NORWAY

National Report for the 12th WMO/UNEP Ozone Research Managers Meeting, Geneva, Switzerland, 24-26 April 2024

1. OBSERVATIONAL ACTIVITIES

In 1990, the Norwegian Environment Agency established the programme *"Monitoring of the atmospheric ozone layer".* Some years later, in 1995, the programme was expanded and "*The Norwegian UV network"* was established. The measurements are undertaken by NILU (financed by the Norwegian Environment Agency) and the Norwegian Radiation and Nuclear Safety Authority (DSA). The sites are marked in Figure 1. In addition, ozone and UV measurements are performed at the Troll station in Antarctica.

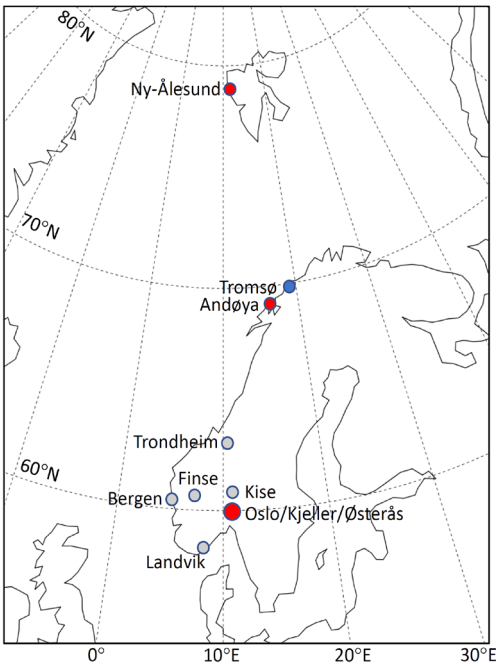

Figure 1: Map of Norwegian ozone and UV sites

Until 2019, ozone and UV measurements in Oslo were performed through a collaboration between NILU and the University of Oslo. In the summer of 2019, the instruments were moved to NILU at Kjeller, situated 20 km east of Oslo. NILU is also responsible for ozone and UV measurements at Andøya and in Ny-Ålesund, with assistance from the Andøya Space Center and the Norwegian Polar Institute for daily maintenance. SAOZ total ozone measurements in Ny-Ålesund is a joint effort between NILU and IPSL/LATMOS, France. Furthermore, NILU cooperates with CNR, Italy, on operation and calibration of an Italian Brewer instrument which is co-located with other ozone and UV instruments at the Sverdrup Station in Ny-Ålesund. NILU has recently installed Pandora instruments in Ny-Ålesund and at the Troll station in Antarctica, two spectrometers capable of measuring total column ozone, NO_2, SO_2 and CH_2O. The instruments are part of the Pandonia Global Network (PGN), a collaboration between NASA and ESA, which aims to monitor air quality and atmospheric composition worldwide and to validate satellite data from sensors such as Sentinel-5P and upcoming Sentinel-4 and Sentinel-5 satellites.

NILU is responsible for the Norwegian total ozone measurements and UV-measurements at four sites (including Troll), whereas DSA is responsible for coordination and calibration of the UV-network and for reporting measurement data relevant for health and environmental effects of natural UV radiation. Table 1 gives an overview of the location of the various stations, the type of measurements, and the institutions/institutes responsible for the daily operation of the instruments. The measurement sites are marked in Figure 1: Red circles represent sites where both quality assured total ozone and UV measurements are performed by NILU, whereas grey circles represent sites with UV measurements run by DSA. The blue circle (Tromsø) shows the location of a historical measurement site.

1.1 Column measurements of ozone

Total ozone measurements using the Dobson spectrophotometer D56 were performed on a regular basis in Oslo from 1978 to 1998. In Tromsø, Dobson measurements with D14 started in 1939 and systematic measurements were performed until 1972. After a break of 12 years, the Tromsø Dobson measurements started up again in 1985 and were continued until 1999. Quality-assured Dobson D8 measurements were also performed in Svalbard from 1950 to 1968 and from 1995 to 2007.

