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Statlig program for forurensningsovervåking

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Monitoring of the atmospheric ozone layer and natural ultraviolet radiation: Annual report 2010

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Utført av NILU – Norsk institutt for luftforskning i samarbeid med Universitetet i Oslo

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Monitoring of the atmospheric ozone layer and natural ultraviolet radiation

Rapport
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Annual report 2010

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Preface

Ozone plays an important role in the life cycle of earth due to its ability to absorb UV radiation from the sun. In the mid 1970's scientists discovered that compounds containing chlorine and bromine (CFCs and halons) were capable of destroying the ozone layer (Molina and Rowland, 1974). The attention and debate about the ozone destruction were further intensified when the Antarctic ozone hole was discovered in the mid 1980's (Farman et al., 1985).

In 1987 the Montreal Protocol was signed in order to reduce the production and use of these ozone-depleting substances (ODS). This international agreement has later been revised several times. Currently, 196 nations have ratified the protocol. 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 expected to be reached somewhat later, but there seem to be a decline also in the stratosphere the last years.

It is now important to follow the development of the ozone layer in order to verify that the Montreal Protocol and its amendments work as expected. For this, we need daily ground based measurements at a large number of sites distributed globally in combination with satellite observations. It is the duty of every industrialised nation to follow up with national monitoring programmes.

The Climate and Pollution Agency (the former Norwegian Pollution Control Authority) established the programme "Monitoring of the atmospheric ozone layer" in 1990, which at that time included measurements of total ozone only. In 1995 UV measurements were also included in the programme.

The Norwegian Institute for Air Research (NILU) is responsible for the operation and maintenance of the monitoring programme. The purpose of the programme is to:

- Provide continuous measurements of total ozone and natural ultraviolet radiation that reach the earth surface
- Provide data that can be used for trend analysis of both total ozone and natural ultraviolet radiation.
- Provide information on the status and the development of the ozone layer and natural ultraviolet radiation
- Notify the Climate and Pollution Agency when low ozone/high UV episodes occur.

Personnel and institutions
Several persons and institutions are involved in the operation and maintenance of the monitoring programme and have given valuable contributions to this report. Prof. Arne Dahlback at the University of Oslo (UiO) is responsible for ozone and UV measurements in Oslo. Kåre Edvardsen (NILU) is responsible for ozone and UV measurements at Andøya. The ozone lidar at ALOMAR is owned and operated by NILU (Kåre Edvardsen and Kerstin Stebel) and the Andøya Rocket Range. Dr. Tove Svendby, (NILU) ensures the data submission to The World Ozone Data Centre (http://www.msc-smc.ec.gc.ca/woudc/). She is also involved in the analysis of both ground based and satellite data together with

Dr. Cathrine Lund Myhre. Lund Myhre is responsible for the program, and is involved in the data analysis amongst others.

Acknowledgment
Based on a project jointly financed by The European Space Agency (ESA; http://www.esa.int/) and The Norwegian Space Centre (Norsk Romsenter, http://www.romsenter.no/) we are now in a position where we explore relevant ozone satellite observations and use these data in the National monitoring of the ozone and UV radiation. Both institutions are highly acknowledged for their support.

Kjeller, August 2011

Cathrine Lund Myhre
Senior scientist and project manager

Contents

1. Summary

This annual report describes the activities and main results of the programme "Monitoring of the atmospheric ozone layer and natural ultraviolet radiation" for 2010, which is a part of the governmental programme for monitoring pollution in Norway.

In the mid 1970's scientists discovered that compounds containing chlorine and bromine (CFCs and halons) were capable of destroying the ozone layer (Molina and Rowland, 1974). The attention and debate about the ozone destruction were further intensified when the Antarctic ozone hole was discovered in the mid 1980's (Farman et al., 1985).

In 1987 the Montreal Protocol was signed in order to reduce the production and use of these ozone-depleting substances (ODS). This international agreement has later been revised several times. Currently, 196 nations have ratified the protocol and effective measures have reduced the use and emissions of ODS significantly. The total amount of ODS in the troposphere reached a maximum around 1995 and is for most of the ODS declining slowly. The concentrations are expected to be back to pre-1980 levels around year 2050. In the stratosphere the peak was reached somewhat later, but there seems to have been a decline also in the stratosphere the last years.

Without the Montreal protocol, the ozone layer would have been dramatically destroyed. There are recent studies indicating that large ozone depletions in the Polar Regions would become a year-round phenomena and ozone hole conditions would develop also in the tropics, with full collapse of the ozone layer around the year ~2060. For mid-summer the study predicated an increase in the ultra violet radiation (UV) of 5-10% for the year 2000 and a UV index(UVI) around 15 within the year 2040. In 2065 the UVI would exceed a value of 30.

It is important to follow the development of the ozone layer in order to verify that the Montreal Protocol and its amendments work as expected and detect other possible changes in the ozone layer, possibly related to other factors.

MAIN CONCLUSIONS FROM THE MONITORING PROGRAMME

- **2010 was a year with generally high ozone values above Norway.**
- **Measurements of ozone profiles and analysis of stratospheric conditions indicate that there was a short period, until mid February, with chemical ozone destruction**
- **The dynamical situation changed after mid February resulting in very high ozone values during late winter and spring months.**
- **The total decrease in the ozone layer during the period 1979-1997 above Oslo was 5.7 % and above Andøya 5.8 %.**
- **The strongest decrease occurred during the spring months: 8.3 % above Oslo, and 8.4 % above Andøya**
- **Since 1998 there have not been significant changes in the ozone layer above Norway.**
- **A small increase is estimated: 1.8 % above Oslo 0.6 % above Andøya. These changes are however not statistically significant.**
- **The ozone layer above Norway has stabilized**

The national monitoring programme

The Climate and Pollution Agency (the former Norwegian Pollution Control Authority) established the programme "Monitoring of the atmospheric ozone layer" in 1990, which at that time included measurements of total ozone only. In 1995 UV measurements were also included in the programme. The Norwegian Institute for Air Research (NILU) is responsible for the operation and maintenance of the monitoring programme.

Due to economical constraints the monitoring program has unfortunately been varying with respect to the number of locations and variables monitored.In 2010 the monitoring programme included measurements of total ozone and UV at three locations, Oslo (60°N), Andøya (69°N) and Ny-Ålesund (only UV) and ozone profile measurements at one location, Andøya. This report summarises the activities and results of the monitoring programme during the year 2010. The report includes trend analyses of total ozone for the period 1979-2010 for Oslo and Andøya and comments on the expected ozone recovery at northern latitudes. Further the total yearly UV dose for 2010 at Oslo and Andøya is included. The Norwegian UV network was established in 1994/95 and consisted until 2006 of nine 5-channels GUV instruments located from 58°N to 79°N. From 2006 the instrument at Ny-Ålesund has been excluded from the network. This was again included in 2010. As a part of the 2010 monitoring programme NILU has been responsible for the daily operation of three of the instruments, located at Oslo, Andøya (69°N) and Ny-Ålesund.

Total ozone

For the year 2010, the ozone layer above Oslo was close to or above the long term mean ozone for all months, particularly February and November had high levels of ozone. At Andøya the monthly mean ozone values for 2010 were slightly above the long term mean most of the whole year with the exception of April with values 10% below the long term mean.

The winter temperature in 2009/2010 in the Arctic stratosphere (above 10-12 km) can be classified as a relatively cold winter; but divided in two distinct periods. It was cold until mid February, then the situation in the stratosphere changed, and the temperature increased abruptly. Consequently, relatively little ozone loss initiated by the formation and presence of polar stratospheric clouds (see picture) was observed during winter and spring 2009/2010. Ozone values more than 6% above the long term mean level in Oslo, and 53% above the long term mean at the last part of February at Andøya were observed.

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

The ozone lidar at Andøya provides measurements of the ozone concentration at altitudes from approximately 8 km to 50 km on days with clear sky and no daylight. The measurements from the ozone lidar are very useful for studying rapid variations in the ozone profiles and are important for detection of chemical ozone loss during spring and for

the understanding of the processes that leads to changes in the ozone layer. In 2010 there was a period with chemical ozone destruction in the Arctic. Relative large ozone loss was observed after January 15, until mid February.

Our monitoring programme indicates that the minimum ozone levels for Oslo was passed in the period 1988-1997 and that the ozone layer above Oslo is now in a recovery phase. During the period 1979-1997 the annual average ozone layer above Oslo decreased by 5.7 % and as much as 8.3 % during spring. For Andøya the decrease was even stronger; 5.8% and 8.4% respectively. For the period 1998-2010 the ozone layer was stable, with an indication of increase, but no significant trends were observed.

Recent global ozone data indicate that there are signs of ozone recovery from mid 1990s in most of the world. This trend strengthened further the last year. However there is some uncertainty, particularly at high latitudes in the Arctic region. The uncertainty is caused by the high natural variability in this region, and the influence of factors like decreasing temperatures in the stratosphere, which is partly due to the increase of greenhouse gases in the troposphere.

There are several dataset with ozone measurements from different satellites available for the region. This is a great benefit and provides increased information and spatial coverage. However, a comparison of the ground based data with satellite data for selected years shows only good agreement during the summer, while the deviations are larger in the autumn and winter months. The satellite ozone data have hardly the required quality to be used in a trend analysis for our region; but the products are very valuable providing information about the spatial distribution of ozone.

UV measurements

The highest UV dose rate in Oslo, 173.0 mW/m^2 occurred 7 July. This is equivalent to a UV index of 6.6. At Andøya the highest UV index, 4.8, was observed on the 3 July. In 2010 there were few periods during summer months with low ozone and corresponding high UV, as was seen in 2009.

Further needs

To predict the development of the ozone layer with acceptable confidence longer data series and improved understanding of atmospheric processes and dynamics are needed. Long term monitoring is a fundamental basis in ozone studies, and is combined with research using global modelling tools. In particular Arctic ozone is of national concern and responsibility for Norway. A possible improvement of the national monitoring programme is to secure funding for better and more measurements of ozone profiles at Andøya to assess the ozone distribution at different altitudes height and the development of stratospheric temperatures.

Furthermore there are long time series with observations of spring time ozone at Svalbard available that has not been analysed. These data series could be used in a very valuable analysis of the ozone situation in the Arctic spring time from 1991 until today with good predictions of Arctic ozone loss during this period and in the future.

2. Ozone measurements in 2010

Total ozone, i.e. the total amount of ozone in a column from the ground to the top of the atmosphere, is measured in Oslo (60°N) and at Andøya (69°N) on a daily basis. The measurements are retrieved from Brewer spectrophotometers at both locations. The ozone profile from 8-45 km is also measured at Andøya, providing information about the ozone altitude distribution during clear weather conditions. In addition we are analyzing total ozone data from various satellites to get a more complete description of the ozone situation in Norway and the Arctic region.

Every year the International Ozone Services, Canada, is calibrating Brewer instrument no. 42 (Oslo) and no. 104 (Andøya) against a reference instrument, last time in June 2010. In addition, the instruments are regularly calibrated against standard lamps in order to check the stability of the instruments. All the calibrations have indicated that both the Oslo and Andøya Brewer instruments have been stable during the years of operation. Calibration reports are available on request.

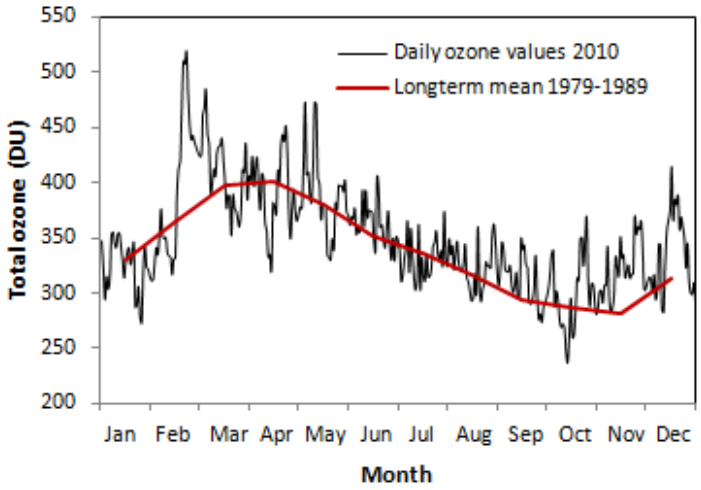

Figure 1a): *Daily total ozone values measured at the University of Oslo in 2010. The red curve shows the long-term monthly mean values from 1979-1989.*

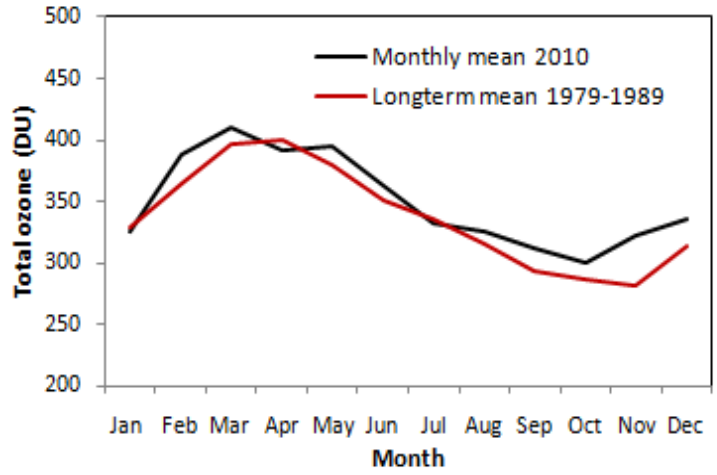

Figure 1b): *Monthly mean ozone values for 2010. The red curve shows the long-term monthly mean values from 1979-1989.*

In the following sections results from the ground based ozone measurements at Oslo and Andøya are described, and in Chapter 3.4.1 on page 25 are satellite measurements from the same sites are presented.

