Monitoring of the atmospheric ozone layer and natural ultraviolet radiation
Annual report 2005

Rapport:	NILU OR 67/2006
TA-nummer:	TA-2197/2006
ISBN-nummer	82-425-1794-0
Oppdragsgiver:	Statens forurensningstilsyn
Utførende institusjon:	Norsk institutt for luftforskning (NILU)
Forfattere:	C.L. Myhre, K. Edvardsen, G.H. Hansen, K. Stebel, B.A.K. Høiskar,T.M. Svendby, A.F. Vik, A. Dahlback (UiO)

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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 2005, the monitoring programme included measurements of total ozone at two locations, Oslo (60°N) and Andøya (69°N) and monitoring of ultraviolet radiation at three locations, Oslo (60°N), Andøya (69°N), and Ny-Ålesund (79°N). This report summarises the activities and results of the monitoring programme during the year 2005. The report also includes trend analyses of total ozone for the period 1979-2005 for both sites and comments on ozone recovery at northern latitudes.

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 2005, 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 as part of a PhD study 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[1]. By combining the two data series, we have been able to study the changes in the ozone layer at Oslo for the period 1979-2005. The results of the trend analysis show a year-round significant decrease of –0.16 ± 0.04% per year. For the spring months the trend analysis gave a significant negative trend of –0.33 ± 0.11% 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 1979-2005. 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 – 2005 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 winter 2004/05 was one of the most severe w.r.t. stratospheric temperatures and ozone depletion in the last 15 years. The ozone values for Oslo and Andøya in 2005 were significantly below the long-term mean through most of the year, and only one month had ozone values above the long-term mean at both locations.

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. This is partly due to the high natural variability in this region and the effect of decreasing temperatures in the stratosphere. 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 and critical 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. In 2005 there are 46 days with quality controlled ozone profiles. The latest measured raw data profiles and the latest analysed ozone data are available at http://alomar.rocketrange.no/alomar-lidar.html.

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

UV measurements

The Norwegian UV network was established in 1994/95 and consists of eight 5-channels GUV instruments located from 58°N to 79°N. As part of this monitoring program NILU was in 2005 responsible for the daily operation of three of the instruments, which are located at Oslo (60°N), Andøya (69°N), and Ny-Ålesund (79°N).

In 2005 there was an extensive intercomparison campaign where all the GUV-instruments in the UV network were included. Preliminary results show that the internal agreement between the instruments as well as the agreements relative to reference data was satisfactory.

The GUV instruments were calibrated in June 2005 against a reference instrument at the Norwegian Radiation Protection Authority during this intercomparison campaign. Unfortunately there has been several breaks in the measurements due to problems with the instruments an replacements of spare parts. Due to the campaign it was not possible to calculate the total yearly UV dose for 2005. The highest UV dose rate in Oslo, 144.4 mW/m^2, was observed 12 July and is equivalent to a UV index of 5.8. At Andøya the highest UV index, 4.4, was observed on 19 July, and for Ny-Ålesund the highest UV level was on 18 June with a UV-index of 1.9.

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. For the period 1979-1993 the Dobson measurements in Oslo were performed by Søren H. H. Larsen (UiO). Dr. Tove Svendby at the Norwegian Institute for Air Research (NILU) has re-evaluated this data series and made them available at The World Ozone Data Centre (http://www.msc-smc.ec.gc.ca/woudc/). Kåre Edvardsen (NILU) is responsible for ozone and UV measurements at Andøya. The ozone lidar at ALOMAR is owned and operated in common by NILU (Georg Hansen and Kerstin Stebel), the Norwegian Defence Research Establishment and the Andøya Rocket Range.

1. Ozone measurements in 2005

Daily measurements of total ozone (the total amount of ozone from the earth surface to the top of the atmosphere) are performed at Oslo (60°N) and Andøya (69°N). Total ozone is measured by Brewer spectrophotometers at both locations.

The International Ozone Services, Canada, calibrates both Brewer instruments against a reference instrument on a yearly basis, last time in June 2005. 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 2005, based on measurements with the Brewer spectrometer no. 42, are shown in Figure 1. The black curve shows the daily ozone values measured in 2005, 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 2005. In 2005 there are missing data for 37 days (10.1%) due to technical problems (2.5%) or not suitable weather and cloud conditions (7.6%).

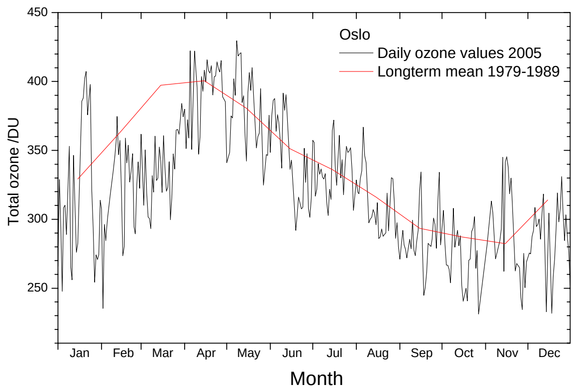


Figure 1a): *Daily total ozone values measured at the University of Oslo in 2005. The red curve shows the long-term monthly mean values from 1979-1989.*

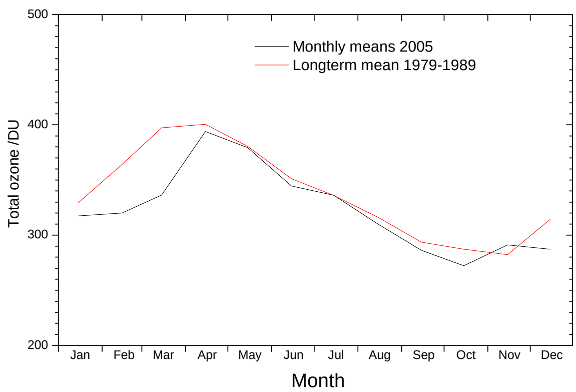


Figure 1b): *Monthly mean ozone values for 2005. The red curve shows the long-term monthly mean values from 1979-1989.*

Figure 1a) displays the daily total ozone values for Oslo together with the long-term mean values. Large day-to-day fluctuations are observed, and the values were constantly low during the spring. In fact, during the period from 25 January to 4 April only 1 day had ozone values above the long term mean.

