Ozone research and monitoring in 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.

1. 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 and total ozone column measurements at the Norwegian Troll station in Antarctica started in 2007. They are financed by the Norwegian Research Council.*

1.1 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 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 in operation since 1991. Near real time data can be found at http://saoz.obs.uvsq.fr. 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).

1.2 Profile measurements of ozone and other parameters relevant to ozone loss

Together with 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.

1.3 UV measurements

1.3.1 *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 month against relative calibration laps in order to keep track of instrument drift. 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.

1.3.2 Spectroradiometers

Spectral UV irradiances (global scans) are measured at least twice every hour with the Brewer instruments at the Department of Physics, University of Oslo, and at ALOMAR.

1.4 Calibration activities

1.4.2 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.

1.4.3 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

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

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. (2008)[2].

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

2.1 Ozone observations in Oslo

Table 1: Annual percentage changes in total ozone over Oslo for the period 1.1.1979 to 31.12.2009. The numbers in parenthesis represent uncertainty (1σ).

Time period		Trend (% per year)
Winter:	December – February	-0.05 (0.10)
Spring:	March – May	-0.16 (0.09)
Summer:	June - August	-0.02 (0.05)
Fall:	September - November	-0.05 (0.04)
Annual		-0.08 (0.04)

In order to detect possible ozone reductions and trends over Oslo we have investigated total ozone values from 1979 to 2008. 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 –0.16% 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 –0.08% 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.

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*[3]*).*

2.2 Ozone observations at Andøya

Table 2: Annual percentage changes in total ozone over Andøya/Tromsø for the period 1979 to 2009. The numbers in parenthesis represent uncertainty (1σ).

Time period	Trend (% per year)
Spring: March – May	-0.00 (0.01)
Summer: June - August	-0.02 (0.04)
Annual (March-September)	-0.00 (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 2. No significant trends were observed for Andøya for this time period.

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*[4]*, Vogler et al., 2006*[5]*).* 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.

[2] Johnsen, B., B. Kjeldstad, T., Nakken Aalerud, L. T. Nilsen, J., Schereder, M. Blumthaler, G. Bernhard, C. Topaloglou, O. Meinander, A. Bagheri, J. R. Slusser, J. Davis (2008), *J. Geophys. Res.*, 113, D15206, doi:10.1029/2007JD009731.
[3] Orsolini, Y. J. and G. Nikulin, (2006) Quart. *J. Roy. Meteor. Soc.*, 132, 667-680.
[4] Hansen, G., and T. Svenøe, (2005) J. Geophys. Res., 110, no. D10, D10103,doi: 10.1029/2004JD005387
[5] Vogler, C., S. Brönnimann, and G. Hansen (2006) *Atmos. Chem. Phys.*, 6, 4763–4773

2.3 UV observations

Table 3: Annual integrated UV doses (kJ/m^2) at three stations during the period 1995 - 2009.

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	219.4		No measurements
2007	351.8	253.3		No measurements
2008	375.3	266.5		No measurements
2009	278.6	254.1		No measurements

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

Annual UV doses for the period 1995 - 2009 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.

3 THEORY, MODELLING, AND OTHER RESEARCH

3.1 University of Oslo

Department of Geosciences runs two models to study stratospheric ozone, namely Oslo CTM3 (updated version of the CTM2) and WACCM. The Oslo CTM3 model is a global three-dimensional chemical transport model covering the troposphere and stratosphere. The CTM3 is updated to the 2009 version of the University of California, Irvine CTM transport. The model core has been substantially changed in this process, comprising faster transport and an update of the photolytic calculations.

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 CTM3 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 compared with observations. The Oslo CTM2 will eventually be out of date, but will still be available.

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.

In general, the *Department of Geosciences* are working substantially on stratospheric modelling in order to better understand how the ozone-layer dynamics work. Comprehensive research on atmospheric ozone modelling has been performed by comparing observations with model results. The results show that it is possible to reconstruct the distribution of the ozone layer. The results are described in several publications.[6,7,8,9]

[6] Isaksen I.S.A., Zerefos C, Kourtidis K, Meleti C, Dalsøren SB, Sundet JK, Grini A, Zanis P, Balis D (2005), *Tropospheric ozone changes at unpolluted and semipolluted regions by stratospheric ozone changes.* Journal of Geophysical Research 110, D02302. doi:10.1029/2004JD004618

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.

