FINLAND

1. GROUND BASED OBSERVATIONS

1.1 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 NO_2 and OClO 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.

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

Ozone soundings have 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. Recently cooperation with ETH Zurich has started in the framework of development of a new backscatter sonde.

At Sodankylä, since December 2002, stratospheric humidity is monitored in winter months using Cryogenically cooled Frost point Hygrometer (CFH) and/or hygrometers developed at the 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.

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.

1.3 UV measurements

1.3.1 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.

1.3.2 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.

1.3.3 Spectroradiometers

FMI has monitored the 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, one diode array spectroradiometer SP-J1009 for monitoring the spectral irradiance on a vertical surface following the solar azimuth, and another for monitoring the direct spectral irradiance at Jokioinen.

1.4 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). The European reference spectroradiometer developed in the project is invited for auditing visits to both observatories on a regular basis. FMI is also responsible for calibration of the Antarctic NILU-UV travelling reference instrument 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.

1.5. Measurement and validation campaigns

The Arcitc research center at FMI has become an important site for ozone validation campaigns. In 2006 and 2007 major ozone campaigns were organised in Sodankylä by NASA, ESA and FMI, 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. FMI Arctic Research Centre (FMI-ARC) also participated in the EUMETSAT EPS campaign in 2007, which involved ozone soundings and groundbased measurements.

FMI has also hosted international intercomparison campaigns of lightweight hygrosondes in 2004 and 2010. The LAPBIAT Atmospheric Sounding Campaign in January-March 2010 involved a large set of stratospheric measurements by applying various measurement techniques. FMI ARC has participated in ozonesonde Match campaigns during each Arctic winter. In 2011 FMI organised the CEOS Nordic Ozone Intercomparison campaign. The goal of the campaign was to characterize Brewer and Dobson spectrophotometer accuracy.

2. SATELLITE OBSERVATIONS AND DATA PRODUCTS

FMI has a strong participation in four satellite instruments that are targeted for monitoring ozone in the atmosphere (GOMOS/Envisat, OSIRIS/Odin, OMI/EOS-Aura). The GOMOS stellar occultation instrument onboard the ESA's Envisat satellite has been operating since spring 2002. High vertical resolution ozone profiles that cover the altitude range from upper troposphere to lower thermosphere during years 2002-2011 are already available. FMI participates in ensuring the GOMOS data quality and in improving the data processing as a member of the ESA's GOMOS quality working group. The full reprocessing of GOMOS data is expected in 2011. Resent research also include developing an algorithm for processing GOMOS bright limb data.

GOMOS data plays an important role in the ESA's climate change initiative for developing essential climate variable (ECV) of ozone. FMI participates in developing the ECV dataset of high resolution ozone profiles using GOMOS data. In addition, FMI is presently studying whether GOMOS ozone data can be used to continue the satellite based high resolution ozone profile dataset of SAGE solar occultation instruments.

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.

FMI is developing GOMOS and OSIRIS monthly averaged zonal averages and these data are distributed via internet (fmilimb.fmi.fi/).

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 which includes level 2 data, gridded level 2 data and level 3 data. The improvement and validation of the UV products are continuously ongoing. In addition, local maps of total ozone columns and UV irradiance together with other atmospheric constituents covering Central and Northern Europe are processed at FMI. These Very Fast Delivery (VFD) products exploit the Direct Broadcast antenna at Sodankylä, Northern Finland. These products are available in the Internet (omivfd.fmi.fi) within 15 min after the overpass of the satellite. As a continuation to FMI's research related to OMI, we have recently studied methods to retrieval ozone profile data using Sentiel-5-precursor/TROPOMI instrument.

FMI is responsible of developing, distributing, archiving of the UV-radiation product of GOME-2. This is done within the EUMETSAT's Satellite Application Facility project of ozone and atmospheric chemistry, O3M-SAF (o3msaf.fmi.fi).

