The 11^{th} International Pyrheliometer Comparison and a Saharan Dust Event

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Abstract. The 11^{th} International Pyrheliometer Comparison (IPC-XI) were held at PMOD/WRC in September/October 2010. The large and growing attention which the IPC's receive testifies the increasing importance of accurate radiation measurements not only for the climate community but also for the solar energy industry. We will give an overview of IPC-XI with special emphasis on the effects of a Saharan Dust Event (SDE) which occurred in the course of the measurements. On the example of the SDE we demonstrate the importance of circumsolar radiation (and hence viewing geometry) for direct solar irradiance measurements. We will also present a new algorithm which was used to compensate the effects of the SDE on pyrheliometers with non-standard viewing geometry. This algorithm is based on the atmospheric scattering parameters inverted from AERONET data together with the SMARTS radiative transfer code and yields some astonishing results. Finally we will briefly discuss the possibility to use more readily available AOD measurements in the correction algorithm instead of the AERONET inversions.

1. Introduction

Solar irradiance is one of the most fundamental parameters in the Earth's energy budget and a key factor in global climate models. To ensure the homogeneity of all solar irradiance measurements world wide and to maintain traceability to the World Radiometric Reference (WRR) all regional and many national radiometric standards are inter-compared during the WMO International Pyrheliometer Comparisons (IPCs) which are held every five years. In 2010 the 11^{th} edition of the IPC (IPC-XI) were organized and held by the World Radiation Centre (WRC) in Davos Dorf, Switzerland. The on-going growth in the solar energy market has boosted the demand for traceable solar irradiance measurements and lead to a record participation in IPC-XI.

The effect of circumsolar radiation on pyrheliometric measurements has been theoretically and observationally assessed in the past. During the second half of the three-weeks IPC-XI a Saharan Dust Event (SDE) offered the opportunity to validate the model results with real observations by a large number of pyrheliometers. The SDE-induced excess in large particles ($> 1\mu\mathrm{m}$ diameter) altered the scattering phase function and hence the circumsolar radiation. Depending on their viewing geometries, all pyrheliometers are not equally sensitive to such changes in the celestial brightness around the solar disk.

2. Participation and Measurements

Apart from the 17 regional and 22 national radiation centres the IPC-XI also attracted 14 manufacturers and other institutions, mostly from the solar energy community. In total 95 pyrheliometers from 42 countries took part in the IPC-XI.

The World Radiometric Reference (WRR) was represented by the six pyrheliometers which form the World Standard Group (WSG)†. Alongside the WSG the new Cryogenic Solar Absolute Radiometer (CSAR) took first-light solar irradiance measurements. The CSAR is based on state-of-the-art technology and prospectively will replace the WSG in the future.

† Due to doubts regarding their stability over the past inter-IPC period (2005-2010), two WSG instruments (HF18748 and PAC3) were excluded from the transfer group.

