

FINLAND

OBSERVATIONAL ACTIVITIES

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

The discovery of the Antarctic "ozone hole" in the mid 1980s initiated several ozone monitoring activities also at northern high latitudes. In Finland, ozone column monitoring has been carried out by the Finnish Meteorological Institute at Sodankylä (67.4°N, 26.6°E) since 1988 and at Jokioinen (60.5°N, 23.3°E) since 1994. At both stations an automated system based on Brewer spectrophotometer is continuously operated. At Sodankylä Arctic research centre (FMI-ARC) wintertime ozone columns are also monitored with a SAOZ spectrophotometer which is operated in cooperation with CNRS-Paris already since 1990. The SAOZ measurements also provide NO₂ and OCIO column amounts. This instrument works at large solar zenith angles and is thus capable of measurements during the wintertime at high latitudes. Multiyear ozone measurements from both stations have shown large inter-annual variations, in addition significant ozone loss has been observed in the Arctic stratospheric vortex during several years since early 1990s. In 2006 and 2007 FMI hosted at Sodankylä a NASA lead comparison/validation campaigns aiming to achieve < 1% total ozone measurement accuracy in both ground based and satellite based platforms. Sub-percent accuracy is needed for reliable monitoring of the effects of Montreal protocol.

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

Ozone soundings has been carried out since 1989 at Sodankylä where balloon ozone sensor measurements are carried out regularly throughout the year, while in Jokioinen these measurements are conducted during winter and spring when chemical ozone depletion is expected.

Another long-term initiative at FMI-ARC related to stratospheric ozone is the measurements of polar stratospheric cloud (PSC) properties. PSCs play an essential role in chlorine activation and subsequent ozone depletion. PSCs are generally divided in two types based on their optical parameters, type II are large particles of primarily water ice, type I are typically smaller particles of nitric acid trihydrate or supercooled ternary solution droplets. At Sodankylä these stratospheric cloud particles have been observed during stratospheric campaigns since 1991/1992 by lidar and since 1994 by aerosol backscatter sondes.

At Sodankylä, since December 2002, stratospheric humidity is monitored in winter months using Cryogenically cooled Frost point Hygrometer (CFH) from university of Colorado and/or alpha-lyman hygrometers developed at Central Aerological Observatory of RosHydromet. Already earlier, in January 1996 an Arctic dehydration event was recorded and investigated at Sodankylä using NOAA/CMDL hygrosonde, a predecessor of CFH. FMI has also hosted an international intercomparison campaign of lightweight hygrosondes in January-February 2004.

The national meteorological institutes in Finland (FMI) and Argentina (SMN) started a joint ozone research program in 1987, including total ozone measurements at Marambio (64.1°S, 56.4°W), Antarctica. In 1988 routine ozone soundings were started at Marambio. Recently FMI and SMN have started Aerosol optical depth and radionuclide measurements at Marambio.

UV measurements

Broadband measurements

FMI operates SL501 broadband instruments at six sites in Finland. These instruments provide on-line information on the erythemal irradiance that is published through the internet along with the UV-Index forecast.

Narrowband filter instruments

FMI cooperates with Argentina and Spain on Antarctic ozone and UV. In 1999 the collaboration was extended to include UV radiation research. The established UV monitoring network consists of NILU-UV instruments in Marambio, Belgrano and Ushuaia, and a travelling reference. In

Sodankylä a NILU-UV radiometer has been used to measure UV radiation of a reference field within a large field experiment of FUVIRC (Finnish Ultraviolet International Research Center). One NILU-UV, in Helsinki, has been acquired for campaign use.

Spectroradiometers

FMI has measured spectral UV irradiance with Brewer instruments in Jokioinen (Mark III since 1995) and Sodankylä (Mark II since 1990). Additionally, a Bentham DM150 has been acquired for campaign use, as well as, more recently, a new diode array spectroradiometer SP-J1009.

Calibration activities

FMI has dark room UV calibration facilities both in Jokioinen and Sodankylä. FMI has participated in several UV measurement comparison campaigns, where it has been established that the quality of Finnish Brewer measurements is excellent and steady. The Brewer instrument of Jokioinen served as one of the core instruments of the QUASUME project (Quality Assurance of Spectral Ultraviolet Measurements in Europe). FMI is also responsible for calibration of the Antarctic NILU-UV instruments and data quality assurance. Brewer ozone measurements in Jokioinen and Sodankylä are calibrated by annual visits of a travelling Brewer standard instrument, which in turn is calibrated against the Brewer Triad at Toronto.

