NOTE

The designations employed and the presentation of material in this publication do not imply the expression of any opinion whatsoever on the part of the Secretariat of the World Meteorological Organization concerning the legal status of any country, territory, city or area, or its authorities, or concerning the limitation of the frontiers or boundaries.

This report has been produced without editorial revision by the Secretariat. It is not an official WMO publication and its distribution in this form does not imply endorsement by the Organization of the ideas expressed.
FOREWORD

The organization and hosting of the WMO International Pyrheliometer Comparisons (IPC) 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.

Prof. Dr. W. Schmutz
Dr. R. P. Canterford

Director of the PMOD/WRC
Acting President of the Commission for Instruments and Methods of Observations
WMO International Pyrheliometer Comparison
IPC-X
26 September - 14 October 2005
Davos, Switzerland

Final Report

Wolfgang Finsterle
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Chapter 1  Organization and Procedures

1.1 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.

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. Cloudy and overcast days were used for technical preparations and training of participants as well as for the IPC-X symposium.

1.2 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 couple of days.
Table 1.1: IPC-X Participation: *World, Regional and National Radiation Centers*

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Table 1.2: IPC-IX Participation: Various Institutions and Manufacturers

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1.3 Data Acquisition and Evaluation

The signals from the WSG instruments and additional radiometers of the WRC as well as auxiliary parameters were acquired by an analog data acquisition system based on eight HP3478A voltmeters with relay scanners that are controlled by a data acquisition computer.

The participating instruments were operated with their standard equipment, either manual or
automated, in order to avoid interface problems and mutual interferences. The data from the manually operated instruments were transmitted to the data acquisition computer via a number of microterminals operated by the participants. Each terminal could accept up to 3 different parameters from two instruments. After each series, a print-out of the values entered by micro-terminal was distributed to be checked by the participants. If necessary, the raw data could be edited manually to correct typing errors.

The participants having their own computer controlled systems (synchronized to the timing of the IPC's measurement series) had the possibility to up-load their data to a dedicated directory on the IPC-X FTP site. LAN/WLAN, floppy disks, or USB memory sticks were accepted means of data transfer. All data on the FTP site were ingested into the data acquisition and evaluation system at the end of each day.

1.3.1 Timing of the Measurements

The measurements were taken in series of 21 minutes with a basic cadence of 90 seconds. Voice announcements and buzzer signals were used to inform the participants about the sequence of operations. All automated data acquisition systems were synchronized to Central European Time (CET). A network time server and a large reference clock on the measuring field were set up for this purpose. The timing for the different types of instrument was as follows:

- Ångström pyrheliometers: Before the start and after the end of the run the zero of the instrument was established. Alternating right and left strip readings were performed, starting with the right hand strip exposed to the sun. The following readings were paired as L-R, R-L, etc., yielding a total of 12 irradiance values per run.

- PACRAD: the run started with the shutter closed, after 60 s the heater was turned on for 40 s (this was introduced after IPC-III in order to have a well defined thermal state of the instrument independent of the operation sequence before the run). At 270 s the zero of the thermopile was read and the heater switched on again. At 450 s the heater voltage, current and thermopile was read, the heater turned off and the shutter opened. From 540 s on readings were taken every 90 s yielding 8 irradiance values per run. After the last reading the shutter was closed.

- HF type pyrheliometers: the run started with the shutter closed, after 90 s the zero was read and the heater turned on until at 180 s the voltage, current and thermopile were read. The heater was then turned off and the shutter opened. From 270 s onward the instrument was read every 90 s yielding 11 irradiance values per run. Some instruments which were providing their data with diskettes performed the calibration between the series and consequently measured 13 irradiance values per run.

- TMI type pyrheliometers: the run started with the shutter closed and the calibration procedure was performed until the end of the first 90 s. Starting at 180 s readings were taken every 90 s yielding 12 irradiance values per run.

