NORWAY

Ozone monitoring and related research activities in Norway involve several institutions and there is no distinct separation between research, development, monitoring and quality control. In this report we present the ozone related activities that have been carried out in Norway the last years.

OBSERVATIONAL ACTIVITIES

In 1990 The Norwegian Pollution Control Authority established the programme *"Monitoring of the atmospheric ozone layer"*, which initially only included measurements of total ozone. Some years later, in 1994/95, the network was expanded and The Norwegian UV network was established. It consists of eight 5-channel GUV instruments located at sites between 58°N and 79°N. In addition the network includes ozone lidar and ozone sonde measurements. Table 1 gives an overview of the location of the various stations, the type of measurements, and the institutions responsible for the daily operation of the instruments at the different sites.

Table 1: Overview of the locations and institutes involved in ozone and UV monitoring activities in Norway.

Station	Location	UV	Total ozone	Ozone profiles		Institute
				Lidar	Sondes	
Grimstad	58°N, 08°E	X	GUV			Norwegian Radiation Protection Authority
Oslo	60°N, 10°E	X	Brewer, GUV			University of Oslo/ Norwegian Institute for Air Research
Østerås	60°N, 10°E	X	GUV			Norwegian Radiation Protection Authority
Bergen	60°N, 05°E	X	GUV			Norwegian Radiation Protection Authority
Finse	60°N, 07°E	X	GUV			Norwegian Radiation Protection Authority
Kise	60°N, 10°E	X	GUV			Norwegian Radiation Protection Authority
Trondheim	63°N, 10°E	X	GUV			Norwegian Radiation Protection Authority
Ørlandet	63°N, 09°E				x*	Norwegian Institute for Air Research
Andøya	69°N, 16°E	x	Brewer, GUV	x		Norwegian Institute for Air Research /Andøya Rocket Range
Ny-Ålesund	79°N, 12°E	x*	GUV			Norwegian Institute for Air Research
Antarctica	72°S, 02°E	x**	NILU-UV			Norwegian Institute for Air Research

**The sondes at Ørlandet and the GUV measurements at Ny-Ålesund were excluded from the national monitoring programme in 2006 due to lack of financial support.*
*** UV measurements at the Norwegian Troll station in Antarctica started in 2007. They are financed by the Norwegian Research Council.*

Column measurements of ozone and short-lived gases relevant to ozone loss

Total ozone measurements using the Dobson spectrophotometer were performed on a regular basis in Oslo from 1978 to 1998 and in Tromsø from 1985 to 1999. Furthermore, quality-assured Dobson measurements were made at Ny-Ålesund, Svalbard, from 1995 to 2007. In 2007 the measurements were stopped due to a technical failure. Brewer measurements started up in Tromsø in 1994, but after the termination of other ozone-related observations at the Auroral Observatory in Tromsø in 1999 the instrument was moved to Andøya, 130 km southwest of Tromsø. Today daily total ozone values from Oslo and Andøya are based on measurements with Brewer spectrometers. 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 global irradiance method. As the Arctic Lidar Observatory for Middle Atmosphere Research (ALOMAR) is located north of the polar circle (69.3°N, 16.0°E, http://alomar.rocketrange.no/), there are about 100 days without total ozone measurements during the winter. At Ny-Ålesund, an Italian Brewer instrument has been operating since 2006, and the data are shared between Italy and Norway.

The Norwegian Institute for Air Research (NILU) is also responsible for measuring ozone and ozone relevant traces gases at two sites: At ALOMAR two UV/VIS DOAS instruments (SYMOCS) have been used to measure total columns of ozone, NO_2, BrO and OClO since 1998. Since 2006 the UV instrument for monitoring BrO/OClO has been out of operation due to lack of financial support. Additionally, there is a DOAS instrument (type SAOZ) at Ny-Ålesund, measuring total columns of ozone and NO_2, which has been operational since 1991. Near real time data can be found at http://www.aerov.jussieu.fr/~fgoutail/SAOZSol-UK.html. The NO_2 and ozone measurements at ALOMAR and Ny-Ålesund are a part of the Network for the detection of Atmospheric Composition Change (NDACC).

Profile measurements of ozone and other parameters relevant to ozone loss
Together with the Norwegian Defence Research Establishment and the Andøya Rocket Range, NILU has operated an ozone lidar at ALOMAR (Andøya) since January 1995. Since 1997 the instrument has been approved as a complementary site of the NDACC, and data are submitted to the NDACC database. The ozone lidar has also been used to measure polar stratospheric clouds and stratospheric temperature profiles. The lidar is run on a routine basis during clear sky conditions, providing ozone profiles in the height range 8 to 50 km. The latest measured raw data profiles and the latest analysed ozone data are available at http://alomar.rocketrange.no/alomar-lidar.html.

