Monitoring of the atmospheric ozone layer and natural ultraviolet radiation
Annual report 2006

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Rapport 989/2007

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Statlig program for forurensningsovervåking

Preface

In 1985, an English scientist (Farman et al., 1985) discovered the Antarctic ozone hole. It soon became apparent that man-made halogen-containing substances (CFCs and halons) were responsible for the dramatic ozone loss during the austral spring.

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 and 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 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 program. The purpose of the program 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 2006 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 summarises the activities and results of the monitoring programme during the year 2006. The report includes trend analyses of total ozone for the period 1979-2006 for both sites and comments on the expected ozone recovery at northern latitudes. Further the total yearly UV dose for 2006 at Oslo and Andøya is included.

Contents

Summary

This annual report describes the activities and main results of the programme "Monitoring of the atmospheric ozone layer and natural ultraviolet radiation" for 2006, 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. For the period 1979 to 1998 total ozone data from a Dobson spectrophotometer are available. The data from this instrument have been re-evaluated and is published (Svendby and Dahlback, 2002). The complete set of revised Dobson total ozone values from Oslo is available at The World Ozone Data Centre[1].

By combining the two data series, we have been able to study the changes in the ozone layer at Oslo for the period 1979-2006. The results of the trend analysis show a year-round significant decrease of $-0.14 \pm 0.04\%$ per year. For the spring months the trend analysis gave a significant negative trend of $-0.22 \pm 0.10\%$ per year. No significant trends were observed during winter, summer, and autumn in Oslo.

For Andøya a similar trend analysis was performed for the period 1979-2006. 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 – 2006 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 stratospheric winter 2005/06 was divided into two extreme periods: One of the coldest early winter periods from end of November to early January and one of the warmest mid- and late winters from mid of January. The warm period from the mid of January resulted in little chemical ozone depletion and as a consequent, the ozone values for Oslo and Andøya was close to the long-term mean most of the year.

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 explained by the high natural variability in this region and the effect of decreasing temperatures in the stratosphere, which is partly due to climate change and other human influence.

Considerably longer data series and improved understanding of atmospheric processes and dynamics are needed to estimate future ozone levels with confidence. The Zeppelin research station at Ny-Ålesund on Svalbard would be an excellent site for observations of the ozone development in this particular important region.

Measurements of ozone profiles
The ozone lidar at Andøya provides measurements of the ozone concentration at altitudes from approximately 8 km to 50 km at 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 understanding the processes that leads to changes in the ozone layer. The development of the

[1] http://www.msc-smc.ec.gc.ca/woudc/

stratospheric ozone layer in 2006 show relative little ozone destruction in springtime particularly in contrast the year 2005. The latest measured raw data profiles and the latest analysed ozone data are available at http://alomar.rocketrange.no/alomar-lidar.html.

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 2006 monitoring program 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, 148.7 mW/m^2, was observed 10 June and is equivalent to a UV index of 6. At Andøya the highest UV index, 4, was observed on 2 July. In June 2006 the GUV instruments were calibrated against a reference instrument at the Norwegian Radiation Protection Authority.

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. This year Dr. Tove Svendby at the Norwegian Institute for Air Research (NILU) has made the data series from Andøya available at The World Ozone Data Centre (http://www.msc-smc.ec.gc.ca/woudc/). The ozone lidar at ALOMAR is owned and operated by NILU (Georg Hansen and Kerstin Stebel), the Norwegian Defence Research Establishment and the Andøya Rocket Range.

1. Ozone measurements in 2006

Daily measurements of total 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.

The International Ozone Services, Canada, has calibrated both Brewer instruments against a reference instrument on a yearly basis, last time in June 2006. 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.

In the following sections the results of the total ozone measurements at Oslo and Andøya will be presented.

1.1 Oslo

Daily ozone values for Oslo in 2006, based on measurements with the Brewer spectrometer no. 42, are shown in Figure 1. The black curve shows the daily ozone values measured in 2006, 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 measurements, when available. 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 was the case for 143 days in 2006. In 2006 there are missing data for 9 days (2.5%) due to technical problems or not suitable weather and cloud conditions. For these days ozone values retrieved from the GUV measurements are used.

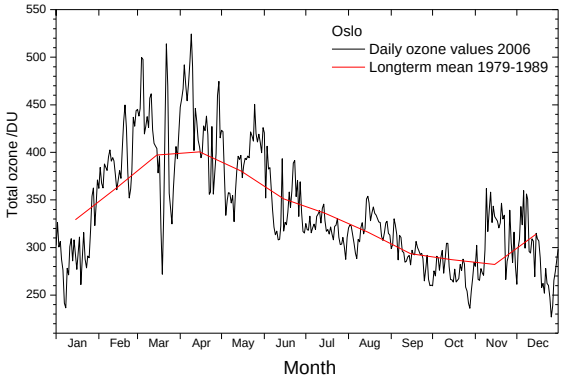

Figure 1a): *Daily total ozone values measured at the University of Oslo in 2006. The red curve shows the long-term monthly mean values from 1979-1989.*

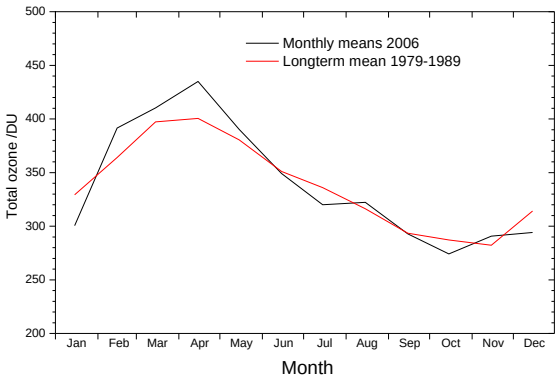

Figure 1b): *Monthly mean ozone values for 2006. The red curve shows the long-term monthly mean values from 1979-1989.*

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, but without long periods of ozone values significantly below the long-term mean, as was registered in e.g. 2005.

