Ozone Research Activities in Germany (2020 – 2024)
Report to the 12th WMO/UNEP Ozone Research Managers Meeting

1. OBSERVATIONAL ACTIVITIES

1.1 Column measurements of ozone and other gases/variables relevant to ozone loss.

1.1.1 Stations (only long-term, ongoing)

A number of German institutes run ground-based long-term observation programs at stations in Germany, the Arctic and Antarctic, and at some lower latitude stations.

Table 1: Stations with long-term column observations

Name	Organization	Instruments	Gases	Years
Ny Ålesund – AWIPEV, Spitzbergen	U. Bremen, AWI U. Bremen	FTIR DOAS	Total O_3, HCl, $ClONO_2$, HF, HNO_3, N_2O, NO_2 O_3, NO_2,	1992 – now 1992 – now
Kiruna, Sweden	KIT MPI-C, U. Heidelberg	FTIR DOAS	Total O_3, HCl, $ClONO_2$, HF, HNO_3, N_2O, NO_2, COS O_3, NO_2	1996 – now 2015 – now
Bremen	U. Bremen	FTIR DOAS	Total O_3, HCl, HF, HNO_3, N_2O, NO_2 O_3 ;NO_2	2002 – now
Lindenberg / Potsdam	DWD	Dobson, Brewer	Total O_3	1964 – now
Hohenpeißenberg	DWD	Dobson, Brewer	Total O_3	1968 – now
Garmisch / Zugspitze	KIT	FTIR	Total O_3, HCl, $ClONO_2$, HF, HNO_3, N_2O, NO_2, COS	1995 – now
Izaña, Canary Islands	KIT	FTIR	Total O_3, HCl, $ClONO_2$, HF, HNO_3, N_2O, NO_2, COS	1999 – now
Paramaribo, Suriname	U. Bremen, AWI	FTIR	Total O_3, HCl, $ClONO_2$, HF, HNO_3, N_2O, NO_2	2004 – now
Palau, West Pacific	AWI, U Bremen	FTIR	Total O_3, HCl, HF, N_2O, NO_2	2016 - now
Neumayer, Antarctica	U. Heidelberg	DOAS	Total O_3, NO_2	1999 – now

1.1.2 Satellite Column Data

Germany provides major contributions to European satellite programs, including those targeting the stratospheric ozone layer. Key players are U Bremen (research, processors, processing, especially UV/VIS), DLR (research, processors, processing, data centers), KIT (research, processors, especially thermal IR), as well as EUMETSAT in Darmstadt and a number of companies building satellites and space equipment.

Table 2: Long-term column observations from satellites with German contribution.

Satellite(s)	Organization	Instruments	Gases	Years
ESA ERS-2 ENVISAT EUMETSAT METOP-A, B, C	U Bremen, DLR DLR/EUMETSAT AC-SAF	GOME SCIAMACHY GOME-2A, B, C	Total O_3, SO_2, NO_2, BrO, OClO, …, tropospheric O_3	1996 – 2002 2003 - 2012 2007 – now
AURA	BIRA/DLR, U Bremen	OMI	Total O_3, tropospheric O_3	2004 – now
ESA Sentinel-5P	DLR/ESA, U Bremen	TROPOMI	Total O_3, SO_2, HCHO, NO_2, …, tropospheric O_3	2018 – now
Suomi NPP	BIRA/DLR, U Bremen	OMPS - NM	Total O_3	2012 - now