3.2 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. [10, 11, 12, 13, 14]
- 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[15])* but also more regional patterns, e.g. those associated with blocking phenomena *(Orsolini and Doblas-Reyes, 2003[16]).*
- The dynamically induced low-ozone episodes (LOE) is studied. *Orsolini et al*. (2003[17]) 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[18]) 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.

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[7] Søvde, O.A. Orsolini, Y.J. , Jackson, D.R. , Stordal, F. , Isaksen, I.S.A. , Rognerud, B. (2011) Estimation of Arctic O_3 loss during winter 2006/2007 using data assimilation and comparison with a chemical transport model, Quarterly Journal of the Royal Meteorological Society**,** 137, 654, 118-128

[8] Eleftheratos, K., C..S. Zerefos, E. Gerasopoulos, I.S.A. Isaksen, B. Rognerud, S. Dalsøren, C. Varotsos and S. Gazerian, (20110 A note on the comparison between total ozone from Oslo CTM2 model and SBUV satellite data, International Journal of Remote Sensing (In press)

[9] Isaksen, I.S.A. and S.B. Dalsøren, Improving estimates of the major atmospheric cleaning agent OH, (2011) Science, 331, DOI: 10.1126,

[10] 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.

[11] 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.

[12] 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.

[13] 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.

[14] 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

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

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

[17] 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.

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

- *Jackson and Orsolini,* (2007[19]) 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 winters 2004/05 and 2006/07 (abstract presented at the EGU General assembly, 2008) and is aimed at better accounting for mixing and inhomogeneous descent within the vortex. The results show that data 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[20]).* For the same area UV maps have been derived for the period 1984-2002, based on various satellite observation data *(Meerkötter et al., 2003[21]).* 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[22])*.
- Department of Community Medicine, University of Tromsø, has in collaboration with NILU conducted two field studies[23,24] and developed a method[25] for estimation of UV induced vitamin D status in humans. The studies applied UV simulations based on meteorological modelling data, UV measurements, questionnaire forms from cohort investigations, and blood sample analyses. The field studies and the developed method formed the basis for a larger cohort study on approx 41.000 women on the relation between oral and UV induced vitamin D status and breast cancer risk. No relation was found. NILU is also in charge of health risk assessment for Europe from UV exposure within the EU project INTARESE.
- The EU CANDIDOZ project (Chemical and Dynamical Influences on Decadal Ozone Change) investigated the chemical and dynamical influences on decadal ozone trends focusing on the Northern Hemisphere. In this project the long-term ozone series at Tromsø[26] and Svalbard[27] was re-evaluated and used to quantify factors contributing to past ozone variability and trends.

3.3 CICERO Centre for International Climate and Research – Oslo

At CICERO changes in the total solar radiation at the surface (*Kvalevåg and Myhre, 2007*[28]) and UV (Kvalevåg et al., 2008[29]) 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*

[19] Jackson D.R., Y. J. Orsolini, submitted to Quart. J. Roy. Meteor. Soc., October 2007.
[20] Engelsen, O., G. Hansen, and T. Svenøe. (2004), *Geophys. Res. Lett*., 31, L12103, doi:10.1029/2003GL019241
[21] Meerkötter, R., J. Verdebout, L. Bugliaro, K. Edvardsen, G. Hansen (2003), *Geophys. Res. Lett*., 30, 18, 1956, doi: 10.1029/2003GL017850
[22] Hansen, G., O. Engelsen, C. Vogler, and S. Brönnimann (2007), Proc. The Polar Environment and Climate – The challenges, EUR 22965 EN, 67-69.
[23] Brustad et al. (2007): Seasonality of UV-radiation and vitamin D status at 69 degrees north. Photochem. Photobiol. Sci., 6, 903-8
[24] Edvardsen, K. (2007): The solar UV radiation level needed for cutaneous production of vitamin D3 in the face. A study conducted among subjects living at a high latitude (68° N). Photochem. Photobiol. Sci., 6, 57-62
[25] Edvardsen et al. (2009): Duration of vitamin D synthesis from weather model data for use in prospective epidemiological studies. Int. J. Biometeorol., 53, 451-459.
[26] Hansen, G., Svenøe, T.(2005): Multilinear regression analysis of the 65-year Tromsø total ozone series, J. Geophys. Res., 110, D10103, doi:10.1029/2004JD005387
[27] Vogler, C., Br¨onnimann, S., and Hansen, G.(2006): Re-evaluation of the 1950–1962 total ozone record from Longyearbyen, Svalbard, Atmos. Phys. Chem., 6, 4763–4773
[28] Kvalevåg, M. M. and Myhre, G.: (2007) J. Climate, 20(19), 4874-4883.
[29] Kvalevåg, M. M., Myhre, G., and Lund Myhre, C. E. (2009), *Atmos. Chem. Phys*., 9, 7737-7751

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*[25]*.)*

4. DISSEMINATION OF RESULTS

4.1 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 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.

