# NOG2025

## Abstracts of Oral and Poster presentations

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# Updates on Norwegian total ozone monitoring

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The Norwegian monitoring programme on total ozone and UV was established in 1990, financed by the Norwegian Environment Agency. Three sites are included in the programme: Kjeller (60°N), Andøya (69°N) and Ny-Ålesund (79°N). In addition, NILU is responsible for total ozone and UV measurements at the Trollhaugen station in Antarctica (72°S). Annual reports are published every summer, summarising the results of the monitoring activities from previous year.

The Norwegian stations are equipped with a Brewer, SAOZ, GUV, NILU-UV, and/or a Pandora instrument, all suitable for total ozone measurements. A short overview of the instruments and results will be presented. In April 2024 a new GUVis-3511 radiometer from Biospherical Instruments was installed at Kjeller. This instrument will replace the old GUV-511, which has been running uninterrupted since 1993 and performed more than 15 million ozone and UV measurements. The new GUVis has been in operation for almost one year, and preliminary results from the measurements will be presented. Software for the GUVis, including lookup tables for ozone and cloud transmittance, is constructed from a radiative transfer model. The methodology will be briefly described.

**Ozone- and UV-measurements in Denmark and Greenland**

**H. Jønch-Sørensen, N. Jepsen**

DMI has been monitoring the ozone layer and UV radiation from measuring stations in Greenland and Denmark since 1992. The observed average ozone layer thickness over Copenhagen show a mild increase since around 1995, most prominent in the spring season. For the locations in Greenland we find no significant change in ozone layer since 1992.
At the Copenhagen location we have since 2005 a dedicated UV-index instrument (YES) and together with the UV-index derived from Brewer instruments we have reliable data on the accumulated CIE UV dose since 2000. The yearly total accumulated dose shows an increase of approximately 17% from 2000 to 2024, an increase that is mainly driven by the month of June, where the increase in UV dose is 29%. For the same period the ozone layer in June shows no trend at all, and the answer to the increase UV radiation may probably be found in a change in cloud cover over the years. However, the effect is not seen in the measured sunshine duration data for Copenhagen. Looking at the ECMWF cloud cover forecast data used for the UV-index processor since 2016 indicates that the amount of low altitude clouds have decreased during the period a result also reported from other locations. We thus assume that the increase of UV dose is caused by changing cloud cover, both total and type of clouds.

## Ground-based total ozone, UV and total solar radiation measurements in Sweden

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Monitoring of total ozone with Brewer spectrophotometers is made at two stations in Sweden. Measurements are running in Norrköping since 1988 and in Vindeln since 1991. In Vindeln also the Dobson spectrophotometer No. 30 is operated. Currently, monitoring of CIE erythema-weighted UV radiation is only performed at SMHI in Norrköping where the measurements started in 1983. The Swedish Meteorological and Hydrological Institute (SMHI) also operates a network for total solar irradiance including three stations with direct, diffuse and global radiation as well as AOD measurements, and 14 simpler stations with only measurements of global radiation and sunshine duration. From the solar radiation network homogenous data series exist for the over 42-year long period 1983-2024 from 11 stations.

Not least in the Nordic countries there is a large year to year variation in the weather. But there is also changes over multidecadal periods. On average the increase in global radiation since 1983 is 12 % in the Swedish radiation network. The relative trends are stronger in southern Sweden than in the north. For the station in Norrköping the increase is 13 %. While the correlation between global radiation and UV radiation is high most time of the year the annual erythema-weighted UV radiation has increased 6.6 % over the same period in Norrköping, i.e. only about half as much as for the global radiation. There is no significant trend in the total ozone over whole measurement period at the Swedish stations. From around year 2000, when ODS concentrations peaked over high northern latitudes, there are weak positive linear trends but they are not (yet) significant. Most probably, the increase in global and UV radiation is caused by a combination of decreasing atmospheric turbidity and decreasing cloudiness/cloud optical thickness. The attenuation UV radiation by clouds are smaller than for the global radiation and a decrease in cloudiness therefore gives a smaller trend for UV than for global radiation. Another factor that could have an influence is the higher measurement uncertainty in the UV measurements, not least in the first 1-2 decades of monitoring.

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# Polar mesospheric ozone loss initiates downward coupling of solar signal in the Northern Hemisphere

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## Abstract

Solar driven energetic particle precipitation (EPP) is an important factor in polar atmospheric ozone balance and has been linked to ground-level regional climate variability. However, the linking mechanism has remained ambiguous. The observed and simulated ground-level changes start well before the processes from the main candidate, the so-called EPP-indirect effect, would start. Here we show that initial reduction of polar mesospheric ozone and the resulting change in atmospheric heating rapidly couples to dynamics, transferring the signal downwards, shifting the tropospheric jet polewards. This pathway is not constrained to the polar vortex. Rather, a subtropical route initiated by a changing wind shear plays a key role. Our results show that the signal propagates downwards in timescales consistent with observed tropospheric level climatic changes linked to EPP. This pathway, from mesospheric ozone to regional climate, is independent of the EPP-indirect effect, and solves the long-standing mechanism problem for EPP effects on climate.

# UV, Ozone and SCR (Secondary Cosmic Rays) parallel measurements in the Euramet BIOSPHERE Project.

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The European Partnership on Metrology (EPM) joint research project BIOSPHERE investigates how the increasing ionization of the atmosphere, caused by extraterrestrial radiation fields (cosmic rays and solar UV radiation) and amplified by anthropogenic emissions, affects the human and ecological health of our planet. One main aspect is how these extraterrestrial radiation fields impact the stratospheric ozone (enforced depletion), resulting in an increase of Ultraviolet (UV) radiation on the ground.

