Monitoring of the atmospheric ozone layer and natural ultraviolet radiation
Annual report 2004

Rapport:	NILU OR 31/2005
TA-nummer:	(TA-2107/2005)
ISBN-nummer	82-425-1672-3
Oppdragsgiver:	Statens forurensningstilsyn
Utførende institusjon:	Norsk institutt for luftforskning (NILU)
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Rapport 933/2005

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Statlig program for forurensningsovervåking

Preface

In 1985, a English scientists (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 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 and it is still too early to determine whether the ozone layer is recovering.

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 2004, 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 2004. The report also includes trend analyses of total ozone for the period 1979-2004 for both sites.

Contents

Summary

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 2004.

Measurements of total ozone
The Brewer instrument at Oslo has been in operation at the University of Oslo since the summer of 1990. In the period 1979 to 1998 total ozone data from a Dobson spectrophoto-meter is available. The data from this instrument has recently 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 (http://www.msc-smc.ec.gc.ca/woudc/). By combining the two data series, we have been able to study the changes in the ozone layer at Oslo for the period 1979-2004. The results of the trend analysis show a year-round significant decrease of –0.17 ± 0.05 % per year. For the spring months the trend analysis gave a significant negative trend of –0.35 ± 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 1979-2004. 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 – 2004 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 International Ozone Services, Canada, calibrated the Brewer instruments against a reference instrument in June 2004

Measurements of ozone profiles
The ozone lidar at Andøya provides measurements of the ozone concentration 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 2004, there are 58 with days quality controlled ozone profiles (64 measurement occasions), of which 29 were during daylight conditions. The latest measured rawdata 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 eight 5-channels GUV instruments located from 58°N to 79°N. As part of this monitoring program NILU was in 2004 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 2004 there were total yearly UV dose of 373.2 kJ/m^2 in Oslo, 243.7 kJ/m^2 at Andøya and 190.52 kJ/m^2 at Ny-Ålesund. The highest UV dose rate in Oslo, 139.2 mW/m^2, was observed 30 June and is equivalent to a UV index of 5.6. At Andøya the highest UV index, 4.5, was observed on 1 July, and for Ny-Ålesund the highest UV level was on 18 June with a UV-index of 2.5.

The GUV instruments were calibrated in June 2004 against a reference instrument provided by 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 the ozone and UV measurements in Oslo. For the period 1979-1993 were the Dobson measurements in Oslo 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 the ozone and UV measurements at Andøya and Ny-Ålesund. NILU by Georg Hansen and Kerstin Stebel operates the ozone lidar at Andøya Rocket Range in cooperation with the Norwegian Defence Research Establishment (Ulf Peter Hoppe).

1. Total ozone measurements in 2004

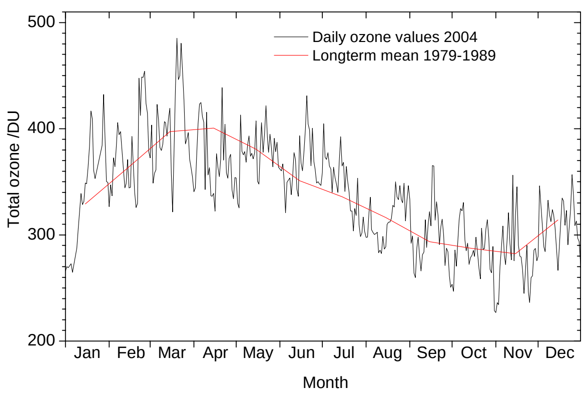
Daily measurements of total ozone (the total amount of ozone from the earth surface to the top of the atmosphere) are performed at Oslo (60°N) and Andøya (69°N). Total ozone is measured by Brewer spectrophotometers at both locations.

The International Ozone Services, Canada, calibrates both Brewer instruments against a reference instrument on a yearly basis, last time in June 2004. 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 2004, based on measurements with the Brewer spectrometer no. 42, are shown in Figure 1. The black curve shows the daily ozone values measured in 2004, 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 173 days in 2004. In 2004 there are missing data for 17 days (4.7 %) due to technical problems or not suitable weather and cloud conditions.



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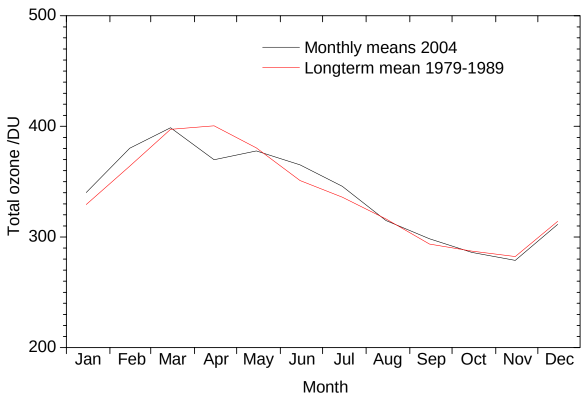


b)

Figure 1a): Daily total ozone values measured at the University of Oslo in 2004. The red curve shows the long-term monthly mean values from 1979-1989.

Figure 1b) Monthly mean ozone values for 2004.