1.2 Profile measurements of ozone and other gases/variables relevant to ozone loss

1.2.1 Stations with profile measurements (only long-term, ongoing)

Table 3: Stations with long-term profile observations

Name	Organization	Instruments	Gases	Years
Ny Ålesund – AWIPEV, Spitzbergen	AWI U Bremen	ECC-Sonde Frostpoint-Sonde Lidar µWave	O_3, temperature H_2O aerosol O_3, CO	1992 – now 2002 - now 1991 - now 1992,2015- now
Jülich / Frankfurt	U Frankfurt	Whole air sampler Aircore-Sonde	CFCs, SF_6, CO_2, many more	1975 – 2005 2016 - now
Lindenberg	DWD, GRUAN lead center	B/M-Sonde ECC-Sonde Frostpoint Sonde	O_3, temperature O_3, temperature H_2O	1974 - 1993 1994 – now 1999 - now
Hohenpeißenberg	DWD	B/M-Sonde Lidar	O_3, temperature O_3, temperature	1967 – now 1987 - now
Garmisch / Zugspitze	KIT	Lidar	aerosol	1977 – now
Palau, West Pacific	AWI	ECC-Sonde Frostpoint Sonde	O_3, temperature H_2O	2016 - now
Neumayer, Antarctica	AWI	ECC-Sonde	O_3, temperature	1992 – now

1.2.2 Satellite Profilers (non-nadir)

Table 4: Long-term profile observations from satellites with German contribution.

Satellite(s)	Organization	Instruments	Gases	Years
ESA ENVISAT	U Bremen	SCIAMACHY (UV-VIS Limb)	O_3, SO_2, NO_2, H_2O, BrO, OClO	2003 - 2012
ESA ENVISAT	KIT	MIPAS (IR Limb)	O_3, F11, F12, F22, CCl_4, ClO, $ClONO_2$, $BrONO_2$, SO_2, OCS, H_2SO_4, N_2O, NO_2, NO, N_2O_5, HNO_3, HNO_4, HOCl, H_2O, CH_4, CO, NH_3, SF_6, Temperature, aerosol, PSCs	2003 - 2012
Suomi NPP	U Bremen	OMPS-LP	O_3 and aerosol	2012 - present

Table 5: Long-term tropospheric ozone from satellites with German contribution.

Satellite(s)	Organization	Instruments	Gases	Years
ESA ENVISAT	U Bremen, DLR	SCIAMACHY (UV-VIS Limb/Nadir)	Tropospheric O_3, NO_2,	2003 - 2012
Suomi NPP	U Bremen, DLR	OMPS -LP + -NM	Tropospheric O_3	2012 - present
METOP-A, B, C	DLR/EUMETSAT AC-SAF	GOME-2A, B, C	tropospheric O_3, NO_2, …	2007 – now
AURA	DLR	OMI	Tropospheric O_3	2004 – now
ESA Sentinel-5P	DLR, U Bremen	TROPOMI	Tropospheric O_3, NO_2, …	2018 - now

1.2.3 Profile measurements from airplanes

German institutions are major contributors to the European research infrastructure IAGOS (In-Service Aircraft for a Global Observing System, https://www.iagos.org/). Flying on commercial airliners, IAGOS provides a comprehensive set of routine trace-gas and aerosol measurements in the upper troposphere and lower stratosphere.

For dedicated research campaigns, Germany operates the "High Altitude and Long Range Research Aircraft" (HALO, https://www.halo-research.de), a Gulfstream G550 research aircraft adapted for atmospheric research and earth observation. HALO offers technical infrastructure for very diversified scientific payloads, including lidars, 1 and 2-D IR and UV/VIS spectrometers, halocarbon measurements, as well as standard trace-gas and aerosol instrumentation. HALO is operated by a consortium of German research centers (DLR, KIT, FZ Jülich, MPG, TROPOS Leipzig, GFZ Potsdam) and the DFG (Deutsche Forschungs-Gemeinschaft, representing German universities). HALO consortium members are the main scientific users of the aircraft, but, in principle, HALO is open to other users as well. See Section 5 for information on recent HALO activities.