To assess the influence of extraterrestrial radiation fields on atmospheric parameters and on solar UV radiation on the Earth surface, BIOSPHERE organizes four measurement campaigns with collocated SCR (Secondary Cosmic Rays) measurements (revealing the cosmic rays events) and solar UV radiation measurements, in GHI (global horizontal irradiance) and DNI (direct-sun normalized irradiance) geometries of observation. From the DNI UV radiation measurements we extract some atmospheric parameters: the total ozone column (TOC) in Dobson Units (DU) and the aerosol optical depth (AOD) for the UV wavelength range (290 nm - 400 nm).

The measurement campaigns took place at Athens (near urban site) in summer, in Brussels (urban site) in winter, in Milešovka (Czech Republic, rural mountain site) in summer/fall and in Lindenberg (Tauche, North-East Germany, rural flatland site) in winter/spring.

In addition to the correlation study confronting SCR measurements to TOC, AOD and UV measurements, we focus here on the quality of the UV radiation and atmospheric parameters' measurements during the first campaigns: UV radiation (GHI) and especially the UV index from spectroradiometers (array spectrometers: Gigahertz-Optik BTS2048-UV-S-WP, Bentham DTMc300 double monochromators) are compared to measurements from UVB pyranometers and a multi-channel filters radiometer (GUV-511 from BIOSPHERICAL Inc.) on the same site. TOC and AOD measurements done with UV DNI spectral measurements with an array spectrometer (Gigahertz-Optik BTS-Solar based on BTS2048-UV-S-WP) are compared to Brewer and photometer measurements done on geographically close sites. This survey analyses the measurement differences, considering the instrumentation itself and the measurement retrieval procedures.

To the end, we will take time to discuss the learnings of BIOSPHERE 1 regarding the relevance of the place of the campaigns to enhance the possibility to observe solar eruption effects on TOC and UV index measurements. Outlook regarding the design of potential BIOSPHERE 2 project and campaigns at high latitudes will be discussed.

# Ozone trends in the stratosphere derived using merged Ozone_CCI datasets

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This presentation is dedicated to evaluation of global and regional trends in ozone profiles using the updated merged datasets developed in the framework of ESA Climate Change Initiative for ozone project.

For trend analyses, two long-term merged datasets of ozone profiles have been created. One is the SAGE-CCI-OMPS+ climate data record of monthly zonal mean ozone profiles. This dataset covers the stratosphere and combines measurements by nine limb and occultation satellite instruments – SAGE II, OSIRIS, MIPAS, SCIAMACHY, GOMOS, ACE-FTS, OMPS-LP, POAM III, and SAGE III/ISS, from 1984 to present. Another dataset is the MErged GRIdded Dataset of Ozone Profiles (MEGRIDOP) with a resolved longitudinal structure, which covers the period from late 2001 to the present. MEGRIDOP is derived from data by OSIRIS, MIPAS, SCIAMACHY, GOMOS, MLS, and OMPS-LP; it contains monthly mean ozone profiles in the altitude range from 10 to 50 km in bins of 10° latitude x 20° longitude. SAGE-CCI-OMPS+ and MEGRIDOP have been actively used in various assessments of ozone trends, including their regional and seasonal dependence.

In the presentation, we will show the obtained results of analyses of stratospheric ozone variability, including updated analyses of stratospheric ozone trends.

**TOTAL OZONE COLUMN OBSERVATIONS IN REYKJAVÍK, ICELAND, 2021–2024**

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In August 2021, the B199 MkIII double monochromator Brewer spectrophotometer has been installed in Reykjavík, Iceland, as a cooperation of the Czech Hydrometeorological institute and the Icelandic Meteorological Office. Since the B199 total ozone measurements are available from approximately mid-February to the end of October, on average there are 10 readings per day. Moreover, alongside the B199 Brewer spectrophotometer, ozone measurements from Reykjavík, Iceland, are also obtained by the collocated D050 Dobson spectrophotometer operated by the Icelandic Meteorological Office. The instrument is operational since 1957. In the analyzed period 2021–2024, it provided one total ozone column reading per day on 97 % of days, including winter. The total ozone measurements from the B199 and D050 spectrophotometers were compared, showing that the general fit of the data is very good. On average, the D050 ozone observations underestimate those of B199 by approximately 0.4 %, with a slightly better fit in the summer months. The D050 total ozone measurements have been corrected for effective temperature, which resulted in a slight improvement of the fit with the B199 data, illustrated by the reduction of the mean bias from -1.4 to -1.1 DU and the decrease of RMSE from 3.65 to 3.50 %. The effect of ozone observation methods has been studied as well, the best agreement of the data was found when both instruments were set to the direct sun mode, but the D050 total ozone readings were lower than the B199 measurements on average by 5.5 DU (1.8 %). Other combinations of observation methods resulted in a higher variability of differences between the B199 and D050 total ozone data, leading to a higher RMSE and a lower coefficient of determination. According to these TOC observations, in the years 2021–2024, total ozone column showed a yearly variation typical for the Northern hemisphere subpolar regions, with the maxima in early spring (on average 416 DU in March) and minima in fall (on average 302 DU in October). No signs of spring ozone depletion have been observed. In 2024, the ozone amounts measured were highest in the study period, with the mean amount of 384 DU, TOC in 2022 and 2023 was on average 35–40 DU lower than in 2024.

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**Ozonesonde Observations at Sodankylä, Finland**

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At Sodankylä more than 58000 balloon borne soundings have been performed since 1949. The radiosonde time series is one of the longest in the European Arctic. Various radiosonde programs at the FMI have included special sensors, such as ozone sensors, aerosol sondes, chilled mirror hygrometers, Geiger counters. In late 1980s ozonesonde measurements were established in Sodankylä, soon after the discovery of the ozone hole over Antarctica. Significant ozone reductions have been observed in the Arctic stratospheric vortex during several years, while largest ozone depletions have been recorded in 2011 and in 2020. Here we first present long-term ozonesonde observations at Sodankylä and comparisons with other sites. Secondly, we present an overview of other related measurements at the Arctic Space Centre in Sodankylä.