The monthly mean total ozone values for 2006 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 2006 ozone values were especially high during the spring.

1.2 Andøya

The total ozone values are based on direct-sun measurements when available. 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. Previous years 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. However, in 2006 no such additional GUV ozone data were required. There are 104 days without ozone observations at Andøya, and all of them are a direct result of the polar night. Table 1 gives an overview of the different instruments and methods that were used at Andøya in 2006.

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

Priority	Method	Total days with observations
1	Brewer instrument, direct sun measurements	93
2	Brewer instrument, global irradiance method	155
3	Measurement by the GUV instrument, and calculation of total ozone	0
4	Lidar (measurements in the Polar night)	13

Daily ozone values for Andøya in 2006, based on measurements with the Brewer spectrometer, are shown in Figure 2a). The black curve shows the daily ozone values from 2006, whereas the red curve shows the long-term monthly mean values for the years 1979-1989. The total ozone values shown during the polar night (November to February) are based on the ozone profiles measured by the ozone lidar at ALOMAR and 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.

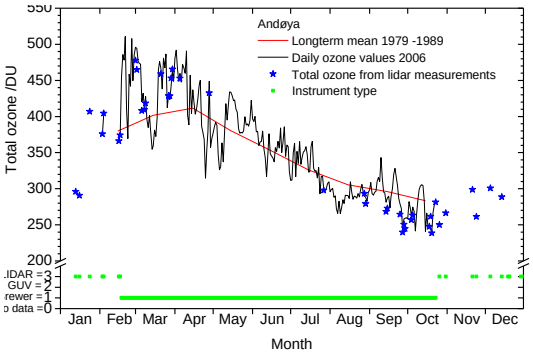

Figure 2a): *Daily total ozone values measured at ALOMAR, Andøya in 2006 by the Brewer, GUV and LIDAR instruments. The use of the different instruments is shown in the lower part of Figure 2a). The red line shows the long-term monthly mean values from 1979-1989.*

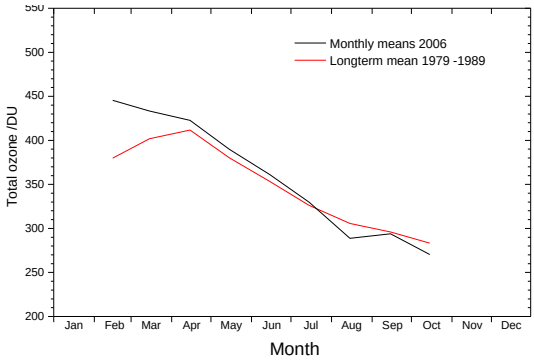

Figure 2b): *Monthly mean ozone values for 2006 compared with the long-term monthly mean values for the period from 1979-1989 shown as the red curve.*

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 2006 shows that the ozone values are close to the long-term mean most of the year except from February and March. The same high spring values were observed in Oslo. In both Oslo and Andøya the enhanced ozone level can be explained by stratospheric warming.

During 2006 automatic procedures have been establish to report real-time ozone data from Andøya to the international community through the World Ozone and Ultraviolet Radiation Data Centre (http://www.woudc.org/). In addition the Andøya ozone series from 2000 to 2006 has been submitted to the international database.

1.3 Ozone-profile measurements with the ozone lidar at ALOMAR, Andøya in 2006

The ozone lidar located at the Arctic Lidar Observatory for Middle Atmosphere Research (ALOMAR) at Andøya is run on a routine basis during clear sky conditions providing ozone profiles in the height range 8 to 45 km. In 2006 measurements have been made during 45 days (50 occasions, of which 8 were during daylight conditions) (see Table 2). These observations have resulted in quality controlled ozone profiles for 40 days. The most recent raw-data profiles as well as the latest analysed ozone data are available at http://alomar.rocketrange.no/alomar-lidar.html.

Table 2: *List of ozone lidar measurements at ALOMAR in 2006. Analysed and quality controlled ozone data sets are available for those days formatted with bold numbers. Measurements performed during night are marked in blue, and daytime measurements are marked in red. Day numbers, which are crossed out, mark days where data of lower quality are available. Stars (*) indicate PSC measurements.*

	Ozone profile
January	~~06*~~, ~~09*~~, **13**, ~~15~~, **16**, **24**
February	**03**, **04**, **16**, **17**
March	**01**, **02**, **06**, **08**, **09**, **20**, **21**, **27**, ~~28~~, **28**, **29**, **30**
April	**05**, **28**
May	-
June	-
July	~~27~~
August	**28**, **29**
September	**14**, **15**, **25**, **27**, **28**, **29**
October	~~04~~, **04**, ~~05~~, **05**, **18**, **19**, **20**, **23**, **26**, ~~31~~, **31**
November	~~20~~, **21**, ~~24~~, **24**
December	**05**, **14**

Problems with electronic noise ("spikes") and the need for replacement of a chopper-motor are the reasons for the lack of measurements in early summer 2006. A comparison to the 2002 measurements shows that the 2006 measurement frequency is about 40% of what could have been achieved in case of excellent conditions, both in terms of weather and better operator coverage. Existing funding restricts the latter.

