Statlig program for forurensningsovervåking

Annual report 2008

Monitoring of the atmospheric ozone layer and natural ultraviolet radiation

1053
2009

Norsk institutt for luftforskning
Norwegian Institute for Air Research

Statlig program for forurensningsovervåking:
Overvåking av ozonlaget og naturlig ultrafiolett stråling

SPFO-rapport: 1053/2009
TA-2532/2009
ISBN 978-82-425-2118-7 (trykt)
ISBN 978-82-425-2119-4 (elektronisk)

Oppdragsgiver: Statens forurensningstilsyn (SFT)
Utførende institusjon: Norsk institutt for luftforskning (NILU)

Monitoring of the atmospheric ozone layer and natural ultraviolet radiation

Rapport
1053/2009

Annual report 2008

Author(s): C. Lund Myhre, K. Edvardsen, K. Stebel, T.M. Svendby, O. Engelsen, R. Kube, A. Dahlback (UiO)

NILU project no.: O-106007/O-106008
NILU report no.: OR 29/2009
ISSN 0807-7207

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 insteisfied when the Antarctic ozone hole was discovere4d in teh 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. 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 reached somewhat later.

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 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:

1. Provide continuous measurements of total ozone and natural ultraviolet radiation that reach the ground.
2. Provide data that can be used for trend analysis of both total ozone and natural ultraviolet radiation.
3. Provide information on the status and the development of the ozone layer and natural ultraviolet radiation
4. Notify the Norwegian Pollution Control Authority when low ozone/high UV episodes occur.

In 2008 the monitoring programme included measurements of total ozone and UV at two locations, Oslo (60°N) and Andøya (69°N) and ozone profiles measurements at one location, Andøya. This report summaries the activities and results of the monitoring programme during the year 2008. The report includes trend analyses of total ozone for the period 1979-2008 for both sites and comments on the expected ozone recovery at northern latitudes. Further the total yearly UV dose for 2008 at Oslo and Andøya is included.

Kjeller, June 2009

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 2008, which is a part of the governmental programme for monitoring pollution in Norway.

Measurements of total ozone
The Brewer instrument at Oslo has been in operation at the University of Oslo since the summer of 1990. Total ozone data from a Dobson spectrophotometer are available for the period from 1979 to 1998.

By combining the two data series, we have been able to study the changes in the ozone layer above Oslo for the period 1979–2008. During this period the ozone layer has a total yearly decrease of 3.2 % and as much as 4.6 % decrease is observed during the spring months since 1979, but the spring trend is not significant. No significant trends are observed for the winter, summer, and autumn months in Oslo.

For Andøya a similar trend analysis is performed for the period 1979–2008. The total ozone values for the period 1979-1994 are based on measurements from the satellite instrument TOMS (Total Ozone Mapping Spectrometer), whereas for the period 1994–2008 total ozone values from the Brewer instrument are used. The results from the trend analysis show no significant trends in total ozone for Andøya.

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

The stratospheric winter 2007/08 can be classified as a cold winter, giving rise to conditions were chemical ozone destruction might occur. According to the observation this was also the case. Significant ozone loss was observed during winter and spring 2008 initiated by the formation and presence of polar stratospheric clouds (see picture). In February the monthly mean ozone value was more than 14% below the long term mean level over Oslo, and also December had very low values in Oslo, 12% below the long term mean.

Recent global ozone data indicate that there might be signs of ozone recovery from mid 1990s in most of the world. However this is uncertain, 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.

We have recently investigated if there is a possible turning point and of the ozone layer above Oslo. The first results of this analysis indicate that the minimum is passed, and that the ozone layer above Oslo is now in a recovery phase. The minimum was passed in the period from 1988-1997. Since then there has been a gradual increase, however the last years there seem to be a stagnation of this development.

There are several satellite dataset with ozone available for the region. A great benefit of using these data in the annual analysis of the ozone layer is the increased information of the 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 winter months. Further the results indicate that the ozone satellite data underestimate slightly the ozone layer in our region.

Considerably longer data series and improved understanding of atmospheric processes and dynamics are needed to predict the development of the ozone layer with acceptable confidence.

Measurements of ozone profiles

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. 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. The development of the stratospheric ozone layer in 2008 shows ozone destruction in springtime, but not as much as in the year 2005.

UV measurements

The Norwegian UV network was established in 1994/95 and consists 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 2008 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 in Ny-Ålesund, the site closest to Arctic is Andøya.

The highest UV dose rate in Oslo, 149.3 mW/m^2, was observed 9 June and is equivalent to a UV index of 6.0. At Andøya the highest UV index, 4.4, was observed on the 3 June.

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 detection 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.

2. Ozone measurements in 2008

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 i 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 2008. 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. Calibration reports are available on request.

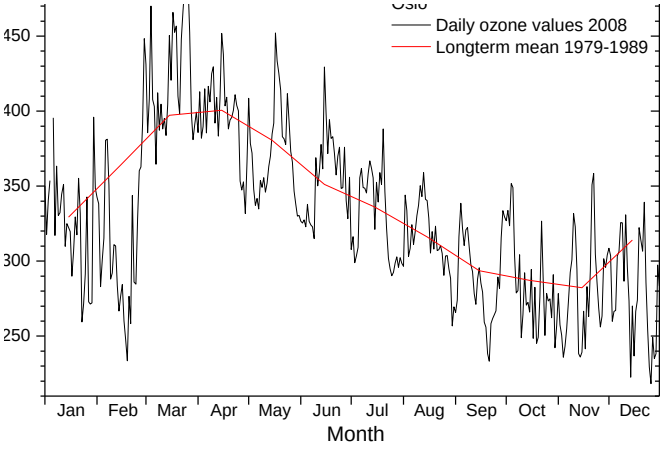

Figure 1a): *Daily total ozone values measured at the University of Oslo in 2008. The red curve shows the long-term monthly mean values from 1979-1989.*

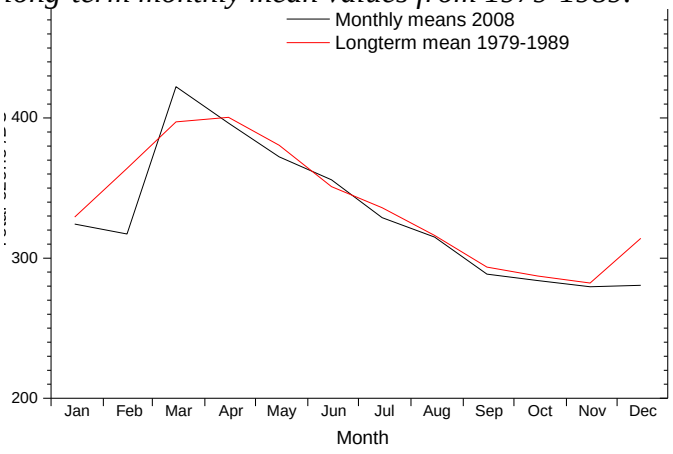

Figure 1b): *Monthly mean ozone values for 2008. The red curve shows the long-term monthly mean values from 1979-1989.*

In the following sections are the results of the ground based ozone measurements f Oslo and Andøya presented, and in Chapter 4 on page 25 are satellite data of ozone presented.

2.1 Total column ozone in Oslo

Daily ozone values for Oslo in 2008, based on measurements with the Brewer spectrometer no. 42, are shown in Figure 1. The black curve shows the daily ozone values measured in 2008, 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 2008 DS measurements were performed 139 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 224 days in 2008. In 2008 there is only one day with missing data, 5th January. This is due to bad weather and cloud conditions.

Figure 1a) displays the daily total ozone values for Oslo together with the long-term mean values. Large day-to-day fluctuations are observed particularly in the spring, and there are periods during spring with ozone values significantly below the long-term mean, which is a common phenomenon. The lowest ozone value was observed 26 December, and was as low as 218 DU. Furthermore there is a period from 26 May to 10 June with values considerable below the long-term mean. The most extreme day was 9 June with ozone values 11% below the long term mean and a UV Index of 6.3 (see section 6.1).

The monthly mean total ozone values for 2008 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 2008 ozone values were close to the mean values in all months, except for February, March and December.

Section 3.2.1 and 3.4 includes a broader discussion and interpretation of the ozone situation in Norway in 2008.

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 119 days without ozone observations at Andøya, and all of them are a direct result of the polar night or not suitable weather conditions. Table 1 gives an overview of the different instruments and methods that were used at Andøya in 2008.

Table 1: *Overview of instruments and methods applied in the observation of the total ozone above Andøya in 2008.*

Priority	Method	Total days with observations
1	Brewer instrument, direct sun measurements	95
2	Brewer instrument, global irradiance method	119
3	GUV instrument, GI method	15
4	Lidar (measurements in the Polar night)	13

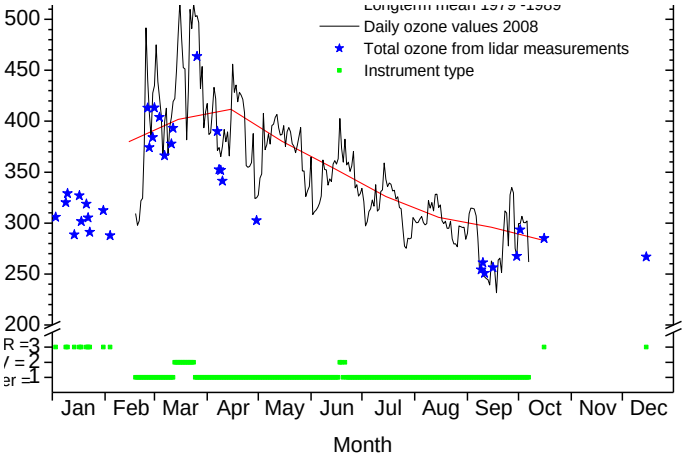

Figure 2a): *Daily total ozone values measured at ALOMAR, Andøya, in 2008 by the Brewer, GUV and LIDAR instruments. The use of the different instruments is shown in the lower part of Figure 2a). The red line shows the long-term monthly mean values from 1979-1989.*

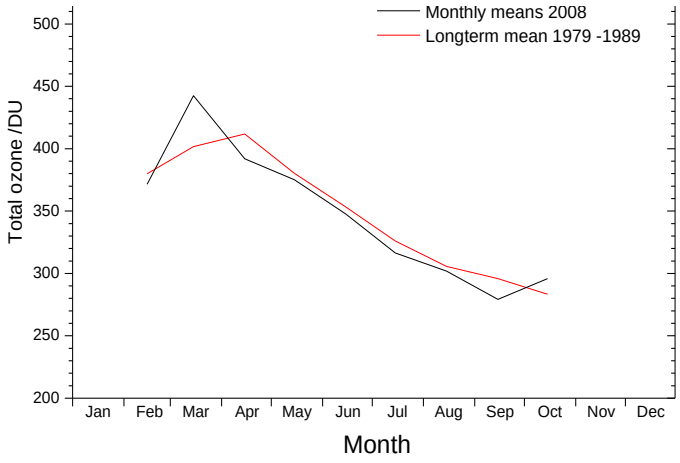

Figure 2b): *Monthly mean ozone values for 2008 compared to the long-term monthly mean values for the period from 1979-1989 shown as the red curve.*

Daily ozone values for Andøya in 2008, based on measurements with the Brewer spectrometer, are shown in Figure 2a). The black curve shows the daily ozone values from 2008, 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 and are indicated by blue stars. These 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 2008 shows that the ozone values are below the long term mean throughout the whole year, except for March and October.