The monthly mean total ozone values for 2005 are shown in Figure 1b and compared with the long-term monthly mean values for the period 1979-1989. Ozone values significantly lower than the long-term mean are present in February, March, and April, but also in the autumn.

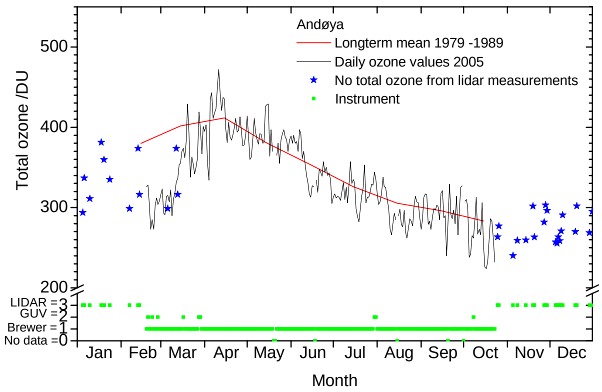
1.2 Andøya

The total ozone values are based on direct-sun measurements when they are 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. On days with bad weather conditions or too large zenith angles, it has been possible to retrieve total ozone values based on the UV-measurements performed by the GUV-instrument at Andøya, see chapter 3. The total ozone observations at Andøya are completed with data from the GUV instruments for 9 days in 2005. There are 95 days without observations at Andøya and 82 of these days is a direct result of the polar night. Table 1 give an overview of the use of the different instruments and methods at Andøya.

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	63
2	Brewer instrument, global irradiance method	169
3	Measurement by the GUV instrument, and calculation of total ozone	9
4	Lidar (measurements in the Polar night)	29

Daily ozone values for Andøya in 2005, based on measurements with the Brewer spectrometer and GUV measurements are shown in Figure 2a). The total ozone values shown during the polar night (December 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 black curve shows the daily ozone values measured in 2005, whereas the red curve shows the long-term monthly mean values for the years 1979-1989. The green marks in the lower part of Figure 2a) shows the frequency and distribution of the various instruments applied.



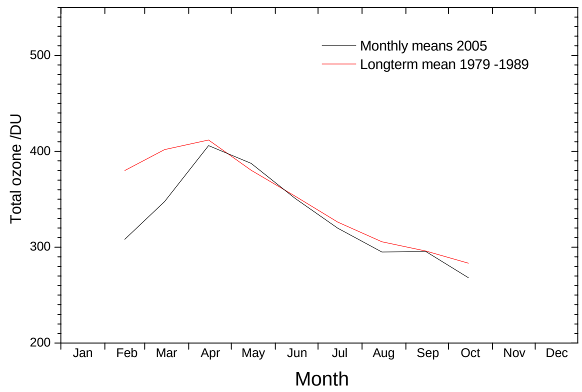


Figure 2a): *Daily total ozone values measured at ALOMAR, Andøya in 2005 by the Brewer, GUV and LIDAR instruments. The use of the different instruments is shown in the lower part of Figure 2a). The red line shows the long-term monthly mean values from 1979-1989.*

Figure 2b): *Monthly mean ozone values for 2005 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 2005 shows that the ozone values are close to the long-term mean for most of the year except for the spring months. In this period the ozone values are significantly lower than the long-term mean.

1.3 Ozone-profile measurements with the ozone lidar at ALOMAR, Andøya in 2005

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 2005 measurements have been made during 51 days (53 occasions, of which 11 were during daylight conditions) [see Table 2]. These observations have resulted in quality controlled ozone profiles for 45 days (46 measurement occasions). The most recent rawdata profiles as well as the latest analysed ozone data are available at http://alomar.rocketrange.no/alomar-lidar.html.

In 2005 quality controlled ozone profiles have been retrieved for 45 days. Apart from overcast weather conditions in autumn 2005 no extra-ordinary technical problems have occurred with the lidar. A comparison to 2002 measurements show that the 2005 measurement frequency is about 45% of what could have been achieved with the system in case of excellent conditions, both in terms of weather and better operator coverage. The last is restricted by the funding.

Table 2: *List of ozone lidar measurements at ALOMAR in 2005. 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 that are crossed out, mark days where data of lower quality are available.*

Month	Ozone profile
January	**05, 06, 10, 18, 20,** ~~2~~**4**
February	**07, 13, 14, 15, 20, 21, 28**
March	**04, 18**
April	**10, 21, 28, 29**
May	**06,** ~~25~~
June	~~03~~, ~~12~~
July	**05, 06,** ~~18~~, ~~20~~
August	~~03~~, **24**
September	**07**
October	**08, 25, 26**
November	**03, 05, 08, 14, 19, 20, 27, 28, 29**
December	**05, 06, 07, 08, 09, 19, 20, 29, 31**

Since 1995 vertical profiling of stratospheric ozone, polar stratospheric clouds and stratospheric temperature has been performed by means of the 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 (2004/05), and a winter with a very cold early phase (2005/06). Polar stratospheric clouds (PSCs) were recorded on several occasions in January and February 2005 as well as in December 2005. An overview of all PSC measurements during the last 3 winters is given in Table 3.