2.1 Total ozone in Oslo

Daily total ozone values from Oslo in 2010, primarily measured from the Brewer spectrometer no. 42, are shown in Figure 1. The black curve shows the daily ozone values from 2010, whereas the red curve shows the long-term monthly mean values for the period 1979-1989. The total ozone values are based on Brewer direct-sun (DS) measurements when available. In 2010 DS measurements were performed 208 out of 365 days. During overcast days or days where the minimum solar zenith angle was larger than 72°, the ozone values were calculated from the global irradiance (GI) method (Stamnes et al., 1991). The Brewer GI method was used 133 days. In 2010 there

were totally 24 days without Brewer DS or GI measurements, caused by bad weather conditions, instrument calibration or technical problems. These days the ozone values were retrieved from the GUV-511 instrument, which is located next to the Brewer instrument at the University of Oslo. The GUV data were harmonized with respect to the Brewer measurements before including them in the 2010 ozone time series.

As seen from Figure 1a) there are large day-to-day fluctuations in total ozone, particularly during winter and spring. The lowest ozone values normally occur in October and November, and the minimum ozone value in 2010 was 238 DU, measured 13 October. This is approximately 20% below the long-term mean for October. In the end of January and mid April there were also a few days where the ozone values were approximately 20% below the long-term mean. However, these episodes were not long lasting and did not have any dramatic impact on the UV-level. In summary, the total ozone values in 2010 were relatively high most of the year. The maximum value of 519 DU was measured 23 February.

The monthly mean total ozone values for 2010 are shown in Figure 1b) and compared with the long-term monthly mean values for the period 1979-1989. The 2010 ozone values were within ± 10 % of the long-term mean all months, except for November when the monthly average ozone value was 14% higher. Section 3.4 gives a broader discussion and inter-pretation of the ozone situation in Norway in 2010.

2.2 Total ozone at Andøya

At Andøya the total ozone values are based on Brewer direct-sun (DS) measurements when available, as in Oslo. For overcast days and days where the solar zenith angle is larger than 80° (sun lower than 10° above the horizon), the ozone values are based on the Brewer global irradiance (GI) method. The GUV-instrument can also provide ozone data when the Brewer instrument is out of order or Brewer measurements are prevented by bad weather conditions.

In 2010 there were 3 days without total ozone observations at Andøya, in addition to the period with polar night when reliable ozone measurements only can be achieved from lidar. From 24 April to 6 May no Brewer DS or GI measurements were performed due to a broken power supply. This data gap was filled in by GUV measurements. The 3 days with absent ozone observations were caused by bad weather conditions. Table 1 gives an overview of the different instruments and methods that were used at Andøya in 2010.

Table 1: *Overview of instruments and methods applied for retrieval of the total ozone at Andøya in 2010.*

Priority	Method	Total days with observations
1	Brewer instrument, direct sun measurements	92
2	Brewer instrument, global irradiance method	139
3	GUV instrument	14
	Lidar (measurements during the Polar night)	27

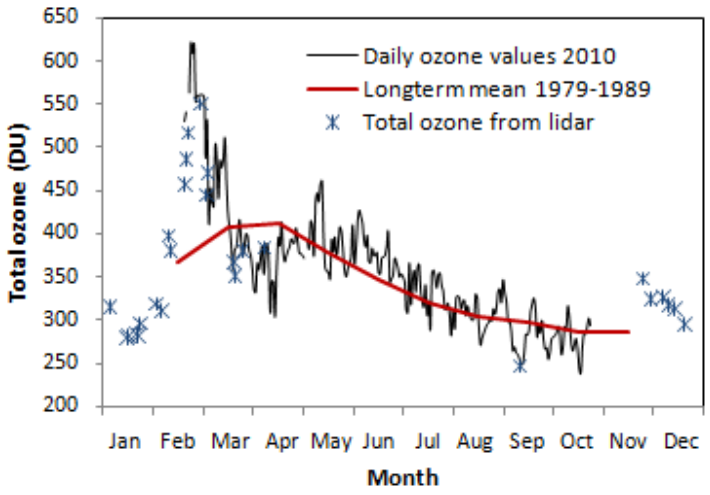

Figure 2a): *Daily total ozone values measured at ALOMAR, Andøya, in 2010 by the Brewer, GUV and LIDAR instruments. The use of the different instruments is shown in the lower part of Figure 2a). The red line shows the long-term monthly mean values from 1979-1989.*

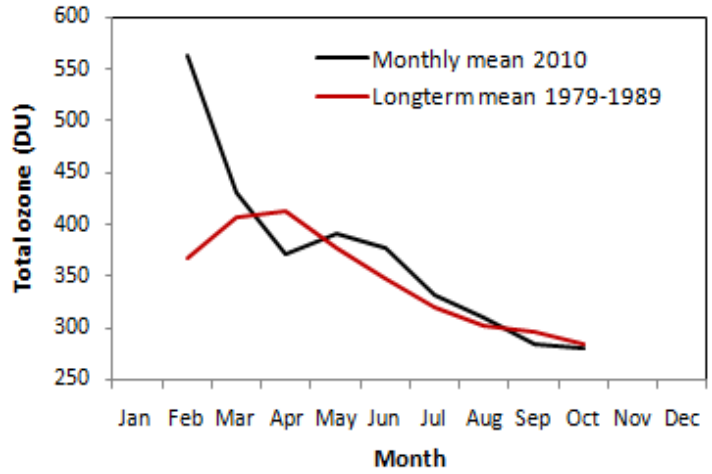

Figure 2b): *Monthly mean ozone values for 2010 compared to the long-term monthly mean values for the period from 1979-1989 shown as the red curve.*

Daily ozone values from Andøya in 2010, based on measurements with the Brewer spectrometer and GUV, are shown in Figure 2a). The black curve shows the daily ozone values, whereas the red curve shows the long-term monthly mean values for the years 1979-1989. Total ozone values during the polar night (November to February) are retrieved from the ozone lidar at ALOMAR. These measurements are indicated by blue stars. The lidar data give a good picture of the ozone variation during the winter months when Brewer and GUV measurements are not achievable.

Monthly mean ozone values at Andøya for 2010 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 2010 shows that the ozone values are fairly close to the long-term mean from May to October. However, February sticks out as an extreme month where the monthly mean ozone value is about 200 DU higher than normal. It should be mentioned that the average February ozone value is based on 9 Brewer GI measurements during the end of February. As indicated by the blue stars in Figure 2a, the ozone values were much lower during the first half of February. If we include the lidar observations in the monthly mean calculations, the February mean value is reduced by 55 DU. Thus, the extremely high February ozone value seen in Figure 2b can easily be misinterpreted and is due to a episode in the end og the month.

2.3 Stratospheric ozone-profile measurements in 2010

2.3.1 Measurements by means of the ozone lidar, located at ALOMAR (69°N, 16°E)

To follow the development of the stratospheric ozone layer during winter 2009/10 and in 2010 lidar measurements have been performed. The instrument used for this purpose is located at the Arctic Lidar Observatory for Middle Atmosphere Research (ALOMAR), at Andøya (69°16'N, 16°00'E, elev. 380 m). It is a classical DIAL (Differential Absorption Lidar) system operating at two wavelength 308 nm (ozone absorption is strong) and 353 nm (weak ozone absorption). The lidar was built in 1994/95 and has been upgraded with a daylight receiver and new receiving electronics, in 1998 and 2008, respectively. It is used to monitor stratospheric ozone, temperatures and Polar Stratospheric Clouds (PSCs). The data contribute to the NDACC, the Network of Detection of Atmospheric Composition Change.

In 2010 measurements have been performed only during clear sky night-time conditions. Funding has not been sufficient for daylight operation. Normally two hours of measurements are needed for the retrieval of an ozone profiles in the height range between 8 and 45 km. Measurements have been made during 27 days. The data have been analysed, quality controlled and the results are reported here. 27 quality controlled ozone profiles have been retrieved. The specific days are summarized in Table 2.

Table 2: *Overview over days with stratospheric ozone profiles retrieved in 2010.*

Month	Ozone profiles	Comments
January	04, 14, 15, 20, 21, 22	
February	01, 04, 08, 09, 17, 18, 19, 26	
March	01, 02, 18, 19, 24	
April	06	
May – August		no daylight measurements
September	09	
October	-	
November	23, 28	
December	05, 09, 13, 19	

2.3.2 Development of the stratospheric ozone layer above Andøya throughout 2010

The development of the stratospheric ozone layer above Andøya throughout 2010 is illustrated in Figure 3. For comparison, the stratospheric ozone layers seen during previous years (1996 and 2003 - 2009) are shown in Figure 4.

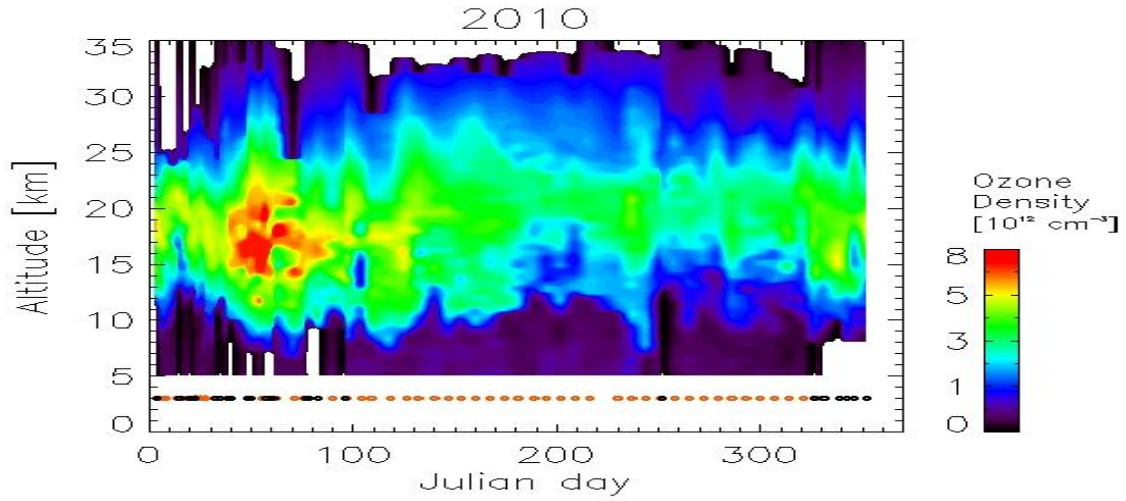

Figure 3: *Development of the stratospheric ozone layer in 2010, derived from profiles measured by the ALOMAR ozone lidar and ozone sondes launched in Sodankylä, Finland (courtesy to the Finnish Meteorological Institute), in 2010. The black dots at the bottom of the plot mark the times when lidar measurements were performed, while the red dots mark days where data from ozone sondes launched from Sodankylä were used. Between the individual measurements the data were linearly interpolated and smoothed with a one-week median filter. Note: vertical blue lines are due to data gaps.*

The lidar measurements document the large inter-annual variability in spring-time ozone depletion in the Arctic (see Figure 4). During winter 2009/10 largely enhanced ozone values were observed in February with total ozone values - retrieved from ozone lidar observations - reaching up to 550 DU on February 26. These very high values can be explained by the specific location of Andøya in relation to the stratospheric vortex. While the area with cold stratospheric air was centred around the pole until mid-January, it elongated around January 30, and finally split into two bulbs around February 15 and ALOMAR was located outside the vortex area. In March the stratospheric ozone values were back to more typical inside-vortex values (see also Chapter 2.2). After a period with low summer-time ozone, the polar vortex was built up again in December 2010 and typical pre-winter ozone values were observed.