Figure 1a) displays the daily total ozone values for Oslo together with the long-term mean values. Large day-to-day fluctuations, particularly during the spring are observed, but no longer periods with deviating ozone values. The monthly mean total ozone values for 2004 are shown in Figure 1b and compared with the long-term monthly mean values for the period 1979-1989. Table 1 gives the percentage difference between the monthly mean total ozone values for 2004 and the long-term monthly mean values for Oslo and Andøya. The ozone values for Oslo in 2004 were close to the long-term mean values from August and throughout the rest of the year. April was the only month where the monthly mean ozone value was considerably below the long-term mean; the difference was -8%. In the summer there was a longer period with noticeable high ozone values lasting from the middle of June to the middle of July resulting in mean ozone values 3 - 4% above the long-term mean in this period.

Table 1: Percentage difference of monthly mean total ozone values for 2004 and the long-term mean for Oslo and Andøya.

Month	Oslo	Andøya
January	+3%	-
February	+4%	-1%
March	<±1%	-1%
April	-8%	-10%
May	-1%	+3%
June	+4%	+4%
July	+3%	-1%
August	<±1%	+1%
September	+2%	-3%
October	<±1%	-4%
November	-1%	-
December	-1%	-

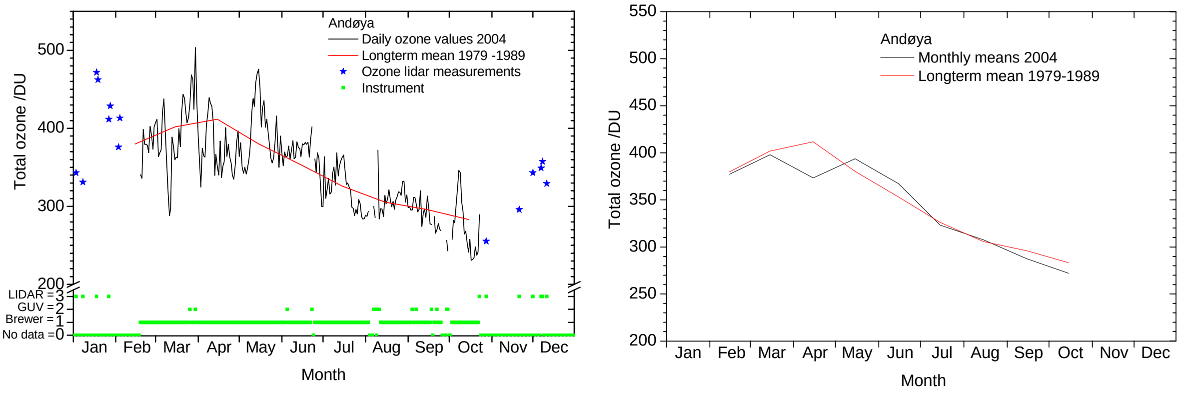
1.2 Andøya

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. For days were measurements of total ozone based on the two methods are not available due to the weather conditions or too large zenith angles, it is possible to retrieve total ozone values based on the UV-measurements performed by the GUV-instrument at Andøya, see section 4. The total ozone observations at Andøya are completed with data based on this instrument for 14 days. It is 130 days without observations at Andøya and 119 of these days is a direct result of the polar night. Table 2 give an overview of the use of the different instruments and methods at Andøya.

Table 2: Overview 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	92
2	Brewer instrument, global irradiance method	130
3	Measurement by the GUV instrument, and calculation of total ozone	14
4	Lidar (measurements in the Polar night)	16

Daily ozone values for Andøya in 2004, 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 available. The black curve shows the daily ozone values measured in 2004, 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.



a) b)

Figure 2a): Daily total ozone values measured at ALOMAR, Andøya in 2004 by the Brewer, GUV and LIDAR instruments. The use of the different instruments is shown in the lower panel of Figure 2a). The red line shows the long-term monthly mean values from 1979-1989.

Figure 2b): Monthly mean ozone values for 2004 compared with the long-term monthly mean values for the period from 1979-1989 shown as the red curve.

In general, the polar stratospheric vortex[(1)] lead to chemical polar ozone destruction, when air masses, which are quasi-isolated in the polar vortex, are illuminated by sun-light. After an early warming in January 2004 temperatures increased and there were few longer periods with conditions favourable for polar stratospheric cloud formation during the spring 2004. However, important natural processes influencing the ozone level in the Northern hemisphere took place in the same period (Randall et al., 2005; Orsolini et al., 2005). Initially, there were intense solar storms in October-November 2003 producing energetic particles in the upper stratosphere. The particles precipitate in the polar stratosphere in the beginning of 2004 and led to substantial NO_x production in the upper atmosphere. There was an upper stratospheric layer of enhanced HNO_3 following the exceptional solar storms. Nitric acid (HNO_3) is a key species involved in the catalytic ozone loss cycles in the middle stratosphere and the enhanced HNO_3 layer resulted in substantial ozone loss in the upper stratosphere from March - May (Randall et al., 2005; Orsolini et al., 2005). This might explain why the total ozone at Andøya was 10 % below the long-term mean in April despite the fact that there were too high temperatures for polar stratospheric cloud formation. Normal total ozone column values were reached again by the end of April 2004.

