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Relationship between the effective cloud optical depth and different atmospheric transmission factors

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ABSTRACT

This study examines the sensitivity of cloud optical depth (COD) for overcast conditions to radiation transmission using data collected in Valencia, Spain. These relationships are provided as simple empirical functions, therefore avoiding the need to apply complex model minimisation schemes to obtain COD. Comparisons are presented between COD obtained by a minimization method and several radiation transmission factors comprising a clearness index (k_t), a modified version (k_t'), a cloud modification factor (CMF) and its modified version (CMF'). Additionally, a statistical model of COD proposed by J.C. Barnard and C.N. Long (2004) is tested with our data. Statistical relationships between COD and these variables were developed for measurements in the ultraviolet Erythema Radiation (UVER) range as well as for broadband measurements covering the full solar spectrum. Measurements collected in 2011 were used to develop power and exponential relationships relating COD to the above transmission factors, and subsequently tested with independent data collected in 2012. In general, expressions relating COD to CMF perform better and exhibit a higher correlation than equivalent expressions relating COD to clearness indices, especially in the UVER range. The expression of Barnard and Long is potentially adequate for the estimation of COD for both UVER and broadband solar radiation in Valencia, but the regression coefficients need tuning for local conditions.

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Contents

1. Introduction

Solar zenith angle and cloudiness are the most significant factors affecting the variability of solar irradiance at the earth's surface, but while zenith angle is readily estimated from astronomical tables, cloudiness is marked by high variability in structure and composition, making estimation of solar radiation in cloudy conditions difficult (Liou, 2002). Therefore, clouds play a fundamental role in the attenuation of solar radiation reaching the earth's surface, and may attenuate as much as 80% of the cloudless sky radiation depending on features such as cloud type, cloud optical depth, and its

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distribution in the sky (Pyrina et al., 2013; Calbó et al., 2005; Alados-Arboledas et al., 2003).

The aim of this study is to explore the use of several radiation transmission factors in order to define characteristics of the cloud regime and to apply these characteristics for the estimation of cloud optical depth (COD) in overcast skies. There are several reasons to justify this particular approach. Firstly cloud optical depth is an inherent property of the cloud environment, and unlike transmission measurements, is essentially independent of atmospheric variables such as solar zenith angle, surface albedo or aerosol load (Serrano et al., 2014; Barnard and Long, 2004); it may be easily exportable to other physical environments with different atmospheric conditions, used as input in radiative transfer models; or used in studies to monitor radiation changes in response to changes in cloud optical depth. An accurate determination of cloud optical depth and its spatial and temporal description remains an important goal in radiation studies. These data may be obtained from satellites, measurements obtained by aircraft campaigns and especially surface measurements, where the cloud optical depth can be inferred through reflection or transmission of solar radiation. Some methods use the transmission of spectral solar radiation (Min and Harrison, 1996) or broadband irradiance to obtain COD (Barker et al., 1998, 2011; Dong et al., 1997; Boers, 1997; Leontieva and Stamnes, 1994). These methods assume plane-parallel layers of homogeneous clouds for overcast skies. The majority of these methods require information on background atmospheric conditions such as the vertical distributions of water vapour, characteristics of aerosols and properties of clouds which are often difficult to acquire. In addition there is a need for high computation times that are required for the applied algorithms.

Numerous studies describe different factors that relate to the transmission of radiation through the atmosphere with overcast skies, both in the UV Erythemal Radiation (UVER) and broadband ranges (Antón et al., 2012; Pandey et al., 2012; Mateos et al., 2009; Barnard et al., 2008; Barnard and Long, 2004; Foyo-Moreno et al., 1999). The UVER is calculated by weighting the spectral curve of the incident solar radiation at the ground level with the spectral action curve proposed by the CIE (Comission Internationale de l'Eclariage) (McKinlay and Diffey, 1987). Therefore, we propose different empirical expressions to calculate the COD in a simple, fast and easy way, using only transmission factors derived from measurements of solar irradiance at surface level for overcast skies both in the UVER and broadband ranges, as they are more readily available. This study conducted in Valencia, Spain, examines empirical expressions for obtaining COD from the clearness index and the cloud modification factor, and also checks the COD regression model proposed by Barnard and Long (2004). Furthermore, another empirical expression that improves Barnard and Long equation is proposed.

The study is divided into various stages. The Instrumentation and methodology section provides details on the radiative transfer model, the method of extracting cloud optical depth, the different atmospheric transmission factors used in this study, and the statistical coefficients applied. The relationship between effective cloud optical depth and different atmospheric transmission factors is presented in the Results section. The Validation of results and discussion section evaluates and compares the various expressions that were obtained. The Summary and conclusion section summarises the main points and provides a recommendation on the best expression to use.

2. Instrumentation and methodology

Measurements were obtained at the Burjassot campus of the University of Valencia (Spain) (39° 30′N; 0° 25′W, 30 m above sea level) on the roof of the Faculty of Physics and the measurement period encompassed two years from 2011 to 2012.

Measurements of UVER were taken using a broadband YES-UVB-1 radiometer by 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 instrument was calibrated in the National Institute for Aerospace Technology (INTA) at El Arenosillo, Spain. This standard calibration consists of a spectral measurement and angular response of the radiometer indoors; later, it is compared with a Brewer MKIII spectroradiometer outdoors (Hülsen and Gröbner, 2007; Vilaplana et al., 2006). It is estimated that the calibration matrix provides a corrected signal with a maximum error of 9% for a solar zenith angle less than 70° (Utrillas et al., 2007).

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 infrared (IR) range. The factory calibration of a recently purchase CM21 pyranometer was transferred to the CM6 pyranometer by direct comparison in 2011. All data were collected using intervals averaged over 1 min by an Agilent 34970A data logger. The calibration uncertainty was believed to be within 5%.

Cloud cover was obtained using a sky camera. It was manufactured by Sieltec Canarias S.L. and consists of a diode array of 640 × 640 elements with the sensitive element consisting in a circular arrangement of 444 pixels in diameter which records sky information. The array has three independent channels that are sensitive to sky radiation in the blue, green and red bands. Each band is assigned to an independent gain and offset and they are designed so that the sum of the three outputs will approximate the sensitivity of the human eye and thus reproduce “true” sky colours. A lens system projects sky features into the circular array in a fashion approximating a cosine law (Steyn, 1980). Initially images with a cloud cover 1 (overcast skies) were chosen and later further filtered to obtain images containing cumulus and stratocumulus clouds which are of interest in this study because they have well-defined shape and exhibit the greatest depletion of solar radiation at the earth's surface (Serrano et al., 2014). Images of the cloud sky were obtained at 5 min intervals. As an approximation of the uncertainty of this camera, we have taken an average uncertainty of 0.05 for all cloud cover estimation less than 1 for an automatic analysis.

Aerosol data, their properties and water vapour were obtained with a CIMEL CE318 sunphotometer which is included in AERONET (Aerosol Robotic Network), and is presently one of the most powerful worldwide tools to provide aerosol optical properties (Holben et al., 1998). The instrument calibration is traced to a master instrument according to the procedure described in Holben et al. (1998) but with the instruments belonging to RIMA network (Red Ibérica de Medidas Fotométrica de Aerosoles, Toledano et al., 2011),

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