FINLAND
National report on the existing and planned ozone research and monitoring activities

1. GROUND BASED OBSERVATIONS

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

In Finland, ozone column monitoring has been carried out by the Finnish Meteorological Institute (FMI) at Sodankylä (67.4°N, 26.6°E) since 1988, at Jokioinen (60.5°N, 23.3°E) during 1994—2015 and at Helsinki since 2016. At the stations an automated system based on Brewer spectrophotometer is continuously operated. Since November 2012 this monitoring programme has taken place in close cooperation with the EUropean BREWer NETwork – EUBREWNET (continuation of the COST Action ES1207, which ended in 2017). 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.

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

Ozone soundings have been carried out since 1989 at Sodankylä on regular basis throughout the year, while in Jokioinen these measurements have been conducted during winter and spring when chemical ozone depletion is expected. Both sites have participated in the ozonesonde Match project, which is a coordinated effort to measure ozone loss in the Arctic vortex. Measurements of polar stratospheric cloud (PSC) properties have been carried out at Sodankylä since 1991/1992 by lidar and since 1994 by aerosol backscatter sondes. Stratospheric water vapor is measured at Sodankylä during all seasons using Cryogenically cooled Frost point Hygrometer (CFH). Sodankylä site is participating in GCOS Reference Upper-Air Network (GRUAN). The national meteorological institutes in Finland (FMI) and Argentina (SMN) jointly carry out regular ozonesonde measurements at Marambio (64.1°S, 56.4°W), Antarctica, since 1988.

1.3 UV measurements

1.3.1 Broadband measurements

FMI operates SL501 broadband instruments at seven sites in Finland (Schmalwieser et al., 2017). These instruments provide on-line information on the erythemal irradiance that is published through the internet along with the UV-Index forecast (http://en.ilmatieteenlaitos.fi/uv-index**)**. FMI measures incoming and outgoing broadband SL501 UV radiation (UV albedo) in the GAW station of Marambio since 2013.

1.3.2 Narrowband filter instruments

FMI has three narrowband NILU-UV filter instruments, from which two measures at the measurement platform of the sounding station in Sodankylä and one is located in Helsinki and used for campaigns. In 2016, FMI purchased two GUV multifilter radiometers, which are used for continuous UV measurements in the Antarctic in the research station of Marambio. They rotate so that one is always measuring in Marambio, and the second one is recalibrated or compared to reference spectroradiometer in Finland (Lakkala et al. 2019). The time series started in March 2017 and has been continuous since then. The near real time data is daily plotted on the web page http://fmiarc.fmi.fi/sub_sites/GUVant/. The GUV measurements are part of the existing Antarctic research cooperation between FMI and SMN.

1.3.3 Spectroradiometers

FMI has monitored the spectral UV irradiance with Brewer instruments in Jokioinen (Mark III during 1995-2015), Helsinki (Mark III since 2016) and Sodankylä (Mark II since 1990, Mark III since 2013). Laboratory characterizations and theoretical approaches are used to homogenize the time

series and to correct the data for known sources of error (Lakkala et al., 2008). Methods for cosine correction, temperature correction and determination of long-term changes in spectral responsivity are applied. Various quality assurance tools are used to identify erroneous measurements. The monitoring program conducted with the FMI Brewer spectroradiometers is described in Mäkelä et al. (2016). All three Brewer spectroradiometers contribute to the EUBREWNET and the European UV Data Base (EUVDB). In addition, level 1 UV index data from Sodankylä is publicly available near real-time from FMI's database (https://litdb.fmi.fi/luo0002_data.php) as well as reprocessed level 2 spectral data (litdb.fmi.fi/brewer_uv_data.php).

A Bentham DM150 spectroradiometer is maintained and used for campaigns. Furthermore, two CCD spectrometers (Flame, from Ocean Optics Inc.) with wavelength range 348–1024 nm are employed, one in Mukteshwar, India, since 2015, and another in Kumpula, Finland, since 2016.