4.2 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.

4.3 Information to the public

4.3.1 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.

4.3.2 UV and ozone from GUV measurements

NILU has developed a web portal for dissemination of UV-observations and UV forecasts for Norway and common global tourist destinations, 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.

4.4 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.

Brustad M., K. Edvardsen, T. Wilsgaard, O. Engelsen, L. Aksnes, E. Lund (2007) Seasonality of UV-radiation and vitamin D status at 69 degrees north, Photochemical and Photobiological Sciences, 6, 903-908, doi:10.1039/b702947k.

Brönnimann, S., Luterbacher, J., Staehelin, J., Svendby, T.M., Hansen, G. and Svenøe, T. (2004) Extreme climate of the global troposphere and stratosphere in the 1940-42 related to El Nino. *Nature, 7011*, 971-974.

Christensen, T., Knudsen, B.M., Streibel, M., Andersen, S.B., Benesova, A., Braathen, G., Claude, H., Davies, J., De Backer, H., Dier, H., Dorokhov, V., Gerding, M., Gil, M., Henchoz, B., Kelder, H., Kivi, R., Kyrö, E., Litynska, Z., Moore, D., Peters, G., Skrivankova, P., Stübi, R., Turunen, T., Vaughan, G., Viatte, P., Vik, A.F., von der Gathen, P. and Zaitcev, I. (2005) Vortex-averaged Arctic ozone depletion in the winter 2002/2003. *Atmos. Chem. Phys., 1*, 131-138.

Dahlback, A., Eide, H., Høiskar, B.A.K., Olsen, R.O., Schmidlin, F.J., Tsay, S-C. and Stamnes, K. (2005) Comparison of data for ozone amount and ultraviolet doses obtained from simultaneous measurements with various standard ultraviolet instruments. *Opt. Eng.*, *4*, 041010.

Dahlback, A., N. Gelsor, J. J. Stamnes, and Y. Gjessing (2007), UV measurements in the 3000-5000 m altitude region in Tibet, *J. Geophys. Res*., 112, D09308, doi:10.1029/2006JD007700

Edvardsen, K., M. Brustad, O. Engelsen and L. Aksnes (2007) The Solar UV Radiation Level Needed for Cutaneous Production of Vitamin D_3 in the Face. A Study Conducted Among Subjects Living at a High Latitude (68°N), Photochemical and Photobiological Sciences, 6, 57-62, doi:10.1039/b613263d.

Edvardsen, K., M. Brustad, O. Engelsen (2009). Duration of vitamin D synthesis from weather model data for use in prospective epidemiological studies. *Int J Biometerol.* 53(5): 451-9.

Engelsen, O., Brustad, M., Aksnes, L. and Lund, E. (2005) Daily Duration of Vitamin D Synthesis in Human Skin with Relation to Latitude, Total Ozone, Altitude, Ground Cover, Aerosols and Cloud Thickness. Accepted for publication in *"Photochemistry and Photobiology"*, 2005. Published online 4 June 2005. doi: 10.1562/2004-11-19-RN-375

Engelsen, O., Hansen, G. and Svenøe, T. (2004) Long-term (1936–2003) ultraviolet and photosynthetically active radiation doses at a north Norwegian location in spring on the basis of total ozone and cloud cover. *Geophys. Res. Lett.*, *31*, L12103, doi:10.1029/2003GL019241.

Engelsen, O. and Kylling, A. (2005), Fast simulation tool for ultraviolet radiation at the earth's surface. *Opt. Eng., 4*, 041012.

Goutail, F., Pommereau, J.-P., Lefèvre, F., Van Roozendael, M., Andersen, S.B., Kåstad Høiskar, B.-A., Dorokhov, V., Kyrö, E., Chipperfield, M.P. and Feng, W. (2005) Early unusual ozone loss during the Arctic winter 2002/2003 compared to other winters. *Atmos. Chem. Phys., 5*, 665–677.

Hansen, G., O. Engelsen, C. Vogler, and S. Brönnimann (2007), Proc. The Polar Environment and Climate – The challenges, EUR 22965 EN, 67-69.