1.2.4 Balloon measurements

While the current focus of atmospheric measurement campaigns is on the HALO research aircraft, a number of German institutes have instruments for flying on large stratospheric balloons. Examples are the MIPAS-Balloon IR emission spectrometer (KIT, providing data on many species), UV/VIS/NIR Differential Optical Absorption Spectrometers (U Heidelberg, providing profiles of O_3, NO_2, HONO, BrO, IO, OClO, CH_2O, $C_2H_2O_2$ ...), whole-air samplers (U Frankfurt, whole air sampling for halocarbons, SF_6, CO_2, age-of-air and other species). U Frankfurt is also flying Air-Core samplers on small balloons on a reasonably regular schedule. In addition, DWD Lindenberg is hosting the Global Climate Observing System Reference Upper Air Network lead center (www.gruan.org) and is flying regular frost-point sondes to measure stratospheric water vapor.

1.3 UV measurements

UV measurements in Germany are coordinated by the Federal Office for Radiation Protection (Bundesamt für Strahlenschutz, BfS). Currently, 41 stations, distributed over Germany, take routine measurements. 14 of the sites use spectroradiometers (double monochromators and diode array radiometers with BTS technology), the others use broadband filter radiometers only. See https://www.bfs.de/uv-aktuell for data and more information.

1.4 Calibration activities

1.4.1 World Calibration Centre for Ozone Sondes

Since 1995, FZ Jülich hosts the World Calibration Centre for Ozone Sondes (WCCOS). WCCOS is part of the quality assurance for balloon borne-ozone sondes in WMO GAW. WCCOS provides an experimental chamber simulating the atmosphere as a balloon ascends from the surface to the stratosphere. The Jülich Ozone Sonde Intercomparison Experiments (JOSIE) have evaluated and substantially improved the performance of ozone sondes. WCCOS leads the “Ozone Sonde Data Quality Assessment (O3S-DQA)” and the Assessment of Standard Operating Procedures (ASOPOS) activities which are providing updated Standard Operating Procedures (SOP's) to reduce uncertainties of ozone sounding records down to the 5% level. To consolidate this, a new methodology of data processing has been developed, using the JOSIE 2009/2010 and JOSIE 2017-SHADOZ results, to resolve instrumental bias and time delay effects in the long-term records of the global ozonesonde network. While physically remaining in Jülich, the scientific oversight and operational planning for WCCOS is currently being transferred to the Belgian Royal Meteorological Institute in Uccle (R. van Malderen).

1.4.2 Regional Dobson Calibration Centre

Since 1999, DWD, in cooperation with Czech CHMI, is hosting the WMO RA VI Regional Dobson Calibration Centre (RDCC-E). Connected to the World Dobson Calibration Center (NOAA Boulder), and other regional Dobson Calibration Centers, RDCC-E provides calibration, maintenance, refurbishment and training for about 20 Dobson spectrometers/ stations in Europe and neighboring regions (including the British Antarctic Dobsons). RDCC-E hosts calibration campaigns at least once a year, except for 2020 and 2021 due to COVID restrictions.
The RDCC-E is currently preparing the transition of the world-wide Dobson network to new improved ozone cross-sections and better accounting for stratospheric temperatures (see https://doi.org/10.5194/amt-2023-220).

1.4.3 Global Climate Observing System Reference Upper Air Network Lead Center

Since 2008, DWD Lindenberg is hosting the lead center of the Global Climate Observing System Reference Upper Air Network (GRUAN, www.gruan.org). GRUAN aims to provide long-term, highly accurate measurements of the atmospheric profile with emphasis to the upper troposphere and lower stratosphere (upper-air). In 2022 and 2023 DWD Lindenberg in cooperation with MeteoSwiss hosted the WMO 2022 Upper-Air Instrument Intercomparison Campaign, see also https://www.gruan.org/community/campaigns/uaii2022 .