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# Assessment of the extremely low total ozone column in the Arctic region during February 2023

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Abstract:

Since the 1990s, the ozone layer has been gradually recovering in the polar regions. However, due to the high interannual variability of Arctic stratospheric circulation, conditions may arise, especially at the end of winter and the beginning of spring, when stratospheric temperatures drop. This leads to the formation of polar stratospheric clouds, which in turn cause chemical depletion of ozone. The aim of this contribution is to assess the impact of atmospheric conditions, using ground-, satellite-based measurements, and reanalyzed data. These conditions led to an extremely low total ozone column (TOC) in February 2023 at the Andøya, Kjeller, and Hradec Králové stations. It was found that between February 10 and 16, 2023, the TOC dropped below two sigma at all three stations compared to the climatological mean since 2000. Measurements from the MLS (Microwave Limb Sounder) confirmed the presence of ClO, especially at the Andøya and Kjeller stations at a pressure level around 30 hPa. At this level, a strong negative correlation ($r_{sp}$=-0.66 for Andøya and -0.61 for Kjeller) was found between ozone and ClO anomalies with respect to the decadal climatological mean. At the Hradec Králové station, the correlation was weaker ($r_{sp}$=-0.38), suggesting a weaker link to stratospheric chemistry. On the contrary, a strong positive correlation ($r_{sp}$=~0.6) was found at this station between ozone at levels 68, 46 and 31 hPa and the tropopause height pressure. The presented results have enhanced our understanding of the relationships between stratospheric chemistry and ozone depletion at European stations. These findings can serve as a basis for further studies focusing on extreme ozone anomalies at the end of winter.

# Time series analysis of uv and total ozone measurements at Princess Elisabeth station, East Antarctica

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Abstract:

The Royal Meteorological Institute of Belgium performs total ozone column and spectral UV measurements with the Brewer spectrophotometer #100 (double monochromator) since 2011 in East Antarctica (Belgian research station Princess Elisabeth, PEA; 71.95°S, 23.35°E, 1380m a.s.l.). The measurements of Brewer#100 in Antarctica do only cover the periods of austral summer (November – February). The other months, PEA station is not inhabited and Brewer#100 not operational. The measured uv radiation, in particular in November and December, is strongly influenced by the variation of the strength of the ozone hole which influences the total ozone column amount (TOC) measured at PEA. For example, in December 2020, when the Antarctic ozone hole was lasting very long, daily maximum uv index values (UVImax) between 13 and 14 were measured. In this contribution we analyse both the UVImax and daily erythemal dose time series measured at PEA. Likewise, Brewer time series of TOC are analysed. Further, we will present first results for a comparison of Brewer TOC with TOC data derived from satellite instruments (Global Ozone Monitoring Experiment, GOME-2, onboard of the MetOp satellite and Tropospheric Monitoring Instrument, TROPOMI, onboard of the S5P satellite).

**Title: Evaluating the BTS-Solar Spectrometer for Total Ozone Column Measurements in an Arctic Environment**

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Kaisa Lakkala, Rigel Kivi, Tomi Karppinen (Finnish Meteorological Institute)

Ralf Zuber (Gigahertz Optik GmbH)

Luca Egli (World Radiation Centre, Physical Meteorological Observatory in Davos)

Xiaoyi Zhao (Environment and Climate Change Canada)

Abstract:

With the production issues of the Brewer spectrometer, the need for alternative ground-based instruments to ensure the continuity of total ozone column (TOC) measurements has become increasingly urgent. The BTS-Solar CCD spectrometer has shown promise as a potential successor, with several studies assessing its data quality and operation performance under various conditions. However, one critical aspect that remains to be fully evaluated is its reliability in extreme environments, particularly in Arctic regions.

To address this, a collaborative project has been initiated to deploy a BTS-Solar spectrometer at the Sodankylä Arctic Research Center in Finland. The site, known for its well-established atmospheric monitoring infrastructure and accessibility, provides an ideal setting to test the instrument's performance under low temperatures, seasonal variations in solar radiation, and other environmental stressors unique to high latitudes. The project aims to assess the long-term stability, calibration requirements, and overall feasibility of the BTS-Solar for TOC monitoring in Arctic conditions.

This presentation will outline the objectives and methodology of the study, including the setup of the BTS-Solar in Sodankylä, data acquisition and transfer protocols, and planned comparisons with co-located instruments such as the Dobson and Brewer spectrophotometers, partly in Davos and in Huelva. Additionally, we will discuss the expected challenges, potential calibration strategies, and the broader implications for future TOC monitoring networks.

By evaluating the BTS-Solar in an Arctic setting, this project will provide crucial insights into its suitability as a next-generation instrument for global TOC observations, particularly in remote and extreme environments.

# First analysis of the WMO-BTS for Sodankylä in comparison with improvements of the DAVOS-BTS at PMOD/WRC in Davos

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Over the past seven years, PMOD/WRC has operated and tested the BTS2048-UV-S-F array spectroradiometer manufactured by Gigahertz Optik GmbH for the application of total column measurement (TCO). PMOD/WRC developed a TCO retrieval software (KoherentTOC) using spectral measurements in the ultraviolet range and a custom double ratio technique. In 2024 four commercially available BTS-Solar, which are based on the BTS2048-UV array spectroradiometer, participated on the regional Brewer and Dobson intercomparison in Davos, Switzerland. The intercomparison of the instruments and TCO from the KoherentTOC algorithm revealed an ozone slant column dependency at high airmasses due to impact of stray light and noise, mostly due to the usage of the standard measurement procedure of the device.

A WMO task force has decided to operate a BTS-Solar (WMO-BTS) at harsh environment and high latitude location at Sodankylä, Finland. At high latitudes, low solar zenith angles with corresponding high airmasses occur in particular during spring and autumn. Currently, double monochromator Brewer instruments are used to measure TCO at these high latitudes due to good stray light suppression and insignificant ozone slant path column dependency.