After 2006 automatic procedures ensured submission of real-time ozone data from Andøya to the international community through the World Ozone and Ultraviolet Radiation Data Centre (http://www.woudc.org/).

2.3 Stratospheric ozone-profile measurements made in 2008 by means of the ozone lidar, located at ALOMAR (69°N, 16°E)

To follow the development of the stratospheric ozone layer during winter 2007/08 and in 2008 lidar measurements have been performed. The ozone lidar is located at the Arctic Lidar Observatory for Middle Atmosphere Research (ALOMAR) at Andøya (69°16'N, 16°00'E, elev. 380 m). The measurements are quality controlled and contribute to the Network of Detection of Atmospheric Composition Change (NDACC). The system has been operated on a routine basis during clear sky conditions. Normally two hours of measurements result in an ozone profiles in the height range between 8 and 45 km. In 2008 sufficient long measurements have been made at 34 days (39 occasions). 34 quality controlled ozone profiles have been retrieved for 33 days. The specific days are summarized in Table 1. Polar stratospheric clouds have been detected in January and February 2008 (see 3.4.1 for more details).

Table 2**:** *Overview over days with stratospheric ozone profiles measured in 2008, retrieved from measurements with the ozone lidar, which is located at ALOMAR.*

Month	Ozone profiles	Comments
January	3, 9, 10, 14, 17, 18, 21a, 21b, 22, 23, 31	
February	4, 26, 27, 29	
March	1, 4, 7, 11, 12, 26	new detector
April	7, 8, 9, 10, 30	
May - August	-	no daylight measurements
September	9, 10, 11, 16, 30	
October	2, 16	
November	-	laser failure
December	15	

Compared to 2007, the number of retrieved profiles has increased from 25 to 34, but this is still far from optimal. Increasing costs based on changed ownership and drift of the system (70% NILU, 30% Andøya Rocket Range) and necessary investments[1] make it difficult to continue the long-time series of stratospheric ozone profile measurements, which has started in 1995. Labor intensive daylight measurements due to high requirements on the alignment of the system have not been made in 2008, due to insufficient funding.

The development of the stratospheric ozone layer above northern Scandinavia throughout 2008 is illustrated in Figure 3. For comparison, the stratospheric ozone profiles seen during previous years (1996 and 2003 - 2007) are shown in Figure 4.

[1] New detector based on transient recorder from Licel GmbH, software development

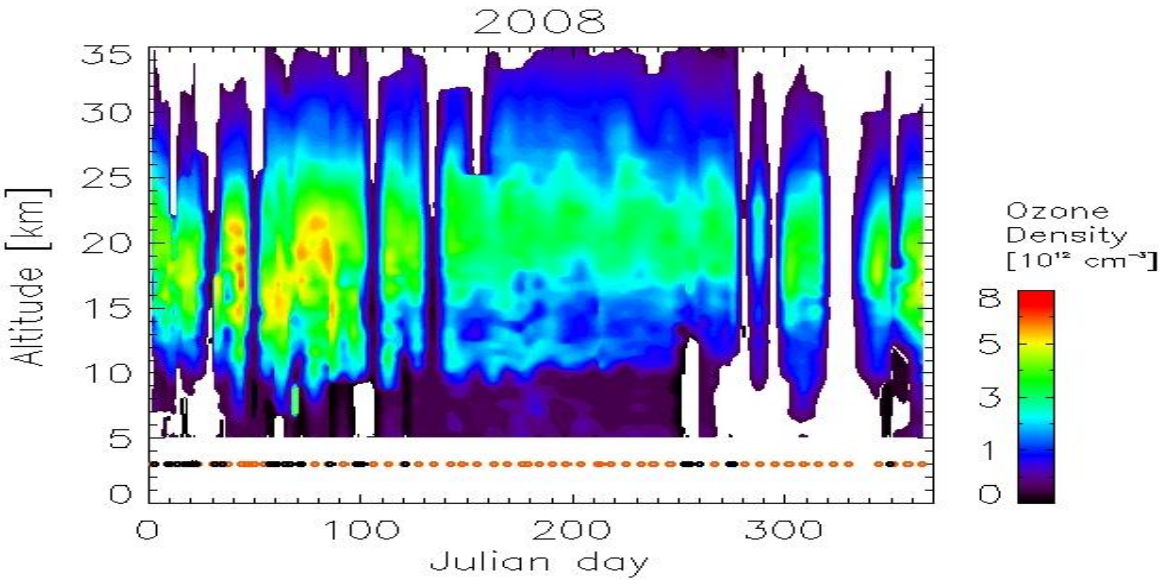

Figure 3: *The stratospheric ozone layer in 2008, derived from profiles measured by the ALOMAR ozone lidar and ozone sondes launched in Sodankylä, Finland, in 2008. The black dots at the bottom of the plot mark the times when lidar measurements were performed, while the red dots mark days where data 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.*

Comparing the winter 2008 with previous ones, the ozone situation was not remarkable in either a positive or negative manner. The spring time ozone was not as low as in the very cold winter 1996, but clearly more depleted than after the warm winter 2004. The averaged ozone depletion has been retrieved by Goutail and co-workers, and based on results e.g. from the SAOZ network they calculated the Arctic depletion to 30% in 1995/96, 20% in 2002/03, 17% in 2003/04, 13% in 2005/06, 23% in 2004/05, 2006/07 and 2007/08 (Goutail, 2008a, b). The development of the stratospheric ozone layer over Andøya is reflecting this inter-annual variability. In accordance with previous reports and Werner et al., 2008, also in 2008 we find a second ozone maximum near 13 km during 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. This has led to a layer with a very low ozone density above the troposphere inversion layer from June/July up to the late autumn. At the end of 2008, in early December 2008, the polar vortex had built up and typical pre-winter ozone values were observed.

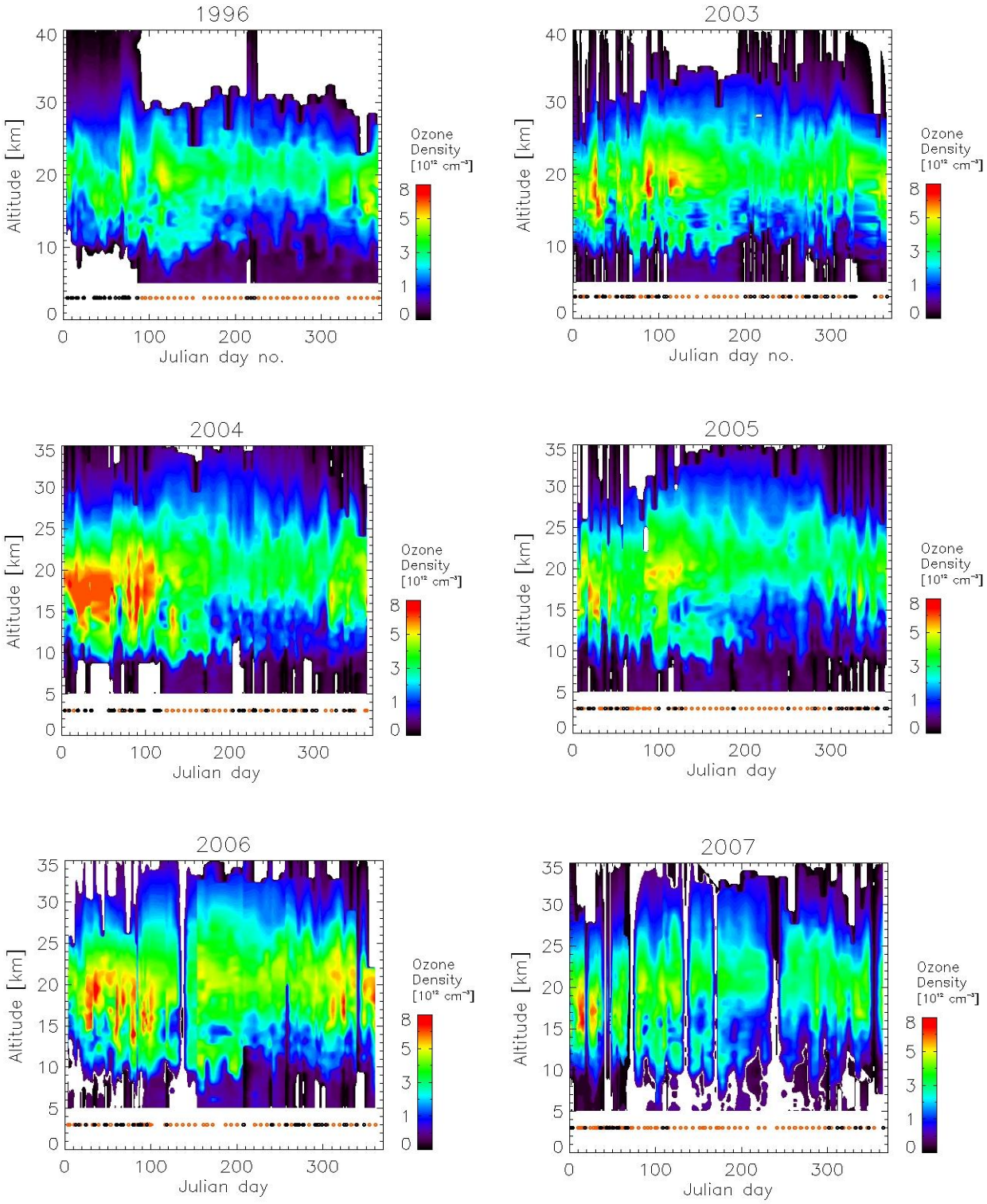

Figure 4: *Ozone profiles measured by the ALOMAR ozone lidar and ozone sondes launched in Sodankylä, Finland, in 1996 and 2003-2007 (analogue to Figure 4).*

3. Ozone measurements and trends for 1979–2008

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.