NILU was also operating an ozone sonde station at Ørlandet (63.4°N, 9.2°E) in the period 1994-2006. Nominally between 1 and 4 sondes were launched per month, depending on the time of the year. These measurements have traditionally been used for national monitoring purposes. In addition, NILU has participated in a number of experimental (match) campaigns where several stations have launched sondes in a coordinated pattern to sample the same air masses at different locations. The campaigns have been used to estimate ozone loss as a function of time and sun-lit hours. Finally, the ozone vertical profile soundings have extensively been used for validation of satellite instruments, especially on the ERS-2 and Envisat platforms. Unfortunately the ozone sonde measurements terminated in 2006 due to lack of financial support.

UV measurements

Narrowband filter instruments
The instruments in the Norwegian UV network (GUV, from Biospherical Ltd) are designed to measure UV irradiances in 4 channels. Using a technique developed by *Dahlback (1996)*[1], we are able to derive total ozone abundance, cloud cover information, complete UV spectra from 290 to 400 nm, and biologically weighted UV doses for any action spectrum in the UV.

In January 2007 NILU started measurements with a similar instrument (the NILU-UV radiometer) at the Norwegian research station Troll in Antarctica. The instrument is calibrated every year against a travelling standard. Near real time (NRT) data are available at http://observatories.nilu.no/Datasets/Radiation/tabid/433/Default.aspx and http://observatories.nilu.no/Datasets/Ozonestratosphere/Totalozone/tabid/765/Default.aspx.

Spectroradiometers
Spectral UV irradiances (both direct and global scans) are measured daily with the Brewer instruments at the Department of Physics, University of Oslo, and at ALOMAR.

Calibration activities

The Brewer instruments
The Brewer instrument at the University of Oslo has been in operation since summer 1990, whereas the Brewer measurements in Northern Norway started in 1994. The International Ozone Services, Canada, calibrates the Brewer instruments in Oslo and Andøya on a yearly basis, and the instruments are regularly calibrated against standard lamps in order to check their stability. The calibrations show that the Brewer instruments have been stable during the years of observations. Also, the total ozone measurements from the Oslo Brewer instrument agreed well with the Dobson measurements performed in the 1990s.

[1] *Dahlback, A. (1996) Appl. Opt., Vol. 35., No. 33, 6514-6521*

The GUV instruments

As a part of the Norwegian FARIN project, described in section 5, a major international UV instrument intercomparison was arranged. Altogether 51 UV radiometers from various nations participated, among them 39 multiband filter radiometers (MBFR's). The instruments were also characterized on site. In addition to measurements of spectral responses, measurements against QTH lamps and cosine responses were performed for a selection of instruments. The data are available on the ftp server zardoz.nilu.no at NILU, under directories /nadir/projects/other/farin/rawdata and /nadir/projects/other/farin/processed. The main results have been published by Johnsen et al., *International intercomparison of multiband filter radiometers in Oslo 2005*, Proc. of SPIE, 2006, and are expected to appear in a peer reviewed journal in 2008.

RESULTS FROM OBSERVATIONS AND ANALYSIS

Ozone observations in Oslo

Table 2: Annual percentage changes in total ozone over Oslo for the period 1.1.1979 to 31.12.2006. The numbers in parenthesis represent uncertainty (1σ).

Time period		Trend (% per year)
Winter:	December – February	-0.17 (0.11)
Spring:	March – May	-0.22 (0.10)
Summer:	June – August	-0.02 (0.06)
Fall:	September – November	-0.08 (0.06)
Annual		-0.14 (0.04)

In order to detect possible ozone reductions and trends over Oslo we have investigated total ozone values from 1979 to 2006. For the period 1979 to 1998 data from the Dobson instrument has been applied, whereas for the period 1999 to 2006 the Brewer measurements have been used. The results of the trend analysis are summarized in Table 1. For spring months a significant negative trend of –0.22% per year is observed. For the winter, summer and fall months no significant trends are detected. When all months are included a significant negative trend of –0.14% per year is observed. The analysis shows that the low ozone values in the 1990's strongly contribute to the observed negative trends in total ozone. For 2006 the annual ozone mean was 1.6% below the long-term annual mean (based on data from1979-1989).

Ozone column variability over Scandinavia and over Oslo in particular, in the summertime has been related to dynamical variability. For example, an intense low-ozone episode in August 2003 was associated to the severe heat wave over Europe that summer. High tropopause and anticyclonic anomalies caused westward-propagating, planetary-scale wave trains, extending as far as eastern Eurasia. These wave trains disturbed even the mid-stratosphere, up to about 30 mb *(Orsolini and Nikulin, 2006[2]).*

Ozone observations at Andøya

Table 3: Annual percentage changes in total ozone over Andøya/Tromsø for the period 1979 to 2006. The numbers in parenthesis represent uncertainty (1σ).

Time period	Trend (% per year)
Spring: March – May	-0.04 (0.01)
Summer: June - August	0.02 (0.04)
Annual (March-September)	-0.02 (0.05)

As mentioned above, 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 time period 1979 – 1994 total ozone values from the satellite instrument TOMS (Total ozone Mapping Spectrometer) have been used in trend analysis because of insufficient calibration of the Tromsø Dobson instrument before 1991 and low data coverage. The result of the trend analysis is summarized in Table 3. No significant trends were observed for Andøya for this time period. The small negative ozone trend in spring is mainly caused by several warm and ozone rich winters after 1998, compensating the significant negative ozone trend from 1979 to 1998.

