RESULTS OF THE TENTH INTERNATIONAL PYRHELIOMETER COMPARISONS (IPC-X)

W. Finsterle
PMOD/WRC, Dorfstr. 33, 7260 Davos Dorf, Switzerland
Tel. +41(0)81 417 51 53, Fax. +41(0)81 417 51 00, wolfgang@pmodwrc.ch

ABSTRACT

The organization and hosting of the WMO International Pyrheliometer Comparisons (IPCs) is a long-standing tradition at the Physikalisch-Meteorologisches Observatorium Davos (PMOD). The first IPC was held in 1959, long before the WMO designated PMOD to act as the World Radiation Centre (WRC) in 1971. The concept of periodical IPCs is now laid down in the WMO *Guide to Meteorological Instruments and Methods of Observation*, WMO-No. 8, (CIMO Guide) as the key process to ensure the world-wide homogeneity of solar irradiance measurements as well as to monitor and maintain the stability of the World Radiometric Reference (WRR).

The tenth holding of the IPC in autumn 2005 was favored by extraordinarily good weather conditions. An exceptionally large number of clear sky days allowed to collect an unprecedented amount of solar irradiance data. Because of the large data volume, statistics allowed to lower the uncertainty of the comparisons and statistically significant discrepancies have been found in the long-term behavior of different types of instruments and the WRR. While the WRR clearly meets the stability criteria required by the CIMO Guide, the discrepancies are larger than what was observed in the past. The search for the source of the discrepancies is an ongoing process. The fact that possible trends are detected and are investigated shows that the concept of the IPC to ensure the stability of the WRR is functioning.

INTRODUCTION

Under the auspices of the Commission for Instruments and Methods of Observation (CIMO), the Tenth International Pyrheliometer Comparison (IPC-X) was held together with the Regional Pyrheliometer Comparisons of all WMO Regions from 26 September through 14 October 2005 at the Physikalisch-Meteorologisches Observatorium Davos/World Radiation Centre (PMOD/WRC) in Davos, Switzerland. This combination of IPC and RPC's slightly extended the practice already introduced at previous IPCs and was considered highly effective in coping best with the urgent needs for carrying out RPCs of most Regions and most efficiently using the limited financial resources available in WMO for supporting these events. This led to the largest number of experts' and instruments' participation compared with all previous IPCs.

The results presented in this report are based on the measurements carried out during the three weeks assigned to the IPC-X. The favorable weather conditions allowed to acquire a record number of calibration points for most participating instruments and to analyze the results statistically.

PARTICIPATION

Seventy-three participants from 16 Regional and 23 National Radiation Centers as well as the World Radiation Data Center and eleven institutions and manufacturers took part in the comparison. They operated a total number of 89 pyrheliometers. The six World Standard Group (WSG) instruments were operated by the WRC staff. Two representatives of WMO were attending the IPC-X during the first few days.

MEASUREMENTS AND PROCEDURES

Measurements of the direct solar irradiance were taken in series of 21 minutes with a basic cadence of 90 seconds. Voice announcements and a buzzer signal were used to inform the participants about the sequence of operations. Instrument-specific timing tables were distributed to account for the different calibration and measurement cycles of the various types of pyrheliometers (Ångström-, HF-, and PMO-type). A cloud detector on the WSG tracking platform was used to eliminate data points where clouds were within the field of view.

Thanks to the favorable weather conditions 113 data series' could be acquired on eleven days during the IPC-X. The World Radiometric Reference (WRR) is defined as a weighted average of the measurements by the currently six pyrheliometers that form the WSG (CROM2L, HF18748, MK67814, PAC3, PMO2, and PMO5). The individual weights (WRR factors) are calculated such that the original WRR defined in 1977 is maintained constant independent of the WSG instruments selected to realize the WRR. The WRR factors are re-calculated every five years from the IPC data and are to be used during the following inter-IPC period. The following formula is used to calculate the WRR factor $WRR_{i,IPC-X}$ for each WSG instrument *i*

$$WRR_{i,IPC-X} = \left\langle \frac{\left\langle WSG_i(t) * WRR_{i,IPC-IX} \right\rangle_i}{WSG_i(t)} \right\rangle_t$$

where $WSG_i(t)$ is the irradiance measured by the WSG instrument *i* at the time *t* and $\langle \rangle_t$ indicates temporal averaging. If the WRR factor changes over time then the affected WSG instrument might have a technical problem that needs to be examined and can lead to the exclusion of the affected instrument from the WSG.

