An Assessment of the UV Broad Band Filter Radiometer Measurement Accuracy

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Abstract

The lack of a standard calibration procedure for UV broad band filter radiometers introduces potentially large uncertainties in their measurement products. Although most UV calibration facilities take critical instrument properties that affect the measurement quality of UV filter radiometers into account, several properties need special consideration to keep the measurement uncertainty within acceptable limits.

At the European Reference Centre for UV Radiation measurements (ECUV) of the Joint Research Centre (JRC) of the European Commission, a UV filter radiometer calibration facility was established. UV filter radiometers are calibrated in the laboratory for their spectral sensitivity. Then, the absolute calibration is obtained by collocated solar measurements with the reference spectroradiometer of the ECUV.

From July 2003 until the end of 2004, various broad band UV filter radiometers were evaluated at the ECUV with the intension to estblish a reference group composed of instruments from institutions which may benefit from the uniform and well maintained UV irradiance scale realised at the ECUV. We present results obtained from collocated measurements performed with the broad band UV filter radiometers and the reference UV spectroradiometer. Besides the spectral characteristics of UV filter radiometers, their angular response and stability must also be considered in order to make a comprehensive uncertainty estimate. The measurements show that the selected group of radiometers agree within 10% to the reference spectroradiometer.

1 Introduction

One of the most widely used instruments to measure atmospheric UV radiation is the broad band UV filter radiometer. Since the introduction of the Robertson-Berger radiometer in 1976 [1] a number of commercial broad band UV radiometers have been developed. Although the broad band UV filter radiometer is an accepted monitoring instrument it must be used carefully in order to make accurate and valuable measurements. There are a number of critical instrument properties that have to be considered during calibrations and measurements: (i) the spectral response function of broad band UV filter radiometers deviates considerably from the theoretical response curve, (ii) the cosine response function of the entrance optics is not perfect, (iii) the long term stability of broad band UV filter radiometers can be poor, and (iv) the optical components can be sensitive to temperature and humidity variations.

The measurements performed at the ECUV with a number of different broad band UV radiometers are used to investigate the measurement quality and long term stability of this instrument type. In this study we present results obtained with two YES Inc. and three Kipp & Zonen instruments. The measurement period used for the investigation started in July 2003 and ended in December 2004. The Brewer MKIII spectroradiometer of the ECUV was used as the reference instrument, i.e. all broad band UV radiometer calibrations are traceable to this spectroradiometer.

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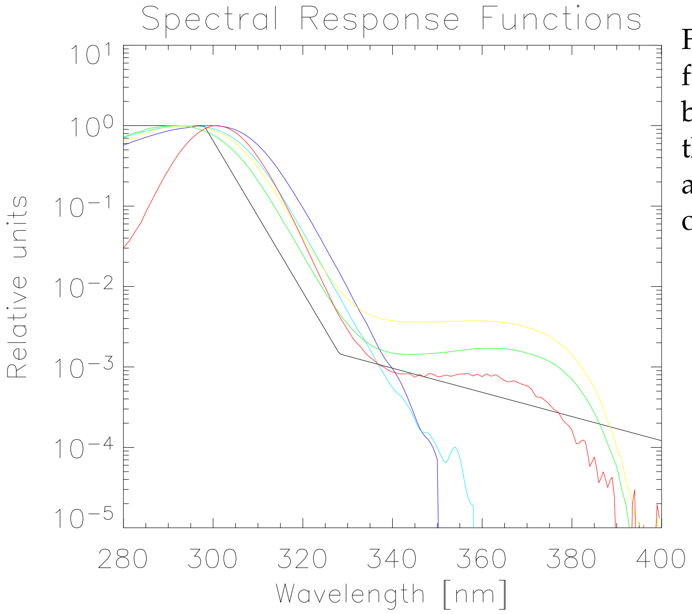

Figure 1: Relative spectral response functions, S_{uvs}, of the five broad band UV filter radiometers used in this study. S_{uvs} is shown on a logarithmic scale (y-axis) as a function of wavelength in nm (x-axis).

2 Instrumentation and Measurements

Figure 1 shows the relative spectral response functions, S_{uvs}, of the two YES Inc. and three Kipp & Zonen instruments on a logarithmic scale (y-axis) as a function of wavelength in nm (x-axis). As one can see, deviations between the response functions of the individual instruments are large and substantially different from the theoretical curve, given with the black line (CIE-1987). The quality of the spectral response function measurements has been verified recently in an intercomparison of several laboratory facilities [3]. Figure 2 shows the measurement platform of the ECUV located at the Joint Research Centre (Italy) with the UV spectrophotometer (Brewer, MKIII) at the right hand side and some broad band UV radiometers in the back.

