Short Communication
SOLAR ULTRAVIOLET RADIATION AT THE EARTH’S SURFACE: FACTORS AFFECTING ITS IMPACT ON HUMAN BEINGS

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Introduction

The ultraviolet (UV) region spans the wavelength range from 200 to 400 nm and accounts for less than 9% of the solar output (around 120 Wm⁻²). UV radiation reaching the earth’s surface is controlled by many factors such as astrophysical (sun’s activity), astronomical (earth-sun distance, solar elevation), atmospheric (absorption and scattering due to gases, such as ozone, aerosols and clouds) and geographical (altitude, albedo, surface orientation) (1).

Solar ultraviolet radiation is usually classified as UV-A (315-400 nm), as UV-B (280-315 nm) and as UV-C (200-280 nm) (2). The UV portion of spectrum relevant to environmental biology is restricted to the UV-B and UV-A ranges. Wavelengths shorter than 280 nm are completely absorbed before reaching the biosphere, UV-B radiation is efficiently but not completely blocked by atmospheric ozone while atmospheric constituents affect UV-A radiation less. The established effect of stratospheric ozone depletion has given rise to concern about its effect on the ecosystems and on human health (3).

The need to identify possible threats to the biosphere requires proper sensors capable to directly detect biological effects caused by ambient UV radiation and possess high sensitivity to small changes of UV-B (4). Polysulphone dosimeters are reliable, portable, and cost-effective, which makes them a suitable choice.

The study of the factors affecting UV impact on people is characterized by an inner complexity due to the need of combining the accurate determination of the ambient UV radiation with the analysis of its biological effects.

Ambient UV radiation

The evolution and growth of most aquatic and terrestrial life forms is influenced by several environmental variables including the intensity of UV radiation at the earth’s surface or under water. The negative correlation between spectral UV-B radiation and total ozone has been properly documented (3). If all other variables (astrophysical, astronomical, atmospheric and geographical) were constant, the degree of UV attenuation would depend only on ozone variability. However, the understanding of all processes affecting surface UV radiation is rather more complicated. Therefore, to quantify the effect of all parameters at different times and space scales is a cumbersome procedure.

Figure 1 is an example of this aspect. The local noon erythemal UV irradiance (i.e. the solar UV irradiance weighted with a function, erythemal action spectra expressing the epidermis
response) on the global scale on June 21st 2003 is shown on the left panel: the latitudinal gradient is governed by the environmental parameters on regional scales. Limitation of the mapping region (right panel) does not decrease the complexity of the UV field (5).

Figure 1. Left: local noon erythemal UV irradiance as measured by TOMS onboard Earth Probe satellite on June 21st 2003. Regional scale variability is superimposed on the latitudinal gradient determined by the differential sun illumination. Right: average erythemal UV daily dose in Italy as determined by a radiative transfer model. The latitudinal gradient is mainly modified by the different elevation of sites above sea level and the climatological atmospheric patterns.

Measuring UV radiation

UV measurements are carried out via different independent instruments with various output formats and without standard calibration procedures (6). The classification of UV sensors is based on their spectral resolution: spectroradiometers (that measure the intensity of radiation every 1 nm or less), moderate and narrow-band radiometers (that measure in bands of ~10 nm) and broad-band radiometers (measuring in a specific range, usually UV-B, UV-A or a combination of both).

The accuracy of instruments, currently estimated at 5% for the best maintained spectroradiometers, is vital for the credibility of UV data. In spectral measurements the uncertainty increases at wavelengths below 300 nm, where the solar signal is weak and masked by instrumental noise (7). Broad-band instruments have higher uncertainty than spectroradiometers.

The impact of environmental UV radiation requires knowledge of action spectra of biological systems, namely of functions expressing the effectiveness of the electromagnetic radiation in causing a specific response of the biological system.

Action spectra have been used for several critical biological responses (Figure 2): DNA damage, inactivation of human fibroblast, keratinocytes and melanocytes, minimal erythema, squamous cell carcinoma in mice, malignant melanoma in fish and plant damage. However, even when measurements of UV radiation are highly accurate, the biologically effective irradiance can vary substantially as a result of experimental errors in the action spectra (such as
a too narrow waveband) and the underlying hypothesis of additive spectral effects, which is not always satisfied in nature (8).

In addition to the UV measurements, radiative transfer models are available to determine UV irradiances on the ground. Some of them are sophisticated multiple scattering codes based on a neural network approach and contribute to improve the understanding of complicated scattering and absorption processes in the atmosphere.

