Traceability of Solar and Lunar Direct Irradiances Measured with Precision Filter Radiometers

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Two Precision Filter Radiometers (PFRs) measuring Solar and Lunar direct irradiances for the retrieval of aerosol optical depth (AOD), have been characterised and calibrated at PTB and PMOD/WRC, respectively. The measured irradiances are used in the classical Langley extrapolation method to assess the precision of the extra-terrestrial Solar and Lunar spectra as well as the accuracy of AOD measurements that can be currently achieved following the SI-traceable methodology.

INTRODUCTION

Atmospheric aerosols are known to impact the climate. They represent also one of the essential climatic variables with the largest uncertainties in the climate change studies. Within the framework of Global Atmospheric Watch (GAW), Aerosol Optical Depth (AOD) is monitored based on direct solar irradiance measurements performed by Precision Filter Radiometers (PFRs). The instrument calibration is carried out at the World aerosol Optical depth Research and Calibration Center (WORCC) in Davos, Switzerland, as mandated by the World Meteorological Organization [1]. The growing interest in night-time observations of AOD, in an effort to close the gap in the annual cycle of the arctic aerosol climatology, led to the development of the Lunar Precision Filter Radiometer. Here we present preliminary characterisations and calibrations of two such instruments.

PFR RELATIVE RESPONSIVITY

The relative spectral responsivities (RR) of sun and lunar PFRs, PFR-S and PFR-L, respectively, have been primarily determined using ns-pulsed OPO systems (EKSPLA NT242) at PTB and at PMOD.

The RR measurements of PFR-S at PTB were carried out relative to a calibrated silicon photodiode using a monitor photodiode while at PMOD the reference detector is a pyroelectric radiometer. The OPO wavelengths were measured by a laser spectrum analyser (LSA) of High Finesse. The PFR signal (V) is provided by a 22-bit data acquisition system (SACRAM) specifically designed for the PFR.

The PFR channels showed a highly nonlinear response under the ns-pulsed OPO irradiation. The nonlinearity was mapped out by changing the laser power and comparing PFR signal readings with those of the linear monitor detector. Channel 4 (368 nm) showed not only nonlinearity but also a hysteresis.

PFR RESPONSIVITY IN SI UNITS

The spectral irradiance responsivity of the PFRs in SI units has been determined at the TULIP setup [2] and at the direct irradiance calibration setup of PMOD/WRC.

The measurements at the TULIP setup were carried out within bandpasses of the channels against a calibrated 3-element silicon trap detector equipped with an aperture. The reference plane of the PFR has been validated against the reference detector introducing displacements along the beam propagation direction. The radiation source in the setup is a quasi-CW laser system generating ca. 200 fs pulses at 80 MHz repetition rate. The spectral bandpass of the fs-laser radiation was limited by a monochromator to 0.8 nm. A homogeneous irradiance field for the measurements is generated by a micro-lens array.

The direct irradiance calibration setup at PMOD/WRC consists of a reference irradiance source (1000W FEL-type lamp) calibrated at PTB and fully motorized XYZ linear translators and rotation stages for azimuth and zenith angles.

The lamp irradiances were measured at 3 distances ranging from 1.5m to 3m and the reference plane was determined by applying the inverse square law. The calibration factors in SI units (Wm^{-2}/V) were calculated as an integral of the TULIP-provided responsivity functions over the measured spectral bandpasses (T). The responsivity functions were extended to wider spectral ranges using the pulsed OPO-based data (TP). For the lamp calibration method, the afore-mentioned responsivities were converted to relative ones (see Figure 1) and convolved with the spectral irradiance of the reference lamp at the distance of the measurement (L-T, L-TP, and L-P for the PFR-L). The percentage deviation of the calibration factors from the TP ones along with the combined uncertainties are presented

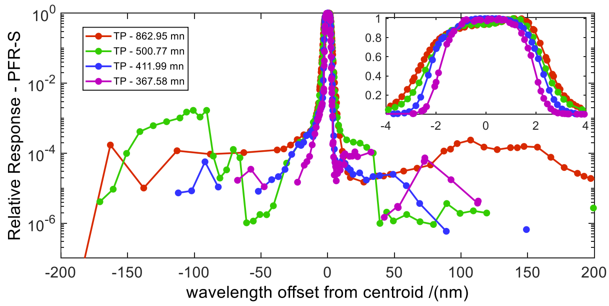

Figure 1: Relative spectral irradiance responsivity of the 4 PFR-S channels measured at PTB.

in Table 1.

Table 1: Percentage differences of calibration factors with respect to TP and combined uncertainties in parenthesis.

	862 nm	500nm	412nm	368 nm
T	-0.80(0.50)	-0.79(0.5)	-0.31(0.50)	-0.39(0.70)
TP	0.00 (0.80)	0.00(0.80)	0.00(0.80)	0.00(0.80)
LT	-0.38(1.63)	-1.57(1.63)	-2.72(1.63)	-3.42(1.76)
LTP	-0.29(1.74)	-0.76(1.74)	-2.68(1.74)	-3.29(1.84)

AOD AND EXTRATERESTIAL SOLAR AND LUNAR SPECTRA

For the evaluation of the calibration accuracy that can been achieved using the publicly available solar extra-terrestrial spectra (ETS), QASUMEFTS [3] and ATLAS [4], we organized a short direct solar irradiance measurement comparison campaign against a PFR-Triad in Davos (48.68°N, 9.85°E, 1600m) in March 2019. In total, measurements during 9 clear days with Langley atmospheric conditions, aerosol loads ranging from 0.01-0.03 AOD at 500 nm, were compared. For a subset of these days (6), a Langley-extrapolation calibration has been performed for the PFR-S. Differences between the ETS convolved with the corresponding RR and the Langley-extrapolated ETS values are shown in Table 2. For TULIP and lamp calibration-based data the agreement at wavelengths below 500 nm is within 1% and 1.5%, respectively. For 862 nm, despite the best agreement of all SI calibrations constants (1σ=0.45%) a negative offset of 1% for ATLAS-ETS is identified.

The same validation method has been used for the PFR-L. For this instrument, datasets measured at Izaña [5] and at Ny-Ålesund were tested with the RIMO lunar ETS irradiance model. For RIMO, we have observed differences of 1.03%, 6.59%, 10.66%, 2.81% at nominal central wavelengths of 862 nm, 500 nm, 412 nm and 675 nm with high standard deviations partly depending on the lunar phase. However, the standard uncertainties of the calibration factors are of the order of 4% due to the 4 orders of magnitude difference in the signal amplification used for laboratory and atmospheric measurements.

In terms of the AOD retrievals using the SI-traceable calibration and the available ETS, the agreement to the reference PFR-Triad is within the accuracy required by the WMO at 412 nm and 500 nm. At 368 nm this is the case only for the calibration factor from the TULIP. Finally, the AOD at 862nm is outside the required limits, with a clear offset of +0.01 in AOD.

Table 2: Percentage differences between ETS and Langley method-obtained extra-terrestrial values at the PFR-S wavelengths.

ETS	ATLAS		QASUMEFTS	
Calibration Factor (CF)	862nm	500nm	412nm	368nm
T	-1.13	0.88	-0.91	-0.70
TP	-2.00	0.47	-0.83	-0.98
L-T	-1.56	1.60	1.03	1.87
L-TP	-1.90	0.86	1.31	1.65
mean	-1.65	0.95	0.15	0.46
std	0.40	0.47	1.18	1.51

These experiments have demonstrated the current measurement accuracies that can be achieved with the PFRs and revealed the major sources of uncertainty that need to be assessed in order to reach the required AOD accuracy of the Langley calibration technique.

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