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STATISTICAL STUDY AND PREDICTION OF VARIABILITY OF ERYTHEMAL ULTRAVIOLET IRRADIANCE SOLAR VALUES IN VALENCIA, SPAIN.

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Abstract

The goal of this study was to statistically analyse the variability of global irradiance and ultraviolet erythemal (UVER) irradiance and their interrelationships with global and UVER irradiance, global clearness indices and ozone. A prediction of short-term UVER solar irradiance values was also obtained. Extreme values of UVER irradiance were included in the data set, as well as a time series of ultraviolet irradiance variability (UIV). The study period was from 2005-2014 and approximately 250,000 readings were taken at 5-minute intervals. The effect of the clearness indices on global irradiance variability (GIV) and UIV was also recorded and bi-dimensional distributions were used to gather information on the two measured variables.

With regard to daily GIV and UIV, it is also shown that for global clearness index (k_t) values lower than 0.6 both global and UVER irradiance had greater variability and that UIV on cloud-free days (k_t higher than 0.65) exceeds GIV. To study the dependence between UIV and GIV the χ^2 statistical method was used. It can be concluded that there is a 95% probability of a clear dependency between the variabilities. A connection between high k_t (corresponding to cloudless days) and low variabilities was found in the analysis of bi-dimensional distributions. Extreme values of UVER irradiance were also analyzed and it was possible to calculate the probable future values of UVER irradiance by extrapolating the values of the adjustment curve obtained from the Gumbel distribution.

Keywords: Variability UVER, UVER prediction, statistical analysis

1. Introduction

UV radiation constitutes 8.73% of the total extra-terrestrial solar spectrum (ASTM, 1973). UV radiation is usually divided into three spectral bands (CIE, 1987) according to its biological effects: UVC (100-280 nm), which is totally absorbed by stratospheric oxygen and ozone; UVB (280-320 nm), which is only partially absorbed or dispersed by atmospheric ozone; and UVA (320-400 nm), which is also partially absorbed by ozone and reaches the Earth's surface. Before travelling through the atmosphere, UVA and UVB radiation represent 5.90% and 1.33 %, respectively, of total solar radiation (Iqbal, 1983). According to estimations made by Frölich & London (1986), the UVA and UV-B bands represent 7.45% of total radiation. Al-Aruri (1990) considers that the UVB band affects nucleic and aromatic acids and that the UVA band affects proteins and DNA. UV radiation on the Earth's surface varies widely and depends mainly on latitude, solar elevation and local atmospheric conditions, such as ozone or turbidity (Murillo et al. 2003) and can be determined by experimental measurements or theoretical estimations.

The emission of certain gases due to human activity is known to alter the composition of the atmosphere. Some of the most serious damage caused is in the reduction of the ozone layer in the stratosphere, causing an inversely proportional increase in ultraviolet (UV) radiation. An understanding of UV radiation is important, since its absorption by the atmosphere is the main cause of atmospheric heating (Haigh, J., 2011), which in turn has important effects on the biosphere with biological, ecological, and physical repercussions (Foyo-Moreno et al. 1998). Examples of these effects include: albumin coagulation; DNA mutation, action on human skin and eyes, erythemal action and carcinogenesis.

Attention has been paid in recent decades to variations in solar radiation over a short timescale, and, as a consequence, instantaneous changes of radiation have been found (Tomson et. al., 2006)

Several authors have studied the instantaneous fluctuations in solar radiation as a result of rapid changes in cloud cover and aerosols (Joonsuk, L. et. al., 2013, Bartlett et al. 1998) and the variability of UV radiation has also been studied (Alados-Arboledas et al. 2003; Mateos et al. 2010). Soubdhan et al. (2009) studied the instant variation across the spectrum of solar radiation, quantifying probable distributions using Dirichlet distributions. Woyte et al. (2007) quantified instantaneous fluctuations of solar radiation using spectral analysis.

With respect to the variability of UV radiation, Sabburg & Wong (2000) studied the effect of cloud on increases in UVB irradiance at ground level, and Sabburg & Parisi (2006) analysed the dependence of such spectral increases on clouds. These authors noted that the phenomenon occurred during overcast conditions and compared results when the sky was clear. Borkowski (2008) modelled variations of UV radiation for different time scales. Calbó et al. (2005) conducted empirical studies on the effects of cloud on UV radiation. Anton et al. (2011) related the UIV to different overcast conditions, in addition to studying the dependence of the statistical coefficient of variations in global solar irradiance and UVER irradiance on the solar zenith angle.