1.4 Calibration activities

FMI is operating dark room UV calibration facilities both in Helsinki and Sodankylä (Lakkala et al. 2016). The optical calibration laboratory in Sodankylä is currently in the process of equipment upgrading. FMI has participated in several UV measurement comparison campaigns, where it has been established that the quality of Finnish Brewer measurements is high and steady. The maintenance of the irradiance scale and the procedures ensuring the traceability of the scale is described by Heikkilä et al. (2016). The Brewer instrument of Helsinki 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 and now hosted by the WMO World Calibration Center for UV radiation in Davos is invited for auditing visits to both observatories on a regular basis. Its last visit was in 2023 (Hülsen 2023). The reference broadband radiometer of FMI is regularly sent for calibration and comparison to the World Radiation Center (WRC) at the Physikalisch-Meteorologisches Observatorium Davos. FMI is also responsible for the calibration of the Antarctic/Marambio GUV-multifilter radiometer and for its data quality assurance. Brewer total ozone measurements in Helsinki and Sodankylä are calibrated by regular visits of a travelling Brewer standard instrument or by visiting the Regional Brewer Calibration Center for Europe (RBCC-E) at Tenerife/Spain.

1.5. Measurement and validation campaigns

FMI stations at Sodankylä and Jokioinen have participated in ozonesonde Match campaigns during Arctic winters since 1994, including the most recent Match campaign in winter 2019/2020.

FMI's Sodankylä spectroradiometer participated in the final UV and ozone comparison campaign of the EU COST 1207 project EUBREWNET (2013-2017), which was held in El Arenosillo, Spain, in May 2017 (Redondas et al. 2019). Since 2018 EUBREWNET is maintained and supported by AEMET. FMI has one member in both the Governance and the Management Committee and FMI's scientists participate in the development of the UV product of the network.

FMI hosted the QASUME audit / UV comparison campaign in Helsinki and at Sodankylä in June 2018 and in May/June 2023. The spectroradiometer of Tarto Univerisity participated in the 2018 campaign together with FMI's spectroradiometers and multichannel radiometers, and the reference spectroradiometer from PMOD-WRC.

FMI organized in collaboration with the University of Helsinki a virus study campaign in Sodankylä in June 2021. The aim was to study the effect of solar UV radiation on airborne transmission of viruses in outdoor air. The facilities of FMI's Arctic Space Centre were used, and experiments were conducted in the optical laboratories and measurement field of the site. UV radiation data from the Brewer spectroradiometers and GUV radiometers were used in the campaign. (https://space.fmi.fi/2021/06/07/measurement-campaign-studies-the-effect-of-solar-uv-on-airborne-transmission-of-viruses-in-outdoor-air/)

2. SATELLITE OBSERVATIONS AND DATA PRODUCTS

FMI has a strong participation in several satellite instruments that are targeted for monitoring ozone in the atmosphere (starting with GOMOS/Envisat and following with OSIRIS/Odin, OMI/EOS-Aura, GOME-2/METOP-A, -B and -C, Sentinel5p).

FMI is hosting the OMI UV surface 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 continued. 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 the Satellite Data Centre of FMI-ARC in Sodankylä, Northern Finland. These products are available in the Internet (http://sampo.fmi.fi/) within 15 min after the overpass of the satellite. Presently similar real time ozone products are developed for OMPS instrument on-board NASA/NOAA Suomi NPP satellite.

FMI is responsible for the Sentinel-5p/TROPOMI surface UV radiation product development processing and archiving. The algorithm is adapted from the corresponding OMI and AC-SAF algorithms (Lindfors et al. 2018). The processing and archiving are located in the Sodankylä National Satellite Data Centre (https://nsdc.fmi.fi). The TROPOMI algorithm serves also as a prototype for the future Copernicus Sentinel 5 surface UV radiation product.

FMI is the Leading Institute for the EUMETSAT's Satellite Application Facility on Atmospheric Composition monitoring, AC SAF (https://ac-saf.eumetsat.int), which focuses on algorithm development, data processing and validation, product dissemination and archiving of atmospheric constituents (trace gases, aerosols, radiation products) of GOME-2 and IASI instruments. The project will continue until 2027 and it's expected to have the next phase for years 2027-2032. FMI is also responsible for developing (Kujanpää and Kalakoski, 2015), validating (Lakkala et al. 2019b), distributing and archiving the UV-radiation products within this project.

