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Statlig program for forurensningsovervåking

Annual report 2009 (1080/2010)

Monitoring of the atmospheric ozone layer and natural ultraviolet radiation

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Monitoring of the atmospheric ozone layer and natural ultraviolet radiation

Rapport
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Annual report 2009

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Preface

Ozone plays an important role in the life cycle of earth due to its ability to absorb UV radiation from the sun. In the mid 1970's scientists discovered that compounds containing chlorine and bromine (CFCs and halons) were capable of destroying the ozone layer (Molina and Rowland, 1974). The attention and debate about the ozone destruction were further intensified when the Antarctic ozone hole was discovered in the mid 1980's (Farman et al., 1985).

In 1987 the Montreal Protocol was put into effect in order to reduce the production and use of these ozone-depleting substances (ODS). This international agreement has later been revised several times. Currently, 196 nations have ratified the protocol. The amount of ODS in the troposphere reached a maximum around 1995. The amount of most of the ODS in the troposphere is now declining slowly and one expects to be back to pre-1980 levels around year 2050. In the stratosphere the peak is expected to be reached somewhat later, but there seem to be a decline also in the stratosphere the last years.

It is now important to follow the development of the ozone layer in order to verify that the Montreal Protocol and its amendments work as expected. For this, we need daily ground based measurements at a large number of sites distributed globally in combination with satellite observations. It is the duty of every industrialised nation to follow up with national monitoring programmes.

The Climate and Pollution Agency (the former Norwegian Pollution Control Authority) established the programme "Monitoring of the atmospheric ozone layer" in 1990, which at that time included measurements of total ozone only. In 1995 UV measurements were also included in the programme.

The Norwegian Institute for Air Research (NILU) is responsible for the operation and maintenance of the monitoring programme. The purpose of the programme is to:

- Provide continuous measurements of total ozone and natural ultraviolet radiation that reach the earth surface
- Provide data that can be used for trend analysis of both total ozone and natural ultraviolet radiation.
- Provide information on the status and the development of the ozone layer and natural ultraviolet radiation
- Notify the Climate and Pollution Agency when low ozone/high UV episodes occur.

Personnel and institutions

Several persons and institutions are involved in the operation and maintenance of the monitoring programme and have given valuable contributions to this report. Prof. Arne Dahlback at the University of Oslo (UiO) is responsible for ozone and UV measurements in Oslo. Kåre Edvardsen (NILU) is responsible for ozone and UV measurements at Andøya. The ozone lidar at ALOMAR is owned and operated by NILU (Kåre Edvardsen and Kerstin Stebel) and the Andøya Rocket Range. Ola Engelsen is working with forecasting and identification of high UV episodes. Dr. Tove Svendby, (NILU) ensures the data submission to The World Ozone Data Centre (http://www.msc-smc.ec.gc.ca/woudc/). She is also involved in the analysis of the satellite data together with Dr. Cathrine Lund Myhre. Lund Myhre is responsible for the program, and is involved in the data analysis amongst others.

Acknowledgment
Based on a project jointly financed by The European Space Agency (ESA; http://www.esa.int/) and The Norwegian Space Centre (Norsk Romsenter, http://www.romsenter.no/) we are now in a position where we explore relevant ozone satellite observations and use these data in the National monitoring of the ozone and UV radiation. Both institutions are highly acknowledged for their support.

Kjeller, November 2010

Cathrine Lund Myhre
Senior scientist and project manager

Contents

1. Summary

This annual report describes the activities and main results of the programme “Monitoring of the atmospheric ozone layer and natural ultraviolet radiation” for 2009, which is a part of the governmental programme for monitoring pollution in Norway.

In the mid 1970’s scientists discovered that compounds containing chlorine and bromine (CFCs and halons) were capable of destroying the ozone layer (Molina and Rowland, 1974). The attention and debate about the ozone destruction were further intensified when the Antarctic ozone hole was discovered in the mid 1980’s (Farman et al., 1985).

In 1987 the Montreal Protocol was put into effect in order to reduce the production and use of these ozone-depleting substances (ODS). This international agreement has later been revised several times. Currently, 196 nations have ratified the protocol and effective measures have reduced the use and emissions of ODS significantly. The total amount of ODS in the troposphere reached a maximum around 1995 and is for most of the ODS declining slowly. It is expected to be back to pre-1980 levels around year 2050. In the stratosphere the peak is reached somewhat later, but there seems to be a decline also in the stratosphere the last years.

Without the Montreal protocol, the ozone layer would have been dramatically destroyed. There are recent studies indicating that large ozone depletions in the Polar Regions will became year-round and there will be ozone hole conditions also in the tropics, with full collapse of the ozone layer around the year ~2060. For mid-summer the study predicated an UV increase of 5-10% for the year 2000 and later a UV index around 15 was reached within the year 2040 and exceeding a value of 30 by the year 2065.

It is important to follow the development of the ozone layer in order to verify that the Montreal Protocol and its amendments work as expected.

MAIN CONCLUSIONS FROM THE MONITORING PROGRAMME

- Total decrease in the ozone layer above Oslo since 1979 is 2.4 %
- There are strong indications that the ozone layer above Norway follows the global trend and is in a recovery state, gradually building up.
- Measurements of ozone profiles and analysis of stratospheric conditions show that in 2009 only one short period with chemical ozone destruction occurred, in January. This is less than the previous years.
- A summer period with low ozone coincided with a period with warm weather and little clouds. This resulted in very high UV levels in late June. At the snow covered measuring station at Finse the UV-index was as high as 8.1. Under those conditions a typical Nordic skin type gets burned in less than 20 minutes.

The national monitoring programme

The Climate and Pollution Agency (the former Norwegian Pollution Control Authority) established the programme "Monitoring of the atmospheric ozone layer" in 1990, which at that time included measurements of total ozone only. In 1995 UV measurements were also included in the programme. The Norwegian Institute for Air Research (NILU) is responsible for the operation and maintenance of the monitoring programme.

In 2009 the monitoring programme included measurements of total ozone and UV at two locations, Oslo (60°N) and Andøya (69°N) and ozone profile measurements at one location, Andøya. This report summarises the activities and results of the monitoring programme during the year 2009. The report includes trend analyses of total ozone for the period 1979-2009 for both sites and comments on the expected ozone recovery at northern latitudes. Further the total yearly UV dose for 2009 at Oslo and Andøya is included. The Norwegian UV network was established in 1994/95 and consisted until 2006 of nine 5-channels GUV instruments located from 58°N to 79°N. From 2006 the instrument at Ny-Ålesund has been excluded from the network. As a part of the 2009 monitoring programme NILU has been responsible for the daily operation of two of the instruments, located at Oslo (60°N) and Andøya (69°N). After the exclusion of the instrument at Ny-Ålesund, the site closest to Arctic is Andøya.

Total ozone

For the year 2009, the ozone layer above Oslo was close to the long term mean ozone for all months, except for February with an unusual high level and April with a low level. At Andøya the monthly mean ozone values for 2009 are slightly below the long term mean throughout the whole year with the exception of the last part of February.

The stratospheric winter 2008/09 can be classified as a warm winter. Consequently, little ozone loss initiated by the formation and presence of polar stratospheric clouds (see picture) was observed during winter and spring 2009. Rather, there was a very warm stratospheric February resulting in ozone values more than 12% above the long term mean level in Oslo, and 18% above the long term mean at Andøya. There are no ozone measurements at Andøya early in February due to polar night. Also January had high ozone values in Oslo.

The ozone lidar at Andøya provides measurements of the ozone concentration at altitudes from approximately 8 km to 50 km on days with clear sky and no daylight. The measurements from the ozone lidar are very useful for studying rapid variations in the ozone profiles and are important for detection of chemical ozone loss during spring and for the understanding of the processes that leads to changes in the ozone layer. In 2009 there was only a short period with chemical ozone destruction in January, less than the previous years.

During the period 1979-2009 the ozone layer above Oslo show a total decrease of 2.4 % (standard deviation 1.1 %) and as much as 4.7 % (standard deviation 2.7 %) decrease during the spring. For Andøya a similar trend analysis show no significant change in the total ozone.

Recent global ozone data indicate that there are signs of ozone recovery from mid 1990s in most of the world. This is further strengthened the last year. However this is connected with some uncertainty, particularly at high latitudes and in the Arctic region. The uncertainty is caused by the high natural variability in this region, and the influence of factors like decreasing temperatures in the stratosphere, which is partly due to the increase of greenhouse gases in the troposphere.

Our monitoring programme indicates that for Oslo the minimum was passed in the period 1988-1997 and that the ozone layer above Oslo is now in a recovery phase. However the last years there might be sign of a stagnation of this development.

The colourful mother of pearl clouds at the picture are polar stratospheric clouds observed above Lillestrøm in January 2005. (Geir Braathen, NILU.)

There are several satellite dataset with ozone from different satellites and instruments available for the region. This is a great benefit and provides increased information and spatial coverage. A comparison of the ground based data with satellite data for selected years show good agreement during the summer, while the deviations are larger in the autumn and winter months. The satellite ozone data have hardly the required quality to be used in trend analysis for our region. The data sets from the different instruments and different periods do not agree with each other to a satisfactory level. Additionally it seems to be a seasonal difference between the ground based data and the satellite data which make it impossible to study annual and seasonal trends.

UV measurements
The highest UV dose rate in Oslo, 173.0 mW/m^2 occurred 30 June. This is equivalent to a UV index of 7.0 and 16% above the highest level in 2008. The maximum dose in 2009 was due to a combination of low ozone and few clouds coinciding with the time of the year with maximum solar radiation. At Andøya the highest UV index, 4.7, was observed on the 22 June.

Further needs
Longer data series and improved understanding of atmospheric processes and dynamics are needed to predict the development of the ozone layer with acceptable confidence. Long term monitoring is a fundamental basis in ozone studies, and is combined with research using global modelling tools. In particular Arctic ozone is of national concern and responsibility. One possible improvement of the national monitoring will be to re-start the UV measurements at Svalbard employing an instrument also providing ozone observations. Furthermore there are long time series with observations of spring time ozone at Svalbard available that is not analysed previously. This data series would provide very valuable analysis of the ozone situation in the Arctic spring time from 1991 until today.

2. Ozone measurements in 2009

Daily measurements of total column ozone, which means the total amount of ozone from the earth surface to the top of the atmosphere, are performed in Oslo (60°N) and at Andøya (69°N). Total ozone is measured by Brewer spectrophotometers at both locations. At Andøya also the ozone profile from 8-45 km is measured, providing information about the ozone height distribution at clear weather conditions. We have also included analysis of ozone satellite data to have a more complete description of the ozone situation in Norway and the Arctic region.

The International Ozone Services, Canada, has calibrated both Brewer instruments against a reference instrument on a yearly basis, last time in June 2009. In addition, the instruments are regularly calibrated against standard lamps in order to check the stability of the instruments. The calibrations indicate that both instruments have been stable during the years of operation. In the following sections are the results of the ground based ozone measurements from Oslo and Andøya presented, and in Chapter 4 on page 27 are satellite data of ozone presented.

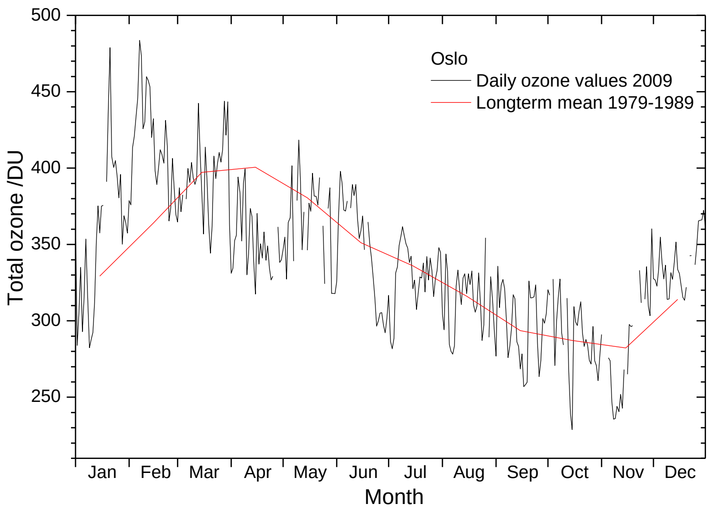


Figure 1a): *Daily total ozone values measured at the University of Oslo in 2009. The red curve shows the long-term monthly mean values from 1979-1989.*

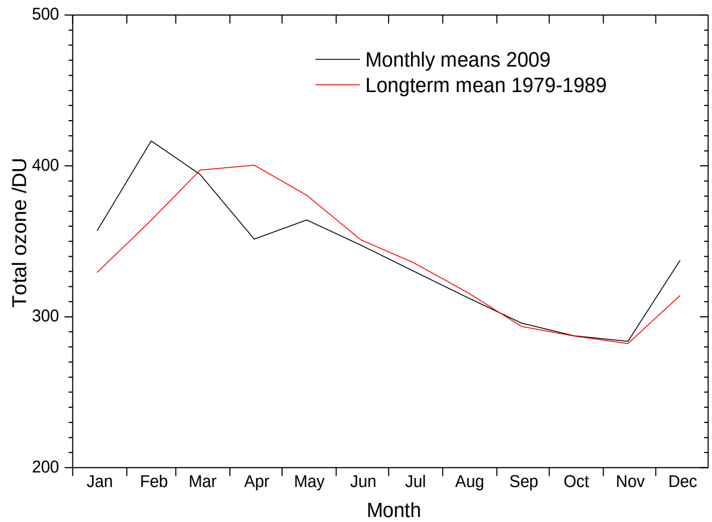


Figure 1b): *Monthly mean ozone values for 2009. The red curve shows the long-term monthly mean values from 1979-1989.*

2.1 Total ozone column in Oslo

Daily ozone values for Oslo in 2009, based on measurements with the Brewer spectrometer no. 42, are shown in Figure 1. The black curve shows the daily ozone values measured in 2009, whereas the red curve shows the long-term monthly mean values for the years 1979-1989. The total ozone values are based on direct-sun (DS) measurements, when available. In 2009 DS measurements were performed 142 days. For overcast days and days where the solar zenith angle is larger than 72° (sun lower than 18° above the horizon), the ozone values are based on the global irradiance method (Stamnes et al., 1991). This is the case for 201 days in 2009. In 2009 there are totally 22 days with missing data. This is partly due to bad weather with heavy clouds (15 days) and technical causes (7 days).

As seen from Figure 1a) there are large day-to-day fluctuations, particularly in the spring. During spring and summer there are periods with ozone values significantly below the long-term mean. The lowest ozone value was observed 15 October, and was as low as 228 DU. There were two periods with low ozone values during late spring and summer. The first period was from 29 May to 1 June with ozone values 13% below the long term mean, and the next period lasted from 24 June to 5 July. In the last period the ozone level was as much as 18% below the long term mean. In this period there were very high UV-levels compared to normal in Western and Southern part of Norway. These episodes are further described in *section "6.2 Elevated UV levels due to low ozone episodes in 2009"* on page 37.

The monthly mean total ozone values for 2009 are shown in Figure 1b) and compared with the long-term monthly mean values for the period 1979-1989. As seen from the Figure the 2009 ozone values were close to the mean values in all months, except for February with unusual high level, and April with low level. Section 3.2.1 and 3.4 includes a broader discussion and interpretation of the ozone situation in Norway in 2009.

