SOLAR HEALTH-EFFECTIVE UV RADIATION - SHORT-TERM FORECASTING AND MEASUREMENTS

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1 INTRODUCTION

Solar UV radiation has a number of effects on human health. Detrimental effects such as erythema and skin cancer can be triggered by high values of effective irradiance and/or high UV doses, while beneficial effects such as the production of pre-vitamin D3 from 7-dehydrocholesterol in the body and its subsequent isomerization to vitamin D3 (cholecalciferol), which is actually not a vitamin but a prohormone as it is built in the body, may be suppressed by low doses of UV radiation (Holick 2008). Vitamin D3 deficiencies result in impaired bone mineralization, and lead to bone softening diseases, rickets in children and osteomalacia in adults, and possibly contribute to osteoporosis. Among other beneficial effects, adequate vitamin D3 doses in the body appear to limit tumor progression (Boscoe and Schymura 2006).

While much attention of effective UV irradiance has been given in the past decades on the erythemal irradiance and forecasting its daily maximum values, more recent studies have shown that vitamin D3 deficiencies may occur especially in regions and seasons with high solar zenith angles (SZA), i.e. at mid and high latitudes particularly during winter, and for periods with high atmospheric ozone values and thick clouds. Future regional changes in cloudiness as a result of global climate change as well the long-term ozone recovery may also affect UV radiation. Higher vitamin D3 deficiencies can be expected to occur with the population living in large cities and urban areas, where the shading effect of buildings, the higher aerosol concentration and more cloudiness, as well as the higher rate of indoor stay lead to lower UV radiation doses compared to the population in rural areas.

In this study, we present results of a comparison between 24h-forecasts of the UV index issued by DWD, and UV index values derived from spectral irradiance measurements performed at the Meteorological Observatory Lindenberg (Germany). The 4-year data base of UV measurements and concurrent measurements of global irradiance and column ozone has been used to identify relationships between erythemal and vitamin D3 effective UV irradiance in dependence of SZA, column ozone and cloudiness. Optically very thick clouds can drastically diminish the ratios between vitamin D3 and erythemal irradiance. Vitamin D3 effective irradiance has not been included in the UV forecast yet, but its importance to the population especially in urban areas of mid and high latitudes makes it a potential candidate to be included in future UV forecasting.

2. FORECAST AND MEASURED ERYTHEMAL IRRADIANCE

2.1 UV INDEX FORECASTS BY DWD

DWD provides forecasts of the daily maximum of the erythemally effective UV irradiance by the application of a radiative transfer model to dynamical forecasts of total column ozone and to the results of DWD's numerical weather prediction system (Staiger and Koepeke 2005). The hourly based forecasts account for the impact of cloudiness by cloud modification factors. They are based on the predicted solar global radiation and comprise important effects for radiative transfer such as cloud optical depth, different cloud layers, multiple reflection and obscuration of the solar disc by clouds (Staiger et al. 2008). The UV index defined as the erythemal irradiance according to the action spectrum by CIE (1987) in (Wm⁻²)-multiplied by 40 is calculated from the forecast erythemal irradiance. UV index forecasts also include the effects of regional and seasonal varying aerosol amount and absorption. Independent variables of the aerosol function are solar zenith angle, aerosol optical depth (AOD) at 550 nm and single scattering (SSA) albedo at 300 nm, and 70% relative humidity. Since respective forecasts are not yet available, regional monthly mean values of AOD have been derived from monthly satellite measurements (NASA Moderate Resolution Imaging Spectroradiometer MODIS). An additional function accounts for the altitude effect on UV irradiance based on the height above sea level as well as AOD, SSA and SZA. In case of predicted snow cover the UV index is adjusted to the changed regional albedo.

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2.2 UV RADIATION MEASUREMENTS AT LINDENBERG

Solar spectral irradiance is measured by fast scanning spectroradiometers of the type SPECTRO 320 D in the spectral region 290 to 450 nm with 0.2 nm wavelength steps at the Lindenberg Observatory (52.2086° N, 14.1213° E, 127 m asl). One spectral scan that is repeated every minute takes about 23 s (Feister et al. 2008). Measurements are taken between sunrise and sunset. Biologically effective irradiances have been derived as wavelength-integrals of spectral irradiance that are weighted by action spectra of erythema according to CIE (1987) and vitamin D3 (CIE 2006) used as weighting functions. The highest 30-minute running average of individual UV index values between sunrise and sunset is defined as the measured daily maximum UV index.

2.3 COMPARISON BETWEEN UV INDEX FORECASTS AND MEASUREMENTS

Daily maximum UV index forecast values are compared with measured UV index values in Fig. 1 for all cases from 2005 to 2008. The UV forecast values are on the average slightly smaller (5 – 10%) than the measured values. If only UV index values for sunny forecast conditions are considered by selecting cases when the erythemal UV forecast for clear sky and for actual cloudiness differed by less than 10%, the forecast UV index is quite close to the measurements with 1 to 2% difference on the average. Outliers can mainly be attributed to cloud forecast errors or just a wrong timing of the cloud forecasts, as it is illustrated in Fig. 2 for a few dates by circles. In one case on May 6, 2006, an extreme aerosol load, which was due to natural aerosols probably from strong pollen emissions of plants, was identified to be the cause of the overestimated UV index forecast even for clear sky, because aerosol forecasts that would account for such an enhancement are not yet included in the UV forecasts.