3. RESULTS FROM OBSERVATIONS AND ANALYSIS

FMI has developed quality control (QC) and quality assurance (QA) practices that are suitable for many kinds of UV instruments. At FMI, at the moment, only Brewer UV measurements are considered to have a sufficient quality for assessment of long-term changes. The QC/QA procedures of the Brewers include daily maintenance, laboratory characterizations, calculation of long-term spectral responsivity, data processing and quality assessment. New methods for the cosine correction, the temperature correction and calculation of long-term changes in spectral responsivity were implemented. The Sodankylä spectral time series is among the longest in Europe. 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. The reanalysis of the entire time period is under work.

FMI has participated to UV albedo measurement campaigns. Measurements of snow albedo are still a big challenge due to the demanding measurement conditions as well as measurement uncertainties. The UV albedo has been quantified over Sodankylä. The results show that the albedo of snow depends on the properties of the snow, and that the grain size of the snow differs between the European Arctic and Antarctic regions, which introduce a different UV albedo in these regions. Other atmospheric parameters, e.g., cloudiness and temperature, can influence the albedo. At Sodankylä, the snow albedo was found to change within a few hours, due to the effect of temperature on snow's properties.

Ozonesonde observations have been conducted in Sodankylä since 1989. This data along with the data from other Arctic stations have been analyzed. It was seen 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 has hosted two major field campaigns of comparison of light-weight instruments capable of water vapour measurements in the upper troposphere and lower stratosphere. The campaigns has led to a 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 including PSCs and dehydration.

4. 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 climate model covering the middle atmosphere (MAECHAM), a coupled atmosphere-ocean model (HadGEM1) and a model of the ionosphere (Sodankylä Ion Chemistry model). The modelling work includes both studies of long term trends of stratospheric ozone and water vapour utilizing reanalyzed meteorological data (ECMWF reanalysis data) as well as process studies (PSC, chlorine activation, ozone loss rates). The studies are also focused on impacts of ozone depletion and recovery on surface climate, which are shown to be significant in the Southern Hemisphere. These results add to increasing number of evidences that the stratosphere plays an important role in climate change and call for a better representation of the stratosphere in models used for climate studies, in particular for a wider use of chemistry-climate models (CCMs) which include stratospheric ozone chemistry. FMI has participated in preparation of the SPARC assessment of CCMs (CCMVal-2, http://www.atmosp.physics.utoronto.ca/SPARC/ccmval_final/index.php) in support of WMO ozone assessment 2010 and the upcoming IPCC report. The scientific use of satellite measurements is increasingly important. 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 are 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).

5. DISSEMINATION OF RESULTS

5.1 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 (EUVDB). EUVDB 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 EUVDB.

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).

5.2 Information to the public

FMI provides a 2-day global forecast of the UV Index (www.fmi.fi/uvi). The forecast, which is published in the internet, includes contour maps of the local solar noon maximum clear sky maximum UV Index. Additionally, local clear sky UVI forecasts are provided for several sites in Finland and globally. 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.

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, remote sensing projects as well as measurements and analysis results are available through FMI web pages, www.fmi.fi. FMI-ARC observations and analyses are available at fmiarc.fmi.fi.

Ozone depletion has a large public interest due to related health (UV) and environmental issues. The unprecedented stratospheric conditions and severe ozone loss in the spring of 2011 triggered a wide interest in the Finnish media (Figure 1).