2. RESULTS FROM OZONE OBSERVATIONS AND ANALYSIS

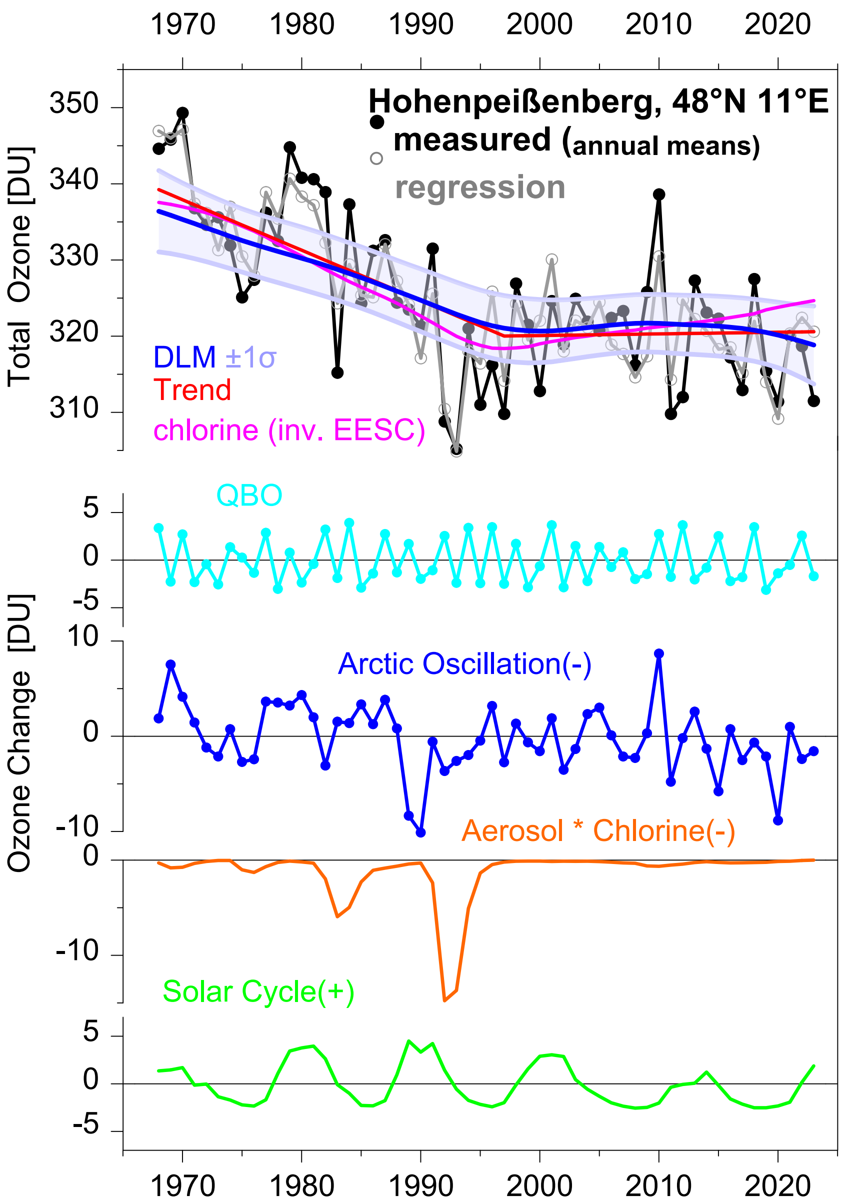

Figure 1: Top panel: Observed annual mean total ozone columns at Hohenpeißenberg, Germany (black dots), along with long-term variations estimated by multiple linear regression using equivalent effective stratospheric chlorine (pink line) or a hockey stick linear trend (red line), or by a dynamic linear model (DLM, blue line). The grey circles show the reconstructed time series from multiple linear regression. Lower panel: ozone variations attributed to other influence factors in the multiple linear regression.

As one example, Fig. 1 shows the observed evolution of total ozone at a German station, along with results from two multilinear regression and a dynamic linear model (DLM), which attribute the observed variations and long-term trends to a number of influencing factors. The observed data are consistent with long-term ozone decline due to increasing ozone-depleting substances (ODSs) from 1968 until the late 1990s, and a beginning slow recovery of ozone since the late 1990s. The observed rates of change in both periods (red and blue lines in top panel of Fig. 1) are largely consistent with the evolution of ODSs or stratospheric halogen loading (e.g. given by

Equivalent Effective Stratospheric Chlorine = EESC, pink line in Fig. 1). Note also that the long-term behavior of total ozone above Germany is very similar to the general behavior at Northern mid-latitudes, and even very similar to near global total ozone.