[2] *Orsolini, Y. J. and G. Nikulin, (2006) Quart. J. Roy. Meteor. Soc., 132, 667-680.*

In recent years the historical total ozone series from Tromsø (Fery spectrograph: 1935-1939, Dobson #14: 1939-1972, 1985-1999) and Svalbard (1950-1962) have been re-analyzed, homogenized, and evaluated by multi-linear regression methods *(Hansen and Svenøe, 2005[3], Vogler et al., 2006[3]).* The analysis revealed a strong influence of the local stratospheric temperature at the 30 mbar level and a composite influence of climate tele-connection patterns.

UV observations

Table 4: Annual integrated UV doses (kJ/m^2) at three stations during the period 1995 - 2006.

Year	Oslo	Andøya	Tromsø*	Ny-Ålesund
1995	387.6			
1996	387.4		253.6	218.5
1997	415.0		267.0	206.5
1998	321.5		248.4	217.7
1999	370.5		228.0	186.1
2000	363.0	239.7		231.0
2001	371.0	237.0		208.6
2002	382.5	260.0		201.8
2003	373.2	243.4		No measurements
2004	373.2	243.7		190.5
2005	*No annual UV doses due to calibration campaign*			
2006	372.4	217.3		No measurements

*The GUV instrument at Andøya was operating at Tromsø in the period 1996 – 1999

Annual UV doses for the period 1995 - 2006 are shown in Table 3 for the three GUV instruments located at Oslo, Andøya and Ny-Ålesund. For periods with missing data we have estimated the daily UV doses from a radiative transfer model, FastRt, *http://nadir.nilu.no/~olaeng/fastrt/fastrt.html*. UV measurements at Ny-Ålesund were excluded from the national monitoring programme in 2006 due to lack of financial support.

THEORY, MODELLING, AND OTHER RESEARCH

University of Oslo

Department of Geosciences runs two models to study stratospheric ozone, namely Oslo CTM2 and WACCM. The Oslo CTM2 model is a global three-dimensional chemical transport model covering the troposphere and stratosphere. The model can be run in different horizontal and vertical resolution and can be forced by either IFS or ERA-40 data. Two comprehensive and well-tested chemistry schemes are included in the model, one for the troposphere and one for the stratosphere. An extensive heterogeneous chemistry has been included. Photo dissociation coefficients are calculated on-line. Emissions of source gases are also included. The Oslo CTM2 model is used in various experiments to look at the chemical changes in ozone. Past time slice runs have used emissions from the Edgar Hyde database to look at the chemical changes up to present. IPCC SRES scenarios have been used for calculating chemical changes in future ozone. Because of large uncertainties in future emissions in the source gases, several time slice runs with different scenarios have been performed. A specific run to look at changes in stratospheric ozone from 2000 through 2007 has been performed and will be compared with observations.

The WACCM model is a general circulation model (Whole Atmosphere Community Climate Model) developed at the National Center of Atmospheric Research (NCAR).It is now running at the University of Oslo. WACCM is a coupled climate chemistry model providing a platform for various predictions about the interaction between chemistry and climate. It has 66 vertical levels from the surface through the troposphere, stratosphere and the mesosphere. The model is currently used with the standard chemistry module, however the scheme from Oslo CTM2 will be included to make the results compatible with those from the CTM2. We plan to study impacts of climate chemistry interactions on ozone recovery, and to study the impact of very short lived bromine source gases on stratospheric ozone.

[3] *Hansen, G., and T. Svenøe, (2005) J. Geophys. Res., 110, no. D10, D10103,doi: 10.1029/2004JD005387*
[3] *Vogler, C., S. Brönnimann, and G. Hansen (2006) Atmos. Chem. Phys., 6, 4763–4773.*

Department of Physics UV doses are calculated from a radiative transfer model and ozone measurements from available satellite instruments (TOMS and OMI). The cloud parameterisation in the model is derived from reflectivity data from the same satellite instruments. The calculated UV doses are used in UV effect studies, i.e various cancers and Vitamin D production in humans.