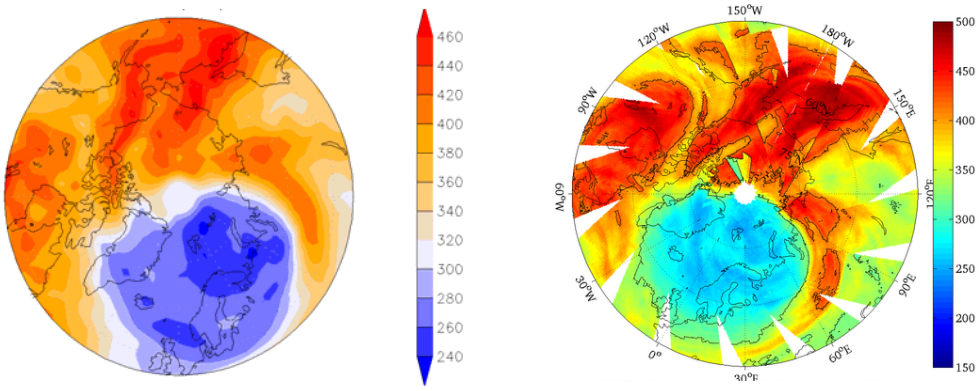

Figure 1. Total ozone (DU) above Scandinavia on March 28, 2011. The exceptional Arctic ozone depletion was noted by media in Finland. Both ground based and satellite measurements as well as model forecasts were referred in the media. Left panel, FinROSE-ctm data. Right panel, OMI total ozone data.

5.3 Recent relevant scientific papers

- *Lindfors, A., and A. Arola; On the wavelength-dependent attenuation of UV radiation by clouds, Geophys. Res. Lett., 35, L05806, doi:10.1029/2007GL032571, 2008.*
- *Harris, N. R. P., E. Kyrö, J. Staehelin, D. Brunner, S-B. Andersen, S. Godin-Beekmann, S. Dhomse, P. Hadjinicolaou, G. Hansen, I. Isaksen, A. Jrrar, A. Karpetchko, R. Kivi, B. Knudsen, P. Krizan, J. Lastovicka, J. Maeder, Y. Orsolini, J.A. Pyle, M. Rex, K. Vanicek, M. Weber, I. Wohltmann, P. Zanis, and C. Zerefos, Ozone trends at northern mid- and high latitudes– a European perspective, Annales Geophysicae, 26, 1207–1220, 2008*
- *Karpechko A. Yu., N. P. Gillett, G. J. Marshall, and A. A. Scaife, Stratospheric influence on circulation changes in the Southern Hemisphere troposphere in coupled climate models, Geophys. Res. Lett., 35, L20806, doi:10.1029/2008GL035354, 2008*
- *Seckmeyer, G., M. Glandorf, C.Wichers, R. L. McKenzie, D. Henriques, F.Carvalho, A.Webb, A-M. Siani, A. Bais, B. Kjeldstad, C. Brogniez, P.Werle, T. Koskela, K.Lakkala, , J.Gröbner, H.Slaper, P. denOuter, U.Feister, 2008: Europe's darker atmosphere in the UV-B. Photochem. Photobiol. Sci., 2008, 7, 925–930.*
- *Redondas A., Torres C., Meinander O., Lakkala K., García R., Cuevas E., Ochoa H., Deferrari G., Díaz S. Antarctic network of lamp-calibrated multichannel radiometers for continuous ozone and uv radiation data, Atmos. Chem. Phys. Discuss., 8, p. 3383-3404., 2008*
- *Hassinen S, Tamminen J, Tanskanen A, Koskela T, Karhu J, Lakkala K, Mälkki A, Description and Validation of the OMI Very Fast Delivery Products, J. Geophys. Res., 113, D16S35, doi:10.1029/2007JD008784, 2008*
- *Meinander O., Kontu A., Lakkala K., Heikkilä A., Ylianttila L., Toikka M., Diurnal variations in the UV albedo of Arctic snow, Atmos. Chem. Phys., 8, 6551-6563, 2008*
- *Lakkala K., Arola A., Heikkilä A., Kaurola J., Koskela T., Kyrö E., Lindfors A., Meinander O., Tanskanen A., Gröbner J., Hülsen G., Quality assurance of the Brewer UV measurements in Finland, Atmos. Chem. Phys., 8, p. 3369-3383. 2008*
- *Redondas A., Torres C., Meinander O., Lakkala K., García R., Cuevas E., Ochoa H., Deferrari G., Díaz S., Antarctic network of lamp-calibrated multichannel radiometers for continuous ozone and uv radiation data, Atmos. Chem. Phys. Discuss., 8, p. 3383-3404. 2008*