Table 1: Overview of the locations and institutes responsible for ozone and UV monitoring activities in Norway

Station	Location	UV	Total ozone	Institute
Landvik/Grimstad	58ºN, 08ºE	GUV-541		DSA
Kjeller (Oslo)	60ºN, 11ºE	GUV-511, NILU-UV	Brewer MKV, GUV	NILU
Østerås	60ºN, 10ºE	GUVis-3511; Bentham		DSA
Bergen	60ºN, 05ºE	GUV-541		DSA
Finse	61ºN, 07ºE	GUV-541, GUVis3511		DSA
Kise	61ºN, 11ºE	GUV-541		DSA
Trondheim	63ºN, 10ºE	GUV-541, GUVis3511		DSA
Andøya	69ºN, 16ºE	GUV-541	Brewer MKIII, GUV	NILU
Ny-Ålesund in Svalbard	79ºN, 12ºE	GUV-541	SAOZ, GUV, Pandora, (Brewer MKIV)	NILU
Troll in Antarctica	72ºS, 02ºE	NILU-UV	NILU-UV, Pandora	NILU

In 1990 Brewer instrument no. 42 was installed at the University of Oslo (Blindern), however, the instrument was moved to NILU (Kjeller) in 2019 to ensure continuous operation. In 1994 Brewer measurements (with B104) started up in Tromsø, but after the termination of other ozone related activities at the Auroral Observatory/University of Tromsø in 1999, the instrument was moved to the ALOMAR Observatory at Andøya, 130 km southwest of Tromsø. The ozone values are derived from direct sun measurements when available. On overcast days and days where the solar zenith angle is large, the ozone values are calculated from the Brewer global irradiance (GI) method and the GUV instruments (Stamnes et al., 1991; Svendby et al., 2021). Except for the period from 1973 to 1984, total ozone has been measured on a regular basis in Tromsø/Andøya since 1935, which makes this time series one of the longest in the world.

Measurements of total ozone in Svalbard has been performed for several decades. Since 1991 a Differential Optical Absorption Spectroscopy instrument (type SAOZ) in Ny-Ålesund has measured total columns of ozone and NO_2. SAOZ no. 8 is part of IPSL/LATMOS (France)' global network and the data analysis is performed centrally at the French institute. As SAOZ measurements only can provide ozone values at solar zenith angles between 95 and 85º, the observations are limited to mid-February to early May, and early August to late October. A GUV instrument is used to derive total ozone on days with missing SOAZ measurements. Since 2017, a cooperation between NILU and CNR (Italy) has ensured data from the Italian Brewer instrument #50 in Ny-Ålesund. Also, a newly installed Pandora spectrometer (2019) provides a valuable supplement to the ozone measurements in Ny-Ålesund (Svalbard).

Since 2007, total ozone has been measured by NILU at the Norwegian Troll station in Antarctica. This is done with the NILU-UV radiometer (see section 1.3). A new Pandora instrument was installed in 2023 as part of the TONe (Troll Observing Network) infrastructure project.

1.2 Profile measurements of ozone

An ozone lidar has been in operation at ALOMAR (Andøya) since 1995. Initially, this was a cooperation between the Norwegian Defence Research Establishment (FFI), NILU, and Andøya Rocket Range. FFI withdrew from the cooperation in 2006 and some years later the ozone lidar measurements were excluded from the national monitoring programme due to lack of financial support, with the consequence that also NILU had to withdraw from the cooperation. The lidar is still operational, but it is only operated occasionally by Andøya Space Center and there is currently no funding for data analysis.

1.3 UV measurements

In total, nine sites are included in the Norwegian UV network. The instruments, GUV and/or GUVis from Biospherical Instruments Inc, are designed to measure UV irradiances in 4 or 5 channels. Using a technique developed by Dahlback (1996) and/or a statistical method developed at DSA, it is possible to

derive a range of different UV products, including complete UV spectra from 290 to 400 nm, biologically weighted UV doses for any action spectrum in the UV wavelength region, as well as total ozone column and cloud cover information.

Spectral UV irradiances (global scans) are also measured regularly with the Brewer instruments at Kjeller, at Andøya (ALOMAR), and with the Italian Brewer instrument in Ny-Ålesund.

Since 2007 NILU has measured total ozone and UV with a filter instrument (NILU-UV radiometer) at the Norwegian research station Troll in Antarctica. A NILU-UV instrument is also installed at NILU, Kjeller, and runs side-by-side with Brewer #42 and GUV-511.

1.4 Measurements of substances controlled under the Montreal Protocol

NILU is running a Medusa-GCMS at the Zeppelin Observatory, Svalbard, which provides high-quality measurements of 13 ODSs and 11 HFCs regulated through the Montreal Protocol. This is a part of the national programme for monitoring of greenhouse gases, financed by the Norwegian Environment Agency. Annual reports are produced by NILU (latest: Platt et al., 2023) and data are stored in the EBAS database (http://ebas.nilu.no).

