Monitoring of the atmospheric ozone layer and natural ultraviolet radiation.
Annual report 2003

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Forfattere:	Britt Ann Kåstad Høiskar, Geir O. Braathen, Arne Dahlback, Kåre Edvardsen, Georg Hansen, Kerstin Stebel, Tove Svendby, Aasmund Fahre Vik

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Rapport 905/2004

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Statlig program for forurensningsovervåking

Preface

In 1985, 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 measurements of ultraviolet radiation (UV) 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 reaches 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 2003, the monitoring programme included measurements of total ozone and ultraviolet radiation at two locations, Oslo (60°N) and Andøya (69°N). This report summarises the activities and results of the monitoring programme during 2003. The report also includes trend analyses of total ozone for the period 1979-2003 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 2003.

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 spectrophotometer are also available. The data from this instrument has recently been re-evaluated as part of a PhD study (Svendby, 2004). 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 -0.21±0.05 % per year. For the winter and spring months the trend analysis gave a significant negative trend of -0.33±0.13 % per year and -0.41±0.12 % per year, respectively. No significant trends were observed during summer and autumn.

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 Brewer instruments were calibrated against a reference instrument in June 2003 by the International Ozone Services, Canada

Measurements of ozone profiles

The ozone lidar at Andøya provides measurements of the ozone concentration from approximately 8km to 50km on days with clear sky. The measurements from the ozone lidar are very useful for studying rapid variations in the ozone profiles and are important for understanding the processes that lead to changes in the ozone layer. In 2003, there are 79 days with ozone lidar measurements. These measurements resulted in quality controlled ozone profiles for 48 days (50 measurement occasions). 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 2003 responsible for the daily operation of two of the instruments, which are located at Oslo (60°N) and Andøya (69°N).

In 2003 a total yearly UV dose of 373.2kJ/m^2 and 243.4kJ/m^2 was measured in Oslo and Andøya, respectively. The highest UV dose rate in Oslo, 149.7mW/m^2, was observed 16 July and is equivalent to a UV-index of 6.0. At Andøya the highest UV-index, 4.5, was observed on 9 June.

The GUV instruments were calibrated in June 2003 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 ozone and UV measurements in Oslo. The Dobson measurements in Oslo for the period 1979-1993 were performed by Søren H. H. Larsen (UiO). Dr. Tove Svendby at Norwegian Institute for Air research (NILU) has recently 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 is operated by NILU (Dr. Georg Hansen and Dr. Kerstin Stebel), the Andøya Rocket Range and the Norwegian Defence Research Establishment (Dr. Ulf Peter Hoppe).

1. Total ozone measurements in 2003

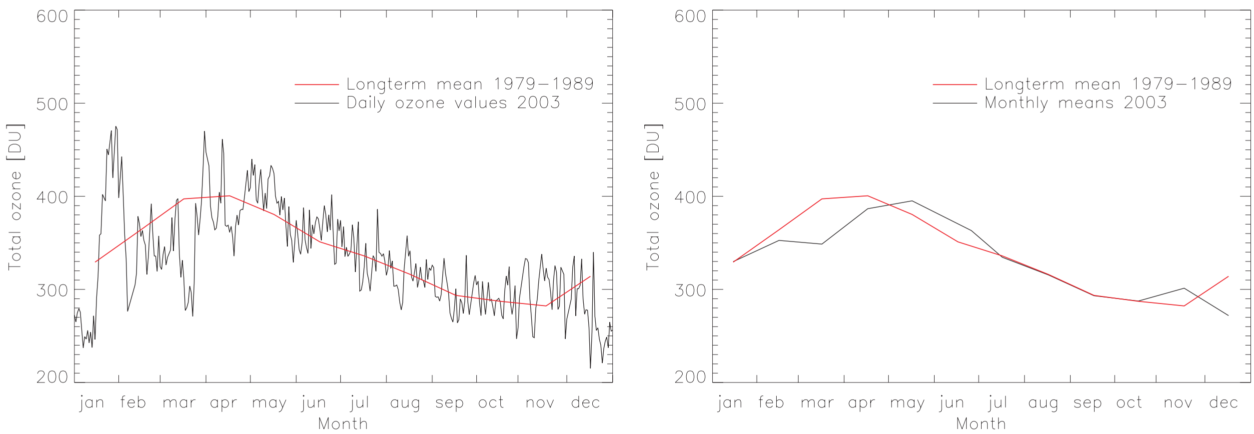
Daily measurements of total ozone (the total amount of ozone from the earth's surface to the top of the atmosphere) are performed at Oslo (60°N) and Andøya (69°N). Total ozone is measured by Brewer spectrophotometers at both locations.