- *Johnsen B., Kjeldstad B., Aalerud T.N., Nilsen L.T., Schreder J., Blumthaler M., Bernhard G., Topaloglou C., Meinander O., Bagheri A., Slusser J.R., Davis J., Intercomparison and harmonization of UV Index measurements from multiband filter radiometers, J. Geophys. Res., 113, D15206, doi:10.1029/2007JD009731, 2008*
- *Meinander O., Kontu A., Lakkala K., Heikkilä A., Ylianttila L., Toikka M., UV albedo of arctic snow in spring Atmos. Chem. Phys. Discuss., 8, p. 4155-4198. 2008*
- *Smith, A.K., Marsh, D.R., Russell, J.M., Mlynczak, M.G., Martin-Torres, F.J., Kyrölä, E., Satellite observations of high nighttime ozone at the equatorial mesopause. J. Geophys. Res., D17, D17312, 2008*
- *Taha, G., Jaross, G., Fussen, D., Vanhellemont, F., Kyrölä, E., and McPeters, R. D., Ozone profile retrieval from GOMOS limb scattering measurements. J. Geophys. Res., 113, D23307, 2008*
- *Tukiainen, S., Hassinen, S., Seppälä, A., Auvinen, H., Kyrölä, E., Tamminen, J., Haley, C.S., Lloyd, N., and Verronen, P., Description and validation of a limb scatter retrieval method for Odin/OSIRIS. J. Geophys. Res., VOL. 113, 2008*
- *Martz F, Turunen M, Julkunen-Tiitto R, Lakkala K, Sutinen M.-L., Effect of the temperature and the exclusion of UVB radiation on the phenolics and iridoids in Menyanthes trifoliata L. leaves in the subarctic, Environmental Pollution, 157,pp.3471-3478, 10.1016/j.envpol.2009.06.022. 2009*
- *van Dijk A, den Outer P, Slaper H, Koskela T, Lakkala K, Bais A, Feister U, Janouch M, Josefsson W, Ground-level UV estimates for Europe from OMI satellite observations: a comparison with ground-based measurements, JGR-Atmospheres, 2009*
- *Lindfors A, Heikkilä A, Kaurola J, Koskela T, Lakkala K, Reconstruction of solar spectral surface UV irradiances using radiative transfer simulations, Photochemistry and Photobiology, 85, pp. 1233-1239, 2009*
- *Lindfors A, Tanskanen A, Arola A, van der A R, Bais A, Feister U, Janouch M, Josefsson W, Koskela T, Lakkala K, den Outer P.N., Smedley A.R.D., Slaper H, Webb A.R., The PROMOTE UV Record: Toward a Global Satellite-Based Climatology of Surface Ultraviolet Irradiance. Selected Topics in Applied Earth Observations and Remote Sensing, IEEE Journal of, 2,(3),pp. 207-212,10.1109/JSTARS.2009.2030876., 2009*
- *Paatero J, Vaattovaara P, Vestenius M, Meinander O, Makkonen U, Kivi R, Hyvärinen A, Asmi E, Tjernström M, Leck C, Finnish contribution to the Arctic Summer Cloud Ocean Study (ASCOS) expedition, Arctic Ocean 2008, Geophysica 45(1-2), 2009, 119-146, 2009*