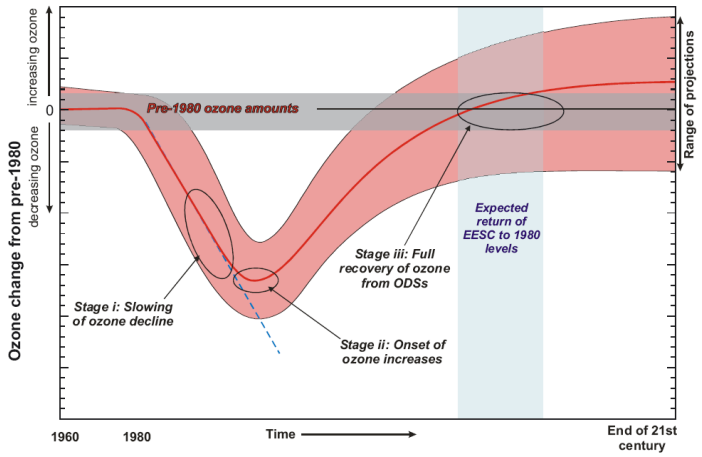

***Figure 5**: A schematic diagram of the temporal evolution of global ozone amounts beginning with pre-1980 values (Bodeker and Waugh, 2007).*

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) emissions, and stopping at the end of the 21st century. Observed and expected ozone amounts is illustrated by the solid red line and show depletion from pre-1980 values and the three stages of recovery from this depletion. 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 ozone abundances have not decreased the last years for most of the world, and there might be signs of recovery from the mid 1990s. However, it is still uncertain whether this improvement is actually 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 9 and Figure 10). 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 33 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 – 2008

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 2008. 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 18 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.

Figure 6a) shows the variations in the monthly mean ozone values in Oslo from 1979 to 2008. The total ozone values from 1979 to 1998 are from the Dobson instrument, whereas for the period 1999-2008 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.

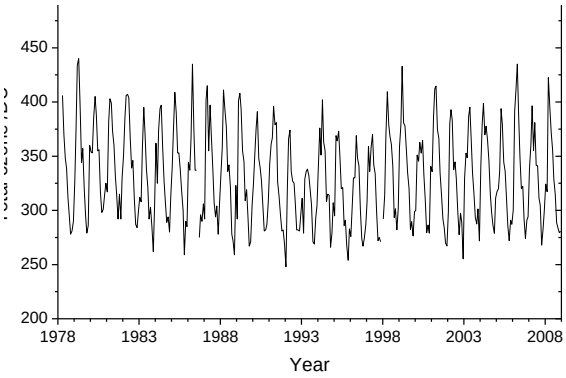

Figure 6a: *Time series of monthly mean total ozone in Oslo 1979-2008.*

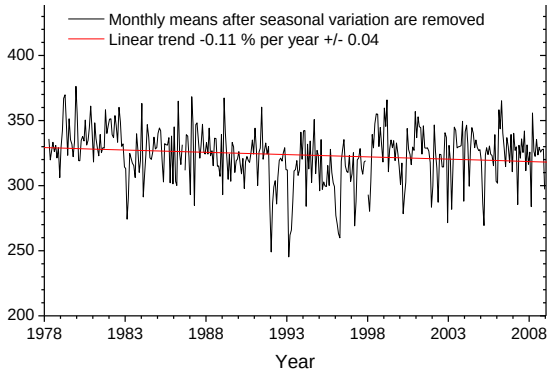

Figure 6b: *Variation in total ozone over Oslo for the period 1979–2008 after the seasonal variations have been removed.*

In order to look at possible ozone reduction for the period 1979 to 2008 we have removed the seasonal variations by subtracting the long-term monthly means and adding the long-term yearly mean value, presented 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 -0.11 % per year in the ozone layer above Oslo for the period 1979-2008. In total this is a reduction of 3.2 % over the entire period. The comparable value for 1979-2007 was 0.12 % per year.

Seasonal analyses show that no significant trends are observed for any of the 4 seasons (winter, spring, summer and fall). This is the first year with no significant trends for any of these seasons. 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 1979-2008, with a standard deviation of 0.10. The comparable value for 1979-2007 was –0.21%, with a standard deviation of 0.10. This is a relatively large change in the trend for the spring months caused by relatively high O_3 values in the spring in 2008. For the winter season, the results are opposite; a negative trend of –0.16% per year is calculated for the period 1979-2008 with a standard deviation of 0.10. The comparable value for 1979-2007 was –0.13%, with a standard deviation of 0.11. This indicates that the dominating change in the ozone level has shifted towards earlier time of the year the last years. A further analysis (as

described in section 3.2.1) indicates that there are low values in December the last years explaining this shift.

Table 3: *Percentage changes in total ozone per year for Oslo for the period 1.1.1979 to 31.12.2008. 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**	-0.16 (0.10)
Spring:	**March – May**	-0.16 (0.10)
Summer:	**June - August**	-0.02 (0.05)
Fall:	**September - November**	-0.06 (0.05)
Annual:		-0.11 (0.04)

3.2.1 Possible indications of ozone recovery above Oslo

The trend analysis for Oslo shows that there has been a decrease in the total ozone amount above this site of 3.2 % for the period 1979-2008. 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, which is indicated in the shift in the spring and winter trends as described in the previous section.

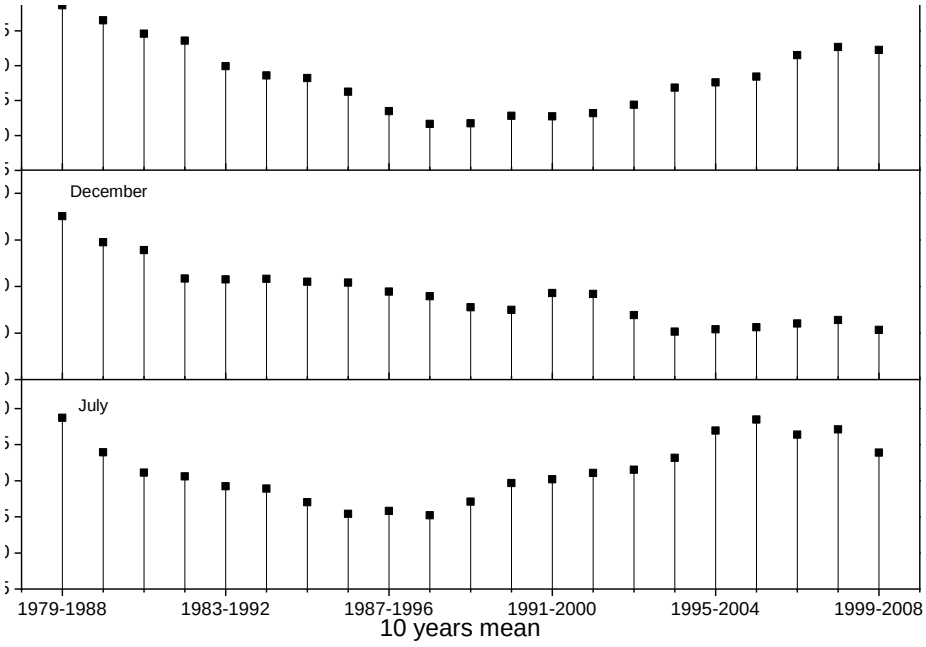

Figure 7: *10 years running mean for the period 1979-2008 based on annual mean (top panel) monthly mean for December (mid panel) and monthly mean for July (lower panel).*

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 -1.9%. 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 of instruments. This might have introduced an uncertainty in the exact time period of the shift. However, based on this recent analysis, it seems like the minimum is passed and that the ozone layer above Oslo is in a recovery state.

The lower panels show the 10 years running means for December and July. These months are selected as they are the months which are most different from the annual mean results. December is the month that has had the largest decrease over the period from 1979-2008. The results for December are surprising and show continues decease over the entire period of almost 8% from the period 1979-1988 to 1999-2008. For July the results are different; a decrease until the period 1986-1995, followed by an increase up to the levels at the start of the measurement period. 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.

3.3 Trends for Andøya 1979 – 2008

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 8a) shows the variations in the monthly mean ozone values at Andøya from 1979 to 2008. The variations in total ozone at Andøya for the period 1979–2008, after removing the seasonal variations, are shown in Figure 8b) together with the annual trend.

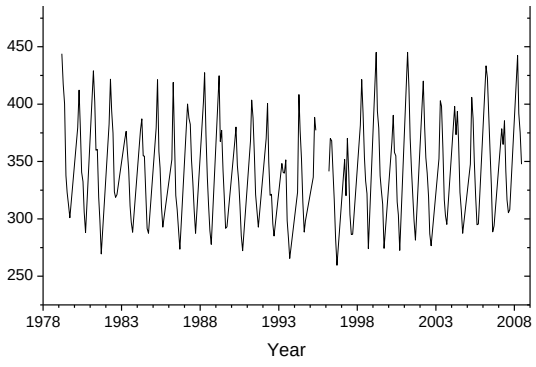

Figure 8 a): *Time series of monthly mean total ozone at Andøya/Tromsø 1979–2008.*

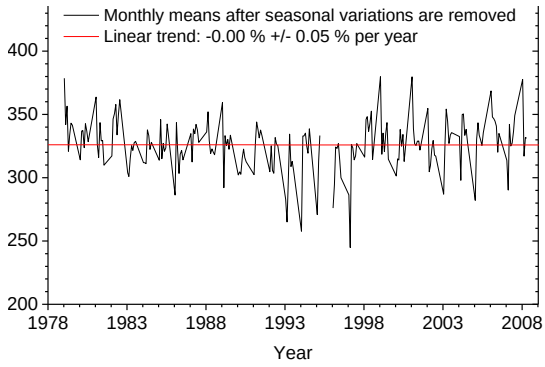

Figure 8 b): *Variation in total ozone at Andøya for the period 1979–2008 after the seasonal variations is removed. Only data for the months March–September are included.*

A simple linear regression has been fitted to the data in Figure 8b) 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 1979-2008.

