at the Earth's surface, with varying amounts of very short lived Bromine species added (blue lines). Plot by K. Pfeilsticker IUP Heidelberg.

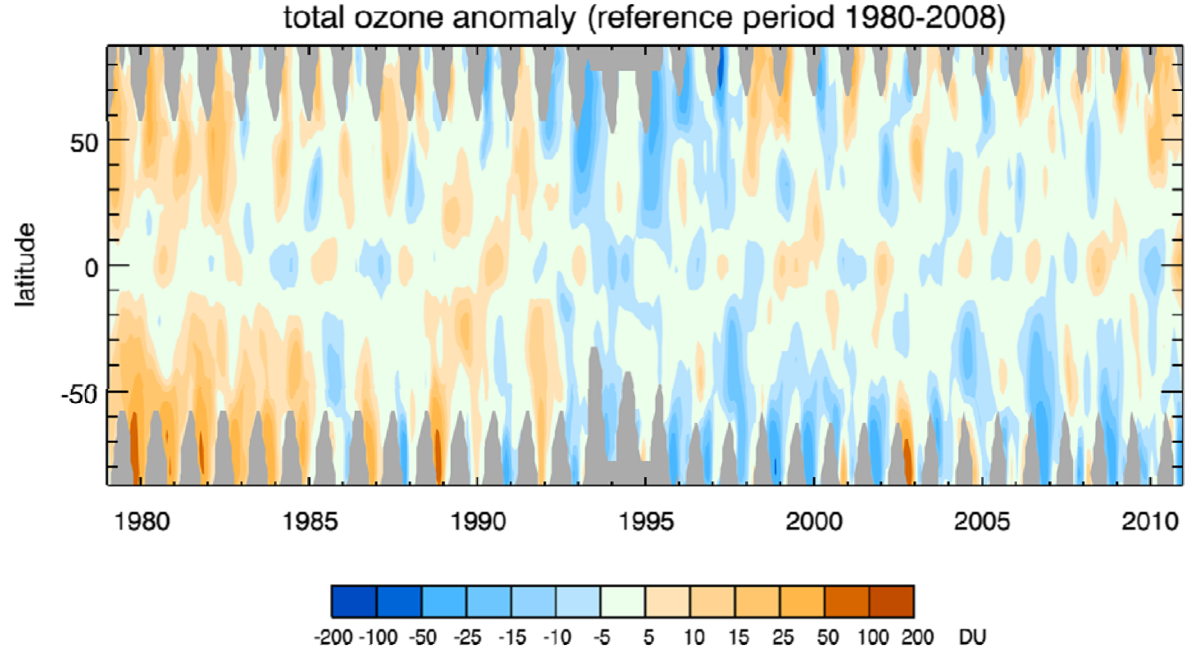

Fig. 3: Evolution of total ozone anomalies since 1979. Plot is based on the merged SBUV/TOMS/OMI MOD V8 data record (1978-1996) and merged GOME1/ SCIAMACHY/ GOME2 (GSG) record. Anomalies were calculated from area weighted monthly mean zonal mean data in 5° latitude steps, by removing the seasonal mean from the period 1980-2008 (Plot by M. Weber, IUP Bremen).

