Development of the Ozone Layer and UV Radiation at Svalbard – An assessment for MOSJ

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Introduction

The stratospheric ozone layer in Earth's atmosphere is the most powerful protection of all life on the land surface and in the surface layer of the oceans against lethal ultra-violet radiation from the sun and thus a precondition for the existence of life in these compartments. The effectiveness of the ozone layer for this purpose depends on the amount of ozone molecules per square unit integrated throughout the entire atmosphere, the so-called total column amount. It is given in Dobson units: 1 Dobson Unit of ozone (1 DU) amounts to an atmospheric layer of 0.01 cm pure ozone under surface pressure and temperature conditions (1013 mbar, 273.15 K). Most of atmospheric ozone is found in the stratosphere, an atmospheric layer extending from somewhere between 8 and 18 km up to about 50 km. At high latitudes the bottom of the stratosphere is typically at 10±2 km, thus increasing the thickness of the layer. In the lowermost part of the atmosphere, the troposphere, ozone levels are usually much lower than in the stratosphere. So, under normal conditions the ozone layer is thickest in the polar regions.

In the early 1980s, severe reduction of the ozone layer was observed in Austral spring in Antarctica, and the situation worsened from year to year. Around 1990, the reduction, now called Antarctic ozone hole, reached levels of about 70% of the total column (complete removal of ozone from 12 to 20 km altitude) and a geographical extent well beyond the Antarctic continent. The cause of the depletion was identified to be man-made chemicals: Chlorofluorocarbon compounds (CFCs), which are chemically stable at earth surface conditions but disintegrate in the stratosphere. Under the special geophysical conditions found in the polar stratosphere they initiate chemical processes leading to rapid destruction of ozone. Comprehensive descriptions of this development and the processes involved can be found in the dedicated assessments of the World Meteorological Organisation (WMO, 1995; WMO, 1999; WMO, 2003).

As a consequence of ozone depletion, UV irradiance increased to levels only found in tropical and subtropical regions otherwise. This development raised serious concern about a similar development at Northern high latitudes with severe consequences for the densely populated areas and lead to the start-up of comprehensive monitoring programmes of ozone and UV radiation in many countries worldwide.

In the following, an assessment of the development of the ozone layer over Svalbard since the early 1980s and resulting UV levels since 1995 is given. The limitation with regard to UV radiation is due to the start-up of coordinated UV measurements only in 1995, while ozone could be complemented with satellite measurements which started in 1979.

The ozone layer development over Svalbard since 1979

At high latitudes the ozone layer shows a pronounced annual cycle with maximum values in spring (April) and minimum values in autumn. The distinctiveness of the cycle increases with latitude. Figure 1 shows the annual cycle of total ozone monthly means for Arosa (48º N), Tromsø (69º N) and Svalbard (79º N). The day-to-day variability of total ozone is largest in spring and smallest in late summer.

In this assessment, we focus on two periods: spring (April) and summer (June). April is important because in this month ozone is very sensitive to the chemical processing due to CFCs. UV levels are noticeable, at the same time as biological production in marine ecosystems starts. In June, sun elevation is largest, causing maximum UV levels. On the other hand, ozone variability is smaller, and long-term changes are much less, so that this month can be regarded as a kind of baseline.

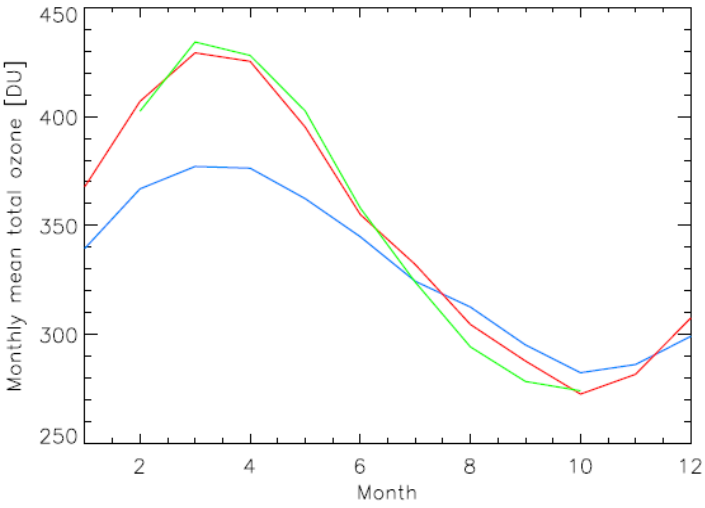


Figure 1. Annual cycles of total ozone monthly means at Arosa, in Switzerland (blue), Tromsø (red) and Svalbard (green), based on measurements before 1972.