2.2 Total column ozone at Andøya

At Andøya the total ozone values are based on direct-sun measurements when available, as in Oslo. For overcast days and days where the solar zenith angle is larger than 80° (sun lower than 10° above the horizon), the ozone values are based on the global irradiance method. The GUV-instrument has been used for ozone retrieval when the Brewer instrument has been out of order or Brewer measurements have been prevented by bad weather. There are 2 days without ozone observations at Andøya, except for the period with polar night where it is only possible to measure ozone with the lidar. These 2 days with lacking observations are due to bad weather conditions. Table 1 gives an overview of the different instruments and methods that were used at Andøya in 2009.

Table 1: *Overview of instruments and methods applied in the observation of the total ozone above Andøya in 2009.*

Priority	Method	Total days with observations
1	Brewer instrument, direct sun measurements	94
2	Brewer instrument, global irradiance method	150
3	GUV instrument	2
	Lidar (measurements during the Polar night)	19

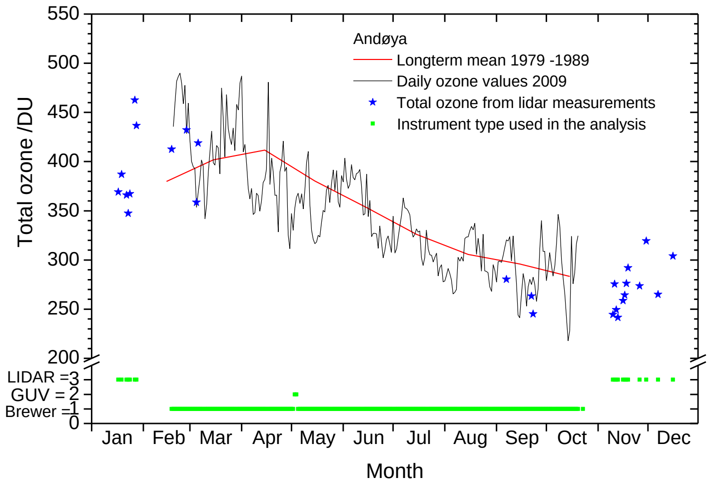


Figure 2a): *Daily total ozone values measured at ALOMAR, Andøya, in 2009 by the Brewer, GUV and LIDAR instruments. The use of the different instruments is shown in the lower part of Figure 2a). The red line shows the long-term monthly mean values from 1979-1989.*

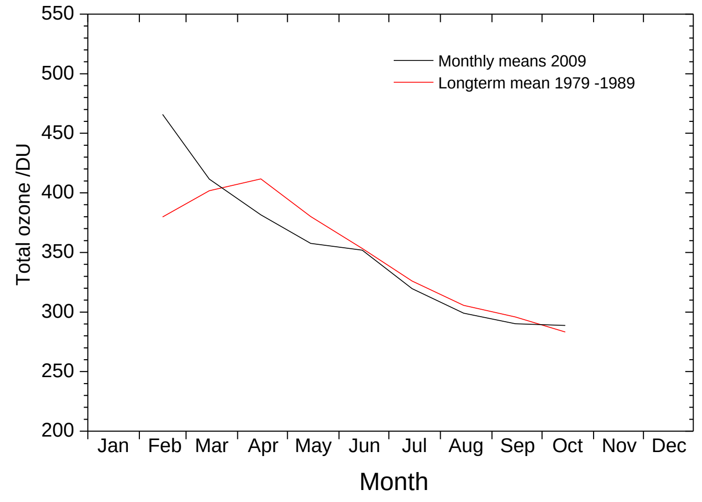


Figure 2b): *Monthly mean ozone values for 2009(black curve) compared to the long-term monthly mean values for the period 1979-1989 (red curve).*

Daily ozone values for Andøya in 2009, based on measurements with the Brewer spectrometer, are shown in Figure 2a). The black curve shows the daily ozone values from 2009, whereas the red curve shows the long-term monthly mean values for the years 1979-1989. Total ozone values during the polar night (November to February) are based on ozone profiles measured by the ozone lidar at ALOMAR. These measurements are indicated by blue stars. The lidar data give a good picture of the ozone variation during the winter months when Brewer and GUV measurements are not achievable. The green marks in the lower part of Figure 2a) shows the frequency and distribution of the various instruments applied.

Monthly mean ozone values based on the daily ozone measurements from the Brewer instrument are shown in Figure 2b). For January, November, and December (polar night) there are not sufficient data to calculate monthly means. The comparison between the long-term mean and the monthly mean ozone values for 2009 shows that the ozone values are slightly below the long term mean throughout the whole year, except for February which is exceptionally high.

2.3 Stratospheric ozone-profile measurements made in 2009 by means of the ozone lidar, located at ALOMAR (69°N, 16°E)

To follow the development of the stratospheric ozone layer during winter 2008/09 and in 2009 lidar measurements have been performed. The instrument, which is used for this purpose, is located at the Arctic Lidar Observatory for Middle Atmosphere Research (ALOMAR), at Andøya (69°16'N, 16°00'E, elev. 380 m). It is a classical DIAL (Differential Absorption LIDAR) system operating at two wavelengths; 308 nm (ozone absorption is strong) and 353 nm (weak ozone absorption). The LIDAR was built in 1994/95 and was upgraded with a daylight receiver and new receiving electronics in 1998 and 2008, respectively. It is used to monitor stratospheric ozone, temperatures and Polar Stratospheric Clouds (PSCs). The data contribute to NDACC, the Network of Detection of Atmospheric Composition Change.

In 2009 measurements have been performed only during clear sky night-time conditions. Funding has not been sufficient for daylight operation (5 test measurements have been made). The data have been analysed, quality controlled and the results are reported here. Normally it takes two hours to measure an ozone profile in the height range between 8 and 45 km. 26 quality controlled ozone profiles have been retrieved in 2009. The specific days are summarized in Table 2.

Table 2: *Overview over days with stratospheric ozone profiles retrieved in 2009.*

Month	Ozone profiles	Comments
January	17, 19, 22, 23, 24, 27, 28	
February	18, 27	
March	05, 06	
April – August	-	no daylight measurements
September	07	
October	22, 23	
November	10, 11, 12, 13, 16, 17, 18, 19, 26, 30	
December	07, 15	

2.3.1 Development of the stratospheric ozone layer above Andøya throughout 2009

The altitude profile of the stratospheric ozone layer above Andøya throughout 2009 is illustrated in Figure 3. For comparison, the stratospheric ozone layers seen during previous years (1996 and 2003 - 2008) are shown in Figure 4.

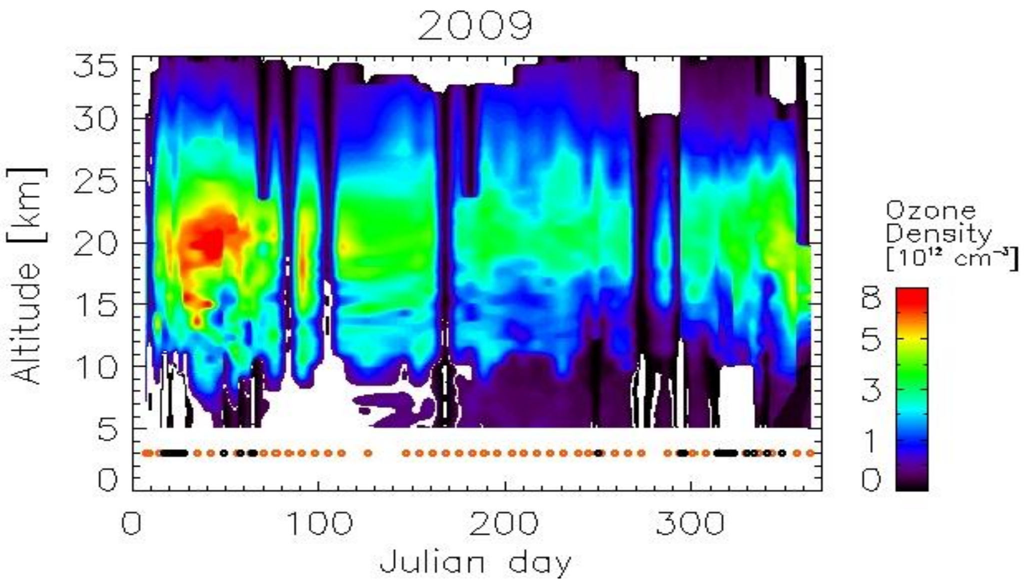
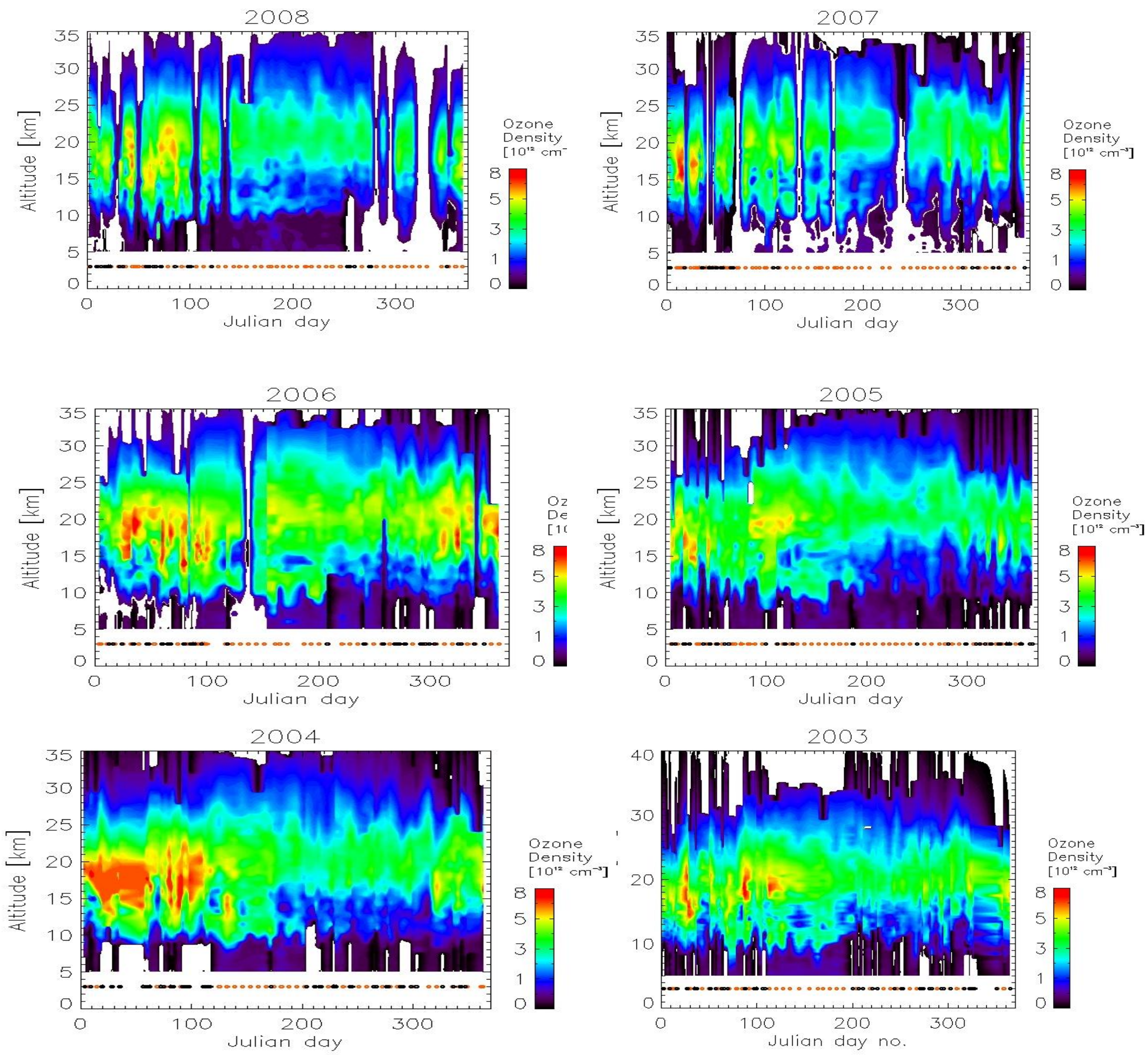


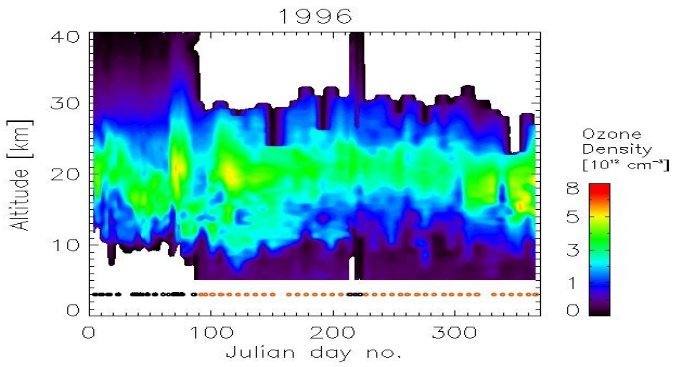
Figure 3: *Development of the stratospheric ozone layer in 2009, derived from profiles measured by the ALOMAR ozone lidar and ozone sondes launched in Sodankylä, Finland (courtesy to the Finnish Meteorological Institute), in 2009. The black dots at the bottom of the plot mark the times when lidar measurements were performed, while the red dots mark days where data from ozone sondes launched from Sodankylä were used. Between the individual measurements the data were linearly interpolated and smoothed with a one-week median filter. Note: vertical blue lines are due to data gaps.*

The lidar measurements document the large inter-annual variability in spring-time ozone depletion. Comparing the winter 2008/09 and spring values with previous years, it is evident that spring-time ozone was only slightly reduced in 2009. Because the low temperatures needed for formation of PSCs occurred during a limited time period (see section 3.4), only limited ozone loss occurred in spring 2009.

According to the SAOZ network (using Passive ozone from REPROBUS), most of the ozone loss occurred between January 10 and January 30 at a rate of 0.5% per day. This led to a cumulative loss of 12 ± 3% around late January, 2009 (see Goutail et al., 2009. This is similar to what was observed in 1998/99, 2000/01, 2001/02 and 2005/06 winters.

In 2009, as in previous years, we find a weak second ozone maximum near 14-15 km in late spring/early summer, between the tropopause and the absolute ozone maximum near 20 km. This is caused by a combination of air mass transport and chemical ozone destruction. After a period with low summer-time ozone, the polar vortex was built up again in early December 2009, temperatures felt below that’s of the PSC formation after mid December, and typical pre-winter ozone values were observed.





***ure 4:** Ozone profiles measured by the OMAR ozone lidar and ozone sondes nched in Sodankylä, Finland, in 1996 and 03-2008 (analog to Figure 3)*.

3. Ozone measurements and trends for 1979–2009

3.1 Background

3.1.1 Status of the global ozone layer

In 2007 World Metrological Organisation (WMO) and UNEP published the Scientific Assessment of Ozone Depletion: 2006 (WMO, 2007). This report summarizes the state of the art with respect to ozone, ozone recovery and UV changes. The most relevant conclusions are briefly summarised below.