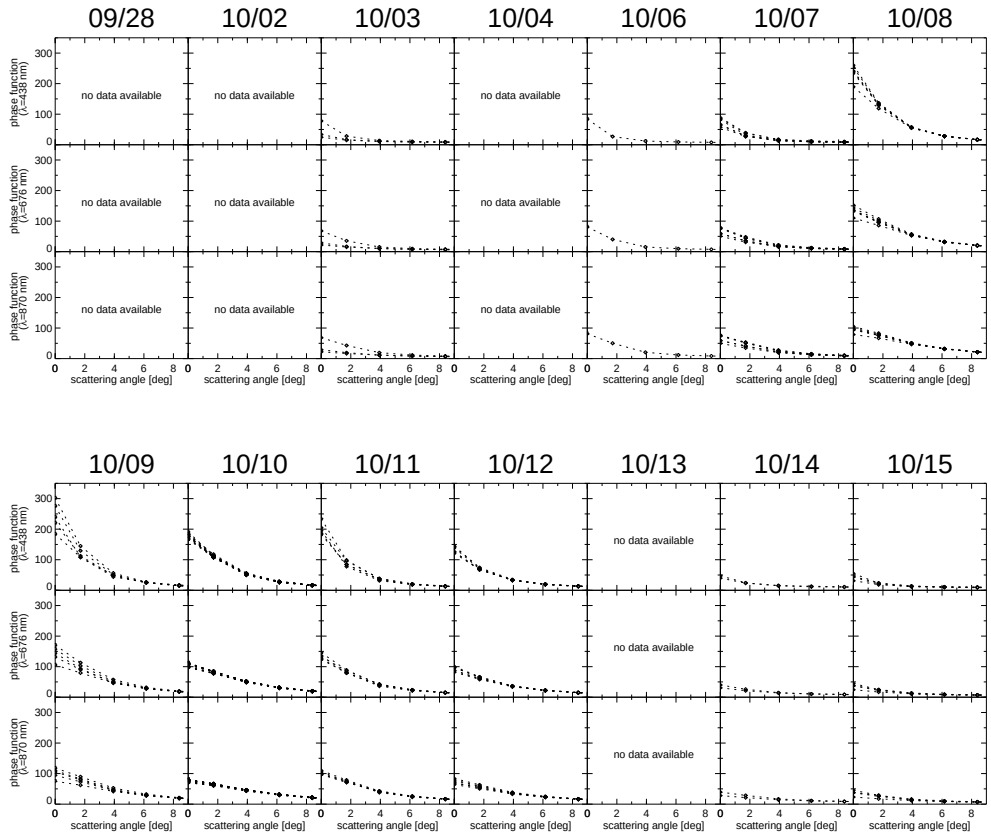

Figure 1. Scattering phase functions derived from AERONET inversions.

2.1. *Weather Conditions*

During the first week of the IPC-XI the weather conditions did not allow to take measurements. Instead, a course on radiation measurements was held as well as seminar presentation given by many of the participants. After the cloudy and overcast first week the sky cleared up to allow measurements on most days until the end of the three-weeks period of the comparison (September 27 through October 15, 2010). Aerosol Optical Depth (AOD 500 nm) was below 0.1 on five entire days. On October 8 high-altitude southerly winds blew in a dust plume from the Sahara desert (Saharan Dust Event, SDE). The dust plume gradually dissolved afterwards and the atmosphere recovered to its original condition by October 14.

2.2. *Data Selection*

An ad-hoc group of experts was formed to supervise the IPC-XI. The ad-hoc group agreed on a set of data selection criteria which are listed in Finsterle 2011. Data from nine days were considered for the final evaluation.

3. Effect of the Saharan Dust Event on Pyrheliometric Measurements and Instrument Comparisons

According to the WMO definitions (CIMO Guide, WMO-No. 8) direct solar radiation comprises the radiation from the sun and a narrow annulus of sky around the solar disk, the circumsolar or aureole radiation. The CIMO Guide recommends the use of a view-limiting geometry with opening half-angle of 2.5° and slope angle of 1°. We refer to the CIMO recommendations as *standard* viewing geometry.

