Solar erythemal irradiance in Ibarra, Ecuador (high altitude equatorial city). Ground and satellite measurements and model calculations.

Irradiancia solar eritémica en Ibarra, Ecuador (ciudad ecuatorial de gran altitud). Mediciones terrestres y satelitales y cálculos con modelos.

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RESEARCHS / INVESTIGACIÓN

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Abstract: The knowledge of the UV Index values, as an indicator of solar risk, allows us to adopt appropriate protection measures. This research analyzes the erythemal irradiance (directly linked with the UV Index) from July to September 2017 measured in Ibarra, Ecuador with a UV radiometer. We found that 72 days hold UVI values higher than 11 over 82 measured days, i.e. there are stages in 87.8% of the days when the UVI overcome the “extreme” value (according the WMO and WHO classification). Also, 14 days show UVI values over 20 (extremely high). Such classification doesn’t seem quite adequate for this particular region. This region has important characteristics that increase the UVI: high altitude (2225 m s.a.l.), low atmospheric ozone values (248.8±12.2 DU measured from 2005 to 2016 by OMI/NASA satellite), and great cloudiness percentage (with an annual average value of 78.5%) of “cumulus” type. This study demonstrated the need for skin protection for individuals who perform outdoor activities in Ibarra, a place considered “high risk” for skin damage progression due to its high altitude and closeness to the equator, even under cloudy skies.

Key words: Solar risk, UV Index, clouds, Ibarra, Ecuador

Introduction

The Sun, located 150 million kilometers from Earth, emits electromagnetic radiation whose spectrum covers several wavelengths, ranging from microwaves to gamma rays. Fortunately, life is possible as we know it, since the terrestrial atmosphere filters most of these radiations, preventing any powerful solar ultraviolet radiation (UVR) from reaching the terrestrial surface level, as well as X and gamma radiations.

UVR is usually subdivided into three bands: UVA (400–315 nm), UVB (315–280 nm) and UVC (280–100 nm). UVR at wavelengths shorter than 320 nm is more photo-biologically active than UVB resulting from 250 nm is biologically active to cause erythema (a skin condition characterized by redness) in the skin. Therefore, UVA penetrates the human skin more deeply than UVB resulting in greater risk for initiation of the carcinogenic process in skin.

Stratospheric ozone is the main absorber in the atmosphere which determines the amount of UVR that reaches the ground. Ozone production and destruction require solar radiation with wavelengths shorter than 240 nm (which is mainly UVC radiation). Total column ozone is measured with ground and satellite-based instruments. A typical ozone value in the mid-latitudes is found in the region of 300 Dobson Unit (DU), where 1 DU = 2.69x10¹⁶ mol O₃/cm². In the absence of all other factors, less ozone in the atmosphere allows for more solar UVB radiation to reach the ground, and vice versa. Among the myriads of elements that enables life on Earth, a crucial one is the impact the ozone layer plays on the decrease of this solar radiation.

It’s estimated that followed by stratospheric ozone, the percentage of cloudiness is the second most effective filter limiting the amount of solar UVR that reaches the Earth’s surface. However, cloud cover can either attenuate or enhance the amount of solar UVR reaching the ground. Whether attenuation or enhancement occurs is determined by factors such as cloud location (which refers to cloud height and determining if the cloud is covering the solar disc). Other factors include opti-
cal thickness and liquid water content. According to Juzeniene et al., people burn less on a cloud-covered day or in winter. However, a distinctive situation occurs when the clouds are of cumulus-type close to (but not covering) the Sun: An enhancement follows and the terrestrial values of solar UV radiation overcomes the extraterrestrial (outside of Earth’s atmosphere) UV radiation. In particular, several investigations have found extreme values of solar terrestrial radiation in different places: Puna de Atacama, Argentina; Ecuador; Recife, Brazil; San Pablo, Brazil; Maceió, Brazil; Salum et al. analyzed the change of energy in one peak of enhanced total solar irradiance due to clouds.

Solar UV Index (UVI) is the time-dependent wavelength-weighted average UV irradiance in W/m² multiplied by 40 [m²/W]. The World Health Organization (WHO) and the World Meteorological Organization (WMO) made a classification of the UVI (see Table 1). This classification has been the subject of critical analysis because the UVI in many parts of South America, and countries close to latitude 0° and high altitude, have values above 11.

MED (or minimal erythemal dose) is the dose of UVR required to produce a barely perceptible erythema. The effective UV spectrum is the mathematical product of the solar UV spectrum and the erythemal response spectrum. The effective UV intensity is the integral of the UV spectrum over the wavelength, and usually is measured in (MED/h) or UVI. The action response spectrum is the relative response of each wavelength for causing some biological effect. Figure 1 shows the action response spectrum of erythemal action spectrum and the SCUP (Skin Cancer Utrecht-Philadelphia) action spectrum. The SCUP spectrum is used as a model of UV carcinogenesis of the skin. Figure 1 shows that the biggest response, for both effects, is in the UVR range. In these cases the UVI Index is a good indicator for the skin cancer risk, too.

The MED values depend largely on the phototype of the skin. The skin classification (see Table 2) of Fitzpatrick is based on the color and the responses to sun exposure in terms of tanning and burning degrees.

In the Bolivian Andes, at around 4000 m altitude, the UVI is the highest in the world, showing UVI above 16, and commonly reaching UVI values above 20. Measurements have been made in the desert of Arica in Chile, where it was observed that the increase in percentage of UV irradiance per 1000 m of altitude above sea level are 5.1% in summer and 5.8% in winter.