Solar UV radiation induces a number of pathological changes, including erythema and skin cancer (UNEP, 2015). However, a number of studies have described the benefits of sun exposure – mainly related to the synthesis of vitamin D_3 (Holick, 2004).

Sabziparvar reported effective erythema radiation observations in 2009 in Esfahan, an arid region of Iran, using the hourly and daily measurements of clear-sky global radiation and biologically important UVER on a horizontal surface. Bilbao et al. (2010) reported UV solar radiation of 290-385 nm at ground level in Valladolid, Spain, from Feb-2001 to June 2008. UV radiation changes over time followed a sinusoidal pattern with maximums in summer and a complete statistical study was carried out of the hourly and daily values of solar radiation.

The aim of this work was first to make a statistical study of GIV and UIV and their interrelationship with global and UVER clearness indices and ozone. The results are divided into 4 parts: the first subsection studied daily GIV and UIV dependence on k_t (defined as the ratio of global horizontal irradiance at the Earth's surface, I_G, over extra-terrestrial horizontal irradiance, I_0); the second analyzes the dependence between GIV and UIV and the other variables and the extent to which they are related. The third predicts short-term UVER solar irradiance and the fourth includes a UIV time series. The time series is used to study the causal relationship between a number of variables that influence each other and change over time. Extreme values statistical theory is used to predict UVER irradiance values for the next ten years.

2. Method

2.1. Site

Measurements of global horizontal and UVER horizontal solar irradiance were made at a radiometric station installed on the flat roof (without obstructions or shade) of the Earth Physics Department at the Universitat de València (see Figure 1) in the Burjassot Campus (Valencia) (coordinates: 0 ° 24 'W, 39 º 30' N and 60 m above sea-level). Burjassot is a town of some 37,000 inhabitants seven km northwest of the city of Valencia and within its metropolitan area. Valencia is on the east coast of Spain and has a subtropical Mediterranean climate with an average annual temperature of 22.8 °C during the day, mild winters and long warm to hot summers. The region receives large UV radiation doses throughout the year. Sunshine duration hours are 2,660 per year, from 150 in December to 314 in July (State Meteorological Agency: '<u>Standard Climate Values. Valencia</u>').

Fig. 1. Radiometric measurement station from Universidad de Valencia

2.2. Instrumentation

Measurements of global solar irradiance were made on a horizontal surface using a Kipp and Zonen CM-6 pyranometer, which has a spectral range of between 305 and 2800 nm. Its directional response from 0 to 80° zenith angle is less than 2%, with a temperature dependence within 4% over an ambient temperature range -10 ºC to +40 ºC, all of this according to the manufacturer´s specifications (http://www.kippzonen.com/Product/12/CMP6-Pyranometer#.WhvtJlXiaUk). A field calibration was performed in 2011 by comparison with a CM21 pyranometer which acted as a travelling standard and was previously calibrated at the Kipp and Zonen laboratory on 31 March 2010 (Serrano et al., 2014). Pyranometer calibration uncertainty was within approximately ±5%.

To measure UVER irradiance on a horizontal plane a YES UVB-1 pyranometer (Yankee Environmental Systems) was used with a spectral range of 280-400 nm with a cosine error less than 5% for solar zenith angles below 60º according to the manufacturer (http://www.yesinc.com/products/data/uvb1/). But, for zenith angles above 60º the YES UVB-1 has non-negligible cosine errors– unless a calibration matrix with double entries (zenith angles, total column ozone) be used (Vilaplana et al., 2006). For a constant ozone value of 310 DU, the calibration matrix provides a corrected signal with an error below 9% for zenith angles of less than 65 degrees – and reaching 16% for zenith angles of 75 degrees (Vilaplana et al., 2006). For this reason, although all the data was estimated using the above-mentioned matrix, measurements corresponding to zenith angles smaller than 70 degrees were used in the calculations, thus ensuring an error of less than 12% in the experimental values.

This instrument was calibrated at the National Institute for Aerospace Technology in Spain. This standard calibration initially consists of an indoor measurement of the spectral response of the radiometer. It was then compared with an outdoor Brewer MKIII spectroradiometer (Hulsen and Grobner, 2007; Vilaplana et al., 2006). Correction factors, using the Libradtran model, are determined with the objective of converting the unique spectral response of the instrument signal into an erythemal response close to the erythema action spectral sensitivity (CIE 1998).

