

Calibration Checks for Broadband Erythemal UV Radiometers

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Abstract. In the framework of the Swiss Atmospheric Radiation Monitoring program (CHARM) of MeteoSwiss, UV erythemally-weighted irradiance is measured using SolarLight 501A UV broadband radiometers (biometers) at four stations in Switzerland. While the global component is measured at all stations, the direct and diffuse components are also measured at two stations. Recommendations for measuring UV erythemal irradiance with broadband radiometers require the instruments to be calibrated by comparison to a traceable absolute spectral irradiance reference, taking into account the difference between the instrument spectral response and the theoretical CIE (Commission Internationale de l'Eclairage) erythemal response [e.g., WMO, 1996]. Because such calibrations should be relatively frequent (at least yearly), a method for checking the calibration of a given instrument by comparison with a reference instrument traceable to absolute spectral irradiance has been devised at MeteoSwiss. The method is described below, and issues of inter-instrument reproducibility and operational uncertainty are explored. Three instruments were chosen as reference and were fully calibrated according to the recommendations mentioned above by two different centers and were subsequently measuring side by side in operational mode during several test periods. The reproducibility of observations made according to the recommendations could then be checked, and was found to be compatible with the usually quoted uncertainty of 5-10%.

Introduction

MeteoSwiss uses a total of about twenty biometers for its monitoring of UV radiation within the CHARM network. A method to check calibration values with respect to reference biometers was devised, which allowed reducing calibration costs and logistics, while ensuring satisfactory accuracy. Three instruments (SL1903, SL1904 and SL1905) were chosen to be used as reference at MeteoSwiss based on the availability of past characterizations and stability. One instrument (SL1903) was sent for characterization to the European Reference Centre for Ultraviolet Radiation measurements (ECUV) from the Joint Research Centre at Ispra, Italy, while the two others were sent to the U.S. Central UV Calibration Facility (CUCF) at Boulder, U.S.A. After characterization at the calibration centers, the three biometers were installed in parallel at the Payerne site for measurement of global UV radiation between 31 August and 5 October 2004. The signals were sampled constantly at a 1 Hz frequency with 1-min averages recorded.

The method for calibration checks with respect to reference biometers is described here and some results of the calibration checks are presented. Results from the comparisons between the three reference biometers for 14 clear-sky days are also reported here. The uncertainty of well characterized biometers is estimated to be on the order of 5-10% [Lantz et al, 1999]. The goal of the analysis reported here is to verify whether the agreement between

biometers characterized at different centers and operating in standard network measurements conditions is compatible with the stated uncertainty

Calibration check method

A draft "Practical Guide to Operating Broadband Instruments Measuring Erythemally Weighted Irradiance" to be published jointly by WMO SAG UV and Working Group 4 of the COST-726 Action states that the raw signal must be converted into units of erythemal irradiance by application of a calibration function. This requires knowledge of the time (for solar zenith angle) and ozone amount at the time of measurement:

$$E_{\text{CIE}} = (U - U_0) C_{\text{cal}} f(\theta_z, TO_3) C_{\text{cos}} C_{\text{temp}}, \text{ where:}$$

- E_{CIE} is the erythemal effective irradiance,
- U is the measured electrical signal from the radiometer,
- U_0 is the electrical offset for dark conditions,
- C_{cal} is a constant calibration coefficient,
- $f(\theta_z, TO_3)$ is a calibration function of solar zenith angle (θ_z) and total ozone column (TO_3),
- C_{cos} is the cosine correction function, and
- C_{temp} is the temperature correction function.

The combination of terms $C_{\text{cal}} f(\theta_z, TO_3) C_{\text{cos}}$ results in a function of solar zenith angle and total ozone column that is determined by the characterization and calibration of the instrument at the reference center.

The calibration check method uses the assumption that similar instruments (e.g., two SolarLight biometers) will behave similarly with respect to θ_z and TO_3 , which should allow using the calibration and characterization of a reference biometer for another instrument and apply a correction function f_{cor} of θ_z and TO_3 determined during a calibration check period when instruments are compared to the reference.