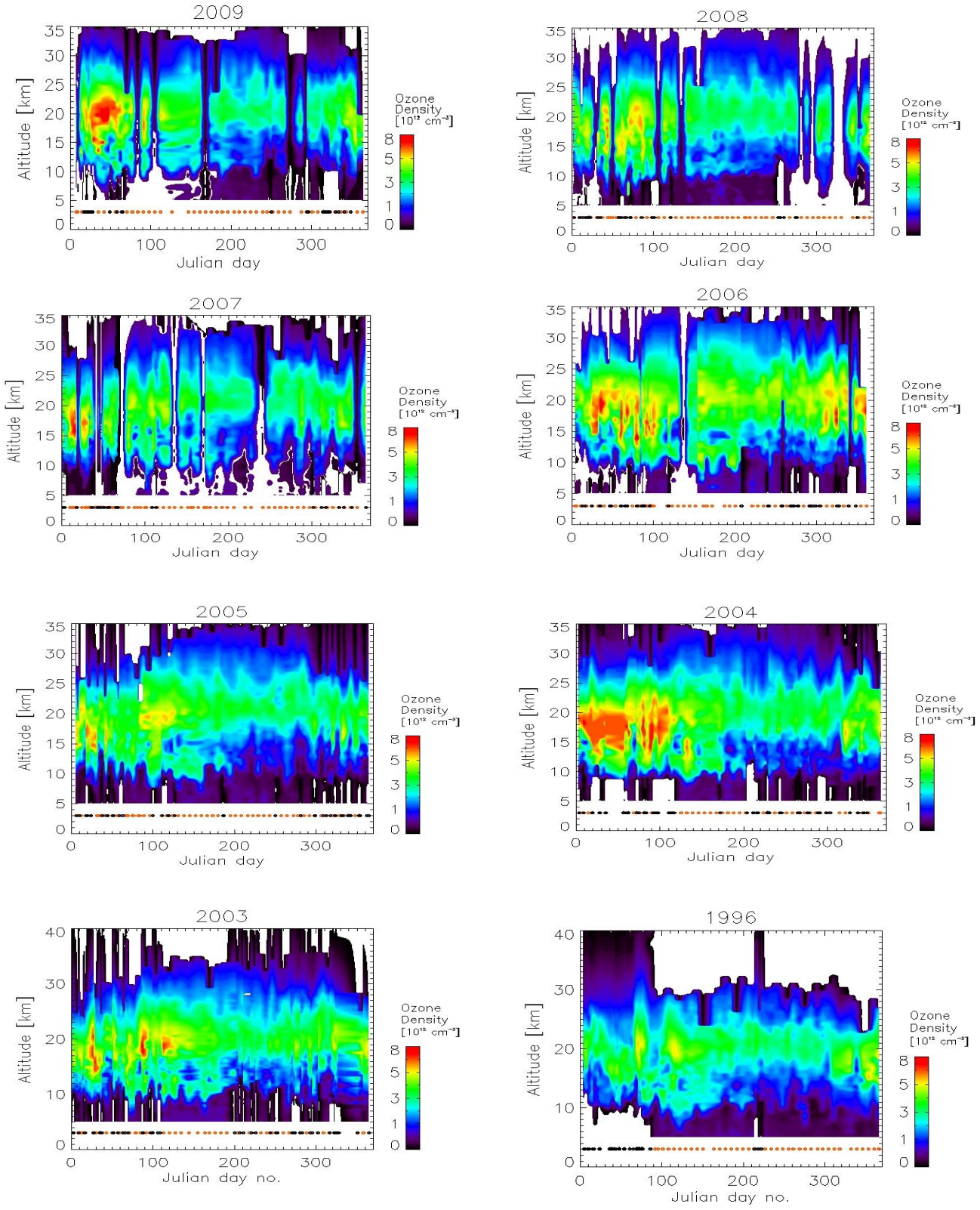

Figure 4: *Ozone profiles measured by the ALOMAR ozone lidar and ozone sondes launched in Sodankylä, Finland, in 1996 and 2003-2009 (analog to Figure 3).*

3. Ozone measurements and trends for 1979–2010

3.1 Background

3.1.1 Status of the ozone layer

In 2010 World Metrological Organisation (WMO) and UNEP published a new Scientific Assessment of Ozone Depletion: 2010 (WMO, 2010). This report summarizes the current knowledge and status of the ozone layer, ozone recovery, UV changes, development of relevant trace gases (halocarbons, Chlorine, Bromine) in the atmosphere. The most relevant conclusions are briefly summarised in this section.

Recovery of the ozone layer is a process beginning with a lessening in the rate of decline, followed by a levelling off and an eventual increase in ozone driven by the changes in the concentrations of ozone-depleting substances.

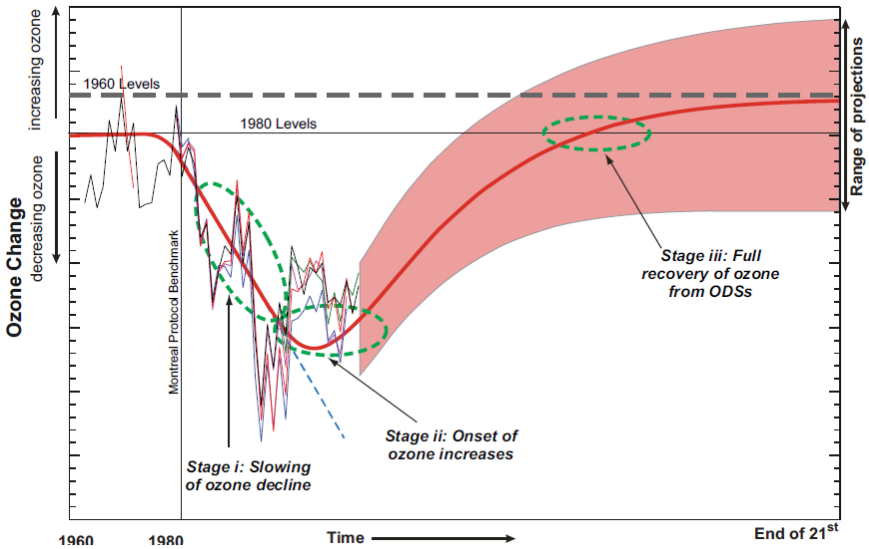

Figure 5*: A conceptual diagram of the evolution of column ozone between 60°N and 60°S between 1960 and 2100 (the x-axis is not to scale). The thick red line is a representation of the ozone amounts observed to date and projected for the future. The red-shaded region represents the model results predicted for the future. The Montreal Protocol 1980 ozone level benchmark is shown as the horizontal line. The dashed thick grey line represents the somewhat uncertain 1960 levels. The three recovery stages are shown by dashed ellipses).Figure from WMO, 2010.*

Figure ***5*** is taken from the report and shows a schematic diagram of the temporal evolution of global ozone amounts beginning with pre-1980 values. This represents a time before significant ozone depletion occurred due to emission of anthropogenic ozone depleting substances (ODS). The thin black, red, and blue lines are ground based and satellite observations averaged over 60S-60N latitudes. Modelled and predicted ozone amounts are illustrated by the solid red line and show depletion from pre-1980 values and the three stages of recovery. The model results and observations show very similar results, except that the observations have large annual variations. The red-shaded region represents the range of observations and model results for both near-term and long-term ozone changes. It is worth noting that the range is rather large and both a so-called over recovery or under recovery is

possible. The factors influencing the prediction of the ozone layer are explained at the end of this section.

The 2006 (WMO 2007) Assessment showed that globally averaged column ozone ceased to decline around 1996, meeting the criterion for the first stage of recovery. Ozone is expected to increase as a result of continued decrease in ODSs (second stage of recovery). According to the new Assessment (WMO 2010) the total global ozone abundances have not decreased the last years and average total ozone values in 2006–2009 remain at the same level as the previous Assessment, at roughly 3.5% and 2.5% below the 1964–1980 averages respectively for 90°S–90°N and 60°S–60°N. The future ozone increase is accelerated by cooling of the upper stratosphere. Global ozone is not very sensitive to circulation changes, so high confidence can be placed in this projection, according to WMO (2010).

The most dramatic ozone depletion has been observed in the Polar Regions, but the detection of recovery near the poles is difficult. This region also exhibits the highest level of natural variability, which again makes the predictions most uncertain. In the Antarctic the ozone layer continues to reach very low levels in the spring. In the Arctic and high northern latitudes the situation is more irregular as severe ozone depletion occurs during springtime in years with low stratospheric temperatures, exemplified with the different situations in 2005 and 2006 and also the new record minimum levels in the Arctic in winter 2010/2011 (not a part of the report.) The yearly and seasonal trends are strongly linked to the spring ozone levels.

According to the new Assessment (WMO 2010) the observed Antarctic springtime column ozone does not yet show a statistically significant increasing trend. Year-to-year variability, due to meteorology, is much larger than the expected response to the small ODS decreases in the Antarctic vortex. The evolution of Antarctic springtime column ozone over the rest of the century is expected to be dominated by the decline in ODS abundance. Model simulations show that greenhouse gas changes have had, and will continue to have, a small impact on the ozone hole compared to the effects of the ODS changes. In spring and early summer, Antarctica will continue to experience elevated surface UV levels. There is increased evidence that the Antarctic ozone hole has affected the surface climate in the Southern Hemisphere. Climate models demonstrate that the ozone hole is the dominant driver of the observed changes in surface winds over the Southern Hemisphere mid and high latitudes during austral summer. These changes have contributed to the observed warming over the Antarctic Peninsula and cooling over the high plateau. The changes in the winds have also been linked to regional changes in precipitation, increases in sea ice around Antarctica, warming of the Southern Ocean, and a local decrease in the ocean sink of CO_2.

Increase in total column ozone in the Arctic and high northern latitudes will partially depend on the possible dynamical and temperature changes in the coming decades, both in the stratosphere as well as the troposphere. The ozone loss in Arctic winter and spring between 2007 and 2010 has been variable, but has remained in a range comparable to the values prevailing since the early 1990s. Substantial chemical ozone loss continues to occur during cold Arctic winters. The evolution of ozone in the Arctic is projected to be more sensitive to climate change than in the Antarctic. The projected strengthening of the stratospheric circulation is expected to significantly increase lower stratospheric ozone in the Arctic, enhancing the GHG-induced ozone increase from upper stratospheric cooling and speeding up the return to 1980 levels.

The ozone levels in the Arctic and high northern latitudes will also be strongly influenced by changes in stratospheric winter temperatures during the next years, and possibly result in delayed recovery or record low ozone observations. Considerably longer data series and improved understanding of atmospheric processes and their effect on ozone are needed to estimate future ozone levels with confidence.

The large red range for the projected future ozone layer in Figure 5 is resulting from uncertainty in many factors affecting the future evolution of the ozone layer. Stratospheric halogen loading is expected to remain the most important factor affecting future stratospheric ozone, and their future trends are connected with uncertainty. One important ODS group are the HCFCs (chlorine containing halocarbons replacing CFCs). At the 2007 Meeting of the Parties to the Montreal Protocol, the Parties agreed to an earlier phase-out of HCFCs, with nearly a full phase-out in developing countries by 2030. Many of these compounds are still increasing significantly per year, which is also evident from our measurements at Zeppelin (Myhre et al., 2011). Another important factor is the development of the long-lived greenhouse gases nitrous oxide (N_2O), and methane (CH_4). Natural ozone loss in the absence of chlorine is primarily due to the reactions involving nitrogen (NO_x) and hydrogen (HO_x) radicals. NO_x and HO_x levels are controlled by the amount of N_2O, H_2O, and CH_4. CH_4 and N_2O are both increasing due to human activity. Also anthropogenic enhancements of the stratospheric sulphate aerosol layer, from both increased surface sulphur emissions and possible geo-engineering actions are important for the future ozone level. According to WMO (2010) present knowledge reveals that the addition sulphate aerosols into the stratosphere as a possible geo-engineering action would have large impacts on the future evolution of stratospheric ozone. Finally, better understanding of atmospheric dynamics and circulation is likely to improve future ozone predictions. In total, the increase in greenhouse gas emissions and subsequent changes in climate, including cooling of the stratosphere is an overarching theme linking many of the factors likely to affect ozone in the future. According to the report it will be challenging to attribute ozone increases to the decreases in ODSs during the next few years because of natural variability, observational uncertainty, and confounding factors, such as those mentioned.

According to WMO studies of long-tem trends of ozone, as presented in the sections 3.2 and 3.3, are essential in the assessment of the ozone recovery.

3.1.2 What would have happened to the ozone layer without the Montreal protocol?

There is a recent comprehensive and interesting paper published in the journal *Atmospheric Chemistry and Physics* that investigates the broad effects and consequences if chlorofluoro-carbons had not been regulated through the Montreal protocol (Newman et al, 2009). Newman and his co-workers uses a state of the art radiation-chemical-dynamical model to simulate a future world were the ozone depleting substances (ODS) were never regulated. In their study they allow the ODSs to grow at a rate of 3% per year. This is a modest growth as the annual CFC production rate up to 1974 was as high as 12-17%. Their simulations showed that 17% of the globally-averaged column ozone was destroyed by 2020, and 67% was destroyed by 2065 in comparison to 1980. Large ozone depletions in the polar region became year-round rather than just seasonal and very large temperature decreases were found in the stratosphere in the tropics in response to circulation changes and decreased shortwave radiation absorption by ozone. This led to heterogonous chemical destruction of ozone also in the tropical region similar to the present processes occurring in Antarctica. The result was a full collapse in the tropical ozone approaching zero by the year 2058. In response to the dramatic ozone changes, ultraviolet radiation increases substantially globally: For mid-

summer an UV increase of 5-10% was calculated for the year 2000 and later a UV index around 15 was reached within the year 2040 and exceeding a value of 30 by the year 2065. (See Table 9 at page 35 for description of UV index.) The UV increase would more than double the erythemal dose in the summer mid latitudes by 2060.

3.2 Trends for Oslo 1979 – 2010

Total ozone measurements using the Dobson spectrophotometer (No. 56) was performed on a regular basis in Oslo from 1978 to 1998. The data from this instrument has been re-evaluated and published (Svendby and Dahlback, 2002) and the complete set of Dobson total ozone values from Oslo is available at The World Ozone Data Centre (http://www.msc-smc.ec.gc.ca/woudc/).