Since 1995 vertical profiling of stratospheric ozone, polar stratospheric clouds and stratospheric temperature has been performed by means of the ozone lidar at ALOMAR. Very different stratospheric winters have occurred in recent years: a generally warm winter without noticeable ozone depletion (2003/04), a winter with a relatively long cold period with significant ozone depletion (1995/96, 1999/00, 2004/05, 2006/07), and a winter with a very cold early phase and a warm later phase (2005/06).

The Arctic stratospheric winter 2005/06 can be divided into two extreme periods: One of the coldest early winter periods from end of November to early January and one of the warmest mid- and late winters from mid of January during the last 15 years. This development gave rise to frequent formations of polar stratospheric clouds (PSCs) in Northern Norway during December and early January, but few PSCs and little ozone depletion later in the season after the temperature rise.
The polar vortex was already well developed in the beginning of December 2005. Nevertheless, few PSCs were oerved at ALOMAR until 20 December. They were observed twice with both the DIAL system and the co-located RMR lidar, and at three other occasions with the RMR system only. In the short time period of 25 December 2005 to 10 January 2006, the temperatures dropped to the lowest values since January 1996; the lowest temperature (outside the PSC layers) of ~182 K was observed on 6 January 2006, in very good agreement with ECMWF data. Since January 1996 this is the day with the strongest backscatter ratio recorded (BSR) from a PSC (a BSR at 353 nm of 4.8). Figure 3 a-d) show the backscatter ratios at 308 and 353 nm at four days during the coldest period (29 and 31 December 2005; 6 and 9 January 2006). The lidar ratio on 6 January 2006 indicates that the PSC consisted of water/ice crystals. This is confirmed by lidar measurements at Esrange, Sweden, for the same

day. This type of PSC requires extremely low temperatures, 188 K (-85 ^{o}C). A major stratospheric warming occurred on January 26, 2006, preceded by an abrupt rise in upper stratospheric temperatures during 13-16 January. On 13 January a temperature maximum close to 310 K was observed at 40 km altitude.

Before mid-January the polar vortex was centred round the pole. Later it became displaced toward sunlit areas during a major mid-winter stratospheric warming. Although the vortex was re-established in late winter (early March) and persisted until April, it never cooled enough to reach ozone depletion conditions. Hence, 2005/06 was one of the winters with the lowest ozone loss since the early 1990s. From the SAOZ network the observed cumulative ozone loss was estimated to about 13%, only a little larger than in 2000/01 and 2001/02 (Goutail et al., 2005).

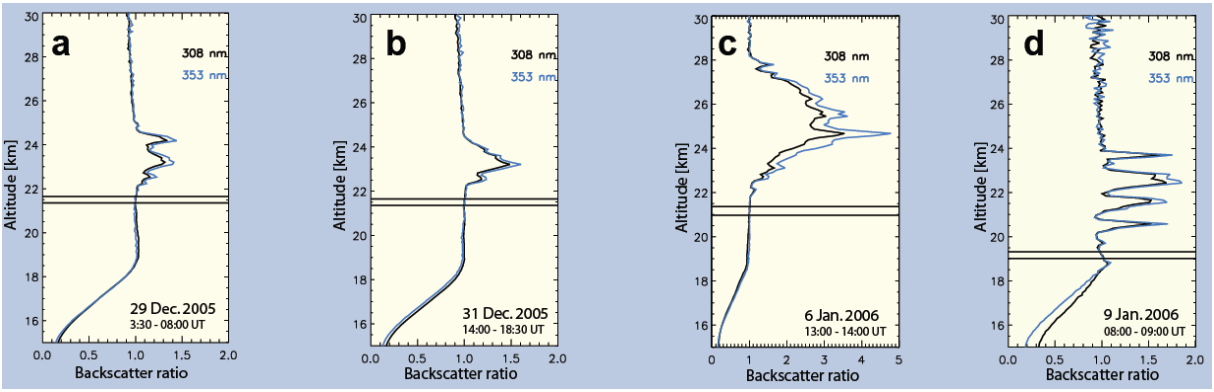

Figure 3: *Backscatter ratios at 308 nm (black) and 353 nm (blue) as measured by the ALOMAR ozone lidar. From left to right: Observations made on 29 December, 31 December, 6 January and 9 January. Note that the scale of the abscissa is different for the 6 January panel, due to the much higher backscatter ratio on that day.*

The development of the ozone layer above Northern Scandinavia throughout the whole year 2006 is illustrated in Figure 4 (upper panel). For comparison the 2005 ozone layer is shown in the same figure (lower panel). The contrast in the development of the stratospheric ozone layer in 2006, with relative little ozone destruction in springtime, and during the winter 2004/05, where significant ozone depletion occurred, is easy to recognize.