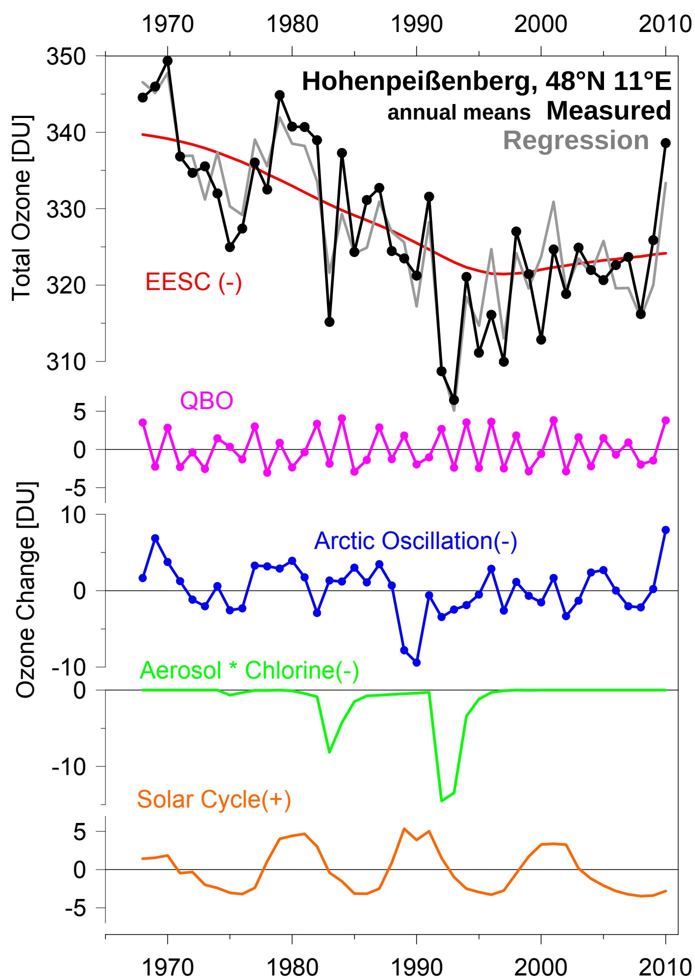

Fig. 4: Observed annual mean total ozone at Hohenpeissenberg, and multiple linear regression analysis of the magnitude of contributing factors. Top: Black: Observations at Hohenpeissenberg (47.8°N, 11°E). Gray: Multiple linear regression result. Red: Ozone variation attributed to Effective Equivalent Stratospheric Chlorine (EESC). Lower graphs: Ozone variation attributed to the QBO (magenta), to the Arctic Oscillation (AO, blue), to enhanced stratospheric aerosol (green), and to the 11-year solar cycle (orange). Plot by W. Steinbrecht, DWD.

AWI has been instrumental in coordinating MATCH ballon-sonde campaigns for the observation of polar ozone losses. MATCH campaigns have been carried out for over 15 years and are a major component of European and world-wide ozone research. They document the long-term evolution of polar ozone loss over the Arctic. Research and data from both IMK and AWI indicate that the unusally cold Arctic winter vortex of 2010/2011 has resulted in large ozone losses, maybe even exceeding the record losses observed in 2005.

3. THEORY, MODELLING, AND OTHER RESEARCH

State of the art chemistry climate models (CCMs) and chemistry transport models (CTMs) 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 programs like the SPARC-CCMVAL activity, which is co-led by DLR staff. 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 since the 1960s up to 2100, and have contributed significantly to SPARC CCMVAL and to the WMO Scientific Assessments of Ozone (2006 and 2010). As an example, Fig. 5 shows the evolution of extra-polar total ozone from a model simulation by DLR, which in the past compares very well with observations. ECHAM based state-of-the-art CCMs now give a reasonable reproduction of mean parameters and long-term variability characteristics of the ozone layer.

Scientific studies based on the observations of the Arctic and Antarctic winters 2002 to 2004 and the results of several CTMs and CCMs, e.g. at IMK, showed that downward NOx transport from the mesosphere, 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. FZ Jülich is using and developing the CLAMS model, and is closely cooperating with AWI, e.g, in the analysis of the MATCH campaigns All these studies have significantly improved knowledge and understanding of chemi-

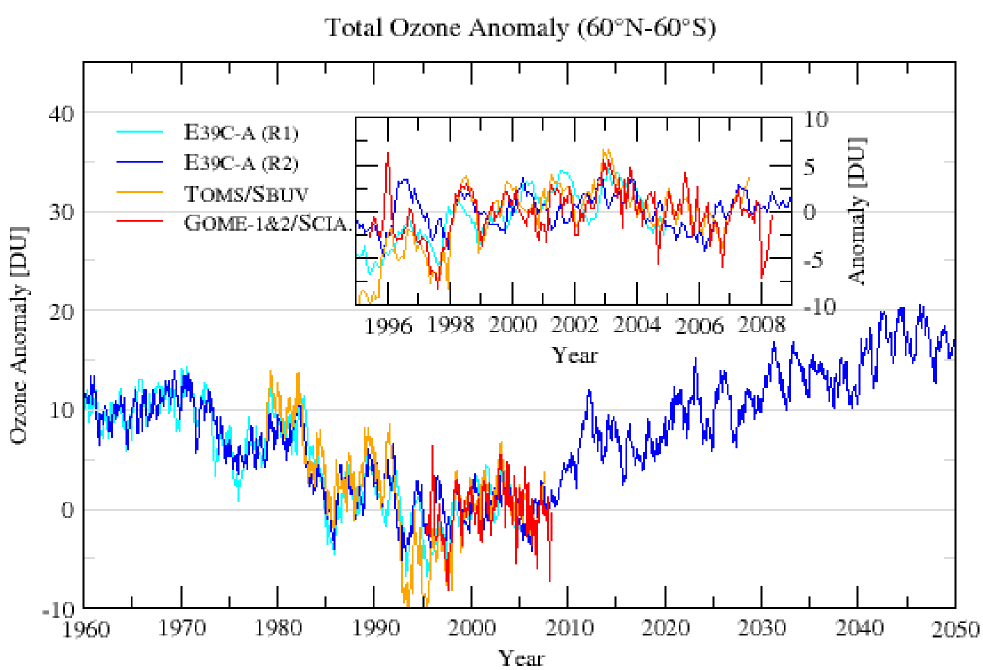

Fig. 5: Extra-polar total ozone anomalies modelled by DLRs E39C model from 1960 to 2050, and observed by various satellite instruments since 1979. Note the chlorine related decline from 1970 to the mid 1990s, the beginning recovery, and the expected super recovery after 2030 due to stratospheric cooling and predicted transport changes (courtesy of M. Dameris, DLR Oberpfaffenhofen).

cal ozone loss processes, especially 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 and aerosol retrievals, but also some modeling and analysis on time-scales ranging from ozone episodes to decadal changes. Scientific support includes validation and for the GOME and SCIAMACHY projects, and the generation of consistent long-term data sets.