Halogenated compounds, including 6 CFCs, 5 HCFCs, and 8 HFCs are also measured at the Troll Observatory in Antarctica. Since 2008 air samples have been collected weekly in 3-L stainless steel canister. A publication with ODS trends and source apportionment is in progress, and the data will soon be available in EBAS database.

1.5 Calibration activities

The Brewer instruments

The Brewer instruments in Oslo (B42) and at Andøya (B104) have been in operation since the early 1990s. Every year International Ozone Services Inc. (IOS), Canada, calibrate the Brewer instruments at the sites. However, in 2020 and 2021 calibrations by IOS were prohibited due to travel restrictions under Covid-19. Unfortunately, a significant drift in the standard lamps revealed severe instrumental problems with B104 in early 2021, and after inspections by IOS in the summer 2022 and 2023 it has been concluded that the Andøya data from 2021 and parts of 2022 most likely are unrecoverable. The Brewer in Oslo/Kjeller has been stable for most of the years of observations and has run without major interruptions since 1991. In addition to B104 and B042, the Italian Brewer B050 in Ny-Ålesund was calibrated by IOS in the summer 2023. NILU and CNR share costs for these calibrations.

The GUV and NILU-UV instruments

DSA houses an optical calibration laboratory and facilities for outdoor calibrations (Johnsen et al., 2008). All the 13 GUV instruments in the Norwegian UV network are yearly calibrated on site against a travelling reference GUV, managed by DSA. The travelling reference is traceable to the European travelling reference spectroradiometer QASUME, and regularly operated side by side a Bentham spectroradiometer operating at the roof of the DSA building. A compilation of results from 6 QASUME audits (including Ny-Ålesund in 2009) where DSA spectroradiometers and GUV instruments belonging to the Norwegian UV-network participated, reveals an interquartile range of daily mean UV-index ratios (solar zenith angle < 80°) within +/-5 % for all instruments and campaigns performed within the period 2003-2019 (paper in progress). Either reference instruments are regularly participating in blind test inter-comparisons. Annual calibration factors are calculated for the GUV instruments prior to final publications of ozone and UVI. Currently, efforts are made to finance new instrumentation at the network locations, in order to ensure still continuous, high-quality measurements, and to provide a wider spectral range and versatility of use of monitoring data. A new 19-channel GUV instrument, fitted with a rotating shadow band was purchased by DSA in 2018 and is now in regular operation at DSA. The instrument provides diffuse sky observation, enabling derivation of beam irradiance and atmospheric extinction parameters.

The NILU-UV has a similar design to the GUV-instruments described above, but the instrument stability is routinely controlled by calibration lamps. The instrument at Troll (Antarctica) is calibrated every month against three calibration lamps to keep track of potential instrument drift.

Pandora

The Pandora instruments in Ny-Ålesund (P152) and at Troll (P242) were installed in 2019 and 2023, respectively. The instruments are built by SciGlob in the US, and calibrated at the LuftBlick laboratories in Innsbruck, Austria, before shipped and installed on site. A field calibration was performed in Ny-Ålesund in 2019, resulting in valid data product from 2020.The instrument runs stable, and both sun and moon measurement products are available. Data are stored in the ESA Atmospheric Validation Centre EVDC (https://evdc.esa.int) and are provided to users in near-real-time.

For the Antarctic instrument, the field calibration process started in 2023 and is still ongoing. The first validated Troll data is expected from Q2 2024.

The calibration process of all Pandora instruments is online and performed by LuftBlick. Instruments are normally not taken down or shipped back to the laboratory for physical calibrations.

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

Results from the national programme *"Monitoring of the atmospheric ozone layer and natural ultraviolet radiation"* are published by the Norwegian Environment Agency and NILU every year. Section 2.1 to 2.3 include trend results from the last report (Svendby et al., 2023).

2.1 Ozone observations in Oslo and Kjeller (60°N)

Total ozone values from Oslo (and Kjeller after 2019) from 1979 to 2022 have been investigated. For the period 1979 to 1998 data from the Dobson instrument has been applied, whereas for the period 1998 to 2022 data is from the Brewer instrument. The results of the trend analysis are summarized in Table 2. The second column indicates that a large ozone decrease occurred during the 1980s and first half of the 1990s. For the period 1979-1997 there was a significant decline in total ozone for all seasons. For the winter and spring, the decrease was as large as -6.0%/decade and -8.0 %/decade, respectively. The negative ozone trend was less evident for the summer, but nevertheless it was significant to a 2σ level.