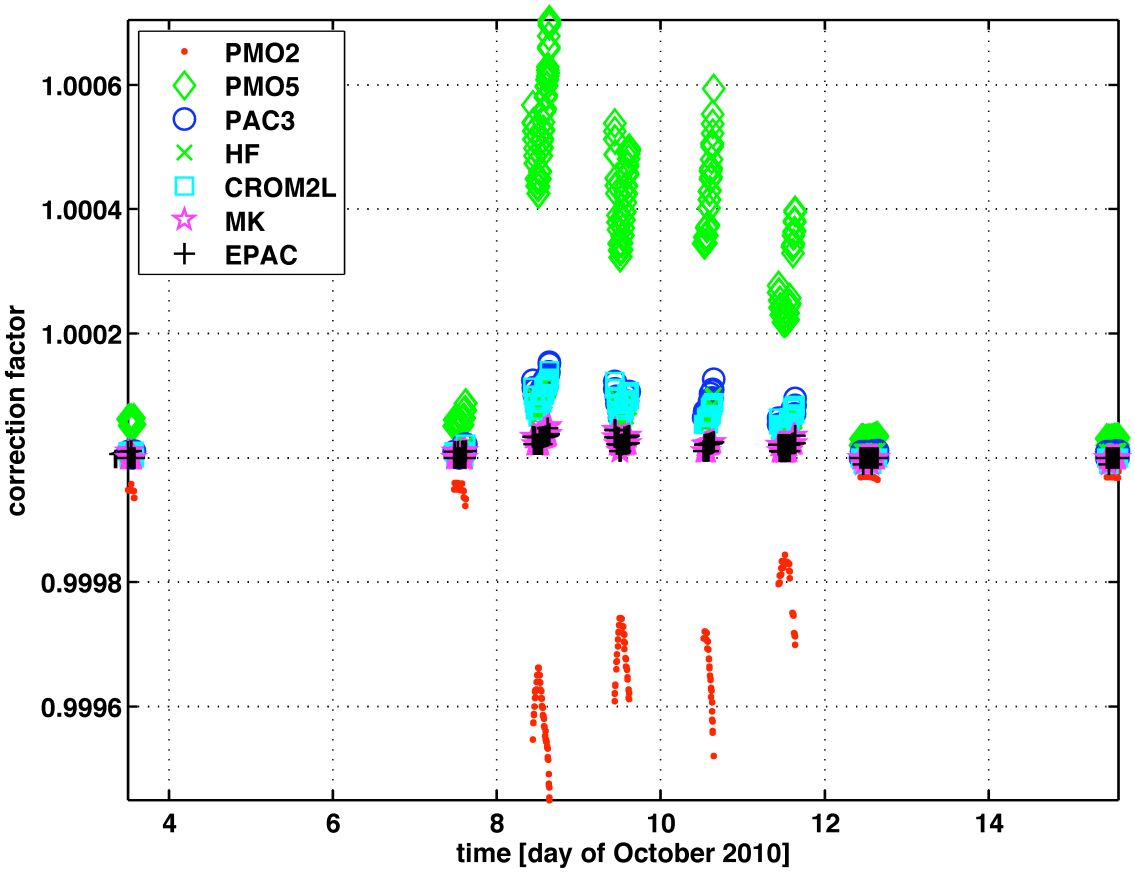

Figure 2. The correction factors during the October 2010 SDE for the WSG instruments due to their different view-limiting geometries.

Most modern pyrheliometers implement the standard viewing geometry. However, some of the older and/or prototype instruments' viewing geometries deviate from the standard, most notably the WSG instruments PMO2, PMO5, and CROM2L (Tab.1).

If only pyrheliometers with equivalent viewing geometry were to be compared no circumsolar correction was needed because all instruments would be equally affected by the circumsolar radiation and changes thereof. On the other hand does circumsolar radiation bias the ratio between the readings of pyrheliometers with different viewing geometries. Moreover, changes in the circumsolar "profile" (i.e. scattering phase function) can yield to spurious changes and diurnal trends in their ratios if different instruments "see" a different area of the sky.

Based on the aerosol inversion products from the AERONET (http://aeronet.gsfc. nasa.gov/) Davos station and the Simple Model of the Atmospheric Radiative Transfer of Sunshine (SMARTS, Gueymard 2001) we assess the circumsolar contribution to pyrheliometric measurements with different viewing geometries. The AERONET inversions suggest a more than doubling of the forward scattering between October 7 and 8, 2010 (Fig. 1), resulting in spurious readings, particularly by PMO2 and PMO5 (Fig. 2). Although the correction appears to be quite small ($< 0.1\%$) its application significantly smoothed out the final results. In fact, the SDE was only detected because of the spurious jumps in the instrument ratios.