4. DISSEMINATION OF RESULTS

4.1 Data reporting

Data are regularly submitted to the data centers at Toronto, Thessaloniki, NILU and NDACC.

4.2 Information to the public

A noteworthy German contribution to WMO's World Data Centers is the World Data Centre for Remote Sensing of the Atmosphere (WDC-RSAT). WDC-RSAT is hosted by the Cluster for Applied Remote Sensing at the German Aerospace Centre (DLR-CAF). WDC-RSAT offers scientists and the general public free access to a continuously growing collection of atmosphere-related satellite-based data sets and services. WDC-RSAT provides support for many Projects, e.g. the EU-funded MACC project, .See http://wdc.dlr.de/ for more information.

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.

4.3 Relevant scientific papers

Anton, M; Loyola, D; Lopez, et al.; Comparison of GOME-2/MetOp total ozone data with Brewer spectroradiometer data over the Iberian Peninsula, Ann. Geophys., 27, 1377-1386, 2009.

Aschmann, J; Sinnhuber, BM; Atlas, EL; Schauffler, SM; Modeling the transport of very short-lived substances into the tropical upper troposphere and lower stratosphere, Atmos. Chem. Phys., 9, 9237-9247, 2009.

Baumgärtner, AJG; Jöckel, P; Dameris, M; Crutzen, PJ; Will climate change increase ozone depletion from low-energy-electron precipitation?, Atmos. Chem. Phys., 10, 9647-9656, 2010.

Baumgärtner, AJG; Jöckel, P; Riede, H; Stiller, G; Funke, B; Energetic particle precipitation in ECHAM5/MESSy - Part 2: Solar proton events, Atmos. Chem. Phys., 10, 7285-7302, 2010.

Baumgärtner, AJG; Jöckel, P; Brühl, C; Energetic particle precipitation in ECHAM5/MESSy1-Part 1: Downward transport of upper atmospheric NOx produced by low energy electrons, Atmos. Chem. Phys., 9, 2729-2740, 2009.

Becker, E; von Savigny, C; Dynamical heating of the polar summer mesopause induced by solar proton events, J. Geophys. Res., 115, D00I18, 2010.

Bobrowski, N; Kern, C; Platt, U; Hormann, C; Wagner, T; Novel SO2 spectral evaluation scheme using the 360-390 nm wavelength range, Atmos. Meas. Tech., 3, 879-891, 2010.

Braesicke, P; Brühl, C; Dameris, et al., Model intercomparison analysing the link between column ozone and geopotential height anomalies in January, Atmos. Chem. Phys., 8, 2519-2535, 2008.

Butz, A; Bosch, H; Camy-Peyret, C; Chipperfield, MP; Dorf, M; Kreycy, S; Kritten, L; Prados-Roman, C; Schwarzle, J; Pfeilsticker, K; Constraints on inorganic gaseous iodine in the tropical upper troposphere and stratosphere inferred from balloon-borne solar occultation observations, Atmos. Chem. Phys., 9, 7229-7242, 2009.

Chauhan, S; Höpfner, M; Stiller, GP; von Clarmann, T; et al.; MIPAS reduced spectral resolution UTLS-1 mode measurements of temperature, O-3, HNO3, N2O, H2O and relative humidity over ice: retrievals and comparison to MLS, Atmos. Meas. Tech., 2, 337-353, 2009.

Cordero R.R., Seckmeyer G., Pissulla D., Labbe F.: Exploitation of Spectral Direct UV Irradiance Measurements" Metrologia 46, pp 19-25, 2009

Cordero R.R., Seckmeyer G., Pissulla D., Labbe F.: Uncertainty of experimental integrals: application to the UV index calculation, Metrologia 45, 1-10, 2008 Crutzen, PJ; Oppenheimer, M; Learning about ozone depletion, Clim. Change, 89, 143-154, 2008.

Dhomse, S; Weber, M; Burrows, J; The relationship between tropospheric wave forcing and tropical lower stratospheric water vapor, Atmos. Chem. Phys., 8, 471-480, 2008.

Dikty, S; Schmidt, H; Weber, M; von Savigny, C; Mlynczak, MG; Daytime ozone and temperature variations in the mesosphere: a comparison between SABER observations and HAMMONIA model, Atmos. Chem. Phys., 10, 8331-8339, 2010.

Dikty, S; Weber, M; von Savigny, C; Sonkaew, T; Rozanov, A; Burrows, JP; Modulations of the 27 day solar rotation signal in stratospheric ozone from Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIAMACHY) (2003-2008), J. Geophys. Res., 115, D00I15, 2010.

Elbern, H; Schwinger, J; Botchorishvili, R; Chemical state estimation for the middle atmosphere by four-dimensional variational data assimilation: System configuration, J. Geophys. Res., 115, D06302, 2010.

Eyring, V; Isaksen, ISA; Berntsen, T; et al.; Transport impacts on atmosphere and climate: Shipping, ATMOSPHERIC ENVIRONMENT, 44, 4735-4771, 2010.