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

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 percentage difference between the monthly mean total ozone values for Andøya in 2004 and the long-term monthly means are given in Table 1. The table and Figure 2 clearly indicate an episode with low ozone values in the autumn months. Actually, the Brewer data show that the ozone values were as much as ~ -17% below the mean value of October in the period around 10 - 15 October. Unfortunately measurements with the Brewer and GUV instruments are difficult later than October due to the polar night. However data based on the lidar measurements and from TOMS (Total Ozone Mapping Satellite) are also available. The observed low ozone episode will be discussed in relation to the lidar data in the next chapter.

2. Ozone-profile measurements with the ozone lidar at ALOMAR, Andøya in 2004

The ozone lidar located at the ALOMAR Observatory at Andøya is run on a routine basis during clear sky situations providing ozone profiles in the height range 8 to 50 km. In 2004 there are 64 days (74 occasions, of which 29 were during daylight conditions) with ozone lidar measurements, see Figure 3. These measurements have resulted in quality controlled ozone profiles for 58 days (64 measurement occasions). The latest measured rawdata profiles and the latest analysed ozone data are available at http://alomar.rocketrange.no/alomar-lidar.html.

Table 3: List of ozone lidar measurements at ALOMAR in 2004. Analysed and quality controlled total ozone data; 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.

Month	Ozone profile
January	~~0~~4, 09, 19, 20, 28, 29
February	04, 05, 25, 26, 28
March	01, 02, 03, 12, 13, 15, ~~16~~, 21, ~~2~~2, 24, ~~25~~
April	01, 02, 04, 06, 07, 19, 20, ~~2~~1, ~~2~~2, 23, 24, 25, 26
May	~~05~~, ~~07~~, ~~24~~
June	20
July	22, 29, 30
August	02, 03, 04, 15, 16, 17, 30
September	01, 20, 23
October	~~02~~, 03, 04, 15, 17, ~~2~~4, 29
November	22
December	02, 08, 09, 12

During 2004 lidar measurements have been made during 64 days, which is about 20 % lower than in 2003 and ca. 50% lower than in 2002. This reduction in number of measurements preformed is, to a large extent, due to reduced funding for ozone monitoring and research.

The development of the ozone layer above Northern Scandinavia between about 6 and 40 km altitude above ground throughout the whole year 2004 is illustrated in Figure 3. The black diamond symbols at the bottom of the figure mark the times when lidar measurements at ALOMAR have been performed. During longer time-periods without lidar measurements, ozone profiles measured by ozone sondes launched in Sodankylä, Finland (67°N, 27°E) were used. The latter measurements are marked with red diamonds.

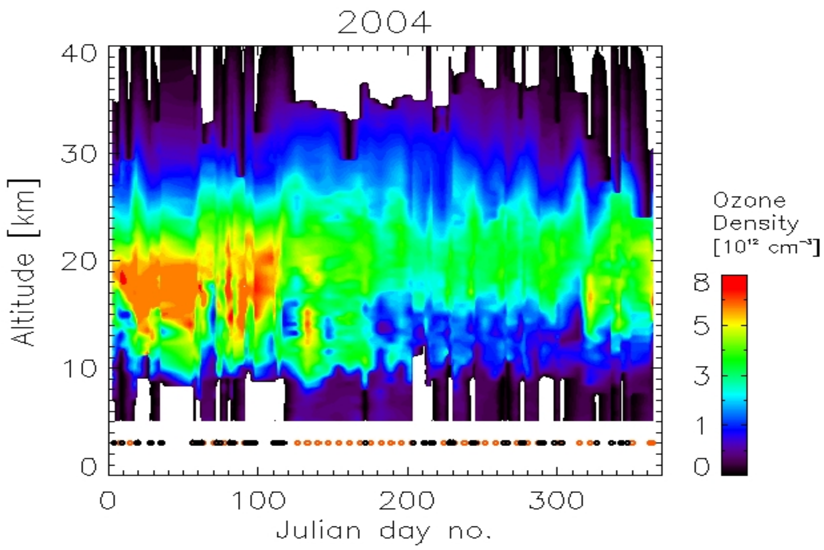


Figure 3: Ozone profiles measured by the ALOMAR ozone lidar and ozone sondes launched in Sodankylä, Finland, in 2004. The black diamonds at the bottom of the plot mark the times when lidar measurements were performed, while the red diamonds mark days where data from ozone sondes launched from Sodankylä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

The ozone values in spring 2004 were close to normal, seen as red areas in Figure 3. This is a consequence of lower than usual polar stratospheric cloud (PSC) formation potential and nearly no ozone reduction in the Arctic vortex during winter 2003/04. Only during two days in early and middle December 2003 upper stratospheric temperatures above ALOMAR reached temperatures low enough for PSC formation. After an early warming in January 2004 temperatures strongly increased and inhibited polar stratospheric cloud formation and resulted in an undisturbed Arctic ozone layer in spring 2004. For comparison, in Figure 4 ozone values during 2003, where moderate ozone reduction occurred, and during winter 1996, where extensive ozone loss has been observed, are shown.