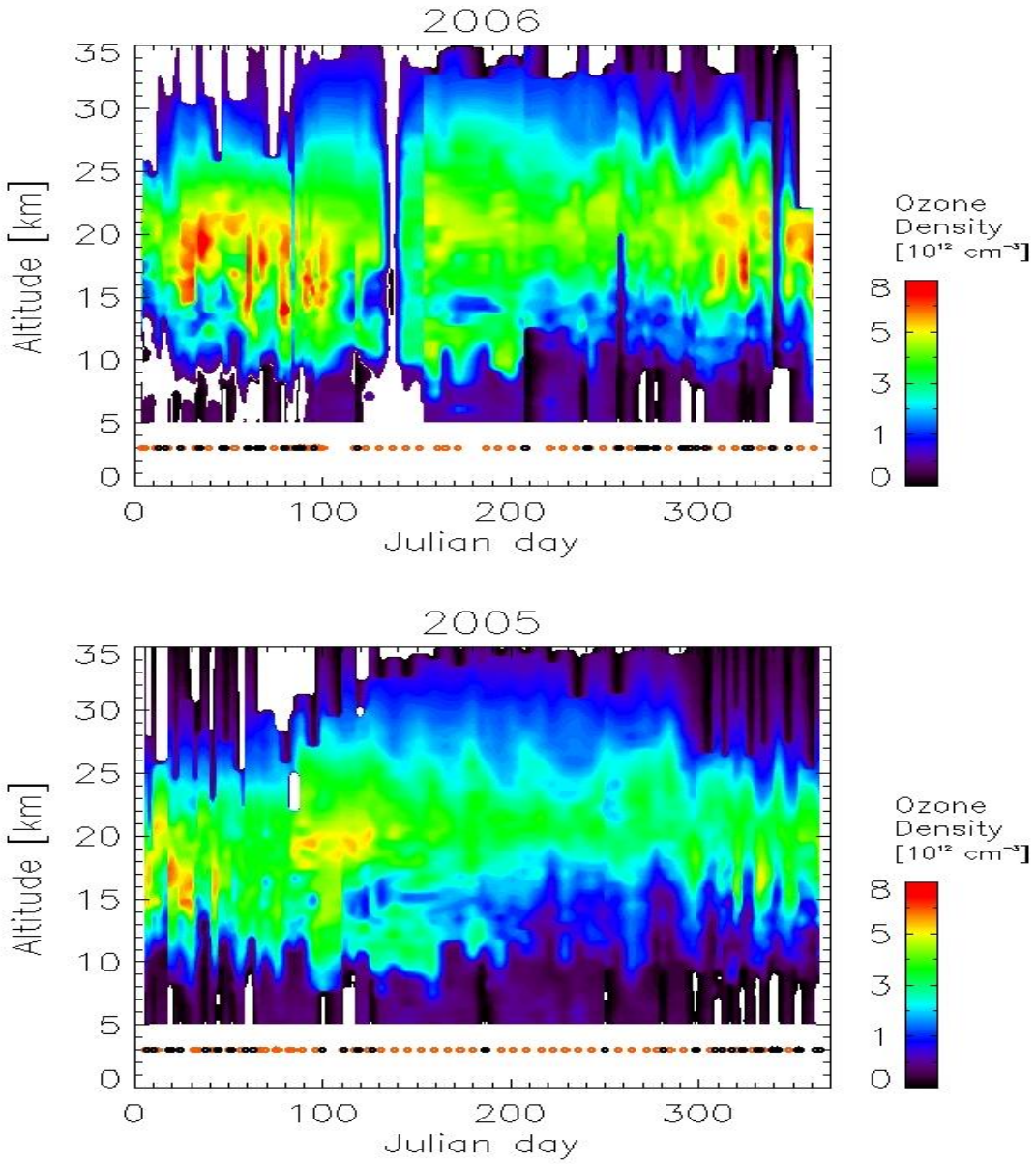

Figure 4: *Ozone profiles measured by the ALOMAR ozone lidar and ozone sondes launched in Sodankylä, Finland, in 2006 (upper panel) and in 2005 (lower panel). The black dots at the bottom of the plot mark the times when lidar measurements were performed, while the red dots mark days where data from ozone sondes launched from Sodankylä were used. Between the individual measurements the data were linearly interpolated and smoothed with a one-week median filter.*

1.4 The ozone situation in Norway 2006

Table 3 gives the percentage difference between the monthly mean total ozone values for 2006 and the long-term monthly values for Oslo and Andøya.

Table 3: *Percentage difference of monthly mean total ozone values for 2006 and the long-term mean for Oslo and Andøya.*

Month	Oslo	Andøya
January	-9.6	-
February	7.0	14.7
March	3.2	7.3
April	7.9	2.6
May	2.5	2.5
June	-0.6	2.1
July	-5.0	1.1
August	1.9	-5.8
September	<±0.5 %	-0.7
October	-4.7	-4.8
November	2.9	-
December	-6.8	-

In contrast to 2005, the ozone values for Oslo and Andøya in 2006 were close to the long-term mean most of the year. In Oslo 8 out of 12 months deviated less than 5% from the long term mean and only one month, January, was considerable below the long-term mean value. Instead, high monthly mean total ozone values were registered in the spring. In April the average ozone value was 7.9% above the long-term mean. The situation was similar at Andøya, where the monthly mean total ozone value in February was as much as 14.7% above the long-term mean.

The low ozone values commonly observed in the spring the last decades are a direct result of the stratospheric conditions and chlorine 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 compounds by heterogeneous chemistry on polar stratospheric clouds (PSC). The active chlorine reacts with ozone and results in severe ozone depletion. There are two main types of polar stratospheric clouds, 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).

It is worthwhile to mention the very cold situation in December 2005 gave rise to PSC type II. This is the second season this PSC type, which only occur at extreme cold conditions, were observed in the Arctic. The first observation occurred during the record year 2005/2006.

It should also be mentioned that a colder upper stratosphere is a suggested feedback to the increased level of greenhouse gases in the troposphere. Thus, it is important to detected signs of climate changes from the increased occurrence of PSCs and particularly the abundance of PSC type II. However, the latest years clearly manifest the great variability of the ozone layer typical for the Northern region (Weatherhead and Andersen, 2006).

[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.