Figure 2 shows total ozone monthly means in April (upper panel) and June (lower panel) from 1979 to 2004. The data series are composed from several sources both in-situ (SAOZ, Dobson, GUV) and remote sensing (TOMS), which are also shown individually with different colours (see figure caption).

The April values are characterized by a marked negative trend from 1979 until the mid-1990s with a very pronounced minimum in 1997. After 1997 total ozone has been generally higher than in the early 1990s. The negative trend is, however, not consistent throughout the above period; there are a number of years in between where ozone values are at the same level as at the beginning of the period. As described in Hansen and Svenøe (2005), this pattern reflects the processes influencing polar ozone in spring. In years with high ozone values in April, e.g., 1991, 1994, 1998 and 1999, the polar stratospheric vortex has broken up by then, leading to the normal maximum ozone values of the annual cycle. In years with a vortex persisting into April, ozone depleted air masses will cause reduced monthly mean total ozone. It is, however, not clear how much of the reduction is caused by the lifetime of the vortex and how much by the degree of depletion inside the vortex. In 1997 both effects combined: the vortex persisted throughout April and the depletion inside was severe.

Assuming a (negative) linear trend since 1979, an analysis of the period 1979 – 2003 yields a trend of –18 DU/decade or 4.2% per decade. Assuming that the depletion only occurs in years with a pronounced and long-lasting vortex and forcing the depletion to zero in the other years, the (modified) linear trend becomes –31 DU per decade or

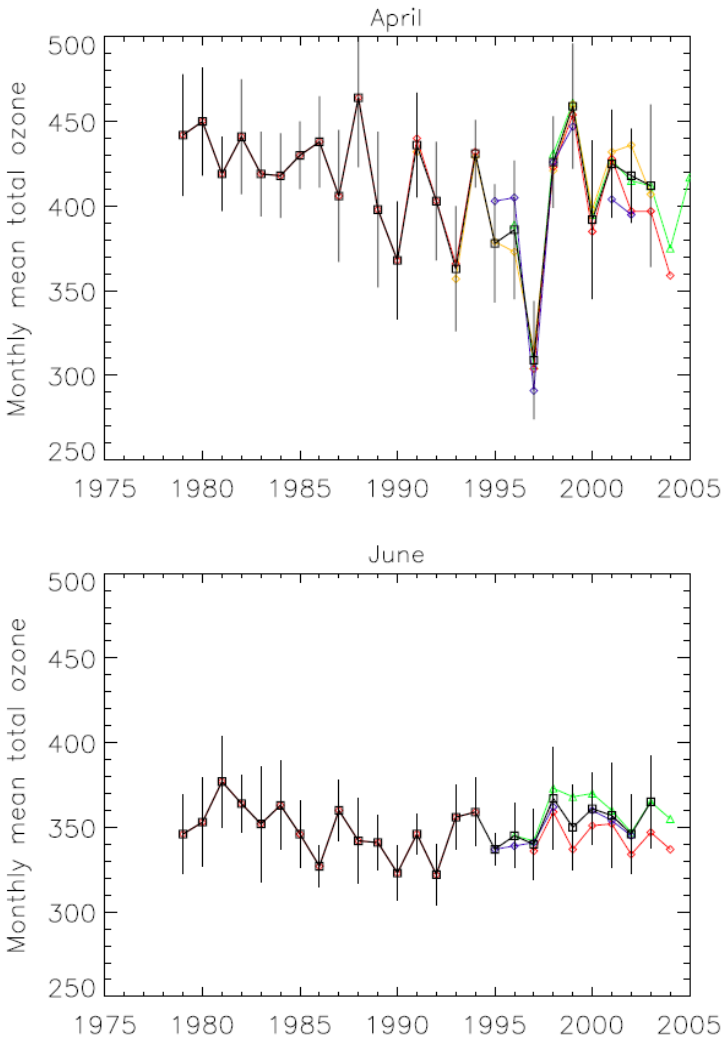


Figure 2. Total ozone monthly means for April (upper panel) and June (lower panel) with standard deviation of daily values included (vertical bars). Data series composed of TOMS data (red; used 1979-2001), SAOZ (yellow, 1991-2002; only April), Dobson (blue; 1995-2002), GUV (green; 1996-2004).

–7.2% per decade. The same value (-7.2%/decade) is found if one limits the trend analysis to the period 1979 – 1997, but in this case it does not matter if one chooses a simple linear trend or a modified version as outlined. In conclusion, the decisive parameter for future trends in total ozone in April is the lifetime (persistence) of the vortex in the winter season; in years with a stable vortex and low stratospheric temperatures severe ozone reduction will occur. Studies of data from Tromsø do, so far, not indicate a turn-around of ozone depletion trend follow the turn-around of atmospheric chlorine trends (Hansen and Svenøe, 2005).