Hansen, G. and T. Svenøe, (2005) Multi-linear regression analysis of the 65-year Tromsø total ozone series. *J. Geophys. Res., 110* (D10), D10103, doi:10.1029/2004JD005387.

Harris, N.R.P., E. Kyrö, J. Staehelin, D. Brunner, S-B. Andersen, S. Godin-Beekmann, S. Dhomse, P. Hadjinicolaou, G. Hansen, I. Isaksen, A. Jrrar, A. Karpetchko, R. Kivi, B. Knudsen, P. Krizan, J. Lastovicka, J. Maeder, Y. Orsolini (2008), J.A. Pyle, M. Rex, K. Vanicek, M. Weber, I. Wohltmann, P. Zanis, and C. Zerefos' Ozone trends at northern mid- and high latitudes – a European perspective, *Ann. Geophys., in press.*

Hoor, P., J. Borken-Kleefeld, D. Caro, O. Dessens, O. Endresen, M. Gauss, V. Grewe, D. Hauglustaine, I.S.A. Isaksen, P. Jøckel, J. Lelieveld, E. Meijer, D. Olivie, M. Prather, C. Schnadt Poberaj, J. Staehelin, Q. Tang, J. van Aardenne, P. van Velthoven, and R. Sausen, The impact of traffic emissions on atmospheric ozone and OH: Results from QUANTIFY, *ACP*, 2009

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, GOME ozone profiles retrieved by neural network techniques: A global validation with lidar measurements, J*. of Quantitative Spectroscopy and Radiative Transfer*, 107, 105-119, 2007.

Jackson D.R., Y. J. Orsolini, Estimation of Arctic ozone loss in winter 2004/05 based on assimilation of EOS MLS observations, (2007) submitted to Quart. J. Roy. Meteor. Soc., October 2007

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 within the framework of the Network for the Detection of Stratospheric Change. *J. Environ. Monit., 9*, 721-733.

Kylling, A., Webb, A.R., Kift, R., Gobbi, G.P., Ammannato, L., Barnaba, F., Bais, A., Kazadzis, S., Wendisch, M., Jäkel, E., Schmidt, S., Kniffka, A., Thiel, S., Junkermann, W., Blumthaler, M., Silbernagl, R., Schallhart, B., Schmitt, R., Kjeldstad, B., Thorseth, T.M., Scheirer, R. and Mayer, B. (2005) Spectral actinic flux in the lower troposphere: measurement and 1-D simulations for cloudless, broken cloud and overcast situations. *Atmos. Chem. Phys., 2,* 1421-1467.

Kvalevåg, M. M. and Myhre, G.: Human impact on direct and diffuse solar radiation during the industrial era, (2007) J. Climate, 20(19), 4874-4883.

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.

Lagunova, Z. Porojnicu, A.C., Dahlback, A., Berg, J.P., Beer, T.M., and Moan, J. (2007) Prostate cancer survival is dependent on season of diagnosis. Prostate 67, 1362-1370. doi: 10.1002/pros.20577

Lakkala, K.; Redondas, A.; Meinander, O.; Torres, C.; Koskela, T.; Cuevas, E.; Taalas, P.; Dahlback, A.; Deferrari, G.; Edvardsen, K.; Ochoa, H.. (2005) Quality assurance of the solar UV network in the Antarctic. *J. Geophys. Res.* ;110 ,D15101, doi:10.1029/2004JD005584.

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) Pole-to-pole validation of Envisat GOMOS ozone profiles using data from ground-based and balloon sonde measurements, J. Geophys. Res., 109, D23305, doi:10.1029/2004JD004834, 2004

Moan, J.E., Porojnicu, A.C., Robsahm, T.E., Dahlback, A., Juzeniene, A., Tretli, S. and Grant, W. (2005) Solar radiation, vitamin D and survival rate of colon cancer in Norway. *J. Photochem. Photobiol. B, Biol. 3*, 189-193.

Moan, J., Porojnicu, A.C., and Dahlback, A. (2007) Epidemiology of cutaneous malignant melanoma. In: Skin cancer prevention. Ed. U.Ringborg, Y.Brandberg, E.W.Breitbart and R.Greinert. ISBN 0849398894. Informa Healthcare, NY, USA, pp. 179-201

Moan, J., Porojnicu, A.C., Dahlback, A., and Setlow, R.B. (2008) Addressing the health benefits and risks, involving vitamin D or skin cancer, of increased sun exposure, *PNAS*., vol. 105, 668-673.