2.1 Calibration

The purpose of the first step in the calibration process is to allocate a sensitivity to the broad band UV radiometer in Volts per W/m^2, referred to as the "radiometric calibration factor", ρ_{uvs}. The index "uvs" stands for "UV Sensor" which represents one of the five broad band UV radiometer used in this study. To determine ρ_{uvs} the broad band UV radiometer has to measure atmospheric UV radiation under (ideally) cloud-free measurement conditions, side-by-side to the reference spectrophotometer. Only synchronised spectral and broad band measurements are used to determine ρ_{uvs} according to

$$\rho_{uvs} = \frac{U_{uvs}}{\int E_{Bre}(\lambda)\, S_{uvs}(\lambda)\, d\lambda}. \tag{1}$$

U_{uvs} denotes the radiometer readings (in Volts) and $E_{Bre}(\lambda)$ represents the spectrophotometric measurements. The calibration formula given in equation 1 yields a classic sensitivity, i.e. the ratio between the reading of the radiometer (enumerator) and the UV radiative flux which is physically detected by the radiometer (denominator). Note, that the denominator does not account for the deviation between physical and theoretical response functions. The radiometric calibration factor ρ_{uvs} therefore yields the UV irradiance, I_{uvs}, as it is physically detected by the broad band UV radiometer, according to

$$I_{uvs} = \frac{U_{uvs}}{\rho_{uvs}}. \tag{2}$$

As broad band UV radiometers usually have spectral response functions which do not match the theoretical function (see Fig. 1) the UV irradiance, obtained according to equation 2, is physically unsatisfactory. Therefore, a measurement correction is required to minimise the so-called "spectral mismatch error", i.e. the error between the UV irradiance obtained according to equation 2 and the true, Erythema weighted (CIE-1987) irradiance.

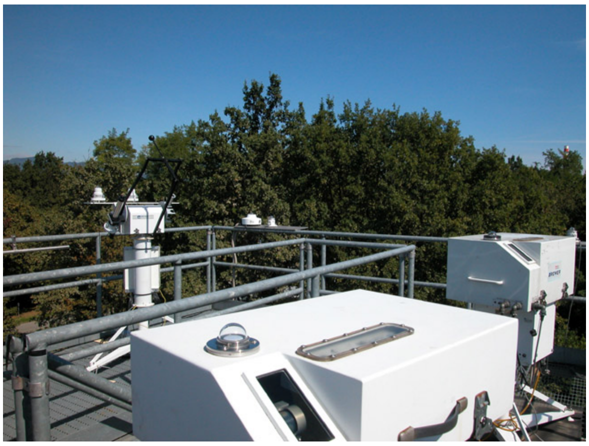

Figure 2: Measurement platform of the ECUV located at the Joint Research Centre (Italy) with the UV spectrophotometer (Brewer, MKIII) at the right hand side and some broad band UV radiometers in the back.

2.2 Measurement Correction Methods

Without any measurement correction, the broad band UV radiometer can provide results that deviate by a factor of 2 or more from the true values. The magnitude of the deviation depends mainly on the extent of the spectral mismatch and the measurement condition. In addition to the spectral mismatch error, other factors as mentioned in Section 1 potentially reduce the measurement quality of broad band UV radiometers.

The variable measurement conditions taken into account in this study include the solar zenith angle, Θ_0, and the total Ozone column density, $[O_3]$. Other atmospheric factors affecting UV irradiances, such as extinction of UV radiation due to aerosols, are not explicitly accounted for as they are assumed to be small compared to the effects that varying solar zenith angles and the Ozone column densities have on the spectral distribution of the UV radiation. In this second step of the calibration process we use two correction methods which both can significantly reduce the spectral mismatch induced measurement error of broad band UV radiometers.

2.2.1 Model-based correction method

The model-based correction method improves the broad band UV radiometer measurements for atmospheric conditions typically encountered during field applications. The variable model parameters used to determine the various correction factors are the solar zenith angle, Θ_0, and the Ozone column density, $[O_3]$. Other fixed model parameters were chosen in order to represent the measurement conditions at the ECUV as close as possible. Table 1 summarises the most important TUV model parameters as they were used to calculate the correction factors for this study. The modelled spectra are used to determine the conversion factors, $\gamma(O_3, \Theta_0)$, defined as

$$\gamma(O_3, \Theta_0) = \frac{\int E_{TUV}(O_3, \Theta_0, \lambda)\, S_{uvs}(\lambda)\, d\lambda}{\int E_{TUV}(O_3, \Theta_0, \lambda)\, S_{cie}(\lambda)\, d\lambda} \tag{3}$$

The solar zenith angles, Θ_0, are varied between $0°$ and $85°$ (using steps of $5°$) and the Ozone column densities, $[O_3]$, are varied between $200DU$ and $500DU$ (using steps of $10DU$), yielding 18 times 31 conversion factors. Hence, the variable effects of other atmospheric compounds on the UV radiation, e.g. extinction due to aerosols, are not explicitly included in the model-based correction method. However, the dedicated model parameters as listed in table 1 account for many local measurement conditions. If broad band UV irradiances under exceptional conditions have to be measured with broad band UV radiometers, it is recommended to calculate new conversion factors using model parameters that are representative for the exceptional condition (e.g. snow covered land surface at a location which is normally snow free).

