Cloud modulation of shortwave and ultraviolet solar irradiances at surface

Efecto de las nubes en la radiación solar de onda corta y ultravioleta en superficie

D. Mateos^(*), R. Román, J. Bilbao, A. de Miguel, A. Pérez-Burgos

Atmosphere & Energy Lab, University of Valladolid, P^o Prado de la Magdalena s/n, 47005, Valladolid, Spain

^(*) Email: dmateos@fa1.uva.es

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ABSTRACT:

The cloudiness effect on solar radiation was analyzed in this study. Measurements of UV erythemal (UVER) and total shortwave (SW) radiation were registered in Valladolid, Central Spain. Simulations by the radiative transfer model SMARTS 2.9.5 were used to calculate the cloud modification factor (CMF). The dependences of CMF (for UVER and SW ranges) on cloud cover and cloud type were analyzed showing a clear decreasing trend with cloud cover, which was stronger for medium clouds than for high ones. A similar analysis was carried out for the ratio between CMF_{UVER} and CMF_{SW} . This ratio presents a clear influence on cloud cover, solar zenith angle (SZA) and cloud type. The smallest SZAs and the high clouds produce a constant trend close to the unity. However, medium and low SZAs and medium clouds lead to higher attenuation of SW radiation.

Keywords: Ultraviolet Erythemal Radiation, Total Shortwave Radiation, Cloud Cover, Cloud Type, Cloud Modification Factor.

RESUMEN:

Este estudio está basando en el efecto de las nubes en la radiación solar. Se realizaron medidas de radiación UV eritemática (UVER) y de onda corta (SW) en Valladolid, España. El modelo de transferencia radiativa SMARTS 2.9.5 fue utilizado para poder evaluar el Factor de Modificación de Nubes (CMF). Las dependencias del CMF (en los intervalos UVER y SW) con la cubierta y el tipo de nubes muestran una clara tendencia decreciente con la cubierta de nubes siendo más fuerte para nubes medias que para altas. También se analizó el cociente entre CMF_{UVER} y CMF_{SW} . Esta variable presenta variabilidad ante la cubierta de nubes, ángulo cenital solar (SZA) y tipo de nubes. Los SZAs más bajos y las nubes altas producen un valor constante cercano a la unidad para cualquier valor de la cubierta de nubes. Sin embargo, el resto de valores de SZA y nubes medias conducen a una mayor atenuación de la radiación solar de onda corta.

Palabras clave: Radiación Ultravioleta Eritemática, Radiación de Onda Corta, Cubierta de Nubes, Tipo de Nubes, Factor de Modificación de Nubes.

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1. Introduction

The solar radiation levels at surface are strongly modulated by clouds. The cloud effect on solar ultraviolet (UV) radiation is only partially explored due to the lack of measurements of cloud optical properties. Hence, the interest in the cloud-radiation interaction has increased in the past few years [1]. The use of measurements and simulations by radiative transfer models is a common topic to get further in the knowledge about cloud effects. The Cloud Modification Factor (CMF), which is defined as the ratio between measured radiation in all sky condition and calculated radiation for a cloudless sky [1], provides a first distinction of cloud radiative effects [2]. CMF can be evaluated for different spectral intervals, as total shortwave (CMF_{SW}) and ultraviolet (CMF_{UV}) ranges. Several studies have analyzed the dependence of CMF_{UV} on cloud cover [3,4].

The aim of this study is to investigate the dependence of CMF evaluated for the UV erythemal (CMF_{UVER}) and total shortwave radiation on cloudiness. Hence, studies about cloud cover, cloud type and solar elevation angles were carried out. The ratio between both CMF was also calculated and its dependence on cloud cover and different cloud types was analyzed.

2. Site, instrumentation and methodology

The Solar Radiometric Station (SRS, lat. 41° 40'N, long. 4°50'W and 840m a.s.l.), is located in a

wide-open area (free of obstructions) close to Valladolid, Spain. The climate is Mediterranean-continental with dry and warm summers (~35°C) and cold and wet winters (~-7°C). The cloudless skies are predominant in the summer months while the cloudy ones are majority in fall and winter. The measuring station contains a large number of radiometric and meteorological sensors. In this study, the records of the UVB-1 pyranometer of Yankee Environmental Systems and the CM-6B pyranometer of Kipp & Zonen were used. The data quality control followed in this work was explained in detail in previous articles [5]. The measurements of UV erythemal radiation (UVER) are recorded by the UVB-1 Yankee Environmental Systems Inc. (YES) radiometer which has a spectral sensitivity close to the erythemal action spectrum (280–400 nm). Total shortwave radiation on a horizontal surface was measured by a Kipp & Zonen radiometer model CM-6B (305–2800 nm of spectral range). Further details about the instruments and the calibration processes can be found in, e.g., [6]. 90,978 pairs of UVER-SW data were obtained during the period 2002–2009.