The International Ozone Services, Canada, calibrates both Brewer instruments against a reference instrument on a yearly basis, last time in June 2003. 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 2003, based on measurements with the Brewer spectrometer no. 42, are shown in Figure 1. The black curve shows the daily ozone values measured in 2003, 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). Total ozone values for the last five years based on the two methods have been compared, and the agreement is within ±1% (Arne Dahlback, personal communication).



a) b)

Figure 1a): Daily total ozone values measured at the University of Oslo in 2003. The red line shows the long-term monthly mean values from 1979-1989.

Figure 1b): Monthly mean ozone values for 2003.

Large day-to-day fluctuations in total ozone are observed during the spring. In the first half of January the total ozone values were approximately 25% below the long-term mean. A rapid increase in the total ozone values from approximately 250DU to 470DU occurred within a few days in mid-January. The low ozone values observed in early January can be explained by a persistent and stationary high-pressure system above the North Atlantic, followed by a rapid build-up of ozone in mid-January associated with transport. A similar low-ozone episode occurred above Scandinavia in mid-March, see Figure 2. This episode lasted for 3-4 days.

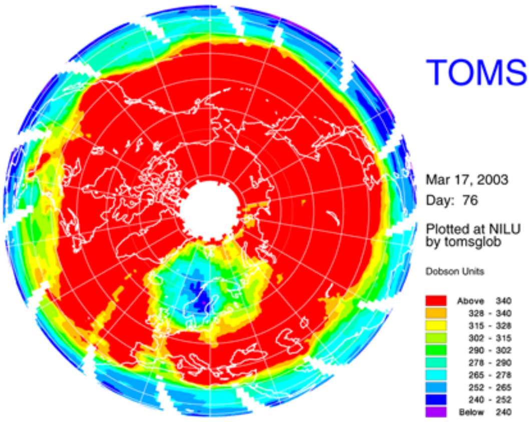
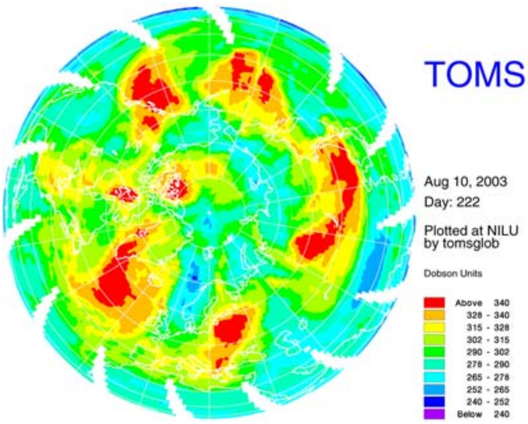


Figure 2: Total ozone over the Northern Hemisphere measured by the satellite instrument TOMS (Total Ozone Mapping Spectrometer) 17 march 2003 (http://toms.gsfc.nasa.gov/ozone/ozone.html).

A new phenomena that receives increasing attention is short-duration summertime low-ozone episodes (Orsolini et al., 2003). When such events occur, e.g. over Scandinavia, the ozone column is reduced due to anticyclonic, high tropopause conditions, and ozone-poor Arctic air aloft. The low-ozone episodes may result in high UV radiation at ground level if it occurs at days with clear sky or if the sky is only partly covered with clouds.

A strong episode occurred over Oslo in August 2003 during the European "heat wave", see Figure 3.



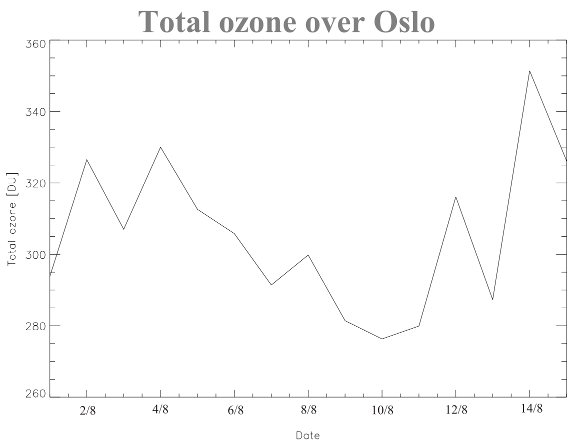


Figure 3a): Total ozone over the Northern Hemisphere measured by the satellite instrument TOMS 10 august 2003.

Figure 3b): Total ozone measured above Oslo in the beginning of August 2003.

The monthly mean total ozone values for 2003 are shown in Figure 1b. The percentage difference between the monthly mean total ozone values for Oslo in 2003 and the long-term monthly means are given in Table 1. The monthly mean ozone value for January is close to the long-term mean since the low ozone values in the beginning of the month is compensated by the extremely high values in the end of the month. The monthly mean ozone values are close to the long-term mean for all months except for March and December where the monthly means are 12% and 13% below the long-term mean, respectively.