Eyring, V; Cionni, I; Bodeker, GE; et al.; Multi-model assessment of stratospheric ozone return dates and ozone recovery in CCMVal-2 models, Atmos. Chem. Phys., 10, 9451-9472, 2010.

Feck T., J.-U. Grooß, M. Riese: Sensitivity of Arctic ozone loss to stratospheric H2O, Geophys. Res. Lett., 35, L01803, doi:10.1029/2007GL031334, 2008.

Garny, H; Dameris, M; Stenke, A; Impact of prescribed SSTs on climatologies and long-term trends in CCM simulations, Atmos. Chem. Phys., 9, 6017-6031, 2009.

Grenfell, JL; Kunze, M; Langematz, U; Mieth, P; Steil, B; The 27-day solar rotational cycle in the Freie Universitat Berlin Climate Middle Atmosphere Model with interactive chemistry (FUB CMAM CHEM), J. Atmos. Solar-Terr. Phys., 72, 705-712, 2010.

Grooß, JU; Müller, R; Konopka, P; Steinhorst, HM; Engel, A; Möbius, T; Volk, CM; The impact of transport across the polar vortex edge on Match ozone loss estimates, Atmos. Chem. Phys., 8, 565-578, 2008.

Gruzdev, AN; Schmidt, H; Brasseur, GP; The effect of the solar rotational irradiance variation on the middle and upper atmosphere calculated by a three-dimensional chemistry-climate model, Atmos. Chem. Phys., 9, 595-614, 2009.

Günther, G; Müller, R; von Hobe, M; et al.; Quantification of transport across the boundary of the lower stratospheric vortex during Arctic winter 2002/2003, Atmos. Chem. Phys., 8, 3655-3670, 2008.

Hendrick, F; Rozanov, A; Johnston, PV; et al.; Multi-year comparison of stratospheric BrO vertical profiles retrieved from SCIAMACHY limb and ground-based UV-visible measurements, Atmos. Meas. Tech., 2, 273-285, 2009.

Homan, CD; Volk, CM; Kuhn, AC; et al.; Tracer measurements in the tropical tropopause layer during the AMMA/SCOUT-O3 aircraft campaign, Atmos. Chem. Phys., 10, 3615-3627, 2010.

Jurkat, T; Voigt, C; Arnold, F., et al.; Airborne stratospheric ITCIMS measurements of SO2, HCl, and HNO3 in the aged plume of volcano Kasatochi, J. Geophys. Res., 115, D00L17, 2010.

Khosrawi, F; Müller, R; Proffitt, MH; Ruhnke, R; et al.; Evaluation of CLaMS, KASIMA and ECHAM5/MESSy1 simulations in the lower stratosphere using observations of Odin/SMR and ILAS/ILAS-II, Atmos. Chem. Phys., 9, 5759-5783, 2009.

Khosrawi, F; Muller, R; Proffitt, MH; Urban, J; et al.; Seasonal cycle of averages of nitrous oxide and ozone in the Northern and Southern Hemisphere polar, midlatitude, and tropical regions derived from ILAS/ILAS-II and Odin/SMR observations, J. Geophys. Res., 113, D18305, 2008.

Kiesewetter, G; Sinnhuber, BM; Weber, M; Burrows, JP; Attribution of stratospheric ozone trends to chemistry and transport: a modelling study, Atmos. Chem. Phys., 10, 12073-12089, 2010.

Kiesewetter, G; Sinnhuber, BM; et al.; A long-term stratospheric ozone data set from assimilation of satellite observations: High-latitude ozone anomalies, J. Geophys. Res., 115, D10307, 2010.

Konopka, P; Grooß, JU; Ploger, F; Müller, R; Annual cycle of horizontal in-mixing into the lower tropical stratosphere, J. Geophys. Res., 114, D19111, 2009.

Kritten, L; Butz, A; Dorf, M; Deutschmann, T; Kuhl, S; Prados-Roman, C; Pukite, J; Rozanov, A; Schofield, R; Pfeilsticker, K; Time dependent profile retrieval of UV/vis absorbing radicals from balloon-borne limb measurements - a case study on NO2 and O-3, Atmos. Meas. Tech., 3, 933-946, 2010.

Kuhl, S; Pukite, J; Deutschmann, T; Platt, U; Wagner, T; SCIAMACHY limb measurements of NO2, BrO and OClO. Retrieval of vertical profiles: Algorithm, first results, sensitivity and comparison studies, Adv. Spac. Res., 42, 1747-1764, 2008.

Kunz, A; Konopka, P; Müller, R; Pan, LL; Schiller, C; Rohrer, F; High static stability in the mixing layer above the extratropical tropopause, J. Geophys. Res., 114, D16305, 2009.

Kunz, A; Schiller, C; Rohrer, F; Smit, HGJ; Nedelec, P; Spelten, N; Statistical analysis of water vapour and ozone in the UT/LS observed during SPURT and MOZAIC, Atmos. Chem. Phys., 8, 6603-6615, 2008.