Satellite observations and instrument development

FMI has a strong participation in three satellite instruments that are targeted for monitoring ozone in the atmosphere (GOMOS/Envisat, OSIRIS/Odin, OMI/EOS-Aura). The GOMOS instrument onboard the ESA's Envisat satellite has been operating since spring 2002. Ozone profiles that cover the altitude range from upper troposphere to lower thermosphere during years 2002-2007 are already available.

The OSIRIS instrument onboard the Swedish small satellite Odin has measured ozone profiles since 2001. The ozone profiles are processed also at FMI and during the last years the validation and optimization of the algorithms have taken place.

The Dutch-Finnish OMI instrument onboard the NASA's EOS-Aura satellite has measured total ozone columns since 2004. FMI is hosting the OMI UV irradiance processing and archiving facility and the validation of the ozone and UV products are ongoing. In addition, local maps of total ozone columns and UV irradiance covering Central and Northern Europe are processed at FMI. These Very Fast Delivery products exploit the Direct Broadcast antenna at Sodankylä, Northern Finland. The total ozone and UV irradiance maps are available in the Internet (omivfd.fmi.fi) within 15 min after the overpass of the satellite.

To continue the high resolution ozone profile measurements of OSIRIS and GOMOS instruments FMI proposed the OLIVIA (Occultation and limb viewing of the atmosphere) instrument to the ESA Earth Explorer program in 2005.

RESULTS FROM OBSERVATIONS AND ANALYSIS

Only Brewer UV measurements are considered to have a sufficient quality for assessment of long-term changes. The smaller the change is the longer time series is required for detection of it. A study on the Sodankylä UV time series 1990-2001 revealed no consistent trend during this 12 year period. An increase in UV radiation was observed in early 1990s and then a decrease towards the end of the period with the largest values occurring in 1993 and after the cold winters of mid 1990s. These observations are consistent with the ozone layer development in the same period.

Ozonesonde observations have been conducted in Sodankylä since 1989. This data along with the data from other Arctic stations have been analyzed. It was found that during the recent decades the largest ozone changes in the stratosphere and troposphere have occurred in the late winter/spring period. The observed negative trend in the stratosphere prior to 1996-1997 can be attributed to the combined effect of chemical and dynamical changes, while the observed increase since then is primarily due to the dynamical changes. In the troposphere, trends have been positive

regardless of the chosen time period. This may be related to the long-term changes in Arctic oscillation as it regulates the transport of ozone and its precursors from industrialized regions towards the pole and it may also modulate stratosphere-troposphere exchange.

Water vapour changes in the UTLS have a large impact on the climate system. Yet the accurate measurements of the UTLS water vapour remain a technological challenge. FMI hosted a major field campaign of comparison of light-weight instruments capable of water vapour measurements in the upper troposphere and lower stratosphere. This campaign led to better understanding of the accuracy of the in situ instruments and contributed to significant improvement of the technology. In addition, the data provided a unique opportunity to study meteorological processes in the lower stratosphere and upper troposphere.

THEORY, MODELLING, AND OTHER RESEARCH

The modelling activities related to middle atmospheric ozone includes the use of a global 3D chemistry transport model of the stratosphere and mesosphere (FinROSE-ctm), a global chemistry coupled climate model covering the altitude range from the surface to ca. 250 km (HAMMONIA) and a model of the ionosphere (Sodankylä Ion Chemistry model). The modelling work includes both studies of long term trends of stratospheric ozone utilizing reanalyzed meteorological data (ERA-40) as well as process studies (PSC, chlorine activation, ozone loss rates). Also trajectory modelling is utilized for studying the ozone and water vapour distribution in the UTLS region and for determining ozone loss rates from sounding campaign measurements (e.g. the International Polar Year Antarctic Match campaigns). The scientific use of satellite measurements is increasingly important and an assimilation system combining OSIRIS and GOMOS profile data with a CTM model has been developed. In addition, the impact of solar proton events on the stratosphere and mesosphere is studied. In this study the unique night time ozone profile measurements of the GOMOS instrument are used. GOMOS data is also used for studying turbulence and gravity waves in the stratosphere.

FMI has developed models for reconstruction of the past UV time series as well as for assessment of the future UV levels. These data are essential for assessment of the long-term changes in surface UV. FMI contributed to the Arctic Climate Impact Assessment (ACIA) with a shared lead authorship of the chapter on ozone and UV. FMI has participated in multidisciplinary research projects that aim at better understanding of the effects of increased UV exposures on human health, terrestrial and aquatic ecosystems, or materials.