Table 1: Percentage difference of monthly mean total ozone values for 2003 and the long-term mean for Oslo and Andøya.

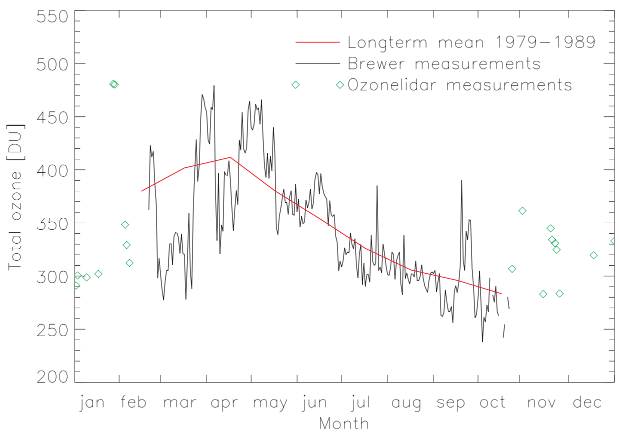
Måned	Oslo	Andøya
January	<1%	---
February	-3%	---
March	-12%	-12%
April	-3%	-2%
May	+4%	+5%
June	+3%	+2%
July	<±1%	-3%
August	<±1%	<±1%
September	<±1%	<±1%
October	<±1%	-5%
November	+6%	--
December	-13%	--

1.2 Andøya

Daily ozone values for Andøya in 2003, based on measurements with the Brewer spectrometer are shown in Figure 4a. The black curve shows the daily ozone values measured in 2003, 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 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. 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. They give a good picture of the ozone variation during the winter months when Brewer measurements are not available.

The polar stratospheric vortex(1) built up early in the winter 2002/03 and very low stratospheric temperatures were reached in December 2002. During the cold period polar stratospheric clouds were seen throughout the Arctic. These conditions lead to chemical polar ozone destruction, when airmasses, which are quasi-isolated in the polar vortex, are illuminated by sunlight. During the spring 2003 Andøya was most of the time located inside the polar vortex and the observed ozone values were -15% to -25% below the long-term mean, see Figure 4. Short-term variations are observed, e.g. in early February the polar vortex moved north of Andøya and higher total ozone values (10-15% above long-term mean) were observed. Normal total ozone column values were reached again in early April 2003, after a final warming of the stratosphere during the end of March and the break up of the polar vortex in early April 2003.

[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.



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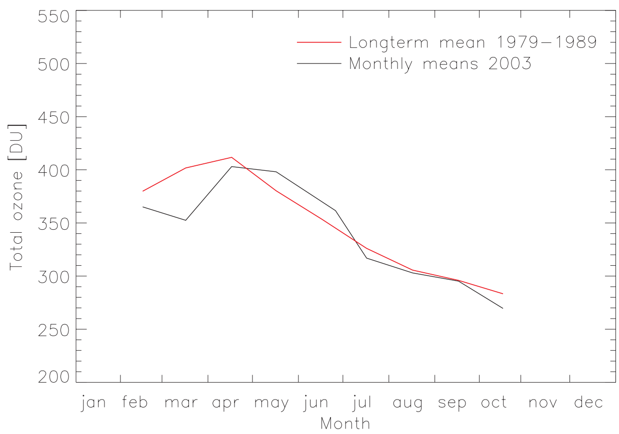


b)

Figure 4a): Daily total ozone values measured at ALOMAR, Andøya in 2003. The red line shows the long-term monthly mean values from 1979-1989.

Figure 4b): Monthly mean ozone values for 2003.

Monthly mean ozone values based on the daily ozone measurements from the Brewer instrument are shown in Figure 4 b. 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 2003 and the long-term monthly means are given in Table 1.

2. Ozone-profile measurements with the ozone lidar at ALOMAR, Andøya in 2003

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 2003 there are 79 days with ozone lidar measurements, see Table 2. These measurements have resulted in quality controlled ozone profiles for 48 days (50 measurement occasions). The latest measured rawdata profiles and 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 2003. 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.