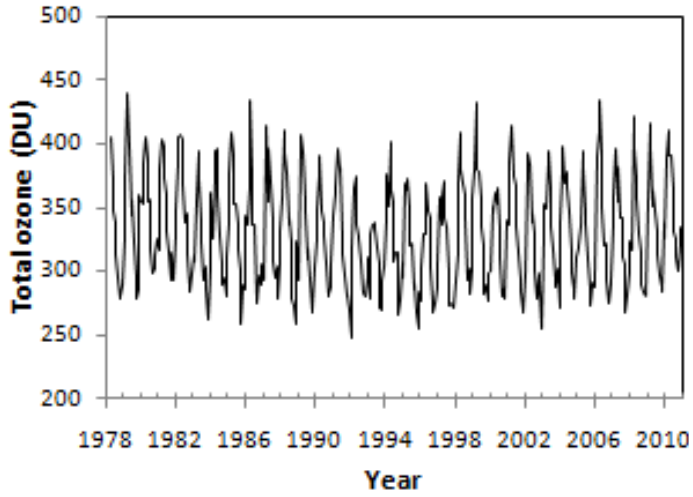

Figure 6a: *Time series of monthly mean total ozone in Oslo 1979-2010.*

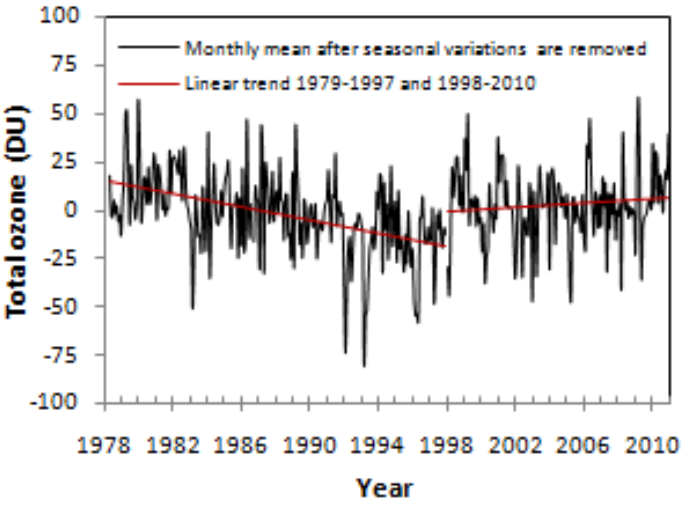

Figure 6b: *Variation in total ozone over Oslo for the period 1979–2010 after the seasonal variations have been removed. Trend lines are including in red.*

The Brewer instrument no. 42 has been in operation at the University of Oslo since the summer 1990. The International Ozone Services, Canada, calibrated the Brewer instrument in June 2010. In addition the Brewer instrument has regularly been 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 20 years of observations. The entire set of Brewer DS measurements from Oslo was re-evaluated and submitted to The World Ozone Data Centre in 2010. The overlapping measurements of Dobson and Brewer in Oslo from 1990 to 1998 show that the two instruments agree well, but 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. There is an ongoing process coordinated trough WMO assessing this problem, and updated recommendations for Brewer and Dobson analysis are expected during 2011. For information about the process, see e.g. http://igaco-o3.fmi.fi/ACSO/.

Figure 6a) shows the variations in monthly mean ozone values from Oslo for the period 1979 to 2010. 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.

In order to study possible ozone trends for the period 1979 - 2010 we have removed the seasonal variations by subtracting the long-term monthly mean ozone value from the data series, shown in Figure 6b). Based on the indications of ozone recovery in our data (Myhre, 2010) and in accordance with the conclusion in the last Ozone Assessment (WMO, 2010) we decided to divide the trend analysis in two periods. We have divided the time series into two periods: 1) 1978-1997, and 2) 1998-2010. The ozone measurements from first time period are entirely derived from the Dobson instrument and reflect a time period where a gradual decline in stratospheric ozone was observed at most mid and high latitude stations. The second period is based on Brewer measurements, with some additional GUV measurements. For the two time periods simple linear regression lines have been fitted to the data to describe trends in the ozone layer above Oslo. The results are summarized in Table 3. The numbers in the table represent seasonal and annual percentage changes in total ozone (per decade) for the two time periods. The numbers in parenthesis gives the uncertainty (1σ) in percent/decade. A trend larger than 2σ is considered to be significant. In winter and spring the ozone variability is relatively large and the corresponding ozone trend must be large in order to be classified as statistical significant.

The second column in Table 3 describes the dramatic ozone decrease that occurred during the 1980s and first half of the 1990s. For the period 1979-1997 there was a significant decline in total ozone for all seasons. For the winter and spring the decrease was as large as -6.1%/ decade and -8.3%/decade, respectively. The negative ozone trend was less evident for the summer, but nevertheless it was significant to a 2σ level.

For the period 1998-2010 the picture is very different. This is a fairly short time period, only including 13 year, and due to substantial annual fluctuations one should be cautious to draw any definite conclusions about trends. Nevertheless, the regression analysis gives a good indication of the status of the ozone layer for recent years. As seen from the last column in Table 3 none of the trend results are significant to a 2σ level. During the summer period there has been an ozone decline during the last 13 years, whereas the trend is positive for all other seasons. For the winter season the ozone increase from 1998 to 2010 has been as large as 4.5%/ decade. However, this ozone increase is strongly influenced by the record low ozone values in 1998 and the high winter ozone values in 2010. If we omit 1998 and 2010 from the regression analysis the trend for the 1999-2009 period will be negative (-0.9%/decade) instead of highly positive. This clearly demonstrates how the trend results can be affected by extreme values in the start and/or end of a short regression period. This is also partly true for the negative summer trend over this period. The summer ozone values of 1998 where unusually high, thus there seem to be a clear downward trend from this year. However, omitting this year from the regression analysis gives a summer trend of -0.6 (not significant to a 2σ level.)

All in all 2010 had relatively high ozone values and only three out of twelve months had monthly mean ozone values below the long-term average mean. Figure 6b and Table 3 clearly demonstrate that the gradual ozone decrease that occurred during the 1980s and 1990s has stopped, and we can now see signs of ozone recovery. This will be further discussed in section 3.4 on page 23.

Table 3: *Percentage changes in total ozone per year for Oslo for the period 1.1.1979 to 31.12.2010. The numbers in parenthesis gives the uncertainty (1σ) in percent. Data from the Dobson and Brewer instruments have been used in this study. A trend larger than 2σ is considered to be significant.*

Season	Trend (% /decade) 1979-1997	Trend (% /decade) 1998-2010
Winter (Dec – Feb)	-6.1 (2.4)	4.5 (4.0)
Spring (Mar – May)	-8.3 (1.4)	1.6 (3.3)
Summer (Jun – Aug)	-3.3 (1.1)	-2.7 (1.6)
Fall (Sep – Nov)	-4.3 (1.0)	2.9 (2.0)
Annual (Jan – Dec):	-5.7 (1.0)	1.8 (1.7)

3.3 Trends for Andøya 1979 – 2010

The Brewer instrument has been in operation at Andøya since 2000. In the period 1994 to 1999 the instrument was located at Tromsø, approximately 130 km North of Andøya. Studies have shown that the ozone climatology is very similar at the two locations (Høiskar et al., 2001), and the two datasets are considered equally representative for the ozone values at Andøya. For the time period 1979–1994 total ozone values from the satellite instrument TOMS (Total ozone Mapping Spectrometer) have been used.

Figure 7a) shows the variations in the monthly mean ozone values at Andøya from 1979 to 2010. The extreme February 2010 value is seen as a peak in the plot. It should be kept in mind that this peak is due to an extreme ozone event in the end of February 2010 and that data from the first half of February is absent due to the Polar night.

The variations in total ozone at Andøya for the period 1979–2010, after removing the seasonal variations, are shown in Figure 7b) together with the annual trends. October – February months are not included in the trend analysis due to lack of data and uncertain ozone values during seasons with low sun. Simple linear regression lines have been fitted to the data in Figure 7b). Similar to the Oslo site we have chosen to divide the ozone time series into two periods: 1) 1979-1997, and 2) 1998-2010. The results of the trend analysis are summarized in Table 4. The trend patterns from Andøya have many similarities to the Oslo trend pattern.

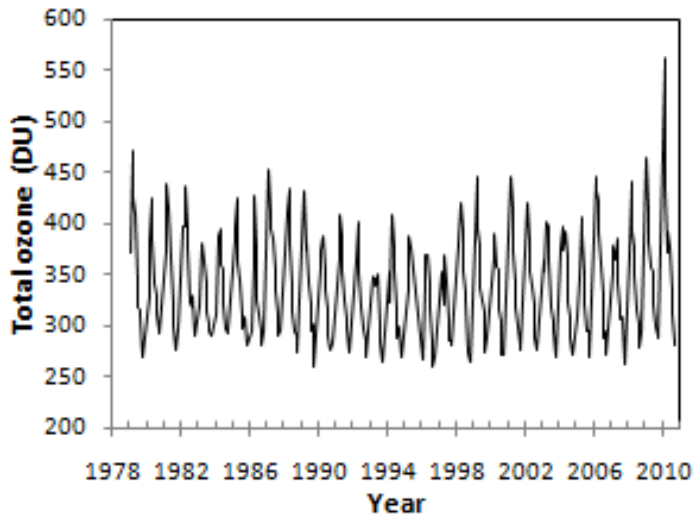

Figure 7 a): *Time series of monthly mean total ozone at Andøya/Tromsø 1979–2010.*

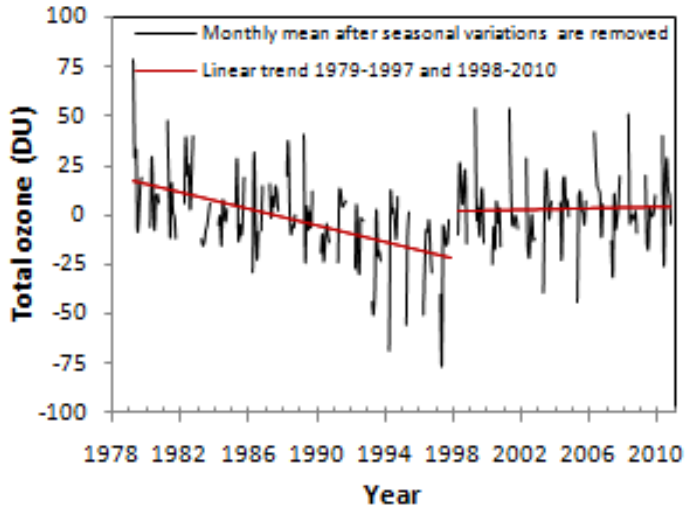

Figure 7 b): *Variations in total ozone at Andøya for the period 1979–2010 after the seasonal variations are removed. Only data for the months March–September are included.*

For the first time period from 1979 to 1997 there is a significant ozone decrease for all seasons. The negative trend for the spring season is -8.4%/decade, whereas the trend for the summer months is -2.8%/decade. The annual trend in total ozone is -5.8%/decade. In contrast, no significant trends are observed for the second period from 1998 to 2010. A small ozone decrease of -0.5%/decade is observed for the spring and an equally large increase is found for the summer. The annual trend for the period 1998-2010 is 0.6%/decade. However, these results are far from significant at neither 1σ nor 2σ significance level.

Table 4: *Percentage changes in total ozone per decade for Andøya for the periods a)1979-1997, and 2) 1998- 2010. The numbers in parenthesis gives the uncertainty (1σ). A trend larger than 2σ is considered to be significant. Data from the Dobson and Brewer instruments have been used in this study, in addition to a few GUV data.*

Season	Trend (% /decade) 1979-1997	Trend (% /decade) 1998-2010
Spring (Mar – May):	-8.4 (1.5)	-0.5 (2.8)
Summer (Jun – Aug):	-2.8 (0.9)	0.4 (1.6)
Annual (Mar – Sep):	-5.8 (1.0)	0.6 (1.5)

3.4 The ozone situation above Norway 2010

The percentage difference between yearly mean total ozone and the long-term yearly mean is shown in Figure 8 (Oslo) and Figure 9 (Andøya) for the full period with observations. The low values in 1983, 1992 and 1993 are related to the eruption of the El Chichón volcano in Mexico in 1982 and the Mount Pinatubo volcano at the Philippines in 1991.

The Figure shows that the low ozone values in the 1990's contribute strongly to the observed negative trends in total ozone above Oslo. Note also that the yearly mean ozone value for 2005 was as much as 5% lower than the long-term yearly mean. For 2010 the annual mean was 3.4 % above the long-term mean.

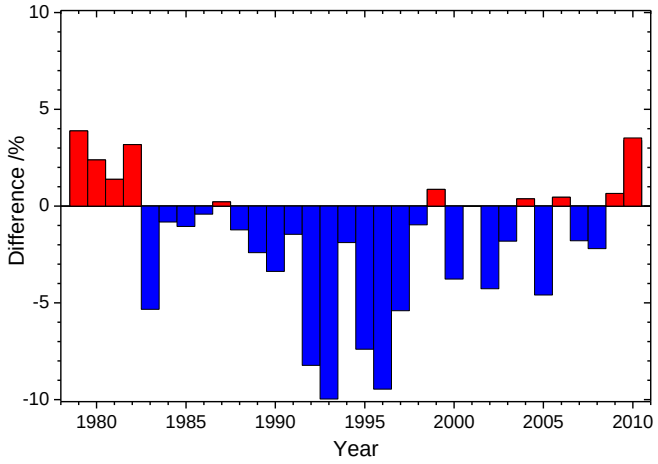

Figure 8: *Percentage difference between yearly mean total ozone in Oslo and the long-term yearly mean for 1979-1989.*

The percentage difference between yearly mean total ozone and the long-term yearly mean at Andøya is shown in Figure 9. For 2010 the yearly mean ozone value was as much as 4.0% above the long-term yearly mean value for the period 1979–1989.

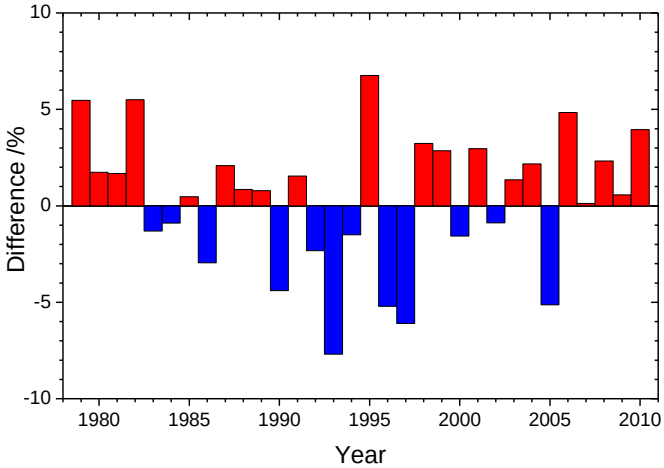

Figure 9: *Percentage difference between yearly mean total ozone in Andøya and the long-term yearly mean for 1979-1989 for the months March-September.*

Table 5 gives the percentage difference between the monthly mean total ozone values for 2010 and the long-term monthly values. Both Oslo and Andøya are listed in the table.