Similar trend analyses, also using satellite data, are carried out by a number of German groups, e.g. at Bremen University, KIT, DLR and FU-Berlin.

A study on changes in UV radiation based on ground-based measurement data over several decades is currently in progress. Results are expected shortly. As usual, UV over Germany is influenced by many more factors than stratospheric ozone alone. Thus, ozone- or ODS-related long-term UV changes are generally small and hard to detect over Germany. It is, however, noteworthy that due to the still quite enhanced ODS levels, large polar ozone depletion can occur in the Arctic spring, e.g. in years like 2011, 2016 or 2020. In such years, ozone poor air can reach Germany, and in combination with clear weather and a high tropopause, can result in substantially enhanced UV doses from March to May or June. Usually UV-warnings will be issued in such cases, see also 4.2 below.

3. THEORY, MODELLING, AND OTHER OZONE RELATED RESEARCH

A number of German groups use a range of models, including chemistry transport (CTM) and chemistry-climate models (CCMs), to simulate and understand changes and trends of stratospheric ozone, and to predict the future evolution of the ozone layer. German activities are well interfaced to international programs like the SPARC/IGAC Chemistry-Climate-Modelling Initiative (CCMI), which has been co-led by DLR.

ECHAM-MESSY (=EMAC), an improved CCM has been established by a consortium from DLR, MPI for Chemistry, the University in Mainz, MPI for Meteorology in Hamburg, FU Berlin, and KIT. EMAC has simulated decadal trends from the 1960s to 2100. These results have contributed significantly to WMO/UNEP Scientific Assessments of Ozone. At MPI for Chemistry a version of EMAC with interactive stratospheric and tropospheric aerosol, including volcanic effects, has contributed to the SPARC-Initiative SSIRC. The working group Atmospheric Dynamics at the Institut für Meteorologie of Freie Universität Berlin also uses EMAC, as well as observations, to study the effects of changes in anthropogenic emissions of ozone depleting substances (ODSs) and green-house gases (GHGs) on stratospheric ozone.

At KIT, chemistry-climate interactions and ozone relevant VOC distributions in the UTLS region are simulated with the ICON-ART model. In the future, ICON, developed by DWD and MPI-M, and used for weather forecasting by DWD, will deliver UV forecasts (via KIT's ART module).

AWI is developing and employing the ATLAS CTM, e.g. for modeling polar ozone depletion and transport pathways from the troposphere to the stratosphere. AWI is also developing SWIFT, a fast but accurate ozone chemistry scheme intended for use in Earth System and Climate Models (e.g. for IPCC).

FZ-Jülich regularly performs simulations of polar ozone depletion and its interaction with other processes like vertical NO_y redistribution using the Lagrangian CTM CLaMS, also used extensively for various aircraft campaigns (e.g. PHILEAS = Probing High Latitude Export of air from the Asian Summer Monsoon).

DLR runs the SACADA 4D-Var chemistry data assimilation system which provides consistent and continuous daily global stratospheric analyses since July 2013 based on Microwave Limb Sounder (MLS) profile data of O3, HNO3, H2O, N2O and HCl.

4. DISSEMINATION OF RESULTS

4.1 Data reporting

Routine ozone layer data are submitted to the WOUDC, to NDACC and to the NILU data center (e.g. MATCH campaigns). In addition, DLR hosts the World Data Center for Remote Sensing of the Atmosphere, and provides operational processing and data delivery for total ozone columns and other traces gases from European satellites. Results and data are also available from most institutes (see Section 9 for websites).

4.2 Information to the public

BfS and DWD provide the public with UV-information including warnings and daily forecasts of the UV-index. UV-forecasts for clear sky and cloudy conditions are available for free on a global scale (http://kunden.dwd.de/uvi /) and nationally (http://www.uv-index.de , https://www.bfs.de/DE/themen/opt/uv/uv-index/prognose/prognose_node.html).