Norwegian Institute for Air Research (NILU)
At NILU there has been a main research focus to understand the dynamical influence on the variability in column ozone, especially at the northern hemisphere at mid and high latitudes. Satellite validation of ozone profiles and total ozone is also a central activity. Some activities and results are listed below:

- The stratospheric lidar data from ALOMAR have been extensively used for the validation of GOME and ENVISAT's atmospheric instruments (GOMOS, MIPAS and SCIAMACHY). This is described in a series of publications. [4, 5, 6, 7, 8]
- Leading modes of climate variability have been shown to induce a strong signature on the trend and year-to-year variability in ozone. These modes include planetary-scale components of the atmospheric circulation (the North Atlantic Oscillation, the Aleutian-Icelandic Seesaw) *(Orsolini, 2004[9])* but also more regional patterns, e.g. those associated with blocking phenomena *(Orsolini and Doblas-Reyes, 2003[10]).*
- The dynamically induced low-ozone episodes (LOE) is studied. *Orsolini et al*. (2003[11]) explained occurrences of summertime LOEs over the northern high latitudes, and Scandinavia in particular, and looked at their impact on the UV erythemal dose at the ground. An intense LOE occurred over Scandinavia during the European Heat Wave of the summer 2003 *(Orsolini and Nikulin, 2006[7]).*
- *Orsolini et al.,* (2005[12]) have studied the changes in atmospheric composition (HNO_3, NO_X), and ozone depletion occurring in the aftermath of the exceptional autumn 2003 solar storms. A highly anomalous layer enriched in nitric acid was observed in the upper stratosphere following the storms, and then slowly descended throughout the winter. Simultaneous observations of NO_2, including the nighttime polar stratosphere, revealed strongly enrichment of NO_X layers following the storms. The formation mechanism for the nitric acid layer does not seem to involve polar stratospheric clouds or aerosols, but rather, is likely to involve heterogeneous chemistry on water ion clusters, a relatively new and unknown topic.
- *Jackson and Orsolini,* (2007[13]) have developed a new technique for the estimate of ozone loss in the stratospheric polar vortex based on the assimilation of EOS MLS and SBUV observations in the Met Office data assimilation system. The method has been used to assess Arctic ozone loss during the winter 2004/05, and is aimed at better accounting for mixing and inhomogeneous descent within the vortex. The results show that data

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[4] *Steck, T. von Clarmann, H. Fischer, B. Funke, N. Glatthor, U. Grabowski, M. Höpfner, S. Kellmann, M. Kiefer, A. Linden, M. Milz, G. P. Stiller, D. Y. Wang, M. Allaart, Th. Blumenstock, P. von der Gathen, G. Hansen, F. Hase, G. Hochschild, G. Kopp, E. Kyrö, H. Oelhaf, U. Raffalski, A. Redondas Marrero, E. Remsberg, J. Russell III, K. Stebel, W. Steinbrecht, G. Wetzel, M. Yela, G. Zhang, (2007), Atmos. Chem. Phys., 7, 3639–3662.*

[5] *Iapaolo M., S. Godin-Beekmann, F. Del Frate, S. Casadio, M. Petitdidier, I.S. McDermid, T. Leblanc, D. Swart, Y. Meijer, G. Hansen, and K. Stebel, (2007) J. of Quantitative Spectroscopy and Radiative Transfer, 107, 105-119.*

[6] *Brinksma, E.J., A. Bracher, D. E. Lolkema, A. J. Segers, I. S. Boyd, K. Bramstedt, H. Claude, S. Godin-Beekmann, G. Hansen, G. Kopp, T. Leblanc, I. S. McDermid, Y. J. Meijer, H. Nakane, A. Parrish, C. von Savigny, K. Stebel, D. P. J. Swart, G. Taha, and A. J. M. Piters, (2006) Atmos. Chem. Phys.* ***6****, 197-209.*

[7] *Keckhut, P., McDermid, S., Swart, D., McGee, T., Godin-Beekmann, S., Adriani, A., Barnes, J., Baray, J.-L., Bencherif, H., Claude, H., di Sarra, A.G., Fiocco, G., Hansen, G., Hauchecorne, A., Leblanc, T., Lee, C.H., Pal, S., Megie, G., Nakane, H., Neuber, R., Steinbrecht, W. and Thayer, J. , (2004) Review of ozone and temperature lidar validations performed in the framework of the NDSC, J. Environ. Mon., 6, 721-733.*

[8] *Meijer, Y. J., Swart, D. P. J., Allaart, M., Andersen, S. B., Bodeker, G., Boyd, I., Braathen, G., Calisesi, Y., Claude, H., Dorokhov, V., von der Gathen, P., Gil, M., Godin-Beekmann, S., Goutail, F., Hansen, G., Karpetchko, A., Keckhut, P., Kelder, H. M., Koelemeijer, R., Kois, B., Koopman, R. M., Kopp, G., Lambert, J.-C., Leblanc, T., McDermid, I. S., Pal, S., Schets, H., Stubi, R., Suortti, T., Visconti, G. and Yela, M., (2004) J. Geophys. Res., 109, D23305, doi:10.1029/2004JD004834, 2004*

[9] *Orsolini, Y. J., (2004) J. Meteor. Soc. of Japan, 82, vol. 3, 941-948.*

[10] *Orsolini, Y. J. and F.J. Doblas-Reyes. (2003) Q. J. of the Royal Meteorol. Soc., 129, 3251-3263, 2003.*

[11] *Orsolini, Y.J., H. Eskes, G. Hansen, U-P. Hoppe, A. Kylling, E. Kyro, J. Notholt, R. Van der A. P. Von der Gathen, (2003) Q. J. R. Meteorol. Soc., 129, 3265-3276.*

[12] *Orsolini, Y. J., G.L. Manney, M. Santee and C.E. Randall, (2005) Geophys, Res. Lett., Vol. 32, No. 12, L12S01, 10.1029/2004GL021588.*

[13] *Jackson D.R., Y. J. Orsolini, submitted to Quart. J. Roy. Meteor. Soc., October 2007.*

assimilation methods are very promising to potentially lead to more accurate ozone-loss estimates.

