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Scientific paper

Three years spectral resolved UV-measurements at Koldewey-Station (1997–1999)

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Abstract: In May 1997 long-term measurements of spectral resolved UV-B irradiation (wavelength range of the instrument 280 to 322 nm) at the NDSC-Station in Ny-Ålesund (Spitsbergen) were started using a self-developed very fast multichannel spectroradiometer. In March 1998 a multichannel UV-A spectro-radiometer was installed at Ny-Ålesund to supplement the spectral range of the measurements from 318 to 400 nm. For the evaluation of the data with regard to changes in total ozone the ratio of the measured irradiation at two wavelengths (300 nm/320 nm) has been used to minimize the influence of other atmospheric parameters like clouds or aerosols. This ratio, called ozone index, is compared with ozone sonde data as well as daily TOMS data of total ozone. This comparison shows a good anticorrelation between the irradiation at short wavelengths and total ozone. Apart from ozone, influences of clouds and varying ground albedo have been investigated. The evaluation of the UV-B data has been supported by radiative transfer modeling.

1. Introduction

Since the discovery of the Antarctic ozone hole first noted by Chubachi (1984) and Farman *et al.* (1985), and more recently the seasonal ozone depletion in the northern high latitudes reported for example by Müller *et al.* (1997) and Rex *et al.* (1997), there is a strong interest in the changes of stratospheric ozone. A direct effect of ozone depletion is the increasing UV-B radiation reaching the Earth's surface. Comparison of UV data with total ozone were recently presented for mid latitude sites by Casale *et al.* (2000) or Krzyŝin (2000). The scattering of UV-B radiation by aerosols and clouds plays also an important and complex role. A change in UV climate may possibly be detrimental to the biosphere (*e.g.* to marine life in the upper layers of the sea or to terrestrial vegetation) and to human (*e.g.* skin cancer).

One of the main objectives of UV measurements is the observation of long-term trends in UV irradiance. Among the most interesting geographical regions to study the changes in UV radiation are Antarctica and the Arctic due to the strong ozone depletion observed in the polar regions. Since 1997 the Alfred-Wegener-Institute records continuously UV-B in Antarctica (at the German Neumayer-Station and at the Argentinean Station Jubany on King George Island) as well as on Spitsbergen (NDSC-Station Ny-Ålesund).

2. The UV spectroradiometers

For the best long-term stability of the instrument in remote areas like Spitsbergen it is advantageous to avoid any movable parts like rotatable gratings as essential in scanning spectroradiometric systems. For this reason we have designed a non-scanning spectroradiometer which is based on a Bentham DM150 double monochromator with a multichannel detector system. The DM150 is operated with a comparatively broad center slit to allow the simultaneous detection of the whole UV-B range at 32 wavelengths. A low-resistance microchannel plate photomultiplier tube (MCP-PMT) with 32 channels working in single photon counting mode is used as detector. Due to the fixed gratings, our spectroradiometer is less sensitive towards transport by ship or aircraft, and it does not require recalibration during the Arctic campaigns from March until October.

The spectral global irradiance is measured with a teflon cosine diffuser. However, the data presented in this work are not cosine corrected. The spectral range of the UV-B instrument is from 280 nm up to 322 nm which leads to a distance of 1.35 nm between two channels due to the 32 detection channels of the MCP-PMT. The simultaneous detection of the total wavelength range enables a comparatively high time resolution. A spectrum can be recorded every second. However, in the routine operation mode 5 min averages are stored by the computer. The whole system is mounted in a weatherproof housing and the temperature is stabilized within 1°C. The entrance optics are covered by a quartz dome. Humidity inside the housing is kept below 20% by means of a drying agent (P_2O_5).