- Active cavity type pyrheliometers: the run started with a reference phase (shutter closed) of 90 s, followed by a measurement phase (shutter open) of 90 s. This was repeated for the next 18 minutes. A total of 6 open and 7 closed readings were taken yielding a total of 6 irradiance values during a run. PMO2 was read at twice that pace, with a reference phase of 32 s and a measurement phase of 58 s, producing 13 irradiance values per run so that for all readings of the basic sequence a PMO2 irradiance was available.

- Normal Incidence Pyrheliometers (NIP): it took 12 irradiance values every 90 s after an initial zero reading at 90 seconds.
1.3.2 Data Evaluation

For each instrument the irradiance was obtained with the appropriate evaluation procedure as listed below. After each day a summary of the computed irradiances was printed and distributed to be checked by the participants. As an indication the mean and standard deviation of the ratios to PMO2 were also given for each series. In all further steps of the data evaluation procedures none of the WSG instruments played a specific role.

The procedure used to calculate the irradiance $S$ of each instrument type is described below. The notations are:

- $V_{th}$ output of the thermopile
- $U_h, U_i$ voltage across the heater (h) or across the standard resistor (i)
- $R_n$ standard resistor
- $C$ calibration factor
- $C_2$ correction factor for lead heating
- $P$ electrical power in the active cavities

- Ångström-pyrheliometers: the current through the right or left strip was measured as voltage drop across a standard resistor and the irradiance was obtained as:

$$S = C \frac{U_i(left)U_i(right)}{R_n^2}$$

This corresponds to the geometric mean of the irradiances at the time of right and left readings. Thus, the ratio to WRR was calculated using the geometric mean of the WSG irradiances at the corresponding instances.

- PACRAD and HF type pyrheliometers: the irradiance was calculated from the thermopile output $V_{th}$(irrad) when the receiver was irradiated. The sensitivity was determined by the calibration during which the cavity was shaded and electrically heated and $U_h$ and $U_i$ were measured together with the corresponding thermopile output $V_{th}$(cal). Furthermore, the zero of the thermopile $V_{th}$(zero) was measured and subtracted.

$$S = C \frac{V_{th}(irrad) - V_{th}(zero)}{V_{th}(cal) - V_{th}(zero)} \frac{U_i}{R_n} \left( \frac{U_h}{R_h} - \frac{U_i}{R_n} \frac{C_2}{} \right)$$

- TMI type pyrheliometers: most were operated in the “normal” way, that is by calibrating the readout directly in units of mW cm$^{-2}$. The values were entered in W m$^{-2}$ and no irradiance calculation was needed. Others were operated and evaluated like HF pyrheliometers.

- Active cavity pyrheliometers: the irradiance was obtained from $P$(closed) averaged from the closed values before and after the open reading $P$(open).

$$S = C(P$(closed) - P$(open))$$

The power calculation was done according to the prescription of the instrument type with

$$P = U_h^2 \quad \text{or} \quad P = U_h U_i \quad \text{or} \quad P = \frac{U_i}{R_n}$$

- Normal Incidence Pyrheliometer (NIP): the thermopile reading was divided by the calibration factor after subtraction of the zero point reading$^1$.

$^1$Some NIP operators assumed a vanishing zero signal. They did not perform zero readings.
• PMO2: As during preceding IPCs, PMO2 was used as the reference instrument for the daily summaries because it can be operated fast enough to provide an irradiance value every 90 seconds. The values of PMO2 were obtained with the algorithm for active cavity radiometers. At the end of the open phase, 8 readings were taken in rapid succession of about one reading per second. For the on-line calculations the first reading was used as reference for the values entered by the terminals. The standard deviation of the 8 readings was used during the final evaluation as a quality control parameter to assess the atmospheric stability during each acquisition sequence (see Sect. 2.1).

1.3.3 Auxiliary Data

The meteorological parameters (air temperature, relative humidity, atmospheric pressure) were obtained from the automated weather station ASTA of MeteoSwiss located at PMOD/WRC (see Sect. 3.2.2). The ASTA values are 10-minute averages.

A cloud sensor flagged all data points when clouds were within 15 degrees of the Sun. The flagged points were not used to evaluate Ångstrom type pyrheliometers.