A wealth of general information and educational material on atmospheric constituents and the ozone layer is available from German institutes (see Section 9 for websites). For example, DLR provides animations showing the ozone measurements from TROPOMI at https://www.dlr.de/eoc/en/desktopdefault.aspx/tabid-11051/#gallery/INPULS-TROPOMI_L3_P1D_O3-SHK.

4.3 Relevant scientific papers

Instead of giving a long list of scientific papers, which nowadays are easily found using publication databases like Google Scholar, Harvard Abstract Server or Scopus, the following Figure shows the temporal evolution of scientific publications on stratospheric ozone with co-authors from German institutions. The Figure shows a general increase from about 25 publications per year around 2000 to about 45 publications around 2018. Recently, the number decreased to about 30 publications per year for the 2022 to 2023 period.

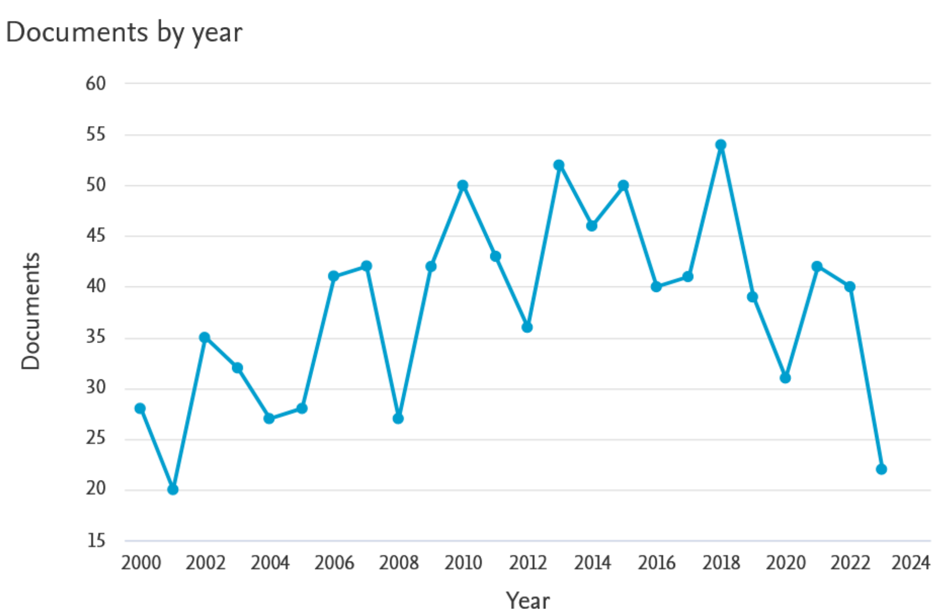

Figure 2: Number of scientific publications per year on ozone and the stratosphere and with co-authors from German institutions. Data compiled using SCOPUS.

5. PROJECTS, COLLABORATION, TWINNING AND CAPACITY BUILDING

Germany is collaborating in the large European Infrastructure Projects, especially In-service Aircraft for a Global Observing System (IAGOS), Integrated Carbon Observation System (ICOS), Aerosol, Clouds and Trace gas Research Infra-Structure (ACTRIS), Integrated access to balloon-borne platforms for innovative research and technology (HEMERA), the ESA projects Climate Change Initiative (CCI+) ozone and CCI+ precursors, the Copernicus Climate Change Service (C3S), and in the Copernicus Atmospheric Monitoring System (CAMS).