Instruments to be checked are operated concurrently and collocated with a reference biometer during a period long enough for including several clear-sky days with sig-



Figure 1, Biometers measuring concurrently the erythemal UV irradiance for a calibration check period at the BSRN Payerne (Switzerland) station of MeteoSwiss.

nificant changes of the total ozone column (typically on the order of a Spring month in the Northern hemisphere). For each 1-min average measurement, the ratio between the raw signal of the reference biometer and the raw signal of the tested instrument is computed. The correction function f_{cor} for the tested instrument is determined by fitting on the ratios, a two-dimensional polynomial function including all combinations of θ_z and TO_3 up to the 2nd-order as well as one solar zenith angle 3rd-order term:

$$f_{\text{cor}}(\theta_z, TO_3) = p_0 + p_1\theta_z + p_2TO_3 + p_3\theta_z TO_3 + p_4\theta_z^2 + p_5TO_3^2 + p_6\theta_z^3$$

In case such a function can be used to describe the dependency of the raw signal ratios on solar zenith angle and total ozone column, the tested instrument is assumed to behave similarly to the reference, and the method is considered valid for this instrument. The criterion used for this test is that 90% of the distribution the residual of the ratios to the polynomial fit should lie within $\pm 5\%$. In case the instrument does not pass this test, the calibration check procedure is considered as not sufficient, and the instrument should be fully calibrated before being used operationally.

Out of 21 instruments tested, 14 fulfilled the above-mentioned criterion. Figure 2 shows the correction function obtained for one of the instruments fulfilling the criterion.

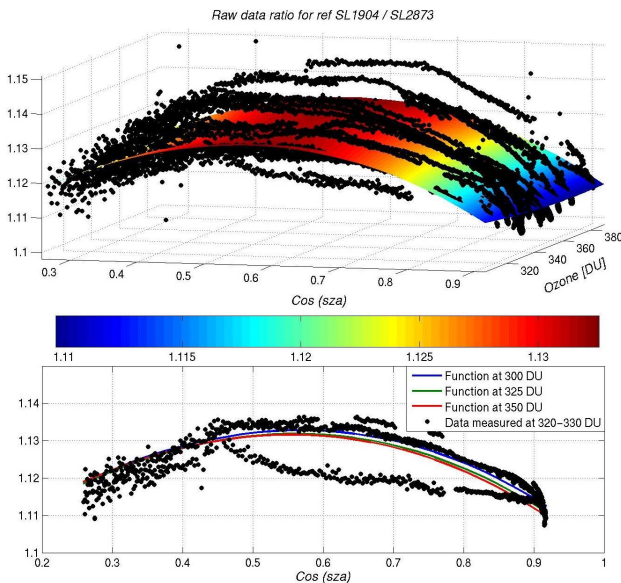


Figure 2, Ratio between raw signals of biometers SL1904 (reference) and SL2873; upper panel: data and fit function vs. $\cos(\theta_z)$ and TO_3 ; lower panel: curves from fit function at $TO_3 = 300, 325,$ and 350 DU and data measured around 325 DU.

Since the calibration method has been implemented, five calibration check periods have occurred usually involving eight tested instruments and one reference. For instruments fulfilling the method criterion, the width of the residual distribution (5th to 95th percentile) lied within $\pm 1\%$ and $\pm 5\%$ (selection criteria). For the other instruments, the width of the residual distribution could go up to $\pm 15\%$, suggesting instrument malfunction, which could not be directly diagnosed if the instrument would not have been compared to a reference.

After calibration checks, biometers were used opera-

tionally in the CHARM network. At some locations, redundancy allows comparing different instruments, and checking the reproducibility of the measurements for real fully automated operation. Such comparisons typically yielded reproducibility on the order of 5%. Figure 3 shows a comparison at Payerne for 1-min average measurements

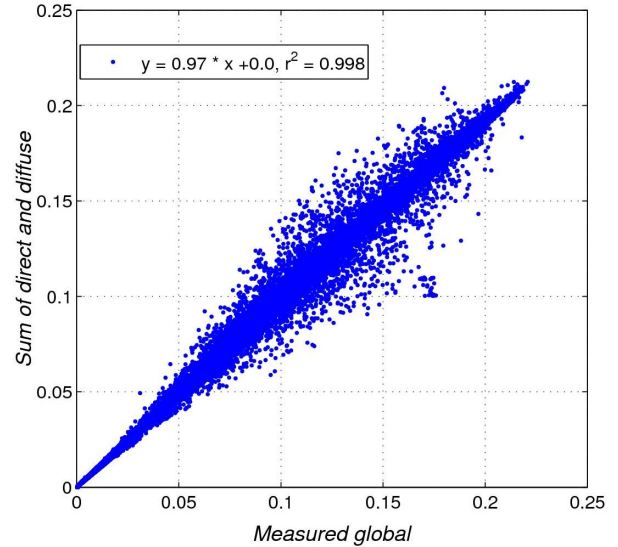


Figure 3, Comparison between the global downward UV erythemal irradiance measured with SL2873, and the sum of the direct and diffuse components measured with SL2874 and SL3551, respectively during the period June-September 2006.

during four summer months (JJAS) between the measured global downward UV erythemal irradiance and the sum of the direct and diffuse components measured separately.

Specific comparisons were also carried for the three instruments selected as reference.