- The ozone data from Tromsø have been used to establish a multi-decadal UV climatology at a nearby site (Skrova, Lofoten) with meteorological information *(Engelsen et al., 2004[14]).* For the same area UV maps have been derived for the period 1984-2002, based on various satellite observation data *(Meerkötter et al., 2003[15]).* In the frame of the EU project UVAC it was found that there is a positive correlation between maximum daily doses around 1 May and cod recruitment, in contradiction to the work hypothesis assuming a negative influence of UV on cod eggs and larvae.
- The Svalbard ozone data have been used, together with long-term observations of cloud cover at Hopen Island (Svalbard), to calculate high-Arctic UV climatology. A preliminary analysis shows that spring UV doses in fact have decreased due to an increase of cloud coverage which is larger than the simultaneous decrease in ozone *(Hansen et al., 2007[16])*.
- NILU in collaboration with the Institute for Community Medicine at the University of Tromsø, pursue research on the relationship between UV exposure, diet and vitamin D status in humans and their effects on diseases. The project applies UV simulations based on meteorological modelling data, UV measurements, questionnaire forms from cohort investigations, and blood sample analyses. NILU is in charge of health risk assessment for Europe from UV exposure within the EU project INTARESE.
- The effect of UV radiation on atmospheric chemistry is studied in EU and national projects, e.g. the UV effects on ozone and mercury.

CICERO Centre for International Climate and Research – Oslo

At CICERO changes in the total solar radiation at the surface (*Kvalevåg and Myhre, 2007*[17]) and UV (Kvalevåg et al., 2008) over industrial areas have been calculated. In the calculations changes in gases (ozone, CO_2, H_2O, CH_4, NO_2, SO_2), direct as well as indirect aerosol effect of sulphate black and organic carbon, surface albedo changes, and contrails are taken into account. For changes in the total solar radiation at the surface, aerosols is a dominating factor for the dimming over land areas, but increase in tropospheric ozone, H_2O, CH_4, NO_2 also give a small contribution. At high latitudes reduced total ozone is causing an increase in the total solar radiation at the surface *(Kvalevåg and Myhre, 2007[18])*. The changes in UV follow to a large degree the changes in the total solar radiation since pre-industrial times, i.e. with increasing values at high latitudes and a reduction over most land regions. Ozone plays a major role in this pattern, but other gases such NO_2 and SO_2 and aerosols significantly contribute to the reduced UV over most land areas *(Kvalevåg et al., 2008[18].)*

DISSEMINATION OF RESULTS

Data reporting: Ozone

The complete set of revised Dobson total ozone values from Oslo is available at The World Ozone Data Centre (WOUDC) http://www.msc-smc.ec.gc.ca/woudc/. There are established daily routines submitting ozone data from the University of Oslo and from Andøya to WOUDC. The averaged ozone profiles (2 hours) from Andøya are reported to NDACC twice a year. Preliminary lidar profiles are reported weekly to GEOMON and quality-controlled data products are submitted yearly.

NILU has collected ozone measurements from Arctic balloon flights through the Nadir database since 1988. Files are transferred and stored in the NASA-AMES 2160 format, and an automatic

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[14] Engelsen, O., G. Hansen, and T. Svenøe. (2004), Geophys. Res. Lett., 31, L12103, doi:10.1029/2003GL019241
[15] Meerkötter, R., J. Verdebout, L. Bugliaro, K. Edvardsen, G. Hansen (2003), Geophys. Res. Lett., 30, 18, 1956, doi: 10.1029/2003GL017850
[16] Hansen, G., O. Engelsen, C. Vogler, and S. Brönnimann (2007), Proc. The Polar Environment and Climate – The challenges, EUR 22965 EN, 67-69.
[17] Kvalevåg, M. M. and Myhre, G.: (2007) J. Climate, 20(19), 4874-4883.
[18] Kvalevåg, M. M., Myhre, G. and Myhre, C. E. L. (2008): Anthropogenic changes in the UV radiation at the surface during the industrial era, To be submitted, 2008.

script has been set up to convert incoming data into the CREX format that is used at ECMWF. This script also performs a series of data quality checks and can do simple corrections on erroneous input files.

Data reporting: UV

NILU has submitted spectral UV measurements from Norway to the European UV database (EUVDB). In the framework of the EU project EDUCE NILU has developed quality assurance software for spectral UV measurements. The QA software is applied automatically to all UV data submitted to EUVDB. Currently there are Brewer and Bentham UV spectral data from Andøya for the period 1998-2001 in the database.

