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Factors affecting UV irradiance at selected wavelengths at Hoher Sonnblick

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ABSTRACT

The effects of clouds and surface albedo on spectral UV irradiance are investigated at the mountain observatory Hoher Sonnblick (47.05°N, 12.95°E, 3106 m a.s.l.) in the Central Austrian Alps. Spectral UV radiation in the presence of clouds is measured with a Bentham spectroradiometer along with detailed cloud observations. Ratios of measured to modeled clear sky UV intensities (cloud modification factors) are evaluated for over 9000 spectral UV measurements to quantitatively provide the dependency of cloud modification factors on total cloud amount, cloud type, wavelength, and effective surface albedo. Effective albedo can be altered through changes in snowline height and clouds below the station. Average albedo is increased by 0.28 ± 0.15 due to cloud cover $\geq 4/8$ below the observatory, accounting for cloud modification factors in the range of 1.02–1.14 in 75% of the investigated cases. Compared to snow-free conditions, an irradiance enhancement of 1.22 at 305 nm arises from a mean albedo of 0.68 and clear sky conditions, corresponding to a snowline height of 1000 m. Enhancements through augmented albedo can be considerably stronger under the presence of cloudiness. Enhancements through clouds are most commonly found with clouds below the station, accounting for about 40% of all cases of enhancements, often occurring in the presence of cumulus clouds (Cu, Sc, Ac) with an unobstructed solar disk. Analysis of total sky images reveals that enhancements can also be observed when the solar disk is obstructed by clouds or the sky is overcast.

1. Introduction

Clouds can cause strong variations in surface UV levels and limit the detectability of ozone-induced trends in UV radiation (e.g., (den Outer et al., 2005; Glandorf et al., 2005; Seckmeyer et al., 2008)). Also, change of cloud cover in the course of a changing global climate is of special interest for estimating future surface UV levels. Yet, most recent studies focus on UV trends based on ozone and temperature projections, but still explicitly exclude the influence of clouds on future UV levels (e.g., (Kazantzidis et al., 2010; Tourpali et al., 2009)). However, in the IPCC Fourth Assessment Report it is proposed that cloud cover over mid-latitudes may decrease by up to 4% by the end of the 21st century (Meehl et al., 2007). During an earlier period, Chubarova (2008) detected erythemally weighted UV irradiance enhanced by 2.1% due to increased effective cloud transmission in measured and reconstructed time series in Moscow since 1980. Similarly den Outer et al. (2005) found that reduced cloud cover and therefore lower attenuation can cause significantly raised doses of erythemally effective radiation. As important clouds are, they still represent one of the biggest problems in radiative transfer modeling, mainly because of a lack of adequate cloud description in the models (Bais et al., 2007).

Albedo is of great importance too, especially in seasonally snow-covered and mountainous regions. UV irradiance can be strongly enhanced with snow-covered ground due to multiple occurrences of scattering and reflection between the ground and the atmosphere, even more so under overcast sky conditions because of increased atmospheric backscattering. For example, Renaud et al. (2000) investigated the influence of snow cover

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and clouds at Davos, Switzerland, finding that snow-covered ground may increase erythemally weighted irradiance by 15–25% under cloudless conditions compared to snow-free ground. More recently, Reuder et al. (2007) found clear sky UV index values typically enhanced by 20% over the values measured over the adjacent areas with lower albedo at the salt-lake of Salar de Uyuni, Bolivia, due to the high surface albedo. Adding the influence of cloudiness, McKenzie et al. (1998) showed that, due to snow, UV-B increased by about 30% under clear sky and about 70% under cloudy conditions with an unobstructed solar disc at Lauder, New Zealand. Kylling and Mayer (2001) investigated the influence of snowline changes on UV irradiance at 340 nm, studying snow-free conditions and then moving the snowline from 1000 to 0 m at Tromsø, Norway. With descending snowline, enhancements in UV of 23–27% for cloudless sky were detected while for overcast conditions the enhancements were even higher, around 40–60%.

