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A Method to Estimate Erythemal UV from Total Solar Irradiance Measurements Based on 9 Years of 1-minute Data at Lauder, New Zealand

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Abstract. The radiative effect of clouds on the incident surface solar radiation highly depends on the spectral band of the solar spectrum that is considered. In particular, cloud effects are known to be different for the broadband erythemal ultraviolet (hereafter, UVE) irradiance and the total global solar irradiance (TR) due to the much more important molecular (Rayleigh) scattering on the UV than on the visible and near infrared wavelengths. In this work we investigate these differences by analyzing 9 years (2000-2008) of 1-minute UVE and TR measured at Lauder (45.04S, 169.68E, 370m asl), New Zealand. Clear sky models for UVE and TR are considered and their performances are tested. Effective cloud transmittance, also known as cloud modification factor (CMF) is calculated as the ratio between the 1-minute measurements and the clear sky estimation from modeling, both for UVE (CMF(UV)) and TR (CMF(TR)). The two CMF are then compared. The analyses are undertaken as a function of solar zenith angle (SZA), and Sun visibility derived from a Total Sky Imager (TSI) device. Differences between CMF(UV) and CMF(TR) are maximum for intermediate values of the latter, being CMF(UV) always greater than CMF(TR) (that is, UVE less affected by clouds). A methodology to calculate CMF(UV) as a function of CMF(TR) and SZA is proposed, and subsequently validated using 2 years of independent data (2009-2010). The agreement between estimated and measured UVE is remarkably good: absolute differences are less than 0.5 UVI units (being the greatest at lower SZA), and relative differences are less than 10% (the greatest at higher SZA), despite of a systematic error that needs to be corrected.

Keywords: Erythemal UV, Total solar radiation, Cloud modification factors.
PACS: 92.60.Vb

INTRODUCTION

Clouds affect the whole solar radiation spectrum, therefore they also have an impact on ultraviolet (UV) radiation. Obviously, the basic and most usual effect of clouds is to reduce the amount of UV radiation that reaches the ground, when compared with an otherwise equivalent cloudless situation. Since Rayleigh scattering (from atmospheric gases) has a much greater influence on UV than on visible (VIS) radiation, the reducing effect of clouds on UV is lower than on VIS, especially in cases of broken or scattered cloudiness. These results have been broadly reported in the literature; a detailed review of the behavior of UV radiation in the atmosphere, and the effects of clouds on UV radiation was provided by [1]. It is important to note that clouds may also produce UV enhancements, that is, values of UV irradiances greater than the expected for a cloudless sky.

In the present work, the behavior of both UV radiation (specifically the UV Index, which is related to erythemal UV) and total solar radiation TR, in regards to sky conditions, is explored. A method to estimate UVI for any sky condition based on the TR measurements is presented and validated.

DATA AND METHODS

The data sets used in this study come from the meteorological and radiometric station located at Lauder, New Zealand (45.04ºS, 169.68ºE, 370 m asl). This station belongs to the National Institute of Water and Atmosphere Research (NIWA) and is a primary source of radiation data in the Southern Hemisphere; the quality of the data is guaranteed by the strict supervision from NIWA personnel and confirmed by its adscription to the BSRN (Baseline Surface Radiation Network) [2].

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For the present work, 9 years (2000-2008) of 1-minute data of UVI measurements (from a YES-UVB-1 radiometer) and TR measurements (using an Eppley pyranometer) were used to develop the estimation method. Total cloud fraction (CF) and the sunny conditions (Sun visible or obscured) were considered as ancillary data from a Total Sky Imager (TSI) from Yankee Environmental Systems. Two additional years of the same data (2009-2010) were used to validate the method.

In order to study the effect of clouds on UVI and TR, for each record the cloud modification factors (CMF) were calculated for both UVI and TR. A CMF is defined as the ratio between measured radiation and the estimated radiation under a clear sky situation with all other variables (solar zenith angle SZA, aerosol optical depth AOD,…) kept the same as in the measured value. That is:

$$\mathrm{CMF(UV)} = \frac{\mathrm{UVI}_{meas}}{\mathrm{UVI}_{clear}}\,;\ \mathrm{CMF(TR)} = \frac{\mathrm{TR}_{meas}}{\mathrm{TR}_{clear}}$$

To estimate UVI_{clear}, a previously available parameterized model [3] was considered, taking as inputs sun photometer AOD measurements at 412 nm (also available at the site), with an Angstrom alpha of 1.4 and a constant single scattering albedo of 0.92, as well as the total ozone column from satellite measurements, the corresponding SZA, and a fixed ground albedo The TR clear sky estimations were calculated using a simpler formula [4]:

$$\mathrm{TR}_{clear} = a\cos(SZA)^{b}$$

were $a = 1150\ \mathrm{W/m^2}$ and $b = 1.2$.

