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Tutorial Review

Wavelength dependence of the effective cloud optical depth

D. Serrano [a,*], M.J. Marín [b], M. Núñez [a,c], M.P. Utrillas [a], S. Gandía [a], J.A. Martínez-Lozano [a]

[a] Solar Radiation Group, Departament de Física de la Terra i Termodinàmica, Universitat de València, Campus de Burjassot, 46100 Valencia, Spain
[b] Solar Radiation Group, Departament de Matemàtiques per a l'Economia i l'Empresa, Universitat de València, Campus dels Tarongers, 46022 Valencia, Spain
[c] School of Geography and Environmental Studies, University of Tasmania, Private Bag, 78, Hobart, Tasmania 7001, Australia

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ABSTRACT

This study examines the wavelength dependence of cloud optical depth. To accomplish this task two different wavelength bands of the solar spectrum were considered in the cloud optical depth retrieval which was conducted in Valencia, Spain. The first retrieval used global irradiance measurements in the UVER range taken from a YES-UVB-1 radiometer in combination with multiple scattering model estimates; while the second retrieval was obtained in the Broadband range, with measurements of global solar surface irradiance from a CM6 pyranometer and a multiple scattering model. Whilst the dependence of the cloud optical depth (τ) on the wavelength is small, the best result was displayed by the SBDART model with less than 2% deviation between two ranges and moderately worse results were obtained with the LibRadtran model. Finally, seasonal statistical data for optical depth are presented for 2011 and 2012.

Contents

1. Introduction

Solar radiation and particularly UV radiation affects human health, inducing erythema or sunburn, DNA damage, and skin cancer (Diffey, 1991; Norval, 2006; Gao et al., 2010; Juzeniene et al., 2011; Mateos et al., 2011). Solar zenith angle and cloudiness are the most significant parameters affecting the variability of solar irradiance at the earth's surface, but while zenith angle is readily estimated from astronomical tables, cloudiness is marked

* Corresponding author.
E-mail address: david.serrano@uv.es (D. Serrano).

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by high variability in structure and composition, making estimation of solar radiation in cloudy conditions difficult at all wavelengths (Boers et al., 2000; Foyo-Moreno et al., 2003; Krzyścin et al., 2003; Calbó et al., 2005; Mateos et al., 2014).

Theoretical calculations suggest that water clouds can absorb up to 15–20% of the incident solar radiation and the depletion of solar radiation by clouds is conveniently determined by the cloud optical depth (τ), which may range typically from 1 to over 100 in the atmosphere (Stephens, 1994). Given its importance in affecting surface solar irradiance, accurate determination of τ and its spatial and temporal characterization remains a primary goal of the scientific community in atmospheric physic (Leontieva et al., 1994; Beaulne et al., 2005; Liu et al., 2013).

This study presents our estimates of cloud optical depth for low and middle liquid water clouds at a regional to local scale, determined from surface irradiance observations in the erythemal band and in the broadband. The erythemal band (UVER) is calculated by weighting the spectral curve of the incident solar radiation at ground level with the spectral action proposed by the CIE (Commission Internationale de l'Éclairage) (CIE, 1998).

The technique consists in relating surface irradiance measurements to cloud optical depth τ, using radiative transfer models that include a plain homogeneous cloud layer of a given cloud optical depth τ. Some of the previous works by Leontieva et al. (1994) and Barker et al. (1998) used broadband pyranometer measurements and a radiative transfer model to define an effective cloud optical depth for overcast skies.

Of interest to this study is the wavelength-dependence of τ which is considered in the literature to be almost independent of wavelength. Mie scattering calculations suggest the τ vary by less than 2%, between 300 and 1000 nm (Hu and Stamnes, 1993; Fu, 1996; Key et al., 2002; Liou, 2002; Min et al., 2004).

The analysis is based on experimental data obtained over a two year period in Valencia (Spain). Due to the high variability of cloud properties, and the difficulty in reproducing complex three-dimensional cloud structures in broken conditions with radiative transfer models, this analysis is limited to overcast conditions. Therefore, one-dimensional radiative transfer simulations with SBDART (Santa Barbara Disort Atmospheric Radiative Transfer) model on the version 2.4 (Ricchiazzi et al., 1998) and LibRadtran (Library for Radiative Transfer) model, version 1.7 (Mayer and Kylling, 2005) are used to explain the observations. This approach is a practical way of dealing with non-homogeneous clouds and it was used in other studies such as Leontieva and Stamnes (1994), Min and Harrison (1996), Barker et al. (1998), Barnard and Long (2004), Binyamin et al. (2010), Antón et al. (2012), Serrano et al. (2014) and amongst others. Therefore, the obtained results refer to statistics of effective cloud optical depth and the term "effective" indicates the τ value that is used as input into the code and that best agrees with experimental irradiance data.