Table 4: *Percentage changes in total ozone per year for Andøya for the period 1979 to 2008. 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**	-0.01% (0.1)
Summer:	**June – August**	-0.02% (0.04)
Annual:	**March – September**	0.00% (0.05)

3.4 The ozone situation above Norway 2008

The percentage difference between yearly mean total ozone and the long-term yearly mean is shown in Figure 9 (Oslo) and Figure 10 (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 Figures 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 7% lower than the long-term yearly mean. For 2008 the annual mean was 2.2% below the long-term mean.

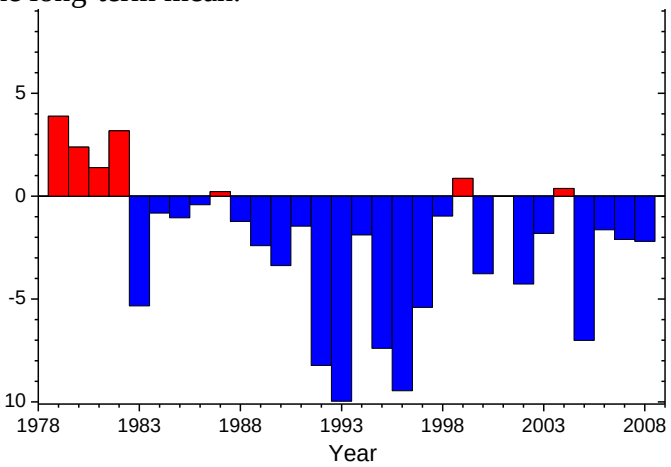

Figure 9: *Percentage difference between yearly mean total ozone in Oslo and the long term yearly mean for 1979-1989.*

The percentage difference between yearly mean total ozone and the long-term yearly mean at Andøya is shown in Figure 10. For 2008 the yearly mean ozone value was -1.1% above the long-term yearly mean value for the period 1979–1989, in contradiction to the last year were the annual value was 1.2% below the long term mean.

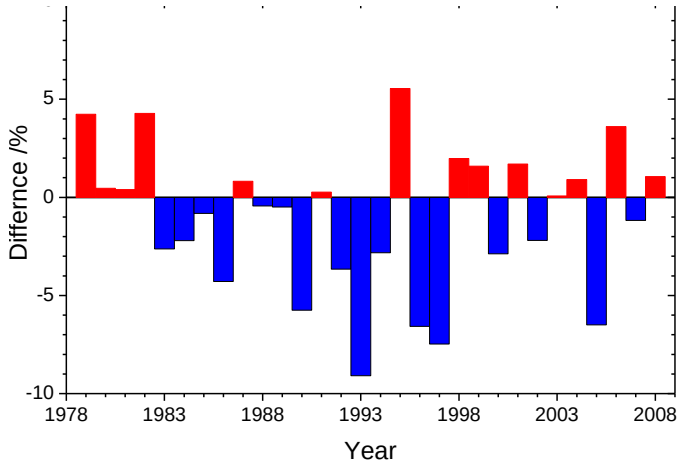

Figure 10: *Percentage difference between yearly mean total ozone in Oslo and the long term yearly mean for 1979-1989 for the months March-September.*

Table 5 gives the percentage difference between the monthly mean total ozone values for 2008 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 2008 and the long-term mean for Oslo and Andøya.*

Month	Oslo	Andøya
January	-1.5	
February	-14.8	-2.3
March	6.0	9.2
April	-1.1	-5.0
May	-2.2	-1.4
June	1.4	-1.6
July	-2.2	-3.0
August	<+/- 0.5	-1.2
September	-1.7	-6.0
October	-1.1	4.2
November	-1.0	
December	-12.0	

In 2008 the ozone values in Oslo were below the long-term mean values for most of the months, with exceptions of March and June. In particular February and December was considerable below the long-term mean, -14.8% and 12.0% respectively. Additionally there was a short period in the beginning of June and beginning of July with ozone values around ~ 15% below the long-term mean. This is evident from Figure 1. These low ozone values lead to increased UV, and UV-indices as high as 6 was recorded, as seen in Figure 19.

The ozone situation at Andøya was similar to Oslo in 2008, but with higher values in March, and lower values in April. Also at these sites there were only two months with ozone levels

above the long term mean. The episode with low ozone values during the summer was also evident at Andøya.

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[2] 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 from the increased occurrence of PSCs and particularly the abundance of PSC type II. However, the observations of the latest years clearly manifest the great variability of the ozone layer typical for the Northern region (WMO, 2007; Weatherhead and Andersen, 2006).

To analyze the variability and better explain the observed ozone values, we have assessed the stratospheric temperature development in 2008 and compared it to previous years.

3.4.1 Polar stratospheric clouds, stratospheric temperatures (from ECMWF data) and spring-time ozone in 2007/08

Stratospheric ozone, temperatures and polar stratospheric clouds (PSCs) have been monitored by means of the ozone lidar at ALOMAR since 1995. In 2008 PSCs have been observed between mid January to the beginning of February. The lidar measurements document the large inter-annual variability in PSC occurrence and spring-time ozone depletion. 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 very cold winter like 1994/95 and 1995/96. An overview of days where PSCs have been observed is given in Table 6. Polar stratospheric clouds have been measured as early as 1 December in 2002 and as late as 21 February in 2005. The numbers of days with PSCs have been varying from zero (winter 1998/99, 2001/02, 2003/04 and 2006/07) to 12 days (in early 1996).

This statistic gives an impression of the PSC frequency above Andøya, but it is not an exclusive list as it is based on the performed lidar observations. These observations are varying in frequency from year to year, reflecting the funding situation of the programme and instrumental breaks.

[2] 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.

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

The PSC occurrence is governed by stratospheric temperatures, which are shown in Figure 11. Temperatures at around 20 km altitude, in the winter 2007/08 are shown as a thick green line. For comparison, temperatures from previous winters are included. Lidar observations are marked with *. Periods where PSCs have been observed are indicated by red symbols in the bottom of the Figure. Stratospheric temperatures above ALOMAR have dropped below the PSC threshold values already in December 2007 but for that period no lidar measurements are available. During the second cold period in January early February, PSCs have been observed by the lidar. The PSC profiles, in terms of backscatter ration at 353 nm, and the corresponding temperature profiles are shown in Figure 12.

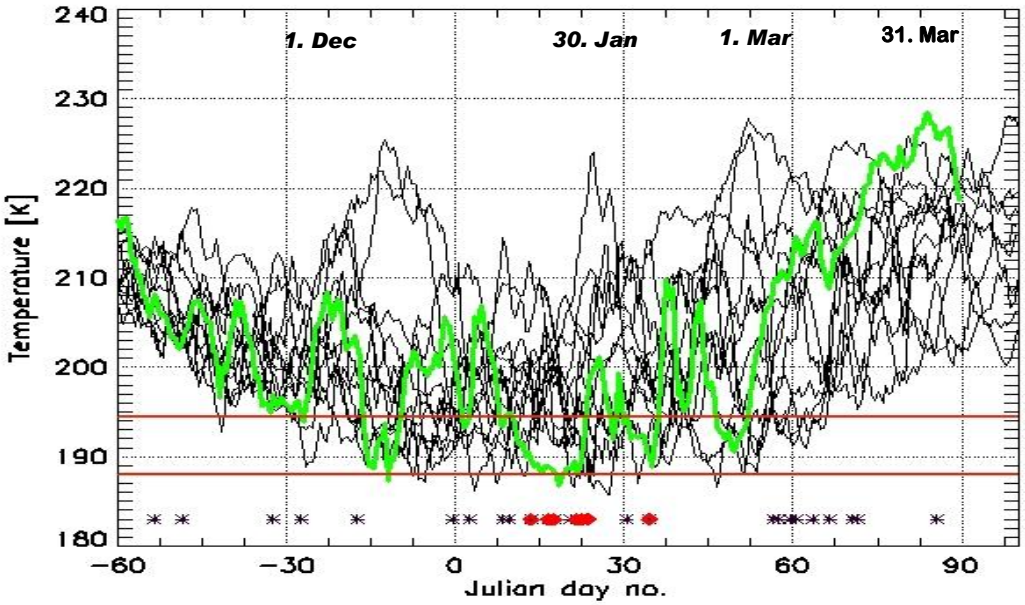

Figure 11: *Stratospheric temperatures at ca. 20 km altitude above Andøya 1995/96 and 2007/08 (data from ECMWF). The temperature development during winter 2007/08 is highlighted in green. The two vertical red lines indicate the temperature thresholds needed for PSC type I (NAT) and II (ice) formation. Lidar observations made are marked with *, PSCs observed are indicated by red symbols.*