FMI coordinates the research project UVEMA exploring the Effects of UV radiation on MAterials. The study focuses on rubber compounds, natural fibre composites and carbon fibres provided by the industrial partners of the project. A program of long-term outdoor material testing has been set up at seven European sites, including Jokioinen Observatory and Arctic Research Centre at Sodankylä. Prevailing UV radiation and weather conditions are being monitored alongside with the program at each station. Exposed material samples will be investigated in respect of various properties: colour, quality/coarseness of the surface and compression/flexural/tensile strength. As an outcome, more reliable estimates for the useful life-time of the materials are to be gained.

FMI Arctic Research Centre at Sodankylä hosts the experimental fields of FUVIRC-experiment (Finland UV International Research Centre) to study biological impacts of UV-B radiation to boreal plants at enhanced UV-radiation condition. There are two experimental sites representing typical landscape types of northern Fennoscandia, a boreal pine forest test field and peat land test field. Enhancement of the ambient UV-exposure can be regulated to desired values through extensive monitoring and control system. The field serves atmospheric chemistry, human health, and biological research initiatives by providing extensive UV monitoring data, guidance (i.e. calibration of instruments, maintenance of field test sites), and research facilities (i.e. laboratories, instruments, equipment and accommodation for visiting researchers).

DISSEMINATION OF RESULTS

Data reporting

FMI has participated in the Global Atmospheric Watch (GAW) programme since 1994. Within the program, FMI maintains the Pallas-Sodankylä GAW station and conducts an extensive research programme related to atmospheric aerosols. Within this twin GAW station surface and boundary layer measurements are done in FMI clean air site of Pallas while upper air measurements, UV and Ozone monitoring takes place at Sodankylä (fmiarc.fmi.fi). In upper air research Sodankylä functions as an auxiliary station in the global Network of Detection of Atmospheric Composition Change (NDACC).

FMI maintains the European UV Database (EUVDDB). EUVDDB is a regional WMO database containing some two million UV spectra (uvdb.fmi.fi/uvdb/). The UV spectra of the two Finnish Brewer instruments are submitted to EUVDDB.

Regular ozone soundings have been performed at Marambio since 1988, the ozone data is sent to two international databases at the World Ozone and Ultraviolet Data Centre (WOUDC, Toronto, www.woudc.org) and the Norsk institutt for luftforskning (NILU, Oslo, www.nilu.no/nadir/). Furthermore, the UV measurements are available at polarvortex.org. Both the ozone and UV measurements are used in scientific publications, and form a significant contribution to the WMO ozone bulletins (www.wmo.ch).

Information to the public

FMI provides a 2-day forecast of the UV Index in Europe (www.fmi.fi/uvi). The forecast, which is published in the internet, includes a contour map of the local solar noon maximum clear sky maximum UV Index. Additionally, local clear sky UVI forecast is provided for several sites in Finland and Europe. The Finnish broadband UVI measurements are also incorporated in the web page. FMI has actively participated in increasing the awareness of general public on the health effects of UV radiation. In addition, FMI contributed to the Arctic Climate Impact Assessment (ACIA) document with a shared lead authorship of the chapter on ozone and UV.

Ozone depletion has a large public interest due to related health (UV) and environmental issues, e.g. the unprecedented stratospheric conditions and severe ozone loss in the winter and spring 2004/2005 triggered a wide interest in the Finnish media. The major scientific results are published in international refereed journals and are also presented at relevant international conferences. Popularized information is distributed through press releases and interviews. Information about research activities as well as measurements and analysis results are also available through FMI web pages; Arctic and Antarctic research at FMI, www.fmi.fi/research_polar/polar.html, FMI-ARC observations and analyses, fmiarc.fmi.fi, Remote sensing projects and general Ozone and UV related information, www.fmi.fi/research_atmosphere/atmosphere.html.

Recent relevant scientific papers

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PROJECTS AND COLLABORATION

The major national funding organisations are the Academy of Finland and the National Technology Agency of Finland. The Antarctic research related to ozone and UV and the as well as the research of the impact of solar proton events on stratosphere and mesosphere is partly funded by the Academy of Finland. FMI collaborates with Finnish Universities on atmospheric modelling and developing data retrieval methods and assimilation techniques for the GOMOS and OSIRIS instruments.