Month	Ozone profile
January	**02**, **03**, ~~09~~, **17**, **27**, **28**
February	**04**, **05**, **07**, **20**, **21**, **26**
March	**02**, **05**, **07**, **11**, ~~28~~, **29**
April	**07**, ~~09~~, **10**, **16**, **19**
May	* ~~05~~, ~~09~~
June	~~02~~, ~~05~~, ~~10~~, ~~12~~, ~~18~~, ~~19~~, ~~20~~, ~~21~~, ~~23~~, ~~24~~, ~~29~~, ~~30~~
July	~~08~~, ~~11~~, ~~14~~, ~~18~~, **19**, ~~22~~, **26**, ~~27~~, ~~29~~, **30**, ~~31~~
August	~~01~~, ~~04~~, ~~05~~, **09**, ~~10~~,~~13~~, **14**, ~~19~~
September	~~01~~, ~~08~~, ~~10~~, **28**, ~~29~~, **30**
October	**01**, **07**, **10**, **20**, **23**, ~~30~~
November	~~10~~, **13**, **18**, **19**, ~~20~~, **21**, **22**, **24**
December	~~16~~, **17**, ~~31~~

*: re-construction works

The number of ozone profiles of high quality in 2003 was relatively low (about half of 2002) compared to previous years. This is, to a large extent, due to 70-80% reduced funding for ozone monitoring and research. Reduced personnel resources led to less frequent instrumental alignment. This resulted, in particular during the summer month, in data with insufficient quality.

The development of the ozone layer above Northern Scandinavia between about 6 and 40 km altitude above ground throughout the whole year 2003 is illustrated in Figure 5. 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.

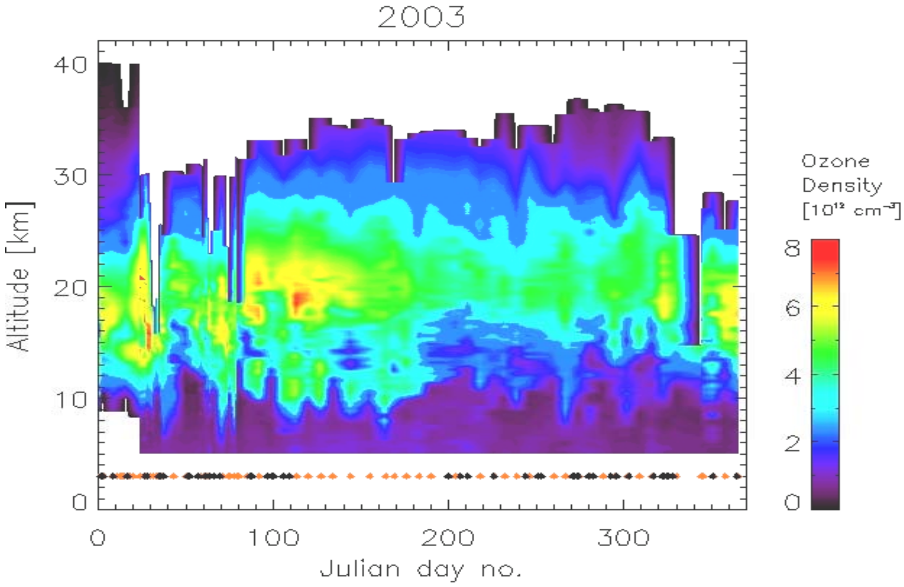


Figure 5: Ozone profiles measured by the ALOMAR ozone lidar and ozone sondes launched in Sodankylä, Finland, in 2003. The black diamonds at the bottom of the plot mark the times when lidar measurements were performed, while the red diamonds mark days where data from ozone sondes launched from Sodankylä were used. Between the individual measurements the data were linearly interpolated.

Besides the reduced springtime ozone values, Figure 5 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. A warming of the Arctic stratosphere in December and a weak polar vortex caused the increase of the ozone values at the end of 2003.

3. Ozone measurements 1979 – 2003

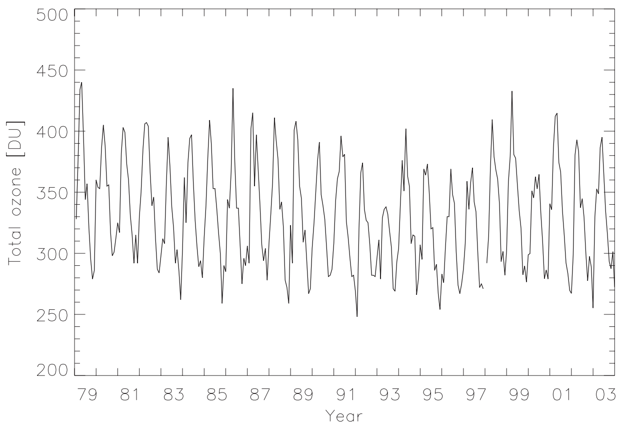
3.1 Oslo

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 as part of a PhD study (Svendby, 2004). 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 Brewer instrument in Oslo was calibrated in June 2003 by the International Ozone Services, Canada. 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. The Brewer data will be re-evaluated during 2004/2005 and corrected in accordance with the procedures recommended by WMO (Staehelin, 2003).