To validate the clear sky models, clear sky measurements were selected with a double criteria (CF = 0 from TSI and CF = 0 from the Long and Ackerman algorithm [4], based on total radiation measurements). Agreements between measurements and estimations are within ±0.5 in UVI and $\pm 40\mathrm{W/m^2}$ in TR as shown in Figure 1. Relative agreements, shown also in Figure 1, are within ±2-3% (1σ) for SZA < 70 deg..

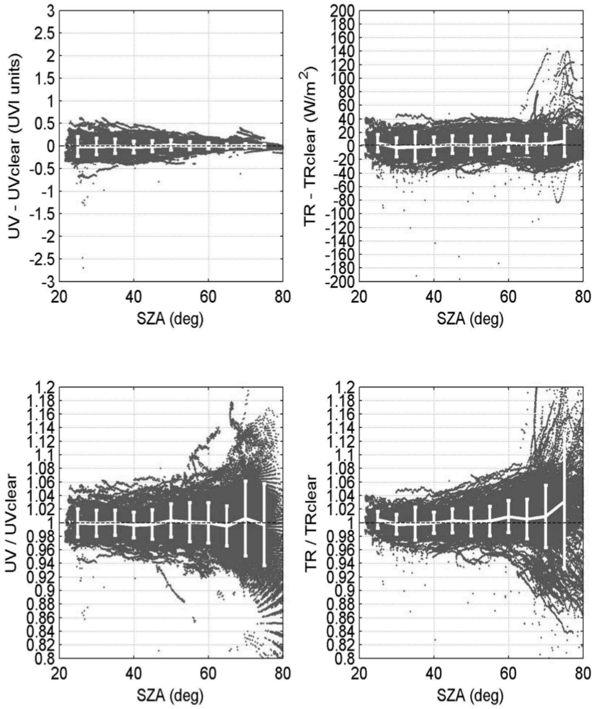

FIGURE 1. Representation of the absolute (top) and relative (bottom) differences between clear sky models and measurements. For UVI (left) and TR (right). White bars represent $\pm 1\sigma$ for different SZA.

RESULTS AND DISCUSSION

The different effect of clouds on UVI and TR, as well as the effect of Sun visibility and SZA on the CMF, is shown in Figure 2. Note that the original dataset was reduced to the data within eleven bins of SZA of 1 degree width. CMF(UV) vs. CMF(TR) plots (left panels) show that conditions with Sun visible and Sun obscured are well distinguished (points forming two clusters); moreover, the larger is SZA, the more contrasted and deviated from the 1:1 line are these clusters.

The right panel in Figure 2 shows the average values of CMF(UV) for each bin of CMF(TR) and SZA. From this representation it is easy to see that differences between CMF(UV) and CMF(TR) are maximum for intermediate values of the latter. For example, when CMF(TR) = 0.3, it turns out that average CMF(UV) is in the range 0.35-0.55, and when CMF(TR) = 0.6, average CMF(UV) is in the range 0.65-0.85. The higher values in these ranges correspond always to the greater SZA. In addition, the largest discrepancies between CMF(TR) and CMF(UV) are found for large CF conditions (not shown). Note also that the enhancement cases (CMF > 1) are more common and larger for TR than for UVE.

From the values shown in Figure 2 (right), look-up tables of CMF(UV) as a function of CMF(TR) and SZA were created as the method for retrieving UVI for all cloud conditions, provided that TR measurements are available.

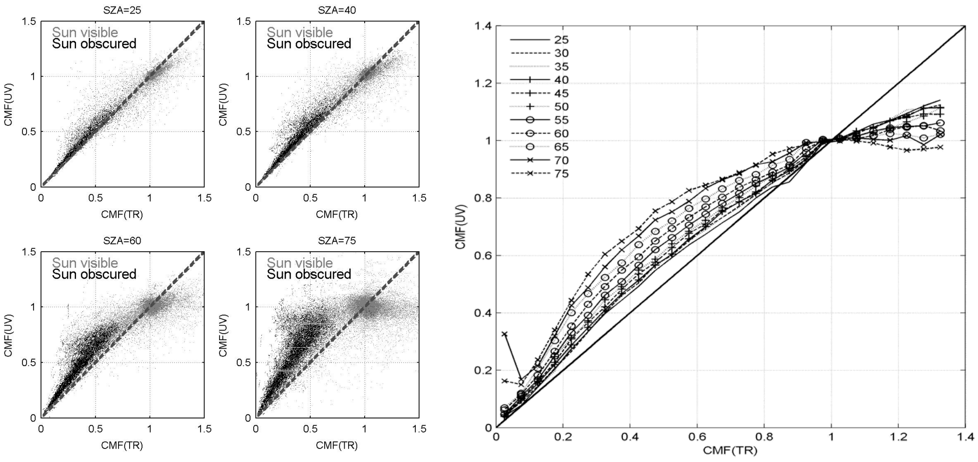

FIGURE 2. The effect of clouds on UV radiation against the effect on total radiation, represented by using the corresponding CMF. (Left) All values for a given SZA (+/- 0.5º), distinguishing two types of points depending upon the Sun visibility. (Right) The average CMF (UV) for values within a given range of CMF (TR) (+/- 0.05) and SZA (+/- 0.5º).