Germany is actively involved in the European satellite projects AC-SAF from EUMETSAT and Sentinel-5P from ESA, and plays a leading role in the ESA Earth Explorer 11 candidate mission CAIRT (The Changing-Atmosphere Infrared Tomography Explorer), one of two satellite concepts selected by ESA for Phase A studies. CAIRT (www.cairt.eu) would perform infrared limb imaging from the upper troposphere to the lower thermosphere (about 5 to 115 km altitude), providing many key products and diagnostics to investigate and monitor changes in the middle atmosphere circulation and composition, including recovery of the ozone layer. A final selection for the Earth Explorer 11 satellite will be made by ESA in mid-2025 with the aim for a launch in the early 2030s.

The SPARC-OCTAV activity (Observations and Trends And Variability) uses a multiplatform approach to determine trends in the UTLS. To reduce the influence of dynamical variability, all observations (balloon, aircraft, satellite) are put on a coordinate system relative to the tropopause and to the jet-streams, using consistent reanalysis data and tropopause metrics. SPARC-OCTAV is co-lead by U-Mainz, NASA-JPL, and NOAA Boulder, and is supported by WMO's GAW program.

DLR and U-Bremen are co-leading the SPARC-LOTUS activity (Long-term Ozone Trends and Uncertainties in the Stratosphere), which has been the main contributor for ozone profile trends reported in the 2022 WMO/UNEP ozone assessment.

A number of German research projects are financed by BMBF within its sustainability / climate focus. See https://www.fona.de/en/measures/funding-measures/ . Here the most relevant initiatives in the reporting period are the Role of the Middle Atmosphere in Climate (ROMIC II, https://romic2.iap-kborn.de) initiative and the large national projects centered around the HALO research aircraft (https://halo-research.de). HALO flew 7 dedicated missions in the 2020 to 2023 period, targeting atmospheric chemistry and transport in various regions from the tropics to the Arctic. Additionally, a large number of HALO-related research projects are funded by the Deutsche Forschungs-Gemeinschaft (DFG, see https://gepris.dfg.de/gepris/projekt/28423678 and https://physik.uni-greifswald.de/ag-von-savigny/projects/dfg-research-unit-volimpact-for-2820/). Funding is also provided by DLR Bonn/ BMWi to support innovative space applications including advanced ozone data products.

A special focus on lower stratospheric ozone and stratospheric processes is part of the DFG-Sonderforschungsbereich Transregio TR-301 (TPChange: The tropopause region in a changing atmosphere) led by JGU Mainz and GUF Frankfurt/Main.

Regarding UV-studies, BfS has supported Leibniz University of Hannover for a feasibility study on microscale modelling of UV exposure in urban environments for skin cancer prevention. In a follow-up project, the development of a UV module was supported for the urban climate model PALM (https://palm.muk.uni-hannover.de/trac/wiki/palm), to model the erythemal UV irradiance and estimate the efficiency of UV-reducing structures on UV exposure, in order to prevent skin cancer.

6. IMPLEMENTATION OF THE RECOMMENDATIONS OF THE 11th OZONE RESEARCH MANAGERS MEETING

Germany has followed many of the recommendations of the 11th ORM by

- continuing systematic long-term observations and maintaining their quality
- funding and carrying out extensive research on ozone layer processes, ozone layer recovery and climate change
- continuing QA/QC tasks and capacity building, e.g., through WCCOS ozone sonde activities, as well as RDCC calibration campaigns
- regularly submitting data to the international data centers
- participating in internationally coordinated modelling activities like the Chemistry-Climate Modelling Initiative (CCMI)
- contributing substantial manpower, data, and expertise to the 2022 WMO/UNEP ozone assessment.

7. FUTURE PLANS

Germany plays a leading role in the ESA / EUMETSAT satellite missions Sentinel-4 and Sentinel-5. It will continue contributing to EU initiatives, especially the Copernicus Climate Change Service (C3S), the Copernicus Atmospheric Monitoring System (CAMS), and to European Research Infrastructures, especially In-service Aircraft for a Global Observing System (IAGOS), Integrated Carbon Observation System (ICOS), and Aerosol, Clouds and Trace gas Research Infra-Structure (ACTRIS).