Table 5: *Percentage difference between the monthly mean total ozone values for 2010 and the long-term mean for Oslo and Andøya.*

Month	Oslo (%)	Andøya (%)
January	-1.3	
February	6.7	52.9
March	3.3	6.1
April	-2.4	-10.1
May	2.6	3.7
June	3.5	8.5
July	-1.2	3.9
August	2.8	2.4
September	6.2	-4.4
October	4.4	-1.5
November	14.2	
December	6.8	

The ozone situation was similar in Oslo and Andøya in 2010, generally the ozone values was high at both locations throughout the year. In particular February at Andøya was considerable above the long-term mean as described elsewhere (page 12). In Oslo the ozone levels was as much as 14.2 % above the long-term mean in November. In 2009 the ozone values in were below the long-term mean values for all spring and summer months, while this was not the case in 2010; only April had ozone values below the long term mean during this season at both locations and also in July in Oslo. The low ozone values commonly observed in the spring the last decades are a direct result of the stratospheric conditions, and the chlorine and bromine compounds emitted by anthropogenic sources. The polar stratospheric vortex[1] leads to chemical ozone destruction when air masses, quasi-isolated in the polar vortex, are illuminated by sunlight. Sunlight initiates the formation of active chlorine and bromine compounds (e.g. HCl and HBr) by heterogeneous chemistry on polar stratospheric clouds (PSC). The active chlorine and bromine reacts with ozone and results in severe ozone depletion. The PSCs are a basis for the chemical ozone destructions observed in the Antarctica and the Arctic. There are two main types of PSCs, called PSC I and PSC II. The approximate threshold formation temperature for type I is 195 K (-78^{o}C) and for type II 188 K (-85^{o}C) and the first observation of PSC type II in the Arctic was in 2005.

A colder upper stratosphere is a suggested feedback to the increased level of greenhouse gases in the troposphere, and also containing higher concentrations of water vapour particularly from CH_4. Thus, it is important to detect signs of climate changes and influence on the occurrence of PSCs and particularly the abundance of PSC type II. However, the observations

[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.

of the latest years clearly manifest the great variability of the ozone layer typical for the Northern region (WMO, 2010; Weatherhead and Andersen, 2006).

To explore the reason for the high values in February and better explain the observed ozone values, we have assessed the stratospheric temperature development in 2010.

3.4.1 Stratospheric temperatures (from ECMWF data) and polar stratospheric cloud observations during winter 2009/10

Polar stratospheric clouds (PSCs) have been monitored with the stratospheric ozone lidar since it was established at ALOMAR in 1994/95. PSCs form when the temperature in the stratosphere drops during the polar winter. They occur with different compositions and physical phases. Originally they were classified according to their occurrence above (type I) and below (type II) the water ice frost point (T_{ice}). Type I PSCs were later on sub-classified into non-spherical solid particles (type Ia) and spherical liquid particles (type Ib). Besides the actual temperatures, an important factor steering PSC formation is the temperature history of the air mass.

Chemical reactions occurring on the PSC surfaces can transform passive and halogen compounds (e.g. HCl and HBr) into active chlorine and bromine (e.g. ClO and BrO). Under sunlit conditions these active species react with ozone through catalytic cycles and thereby cause rapid and massive ozone destruction.

Stratospheric temperatures (at around 23 km altitude) above Andøya are shown in Figure 10. The temperature development during the last 15 winter seasons is shown. The red line shows the temperatures during the winter 2009/10. Dates on which the ozone lidar at ALOMAR has been operated are marked with black symbol "+". Measurements during which PSCs have been observed are indicated by red symbols.

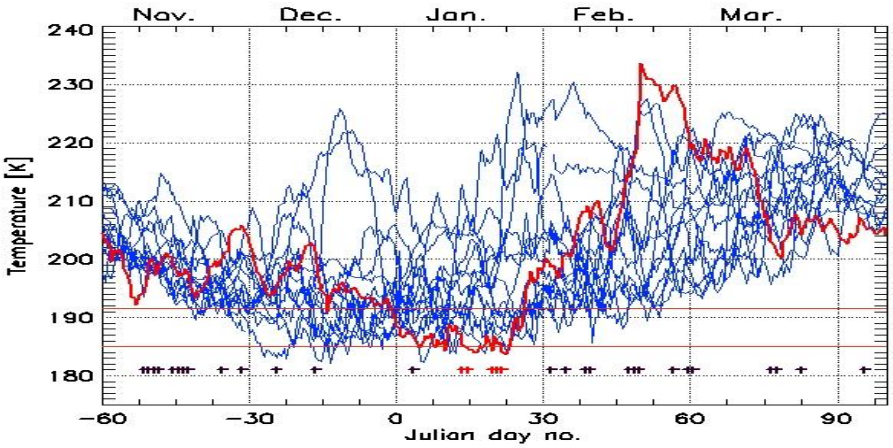

Figure 10: *Stratospheric temperatures at ca. 23 km (a potential temperature of 550K), between 1995/96 and 2009/10. Data are from ECMWF. The temperature development during winter 2009/10 is highlighted in red. The two vertical red lines indicate roughly the temperature thresholds needed for PSC type I (NAT) and II (ice) formation. Days with lidar observations are marked with black "+" symbols, PSCs observed are indicated by red "+" symbols.*

The cold polar vortex was formed in early December 2009 and it was centered around the pole until mid-January. In general, temperatures in the Arctic stratosphere fell to low enough values for PSC formation in Mid-December 2009. Due to the location of Andøya at the edge of the stratospheric vortex, PSC formation temperatures were reached at this site only in January 2010. After that temperatures were too high for PSC occurrence. Compared to previous winters the winter 2009/10 was one of the coldest in January, but a final stratospheric warming occurred early, around February 10.

During winter 2009/10 PSC occurrence could be documented by lidar measurements on 14, 15, 20, 21, and 22 January 2010. Average backscatter profiles are shown in Figure 11. While no PSCs were seen on January 4, PSC with large vertical extend - between 17.5 and 26.5 km with high backscatter ratio of up to 3 were seen for all measurements made during the second half of January.

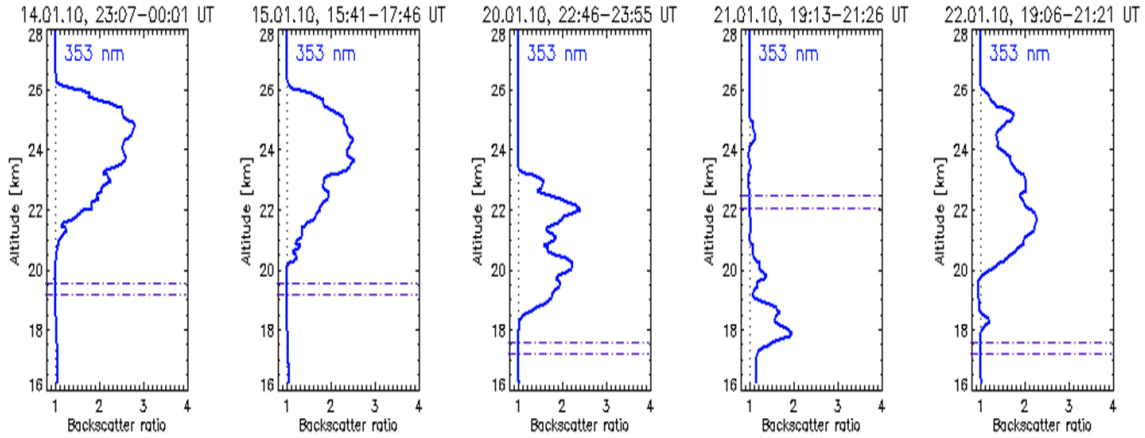

Figure 11: *Polar stratospheric cloud observations in January 2010. Shown is the averaged backscatter at 353 nm. The dashed dotted horizontal lines indicate the normalization range used for the data analysis.*

The lidar observations document the large inter-annual variability in PSC occurrence at the northern Scandinavian observatory. An overview of days on which PSCs have been observed with help of the ozone lidar during the last 15 winters is shown in Table 6. Polar stratospheric clouds have been measured between 1 December (in 2002) and 21 February (in 2005). The numbers of days on which PSCs have been seen vary between zero (winter 1998/99, 2001/02, 2003/04 and 2006/07) and 12 (in early 1996). Very different stratospheric winters have occurred in recent years: warm winters with very low PSC formation potential (1998/99, 2001/02, and 2005/06, and 2008/09) and very cold winter like 1994/95 and 1995/96. 2009/10 was another cold winter in the Arctic stratosphere. Already may we, based on preliminary data, know that the winter 2010/2011 revealed record low ozone values.

Table 6: *List of days with PSCs seen by means of the ozone lidar at ALOMAR.*

Winter	December	January	February
1995/96	-	5, 7, 9, 11, 17, 18, 23, 24	12, 13, 16, 17
1996/97	-	7, 16, 19	9/10
1997/98	-	16/17	-
1998/99	-	-	-
1999/00	21	21, 22, 26, 29	6
2000/01	-	21, 23	-
2001/02	-	-	-
2002/03	1, 2, 3, 4, 5, 7, 16, 25	9	5
2003/04	-	-	-
2004/05	-	5, 6, 24	7, 13, 14, 15, 20, 21
2005/06	6, 19, 20, 29, 31	6, 9	-
2006/07	-	-	-
2007/08	-	14, 17, 18, 21, 22, 23	4
2008/09	15	-	-
2009/10	-	14, 15, 20, 21, 22	-

3.4.2 Total ozone loss during the 2009/10 Arctic winter derived from the SAOZ network

A general picture of the ozone depletion in winter 2009/10 was obtained by the Systeme d'Analyse par Observation Zenitale (SAOZ) network, a network of eight zenith sky visible spectrometer distributed in the Arctic. The SAOZ in Ny-Ålesund is located at the observation platform of the Sverdrup Station of the Norwegian Polar Institute. It has been operated by NILU since 1990. According to observations made within the SAOZ network, relative large ozone loss in the Arctic vortex was observed in winter 2009/10. Ozone destruction on the PSC surfaces was possible after January 15, 2010 when the cold areas received sunlight. Due to a final warming occurring early, around February 10, chemical ozone destruction was only possible for a limited time period. Using passive ozone from the REPROBUS model (or using passive ozone from SLIMCAT model), most of the loss was found between January 1 and February 20 at a rate of 0.5% per day leading to accumulative loss of 26% + 2%. After that date the loss stopped. This is comparable to what was observed during previous cold winters, e.g. in spring 1995, 1996, 1997, 2000, 2005 and 2008. See Goutail et al. (2010) for more details.

4. Satellite observations of ozone above Norway and the Norwegian Arctic region

It is very valuable to investigate the available ozone measurements from satellite in the Scandinavian and Arctic region, and compare the results with our ground-based observations. A great benefit of using the satellite data in the annual analysis of the Norwegian ozone layer is the increased information of the spatial distribution of ozone. This will improve the national monitoring of the ozone layer and the UV radiation as it allows more information than the point observations (like geographical variations), e.g. in Oslo and at Andøya. Satellites also make it possible to investigate the geographical extent of low ozone episodes during spring and summer and thereby discover enhanced UV intensity on a regional level. Based on a project jointly financed by The European Space Agency (ESA) (http://www.esa.int/) and The Norwegian Space Centre (NRS) (Norsk Romsenter, http://www.romsenter.no/) we are now in a position where we can explore and utilize ozone satellite observations in a better way in the National monitoring of the ozone and UV radiation in the future. The project started in October 2007 and ended late 2010. The results from this work are included in this report.

4.1 Short introduction to ozone observations from space

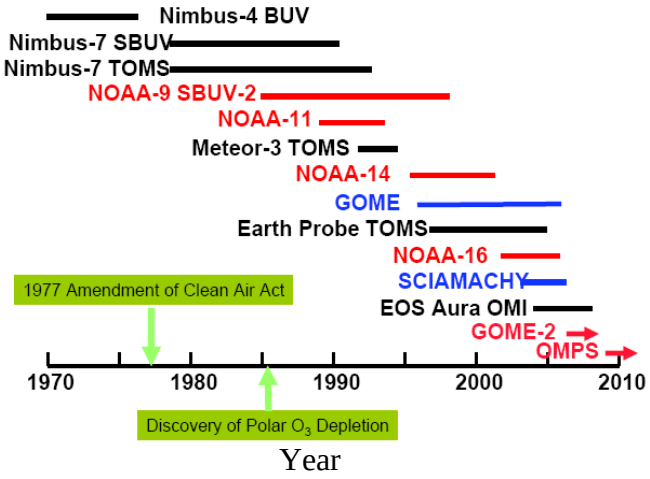

Figure 12: *An overview of the various satellites and their instruments measuring ozone from space since the beginning of 1970's (Figure from NASA).*

The amount and distribution of ozone in the stratosphere varies greatly over the globe mainly controlled by two factors: the fact that the maximum production of ozone takes place at 40 km height in the tropical region, and secondly the large scale stratospheric transport patterns towards the mid- and high latitudes. In addition there are small scale transport and circulation patterns in the stratosphere determining the daily ozone levels. Thus, observing ozone fluctuations over just one spot is not sufficient to give a precise description of the ozone situation in a larger region. Satellite observations are filling these gaps. However, satellite observations rely on proper ground based monitoring as satellites have varying and unpredictable life times, and calibration and validation rely on high quality ground based observations. Thus satellite observations are complementary to ground based observations, and both are highly necessary.

Observations of seasonal, latitudinal, and longitudinal ozone distribution from space have been performed over more than 40 years using a variety of satellite instruments. The American institutions NASA and NOAA (National Oceanic and Atmospheric Administration) started these observations and later The European Space Agency also initiated their ozone programmes. Figure 12 gives a brief overview of the various ozone satellite missions measuring total column ozone since the beginning of the 1970's.