Spectral characterization of reference biometers

The reference biometers were initially characterized by the manufacturer prior to 1997 and underwent a second characterization at a Swiss facility (Novartis) between the end of 1998 and the beginning of 1999. They were characterized a third time before their calibration at CUCF or ECUV in 2004. Figure 4 shows the normalized spectral characterizations of the three biometers. The different characterizations give similar results between 290 and 330 nm, while some differences are present at wavelengths shorter than 290 nm and longer than 330 nm. Closer inspection reveals that there may also be substantial differences in the middle region. The 320-325 nm close-up part of Figure 4 shows that the responses of SL1903 and SL1905 according to the 2004 characterizations differ by about 40% in this region.

Characterizations made by a given center at a given time are usually very similar, while the largest differences occur for characterizations made by different centers or at different times. The 3 original characterizations by the manufacturer yield almost identical results, except for SL1905 at wavelengths shorter than 275 nm. Similarly, the second set of characterizations by Novartis also yields strikingly similar results, although SL1905, characterized earlier than SL1903 and SL1904, seems to have a lower response in the central region. Finally, in the third set of characterizations, SL1904 and SL1905, which are

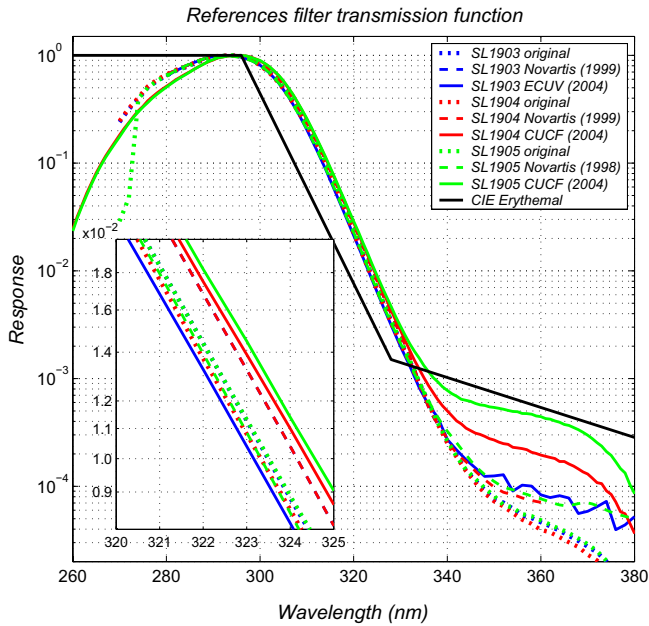


Figure 4, Comparison of filter transmission function for UV reference biometers (note: the dotted blue curve – original SL1903 – is covered by the dotted green curve – original SL1905 – and the dashed blue curve – Novartis SL1903 – is covered by the dashed red curve – Novartis SL1904).

characterized by CUCF, give similar results but substantially different from the previous characterizations, in the wavelength range above 330 nm, while SL1903, characterized by ECUV, is similar to the Novartis characterization in the range above 330 nm, and similar to the original characterization in the range below. Such differences may be due to instrument ageing characteristics or the influence of environmental conditions [Huber et al., 2003]. However, in light of the substantial differences that can result from small wavelength shifts and of the inconsistencies in the evolution of the biometers characteristics, it remains to be determined whether the observed differences result from instrument differences or from differences in the methods of the reference centers. In another study, Schreder et al. [2004] observed differences up to 20% between biometers spectral characterizations by different centers.

Comparison of reference biometer results

Beyond spectral and angular response, the biometers were also calibrated against traceable absolute spectral irradiance references at ECUV or CUCF. Because of the mismatch between the filter response and the theoretical erythemal function, the calibration factor is expressed as a function of total ozone column (TO_3) and solar zenith angle (θ_z), as mentioned above. It is determined using spectral and cosine characterization, as well as absolute calibration. UV erythemal irradiances compared below are obtained using these calibration functions.

The ratio between the pairs SL1903/SL1904, and SL1905/SL1904 are shown on Figure 5 and 6 as function of $\cos(\theta_z)$ and TO_3 . In these figures, each black dot represents the ratio of the observations from two biometers for concurrent measurements. The semi-transparent surface is a fit of a two-dimensional polynomial function of θ_z and TO_3 .