The June monthly means, shown in the lower panel of Figure 2 do not show a significant long-term trend in total ozone over the last 25 years. A first detailed multi-linear regression analysis (Hansen et al., 2005) revealed a modified linear trend of 3 DU/decade or 0.8% / decade.

Since the beginning of this century, concentrations of CFC compounds in the stratosphere have stabilised and started to decrease due to phase-out in production and use in accordance with the Montreal Protocol. This is also seen in CFC measurements at Zeppelin Mountain, Ny-Ålesund. As a consequence, one can expect that the amount of ozone depletion in cold stratosphere winters will gradually decrease. However, with present rates of CFC concentration decrease, the pre-ozone-hole state of the stratosphere will be reached not before 2040-2050, assuming an otherwise unchanged stratosphere (temperature, water vapour content). Climate change (warming at the Earth's surface) is expected to cause a cooling and moisturising of the stratosphere, both of which will delay the recovery of the stratospheric ozone layer.

UV levels at Svalbard

Generally, UV radiation levels at a high-latitude site like Ny-Ålesund are relatively low, due to the small solar elevation even in summer. However, some factors can change this even in case of a normal ozone layer. Firstly, daily doses increase because of the midnight sun. In addition, UV levels are increased by the usually very low aerosol load (high transparency) of the atmosphere and, even during much of the summer half-year, the strongly enhanced surface albedo of snow and ice. The most important parameter for UV intensities (besides ozone in case of UV-B), however, is cloud coverage.

UV radiation has been measured continuously at Ny-Ålesund since June 1995 by means of a GUV multi-channel filter instrument. Figure 3 shows the monthly doses for April and June and the maximum daily dose in a two-weeks period centred around May 1 since 1996. As to be expected from the ozone monthly means, the UV monthly doses are highest in the mid-1990s and decrease throughout the decade. In April, the highest monthly doses are found in 1997 and 2000. In June, on the other hand, cloud coverage obviously plays an important role: The lowest ozone monthly mean is found in 1997, but also the UV monthly dose is (almost) lowest.

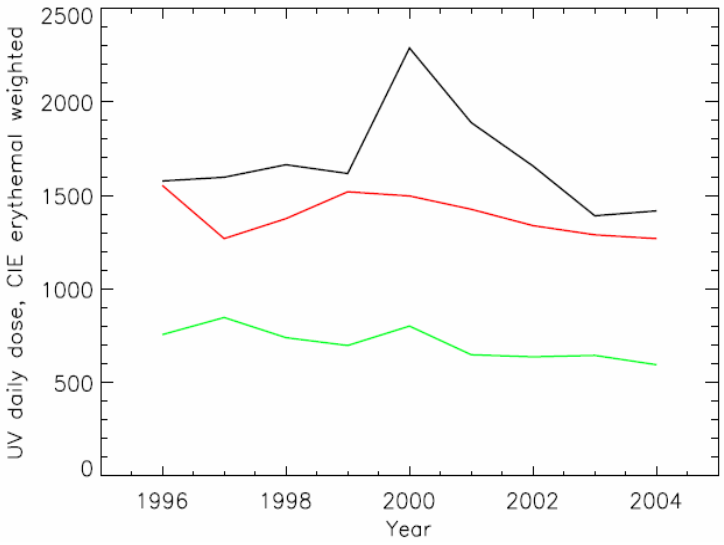


Figure 3. UV monthly doses (normalised to daily doses) and maximum daily dose around 1 May, all CIE erythemally weighted. Green: average April daily dose; red: average June daily dose; black: maximum daily dose around 1 May.

For biological processes with rapid changes in spring, maximum daily doses in the most active or vulnerable phase may be more important than doses integrated over a whole month. The maximum daily dose around 1 May ± 1 week, also shown in Figure 3, may be a more appropriate parameter for such a purpose. Not unexpectedly, this parameter shows a larger year-to-year variability, due to cloud coverage variability in this limited period. In the case shown here there is a pronounced maximum in the years 2000 and 2001.

In general, the available time series for UV (9 years) are not sufficient to make meaningful statements on long-term trends. In this particular case, the series started at the minimum point of a long-term trend in one of the important parameters, total ozone. This results in a negative trend for UV doses. The situation may be improved by reconstructing UV doses before 1996 by means of radiative transfer modelling, a technique which has been improved significantly in recent years (e.g., Engelsen et al., 2004). Here, the measured doses could be used for calibrating calculated doses.

References

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