4.2 Satellite ozone observations above the Norwegian sites from 1978–2010

Figure 13 shows the available ozone observations from satellite overpasses above the two Norwegian ozone sites. Observations above Oslo are shown in the left panel and observations above Andøya are shown in the right panel. The colours and the arrows indicate the various data sources. The satellite measurements are performed by Nimbus TOMS, Meteor TOMS, Earth Probe TOMS, ERS-2 GOME, Envisat SCIAMACHY and AURA OMI.

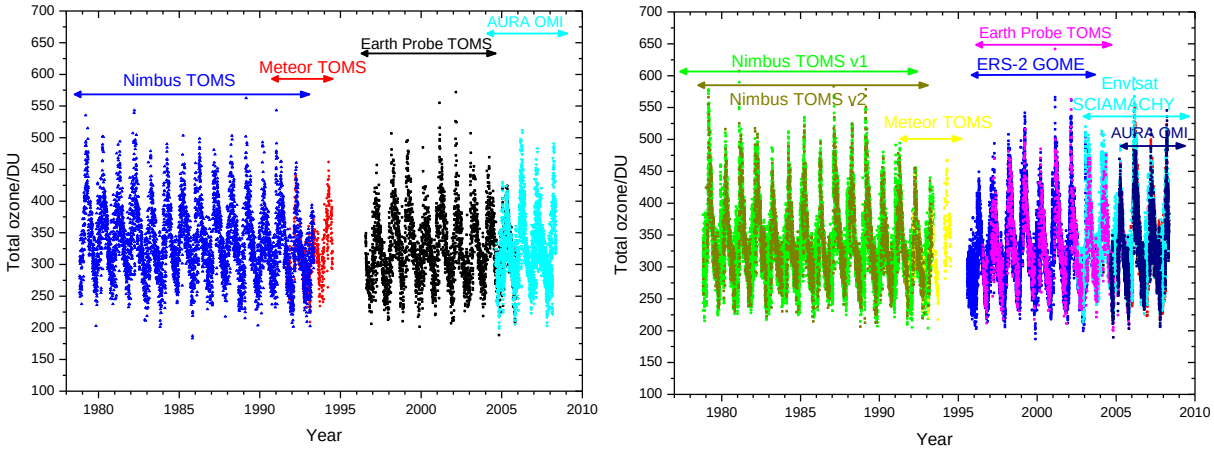

Figure 13: *Freely available ozone observations from satellite overpasses above Oslo (left panel) and Andøya (right panel). The coloured arrows indicate the various satellites and instruments.*

With respect to the monthly mean values, there are relatively large differences between the ground based data and the satellite data, and also between the various satellite data for overlapping time periods. There seems to be both seasonal and systematic differences between the various satellite data. These recent results obtained through the SatLuft project strongly indicate that a re-evaluation of the satellite data is necessary for trend analyses in the future.

We have compared the monthly mean ozone values from ground based data and satellites for the full period, 1979-2010. Figure 14 shows the differences between the ground based monthly mean ozone observations from Oslo and Andøya and the monthly mean ozone data from the available satellite products. The comparison clearly illustrates that there are significant deviations.

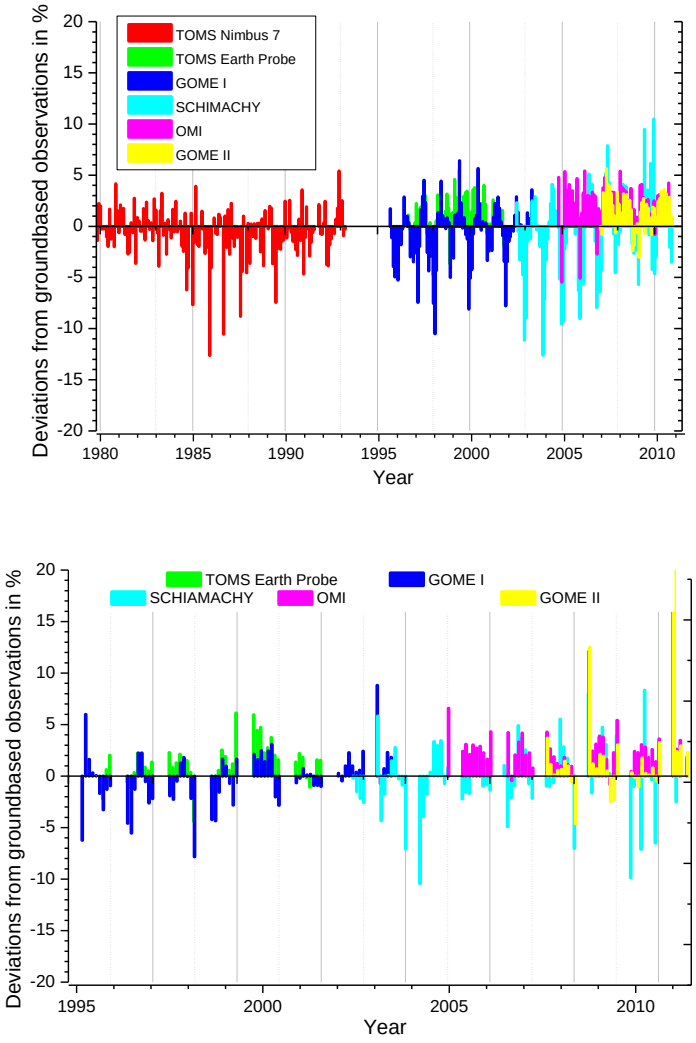

Figure 14: *Difference between ground based (GB) and satellite retrieved monthly mean ozone values from 1979 to 2010 for Oslo and 1995-2010 for Andøya. Deviations (GB minus satellite values) are given in %. Upper panel: Oslo, Lower panel: Andøya.*

For Oslo, TOMS (EP), GOME (1) and SCHIMACHY overestimate the ozone values while the other satellite data tends to underestimates the values from the ground based observed ozone values. For Andøya the situation is somewhat different; TOMS (EP), OMI and SCHAMACHY are underestimating the ground based values. There are also clear seasonal variations in the deviations giving high the standard deviations, and the variances are very high for most comparisons. Consequently, the average values are not a proper measure for the discrepancies between the ground based and satellite retrieved data. Note the relatively low averages deviations between the ground based values and SCIAMACHY, but the very high variance. This is also evident from Figure 14.

Table 7 gives an overview of the average deviations between the various data products together with standard deviations and variance for Oslo.

For Oslo, TOMS (EP), GOME (1) and SCHIMACHY overestimate the ozone values while the other satellite data tends to underestimates the values from the ground based observed ozone values. For Andøya the situation is somewhat different; TOMS (EP), OMI and SCHAMACHY are underestimating the ground based values. There are also clear seasonal variations in the deviations giving high the standard deviations, and the variances are very high for most comparisons. Consequently, the average values are not a proper measure for the discrepancies between the ground based and satellite retrieved data. Note the relatively low averages deviations between the ground based values and SCIAMACHY, but the very high variance. This is also evident from Figure 14.

Table 7: *Average deviations in % between ground based and various satellites retrieved monthly mean ozone values from Oslo and Andøya. Standard deviation and variance are also included.*

Oslo					
Instrument	**Period**		**Mean**	**St. Dev**	**Variance**
TOMS (Earth probe)	Aug-96	Dec-01	0.99	2.51	6.31
TOMS (Nimbus 7)	Nov-78	Apr-93	-0.69	2.46	6.04
GOME 1	Aug-95	Jun-03	-0.78	3.06	9.34
OMI	Oct-04	Oct-10	2.30	2.01	4.03
SCIAMACHY	Jul-02	Dec-10	-0.45	4.13	17.06
GOME 2	Apr-07	Dec-10	1.64	1.78	3.17
Andøya					
Instrument	**Period**		**Mean**	**St. Dev**	**Variance**
TOMS (Earth probe)	Aug-96	Dec-01	1.32	1.99	3.97
GOME 1	Aug-95	Jun-03	-0.2	2.71	7.34
OMI	Oct-04	Oct-10	2.84	2.84	8.05
SCIAMACHY	Jul-02	Dec-10	0.14	4.05	16.36
GOME 2	Apr-07	Dec-10	-1.76	4.51	20.33

Our goal in the SatLuft project was to define and construct an integrated data set from satellites that is suitable for trend analysis for the Scandinavian region. Based on the analysis we concluded that the ozone data from satellite observations above Oslo and Andøya are too uncertain for reliable trend analysis as the variations between both the ground based data and among the various satellite data are too large (see also Myhre et al., 2010)

5. The 4th IPCC report: Coupling of stratospheric ozone and climate

Climate change will affect the evolution of the ozone layer in several ways; through changes in transport, chemical composition, and temperature (IPCC, 2007; WMO, 2007). In turn, changes to the ozone layer will affect climate through the influence on the radiative balance, and the stratospheric temperature gradients. Climate change and the evolution of the ozone layer are coupled, and understanding of the processes involved is very complex as many of the interactions are non-linear.

Radiative forcing[2] is a useful tool to estimate the relative climate impacts due to radiative changes. The influence of external factors on climate can be broadly compared using this concept. Revised global-average radiative forcing estimates from the 4th IPCC are shown in Figure 15 (IPCC, 2007). The estimates are for changes in anthropogenic factors since pre-industrial times. Stratospheric ozone is a greenhouse gas. The change in stratospheric ozone since pre-industrial times has a weak negative forcing of -0.05 W/m^2 with a *medium* level of scientific understanding. This new estimate is weaker than in the previous report where the estimate was –0.15 W/m^2. The updated estimate is based on new model results employing the same data set as in the previous report, where observational data up to 1998 is included. No study has utilized ozone trend observations after 1998 (Forster et al., 2007).

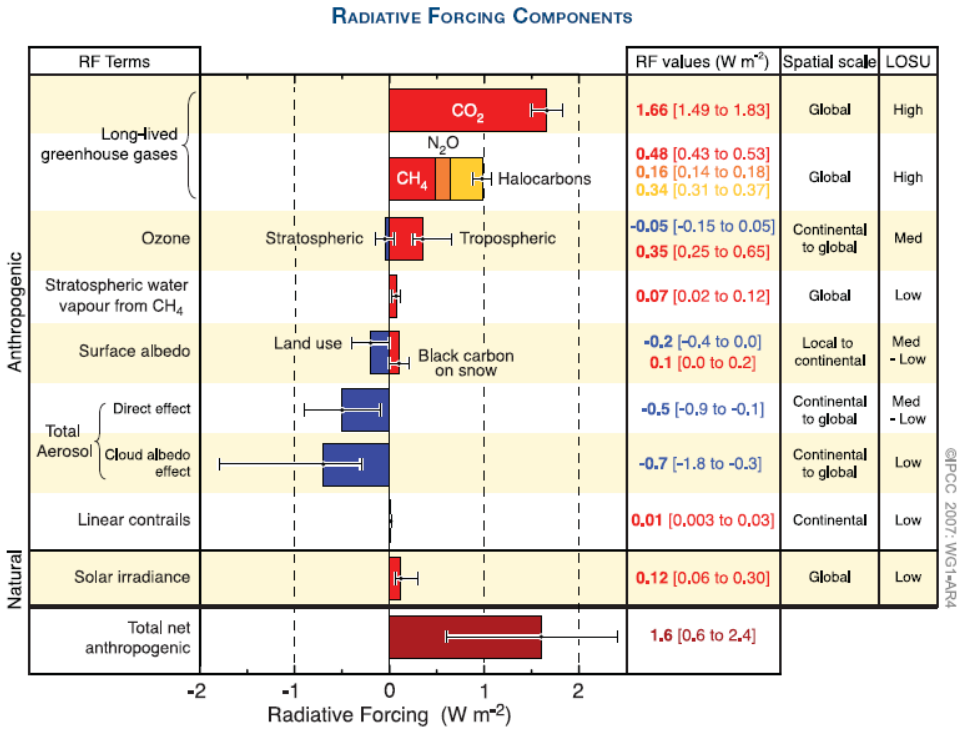

Figure 15: *Global-average radiative forcing estimates for important anthropogenic agents and mechanisms as greenhouse gases, aerosol effects, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU).*

[2] Radiative forcing is a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere. It is an index of the importance of the factor as a potential climate change mechanism. It is expressed in Wm^{-2} and positive radiative forcing tends to warm the surface. A negative forcing tends to cool the surface.

The temporarily and seasonally non-uniform nature of the ozone trends has important implications for the radiative forcing. Total column ozone changes over mid latitudes is considerable larger at the southern hemisphere (-6%) than at the northern hemisphere (-3%). According to the IPCC report the negative ozone trend has slowed down the last decade, also described in section 2.1 of this report. However, it is not yet clear whether these recent changes are indicative of ozone recovery (Forster et al., 2007).

Stratospheric ozone is indirectly affected by climate change through changes in dynamics and in the chemical composition of the troposphere and stratosphere (Denman et al., 2007). An increase in the greenhouse gases, especially CO_2, cools the stratosphere. In general a decrease in stratospheric temperature reduces ozone depletion leading to higher ozone column. However, there is a possible exception in the Polar Regions where lower stratospheric temperatures lead to more favourable PSC conditions and possible formation of more PSCs. This is of particular importance in the Arctic region (WMO, 2007). Moreover, ozone absorbs UV radiation. Absorption of UV radiation provides the heating responsible for the observed temperature profile above the tropopause. Changes in stratospheric temperatures, induced by changes in ozone or greenhouse gas concentrations will alter dynamic processes.

