Ultraviolet, DNA damage and erythemal solar irradiances incident over different places of Argentina

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Abstract: - We present mathematical model results of biological (DNA damage and erythemal) solar irradiances in the ultraviolet range (280 – 400 nm), along the months of the year for clear sky days, incident over different places of Argentina, the extreme North (La Quiaca at Puna of Atacama high altitude intertropical desert), the Central region (Rosario and Buenos Aires at the East of the country in the Humid Pampa and Malargüe at the West near the Andes mountains) and the South at the Argentinean Marambio Base in Antarctic Peninsula. The DNA damage and erythemal irradiances are determined by integrating in wavelength the spectral solar radiation multiplied by the corresponding biological action spectrum. The wavelength dependence of the solar irradiance is obtained for different places of the country, from the TUV (Tropospheric UV and Visible Radiation) algorithm, that solves the atmospheric radiative transfer problem in the UV and Visible ranges. The integrated total UV and UVB (280 nm – 320 nm) solar irradiances are also presented for Malargüe. The atmospheric variables and parameters are determined from TOMS/NASA satellite and ground data. The ratio between the DNA damage and erythemal irradiances determines a *function* that permits to derive the biological action of UV solar radiation on the DNA basic molecule, from the knowledge of the erythemal irradiance, that it is normally measured with biometers. This function is presented for the locations indicated above. In order to test the model calculation of the erythemal irradiance, we compare this irradiance with that measured with an EKO biometer at CEILAP (Center of Lasers and Applications placed at the Buenos Aires suburbs).

Key-Words: Solar – UV – UVB – erythemal – DNA damage – irradiance – Argentina

1 Introduction and Problem Formulation

The solar UV radiation is the most energetic one that arrives at the Earth surface, in the range 280 nm – 400 nm. It has enough energy per photon for breaking molecular bonds. So, these photons can induce large modifications when they interact with biological systems [1]. In particular, the basic DNA molecule can be significantly damaged with photons with wavelengths in the UVB (280 nm – 320 nm) range. The damage can be evaluated as function of the wavelength through the *effectiveness response* or *action spectrum* $B_{biol}(l)$ [1,2]. Multiplying this function by the spectral solar UV irradiance $I(l,t)$, the *spectral biological solar irradiance* can be determined [2]:

$$\mathrm{D}_{biol}\,(l,t) = I\,(l,t)\;B_{biol}(l) \qquad (1)$$

The *integrated biological solar irradiance* in the range where the spectral biological irradiance given by Eq. (1) is significant is then

$$\mathrm{D}_{biol}\ (\mathrm{t}) = \int I\,(l,t)\;B_{biol}\,(l)\,d\,l \qquad (2)$$

and the corresponding *dose* in a given time interval is

$$\mathrm{D}_{biol} = \int \mathrm{D}_{biol}\ (\mathrm{t})\ dt \qquad (3)$$

The most common action spectra for human skin exposed to UV radiation are the *erythemal* (or skin reddening), *carcinogenesis* and *DNA damage*. In order to estimate the risk for exposure to solar radiation, the *erythemal* solar irradiance is employed [3], based in the corresponding action spectrum as given by McKinlay and Diffey [4] and adopted as a standard for the CIE (Commission Internationale de l'Ecleirage). It has a constant behavior for wavelengths lowers than 298 nm and a strong decrease up to 328 nm, continuing its decrease for larger wavelengths but with a smaller slope. The product of the erythemal action spectrum and the solar UV irradiance spectrum, i.e. the *spectral solar erythemal irradiance* (eq. 1) has a Gaussian type behavior. At low solar zenith angles, about 90 % is in the UVB range and the rest is in the UVA (320 nm – 400 nm).