Precision Filter Radiometers (PFR) were used to determine Aerosol Optical Depth (AOD) at four wavelengths (367.6 nm, 412.0 nm, 501.2 nm, and 862.4 nm, see Sect. 3.2.3).

1.4 Approval and Dissemination of the Results

According to Resolution 1 of CIMO-XI an Ad-hoc Group was established to discuss the preliminary results of the IPC-X, based upon criteria defined by the WRC, evaluate the above reference and recommend the updating of the calibration factors of the participating instruments. It was chaired by the Bruce W. Forgan, (Australia, RA V) and composed as follows: Mohamed Hussein Korany (Egypt, RA I), Kohei Honda (Japan, RA II), Pedro Mostaj Aquilera (Chile, RA III), Augustin Muhlia (Mexico, RA IV), Don Nelson (USA, RA IV), Zlotan Nagy (Hungary, RA VI), Klaus Behrens (Germany, CIMO Expert Team). The WRC was represented by Wolfgang Finsterle and Werner Schmutz.

The procedures used to compute the new WRR factors of the WSG and participating instruments are explained in Section 2.2.
Chapter 2  Measurements and Results

Measurements were taken on eleven days (2005 September 26, 28, and 30, October 4, 8, 9, 10, 11, 12, 13, and 14). October 10\textsuperscript{th} was the most productive day, yielding 18 series’ of 21 minutes duration. On all days 113 series’ were acquired. All data points that satisfy the following data selection criteria were considered in the final evaluation.

2.1  Data Selection Criteria for the Final Evaluation

At the beginning of IPC-X, the Ad-hoc Group responsible for the approval of the final evaluation procedure (c.f. Sect. 1.4) met and set the following criteria for the acceptance of IPC-X data:

1. Only observations falling within the appropriate measurement periods be accepted and that the last series for any group of instruments stop before the end of the period is reached (based on calculations associated with the instrument field of view).

2. That no measurements be used for Ångström pyrheliometers if a cloud is within 15 degrees of the sun. No measurements will be used for the absolute cavity radiometers (field-of-view = 5\degree) if a cloud is within 8 degrees of the sun.

3. That no data be used if the 500 nm AOD is greater than 0.12.

4. That an individual point be excluded from a series if the variation of the 8 fast PMO2 measurements is greater than 0.5 Wm\textsuperscript{-2}.

5. That the minimum number of acceptable data points be 150 for the PMO2 taken over a minimum of three days during the comparison period.

2.2  Computation of the New WRR Factors

2.2.1  WSG Instruments

The WRR factor \( WRR_{i,IPC} \) for the WSG instrument \( i, i \in \{ PMO2, CROM2L, MK67814, HF18748, PAC3, PMO5 \} \), by definition is the ratio of the WRR to the WSG instrument \( i \) averaged over the duration of the IPC:

\[
WRR_{i,IPC-X} = \left\langle \frac{WRR(t)}{WSG_i(t)} \right\rangle_t
\]

where \( WRR(t) \) and \( WSG_i(t) \) are the reference irradiance and the irradiance measured by WSG instrument \( i \) at the time \( t \), and \( \langle x(t) \rangle_t \) denotes the temporal average of \( x(t) \). The reference irradiance \( (WRR) \) is defined as the mean value of the simultaneous readings of at least three WSG instruments, multiplied by their corresponding WRR factors from the previous IPC:

\[
WRR(t) = \left\langle WSG_i(t) \ast WRR_{i,IPC-IX} \right\rangle_t.
\]

We thus get

\[
WRR_{i,IPC-X} = \left\langle \frac{(WSG_i(t) \ast WRR_{i,IPC-IX})_t}{WSG_i(t)} \right\rangle_t.
\]

The new WRR factors for WSG instruments are given in Table 2.1.
2.2.2 Participating Instruments

For each participating instrument $j$ the new WRR factor is calculated according to

$$ WRR_{j,IPC-X} = \left( \frac{WRR(t)}{IRR_j(t)} \right)_t, $$

where $IRR_j(t)$ is the irradiance measured by the instrument $j$ at the time $t$ and $WRR(t)$ the constant reference irradiance.