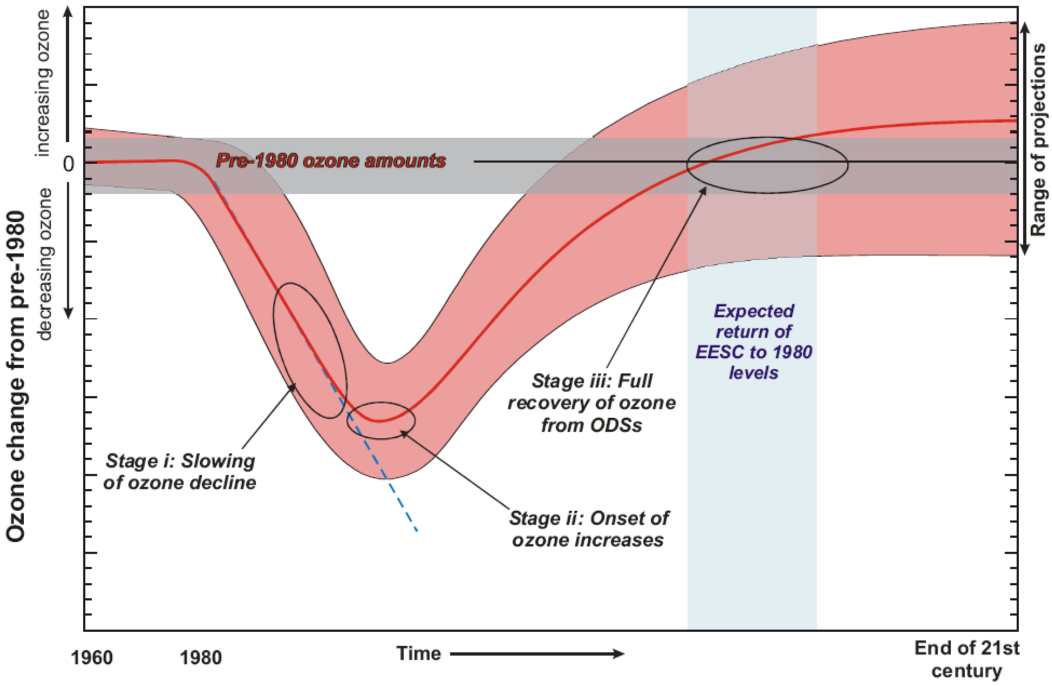


***Figure 5**: A schematic diagram of the temporal evolution of global ozone amounts beginning with pre-1980 values (Bodeker and Waugh, 2007).*

Recovery of the ozone layer is a process beginning with a lessening in the rate of decline, followed by a levelling off and an eventual increase in ozone driven by the changes in the concentrations of ozone-depleting substances. Figure 5 is taken from the report and shows a schematic diagram of the temporal evolution of global ozone amounts beginning with pre-1980 values. This represents a time before significant ozone depletion occurred due to emission of anthropogenic ozone depleting substances (ODS). Observed and expected ozone amounts are illustrated by the solid red line and show depletion from pre-1980 values and the three stages of recovery. The red-shaded region represents the range of observations and model results for both near-term and long-term ozone changes. The blue-shaded region represents the time period when declining global ODS concentrations are expected to reach 1980 values. The full recovery of ozone from ODSs may be delayed by natural factors (e.g., a volcanic eruption) that could change the sensitivity of ozone to ODSs.

According to the report the total global ozone abundances have not decreased the last years and there might be signs of recovery from the mid 1990s. However, it is still uncertain to what extent this improvement is attributable to the observed decline in ozone-depleting substances. Both data and models show increases in ozone, but the observed increase at high northern latitude is considerable larger than the model predictions. This region also exhibits the highest level of natural variability, which again makes the predictions most uncertain. In the Antarctic the ozone layer continues to reach very low levels in the spring. In the Arctic and high northern latitudes the situation is more irregular as severe ozone depletion occurs during springtime in years with low stratospheric temperatures, exemplified with the different situations in 2005 and 2006. The yearly and seasonal trends are strongly linked to the spring ozone levels.

The most dramatic ozone depletion has been observed in the Polar Regions, but the detection of recovery near the poles is difficult. Increase in total column ozone in the Arctic and high northern latitudes will partially depend on the possible dynamical and temperature changes in the coming decades, both in the stratosphere as well as the troposphere. Further, the ozone trend analyses for the high northern latitudes are still affected by the unusually low ozone levels in the mid 1990s following the Mt. Pinatubo eruption. Thus, any upward trend from this point might be misleading, as the ozone levels were particularly low during the 1990s (illustrated in Figure 10 and Figure 11). The solar cycle and its peak in 2000-2002 also contribute to the uncertainty of ozone recovery in our region. These two factors are often omitted from the models and can explain the underestimation of the modelled ozone levels compared to the measurements in this region.

The ozone levels in the Arctic and high northern latitudes will be strongly influenced by changes in stratospheric temperatures during the next years, and possibly result in delayed recovery or record low ozone observations. Considerably longer data series and improved understanding of atmospheric processes and their effect on ozone are needed to estimate future ozone levels with confidence. Further, anthropogenic changes of the atmosphere (like change in temperature profile, emission of greenhouse gases like N_2O, and increase of stratospheric water vapour as a result of increase of atmospheric CH_4) might affect the ozone recovery. Whether ozone stabilizes at a higher or lower level than the pre-1980 level is uncertain. However, the vertical distribution of ozone in the future is almost certain to be different from the pre-depleting period.

According to WMO studies of long-tem trends of ozone, as presented in the sections 3.2 and 3.3, are essential in the assessment of the ozone recovery.

3.1.2 What would have happened to the ozone layer without the Montreal protocol?

There is a recent comprehensive and interesting paper published in the journal *Atmospheric Chemistry and Physics* that investigates the broad effects and consequences if chlorofluoro-carbons had not been regulated through the Montreal protocol (Newman et al, 2009). Newman and his co-workers uses a state of the art radiation-chemical-dynamical model to simulate a future world were the ozone depleting substances (ODS) were never regulated. In their study they allow the ODSs to grow at a rate of 3% per year. This is a modest growth as the annual CFC production rate up to 1974 was as high as 12-17%. Their simulations showed that 17% of the globally-averaged column ozone was destroyed by 2020, and 67% was destroyed by 2065 in comparison to 1980. Large ozone depletions in the polar region became year-round rather than just seasonal and very large temperature decreases were found in the stratosphere in the tropics in response to circulation changes and decreased shortwave radiation absorption by ozone. This led to heterogonous chemical destruction of ozone also in the tropical region similar to the present processes occurring in Antarctica. The result was a full collapse in the tropical ozone approaching zero by the year 2058. In response to the dramatic ozone changes, ultraviolet radiation increases substantially globally: For mid-summer an UV increase of 5-10% was calculated for the year 2000 and later a UV index around 15 was reached within the year 2040 and exceeding a value of 30 by the year 2065. (See Table 9 at page 35 for description of UV index).The UV increase would more than double the erythemal dose in the summer mid latitudes by 2060.

3.2 Trends for Oslo 1979 – 2009

Total ozone measurements using the Dobson spectrophotometer (No. 56) was performed on a regular basis in Oslo from 1978 to 1998. The data from this instrument has been re-evaluated and published (Svendby and Dahlback, 2002). The complete set of revised Dobson total ozone values from Oslo is available at The World Ozone Data Centre (http://www.msc-smc.ec.gc.ca/woudc/).

The Brewer instrument has been in operation at the University of Oslo since the summer 1990. The International Ozone Services, Canada, calibrated the Brewer instrument in Oslo in June 2009. In addition, the Brewer instrument is regularly calibrated against standard lamps in order to check the stability of the instrument. The calibrations show that the Brewer instrument has been stable during the 19 years of observations. The total ozone measurements from the Brewer instrument agree well with the Dobson measurements. However, there is a seasonal variation in the difference between the Brewer and Dobson instrument that has not been accounted for in the trend analysis presented here. There is an ongoing process coordinated trough WMO assessing this problem, and updated recommendations for Brewer and Dobson analysis are expected during 2011. For information about the process, see e.g. http://igaco-o3.fmi.fi/ACSO/.

Figure 6a) shows the variations in the monthly mean ozone values in Oslo from 1979 to 2009. The total ozone values from 1979 to 1998 are from the Dobson instrument, whereas for the period 1999-2009 the Brewer measurements have been used. The large seasonal variations are typical for stations at high latitudes. This is a dynamic phenomenon and is explained by the springtime transport of ozone from the source regions in the stratosphere above the equator.

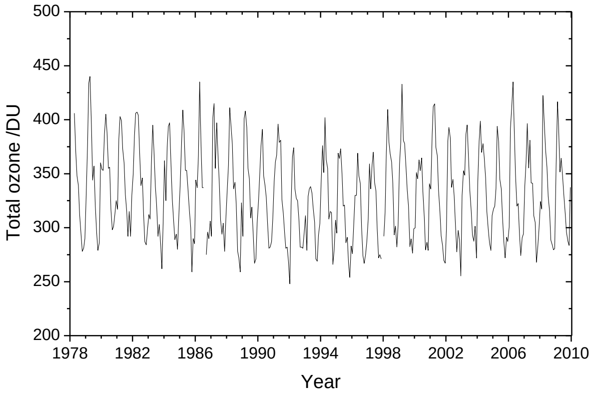


Figure 6a: *Time series of monthly mean total ozone in Oslo 1979-2009.*

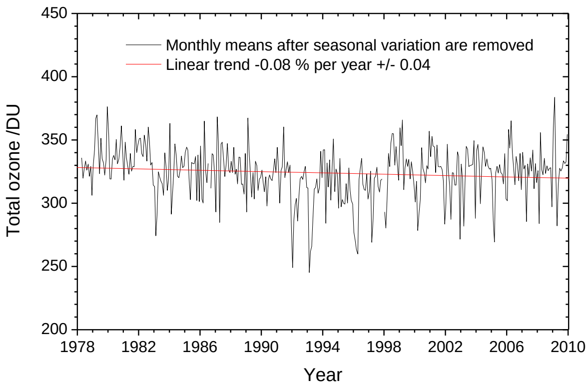


Figure 6b: *Variation in total ozone over Oslo for the period 1979–2009 after the seasonal variations have been removed.*

In order to look at possible ozone reduction in the period 1979 to 2009 we have removed the seasonal variations by subtracting the long-term monthly means and adding the long-term yearly mean value, shown in Figure 6b). A simple linear regression has been fitted to the data to obtain a long-term trend of the ozone layer above Oslo. The results of the trend analysis are summarized in Table 3. We find a significant reduction of -0.08 % per year in the ozone layer above Oslo for the period 1979-2009. In total this is a reduction of 2.4 % over the entire period. The comparable value for 1979-2008 was 0.11 % per year (3.2% over the full period). This indicates clearly that the declining trend is now flattening out.

Seasonal analyses show that no significant trends are observed for any of the 4 seasons (winter, spring, summer and fall), as last year. It should be noted that the ozone variability is relatively large in winter and spring, and that the corresponding ozone trend must be large in order to be classified as statistical significant. For spring months a negative trend of –0.16% per year is calculated for the period 1979-2009, with a standard deviation of 0.09. This is the same for the period 1979-2008. For the winter season, the last year has influenced the trend substantially. For the period 1979-2009 small negative trend of -0.05 is calculated, while for the period 1979-2008 a strong negative trend of –0.16% per year was calculated. This remarkably strong reduction in the winter trend is due to very high levels of ozone particularly in February. This will be further explored in section 3.4 on page 22.

Table 3: *Percentage changes in total ozone per year for Oslo for the period 1.1.1979 to 31.12.2009. The numbers in parenthesis gives the uncertainty (1 σ) in percent. Data from the Dobson and Brewer-instruments have been used in this study. A trend larger than 2σ is considered to be significant.*

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

3.2.1 Indications of ozone recovery above Oslo

The trend analysis for Oslo shows that there has been a decrease in the total ozone amount of 2.4% over the period 1979-2009. To investigate a possible turning point we have calculated 10 years annual running means for the period. We have also calculated 10 years running mean for each month to investigate possible changes in the seasonal variation of ozone during this period.

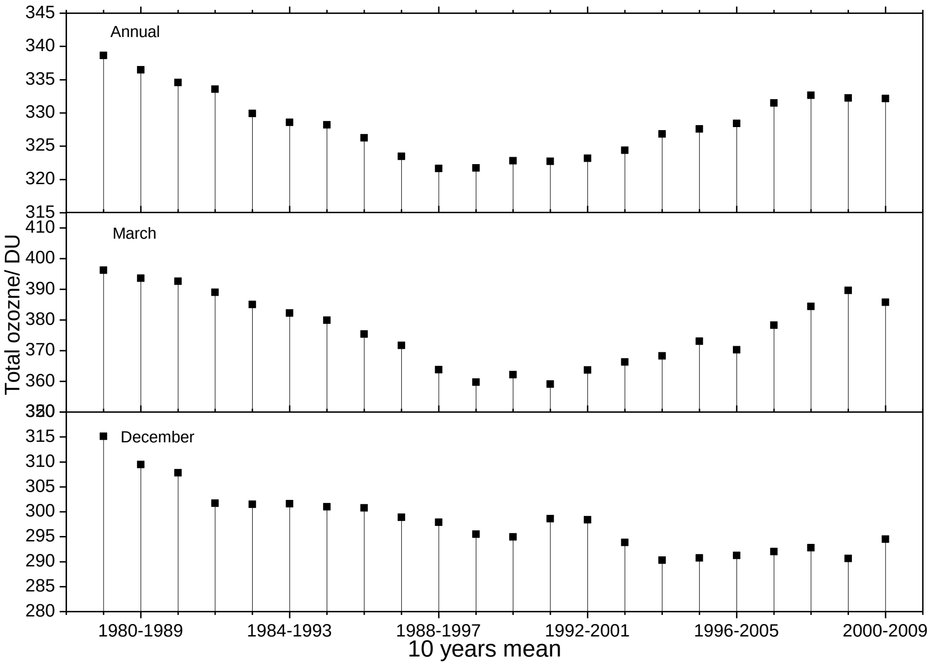


Figure 7: *10 years running mean for the period 1979-2009 based on annual mean (top panel) monthly mean for March (mid panel) and monthly mean for December (lower panel).*

The upper panel in Figure 7 shows the 10 years running mean based on annual mean total ozone. The Figure clearly shows that the ozone amount above Oslo decreased throughout the 1980s and 1990s, and the period with the lowest ozone values was from 1988-1997. Since then there has been a gradual increase. The last years there seem to be a stagnation of this development. The difference in the annual mean for the first period 1979-1988 and the last period 1999-2008 is only -1.8%. There was a shift of instrument in 1998, from Dobson to Brewer spectrometer, and there is a known seasonal discrepancy between data from these two instruments. This might have introduced an uncertainty in the exact time period of the shift. However, based on this analysis, it seems like the minimum is passed and that the ozone layer above Oslo is in a recovery state. The last year of observations confirms this conclusion.

The lower panels show the 10 years running means for March and December. For March the results are similar to the annual mean variations; a decrease until the period 1986-1995, followed by an increase up to the same levels as the start of the measurement period. December is selected as it is a month which is quite different from the annual mean results. December has had the largest decrease over the period from 1979-2009 and shows continues decline over the entire period of almost 7%. This indicates that there has been a seasonal change in the ozone level above Oslo. These are preliminary results, and further analysis is under way.

Figure 8 shows the average monthly mean values calculated for the three different period 1980-1989, 1990-1999, and 2000-2009. The first period has the highest value throughout the year, the second period the lowest value, and the last period from 2000-2009 is approaching the ozone values in 1980-1989. The results confirm that the ozone layer is in a recovery state above Oslo.