The spectroradiometer is calibrated in a laboratory in Bremerhaven prior installation at Spitsbergen and after its return. A 1000W FEL quartz-halogen lamp is used which was calibrated by the Physikalisch-Technische Bundesanstalt (PTB). The main quality assurance is given by comparison of the absolute energy calibration before the campaign and after the instruments return. All changes found up to now in 3 years have been below 5% for all wavelengths. Apart from this absolute energy calibration we use a 200 W quartz lamp from a slide projector with a very precise and stable power supply, to check energy calibration in field. Wavelength calibration is performed in the laboratory and checked again in field using a Penray mercury lamp.

A slightly modified instrument was built to measure the UV-A range. It is installed at Ny-Ålesund since March 1998, measuring from 318 nm up to 400 nm with the 32 detector channels corresponding to a distance of 2.65 nm between two channels. Beside this, the UV-A and UV-B instruments are quite similar, with identical recording and data storing modus.

Figure 1 shows the UV-A/B spectrum measured at Ny-Ålesund for March 20th 1998 at local noon. Results for our UV-B instrument, obtained during a German intercomparison of UV spectroradiometers in 1997 in Garmisch-Partenkirchen, are described in a report by Seckmeyer *et al.* (1997).

3. Daily UV-B irradiance

Figure 2 shows the daily UV-B irradiances integrated from 290–320 nm for the years 1997–1999. In 1997 the measurements began in May, whereas in the following years they

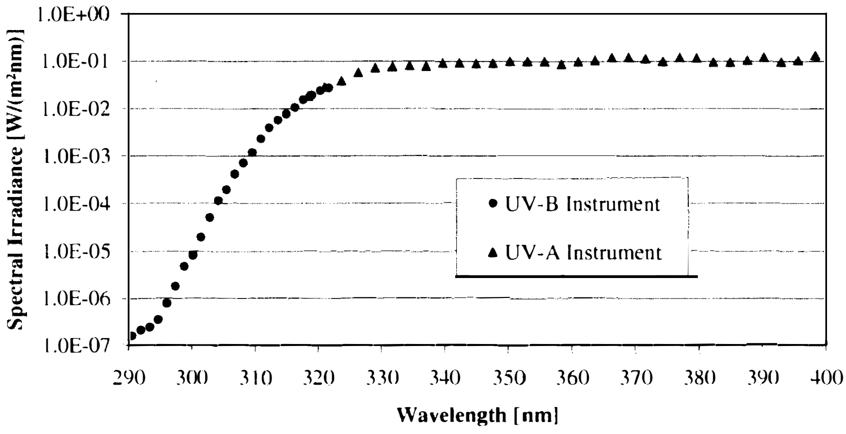

Fig. 1. UV-B/A spectrum measured at Koldewey-Station at March 20th 1998, 12.05 UTC.

restarted in March simultaneously with the polar sunrise. The figure shows the annual variation due to altering sun elevation with a maximum at midsummer with a large variability from day to day caused by fluctuating cloud conditions. A comparison of the three years also reflects the different weather situations. In 1998 there was a summer with a large amount of sunshine duration leading to 21 days with daily irradiance over 40 kJ/m^2. In 1997 only 10 days exceeded this value and in the summer of 1999, the value of 40 kJ/m^2 was exceeded only once.

Apart from these differences all datasets show a rather noisy distribution of daily irradiance due to the changes in attenuation by different cloud situations. This variation is low in spring before mid of May, high through the summer and starts to be low again in early (1998), mid (1997) or late (1999) September. This season dependent behavior of daily irradiance values is caused by changes in the ground albedo which shows a large annual variation around Spitsbergen. During winter and early spring the whole island and the frozen Kongsfjord, where the measuring site is located, is covered by snow leading to an albedo between 0.8 and 0.9. In late spring, when sea ice and snow are melting, the albedo decreases to about 0.1. Degünther *et al.* (1998) have recently shown that the ground albedo up to 50 km around the measuring site effects the UV radiation at ground. For this reason, melting of snow is a rather slow process in lowering the average albedo around the measuring site. In September a snow cover builds up again attended by a sudden increase of ground albedo.