In a recent publication, Holick emphasized the importance of the biological effects of sunlight on health, linking the exposure to UVR radiation to brain activity, and a balance in the sun exposure needed to synthesize vitamin D and the sun exposure to produce sun burning.

### Methods

In this research we used a calibrated ultraviolet radiometer Erythemal-type, Kipp&Zonen. Once the data (in millivolts) were stored, they were converted to irradiance data (in watts per square meter). This radiometer (called biometer) was installed along with a data logger in Ibarra, Ecuador, (0.36° N.
The Aura/NASA satellite. We analyzed these data for Ibarra, measurements done by the OMI/KMNI instrument on board of the Aura/NASA satellite. This classification is not valid for Ibarra. This is of interest, not only to the inhabitants of the region who have a phototype III or IV, but also to Caucasians or fair skinned people because skin cancer risk is higher than for phototype II and I. Figure 4 shows the lower limits for “high”, “very high” and “extreme” UVI classification, according to WMO/WHO for the three days per month with higher UV Index.

In the case of September 3, the modelling clear sky situation was compared to the measured (real) condition between 12:46 pm and 1 pm (local hours = UT -5 hours). This interval is of interest since there is a peak due to the cloud condition. The measured value has a maximum UVI equal to 22.1 at 12:16 and the modeled value of 19.4 for the same time. This is an increase of 14.2%, with respect to clear sky conditions. This value (UV Index = 22.1) was the highest value in the analyzed period.

iii- Energy analysis

In order to determine the change of energy caused by this increase in solar irradiance due to clouds, we need to calculate the irradiation, that corresponds to the integration (continuous sum) of irradiance, also called insolation. Before that step we must calculate the erythemal irradiance, which is the UV Index divided by 40 [m2/W].

For September 3, we integrated the erythemal irradiance between 12:46 pm and 1 pm. The results are: ETUV = 389.9 [J/m^2] and Ereal = 400.3 [J/m^2], or a difference of 2.7%.

Now, a healthy solar exposure time to UV radiation can be obtained by the MED value for a given phototype, according to the Fitzpatrick classification. Considering that for a phototype
Figure 2. Measured UVI values (black line) as function of time for July (top), August (center) and September (bottom) 2017, at Ibarra, Ecuador. Averaged UVI values (blue line) determined with the TUV model\(^\text{18}\) considering monthly mean conditions clear sky days for each month, are also included. In red and orange lines are indicated the lower limits of “extreme” and “very high” UV Index classification.
Figure 3. UV Index from January 1st, 2010 to December 31st, 2016, measured by the OMI/KNMI instrument on board of Aura/NASA satellite. The blue horizontal line corresponds to the mean value in the analyzed period 11.0±2.0.

Figure 4. The days with the highest values of UV Index for each month (July, August and September of 2017), measured at Ibarra, Ecuador. The blue curve was calculated with TUV model considering clear sky conditions. In red, orange and yellow lines are indicated the lower limits of “extreme”, “very high” and “high” UV Index classification.
Ill the mean MED is equal to 400 J (see Table 2), in both cases (modelling and measuring), a person of skin type III should be exposed to the Sun for less than 16 minutes around noon.

v- Ozone analysis

Among the parameters that have a particular effect on the UVI (or the UV erythemal solar irradiance) on a clear sky day, in addition to the geographic location, the atmospheric ozone content is of large significance[53].

In order to identify the atmospheric situation of Ibarra, we obtained the ozone total column from the OMI/Aura NASA satellite database. The downloaded data are: [259±10] [DU]; [261±8] [DU] and [265±12] [DU] for July 28, August 27 and September 3, respectively. The values for the total ozone column are rather low with respect to the mean global value of around 300 UD, with an average value of (248.8 ± 12.2) DU, representing the mean of 12 years of data (from 2005 to 2016).

Discussion

This thorough analysis demonstrated the need for skin protection for people who predominantly perform activities outdoors in Ibarra, at high altitude, near the equator in Ecuador, even under cloudy skies. This conclusion is based on the fact that a maximum UV Index value, higher than 22 (0.55 W/m²), was recorded on September 3 at 12:16 local time (= Universal time - 5 hours). This is significant, since sunburned skin is the inflammatory acute effect of UV radiation. If the UV dose is higher than the threshold damage response, keratinocytes triggers apoptosis and die. In particular, UVB (directly related to the UVI) stimulates the formation of DNA photo-lesions[14].

From the 82 day measured, 72 days (corresponding to 87.8%) had UVI values higher than 11. These are considered by WMO and WHO standards to be “extreme UVI, and 14 days have UVI values over 20 (extremely high), which corresponds to 17.1 %. These extreme values confirm the influence of clouds reinforcing ultraviolet radiation in particular situations, especially the clear sky situation for September 3 when the UV Index is higher than 11 (lower limits of “extreme UVI”) from 9:44 am to 2:39 pm, i.e. almost 5 hours of the day.

On the other hand, clouds can have a positive impact on the solar erythemic irradiance, in some instances significantly reducing the solar radiation, e.g. on September 9 at 12:18 there was a sharp fall of the UV Index from 17.1 (clear sky conditions) to a value of 5 (~decrease of 71.2% of the UVI).

Special care must be taken by those of skin phototype mostly equal or lower than III when exposed to the Sun at high altitude sites near the Equator, such as Ibarra in Ecuador and nearby regions.

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