Table 3: *An overview of all PSC (polar stratospheric clouds) measurements during the winter 3 years.*

Month	# PSC obs.	Maximum BSR_{353}	Min. temperature
Dec. 2003	---	---	189 K (26 km)
Jan. 2004	---	---	199 K (22 km)
Feb. 2004	---	---	201 K (20 km)
Dec. 2004	---	---	193 K (29 km)
Jan. 2005	3	1.7 (January 24)	188.5 K (22 km)
Feb. 2005	6	2.0 (February 7)	189.2 K (19.6 km)
Dec. 2005	4	1.6 (December 31)	184 K (25 km)
Jan. 2006	2	4.8 (January 6)	182 K (27 km)
Feb. 2006	---	---	205 K (31 km)

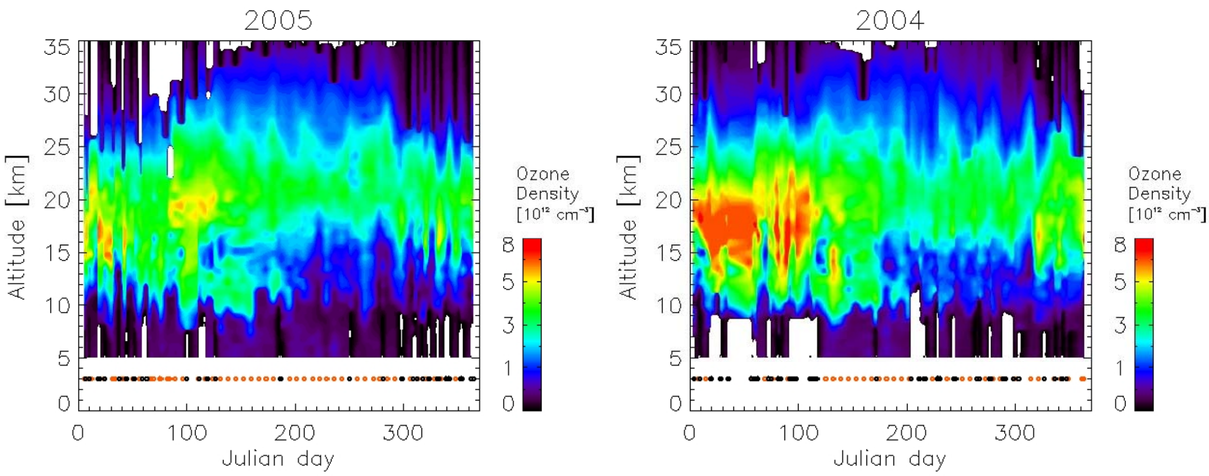


Figure 3: *Ozone profiles measured by the ALOMAR ozone lidar and ozone sondes launched in Sodankylä, Finland, in 2005 (left panel) and in 2004 (right panel). The black dots at the bottom of the plot mark the times when lidar measurements were performed, while the red dots mark days where data from ozone sondes launched from Sodankylä were used. Between the individual measurements the data were linearly interpolated and smoothed with a one-week median filter.*

The development of the ozone layer above Northern Scandinavia throughout the whole year 2005 is illustrated in Figure 3 (left panel). For comparison the 2004 ozone layer is shown in the same figure (right panel). The contrast in the development of the stratospheric ozone layer during a relative warm winter 2003/04, without noticeable ozone depletion, and the winter 2004/05, with a long cold period, and significant ozone depletion is easy to recognize.

1.4 Discussion of the ozone situation in Norway 2005

Table 4 gives the percentage difference between the monthly mean total ozone values for 2005 and the long-term monthly values for Oslo and Andøya. The ozone values for Oslo in 2005 were significantly below the long-term mean in 9 of 12 months and only one month, November, gave ozone values above the long-term mean. In March the ozone values were 18% below the long-term mean, and this was the month with the highest deviation. However, it is worth noting that the ozone values were low through the whole year and 6% below the long-term mean also in October. The situation is very similar at Andøya. Only May had monthly mean ozone values above the long-term mean and 7 of 9 months had monthly mean ozone values significantly below the long-term mean. February had ozone values as much as 23% below the long-term mean, however for this month there are only measurements for 13 days due to polar night and bad weather conditions for lidar measurements.

The low ozone values in the spring are a direct result of the stratospheric condition this winter with the particularly strong PSC-activity. The polar stratospheric vortex[2] leads to chemical polar ozone destruction, when air masses, which are quasi-isolated in the polar vortex, are illuminated by sunlight. Sunlight initiates the formation of active chlorine compounds by

[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.

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).

Table 4: *Percentage difference of monthly mean total ozone values for 2005 and the long-term mean for Oslo and Andøya.*

Month	Oslo	Andøya
January	-4 %	-
February	-14 %	-23 %
March	-18 %	-16 %
April	-2 %	-1 %
May	<±0.5 %	2 %
June	-2 %	-1 %
July	<±0.5 %	-2 %
August	-2 %	-4 %
September	-3 %	<±0.5 %
October	-6 %	-6 %
November	3 %	-
December	-9 %	-

The winter 2004/05 was one of the most severe w.r.t. stratospheric temperatures and ozone depletion in the last 15 years. Maximum depletion rates in early March caused total ozone reduction of close to 30% (as in 1996 and 2000). Figure 4 shows an example of the stratospheric temperature in January 2005**.** 26 January 2005 The Alfred Wegner Institute observed the first PSC II ever above Ny-Ålesund and at the Koldewey station. This pure ice crystal PSC formed at the lowest temperatures has previously only been observed in the Antarctic region. This type of PSC is even more efficient with respect to ozone depletion than type I.