2. Ozone measurements 1979–2006

2.1 Background

Studies of long-tem trends as presented in the following sections 2.2 and 2.3 are essential in the assessment of the ozone recovery. 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. It was published a review in Nature (2006) presenting an overview of the signs of the recovery of the ozone layer (Weatherhead and Andersen, 2006).

According to the review (Weatherhead and Andersen, 2006), the total ozone abundances have not decreased the last eight 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-deleting 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 (see Figure 6 and Figure 8). The 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 thestratosphere as well as the troposphere. Further, the ozone trend analysis 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 this time period (illustrated in Figure 6 and Figure 8). 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 modeled ozone levels compared to the measurements in this region.

Weatherhead and Andersen (2006) concluded that the ozone levels in the Arctic and high northern latitudes will be strongly influenced by 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, they emphasized that anthropogenic changes of the atmosphere 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.

2.2 Trends for Oslo 1979-2006

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 as part of a PhD study (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 2006. 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 15 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 5a) shows the variations in the monthly mean ozone values in Oslo from 1979 to 2006. The total ozone values from 1979 to 1998 are from the Dobson instrument, whereas for the period 1999-2006 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.

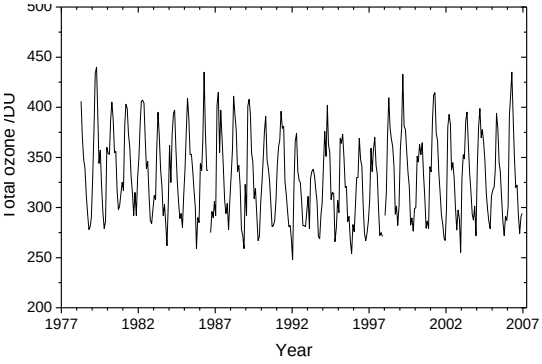

Figure 5a: *Time series of monthly mean total ozone in Oslo 1979-2006.*

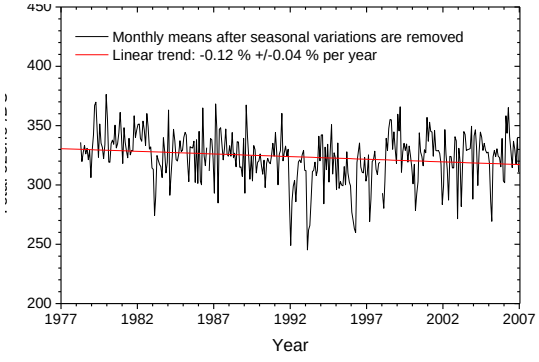

Figure 5b: *Variation in total ozone over Oslo for the period 1979–2006 after the seasonal variations have been removed.*

In order to look at possible ozone reduction for the period 1979 to 2006 we have removed the seasonal variations by subtracting the long-term monthly means and adding the long-term yearly mean value, presented in Figure 5b). A simple linear regression has been fitted to the data to obtain a long-term trend of the ozone layer. The results of the trend analysis are summarized in Table 4. For spring months a significant negative trend of –0.22% per year is observed. The comparable value for 1979-2005 was –0.33%. Thus, the last winter with little ozone destruction has changed the annual downward trend significantly. For the winter, summer and fall months no significant trend is observed. When all months are included a significant negative trend of –0.14% per year is observed above Oslo.

Table 4: *Percentage changes in total ozone per year for Oslo for the period 1.1.1979 to 31.12.2006. The numbers in parenthesis gives the uncertainty (1 σ). 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	-0.17 (0.11)
Spring:	March – May	-0.22 (0.10)
Summer:	June - August	-0.02 (0.06)
Fall:	September - November	-0.08 (0.06)
Annual		-0.14 (0.04)

The percentage difference between yearly mean total ozone and the long-term yearly mean is shown in Figure 6. 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.

Figure 6 shows that the low ozone values in the 1990's contribute strongly to the observed negative trends in total ozone. Further, the yearly mean ozone value for 2005 was as much as 7% lower than the long-term yearly mean. For 2006 the situation was very different, with an annual mean only 1.6% below the long-term mean.

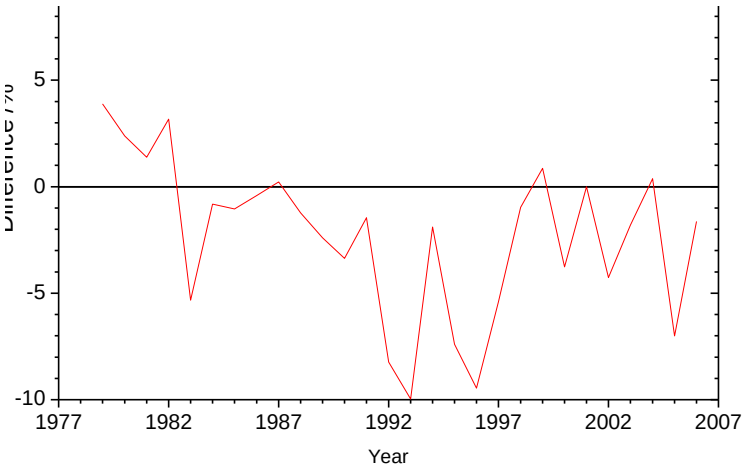

***Figure 6**: Percentage difference between yearly mean total ozone in Oslo and the long term yearly mean for 1979-1989*

2.3 Trends for Andøya 1979-2006

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 7a) shows the variations in the monthly mean ozone values at Andøya from 1979 to 2006. The variations in total ozone at Andøya for the period 1979–2006, after removing the seasonal variations, are shown in Figure 7b).

