Towards a Traceable Global Solar UV Monitoring Network

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Abstract. In view of improving the status of solar UV measurements within the UV monitoring community, the World Calibration Center for UV (WCC-UV) organized in 2022 the 3rd solar ultraviolet broadband radiometer campaign UVC-III under the auspices of the WMO. 73 instruments were characterized in the laboratory of the WCC-UV and calibrated outdoors relative to the QASUME reference spectroradiometer. After an up to three-month calibration period all devices were returned to their owners including a calibration certificate demonstrating traceability to the international system of units (SI). The expanded uncertainty of the responsivity was less than 5 % for the majority of the radiometers. The deviation to the original responsivity factors was analyzed. From this data one can extract three components affecting the overall measurement uncertainty of solar UV measurements using broadband radiometers on different time scales: Usage of additional correction factors next to the responsivity, control of the humidity inside the device and recalibration frequency. However, it must be noted that the responsivity and measurement equations used by the participating institutes not always follow the recommendations of the WMO as well the sometimes scarce to non-existent recalibration frequency of the solar UV radiometers.

INTRODUCTION

Currently, the responsivities obtained from the manufacturers of UV broadband radiometers are usually not suitable to achieve measurements of solar UV irradiance with expanded uncertainties smaller than 5%. Furthermore, neither National Metrology Institutes (NMI) nor instrument manufacturers currently offer SI-traceable calibrations of solar UV broadband filter radiometers. The currently suggested calibration methodology [1] is to use a combination of laboratory-based instrument characterizations, combined with an outdoor calibration using the sun as a source. In view of improving the status of the solar UV measurements within the UV monitoring community, the WCC-UV organized the UVC-III in 2022. This is the 3rd solar ultraviolet broadband radiometer campaign after the campaigns in 2006 and 2017 [2][3]. Over 70 instruments were characterized in the laboratory of the WCC-UV and calibrated outdoors relative to the QASUME reference spectroradiometer. After the calibration period all devices were returned to their owners including a certificate demonstrating traceability to the international system of units (SI).

CHALLENGES

UV broadband radiometer select a very narrow spectral range with a sensitivity optimized for solar intensities. Their spectral responsivity (SRF) changes with a steep flank of over 4 decades between the UVB to the UVA wavelength range. The solar spectra increase over several decades from UVB to UVA – opposite to the spectral responsivity of the detector. One needs to normalize the detector specific responsivity to a standard UV weighting function, such as the erythemal weighting function [4][5].

The radiometers sample sunlight from the whole hemisphere. Radiation at high solar zenith angles (SZA) is usually over or underestimated due to the design of the radiometer resulting in a specific angular responsivity

(ARF). The correction depends on the varying distribution of direct and scattered light from the sun in the atmosphere. This poses a problem because the sky distribution is usually not known for radiometers installed in the field.

The task of UV radiometers is to measure solar UV Irradiance which can be up to 100 times larger than standard laboratory irradiance sources used during the calibration in the laboratory. The sensitivity of the radiometer usually changes significantly over the period of operation, requiring recalibrations at regular intervals.

INSTRUMENTS AND METHODOLOGY

Three setups are employed at the WCC-UV for the laboratory calibration: Spectral and angular responsivity measurements and the standard lamp calibration setup for the reference spectroradiometer.

- The spectral responsivity setup uses a 500 W Xe-Lamp light source, an Acton SP2500 double monochromator producing quasi-monochromatic light which is used to illuminate the test detector (Figure 1, left).
- The angular response setup uses a 1000 W Xe lamp as artificial “sun” which illuminates the detector with a collimated beam. The detector is mounted on a goniometer. Rotating the radiometer in the light beam simulates the path of the sun around the radiometer from the sunrise to sunset (Figure 1, right).
- Finally, the reference spectroradiometer is calibrated using 1000 W FEL type irradiance standards – which is the most important measurement to have SI-traceable measurements. The spectroradiometer in use at PMOD/WRC is the instrument QASUME, with the core part being a DM150 double monochromator (Bentham UK) [6].

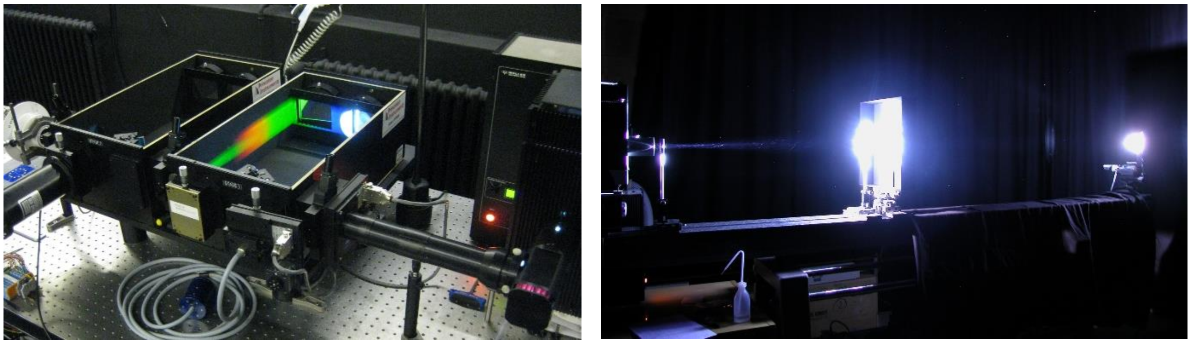

FIGURE 1. The spectral responsivity setup with a SP2500 Acton double monochromator in the center (left picture) and the angular responsivity setup with the 1000 W Xe light source illuminating the test radiometer mounted on a goniometer (right picture).

