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Transmittance of a cloud is wavelength-dependent in the UV-range

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Abstract. Spectral irradiance measured at two stations at different altitudes (the Zugspitze-summit at 2964 m a.s.l. and the Fraunhofer-Institute for Atmospheric Environmental Research at 730 m a.s.l., 8 km apart in horizontal direction) was used to examine the spectral attenuation of the UV-irradiance by a homogeneous cloud-layer at an altitude of about 1200 m. Calculating the ratio of the global spectral irradiance beneath a homogenous cloud-cover (22 October, 1995) to the global spectral irradiance on a cloudless day (24 October, 1995) both measured at the valley station, delivered the spectral transmittance of the cloud. By means of data measured on the Zugspitze on the same two days possible differences in the atmospheric conditions above 2964 m were eliminated and thus the influence of the cloud on the UV-irradiance at Garmisch-Partenkirchen was separated. The transmittance of the cloud-layer was found to be wavelength-dependent, ranging from 45% in the UVA to 60% in the UVB. Therefore it can be assumed that clouds are not generally "grey" (i.e. that the attenuation is dependent on wavelength).

Introduction

One of the strongest impacts on ground-level UV-irradiance is caused by clouds. Previous studies have shown that clouds can both decrease and, by reflection, increase UV-radiation on the ground for broken cloud cover [*Seckmeyer et al.* 1994]. It is undoubted that clouds can cause large year to year variability in UV and therefore play an important role in the determination of possible trends especially with respect to the biologically highly effective UVB radiation. Therefore it is important to know how the attenuation by clouds depends on the wavelength. A large number of studies assume that the attenuation by clouds is uniform across the UV-wavelength-band [*Webb* 1991] and use that assumption for the evaluation of the role of clouds in the ultraviolet radiation environment [*Frederick et al.* 1990, *Lubin et al.* 1991]. However first attempts have been made to investigate how the spectral transmission of clouds deviates from an assumed neutral density filter [*Nann and Riordan* 1991]. The present study gives an example for the attenuation by an almost homogenous cloud-cover which is not spectrally flat in the UV-range. It has to be kept in mind, that the measured irradiance at the ground is a combination of different effects, since cloud effects are modulated by the surface albedo [*McKenzie et al.* 1994]. For our study we use the term "transmittance of a cloud" for the ratio of UV-irrandiance with cloud cover and the UV-irradiance without cloud cover.

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Instrumentation and Sites

The spectral global irradiance is recorded continuously between 285 to 410 nm at two sites in different altitudes; the sampling-interval is 0.25 nm. One scan takes between 6 and 10 minutes. The instrumentation [*Seckmeyer et al.* 1996] meets the requirements proposed by the Network for the Detection of Stratospheric Change (NDSC) [*McKenzie et al.* 1995] and therefore is suitable for gathering data of high quality. One site is the summit of the Zugspitze (latitude 47°25′ N, longitude 10°59′ E, 2964 *m* above sea level), about 8 *km* in straight line from the Fraunhofer-Institute in Garmisch-Partenkirchen (IFU). The system is deployed on the roof of the terminal-building of the Bayerische Zugspitzbahn. This position permits an uninterrupted view of the sky in all directions, and the surrounding topography does not provide any obstacles to global irradiance measurements, except some buildings of negligible dimensions. The ground falls away towards north and north-east about 2000 m on the one hand, the sun rises behind the range of the Alps on the other. The second instrument is located on the roof-platform in the IFU-Institute (longitude 11°4′ E, latitude 47°29′ N) at an altitude of 730 m above sea level.