Based on the experience during IPC-XI, the WRC decided to implement the aureole correction with the WSG standard operating procedures. It is expected to reduce systematic scatter in pyrheliometer calibrations during SDEs, which occur a few times per year. The aureole correction is currently based on AERONET inversions, a simplified algorithm based directly on AOD measurements is being evaluated.

Table 1. The view-limiting geometries for the WSG instruments (all linear dimensions in mm, angles in degrees).

Instrument	front aperture radius	rear aperture radius	distance between apertures	opening half-angle	slope angle
PMO2	3.6	2.5	75.0	2.75	0.84
PMO5	3.7	2.5	95.4	2.22	0.72
PAC3	8.18	5.64	190.5	2.46	0.76
CROM2L	6.29	5.0	144.05	2.50	0.51
HF18748	5.81	3.99	134.7	2.47	0.77
MK67814	8.2	5.56	187.6	2.50	0.78

4. IPC-XI Results

4.1. *Stability of the WRR*

Two WSG instruments (HF18748 and PAC3) appeared to have drifted or experienced jumps with respect to the group average over the past inter-IPC period (2005-2010). These two instruments were excluded from the transfer of the WRR but received new WRR factors based on the remaining four WSG instruments, which appeared stable over the past five years (changes smaller than 250 ppm). This scenario was validated by comparing the new WRR to those pyrheliometers which had participated in IPC-X and IPC-XI. The WRR was thus considered stable of the past five years. The detailed results of the stability analysis are presented in Finsterle 2011.

4.2. *Participating Instruments*

Apart from assigning new WRR factors, the IPC also serves the purpose to confirm the proper functionality of the participating instruments. While most instruments performed flawlessly, a number of subtle problems were found and corrected which could not have been detected even by a vigilant operator without access to high-accuracy comparison results like the ones provided during an IPC. The resolved issues included shaky control switches and faulty resistors, which lead to small systematic deviations from the reference. It is thanks to the careful analysis of the daily performance by the operator that all instrumental issues could be resolved in due time and a new WRR factor could eventually be calculated for *all* participating instruments.

4.3. *The Cryogenic Solar Absolute Radiometer (CSAR)*

The Cryogenic Solar Absolute Radiometer (CSAR) saw first light shortly before the IPC-XI and all components were not yet fully operational during the IPC-XI. Particularly the Monitor for Integrated Transmittance of the entrance window (MITRA) still suffered from high noise levels of unknown origin. Together with problems with the temperature stabilization on the cryogenic stage this resulted in only one day of valid CSAR measurements (October 7). On that day, the CSAR readings were a few tenth of a percent *below* WRR. This would be in line with the latest WRR-to-SI difference published by Fehlmann et al. 2012.

5. Discussion and Conclusion

The 11^{th} International Pyrheliometer Comparison IPC-XI were successfully held at PMOD/WRC, Davos Dorf, Switzerland from September 27 through October 15, 2010. The popularity of the IPC continued to increase due to the growing demand and participation from the solar energy sector. Good weather conditions allowed for a robust data base and an accurate determination of the new WRR factors for all participating instruments. Some participating instruments suffered from subtle instrumental problems which could be resolved in time.

A Saharan Dust Event (SDE) induced an enhancement of the circumsolar (aureole) radiation during about half of the measurement days, resulting in spurious sensitivity changes of order 0.01% in pyrheliometers with non-standard viewing geometry. A correction algorithm was developed and applied to standardize the aureole component in the affected instruments, after which the spurious sensitivity changes vanished. After the IPC-XI the correction algorithm was implemented in the standard evaluation procedures of the WSG readings.

The WRR was stable over the past inter-IPC period (2005-2010) although two of the WSG instruments suffered from drifts or jumps of up to 0.1% and were excluded from transferring the WRR. The new Cryogenic Solar Absolute Radiometer (CSAR) was designed an built with state-of-the-art technology to provide a future alternative to the aging WSG instruments. First results from the CSAR confirm the latest WRR-to-SI differences (Fehlmann et al. 2012).

References

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