Kunze, M; Braesicke, P; Langematz, U; Stiller, G; Bekki, S; Brühl, C; Chipperfield, M; Dameris, M; Garcia, R; Giorgetta, M; Influences of the Indian Summer Monsoon on Water Vapor and Ozone Concentrations in the UTLS as Simulated by Chemistry-Climate Models, J. Clim., 23, 3525-3544, 2010.

Laube, JC; Engel, A; Bönisch, H; et al.; Fractional release factors of long-lived halogenated organic compounds in the tropical stratosphere, Atmos. Chem. Phys., 10, 1093-1103, 2010.

Mangold, A; Grooß, JU; et al.; A model study of the January 2006 low total ozone episode over Western Europe and comparison with ozone sonde data, Atmos. Chem. Phys., 9, 6429-6451, 2009.

Milz, M; von Clarmann, T; Bernath, P; et al.; Validation of water vapour profiles (version 13) retrieved by the IMK/IAA scientific retrieval processor based on full resolution spectra measured by MIPAS on board Envisat, Atmos. Meas. Tech., 2, 379-399, 2009.

Morgenstern, O; Giorgetta, MA; Shibata, K; Eyring, V; et al.; Review of the formulation of present-generation stratospheric chemistry-climate models and associated external forcings, J. Geophys. Res., 115, D00M02, 2010.

Müller, R; A brief history of stratospheric ozone research, Meteorol. Z., 18, 3-24, 2009.

Müller, R; Grooß, JU; Lemmen, C; Heinze, D; Dameris, M; Bodeker, G; Simple measures of ozone depletion in the polar stratosphere, Atmos. Chem. Phys., 8, 251-264, 2008.

Müller, R; Tilmes, S; Grooß, JU; Engel, A; et al.; Impact of mesospheric intrusions on ozone-tracer relations in the stratospheric polar vortex, J. Geophys. Res., 112, D23307, 2007.

Noel, S; Bramstedt, K; Rozanov, A; et al.; Water vapour profiles from SCIAMACHY solar occultation measurements derived with an onion peeling approach, Atmos. Meas. Tech., 3, 523-535, 2010.

Oetjen, H; Wittrock, F; Richter, A; et al.; Evaluation of stratospheric chlorine chemistry for the Arctic spring 2005 using modelled and measured OClO column densities, Atmos. Chem. Phys., 11, 689-703, 2011.

Palm, M; Hoffmann, CG; Golchert, SHW; Notholt, J; The ground-based MW radiometer OZORAM on Spitsbergen - description and status of stratospheric and mesospheric O-3-measurements, Atmos. Meas. Tech., 3, 1533-1545, 2010.

Pissulla, D. , Seckmeyer G., et al.: Comparison of different calibration methods to derive spectral radiance as a function of incident and azimuth angle, Photochem. Photobiol. Sci., 2009, 8, 516 - 527, DOI: 10.1039/b817018e, 2009

Plöger, F; Fueglistaler, S; Grooss, JU; et al.; Insight from ozone and water vapour on transport in the tropical tropopause layer (TTL), Atmos. Chem. Phys., 11, 407-419, 2011.

Pukite, J; Kuhl, S; Deutschmann, T; Platt, U; Wagner, T; Extending differential optical absorption spectroscopy for limb measurements in the UV, Atmos. Meas. Tech., 3, 631-653, 2010.

Punge, HJ; Giorgetta, MA; Net effect of the QBO in a chemistry climate model, Atmos. Chem. Phys., 8, 6505-6525, 2008.

Schäler, B; Offermann, D; Küll, V; Jarisch, M; Global water vapour distribution in the upper troposphere and lower stratosphere during CRISTA 2, Adv. Spac. Res., 43, 65-73, 2009.

Schmale, J; Schneider, J; Jurkat, T; et al.; Aerosol layers from the 2008 eruptions of Mount Okmok and Mount Kasatochi: In situ upper troposphere and lower stratosphere measurements of sulfate and organics over Europe, J. Geophys. Res., 115, D00L07, 2010.

Schmidt, H; Brasseur, GP; Giorgetta, MA; Solar cycle signal in a general circulation and chemistry model with internally generated quasi-biennial oscillation, J. Geophys. Res., 115, D00I14, 2010.

Schmidt, T; Cammas, JP; Smit, HGJ; Heise, S; Wickert, J; Haser, A; Observational characteristics of the tropopause inversion layer derived from CHAMP/GRACE radio occultations and MOZAIC aircraft data, J. Geophys. Res., 115, D24304, 2010.

Schneider, M; Redondas, A; Hase, F; Guirado, C; Blumenstock, T; Cuevas, E; Comparison of ground-based Brewer and FTIR total column O-3 monitoring techniques, Atmos. Chem. Phys., 8, 5535-5550, 2008.

Schneider, M; Hase, F; Blumenstock, et al.; Quality assessment of O-3 profiles measured by a state-of-the-art ground-based FTIR observing system, Atmos. Chem. Phys., 8, 5579-5588, 2008.

Schneider, M; Hase, F; Technical Note: Recipe for monitoring of total ozone with a precision of around 1 DU applying mid-infrared solar absorption spectra, Atmos. Chem. Phys., 8, 63-71, 2008.