This study presents first new approaches, tests and validations addressing the challenges in terms of stray light and noise reduction and detectability of the BTS Solar instrument, in particular for upcoming operation of the WMO-BTS. From a technical perspective, the noise reduction of the measured spectra is improved by an optimized measurement procedure for the specific measurement task. This improvement allows developing new stray light reduction method on the spectral level which is purely based on the technical possibilities of the BTS as it is. The improvements are developed and tested with the BTS-Solar for PMOD/WRC and applied to the WMO-BTS. The spectra of the WMO-BTS are compared with the spectra of the world reference for UV radiation (QASUME) and the resulting TCO from the KoherenTOC retrieval software are validated with a Brewer double monochromator at PMOD/WRC.

# Brewer Stray light corrections

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Single monochromator Brewers (MKII and MKIV models) are influenced by out-of-band stray light, a phenomenon that can lead to a systematic underestimation in ozone concentration calculations. This stray light arises from a combination of factors, including scattering by the different optical elements, scattering by dust particles and diffraction on the apertures.

Different methods have been proposed to correct the stray light effect in Brewer spectrophotometers. Among them, two methods are used to correct stray light in most of the single monochromator Brewers participating in Eubrewnet, an empirical method (Redondas et al., 2018) that uses the comparison with a double monochromator Brewer, and a method based on a model (Savastiouk et al., 2023).

The empirical method characterises the scattered light effect by means of a power law of the ozone slant column (OSC), and calculate the ozone using an iterative process

$$X_{i+1} = X_i + \frac{k(X_i \mu)^s}{\alpha \mu}$$

Where $X_i$ is the ozone in each iteration, $\mu$ is the air mass, $\alpha$ is the absorption coefficient of the Brewer, and k and s are two parameters retrieved from the reference comparison.

The second approach utilizes the PHYCS model (physics of the instrument response to stray light), which assumes that the stray light contribution is only minimally dependent on wavelength and is directly proportional to the intensity measured at 320 nm ($I_5$). This proportionality is defined by two stray light coefficients: α for slits 2–5 and β for slit 1.

$$I_{ic} = I_i - \alpha I_5 \; with \; i = 2-5$$

$$I_{1c} = I_1 - \beta I_5$$

At Eubrewnet, the empirical method has been applied since its beginning in 2016, and currently the PHYCS model-based method is also being implemented, as well as an estimate of the ozone uncertainty calculated

using this new approach. This work presents some preliminary results of the comparison between the two methods, as well as their uncertainty.

Redondas, A., Carreño, V., León-Luis, S. F., Hernández-Cruz, B., López-Solano, J., Rodriguez-Franco, J. J., Vilaplana, J. M., Gröbner, J., Rimmer, J., Bais, A. F., Savastiouk, V., Moreta, J. R., Boulkelia, L., Jepsen, N., Wilson, K. M., Shirotov, V., and Karppinen, T.: EUBREWNET RBCC-E Huelva 2015 Ozone Brewer Intercomparison, Atmos. Chem. Phys., 18, 9441–9455, https://doi.org/10.5194/acp-18-9441-2018, 2018.

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# Uncertainty implementation on total ozone EuBrewNet products

**Francisco C. Parra-Rojas**[1,2], Alberto Redondas[2,3], Alberto Berjón[1,2], Javier López-Solano[4], Virgilio Carreño[2,3]

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Brewer spectrophotometers are among the most widely used instruments for measuring the Total Ozone Column (TOC) worldwide. To date, the uncertainty in these measurements has not been quantitatively obtained, with an estimated value of approximately 1%. An algorithm for obtaining the uncertainty in ozone measurements through Brewer spectrophotometers has been developed. That algorithm has been tested with the observations at the IZO16 campaign, where the observations, characterizations, and instrument calibrations were performed during the campaign. The uncertainty using the observation campaign is 2.5% for the reference instrument (calibrated through the Langley method) and almost 2.8% for the network instrument (calibrated with the 1-Point transfer technique) with the standard algorithm at noon. The relative weights of the instrumental parameters have also been determined. Note that the sensitivity analysis has been performed without taking into account the cross correlations between the variables. The ozone absorption coefficient covers approximately 85% of the total ozone uncertainty, mostly due to the uncertainty of the ozone effective cross section.

On the other hand, an updated algorithm (V2) has been processed and implemented in EuBrewNet, considering the station altitude, the climatology of the ozone layer, and a new ozone cross section [1, 2]. The new algorithm produces an offset to the standard algorithm of 6 DU on average. The main contribution is due to the change of the cross section with about 3 DU, followed by the Rayleigh coefficients with 2.5 DU, and the remaining 0.5 DU is due to the effective height in the air mass calculation and the effect of the effective temperature. The V2 uncertainties due to the atmospheric variability being included in EuBrewNet have also been calculated.

Finally, the Brewer uncertainty of the Direct Sun measurements in the Total Ozone Column retrieval has been implemented in EuBrewNet's server. New parameters have to be added to the calibration report. Within the configuration parameters, default values have been calculated based on the RBCC-E calibration campaigns and included in the uncertainty algorithm. Atmospheric parameterization (ozone climatology profiles) has also been introduced in EuBrewNet for the updated V2 algorithm. The complex process is split into 12 subprocesses monitored by the processing flag, which are also related to the components of the uncertainty. These components are associated with random or systematic uncertainties to calculate these parameters. EuBrewNet also provides the data for seven stations proposed by ESA in GEOMS and in EuBrewNet format. We have currently implemented a Processing Flag showing the processing level of the product and the configuration values used in the calculation (default or "true" values), and a Quality Data Flag to contribute to a better understanding of the Brewer configurations and processing.

To date, EuBrewNet is able to produce correlated and non-correlated uncertainty results.