The UV spectral irradiance is obtained solving the following radiative transfer equation [5]

$$\cos\theta\frac{\mathrm{dR}(\tau_{\mathrm{v}}(\lambda,\mathrm{z}),\theta,\varphi)}{\mathrm{d}\tau_{\mathrm{v}}} = \overbrace{-\,\mathrm{R}(t_{\mathrm{v}},q,j)}^{(I)} + \overbrace{\frac{w_0}{4p}\int_0^{2p}\int_0^{p}\mathrm{R}(t_{\mathrm{v}},q',j')\,\mathrm{P}(t_{\mathrm{v}},q,j,q',j')\,\mathrm{sen}q'\,\mathrm{d}q'\,\mathrm{d}j'}^{(\mathrm{II})} \qquad (4)$$

This equation describes the radiance *(R)* variation in the direction *(q, j)*, with respect to the vertical optical depth t_v. The terms in the right are:

(I) The radiance *attenuation* (due to absorption and scattering) along the direction *(q, j)*;

(II) The *source function*, that represents the irradiance increase in the direction *(q, j)* due to the scattering of the radiance incident from all directions. It can be decomposed in two parts: one originated in the *direct* solar radiation component and the other in the *diffuse* radiation from all directions. So,

$$(\mathrm{II}) = \frac{w_0}{4p}\,\mathrm{I}_0\ \mathrm{e}^{-t\,/\cos q_0}\ \mathrm{P}(q,j,q_0,j_0) + \frac{w_0}{4p}\int_0^{2p}\int_0^{p}\mathrm{R}(t_{\mathrm{v}},q',j')\,\mathrm{P}(t_{\mathrm{v}},q,j,q',j')\,\mathrm{sen}q'\,\mathrm{d}q'\,\mathrm{d}j' \qquad (5)$$

where: *wo* is the single scattering albedo [4], *Io* the extraterrestrial solar UV irradiance and *P* the scattering phase function [5]. The program automatically transforms the radiance (intensity of radiation arriving to a given place from all directions) to the irradiance (intensity of radiation on a given surface)

2 Problem Solution

We present results of the mathematical modeling of the erythemal irradiance, solving the radiative transfer equation (4), employing the TUV code developed by Madronich (www.acd.ucar.edu/TUV). For the present case, we consider the two-stream approximation with the delta-Eddington scheme. The internationally adopted McKinlay and Diffey [4] action spectrum is used. The calculations are done for CEILAP (Center of Research in Lasers and Applications) located at the Buenos Aires suburb (34.61ºS,58.41ºW, 20 m asl), along the hours of typical clear sky days of different months of the June 2004 – February 2005 period (see the 3-D figure 1).

The main atmospheric constituents that attenuates significantly this irradiance, ozone and aerosol, are extracted from ground measurements made at the Argentina National Weather Service with a Dobson spectroradiometer and from TOMS (Total Ozone Mapping Spectrometer) / NASA (jwocky.gsfc.nasa.gov) satellite instrument data base. The ground solar reflectivity (or albedo) is assumed to be 0.06 as in previous work [6]. This result compares rather well (see the same figure) with the measurements done at the same place and days, with an EKO biometer (erythemal irradiance meter that select the UV solar irradiance with a filter that simulates the McKinlay and Diffey action spectrum). This biometer was calibrated with NIST/USA traceable lamps. An interesting situation at October 14, 2004 is described theoretically and through measurements, by the large increase with respect to the normal expected value of the erythemal (and consequently DNA damage) irradiance. It was originated by the significant decrease of the ozone total column due to the passage over Buenos Aires those days, of the prolongation (extension to outer regions) of the Antarctic Ozone Hole. This can be seen in the TOMS / NASA images (jwocky.gsfc.nasa.gov) for those days (October 12 to

October 16, 2004), with values for Buenos Aires more than 10% lowers than those of similar days of other near years in normal conditions of the ozone layer. It must be pointed out that the ozone hole condition is defined for values of the total column of this atmospheric gas equal or lowers than 220 DU, but the extension normally has higher values (i.e. 272 DU for October 14, 2004 over Buenos Aires). Since for each 1% decrease of the ozone total column, a corresponding increase in the UVB irradiance of the same magnitude must be expected [7], the UVB solar irradiance shows a peak due to this significant event. Also, large values for January and February 2005 are measured since the decrease in solar irradiance due to large air mass at noon and geometrical projection of the incident surface, is compensated by the natural decrease of the ozone value tending to the Autumn minimum.