Spectral Transmittance of a Cloud

Concerted analysis of the data measured at both sites, Zugspitze and Garmisch, on selected days offers the possibility of separating various influences on the UV-irradiance by means of experimental methods only; an example is given here. The 22nd and the 24th of October are the days chosen to examine the spectral influence of clouds on the UV-irradiance on the ground. On the Zugspitze the sky was perfectly clear at both days, whereas in Garmisch-Partenkirchen, the sky was mostly overcast on 22 October, 1995 and cloudless on 24 October, 1995. Cloud cover on the 22nd was closed and almost homogeneous in an altitude of about 1200 m with a thickness between 100 m and 200 m after 11 a.m. CET (Central European Time), as observed by the German Weather Service from the observatory on the Zugspitz-summit. The minimum solar zenith angle (local noon) was 58.4 degrees on the 22nd and 59.1 on the 24th of

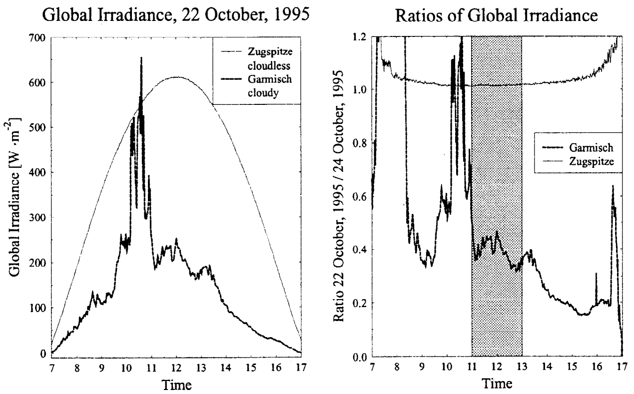

Figure 1. Left: Global irradiance at both sites on 22 October, 1995; **right:** ratio of global irradiance on the 22nd to 24th of October for Zugspitze and Garmisch

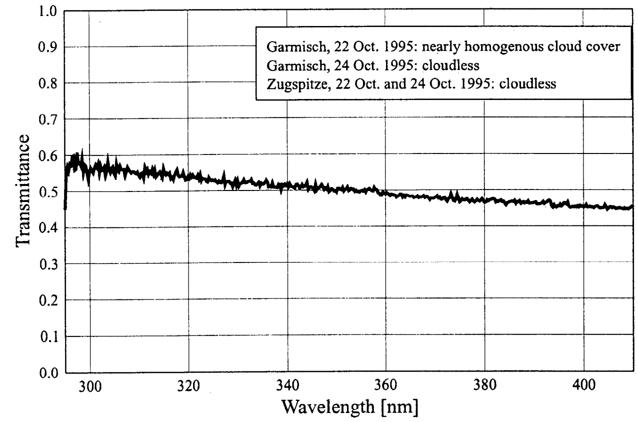

Figure 3. Transmittance of a homogeneous cloud cover at Garmisch-Partenkirchen on 22 October, 1995 as a function of wavelength

October, both at 12:00 CET. Ozone columns were derived from measurements of the direct solar spectral irradiance for the cloudless situations and found to be 254 Dobson units (DU) on 22nd October and 266 DU on the 24th at the Zugspitze and 276 DU on the 24th at Garmisch-Partenkirchen. In order to proof the comparability of the two days with respect to tropospheric ozone concentrations, we estimated the fraction of ozone column in the atmospheric layer between Zugspitze and IFU. Linear interpolation between in situ measurements of the ozone concentrations at three altitudes (IFU, Wank 1780 m a.s.l., and Zugspitze) [R. Sladkovic, personal communication] resulted in 8.1 DU for October 22 and 8.4 DU for October 24, respectively. This shows that the amount of tropospheric ozone was very similar on the two days. In figure 1 the global total irradiance measured with a Kipp & Zonen CM21 pyranometer on the 22nd is shown on the left hand side. The ratio of global irradiance on the 22nd and the 24th is smooth and almost at unity at the Zugspitze, whereas the ratio of both days at Garmisch shows strong variation due to attenuation by the cloud cover (right). Six spectra of both sites and both days have been averaged over a time interval in which variations of the irradiance are low, i.e. between 11 a.m. and 1 p.m. CET (indicated in figure 1 by the shaded area) using the arithmetical mean. The resulting spectra (22nd of October) are plotted in figure 2. From the information contained in the four spectra obtained (Zugspitze 22nd and 24th **and** Garmisch 22nd and 24th, each averaged over an interval of two hours) the differences in atmospheric conditions between the two days can now be eliminated and thus the spectral transmittance Υ of the UV-irradiance by this particular cloud can be calculated by:

$$\Upsilon := \left[\frac{E_{GAP,22ndOct.}(\lambda)}{E_{GAP,24thOct.}(\lambda)}\right] \cdot \left[\frac{E_{Zugsp.,22ndOct.}(\lambda)}{E_{Zugsp.,24thOct.}(\lambda)}\right]^{-1}$$