Table 2: Percentage changes in total ozone over Oslo/Kjeller for the period 1.1.1979 to 31.12.2022. The numbers in parenthesis represent uncertainty (1σ)

Time period	Trend (%/decade) 1979-1997	Trend (%/decade) 1998-2022
Winter (Dec – Feb)	-6.0 (2.3)	1.6 (1.4)
Spring (Mar– May	-8.0 (1.3)	-0.2 (1.0)
Summer (Jun – Aug)	-3.5 (1.0)	-0.9 (0.6)
Fall (Sep – Nov)	-4.2 (1.0)	1.7 (0.7)
Annual (Jan-Dec)	-5.9 (1.0)	0.4 (0.6)

For the period 1998-2022 the picture is different, with less dramatic trends. There is a statistically significant ozone increase of 1.7%/decade for the fall. For the winter season December to February, it is also observed a positive ozone trend over the last decades, but the change is not statistically significant. The annual ozone trend from 1998 to 2022 is 0.4% /decade.

2.2 Ozone observations at Andøya (69°N)

Ozone measurements in Northern Norway were performed in Tromsø until 1999 and at ALOMAR/Andøya from 2000. Correlation studies have shown that the ozone climatology is very similar at the two locations and that the two datasets are considered as equivalent representing one site. For the years with absent Dobson total ozone measurements in Tromsø in 1979 and the

Table 3: Percentage changes in total ozone over Andøya/Tromsø for the period 1979 to 2018. The numbers in parenthesis represent uncertainty (1σ).

Time period	Trend (%/decade) 1979-1997	Trend (%/decade) 1998-2022
Spring (Mar – May):	-7.5 (1.5)	-1.6 (1.0)
Summer (Jun – Aug):	-3.4 (1.0)	-0.9 (0.6)
Autumn (Sept – Oct):	-3.4 (1.1)	1.2 (0.7)
Annual (Mar – Oct):	-5.2 (1.0)	-0.7 (0.6)

1980s, total ozone values from the satellite instrument TOMS (Total ozone Mapping Spectrometer) over Andøya were used in the trend studies. The results of the analyses are summarized in Table 3. Like Oslo, the ozone layer above Andøya declined significantly from 1979 to 1997. This decline was evident for all seasons. For the second period from 1998 to 2022, no significant trends have been found for any seasons. The annual ozone trend from 1998 to 2022 is -0.7%/decade.

2.3 Ozone observations in Ny-Ålesund (79°N)

The first Arctic ozone measurements started in Svalbard in 1950 when a recalibrated and upgraded Dobson instrument (D8) was sent to Longyearbyen. Søren H.H. Larsen was the first person who performed systematic ozone measurements in the Polar region (Henriksen and Svendby, 1997). Regular Dobson ozone measurements were performed in Svalbard until 1962 (Vogler et al.,2006). After that more sporadic measurements were performed. However, the Dobson instrument required manual operation and it was replaced with more automated SAOZ and GUV instruments in 1990 and 1995, respectively.

Table 4: Percentage changes in total ozone over Ny-Ålesund for the period 1979 to 2018. The numbers in parenthesis represent uncertainty (1σ).

Time period	Trend (%/decade) 1979-1997	Trend (%/decade) 1998-2022
Spring (Mar – May):	-10.8 (1.7)	-0.8 (1.6)
Summer (Jun – Aug):	-2.4 (1.2)	-1.1 (0.7)
Autumn (Sept - Oct):	-1.2 (1.0)	1.0 (1.0)
Annual (Mar – Sep):	-5.9 (1.1)	-0.5 (0.9)

The ozone trend studies presented in Table 4 are based on a combination of Dobson, SAOZ, GUV and satellite measurements. For the years 1979 to 1994 the monthly mean ozone values have been supplied with TOMS Nimbus 7 and Meteor-3 overpass data. For the last 27 years only ground-based measurements have been used in trend studies. Since 2020 Brewer DS data (from the Italian B50) and Pandora data have been valuable supplements to the ozone time series.

As seen from Table 4 the ozone trend pattern in Ny-Ålesund has many similarities to the Oslo and Andøya trend series. A massive ozone decline was observed from 1979 to 1997, especially during winter and spring. No significant trends were observed for the second period from 1998 to 2022.