![Figure 2. Action spectra for some selected UV-related effects (erythema, carcinogenesis in mice, photosynthesis inhibition and DNA damage). The relative response among different spectra is normalised to unity at 300 nm to allow an intercomparison](image)

**Human UV exposure**

The relationship between UV radiation and its biological consequences has been studied already for several years (9). Interest in this subject increased as a result of recent findings on stratospheric ozone decrease and the consequential increase of solar UV at ground. When UV photons impinge on people, the difficulty of the problem further increases, because solar exposures vary according to the length of time spent outdoors, the time of day and the period of the year, type of activity undertaken, body posture, and the UV protective used [10]. Depending on the amount of available ambient UV radiation, the individual response is determined by: (a) the amount of absorbed UV dose (hourly, daily, monthly etc.); (b) the characteristics of the interface radiation-matter (epidermis); (c) the photoreactions occurring in the inner layers.
Polysulphone personal dosimetry

The documented worldwide increase in skin cancer cases in recent years has stimulated research on the acute and chronic effects of UV radiation on protected/unprotected skin and eyes.

Polysulphone (PS) dosimetry (11) is oriented towards the understanding of the role of (a), (b) and (c) on target groups. They have been widely used to quantify personal UV exposure of humans in different settings during ordinary daily activities (12).

PS dosimeters, small devices requiring no external power input, are made up of a thin film (usually 40 µm) with spectral sensitivity similar to the erythemal response (Figure 3). When the dosimeter is exposed to solar UV, the diphenyl sulphone group in polysulphone absorbs UV at wavelengths shorter than 330 nm and an increase of optical absorbancy occurs. Since the largest change in the optical absorbancy, before and after the UV exposure, is at 330 nm, measurements of optical absorbancy change at this wavelength can be related to the ambient UV dose through a calibration curve. By using measured ambient UV irradiances in combination with an understanding of the distribution of solar UV in the human body, estimates of long term exposures can be determined. PS dosimeters cannot be reused after exposure to the sun.

Figure 3. Polysulphone dosimetry device for the study of the distribution of UV radiation on the human body: a dosimeter (left) is made by attaching a PS film on a PVC holder (size 3 cm x 3 cm with a 1.6 cm x 1.2 cm aperture). It can be used on manikins, too (right)

Results and conclusions

Experiments carried out in Rome and vicinity during the summer of 2004, both with manikins and volunteer bathers, show that PS dosimeters targeting specific population groups, allow for quantitative measurements of personal UV exposures. The measured doses on different sites of the human body can be determined by a calibration curve (Figure 4).
Figure 4. Calibration curve for evaluating personal exposures from changes of dosimeter absorbancy (Rome, July 2nd 2004). Each point refers to the change in absorbancy (vertical axis) recorded by a single dosimeter after a fixed exposure time. On the horizontal axis, the corresponding ambient dose as measured by a reference instrument is reported.

Preliminary results obtained with manikins are presented in Table 1 for supine and sitting postures.

Table 1. Percentage of personal dose with respect to ambient dose for two different postures

<table>
<thead>
<tr>
<th>Posture</th>
<th>shoulder</th>
<th>breast</th>
<th>cheek</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supine</td>
<td>21%</td>
<td>59%</td>
<td>63%</td>
</tr>
<tr>
<td>Sitting</td>
<td>83%</td>
<td>93%</td>
<td>102%</td>
</tr>
</tbody>
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Doses affecting human beings are influenced mainly by the orientation of the body surface respect to the sun. UV dose tends to increase when the portion of body is exposed towards the incoming direct radiation. The albedo effect of the ground increases the percentage of personal dose more in the sitting than in the supine posture. In the sitting posture the dose is 1.6 (breast and cheeks) and 4 (shoulders) greater than the supine. Note also that the albedo effect, in combination with local atmospheric parameters, can enhance personal exposure beyond ambient level (102% for cheeks). Results are congruent with those obtained on volunteer bathers with a single dosimeter on the breast. Doses on individuals are modulated not only by the orientation of the body respect to the sun but also by the length of time spent in the shade. The values of volunteers exposure doses are up to 60% of ambient dose.

A proper methodology for measuring the level of UV radiation on different parts of the body, based on polysulphone dosimetry, has been discussed and tested. Results can be interpreted only if the local characterization of ambient UV radiation is taken into account. Future efforts will be addressed at the search for biological markers whose modification is a direct or indirect effect of UV radiation. Moreover, possible correlations between markers and personal absorbed doses will be studied.
References

1. Kerr JB. Understanding the factors that affect surface UV radiation. 48th SPIE MEETING, S.Diego (CA); 2003