# Uncertainty Evaluation for Comparison Result of National Radiometric Standardsand World Radiometric Reference

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**Abstract**: Theuse of data of National Radiometric Standardtook place in the WMO International Pyrheliometer Comparisons IPC-XI to evaluate the expended uncertainty of the comparison resultbetweenNational Radiometric Standards (NRS) and the World Radiometric Reference (WRR) in Davos/World Radiometric Center. The result of expended uncertaintyis 0.17%, which meets the requirements of the World Meteorological Organization (WMO) and has reached the world advanced level.In this paper, the method can be used as a reference and basis for evaluating the uncertainty of thecomparison results of the Provincial solar radiation standard.

**Key words**: National Radiometric Standard, World Radiometric Reference, Measurementcomparison, Uncertainty

## 1 Introduction

Solar radiation is the main energy source to promote the atmospheric movement of the earth. Solar radiation observation is significant to the development of meteorological science and the study of climate change[1-3]. In order to ensure the accuracy and reliability of observation data of solar radiation in China, National MeteorologyCenter establishes National Radiometric Standards. TheStandardsconsist of two H-F type cavity radiometers (serial No19743 & 20294) and a PMO-6 type cavity radiometer (serial No. 850406)[4]. Since 2000, NationalRadiometric Standardscontinuouslyparticipated in the InternationalPyrheliometerComparisons (IPC) which is hosted by Physikalisch-MeteorologischesObservatorium Davos/World Radiometric Center (PMOD/WRC). By participating in the IPC, National Radiometric Standard was traced to the World Radiometric Reference (WRR).

In IPC, WRC comparedthe radiation data which provided by the participator withthe WRR, and gave the average value of the ratio (WRR factor) and its standard deviation, but did not evaluate the uncertainty of the WRR factor.

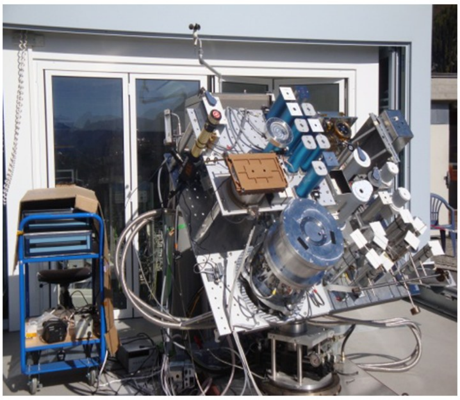
In this paper, the uncertainty of comparison factorbetweenNational Radiometric Standard with WRR will be evaluated by analyzing the data of the eleventh international pyrheliometercomparisons (IPC-XI).

## 2 Introductionto The Eleventh InternationalPyrheliometerComparisons (IPC-XI)

IPC-XI started from September 27 2010 to October 15 2010 at PMOD/WRC[5]. In this comparison 664 pairs of readings were synchronouslymeasured by PMO-6 (No850406) and WorldStandardGroup (WSG, which includes a group of absolute cavity radiometers and used to determine WRR. see Figure 1). Some pairs of readings were eliminated for some reasons such as adverse weather conditions when reading. Finally there were 323 pairs of readings which were adopted to calculate the WRR factor. The WRR factor of CRR was 1.000198 with the standard deviation 0.000876[6]. The error between CRR and WSG is showed in Figure 2.