3. RATIOS BETWEEN EFFECTIVE VITAMIN D3 AND ERYTHEMAL IRRADIANCE

Fig. 3 shows the action spectra for vitamin D3 (CIE, 2006) – subsequently called VD3 - and erythema (CIE,1987) – called ERY - as well as one spectrum of measured solar irradiance. The spectral products between spectral irradiance and action spectra are also shown to illustrate the wavelength region contributing to the integrated biologically effective irradiances. Mainly UV-B (< 315 nm) radiation contributes to VD3, while ERY is also affected by radiation from the UV-A (315 – 400 nm) region. Therefore, variations in SZA and column ozone affect VD3 more than they affect ERY with the result that ratios VD3/ERY are dependent on both parameters. The ratios VD3/ERY derived from spectral irradiance measurements taken at one-minute time steps for the period 2005 top 2008 are shown in Fig. 4. Sunny cases have been selected for this Figure by using ratios between direct irradiance measured by pyrheliometers (in this case referred to a horizontal plane) and global irradiance as measured by pyranometers at one-minute time steps such that the contribution of direct irradiance on a horizontal plane to global irradiance was greater than 75%. It can be seen in Fig. 5 that the VD3/ERY ratios for sunny conditions increase with decreasing SZA. The ozone effect on the VD3/ERY ratios is illustrated by a few
examples with low and high ozone values. VD3/ERY ratios are higher for low ozone of around 240 DU such as on October 28 and 29, 2005, and smaller with high ozone such as on March 18, 2008 with an ozone value of 439 DU. The dashed curves are results of model calculations using the LibRadtran model (Mayer and Kylling 2005) with clear sky conditions for low ozone (200 DU, upper curve) and high ozone (500 DU, lower curve). The dotted curves in Fig. 4 show ratios VD3/ERY calculated for ozone values of 200 DU and 500 DU from a parameterization formula derived by Fioletov et al. (2009) from Brewer UV measurements in Canada. The parameterization provides ratios close to the clear-sky radiative transfer model results, except for high SZA and high ozone, where the parameterization shows somewhat higher values than those derived by the LibRadtran model.

Selecting cloudy cases by percentage values of direct to global irradiance smaller than 1% shows a similar dependence of the VD3/ERY ratios as for sunny cases (Fig. 5). However, there are many smaller ratios and even very low values that are much smaller than the clear-sky model result for high ozone with cloudy conditions (Fig. 5) compared to the ratios for sunny conditions (Fig. 4). A few days with very low VD3/ERY ratios are marked by different colors in Fig. 5. A closer inspection of those days shows that optically very thick clouds caused the extremely low ratios VD3/ERY. They appear, as if column ozone would have been strongly enhanced to unrealistically high values by far exceeding 500 DU. The extremely low ratios VD3/ERY are caused by enhanced multiple scattering by cloud water droplets and ice particles in those optically very thick clouds, and therefore, enhanced absorption by tropospheric ozone (Mayer et al. 1998). In those cases, the parameterization of the VD3/ERY ratios, (Fioletov et al., 2009 in Fig. 4) in dependence of SZA and column ozone would not be applicable.

As an example of the cloud effect, Fig. 6 shows the ratios between erythemal and global irradiance ERY/GLO (lower panel) and the ratios VD3/ERY (middle panel) for one cloudy day (May 27, 2007) compared to the ratios on a cloudless day (June 10, 2007). It can be seen from the ERY/GLO ratios that clouds, as they occurred on May 27, can lead to either higher or smaller ratios ERY/GLO compared to the ratios for clear sky.

On the other hand, the ratios VD3/ERY are not much affected by clouds and are almost similar to corresponding ratios for clear sky. However, if the clouds become optically very thick – in that case global irradiance dropped from more than 900 W m\(^{-2}\) to values between 3 and 15 W m\(^{-2}\) between 13 and 15 UTC –, the ratios VD3/ERY strongly decreased reaching minimum values of about 0.66 around 14.05 UTC.

The corresponding clear sky ratios VD3/ERY that were derived from radiative transfer model calculations for an ozone value of 330 DU, which was measured by Brewer #030 from 8 to 12 UTC on May 27, are shown as circles in Fig. 6. The modeled clear sky ratio VD3/ERY at 14.05 UTC corresponds to about 1.71. The Lindenberg cloud radar showed a base-height of that thick cloud at about 3 km and its top at about 12 km. Precipitation at the ground started before the cloud optical depth and thus scattering reached their maximum values, and lasted for about 1.5 h with at times high intensities reaching 7 mm/min (upper panel in Fig. 6).

4. CONCLUSIONS

The comparison between DWD 24h- forecasts of the UV index and measurements at Lindenberg showed good correspondence. Greater differences are mainly due to errors in the cloud forecast including time shifts between forecast clouds and real cloud occurrence. The ratios between pre-vitamin D3 effective UV irradiance and
Erythemal irradiance VD3/ERY derived from 4 years of measurements show a clear dependence on SZA and on atmospheric ozone. Optically thick clouds can significantly affect the ratios VD3/ERY. In view of the importance of the vitamin D3 issue for the population, it is worthwhile to consider future inclusion of the VD3 effect in addition to the erythemal effect in short-term UV forecasting, where special emphasis should be given to small values and small or minimum doses. The UV forecasts might also consider the special conditions in urban areas and big cities, where a higher air pollution and more cloudiness can occur compared to rural areas. Due to the effect of optically thick clouds on the ratios VD3/ERY, VD3 effective radiation may preferably be derived from radiative transfer model calculations, which can simulate the effect of optically thick clouds, instead of using parameterizations of ratios VD3/ERY.

**Fig. 5** Same as Fig. 4, but for cloudy conditions. Selected days with optically thick clouds are marked by different colours.

**Fig. 6** Lower panel: ratios of measured ERY/GLO on May 27, 2007 (cloudy) and on June 6, 2007 (clear day), and clear-sky model results for May 27 (circles). Upper panel: precipitation intensity on May 27, 2007.

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**REFERENCES**