2.3. Data

Measurements were taken continuously and average values were calculated for 5-min intervals in irradiance units (W/m^2), i.e. the values considered were 5-min interval average values. The measurement period was from 2005 to 2014, with approximately 250,000 measurements, with no data during calibration periods.

The total ozone column data was obtained from measurements performed by the TOMS (total ozone mapping spectrometer) sensor on board NASA's Earth probe satellite until December 2005 and by the Ozone Monitoring Instrument (OMI) sensor, which is nadir-viewing instrument on board NASA's Aura satellite from January 2006. It has been used the tool "Ozone over Your House" to get the total column ozone amounts for Valencia latitude/longitude. Ozone data are returned for multiple sensors being a measure of ozone density through an entire column of atmosphere, from ground to space, and is dominated by stratospheric ozone (https://ozoneaq.gsfc.nasa.gov/tools/ozonemap/). For further information, see NASA DISC at http://disc.gsfc.nasa.gov/Aura/OMI/ (NASA, total ozone mapping spectrometer, accessed 25 January 2015). Data was downloaded from this website once per day on days when UVER was measured.

2.4. Clearness indices

Data sheets were compiled containing the following information: date; time; solar zenith angle (SZA); global solar horizontal irradiance (W/m^2); total ozone column (TOC) in Dobson units; UVER horizontal irradiance (W/m^2); global and UVER horizontal clearness indices.

To characterise the sky conditions at a given point in time when the global horizontal irradiance is known Liu & Jordan (1960) defined the clearness index, k_t, as the ratio of global horizontal irradiance at the Earth's surface, I_G, over extra-terrestrial horizontal irradiance, I_0. Eq.(1)

$$k_t = \frac{I_G}{I_0} = \frac{I_G}{I_{sc} E_0 \cos(SZA)} \tag{1}$$

Where I_{sc} is the solar constant (1367 W/m ^{2}), E_0 is the correction factor of the Earth-Sun distance ($[r_o/r]^2$) and SZA is the solar zenith angle.

In the absence of additional data (e.g. cloud cover, percentage of insolation, etc.) this parameter is the only information available to describe the presence of clouds, in the form of the depletion of incident irradiance on its way through the atmosphere due to absorption and dispersion processes, and therefore indicates the level of solar irradiance at the Earth's surface. As the clearness index is defined from instantaneous values, in this study we obtained 5-min k_t values, although hourly, daily and monthly values have also been used in previous studies. For the independence comparisons tests (see Section 4) the median k_t for each day was calculated statistically from the 5-min k_t value.

Cloud effects were taken into consideration in the GIV and UIV study, assuming sky conditions objectively specified in terms of two ranges of k_t. For $k_t > 0.65$ was considered to be cloudless skies and cloudy skies were $k_t < 0.35$. This criterion was applied to select cloudy/cloudless periods, both 5-min k_t values to daily k_t values calculated as described above. Skies with clearness indices between 0.35 and 0.65 are partly cloudy skies. Different researchers have adopted different values for k_t thresolds. For instance, Orgill and Hollands, (1977), proposed <0.35, 0.35-0.75 and >0.75 for cloudy, partial cloudy and clear sky respectively, Chandrasekaran and Kumar, (1994), used <0.24, 0.24- 0.80 and >0.80, Reindl et al. (1990) have proposed kt > 0.6 and kt < 0.2 for clear sky and cloudy sky, respectively. Li and Lam (2001) and Li et al.

(2004) used kt values of 0–0.15, >0.15–0.7 and >0.7 to define overcast, partly cloudy and clear skies respectively in Hong Kong and Kuye and Jagtap (1992) used kt > 0.65 and 0.12 ≤kt ≤ 0.35, respectively, for very clear skies and cloudy skies, to classify the sky conditions at Port Harcourt, Nigeria.

Following Alados-Arboledas et al. (2003), a new UVER clearness index was used to to characterize the atmospheric effect on UVER to analyse the UVER band measurements equivalent to broadband $k_{t,}$ and known as k_{tUVER} Eq.(2)

$$k_{tUVER} = \frac{UVER}{I_{scUVER} E_0 \cos(SZA)} \qquad (2)$$

Where UVER is the UVER horizontal irradiance measured at the Earth's surface in W/m^2,and I_{SCUVER} (UVER irradiance outside the atmosphere) was obtained from the SUSIM Atlas 3 extraterrestrial spectrum, (http://www.solar.nrl.navy.mil/susim.atlas.data.htm) at a value of 9.89 W/m^2.