- *Meinander O, Wuttke S, Seckmeyer G, Kazantzis S, Lindfors A, Kyrö E, Solar Zenith Asymmetry Cases in Polar Snow UV Albedo, Geophysica (2009), 45(1?2), 183?198, 2009*
- *Orsolini, Y. J., A. Yu. Karpechko, G. Nikulin, Variability of the northern hemisphere polar stratospheric cloud potential: the role of North Pacific disturbances, Quart. J. Roy. Meteor. Soc., 135: 1020–1029, 2009*
- *Manninen, P., T.Koskela, L.Ylianttila, P.Kärhä, and E.Ikonen, 2009: Estimation of the Optical Receiving Plane Positions of Solar Spectroradiometers with Spherical Diffusers on the Basis of Spatial Responsivity Data. Optics Letters, Vol. 34, No. 21.*
- *Lindfors, A., A.Heikkilä, J.Kaurola, T.Koskela and K.Lakkala, 2009: Reconstruction of Solar Spectral Surface UV Irradiances Using Radiative Transfer Simulations. Photochemistry and Photobiology, 2009, 85: 1233–1239*
- *N. Munakata, N., S.Kazadzis, D.Bolseé, N.Schuch, T.Koskela, A.Karpetchko, C.Casiccia, M.B. da Rosa, T.Saida, C.Nishigori, K.Ogata, K.Imafuku, C.-M.Liu, S.Lestari, M.Kanoko, S.Cornain, K.Mulyadi, and K.Hieda: 2009: Variations and trends of biologically effective doses of solar ultraviolet radiation in Asia, Europe and South America from 1999 to 2007. Photochemical & Photobiological Sciences, 2009, DOI: 10.1039/B906975E*
- *Kazantzidis, A., A.F.Bais, M.M.Zempila, S.Kazadzis, P.N. den Outer, T.Koskela and H.Slaper, 2009: Calculations of the human Vitamin D exposure from UV spectral measurements at three European stations. Photochem. Photobiol. Sci., 2009, 8, 45–51.*
- *Arola, A., Kazadzis, S., Lindfors, A., Krotkov, N., Kujanpää, J., Tamminen, J., Bais, A., di Sarra, A., Villaplana, J.M., Brogniez, C., Siani, A.m., Janouch, M., Weihs, P., Webb, A., Koskela, T., Kouremeti, N., Meloni, D., Buchard, V., Auriol, F., Ialongo, I., Staneck, M., Simic, S., Smedley, A. and Kinne, S., A new approach to correct for absorbing aerosols in OMI UV. Geophys. Res. Lett., Vol, 36, L22805, 2009*
- *Liu, C., Liu, Y., Cai, Z., Gao, S., Lu, D., Kyrölä, E., A Madden-Julian Oscillation-triggered record ozone minimum over the Tibetan Plateau in December 2003 and its association with stratospheric "low-ozone pockets". Geophys. Res. Lett., Volume 36, Issue 15, CiteID L15830, 2009*
- *Sofieva, V. F., Kan, V., Dalaudier, F., Kyrölä, E., Tamminen, J., Bertaux, J.-L., Hauchecorne, A., Fussen, D., and Vanhellemont, F., Influence of scintillation on quality of ozone monitoring by GOMOS. Atmos. Chem. Phys., 9, 9197-9207, 2009*
- *Sofieva, V.F., Kyrölä, E., Verronen, P. T., Seppälä, A., Tamminen, J., Marsh, D. R., Smith, A. K., Bertaux, J.-L., Hauchecorne, A., Dalaudier, F., Fussen, D., Vanhellemont, F., Fanton d'Andon, O., Barrot, G., Guirlet, M., Fehr, T., and Saavedra, L., Spatio-temporal observations of the tertiary ozone maximum. Atmospheric Chemistry and Physics, 9, 4439-4445, 2009*
- *Tètard, C., Fussen, D., Bingen, C., Capouillez, N., Dekemper, E., Loodts, N., Mateshvili, N., Vanhellemont, F., Kyrölä, E., Tamminen, J., Sofieva, V., Hauchecorne, A., Dalaudier, F., Bertaux, J.-L., Fanton d'Andon, O., Barrot, G., Guirlet, M., Fehr, T., and Saavedra, L, Simultaneous measurements of OClO, NO2 and O3 in the Arctic polar vortex by the GOMOS instrument. Atmospheric Chemistry and Physics, Vol 9, pp 7857-7866, 2009*
- *Kaurola, J., A. Lindfors, K. Lakkala, G. Hansen, W. Josefsson, L. Vuilleumier, U. Feister, and H. Slaper (2010), On the usability of the ERA-40 reanalysis in the estimation of past surface UV radiation over Europe, J. Geophys. Res., 115, D24107, doi:10.1029/2010JD013810.*
- *Lakkala K, High-quality polar UV measurements: Scientific analyses and transfer of the irradiance scale, PhD Thesis. Finnish Meteorological Institute Contributions 86, 156p., 2010.*
- *Lappalainen N, Huttunen S, Suokanerva H, Lakkala K, Seasonal acclimation of the moss Polytrichum juniperinum Hedw. to natural and enhanced ultraviolet radiation Environ Pollut., Volume: 158 Issue: 3 Pages: 891-900, 2010.*
- *Meinander O., Kazadzis S., Arola A., Kivi R., Kontu A., Suokanerva H., Aaltonen V., Manninen T., Roujean J-L., Hautecoeur O., Spectral albedo of arctic snow during intensive melt period, ACPD, 10, 1-24, 2010*
- *Thölix, L., Backman, L., Ojanen, S.-M., 2010: The effects of driver data on the performance of the FinROSE chemistry transport model, IJRS, 31, 24, 6401-6408.*
- *Karpechko, A. Yu., Gillett, N. P., Hassler, B., Rosenlof, K. H., and Rozanov, E.: Quantitative assessment of Southern Hemisphere ozone in chemistry-climate model simulations, Atmos. Chem. Phys., 10, 1385-1400, 2010*
- *Karpechko, A. Yu., N. P. Gillett, L. J. Gray, and M. Dall'Amico, Influence of ozone recovery and greenhouse gas increases on Southern Hemisphere circulation, J. Geophys. Res., 115, D22117, doi:10.1029/2010JD014423, 2010*
- *Dall'Amico, M, P. A. Stott, A. A. Scaife, L. J. Gray, K. H. Rosenlof, A. Yu. Karpechko, Impact of stratospheric variability on tropospheric climate change, Clim. Dyn, v.34, N2-3, pp. 399-417, doi: 10.1007/s00382-009-0580-1, 2010*