Temporal averaging is done by fitting a gaussian to the distribution of WRR-to-instrument ratios. Outliers are successively removed until the ratios are normally distributed with a probability higher than 90\%, or until all ratios are within a certain range of their arithmetic mean value\(^1\). The new WRR factors for all participating instruments are listed in Table 2.2.

2.3 Status of the WSG

The main objective of the periodic IPC's is the dissemination of the World Radiometric Reference (WRR) in order to ensure worldwide homogeneity of meteorological radiation measurements. The WRR is realized by the WSG which is frequently inter-compared at PMOD/WRC to detect possible deviations of individual members of the group and to ensure the stability of the WRR. Independently, the stability of the WRR can be checked by instruments that have participated in previous IPC's.

Since IPC-IX, which was held in 2000, three member instruments of the WSG suffered from drifts of their WRR factors of -186 ppm/yr (PMO2), +120 ppm/yr (HF18748), and +93 ppm/yr (PAC3), respectively. The WRR factors of the remaining three WSG instruments (PM05, CROM2L, MK67814) changed by less than 10 ppm/yr. These instruments are considered as stable over the past five years. The drift in PMO2 was first suspected to be caused by degradation of the signal amplifiers\(^2\). The instrument therefore underwent thorough testing, including the re-determination of the amplification factors and the standard resistor, but all parameters were consistent with the original characterization of the instrument. Because the lack of any plausible technical reason for the observed drift the measurements by PMO2 are still considered as trustworthy as any other WSG instrument.

In the case of HF18748 the manufacturer suggested to check and clean all cable connections. To avoid changing more than one WSG instrument at a time these tests were postponed until after PMO2 was fully operational again. At the time of writing no results were available.

The apparent drift in PAC3 can be attributed to its well known sensitivity to ambient temperature. Because of the poor weather conditions in 2000 additional data had been acquired after the IPC-IX and was used to determine the WRR factors. Some of these data were acquired as late as December 2000, when temperatures were considerably lower than during the IPC-IX. Therefore the old WRR factor for PAC3 was not representative for the conditions during September/October.

At this point it should be mentioned that the WMO-CIMO guide requires the WSG instruments to perform better than 0.2\% in terms of long-term stability. For this and the above mentioned reasons it seems reasonable to keep all six members in the WSG and to use all of them to transfer the WRR.

---

\(^1\)This threshold range usually is ±0.002 for cavity pyrheliometers. However, for most Angströms, NIIP's and some cavities a different range had to be chosen manually in order to make the most plausible selection of data points.

\(^2\)An almost identical drift occurred in PM05 five years ago and could be corrected by removing the signal amplifiers.
2.4 Transfer of the WRR

Since the instrumental drifts described in Sect. 2.3 nearly compensate each other all six WSG member instruments (i.e. PMO2, PMO5, CROM2L, PAC3, MK67814, HF18748) were included in the transfer of the WRR. This can also be justified by the fact that the WRR factors of the three stable instruments (PMO5, CROM2L, and MK67814) are unchanged by including or rejecting the remaining three instruments PMO2, HF18748, and PAC3.

Table 2.1: New WRR-factors for the WSG instruments computed using PMO2, PMO5, CROM2L, PAC3, HF18748 and MK67814 and the IPC-IX WRR-factors.

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Table 2.2: The new WRR factors for the participating instruments

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$^3$This instrument was operated in "NIP mode", i.e. without heating of the shaded strip. Instead the voltage across the thermo-couple was directly evaluated using the same procedure as for NIP. We recommend to not use this instrument as a reference instrument.
Table 2.2: (continued)

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<th>Instrument</th>
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<th>$C_2$</th>
<th>$C_3$</th>
<th>WRR Factor</th>
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2.5 Stability of the WSG

In Section 2.3 the stability of the WSG was checked by analyzing the trends of individual members of the WSG with respect to the group’s average. The stability of the WSG can also be checked with respect to the WRR factors of those participating instruments that have also participated in IPC-IX (58 instruments, not counting the WSG). This analysis yields a conflicting results which we will discuss here in detail.