STABILITY OF THE WORLD STANDARD GROUP OF PYRHELIOMETERS

WSG Instrument	*WRR factor*	*standard uncertainty [ppm]*	*number of data points*	*relative change since IPC-IX (2000) [ppm]*
CROM2L	1.002998	36	500	-12
HF18748	0.996274	14	938	599
MK67814	1.000708	11	945	48
PAC3	1.001116	12	641	466
PMO2	0.998618	11	1026	-930
PMO5	0.998982	24	520	8

Table 1: The WRR factors and statistics for the WSG instruments. The standard uncertainties and relative changes are given in parts per million (ppm). The number of data points reflects the sampling interval of the respective instrument.

The six WSG instruments were consistent in the sense that their WRR factors were constant throughout the comparison and have changed less than 0.1% since the IPC-IX (held in 2000). Table 1 summarizes the results for the WSG instruments. All WSG instruments meet the long-term stability criterion required by the CIMO Guide [1] (±0.2%). Three WSG instrument drifted less than ±50 parts per million (ppm) while the absolute drifts of the remaining three instruments range from 466 ppm to 930 ppm over the past five years. One might be tempted to exclude the latter three instruments from the WSG because of their significantly larger drifts but for various reasons which will be explained in the following it was decided to keep all six instruments in the group. Note that the WRR is not significantly affected by this decision.