Information to the public

Ozone

Daily total ozone values for Oslo are available at http://www.fys.uio.no/plasma/ozone/. The latest measured raw data profiles and the latest analysed ozone data from the ALOMAR Observatory at Andøya are available at http://alomar.rocketrange.no/alomar-lidar.html.

UV and ozone from GUV measurements

NILU has developed a web portal for dissemination of UV-observations and UV forecasts for Norway, http://uv.nilu.no. The content of the UV web pages are:

- UV forecast for three days for user-selected locations in Norway. The UV forecast is given for clear-sky, partly cloudy and cloudy conditions.
- Global UV forecast for common tourist destinations.
- Measured UV doses and total ozone values measured at the Norwegian stations.
- Facts on UV radiation and the ozone layer.
- Information about sun protection for different locations and situations.

The public may receive UV forecasts at user-selected locations by SMS or e-mail. The web application has been developed by NILU in co-operation with the Norwegian Radiation Protection Authority, Storm Weather Center, and the Norwegian Pollution Control Authority. In 2006 the Norwegian Meteorological Institute developed an additional UV forecast service where the weather forecast is an integrated part of the forecasted UV index.

UV indices and cloud effects measured by a GUV-instrument at the Department of Physics, University of Oslo, are presented and updated every 30 min at: http://www.fys.uio.no/plasma/ozone/. The observations performed by the Norwegian Radiation Protection Authority are available at http://www.nrpa.no/uvnett/ together with annual doses and information on sun protection.

World Meteorological Organisation Ozone Assessment 2006

NILU has contributed to the latest extensive report of WMO on the status of the ozone layer, with co-authorship of two chapters (Y. Orsolini).

Relevant scientific papers

The ozone and UV measurements performed in Norway give rise to research in collaboration with national and international partners. The reference list below gives an impression of the international collaboration and ongoing research in the Norwegian ozone and UV scientific community since 2004.

Bjerke, J.W.; Elvebakk, A.; Dominguez, E.; Dahlback, A. (2005), Seasonal trends in usnic acid concentrations of Arctic, alpine and Patagonian populations of the lichen Flavocetraria nivalis. Phytochemistry; 66:337-344

Braathen, G.O., Godin-Beekmann, S., Keckhut, P., McGee, T.J., Gross, M.R., Vialle, C. and Hauchecorne, A. (2004) Intercomparison of stratospheric ozone and temperature measurements at the Observatoire *de Haute Provence during the OTOIC NDSC validation campaign from 11 July 1997. Atmos. Chem. Phys. Discuss., 5, 5303-5344.*

Brinksma, E.J., A. Bracher, D. E. Lolkema, A. J. Segers, I. S. Boyd, K. Bramstedt, H. Claude, S. Godin-Beekmann, G. Hansen, G. Kopp, T. Leblanc, I. S. McDermid, Y. J. Meijer, H. Nakane, A. Parrish, C. von Savigny, K. Stebel, D. P. J. Swart, G. Taha, and A. J. M. Piters, (2006) Geophysical Validation of SCIAMACHY Limb Ozone Profiles, Atmos. Chem. Phys. ***6****, 197-209.*

Brunner, D., Staehelin, J., Rogers, H.L., Köhler, M.O., Pyle, J.A., Hauglustaine, D.A., Jourdain, L., Berntsen, T.K., Gauss, M., Isaksen, I.S.A., Meijer, E., van Velthoven, P., Pitari, G., Mancini, E., Grewe, V. and Sausen, R. (2005) An evaluation of the performance of chemistry transport models - Part 2: Detailed comparison with two selected campaigns. Atmos. Chem. Phys., 1, 107-129.

Brustad, M., Alsaker, E., Engelsen, O., Aksnes, L. and Lund, E. (2004) Vitamin D status in middle-aged women at 65-71 degrees north in relation to dietary intake and exposure to ultraviolet radiation. Public Health Nutr., 2, 327-335, doi:101029/2002JD003325.

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PROJECTS AND COLLABORATION

Norwegian institutions and scientists are participating in numerous international and national projects. The following section gives an overview of the most important projects related to ozone and UV research in Norway.

International projects

ASSET: "Assimilation of Envisat data" (ASSET) project (2003-2006) was a major European initiative in Earth Observation. Its overall rationale was to use the techniques of data assimilation to develop a European capability for chemical and UV forecasting, and provide analyses for coupled climate/chemistry studies. The objectives were: (1) assess the strategies for exploiting research satellite data by the Numerical Weather Prediction (NWP) community, and (2) using this data to investigate the distribution and variability of atmospheric chemical species. ASSET had several achievements, some of them firsts in the field; we highlight two: (i) The first implementation of an algorithm to assimilate limb radiances into a NWP system, demonstrating the feasibility of direct assimilation of limb radiances; (ii) The first intercomparison of ozone analyses. NILU was a partner and constructed a database to disseminate the results from the ASSET project to the EO community. Lahoz et al. (2007), *Atmos. Chem. Phys.*, **7**, 1773-1796. Web-site: http://darc.nerc.ac.uk/asset,