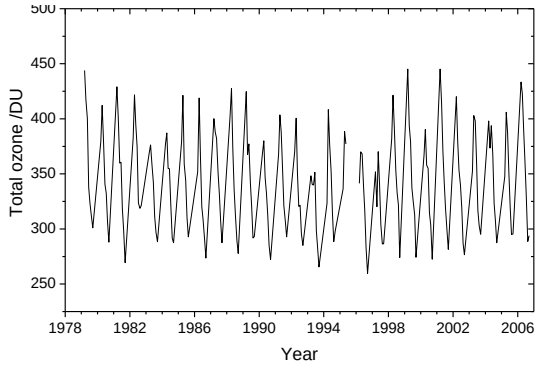

Figure 7 a): *Time series of monthly mean total ozone at Andøya/Tromsø 1979–2006*

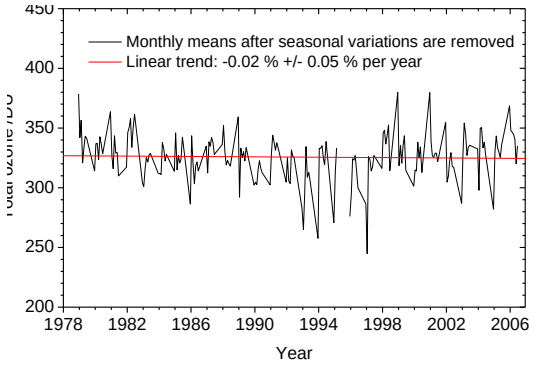

Figure 7 b): *Variation in total ozone at Andøya for the period 1979–2006 after the seasonal variations are removed. Only data for the months March–September are included.*

A simple linear regression has been fitted to the data in Figure 7b) to obtain the trend in the data set. The result of the trend analysis is summarized in Table 5. No significant trends were observed for Andøya for this time period.

Table 5: *Percentage changes in total ozone per year for Andøya for the period 1979 to 2006. 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	-0.04 % (0.01)
Summer:	June – August	0.02 % (0.04)
Annual	(March – September)	-0.02 % (0.05)

The percentage difference between yearly mean total ozone and the long-term yearly mean is shown in Figure 8. For 2006 the yearly mean ozone value was 3.6% higher than the long-term yearly mean value for the period 1979–1989. This makes 2006 the year with the forth highest ozone relative to the long-term mean in the period from 1979-2006.

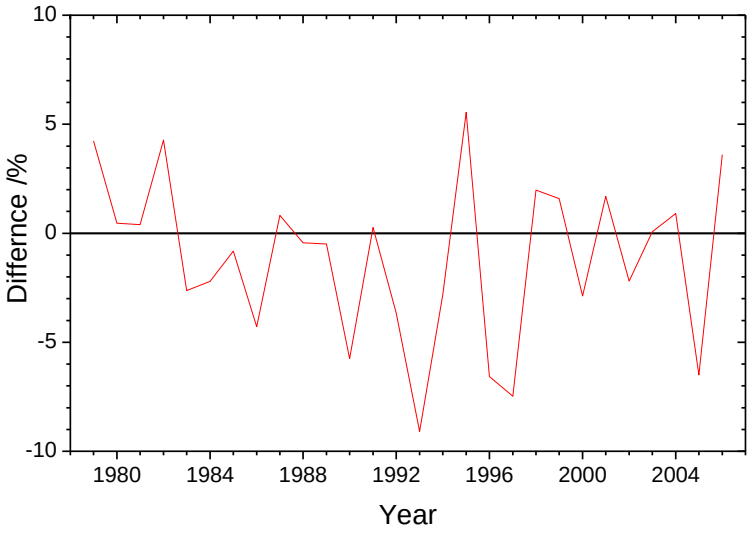

Figure 8: *Percentage difference between yearly mean total ozone at Andøya and the long-term yearly mean for 1979–1989 for the months March–September.*

3. The 4th IPCC report: 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 9 (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 utilised ozone trend observations after 1998 (Forster et al., 2007).