Orsolini, Y. J. (2004) Seesaw Ozone Fluctuations between the North Pacific and Atlantic in Late Winter, *J. Meteor. Soc. Japan*, *3*, 941-948.

Orsolini, Y. J. and F.J. Doblas-Reyes. (2003) Ozone signatures of climate patterns over the Euro-Atlantic sector in the spring, *Q. J. of the Royal Meteorol. Soc*., 129, 3251-3263, 2003.

Orsolini, Y.J., Manney, G.L., Santee, M.L. and Randall, C.E. (2005) An upper stratospheric layer of enhanced HNO_3 following exceptional solar storms. *Geophys. Res. Lett., 32*, L12S01, doi:10.1029/2004GL021588.

Orsolini, Y. J. and G. Nikulin, A low-ozone episode during the European heat wave of August 2003, (2006) Quart. *J. Roy. Meteor. Soc.*,, 132, 667-680.

Orsolini, Y.J., J. Urban and D. Murtagh**,** A climatology of nitric acid satellite observations from the Odin/SMR instrument (2001-2007), PART II : High-altitude polar enhancements, Atmospheric Chemistry and Physics, 2008 (submitted).

Porojnicu, Alina Carmen; Lagunova, Zoya; Robsahm, Trude Eid; Berg, Jens Petter; Dahlback, Arne; Moan, Johan Emilian. Changes in risk of death from breast cancer with season and latitude : Sun exposure and breast cancer survival in Norway.. *Breast Cancer Research and Treatment* 2007;102(3):323-328

Porojnicu, Alina Carmen; Robsahm, Trude Eid; Dahlback, Arne; Berg, Jens Petter; Christiani, David; Bruland, Øyvind S; Moan, Johan Emilian. Seasonal and geographical variations in lung cancer prognosis in Norway does Vitamin D from the sun play a role? . *Lung Cancer* 2007;55(3):263-270

Randall, C.E., Harvey V.L., Manney G.L., Orsolini Y. J., Codrescu M., Sioris C., Brohede S., Haley C., Gordley L.L., Zawodny J.M., and J.M. Russell (2005) III, Stratospheric effects of energetic particle precipitation in 2003-2004, *Geophys. Res. Lett*., 32, No. 5, L05802, doi:10.1029/2004GL022003.

Robsahm, T.E., Tretli, S., Dahlback, A. and Moan, J.E. (2004) Vitamin D-3 from sunlight may improve the prognosis of breast-, colon- and prostate cancer (Norway). *Cancer Causes Control*, *2*, 149-158

Rodríguez, E., Frioud, M., Gausa, M., Stebel, K., Mogo, S., Prats, N., Torres, B., Toledano, C., Bastidas, A., Berjón, A., Cachorro, V., de Frutos, A.M. (2008), Optical properties of tropospheric aerosols derived from lidar and sun photometer measurements at ALOMAR (69N) in 2005 and 2006. *Óptica Pura y aplicada, 42, 183-190.*

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, Bias determination and precision validation of ozone profiles from MIPAS-Envisat retrieved with the IMK-IAA processor, Atmos. Chem. Phys., 7, 3639–3662, 2007

Sobolewski, P., J. W. Krzy´scin, J. Jarosławski, and K. Stebel (2008), Measurements of UV radiation on rotating vertical plane at the ALOMAR Observatory (69N, 16E), Norway, June 2007, *Atmos. Chem. Phys. Discuss*., 8, 21–45.

Svendby, T.M. and Dahlback, A. (2004) Statistical analysis of total ozone measurements in Oslo, Norway, 1978-1998. *J. of Geophys. Res.*; 109, D16107, doi:10.1029/2004JD004679.

Vandaele, A. C., Fayt, C., Hendrick, F., Hermans, C., Humbled, F., Van Roozendael, M., Gil, M., Navarro, M., Puentedura, O., Yela, M., Braathen, G., Stebel, K., Tørnkvist, K., Johnston, P., Kreher, K., Goutail, F., Mieville, A., Pommereau, J.-P., Khaikine, S., Richter, A., Oetjen, H., Wittrock, F., Bugarski, S., Frieß, U., Pfeilsticker, K., Sinreich, R., Wagner, T., Corlett, G. and Leigh, R. (2005) An intercomparison campaign of ground-based UV-visible measurements of NO_2, BrO, and AClO slant columns: Methods of analysis and results for NO_2. *J. Geophys. Res., 110*, D08305, doi:10.1029/2004JD005423.

van der Mei I.A.F., Ponsonby A.-L., Engelsen O., Pasco J.A., McGrath J.J., Eyles D.W., Blizzard L., Dwyer T., Lucas R., Jones G. (2007) The high prevalence of vitamin D insufficiency across Australian populations is only partly explained by season and latitude. Environmental Health Perspectives, Aug:115(8), 1132-39.