Schönhardt, A; Richter, A; Wittrock, F; Kirk, H; Oetjen, H; Roscoe, HK; Burrows, JP; Observations of iodine monoxide columns from satellite, Atmos. Chem. Phys., 8, 637-653, 2008.

Seckmeyer G., et al..: Variability of UV irradiance in Europe, Photochem. Photobiol. Sci., 84: 172–179, 2008

Seckmeyer G., et al.: Europe's darker atmosphere in the UV-B, Photochem. Photobiol. Sci., 2008, 7, 925 - 930, 2008

Seckmeyer G., Bais A., Bernhard G., et al., Instruments to measure solar ultraviolet radiation, part 3: Multi-channel filter instruments, WMO-GAW report 190, TD 5037, 2010

Seckmeyer G., Bais A., Bernhard G., et al., Instruments to measure solar ultraviolet radiation, part 4: Array Spectroradiometers, WMO-GAW report 191, TD 5038, 2010Seitz, K; Buxmann, J; Pohler, D; et al.; The spatial distribution of the reactive iodine species IO from simultaneous active and passive DOAS observations, Atmos. Chem. Phys., 10, 2117-2128, 2010.

Sinnhuber, BM; Sheode, N; Sinnhuber, M; et al.; The contribution of anthropogenic bromine emissions to past stratospheric ozone trends: a modelling study, Atmos. Chem. Phys., 9, 2863-2871, 2009.

Smit, H.G.J., et al., Assessment of the performance of ECC-ozonesondes under quasi-flight conditions in the environmental simulation chamber: Insights from the Jülich Ozone Sonde Intercomparison Experiment (JOSIE), J. Geophys. Res., 112, D19306, 2007.

Sonkaew, T; Rozanov, VV; von Savigny, C; Rozanov, A; Bovensmann, H; Burrows, JP; Cloud sensitivity studies for stratospheric and lower mesospheric ozone profile retrievals from measurements of limb-scattered solar radiation, Atmos. Meas. Tech., 2, 653-678, 2009.

Spangehl, T; Cubasch, U; Raible, CC; Schimanke, S; Korper, J; Hofer, D; Transient climate simulations from the Maunder Minimum to present day: Role of the stratosphere, J. Geophys. Res., 115, D00I10, 2010.

Steinbrecht, W; McGee, TJ; Twigg, LW; Claude, H; Schönenborn, F; Sumnicht, GK; Silbert, D; Intercomparison of stratospheric ozone and temperature profiles during the October 2005 Hohenpeissenberg Ozone Profiling Experiment (HOPE), Atmos. Meas. Tech., 2, 125-145, 2009.

Steinbrecht W, Claude H, Schönenborn F, et al., Ozone and temperature trends in the upper stratosphere at five stations of the Network for the Detection of Atmospheric Composition Change, Int. J. Remote. Sens., 30, 3875-3886, 2009.

Stenke, A; Dameris, M; Grewe, V; Garny, H; Implications of Lagrangian transport for simulations with a coupled chemistry-climate model, Atmos. Chem. Phys., 9, 5489-5504, 2009.

Tegtmeier, S; Krüger, K; Wohltmann, I; Schoellhammer, K; Rex, M; Variations of the residual circulation in the Northern Hemispheric winter, J. Geophys. Res., 113, D16109, 2008.

Tegtmeier, S., M.Rex, I.Wohltmann, K.Krüger, Relative importance of dynamical and chemical contributions to Arctic winter time ozone, Geophys. Res. Lett., L17801, doi:10.1029/2008GL034250, 2008.

Thomas, MA; Timmreck, C; Giorgetta, MA; Graf, HF; Stenchikov, G; Simulation of the climate impact of Mt. Pinatubo eruption using ECHAM5-Part 1: Sensitivity to the modes of atmospheric circulation and boundary conditions, Atmos. Chem. Phys., 9, 757-769, 2009.

Tilmes, S; Pan, LL; Hoor, P; et al.; An aircraft-based upper troposphere lower stratosphere O-3, CO, and H2O climatology for the Northern Hemisphere, J. Geophys. Res., 115, D14303, 2010.

Tilmes, S; Muller, R; Salawitch, RJ; Schmidt, U; Webster, CR; Oelhaf, H; Camy-Peyret, CC; Russell, JM; Chemical ozone loss in the Arctic winter 1991-1992, Atmos. Chem. Phys., 8, 1897-1910, 2008.

Ungermann, J; Kaufmann, M; Hoffmann, L; Preusse, P; Oelhaf, H; Friedl-Vallon, F; Riese, M; Towards a 3-D tomographic retrieval for the air-borne limb-imager GLORIA, Atmos. Meas. Tech., 3, 1647-1665, 2010.