Cloud cover and type data were obtained from the visual observations of the Spanish Meteorological Agency (AEMet) in a close station. Cloudiness was recorded three times per day (7:00, 13:00 and 18:00 GMT) in octas. For the period 2002–2009, 8,766 data about cloud cover and cloud type (low, medium or high) were available. In order to link cloud information with radiometric data, the measurements of solar radiation recorded ten minutes before and after of the cloud

observations were averaged. Finally, 5,368 data present radiometric measurements and cloud information.

To evaluate the Cloud Modification Factor, the estimation of UVER and SW radiation under cloudless skies was carried out using the radiative transfer model SMARTS 2.9.5 [7]. The set-up used was as follows: standard profiles from USA atmosphere (45°N) in 1976; total ozone column data from OMI, GOME, and GOME-2 remote sensing instruments; aerosol rural profile; monthly mean aerosol optical thickness at 500nm from AERONET network; the spectral resolution was 0.5 from 280 to 400 nm, 1nm in 400-1750 nm, and 10nm up to 2800 nm; and the surface albedo was taken as Lambertian with constant values of 0.03 and 0.17 for UVER and SW, respectively.

3. Results and discussion

Figure 1 shows the dependence of CMF on cloud cover for three different intervals of solar zenith angle (SZA): $25^\circ < \text{SZA} < 40^\circ$, $40^\circ < \text{SZA} < 55^\circ$, and $55^\circ < \text{SZA} < 70^\circ$. As expected, CMF values present a decreasing trend with cloud cover. CMF_{UVER} and CMF_{SW} seem to have a similar trend. However, the values of the CMF_{UVER} are slightly higher than the CMF_{SW} ones. The standard deviation also increases with cloud cover, being close to 0 under cloudless conditions, but it does not show any clear trend. This fact could be explained with the high variability of cloud optical properties registered during 7 years in the database. It is worth mentioning here, that each CMF average value in Fig. 1 was calculated with a number of data between 48 and 290 data.

The small difference in the values of each category of SZA suggests removing this dependence when the cloud type is analyzed. Hence, Fig. 2 shows the dependence of CMF values on cloud cover for different cloud types: all cases, and medium and high clouds. The role played by low clouds can be observed in an early paper [8]. Different trends are observed for medium and high clouds, and the all cases category is placed between them. High clouds produce higher values of CMF (both UVER and SW) than the medium clouds. This fact could be attributed to the optical characteristics of ice

clouds. They present smaller cloud optical thickness and larger reflectivity than water clouds. The standard deviation also presents the high variability observed in Fig. 1.

Fig. 1. Dependence of CMF average values (UVER upper panel, SW lower panel) on cloud cover as a function for three intervals of solar zenith angle (SZA). Standard deviation intervals are given.

Fig. 2. Dependence of CMF average value (UVER upper panel, SW lower panel) on cloud cover for three different cloud types. Standard deviation intervals are given.

Figure 3 shows the dependence of the ratio between CMF_{UVER} and CMF_{SW} on cloudiness for three groups of solar zenith angle. This ratio presents a clear influence of SZA, for the smallest ones the average values of the ratio are almost constant with cloud cover and very close to 1. If the SZA increases, the ratio rises up to ~ 1.5 for the group with highest SZA. Several authors found that the reflections upwards by the cloud and the dispersions downwards again by the atmosphere (Rayleigh scattering) above the cloud produce that shorter wavelengths make it through the cloud more effectively than the longer wavelengths [9].

Figure 4 presents the influence of the cloud type on this ratio. As occurred in Fig. 2, high clouds produce less attenuation than medium clouds with values of the ratio close to 1. Significant differences between both types of clouds were achieved beyond 5 octas. Under cloudless and partially cloudy conditions, the all cases points reproduce well both types of clouds.

4. Conclusions

The influence of cloudiness on solar radiation was investigated by measurements of 7 years in Central Spain. CMF values were calculated by measurements and radiative transfer simulations and their dependence on cloud cover and cloud type were studied. The average values of CMF_{UVER} and CMF_{SW} in each category show a clear dependence with cloud cover but no significant one with SZA. Medium clouds produce CMF values smaller than the high clouds, so this type presents stronger attenuation of solar radiation. The ratio between CMF_{UVER} and CMF_{SW} was analyzed. The dependencies of this variable on cloud cover, solar zenith angle and cloud type point out the different effect of clouds on SW and UVER spectral ranges. UVER radiation is less attenuated, as expected by the results found by other authors [9].

Fig. 3. Dependence of the ratio CMF_{UVER}/CMF_{SW} on cloud cover for three intervals of solar zenith angle (SZA). The dashed line means ratio equal to 1. Standard deviation intervals are given.

Fig. 4. Dependence of the ratio CMF_{UVER}/CMF_{SW} on cloud cover for three different cloud types. The dashed line means ratio equal to 1. Standard deviation intervals are given.

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