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# Towards LED based UV sources for calibrations of solar UV equipment

**Abstract for NOG2025**

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Ozone measurements and detection of trends in solar ultraviolet (UV) radiation require accurate calibrations that are repeatable over various decades. Calibration of spectroradiometric measurement instruments has traditionally been realised using incandescent lamps as transfer standards. However, their availability is diminishing due to a production phaseout of incandescent lighting products. Therefore, novel approaches for calibration are needed in the near future to replace incandescent lamps.

The European Partnership in Metrology (EPM) program of the European Union is financing project Newstand - "New calibration standards and methods for radiometry and photometry after phaseout of incandescent lamps." With improved technology of today, LEDs are already available with relatively high intensity levels down to the wavelengths of 250 nm, which is more than enough for solar UV measurements. They do have a problem though that the spectrum of an LED is very narrow band. This can be overcome by combining LEDs at different wavelengths or by broadening the spectrum with phosphors absorbing at the peak wavelength of the LED and emitting at slightly higher wavelengths in the UV region. Both approaches are tested in the project.

Aalto is developing a prototype light source for this project, combining commercial UVC LEDs with UV-emitting phosphors to achieve a broader spectral output. The design features a 9×9 LED matrix emitting at 266 nm, with a UV phosphor compound placed in front of the matrix, sandwiched between two quartz plates. The phosphor is specifically selected to absorb the LED emission and emit at longer wavelengths. To enhance light intensity, a plano-convex lens is incorporated to collect and direct the scattered light. A 75 mm diameter lens provides spectral irradiance comparable to traditional incandescent UV sources. Aalto is refining the system for a more practical form factor while also exploring alternative LED sources and phosphor compounds.

# Solar UV dosimeter calibrations in the frame of the Melida's EMP project 22NRM05

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The WCC-UV participates in Work Package 1 of the MeLiDos Project running in the frame of the European Partnership in Metrology (EPM) which started in June 2023. In the beginning of the project UV dosimeters were characterized for its relative spectral and angular responsivity (SRF and ARF) in the laboratories of the participating institutes (LNE, RISE, CMI, Aalto and PMOD/WRC). The main difference between personal dosimeters and standard UV radiometers is their very compact design and data accessibility only using mobile phone applications. Three different dosimeters have been selected so far from companies in Germany, Norway and New Zealand. The two instruments have one UVB channel, the third one in total 6 channels from UVB to the infrared. At PMOD/WRC, only the UVB channels were considered. For this project, the data of the one dosimeter could be read out using a dedicated APK supplied by the manufacturer using an android mobile phone. The other two dosimeters were connected to a serial interface board or could be read out using a USB interface connected to a PC.

The calibration of the dosimeters at PMOD/WRC follows the procedure described in Hülsen and Gröbner, 2007. The SRF measurements were carried out in the laboratory. Due to the independent data acquisition, special care was taken to synchronize the wavelength setting of the tunable source with the sampling of the dosimeter. The SRFs of the two instruments showed significant deviations from the erythemal action spectra in the UVB and UVA spectral range while one is in good accordance with the erythemal action curve. The measured ARFs show large deviations from a Lambertian receiver, especially for larger zenith angles. At 70 degrees the cosine error is 20 % up to 60 %. This leads to a diffuse cosine error of 0.814 to 0.915.

The absolute sensitivity was determined by outdoor measurements relative to the Qasume reference spectroradiometer. This outdoor measurement was affected by poor weather conditions in the autumn of 2024. Only one day could be used for the calibration in September and two days in October. The latter are however outside of the nominal calibration period due to solar zenith angles larger than 50°. Because of its rounded shape the leveling of the Norwegian dosimeter has a larger uncertainty of 5.9 %. This is also true for the ARF measurement described above. The manufacturer calibration of two instruments were well inside the calibration uncertainty. No manufacturer calibration is currently available for the dosimeter from New Zealand. The associated uncertainties of the calibration are similar to standard UV radiometers.

Reference:
G. Hülsen and J. Gröbner, 2007, "Characterisation and calibration of ultraviolet broadband radiometers measuring erythemally weighted irradiance", Applied Optics, 46, 5877-5886, https://doi.org/10.1364/AO.46.005877

**Jostein Hoftuft**

**Using pyranometer data to assess drift in multiband radiometers: Update”**

The Norwegian Radiation and Nuclear Safety Authority’s (DSA) new ground-based UV-radiometers are using 19 spectrally resolved band channels ranging from UV to IR. Every year a reference UV-radiometer is sent to all 9 stations in the Norwegian UV-monitoring network, to monitor drift in the instruments. Since this is done only once a year, we do not know if the change in the instrument’s response is happening slowly over the whole year, or if it’s happening fast at certain events.

On 8 out of 9 stations, the UV-radiometers are co-located with a pyranometer. The correlation between each channel and pyranometer is calculated over time. We examine if the change in correlation over time can be used to monitor drift in any of the channels. The change of the correlation is to be compared to the drift of the UV-radiometer as measured against our reference UV-radiometer. The drift of the pyranometer is also assed using clear sky normal.

## Skin Colour and Pigmentation as biomarkers for personal UV-Exposure?

**Schmalwieser Alois**

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While pigmentation in human skin is a well-known phenomenon, only little is known about seasonal and life-long changes in personal pigmentation. Since pigmentation is a direct reaction to UV radiation exposure, we are investigating sun-initiated changes in skin colour and pigmentation since a couple of years by objective measurements to answer the question if skin colour and pigmentation can be used as biomarkers for personal UV radiation exposure. Objective measurements comprise (non-invasive) skin reflectometry using the Lab-colour-space in conjunction with personal UV Radiation Exposure measurements. In this talk an overview will be given on the methodology as well as a summary of our past and recent studies.

