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Spectral signature of ultraviolet solar irradiance in Zacatecas

J. L. Pinedo V., F. Mireles G., C. Ríos M., L. L. Quirino T. and J. I. Dávila R.
Universidad Autónoma de Zacatecas, Zacatecas, Zac., México

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RESUMEN

En este trabajo se presenta un análisis de la radiación espectral global ultravioleta (290-400 nm) registrada en Zacatecas, una ciudad vecina al trópico de cáncer, situada a 2500 m sobre el nivel del mar, latitud de 22°N y longitud de 102°O. Los espectros correspondientes han sido medidos mediante un espectroradiómetro Bentham con un paso de 0.5 nm de longitud de onda. Las mediciones muestran niveles de radiación ultravioleta (UV) relativamente elevados, que pueden ser característicos de las zonas vecinas al trópico de cáncer. Frente al aumento de incidencia de cáncer en la piel en la población del estado de Zacatecas, estas mediciones ponen en relieve la necesidad de formular un plan preventivo de daños.

PALABRAS CLAVE: Solar, espectral, ultravioleta, radiación, climatología.

ABSTRACT

This study presents an analysis of the global ultraviolet spectral irradiance (290-400 nm) registered in Zacatecas, a city near the Tropic of Cancer, located at 2500 m above sea level, latitude of 22° N and longitude of 102°W. The spectra have been measured using a Bentham radiometer with a 0.5 nm step in wavelength. The measurements show relatively high levels of ultraviolet irradiance (UV), which may be characteristic of areas close to the Tropic of Cancer. Faced with an increase of the incidence of skin cancer among the population of Zacatecas, these measurements highlight that a damage prevention plan is required.

KEY WORDS: Solar, spectral, ultraviolet, irradiance, climatology.

INTRODUCTION

Ultraviolet radiation is defined as the portion of the electromagnetic spectrum between X-rays and visible light, that is between wavelengths of 40 and 400 nm (energy comprised between 30 and 3 eV). The UV spectrum can be divided into broad bands: vacuum UV (40-190 nm), far or extreme UV (190-220 nm), UVC (220-290 nm), UVB (290-320 nm), and UVA (320-400 nm) (Zeman, 2006). Only the last three bands of solar radiation (UVC, UVB and UVA) reach the Earth's atmosphere, and only the last two (UVB and UVA) reach the Earth's surface.

Solar radiation measurement studies, and in particular those of ultraviolet irradiance, have acquired greater relevance in recent years. Indeed, electromagnetic UV radiation has important chemical and biological effects; therefore implications for human health, as well as for fauna and flora (Caldwell *et al*., 1986; Worrest *et al*., 1989; Bigelow *et al*., 1998; Sutherland *et al*., 1997; Chaney *et al*., 2005).

It is well known that the spectral composition of radiation reaching the Earth's surface depends on the reactions of solar radiation with the atmospheric constituents and the solar ray path in the atmosphere. Selective absorption results from variable amounts of ozone and water vapour as well as from uniformly mixed gases (CO_2 and O_2). Scattering is produced by the air molecules and the highly anisotropic absorption process arises from aerosol effects. The solar path on the atmosphere depends on latitude, altitude and solar entrance angle, which changes day to day over the year and second to second in the day.

Climatic variations modify the turbidity of the atmosphere and the radiation composition, amplifying or reducing its spectral intensity. Additionally the atmospheric concentration of several constituents (ozone, CO_2, NO_2) has been increasing in the past decades, inducing consequently a non natural modification of the spectral composition of solar radiation.

The depletion observed in the ozone layer in the stratosphere (Molina and Rowland, 1973; Farman *et al*., 1985; Abbatt and Molina, 1993; WMO, 1994; Bojkov *et al*., 1995) is susceptible to induce an increase in UV radiation at the shorter wavelengths (280-330 nm) in the troposphere and on the Earth's surface. This has incited the international scientific community to become aware of the need for establishing a UV climatology and monitoring its long term variations.