GEOMON Global Earth Observation and Monitoring of the atmosphere (2007-2010) is a European project contributing to GEOSS. Its mission is to build an integrated pan-European atmospheric observing system of greenhouse gases, reactive gases, aerosols, and stratospheric ozone. Ground-based and air-borne data are sustained and analysed, complementary with satellite observations, in order to quantify and understand the ongoing changes of the atmospheric composition. The key objectives of the ozone activities are to continue the monitoring of O_3, NO_2, BrO, Cl_y/F_y, T, H_2O, aerosol/PSC from ground (NDACC) and space. Further the development of homogenisation and consistency of time series are central and the identification of links between stratospheric ozone and climate changes. Both NILU and the University of Oslo (Dep. of Geosciences) participate in this project. Web-site: *http://geomon.ipsl.jussieu.fr/*

NDACC: The Network for the Detection of Atmospheric Composition Change (1991-> present) is a set of high-quality remote-sounding research stations for observing and understanding the physical and chemical state of the stratosphere. Ozone and key ozone-related chemical compounds and parameters are targeted for measurement. The NDAAC is a major component of the international middle atmosphere research effort and has been endorsed by national and international scientific agencies, including the International Ozone Commission, the United Nations Environment Programme, and the World Meteorological Organization. Web-site: http://www.ndsc.ncep.noaa.gov/

SCOUT-O3: Stratospheric-Climate Links with Emphasis on the Upper Troposphere and Lower Stratosphere (2004-2008). This is an integrated project funded by EU. The central aim of the project is to provide scientific knowledge for global assessments on ozone depletion and climate change for the Montreal and Kyoto Protocols. The SCOUT-O3 project aims to provide new knowledge for EU and national governments, which could be used to develop the European position for sustainable development. SCOUT-O3 involves the research efforts of 59 partners with more than 100 scientific groups; and takes full advantage of new and existing research facilities developed at a national level. Both NILU and the University of Oslo (Dep. of Geosciences) participate in this project. Web-site: http://www.ozone-sec.ch.cam.ac.uk/scout_o3/

INTARESE: *Integrated assessment of health risks of environmental stressors in Europe* (2005-2009) brings together a team of internationally lead scientists in the areas of epidemiology, environmental science and biosciences to collaborate on developing and applying new, integrated approaches to the assessment of environmental health risks and consequences, in support of European policy on environmental health. NILU is responsible for implementation of the human health risk assessment of ultraviolet radiation. Web-site: http://www.intarese.org

National projects

ARCTIC_LIS *Arctic variability and climate change linked to stratosphere* (2007-2011) is a NILU-UiO collaboration funded by the Norwegian Research Council. It aims to investigate the impact of climate change on stratospheric ozone chemistry and transport, especially upon the ozone recovery, using a comprehensive, stratospheric chemistry model. It will also carry out exploratory studies on processes, still poorly represented or missing altogether in current chemistry-climate models, and which will be under scrutiny during the International Polar Year: I) the role of solar cycle and solar-terrestrial coupling from energetic particle precipitation (EPP), on the stratospheric ozone and nitrogen chemistry and budget, II) the role of very-short-lived bromine compounds on polar ozone depletion.

FARIN: *Factors Controlling UV radiation in Norway* (2002-2006). The Norwegian Research Council funds the project. The main objective of the project is to quantify the various factors controlling UV radiation in Norway, including clouds, ozone, surface albedo, aerosols, latitude, and geometry of exposed surface including a comprehensive instrument comparison with spectral and broad band meters included in the project. The project applies both UV measurements (including the Norwegian GUV network) and radiative transfer modelling. Web-site: http://www.nilu.no/farin/

LLAE *Light and Life in African Environments* (2002-2007). In this project a network of NILU-UV instruments has been established in the African tropical belt: Serrekunda (Gambia), Kampala (Uganda), and Dar-es-Salaam (Tanzania). Further, 3 instruments are located in Kilimanjaro (Tanzania) at 1800 m, 3700 m and 5700 m. Total ozone columns, UV-doses and cloud effects are derived from the measurements at all sites. The project was funded by Norwegian Council for Higher Education's Programme for Development Research and Education. The project continues in 2008 with funding from internal sources from Department of Physics, University of Oslo.

MAREAS *Material fluxes from the Russian Rivers Ob and Yenisey: Interactions with climate and effects on Arctic Seas* (2003-2006). The main objectives of the project are to improve flux assessments of DOC, nutrients and contaminants from the Ob and Yenisey rivers in Russia and to study the hydro-optical properties of the Kara Sea. The linkage between DOC, UV light regimes, primary production and contaminant will also be elucidated.