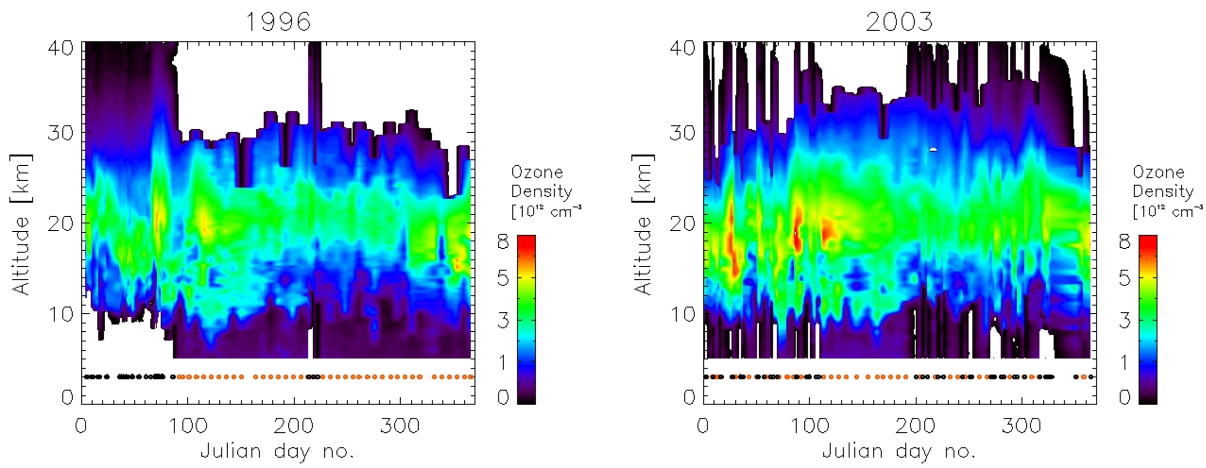


Figure 4: Ozone profiles measured by the ALOMAR ozone lidar and ozone sondes launched in Sodankylä, Finland, in 1996 (left panel) and 2003 (right panel) [analog to Figure 1].

However, despite the fact that there were few PSCs present, there were periods with low ozone values, possibly due to the enhanced HNO_3 layer as described in section 1.2. Figure 3 shows the reduction of the ozone layer during summer and autumn, and in particular below 15 km altitude, which is characteristic for the polar region. Normal early-winter values are seen from November/December 2004, with one exception. During 2004 the estimated total ozone values mainly follow the mean long-term averaged values. A short episode with low ozone values in the height from 12-15 km is detected in the end of October and beginning of November. Thus, the lidar measurements confirm the short period with low ozone values illustrated in Figure 2, at the end of October and beginning of November 2004. Based on the lidar measurements it is apparent that the low ozone values observed in this period is mainly due to low values in the height region from ca 11-15 km. The TOMS data from this period are shown in Figure 5.

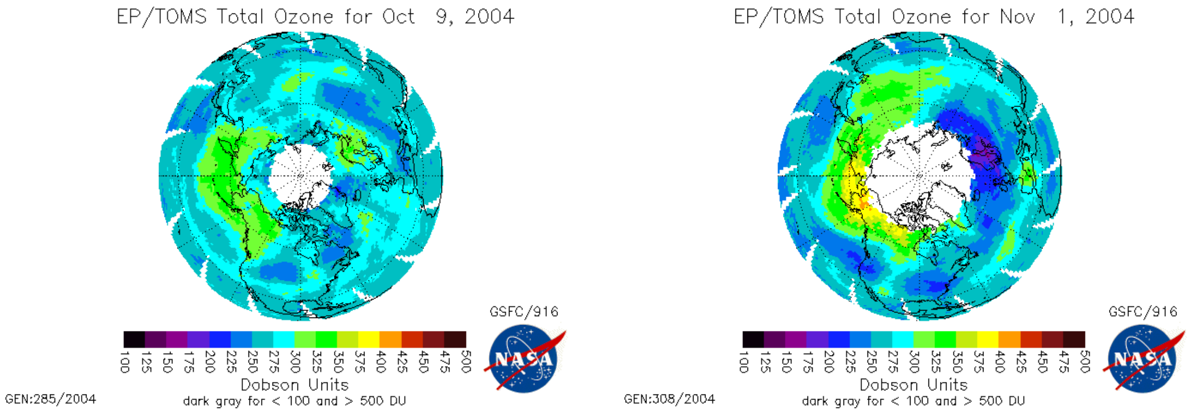


Figure 5: TOMS data of daily total ozone values for 9 October, 1 November 2004.

The figures show total ozone observations close to the long-term mean for 9 October in the left panel. The right panel shows the observations from 1 November where the value at Andøya had its minimum. Based on the different observations it is clear that there was an episode with remarkably low ozone in the period from the middle of October to the middle of November. The reduction in the total ozone value was in the order of 15-20 % below the monthly mean values, and there was apparently no ozone, or extremely low values, in the height region from 12-15 km. The reason for this is not fully explored, but temperature observations and information about the pressure systems indicate that it is a dynamical situation resulting in high tropopause level. Low ozone values are characteristic for these conditions.