FMI participates actively in the ESA Climate Change Initiative for ozone (Ozone_cci) and Copernicus Climate Change Service with responsibility of developing Level 3 data products from ozone profiles data by several satellite instruments. In the framework of the Ozone_cci project, several useful datasets of ozone profiles have been developed: they include the HARMonized dataset of OZone profiles (HARMOZ, Sofieva et al., 2013), monthly zonal mean data from several limb and occultation instruments, as well as the merged SAGE-CCI-OMPS dataset of ozone profiles (Sofieva et al., 2017b; 2023) and Merged GRIdded Dataset of Ozone Profiles (MEGRIDOP, Sofieva et al., 2021). Both merged datasets are widely used for analyses of ozone trends (WMO, 2018, 2022; Petropavlovskikh et al., 2019; Weber et al., 2018- 2012; Sofieva et al., 2017; Ball et al., 2018, Szelag et al., 2020). In the framework of ESA project SUNLIT, a tropospheric ozone column dataset has been created using combination of nadir and limb satellite instruments (Sofieva et al., 2022).

3. RESULTS FROM OBSERVATIONS AND ANALYSIS

At FMI, only Brewer UV measurements are now considered to have a sufficient quality for assessment of long-term changes (e.g., Heikkilä et al. 2017b). The spectral UV time series of Sodankylä is among the longest in the Arctic. Recent results of observed spectral UV radiation changes are analyzed in Lakkala et al., 2024., in which also the UV time-series from Marambio is analysed. FMI has developed quality control (QC) and quality assurance (QA) practices that are suitable for many kinds of UV instruments. The cosine error correction method developed at FMI was successfully implemented in the processing of the results of the final comparison campaign of EUBREWNET (Lakkala et al. 2018a).

FMI's ground based and satellite UV and ozone measurements have been used to prepare the yearly published Ozone and UV chapter of the State of the Climate in the Bull. Amer. Meteor. Soc. (e.g. Bernhard et al. 2017, 2018, 2019, 2020, 2021, 2022, 2023). The UV and ozone time series of FMI have been used to assess past and future UV levels (Eleftheratos et al. 2022, Fountoulakis et al. 2020). Columnar amounts of atmospheric SO_2 measured by the FMI spectroradiometers was used in a study detecting volcanic SO_2 plumes (Zerefos et al. 2017).

UV measurements were used for validation of satellite and modelled data (e.g., Kosmopolous et al., 2021). The validation of the TROPOMI Surface UV radiation product was conducted using ground-based data from sites located in arctic, subarctic, temperate, equatorial and Antarctic areas

(Lakkala et al., 2020), as well as the validation of the GOME-2 Surface UV radiation offline product and data record (Lakkala et al., 2019b).

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, and materials (Jääskeläinen et al. 2017, Karppinen et al. 2017). FMI's UV measurements were used in studies on the impact of meteorological factors on COVID-19 incidence (Haga et al., 2022). FMI's researchers contributed to the analysis of the UV-Indien network data (Lamy et al., 2021a, Lamy et al., 2021b). Research on the effects of UV radiation on materials has yielded new methods for the research on the effects of UV radiation on materials (Heikkilä 2014), new knowledge on the wavelength sensitivity of photo-degradation, especially photo-yellowing (Heikkilä & Kärhä 2014, Heikkilä et al. 2015) and novel instrumentation for the research thereon (Vaskuri et al. 2015, 2017).

FMI has performed and participated actively in studies of ozone trends in the stratosphere (WMO, 2018, 2022; Godin-Beekman et al, 2022; Petropavlovskikh et al., 2019; Weber et al., 2018-2023; Sofieva et al., 2017; Ball et al., 2018, Shams et al., 2019, Szelag et al., 2020).

FMI researcher strongly contributed to the WMO's Scientific Assessment of Ozone Depletion 2018 and 2022 as co-authors and contributing authors.

FMI researchers also study the influence of energetic particle precipitation on mesospheric and stratospheric ozone (e.g., Andersson et al., 2018; Kalakoski et al., 2020, 2023; Jia et al., 2020; Nielsen et al., 2021; Szeląg et al., 2022).

The UV measurements of the NILU-UV Antarctic network were quality controlled and analysed (Lakkala et al. 2018). The quality assurance procedures of the new GUV radiometer measurements was described by Lakkala et al. (2020), and the data of the first two years was analysed by Aun et al. (2020). The Marambio UV data from the FMI were used in the Antarctic chapter of the BAMS State of the Climate report to demonstrate the effects of the long-lived ozone depletion period in the year 2020 (Kramarova et al., 2021). The year 2020 was also a record-breaking year for Arctic ozone depletion, also observed by FMI (Bernhard et al., 2020).