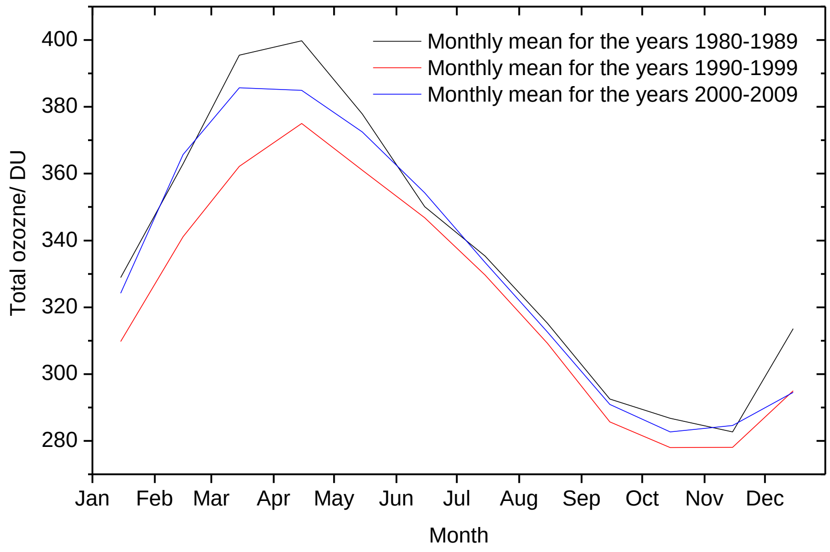


Figure 8: *Monthly mean ozone for three selected periods. Black curve represents the period 1980-1989, red curve represents 1990-1999, whereas blue curve represents the period from 2000 to 2009.*

3.3 Trends for Andøya 1979 – 2009

The Brewer instrument has been in operation at Andøya since 2000. In the period 1994 to 1999 the instrument was located at Tromsø, approximately 130 km North of Andøya. Studies have shown that the ozone climatology is very similar at the two locations (Høiskar et al., 2001), and the two datasets are considered equally representative for the ozone values at Andøya. For the time period 1979–1994 total ozone values from the satellite instrument TOMS (Total ozone Mapping Spectrometer) have been used.

Figure 9a) shows the variations in the monthly mean ozone values at Andøya from 1979 to 2009. The variations in total ozone at Andøya for the period 1979–2008, after removing the seasonal variations, are shown in Figure 9b) together with the annual trend.

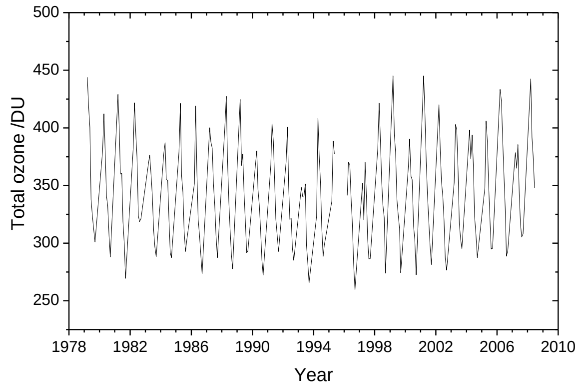


Figure 9 a): *Time series of monthly mean total ozone at Andøya/Tromsø 1979–2009.*

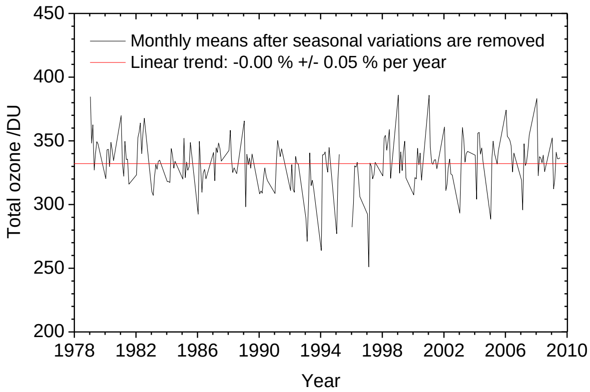


Figure 9 b): *Variations in total ozone at Andøya for the period 1979–2009 after the seasonal variations are removed. Only data for the months March–September are included.*

A simple linear regression has been fitted to the data in Figure 9b) to obtain the trend in the data set. The result of the trend analysis is summarized in Table 4. No significant trends were observed for Andøya for this time period. Both annual and seasonal trends are close to zero over the period 1979-2009.

Table 4: *Percentage changes in total ozone per year for Andøya for the period 1979 to 2009. The numbers in parenthesis gives the uncertainty (1σ). Data from the Dobson and Brewer instruments have been used in this study. A trend larger than 2σ is considered to be significant.*

Time period	Trend (% per year)
Spring: March – May	0.00% (0.09)
Summer: June – August	0.02% (0.04)
Annual: March – September	0.00% (0.04)

3.4 The ozone situation above Norway 2009

The percentage difference between yearly mean total ozone and the long-term yearly mean is shown in Figure 10 (Oslo) and Figure 11 (Andøya) for the full period with observations. The low values in 1983, 1992 and 1993 are related to the eruption of the El Chichón volcano in Mexico in 1982 and the Mount Pinatubo volcano at the Philippines in 1991.

The Figure shows that the low ozone values in the 1990's contribute strongly to the observed negative trends in total ozone above Oslo. Note also that the yearly mean ozone value for 2005 was as much as 5% lower than the long-term yearly mean. For 2009 the annual mean was 0.7 % above the long-term mean.

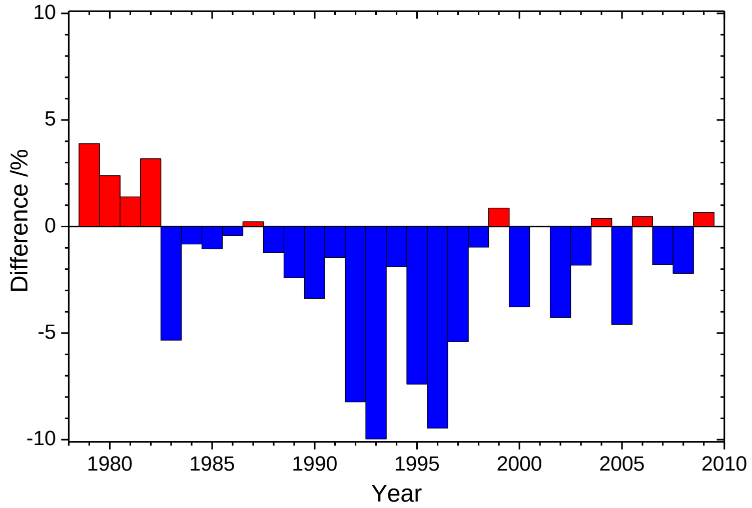


Figure 10: *Percentage difference between yearly mean total ozone in Oslo and the long term yearly mean for 1979-1989.*

The percentage difference between yearly mean total ozone and the long-term yearly mean at Andøya is shown in Figure 11. For 2009 the yearly mean ozone value was 0.6 % above the long-term yearly mean value for the period 1979–1989.

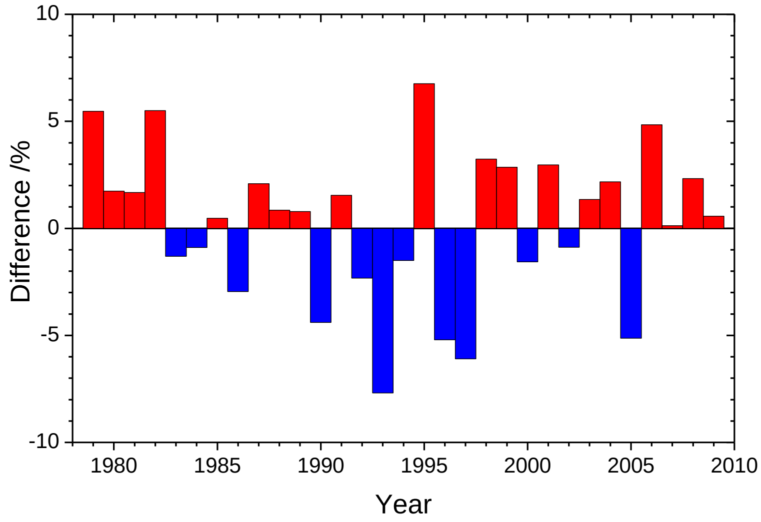


Figure 11: *Percentage difference between yearly mean total ozone in Andøya and the long term yearly mean for 1979-1989 for the months March-September.*

Table 5 gives the percentage difference between the monthly mean total ozone values for 2009 and the long-term monthly values. Both Oslo and Andøya are listed in the table.

Table 5: *Percentage difference between the monthly mean total ozone values for 2009 and the long-term mean for Oslo and Andøya.*

Month	Oslo (%)	Andøya (%)
January	7.8	
February	12.6	18.4
March	-0.8	2.4
April	-14.0	-7.9
May	-4.5	-6.3
June	-1.0	-0.4
July	-1.7	-2.0
August	-1.1	-2.2
September	0.8	-2.0
October	0.1	1.9
November	0.5	
December	6.9	

The ozone situation was similar in Oslo and Andøya in 2009. In 2009 the ozone values were below the long-term mean values for all spring and summer months, and above the long term mean in the autumn and winter months. In particular February and December (only Oslo) was considerable above the long-term mean. In Oslo the ozone levels was 12.6 % above the long term mean and as much as 18.4 % at Andøya (only measurements for the second half of February is included due to polar night).

It is also worth noting the low values in April, as often, at both locations. The low ozone values commonly observed in the spring the last decades are a direct result of the stratospheric conditions, and the chlorine and bromine compounds emitted by anthropogenic sources. The polar stratospheric vortex[1] leads to chemical ozone destruction when air masses, quasi-isolated in the polar vortex, are illuminated by sunlight. Sunlight initiates the formation of active chlorine and bromine compounds (e.g. HCl and HBr) by heterogeneous chemistry on polar stratospheric clouds (PSC). The active chlorine and bromine reacts with ozone and results in severe ozone depletion. The PSCs are a basis for the chemical ozone destructions observed in the Antarctica and the Arctic. There are two main types of PSCs, called PSC I and PSC II. The approximate threshold formation temperature for type I is 195 K (-78 ^{o}C) and for type II 188 K (-85 ^{o}C) and the first observation of PSC type II in the Arctic was in 2005.

A colder upper stratosphere is a suggested feedback to the increased level of greenhouse gases in the troposphere. Thus, it is important to detect signs of climate changes and influence on the occurrence of PSCs and particularly the abundance of PSC type II. However, the observations the latest years clearly manifest the great variability of the ozone layer typical for the Northern region (WMO, 2007; Weatherhead and Andersen, 2006).

To explore the reason for the high values in February and better explain the observed ozone values, we have assessed the stratospheric temperature development in 2009.

3.4.1 Polar stratospheric clouds, stratospheric temperatures during the winter 2008/09

Polar stratospheric clouds (PSCs) have been monitored since 1995. PSCs occur when the temperatures in the stratosphere drop below certain threshold temperatures needed for PSC type I (NAT) and II (ice) formation. On the PSC surface, chemical reactions occur, which transform passive and innocuous halogen compounds (e.g. HCl and HBr) into active chlorine and bromine (e.g. ClO and BrO). Under sunlit conditions, these active species react with ozone through catalytic cycles which cause rapid ozone destruction.

Stratospheric temperatures around 20 km altitude (corresponding to a potential temperature of 475K), based on data from ECMWF[2] data are shown in Figure 12. Temperatures during winter 2008/09 are shown as a thick red line. The dates on which the lidar have been operated at ALOMAR are marked with *. Measurements when PSCs have been observed are indicated by green symbols.

During winter 2008/09 the low temperatures (<194K) needed for the formation of PSCs occurred during a limited period in December 2008 and early January 2009. During this time period only one lidar observation, made on December 15th 2008, showed a very faint, ca. 100 m thick, PSC layer around 23.4 km altitude. This was observed for a limited time period of 20 minutes (14:40 –15:00 UT).

[1] During the winter there is no sunlight in the Arctic and so the lower stratosphere becomes very cold. Thermal gradients around the Arctic cold pool give rise to an enormous cyclone that is referred to as the polar stratospheric vortex. It is in the core of the polar vortices that winter- and springtime ozone depletion occur.
[2] European Centre for Medium-Range Weather Forecasts

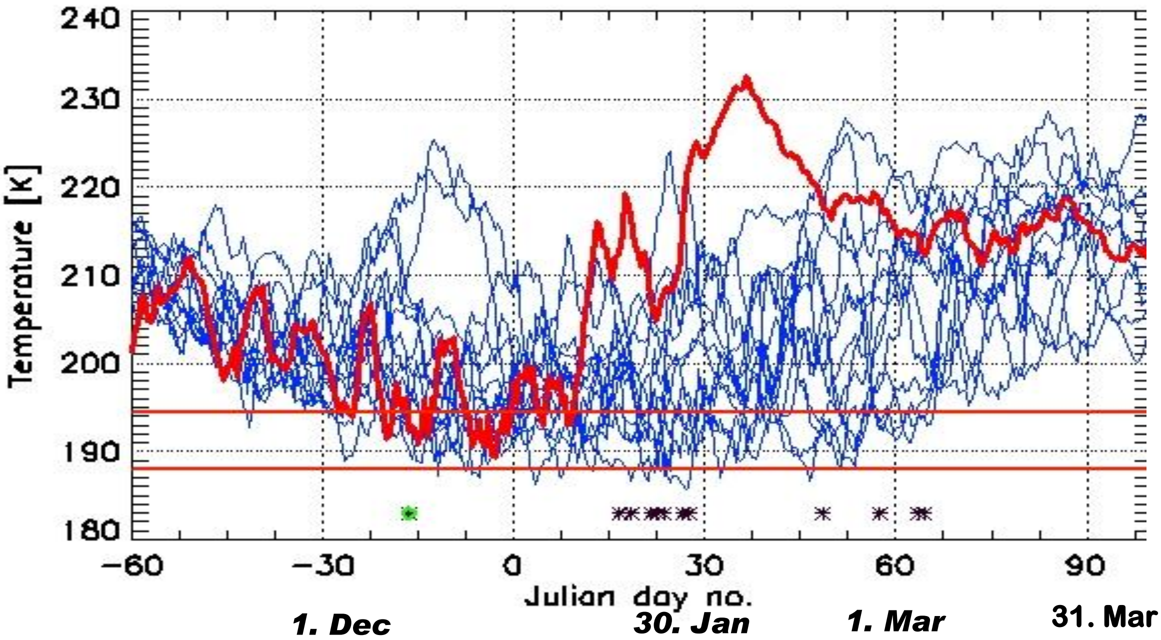


Figure 12: *Stratospheric temperatures around 20 km between 1995/96 and 2008/09 (data from ECMWF). The temperature development during winter 2008/09 is highlighted in red. The two vertical red lines indicate the temperature thresholds needed for PSC type I (NAT) and II (ice) formation. LIDAR observations made are marked with *, PSCs observed are indicated by green symbols.*

After the time period with low temperature, in mid-January a stratospheric warming occurred. After that temperatures were too high for PSC occurrence the rest of the winter.