2.4 Ozone observations at Troll (72°S)

The total ozone series from Troll Station, Antarctica has been re-analysed and compared with satellite measurements (Sztipanov et al., 2020). The inter-comparison shows good agreement and confirms the suitability of the NILU-UV instrument for long-term monitoring of ozone and UV under the extreme conditions at the site. A new Pandora instrument was installed at Troll in 2023 as part of the TONe (Troll Observing Network) infrastructure project, which aims to strengthen research within Antarctica.

2.5 UV observations

The Norwegian UV network, established in 1995, consists of 5-channel GUV instruments located at nine stations between 58°N and 79°N (see Figure 1). NILU is responsible for the daily operation of three of the instruments, located at Kjeller (Oslo), Andøya and Ny-Ålesund. The Norwegian Radiation and Nuclear Safety Authority (DSA) is responsible for the operation of the measurements performed in Trondheim, Bergen, Kise, Landvik, Finse, and Østerås. Complete (gap-filled), QC/QA controlled

irradiance and dose products for all stations and the full period 1995-2022 are available for public and scientific use at https://github.com/uvnrpa.The products include minute, hourly, daily, monthly and yearly doses for currently 11 action spectra. Additionally, the repository contains irradiance and dose products for clear sky conditions. The gap-filling method applies Libradtran radiative transfer model with input of total ozone from satellite overpass data, and cloud modification factors derived from ancillary observations and measurements at each station location. Figure 2 shows annual integrated UV-dose (CIE1987) for the period 1995(96) – 2022.

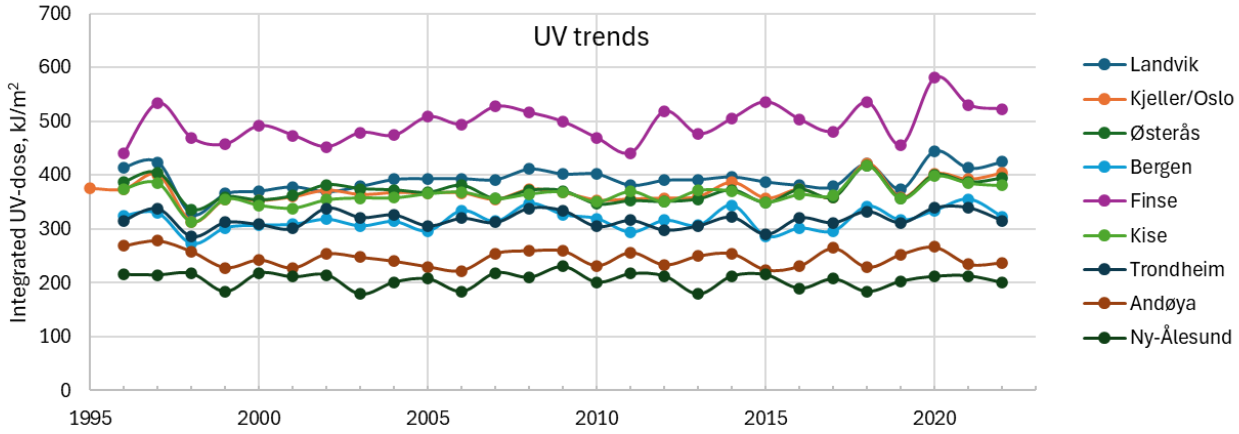

Figure 2: Annual integrated CIE1987 UV-dose for the period 1995(96) – 2022.

The highest UV-doses are measured at the alpine station Finse, which is covered by snow large parts of the year. Lowest UV-doses are measured at the Arctic station in Ny-Ålesund (79°N). Trends in annual UV-doses for the period 1996 - 2022 at the nine UV stations are shown in Table 5. All stations show positive UV-trends, except for the northernmost station in Ny-Ålesund where reduced albedo (less ice/snow) contributes to reduced surface UV-radiation.

Table 5: Trend in annual integrated CIE1987 UV-doses (kJ/m^2) for the period 1996-2022. For Oslo/Kjeller the measurements started in 1995

%/decade	Landvik	Kjeller/ Oslo*	Østerås	Bergen	Finse	Kise	Trondheim	Andøya**	Ny-Ålesund
Trend (±1σ)	3.2 (1.5)	2.8 (1.3)	1.2 (1.4)	2.3 (1.5)	4.1 (1.6)	3.5 (1.3)	0.9 (1.2)	0.7 (1.8)	-1.0 (1.6)

* The instrument was moved from Univ. of Oslo to Kjeller (20km east of Oslo) in 2019, which might have affected UV radiation
** Data from 1996 to1999, when the instrument was in Tromsø, is omitted from trend analysis

In addition to the nine stations listed in Table 5, UVI is measured at the Troll station in Antarctica. These measurements reveal that UVI often exceeds 10 during the ozone hole period in early November and early December (Svendby et al., 2023).