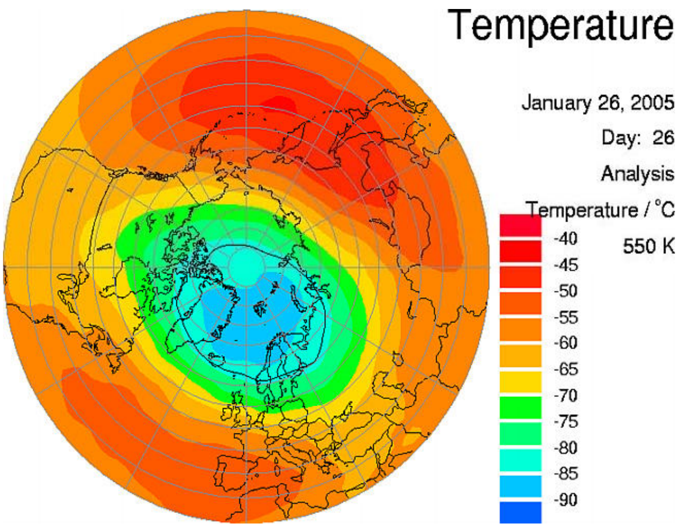


Figure 4: *Stratospheric temperatures from 26. January 2005 .*

The main geophysical characteristics of the winter 2004/05 can be summarized as:

- The early establishment and cooling of the vortex in November/December 2004.
- The cold region was geographically larger, but not as cold and large in vertical extent as in 1995/96.
- No large stratospheric warming occurred in January and February 2005 (movement of cold pool towards North Atlantic).
- The vortex and the cold pool was moved towards lower latitudes in the European sector, causing severe ozone depletion there in March, but also weakening and splitting of vortex in mid/late March 2005.

The reason for the strong PSC activity might be related to the observed cooling of the stratosphere the last decades (IPCC, 2001; Ramaswamy et al., 2006). According to Ramaswamy et al. (2006) climate model simulations indicate that the observed cooling is mainly attributable to the combined effect of changes in anthropogenic factors as reduction in stratospheric ozone and the increase of greenhouse gases in the troposphere, and natural factors like solar variations and volcanic aerosols. Their conclusion is that anthropogenic factors drive the overall cooling and the natural ones modulate the evolution of the cooling. An increase in the stratospheric water vapour will also contribute to the cooling and might have impacts on the PSCs. The sources of stratospheric water are not fully understood, but anthropogenic activities seem to be important. A water vapour trend is uncertain but an increase of 1% per year is estimated and several explanations are suggested: increase of methane (and the oxidation of CH_4), increased aircraft emissions, warming of the tropical tropopause, volcanic eruptions, changes in stratospheric circulations and tropospheric–stratospheric exchange (Stenke and Grewe, 2005). The influence on PSCs seems to be different on the two hemispheres, with smaller influence on the northern hemisphere than on the southern. However, this is connected with large uncertainty (Stenke and Grewe, 2005).

Another important subject is to understand the reason of the low ozone values during the summer and autumn months following a spring with extensive ozone depletion. Several scientific reports (e.g. Hadjinicolaou and Pyles, 2004; Fioletov and Shepard, 2005) conclude that polar ozone depletion in the winter and spring results in a dilution of the ozone at mid latitudes several months later due to dynamical processes.

Unfortunately total ozone observations at Ny-Ålesund have not been included in the national monitoring program since 2002 due to lack of funding. This makes it difficult to examine the influence of polar ozone values on levels at lower latitudes and to investigate a possible trend in the Norwegian Arctic region. The studies mentioned above focus mostly on the latitudes $60^{o}S–60^{o}N$, and do not investigate the effect on high latitudes. The knowledge is low in this region. Furthermore, observations at Ny-Ålesund would be highly important in the detection of a possible effect of a colder stratosphere and the impact on the formation of the PSC and the influence on ozone level at both high and mid latitudes.

2. Ozone measurements 1979–2005

2.1 Oslo

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 2005. 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 2005. The total ozone values from 1979 to 1998 are from the Dobson instrument, whereas for the period 1999-2005 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.

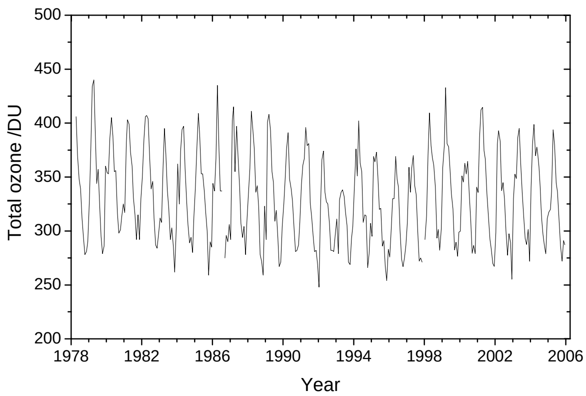


Figure 5a: *Time series of monthly mean total ozone in Oslo 1979-2005.*

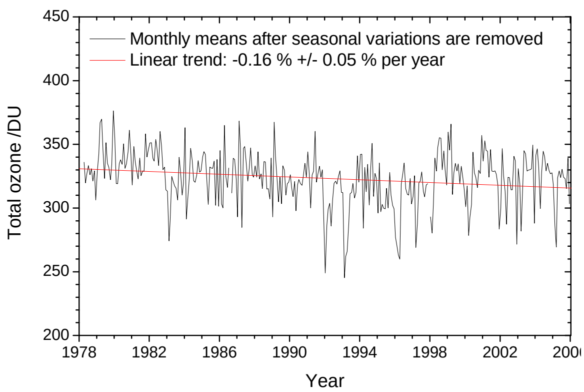


Figure 5b: *Variation in total ozone over Oslo for the period 1979–2005 after the seasonal variations have been removed.*

In order to look at possible ozone reduction for the period 1979 to 2005 we have removed the seasonal variations by subtracting the long-term monthly means and adding the long-term yearly mean value, Figure 5b). A simple linear regression has been fitted to obtain the trend in the data set. The results of the trend analysis are summarized in Table 5. For spring months a significant negative trend of –0.33% per year is observed. The comparable value for 1979-2004 was –0.35%. For the winter, summer and fall months no significant trend is observed. When all months are included a significant negative trend of –0.16% per year is observed.