The lidar measurements document the large inter-annual variability in PSC occurrence. An overview of days on which PSC have been observed is given in Table 6. Polar stratospheric clouds have been measured between 1 December (in 2002) and 21 February (in 2005). The numbers of days on which PSCs have been seen vary between zero (winter 1998/99, 2001/02, 2003/04 and 2006/07) and 12 (in early 1996). Very different stratospheric winters have occurred in recent years: warm winters with very low PSC formation potential (1998/99, 2001/02, and 2005/06, and 2008/09) and very cold winter like 1994/95 and 1995/96.

Table 6: *List of days with PSCs seen by means of the ozone lidar at ALOMAR.*

Winter	December	January	February
1995/96	-	5, 7, 9, 11, 17, 18, 23, 24	12, 13, 16, 17
1996/97	-	7, 16, 19	9/10
1997/98	-	16/17	-
1998/99	-	-	-
1999/00	21	21, 22, 26, 29	6
2000/01	-	21, 23	-
2001/02	-	-	-
2002/03	1, 2, 3, 4, 5, 7, 16, 25	9	5
2003/04	-	-	-
2004/05	-	5, 6, 24	7, 13, 14, 15, 20, 21
2005/06	6, 19, 20, 29, 31	6, 9	-
2006/07	-	-	-
2007/08	-	14, 17, 18, 21, 22, 23	4
2008/09	15	-	-

Figure 13 shows the average stratospheric temperature in the region 65-90°N. The figure is prepared by NOAA's (National Oceanic and Atmospheric Administration) Climate Prediction Center.

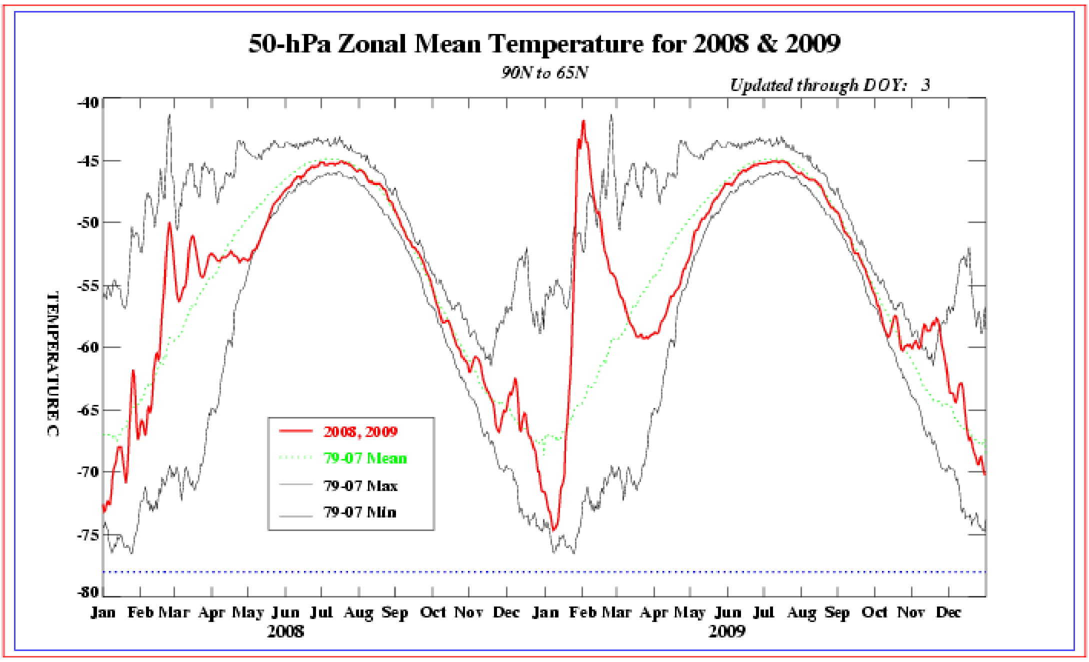


Figure 13: *The average stratospheric temperature in the region 65-90°N for 2008 and 2009. The figure is taken from http://www.cpc.noaa.gov/products/stratosphere/temperature/.*

The Figure clearly shows that there were remarkably high temperatures in the stratosphere in February the last two years, particularly in 2009. This has a direct influence on the ozone level at our latitudes as it prevents the formation of PSCs and subsequent chemical ozone destruction. The PSC threshold formation temperature is 195 K (-78 °C) for the PSC type I. The warm stratospheric winter lead to high ozone values in the winter/spring. The low ozone values in the late spring and summer is probably explained by dynamical processes (like less transport of ozone rich air from lower latitudes).

4. Satellite observations of ozone above Norway and the Norwegian Arctic region

It is very valuable to investigate the available ozone measurements from satellite in the Scandinavian and Arctic region, and compare the results with our ground-based observations. A great benefit of using the satellite data in the annual analysis of the Norwegian ozone layer is the increased information of the spatial distribution of ozone. This will improve the national monitoring of the ozone layer and the UV radiation as it allows more information than the point observations (like geographical variations), e.g. in Oslo and at Andøya. Satellites also make it possible to investigate the geographical extent of low ozone episodes during spring and summer and thereby discover enhanced UV intensity on a regional level. Based on a project jointly financed by The European Space Agency (ESA) (http://www.esa.int/) and The Norwegian Space Centre (NRS) (Norsk Romsenter, http://www.romsenter.no/) we are now in a position where we can explore and utilize ozone satellite observations in a better way in the National monitoring of the ozone and UV radiation in the future. The project started in October 2007 and ends in 2010. The results from this work are included in this report. One of the main goals is to compare ozone trends above Oslo and Andøya retrieved from ground based observations and satellite observations.

4.1 Short introduction to ozone observations from space

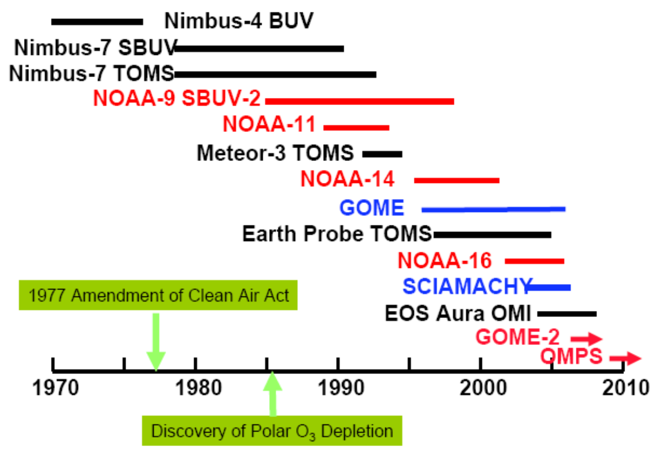


***Figure 14:** An overview of the various satellites and their instruments measuring ozone from space since the beginning of 1970's (Figure from NASA).*

The amount and distribution of ozone in the stratosphere varies greatly over the globe mainly controlled by two factors: the fact that the maximum production of ozone takes place at 40 km height in the tropical region, and secondly the large scale stratospheric transport patterns towards the mid- and high latitudes. In addition there are small scale transport and circulation patterns in the stratosphere determining the daily ozone levels. Thus, observing ozone fluctuations over just one spot is not sufficient to give a precise description of the ozone situation in a larger region. Satellite observations are filling these gaps. However, satellite observations rely on proper ground based monitoring as satellites have varying and unpredictable life times, and calibration and validation rely on high quality ground based observations. Thus satellite observations are complementary to ground based observations, and both are highly necessary.

Observations of seasonal, latitudinal, and longitudinal ozone distribution from space have been performed over more than 40 years using a variety of satellite instruments. The American institutions NASA and NOAA (National Oceanic and Atmospheric Administration) started these observations and later The European Space Agency also initiated their ozone programmes. Figure 14 gives a brief overview of the various ozone satellite missions measuring total column ozone since the beginning of the 1970's.

4.2 Comparison of ground based total ozone observations with satellite ozone observations for 2009

We have compared the ground based ozone measurements from Oslo and Andøya for 2009, with available satellite data for this site for the year 2009. The results for are presented in Figure 15.

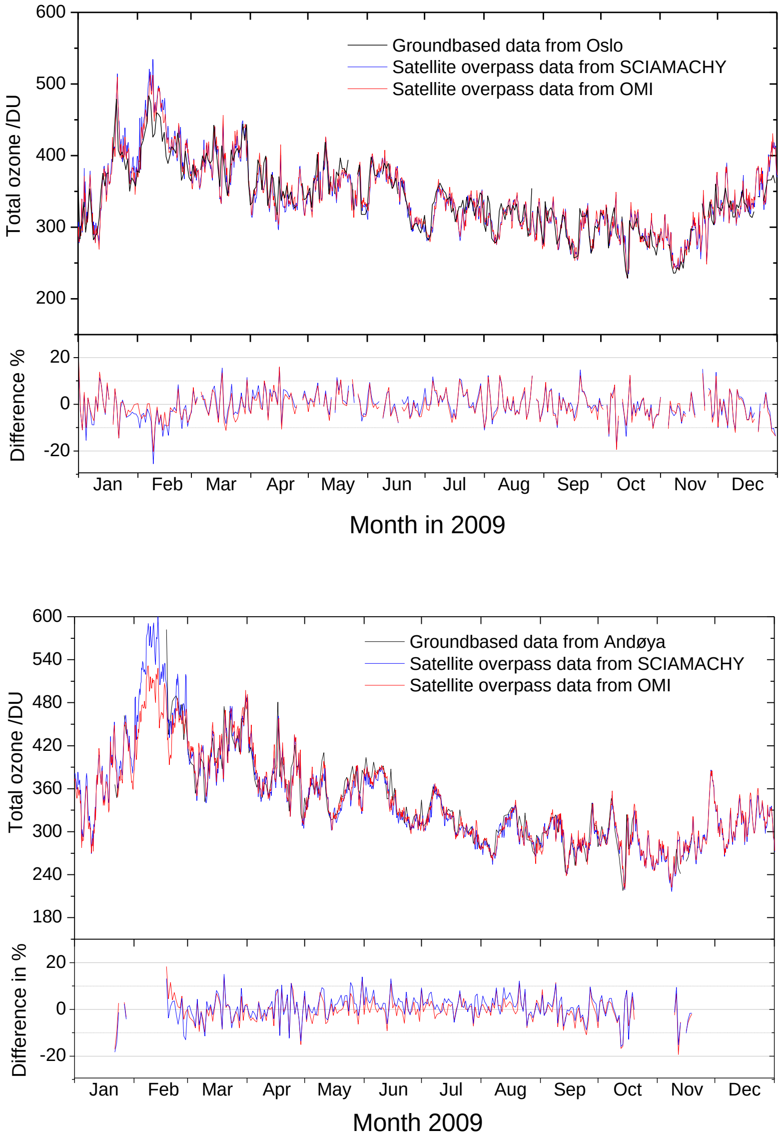


***Figure 15**: Comparison of ground based total ozone observations with satellite ozone observations (upper plot: Oslo, lower plot: Andøya). The top panel shows ozone observations compared to ozone data from OMI and SCHIAMACHY. The lower panel shows the percent difference.*

The black curve represents the ground based data, and the red and blue curves represent OMI and SCIAMACHY data respectively. The lower panels show the difference between the ground based data and the satellite retrieved data in percent. The average deviation for Andøya is -0.5 % (standard deviation of 5.4%) for OMI and 0.7% (standard deviation of

5.8%) for SCHIAMACHY. For Oslo the average deviation is -0.8 % (standard deviation of 5.4%) for OMI and -0.4 % (standard deviation of 6.4%) for SCHIAMACHY.

The largest difference is an over estimation of 25% for the SCIAMACHY data at selected days in February in Oslo and 20% for the OMI at Andøya in November. Also an overestimation of around 15 % is observed in the spring for both data sets at one day.

The comparisons indicate that the deviation between ground based data and satellite data seems to have a yearly cycle with highest values during the autumn/spring months. Ozone satellite data slightly overestimate the ozone values in spring and autumn, and underestimate the ozone value in the summer. This explains the low average deviation, but the high standard deviation (and variance not shown). It is currently unclear if this is caused by biased ground based data, or uncertain satellite retrievals. As expected the agreement is best during the summer months when the sun is far above the horizon.

4.3 Satellite ozone observations above the Norwegian sites from 1978–2009

Figure 16 shows the available ozone observations from satellite overpasses above the two Norwegian ozone sites in the period 1978-2009. Observations above Oslo are shown in the left panel and observations above Andøya are shown in the right panel. The colours and the arrows indicate the various data sources. The satellite measurements are performed by Nimbus TOMS, Meteor TOMS, Earth Probe TOMS, ERS-2 GOME, Envisat SCIAMACHY and AURA OMI.

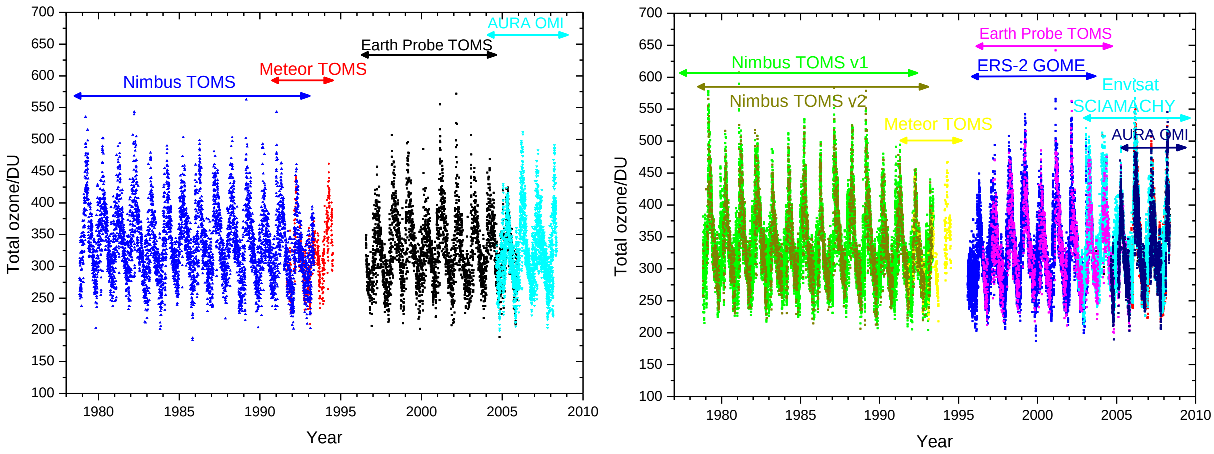


Figure 16: *Freely available ozone observations from satellite overpasses above Oslo (left panel) and Andøya (right panel). The coloured arrows indicate the various satellites and instruments.*

We have compared the monthly mean ozone values from ground based data and satellites for the full period, 1979-2009. Figure 17 shows the differences between the ground based monthly mean ozone observations from Oslo and Andøya and the monthly mean ozone data from the available satellite products. The comparison clearly illustrates that there are significant deviations.