Comparing the erythemal irradiance at noon calculated with the TUV computational code and the EKO measurements along the months of the year, we obtain a small percentage error of (4.4 ± 12.3)% and an absolute error of (11.4 ± 5.2)%. The first one is determined directly summing the difference for each month with its sign and it shows that there are almost no systematic bias between data and model calculation. The second value is in the range of an expected difference for the mean of the absolute value errors coming from the instrument (non perfect cosine response, temperature dependence, difference between the Mc Kinlay and Diffey action spectrum and the filter instrument dependence on the wavelength [6], etc) and the calculation (atmospheric and soil reflectivity conditions only approximately reproduced, two stream approximation technique for solving the radiative transfer equation, etc).

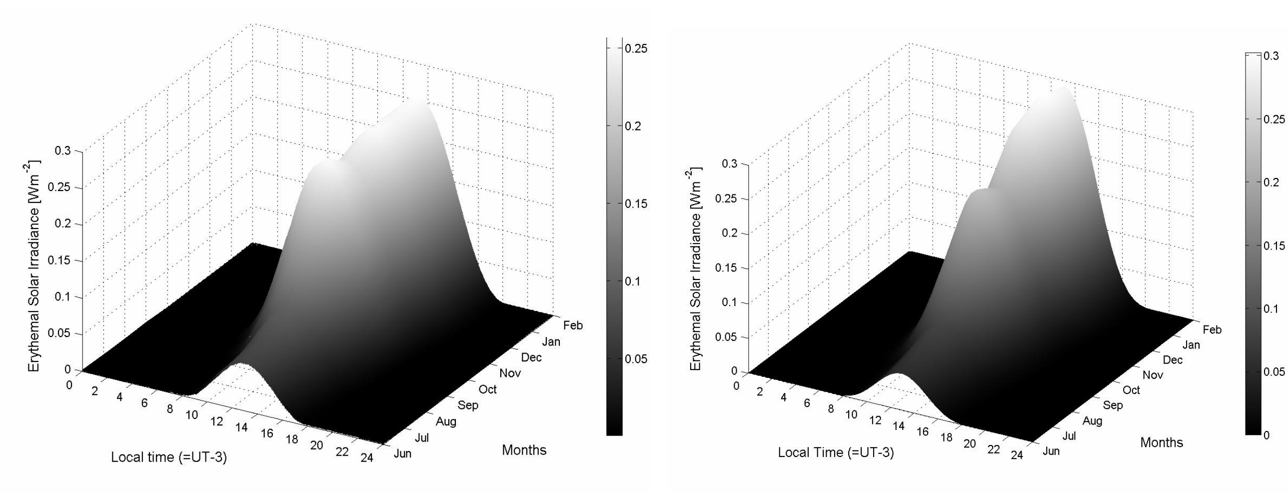

Figure 1. 3D representation of the solar erythemal irradiance for clear sky days incident at CEILAP (Buenos Aires suburbs) in the May 2004-February 2005 period, as function of the hours of the day (local time = UT – 3 hours). Right: measurements done with an EKO biometer. Left: TUV model calculations for the same days. Ozone values are from TOMS/NASA data base or ground measurements done with a Dobson Spectroradiometer at Servicio Meteorológico Nacional. Aerosol optical depth is considered as was derived by Cede [8] and the albedo is 0.06, combining the values for different soil reflectivities for the surroundings given by Blumthaler and Ambach [9]

So, we have confidence that calculations of the same kind for other places with appropriate atmospheric variables and albedo, will represent rather well the situation in the corresponding location. Since we are interested in determining the DNA damage and to our knowledge there are no instrument that measures this quantity, we will use a relation function between the DNA damage irradiance (which considers the Setlow [10] action spectrum) and the erythemal one which is commonly available using biometers, as was done by Morys and Berger [11], Piacentini [12] and Micheletti and Piacentini [13], relating carcinogenic and plant damage with erythemal solar irradiances.