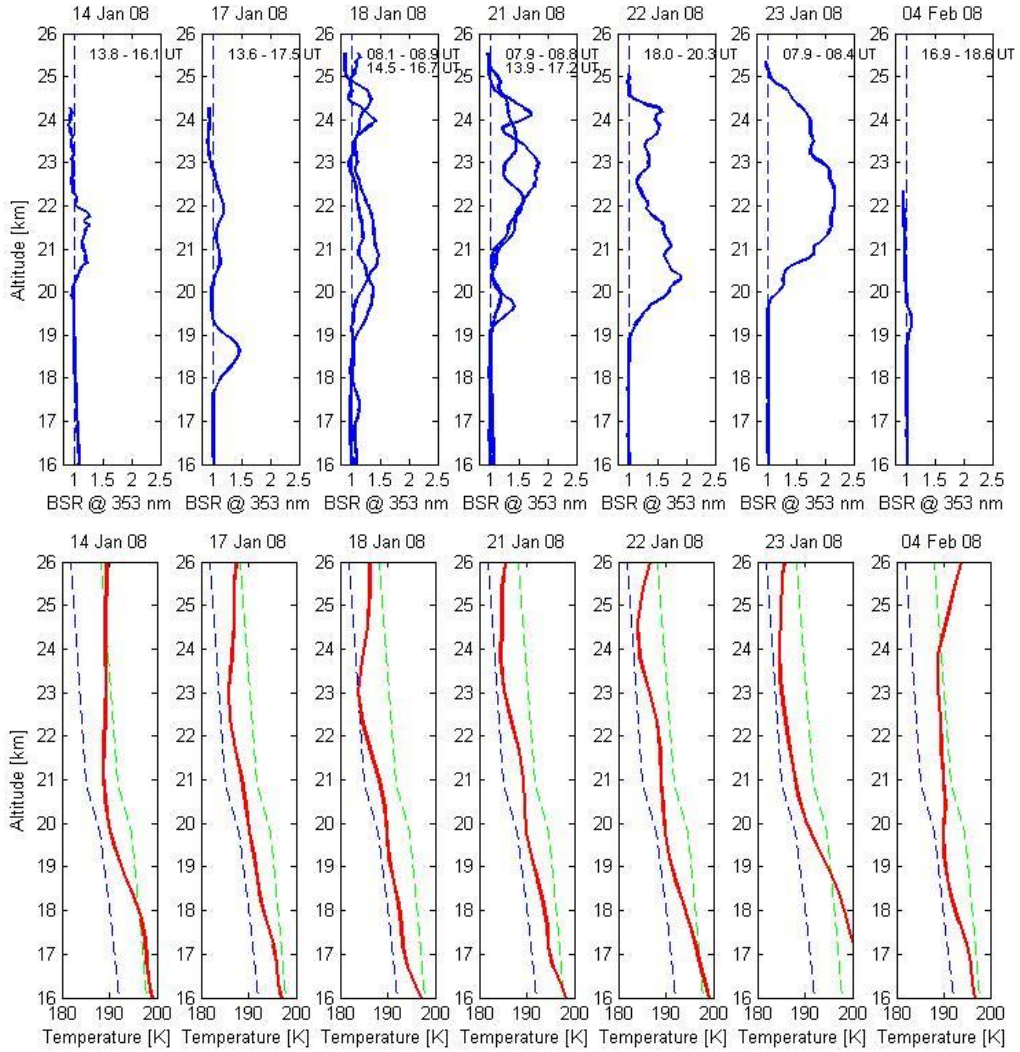

Figure 12: *Polar stratospheric cloud observations (upper panel) and temperatures (data from ECMWF, lower panel) during spring 2008. The threshold temperatures for PSC type I (NAT) and II (ice) formation are indicated in green and blue, respectively.*

In summary, the Arctic winter 2007/2008 was characterised by low stratospheric temperatures from December 2007 to end of February 2008. The temperatures dropped below 194 K from December 1, 2007. A minor stratospheric warming occurred at the end of January and a second one in February. Compared to previous winters the final warming, which lead to the break-down of the vortex, occurred early, around February 25. Low temperatures in 2008 initiated formation of PSCs. Chemical reactions can occur on the PSC surfaces, which transform passive and innocuous halogen compounds into active chlorine and bromine. Under sunlit conditions, these active species react with ozone through catalytic cycles which cause rapid ozone destruction. This has only been possible after January 15, when the cold area was displaced toward sunlit regions. Goutail et al. (2008a, 2008b) measured and calculated a cumulative loss of ozone in the Arctic of about 23% on March 10, 2008 which is much – although not as much as during the most severe winters like 1994/95 and 1995/96. This is large ozone depletion is also seen for January and February in Figure 1 on page 9 and in the monthly mean value for Oslo which was 14.8 % below the long term mean in February (Table 5 on page 21).

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 about the point observations, 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 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

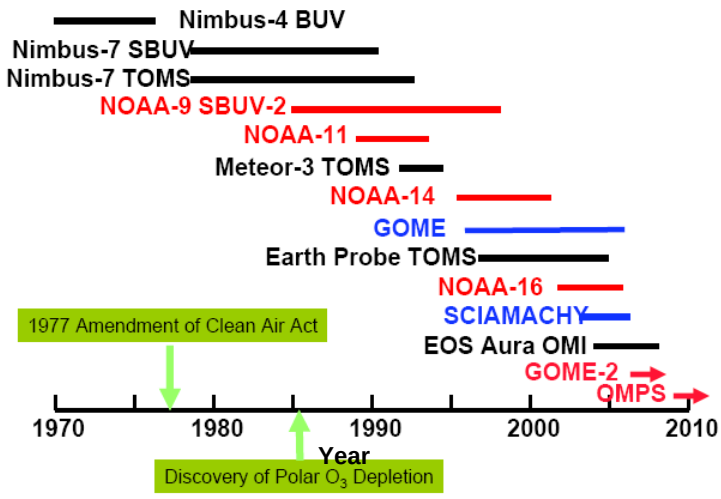

Figure 13: *An overview of the various satellites and their instruments measuring ozone from space since the beginning of 1970's (Figure from NASA).*

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 relying 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 13 gives a brief overview of the various ozone satellite missions measuring total column ozone since the beginning of the 1970's.

4.1.1 Comparison of ground based total ozone observations with satellite ozone observations for 2008

We have compared the ground based ozone measurements at Andøya for 2008, as described in section 2, with available satellite data for this site for the year 2008. Satellite overpass data for Oslo for 2008 was not available at the time of the report. The results for Andøya are presented in Figure 14.

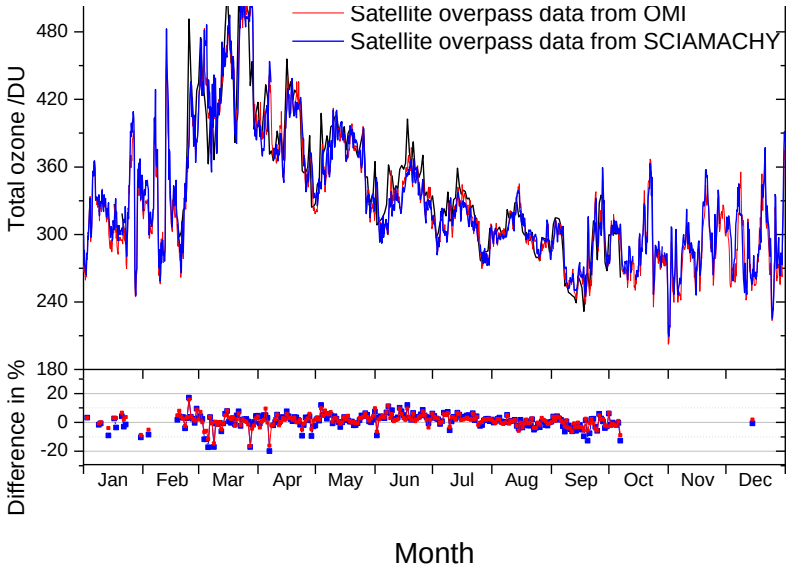

***Figure 14**: Comparison of ground based total ozone observations with satellite ozone observations. The right panel show observations from Andøya compared to ozone data from OMI and SCHIAMACHY. The lower panel shows the percent difference.*

The black curve represents the ground based data, and the red and blue curves represent OMI and SCIAMACHY data respectively. The lower panel shows the difference between the ground based data and the satellite retrieved data in percent. The average deviation for Andøya is 1.2% for OMI and 0.7% for SCHIAMACHY. The largest difference is an underestimation of 15% for the OMI data and 20% for the SCIAMACHY data at selected days in the spring. Also an overestimation is observed in the spring of around 15% for both data sets at one day. The Figure also illustrates that the total ozone retrieved from the lidar system on 13 December agrees very well with the satellite values. It is also important to note the sign of a systematic difference between the ground based data and the satellite retrieved data with an underestimation of ozone from the satellites during summer.

These comparisons indicate that the ozone satellite data slightly underestimate the ozone layer in our region, but this is uncertain and need further investigations. 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. However, it is worth to mention that the underestimation seems to have a yearly cycle with highest values during the autumn/spring months.

4.2 Satellite ozone observations above the Norwegian sites from 1978–2008

Figure 15 shows the available ozone observations from satellite overpasses above the two Norwegian ozone sites in the period 1978-2008. 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. Data from the satellites Nimbus, Meteor, Earth Probe, ERS-2, Envisat and AURA are included, and the observations are based on measurements performed by the instruments TOMS, GOME, SCIAMACHY and OMI, respectively.

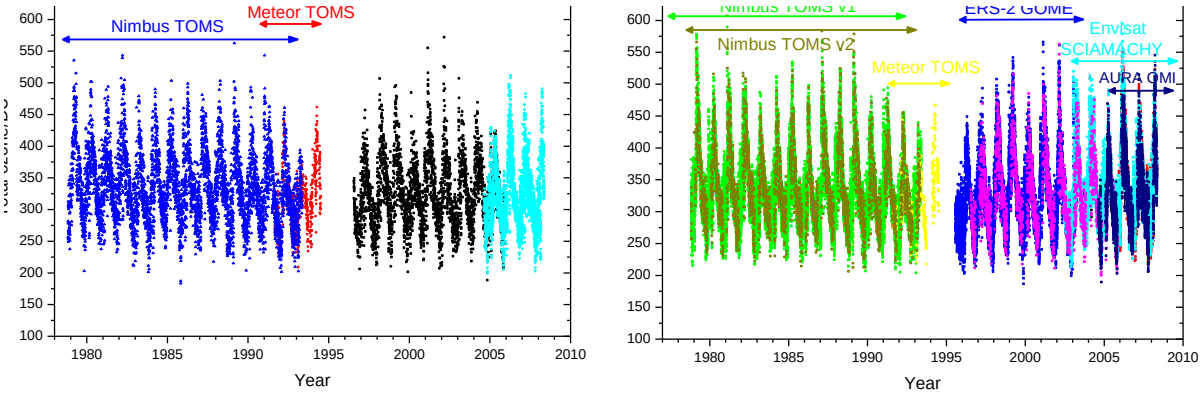

***Figure 15**: Freely available ozone observations from satellite overpasses above Oslo (left panel) and Andøya (right panel). The coloured arrows indicate the various satellites and instruments.*

We have compared the monthly mean ozone values from ground based data and satellites for the full period, 1979-2008. Figure 16 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.