A long-term increase in stratospheric water content is observed. This might have important consequences for the ozone layer as stratospheric water vapour is among the main sources of OH in the stratosphere. OH is one of the key species in the chemical cycles regulating the ozone levels. There are several sources for stratospheric water where CH_4 is one of the most important. Other sources are volcanoes, natural and anthropogenic biomass burning and air crafts. In the new IPCC report, the increase in stratospheric water vapour resulting from anthropogenic emissions of methane (CH_4) has a positive forcing of 0.07 W/m^2, shown in Figure 15.

The evolution of stratospheric ozone over the next few decades will depend on natural, and human-caused factors such as stratospheric halogen loading. The evolution of ozone will also depend on changes in many stratospheric constituents: it is expected that the reduction of ozone-depleting substances in the 21st century will cause ozone to increase via chemical processes. However, this increase could be strongly affected by temperature changes (due to greenhouse gases), other chemical changes (e.g., due to water vapour) and transport changes. According to model studies presented in the last IPCC report (Denman et al., 2007) Antarctic ozone development follows mainly the behavior of chlorine and bromine compounds. The peak depletion is expected to have occured around the year 2000 followed by a slow increase. Most models predict that Antarctic ozone amounts will increase to 1980 levels close to the time when modelled halogen amounts decrease to 1980 values, which is in the year 2065. Increased atmospheric fluxes of chlor-fluor-carbons (CFCs) have recently been reported which may point to a still later recovery. The various models do not predict consistent values for minimum arctic column ozone. However, all the models predict that the Arctic ozone will recover earlier than the Antarctic ozone, mainly explained by circulation differences combined with a reduction in stratospheric temperatures.

6. UV measurements and levels

The Norwegian UV network was established in 1994/95 and consists of nine 5-channel GUV instruments located from 58°N to 79°N, illustrated in Figure 16. NILU is responsible for the daily operation of three of the instruments, located at Oslo (60°N), Andøya (69°N) and Ny-Ålesund (79°N). The Norwegian Radiation Protection Authority (NRPA) is responsible for the operation of the measurements performed at Trondheim, Bergen, Kise, Landvik, Finse and Østerås. On-line data from the UV network is shown at http://uv.nilu.no and at http://www.nrpa.no/uvnett/.

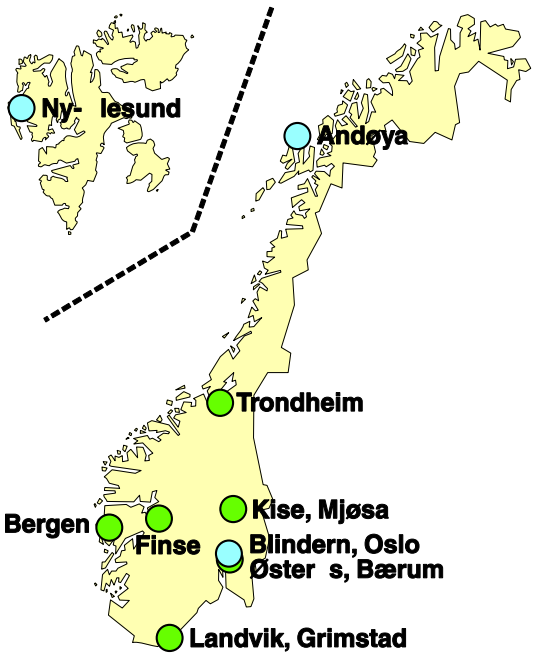

Figure 16: *Map of the stations included in the Norwegian UV network. The stations marked with blue are operated by NILU on behalf of The Norwegian Pollution Control Authority (SFT), whereas the Norwegian Radiation Protection Authority operates the stations marked with green.*

This annual report includes results from Oslo, Andøya and Ny-Ålesund. Due to lack of funding, the GUV instrument in Ny-Ålesund was omitted from the monitoring programme in the period 2006-2009, but was included again in 2010.

The Norwegian GUV instruments were included in a well-organised calibration and intercomparison campaign in 2005 as a part of the project FARIN (Factors Controlling UV in Norway)[3]. The project, which was financed by The Norwegian Research Council, aimed to quantify the various factors controlling UV radiation in Norway. This includes e.g. clouds, ozone, surface albedo, aerosols, latitude, and geometry of exposed surface. One part of the project has been the comparison and evaluation of all the UV-instruments in the Norwegian monitoring network. In total 43 UV instruments, including 16 NILU-UVs, were included in the campaign. The three GUVs from NILU were set up at the NRPA, Østerås, during the campaign and the calibration results were satisfactory.

The GUV instruments are normally easy to maintain and have few interruptions due to technical problems. The number of missing days due to technical problems in 2010 is given Table 8. The problems were computer related at both sites. The data loss in Oslo and Andøya does not account for any significant loss of the yearly UV-dose.

6.1 UV measurements in 2010

The UV dose rate is a measure of the total biological effect of UV-A and UV-B radiation (UV irradiance weighted by the CIE action spectra). The measurement unit for dose rate is mW/m^2, but it may also be given as a UV index. A UV index of 1 is equal to 25 mW/m^2. The

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

Table 8: *Number of days with more than 2 hours of missing GUV data in 2010 and 2009. Days where the sun is below the horizon (polar night) are not included.*

Station	Technical problems	
	2010	2009
Oslo	3	14
Andøya	4	12
Ny-Ålesund	0	0

concept of UV index is widely used for public information concerning sunburn potential of solar UV radiation. At Northern latitudes the UV indices typically vary between 0 – 7 at sea level, but can range up to 20 in Equatorial regions and high altitudes (WHO, 2002). Table 9 shows the UV-index scale with the recommended protections at the different levels. The recommendations are based on a moderate light skin type, typical for the Nordic population.

Table 9: *UV-index together with the recommended protection.*

UV-Index	Category	Recommended protection
11+	Extreme	Extra protection is definitively necessary. Avoid the sun and seek shade.
10 9 8	Very high	Extra protection is necessary. Avoid the sun between 12 PM and 3 PM and seek shade. Use clothes, a hat, and sunglasses and apply sunscreen with high factor (15-30) regularly.
7 6	High	Protection is necessary. Take breaks from the sun between 12 PM and 3 PM. Use clothes, a hat, and sunglasses and apply sunscreen with high factor (15+).
5 4 3	Moderate	Protection may be necessary. Clothes, a hat and sunglasses give good protection. Don't forget the sunscreen!
2 1	Low	No protection is necessary.

Figure 17 shows the UV dose rates measured at noon (averaged between 10:30 and 11:30 GMT) for Oslo, Andøya and Ny-Ålesund. The highest UV dose rate in Oslo, 173.0 mW/m^2, was observed 7 July and is equivalent to a UV index of 6.6. The black curves are the measurements and the red curves are model calculations employing the measured ozone values and clear sky. At Andøya the highest UV index was 4.8, with a dose rate of 119.2 mW/m^2, observed 3 July. The highest UV index value for Ny-Ålesund was 65.1, or 65.1 mW/m^2, and was measured June 24. The maximum in Oslo was observed during clear sky conditions and somewhat lower ozone values than the normal, the total ozone column was 316 DU (normal ~ 340 DU) and the corresponding values at Andøya was 316.3 DU (normal ~ 350 DU) during broken clouds condition. At Ny-Ålesund there were clear sky conditions and a very clear atmosphere and a normal total ozone column of 363 DU. The combination of lower ozone and broken clouds has a forcing effect on the UV-radiation at the ground (shown in Figure 17). At these UV-levels a typical Nordic skin type gets sunburnt already after 20 min if no protection is used.

Many people from Norway visit Mediterranean countries during holidays, and UV-indices may easily become twice as high as in Oslo under conditions with clear sky and low ozone. In

Norway the highest UV dose rates generally occur in the spring and early summer in snow covered alpine locations, such as Finse. In such areas the UV indices often reach 8 in this period.

The seasonal variation in the observed UV dose rate is closely related to the solar elevation. The highest UV levels normally occur during the summer months when the solar elevation is highest. In addition to solar elevation, the UV radiation is influenced by e.g. clouds, total ozone and ground reflection (albedo). Varying cloud cover mainly causes the large day-to-day variations in the UV radiation. However, rapid changes in the total ozone column, as may occur during the spring, may also give rise to large fluctuations in the UV-radiation from one day to another. In general the UV-radiation in Ny-Ålesund is largely enhanced during spring due to relatively high albedo from the snow and ice covered areas around the site.

Monthly mean noon UV indices in for Oslo, Andøya and Ny-Ålesund in 2010 are compared in Figure 18. As expected, the monthly UV doses in Oslo were significantly higher than the values observed at Andøya and Ny-Ålesund. If the cloud and ozone conditions at all three sites are similar during the summer, the UV-radiation is highest in Oslo due to higher solar zenith angles most of the day.

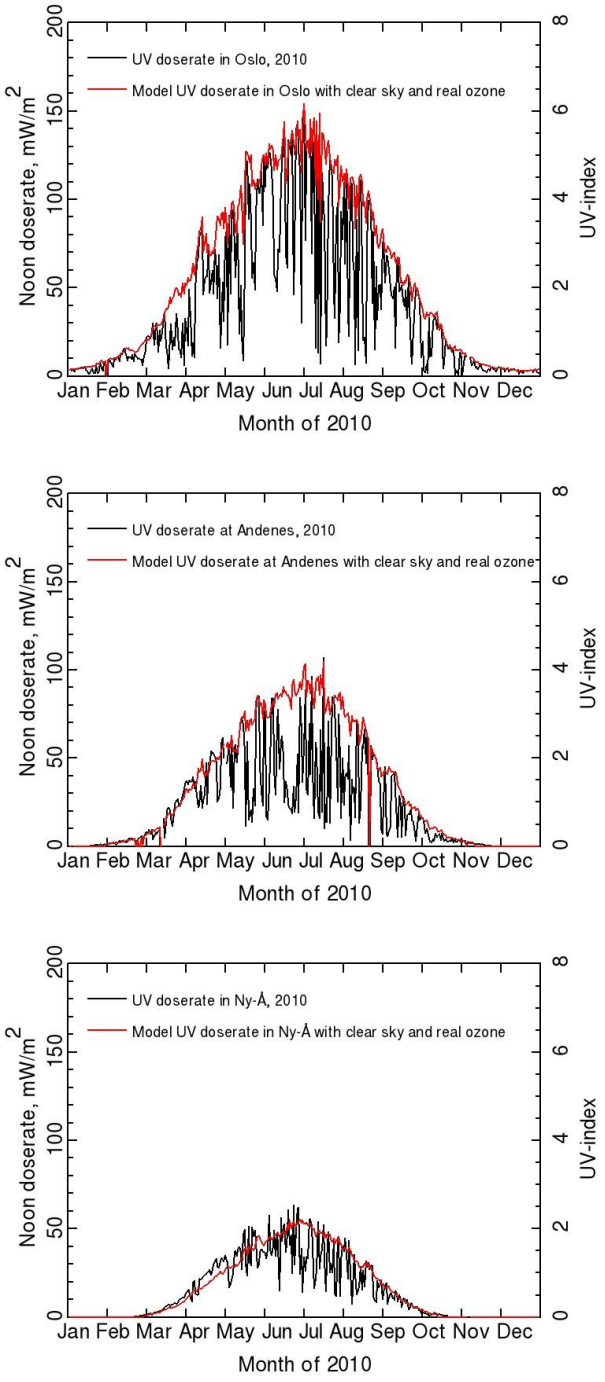

Figure 17: *Hourly averaged UV dose rate measured at noon (between 10:30 and 11:30 GMT). Upper panel: Oslo. Mid panel: Andøya. Lower panel: Ny-Ålesund.*

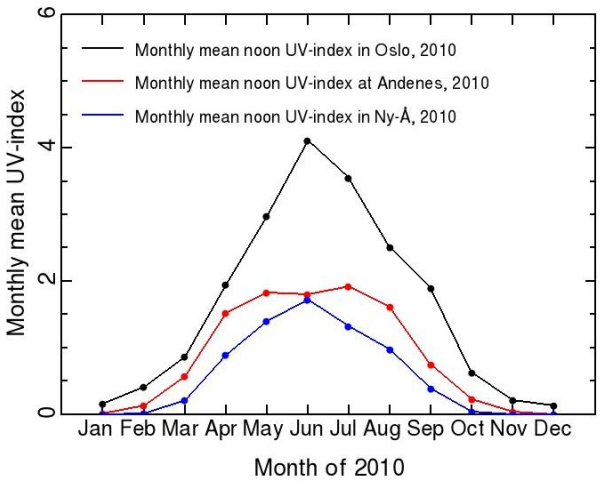

Figure 18: *Monthly mean UV indices in 20010 measured with the GUV instruments located in Oslo, Andøya and Ny-Ålesund.*

6.2 Elevated UV levels due to low ozone episodes in 2010

In 2010 there were few periods with low ozone values during spring and summer months but one episodes in mid April. At 14 April the ozone value in Oslo was 17 % below the long term mean and the corresponding UV index was 3.5. At Finse, which was still snow covered and is located at high altitude (1222 m a.b.l), the UV index was 5.3 at 15 April. Satellite data are crucial in determining the geographical extend of such low episodes