Due to the high reflectance of the snow covered surface, the upward radiative flux on the ground is enhanced, compared to the snow free case. In the presence of clouds this upward flux is reflected downwards again. If clouds are absent the upward flux is scattered down again only by Raleigh scattering. The multiple reflection between snow and cloud cover enhances irradiance on the ground stronger than Rayleigh scattering only, this effect is recently evaluated for a measuring site in the Alps by Renaud *et al.* (2000). Thus the attenuating effect of clouds is partly compensated by this multiple reflection and daily irradiances in Fig. 2 are smoothed during the spring and autumn, when the measuring site is snow covered. The influences of ground albedo and cloud cover on the UV irradiance are evaluated by radiative transfer modeling in Section 6.

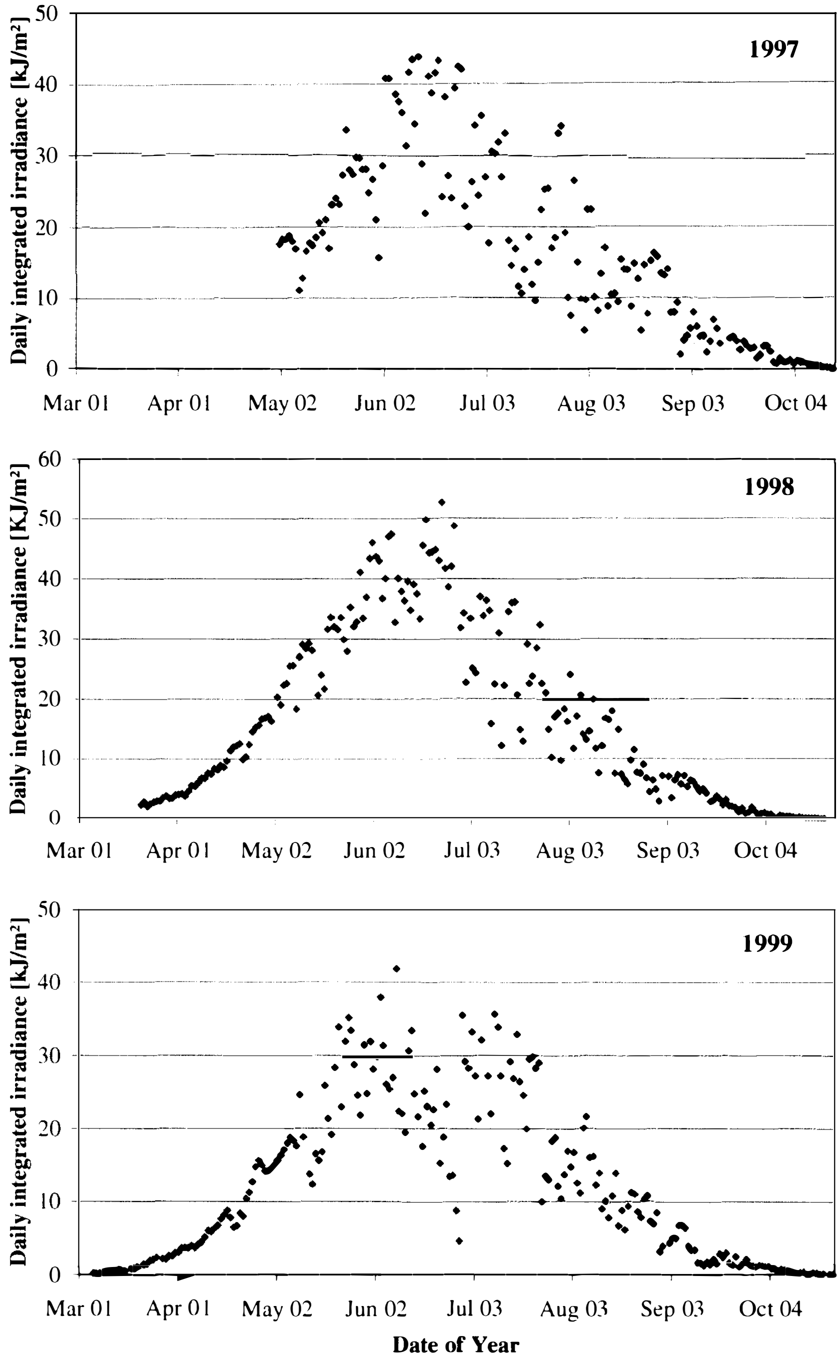

Fig. 2. Daily UV-B irradiances (280–320 nm) at Koldewey-Station.

4. Comparison of the UV-B data with total ozone columns

Apart from ozone, radiative transfer is influenced by several other atmospheric parameters like aerosols, clouds, etc.. To extract changes in the spectra which are due to varying total ozone values from other effects, we use the ratio of the spectral irradiance measured at two wavelengths I (300 nm)/I (320 nm). This ratio is called ozone index in the following. This method is the principle of a Dobson photometer. In the wavelength range 300 to 320 nm the influences of aerosols and clouds have only a very weak dependence on wavelength. Seckmeyer *et al.* (1996) showed that cloud transmittance is not independent from wavelength, but they found only a weak decrease in the transmittance in the UV range of about 10% from 300 to 400 nm. This decrease is almost linear and therefore the effect from 300 to 320 nm is only about 2%. Kylling *et al.* (1997) explain this wavelength dependence as an upward scattering of photons from the cloud particles, which are then downscattered by the wavelength dependent Rayleigh scattering. Nevertheless, Mayer *et al.