A UV-B climatology has been created from broadband measurements, using broad band UV-B instruments. These are mounted in ground stations or on satellites. However, as it becomes clear that a whole band is not responsible for such an effect, rather a mere fraction of it, broadband climatology is coming to be viewed as insufficient for studying the phenomena in depth (de la Casinière *et al*., 2002).

Spectroradiometers measure UV spectral irradiance with a 0.5 nm step in wavelength or less. A band can be reconstructed with precision from a spectrum, but the opposite can only be achieved by using complex radiative transfer computer codes or rigorous transmittance models. Both codes and models demand meteorological data, the amount of aerosols, and the total amount of ozone over the site among others. Indeed radiative transfer codes and transmittance models provide agreement between models and measurements within 6% (Wang and Lenoble, 1994, Idrissa, 1996, Casinière *et al*., 2003). However, while the UV radiation increase, accurate spectral measurements are necessary to follow the eventual modifications and to test or validate the models.

In this paper, we present the analysis of two series of spectral measurements, which give a first impression of the nature of UV radiation in Zacatecas, a city located in the area of the Tropic of Cancer, situated at a considerable altitude (2550 m above sea level) and under a dry atmosphere.

Spectral irradiance measurements are interesting from the physical viewpoint, but the accumulation of data will eventually allow the elucidation of the effects of ultraviolet radiation, which is not less important.

Frequent exposition to UV solar radiation is the major risk factor of skin cancer (Armstrong *et al*., 2001, Wang *et al*., 2005). There are three type of skin cancer: basal cell carcinoma (BCC), the more common but highly curable no melanoma skin cancer; squamous cell carcinoma (SCC), a curable no melanoma skin cancer; and the less common but potentially lethal cutaneous malignant melanoma (CMM).

More than one million of no melanoma skin cancers are diagnosed annually in United States; in contrast, the incidence of CMM has been steadily rising, and 59 580 new CMM cases and 7770 CMM deaths were expected in 2005 (Jemal, 2005). In 2006, The American Cancer Society has estimated 62 190 new cases and 7910 deaths of CMM.

In Mexico, skin cancer is not among the ten more frequent diseases. However statistics must be incomplete: patients with dermatological disease are not attended by public hospitals or health services, the largest part of them does not have formal medical assistance, others have recourse to private medical. So the information rarely transits to official statistics departments. The subject began to draw the attention of specialists several decades ago but studies are so few and limited. Two of the most copious epidemiological studies have been undertaken at the General Hospital in Mexico City: the first one accounts 389 cases of SCC and CMM registered between 1975 and 1992 (Peniche and Peniche, 1993); the second, following the same direction accounts 508 cases of SCC and CMM registered between 1991 and 2002 (Barron *et al*., 2004).

The state of Zacatecas, Mexico, has a population of approximately 1.3 million, and skin cancer is reaching important levels. In the last ten years, the University Clinic has only received approximately 1.5 thousand patients worried about skin cancer. Officially, according to the Zacatecas Health Department, skin cancer morbidity reached 118 cases in 2000 and 127 in 2001 and skin cancer deaths were 27 in 2004 and 16 in 2005.

Effects in the skin did not appear, or rather, were not recorded until recently. Thirty years ago, wide-rimmed hats and long-sleeved clothing were commonly worn in the countryside, sports in broad daylight and tanning were much less frequent than recently, and life expectancy in the state has risen since then from 55 to 70 years. Consequently, solar radiation exposure has increased as the result of a changing lifestyle. This change in people’s habits is perhaps a probable cause of the effects of solar radiation on the skin, but it is also possible that there has been a modification in the intensity of the irradiance reaching the Earth’s surface.

The purpose of this work is not properly to elucidate the relationship between UV solar irradiance and its biological effects. Our aim is to present the experimental basis for the evaluation, analysis and monitoring of UV radiation, with special emphasis on the relevance of spectral measurements.