Figure 6a shows the variations in the monthly mean ozone values in Oslo from 1979 to 2003. The total ozone values from 1979 to 1998 are from the Dobson instrument, whereas for the period 1999-2003 Brewer measurements have been used. The large seasonal variations are typical for stations at high latitudes and can be explained by springtime transport of ozone from the source regions in the stratosphere above the equator.



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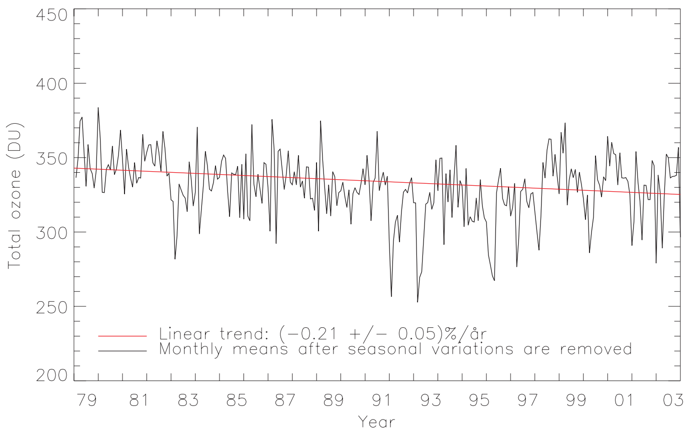


b)

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

Figure 6b): Variation in total ozone over Oslo for the period 1979 – 2003 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, see Figure 6b. 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 3. For the winter and spring months a significant negative trend of –0.33% per year and –0.41% per year respectively is observed. For the summer and fall months no significant trend was observed. When all months are included a significant negative trend of –0.21% per year is observed.

Table 3: Percentage changes in total ozone per year for Oslo for the period 1.1.1979 to 31.12.2003. 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	-0.33 (0.13)
Spring:	March – May	-0.41 (0.12)
Summer:	June - August	-0.05 (0.07)
Fall:	September - November	-0.12 (0.06)
Annual		-0.21 (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 figure shows that the low ozone values in the 1990's contribute strongly to the observed negative trends in total ozone. For 2003 the yearly mean ozone value was 1.8% below the long-term yearly mean.

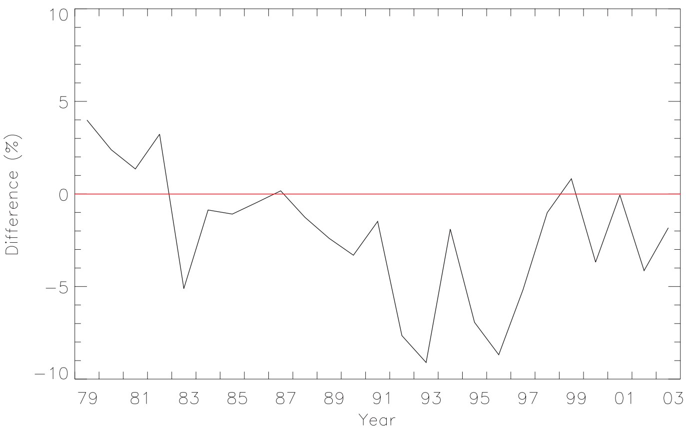
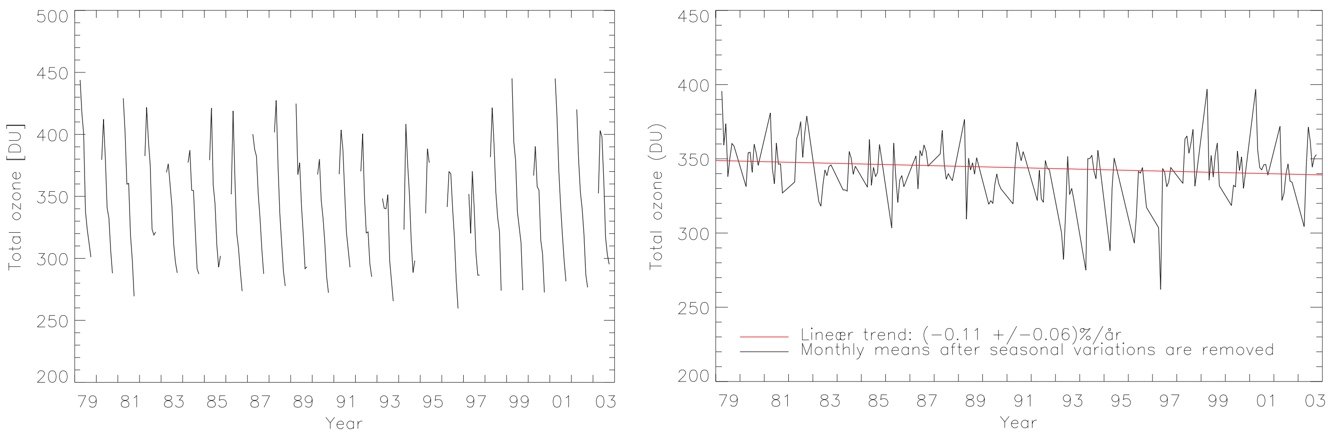