Matthew Robson, Sharon A Robinson, Paul W Barnes, Janet F Bornman, Anna B Harper, Hanna Lee, Roy Mackenzie Calderón, Laura E Revell, Qing-Wei Wang, and the UNEP EEAP.

**Interactive effects of UV radiation, climate and stratospheric ozone depletion on polar and alpine ecosystems, photodegradation of plant material and of pesticides.**

The UNEP Environmental Effects Assessment Panel met at Lammi Biological Station, Finland, in September 2024. The panel considers the importance of research into the interactive effects on ozone depletion and UV radiation with climate change. This presentation highlights the outcomes of this Update considering significant impacts of ultraviolet-B radiation on ecosystems functioning in high-latitude regions. Extended Antarctic ozone depletion during 2020-2023 has led to prolonged UV-B exposure in southern high latitudes, exacerbated by record-low sea ice and early snowmelt. This increased radiation poses risks to Antarctic and Patagonian ecosystems, affecting species at the base of the food chain due to the energetic costs of UV-protective mechanisms. Simultaneously, anthropogenic climate change is driving global glacier retreat, revealing new ground for colonisation in alpine and polar environments which is exposed to UV-B radiation. These terrestrial ecosystems may experience altered colonization dynamics, particularly if UV-adapted species struggle to cope with rising temperatures. Globally, UV radiation plays a crucial role in photodegradation processes affecting carbon cycling. It directly and indirectly influences litter decomposition by breaking down lignin and enhancing microbial activity, with climate and land-use changes further modulating these effects. Additionally, UV-B radiation also affects pesticide persistence and toxicity, impacting environmental and food safety. Understanding these interactions is essential for predicting the future consequences of ozone recovery, climate change, and land-use shifts on ecosystems and biogeochemical cycles.

Abstract Joint Presentation Part 1

# Long-term Solar UV Monitoring (Part I): Data and Trend Results from Dortmund, Germany and Uccle, Belgium

S. Lorenz[1], F. Heinzl[1], M. Janßen[2], A. Mangold[3], V. De Bock[3], P. Scholz-Kreisel[1], D. Weiskopf[1]

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For ☑ Oral Presentation ☐ Poster

Increasing solar ultraviolet radiation (UVR) can significantly impact human health and the environment. We present a comprehensive study of long-term solar UVR data from monitoring stations in Dortmund, Germany, and Uccle, Belgium. Spectrally resolved data were processed and analysed covering the years 1997-2022 for Dortmund and 1991-2022 for Uccle. To investigate the factors influencing UV radiation, additional data on global radiation, sunshine duration, and satellite-derived daily total column ozone were analysed.

The results of descriptive analysis demonstrate the impacts of seasonal ozone course, low-ozone events, and cloud cover on UV radiation. Comparing data from both stations provides valuable insights into the regional transferability of the local measurements. Differences in UV radiation mean values between the sites correlate well with differences in global radiation in most cases.

For temporal trend analysis (1997 to 2022), an advanced linear trend model was applied to monthly mean values. The results show a statistically significant increase in the monthly mean of daily erythemal radiant exposure, with a rise of 13% from 1997 to 2022 in Dortmund and nearly 20% in Uccle over the same period. During the summer months, a slight decrease in total column ozone was observed. The increase in global radiation is similar to the UV data, and the sunshine duration in Dortmund increases about twice as much as global radiation, indicating that significant changes in cloud cover are a primary driver of the UV radiation increase.

The obtained results reinforce the need for continuous and precise ground-level UV monitoring. Moreover, the observed trends in increasing solar UV radiation should be considered in future climate change adaptation and prevention strategies.

Abstract Joint Presentation Part 2

# Long-term Solar UV Monitoring (Part II): Trend Model and Imputation Method for Data Gap Handling

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For ☑ Oral Presentation ☐ Poster

Analysing trends in long-term solar UV monitoring data sets presents challenges, particularly in handling data gaps and selecting an appropriate trend model for meaningful results.

Data gaps can hamper the calculation and comparison of monthly or annual means, potentially leading to incorrect conclusions in data evaluation and trend analysis of UV data. To address this, we developed and validated a statistical imputation method, which estimates missing data by considering actual local solar radiation conditions using predictors correlated with local UV values in an empirical model (global radiation and total ozone column). Our detailed validation shows that the imputation method effectively corrects errors in monthly and annual averages due to gaps when a large amount of available data is used.

While many studies use linear trend analysis based on calculated monthly anomalies, they often address heterogeneity and autocorrelation by modelling deviations from the seasonal pattern rather than the response values themselves. However, this approach can lead to underestimated standard errors of trend estimators when the assumptions of uncorrelated and homoscedastic error terms are violated. In our trend analysis, we improved the standard linear model by accounting for autocorrelation and heteroscedasticity present in our datasets. An additional advantage of our approach is the direct use of monthly mean values, which eliminates the need for calculating monthly anomalies. Our enhanced model provides a more robust framework for analysing trends in long-term solar UV data, ensuring more accurate and reliable results.

Abstract: Three decades of UV monitoring in Norway, including Svalbard.

Bjørn Johnsen[1], Elisabeth L. Hansen[1], Lill T Nilsen[1], Merete Hannevik[1], Gunnar Saxebøl[1], Jostein Hoftuft[1], Tove Svendby[2], Arne Dahlback[3], Berit Kjeldstad[4], Erik Berge[5]

DSA[1], NTNU[2], NILU[3], UIO[4], METno[5]

The Norwegian UV-monitoring network has been operating for nearly 30 years. We will here give a brief presentation of major results, including trends in surface UV and drivers.