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), one climate model covering the middle atmosphere (CESM/WACCM), a model of the ionosphere (Sodankylä Ion and neutral Chemistry model) and the chemistry-transport model SILAM covering both the troposphere and the stratosphere. A model study using the FinROSE-CTM was made to evaluate the stratospheric water vapour distribution and variability in the Arctic (Thölix et al., 2018). A dissertation on Modelling of Arctic stratospheric ozone and water vapour and their changes was successfully defended (Thölix, 2018).

FMI performs operational forecasts of global, European and regional air quality for more than 10 years, including the chemical composition of the stratosphere and the ozone layer status. The 5-days forecasts are publicly available. The SILAM simulations are used for both ozone monitoring (e.g., unusually small ozone hole over Antarctica in 2019, https://en.ilmatieteenlaitos.fi/news/1140594517, Arctic ozone hole in 2020 https://en.ilmatieteenlaitos.fi/press-release/1276664372), as well as for studies of mechanisms of ozone transport and chemical changes (e.g., Sofiev et al., 2020).

FMI measures UV albedo in the research projects A4 and NABCEA. The UV albedo of snow is high, for clean snow over 90 %. A high albedo increases the risk of the painful condition of snow-blindness and sunburn and causes an enhancement in the UV irradiance (UV-index) and in the air chemistry photolysis reaction rates, in comparison to snow-free surfaces. In addition, snow albedo can potentially be used to detect UV-absorbing impurities in snow, including climatically significant soot (Black Carbon) particles (Meinander 2016).

A new method for estimating UV fluxes at ground level in cloud-free conditions was developed by Wandji Nyamsi et al. (2017). FMI participated in the development of correction methods for stray light and temperature dependence of Brewer UV measurements (Pulli et al. 2018; Pulli et al. 2018).

FMI contributes to the project Climate Change and Health: Adapting to Mental, Physical and Societal Challenges (CHAMPS) supported by the Climate Change and Health program of the Research Council of Finland. The role of the FMI is to assess the mental health risks associated with UV radiation.

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 contributes to the global Network of Detection of Atmospheric Composition Change (NDACC). The total ozone values are reported to the WOUDC.

FMI maintains the European UV Database (EUVDB) with a coherent QA system (Heikkilä et al. 2016). EUVDB is a database containing currently over 3.9 million UV spectra (uvdb.fmi.fi/uvdb/) from 49 measurement sites. For five stations, the stored data sets cover over 20 years of measurements. (uvdb.fmi.fi/uvdb/). The UV spectra of two Finnish Brewer instruments are submitted to EUVDB. The UV time series of FMI are used to yearly update the Ozone and UV chapter of the BAMS State of the Climate https://www.ncdc.noaa.gov/bams.