* (1998) showed that an extensive optical path enhancement of the photons in very thick clouds occurs by Mie scattering. This enhancement leads to an additional strong wavelength dependent absorption of the shortwave radiation by ozone in the cloud, which could cause large errors in the results of algorithms for total ozone determination. These errors increase with an increasing amount of tropospheric ozone, particularly ozone in the cloud, and increasing solar altitude, because then the path through the stratospheric ozone layer reaches the minimum and the absorption in the cloud becomes more important in relation to stratospheric absorption. Because on Spitsbergen solar elevation angle does not exceed 35° and air pollution is low there, tropospheric ozone is not a serious problem in data interpretation.

For a comparison of UV-B data with total ozone columns, we use ozone sonde data available for Ny-Ålesund, see for example König-Langlo (1997). But for a day by day comparison sonde data are to rare. thus we use satellite data from the TOMS instrument (Total Ozone Mapping Spectrometer). There are several ground based measurements of ozone performed at Ny-Ålesund by FTIR, DOAS, Differential Absorption LIDAR and millimeter-wave observations. An extensive comparison of all ozone data available in Ny-Ålesund is given by Langer (1999), pointing out several limitations for every system. The TOMS satellite data available showed a very stable behavior in this comparison (Langer, 1999, p. 197) and seemed to be suitable for relating with our 3 years of UV-B data.

Figure 3 shows the ozone index calculated from the 1998 daily UV spectra. These data are compared with total ozone data from TOMS and ozone sonde soundings. All UV spectra were measured at the same solar elevation angle of 30° (*i.e.* airmass 2.0), because ozone absorption depends on the optical path length through the ozone layer. This airmass is reached at 79° North between May 17th and July 29th only, therefore the comparison is restricted to this period. The figure shows a good anticorrelation between total ozone and the ozone index. However, one has to consider that there are some principle error sources in the comparison of ground based and satellite data. At first, there is only a finite coincidence in the time of the daily measurements and second the satellite records an average value over a footprint of 40×40 km^2. Keeping this in mind, the remaining discrepancy between ozone sonde and TOMS total ozone data within 10% is quite reasonable.

