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COMPARISON OF UV-B MEASUREMENTS PERFORMED WITH A BREWER SPECTROPHOTOMETER AND A NEW UVB-1 BROAD BAND DETECTOR

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ABSTRACT

Measurements of the UV-B erythemal dose, based on solar spectra acquired with a Brewer spectrophotometer at Thessaloniki, Greece, are compared to measurements performed with the recently introduced, by the Yankee Environmental Systems, (Robertson type) broad band solar UV-B detector.

The spectral response function of this detector, when applied to the Brewer spectral UV-B measurements, results to remarkably comparable estimates of the erythemal UV-B dose. The two instruments provide similar information on the UV-B dose when they are cross-examined under a variety of meteorological and atmospheric conditions and over a large range of solar zenith angles and total ozone.

1. INTRODUCTION

Although spectral UV-B measurements are highly important for studying the penetration of solar ultraviolet radiation through the atmosphere, its damaging effects on the human beings and the ecosystems are mostly associated with the total dose received during a given period of exposure (Setlow, 1974; McKenzie et al., 1991). To obtain the total dose, spectral measurements are convolved with a suitable action spectrum and the result is integrated over the UV-B spectral region. Action spectra are varying according to the type of the biological damage referred (ACGIH, 1978; Parrish, 1982; McKinlay and Diffey, 1987). In some cases the differences are significant, as it will be shown in the following. The advantage of spectral UV-B measurements is that they are completely independent of the action spectra, so that they can be easily used in many cases, provided that the corresponding action spectra are available.

However, UV-B broadband detectors, operating continuously and capable in providing erythemally weighted UV-B doses, may become useful supplements to the detailed spectral measurements. Then it would be feasible to obtain accurate dose estimates on a daily basis and to perform spectral measurements several times per day, in order to monitor and control the performance and stability of the UV-B detectors. Of course detailed comparison is required between the two methods of measurements, to prove the capability of the UV-B broadband detectors to accurately supplement the spectral measurements. Such a comparison, between a Brewer spectrophotometer and a UV-B (Robertson-type) pyranometer, is presented in this study.

2. INSTRUMENTATION

The Brewer spectrophotometer #005, operating in Thessaloniki, Greece, since 1982 is used during the last three years for regular spectral global UV-B measurements, which are performed on a daily basis at 50^{o} and 63^{o} of solar zenith angle (both in the morning and evening) as well as at local noon. These spectral scans cover the range from 290 nm to 325 nm with a resolution of 0.5 nm. The spectrophotometer's calibration is checked regularly with a 40 Watts halogen lamp traceable to NIST (National Institute of Standards and Technology) standard of spectral irradiance.

Since July 1991 a UV-B pyranometer (Yankee Environmental Systems, model UVB-1), designed to measure the biologically effective solar UV-B radiation, was installed at Thessaloniki and operates continuously at the same location with the Brewer spectrophotometer. The spectral response of the pyranometer approximates the erythemal action spectrum (Parrish, 1982), but a correction factor must be applied on the output in order to match the real erythemal spectrum. This factor is obtained from model estimations (Green, 1974), which takes into account the total ozone, the cloud cover and the aerosol thickness at the time of measurements. The first two parameters are measured in Thessaloniki and thus they can be fed into the model, whereas no data are available on the aerosol thickness and default values are used instead.

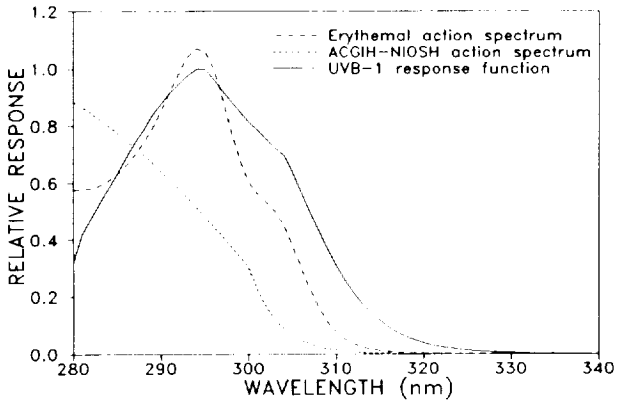

Fig. 1. Relative response of the ACGIH-NIOSH (dotted line) and the erythemal (dashed line) spectra, and the UVB-1 response function (solid line).