GLOBAL SOLAR IRRADIANCE ON THE EARTH’S SURFACE

The electromagnetic radiation coming from the Sun and reaching the Earth’s surface can be measured as *total*, *spectral*, or *monochromatic*. *Total* measurements include the whole range of wavelengths or the whole of corresponding energies, while *spectral* or *monochromatic* measurements are associated with a specific unit of wavelength.

In general the studies of solar radiation on the Earth’s surface can be reported implicitly or explicitly in terms of general energetic quantities, such as *global irradiance*, *diffuse irradiance* and *direct irradiance*, whether they are total or monochromatic dimensions. *Global irradiance* is made up by *direct irradiance* ensuing from the solid angle delimited by the solar disc and by *diffuse irradiance,* which includes all of the radiation scattered by atmospheric molecules and which allow visibility or daylight.

Total global irradiance –which can be denoted by G and whose units are W/m^2– is the solar hemispheric irradiance arriving at any point on the Earth's surface. *Monochromatic global irradiance* is denoted by G_λ, its units are $W/m^2\mu m$ or mW/m^2nm, and it is the hemispheric irradiance corresponding to a narrow band of wavelength, as narrow as possibly measurable (for example: 1 nm, 0.5 nm, 0.1 nm,...).

Global irradiance in the UV band comprises the set of photons whose wavelength is between 290 and 400 nm, that is, the sum of all the monochromatic irradiances between both wavelengths, therefore it can be represented by

$$G_{UV} = \int_{\lambda=290nm}^{\lambda=400nm} G_\lambda d\lambda .$$

Total global irradiance includes all the photons arriving on Earth's surface, that is, all photons of all wavelengths or of all energies arriving from the Sun. Total global irradiance includes UV, visible and infrared irradiance. Given that the wavelengths of global irradiance range from approximately 290 to 2800 nm, the total global irradiance is represented by

$$G = \int_{\lambda=290nm}^{\lambda=2800nm} G_\lambda d\lambda .$$

Evidently, it is not the same all around the world, nor is it the same all year long; however the same systematic behavior should occur over time.

MEASURING GLOBAL SOLAR IRRADIANCE

Two types of solar irradiance measuring systems should be distinguished: *broadband* and *spectral* measuring systems. Examples of broadband measuring systems are UV, UVA, UVB radiometers, and pyranometers, which are instruments for measuring total irradiance. *Spectral* measuring systems are commonly called radiometers, or more specifically, spectroradiometers (Casinière, 2003).

Broadband measuring systems are more common and economical, while spectroradiometers, or spectral irradiance measuring systems, are more sophisticated, more costly, less utilized, and although the tendency is towards ever greater use, they are still considered special instruments and are not exactly conventional. Evidently spectral measuring systems' potential is greater: a spectrum implies a measurement from which detailed information regarding a band can be obtained. On the other hand, a spectrum cannot be obtained from a broadband measurement since the instrument averages all the events during the measurement process.

In general, both solar and spectral systems consist of a receiver, a detector, a signal or detector response processor and a counting system. The receiver makes it possible to receive radiation and to transfer it to the detector. The detector makes it possible to convert the solar energy, directly or indirectly, into an electrical signal.

The receiver in classical pyranometers roughly consists of two superposed glass domes and of a highly absorbent layer coating the detector, the latter being a thermoelectric or a photoelectric sensor. The receiver in a spectroradiometer is a diffusing device that can be used to mix the radiation from the whole sky dome and to light the entrance slit of a monochromator used as a detector (Kondratyev, 1969).

MEASURING SPECTRAL GLOBAL SOLAR IRRADIANCE

The spectral or monochromatic measurements corresponding to this study were carried out under clear sky conditions, on May 3th and November 6th, 2005 with a Bentham spectroradiometer, with a 0.5 nm step in wavelength. The system was calibrated previously using a 1000 W lamp Standard Irradiance, supplied by Optronic Laboratory. The step for calibration was 0.5 nm.