Figure 7: Percentage difference between yearly mean total ozone in Oslo and the long-term yearly mean for 1979-1989.

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 2003. The variations in total ozone at Andøya for the period 1979 – 2003, after the seasonal variations have been removed, is shown in Figure 8b.



a) b)

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

Figure 8b): Variation in total ozone at Andøya for the period 1979 – 2003 after the seasonal variations have been removed. Only data for the months March - September are included in the plot.

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

Table 4: Percentage changes in total ozone per year for Andøya for the period 1979 to 2003. 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	-0.17 (0.13)
Summer: June - August	-0.04 (0.05)
Annual	-0.11 (0.06)

The percentage difference between yearly mean total ozone and the long-term yearly mean is shown in Figure 9. For 2003 the yearly mean ozone value was close to the long-term yearly mean value.

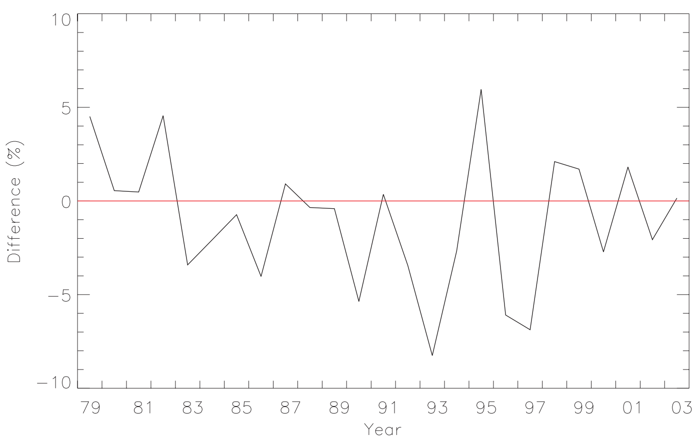


Figure 9: Percentage difference between yearly mean total ozone at Andøya and the long-term yearly mean for 1979 – 1989.

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, see 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 (63°N), Bergen (60°N), Kise (61°N), Landvik (58°N) and Østerås (60°N). On-line data from the UV network is shown at www.stralevernet.no/uv and at www.luftkvalitet.info/uv.

In this annual report UV data from Oslo and Andøya are reported. Due to lack of funding, the GUV instrument in Ny-Ålesund was in 2003 omitted from the monitoring programme, and data from this site is therefore not reported here. In 2004 the operation of the Ny-Ålesund instrument is secured by the monitoring programme.

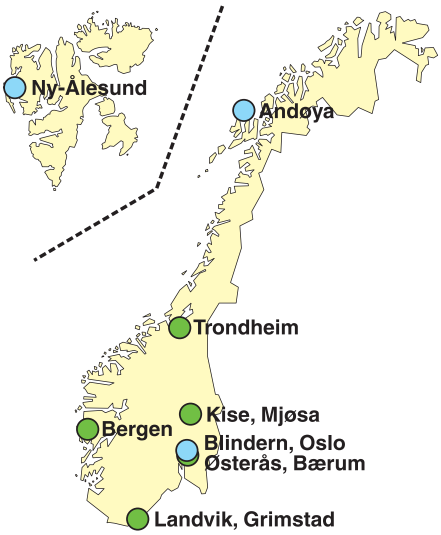


Figure 10: Map of the stations included in the Norwegian UV network. The stations marked with blue are operated by NILU on behalf of The Norwegian Pollution Control Authority (SFT), whereas the stations marked with green are operated by the Norwegian Radiation Protection Authority.

The number of days with missing data in 2003 from the two instruments are given in Table 5. 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 both stations.

Table 5: Number of days with more than 2 hours of missing GUV data in 2003 at Oslo and Andøya and the percentage loss in the yearly UV doses. Days where the sun is below the horizon (polar night) are not included.