Equipment of National Solar RadiationMeasurement Standards which participated in IPC-XI included of PMO-6 type cavity radiometer, Keithley 2000-20 Multimeterand sun tracker. The PMO-6 was set on the sun tracker and aimed at the sun. When the

a. National Radiometric Standard



b.WSG

**Fig. 1 Scene of PMO6 and WSG in IPC-XI**

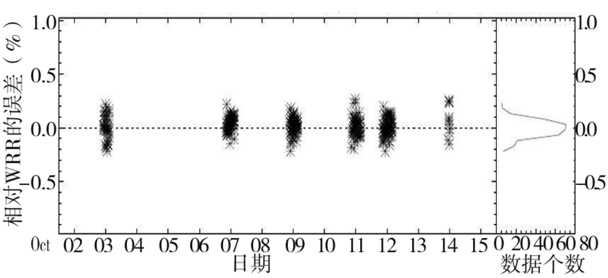



**Fig. 2 error between PMO-6 and WRR**

PMO-6 is working, the internal circuit of radiometer heats the cavity and keeps the temperature stable. When the window of the radiometer is closed, all energy of heating comes from the heating circuit, while when the window of the radiometer is opened, the solar radiation begin to heat the cavity and the temperature of cavity isincreasing. To response the trend, heating circuit decreases heating power automatically to keep the cavity temperature stable. Thus, the difference of the electric heating power between the states of closed window and opened window is just the power of solar direct radiation. The electric heating power of PMO-6 can be calculated by the heating voltage and the heating electric current. The heating voltage and current of PMO-6 are output by two (0 ~ 10) VDC voltage signals. Both of the two signals were all acquainted by Keithley 2000-20 Multimeterwhich automatically measured by computer control.

## 3 Establishment of Measurement Model

WRR factor was found by calculating the ratio of WRR measured value and National Radiometric Standard measured value in the same time and same place. In IPC-XI, the final WRR factor was an average value of repeated measurementratios, hence, the basic measurement model of the comparisonresultcan be expressed as:

$$f = \bar{f_i} = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{W_i}{S_i}\right) \quad (1)$$

Where $f$ is the WRR factor;

$f_i$ is the i-th effective ratio between WRR measurement value and National Radiometric Standard measurement value;

$W_i$ is the $i$-th effective measured value of WRR, unit: W;

$S_i$ is the $i$-th effective measured value of National Radiometric Standard, unit: W;

Infunction (1), $W_i$ is the $i$-th effective value which was measured by WGS, so the measurement error of WSG introduced an error factor $W_{re}$ into function (1).

In thefunction (1), $S_i$ was measured by PMO-6. According to the working principle of PMO-6, $S_i$ can be calculated by function (2) as follow:

$$S_i = C \cdot (P_C - P_O) = C \cdot (V_{Ui} \cdot V_{Ii} - V'_{Ui} \cdot V'_{Ii}) \quad (2)$$

Where $C$ is the calibrationcoefficient of PMO-6;

$P_C$ is the electric heating power when window of POM-6 is closed, unit: W;

$P_O$ is the solar radiation heating power when window of POM-6 is opened, unit: W;

$V_{Ui}$ is the $i$-th effective value of PMO-6 output which indicate heating voltage when the window is closed, unit: V;

$V_{Ii}$ is the $i$-th effective value of PMO-6 output which indicate heating currency when the window is closed, unit: V;

$V'_{Ui}$ is the $i$-th effective value of PMO-6 output which indicate heating voltage when the window is opened, unit: V;

$V'_{Ii}$ is the $i$-th effective value of PMO-6 output which indicate heating currency when the window is opened. unit: V;

In the function (2), the value of $C$ is and its error are given by manufacturer to introduce error factor $C_{re}$. The error factor $V_{re}$ was introduced by the measurement error of the multimeter. Moreover, the angle error of sun tracker introduced an error factor $A_{re}$ into the model. When all the factors were added into the function (2), function (3) could be given as follow:

$$S_i = A_{re} \cdot C_{re} \cdot C \cdot \begin{pmatrix} V_{re} \cdot V_{Ui} \\ \cdot V_{re} \cdot V_{Ii} - V_{re} \cdot V'_{Ui} \\ \cdot V_{re} \cdot V'_{Ii} \end{pmatrix}$$

$$= A_{re} \cdot C_{re} \cdot V_{re}^2 \cdot C \cdot (V_{Ui} \cdot V_{Ii} - V'_{Ui} \cdot V'_{Ii}) \quad (3)$$