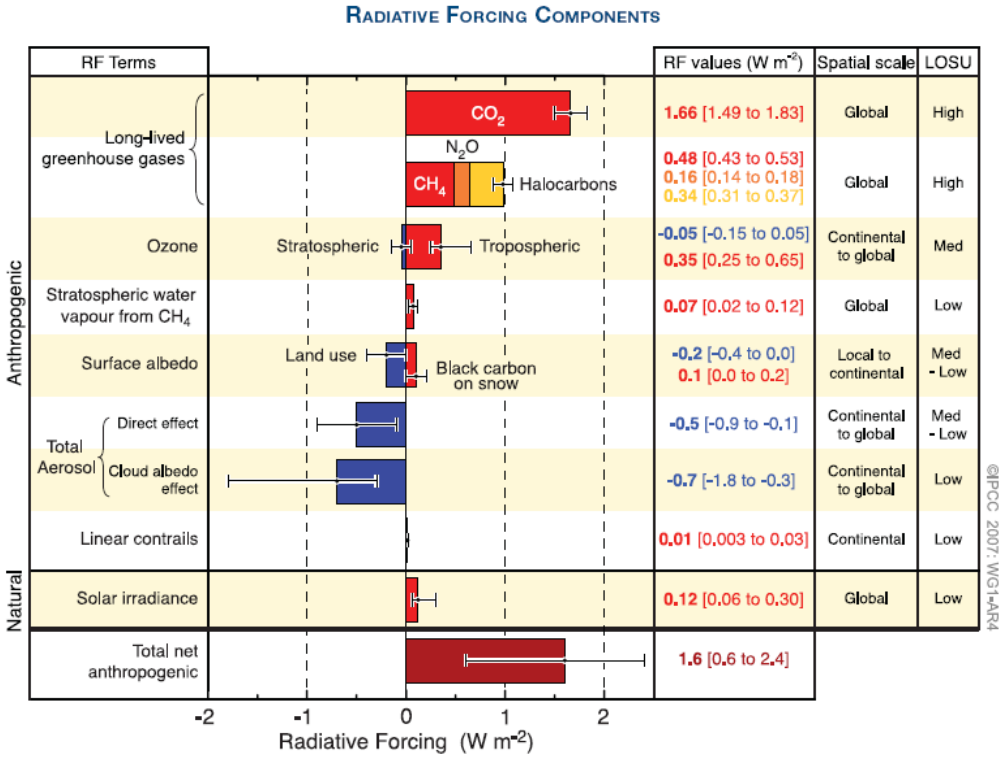

Figure 9: *Global-average radiative forcing estimates for important anthropogenic agents and mechanisms as greenhouse gases, aerosol effects, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU).*

[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 Figure 9.

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.

4. UV measurements

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 10. 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 www.luftkvalitet.info/uv.

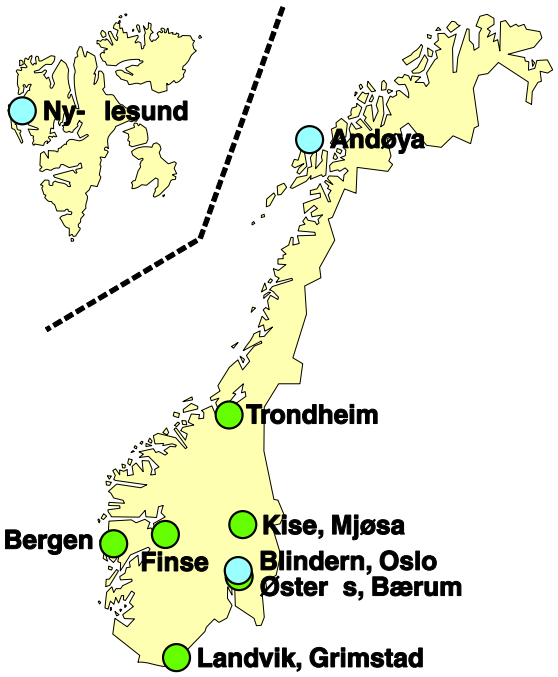

Figure 10: *Map of the stations included in the Norwegian UV network. The stations marked with blue are operated by NILU on behalf of The Norwegian Pollution Control Authority (SFT), whereas the Norwegian Radiation Protection Authority operates the stations marked with green.*

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 in 2006.

The Norwegian GUV instruments were included in a well-organised calibration and inter-comparison campaign in 2005 as a part of the project FARIN (Factors Controlling UV in Norway)[4]. The project, which is financed by The Norwegian Research Council, aims 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 2006 is given Table 6.

Table 6: *Number of days with more than 2 hours of missing GUV data in. Days where the sun is below the horizon (polar night) are not included.*

Station	Technical problems	
	2006	2005
Oslo	4	2
Andøya	12	41

It was few interruptions due to technical problems this year. The data coverage in 2006 is good both in Oslo and at Andøya.

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

4.1 UV measurement results in 2006

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 $25mW/m^2$. The concept of UV index is widely used for public information concerning sunburn potential of solar UV radiation. In 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 7 shows the UV-index scale with the recommended protections at the different levels. The recommendations are based on a moderate light skin type.

Table 7: *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 11 shows the UV dose rates measured at noon (averaged between 10:30 and 11:30 GMT) for Oslo and Andøya. The colour scale indicates the level of potential harm caused by the UV-radiation. The highest UV dose rate in Oslo, 148.7 mW/m^2, was observed 10 June and is equivalent to a UV index of 6. At Andøya the highest UV index was 4, with a dose rate of 97.6 mW/m^2, observed on 2 July. 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 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. In total, varying cloud cover is the dominating process as described in the report "*Monitoring of the atmospheric ozone layer and natural ultraviolet radiation. Annual report, 2004*" (Høiskar et al., 2004).

Monthly, integrated UV doses for Oslo and Andøya in 2006 are compared in Figure 12. The monthly UV doses observed in Oslo are significantly higher than the values observed at Andøya. The low UV- doses at Andøya in June and July are mainly due to the weather conditions, with many overcastted days.