For the stability analysis only instruments whose WRR factors had changed by less than 0.2% over the past five years were considered. Also all instruments that showed unexplained or inconsistent behaviour during either IPC-IX or IPC-X were excluded. On average the WRR factors of the remaining 46 instruments changed by $\pm 471$ ppm with a standard uncertainty of 206 ppm (95% confidence). In other words the probability that WSG was stable over the past five years is less than 5%. However, we found substantial differences between the different types of pyrhiometers, indicating that the observed changes of WRR factors might not be of purely stochastical nature but depend on the type of instrument. The WRR factors of HF and PMO type instruments consistently changed by $-346 \pm 347$ ppm and $-356 \pm 393$ ppm, respectively. On the 95% confidence level these changes are just consistent with the assumption of the WSG being stable, while the WRR factors of AHF’s changed by $-778 \pm 156$ ppm and therefore are inconsistent with the stability assumption. Chances
are low that the differences between HF’s and PMO’s on one side and AHF’s on the other side occur randomly. The groups of TMI, CROM, MAR, and SIAR type pyrheliometers are too small to draw any meaningful statistical conclusion from these types of instrument (cf. Fig. 2.1).

No Ångström type pyrheliometer were included in the WSG stability analysis because only two of them changed by less than 0.2% since the previous IPC. The WRR factors for all Ångström pyrheliometers increased since IPC-IX, which can easily be explained by the different weather conditions prevailing during IPC-X and IPC-IX. In 2000 many data points were affected by clouds in the Ångström’s field-of-view, resulting in an over-estimation of the solar irradiance due to scattered light. In 2005, there were much more clear sky periods than in 2000. Moreover, a cloud detector was used in 2005 to eliminated all data points where clouds were closer than 15 degrees of the Sun.

2.6 Conclusions and Recommendations

Despite the above mentioned difficulties with some instruments or groups of instruments (cf. Sect. 2.5) the WRR is considered stable within the limits required by the WMO-CIMO guide. The reported drifts in the WRR factors of most AHF’s over the past five years (Fig. 2.1) are based purely phenomenological observations at this point. There is no know reason that could cause these drifts and all tests to attribute them to any instrument-specific procedures were negative. While the average drift of the AHF’s is statistically significant it still depends on the selection criteria and also on the choice of the statistical samples, i.e. the way of pooling the instruments for the statistical analysis. We therefore cannot conclude that any of the participating types of cavities is less fit than the others to represent the WRR. The recommended WRR factors are listed in Table 2.2.

The large amount of data collected during IPC-X allowed us to find subtle differences in the behaviour of the various types of instruments. The quest for explanations of the observed differences is still an on-going process to which we invite the whole community to contribute.

\[^4\text{On average, HF’s and AHF’s differ by 427 ± 149 ppm (1-σ level). This means that there is only a 0.5\% probability (2.8-σ) that the observed differences are random.}\]
Chapter 3  Graphical Representation of the Results

3.1  WSG and Participating Instruments

The following figures show the performances of the instruments. The deviation from WRR is plotted. All the points which were used for the analysis (i.e. the points fulfilling the selection criteria listed in Sect. 2.1) have been plotted with a corresponding histogram on the side. The horizontal solid line represents the derived new WRR factor and the dashed lines its 1-$\sigma$ standard deviation. The new WRR factor and its standard deviation is printed on top of each plot with the number of points used to determine this value. The number in parentheses corresponds to the total number of points available for the analysis.

Note: Two participating Ångström type instruments exhibited serious problems. Å8412 (Morocco) was operated in an “actinometric”-type mode, i.e. with no heating power applied to the shaded strip. The reading of the thermocouple was submitted instead of the heater current. These data were analyzed using the standard procedure for NIP’s without zero reading. The uncertainty of the resulting WRR factor therefore is quite high and we do not recommend to use this instrument as a calibration standard.

Å6549 (Uganda) submitted an almost constant reading corresponding to $\sim 830 \text{Wm}^{-2}$. The same happened already during IPC-IX and was then attributed to an faulty operation of the instrument. However, since the instrument was now operated by a different person but still having the same problem it is unlikely that this was the cause. The instrument most likely is broken. Unfortunately, the daily summary data for this instrument did not look too suspicious so the problem went unnoticed. Data from this instrument could not be evaluated and no WRR factor could be calculated.