- *Bertaux, J. L., Kyrölä, E., Fussen, D., Hauchecorne, A., Dalaudier, F., Sofieva, V., Tamminen, J., Vanhellemont, F., Fanton d'Andon, O., Barrot, G., Mangin, A., Blanot, L., Lebrun, J. C., Pèrot, K., Fehr, T., Saavedra, L., Leppelmeier, G. W., and Fraisse, R, Global ozone monitoring by occultation of stars: an overview of GOMOS measurements on ENVISAT. Atmos. Chem. Phys., 10, 12091-12148, 2010*
- *Hauchecorne, A., Bertaux, J. L., Dalaudier, F., Keckhut, P., Lemennais, P., Bekki, S., Marchand, M., Lebrun, J. C., Kyrölä, E., Tamminen, J., Sofieva, V., Fussen, D., Vanhellemont, F., Fanton d'Andon, O., Barrot, G., Blanot, L., Fehr, T., and Saavedra de Miguel, L., Response of tropical stratospheric O3, NO2 and NO3 to the equatorial Quasi-Biennial Oscillation and to temperature as seen from GOMOS/ENVISAT. Atmos. Chem. Phys., 10, 8873-8879, 2010*
- *Keckhut, P., Hauchecorne, A., Blanot, L., Hocke, K., Godin-Beekmann, S., Bertaux, J.-L., Barrot, G., Kyrölä, E., van Gijsel, J. A. E., and Pazmino, A, Mid-latitude ozone monitoring with the GOMOS-ENVISAT experiment version 5: the noise issue. Atmos. Chem. Phys., 10, 11839-11849, 2010*
- *Kyrölä, E., J. Tamminen, V. Sofieva, J. L. Bertaux, A. Hauchecorne, F. Dalaudier, D. Fussen, F. Vanhellemont, O. Fanton D´Andon, G. Barrot, M. Guirlet, T. Fehr, and L. Saavedra de Miguel, GOMOS O3, NO2, and NO3 observations in 2002-2008. Atmospheric Chemistry & Physics, 10, 7723-7738, 2010*
- *Kyrölä, E., Tamminen, J., Sofieva, V., Bertaux, J. L., Hauchecorne, A., Dalaudier, F., Fussen, D., Vanhellemont, F., Fanton d'Andon, O., Barrot, G., Guirlet, M., Mangin, A., Blanot, L., Fehr, T., Saavedra de Miguel, L., and Fraisse, R, Retrieval of atmospheric parameters from GOMOS data. Atmos. Chem. Phys., 10, 11881-11903, 2010*
- *Tamminen, J., Kyrölä, E., Sofieva, V. F., Laine, M., Bertaux, J.-L., Hauchecorne, A., Dalaudier, F., Fussen, D., Vanhellemont, F., Fanton-d'Andon, O., Barrot, G., Mangin, A., Guirlet, M., Blanot, L., Fehr, T., Saavedra de Miguel, L., and Fraisse, R., GOMOS data characterisation and error estimation. Atmos. Chem. Phys., 10, 9505-9519, 2010*
- *Gillett, N. P., Akiyoshi, H., Bekki, S., Braesicke, P., Eyring, V., Garcia, R., Karpechko, A. Yu., McLinden, C. A., Morgenstern, O., Plummer, D. A., Pyle, J. A., Rozanov, E., Scinocca, J., and Shibata, K.: Attribution of observed changes in stratospheric ozone and temperature, Atmos. Chem. Phys., 11, 599-609, doi:10.5194/acp-11-599-2011, 2011*