3 THEORY, MODELLING, AND OTHER OZONE RELATED RESEARCH

3.1 NILU

In recent years, the main activity within ozone and UV research at NILU has been to improve and further exploit the long-term data series. In cooperation with several international partners, the total ozone series have been re-visited, homogenised, and published (see section 4.3). Some other activities and results are listed below:

- The Pandora data is uploaded and provided to the end users and ESAs mission performance centres, e.g. the Sentinel-5P validation data facilities https://mpc-vdaf.tropomi.eu/ via EVDC https//evdc.esa.int. The data shows good agreement with collocated instruments and similar

instruments at the other locations. The latest data from Ny-Ålesund is included in the VDAF validation report https://s5p-mpc-vdaf.aeronomie.be/ProjectDir/reports//pdf/S5P-MPC-IASB-ROCVR-21.01.00.pdf. Publication of the data is currently pending due to the relatively short time series at Ny-Ålesund and ongoing calibration efforts at Troll.

- UVI measurements from the Norwegian stations in the UV-network are regularly disseminated for use in the annual State of the Climate report series, issued by BAMS.

3.2 DSA – the Norwegian Radiation and Nuclear Safety Authority

A continuous focus is kept on ensuring well calibrated UV monitoring data and developing data products relevant to health and environmental assessments. QA involves participation and arrangement of solar inter-comparisons, and administration of annual calibrations with the travelling reference. The methodology involves corrections for spectral and angular characteristics of individual instruments, in combination with spectroradiometer operation and RT modelling. Time series of measurements for the UV stations are compared with RT modelling results, applying ancillary observation data to include the impact of variations in total ozone, surface albedo and cloud optical depth. Gaps in measurements series are substituted with modelled data to get continuous series of station data. Three DSA-stations are upgraded with new GUVis-3511 instruments, with detector channels in the UV, visible and near infrared. A separate GUVis-3511 is serving as a second travelling reference instrument for annual site visits. DSA coordinates implementation of the national UV and skin cancer strategy, where the aim is to reduce the incidence and mortality of skin cancer caused by solar and sunbed exposure. Measures include prevention in the administrative sector, knowledge and awareness about skin cancer prevention and earlier detection of skin cancer. UV forecast to the public is one of the measures, and such services are provided by NILU and Yr, respectively. The service at Yr is a cooperation between the Norwegian Meteorological Institute, the Norwegian Broadcasting Corporation (NRK) and DSA. The strategy is developed by a cross-sectoral working group, and this group together with relevant authorities and experts, voluntary organizations and interest groups participates as a reference group in the implementation of the strategic measures.

3.3 University of Oslo

The Department of Physics was operating the Brewer#42 and a GUV-511 instrument at the University of Oslo until June 2019. The institute has also been involved in ground-based measurements of solar UV radiation in developed countries with extreme UV levels, e.g. at the Tibetan Plateau (Norsang et al., 2014). The University of Bergen and NTNU have also participated in these studies. After the retirement key personnel at UiO, ozone and UV studies were ended at UiO and the instruments were moved to NILU at Kjeller.

3.4 CICERO – Center for International Climate Research

CICERO led the work, together with NOAA, on the Annex of the latest WMO Scientific Assessment of Ozone Depletion (Burkholder and Hodnebrog, 2022). The contribution was related to calculations of climate change metrics, including global warming potentials (GWPs), due to emissions of ozone-depleting substances and related compounds. This work was heavily based on methods and results from a recent review paper on the topic (Hodnebrog et al., 2020a), and partly also from a multi-model study on the effective radiative forcing of the chlorofluorocarbons CFC-11 and CFC-12 (Hodnebrog et al., 2020b).

The historical radiative forcing of total ozone changes from models contributing to the 6th phase of the Coupled Model Intercomparison Project (CMIP6) has been calculated (Skeie et al., 2020). The radiative forcing has increased over the last century due to an increase in tropospheric ozone that are compensated by a decrease in radiative forcing due to ozone depleting substances.