Figure 1 presents six UV spectra measured on May 3th 2005 between 10:00 and 14:00 hours, with corresponding solar zenith angles between 7º and 50º.

The energy corresponding to the UV B (290 – 320 nm), UV A (320 -400 nm) and total UV bands –the sum of both– can be obtained by integrating the area under the curve for each spectrum zone. The results for spectra are presented in Table 1.

This data shows that, under clear sky conditions, the intensity of the UVB irradiance vary between 2 and 4 W/m^2, UVA irradiance vary between 27 and 49 W/m^2, and the irradiance corresponding to the total UV band vary between 29 and 53 W/m^2.

Figure 2 presents eight spectra measured on November 6th between 12:00 and 14:00 hours, local time, corresponding to the peak hours in solar intensity. In contrast with measures made six months before, these spectra show no appreciable variation in intensity.

By integrating the area under the curve for the UV B (290 – 320 nm), UV A (320 -400 nm) and total UV bands, the corresponding energy was obtained, Table 2.

This data shows that, for the sun's peak hours, under clear sky conditions, the intensity of the UVB irradiance is of the order of 4 W/m^2, UVA irradiance is of the order of 46 W/m^2, and the irradiance corresponding to the total UV band is of the order of 50 W/m^2.

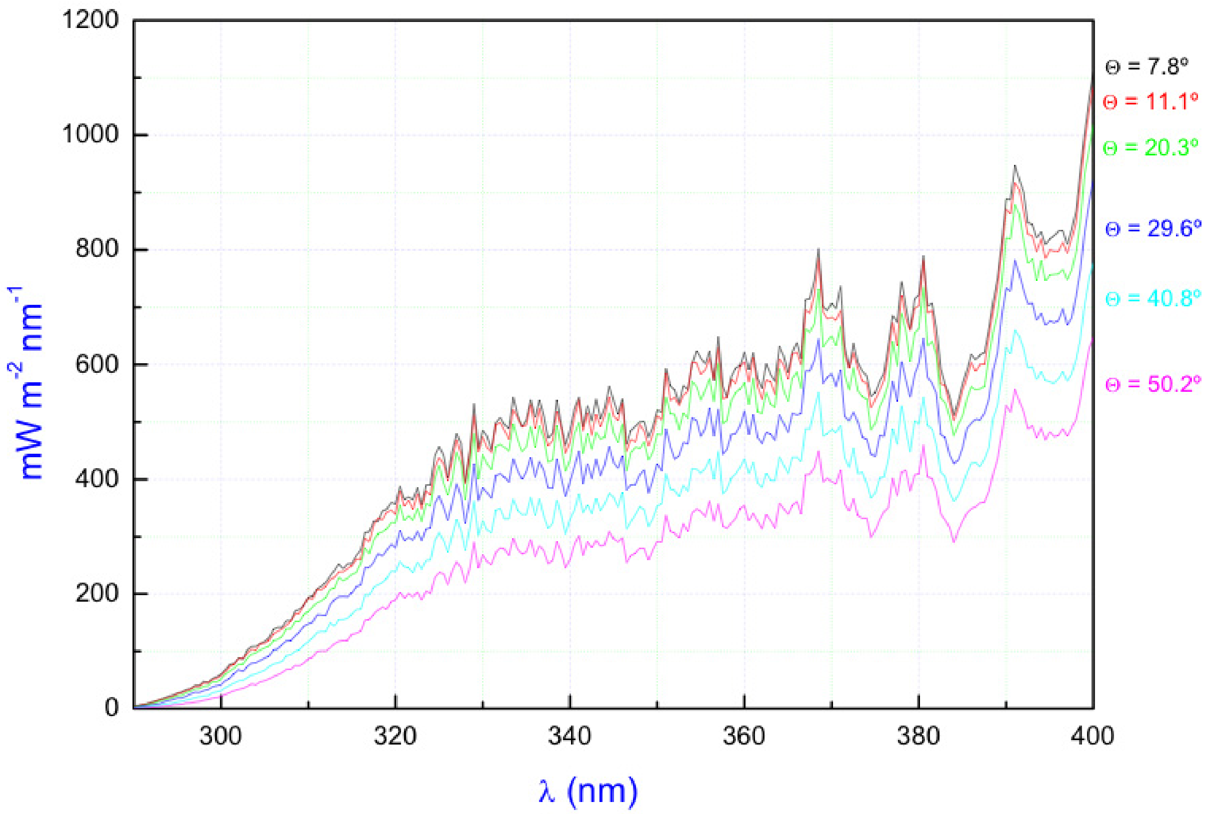

Fig. 1. UV Global Irradiance spectra measured under clear sky condition on May 3th 2005 in Zacatecas, Mexico. Solar zenith angles between 7° and 50°; measured between 10:00 and 14:00 hours.

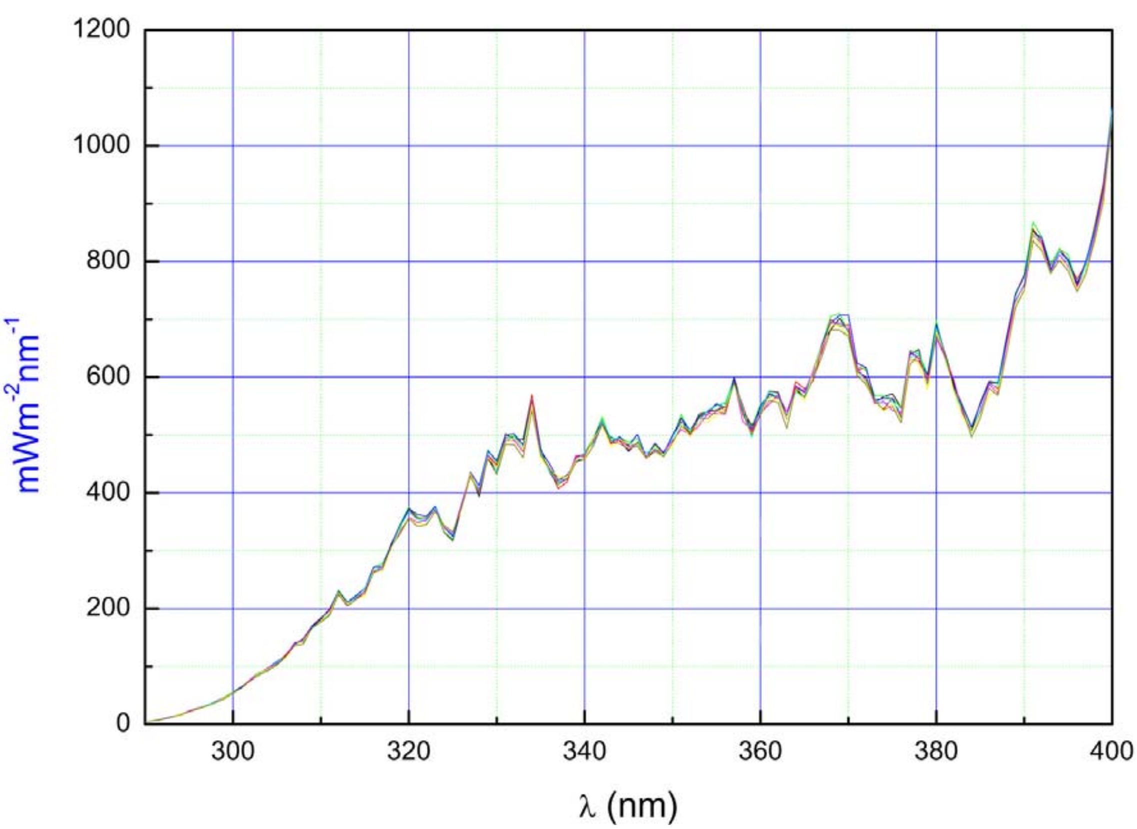

Fig. 2. UV Global Irradiance spectra measured under clear sky condition on November 6th 2005 in Zacatecas, Mexico.