In figure 2 (top) the erythemal and DNA damage irradiances calculated at noon in clear sky days are displayed for different months of the year at the locations indicated in the figure caption. The function obtained calculating the ratio *DNA damage/erythemal* is displayed in figure 2 (bottom). At the North and Central locations of Argentina, the variation of this function is rather similar (a sinus like one) with maximum/minimum ratio of 1.43 at La Quiaca (22.11ºS,67.57ºW, 3459 m asl), 1.79 at Rosario (32.96ºS,60.62ºW, 25 m asl) and 1.67, -a value rather similar to Rosario, for Buenos Aires. The smaller amplitude variation in La Quiaca with respect to the rest of the places is due to the corresponding small variation of ozone (the main influence on UVB irradiance attenuation) over the intertropical region, with respect to middle latitudes where Rosario and Buenos Aires are situated. For the Argentinean Marambio Antarctic Base (64.23ºS,56.72ºW, 300 m asl) the strong influence of the ozone hole (values of the ozone total column lowers than 220 DU) is evident in the August- November period.

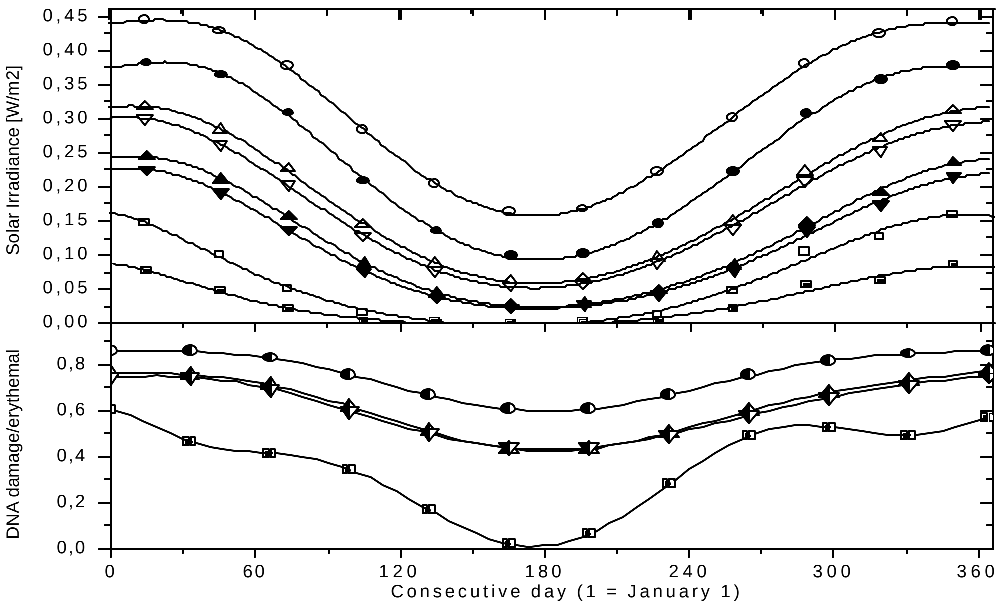

Figure 2. Top: Biological solar irradiance corresponding to erythemal (open symbol) and DNA damage (closed symbol) for different places in Argentina: La Quiaca (circle), Rosario (up triangle), Buenos Aires (down triangle) and Argentinean Marambio Base/Antarctic Peninsula (square). Bottom: DNA damage/erythemal irradiance ratio for the same places (and with the same type of symbols) as given in the top figure. Note: ozone data are from TOMS/NASA data base; aerosol are from Cede work [8], albedo is 0.06 for La Quiaca, Rosario and Buenos Aires and 0.4 for Marambio Base [9].

For Malargüe (35.20ºS, 69.20ºW, 1400 m asl), province of Mendoza, at the border of the Andes mountains in the West of the country, we present results of the total UV and UVB solar irradiances in order to show the fraction of UVB with respect to UV and the possibility for relating the UVB irradiance with the DNA damage one. The corresponding function is given in figure 3. We like to point out that this region is of particular interest since the largest ultraenergetic cosmic particle (Auger) Observatory is being built in this place with the contribution of 15 countries, which is leading to an increasing number of visitors from all over the world to this region, with the corresponding solar exposure risk. A test of the attenuation of UV radiation by the atmospheric constituents, mainly aerosols through the Mie scattering [5], is of interest in the knowledge of the atmosphere, since it represents the main detector of cosmic particles, due to the passage of these particles that induce electromagnetic emission just in the UV range. Results of the erythemal and DNA irradiances and its ratio are also presented in the same figure.