The atmospheric ozone greatly influences the UVER radiation received at the earth´s surface, and is an important attenuating factor of the UVER irradiance and therefore decreases the value of the UV clearness index. TOC values shows their maximum during winter season when the irradiance is the lowest of the year and therefore the clearness index. Besides, in a northern mid latitude as Spain TOC and UVER present their maximum variability in winter and minimum in summer, and according Anton et al. (2008) a TOC depletion higher than 5% between consecutive days produces mean UVER increases from 6.6% to 10%.

3. Methodology

3.1. Global and UVER irradiance variabilities

To study GIV and UIV the corresponding clearness indices were used, as in previous studies (Antón et al., 2011), with the following expressions shown as percentages Eqs.(3) and (4):

$$GIV(\%) = 100 \cdot \frac{\left|k_t^{i+1} - k_t^i\right|}{k_t^i} \qquad (3)$$

$$UIV(\%) = 100 \cdot \frac{\left|k_{tUVER}^{i+1} - k_{tUVER}^i\right|}{k_{tUVER}^i} \qquad (4)$$

Where k_t^i and $k_t^{i+1}$are the clearness indices measured at two consecutive 5- min periods, as for k_{tUVER}.

For the above calculation, measurements taken at zenith angles below 70 degrees were used to remove sunset and sunrise periods (as irradiance can rapidly change even during instants of cloudless skies).

3.2.Analysis of independence of GIV and UIV

Pearson's χ^2statistical test was used to check whether the difference observed in our data was normal and probable or random. Our starting hypothesis was that the variables under study were independent of each other, and was contrasted with the alternative hypothesis that one variable was distributed differently for different levels of the other variable. This method was used because of its few limitations, given that the sample size was adequate and the expected frequencies were not small. The association between UIV and GIV was studied by making a partition of these variabilities at intervals of 1.5% to a maximum value of 7.5%, with the corresponding contingency table. The value of these variabilities was taken as the daily median of the variabilities as calculated every five minutes.

The dependence between these variabilities was first studied using χ^2, considering the independence between UIV and GIV as the initial hypothesis (termed hypothesis H_o). The alternative hypothesis (termed H_1) shows dependency.

UIV and GIV observations were grouped in intervals every 1.5% and a contingency table of these intervals was made. Each interval contains a relative frequency $\frac{x_i}{n}$ in the sample distribution, and a probability p_i, in the population distribution. In accordance with the principle of least squares, an expression of the type $\sum_1^k c_i\left[\frac{x_i}{n}-p_i\right]$ is considered as a measure of deviation, where the coefficients c_i can be chosen arbitrarily. Karl Pearson showed that if $c_i=\frac{n}{p_i}$ is taken, a measure of the deviation is obtained $\chi^2=\sum_1^k\frac{(x_i-np_i)^2}{np_i}$, which is distributed along a Pearson χ^2 curve, when the sample tends to infinity, with (k-1) degrees of freedom. In our case, having two magnitudes and their intervals requires a more general formula for the Pearson distribution, $\sum_1^k\sum_1^r\frac{\left[x_{ij}-np_ip_j\right]^2}{np_ip_j}$, x_{ij} being the number of observations of the range 'i' of the UIV, and of the range 'j'of the GIV; p_{ij} the probability that an observation belongs to the range 'i' of the UIV and of the range 'j' of the GIV. Therefore, the distribution is approximate to a curve χ^2 with (k-1)(r-1) degrees of freedom (Gutiérrez, 1978).

The corrected contingency coefficient of Pawlik and the Cramer's V index was used to measure the degree of dependence between the global and UV irradiance variabilities, with theoretical values that can oscillate between 0, corresponding to no association between the variabilities, to 1 (complete association). If these indices reach the value of 1, this would indicate that the two variabilities are equal to each other. The first index has the following expression:

$$C_{cP}=\frac{C}{C_{\max}} \quad (5)$$

where $C_{\max}$ and C are

$$C_{\max}=\sqrt{\frac{\min\{k-1,r-1\}}{1+\min\{k-1,r-1\}}} \quad (6)$$

$$C=\sqrt{\frac{\chi^2}{\chi^2+n}} \quad (7)$$

The second index used is the following:

$$V=\sqrt{\frac{\chi^2}{n(t-1)}} \quad (8)$$

where χ^2 is the value obtained applying Pearson's statistical test, *k* is the number of rows in the table, *r* is the number of columns, *n* is the total number of observed frequencies, and *t* is the minimum value between the number of rows and the number of columns.