- Variations and trends in cloud cover, including aerosol loads, is the dominating factor influencing yearly E-UV
- Southern Norway exhibits an upward trend in yearly E-UV by +2% to +4% per 10 years (decade) whereas Svalbard exhibit a downward trend by -1.5% per decade
- These changes in yearly E-UV are mainly driven by decreasing cloud occurrence and an increase in relative sunshine duration in southern Norway, while in Svalbard, they are influenced by increasing cloud occurrence, decreasing surface albedo, and shifts in the timing of snowmelt and snow accumulation.
- Over the 30 years period, surface E-UV and UV-A doses in April and June exhibit statistically significant increases by 20-30% in southern Norway and decreases by -15% in spring at Svalbard. Conversely, August in southern Norway exhibit significant decreases by -10% to -15% and Svalbard a significant increase by +15%.

The situation preceding the establishment of the UV-monitoring network, and now 30 years later, has shifted. Where there was once concern about a sharp increase in UV due to depletion of the ozone layer from long-term emissions of ozone-depleting substances, there are now marked increases in UV levels driven by factors generally associated with global warming, such as alterations in cloud formation, precipitation, temperature, surface albedo, and persistent weather conditions.

A summary report describing the network operation, results and use of data will be published before the summer 2025.

# Satellite UV activities at FMI

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This presentation highlights recent satellite UV activities at FMI. In the previous meeting, we introduced a new European surface UV (EUV) radiation product using cloud optical depth retrievals from the geostationary Meteosat satellites and showed results for the SEVIRI instrument onboard Meteosat-8-11. The EUV product is developed in the framework of the EUMETSAT Satellite Application Facility on Atmospheric Composition Monitoring (AC SAF).

Despite the anomaly in the on-board calibration devices and relying on external calibration techniques, the L1c geolocated radiance data from the new Flexible Combined Imager (FCI) onboard Meteosat-12 (launched on 13 Dec 2022) were declared operational on 4 December 2024. The improved spatial resolution of FCI is expected to be beneficial at high latitudes where the increasingly slanted view elongates the pixels in the north-south direction. The FCI version of the EUV processor is running at FMI and initial results will be shown.

Also in the framework of the AC SAF, FMI maintains the offline UV product (OUV) based on total ozone from GOME-2 onboard Metop satellites and AVHRR data from both Metop and NOAA satellites. A new development based on the OUV product is a long UV time-series using the EUMETSAT AVHRR Fundamental Data Record (FDR) data for the cloud cover. The AVHRR FDR cover satellite data starting from 1978 with TIROS-N to the Metop-C satellite until June 2024.

Other FMI satellite UV activities include the processing of the OMI UV product, the development, processing and distribution of the TROPOMI / Sentinel-5 Precursor (S5P) UV product, and UV processor development for the coming Sentinel-5 instrument.

# UV Map Nowcasting and Comparison with Ground-Based UV Measurements for the DACH Region

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We present the methodology and key findings of a recently published study that introduces a new approach to nowcast UV Index maps, developed within the framework of the Austrian Solar UV Measurement Network. Although we focused on the DACH region (Germany, Austria, and Switzerland) in this study, the same methods are routinely applied to nowcast UV Index maps for Europe.

The UV Index maps are based on clear-sky UV Index values obtained from a pre-calculated lookup table (derived from the radiative transfer model libRadtran) by incorporating daily forecast data of surface albedo and aerosol optical depths from the Copernicus Atmospheric Monitoring Service (CAMS) as well as total column ozone data from NASA's Ozone Monitoring Instrument (OMI). The effect of cloudiness is integrated by applying a cloud modification factor gathered from satellite images recorded by the SEVIRI instrument onboard the Meteosat Second Generation satellites.

To assess the representativeness of the calculated UV Index maps, the corresponding pixel values were compared to ground-based measurements for the year 2022 at 27 locations in the DACH region. For all sky conditions, the satellite-derived UV Index values are within ±1.0 UV Index (U1.0) of the ground-measured UV Index for at least 91% of the data at stations below 500 m a.s.l. and in flatter landscapes. For high-altitude sites and in more pronounced topographies, the values for U1.0 decrease, with the lowest agreement of 74.8% found for the Sonnblick station located at 3109 m a.s.l. Discrepancies arise due to differences in the measurement methods: ground-based measurements capture the local conditions, while satellite-derived data represent average values over pixel-sized areas. Under clear-sky conditions, the largest deviations occur at high-altitude, snow-covered sites in complex terrain. In these cases, the surface albedo obtained from the relatively large CAMS pixel (about 29 km × 44 km) reaches its limits when it comes to accurately capturing the small-scale fluctuations in surface albedo on the ground.

Under all sky conditions, cloud variability adds further uncertainties, particularly in complex topography or broken cloud cover scenarios, where satellite cloud data lack the resolution to capture local fluctuations. This study discusses these uncertainties while also highlighting the potential of the generated UV Index maps to provide area-wide information to the population as a valuable complement to ground-based measurements.

# Analysis of the daily and monthly variation in UV radiation levels in the northern mountains of the Czech Republic, 2020–2021

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Ultraviolet (UV) radiation is a portion of the solar radiation reaching the Earth's surface that significantly impacts living organisms, including positive and harmful effects (e.g., sunburn, skin cancer or eye cataracts). This study evaluated the daily and monthly changes in erythemal doses and UV index at two high-altitude areas in the Giant Mountains and the Hrubý Jeseník Mountains in the Czech Republic during the first two years of UV radiation monitoring. The maximal UV index of 10.1 occurred at the Luční bouda meteorological station (1 413 m a.s.l., Giant Mountains) on 5 July 2020, while the maximal UV index of 8.9 was observed at the Vysoká hole meteorological station (1 464 m a.s.l., Hrubý Jeseník Mts.) on 28 June 2020. This study also showed that the combined effect of atmospheric and geographical factors (low total ozone column, cloud-free skies or variable clouds, and high albedo) can cause a significant increase in solar UV radiation. Therefore, it is crucial to take additional precautions to protect the human body when visiting mountainous areas with extreme levels of UV radiation.

