INSTRUMENTS AND OBSERVING METHODS

REPORT No. 44

FIRST WMO REGIONAL PYRHELIOMETER COMPARISON OF RA IV

ENSENDA, MEXICO, 20 to 27 April 1989

Final Report
by
I. Galindo

WMO/TD-No. 345
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NOTE

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INTRODUCTION

1.1 The Executive Council at its thirty-ninth session approved the regional comparison of national standard pyrheliometers of RA IV.

1.2 Considering the importance of Recommendations 10, 11, and 14 (CIMO-IX), which were approved by EC-XXXVIII, Mexico offered to host the First WMO Regional Pyrheliometer Comparison of RA IV. The comparison was carried out from 20 to 27 April 1989 at the Astronomic Observatory of the National Autonomous University of Mexico (UNAM) at Ensenada.

1.3 The International Organizing Committee for the comparison held its first session at Ensenada from 11 to 13 January 1989. The list of participants is given in Appendix A.

1.4 The WMO Secretariat distributed in January 1988 the notification on the comparison. In March 1989, the Secretariat sent the final report of the first session of the International Organizing Committee of the comparison to Members who had indicated their intention to participate in the comparison.

1.5 The International Organizing Committee held its second session at the comparison site at Ensenada on 25 April 1989 (see Appendix A). The Committee analyzed the preliminary results of the comparison including the proposed new WRR reduction factors and calibration factors of the instruments participated in the comparison.
2. PARTICIPATION

2.1 Five Members of RA IV and the WRC Davos participated with 21 experts in the comparison. The list of participants is given in Appendix B.

2.2 15 pyrheliometers (6 Angstrom pyrheliometers, 9 absolute radiometers, including one of the World Standard Group and 2 thermoelectric pyrheliometers), and eight pyranometers participated in the comparison. The list of instruments is attached in Appendix C.

3. DATA ACQUISITION AND EVALUATION

3.1 The Comparison was carried out 7 km northwest of Ensenada at an elevation of 75 m above sea level on the roof of the offices of the National Astronomic Observatory of the National Autonomous University of Mexico (UNAM) at the university complex. This location provided good comparison conditions.

3.2 The pyrheliometers and pyranometers were mounted on wood benches which were fixed on the roof. The control units of the pyrheliometers were protected from the sun.

3.3 AC power (120 V/60 Hz) was available on the benches. Small data loggers with appropriate software were provided for pyrheliometer operators to storage irradiances during the measurements. The stored information was brought through an interface to two personal computers devoted to validation task. Pyranometer outputs were directly delivered to a data logger.

3.4 All participants operated their own pyrheliometers during the period of the Comparison.
3.5 The operation of the radiation measuring instruments including the PMO-5 (WRC) was done manually. Some of the instrument signals were automatically recorded by data loggers, but all participants kept manual records for control purposes as shown in Appendix D.

3.6 Measured data were evaluated on a daily basis. A printout of the series of irradiances measured was provided to each participant.

3.7 Twice a day it was provided the weather forecast for the region. The following meteorological elements were simultaneously measured with the comparison series:
   a) Air-temperature;
   b) Humidity;
   c) Pressure;
   d) Wind speed;
   e) Wind direction;
   f) visibility;
   g) atmospheric turbidity.

3.8 The above-mentioned meteorological variables are given in Appendix L with global/diffuse radiation, solar elevation and relative air mass.

4. PROCEDURES

4.1 Timing

The duration of one series of measurements was 18 minutes. This period was divided into 12 intervals of 90 seconds so that 6, 10 or 12 readings were obtained by individual instruments in one series. The synchronization of measurements was achieved by
voice announcement and buzzer from the computer system each 90 seconds. Voice announcements were made at -5 minutes, -90, and -15 seconds. The buzzer sounds were short pulses -75, -15 and, -5 seconds to indicate data reading. The timing diagrams are shown in Appendix E.

4.2 Operation of instruments

4.2.1 Angstrom Pyrheliometers

Zero adjustments were made before each series. Series started with the right aperture closed. Right and left aperture were closed alternately every 90 seconds. Twelve observations were thus made in each series. The first readings of each series were discarded.

4.2.2 H-F and TMI absolute radiometers

Zero adjustment and self-calibration were made before each series. Zero-point readings were taken first, then the heater current was turned on, and heater voltage/current and thermopile output were read. After this calibration, the heater was turned off and the sensor exposed to the sun. The thermopile output was read every 90 seconds. Twelve values were obtained in each series.

4.2.3 PMO absolute radiometer

Series started with a closed reading, then the PMO radiometer alternated between open and closed shutters every 90 seconds. Six readings were obtained in each series respectively. The instrument was manually operated.

4.2.4 Thermoelectric pyrheliometers

The thermopile output was read automatically every 90 seconds. Twelve values were obtained in each series.
4.3  The radiation data were evaluated using the equations shown in Appendix F.

4.4  The following readings were made:

  i)  Current/voltage, for PMO absolute radiometer;

  ii) Current for Ångström pyrheliometer;

  iii) Self-calibration values (current/voltage) and thermopile voltage for TMI/H-F absolute radiometers.

Data formats for manual records used at the Comparison are attached as Appendix D.