With respect to the effect of $k_{t,}$ and k_{tUVER} on GIV and UIV, bi-dimensional distributions were used to gather information on the two measured variables. The study of contingency tables was complemented by analysing the distributions of marginal frequencies between GIV and UIV ranges in comparison with the k_t ranges.

Additionally, this section describes the study of the comparison of the independence of high UIV and GIV and the variables on which they may depend, such as k_t, k_{tUVER}, and ozone. A value of 3% was used to characterise high variabilities and two intervals were used for the clearness indices (one for values less 35% above the minimum value and the other interval for values less than 35% below the maximum value). The daily median of the 5-min variabilities and clearness indices were calculated and were used in the subsequent comparisons tests. The ozone value was the daily value provided by the NASA. For this comparison test the χ^2comparison was used, considering the independence of the characters as the initial hypothesis.

3.3. Prediction of UVER values

The theory of extreme distributions was used in the present study; this involves studying the sets of extreme values that do not follow normal distributions. The 1954 Gumbel distribution is the most suitable for adjusting these extreme values. The sequence of the stages of implementation are: ordering the data in descending order; assigning probabilities to each data (the Weibull probability was used: $\mathrm{p_i} = \frac{\mathrm{i}}{\mathrm{n+1}}$ with 'n' being the number of maximum values, and 'i' the position of the maximum data after ordination); determining the values of the reduced variable (defined as $\mathrm{y_i} = -\ln\left[\ln(\frac{1}{1-\mathrm{p_i}})\right]$); and plotting the maximum values of UVER in comparison with the reduced variable and performing a least squares fit.

The equation for the Gumbel distribution is $\Phi = e^{-e^{-y}}$. When the random variable is a quantity related to natural phenomena, it is advisable to refer to return time periods rather than probabilities of occurrence. The return periods represent the number of time units in which the variable exceeds a certain value. The equation for the return period in the Gumbel distribution is $T = \frac{1}{1-\Phi(y)}$.

3.4. UIV time series

The components or sources of variation affecting a time series are heterogeneous and grouped into four main components: a) general trend; b) seasonal variations; c) cyclical variations; d) and random variations.

The present study only considered the component of seasonal variations of the UIV– which thus eliminates the seasonal effect – and the procedure was based on the calculation of the indices of seasonal variation (SVI).

The calculation of these indices for analysing UIV consists of the following steps: a) obtaining monthly averages; b) calculation of annual totals; c) least squares fit of the line of these totals versus number of years; d) obtaining the ‘b’ slope of the line. This slope measures the increase or decrease (depending on the sign) experienced by the series (for a monthly period the increase or decrease will have the value of b/12); e) from each mean 0, b / 12, 2b / 12, .., 11b / 12 is subtracted to obtain a new set of means corrected for the trend. The SVI are given from the mean corrected by the equation:

$$\mathrm{SVI} = \frac{\text{monthly corrected mean}}{\text{average of the monthly corrected means}} \cdot 100 \qquad (9)$$

These indices give us the discrepancy in the seasons with respect to a freely chosen median level such as 100.

Finally, extreme episodes of UVER irradiance are studied with the aim of observing if there is a direct relationship between UVER irradiance maximums and its high variability. Outliers are limited by definition. In a typical outlier problem, ‘reliable estimates’ of extreme levels (return) are required. These are well beyond the maximum or minimums in the sample observed.

4. Results and discussion

Statistical classifications of different variables were made to better understand the behaviour of the different variables analyzed in the study.

Table 1 shows the range of values and Standard Deviation obtained from each variable.

Table 1. Range of values and Standard Deviation for GIV, UIV, k_{tUVER} , k_t and ozone.

Two statistical parameters were used to classify the variables: the standardized bias, calculated as the difference between estimated and real value, and the kurtosis coefficient, an indicator which shows the degree of concentration of values around a central zone.

The results were as follows (see Figures 2 to 6): As it can be observed form Figure 2, the statistical distribution for UIV shows that the most of the UIV data are on the left side of the histogram (meaning a higher number of low variability for UV irradiance); more explicitly , a 5% of the values are in a range of variability of 0 to 0.05 W/m^2 and a few larger values of UIV are on the right (meaning a lower number of high variability for UV irradiance; only a 1% of the values have a variability higher than 0.15 W/m^2).

The statistical distribution for GIV, as it can be observed from Figure 3, has similar meaning to the UIV one, but in GIV case the asymmetry is not so clear, with a 4% of the values with a variability between 400 to 600 W/m^2 and only 1% of the values with variability higher than 1000 W/m^2 . The meaning may be that, in general, variability for Global Irradiance is not as low as UV one.