Table 5: *Percentage changes in total ozone per year for Oslo for the period 1.1.1979 to 31.12.2005. 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	-0.20 (0.12)
Spring:	March – May	-0.33 (0.11)
Summer:	June - August	-0.02 (0.06)
Fall:	September - November	-0.09 (0.05)
Annual		-0.16 (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 is related to the eruption of the El Chichón volcano in Mexico in 1982 and the Mount Pinatubo volcano at the Philippines in 1991.

The Figure shows that the low ozone values in the 1990's contribute strongly to the observed negative trends in total ozone. Yet, the yearly mean ozone value for 2005 was as much as 7% lower than the long-term yearly mean. This leaves 2005 as the year with the fourth lowest yearly mean total ozone value (together with 1995) compared to the long-term mean in the period from 1979-2005 in Oslo.

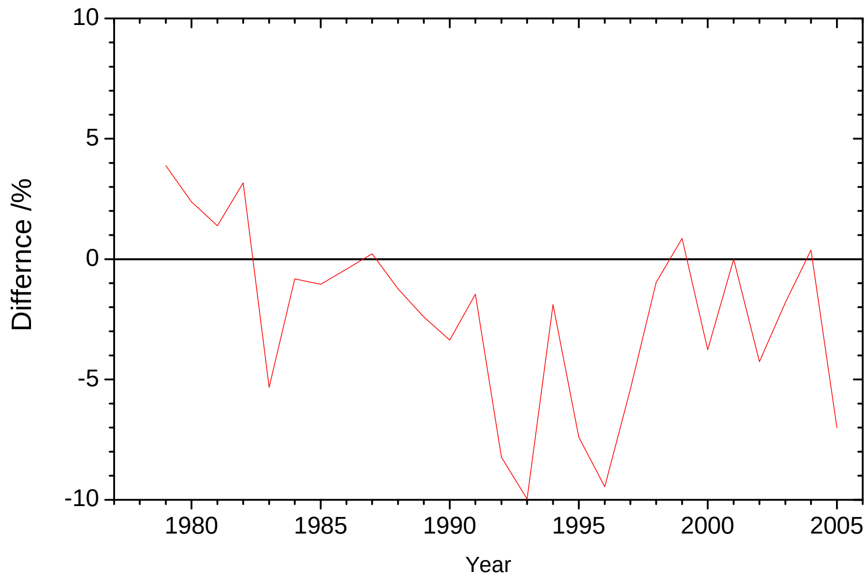


Figure 6*: Percentage difference between yearly mean total ozone in Oslo and the long-term yearly mean for 1979-1989.*

2.2 Andøya

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) were used.

Figure 7a) shows the variations in the monthly mean ozone values at Andøya from 1979 to 2005. The variations in total ozone at Andøya for the period 1979–2005 after the seasonal variations have been removed is shown in Figure 7b).

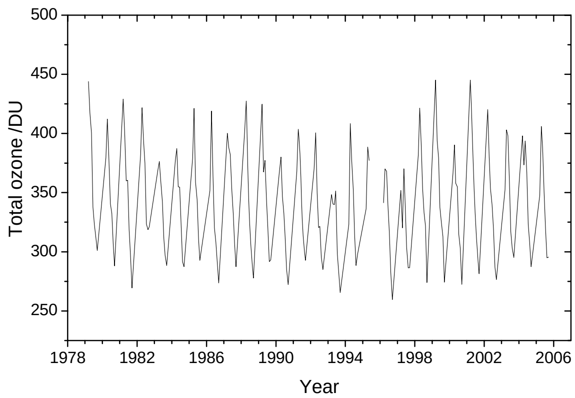


Figure 7 a): *Time series of monthly mean total ozone at Andøya/Tromsø 1979–2005*

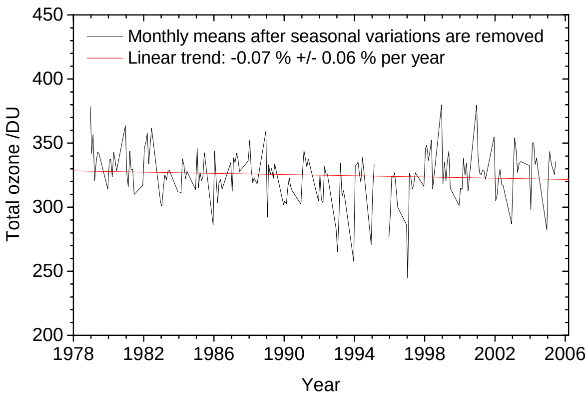


Figure 7 b): *Variation in total ozone at Andøya for the period 1979–2005 after the seasonal variations are removed. Only data for the months March–September are included.*

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 6. No significant trends were observed for Andøya for this time period.

Table 6: *Percentage changes in total ozone per year for Andøya for the period 1979 to 2005. 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	-0.13 % (0.11)
Summer:	June – August	0.00 % (0.05)
Annual	(March – September)	-0.07 % (0.06)

The percentage difference between yearly mean total ozone and the long-term yearly mean is shown in Figure 8. For 2005 the yearly mean ozone value was considerably below the long-term yearly mean value for the period 1979–1989: -6.5% compared to 7.0% for Oslo. This makes 2005 the year with the third lowest ozone values (together with 1996) relative to the long-term mean in the period from 1979-2005.