Vogel, B; Konopka, P; Grooss, JU; et al.; Model simulations of stratospheric ozone loss caused by enhanced mesospheric NOx during Arctic Winter 2003/2004, Atmos. Chem. Phys., 8, 5279-5293, 2008.

von Clarmann, T; Hase, F; Funke, B; et al.; Do vibrationally excited OH molecules affect middle and upper atmospheric chemistry?, Atmos. Chem. Phys., 10, 9953-9964, 2010.

von Clarmann, T; Höpfner, M; Kellmann, et al.; Retrieval of temperature, H2O, O-3, HNO3, CH4, N2O, ClONO2 and ClO from MIPAS reduced resolution nominal mode limb emission measurements, Atmos. Meas. Tech., 2, 159-175, 2009.

von Clarmann, T; Glatthor, N; Ruhnke, R; et al.; HOCl chemistry in the Antarctic Stratospheric Vortex 2002, as observed with the Michelson Interferometer for Passive Atmospheric Sounding (MIPAS), Atmos. Chem. Phys., 9, 1817-1829, 2009.

von Hobe, M; Stroh, F; Beckers, H; Benter, T; Willner, H; The UV/Vis absorption spectrum of matrix-isolated dichlorine peroxide, ClOOCl, Phys. Chem. Chem. Phys., 11, 1571-1580, 2009.

Weigel, K; Riese, M; Hoffmann, L; et al.; CRISTA-NF measurements during the AMMA-SCOUT-O3 aircraft campaign, Atmos. Meas. Tech., 3, 1437-1455, 2010.

Werner, A; Volk, CM; Ivanova, EV; Wetter, T; Schiller, C; Schlager, H; Konopka, P; Quantifying transport into the Arctic lowermost stratosphere, Atmos. Chem. Phys., 10, 11623-11639, 2010.

Wetzel, G; Oelhaf, H; Kirner, O; et al.; First remote sensing measurements of ClOOCl along with ClO and ClONO2 in activated and deactivated Arctic vortex conditions using new ClOOCl IR absorption cross sections, Atmos. Chem. Phys., 10, 931-945, 2010.

Winkler, H; Kazeminejad, S; Sinnhuber, et al.; Conversion of mesospheric HCl into active chlorine during the solar proton event in July 2000 in the northern polar region, J. Geophys. Res., 114, D00I03, 2009.

Winkler, H; Sinnhuber, M; Notholt, J; et al.; Modeling impacts of geomagnetic field variations on middle atmospheric ozone responses to solar proton events on long timescales, J. Geophys. Res., 113, D02302, 2008.

Wolff, MA; Herber, A; Jacobi, HW; Schrems, O; Hoops, J; Ruhe, W; The development of a miniature optical sensor for balloon-borne measurements of ozone profiles, J. Atmos. Ocean. Tech., 25, 57-70, 2008.

5. PROJECTS AND COLLABORATION

Germany is contributing to the preparation of the WMO ozone assessments. For the last assessments, several lead and co-authors, and many contributing authors came from German institutes.

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

FZ-Jülich is coordinating RECONCILE and has been carrying out several air-borne campaigns using the HALOX, FISH and CHRISTA-NF instruments. Jülich's CLAMS – CTM is a key infrastructure for interpreting the measurements, for understanding transport and mixing, the development of PSCs, and for understanding the chemical reactions resulting in ozone loss. Recent key findings are:

- Questions about the photolysis of the ClO Dimer have been resolved. The previous "old" understanding of polar ozone loss has been reconfirmed.
- Even without PSCs, background aerosol at cold temperatures can result in substantial chlorine activation. This has important implications, also for the assessment of geo-engineering schemes.
- Generation and growth of PSC particles must be significantly faster that previously assumed, if we want to explain NOy profiles observed at the end of polar winter.
- Uncertainties in transport and mixing in and around the polar vortex are much larger than is often assumed. This is a key limitation for our ability to precisely determine ozone loss rates in individual winters.

The Institut für Umweltphysik (IUP) at University of Heidelberg coordinates the EU framework 7 project SHIVA (Stratospheric ozone: Halogen Impacts in a Varying Atmosphere), which aims to reduce uncertainties in present and future stratospheric halogen loading and ozone depletion resulting from climate feedbacks between emissions and transport of ozone depleting substances (ODS). In this context, low abundance and very short lived Bromine and Iodine species play an important role. Some key results from IUP Heidelberg are:

- Observations of stratospheric bromine by IUP Heidelberg, in cooperation with the Belgian Institute for Space Aeronomy (BISA) and the National Institute of Water& Atmospheric Research (NIWA), show a positive BrO trend of about +2%/year before 2001, followed by a decline by about -1%/year since 2001.
- Balloon-borne solar occultation spectra of IO and OIO in the tropical UT/LS obtained in 2005 and 2008 yield upper limits for the total gaseous inorganic iodine burden (Iy) of 0.17 to 0.35 ppt in the tropical upper troposphere (16.5 km to 13.5 km) and 0.09 to 0.16 ppt in the tropical lower stratosphere (21.0 km to 16.5 km). These findings complement high and mid-latitude observations indicating upper Iy limits of 0.1 ppt.
- These Bromine and Iodine data have provided valuable input to the recent 2010 WMO/UNEP Scientific Assessment of Ozone Depletion.