The comparison on Figure 5 and 6 show that UV erythemal irradiance measured by the three instruments are

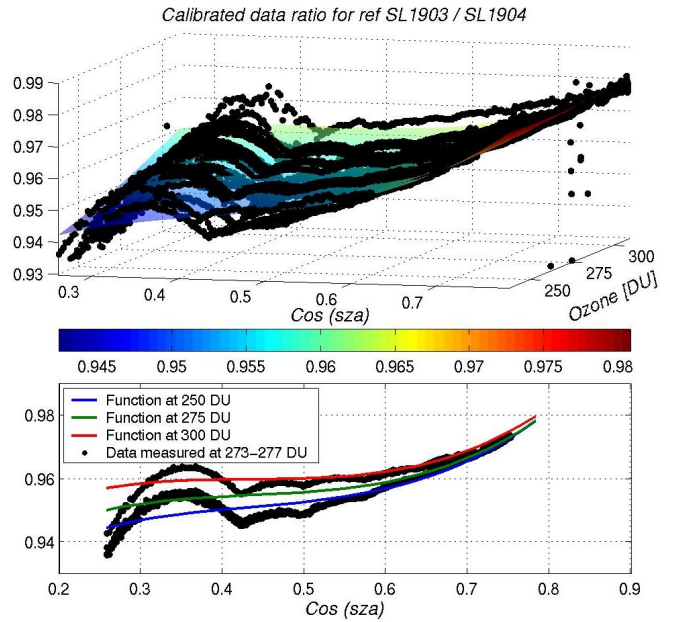


Figure 5, Ratio between calibrated measurements of biometers SL1903 and SL1904; upper panel: data and fit function vs. $\cos(\theta_z)$ and TO_3 ; lower panel: curves from fit function at $TO_3 = 250, 275,$ and 300 DU and data measured around 275 DU.

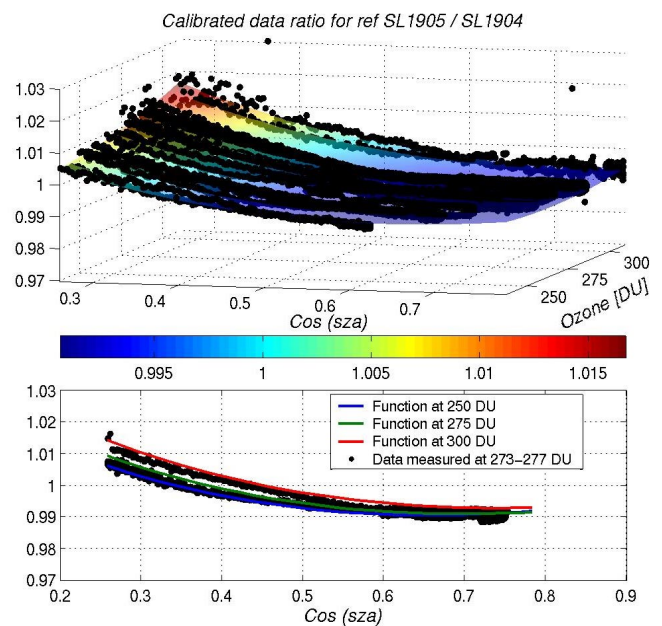


Figure 6, Same as Figure 5 for the ratio between calibrated measurements of biometers SL1905 and SL1904.

within about 7-8% at the ozone and solar angle conditions where they disagree most. The agreement between the instruments calibrated by the same center (SL1905/SL1904) is significantly better than the agreement between the instruments calibrated at different centers (SL1903/SL1904). In addition, for the latter, a hump is present in the ratio for $\cos(\theta_z)$ between 0.3 and 0.4. This hump does not correspond to difference between instruments and seems to be an artifact of the calibration.

The raw data signals of the instruments before applying the calibration functions were also compared. While some difference in absolute normalization existed, the shape of

the (θ_z, TO_3) dependence exhibited less variability than for the calibrated data. All the raw signal data agreed within a couple percent for the SL1903/SL1904 pair and within 3 percent for the SL1903/SL1904 pair, indicating that the spectral characteristics of the three instruments should be similar. Thus, for these comparisons, the calibration process did not decrease the θ_z and TO_3 dependence of the ratio.

Conclusions

A calibration check method for broadband radiometers measuring UV erythemally weighted irradiance has been devised. This method is based on the assumption that instruments of the same type will behave similarly with respect to environmental conditions such as solar zenith angle and total ozone column. The difference in behavior with respect to these parameters is assessed and is used to transfer the calibration characteristics of a reference radiometer to the tested instrument. This method ensures reproducibility on the order of 5%. Analysis of reference radiometer results confirm that the uncertainty is on the order of 10%. More specifically, comparisons of UV erythemal irradiances measured concurrently by broadband radiometers recently calibrated at two different reference centers showed an agreement that is compatible with the stated uncertainty of about 5-10%. Comparisons of the raw data signals for a range of solar zenith angle and total ozone column suggest that the three tested instruments have very similar spectral characteristics. Successive characterizations by independent centers revealed differences between the filter transmission functions, but these do not show a coherent evolution. They may originate in different ageing characteristics of the individual instruments or in differences between the methods used during the characterizations.

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