Stray-Light Correction Methodology for the Precision Solar Spectroradiometer

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A stray-light correction methodology for the Precision Solar Spectroradiometer (PSR) is presented. The correction is based on laboratory-measured line spread functions also taking into account the radiation from the 2nd and 3rd grating orders. The efficiency of the correction is validated on solar and lamp measurement data. The results are compared to those obtained with a PSR equipped with an order-sorting filter and with a Precision Filter Radiometer.

INTRODUCTION

The Precision Solar Spectroradiometer (PSR) is a grating-type array spectroradiometer, developed as a reference instrument for spectral solar irradiance measurements in the spectral range from 300 nm to 1040 nm and for the determination of aerosol optical depth [1]. While previous PSR units were built using an order-sorting filter (OSF) in front of the detector, later instruments were constructed without a physical filter, relying instead on post-processing of the measured spectra using a correction method based on line-spread functions (LSF) and extending the method developed by [2].

STRAY LIGHT CORRECTION METHODOLOGY

The LSFs were measured at PMOD/WRC throughout the full spectral range of the spectroradiometers using a ns-pulsed OPO system. The LSF measurements were performed over 5 to 6 orders of magnitude by varying output power of the laser beam and integration time of the PSR. Figure 1 shows LSF matrices for two PSR units. One instrument is with an OSF in front of the detector while the other one is without it. The 2nd and the 3rd orders of the grating requiring a correction are clearly seen in the matrix shown in the right subfigure.

The measured LSFs of PSR 008 were validated by analogous measurements performed at a similar ns-OPO facility at PTB. The measured LSFs were used to derive a stray-light correction matrix. One problem to be solved was that the wide spectral range of the instrument (about 700 nm) is covered by a detector array with 1024 pixels. Since the bandpass is about 2 nm, there are just a few pixels within LSF peaks. To reduce the related discretisation uncertainties, when inverting the LSF matrix, it was necessary first to interpolate the LSFs to a denser pixel grid before building the matrix.

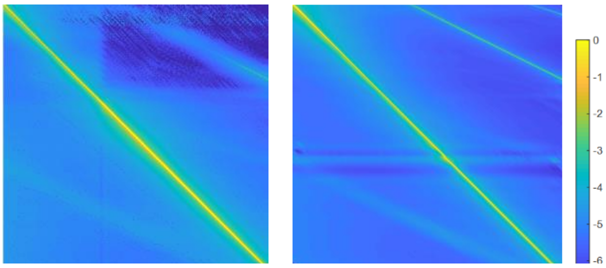

Figure 1. LSF matrices of PSR#004 with OSF (left), and PSR#008, which is without any filter (right). The x and y axis are in pixel space (1024x1024) and cover the spectral range from 300 nm to 1040 nm. The data is shown in logarithmic units.

UNCERTAINTY OF THE CORRECTION

The uncertainty of the stray light correction, u_{LSF}, is described by Eq.1,

$$u_{LSF}^2 = \left[\left(\frac{\sigma_S}{S\sqrt{N}}\right)^2 + \left(\frac{\sigma_D}{S\sqrt{Nd}}\right)^2\right] + \left[\left(1 - \frac{S(ITi)}{S(ITj)}\right)^2 + \left(\frac{3\sigma(Sat)}{Sat\sqrt{3}}\right)^2\right], \quad \text{(Eq.1)}$$

where σ_S and σ_D represent variances of the measured signal (S) and dark counts (D), respectively. The second term of the equation describes the uncertainty contribution resulting from different integration times (IT) and merging of saturated and unsaturated measurements (Sat). Moreover, wavelength shifts also introduce an uncertainty component in the stray light correction results, especially correcting for the 2nd and 3rd dispersion orders. This uncertainty has been determined considering a ±0.5 nm shift and measurements of a transfer standard lamp (FEL). Figure 2 shows the stray light corrections and the associated uncertainties for the irradiance measurements of an FEL lamp using 3 PSR units without any OSF.

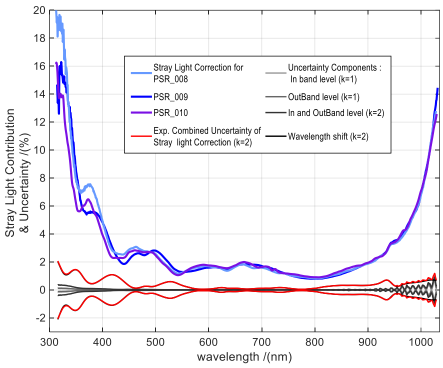

Figure 2. Stray light corrections applied to the new PSR series instruments measuring an FEL lamp and the respective uncertainties of the corrections.