U Bremen and DLR are contributing to the generation of long-term consolidated ozone time series under the ESA Climate Change Initiative (CCI+, projects CCI+ozone and CCI+precursors). U Bremen is a member of the ALTIUS (limb sounder, launch in ~2025) mission advisory group. KIT is the lead institute for the CAIRT (IR limb sounder) mission as part of ESA's Earth Explorer program. Currently, CAIRT is one of two missions remaining to be selected to fly in the early 2030s.

BMBF and DFG will continue funding coordinated and individual research projects, which are relevant to our understanding of the evolution of the ozone layer under a changing climate.

8. NEEDS AND RECOMMENDATIONS

- Monitoring the expected recovery process of the ozone layer remains essential for the next decades. It requires continuing high-quality measurements of total ozone, ozone profiles and other key constituents and atmospheric parameters (e.g. stratospheric temperature).
- To achieve the required accuracy, multiple redundant satellite and ground-based observations have to be maintained. Comprehensive quality assurance and quality control activities have to be continued (standard operating procedures, calibration centres, inter-comparison exercises, best possible absorption cross sections, …).
- The scarcity of future limb sounding satellite instruments remains a great concern. Vertically resolved profiles, not only of ozone, but also other key constituents, are essential for monitoring and attributing future ozone changes, under recovery from man-made halogen loading, but also under the influence of a changing climate.

- The complex interactions of climate change, ozone recovery, UV-radiation and changes in the atmospheric large-scale circulation remain uncertain, as does the future evolution of anthropogenic emissions. High quality, long-term data sets and continued modelling efforts are key prerequisites for understanding the observed past and predicting the future.
- Not all processes controlling the future of the ozone layer are fully understood, or properly modelled. Dedicated measurement campaigns, e.g. from special balloons and research aircraft, and accompanying model simulations and model improvement remain important to improve our process understanding and, ultimately, our predictive capabilities.

9. INSTITUTIONS

AWI, Alfred Wegener Institut für Polarforschung, Helmholtz-Zentrum für Polar- und Meeresforschung, https://www.awi.de/

BfS, Bundesamt für Strahlenschutz, https://www.bfs.de/

DLR, Deutsches Zentrum für Luft- und Raumfahrt, Earth Observation Center, https://www.dlr.de/eoc/; Institut für Physik der Atmosphäre, https://www.dlr.de/pa/

DWD, Deutscher Wetterdienst, www.dwd.de/ozon

FU Berlin, Institut für Meteorologie Freie Universität Berlin, https://www.geo.fu-berlin.de/met

FZ Jülich, Forschungszentrum Jülich, IEK7 Stratosphäre, https://www.fz-juelich.de/iek/iek-7/DE/Home/home_node.html; IEK8 Troposphäre, https://www.fz-juelich.de/iek/iek-8/DE/Home/home_node.html

KIT, Institut für Meteorologie und Klimaforschung, Karlsruhe Institute of Technology, http://www.imk.kit.edu/

MPI-BGC, Max Planck Institut für Biogeochemie, https://www.bgc-jena.mpg.de

MPI-C, Max Planck Institut für Chemie, https://www.mpic.de/

MPI-M, Max Planck Institut für Meteorologie, https://www.mpimet.mpg.de/startseite/

U Bremen, Institut für Umweltphysik Universität Bremen, https://www.iup.uni-bremen.de/deu/

U Frankfurt, Institut für Atmosphäre und Umwelt Universität Frankfurt, https://www.uni-frankfurt.de/41121398/Institut_f%C3%BCr_Atmosph%C3%A4re_und_Umwelt

U Hannover, Institut für Meteorologie und Klimatologie, https://www.meteo.uni-hannover.de/de/

U Heidelberg, Institut für Umweltphysik Universität Heidelberg, https://www.iup.uni-heidelberg.de/de/institute/atmosphere

U Mainz, Institut für Physik der Atmosphäre Universität Mainz, https://www.ipa.uni-mainz.de

TROPOS, Leibniz Institut für Troposphären Forschung, https://www.tropos.de/