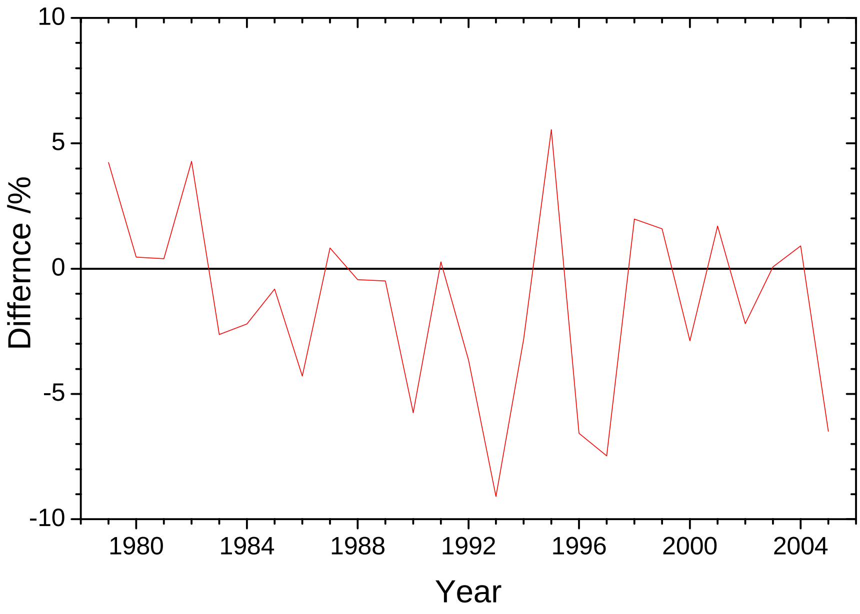


Figure 8: *Percentage difference between yearly mean total ozone at Andøya and the long-term yearly mean for 1979–1989 for the months March–September.*

2.3 Comments on ozone recovery at northern latitudes

Recovery of the ozone layer is a process beginning with a lessening in the rate of decline, followed by a leveling off and an eventual increase in ozone driven by the changes in the concentrations of ozone-depleting substances. The first studies examining the total column ozone are now emerging and there was a review in Nature (2006) presenting an overview of the signs of the recovery of the ozone layer (Weatherhead and Andersen, 2006). In the following this study is summarized with particular focus on the situation on the high northern latitudes and Arctic region.

According to the review (Weatherhead and Andersen, 2006) recent data suggest that that 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 and the increase observed at the high northern latitude is considerable larger than what the models predicts. This region also exhibits the highest level of natural variability, which again makes the prediction for this region 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. Regarding seasonal trends, they are not independent and summer ozone levels are strongly linked to the spring ozone levels.

The most dramatic ozone depletion has been observed in the Polar Regions, but detecting 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 in stratosphere as well as the troposphere. Further the ozone trend analysis for the high northern latitudes at present are to a great extent 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 in this time period, also illustrated in Figure 6 and Figure 8 in this report. The solar cycle and its peak in 2000-2002 also contribute to the uncertainty of the recovery in our region. These two factors are often not included in the models and probably explain the underestimation of the modeled the ozone levels, compared to the measurements in this region.

The conclusions of Weatherhead and Andersen (2006) are that during the next few years ozone levels in the Arctic and high northern latitudes will be strongly influenced by stratospheric temperatures possibly resulting 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 point to the importance of the fact that anthropogenic changes of the atmosphere suggest that the ozone will recover in an atmosphere much different from that which prevailed before the build up of ozone-depleting substances. Whether ozone stabilizes at a level higher or lower than 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.

3. UV measurements

The Norwegian UV network was established in 1994/95 and consists of eight 5-channel GUV instruments located from 58°N to 79°N, illustrated in Figure 9. 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 and Østerås. On-line data from the UV network is shown at www.stralevernet.no/uv and at www.luftkvalitet.info/uv.

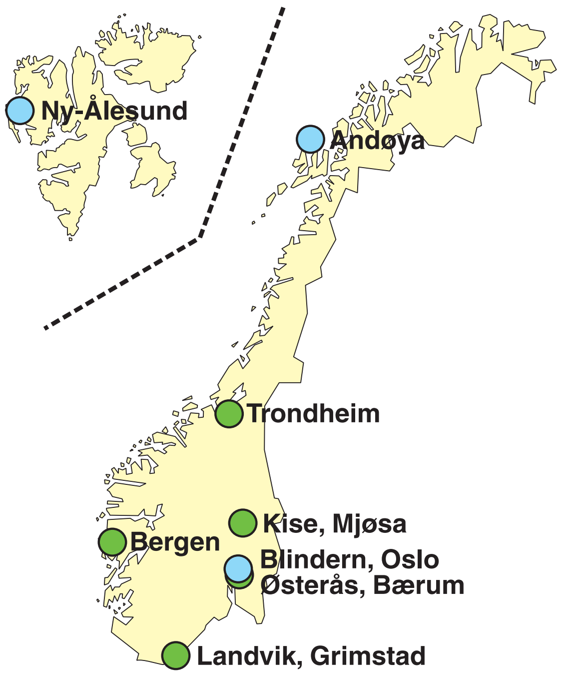


Figure 9: *Map of the stations included in the Norwegian UV network. The stations marked with blue are operated by NILU on behalf of The Norwegian Pollution Control Authority (SFT), whereas the Norwegian Radiation Protection Authority operates the stations marked with green.*

In this annual report UV data from Oslo, Andøya, and Ny-Ålesund will be reported. Due to lack of funding, the GUV instrument in Ny-Ålesund was in 2003 omitted from the monitoring programme. However in 2004 and 2005 the monitoring programme secures the operation of the Ny-Ålesund instrument, and the results are again included in the report.

The three 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)[3]. The Norwegian Research Council finances this project and the aim of FARIN is to quantify the various factors controlling UV radiation in Norway. This includes clouds, ozone, surface albedo, aerosols, latitude, and geometry of exposed surface among others. The project group operates a variety of instruments and models applicable to study the UV controlling factors. These include both scanning spectroradiometers, a network of moderate bandwidth filter instruments and state-of-the-art radiative transfer models.

One part of the project is to compare and evaluate all the UV-instruments in the Norwegian monitoring network. In total 43 UV-instruments (multiband filterradiometers) including 16 NILU-UVs are included in the campaign. The intercomparison campaign took place at NRPA from 9 of May to 9 of June (approximately). The three GUVs from NILU were set up at the NRPA, Østerås, in this period. A comparison to a reference data set was performed and preliminary results from the campaign show that the GUV-instruments in Oslo, at Andøya and Ny-Ålesund gave satisfactory results. The GUV-instruments at Blindern and Andøya demonstrated an internal agreement of ±1%, and a deviation of -1% to -4% relative to the reference data, depending on the solar zenith angle. The instrument at Ny-Ålesund was also highly acceptable but with somewhat different characteristics; internal agreement of ±2%, and -3% to 0% relative to the reference data.