- FARPOCC (Finnish Antarctic Research Programme on Polar Climate Change, www.fmi.fi/research_polar/polar.html)
- MAIST (Middle atmospheric interactions with sun and troposphere)

- FUVIRC (Finnish Ultraviolet International Research Center, fuvirc oulu.fi/index.htm)
- MUTUAL (Multiproxy Approach to Estimate Changes in UV Exposure in Arctic Lakes, www.helsinki.fi/bioscience/ecru/projects/mutual.htm)
- UVEMA (Effects of UV radiation on Materials, uvema.fmi.fi/)

FMI has participated in several EU funded Arctic and Antarctic research projects including tasks such as stratospheric modelling and measurement campaigns. The modelling activities include cooperation with the Max Planck Institute, Hamburg and National Center for Atmospheric Research, USA. Sodankylä has participated in all major European stratospheric ozone campaigns. In 1999, 2003 and 2007 the Marambio activities formed an important part of the international stratospheric ozone research campaigns. In addition, FMI takes part in several activities organized during the International Polar Year 2007/2008.

- QUASUME (Quality Assurance of Spectral Ultraviolet Measurements in Europe)
- RETRO (REanalysis of the TROpospheric chemical composition over the past 40 years, retro.enes.org/)
- CANDIDOZ (Chemical and Dynamical Influences on Decadal Ozone Change)
- SCOUT-O3 (Stratospheric-Climatic Links with Emphasis on the Upper Troposphere and Lower Stratosphere, www.ozone-sec.ch.cam.ac.uk/)
- PROMOTE (PROtocol MONiToring for the GMES Service Element, www.gse-promote.org/)
- ACIA (Arctic Climate Impact Assessment, www.acia.uaf.edu/pages/scientific.html)
- COSMOS (Community Earth System Models, cosmos.enes.org)
- SAUNA (Sodankylä total column ozone intercomparison)

FMI is coordinating the EUMETSAT Satellite Application Facility on Ozone Monitoring (O3M SAF, o3saf.fmi.fi). O3M SAF is one of the SAFs in EUMETSAT SAF network. SAFs are specialised development and processing centres within the EUMETSAT Application Ground Segment (www.eumetsat.int). O3M SAF is developed in co-operation with Koninklijk Nederlands Meteorologisch Instituut (KNMI), Deutsche Zentrum für Luft- und Raumfahrt (DLR), Deutscher Wetterdienst (DWD), Aristotle University of Thessaloniki (LAP), Hellenic National Meteorological Service (HNMS), Danish Meteorological Institute (DMI), Météo-France (M-F) and Koninklijk Meteorologisch Instituut (KMI).

The purpose of the O3M SAF is to produce a set of near real-time and offline products and validation services. Near real-time products are GOME-2 total ozone and ozone profiles, HIRS total ozone and UV clear-sky fields. Offline products derived from GOME-2 data are total column amounts of ozone, NO₂, BrO, ozone profiles, aerosol index and optical depth and UV fields including cloudiness and albedo. The ozone and UV data will be validated against ground-based observations of total ozone and UV as well as balloon borne, microwave and lidar observations of the vertical distribution of ozone. An important part of the O3M SAF activities has been related to scientific work to develop radiative transfer calculation methods and other algorithms used for satellite ozone and related data retrieval.

The Satellite Data Centre of FMI-ARC started in 2002. The activities include a processing facility for the GOMOS/Envisat ozone instrument. The FMI-ARC data centre also process part of the OSIRIS/Odin ozone data. Data reception from the EOS-Aura satellite is also going on for Very Fast Delivery products of the total ozone and UV irradiance maps, available within 15 min after the overpass of the satellite. The Centre is also responsible of reception of OMI data used in near real time O₃ and UV-products.

FMI also hosts the WMO IGACO (Integrated Global Atmospheric Chemistry Observations) Ozone secretariat (www.igaco-o3.fi). IGACO is the atmospheric chemistry component in the Integrated Global Observing Strategy (IGOS). One of the objectives of IGACO strategy, implemented through the GAW programme of WMO, is to ensure long-term continuity and spatial comprehensiveness of atmospheric composition observations, both in the troposphere and the stratosphere.

FUTURE PLANS

Although the basic processes related to stratospheric ozone are now fairly well understood, there remain important research topics related to ozone and UV, such as the interaction between ozone depletion and climate change and the effects of increased UV-irradiance on nature and materials. According to the present understanding the recovery of the ozone layer will take several decades, therefore it is desirable that the research activities will be continued and developed.