The study is divided into various sections. Section 2 discusses instrumentation. Data and Methodology section provides details on the radiative transfer model and the method of extracting cloud optical depth. Cloud optical depths for overcast conditions and the sensitivity of cloud optical depth to wavelength are presented in the Results section.

2. Instrumentation

Different surface instrumentations were used to extract cloud optical depths and to compare them in the UVER and broadband ranges during years 2011 and 2012. The instrumentation is located on the roof of the Faculty of Physics in Burjassot (39.5°N latitude, 0.418°W longitude, 30 m above sea level), Valencia (Spain).

Measurements of UVER were taken using a broadband YES-UVB-1 radiometer (Yankee Environmental Systems, YES). The radiometer YES-UVB-1 has a spectral range between 280 and 400 nm and its spectral sensitivity is close to the erythema action spectrum (CIE, 1998). The diffuse UVER measurements, which were used to calculate values of the single scattering albedo, were obtained using another YES-UVB-1 radiometer with a shadowband. The diffuse UVER measurements were corrected using the modified Batlles model, proposed by Utrillas et al. (2007). According to the previously mentioned article, the corrected diffuse experimental irradiance has a relative uncertainty of 1% in comparison with the Optronic OL754 spectroradiometer and with simulated values from two radiative transfer models.

The sensors are calibrated regularly once a year and in two different phases: firstly, the sensor that measures the global UVER is used as reference and is subjected to a standard calibration as certified by the National Institute of Aerospace Technology (INTA) (Vilaplana et al., 2006; Hülsen and Gröbner, 2007). This calibration consists in measuring the spectral response of the sensor, its angular response, in order to determine the cosine error, and its comparison with a Brewer MKIII outdoors spectroradiometer. The second radiometer, deployed with a shadowband, is calibrated by comparison with the global YES-UVB-1, which serves as a reference.

The UVER data were acquired using an Agilent 34970A data logger and averaged at 1 minute intervals. According to the manufacturer, these devices have an uncertainty of 5% in the irradiance measurement. In this case, the calibration provides a corrected signal with a maximum error of 9% for zenith angles below 70° (Utrillas et al., 2007). This last uncertainty was used to calculate the uncertainty of the methodology utilized in this paper.

Measurements of broadband solar radiation were taken using a CM6 pyranometer by Kipp and Zonen. Its spectral range is between 310 nm and 2800 nm, covering the ultraviolet (UV) to the near-infrared (IR) ranges. In 2011, the CM6 pyranometer was calibrated by intercomparison with the new CM21 pyranometer, which had already been calibrated by Kipp & Zonen. Thus, the values considered here as instantaneous are actually average values with 1 min intervals. The CM6 pyranometer has an uncertainty of about 5%, according to the manufacturer.

We used a sky camera model SONA (Clouds Observing System Automatic) by Canary SIELTEC Company SL to select overcast skies for analysis. This camera consists of a 640×640 diode array and a central circle of 444 pixels in diameter. This device, previously protected by a shadowband to prevent the damage of the optical components, records the sky information. The array has three independent channels that are sensitive to sky radiation in the blue, green and red bands. Each band, assigned to an independent gain and offset, is designed so that the sum of the three outputs will approximate the sensitivity of the human eye and thus reproduce "true" sky colours, enabling identification of both cloud type and cloud coverage. The system enables flagging of cloudless sky, overcast cumulus and stratocumulus conditions. An IDL program was written to display the digital data collected by the sensor in each of the three bands and as a composite image. A band ratio of red/blue was then performed so as to isolate cloudy pixels from sky pixels. Applying a two band filter (black for sky and white for cloud) with a given threshold, clear sky images were separated from the cloudy ones using a binomial filter (0,1). Images containing overcast conditions (all 1 for overcast skies) were chosen and later an observer selected overcast cumulus and stratocumulus conditions. Images of the cloud sky were obtained at 5 min intervals. As an approximation of the uncertainty of this camera, we took an average uncertainty of 0.05 for all cloud cover estimation (Serrano et al., 2014, 2015).

A CIMEL CE318 sunphotometer was used in this study for monitoring total aerosol optical depth in a vertical column of