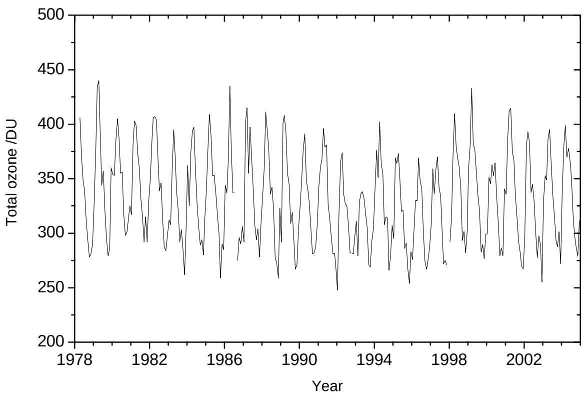
3. Ozone measurements 1979 – 2004

3.1 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 recently 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 2004. 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 11 years of observations. The total ozone measurements from the Brewer instrument agree well with the Dobson measurements. However, there is a seasonal variation in the difference between the Brewer and Dobson instrument that has not been accounted for in the trend analysis presented here.

Figure 6a) shows the variations in the monthly mean ozone values in Oslo from 1979 to 2004. The total ozone values from 1979 to 1998 are from the Dobson instrument, whereas for the period 1999-2004 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.



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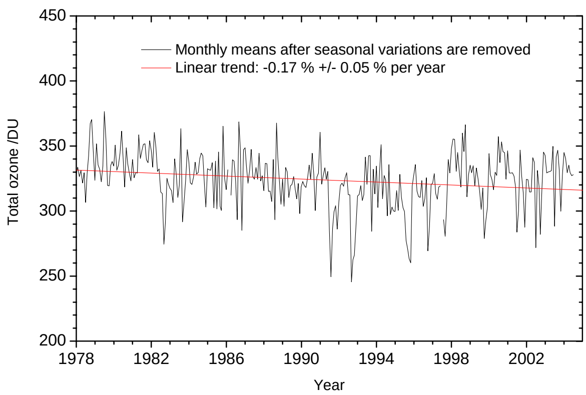

b)

Figure 6a: Time series of monthly mean total ozone in Oslo.

Figure 6b: Variation in total ozone over Oslo for the period 1979 – 2004 after the seasonal variations have been removed.

In order to look at possible ozone reduction for the period 1979 to 2004 we have removed the seasonal variations by subtracting the long-term monthly means and adding the long-term yearly mean value, Figure 6b). 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 3. For spring months a significant negative trend of respectively –0.35% per year is observed. The comparable value for 2003 was –0.33 %. For the winter, summer and fall months no significant trend was observed. When all months are included a significant negative trend of –0.17% per year is observed.

Table 4: Percentage changes in total ozone per year for Oslo for the period 1.1.1979 to 31.12.2004. 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 (% per year)
Winter:	December – February	-0.11 (0.11)
Spring:	March – May	-0.35 (0.11)
Summer:	June – August	-0.02 (0.06)
Fall:	September – November	-0.10 (0.06)
Annual		-0.17 (0.05)

The percentage difference between yearly mean total ozone and the long-term yearly mean is shown in Figure 7. 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 in the Philippines in 1991. The figures shows that the low ozone values in the 1990's contribute strongly to the observed negative trends in total ozone. For 2004 the yearly mean ozone value was 0.4% higher than the long-term yearly mean.

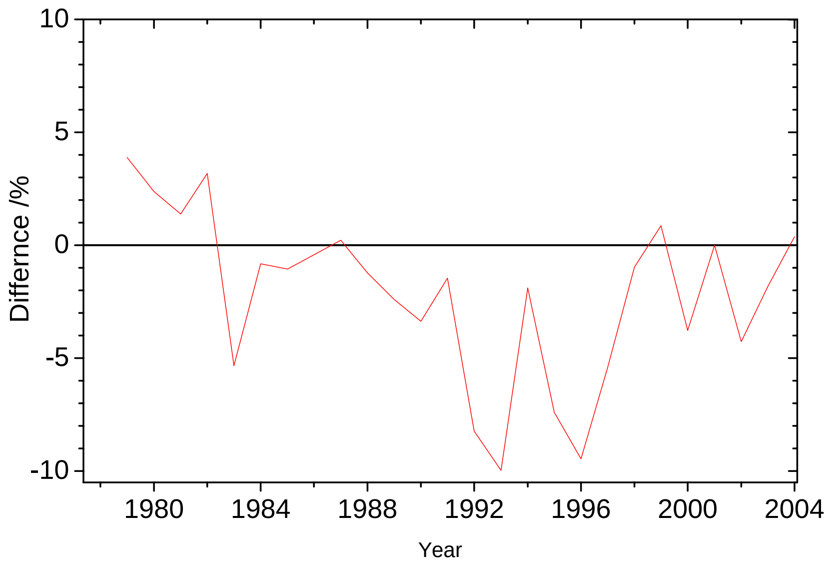

Figure 7: Percentage difference between yearly mean total ozone in Oslo and the long-term yearly mean for 1979-2001.