Table 1

Global Irradiance in W/m^2, for the bands: UV A, UV B and Total UV, from spectral measured on May 3th 2005 in Zacatecas, Mexico

		UV B	**UVA**	**UV**
Solar zenith angle (º)	**Time**	$Gh = \int_{\lambda=290nm}^{\lambda=320nm} G_\lambda d\lambda$	$Gh = \int_{\lambda=320nm}^{\lambda=400nm} G_\lambda d\lambda$	$Gh = \int_{\lambda=290nm}^{\lambda=400nm} G_\lambda d\lambda$
50.2	10:11:31	1.99	27.4	29.3
40.8	10:52:33	2.65	33.5	36.0
29.6	11:41:04	3.34	39.7	42.9
20.3	12:22:35	3.86	44.6	48.3
11.1	13:07:00	4.19	47.4	51.4
7.8	13:57:00	4.33	48.6	52.8

Table 2

Global Irradiance in W/m^2, for the bands: UV A, UV B and Total UV, from spectral measured on November 6th 2005 in Zacatecas, Mexico

		UV B	**UVA**	**UV**
Solar zenith angle (º)	**Time**	$Gh = \int_{\lambda=290nm}^{\lambda=320nm} G_\lambda d\lambda$	$Gh = \int_{\lambda=320nm}^{\lambda=400nm} G_\lambda d\lambda$	$Gh = \int_{\lambda=290nm}^{\lambda=400nm} G_\lambda d\lambda$
40.3	11:49	4.09	46.05	49.76
39.8	11:58	4.10	46.04	49.77
39.4	12:08	4.13	46.28	50.04
39.2	12:17	4.13	46.27	50.03
39.0	12:26	4.07	45.85	49.56
39.0	12:35	4.05	45.68	49.38
39.2	12:45	4.03	45.44	49.11
39.5	12:53	4.00	45.25	48.90

In fact, although the measures have been taken between 12:00 and 14:00 hours, solar zenith angles are very similar, as it is shown in Table 2.

A significant remark is that wavelengths under to 300 nm are observed in the spectrum of UV irradiance in Zacatecas, which correspond to a more energetic spectral zone. This may be a relevant characteristic in the case of solar irradiance in the tropics, that is, with a higher proportion of UVB irradiance in relation to that found at higher altitudes.

DISCUSSION

Few spectral solar irradiance measurements are available in the literature. The current ground measurement sites are not numerous nor close together enough to provide a global climatology of UV-B. Consequently, any additional measurement sites will be important on the task to establish a global UV monitoring network.

The results of these measurements show the high levels of UVB irradiance during peak daylight hours. This research is an important addition in the study of ultraviolet irradiance (UV) in the City of Zacatecas. The measurements may be characteristic of areas close to the Tropic of Cancer under clear sky condition.

We could not determine the cosine error of radiometer receiver, which rigorously needs an angular response measurement. Cosine error can vary between 3% and 18 % depending on the wavelength (Seckmeyer and Bernhard,1993). This means that the total global irradiance can carry an error of ± 10%. Meanwhile the spectra can be considered as a first spectral signature of global irradiance in Zacatecas. Of course the measures could be improved after correcting the angular response.

These results suggest that the formulation of a risk prevention plan against skin cancer is required. This, of course, should include educational aspects and recommendations regarding limit exposure during peak daylight hours, such as the use of appropriate clothing, sun block, and hats.

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J. L. Pinedo V., F. Mireles G., C. Ríos M., L. L. Quirino T. and J. I. Dávila R.
Universidad Autónoma de Zacatecas,
Ciprés No. 10, Frac. La Peñuela, 98068 Zacatecas, Zac., México,
Tel. and Fax: (492) 9 22 70 43 ext 107.
Email: jlpinedo@cantera.reduaz.mx