Several other instruments were affected by technical problems which could be fixed by the technical staff at PMOD/WRC.
3.1.1 WSG Instruments

CROM2L: WRR factor=1.002998, σ=0.000803, n=500

HF18748: WRR factor=0.996274, σ=0.000433, n=938

MK67814: WRR factor=1.000708, σ=0.000347, n=945
Graphical Representation of the Results

PAC3: WRR factor=1.001116, $\sigma=0.000313$, n=641

PMO2: WRR factor=0.998618, $\sigma=0.000346$, n=1026

PMO5: WRR factor=0.998982, $\sigma=0.000542$, n=520
### 3.1.2 Participating Instruments

**28335: WRR factor=1.012882, σ=0.005946, n=904**

![Graph for 28335]

**31144E6: WRR factor=0.997155, σ=0.003472, n=929**

![Graph for 31144E6]

**PMO6-79-121: WRR factor=1.000388, σ=0.000571, n=521**

![Graph for PMO6-79-121]
PMO6-79-122: WRR factor=0.999148, $\sigma=0.000459$, n=522

PMO6-80022: WRR factor=0.997948, $\sigma=0.000518$, n=520

PMO6-81109: WRR factor=0.998413, $\sigma=0.000703$, n=921
PMO6-811103: WRR factor=0.999205, $\sigma=0.000815$, n=317

PMO6-811107: WRR factor=0.999052, $\sigma=0.001515$, n=404

PMO6-850405: WRR factor=0.999194, $\sigma=0.000389$, n=367
Graphical Representation of the Results

PMO6-850405P: WRR factor=0.999033, σ=0.000435, n=382

PMO6-850406: WRR factor=0.999445, σ=0.000621, n=384

PMO6-850410: WRR factor=0.987027, σ=0.000843, n=406
PMO6-911204: WRR factor=0.999011, $\sigma=0.000887$, n=848

A12578: WRR factor=1.006552, $\sigma=0.004324$, n=612

A13439: WRR factor=1.003292, $\sigma=0.001496$, n=709
A15192: WRR factor=1.002164, $\sigma=0.001726$, n=274

A18020: WRR factor=1.004923, $\sigma=0.001832$, n=636

A18587: WRR factor=0.997654, $\sigma=0.002447$, n=693
A212: WRR factor=1.003384, σ=0.001743, n=623

A567: WRR factor=1.000247, σ=0.002902, n=649

A576: WRR factor=1.000059, σ=0.003257, n=702
AHF14915: WRR factor=0.999641, σ=0.000893, n=680

AHF17142: WRR factor=0.999146, σ=0.000778, n=813

AHF27798: WRR factor=0.999413, σ=0.001063, n=676
AHF28553: WRR factor=0.996109, \( \sigma = 0.000709 \), n=737

AHF28965: WRR factor=0.997271, \( \sigma = 0.000719 \), n=717

AHF28968: WRR factor=0.997766, \( \sigma = 0.000750 \), n=911
AHF31110: WRR factor=0.997211, \( \sigma=0.000785 \), n=722

AHF32446: WRR factor=0.998873, \( \sigma=0.000610 \), n=848

AHF32448: WRR factor=0.999874, \( \sigma=0.000859 \), n=706
AHF32454: WRR factor=0.999045, \( \sigma=0.000690, n=706 \)

AHF32455: WRR factor=0.999090, \( \sigma=0.000544, n=943 \)

AHF33396: WRR factor=0.997951, \( \sigma=0.000892, n=673 \)
AWX33393: WRR factor=0.997281, \( \sigma=0.000749 \), \( n=804 \)

CH19046E6: WRR factor=1.012451, \( \sigma=0.003316 \), \( n=770 \)

CH1930018: WRR factor=0.996200, \( \sigma=0.002328 \), \( n=797 \)
CH1940072: WRR factor=1.005958, \( \sigma = 0.001421 \), n=855