*Function (4) can be got by taking function (3) into function (1), meanwhile introduce $W_{re}$ into the model.*

$$f = \frac{1}{n}\sum_{i=1}^{n}\left[\frac{W_{re} \cdot W_i}{A_{re} \cdot C_{re} \cdot V_{re}^2 \cdot C \cdot (V_{Ui} \cdot V_{Ii} - V'_{Ui} \cdot V'_{Ii})}\right]$$

$$= \frac{W_{re}}{A_{re} \cdot C_{re} \cdot V_{re}^2} \cdot \frac{1}{n}\sum_{i=1}^{n}\left[\frac{W_i}{C \cdot (V_{Ui} \cdot V_{Ii} - V'_{Ui} \cdot V'_{Ii})}\right]$$

$$= \frac{W_{re}}{A_{re} \cdot C_{re} \cdot V_{rp}^2} \cdot \frac{1}{n}\sum_{i=1}^{n}\left(\frac{W_i}{S_i}\right)$$

$$= W_{re} \cdot A_{re}^{-1} \cdot C_{re}^{-1} \cdot V_{re}^{-2} \cdot \bar{f_i} \quad (4)$$

Other than the above-mentioned factors, there is also an influence from atmospheric turbulence to the measure values of all the cavity radiometers in the comparison. However, for the average of 323 pairs of values, that influence is considered to be included in the repeatability of measurement. So there is no individual error factor for atmospheric turbulence.

Overall, function (4) is the measurement model of WRR factor $f$.

## 4 Influence Quantities to The Uncertainty of The Comparison Result

According to the measurement model, there are 5 influence quantities to the uncertainty of the comparison result:

① The repeatability of comparison result $f_i$, $u_{r1}$;

②The measurement error of WSG, $u_{r2}$;

③Error of the calibration coefficient for CRR PMO-6, $u_{r3}$;

④Voltage measurement error of the CRR multimeter, $u_{r4}$;

⑤Angle error of the CRR sun tracker, $u_{r5}$;

Because of the product relation among all the 5 input quantities of the measurement model, it is convenient to calculate the combined standard uncertainty by using relative uncertainty.

## 5 EvaluationofUncertainty Components

1) Relative standard uncertainty component introduced by the repeatability of comparison result

According to the comparison report from WRC (WMO IOM Report No.108), there were 323 pairs of readings which were adopted to calculate the WRR factor. The WRR factor of CRR was 1.000198 with the standard deviation 0. 000876. So $f$ = 1. 000198, $s(f_i)$ = 0.000876. The relative standard uncertainty component can be evaluated by type Aevaluation [7]:

$$u_{r1} = s(f) = \frac{1}{\sqrt{323}} \cdot s(f_i)$$

$$= \frac{1}{\sqrt{323}} \cdot 0.000876 = 0.00487\%$$

2) Relative standarduncertainty component introduced by measurement error of WSG

In IPC-XI, measurement value of WRR was given by WSG. According to the report from WRC ' four Pyrheliometersof the WSG instrumentswere stable enough to calculate the WRR' (Page 8, *PMODWRC Annual ReportJahresbericht* 2010), so the WRR value was the average of the four instruments measurement values. To each instrument, relative uncertainty of a single measurement value is 0. 058% ($k$=1.96), so this uncertainty component can be calculated as follow:

$$u_{r2} = \frac{0.058\%}{\sqrt{3} \times 1.96} = 0.01708\%$$

3) Relative standard uncertainty component introduced by error of the calibration coefficient for PMO-6