4. DISSEMINATION OF RESULTS

4.1 Data reporting

Brewer DS total ozone measurements from Kjeller and Andøya are regularly submitted to WOUDC. The Brewer instruments are also part of the EUBREWNET.

Total ozone and NO_2 measured from the SAOZ instrument in Ny-Ålesund are submitted to the Network for the Detection of Atmospheric Composition Change (NDACC) on an annual basis.

A sql database at DSA holds GUV measurements data for the whole period since 1995. The data are available for public and scientific use at https://github.com/uvnrpa.

Measurements of ODSs are stored in the EBAS database (http://ebas.nilu.no).

The Pandora data are stored in the ESA Atmospheric Data Validation Centre EVDC (https://evdc.esa.int) with direct URL https://evdc.esa.int/doi/ 10.48596/pgn.rout2p1-8.NyAlesund.P152s1

4.2 Information to the public

NILU operates a web portal (http://uv.nilu.no) with 3-days global UV forecasts, and with detailed maps for Norway. The UV forecast is given for clear-sky and cloudy conditions and the snow cover is also considered. An API is used for calculating maximum solar exposure time to avoid sunburn and the time to achieve the recommended amount of Vitamin D. The portal also provides information on UV radiation and the ozone layer.

The Norwegian Meteorological Institute has developed an additional UV forecast as a part of the regular meteorological service on yr.no.

Real-time UVI observations performed by DSA and NILU are also available at the web portal https://uvnett.dsa.no/ together with annual doses and information on sun protection.

NILU, DSA, and the Norwegian Meteorological Institute regularly inform the Norwegian public about the state of the ozone layer and UV radiation, especially during the Easter, summer solstice, and during periods of severely reduced ozone layer thickness. This is done through press releases, interviews in newspapers and broadcasting. The Norwegian Cancer Society and DSA are also drivers for press releases and information to the public regarding UV radiation, health effects and required sun protection.

4.3 Relevant scientific papers

Below are some relevant publications, involving Norwegian institutions, from 2020 to 2023:

Bernet, L., Svendby, T., Hansen, G., Orsolini, Y., Kylling, A., Dahlback, A., Goutail, F., Pazmiño, A., Petkov, B.: Total ozone trends at three northern high-latitude stations. Atmos. Chem. Phys., 23, 4165–4184, https://doi.org/10.5194/acp-23-4165-2023, 2023.

Bernhard, G.H., Fioletov, V. E., Grooß, J.-U, Ialongo, I., Johnsen, B., Lakkala, K., Manney, G. L., Müller, R., and Svendby, T.: Ozone and UV radiation [in "State of the Climate in 2022"]. Bull. Amer. Meteor. Soc., 104 (9), S308–S310, https://doi.org/10.1175/BAMS-D-23-0079.1, 2023.

Hocke, K., Sauvageat, E., Bernet, L.: Response of Total Column Ozone at High Latitudes to Sudden Stratospheric Warmings,Atmosphere, vol. 14, 450, 2023, doi.org/10.3390/atmos14030450, 2023.

Petkov, B. H., Vitale, V., Di Carlo, P., Drofa, O., Mastrangelo, D., Smedley, A. R. D., Diémoz, H., Siani, A. M., Fountoulakis, I., Webb, A.R., Bais, A., Kift, R., Rimmer, J., Casale, G. R., Hansen, G. H., Svendby, T., Pazmiño, A., Werner, R., Atanassov, A. M., Láska, K., De Backer, H., Mangold, A., Köhler, U., Velazco, V. A., Stübi, R., Solomatnikova, A., Pavlova, K., Sobolewski, P. S., Johnsen, B., Goutail, F., Mišaga, O., Aruffo, E., Metelka, L., Tóth, Z., Fekete, D., Aculinin, A. A., Lupi, A., Mazzola, M., Zardi, F: An unprecedented Arctic ozone depletion event during spring 2020 and its impacts across Europe. Journal of Geophysical Research: Atmospheres, 128, e2022JD037581. https://doi. org/10.1029/2022JD037581, 2023.

Bernhard, G.H., Fioletov, V. E., Grooß, J.-U., Ialongo, I., Johnsen, B., Lakkala, K., Manney, G. L., Müller, R., Svendby, T.: Ozone and UV radiation [in "State of the Climate in 2021"]. Bull. Amer. Meteor. Soc., 103 (8), S270–S273, https://doi.org/10.1175/BAMS-D-22-0082.1, 2022.