CH1980174: WRR factor=1.001401, \( \sigma = 0.001421 \), n=307

CHP1: WRR factor=1.002837, \( \sigma = 0.000676 \), n=306
CR09L: WRR factor=0.999108, σ=0.001255, n=353

EPAC 11402: WRR factor=1.000563, σ=0.000842, n=865

HF15744: WRR factor=0.998038, σ=0.000739, n=770
AHF18742: WRR factor=1.003773, $\sigma=0.002690$, n=735

HF18747: WRR factor=1.002680, $\sigma=0.000620$, n=763

HF19743: WRR factor=0.999495, $\sigma=0.001795$, n=741
HF27162: WRR factor=1.000185, σ=0.000999, n=583

HF27796: WRR factor=0.996979, σ=0.001005, n=679

HF29223: WRR factor=0.996765, σ=0.001087, n=359
AHF29225: WRR factor=0.996107, \( \sigma=0.000718 \), n=653

AHF30497: WRR factor=0.999346, \( \sigma=0.000540 \), n=788

AHF31103: WRR factor=0.999636, \( \sigma=0.000674 \), n=755
**MAR-1-1: WRR factor=0.998684, σ=0.000798, n=342**

**MAR-1-2: WRR factor=0.998704, σ=0.001256, n=289**

**PMO6-0101d: WRR factor=1.030197, σ=0.000415, n=508**
PMO6-0304d: WRR factor=1.042035, $\sigma=0.000625$, n=442

PMO6-0401d: WRR factor=1.021527, $\sigma=0.000391$, n=517

PMO6-5: WRR factor=0.999959, $\sigma=0.000477$, n=443
PMO6-cc103: WRR factor=0.999424, σ=0.000638, n=762

PMO609: WRR factor=1.003793, σ=0.000658, n=514

PMO611: WRR factor=1.003386, σ=0.000646, n=518
PMO679-123: WRR factor=1.000515, $\sigma=0.002778$, n=399

PMO811108: WRR factor=0.998123, $\sigma=0.000634$, n=782

SIAR-1: WRR factor=1.001928, $\sigma=0.000817$, n=753
SIAR-2a: WRR factor=1.000623, σ=0.000491, n=906

SIAR-2b: WRR factor=0.998620, σ=0.000507, n=979

SIAR-2c: WRR factor=1.000016, σ=0.000934, n=761
Graphical Representation of the Results

**TMI67502: WRR factor=0.999483, σ=0.000899, n=553**

**TMI67604: WRR factor=0.998793, σ=0.000715, n=806**

**TMI68016: WRR factor=1.000087, σ=0.000694, n=73**
TMI68018: WRR factor=0.997134, $\sigma=0.000669$, n=897

TMI68025: WRR factor=0.998135, $\sigma=0.001308$, n=746

TMI69137: WRR factor=1.001704, $\sigma=0.000733$, n=786
3.2 Auxiliary Data

3.2.1 Direct and Diffuse Irradiance

Figure 3.1: Direct (WRR) and diffuse irradiance measured by a shaded Kipp & Zonen CM22 pyranometer.
3.2.2 Meteorological Data

Figure 3.2: Meteorological parameters measured by the ASTA station of Me- 
teoSwiss at Davos.
3.2.3 Airmass and Aerosol Optical Depth (AOD)

Figure 3.3: A four-channel Precision Filter Radiometer (PFR) was used to determine AOD.
Chapter 4  Symposium

4.1 To Build and Share Knowledge

On cloudy, overcast, or rainy (snowy!) days when no measurements were possible the IPC-X symposium was held. Radiation experts from PMOD/WRC as well as other IPC-X participants presented their work and/or national radiation infrastructure in order to share and build knowledge. Guest speaker Prof. A. Ohmura of ETH Zurich emphasized the importance of accurately calibrated radiation measurements climatologic research.

Over the three weeks, more than 30 talks and presentations were given, most of which are available for download on the IPC-X ftp site ftp://ftp.pmmodwrc.ch/stealth/ipc-x/Symposium/.
Chapter 5  Supplementary Information

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