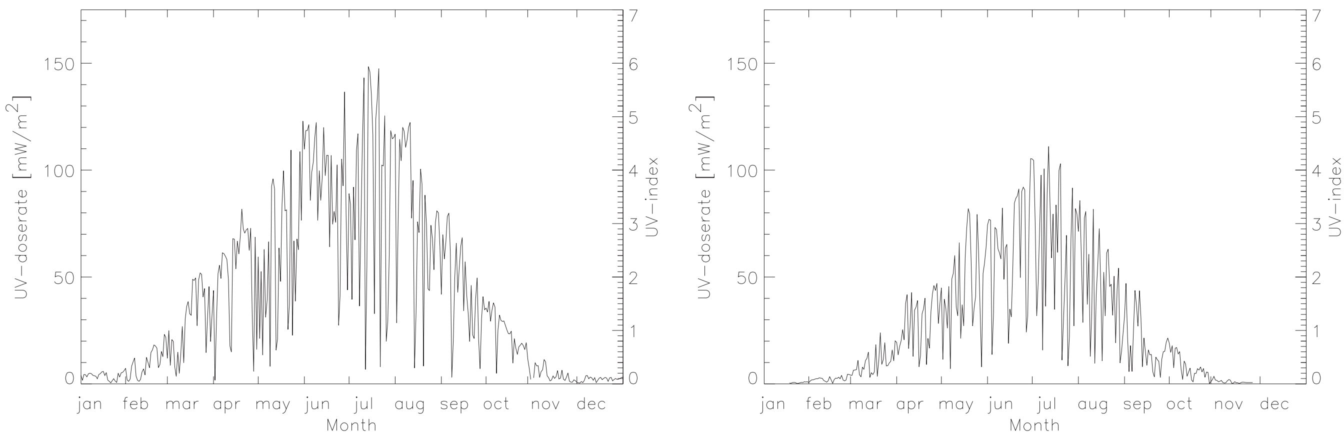
Station	Number of days with missing data	% loss in yearly UV doses
Oslo	5	<0.4%
Andøya	15	<2.0%

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 Measurement results in 2003

Figure 11 shows the UV dose rates measured at noon (averaged between 10:30 and 11:30 GMT) for Oslo and Andøya. 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. At northern latitudes, the UV indices typically vary between 0 - 8 at sea level, but can range up to 20 in Equatorial regions and high altitudes (WHO, 2002).

The highest UV dose rate in Oslo, $149.7mW/m^2$, was observed 16 July and is equivalent to a UV index of 6.0. At Andøya the highest UV index, 4.5, was observed on 9 June.

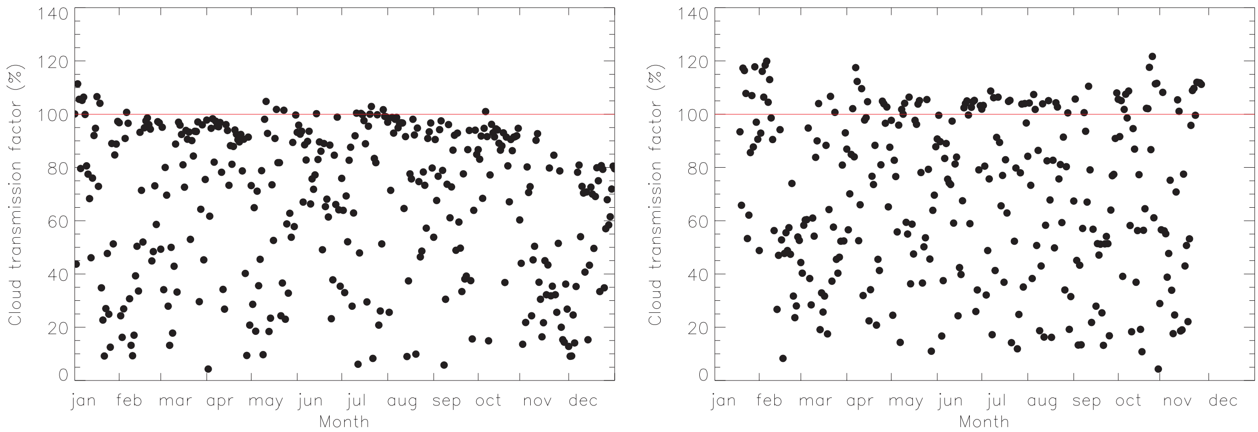


a) b)

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

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). The large day-to-day variations in the UV radiation are mainly caused by varying cloud cover.