This uncertainty can be quoted from the calibration certificate of the PMO-6: $C = 23.9875$ , U = 0.0621%, ($k=1$)[8], So:

$$u_{r3} = 0.0621\%$$

4) Relative standard uncertaintycomponent introduced by error of multimeter

In the comparison, the output signals of PMO-6 were within the range about (7~9) V. according to the calibration certificate, when using this multimeter on (0~10)V range, its measurement error is less than the resolution of the meter (0.0001V) with the uncertainty 0.0005V ($k = 2$). So this uncertainty component can be transferred from the calibration results of the multimeterand change to relative uncertainty. Considering the worst case, the relative uncertainty was the maximum when the output value was minimum (about 7V), the component can be calculated as follow:

$$u_{r4} = \frac{0.0005}{2} \cdot \frac{1}{7} \cdot 100\% \approx 0.00357\%$$

5) Relative standard uncertainty component introduced by error of sun tracker

The relative angle error of sun tracker which was used in IPC-XI is less than 0.15°, during the comparison, NCMM staffmonitored the angle error continuously and kept the light-spot staying at the bull´s-eye. Hence, the relative error factor of this influence was estimated as no more than 0.1%[9]. Probability distribution function of this error is evaluated to be equidistributional, so the coverage factor is $\sqrt{3}$ , thus, this relative uncertainty can be evaluated as follow:

$$u_{r5} = \frac{0.1\%}{\sqrt{3}} = 0.05774\%$$

## 7 Combined Relative Standard Uncertainty

From the measurement model, it is known that the relations among all 5 input quantities are multiplicative; there is notanycorrelation between input variables, so the combinedrelativestandard uncertainty can be calculated by the follow function:

$$u_{crel} = \sqrt{\sum_{i=1}^{5} (p_i \cdot u_{ri})^2} \qquad (5)$$

Where $u_{crel}$ the relative is combined relative standard uncertainty,

$u_{ri}$ is the $i$-th relative standard uncertainty component,

$p_i$ is the $u_{ri}$ corresponds with the index of variables in the measurement model.

The relative standard uncertainties which were evaluated in section 5 are summarized in the Table 1.

**Table 1 relative standard uncertainty components**

| Symbol | Source of uncertainty | Value | $p_i$ |
|---|---|---|---|
| $u_{r1}$ | The repeatability of comparison result $f_i$ | 0.00487% | 1 |
| $u_{r2}$ | The measurement error of WSG | 0.01708% | 1 |
| $u_{r3}$ | Error of the calibration coefficient for PMO-6 | 0.06210% | -1 |
| $u_{r4}$ | Voltage measurement error of the multimeter | 0.00357% | -2 |
| $u_{r5}$ | Angle error of the sun tracker | 0.05774% | -1 |

The relative combined standard uncertainty can be reached by taking the data of Table 1 into the Function (5) as follow:

$$u_{cral} = \sqrt{\sum_{i=1}^{5} (p_i \cdot u_{ri})^2} = 0.08651\% \qquad (5)$$

## 6 Relative Expanded Uncertainty

Because the probability distribution function of $f$ is unknown, the coverage factor $k$ is chosen to be 2, and then the relative expanded uncertainty is:

$$U_{rel} = k \cdot u_{crel} = 2 \times 0.08651\% \approx 0.17\%$$

According to the evaluation of the uncertainty, the comparison result of CRR in IPX-XI can be represented as:

$$f = 1.000198, U = 0.17\%, (k = 2)$$

## 8 Conclusion and Discussion

1) Through the evaluation of this paper, the relative expansion uncertainty of the solar radiation measurement standards and the world radiation benchmark is 0.17%, which meets the requirements of WMO and has reached the world advanced level.

2) It can be found through the estimate of uncertainty that the major sources of uncertainty are error of the calibration coefficient for PMO-6 and angle error of sun tracker. Therefore, maintaining the performance of the instrument and improving the tracking accuracy of the tracker can effectively reduce the uncertainty of the measurement results.

3) China has set up 8 regional testing centers for radiation instruments, and the solar radiation standard instruments are compared every two years. The evaluation method in this paper can provide reference and basis for evaluating the uncertainty of results of domestic radiation instruments comparison.

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