This behavior for both UIV and GIV has the correspondence with Kt_{UVER} and K_t respectively.

In the case of statistical figure for Kt_{UVER} , Figure 4, the right-skewed unimodal distribution means that most of the Kt_{UVER} data are on the left side of the histogram (meaning a higher number of low values for Kt_{UVER}; in other words, a 4% of the data with values between 0.005 and 0.01) and a few larger values of Kt_{UVER} are on the right (meaning a lower number of high values for Kt_{UVER}: only a 1% of the data with values higher than 0.02).

In the case of k_t , see Figure 5, the statistical indices show a left-skewed bimodal distribution. The bimodality suggests the heterogeneity from the values analyzed, in which two tendencies may be observed: one from the cloudless days (around a value of 0.76) and another from overcast days (around a value of 0.32). On the other hand, the left-hand skew for this variable is due to the fact that the higher the number of cloudless days, the higher the number of large k_t values.

The degree of concentration around certain values can also be calculated from this statistical analysis for the variables studied. For UIV, GIV, k_{tUVER} , and k_t the distribution values are shown to follow a platykurtic pattern, in other words, there is a low degree of concentration around the central values of the variable.

Finally for ozone statistical distribution, figure 6, the data show a leptokurtic distribution, meaning that most values are concentrated on the mean value, with about a 8% of the data concentrated on the 300 to 320 DU. For Valencia values of ozone have a low variability. That is the reason why most of values are closer to mean.

Fig. 2. Distribution for UIV.

Fig. 3. Distribution for GIV

Fig. 4. Distribution for k_{tUVER}

Fig. 5. Distribution for k_t

Fig. 6. Distribution for ozone

4.1 Daily variability

The effect of clouds as an important factor related to UVER and global daily irradiance has been explained in previous studies (Cede et al. 2002; Serrano et al. 2006).

We observed that this factor has a larger influence on global irradiance than on UVER irradiance. GIV ranged from 0.4% 5min^{-1} (k_t = 0.8) to 11% 5min^{-1} (k_t = 0.1). In the case of UVER irradiance, the variability was 25.5% lower than global irradiance. The UIV ranged from 0.9% 5min^{-1} (k_t = 0.8) to 8.8% 5min^{-1} (k_t = 0.1).

4.2 Analysis of independence of variabilities

The calculation steps have been the following: First, an analysis of the existence of dependence between variables. By means of the construction of contingency tables, and Pearson's $\chi 2$ statistical test, the dependence / independence between variables has been tested.

Second, an analysis of the degree of dependence between variables. In other words, quantify the dependence or independence between variables. In this case, Pawlik contingency coefficient has been used.

A study was made of the dependence of UIV and GIV and the high variability of these irradiances associated with k_t, k_{tUVER} and ozone was analysed. Statgraphics software has been used in this analysis.

4.2.1 Analysis of independence between GIV and UIV

2327 UIV and GIV observations were grouped into intervals every 1.5% to a maximum value of 7.5% and a contingency table of these intervals was made.

By applying the Pearson's chi-squared test (see Section 3.2) to our data, χ^2 = 1325.13 was obtained, which is greater than $\chi^2_{0,95} = 26.3$ for 16 degrees of freedom (four degrees of freedom for each variable, GIV and UIV), and so it can be concluded that there is a 95% probability of a clear dependency between the variabilities.

The second point of interest is to somehow measure the degree of dependence. For this, Pawlik's corrected contingency coefficient, Eq.(5), and Cramer's V index Eq.(8) were used, whose theoretical values range between 0 and 1, where χ^2 is the value obtained above, k=5, r=5, n=2327, and t=5. The results obtained are C_{cP}=0.68 and V= 0.38, which indicates that the degree of dependence is medium-high.

The next step in our analysis determines the intervals of the magnitudes in which dependence is highest. These are determined by looking at the cells in the table with the greatest difference between the observed (real) and expected values (in case of independence) by providing each cell with the total value of χ^2. The highest dependency occurs when UIV and GIV are in the 6-7.5 range, given that it contributes nearly 29% to the dependence.

4.2.2 Analysis of independence of GIV and UIV of k_t

The differences with a normal distribution (see Section 4) indicate the influence of other factors on the UVER irradiance transmission process. When a large enough sample of a population differs from a normal distribution, then one or more factors have a significant but varied effect (B. Jódar, 1981).