3.2 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 dataset 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 8a) shows the variations in the monthly mean ozone values at Andøya from 1979 to 2004. The variations in total ozone at Andøya for the period 1979 – 2004 after the seasonal variations have been removed is shown in Figure 8b).

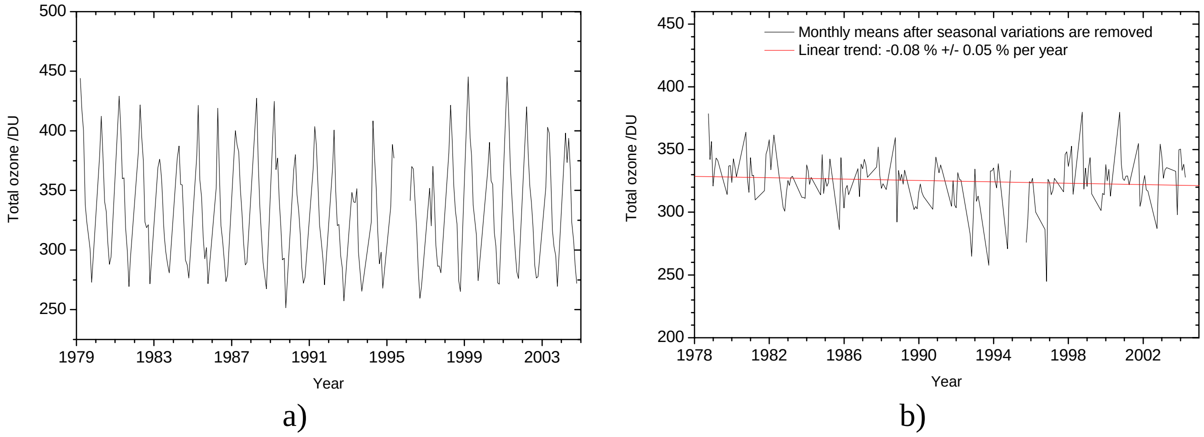

Figure 8 a): Time series of monthly mean total ozone at Andøya.

Figure 8b): Variation in total ozone at Andøya for the period 1979 – 2004 after the seasonal variations is removed. Only data for the months March - September are included.

A simple linear regression has been fitted 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 2004. 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 (0.12)
Summer: June – August	-0.00 (0.05)
Annual (March-September)	-0.08 (0.06)

The percentage difference between yearly mean total ozone and the long-term yearly mean is shown in Figure 9. For 2004 the yearly mean ozone value was slightly above the long-term yearly mean value for the period 1979-1989.

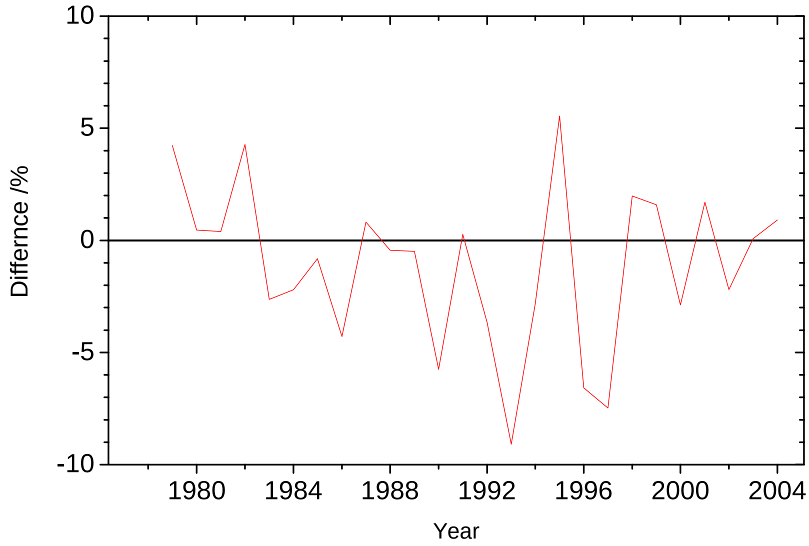

Figure 9: Percentage difference between yearly mean total ozone at Andøya and the long-term yearly mean for 1979 – 1989 for the months March – September.

4. 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 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 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.

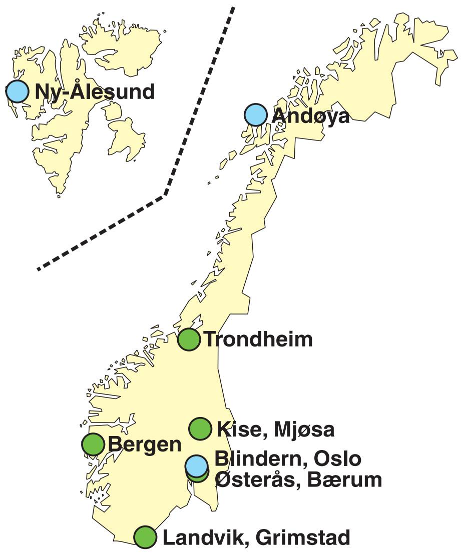

Figure 10: Map of the stations included in the Norwegian UV network. The stations marked with blue are operated by NILU on behalf of The Norwegian Pollution Control Authority (SFT), whereas the Norwegian Radiation Protection Authority operates the stations marked with green.