The pyranometer's measurements are integrated over ten minutes intervals and fed automatically to a computer. Almost eleven months of collocated measurements from both instruments were collected and used in this study. In addition data from two days of measurements with both instruments in July 1991 and May 1992 are also used. During these days spectral measurements with the Brewer spectrophotometer were obtained several times per day (in some cases every 15 minutes).

3. RESULTS AND DISCUSSION

As mentioned previously, the UVB-1 pyranometer's output is similar to the erythemal action spectrum. The Brewer uses for the calculation of the UVB dose the action spectrum recommended by the American Conference of Governmental Industrial Hygienists, ACGIH-NIOSH curve (1978), which is different from the one of Parrish (1982). Both action spectra and the response function of the pyranometer are shown in Figure 1. It appears from this figure that there are slight differences between the response function of the UVB-1 and the erythemal spectrum, which become significant when the solar spectrum convolves with them, since they appear in the longer wavelengths where the solar spectrum is more intense. Therefore differences from 25% to 60% are expected especially in the low zenith angles, based on the Green's (1974) model estimations. On the other hand, the ACGIH-NIOSH curve, which is used in the Brewer's spectra, is extremely different from the erythemal action spectrum and it is expected that the UV-B dose based on the Brewer measurements will be much lower than the one from the UVB-1 pyranometer.

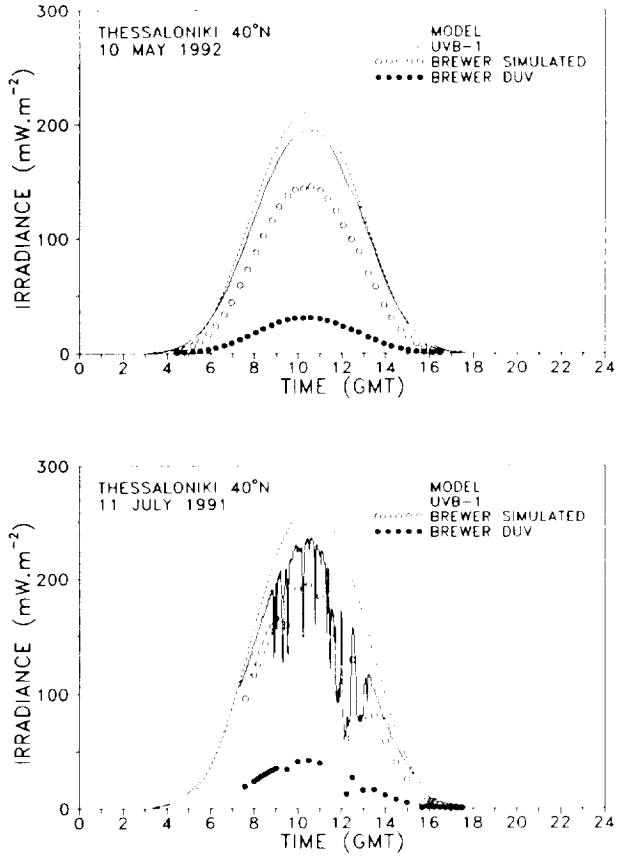

Fig. 2. Examples of the daily variation of the UV-B dose as measured by the Brewer (DUV) and the UVB-1 during a cloud-free (upper) and a partly cloudy (lower) day. Solid line represents the model estimates for clear days (Green, 1974).

This is seen in the examples of Figures 2a and 2b, in which measurements made respectively on July 11, 1991 (a partly cloudy day) and on May 10, 1992 (a cloudless day) are presented for both instruments, along with the model estimation for these days (asuming no clouds) and a simulated Brewer dose weighted with the erythemal action spectrum of the pyranometer. Apparently, only the later dose is comparable with the UVB-1 output since they are both weighted with the same action spectrum. Small differences still observed between them, might be attributed to the fact that the pyranometer's sensitivity extends further to shorter and longer than the Brewer wavelengths (290 nm to 320 nm), and consequently it is receiving more energy than the Brewer.