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

The number of days with missing data in 2005 from the three instruments is given in Table 7.

Table 7: *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	FARIN campaign	Technical problems		Total number of days with missing data 2005
		2005	2004	
Oslo	38	2	5	40
Andøya	54	41	1	95
Ny-Ålesund	84	5*	3	89

* Additionally the data quality is low in the period from 12 July - 10 September due to a combination of failure in the start up routines after the FARIN campaign and a need for more extensive control routines.

For several reasons there are many days with missing UV data in 2005. The main reason is the FARIN campaign, which led to 38 days without measurements at Blindern, 54 days at Andøya and 84 days at Ny-Ålesund. Secondly, there were interruptions due to several technical problems this year. It was necessary to the replace old instrumental components and there was a break down and replacement of one computer.

The instrument at Blindern has been measuring every day expect for the period covering the FARIN campaign and two additional days. For the Andøya GUV it was discovered a problem with leak in the top of the instrument during the FARIN campaign. The cause of this material damage is most likely natural aging of the instrument and exposure to rain, weather, wind, and UV-radiation. The measurement break due to the replacement of this spare part was 32 days inclusive purchase and testing. At Ny-Ålesund it was necessary to replace a computer. Additionally there were problems with the regulation of the temperature of the instrument after the campaign, and there is a need of extending the control routines to avoid similar problems. The data from the period from 12 July to 10 September is therefore connected with a systematic error, which, with some effort, can be corrected for. Unfortunately all the missing days made it impossible to calculate annual doses this year. The FARIN campaign is the main reason as this took place in the period with highest solar intensity, most essential for the calculation of the annual dose. However, there have also been and increase in disruptions due to technical problems with the GUVs.

3.1 UV measurement results in 2005

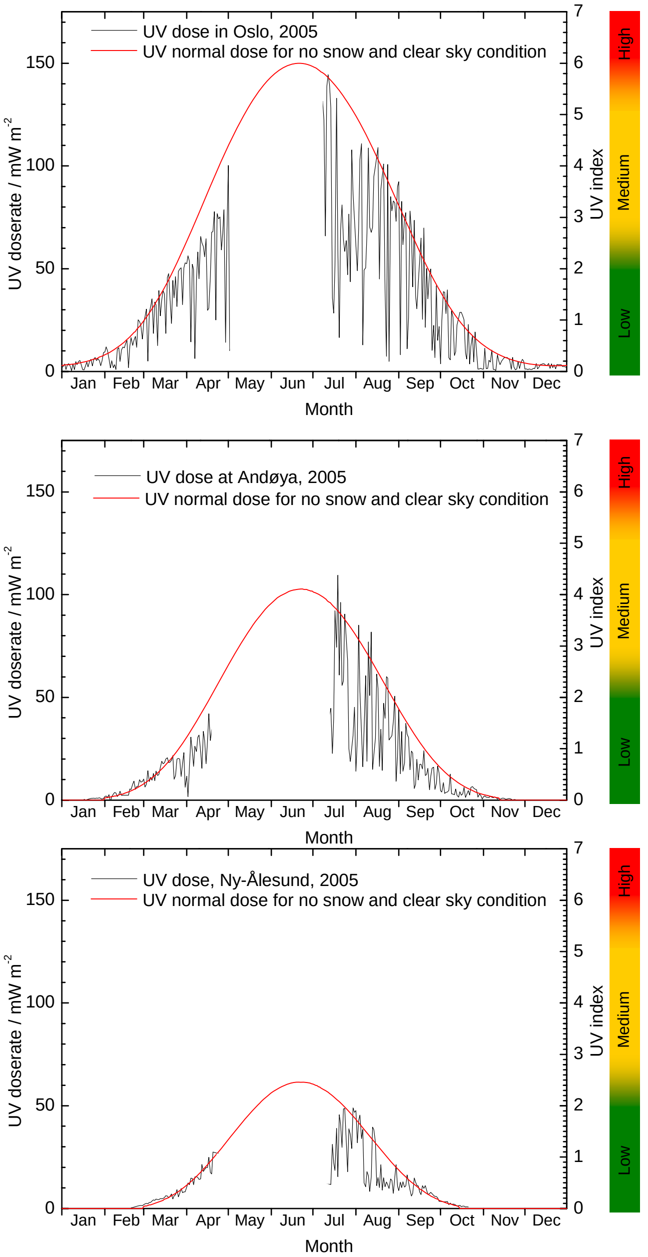


Figure 10: *Hourly averaged UV dose rate measured at noon (between 10:30 and 11:30 GMT) at a) Oslo, b) Andøya, c) Ny-Ålesund*

The UV dose rate is a measure of the total biological effect of UV-A and UV-B radiation. 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). Figure 10 shows the UV dose rates measured at noon (averaged between 10:30 and 11:30 GMT) for Oslo, Andøya and Ny-Ålesund. The colour scale indicates the level of the potential harm caused by the UV-radiation.

The highest UV dose rate in Oslo, 144.4 mW/m^2, was observed 12 July and is equivalent to a UV index of 5.8. At Andøya the highest UV index, 4.4, was observed on 19 July, and for Ny-Ålesund the highest UV level was on 30 July with a UV-index of 1.9. It is important to remember the lack of measurements during June and the beginning of July.