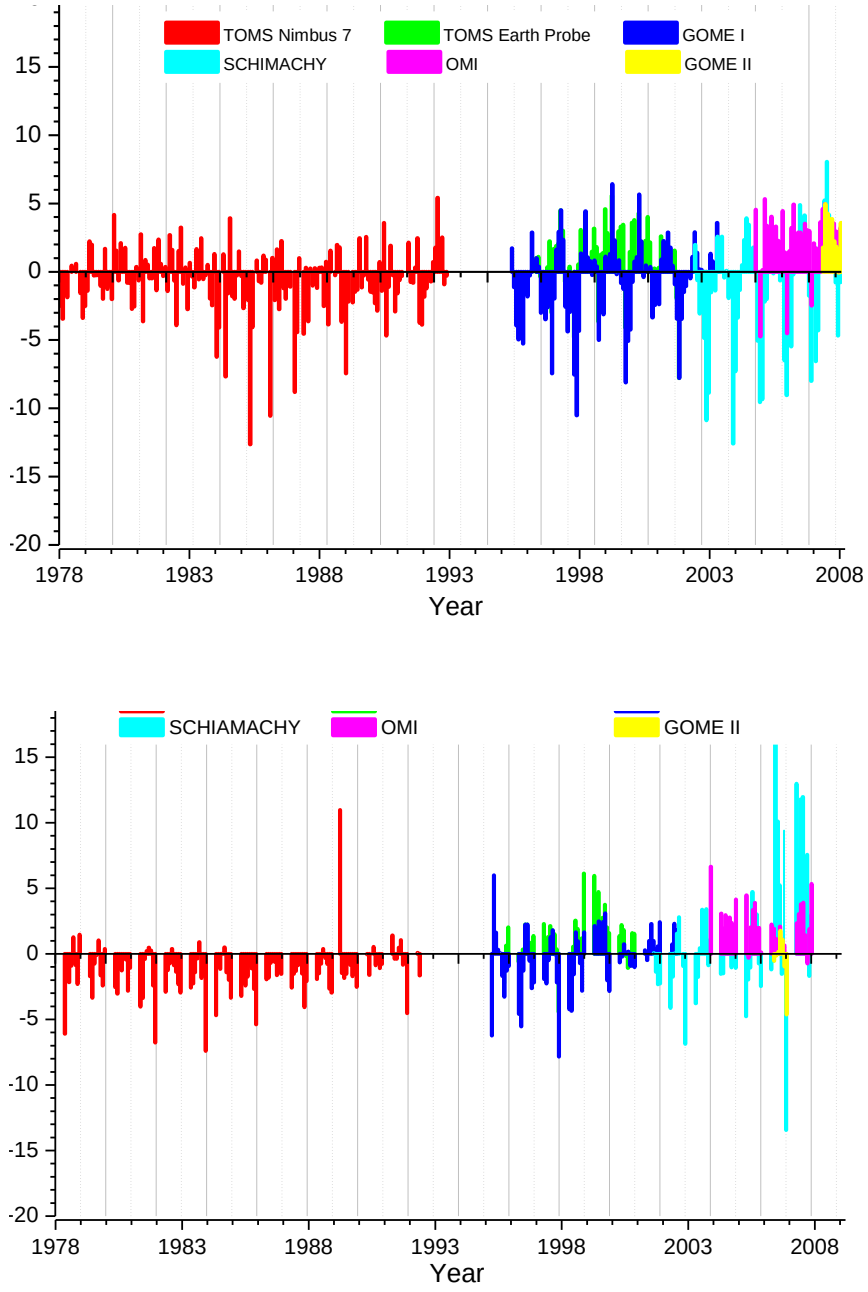

***Figure 16**: Comparison of monthly mean ozone values based on ground based observations, and satellite observations. Deviations are given in %. Upper panel: Oslo, Lower panel: ALOMAR*

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 seem to be both seasonal and systematic differences between the various satellite data. With respect to the comparison of the Andøya data sets in the lover panel, it is particularly important to note the systematic difference in the data in the period from 1979 to 1993. For this period we use ozone 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 used in our trend analysis for Andøya is necessary. This will be done in the near 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 monthly mean ozone values for Oslo for the various data from satellite instruments together with the standard deviations and variance.*

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-08	2.47	2.04	4.17
SCIAMACHY	Jul-02	Dec-08	-0.79	4.12	16.97
GOME 2	Apr-07	Jun-08	2.92	1.58	2.51

OMI and GOME 2 underestimate the ozone values above Oslo; while the other satellite data tends to overestimates the ground based observed ozone values. There are also clear seasonal variations in the deviations. Thus 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 16.

Our goal is to define and construct an integrated data set from satellites that is suitable for trend analysis for the Scandinavian region. For the periods with several overlapping satellite data products, we have chosen to limit the use of SCIMACHY due to the high variance. Further we will also limit the use of TOMS EP as these data seem to underestimate the ozone levels in Oslo compared to the ground based data, and GOME I seem to agree better with the ground based observations.

Based on the analysis we conclude that the ozone data from satellite observations above Oslo which are best suited to be included in a trend analysis and compared to the ground based trends are:

- January 1979 – April 1993: TOMS on the satellite Nimbus-7.
- August 1995- June 2003: GOME 1 on the satellite ERS-2
- July 2003-Sptember 2004: SCIAMACHY on the satellite Envisat
- October 2004-December 2008: OMI on the satellite Aura

These trend analyses are currently under way. Due to the relatively large differences between ground based ozone data from Andøya and satellite data, these differences have to be better explored before it is reasonable to perform a similar trend analysis for this site.

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 17 (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, and observational data only up to 1998 is included. No study has utilized ozone trend observations after 1998 (Forster et al., 2007).

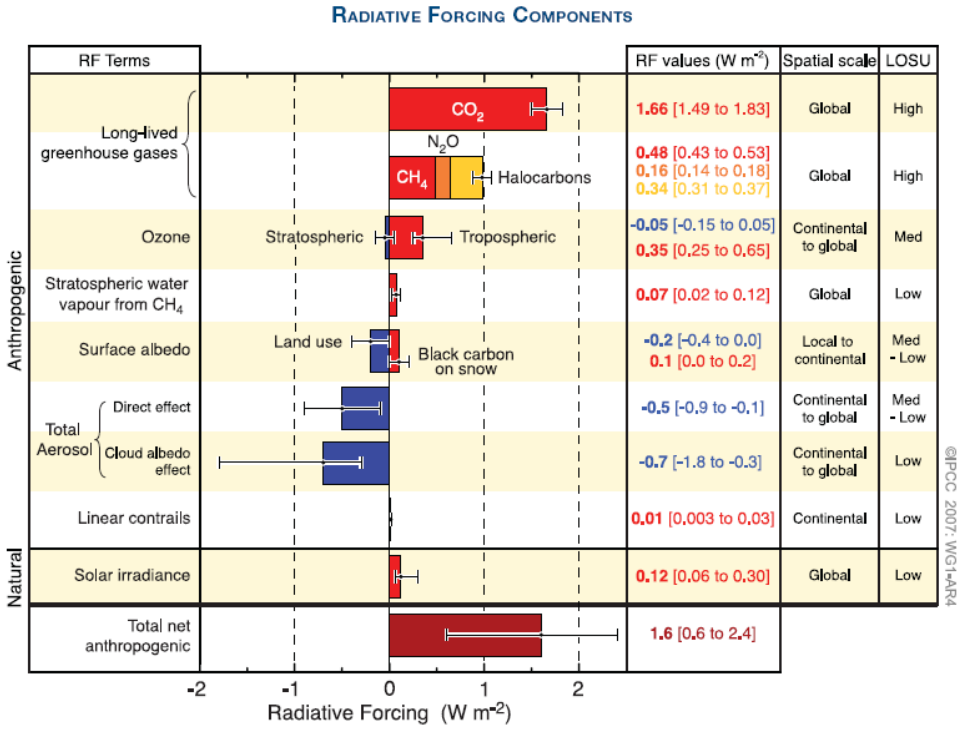

Figure 17: *Global-average radiative forcing estimates for important anthropogenic agents and mechanisms as greenhouse gases, aerosol effects, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU).*

[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 favourable 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 17.

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 new 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, in all stratsopheric ozone model results included in the IPCC report, Arctic ozone increases to 1980 values before the Antarctic ozone does, 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 18. 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://www.nrpa.no/uvnett/ and at http://www.nilu.no.

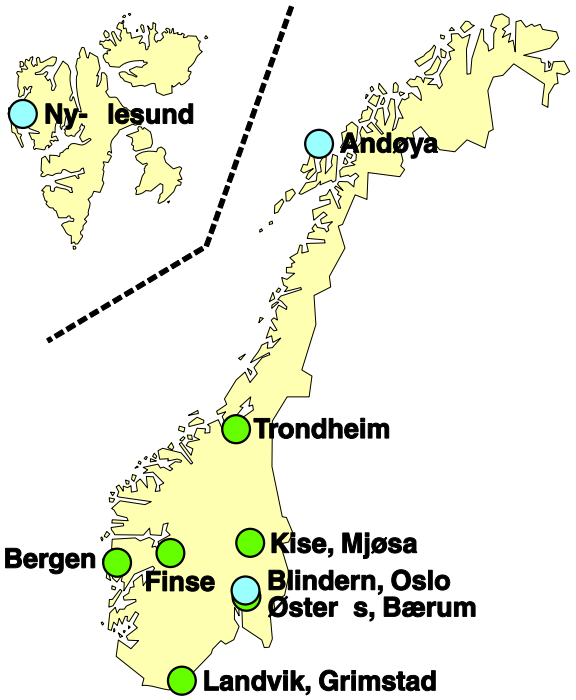

Figure 18: *Map of the stations included in the Norwegian UV network. The stations marked with blue are operated by NILU on behalf of The Norwegian Pollution Control Authority (SFT), whereas the Norwegian Radiation Protection Authority operates the stations marked with green.*

Table 8: *Number of days with more than 2 hours of missing GUV data in 2008 and 2007. Days where the sun is below the horizon (polar night) are not included.*

Station	Technical problems	
	2008	2007
Oslo	11	0
Andøya	0	1

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. 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 2008 is given Table 8. There were practically no interruptions due to technical problems this year at Andøya. In Oslo there were some technical computer problems in late January and early February. Loss of data this time of the year does not influence the results significantly as the UV-radiation is very weak.

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

6.1 UV measurements in 2008

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 19 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, 149.3 mW/m^2, was observed 9 June and is equivalent to a UV index of 6.3. 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 4.4, with a dose rate of 109.3 mW/m^2, observed on 3 June. Both maximums were observed in connection with a small "low ozone event" and very clear atmospheric condition where total ozone dropped around 35 DU within one week in Oslo and over 80 DU within one week at Andøya. This episode with very clear atmosphere and low ozone values resulted in increased surface UV levels, with UV indices over 5.5 several days in the beginning of the summer (shown in Figure 19). 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 observed during the spring in Oslo and at Andøya, may also give rise to large fluctuations in the UV-radiation from one day to another.

Monthly mean noon UV index for Oslo and Andøya in 2008 are compared in Figure 20. 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 higher sun on the sky most of the day.