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 the monitoring programme secures the operation of the Ny-Ålesund instrument, and the results are again included in the report. The number of days with missing data in 2004 from the three instruments is given in Table 6. The gaps in the data are mostly limited to a few hours in the morning or in the afternoon when the solar elevation is low. The effect of the missing data on the yearly UV doses is therefore relatively small for all stations.

Table 6: Number of days with more than 2 hours of missing GUV data in 2004 at Oslo, Andøya and Ny-Ålesund the percentage and loss in the yearly UV doses. Days where the sun is below the horizon (polar night) are not included.

Station	Number of days with missing data	% loss in yearly UV doses
Oslo	5	<1.3%
Andøya	1	<0.3%
Ny-Ålesund	3	<0.9 %

For Andøya, we have used data from a Bentham spectroradiometer located next to the GUV instrument, when data from the GUV instrument is not available. The effective loss in the yearly UV doses for this station is therefore insignificant. For days with missing data in Oslo we have estimated the daily UV doses by using a radiative transfer model (FastRt, http://nadir.nilu.no/~olaeng/fastrt/fastrt.html).

4.1 UV measurement results in 2004

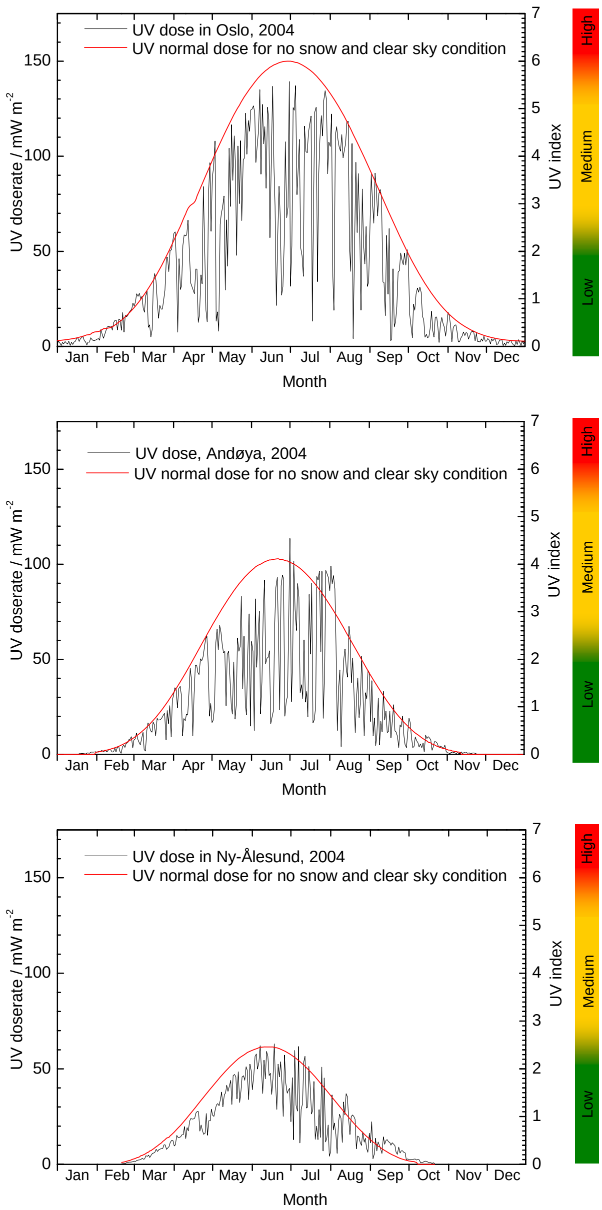

Figure 11: Hourly averaged UV dose rate measured at noon (between 10:30 and 11:30 GMT) at a) Oslo, b) Andøya, c) Ny-Ålesund.

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 11 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, 139.2 mW/m^2, was observed 30 June and is equivalent to a UV index of 5.6. At Andøya the highest UV index, 4.5, was observed on 1 July, and for Ny-Ålesund the highest UV level was on 18 June with a UV-index of 2.5.

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 fluctuation in the UV radiation from one day to another. Another clear evidence of this is the relatively high UV doses measured at Andøya in the end of July and beginning of August. This corresponds to a period with low ozone, illustrated in Figure 2. 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 2004 are compared in Figure 12. The monthly integrated UV doses observed at Oslo are significantly higher than the ones observed at Andøya and Ny-Ålesund.