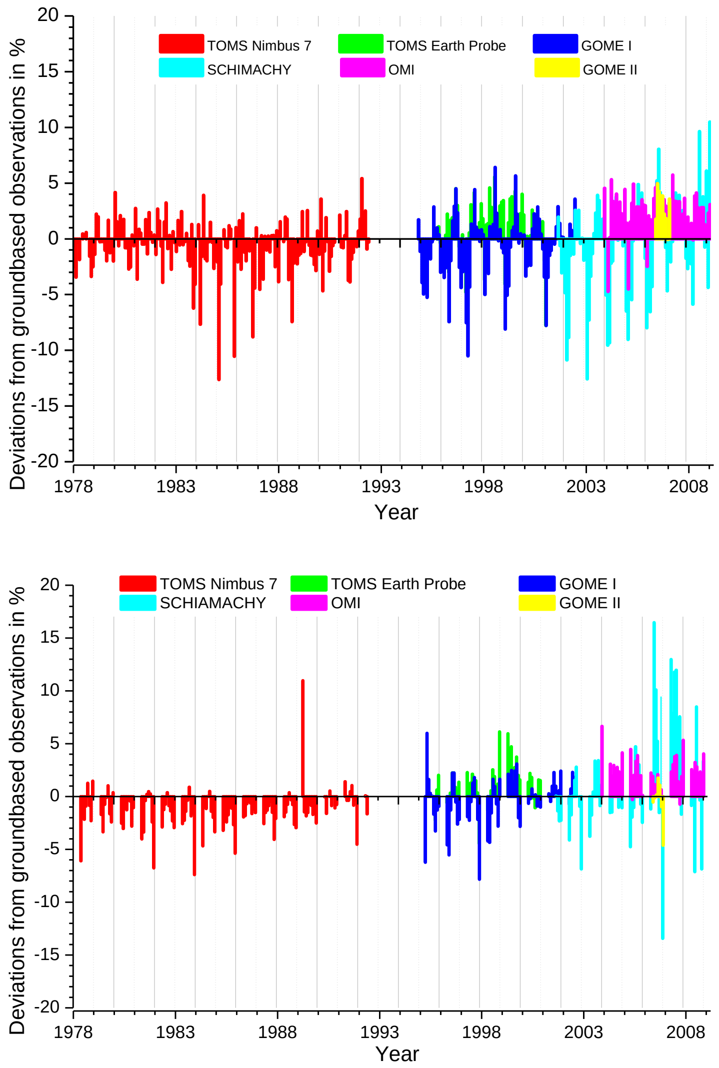


Figure 17: *Difference between ground based (GB) and satellite retrieved monthly mean ozone values from 1979 to 2009. Deviations (GB minus satellite values) are given in %. Upper panel: Oslo, Lower panel: Andøya.*

With respect to the monthly mean values, there are relatively large differences between the ground based data and the satellite data, and also between the various satellite data for overlapping time periods. There seems to be both seasonal and systematic differences between the various satellite data. For the Andøya data sets (in the lower panel) it is interesting to note the systematic difference in the data from 1979 to 1993. For this period we use ozone values retrieved from the satellite instrument TOMS in our trend analysis, thus the difference is explained by new and improved versions of released TOMS data. These recent results obtained through the SatLuft project strongly indicate that a re-evaluation of the satellite data is necessary for trend analyses in the future.

Table 7 gives an overview of the average deviations between the various data products together with standard deviations and variance for Oslo.

Table 7: *Average deviations in % between ground based and various satellites retrieved monthly mean ozone values from Oslo and Andøya. Standard deviation and variance are also included.*

Oslo					
Instrument	**Period**		**Mean**	**St. Dev**	**Variance**
TOMS (Earth probe)	Aug-96	Dec-01	0.99	2.51	6.31
TOMS (Nimbus 7)	Nov-78	Apr-93	-0.69	2.46	6.04
GOME 1	Aug-95	Jun-03	-0.78	3.06	9.34
OMI	Oct-04	Dec-09	2.40	1.93	3.72
SCIAMACHY	Jul-02	Dec-09	-0.45	4.34	18.85
GOME 2	Apr-07	Jun-08	2.92	1.58	2.51
Andøya					
Instrument	**Period**		**Mean**	**St. Dev**	**Variance**
TOMS (Earth probe)	Aug-96	Dec-01	1.32	1.99	3.97
TOMS (Nimbus 7)	Nov-78	Apr-93	-1.34	1.95	3.80
GOME 1	Aug-95	Jun-03	-0.35	2.47	6.09
OMI	Oct-04	Dec-08	2.34	1.53	2.34
SCIAMACHY	Jul-02	Dec-09	1.13	5.29	27.97
GOME 2	Apr-07	Jun-08	-0.47	2.06	4.23

For Oslo, TOMS (Nimbus 7), GOME (1&2) and SCHIMACHY overestimate the ozone values while the other satellite data tends to underestimates the values from the ground based observed ozone values. For Andøya the situation is somewhat different; SCHAMACHY is overestimating the ground based values. There are also clear seasonal variations in the deviations and the standard deviations and variances are very high for all comparisons. Consequently, the average values are not a proper measure for the discrepancies between the ground based and satellite retrieved data. Note the relatively low average deviation between the ground based values and SCIAMACHY, but the very high variance. This is also evident from Figure 17.

Our goal in SatLuft has been to define and construct an integrated data set from satellites that is suitable for trend analysis for the Scandinavian region. Based on the analysis we conclude that the ozone data from satellite observations above Oslo and Andøya still are too uncertain for reliable trend analysis as the variations between both the ground based data and among the various satellite data are too large.

5. The 4th IPCC report: Coupling of stratospheric ozone and climate

Climate change will affect the evolution of the ozone layer in several ways; through changes in transport, chemical composition, and temperature (IPCC, 2007; WMO, 2007). In turn, changes to the ozone layer will affect climate through the influence on the radiative balance, and the stratospheric temperature gradients. Climate change and the evolution of the ozone layer are coupled, and understanding of the processes involved is very complex as many of the interactions are non-linear.

Radiative forcing[3] is a useful tool to estimate the relative climate impacts due to radiative changes. The influence of external factors on climate can be broadly compared using this concept. Revised global-average radiative forcing estimates from the 4th IPCC are shown in Figure 18 (IPCC, 2007). The estimates are for changes in anthropogenic factors since pre-industrial times. Stratospheric ozone is a greenhouse gas. The change in stratospheric ozone since pre-industrial times has a weak negative forcing of -0.05 W/m^2 with a *medium* level of scientific understanding. This new estimate is weaker than in the previous report where the estimate was –0.15 W/m^2. The updated estimate is based on new model results employing the same data set as in the previous report, where observational data up to 1998 is included. No study has utilized ozone trend observations after 1998 (Forster et al., 2007).

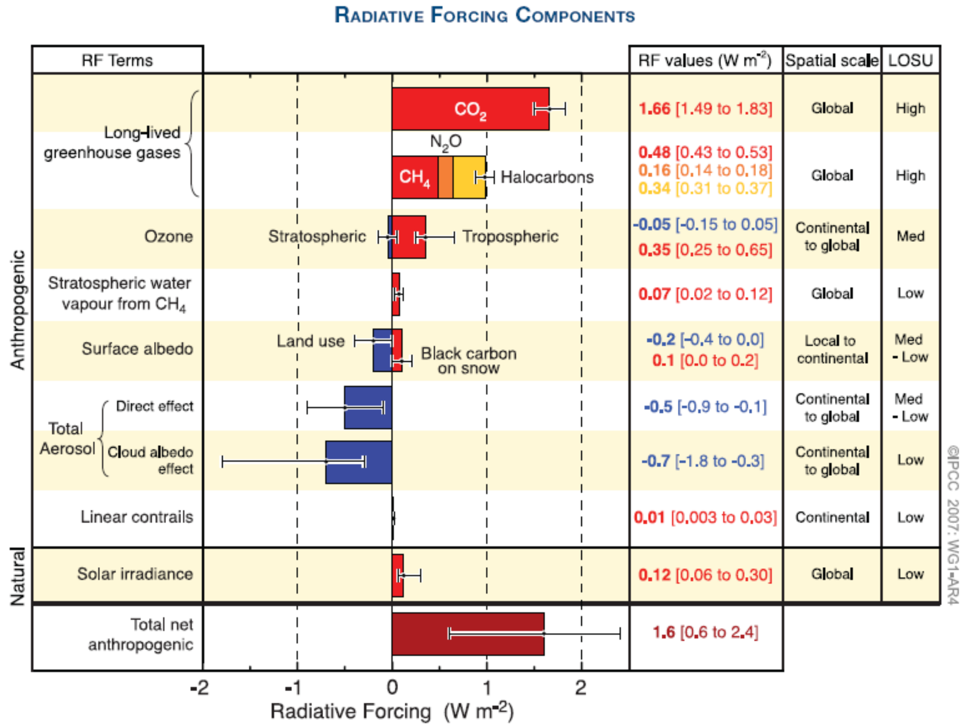


Figure 18: *Global-average radiative forcing estimates for important anthropogenic agents and mechanisms as greenhouse gases, aerosol effects, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU).*

[3] Radiative forcing is a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere. It is an index of the importance of the factor as a potential climate change mechanism. It is expressed in Wm^{-2} and positive radiative forcing tends to warm the surface. A negative forcing tends to cool the surface.

The temporarily and seasonally non-uniform nature of the ozone trends has important implications for the radiative forcing. Total column ozone changes over mid latitudes is considerable larger at the southern hemisphere (-6%) than at the northern hemisphere (-3%). According to the IPCC report the negative ozone trend has slowed down the last decade, also described in section 2.1 of this report. However, it is not yet clear whether these recent changes are indicative of ozone recovery (Forster et al., 2007).

Stratospheric ozone is indirectly affected by climate change through changes in dynamics and in the chemical composition of the troposphere and stratosphere (Denman et al., 2007). An increase in the greenhouse gases, especially CO_2, cools the stratosphere. In general a decrease in stratospheric temperature reduces ozone depletion leading to higher ozone column. However, there is a possible exception in the Polar Regions where lower stratospheric temperatures lead to more favorable PSC conditions and possible formation of more PSCs. This is of particular importance in the Arctic region (WMO, 2007). Moreover, ozone absorbs UV radiation. Absorption of UV radiation provides the heating responsible for the observed temperature profile above the tropopause. Changes in stratospheric temperatures, induced by changes in ozone or greenhouse gas concentrations will alter dynamic processes.

A long-term increase in stratospheric water content is observed. This might have important consequences for the ozone layer as stratospheric water vapour is among the main sources of OH in the stratosphere. OH is one of the key species in the chemical cycles regulating the ozone levels. There are several sources for stratospheric water where CH_4 is one of the most important. Other sources are volcanoes, natural and anthropogenic biomass burning and air crafts. In the new IPCC report, the increase in stratospheric water vapour resulting from anthropogenic emissions of methane (CH_4) has a positive forcing of 0.07 W/m^2, shown in Figure 18.

The evolution of stratospheric ozone over the next few decades will depend on natural, and human-caused factors such as stratospheric halogen loading. The evolution of ozone will also depend on changes in many stratospheric constituents: it is expected that the reduction of ozone-depleting substances in the 21st century will cause ozone to increase via chemical processes. However, this increase could be strongly affected by temperature changes (due to greenhouse gases), other chemical changes (e.g., due to water vapour) and transport changes. According to model studies presented in the last IPCC report (Denman et al., 2007) Antarctic ozone development follows mainly the behavior of chlorine and bromine compounds. The peak depletion is expected to have occured around the year 2000 followed by a slow increase. Most models predict that Antarctic ozone amounts will increase to 1980 levels close to the time when modelled halogen amounts decrease to 1980 values, which is in the year 2065. Increased atmospheric fluxes of chlor-fluor-carbons (CFCs) have recently been reported which may point to a still later recovery. The various models do not predict consistent values for minimum arctic column ozone. However, all the models predict that the Arctic ozone will recover earlier than the Antarctic ozone, mainly explained by circulation differences combined with a reduction in stratospheric temperatures.

6. UV measurements and levels

The Norwegian UV network was established in 1994/95 and consists of nine 5-channel GUV instruments located from 58°N to 79°N, illustrated in Figure 19. NILU is responsible for the daily operation of three of the instruments, located at Oslo (60°N), Andøya (69°N) and Ny-Ålesund (79°N). The Norwegian Radiation Protection Authority (NRPA) is responsible for the operation of the measurements performed at Trondheim, Bergen, Kise, Landvik, Finse and Østerås. On-line data from the UV network is shown at http://uv.nilu.no and at http://www.nrpa.no/uvnett/.

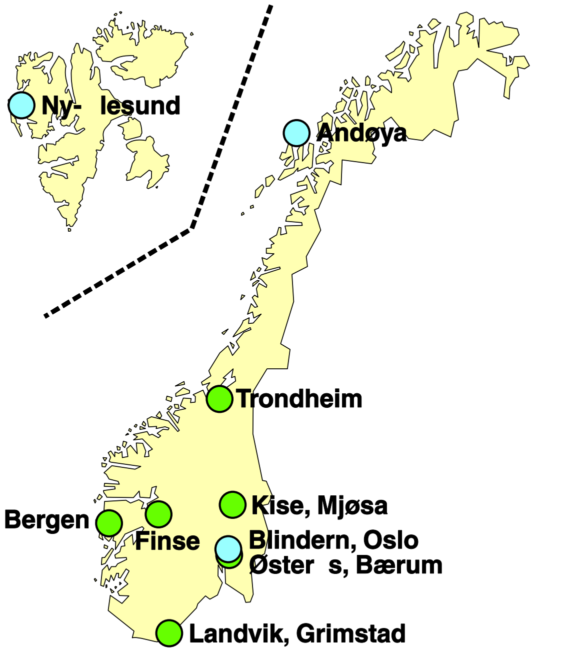


Figure 19: *Map of the stations included in the Norwegian UV network. The stations marked with blue are operated by NILU on behalf of The Norwegian Pollution Control Authority (SFT****)****, whereas the Norwegian Radiation Protection Authority operates the stations marked with green.*

This annual report includes results from Oslo and Andøya. Due to lack of funding, the GUV instrument in Ny-Ålesund has been omitted from the monitoring programme since 2006.

The Norwegian GUV instruments were included in a well-organised calibration and intercomparison campaign in 2005 as a part of the project FARIN (Factors Controlling UV in Norway)[4]. The project, which was financed by The Norwegian Research Council, aimed to quantify the various factors controlling UV radiation in Norway. This includes e.g. clouds, ozone, surface albedo, aerosols, latitude, and geometry of exposed surface. One part of the project has been the comparison and evaluation of all the UV-instruments in the Norwegian monitoring network. In total 43 UV instruments, including 16 NILU-UVs, were included in the campaign. The three GUVs from NILU were set up at the NRPA, Østerås, during the campaign and the calibration results were satisfactory.

Table 8: *Number of days with more than 2 hours of missing GUV data in 2009 and 2008. Days where the sun is below the horizon (polar night) are not included.*

Station	Technical problems	
	2009	2008
Oslo	14	11
Andøya	12	0

The GUV instruments are normally easy to maintain and have few interruptions due to technical problems. The number of missing days due to technical problems in 2009 is given Table 8. The problems were computer related at both sites.The data loss in Oslo and Andøya accounted for about 0.8% and 1.2%, respectively, of the yearly UV-dose.

[4] http://www.nilu.no/farin/

6.1 UV measurements in 2009

The UV dose rate is a measure of the total biological effect of UV-A and UV-B radiation (UV irradiance weighted by the CIE action spectra). The measurement unit for dose rate is mW/m^2, but it may also be given as a UV index. A UV index of 1 is equal to 25 mW/m^2. The concept of UV index is widely used for public information concerning sunburn potential of solar UV radiation. At Northern latitudes the UV indices typically vary between 0 – 7 at sea level, but can range up to 20 in Equatorial regions and high altitudes (WHO, 2002). Table 9 shows the UV-index scale with the recommended protections at the different levels. The recommendations are based on a moderate light skin type, typical for the Nordic population.