The current accepted calibration methodology used at the WCC-UV uses the SRF and ARF measurements to derive the following correction functions:

1. The SRF is used to calculate the correction factor which converts from the detector specific weighing to a normalized UV weighting function, f_n, (e.g., CIE erythema [4][5]) using radiative transfer calculations using a nominal atmosphere.
2. The angular response function is used to derive an angular correction function, *Coscor*, to account for the imperfect angular response of the radiometer.

The responsivity factor, *C*, is derived from the comparison of the radiometer reading, *S*, relative to the QASUME irradiance scans using the sun as light source. Irradiance values, *E*, for the test instrument are calculated using the following equation:

$$E(\lambda) = (S - S_{dark})\, C\, f_n(SZA, TO3)\, Coscor(SZA) \quad (1)$$

UVC-III

In the UVC-III, the performance of 73 UV broadband radiometers were investigated. They belong to 42 different institutions from 29 countries. Most radiometers are analog types: Solar Light 501, Kipp & Zonen UV-S-A/E/B-T, YES UVB-1, EKO, CMS, Indium Sensor, Delta Ohm, and SGLUX. Radiometers with a digital interface were from Kipp & Zonen (SUV-Series), EKO (MS-type) and Solar Light. The majority of instruments had nominal erythemal spectral responsivities. Other radiometers were devised for providing UVB, UVA or UV-Global solar irradiances.

After the laboratory measurements the radiometers were mounted next to QASUME on the roof platform of PMOD/WRC for 2 to 3 weeks (Figure 2).

FIGURE 2. The roof platform of PMOD/WRC with the entrance optic of two reference spectroradiometers in the front and the installation of the test radiometers participating to the UVC-III in the back.

RESULTS

Figure 3 shows the main result of the UVC-III. It shows the responsivity of the participating radiometer before and after the campaign by as the ratio of the original relative to the new responsivity factors. The green circles are the radiometers belonging to the WCC-UV, which are calibrated annually. Therefore, the deviations show both, the uncertainty of the calibration method itself and the change of the sensitivity of those radiometers during one year. Blue circles correspond to the 2nd channel of dual channel UV-S-AE-T radiometers (Kipp & Zonen). Although most instruments are well within the calibration uncertainty of around 5%, some instruments are outside the uncertainty range of ±10 %.

The last point in Figure 3 shows the performance of the UVIOS model simulation [7] relative to the reference dataset derived from the QASUME measurements. For this period of the year the agreement of this model to the measurement of QASUME is excellent.

CONCLUSION

1) The measurement equations used by the participating institutes not always follow the recommendations of the WMO [1].
2) The recalibration frequency of several solar UV radiometers is not sufficient to guarantee reliable solar UV measurements with uncertainties below 10%.
3) The control of the humidity inside the device is crucial for most UV radiometer types [8].
4) The original factory settings of most tested radiometers show calibration errors over 10%.

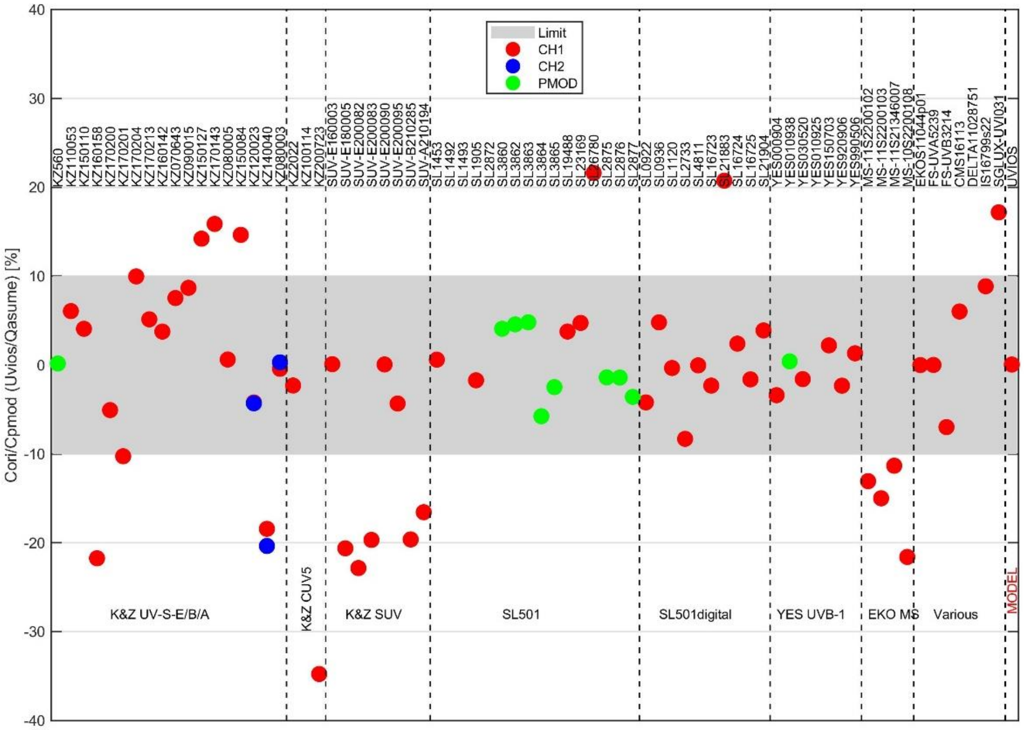

FIGURE 3. The main result of the UVC-III showing the ratio of the sensitivity of the UV radiometers between the original and new calibration.

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