RESULTS FOR THE PARTICIPATING INSTRUMENTS

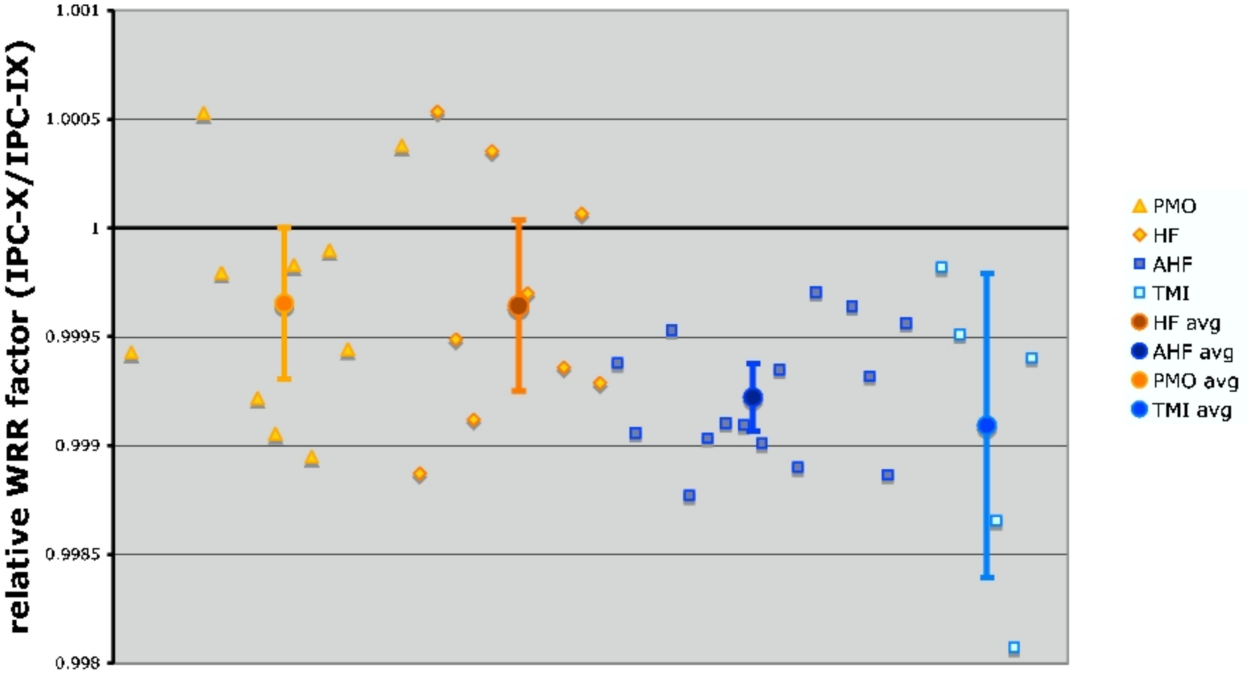

Figure 1: The relative changes of the WRR factors for all instruments that had participated in the IPC's of the years 2000 and 2005.

With the new reference irradiance $WRR(t) = \langle WSG_i(t) * WRR_{i,IPC-X} \rangle_i$ the WRR factor $WRR_{j,IPC-X}$ for each participating instrument j was calculated according to

$$WRR_{j,IPC-X} = \left\langle \frac{WRR(t)}{Irr_j(t)} \right\rangle_t$$

where $Irr_j(t)$ is the irradiance measured by instrument *j* at the time *t*. All instruments which had participated in previous IPC's and the WSG were then used in a statistical analysis of their long-term stability. Compared to the last IPC the WRR factors of the participating instruments is now *lower* by a few hundred ppm on average. Nevertheless, we do not conclude that the WSG has drifted over the past five years for the following reasons:

1. Three out of the six WSG instruments showed virtually no drifts with respect to each other and the WRR. Hence, they were either stable or experienced *parallel* drifts, the latter of which is highly unlikely, considered the three instruments CROM2L, MK67814, and PMO5 originate from different manufacturers and incorporate different principles of operation.
2. In 2000 the weather conditions during IPC-IX only allowed a small number of measurements to be taken and for the proper evaluation of the WSG data from as late as December 2000 (i.e. two month after the IPC-IX took place) had to be used, making the results of IPC-IX statistically less reliable than those of IPC-X.
3. The change is small.

In Figure 1 we see that the AHF- (and possibly TMI-) type instruments appear to have drifted more over the past five years than the PMO- and HF-type instruments. Unfortunately we cannot explain such a behavior yet. A careful analysis of the results from the U.S. National Pyrheliometer Comparisons (NPC) held September 26 through October 6, 2006 at the National Renewable Energy Laboratories (NREL) in Golden, Colorado with participation of the WSG (PMO5) is currently under way and hopefully will help to better understand these results from IPC-X.

CONCLUSION

Although the WRR appears to have slightly drifted with respect to the average of the regional and national standard pyrheliometers we do not conclude that any of the six WSG instruments should be considered less trustworthy than the others or should even be removed from the group. This is particularly true for PMO2 which experienced the largest apparent drift over the past five years (-930 ppm). Interestingly, PMO2 is the one WSG instrument that matches best the apparent drifts of the participating instruments, its exclusion from the WSG would therefore worsen the apparent drifts. Thorough thermal and electrical tests conducted on PMO2 after the IPC-X confirmed that all characteristic parameters of this instrument were stable.

Excluding PAC3 and HF18748 (the other two instruments that appeared to drift over the past five years) from the WSG would slightly reduce the apparent drifts of the participating instruments but would induce a parallel drift on the otherwise stable WSG instruments (CROM2L, MK67814, PMO5), an unsatisfying situation as explained above.

Although the concept of using a conventional reference for direct solar irradiance (the WRR) realized by a set of standard pyrheliometers (the WSG) has proven successful ever since it was first introduced in 1977, the problems with apparent drifts and seemingly different behavior of different types of pyrheliometers raises questions whether one should work towards replacing the current WRR/WSG with a new and reproducible system of reference based on a different technology.

REFERENCES

[1] CIMO Guide WMO No. 8

[2] IPC-X Final Report, WMO/TD No. 1320 (2006)