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Contribution to the study of UV-B solar radiation in Central Spain

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ABSTRACT

A series of Ultraviolet-B broadband solar irradiance, 280–315 nm, measured during the period 2002–2011 in Valladolid (Spain) is analysed. UV-B daily values follow the pattern of the solar elevation angle. Daily maximum value occurred in June, 50.29 kJ m^{-2}, and minimum, 0.88 kJ m^{-2}, in December. The total accumulated UV-B irradiation along a mean year reached 7.1 MJ m^{-2}.

The elemental statistical characteristics of hourly and daily irradiation show that the inter-quartile range is small in winter and increases in spring; maximum stability in UV-B takes place at solar noon and around summer; it can be concluded that this maximum may be considered representative of the UV-B irradiance values.

The monthly-integrated UV-B irradiation values show a large annual cycle with a maximum in July, when the influence of the annual ozone column diminishes and summer solstice occurs. The results show that the harmonic analysis permits constructing long-term monthly UV-B values under clear and all sky conditions and from low number of parameters.

The UV-B percentage attenuated by the atmosphere increases from winter to summer, a maximum value of 8% is obtained in summer and a minimum of 2% in winter. The cloudiness effects on the surface solar UV-B radiation are strong during the winter months, being the cloud transmittance 0.7 in December and 0.94 in July.

1. Introduction

There is a great interest in gathering information on solar energy levels on Earth for practical applications, for better understanding its changes and for studying the effects on different organisms [1–5]. UV-B solar radiation ranges between 280 and 315 nm and it constitutes the shortest wavelengths reaching the surface [6]. UV-B solar radiation represents a part of the solar spectrum (1.3%), and it is involved in chemical and biological processes. The solar UV-B received at the ground is a function of location (latitude, altitude, topography and surface albedo) and time (season and solar zenith angle, SZA). Moreover, it depends strongly on gases (e.g. O_3 and SO_2), on clouds and on aerosols. Studies of these variables permit to evaluate the processes affecting UV and the estimation of UV levels in places where measurements are unavailable.

UV causes a variety of detrimental effects on human beings, animals and plants. UV drives stratospheric and tropospheric chemistry being responsible for the reactions in the stratosphere and causing an increase in stratosphere temperature [7]. Materials for usage, plastics, inks, varnishes and wood also suffer damage from UV radiation as discolouration or modification of mechanical properties [8].

Due to the interest of UV-B, it is necessary to have available long data series. But few stations measure the UV-B irradiance in the Castile and Leon region, Spain. Data are not numerous to provide the climatology of UV-B, although publications have increased at middle latitude [9]. The Spanish Meteorological Service (AEMET) operates a network measurement for UVB and the ozone total column. An alternative way to know UV-B values is based on sensors and radiative transfer models [10–12].

The aim of this paper is to analyse a long period of UV-B data, measured in the interval 280–315 nm, in order to know its changes and characteristics. The analysis finds a wide range of applications in fields as: forestry and agriculture; performance of solar cells; heating for buildings; material deterioration under sunlight and thermal power generation. All these applications become important with recent discoveries about the new photovoltaic cells that shows sensibility in the UV, VIS and IR spectral regions: The announcement was made by Saki Sonoda, professor at the Kyoto Institute of Technology, in the 57th Spring Meeting of the Japan Society of Physics, March 2010. UV levels show an increase in the last years that can be due to a reduction in cloud presence and

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aerosol load [12]. In the following sections, the site description, sensors, collection and data are detailed; two models under clear and all sky conditions for UV-B simulation and forecasting are obtained; the statistical analysis of UV-B values is described, and the inter-annual variability and the UV-B attenuation in the atmosphere are explained; finally, the conclusions and main results are shown.

2. Site, data and methodology

2.1. Measurements

The measurements of UV-B irradiance were collected at the Solar Radiation Station (SRS), Valladolid University, Spain, which is located in a rural area. The coordinates of SRS are: 41°49′N, 4°56′W, 848 m above sea level. The region's climate is influenced by air wind regimes over Atlantic Ocean and the weather is warm in summer [13].

UV-B solar irradiance measurements were obtained through using a UVB-1 YES pyranometer. The sensor output was connected to a Campbell Data Logger (CR10X) which was programmed to record data every 10 s and further compute average UV-B values every 10 min. That is, there are 6 readings for every 10 min intervals in an hour which are added together providing a single hourly reading. The UV-B data experimental error lies in the range 4.6–7%.

The cosine response of the sensor is better than ±5% for solar zenith angles in the range 0°–60°, and its sensitivity is 2.04 W m^{-2} V^{-1}. The output signal of the sensor was multiplied by a calibration factor provided by the manufacturer, which is a function of the SZA; in our case, a polynomial type factor has been obtained by a regression among the discrete values given with the sensor. The factor tries to take into account the cosine effect and the expression of the polynomial regression corresponding to the calibration factor is described in [10].