For 1997 and 1999 the comparison of UV-B and ozone data looks similar to Fig. 3. More interesting is the actual change in UV-B at the ground due to changes in the total ozone. We compare the ratios of the ozone index and the total ozone day by day for two years using average values around noon (± 1 h) to extend the period of comparison. This

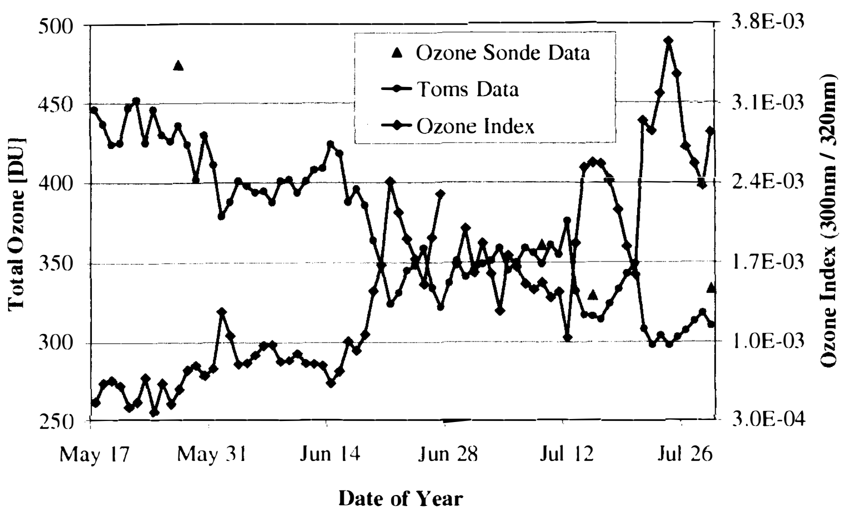

Fig. 3. Comparison of total ozone and ozone index at airmass 2.0 (Koldewey-Station 1998).

also weakens the possible error sources in the comparison with satellite measurements due to the footprint of the satellite. In Fig. 4 the ratios 1997/1998 are shown for the period from May to August, the solar elevation angle cancels down in the quotient. One can realize that small changes in the amount of total ozone cause large responses in the shortwave UV-B radiation at the Earth's surface. The picture is the same, when the 1999 data are included. In order to have a more quantitative comparison, we tried to find a functional correlation between the change in total ozone and in the ozone index. Assuming a simple Lambert-Beer law (1) to describe wavelength dependent attenuation of UV radiation by ozone we find equation (2) fitting the ratio of ozone indices as a function of TOMS data ratio. The parameter ΔB (0.0125 DU^{-1}) was fitted to the data of 97/98. This result quantifies the UV-B response to ozone variations: A 10 DU change in total ozone leads to a change of 12% in the ozone index.

$$I(\lambda)=I_0(\lambda)\exp(-B_\lambda[O_3]), \qquad (1)$$

$$O_3 \text{ Index } (97/98)=\exp(-\Delta B \Delta O_3), \qquad (2)$$

$$\text{mit: } \Delta O_3=[O_3]_{(97)}-[O_3]_{(98)} \text{ und } \Delta B=B_{300nm}-B_{320nm}.$$

Figure 5 shows the result of the fit in comparison with the ratio of the measured ozone indices (1997/1998). Despite some outliers the fit matches within 20%, which is quite reasonable concerning discussed error sources. At some days the deviation is larger as for example at May 30th 1998. The reason is a large spatial gradient in the amount of total ozone for these days. At May 30th TOMS measured 430 DU at Koldewey-Station (78.93°N, 11.95°E) but 402 DU only 0.1° further north (79.03°N, 11.95°E) which corresponds to a distance of just 11 km. A reduction of the total ozone value from 430 DU to 402 DU leads to a reduction of function (2) from 2.97 to 2.09. This fits much better to the measured ratio of 1.63. This shows that the comparison of ground based UV measurements and TOMS data for some days are difficult, but considering the whole measuring period such extreme conditions are rather unusual.