Vogler, C., S. Brönnimann, and G. Hansen (2006) Re-evaluation of the 1950-1962 total ozone record from Longyearbyen, Svalbard, *Atmos. Chem. Phys.*, 6, 4763–4773.

Webb, A.R. and O. Engelsen (2006) Calculated Ultraviolet Exposure Levels for a Healthy Vitamin D Status. Photochemistry and Photobiology. 82(6), 1697–1703.

5. 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

GEOMON Global Earth Observation and Monitoring of the atmosphere (2007-2011) 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/

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

SHIVA: *Stratospheric ozone: Halogen Impacts in a Varying Atmosphere* (2009-2012)

aims to reduce uncertainties in present and future stratospheric halogen loading and ozone depletion, resulting from climate feedbacks between emissions and transport of ozone depleting substances

(ODS). Of particular relevance will be studies of short and very short-lived substances (VSLS) with climate-sensitive natural emissions. We will perform field studies of ODS production, emission and transport in understudied, but critical, regions of the tropics using ship, aircraft and ground-based instrumentation. We will parameterise potential climate sensitivities of emissions based on inter-dependencies derived from our own field studies, and surveys of ongoing work in this area. Web-site: http://shiva.iup.uni-heidelberg.de

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.

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 program 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-http://observatories.nilu.no/Observatories/Troll/tabid/417/Default.aspx

UViversal: *Industrial Verification of a Self-calibrating, Accurate and Non-expert ultraviolet (UV) Irradiance Meter (2009-2011).* The UViversal verification project will develop a new UV irradiance meter, technology which will allow for better UV and ozone measurements, along with making possible for non-experts to precisely measure and monitor UV irradiance. We will enable UViversal to calibrate itself and alter the internal detectors to a non-silicon based technology which will allow for better ozone measurements at lower solar angles and increase the applicability of the instrument throughout the year in areas further north and south.

6. FUTURE PLANS

A short presentation of future plans are summarised below:

- NILU has deployed a NILU-UV instrument that is installed at the Norwegian Antarctic Troll Station (71º S). Analysis, further development, and applications of the instrument are planned for the upcoming years. NILU will continue the focus on the ozone and UV monitoring activity, in order to establish a high quality data series which is important both for validation and UV/ozone research

- Re-evaluation of Tromsø (since 1994) and Oslo (since 1990) Brewer ozone data series according to better instrument specifications and ozone absorption spectrum, will be conducted during 2011 and reported to the WOUDC in Canada.
- NILU will continue the cooperation with CNRS, France, regarding the long-term series of measurements of O_3, NO_2 and other trace gases, with the newly upgraded SAOZ instrument in Ny-Ålesund.
- NILU will continue in participating in the NDACC and UV/vis workgroup.
- Ny-Ålesund will continue to be included in the UV monitoring programme as long as the financial situation allows it.
- NILU already are involved in community medicine activities related to ozone/UV and health and will continue to establish cooperation with the community medicine institutions

7. NEEDS AND RECOMMENDATIONS

For the past 6 years ozone and UV monitoring in Norway has been suffering from lack of funding. Since 2005 the ozone sondes at Ørlandet and UV observations in Ny-Ålesund have been excluded from the national monitoring programme, but Ny-Ålesund will be included in the programme from 2010, if future funding allows it. The UV-monitoring programme in Norway is a split cooperation between the Norwegian Radiation Protection Authority (NRPA) and NILU, but is funded from different sources. This situation is untenable, as the funding to NRPA is on a long-term basis, and the funding to NILU relies more on short term decisions. Also the LIDAR measurements for ozone profile observations at Andøya are in danger of being excluded due to lack of funding.

In general there is a need for predictable multi-annual funding schedules in order to free operations from additional funding sources. In order to manage surveillance programmes and run instruments properly and continuously, stable long-term economic support is warranted. The trend over the last decade has been that long-term monitoring programmes have been supported through other channels, like satellite validation or other short-term research projects. This is a concern regarding the stability and quality of long-term data sets needed for trend analyses, in particular.

Monitoring of UV radiation and atmospheric ozone is not only a matter of environmental issues. Recommendation of closer international collaboration on UV health risk assessment, UV effects, quality assurance of measurements, databases and forecasting is thus obvious.