## UV Exposure from Jogging

**Danhel Hannah et al.**

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Jogging is one of the most popular recreational sport activities over four decades and is done in almost all ages to keep fitness and health. Joggers are exposed to solar UV radiation (UVR) and due to enhanced heat production by physical activity, body coverage by clothes is reduced. This may imply health risk due to overexposure. However, little research has been undertaken so far to estimate UVR exposure during jogging. Therefore, UVR exposure was measured at seven body sites during jogging under cloud-free conditions for solar elevations between 20° and 60°. Results show that the top of the shoulder is the most exposed body site by receiving 80% of ambient UVR on average and up to 120% under certain conditions. All other body parts receive up to 55% on average and up to 85% in special cases. This indicates further that monotonous body alignment to the sun holds higher risk than a frequently alternating alignment. Assuming the longest recommended duration for cardio-vascular beneficial jogging of 50 minutes, photosensitive persons need protection of the shoulders from a UV-Index of 2 onwards on an unvaried path and from a UV-Index of 3 on an all-directional path. Further, results show that measurements of UVR exposure possess an uncertainty of ±15% including mounting.

# Time series analysis of uv and total ozone for Uccle and intercomparison of Brewer016 to Brewer178

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Abstract:

The Royal Meteorological Institute of Belgium performs total ozone column and spectral UV measurements with two Brewer spectrophotometers in Uccle, Belgium (50.8°N, 4.35°E, 100m a.s.l.). The UV time series at Uccle started with measurements of the single monochromator Brewer#016 in 1984 and are complemented by measurements of the double monochromator Brewer#178 since 2002. In this contribution we analyse the time series for the daily erythemal uv dose and the daily maximum UV index (UVImax) for Uccle. The analysis is done on a daily and monthly basis and the differences between Brewer#016 and Brewer#178 are investigated. For Brewer#016, for monthly values, a significant positive trend of 5.6 ± 0.8 % per decade was found for UVImax and 5.6 ± 1.1% for the daily erythemal uv dose for the period 1991–2022 (see Lorenz et al., 2024; https://doi.org/10.1007/s43630-024-00658-8). We will present likewise results for the time period of Brewer#178, and extend the analysis to include years 2023 and 2024. Further, the total ozone column time series of our two Brewer instruments are analysed and results will be presented for trend analysis and differences between the two Brewers.

**Sun protection by head wear**

**Helletzgruber Sarah et al.**

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Hats, caps, and various head wear are commonly worn across the world recreationally, as safety gear (e.g. hard hats), for cultural reasons, or to protect from sun and heat.

In order to evaluate the effective protection of head wear of a variety of types and materials against Ultraviolet radiation, the UV exposure was measured outdoors for more than 20 items of headwear under largely cloud-free conditions in May and June in Vienna, Austria. Measurements were taken by affixing UV-meters of the type SunSaver to 21 body positions on a manikin placed upon a rotating platform. In order to simulate exposure during random directional walking, the platform was rotated at approximately one revolution per minute. Measurements with each piece of headwear were taken for five rotations and at three different solar heights between 20° and 65°. In addition, all items were evaluated in a laboratory setting to determine the UPF of the respective material composition according to ISO standard protocol.

Results show that the top of the head protected is well protected by all items. As expected, protection on nose, for example, varying from 2 up to 30 depending on type of hat and solar height. Lower protection (SPF of up to 10) was found for other areas in the face for hats without face guard while face guards provide SPF up to 50. Protection factor for the middle of the neck is generally less than 20 for hats with a full brim and minimal to none for most. Majority of head wear does not protect shoulders, torso, and limbs.

To sum up, head wear delivers appropriate sun protection of the head. The protection factor depends, beside others, on the size of the brim. As only very large brims protect the shoulders to a certain extent, shoulders need additionally sun protection means like clothing or sun screens.

# The German Solar UV Monitoring Network – Implementation of diode array radiometers and low cost broadband filter radiometer

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For ☐ Oral Presentation ☑ Poster

The German Federal Office for Radiation Protection (BfS) operates a nationwide network for solar ultraviolet (UV) radiation monitoring in cooperation with the Federal Environment Agency (UBA), Germany's National Meteorological Service (DWD) and other associated institutions like the Federal Institute for Occupational Safety and Health (BAuA) or the Leibniz Institute for Tropospheric Research (TROPOS).

Until 2017, the network used scanning double monochromators (DM) for spectral-resolved measurements to ensure our requirements on accuracy. However, these devices are expensive and require high-maintenance. In addition, the measurement time of several minutes is a disadvantage in case of fast changing cloud conditions. An alternative system was found with a diode array radiometer using BTS technology (BTS). Comparative validation measurements of BTS and DM systems have shown that the more cost-effective BTS systems achieve sufficient stray light reduction (dynamic range) with a shorter measurement time than DM and high spectral resolution. This allows the spectral UV irradiance to be determined more accurately at fast changing cloud conditions. For this reason, further stations in the UV monitoring network were expanded with BTS diode array radiometers. One of these was installed in the high mountain region of the Alps, where fast changing cloud conditions as well as the highest solar UV irradiance in Germany often appear.

To inform the public about the current solar UV irradiance the BfS publishes daily courses of the UV Index as derived from the measurements of all measurement stations continuously updated over the day. However, the information is generally valid to the region of the measurement station due to the strong dependence of the solar UV irradiance on the cloudy conditions. For comprehensive information, the number of measurement stations of the German solar UV monitoring network is insufficient. To this end, the existing network is being expanded to further additional stations equipped with small and low-cost UV Index sensors which achieve the desired level of accuracy for UV Index determination. Part of the expansion will be done in cooperation with the German ODL (ambient gamma dose rate) network with its 1800 stations.

In 2025 the German network includes 14 stations for spectrally resolved measurements and more than 30 additional stations equipped with new broadband filter radiometer for direct measurement of the erythemal irradiance. The expansion of the network will be presented with a special focus on the applied devices, the validation and the measurement results, and the communication of the current erythemal irradiance to the public.