The clear seasonal variation in the observed UV dose rate is caused by the solar elevation. The highest UV levels normally occur during the summer months when the solar elevation is highest. The most important factors that influence the UV radiation is solar elevation, 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 radition. Annual report, 2004*" (Høiskar et al., 2004)

Monthly, integrated UV doses for Oslo, Andøya and Ny-Ålesund in 2005 are compared in Figure 11 for the months with available data. The monthly integrated UV doses observed at Oslo are significantly higher than the ones observed at Andøya and Ny-Ålesund.

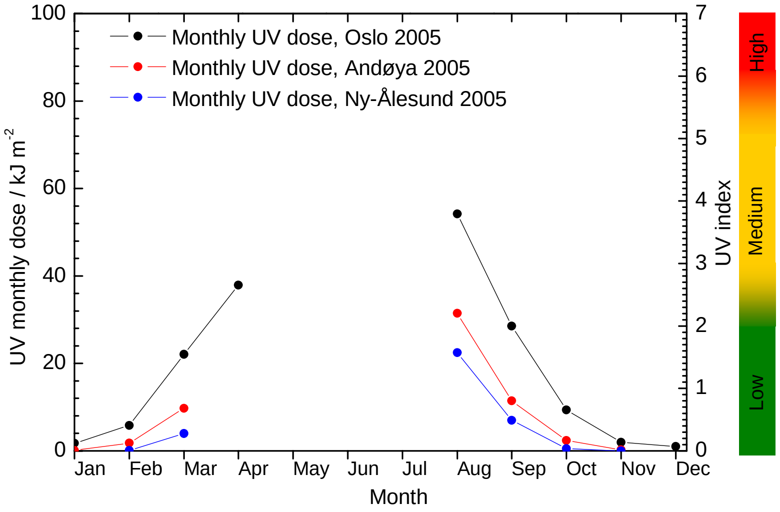


***Figure 11**: Monthly integrated UV doses in 2005 measured with the GUV instruments located in Oslo, Andøya and Ny-Ålesund.*

3.2 Annual UV doses 1995–2005

Annual UV doses for the period 1995–2005 are not possible to achieve, as there were break in the measurements at all locations during the FARIN campaign. This lasts from the end of April/beginning of May to mid July. 40–68% of the surface UV radiation during one year is received in this period, depending of the latitude and exact time of break. For Oslo, Andøya and Ny-Ålesund the break resulted in ca. 42%, 54% and 68% reduction of the UV radiation respectively. Thus, reliable calculations of the annual doses are not possible to complete for 2006.

4. References

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

Fioletov, V.E. and Shepherd, T.G. (2005) Summertime total ozone variations over middle and polar latitudes. *Geophys. Res. Lett., 32,* doi:10.1029/2004GL022080.

Hadjinicolaou, P. and Pyle, J.A. (2004) The impact of Arctic ozone depletion on northern middle latitudes: Interannual variability and dynamical control. *J. Atmos. Chem., 47*, 25-43.

Høiskar, B.A.K., Braathen, G.O., Dahlback, A., Bojkov, B.R., Edvardsen, K., Hansen, G.H. and Svenøe, T. (2001) Overvåking av atmosfærens ozonlag og naturlig ultrafiolett stråling. Årsrapport 2000. Kjeller (NILU OR 35/2001).

Høiskar, B.A.K., Braathen, G.O., Dahlback, A., Edvardsen, K., Hansen, G., Stebel, K., Svendby, T. and Vik, A.F. (2004) Monitoring of the atmospheric ozone layer and natural ultraviolet radiation. Annual report 2003. Kjeller (NILU OR 53/2004).

IPCC (2001) Climate change 2001: The scientific basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Ed. by: Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., van der Linden, P.J., Dai, X., Maskell, K. and Johnson, C.A. Cambridge, Cambridge University Press.

Ramaswamy, V., Schwarzkopf, M.D., Randel, W.J., Santer, B.D., Soden, B.J. and Stenchikov, G.L. (2006) Anthropogenic and natural influences in the evolution of lower stratospheric cooling. *Science, 311,* 1138-1141.

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.

Stenke, A. and Grewe, V. (2005) Simulation of stratospheric water vapor trends: impact on stratospheric ozone chemistry. *Atmos. Chem. Phys., 5,* 1257-1272.

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.

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/.

Norsk institutt for luftforskning (NILU)

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REPORT SERIES SCIENTIFIC REPORT	REPORT NO. NILU OR 67/2006	ISBN 82-425-1794-0 ISSN 0807-7207	
DATE	SIGN.	NO. OF PAGES 21	PRICE NOK 150.-
TITLE Monitoring of the atmospheric ozone layer and natural ultraviolet radiation Annual report 2005		PROJECT LEADER Cathrine Lund Myhre NILU PROJECT NO. O-106007/O-106008	
AUTHOR(S) C.L. Myhre, K. Edvardsen, G.H. Hansen, K. Stebel, B.A.K. Høiskar,T.M. Svendby, A.F. Vik, A. Dahlback (UiO)		CLASSIFICATION * A CONTRACT REF. Harold Leffertstra	
REPORT PREPARED FOR Statens forurensningstilsyn Postboks 8100 Dept. 0032 Oslo			

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 2005.

NORWEGIAN TITLE

Overvåkning av ozonlaget og naturlig ultrafiolett stråling. Årsrapport 2005.

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 2005. For Oslo og Andøya er trenden i totalozon beregnet for perioden 1979-2005.

** Classification:*		
	A	*Unclassified (can be ordered from NILU)*
	B	*Restricted distribution*
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Statlig program for forurensningsovervåking omfatter overvåking av forurensningsforholdene i luft og nedbør, skog, grunnvann, vassdrag, fjorder og havområder.

Overvåkingsprogrammet dekker langsiktige undersøkelser av:

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

Telefon: 22 57 34 00
Telefaks: 22 67 67 06
E-post: postmottakft.no
Internett: www.sft.no
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Norsk instiutt for luftforskning
Postboks 100, 2027 Kjeller
Besøksadresse: Instituttveien 18

Telefon: 63 89 80 00
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