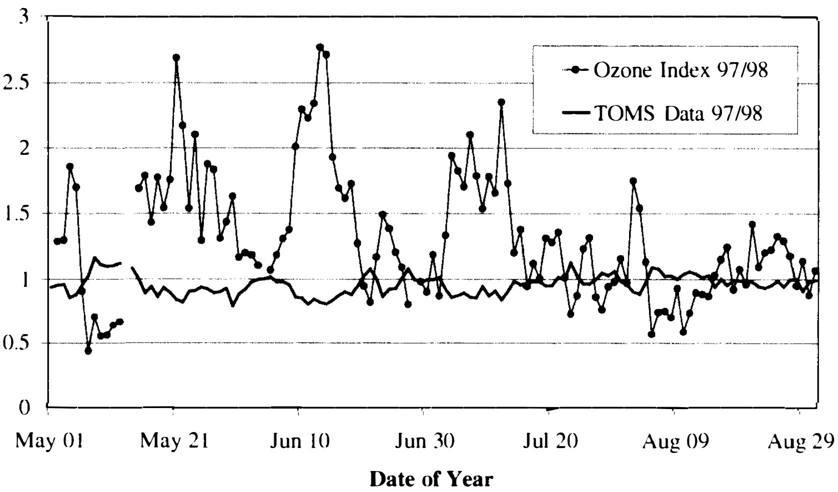

Fig. 4. Comparison of the ratios (1997/1998) of total ozone and ozone indices.

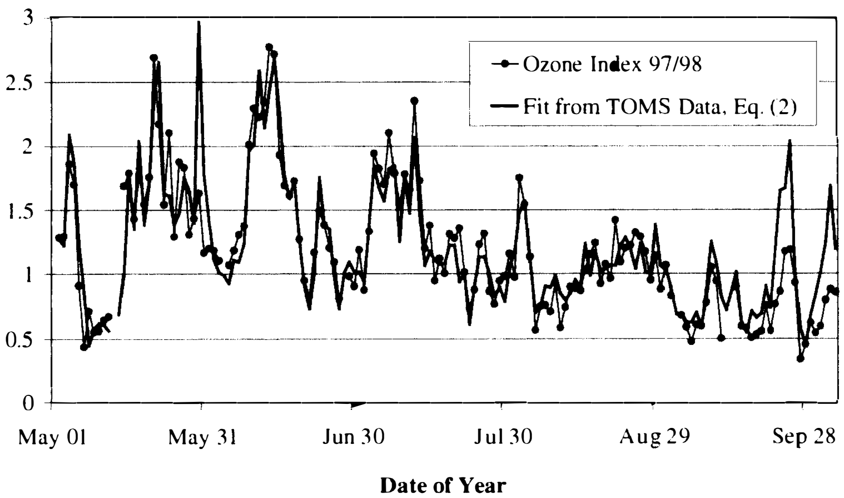

Fig. 5. The ratios of the ozone indices (1997/1998) as function of TOMS total ozone data.

We have been able to verify the relation between changes in total ozone and UV radiation on the basis of the 1999 data. Figure 6 shows the ratios 97/99 and 98/99 of the ozone indices in comparison with the fit. Although only the 97/98 data have been used for the fitting procedure it describes the ratios to 1999 as well.