2.2.2 Observation-based correction method

The observation-based correction method uses spectroradiometric measurements to infer the final calibration factors, which include the correction of the spectral mismatch error. In Bodhaine et al. [2] a detailed description of the observation-based correction method can be found. The observation-corrected Erythema weighted irradiance, I_{uvs}, is determined according to

$$I_{uvs} = \frac{U_{uvs}}{\delta_{uvs}(O_3, \Theta_0)}. \tag{4}$$

Table 1: TUV radiative transfer model parameters representing typical measurement conditions at the ECUV. (BL: Boundary Layer; FT: Free Troposphere; ST: STratosphere)

Layer	Aerosol				Other parameters						
	α	β	g	$\widetilde{\omega_0}$	Albedo	SO_2 [DU]	NO_2 [DU]	Lat North	Lon East	Profile	P_{Surf} [hPa]
BL	1.6	0.08	0.7	0.95	0.1	0.16	0.29	45.8	8.6	mls	1015
FT		0.008	0.6	1.0							
ST		0.0013	0.6	1.0							

where $\delta_{uvs}(O_3, \Theta_0)$ denotes the spectral mismatch corrected calibration factor of the broad band UV radiometer. As the observation-based correction method uses measured spectra to determine the corrected calibration factors, all atmospheric parameters affecting the spectral UV irradiance will be included in the calibration factor. Therefore, the observation-based correction method is – strictly spoken – only valid for the location at which the calibration has taken place. However, a large number of measurements under many measurement conditions (covering a large number of solar zenith angles and Ozone column densities) should improve the statistics of the corrections sufficiently to provide an universal corrected calibration factor table as a function of Θ_0 and $[O_3]$.

3 Results and Conclusion

From July 2003 until the end of 2004 a total of 12864 useful broad band UV radiometer measurements could be collected with the five radiometers at the ECUV. To get the best results out of the measurements the YES instruments had to be corrected according to the observation-based method while for the Kipp & Zonen instruments the model-based correction method had to be used. It is likely that the observation-based correction method removes certain instrument-specific measurement errors more efficiently than the model-based correction method. This, however, does not legitimate to draw conclusions about the quality of the instruments. As will be shown later, both correction methods can reduce measurement errors equally well, despite the significant differences in optical properties that exist among all five instruments.

For the assessment of the measurement accuracy all corrected broad band UV radiometer measurements where subtracted from the integrals of the spectrally measured Erythema weighted irradiances. With the differences, which represent the best possible estimate of the Erythema weighted irradiance measured by broad band UV radiometers, a probability distribution function ("PDF") is determined. Figure 3 shows the individual PDFs, which are normalised for better comparability in the figure only. The statistical moments of the broad band UV radiometer measurements are determined with the enveloping function, i.e. the sum of all PDFs. The mean value, i.e. the mean difference between the spectrally derived and the broad band radiometer based irradiances, is as small as $5.6 \cdot 10^{-4}\, W/m^2$. This difference corresponds to a UV Index of only 0.02. However, the standard deviation at a 2σ-level is as large a 10%, meaning that although dedicated measurement corrections were applied large deviations are still possible.

To measure Erythema weighted UV irradiances with broad band UV filter radiometers, careful calibrations and measurement corrections must be applied. Under ideal measurement conditions the differences between spectrally derived and properly corrected broad band radiometer measurements of the Erythema weighted irradiance can be arbitrarily low. However, it is far more difficult to determine the accurate UV irradiance under variable atmospheric measurement conditions. Nevertheless, it can be concluded that the broad band UV radiometer is a suitable instrument for UV monitoring, especially under fair weather conditions, provided that it is regularly calibrated and corrected properly.

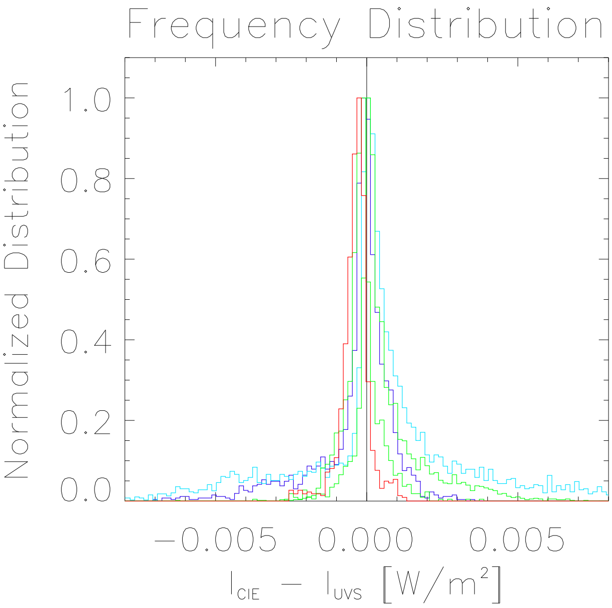

Figure 3: Probability distribution functions of the difference between spectral and corrected broad band radiometer measurement of the Erythema weighted irradiances for all five broad band UV radiometers (normalisation is for better comparability only).

References

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