6. PROJECTS AND COLLABORATION

The major national funding organisations are the Academy of Finland and the National Technology Agency of Finland. The ozone and UV related research 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.

- SAARA (Studies of the Changing Antarctic Atmosphere using Soundings, Remote Sensing and Modelling: A Bi-polar Approach)
- MIDAT (Middle atmosphere dynamics and chemistry in climate change)
- ASTREX (Advanced Analyses of Stratosphere- Troposphere Exchange)
- UTLS WaVa (Arctic upper troposphere lower stratosphere water vapour)
- COOL (Aerosol intervention technologies to cool the climate: costs, benefits, side effects, and governance)
- FUVIRC (Finnish Ultraviolet International Research Center, http://fmiarc.fmi.fi/fuvirc/fuvirc_hs)
- UVEMA (Effects of UV radiation on Materials, uvema.fmi.fi/)
- MACC (EU project, FMI participating in task related to UV-radiation)
- O3M-SAF (EUMETSAT's Satellite application facility on ozone and atmospheric chemistry)
- IGACO-O3/UV secretariat (WMO and GAW-ozone)
- ACSO (Absorption cross sections of ozone, IGACO-O3/UV activity)

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. 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 took part in activities organized during the International Polar Year 2007/2008.

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 fur Luft- and Raumfarhrt (DLR), Deutscher Wetterdienst (DWD), Aristotle University of Thessaloniki (LAP), Hellenic National Meteorological Service (HNMS), Danish Meteorological Institute (DMI), Meteo-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, NO_2 and UV fields. Offline products derived from GOME-2 data are total and/or tropospheric column amounts of ozone, NO_2, BrO, SO_2, HCHO, H_2O, OClO, ozone profiles, aerosol index and UV fields including cloudiness and albedo. The ozone and UV data is 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 and processing from the EOS-Aura satellite is also going on for Very Fast Delivery products of the total ozone, SO_2, aerosol index and UV irradiance products, 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 O_3 and UV-products.

FMI also hosts the WMO IGACO (Integrated Global Atmospheric Chemistry Observations) Ozone secretariat (www.igaco-o3.fi). 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. During 2009-2011 the most active task related to IGACO-O3/UV has been the evaluation of absorption cross sections within the so called ACSO activity.

7. FUTURE PLANS

Although the basic processes related to stratospheric ozone are now believed to be fairly well understood, there remain important research topics related to ozone and UV, such as the interaction between ozone depletion/recovery and climate change and the effects of UV-irradiance on nature, agriculture, and on materials. According to the present understanding the recovery of the ozone layer will take several decades, but the scenarios contain many uncertainties, among which man's behaviour is not the smallest. Therefore it is desirable that the research and monitoring activities will be continued and developed.