5. Effects of clouds and ground albedo by UV radiative transfer modeling

The radiative transfer program *Libradtran* developed by Kylling and Mayer (1998) was applied to study the effects of clouds and ground albedo on the UV irradiance on the ground. *Libradtran* is based on a numerical solution of the 1 dimensional radiative transfer equation using the discrete-ordinate algorithmn introduced by Stamnes *et al.* (1988) or

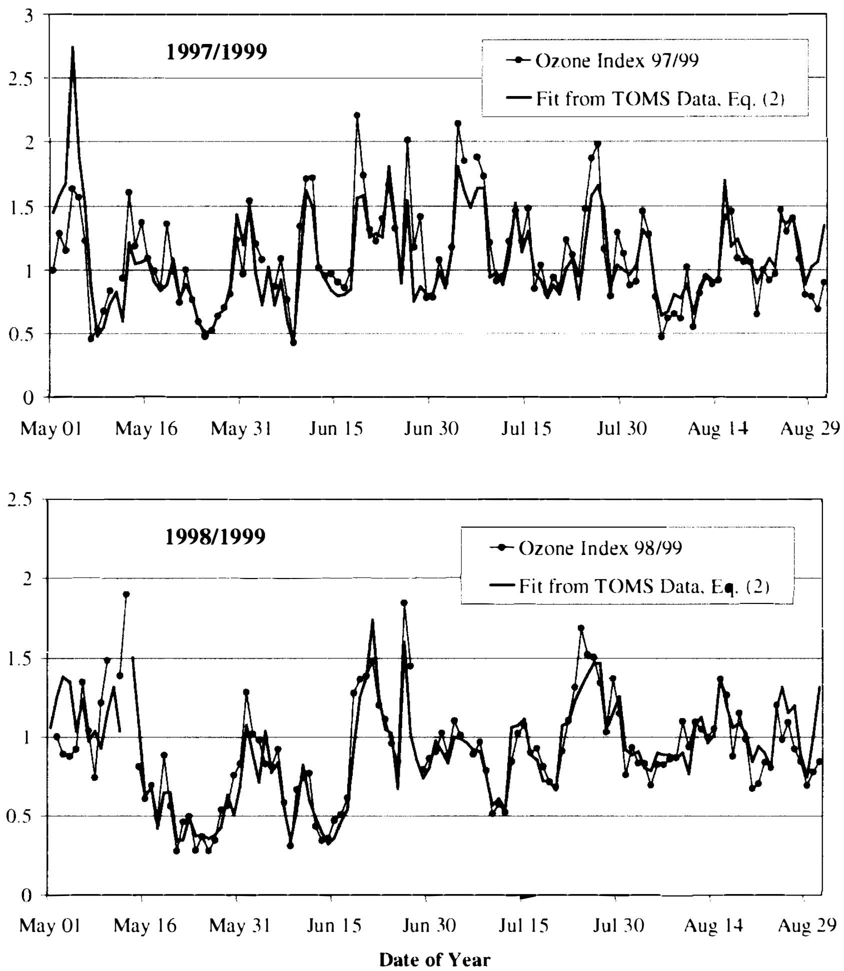

Fig. 6. The ratios of the ozone indices as function of TOMS data regarding to the 1999 data which were not included in the fitting procedure (eq. 2).

optional the two-stream radiative transfer solver. Due to the 1 dimensional description all cloud scenarios studied in the following are homogeneous cloud layers. Parameters to define these cloud covers are the altitude of the lower and upper cloud boundary, the liquid water content and the effective droplet radius. In this parameterization the optical properties of the cloud are calculated as described by Hu and Stamnes (1993). Aerosols are taken into account by employing the aerosol model of Shettle (1989).

For modeling of the interaction between cloud cover and ground albedo concerning UV radiative transfer we studied different cloud scenarios combined with the ground albedo of a snow covered (0.8) and a snow free (0.1) landscape. Figure 7 shows the modeling results for both albedo cases in a clear sky scenario and with a homogeneous cloud cover (with a lower/upper cloud boundary of 1 km/2 km, a liquid water content of 0.3 g/m^3, and an effective droplet radius of 10 micron). All calculations were done for 25° solar altitude, a total ozone value of 300 DU, and moderate maritime type aerosol conditions.