The proposed method was validated using 2 years of independent data (2009-2010). Results of the comparison between estimated and measured UVI are summarized in Figure 3. The agreement is remarkably good: absolute differences are less than 0.5 UVI units (25-75 percentile) and relative differences are within 10%. A 2-3% positive systematic bias is found, and must be further investigated. At this stage, it seems to be the consequence of a change in the calibration factors of the total radiation pyranometers.

A detailed analysis of the method results, for two selected days, is shown in Figure 4. The first day is an example of a day with fairly good UVI modeling both in the morning (clear sky) and in the afternoon (passing stratocumulus with high CF). Note that the method can manage the high TR enhancements at around 17 h, producing a correct (not enhanced) UVI. The second day was a day with passing broken clouds (low CF). The method highly overestimated the reducing effects of the clouds on UVI. i.e., produced too low UVI values. This is related with the larger dispersion of values of CMF(UV) for a given value of CMF(TR), which was ignored when building the look-up-tables based on averages.

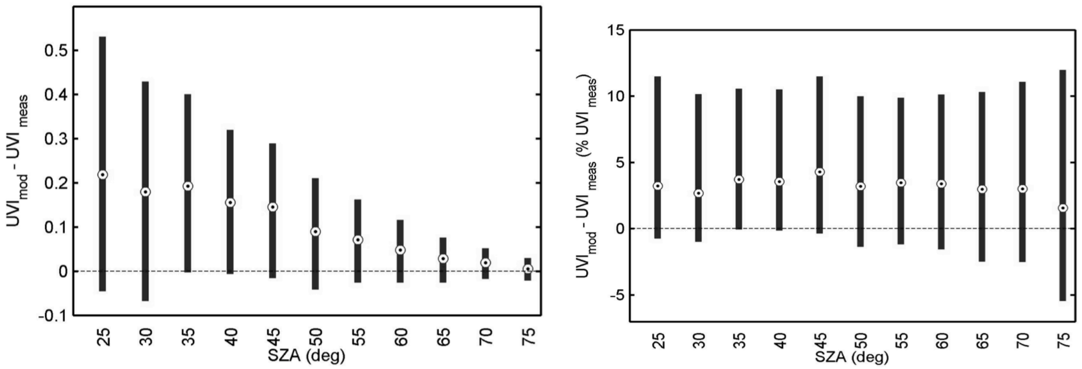

FIGURE 3. Absolute (left) and relative (right) differences between the UVI estimated by the suggested method and the corresponding measurements.

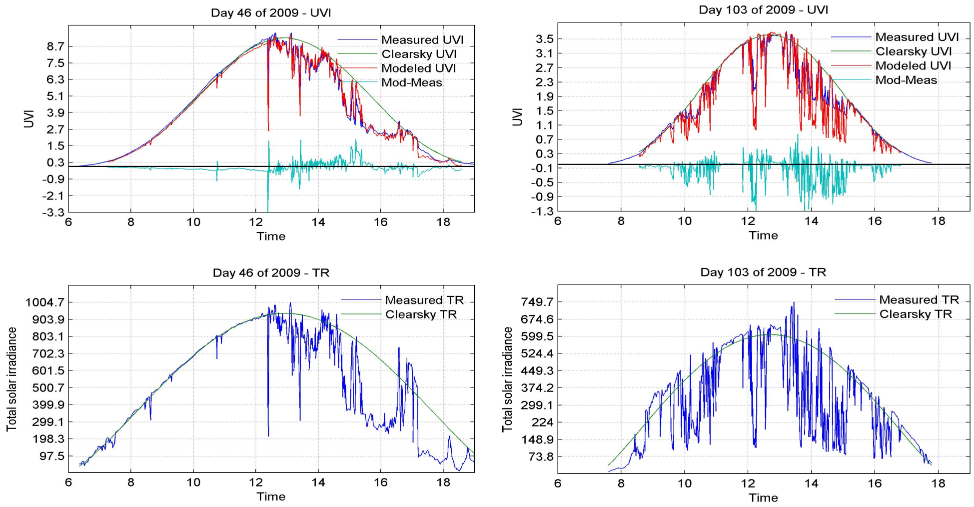

FIGURE 4. Behavior of UV radiation (UVI) and total radiation (TR): measurements, clear sky models, and all-sky estimations for two different days in 2009.

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