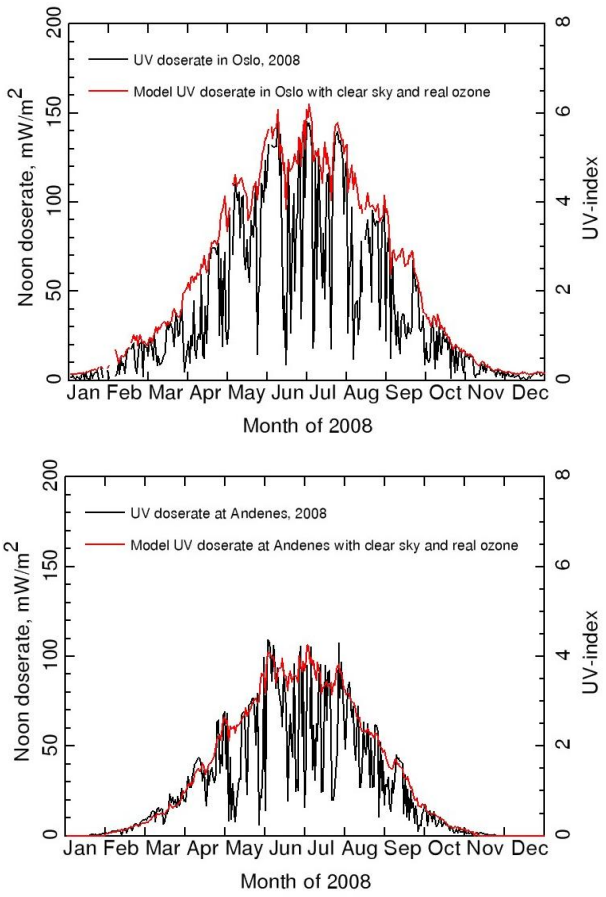

Figure 19: *Hourly averaged UV dose rate measured at noon (between 10:30 and 11:30 GMT). Upper panel: Oslo. Lower panel: Andøya.*

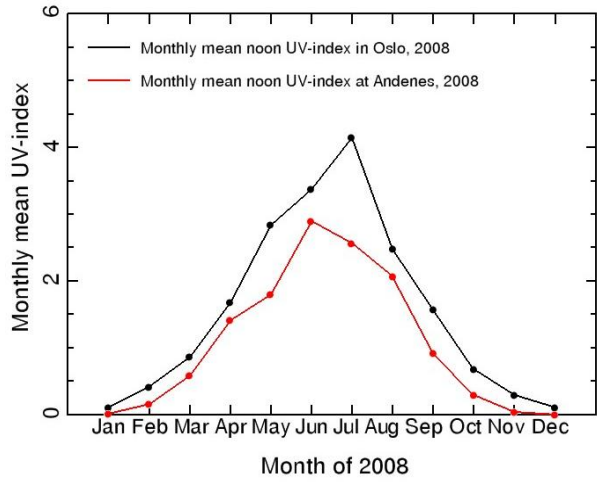

Figure 20*: Monthly mean UV doses in 2008 measured with the GUV instruments located in Oslo and Andøya.*

6.2 Elevated UV levels due to low ozone episodes in 2008

To detect elevated UV-levels due to low ozone values in 2008 we analysed all daily ozone fields available from Ozone Monitoring Instrument (OMI) throughout 2008 for Scandinavia and the associated Arctic, i.e. the area 54-82 ^{o}N and 4-32 ^{o}E. The spatial and temporal distribution of the lowest ozone event as well as the potentially strongest ultraviolet radiation was derived. During 2008 the lowest ozone column (216 DU) in Scandinavia was detected at 21 September as shown in Figure 21, right panel.

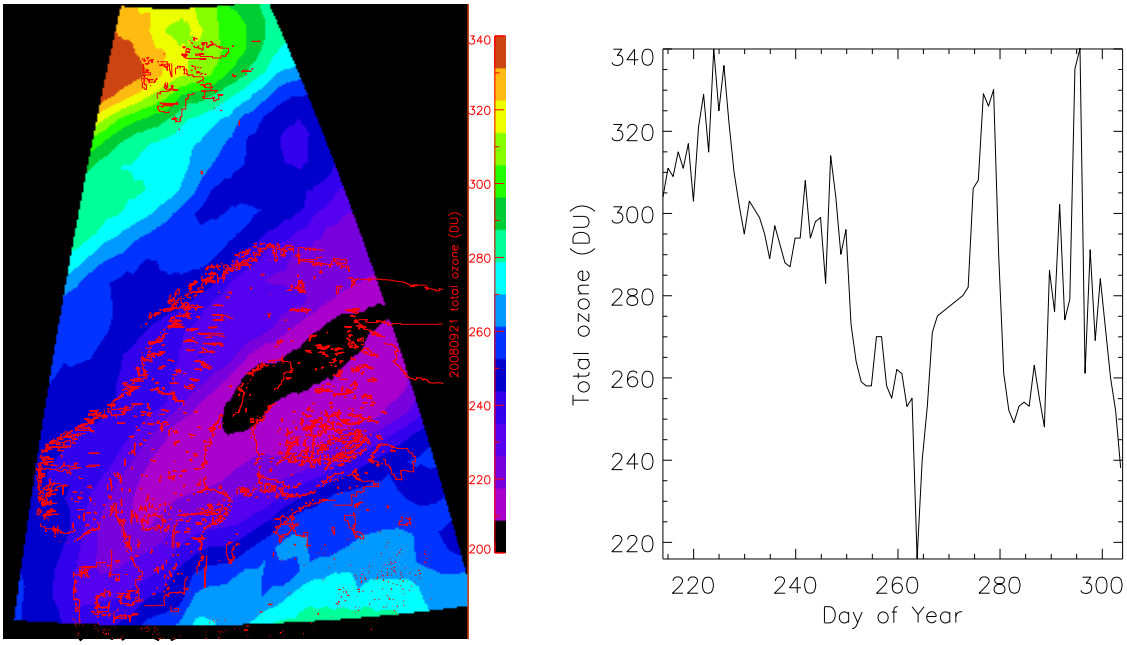

Figure 21: *Left panel: The spatial distribution of ozone columns over Scandinavia at the day with lowest total ozone columns in 2008, i.e. 21 September. Right panel: Time series of ozone columns (DU) before and after the day of lowest ozone.*

The right panel shows the time series of total ozone before and after the day of lowest ozone. The mean (1979-2008) ozone columns for the same period in Oslo is 295 DU, and the mean (1979-2008) total ozone over Oslo in September is 290 DU. Thus 21 September had ozone values ~25% below the monthly mean value.

However, the solar elevation is not very high in the autumn compared to other days closer to the summer solstice. Thus the day with the highest risk of sunburn (daily erythemal dose) was found to be 1 July 2008. The UV-dose for this day is shown in Figure 22.

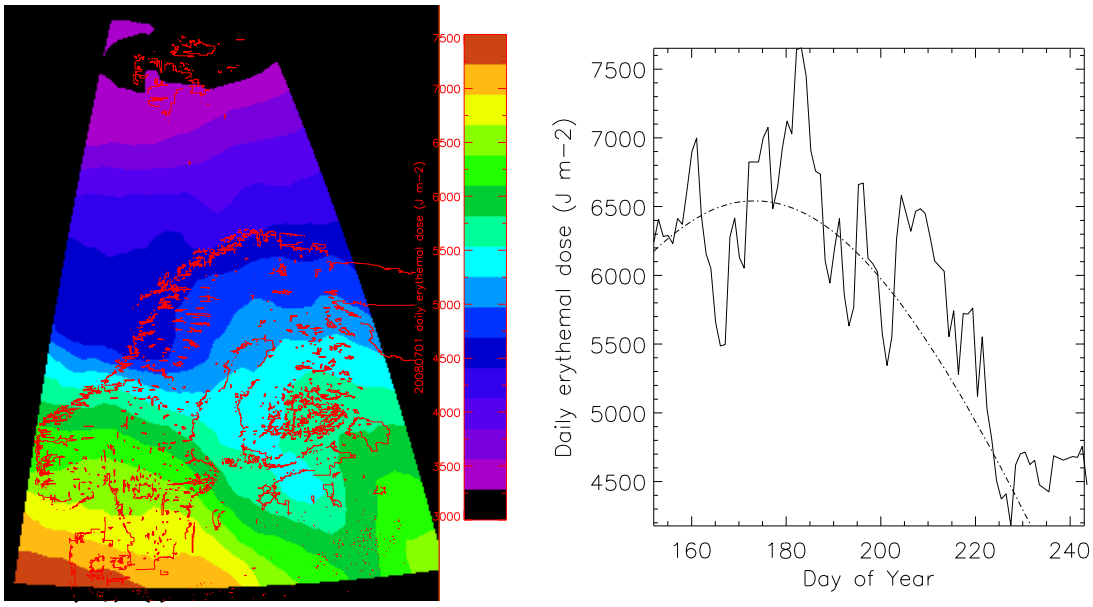

Figure 22: *Left panel: The spatial distribution of the simulated clear sky erythemal ultraviolet doses 1 July 2008. Right panel: Simulated time series of erythemal daily doses under clear sky conditions before and after the day of strongest ultraviolet radiation over Scandinavia in 2008 i.e. 1 July.*

The Figure shows that there is a strong increase in the UV level after day 175 (24 June). The dashed curve illustrates the corresponding ultraviolet doses under mean (1979-2008) ozone conditions for the same period (i.e. 342 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.

Figure 23 shows the global erythemal UV index retrieved from SCIAMACHY 1 July.