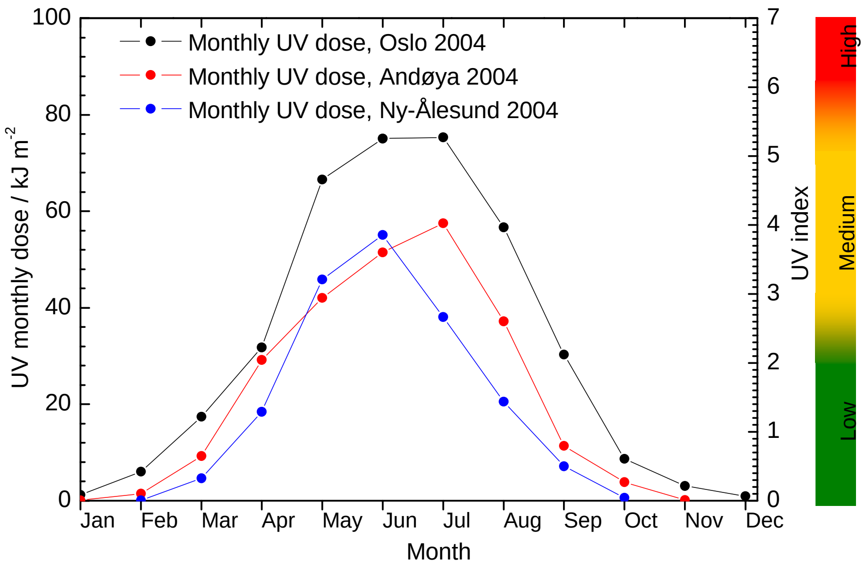

Figure 12: *Monthly integrated UV doses in 2004 measured with the GUV instruments located in Oslo and at Andøya.*

4.2 Annual UV doses 1995 – 2004

Annual UV doses for the period 1995 - 2004 are shown in Table 7 for the three GUV instruments. The uncertainty in the daily UV doses is estimated to ±5% at a 2σ level (Johnsen et al., 2002). For periods with missing data we have estimated the daily UV doses by using a radiative transfer model (FastRt, http://nadir.nilu.no/~olaeng/fastrt/fastrt.html). This gives an additional uncertainty in the annual UV doses of ±1.6% for all stations and years, except for Andøya, where the uncertainty amounts to ±2% for 2000 and ±5% for 2001.

The time series are still too short for trend analysis since the inter-annual variations in the UV doses 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 global dimming. 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 global dimming aerosols may possibly mask the temperature rise at the surface caused by the increase of greenhouse gases. Interestingly, a study presented in Science in May 2005 reports that surface measurements of total solar radiation from 1990 to present show an increase in the radiation received by the earth's surface (Wild et al., 2005). This was particularly evident for the sites at the Northern hemisphere. Both changes in ozone, aerosols, as well as clouds might 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 solar radiation received at the surface.

Table 7: Annual integrated UV doses (kJ/m2) 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

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

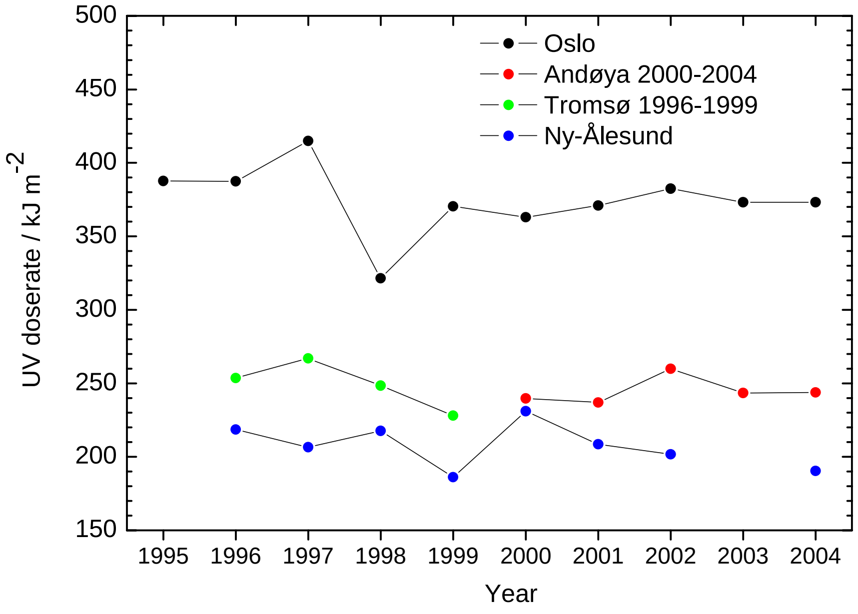

Figure 13: Annual integrated UV doses (kJ/m2) at the three stations during the period 1995 - 2004.

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P.O. Box 100, N-2027 Kjeller

REPORT SERIES SCIENTIFIC REPORT	REPORT NO. NILU OR 31/2005	ISBN 82-425-1672-3 ISSN 0807-7207	
DATE	SIGN.	NO. OF PAGES 20	PRICE NOK 150.-
TITLE Monitoring of the atmospheric ozone layer and natural ultraviolet radiation Annual report 2004		PROJECT LEADER Cathrine Lund Myhre NILU PROJECT NO. O-8985	
FORFATTER(E) C.L. Myhre, B.A.K. Høiskar, G.O. Braathen, A. Dahlback, K. Edvardsen, G.H. Hansen, K. Stebel, T.M. Svendby and A.F. Vik		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 2004.			
NORWEGIAN TITLE Overvåkning av ozonlaget og naturlig ultrafiolett stråling. Årsrapport 2004			
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 2004. For Oslo og Andøya er trenden i totalozon beregnet for perioden 1979-2004.			

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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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- forsuring (sur nedbør)
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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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