The UV-B series was composed of 189,233 10-min diurnal data. A quality control test has been developed, taking into account the detection limits of the sensor [14]. From 31,762 hourly UV-B values, a total 2580 UV-B daily values were obtained. UV-B data between 2006 and 2008 are not available due to calibration activities and irregular work of the instrument.

Global solar irradiance (305–2800 nm) on a horizontal surface was measured by Kipp & Zonen pyranometer Model CM-6B. The sensor output was also connected to the same Data Logger used for UV-B, taking 10-min and hourly global measurements. The sensor is calibrated each year by another CM-6B used solely for this purpose [11]. The latest calibration was carried out in 2009 at the Institute of Renewable Energy, (Ciemat), Madrid, Spain, through an outdoor intercomparison with a reference sensor (Kipp & Zonen CM22, sn 030076) traceable by the World Radiometric Reference. The calibration constant has uncertainties below 2%, and the experimental error of the measurements is below 5% according to sensor specifications.

The global solar irradiance data set consisted of 237,378 10-min diurnal data. The solar irradiance was checked taking into account the detection limits of the sensors [14]. From the 10-min data, mean hourly and daily values were obtained and a total of 2732 daily data were finally considered for the study.

2.2. Methodology

A statistical study of the most representative UV-B indices has been carried out and the accumulated values have been evaluated. The used statistical indices have been: mean (M) median (Md), standard deviation (SD), maximum (Mx), minimum (Mn), first ($Q1$) and third quartile ($Q3$), percentiles 5 ($P5$) and 95 ($P95$), inter-quartile range ($Q3-Q1$), and the coefficient of quartile variation (V), which is defined by: $V = 100\,(Q3-Q1)/(Q3+Q1)$ [10],.

In this work the extraterrestrial UV-B and global irradiance (irradiance at top of the atmosphere) on a horizontal surface have been used. Both were calculated multiplying the solar constant by the cosine of the solar zenith angle, (SZA). The solar constant for UV-B is 17.5 W m^{-2} and 1367 W m^{-2} for global range [23].

In addition, the measurements under clear conditions have been selected. To this end the daily clearness index k_t (ratio of the global-to-extraterrestrial solar radiation) was introduced. The days with a clearness index higher than 0.7 were considered as a possible cloud-free (clear) day. Then, these possible clear days were visually analysed, and if a day showed a smooth evolution and a symmetric behaviour around the noon, the radiometric measurements taken in that day were considered as clear measurements.

2.3. Data modelling

Two models for estimating the mean monthly average daily values of UVB for all sky conditions and for clear conditions were developed. The parameters of the harmonic functions are a linear combination of trigonometric variables [15–18], and they can be written in the form:

$$Y(t) = \overline{Y} + \sum_{m=1}^{N/2} Y_m \cos\left(\frac{2\pi m}{p}t + \Phi_m\right) \tag{1}$$

where $Y(t)$ is the estimates irradiance; $\overline{Y}$ is the monthly mean value; m is the month of the year; p is the period (12 months); N is the number of month; the month amplitude is $Y_m = \sqrt{\alpha_m^2 + \beta_m^2}$ and the month phase angle is $\Phi_m = \mathrm{arc\,tg}(-\alpha_m/\beta_m)$. If $Y_1, \ldots Y_N$ are a particular monthly average then the least squares estimates for the coefficients α_m and β_m are:

$$\alpha_m = \frac{2}{N}\sum_{i=1}^{N} Y_i \sin\left(\frac{2\pi m}{p}t\right) \tag{2}$$

$$\beta_m = \frac{2}{N}\sum_{i=1}^{N} Y_i \cos\left(\frac{2\pi m}{p}t\right) \tag{3}$$

where $m = 1, 2, \ldots N/2-1$. After the analysis, the obtained expression for all sky conditions using all experimental data is:

$$\mathrm{UVB} = 19.33 + 17.96\sin(\omega t - 1.544) \tag{4}$$

and for clear sky (using data measured in cloudless days):

$$\mathrm{UVB_{clear}} = 23.53 + 20.41\sin(\omega t - 1.472) \tag{5}$$

where $\omega = 2\pi m/p$ is the frequency. Fig. 1 shows the evolution of the monthly average values of extraterrestrial (UVB_0), and the estimated UV-B irradiation for all skies, UVB (Eq. (4)), and clear skies, UVB_{clear} (Eq. (5)) in Valladolid (kJ m^{-2}). It can be observed that UV-B shows a great decrease from the top of atmosphere to the surface due to the atmospheric absorption and scattering. The shift between the maxima of extraterrestrial and UVB clear can be related to the ozone amount cycle [19], which presents lower values in July given a higher irradiation in that month instead of June. A little shift also appears between the maxima of UVB_0 and UVB_{clear} which must be attributed to the non-symmetric distribution of the monthly cloud amount [22]. Finally, the UVB irradiation under clear conditions is higher than for all sky conditions due to in all sky conditions the measurements with sun-obscured by clouds