The Institut für Meereskunde (IFM-Geomar) at the University of Kiel contributes to several national and EU projects, including TransBrom, SHIVA, HALOCAT, SOPRAN, SOLAS, CCMVal. The Institute measures Bromine species in the Ocean and Marine Boundary layer along large scale ship transects, and models the transport of short lived Bromine into the stratosphere. It also models connections between the solar cycle, the Middle Atmosphere and the Ocean, on decadal and climatic time-scales.

Since 2009, J. Orphal from IMK Karlsruhe has been Chair of the "Absorption Cross Sections of Ozone" International Committee at WMO (WMO/IO3C/IGACO-O3). He has been leading an international initiative to review and recommend improved ozone absorption cross-sections. A new standard has been established and is currently being implemented world-wide (Dobson, Brewer, NDACC, UV-visible satellites …). This new standard will improve the consistence of all atmospheric ozone measurements in the next decades. A final report will be published in 2011.

MIPAS data from IMK are a very important contribution to many ozone related studies, including monitoring of the ozone content of the polar vortices (compare Fig. 6). MIPAS data are used, for example, in the following international activities:

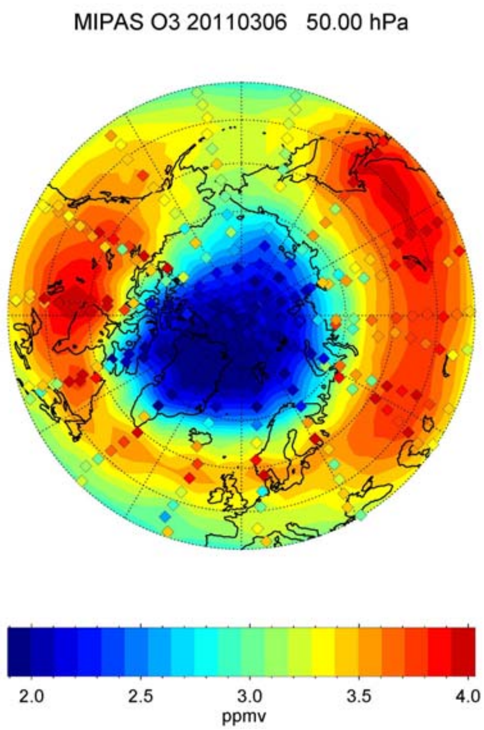

Fig. 6: Extremely low levels of stratospheric ozone over the North Pole in March 2011, due to very special dynamic conditions (stability of the Artic vortex) in 2011. The data were obtained at IMK-KIT from MIPAS measurements aboard ENVISAT. Plot provided by T. von Clarmann, IMK Karlsruhe.

- WMO-SPARC-CCMVAL: (Hegglin et al., 2010, http://www.agu.org/pubs/crossref/2010/2010JD013884.shtml),
- HEPPA (http://www.acd.ucar.edu/Events/Meetings/HEPPA/),
- WMO-SPARC-SDI (http://edoc.gfz-potsdam.de/gfz/get/16495/0/e495c0297f6f21e2717bca7757e5a63c/ 16495.pdf),
- the ESA Climate Change Initiative (http://www.esa-ozone-cci.org/),
- the SPARC/IO3C/WMO-IGACO-O3/UV Activity on Past changes in the Vertical Distribution of Ozone (http://igaco-o3.fmi.fi/VDO/index.html),
- the SHARP Research Unit (http://www.geo.fu-berlin.de/v/sharp/en/outline/index.html)

6. FUTURE PLANS

Generally, German ozone observations and research activities are expected to continue along the indicated lines. Funding is expected to continue from national and European sources and projects, however, with a generally decreasing trend.

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.

Future stratospheric ozone related research at IMK, FZJ, and other institutes will be focused on the coupling between changes in stratospheric circulation with ozone chemistry, links between the mesosphere and stratospheric ozone chemistry, e.g. by NOx subsiding from the thermosphere through the mesosphere into the stratospheric polar winter vortex, as well as exploitation of data from new and future instruments (GLORIA, PREMIER) for ozone chemistry.

German modeling activities will continue to focus on the expected evolution of ozone (recovery, super-recovery, tropical decline), but also on the important links with climate change (tropospheric warming, stratospheric cooling, changes in wave driving, possible acceleration of the Brewer Dobson circulation).

Regarding UV, Array instruments (see WMO array document, dosimeters) for UV-Monitoring are becoming more and more useful for UV-Studies in Germany. Especially the Vitamin D question has an increasing new importance.

7. 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 be insured for the next decades. Without such high-quality data it becomes 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 coupling of ozone, atmospheric chemistry, transports and climate changes is still not fully understood. Further research is needed to better understand the underlying processes and to improve model predictions of the expected substantial changes in both ozone and temperature distributions of the middle atmosphere.
- In this context, there is a need for better and more consistent long-term temperature data in the stratosphere.
- Quality Assurance/Quality Control activities like calibration centres must be supported to maintain the high quality standards of the ground stations. This is necessary for satellite validation, for ozone monitoring, and for trend analyses.
- Availability of space-borne infrared limb emission instruments after MIPAS (i.e. 2014) is essential for future ozone research.
- In UV research, there is a need not only to concentrate on high UV levels, but also on too low UV levels, e.g. in winter time or a consequence of ozone super-recovery.