The influence of each factor should not be considered in isolation. Following Paul Dirac, there is no theoretical reason to assume that the effect of two causes acting simultaneously can be estimated from separate effects. Accordingly, in the analysed variance in the experimental data (S. Gutíerrez, 1978), all the causes whose influence is under study (termed *factors*) may also have variations (termed *levels*).

This study considers the GIV coefficient and k_t as causes that act as factors (including the UIV coefficient). Arbitrary partitions are made in the range of these factors and are termed levels.

Table 2 shows the relative frequencies (n_{ij}/n) for each cell. The last row and column are relative marginal frequencies.

One of the objectives of the analysis of bi-dimensional distributions is to determine whether the variables are independent and if there is an association or relationship between both.

According to the theory of statistical distributions of two characters, it can be ensured that the two variables are dependent if the product of the relative marginal frequencies gives different results to those of the relative frequencies in each cell (for at least one different value). In our case, from the data shown in Table 1, it follows that the variables GIV and UIV are dependent on k_t.

It therefore follows that the relationship between k_t, GIV and UIV is not due to chance.

Table 2

Relative frequencies of GIV and UIV dependence on k_t.

For k_t the highest correspondence is given at the interval from 0.6 to 0.8 (80% for GIV and 75.6 for UIV). On the other hand, it can be observed that for these variabilities, most values are concentrated at the 0 to 1.5 k_t interval (62.4% and 36.8% respectively). A connection between high k_t (cloudless days) and low variabilities can therefore be deduced (see Figure 1), as has been found in previous studies (Gonzalez and Calbó, 1999; Gueymard and Ruiz –Arias, 2014).

4.2.3.Analysis of independence of high GIV and UIV of various parameters

Part of the study focused on whether or not there was a relationship between the high variability in UIV and GIV and on quantifying the degree of dependence, for which the daily median of 5-min values was used for the different variables. The statistical parameter used to evaluate the relationship between the variables was the χ^2 test, considering the independence of the variables as the initial hypothesis.

Relationship between high UIV and GIV and k_t

The χ^2 test provides a value of $\chi^2 = 4.61 > \chi^2_{0.95} = 3.84$. It can be assumed that the initial hypothesis of independence can be rejected, so that UIV and GIV are dependent on k_t. However, according to the values obtained for Pawlik’s corrected contingency coefficient and Cramer’s V ($C_{cP} = 0.09$ and $V = 0.06$) there is very little dependence.

As regards the range of k_t values that produce the highest dependence, this is slightly higher when k_t is above 0.65 (cloudless days).

Relationship between high UI,V GIV and k_{tUVER}

In this case, the χ^2 test provides a value of $\chi^2 = 9.04 > \chi^2_{0.95} = 3.84$. Therefore the initial hypothesis of independence can also be rejected, which means that high UIV and GIV variabilities are dependent on $k_{tUVER.}$

As the Pawlik and Cramer coefficients are $C_{cP} = 0.13$ and $V = 0.09$, it can be concluded that the dependence is very small in this case and is more marked in the k_{tUVER} values above the upper range.

Relationship between high UIV and GIVand ozone

However in the case of ozone, the χ^2 test provides a value of $\chi^2 = 0.92 < \chi^2_{0.95} = 3.84$, and therefore confirms the initial hypothesis of independence. High UIV and GIV do not depend on the amount of ozone in the atmosphere.

Table 3 shows a summary of the different results obtained in comparing the influence of different parameters on high UIV and GIV values.

Table 3. Pawlik and Cramer coefficients for k_t, k_{tUVER} and ozone

4.3 Prediction of UVER values

It is of interest to analyze the UVER irradiance trend because of its biological effects (Bais et al. 2015; Thomas et al. 2012). Herman (2009) studied the rise in global UVER over 30 years (1979 to 2008) and obtained a monthly averaged ozone time series in order to estimate changes in UVER irradiance. His main findings were: at a latitude of 32.5N, the ozone series slope is -0.3 per DU tenth per year. He also studied the relative change in UVER and obtained a value of 0.002 per year and detected an increase in UVER irradiance of about 6% in 30 years. The possible reasons were changes in ozone and reflectivity due to clouds and aerosols.

Fig. 7. Regression of maximum UVER values (continuous line). Dashed line is the standard deviation of the regression (n=200).

Applying methodology described in Section 3.5, the resulting adjustment equation is

$$\mathrm{UVER} = 0.0028 \cdot \ln(\mathrm{y}) + 0.249 \qquad (10)$$

with a coefficient of determination $\mathrm{R}^2 = 0.9755$, as shown in Figure 7.