Multiple reflections of incoming radiation at the ground and cloud bases may not only decrease the attenuating effect of clouds on UV, but, in certain cases, also lead to surface UV levels that are higher than the respective values under clear sky conditions. Total cloud cover as well as the distribution of cloud types plays a crucial role in these cases. Low cloud fractions frequently lead to moderate enhancements because the sun is often unobstructed and the clouds are brighter than the sky that they hide. Accordingly, Herman et al. (1999) and Kerr et al. (2003) report significant enhancements under such conditions. More recently, Sabburg and Parisi (2006) found enhanced UV index values ranging from 20 to 30% above clear sky values at Toowoomba, Australia. As cloud fraction increases further, the sun is more likely to be obscured, causing irradiance values to significantly fall below clear sky values (Pfister et al., 2003).

Only few studies have previously focused on the spectral dependency of cloud modification factors in the UV (e.g., (Krzyścin et al., 2003; Pfister et al., 2003; Sabburg and Parisi, 2006)). In this study, the influence of clouds, surface albedo, and the combination of the changes herein are investigated to quantify their respective influence on spectral surface UV levels and to aid the estimation of future UV levels in the course of a changing climate. Also, the detailed description of the clouds' influence may help to further develop their incorporation in radiative transfer models.

2. Method and data

The mountain observatory at Hoher Sonnblick serves as a suitable platform to analyze the frequent and significant changes in surface albedo as well as complex cloudiness, including frequent cloud cover below the site, in the context of a complex terrain, supported by a broad array of measured atmospheric parameters that is available on-site.

2.1. Cloud modification factor

The influence of cloudiness on UV radiation at a specific wavelength λ, given as the ratio of measured UV irradiance under actual cloud cover $E(\lambda)_w$ to calculated clear sky UV irradiance $E(\lambda)_k$, is investigated. This ratio is called cloud modification factor (CMF).

$$CMF(\lambda) = \frac{E(\lambda)_w}{E(\lambda)_k} \quad (1)$$

Hence, the cloud modification factor is determined through a combination of actual measurements and radiative transfer model calculations. The one dimensional radiative transfer model DISORT (Mayer and Kylling, 2005) is used to determine the spectral UV irradiance for clear sky conditions at Hoher Sonnblick. The boundary conditions at the time of the spectral measurement are used as input data for the calculation. They are solar zenith angle, total ozone column, aerosol optical depth and surface albedo. The computed spectral irradiances for clear sky conditions are then compared to measured values acquired under actual cloud cover, yielding the cloud modification factor for a specific wavelength. $CMF<1$ denotes attenuation of incoming UV irradiance. $CMF>1$ indicates enhanced irradiance with respect to clear sky. This method was applied to all 9390 spectra that had been acquired during the investigated period (1998–2003).

2.2. Instrumentation

Spectral UV measurements at Sonnblick observatory have been performed with the single-monochromator Brewer MkIV #093 spectrophotometer since 1993 and a double-monochromator Bentham DM150 spectroradiometer since 1997, which is affiliated with the "Network for the Detection of Atmospheric Composition Change" (NDACC).

The Brewer measures spectral global UV irradiance in the spectral range from 290 nm to 325 nm with a step width of 0.5 nm and total ozone column several times per day. Two independent calibrations are performed on a regular basis (1–2 months) with a set of portable 50 W lamps (Sci-Tec Instruments Inc., Canada) and with a self-built portable 1000 W lamp-assembly, which is calibrated to another NIST (National Institute of Standards and Technology, United States) calibrated 1000 W lamp in the optical laboratory of the Institute of Meteorology.

The Bentham spectroradiometer is scheduled to measure spectral global irradiance in the spectral range from 280 nm to 500 nm with a step width of 0.5 nm every 30 min. It is calibrated periodically to the self-built 1000 W lamp-assembly, a NIST calibrated 1000 W lamp and a PTB (Physikalisch-Technische Bundesanstalt, Germany) calibrated 1000 W lamp.

Comparisons of the Brewer #093 with the travelling standard Brewer #017 and with the Bentham DM150 spectroradiometer are performed periodically. Comparisons of total ozone measurements with the traveling Brewer are available since 1993 and show deviations of less than $\pm 1\%$, comparative measurements in the UV-B range lie within $\pm 5\%$.

Spectra from the Bentham are used for the estimation of the cloud effects because of the instrument's advantage in temporal resolution over the Brewer, which contributes ozone data as input variable for radiative transfer modeling to the present study. Spectra are selected from the period 1998–2003 for availability of cloud observations and are classified for solar disk visibility and cloud conditions.

2.3. Cloud observations

Detailed synoptic cloud observations at Sonnblick observatory are carried out three-hourly by the Austrian weather