The comparison of the two instruments for the common period of operation August 1991 through April 1992 is shown in Figure 3. In this figure the

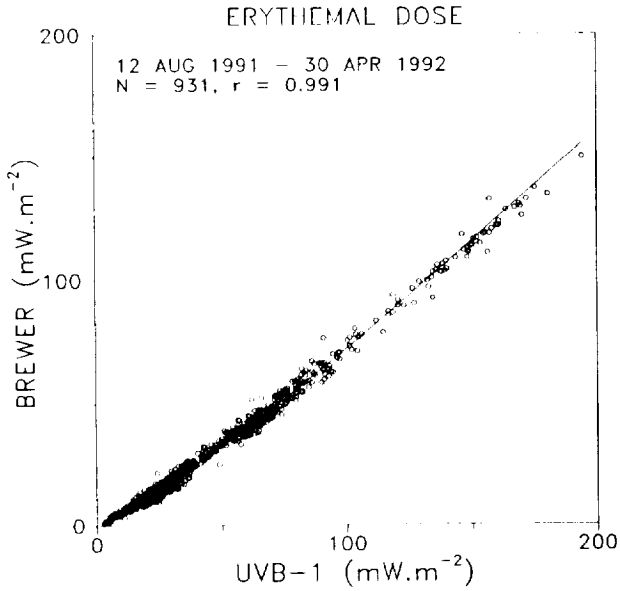

Fig. 3. Comparison of the UV-B erythemal dose as derived from the Brewer and the UVB-1 instruments. Solid curve represents a power-low best fit of the data pairs.

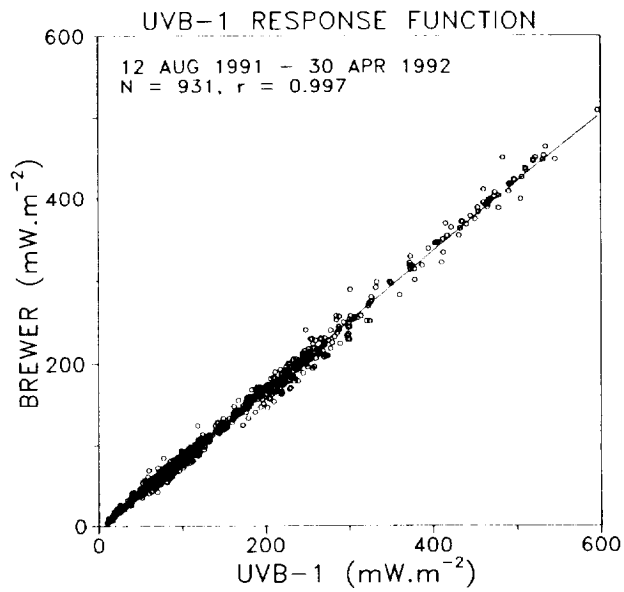

Fig. 4. Comparison of the UV-B radiation as derived from the Brewer (weighted with the UVB-1 response function) and the UVB-1 instruments. Solid line represents a linear best fit of the data pairs.

Brewer dose was computed from spectra weighted with the erythemal action spectrum and it appears that the output of the two instruments differ by about 25%. The regression describing the relation between the two data sets seems to be different than the expected linear model. Better results are achieved when using a power law fit instead, with a highly significant (at the 99.9% confidence limit) correlation coefficient ($r = 0.995$, $n = 931$ pairs). This deviation from the linear regression could be attributed either to the differences in the cosine response of the two detectors, or to the model estimated correction factor applied to the pyranometer. To eliminate any possible effects induced by the correction factor we compared the uncorrected output of the UVB-1 with the integrated output of the Brewer, weighted with the spectral response function of the pyranometer. It is expected that these two quantities should be similar since they are affected only by the slightly different spectral ranges of the two instruments. This can seen in the scatter diagram of Figure 4, in which the relation between the Brewer and the UVB-1 now becomes linear, again with a highly significant correlation coefficient $r = 0.997$.

It is believed, therefore, that the model correction factor is responsible for the non-linear relation between the erythemal dose measured by the two instruments, rather than the suspected differences in their cosine response. This could be due to the default aerosol thickness used in the model and it needs further work to check the sensitivity of this model on the various aerosol loads.

4. CONCLUSIONS

From the comparison of the Brewer global spectral measurements, integrated over the UV-B region, with the global UV-B radiation as measured by the UVB-1 pyranometer, under a variety of atmospheric conditions it appears that there is a linear relation between them with a highly significant correlation coefficient ($r = .997$) and a relatively low error estimate ($s = \pm 7$). In addition, there is no sign of significant drifts between the two instruments, at least during the 9 months period of study. The above suggest that the UVB-1 pyranometer is capable in supplementing the Brewer spectral measurements throughout the year. Slight differences between the erythemal doses, as they are derived from both instruments, are attributed to our insufficient information concerning the aerosol thickness over Thessaloniki, because it enters in the Green's model used to obtain the erythemal in the UVB-1 sensor.

ACKNOWLEDGMENTS

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