It must be pointed out that the function that relates the DNA damage and erythemal irradiance in the present work, is valid for establishing monthly mean variations between them (and the effect of the overpass of the ozone hole at high southern latitudes), but if specific daily values are needed, a more general matrix N-Dimensional calculation (considering different possible values of the atmospheric variables and soil parameters for each place) must be done.

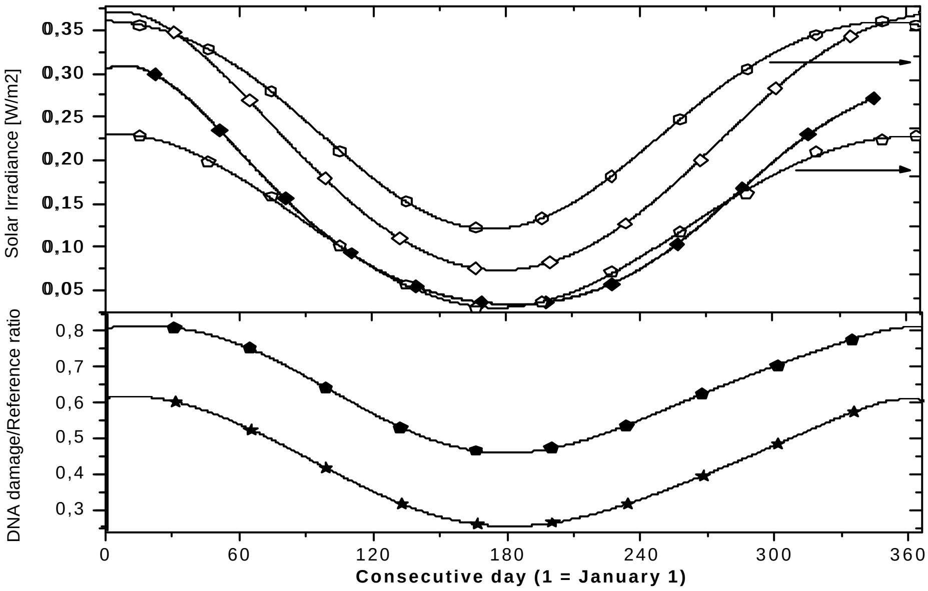

Figure 3. Top: Solar total UV (multiplied by 0.1 for scale reasons) (open hexagon), UVB (open pentagon), erythemal irradiance (open diamond) and DNA damage irradiance (closed diamond) for Malargüe, Province of Mendoza, Argentina. Note: The arrows indicate the corresponding vertical scale. Bottom: DNA damage/ erythemal irradiance ratio (close pentagon) and DNA damage /UVB irradiance ratio (multiplied by 10 for scale reasons) (close star), for the same place. Note: ozone and aerosol optical depth data are from TOMS/NASA data base and albedo is 0.06 [9].

4 Conclusion and Perspectives

The main conclusions derived from the present work are:

- It is possible to indirectly determine the time dependence of the DNA damage irradiance, from measurements of the erythemal irradiance made with the biometer instrument, as those of the Argentina National Service UV Monitoring Network, that was analyzed in detail in previous works [14-16].
- The time variation of the DNA damage irradiance is similar to the erythemal one, with a larger variation in the first case with respect to the second, due to the abrupt decrease of the corresponding action spectrum in the UVB range and consequently more sensitivity to the ozone photoabsorption cross section.
- Since extreme values of the erythemal [13] as well as the global solar irradiance [17] have been measured in the Puna of Atacama desert near La Quiaca, -the largest measured values in the world up to the present, the DNA damage irradiance will also be extreme in the North-West of Argentina and adjacent regions of the same high altitude desert.
- UVB solar irradiance can also be related to the DNA damage one, as was shown for Malargüe, Province of Mendoza.
- The present calculations are monthly mean values and can be used for the analysis of UVB and biological solar irradiances in Argentina for several years in the past and future, since the yearly mean ozone total column, -the variable that influence most these biological irradiances, is evolving rather constant in this period at middle latitudes of the Southern Hemisphere [18].
- These results are of importance for the study of the effects induced by solar irradiance on living systems exposed to the intense Sun.

The present study will be extended in order:

- To analyze other regions of Argentina and Latinamerica.
- To include other biological actions related with the human health (eyes damage, vitamin D fixation at skin, immunosuppression, carcinogenesis, etc).

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