VALIDATION

The efficiency of the PSR stray light correction with respect to the suppression of the radiation from higher dispersion orders has been evaluated using laboratory-based and sun measurement data. Specifically, a UV LED-based source [3] with an emission spectrum in the range 300 nm – 420 nm has been used. The stray light contribution of 0.8% due to the higher grating orders could be corrected by nearly a factor of 10 as shown in Figure 3. Moreover, a comparison of direct solar irradiance spectra measured with the two types of PSRs showed an agreement within ±1% while correcting for up to 40% of the stray light contribution (Figure 4). Similar results were obtained when comparing the solar irradiance at 862 nm and 500 nm measured by

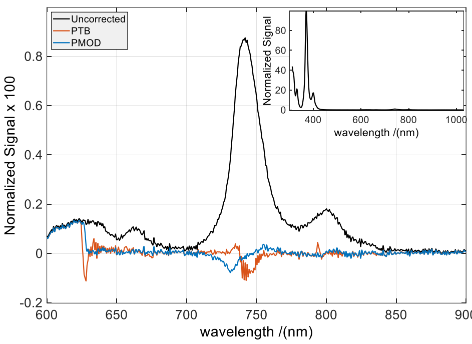

Figure 3. UV-LED source spectrum corrected for straylight contribution (red – PTB data, blue – PMOD data) and uncorrected spectrum (black).

PSR#009 to the respective values measured at these wavelengths by the Precision Filter Radiometer (PFR-N24) forming part of the AOD WMO reference PFR-Triad (see Figure 5). In total, results of 9724 common measurements were compared covering solar zenith angles (SZA) from 40° to 75°. The normalized ratios show negligible SZA dependencies

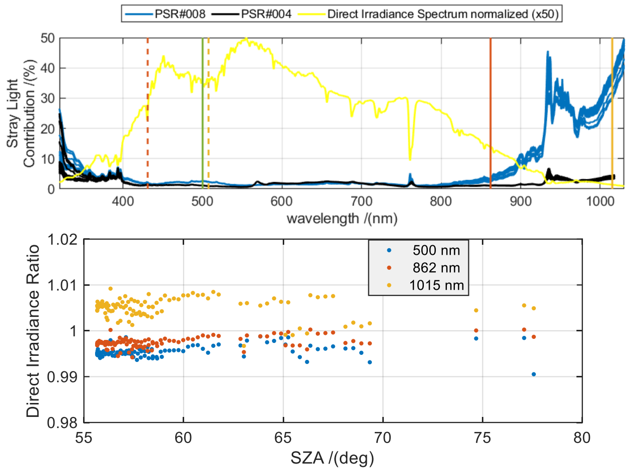

Figure 4. Upper panel: stray light contribution in the direct solar irradiance spectra measured by PSR#004 (black) and PSR#009 (blue). Lower panel: direct solar irradiance ratio PSR #009/#004 at selected wavelengths.

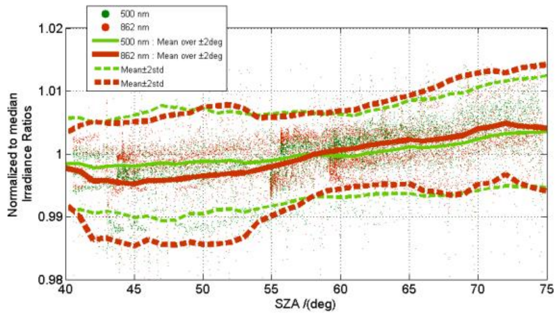

Figure 5. Direct irradiance ratio of PFR-N24 and PSR#009 at 500 nm and at 862nm (dots: data points; solid and dashed lines: mean and ±2σ of the data points over ± 3° of the SZA, respectively).

(within 1%). As they are similar for both wavelengths, it is an indication that spectral leakages have been compensated within the estimated uncertainty of ±1% (k=2).

CONCLUSION

The mathematical suppression of the stray light due to higher grating orders can be realized with an uncertainty of less than 1%. Thus, the approach based on the numerical stray-light correction produces results equivalent to those using an order-sorting filter.

REFERENCES

1. Gröbner, J., and N. Kouremeti, The Precision solar Spectroradiometer (PSR) for direct solar irradiance measurements, Solar Energy 185, 199-210, 2019
2. Zong et al., Simple spectral stray light correction method for array spectroradiometers, Appl. Opt. 45, 1111-1119, 2006.
3. Sildoja, Meelis-Mait et al, LED-based UV source for monitoring spectroradiometer properties, Metrologia 55 S97,2018.