Table 9: *UV-index together with the recommended protection.*

UV-Index	Category	Recommended protection
11+	Extreme	Extra protection is definitively necessary. Avoid the sun and seek shade.
10 9 8	Very high	Extra protection is necessary. Avoid the sun between 12 PM and 3 PM and seek shade. Use clothes, a hat, and sunglasses and apply sunscreen with high factor (15-30) regularly.
7 6	High	Protection is necessary. Take breaks from the sun between 12 PM and 3 PM. Use clothes, a hat, and sunglasses and apply sunscreen with high factor (15+).
5 4 3	Moderate	Protection may be necessary. Clothes, a hat and sunglasses give good protection. Don't forget the sunscreen!
2 1	Low	No protection is necessary.

Figure 20 shows the UV dose rates measured at noon (averaged between 10:30 and 11:30 GMT) for Oslo and Andøya. The highest UV dose rate in Oslo, 173.0 mW/m^2, was observed 30 June and is equivalent to a UV index of 7.0. The black curves are the measurements and the red curves are model calculations employing the measured ozone values and clear sky. At Andøya the highest UV index was 4.7, with a dose rate of 118.5 mW/m^2, observed 22 June. Both maxima were observed in connection with broken clouds conditions and somewhat lower ozone values than the normal. In Oslo the total ozone column was 316 DU (normal ~ 340 DU) and the corresponding values at Andøya was 325 DU (normal ~ 350 DU). The combination of lower ozone and broken clouds has a forcing effect on the UV-radiation at the ground (shown in Figure 20). At these UV-levels a typical Nordic skin type gets sunburnt already after 20 min if no protection is used.

Many people from Norway visit Mediterranean countries during holidays, and UV-indices may easily become twice as high as in Oslo under conditions with clear sky and low ozone. In Norway the highest UV dose rates generally occur in the spring and early summer in snow covered alpine locations, such as Finse. In such areas the UV indices often reach 8 in this period.

The seasonal variation in the observed UV dose rate is closely related to the solar elevation. The highest UV levels normally occur during the summer months when the solar elevation is highest. In addition to solar elevation, the UV radiation is influenced by e.g. clouds, total ozone and ground reflection (albedo). Varying cloud cover mainly causes the large day-to-day variations in the UV radiation. However, rapid changes in the total ozone column, as may occur during the spring, may also give rise to large fluctuations in the UV-radiation from one day to another.

Monthly mean noon UV indices in for Oslo and Andøya in 2009 are compared in Figure 21. As expected, the monthly UV doses in Oslo were significantly higher than the values observed at Andøya. If the cloud and ozone conditions in Oslo and Andøya are similar during the summer, the UV-radiation is higher in Oslo than Andøya due to lower solar zenith angles most of the day.

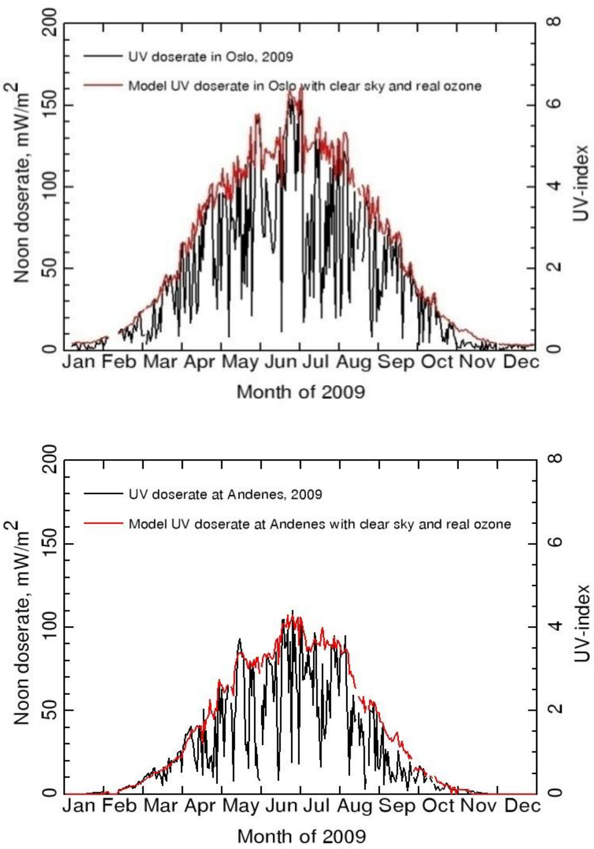


Figure 20: *Hourly averaged UV dose rate measured at noon (between 10:30 and 11:30 GMT). Upper panel: Oslo. Lower panel: Andøya.*

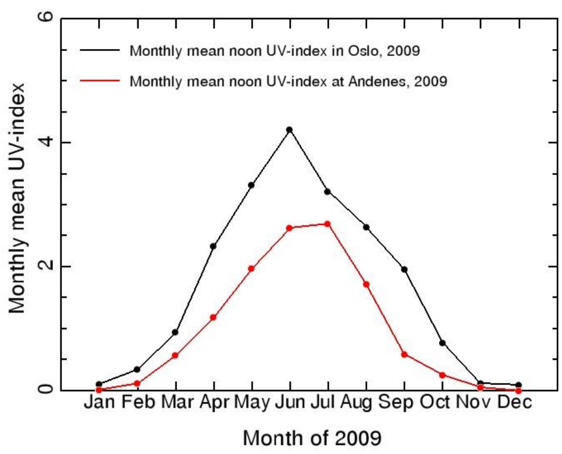


Figure 21: *Monthly mean UV indices in 2009 measured with the GUV instruments located in Oslo and Andøya.*

6.2 Elevated UV levels due to low ozone episodes in 2009

In 2009 there were two periods with low ozone values during late spring and summer. The first period was from 29 May to 1 June, where the ozone value in Oslo was 13 % below the long term mean and the corresponding UV index was 5.5. The public was informed trough media as this was the first warm summer days in southern Norway in 2009 and occurred during a long weekend (Whitsun). The next period was longer and lasted from 24 June to 5 July. The highest level was registered 2 July with ozone values 18% below the long term mean and a UV Index of 6.3. At Finse, which was still snow covered and is located at high altitude (1222 m a.b.l), the UV index was as high as 8.1 the 25th of June. This is classified as very high levels and is unusual. This period there were elevated UV-levels compared to normal in Western and Southern part of Norway, and the public was informed trough media (e.g. TV2 and VG). The information to public was based on ozone and UV ground based observations, ozone forecast for the next days, combined with the use of satellite data. Satellite data are crucial in determining the geographical extend of such low episodes

We have analysed all daily ozone fields available from the Ozone Monitoring Instrument (OMI) instrument throughout 2009 for Scandinavia and the associated Arctic, i.e. the area 54-82^o N,4-32^o E. The spatial and temporal distribution of the lowest ozone event as well as the potentially strongest ultraviolet radiation in 2009 was derived from the OMI satellite data. During 2009, the lowest ozone column (199 DU) in Scandinavia was detected at 8 November 2009. This is shown in Figure 22. All ozone column data pertaining to solar elevations less than 5 degrees were disregarded from the map calculations. The right panel shows the time series of total ozone before and after the day of lowest ozone.

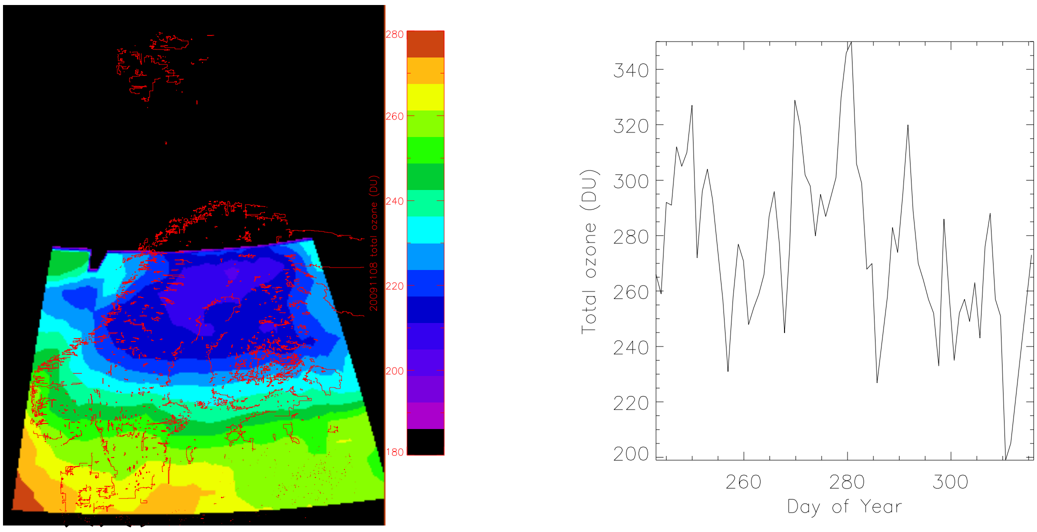


Figure 22: *Left panel: The spatial distribution of total ozone at the day of lowest ozone levels in 2009 over Scandinavia, i.e. 8 November 2009. The mean (1979-2008) ozone column for November in Oslo is 282 DU. Right panel: Time series of ozone columns (DU) before and after the day of lowest ozone columns in 2009 over Scandinavia. The mean (1979-2008) ozone columns for the same period in Oslo is 295 DU.*

Because the solar elevation is fairly low in autumn (November), other days closer to the summer solstice had higher daily ultraviolet doses. The day with the highest risk of sunburn (daily erythemal dose) was the 26 June 2009. The daily erythemal dose may be a more relevant measure of ultraviolet radiation exposure than the UV index because it accounts for the long summer days at high latitudes in summer. Erythemal daily doses are presented in Figure 23.

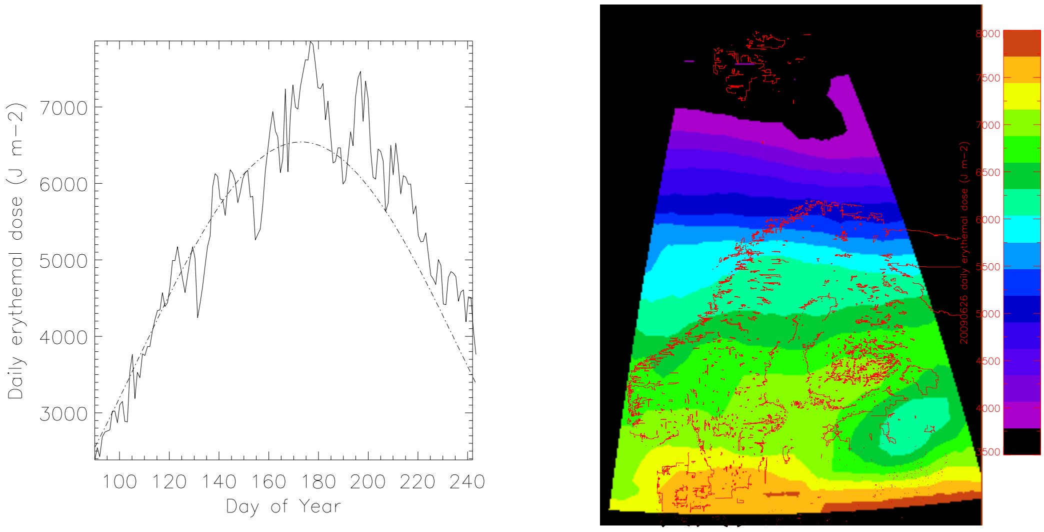


Figure 23: *Left panel: Time series of erythemal daily doses under simulated clear sky conditions before and after the day of potentially strongest ultraviolet exposure in 2009 averaged over the region shown in the right panel. The dashed curve illustrates the corresponding ultraviolet doses under mean (1979-2008) ozone conditions. Right panel: Spatial distribution of simulated clear sky erythemal ultraviolet doses at the day of potentially strongest ultraviolet exposure in 2009 over Scandinavia, i.e. 26 June 2009.*

The Figure shows that there is a strong increase in the UV level after day 165 (15 June). The maximum daily dose was as high as 7900 J m^{-2} at 26 June. At this day, the UV-Index in Oslo was 6.1 and the ozone value was 15% below the long term mean. The dashed curve illustrates the corresponding ultraviolet doses under mean (1979-2008) ozone conditions (i.e. 345 DU in Oslo).The spatial distribution of the simulated clear sky erythemal ultraviolet doses at the day of potentially strongest ultraviolet exposure is shown to in the right panel. The Figure illustrates that there are high UV-doses in all southern part of Norway. At Landvik, outside Kristiansand in the southern part of Norway, UV-index was as high as 6.3 at the 27 of June, according to the measurements of the Norwegian Radiation Protection Authorities.

Figure 24 (left panel) shows the European erythemal UV index retrieved from SCIAMACHY 27 June 2009 with high values in the southern part of Norway. The right panel is from 9 July and illustrates a day with high ozone values. The ozone observations in Oslo the ozone was 7% above long term mean at this day.

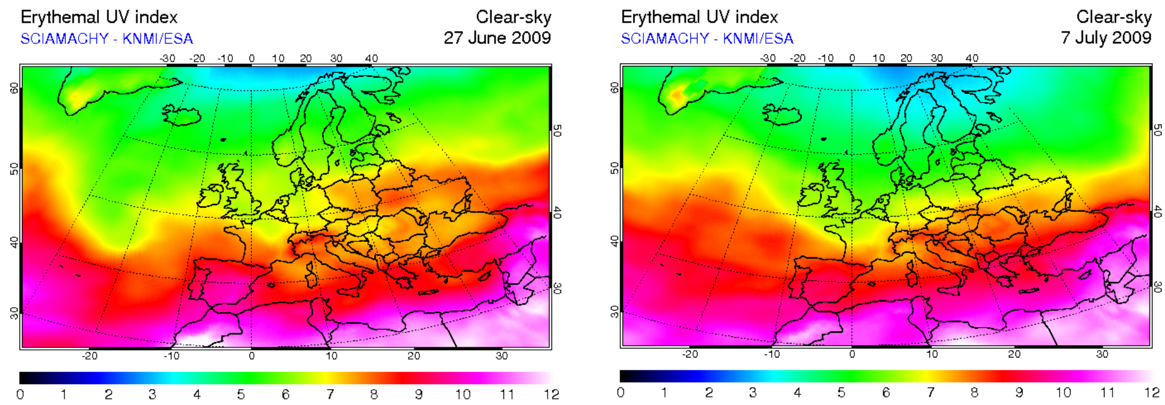


Figure 24: *European erythemal UV index from SCIAMACHY at 27 June and 7 July 2009.*

6.3 Annual UV doses 1995 – 2009

Annual UV doses for the period 1995 – 2009 are shown in Table 10 for the two GUV instruments in Oslo and Andøya. Annual UV doses for 2005 are not included in the Table as there were large gaps in the data set, mainly caused by a calibration campaign. The uncertainty in the daily UV doses is estimated to ±5% at a 2σ level (Johnsen et al., 2002). 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). This gives an additional uncertainty in the annual UV doses of ±1.6% for all stations and years, except for Andøya where the uncertainty amounts to ±2% for 2000 and ±5% for 2001. In 2009 Oslo had the second highest annual integrated UV-dose since 1997, and Andøya had the third highest UV-dose since the instrument was moved to this location in 2000.