The resulting "cloud effect" on the 22nd of October in Garmisch-Partenkirchen is shown in figure 3. The transmittance of the cloud layer is between 60% in the UVB and 45% in the UVA. The spectral irradiance measured at the Zugspitze herein serves for the elimination of differences in atmospheric conditions between both days. Figure 4 shows the ratio of the averaged spectral irradiance at the Zugspitze on the 22nd of October to the 24th of October. In the UVB the ratio increases strongly since the total ozone column was 12 DU higher on the 24th than on the 22nd of October. The ratio does not show any wavelength-dependence above 330 nm.

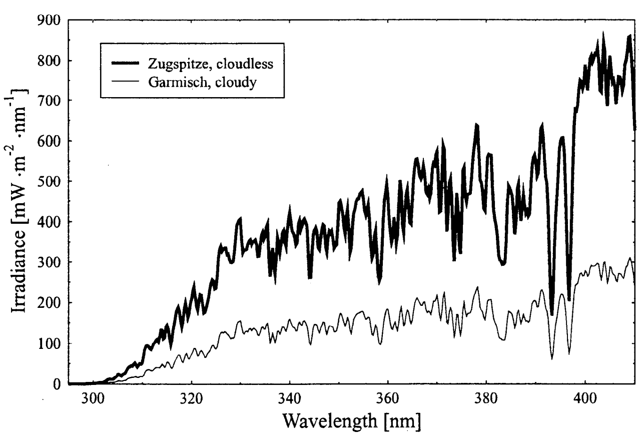

Figure 2. Averaged spectral global irradiance at Zugspitze and Garmisch on 22 October, 1995

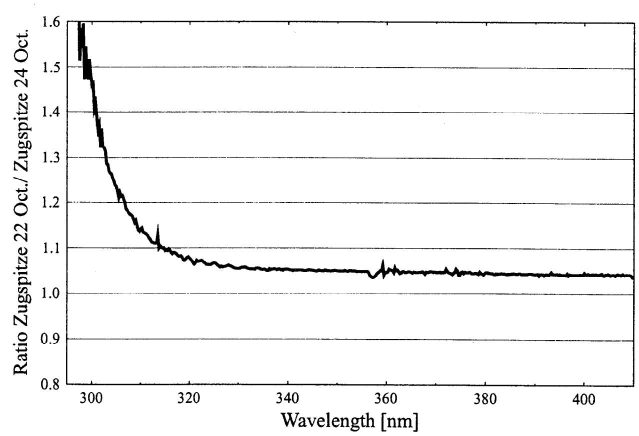

Figure 4. Ratio of averaged spectral global irradiance at Zugspitze on the 22nd to the 24th of October 1995

About half of the 5% difference in the UVA between the two days is due to the difference in the solar zenith angle. The flatness of the curve in the UVA range indicates that the found effect is not an artefact originating from comparing two days. The differences between both days are eliminated through the calculation above.

Discussion and Conclusions

The measurements presented above show that - after correction for effects of different atmospheric conditions on the two days - a cloud layer causes a wavelength-dependent attenuation of irradiance in the UV. This wavelength-dependence can be explained either by the wavelength-dependent scattering of radiation within the cloud or by redistribution of UV-radiation due to the cloud or more likely by a combination of both mechanisms [A. Kylling, personal communication 1996]. Further research is required to clarify this topic. Nevertheless, the cloud-effect found in this study is small compared to the wavelength-dependence of the ozone absorption cross-section in the short-wave UVB. It has to be emphasized, that the result of the above examination is only representative for this special day. Different clouds (i.e. different altitude, morphology etc.), especially inhomogeneous or broken cloud cover, will probably cause different effects. However the example proves that it can be assumed that clouds affect UV irradiance differently at different wavelengths.

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