Burkholder, J. B. and Hodnebrog, Ø.: Summary of Abundances, Lifetimes, ODPs, REs, GWPs, and GTPs, Annex in Scientific Assessment of Ozone Depletion: 2022, GAW Report No. 278, 509 pp., World Meteorological Organization (WMO), Geneva, 2022.

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5. PROJECTS, COLLABORATION, TWINNING AND CAPACITY BUILDING

In the last two decades, the number of Norwegian projects and funding has been slightly reduced due to less focus on stratospheric ozone. Below is an overview of important projects and collaborations/activities:

- The national monitoring programme, financed by the Norwegian Environment Agency, supports NILUs monitoring activities of ozone, UV, ODSs, and HFCs.
- The **Atmo-TROLL** project finances measurements of ozone, UV, and halogenated compounds at Troll. It is coordinated by NILU and funded by The Research Council of Norway.
- With funding from **TONe** (Troll Observing Network) infrastructure project, NILU has installed a Pandora instrument at the Troll station in Antarctica.

- **SIOS** (Svalbard Integrated Arctic Earth Observing System) infrastructure project has financed a Panora instrument in Ny-Ålesund which is run by NILU.
- The Brewers at Kjeller and Andøya are part of the EUropean BREWer NETwork (**EUBREWNET**)
- Cooperation between NILU and CNR (Italy) regarding calibration and maintenance of Brewer#50
- IOS (International Ozone Services) perform annual on-site calibrations of the Norwegian Brewer instruments.
- Cooperation between NILU and IPSL/LATMOS (France) on SAOZ data analysis.
- Norwegian Polar Institute and Andøya Space Center are involved in instrument maintenance.
- **AGAGE (**Advanced Global Atmospheric Gases Experiment) ensures quality control of ODSs.
- DSA is involved in **community medicine projects**, utilizing UV network data, as melanoma projects in co-operation with the Norwegian Cancer Registry and University of Oslo
- DSA uses UV monitoring data and UV forecasting services in several internal and national projects as part of implementing the national UV- and skin cancer strategy. One example is assessing shadow factor in outdoor environments in kindergartens and schoolyards, for existing situations and when introducing new shade constructions. UV forecasting is included in several actions to promote better sun behaviour.
- The Research Council of Norway project "**AMMONIA**: Climate and environmental impacts of green ammonia (NH_3)" (2023-2027), a competence-building project for industry, is led by CICERO and is studying stratospheric ozone depletion due to N_2O.

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

In line with the recommendations of the 11th ORM meeting, Norway has continued funding measurements of ODSs.

Measurements of total ozone and UV radiation continues as before. Annual calibrations of the instruments ensure high-quality data at all the Norwegian sites. New Pandora instruments in Ny-Ålesund (79°N) and Troll in Antarctica (72°S) will improve the data coverage and quality at high latitude stations.

7. FUTURE PLANS

A short overview of future plans is summarised below:

- The existing ozone and UV monitoring activity at NILU and DSA will continue, with a focus on long-term continuity and high-level quality assurance and data accessibility.
- The cooperation with CNRS, France, regarding long-term series of O_3 and NO_2 measurements with the SAOZ instrument in Ny-Ålesund will continue.
- Continued cooperation with CNR, Italy, regarding ozone and UV research in Ny-Ålesund.
- The GUV instruments are getting old (~30 year) and need to be replaced by new instruments, preferably GUVis from Biospherical Instruments Inc. The data collection system will also be upgraded.
- Efforts on improving measurement accuracy will continue at DSA, implementing instruments for monitoring long term drift in QTH secondary standard lamps for network instrument calibrations.

8. NEEDS AND RECOMMENDATIONS

Currently, no ozone profiling measurements are performed by Norwegian institutes/institutions in Norway. A long-term commitment to support measurements and data analysis of the lidar operated by Andøya Space Center would be welcome. Recent winters with record low and persistent stratospheric temperatures and presence of PSCs underlines the need to quantify ozone loss.

The UV-monitoring programme in Norway is a cooperation between DSA and NILU. The original instruments are ~30 years old and access to spare parts has become very limited. To continue high quality measurements the old instruments must be replaced. Several applications to Norwegian funding agencies in recent years have not been successful, however, for the period 2024-2026 DSA has received funding from the Ministry of Health and Care Services to renew their UV-instruments. Funding for new instruments at two NILU sites is still needed.

In general, there is a need for predictable multi-annual funding schedules to free operations from additional funding sources. To manage monitoring programmes and run instruments properly and continuously, stable long-term financial support is indispensable.

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