The time series of UV doses are still too short for trend analysis since the inter-annual variations are larger than the expected long-term changes. However, a graphical illustration of the yearly integrated UV-dose is shown in Figure 25, as there is an increased focus on measurements of solar radiation in relation to the so-called dimming and brightening. Global dimming is a process where atmospheric aerosols reduce the radiation received by the earth surface through scattering and absorption of solar radiation. Understanding of global dimming is of crucial important in the investigation of climate change; because aerosol dimming may mask the temperature rise at the surface caused by the increase of greenhouse gases. A study presented in Science in May 2005 (Wild et al., 2005) shows that the surface levels of total solar radiation from 1990 to present has increased. This was particularly evident for the sites at the Northern hemisphere. Changes in ozone, aerosols and clouds influence the UV level and long-term changes in the solar radiation received at the earth surface. It is therefore essential to continue the UV and ozone monitoring activity in the future to observe and investigate long-term variations of ground level solar radiation.

Table 10: *Annual integrated UV doses (kJ/m2) at the three stations during the period 1995 – 2009.*

Year	Oslo (kJ/m^2)	Andøya (kJ/m^2)	Tromsø (kJ/m^2)*	Ny-Ålesund (kJ/m^2)
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 gaps in the data caused by a calibration campaign			
2006	372.4	219.4		No measurements
2007	351.8	253.3		No measurements
2008	375.3	266.5		No measurements
2009	378.6	254.1		No measurements

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

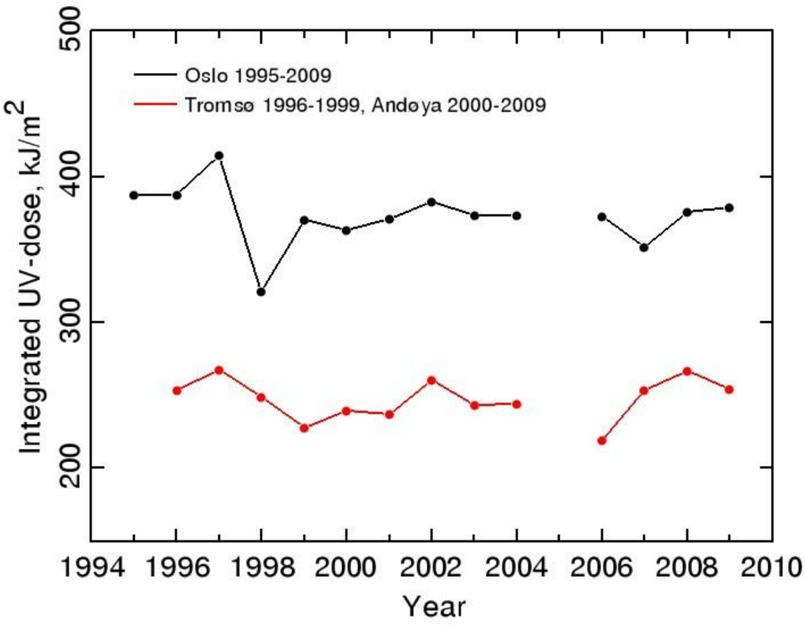


Figure 25: *Annual integrated UV doses (kJ/m^2) at Oslo and Tromsø/Andøya during the period 1995 – 2009.*

7. UV-radiation, vitamin D, and breast cancer in Norway

During the last two decades intensive research has suggested that vitamin D has a preventive effect on some autoimmune diseases (Cantorna, 2000), some forms of cancer (Cui et al., 2006; Garland et al., 2006; Giovannucci et al., 2006; Giovannucci, 2006), and a positive effect on cancer. The exact biological processes involved still remains unclear, but it seem that vitamin D has multiple effects beyond the traditional role in the calcium regulation process. Vitamin D compounds have been demonstrated to have effects on cell cycle progression, differentiation and programmed cell death, which in general is cancer related. Thus, in the last few years there has been a discussion on whether moderate exposure to solar ultraviolet (UV) radiation has a positive overall health effect or not (Lucas et al., 2008). Sun exposure is an established risk factor for basal cell carcinoma, squamous cell carcinoma and melanoma (see e.g. Armstrong et al., 2001).

Some studies have shown that it is possible that solar induced vitamin D may have a preventive effect in developing breast cancer while other studies show no association. In the study of Edvardsen et al., 2009 it was not found any significant association between vitamin D intake or vitamin D effective UV-dose, and risk of breast cancer among women living at high latitudes. In fact there is an inverse relationship between UV-radiation and risk of breast cancer in the Nordic countries, for which the reason still remains unclear.

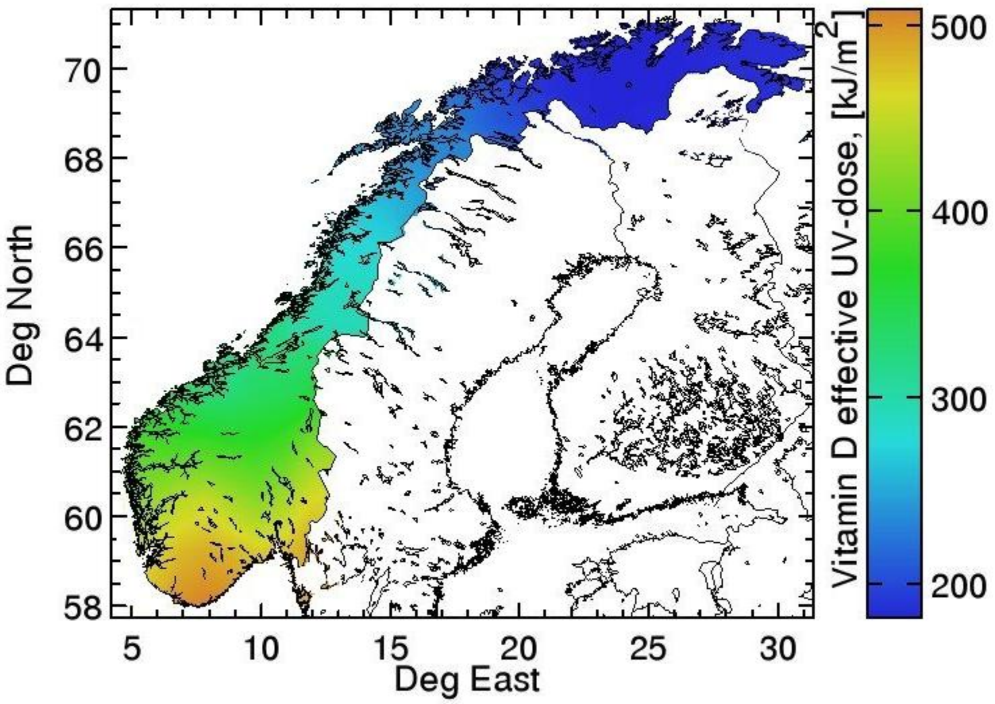


Figure 26: *Yearly mean vitamin D effective UV-dose, mean 1979 – 1998. All three main driving forces for vitamin D effective UV-radiation (total atmospheric ozone, cloudiness and solar zenith angle) are accounted for in the estimations.*

8. References

Armstrong, B.K. and Kricker, A. (2001) The epidemiology of UV induced skin cancer. *J. Photochem. Photobiol. B-Biol.*, *63*, 8-18.

Bodeker, G.E., Waugh, D.W., Akiyoshi, H., Braesicke, P., Eyring, V., Fahey, D.W., Manzini, E., Newchurch, M.J., Portmann, R.W., Robock, A., Shine, K.P., Steinbrecht, W. and Weatherhead, E.C. (2007) The ozone layer in the 21st century. In: *Scientific assessment of ozone depletion: 2006.* Geneva, World Meteorological Organization (Global Ozone Research and Monitoring Project—Report No. 50).

Cantorna, M.T. (2000) Vitamin D and autoimmunity: Is vitamin D status an environmental factor affecting autoimmune disease prevalence? *Proc. Soc. Exp. Biol. Med.*, *223*, 230-233.

Cui, Y. and Rohan, T.E. (2006) Vitamin D, calcium, and breast cancer risk: a review. *Cancer Epidemiol. Biomarkers Prev.*, *15*, 1427-1437.

Denman, K.L., Brasseur, G., Chidthaisong, A., Ciais, P., Cox, P.M., Dickinson, R.E., Hauglustaine, D., Heinze, C., Holland, E., Jacob, D., Lohmann, U., Ramachandran, S., da Silva Dias, P.L., Wofsy, S.C. and Zhang, X. (2007) Couplings between changes in the climate system and biogeochemistry. In: *Climate Change 2007: The physical science basis. Contribution of Working Group I to the fourth assessment report of the Intergovernmental Panel on Climate Change.* Ed. by S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller. Cambridge, Cambridge University Press.

Edvardsen, K., Brustad, M., Engelsen, O. and Aksnes, L. (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 degrees N). *Photochem. Photobiol. Sci.*, *6*, 57-62.

Farman, J.C., Gardiner, B.G. and Shanklin, J.D. (1985) Large losses of total ozone in Antarctica reveal seasonal ClO_x/NO_x interaction. *Nature*, *315*, 207-210.

Forster, P., Ramaswamy, V., Artaxo, P., Berntsen, T., Betts, R., Fahey, D.W., Haywood, J., Lean, J., Lowe, D.C., Myhre, G., Nganga, J., Prinn, R., Raga, G., Schulz, M. and Van Dorland, R. (2007) Changes in atmospheric constituents and in radiative forcing. In: *Climate Change 2007: The physical science basis. Contribution of Working Group I to the fourth assessment report of the Intergovernmental Panel on Climate Change.* Ed. by S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller. Cambridge, Cambridge University Press.

Garland, C.F., Mohr, S.B., Gorham, E.D., Grant, W.B. and Garland, F.C. (2006) Role of ultraviolet B irradiance and vitamin D in prevention of ovarian cancer. *Am. J. Prev. Med.*, *31*, 512-514.

Giovannucci, E. (2006) The epidemiology of vitamin D and colorectal cancer: recent findings. *Curr. Opin. Gastroenterol.*, *22*, 24-29.

Giovannucci, E., Liu, Y., Rimm, E.B., Hollis, B.W., Fuchs, C.S., Stampfer, M.J. and Willett, W.C. (2006) Prospective study of predictors of vitamin D status and cancer incidence and mortality in men. *J. Natl. Cancer Inst.*, *98*, 451-459.

Goutail, F., Lefèvre, F., Pommereau, J.P., Pazmiño, A., Chipperfield, M., Feng, W., Van Roozendael, M., Eriksen, P., Stebel, K., Dorokhov, V., Kyro, E., Adams, C., Fraser, A.M. and Strong, K. (2009) Total ozone loss during the 2008/2009 Arctic winter and comparison to previous years. Poster presented at General Assembly of the European Geosciences Union (EGU), Vienna, Austria, 19 – 24 April 2009.

IPCC (2007) Summary for policymakers. In: *Climate Change 2007: The physical science basis. contribution of Working Group I to the fourth assessment report of the Intergovernmental Panel on Climate Change.* Ed. by S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller. Cambridge, Cambridge University Press.

Johnsen, B., Mikkelborg, O., Hannevik, M., Nilsen, L.T., Saxebø, G. and Blaasaas, K.G. (2002) The Norwegian UV-monitoring program, period 1995/96 to 2001. Østerås, Statens strålevern (Strålevern Rapport 2002:4).

Lucas, R.M., McMichael, A.J., Armstrong, B.K. and Smith, W.T. (2008) Estimating the global disease burden due to ultraviolet radiation exposure. *Int. J. Epidemiol., 37*, 654-667.

Newman, P.A., Oman, L.D., Douglass, A.R., Fleming, E.L., Frith, S.M., Hurwitz, M.M., Kawa, S.R., Jackman, C.H., Krotkov, N.A., Nash, E.R., Nielsen, J.E., Pawson, S., Stolarski, R.S. and Velders, G.J.M. (2009) What would have happened to the ozone layer if chlorofluorocarbons (CFCs) had not been regulated? *Atmos. Chem. Phys., 9*, 2113–2128.

Stamnes, K., Slusser, J. and Bowen, M. (1991) Derivation of total ozone abundance and cloud effects from spectral irradiance measurements. *Appl. Opt., 30*, 4418-4426.

Svendby, T.M. and Dahlback, A. (2002) Twenty years of revised Dobson total ozone measurements in Oslo, Norway. *J. Geophys. Res., 107D*, 4369, doi: 10.1029/2002JD002260.

Veierod, M.B., Weiderpass, E., Thorn, M., Hansson, J., Lund, E., Armstrong, B. and Adami, H.O. (2003) A prospective study of pigmentation, sun exposure, and risk of cutaneous malignant melanoma in women. *J. Natl. Cancer Inst., 95*, 1530-1538.

Weatherhead, E.C. and Andersen, S.B. (2006) The search for signs of recovery of the ozone layer. *Nature, 441*, 39-45.

Werner, R., Stebel, K., Hansen, G.H., Hoppe, U.-P., Gausa, M., Kivi, R., von der Gathen, P. and Orsolini, Y. (2008) Study of the inter-annual ozone variation at European high latitudes. Poster presentation at Quadrennial Ozone Symposium, Tromsø, Norway, June 29th - July 5th, 2008.

Werner, R., Stebel, K., Hansen, G.H., Hoppe, U.-P., Gausa, M., Kivi, R., von der Gathen, P. and Orsolini, Y. (2008) Study of the inter-annual ozone variation at European high latitudes. Poster presented at 37th COSPAR Scientific Assembly, Montreal, Canada, 13-20 July 2008 (paper number: A11-0166-08).

WHO (2002) Ultraviolet radiation: Global solar UV-index. Geneva, World Health Organization (Revised Fact Sheet No 271). URL: http://www.who.int/mediacentre/factsheets/fs271/en/.

Wild, M., Gilgen, H., Roesch, A., Ohmura, A., Long, C.N., Dutton, E.G., Forgan, B., Kallis, A., Russak, V. and Tsvetkov, A. (2005) From dimming to brightening: Decadal changes in solar radiation at Earth's surface. *Science, 308*, 847-850.

WMO (2007) Scientific assessment of ozone depletion: 2006. Geneva, World Meteorological Organization (Global Ozone Research and Monitoring Project – Report No. 50).

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Tittel - norsk og engelsk
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Sammendrag – summary
Rapporten presenterer måledata for totalozon, vertikalfordelingen av ozon og UV-stråling over norske målestasjoner i 2009. For Oslo og Andøya er trenden i totalozon beregnet for perioden 1979-2009. This is an annual report describing the activities and main results of the monitoring programme “Monitoring of the atmospheric ozone layer and natural ultraviolet radiation” for 2009.

4 emneord	4 subject words
Stratosfærisk ozon UV-stråling Målinger og observasjoner Montreal-protokollen	Stratospheric ozone UV radiation Measurements and observations Montreal protocol

Statlig program for forurensningsovervåking

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Om Statlig program for forurensningsovervåking

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- overgjødsling
- forsuring (sur nedbør)
- ozon (ved bakken og i stratosfæren)
- klimagasser
- miljøgifter

Overvåkingsprogrammet skal gi informasjon om tilstanden og utviklingen av forurensningssituasjonen, og påvise eventuell uheldig utvikling på et tidlig tidspunkt. Programmet skal dekke myndighetenes informasjonsbehov om forurensningsforholdene, registrere virkningen av iverksatte tiltak for å redusere forurensningen, og danne grunnlag for vurdering av nye tiltak. Klima- og forurensningsdirektoratet er ansvarlig for gjennomføringen av overvåkingsprogrammet.

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