By extrapolating the values of the adjustment curve it is possible to calculate probable future UVER values. As extrapolation is most reliable near the set of points used for adjustment, a period of ten years was selected (from 2014). Firstly, the value of the Gumbel distribution is determined (0.9 for this period) followed by the reduced 'y' variable (2.25). The last value of the reduced variable used in the adjustment is 5.5361 (see Figure 7). The abscissa is then moved to the value of 7.78. If this value is substituted in an adjustment equation, an UVER value of 0.2547 $\mathrm{W \cdot m^{-2}}$ can be predicted, giving an increase of 0.43%, since the UVER of the reduced variable is 0.2536$\mathrm{W \cdot m^{-2}}$.

To verify the regression for maximum UVER values, higher 2015 UVER values were chosen (this year is not included in the rest of the study) and confirmed that the values considered for the verification are inside the area limited by UVER $\pm\sigma$ (standard deviation).

Table 4. Verification of maximum UVER values regression.

4.4 UIV time series

This section deals with the analysis of a set of observations of a magnitude measured sequentially in time in the form of a time series. A study of the time series of a variable reflects its historical evolution and enables forecasts to be made, provided that the circumstances producing the results remain unchanged.

In this study the SVI of the UIV was calculated by applying Eq.(9) (for results see Figure 8). The SVI shows the annual (or monthly, quarterly, etc.) percentage increase or decrease in the seasonal component. These rates should not impinge on the annual series and therefore the annual average should always be equal to 1 (or 100%).

Fig 8. Seasonal variation index of UIV throughout a year (n=200)

These coefficients show the positive or negative deviation with respect to the threshold value of the month of the year – the seasonal effect. The registered UIV reading in January is 100-63, which is 37% below the normal level of 100%. Similarly, in the months of September and October, the seasonal influence produces variabilities of over 20% above the normal level of 100%. Thus, there is negative deviation in January and February, as the SVI is lower than the base of 100. On the other hand, in August, September and October there is positive deviation greater than 100.

5. Conclusions

k_t values lower than 0.6 were found to show greater variability for both global irradiance and UVER, i.e. as cloud cover increases (lower k_t values) GIV becomes higher than UIV. Cloud cover has a greater influence on global irradiance than on UVER irradiance.

Perhaps the reason has to be related to the main scattering process when talking about water vapor: Mie scattering. In comparison with Rayleigh scattering coefficient, Mie coefficient, is less sensitive to wavelength than the first. This may be the reason why GIV is higher than UIV when clouds increases.

Another important trend is that UIV on cloudless days (k_t higher than 0.65) is greater than GIV, which may be explained by two main factors: diurnal changes in total ozone levels and the influence of aerosols.

It was also observed that there is a medium-high dependence on the degree of variability between global irradiance and UVER irradiance, so it can be concluded that there is a relationship between these two variabilities, with the strongest association for high variabilities (above 4.5 %), since they contribute about 50% to the dependency construction of the variability.

It can also be concluded that GIV and UIV are dependent on k_t. From Table 1 it can be deduced that there is a relationship between high k_t values (cloudless days) and low variabilities, which agrees with the findings in Figure 1.

It was also established that high UIV and GIV are slightly dependent on k_t and k_{tUVER}. This dependence is slightly higher on cloudless days and for k_{tUVER}.values above the upper range, since in these ranges the clearness indices contribute around 55% and 59%, respectively, to the construction of dependence. This indicates that, for high k_t values, the effects of sky conditions on the two statistical samples (GIV and UIV) are similar. For low k_t both variabilities depend slightly less on each other, indicating that there may be a factor which affects these variabilities differently, such as higher atmospheric water vapour content and/or presence of aerosols. However, there is no association between high GIV and UIV and the amount of ozone in the atmosphere. Ozone changes do have an influence on UVER, but this is not significant in the case of high UIV. The reason for the higher variability may be due to the more rapid rate of change for cloud optical thickness. Therefore most of the variation may be due to cloud OD variation. (Iqbal 1983).

Regarding SVI, there was a negative deviation in January and February, whereas in August, September and October, a positive deviation was found, as it was greater than 100. In summer, most days have high k_t and high temperatures, which induce atmospheric smog. As Valencia is an industrial city with dense traffic and considerable contamination, Mie dispersion is the most likely reason for the seasonal influence.

As regards climate change, a prediction was made of the evolution of UVER irradiance based on statistical data which predicted increased irradiance in Valencia in the next ten years (Latitude 39.3ºN), in agreement with the findings of Hegglin & Shepherd (2009) and Roman et al. (2015).

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