The cloud transmission factor (CLT) is a measure of the effect of clouds and ground reflection (albedo) on the UV radiation at the ground and is related to the radiation one would expect at clear-sky condition and zero ground reflection. Values above 100, see Figure 12, mean that clouds and/or ground reflection increases the UV level compared to clear-sky and zero-ground reflection. A detailed description of the retrieval of CLT is given by Høiskar et al. (2003). The CLT for Oslo and Andøya is shown in Figure 12. CLTs below 10 are observed several times during 2003 at both locations, meaning that the cloud cover decreases the UV radiation with more than 90% on these days. The highest CLT values are observed during the winter where the CLT can reach up to 120. The main reason for the high CLTs during the winter is the high ground reflection due to snow. Clouds may also increase the UV radiation significantly if they are partially covering the sky without occulting the sun. This is probably the reason for the days with high CLTs during the summer.



a) b)

Figure 12: Cloud transmission factor measured in a) Oslo and at b) Andøya in 2003. The cloud transmission factor is a measure of the effect of clouds and ground reflection (albedo) on the UV radiation at ground and is related to the radiation one would expect under clear-sky condition and zero ground reflection (red line). Values above the red lines mean that clouds and/or ground reflection increases the UV level compared to clear-sky and zero-ground reflection.

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. By combining the results shown in Figure 11 and Figure 12 we can remove the effect of clouds and ground reflection on the UV dose rates. The effect of varying total ozone on the UV dose rates is shown in Figure 13. Comparison of Figure 11 and Figure 13 shows that variations in cloud cover is more important for the day-to-day variations in the UV radiation than variations in the total ozone column.

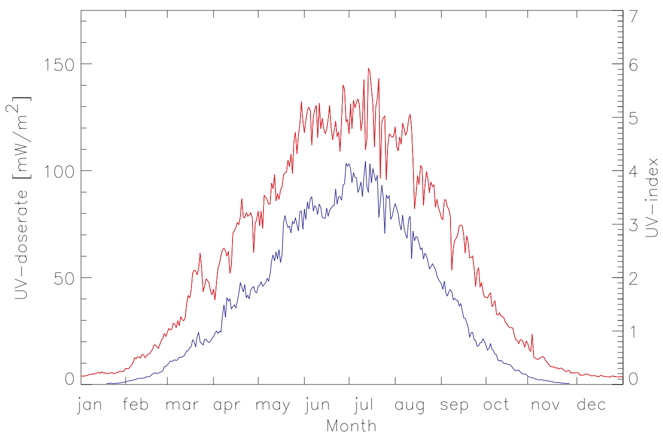


Figure 13: Hourly averaged UV dose rate at noon (between 10:30 and 11:30 GMT) for Oslo and Andøya when the effect of varying cloud cover and ground reflection on the UV dose rate is removed.

Monthly, integrated UV doses for Oslo and Andøya in 2003 are shown Figure 14. The monthly integrated UV doses observed at Oslo are significantly higher than the ones observed at Andøya.

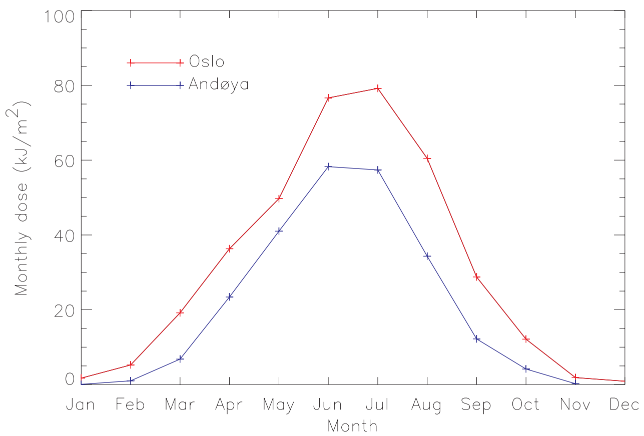


Figure 14: Monthly integrated UV doses in 2003 measured with the GUV instruments located in Oslo and at Andøya.

4.2 Annual UV doses 1995 - 2003

Annual UV doses for the period 1995 - 2003 are shown in Table 6 for the two GUV instruments. The uncertainty in the daily UV doses is estimated to ±5% at a 2-sigma 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 much larger than the expected long-term change. It is therefore important to continue the UV monitoring activity in the future.

Table 6: Annual integrated UV doses (kJ/m^2) at the three stations during the period 1995 - 2003.

Year	Oslo	Andøya	Tromsø*
1995	387.6		
1996	387.4		253.6
1997	415.0		267.0
1998	321.5		248.4
1999	370.5		228
2000	363.0	239.7	
2001	371.0	237.0	
2002	382.5	260.0	
2003	373.2	243.4	

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

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Norsk institutt for luftforskning (NILU)

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TITLE

Monitoring of the atmospheric ozone layer and natural ultraviolet radiation.

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 2003.

** Kategorier:* *A* *Åpen - kan bestilles fra NILU*
B *Begrenset distribusjon*
C *Kan ikke utleveres*