The figure shows that the cloud cover leads to a reduction of the spectral irradiance

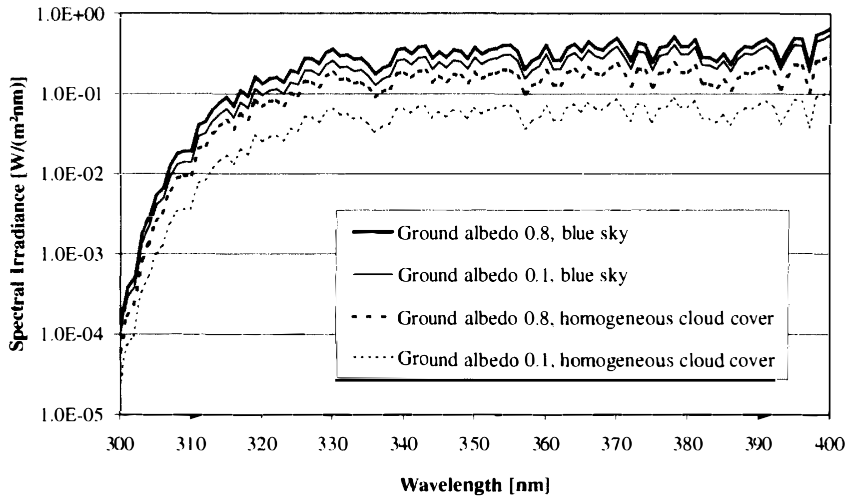

Fig. 7. Influence of ground albedo and clouds on UV irradiation at ground. The homogeneous cloud layer is determined through a lower boundary at 1 km, an upper boundary at 2 km, a liquid water content of 0.3 g/m³, and an effective droplet radius of 10 microns. All calculations were carried out at 25° solar altitude, 300 DU and moderate maritime type aerosol conditions.

Table 1. Integrated UV-A/UV-B irradiance at ground for 25° solar elevation in different ground albedo and cloud scenarios divided by clear sky values.

	Cloud 1	Cloud 2	Cloud 3
Ground Albedo 0.8	0.510/0.489	0.432/0.423	0.388/0.374
Ground Albedo 0.1	0.228/0.262	0.208/0.182	0.175/0.152

Cloud 1: liquid water content 0.3 g/m³, lower/upper boundary 1 km/2 km
Cloud 2: liquid water content 0.5 g/m³, lower/upper boundary 1 km/2 km
Cloud 3: liquid water content 0.2 g/m³, lower/upper boundary 1 km/3 km
Effective droplet radius for all clouds: 10 microns

at ground which is much larger in the snow free case. The reason for this behavior is the occurrence of multiple reflection between the snow surface and the cloud as discussed in Section 2. Table 1 gives quantitative results for the integrated irradiances (UV-A and UV-B) assuming different cloud scenarios. The reduction of the irradiance in snow free situations is more than twice as much as in the snow covered case. This gives the explanation for the obvious increase of noise in the daily UV irradiance during the melting of the snow in late spring and noise reduction with the first snowfalls in late summer shown in Fig. 2. The smoothing is not dependent on the weather condition of each single day. It is a more statistical statement in consequence of shifting up the-due to clouds-lower daily irradiance values of the ensemble in relation to the high values (sunny days).

6. Conclusions

During the first three years of our monitoring program the instrument proved to be very stable and to work reliable under the extreme climatic conditions at Spitsbergen. Comparing the data from different years, the results show that the dominant influences are weather conditions and ground albedo. Due to the strong effects of clouds and the steep increase of intensity towards the long wavelengths, which are only little affected by ozone absorption, the influence of total ozone on radiative transfer is not visible in comparison to the measured integrated irradiance. The only visible effects are on the shape of the spectrum, represented by the ozone index. The data show an amplification of the 300 nm radiation at the surface by 12% for every 10 DU ozone loss with respect to 320 nm. Regarding a trend in UV radiation on the ground, as a result from all possible effects, it can be revealed that a longer period of observations is still needed before reliable statements can be made.

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