MERFATE *Occurrence and fate of springtime atmospheric deposition of mercury in the Arctic* (2007-2010), funded by the Norwegian Research Council. Deposition of mercury (Hg) from the atmosphere to the sensitive polar ecosystems is of particular interest in the Arctic. This is because studies have indicated the possibility of large depositional fluxes of Hg occurring during the polar spring (so-called Hg Atmospheric Depletion Events or AMDEs). UV radiation is one of the main driving factors in these processes and NILU and NTNU pursue further knowledge about this role of UVR.

SATLUFT *Use of Satellite observations in the national and regional assessment of air quality, the atmospheric ozone layer, ultraviolet radiation, and greenhouse gases (2007-2010).* The main objectives of the project are to use Earth Observation data to improve the national and regional monitoring and assessment of the stratospheric ozone layer and surface UV exposure, the air quality in Europe and greenhouse gases. NILU coordinates this project which is funded by the Norwegian Space Centre and the European Space Agency,
Web-site: http://www.nilu.no/projects/SatLuft/index.cfm

Atmo-TROLL: *Atmospheric research and monitoring at Troll – a long-term observational program (2007-2010).* This programme intends to establish new knowledge on annual and short-term variability as well as long-term changes of climate and pollution parameters. The list of parameters comprises physical, optical and chemical properties of aerosols, ozone and UV, organic and inorganic pollution including Hg, CO and NMHC and surface ozone. The project is coordinated by NILU and funded by The Research Council of Norway.
Web-site: http://observatories.nilu.no/Observatories/Troll/tabid/417/Default.aspx

UTLS-Air: *Chemistry in the upper troposphere and lower stratosphere - impact of aircraft emissions* (2003-2006). The overall scientific aim of this project is to improve our understanding of the processes controlling the chemistry in the upper troposphere-lower stratospheric region with a special focus on aircraft impact. The present and future impact of aircraft will be studied.
Web-site: http://folk.uio.no/asovde/utls-air/home.html

FUTURE PLANS

A short presentation of future plans are summarised below:

- The Quadrennial Ozone Symposium 2008 will be arranged in Tromsø, Norway from June 29th - July 5th. The Symposium is jointly organized by the International Ozone Commission and the European Commission and the local organising committee is lead by Ivar Isaksen, Dept. of Geophysics, University of Oslo.
- The Tromsø Dobson #14 will be moved to Tibet University, Lhasa, Tibet, probably in 2009. The Oslo Dobson #56 will be moved to Makerere University, Kampala, Uganda, probably in 2009 (this is managed by Dept. of Physics, University of Oslo).
- NILU has deployed a NILU-UV instrument that is installed at the Norwegian Antarctic Troll Station (71° S). Analysis, further development, and applications of the instrument are planned for the upcoming years and effect studies are forthcoming.
- NILU plans to use multiple information sources (satellite, laboratory data, chemical model, data assimilation) to quantify uncertainties in key chemical parameters and transport mechanisms associated with stratospheric ozone chemistry. Multiple assimilation and chemistry transport model experiments will quantify uncertainties by confronting models with observations; these uncertainties will be input to multi-model climate-chemistry model (CCM) experiments. A 12-partner proposal led by NILU has been submitted to FP7.
- University of Oslo plans to study impacts of climate chemistry interactions on ozone recovery, and to study the impact of very short lived bromine source gases on stratospheric ozone.
- Adaptation and maintenance of NILU-developed UV radiation simulation software to specific user needs continues, especially with respect to the popular FastRT model.
- Further efforts will be put into the re-evaluation of the Svalbard total ozone data 1950-1962. More recent data from this site are stored in the WOUDC database (since 1984), but a comparison with TOMS and SAOZ measurements shows significant offsets. Therefore, these data should be quality-assessed.

- The historical Dobson ozone time series from Tromsø contains many days where a profile analysis using the Umkehr method may be applicable. The period prior to 1950 is very interesting as there were several winters with frequent PSC displays and low ozone values in late winter. However, for such a study funding has to be secured.
- There will be more focus on studies of solar radiation and the aerosols influence on the direct and diffuse radiation.
- There will be more focus on studies of the effects of UV radiation on both biological systems and materials.

NEEDS AND RECOMMENDATIONS

At present, ozone monitoring has a weak financial basis in Norway. Since the WMO-UNEP meeting in 2005 the ozone sondes at Ørlandet and UV observations in Ny-Ålesund have been excluded from the national monitoring programme due to lack of financial support for these monitoring activities. Also the UV instrument for monitoring BrO/OClO terminated this year due to low financial support. In order to secure a continuous operation of total ozone monitors and profiling instruments, predictable multi-annual funding schedules should be established in order to free operations from additional funding pathways, e.g. satellite validation projects and short-time research projects. There is a certain need of stable long-term economic support to be able to run instruments properly and continuously, which rarely are secured through research projects. The re-evaluation of the historical ozone series has clearly revealed the need of observational continuity to establish high-quality long-term data sets, which are essential for climatologically studies in a wider sense.

We also recommend an even closer international collaboration on UV radiation, particularly with respect to UV health risk assessment, UV effects, quality assurance of measurements, databases and forecasting.

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