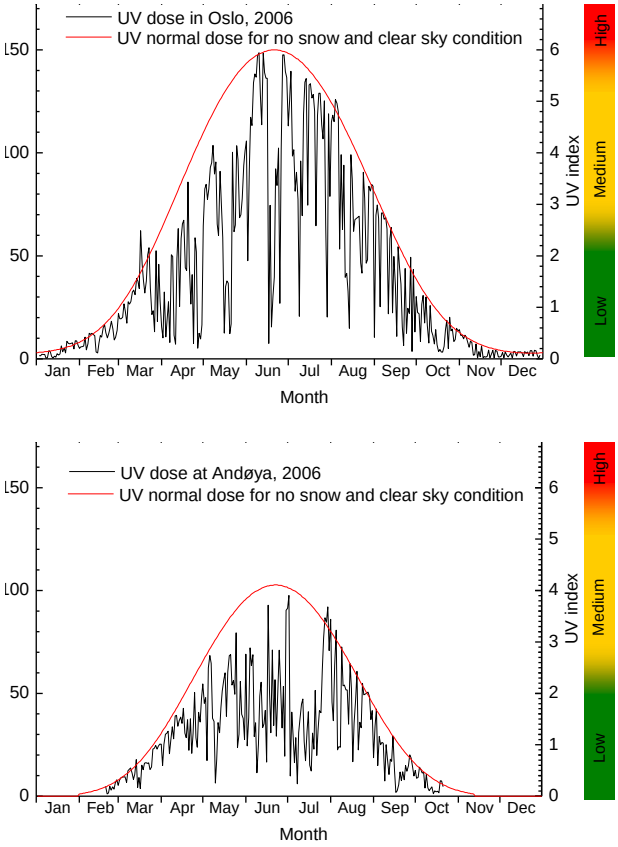

Figure 11: *Hourly averaged UV dose rate measured at noon (between 10:30 and 11:30 GMT) at a) Oslo, b) Andøya*

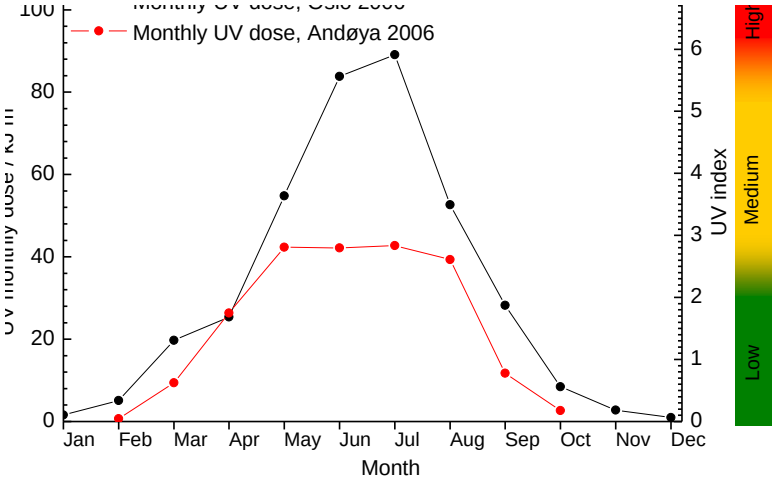

Figure 12*: Monthly integrated UV doses in 2006 measured with the GUV instruments located in Oslo and Andøya*

4.2 Annual UV doses 1995–2006

Annual UV doses for the period 1995 - 2006 are shown in Table 8 for the three 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 (B. 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.

Table 8: *Annual integrated UV doses (kJ/m^2) at the three stations during the period 1995 - 2004.*

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	217.3		No measurements

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

The time series of the UV doses are still too short for trend analysis since the inter-annual variations mainly are larger than the expected long-term change. However, a graphical illustration of the yearly integrated UV-dose is shown in Figure 13, 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; by dimming aerosols may possibly 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 in the ground level solar radiation.

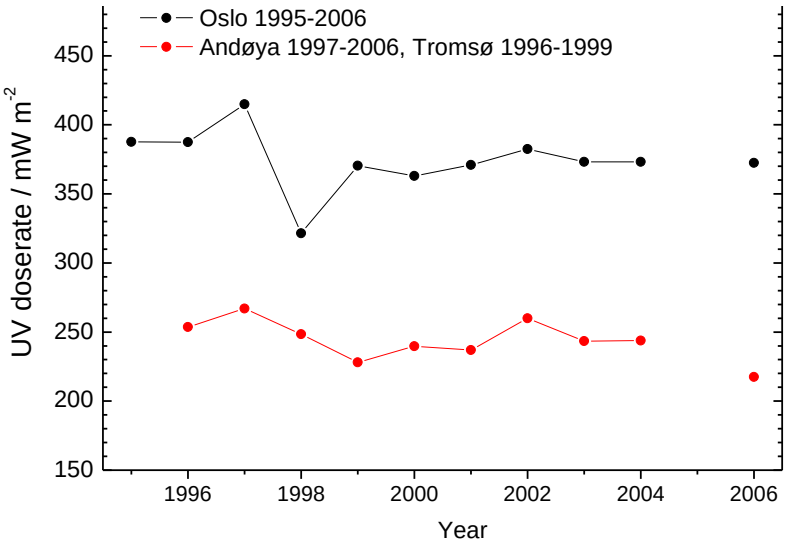

Figure 13: *Annual integrated UV doses (kJ/m^2) at the three stations during the period 1995 - 2006.*

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ABSTRACT

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 2006.

NORWEGIAN TITLE

Overvåkning av ozonlaget og naturlig ultrafiolett stråling. Årsrapport 2006.

KEYWORDS		
Stratospheric ozone	UV radiation	Measurements and observations

ABSTRACT (in Norwegian)

Rapporten presenterer måledata for totalozon, vertikalfordelingen av ozon og UV-stråling over norske målestasjoner i 2006. For Oslo og Andøya er trenden i totalozon beregnet for perioden 1979-2006.

** Classification:* *A* *Unclassified (can be ordered from NILU)*
B *Restricted distribution*
C *Classified (not to be distributed)*

Statlig program for forurensningsovervåking omfatter overvåking av forurensningsforholdene i luft og nedbør, skog, grunnvann, vassdrag, fjorder og havområder.

Overvåkingsprogrammet dekker langsiktige undersøkelser av:

- overgjødsling av ferskvann og kystområder
- 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. SFT er ansvarlig for gjennomføringen av overvåkingsprogrammet.

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