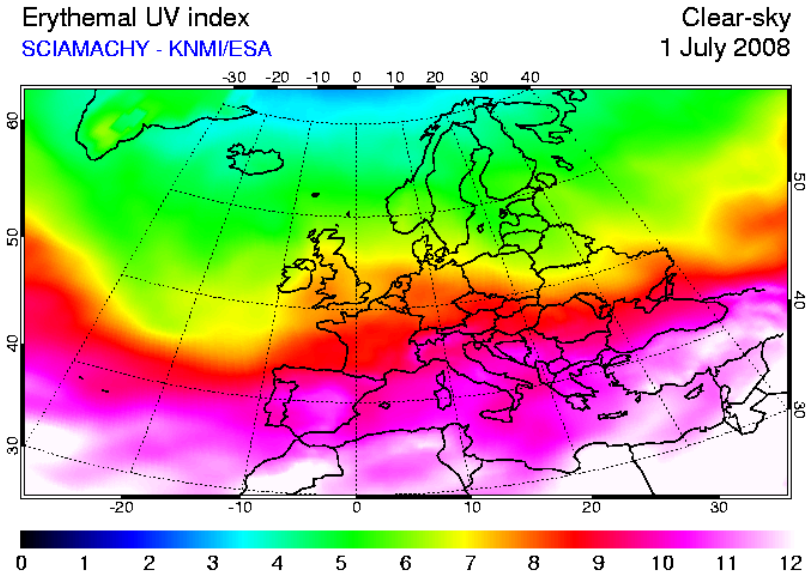

Figure 23: *Global erythemal UV index from SCIAMACHY at 1 July*

6.3 Annual UV doses 1995 – 2008

Annual UV doses for the period 1995 – 2008 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 by using 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 2008 Oslo had the second highest annual integrated UV-dose during the last 11 years, and Andøya had the highest UV-dose since the instrument was moved to this location.

Table 10: *Annual integrated UV doses (kJ/m^2) at the three stations during the period 1995 – 2008.*

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

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

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 24, as there is an increased focus on measurements of solar radiation in the investigation of 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.

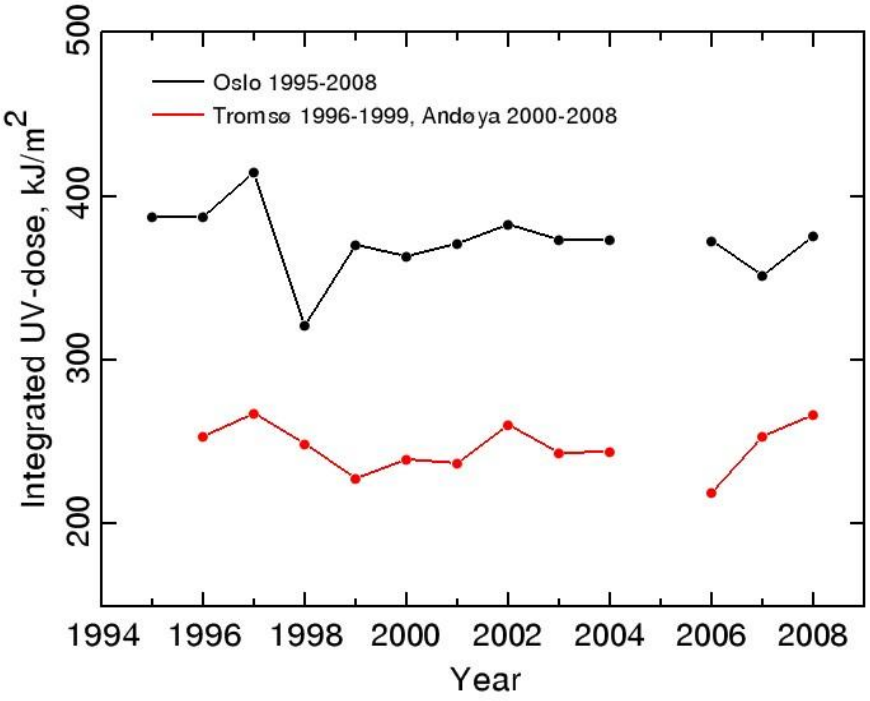

Figure 24: *Annual integrated UV doses (kJ/m^2) at Oslo and Tromsø/Andøya during the period 1995 – 2008.*

7. Example of utilization of the Norwegian UV measurements

In 2005 it was carried out a study at Andøya to pursue an *in vivo* threshold of UV-radiation needed for cutaneous production of vitamin D when only the face of the participants in the study was exposed to UV radiation (Edvardsen et al., 2007). The vitamin D status was measured by analysing blood samples weekly from a study group of 15 subjects over a period of 2 months during late winter, when UV radiation can be expected to increase substantially from rising solar elevations (mid March). Statistical analyses showed no significant positive association between the mean UV radiation dose and the mean vitamin D level for the group. On an individual basis, however, it was found that subjects with very low initial concentration of vitamin D (<30 nmol/l) seemed to respond to UV radiation as early as in the beginning of March. For other individuals diet seemed to be the dominant controlling factor for blood serum vitamin D levels.

The vitamin D effective UV radiation was measured with the Brewer MK-III spectrophotometer every half hour. The participants in the study kept a strict timetable for beeing outside, and in this way it was possible to calculate the vitamin D effective UV dose they had been exposed to. Figure 25 shows the daily maximum biologically effective dose rate (BED-rate) for production of vitamin D in human skin (skin type II) throughout the experiment period.

In general the sun needs to have at least 15° elevation (around day 60 at 69°N) to reach the threshold level (the dashed line in the Figure). However, high ozone values in combination with cloudy conditions may force the UV radiation below the threshold value in March and April, and human vitamin D production will be absent.

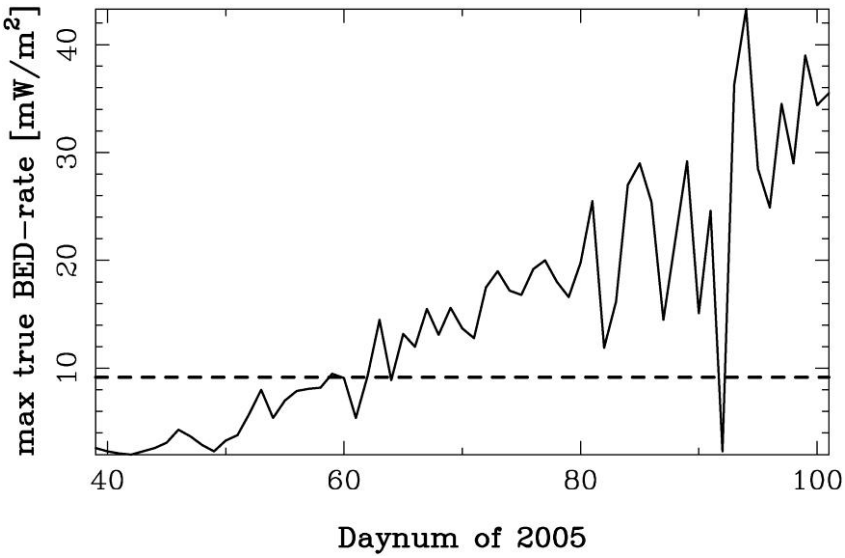

Figure 25: *The daily maximum biologically effective dose rate for the experimental period. The dashed line indicates the threshold level for cutaneous vitamin D production to take place.*

8. References

Bodeker, G.E. and Waugh, D.W. (Lead Authors), 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).

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* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. 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* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge, Cambridge University Press.

Goutail, F., Lefèvre, F., Pommereau, J.P., Chipperfield, M., Feng, W., Van Roozendael, M., Andersen, S.B., Stebel, K., Dorokhov, V., Kyro, E., Fraser, A.C. and Strong, K. (2007) Total ozone loss during the 2006/2007 Arctic winter and comparison to previous years. *Geophys. Res. Abstr., 9,* 01912.

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. (2008) Total Ozone Loss during the 2007/2008 Arctic Winter and Comparison to Previous Years. Poster presented at Quadrennial Ozone Symposium, Tromsø, Norway, June 29th - July 5th, 2008. Kjeller (NILU PP 26/2008).

Goutail, F., Lefèvre, F., Pommereau, J.P., Van Roozendael, M., Chipperfield, M., Feng, W., Kyro, E., Andersen, S.B., Stebel, K. and Dorokhov, V. (2006) Total ozone loss during the 2005/2006 Arctic winter and comparison to previous years. Poster presented at General Assembly of the European Geosciences Union (EGU) Vienna, Austria, 02 – 07 April 2006. Kjeller (NILU PP 38/2006).

Høiskar, B.A.K., Braathen, G.O., Dahlback, A., Bojkov, B.R., Edvardsen, K., Hansen, G.H. and Svenøe, T. (2001) Monitoring of the atmospheric ozone layer and natural ultraviolet radiation. Annual report 2000. Kjeller (NILU OR 35/2001) (in Norwegian).

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* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. 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).

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.

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).

Statlig program for forurensningsovervåking
Overvåking av ozonlaget og naturlig ultrafiolett stråling

Statens forurensningstilsyn (SFT)
Postboks 8100 Dep, 0032 Oslo - Besøksadresse: Strømsveien 96
Telefon: 22 57 34 00 - Telefaks: 22 67 67 06
E-post: postmottak@sft.no - Internett: www.sft.no

Utførende institusjon	ISBN-nummer
Norsk institutt for luftforskning	978-82-425-2118-7 (trykt) 978-82-425-2119-4 (elektronisk)

Oppdragstakers prosjektansvarlig	Kontaktperson SFT	TA-nummer
Cathrine Lund Myhre	Harold Leffertstra	2532/2009

	År	Sidetall	SFTs kontraktnummer
	2009	41	4008013

Utgiver	Prosjektet er finansiert av
Norsk institutt for luftforskning NILU OR 29/2009	SFT

Forfatter(e)
C. Lund Myhre, K. Edvardsen, K. Stebel, T.M. Svendby, O. Engelsen, R. Kube (NILU), A. Dahlback (UiO)

Tittel - norsk og engelsk

Overvåkning av ozonlaget og naturlig ultrafiolett stråling. Årsrapport 2008.

Monitoring of the atmospheric ozone layer and natural ultraviolet radiation. Annual report 2008.

Sammendrag – summary

Rapporten presenterer måledata for totalozon, vertikalfordelingen av ozon og UV-stråling over norske målestasjoner i 2008. For Oslo og Andøya er trenden i totalozon beregnet for perioden 1979-2008.

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 2008.

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

Statens forurensningstilsyn
Postboks 8100 Dep,
0032 Oslo
Besøksadresse: Strømsveien 96

Telefon: 22 57 34 00
Telefaks: 22 67 67 06
E-post: postmottak@sft.no
www.sft.no

Statlig program for forurensningsovervåking omfatter overvåking av forurensningsforholdene i luft og nedbør, skog, vassdrag, fjorder og havområder. Overvåkingsprogrammet dekker langsiktige undersøkelser av:

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

Overvåkingsprogrammmet 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. SFT er ansvarlig for gjennomføringen av overvåkningsprogrammet.

TA-2532/2008
ISBN 978-82-425-2118-7 (trykt)
ISBN 978-82-425-2119-4 (elektronisk)