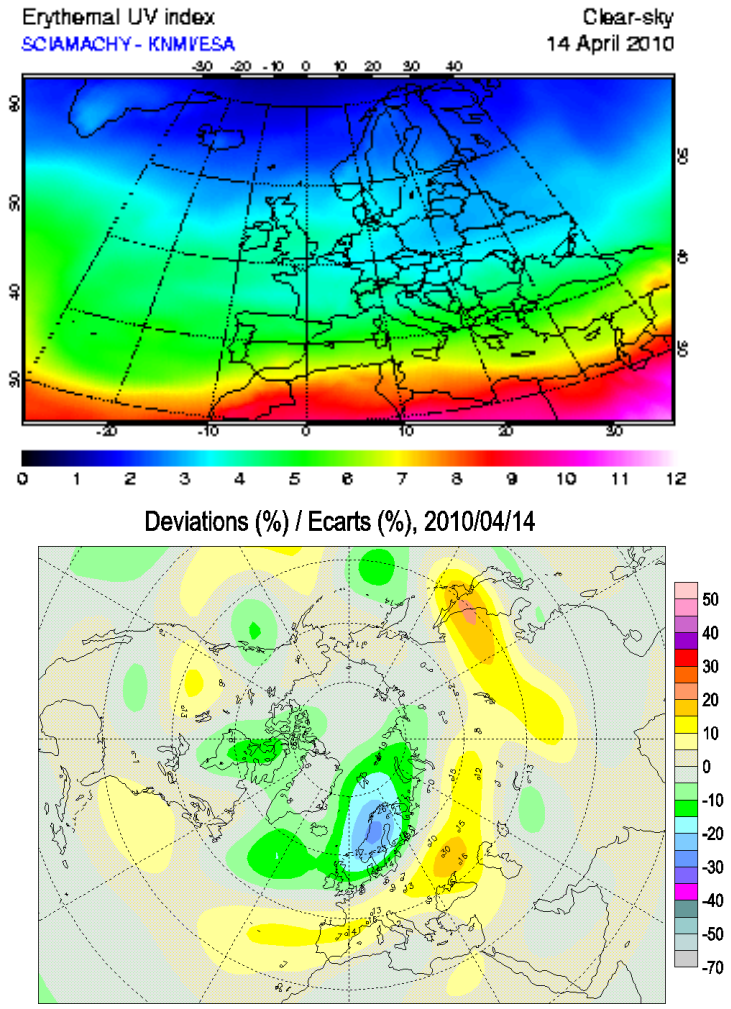

Figure 19 (upper panel) shows the European erythemal UV index retrieved from SCIAMACHY 14 April 2010 with high values in the southern part of Norway. The lower panel shows the deviation in ozone from daily normal values. This map is prepared by the World Ozone and Ultraviolet Radiation Data Centre. The map shows that Scandinavia including Svalbard experienced low ozone values, around 10-25% below the mean value.

Figure 19: *Upper panel: European erythemal UV index from SCIAMACHY at 14 April 2010. Lower panel: % deviation in total ozone at the same day. (Map from the World Ozone and Ultraviolet Radiation Data Centre.)*

6.3 Annual UV doses 1995 – 2010

Annual UV doses for the period 1995 – 2010 are shown in Table 10 for the GUV instruments in Oslo, at Andøya and in Ny-Ålesund. Annual UV doses for 2005 are not included in the Table as there were large gaps in the data set caused by a calibration campaign. The uncertainty in the daily UV doses is estimated to ±5 % at a 2σ level (Johnsen et al., 2002). For periods with missing data we have estimated the daily UV doses from 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 is ±2 % for 2000 and ±5 % for 2001. In 2009 Oslo had the second highest annual integrated UV-dose since 1997, and Andøya had the third highest UV-dose since the instrument was moved to this location in 2000. The annual doses were lower in 2010. This is mainly due to variations in cloud cover.

The time series of UV doses are still short for trend analysis. However, a graphical illustration of the yearly integrated UV-dose is shown in Figure 20, as there is an increased focus on measurements of solar radiation in relation to the so-called dimming and brightening.

Table 10: *Annual integrated UV doses (kJ/m2) at the three stations during the period 1995 – 2010.*

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		Excluded from the program
2004	373.2	243.7		190.5
2005	No annual UV doses due to gaps in the data caused by a calibration campaign			
2006	372.4	219.4		Excluded from the program
2007	351.8	253.3		Excluded from the program
2008	375.3	266.5		Excluded from the program
2009	378.6	254.1		Excluded from the program
2010	360.5	225.6		201.6

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

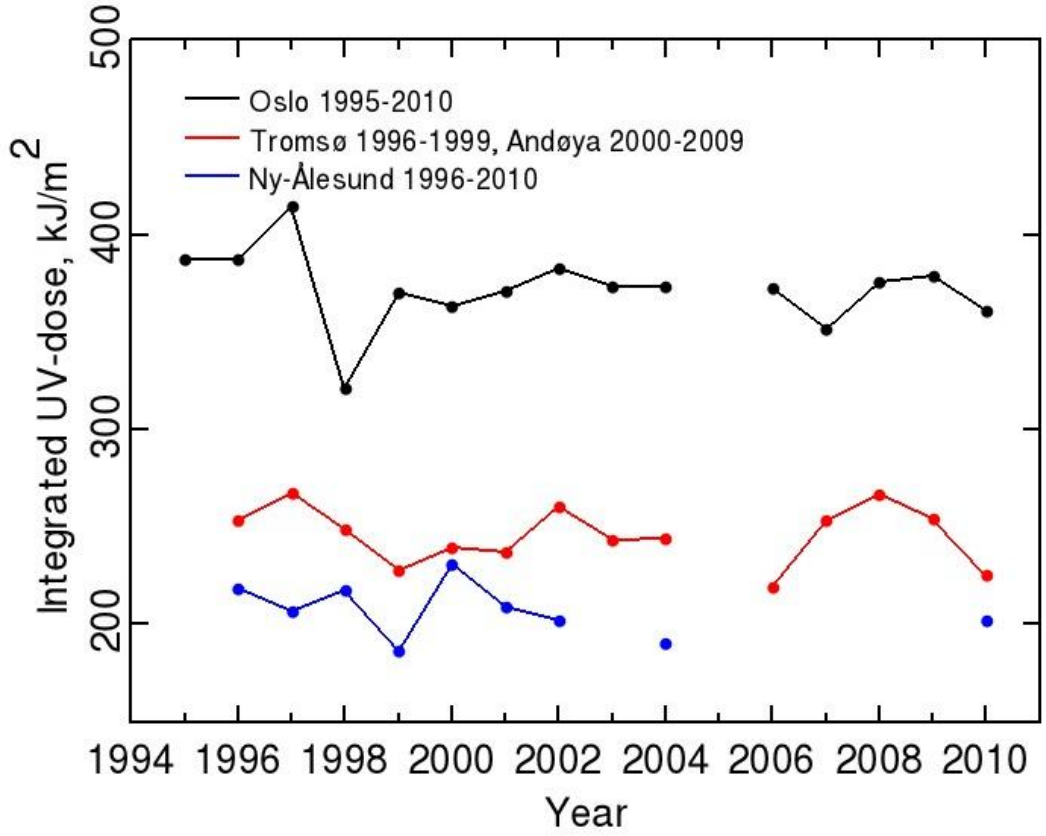

Figure 20: *Annual integrated UV doses (kJ/m^2) at Oslo, Tromsø/Andøya and Ny-Ålesund during the period 1995 – 2010.*

7. Comments on long term changes in UV and coupling to changes in ozone, pollution and aerosols

Global dimming is a process where atmospheric aerosols reduce the radiation received by the earth surface through scattering and absorption of solar radiation. Understanding of global dimming is of crucial important in the investigation of climate change; because aerosol dimming may mask the temperature rise at the surface caused by the increase of greenhouse gases. A study presented in Science in May 2005 (Wild et al., 2005) shows that the surface levels of total solar radiation from 1990 to present has increased. In a collaborative work (Kvalevåg et al., 2009) using data from the monitoring program we studied the effect of human-induced changes in the surface erythemally weighted ultra-violet radiation (UV-E) since 1750. In addition to the effect of changes in ozone, we also investigate the effect of changes in SO_2, NO_2, the direct and indirect effects of aerosols, albedo changes and aviation-induced contrails and cirrus. The results show an increase of surface UV-E in polar regions, most strongly in the Southern Hemisphere. Furthermore, the study also shows an extensive surface UV-E reduction over most land areas; a reduction up to 20% since 1750 is found in some industrialized regions. Based on the work, we argue that SO_2, NO_2, ozone, and direct and indirect effects of aerosols have reduced surface UV-E by up to 15–20%, during the industrial era. The strongest reduction is seen over South East Asia, Europe and North America.

It has previously been indicated that pollutants could mask expected increase of UV from stratospheric ozone depletion, especially through absorption of black carbon over urban areas. We show that this has occurred over most land regions through the time period 1750-2000. This UV-dimming has similarities with the dimming of total solar radiation at the surface. Changes in ozone, aerosols, pollution and clouds influence the UV level and long-term changes in the solar radiation received at the earth surface. An implication of this study is that future changes in UV radiation clearly depend on a complex mixture of factors, among them ozone and atmospheric pollutants. This links health, UV radiation, air pollution, and climate change. It is therefore essential to continue the UV and ozone monitoring activity in the future to observe and investigate long-term variations of ground level solar radiation.

8. UV-radiation, vitamin D, and breast cancer in Norway

During the last two decades intensive research has suggested that vitamin D has a preventive effect on some autoimmune diseases (Cantorna, 2000), some forms of cancer (Cui et al., 2006; Garland et al., 2006; Giovannucci et al., 2006; Giovannucci, 2006), and a positive effect on cancer. The exact biological processes involved still remains unclear, but it seem that vitamin D has multiple effects beyond the traditional role in the calcium regulation process. Vitamin D compounds have been demonstrated to have effects on cell cycle progression, differentiation and programmed cell death, which in general is cancer related. Thus, in the last few years there has been a discussion on whether moderate exposure to solar ultraviolet (UV) radiation has a positive overall health effect or not (Lucas et al., 2008). Sun exposure is an established risk factor for basal cell carcinoma, squamous cell carcinoma and melanoma (see e.g. Armstrong et al., 2001).

Some studies have shown that it is possible that solar induced vitamin D may have a preventive effect in developing breast cancer while other studies show no association. In the study of Edvardsen et al., 2009 it was not found any significant association between vitamin D intake or vitamin D effective UV-dose, and risk of breast cancer among women living at high latitudes. In fact there is an inverse relationship between UV-radiation and risk of breast cancer in the Nordic countries, for which the reason still remains unclear.

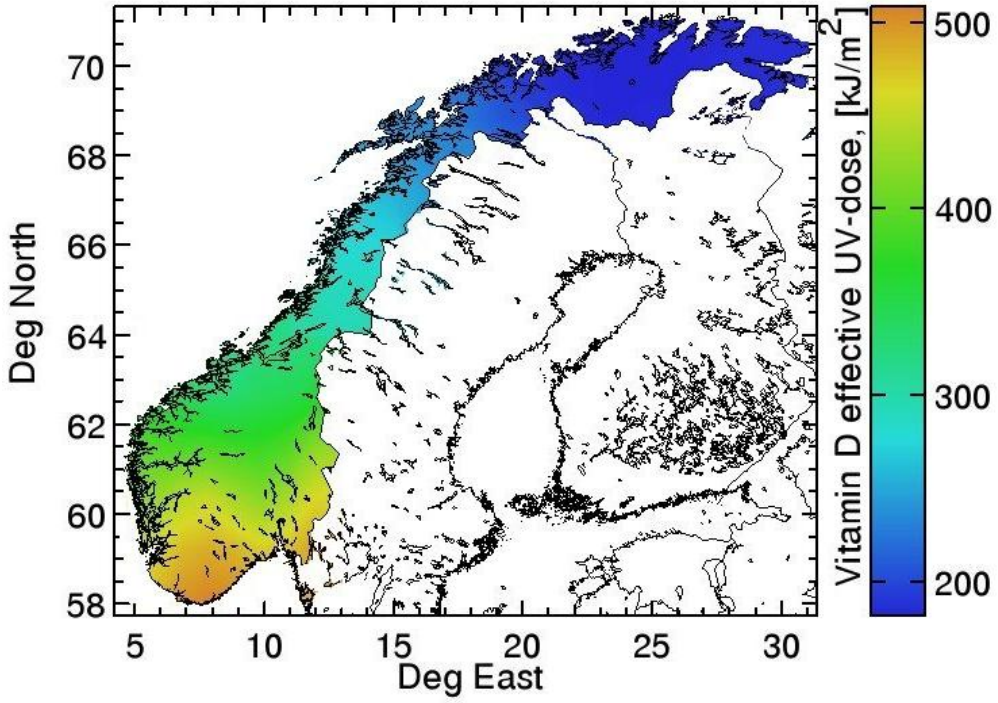

Figure 21: *Yearly mean vitamin D effective UV-dose, mean 1979 – 1998. All three main driving forces for vitamin D effective UV-radiation (total atmospheric ozone, cloudiness and solar zenith angle) are accounted for in the estimations.*

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KLIMA- OG FORURENSNINGS-DIREKTORATET

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Overvåking av ozonlaget og naturlig ultrafiolett stråling. Årsrapport 2010.

Monitoring of the atmospheric ozone layer and natural ultraviolet radiation. Annual report 2010.

Sammendrag – summary
Rapporten presenterer måledata for totalozon, vertikalfordelingen av ozon og UV-stråling over norske målestasjoner i 2010. For Oslo og Andøya er trenden i totalozon beregnet for perioden 1979-2010. Ozonverdiene over Norge var generelt høye i 2010. Den klare reduksjonen av ozonlaget over Norge i perioden 1979-1997 stoppet opp i 1998 og ozonlaget over Norge ser nå ut til å ha stabilisert seg.

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 2010.
2010 was a year with generally high ozone values above Norway. A clear decrease in the ozone layer above Norway during the period 1979-1997 stopped after 1998 and the ozone layer above Norway seems now to have stabilized.

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

Statlig program for forurensningsovervåking

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Om Statlig program for forurensningsovervåking

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

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

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. Klima- og forurensningsdirektoratet er ansvarlig for gjennomføringen av overvåkingsprogrammet.

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