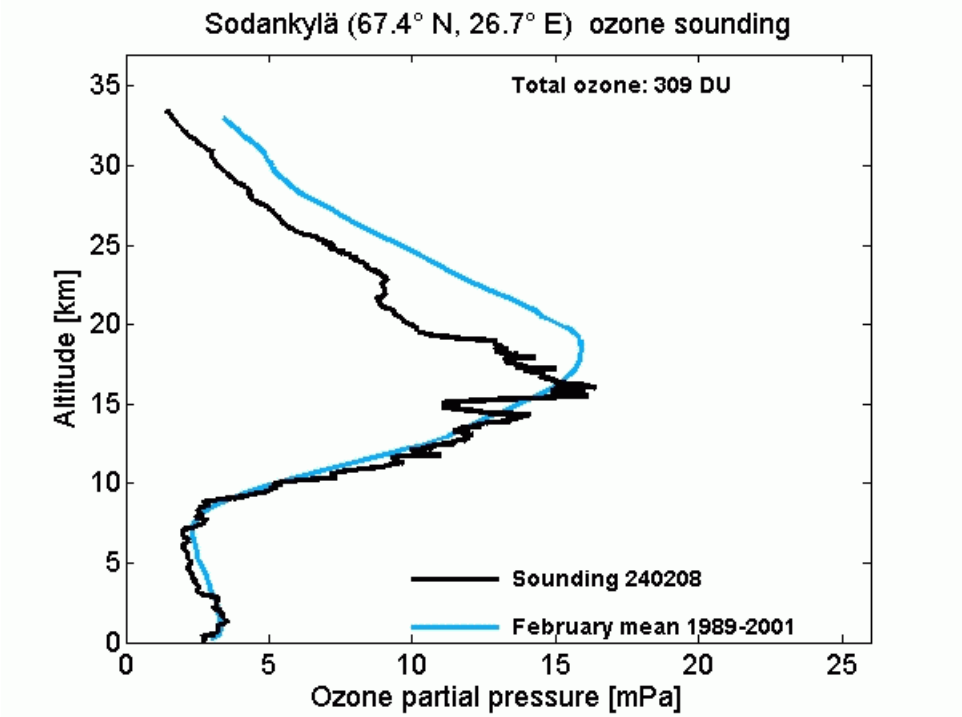

Figure 1. Ozone sounding at Sodankylä in February 2024. The ozone soundings have been made on regular basis in an effort to study Arctic stratospheric and tropospheric ozone changes. Results of the ozone soundings have been made publicly available through the FMI web site.

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/). The ozone

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 3-day global forecast of the UV Index (http://en.ilmatieteenlaitos.fi/uv-index). The forecast, which is published on 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 near-real-time on the web page. Several newspapers, radio channels and TV publish the forecasted or measured values during April to August. Warnings of high UV index are included in the general warning maps, and the global forecasted UV index is made available through a mobile phone application. FMI has actively participated in increasing the awareness of general public on the health effects of UV radiation, e.g. each year an UV info day is organized for the journalists as collaboration between FMI and other Finnish research institutes. Ozone depletion has a large public interest due to related health (UV) and environmental issues. Popularized information is distributed through press releases, interviews and social media (e.g. @IlmaTiede). Information about research activities, remote sensing projects as well as measurements and analysis results are available through FMI web pages, http://en.ilmatieteenlaitos.fi. FMI-ARC observations and analyses are available at http://fmiarc.fmi.fi.

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6. PROJECTS AND COLLABORATION

The major national funding organisations are the Research Council of Finland and Business Finland, the Finnish Funding Agency for Innovation. Both of them have partially funded the ozone research in Finland in addition to FMI. FMI collaborates with Finnish universities and Research Institutes on atmospheric modelling and developing data retrieval methods, assimilation techniques for the satellite instruments and UV effect research. FMI has worked to enhance multidisciplinary UV research in Finland by organizing national seminars on UV effects. FMI representative (Anu Heikkilä) has been nominated as a member in the UV-SAG (Scientific Advisory Group for Solar UV Radiation) of WMO (World Meteorological Organization). FMI representative (Kaisa Lakkala) has participated in the WMO GAW Rolling Review of Requirements process and the preparation of the Statement of Guidance for UV radiation (Expert Team on Atmospheric Composition Network Design and

Evolution), and contributed to the WMO GAW Expert Team on Atmospheric Composition Data Management as representative of the EUBREWNET. FMI representative (Anu Heikkilä) has been also invited as a full panel member in the UNEP-EEAP (United Nations Environmental Program – Environmental Effects Assessment Panel). FMI was chairing the Nordic Ozone and UV WG of the NORDMET in 2015-2022. FMI participates actively in European Space Agency Climate Change Initiative for ozone project

A list of projects related to UV and ozone research during 2017-2023:

- Match: an international project, coordinated by AWI, to measure stratospheric ozone loss
- GRUAN (GCOS Reference Upper-Air Network)
- EMRP project ATMOZ - Traceability for atmospheric total column ozone
- ICASIF (Influence of Clouds and atmospheric Aerosols on Solar energy in India and Finland) – principal financier: Academy of Finland
- UVEMA (Effects of UV radiation on Materials, uvema.fmi.fi/)
- CAMS (EU project, FMI participating in task related to UV-radiation. Evaluation and Quality Assurance reports can be found at https://atmosphere.copernicus.eu/supplementary-services, link valid on 2020-02-26)
- NABCEA - Novel Assessment of Black Carbon in the Eurasian Arctic: From Historical Concentrations and Sources to Future Climate Impacts, 2016-2020
- AC-SAF (EUMETSAT's Satellite application facility on ozone and atmospheric chemistry): (https://acsaf.org/)
- IGACO-O3/UV secretariat (WMO and GAW-ozone): IGACO (International Global Atmospheric Chemistry Observations) is a strategy which aims for bringing together ground-based, aircraft and satellite observations of 13 chemical species in the atmosphere. The implementation of IGACO-O3/UV has been organized through the Global Atmospheric Watch (GAW) programme of WMO. Everyday work during 2005 - 2015 has been coordinated by WMO jointly with a secretariat hosted by FMI with a Memorandum of Understanding with the WMO. The implementation plan of IGACO-O3/UV was published in 2008 (http://www.igaco-o3.fi/linked/en/IGACO-O3_UV_Implementation_Plan.pdf). During the last years IGACO-O3/UV has concentrated on two activities: ACSO (Absorption Cross Sections of Ozone, http://igaco-o3.fmi.fi/ACSO) and SI2N (SPARC-IO3C-IGACO-O3-NDACC initiative on Past Changes on Vertical Distribution of Ozone, http://igaco-o3.fmi.fi/VDO/).
- ACSO (Absorption cross sections of ozone, IGACO-O3/UV activity): Review the presently available ozone absorption cross sections. Determine the impact of changing the reference ozone absorption cross sections for all of the commonly used (both ground-based and satellite) atmospheric ozone monitoring instruments. Recommend whether a change needs to bemade to the presently used WMO/IO_3C standard ozone absorption cross section data
- AURORA (Advanced Ultraviolet Radiation and Ozone Retrieval for Applications) – is a space research project funded by the European Commission's H2020 programme in the field of Earth Observation, from 02/2016 to 07/2019. AURORA's overall objective was to use the different tools of the Sentinel-4 and Sentinel-5 missions of the Copernicus programme to monitor the profile of ozone in the atmosphere with unprecedented accuracy.
- ESA Climate Change Initiative project (Ozone_cci, http://www.esa-ozone-cci.org) aimed at the creation of homogenized and merged ozone profile datasets based on limb or occultation measurements from ESA and ESA Third Party Mission instruments. FMI is responsible for creating Level 3 datasets.
- Copernicus Climate Change Service (C3S) for ozone. FMI is responsible for Level 3 datasets from limb instruments, including long-term merged satellite climate data records.
- Synergy of Using Nadir and Limb Instruments for Tropospheric Ozone monitoring (SUNLIT), ESA, 2018-2020
- CHAMPS (Climate change and Health: Adapting to Mental, Physical and Societal challenges), project funded by the Finnish Academy Climate Change and Health (CLIHE) -program (2020-2024).
- HAPS (Identification of High Altitude Pseudo Satellites in Support of Satellite Air Quality Activities). ESA (2019-2021), FMI is responsible for atmospheric composition modelling and assimilation of HAPS data.

- Ozone Recovery from Merged Observational Data and Model Analysis (OREGANO), ESA 2022-current

7. FUTURE PLANS

FMI aims to maintain its ongoing measurement programs and research activities in the Arctic and the Antarctic through nationally and internationally funded projects. The new GUV measurements in Marambio will continue the long-term UV time series. The continuation of the time series deals with two important topics: 1) long term stratospheric changes and 2) the atmospheric radiation budget in Polar Regions, specifically UV radiation. The work is in part dealing with the collection of key environmental datasets at Antarctica (ozone profiles, UV radiation), but emphasis is also put on the data analysis and utilization of data in modelling studies. The long-term observational data sets of ozone and UV are important for monitoring purposes supporting the Montreal Protocol. Our research also fits the scientific topics given by the international Scientific Committee on Antarctic Research (SCAR) on Antarctica and Climate. The future work on Snow UV albedo can offer a new potentially significant application of UV radiation measurements to reveal UV-absorbing impurities in snow, including the climatically significant soot (Black Carbon, BC) particles.

8. NEEDS AND RECOMMENDATIONS

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 ozone trends in the lower stratosphere and in polar regions, the interaction between ozone depletion/recovery and climate change and the effects of UV-irradiance on nature, human health, agriculture, and on materials. Also, future ozone recovery scenarios contain many uncertainties. Therefore, it is important to ensure the continuity of long-term observational data sets of ozone and UV.