5.  COMPARISON REFERENCE

5.1  As Comparison reference, a Regional Standard Group (RSG) was established. This group consisted of one instrument of the World Standard Group (PMO-5), two cavity radiometers HF 18747 (RRC Toronto) and the TMI 67502 (RRC Boulder), and the Ångström instrument A 18587 (RRC Mexico). -- PMO-5 acted as the working standard for preliminary data evaluation. PMO-5 provided 6 reference values for each series.

5.2  The determination of the regional radiometric reference was made according to the following:
5.3 The radiometric references of each measurement are listed in Appendix G.

6. COMPARISON MEASUREMENTS

6.1 Measurements were taken on 22 and 23 April, 1989 with a total of 80 measurements.

6.2 All the 80 measurements have fulfilled the criteria mentioned in paragraph 7.1.

7. REFERENCE EVALUATION

7.1 A 2% criterion was applied to the selection of individual values.

7.2 A 0.25% criterion was applied to the mean values of series to be included in the final evaluation.

7.3 Daily data for each instrument are given in Appendix H.

8. COMPARISON RESULTS

8.1 The WRR reduction factor for all pyrheliometers which participating
in the Comparison were adopted by the second session of the International Organizing Committee (Ensenada, 24 April 1989) and they are listed in Appendix I.

9. **CALIBRATION OF PYRANOMETERS**

9.1 Calibration of the pyranometers was made according to the WMO publication No. 8, WMO GUIDE TO METEOROLOGICAL INSTRUMENTS AND METHODS OF OBSERVATION, fifth edition, para. 9.4.1.3: "By reference to a standard pyrheliometer and a shaded pyranometer".

9.2 The calibrated pyranometer (Mexico) together with the pyranometers to be calibrated were exposed to the sun. Signals were recorded every 90 seconds by a data logger.

For each measurement, the calibration factor (K) was calculated as follows:

\[ K = \frac{G_{\text{ref}}}{V}, \]

where \( V \) is the output voltage of the pyranometer to be calibrated.

9.3 The mean values of \( K \) were adopted as the final calibration factors. They are given in Appendix K.

10. **OTHER ACTIVITIES**

10.1 At the end of the Comparison the following presentations were made:
- J.R. Hickey. Eppley Lab.: "10 Years of Solar Irradiance Measurements from the ERB Experiment on Nimbus 7"

- Chester V. Wells. SERI: "Measurement Uncertainty Analysis: I. Principles and Methods"

- Chester V. Wells. SERI: "II Application to Solar Radiation Instruments, Calibration and Measurements"

- Don Nelson. NOAA. ERL: "Current Status on the U.S. Solar Radiation Network"

11. Acknowledgments

The participants expressed their gratitude to the host country and to the National Astronomical Observatory of UNAM for the excellent organization of the comparison as well as for providing excellent facilities and working conditions for the event. They also expressed their thanks to the Project Leader and participating staff of the National Astronomical Observatory, to WMO, and to the WRC. Hospitality of the host country was highly appreciated.

12. Remarks

The final results of the Comparison will be submitted to the presidents of CIMO and RA IV for approval and they will be included as a recommendation of the next session of RA IV.
LIST OF PARTICIPANTS

I. Galindo (Chairman) (representing RA IV Regional Radiation Centre Mexico) Mexico

J. de Luisi (representing RA IV Regional Radiation Centre Boulder) USA

D. Wardle (representing RA IV Regional Radiation Centre Toronto) Canada

M. Alvarez Mexico

J.L. Bravo Mexico

E. Ledesma Mexico

WMO Secretariat

S. Klemm Senior Scientific Officer, WWW Department
### APPENDIX B

**LIST OF PARTICIPANTS OF THE FIRST REGIONAL PYRHELIOMETER COMPARISON OF RA IV**

<table>
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<td>Agustin Muhlia</td>
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<td>José Luis Bravo</td>
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<td>Mauro Valdes B.</td>
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<td>Tom Grajnar</td>
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<td>Alfonso Liao Lee</td>
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<td>J. Stallkamp</td>
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<td>Chester V. Wells</td>
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<td>César Noguera</td>
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<td>C. Wehrli</td>
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## APPENDIX C

### List of instruments

(a) Pyrheliometers

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<td>SWITZERLAND</td>
<td>WRC II PMO 5</td>
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<td>USA</td>
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(b) Pyranometers

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PRIMERA INTERCOMPARACION PIRHELIOMETRICA REGIONAL (AR-IV)  
Ensenada, B. C., México.  
Abril de 1989.

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CHRONOLOGY OF THE OBSERVATIONS

A1: ANNOUNCE - FIVE MINUTES BEFORE OBSERVATIONS
A2: BEEP AND ANNOUNCE - TIME ZERO
A3: BUZZER AND ANNOUNCE - SHADE THE LEFT (OR RIGHT) HAND STRIP
A4: BEEP AND ANNOUNCE - FIFTEEN SECONDS BEFORE MEASUREMENT
A5: FOUR BEEPS (EACH SECOND) BEFORE HIGH TONE BEEP FOR READING
BLOCK DIAGRAM OF THE DATA ACQUISITION AND PROCESSING SYSTEM
FOR PYRHELIOMETERS
BLOCK DIAGRAM OF THE DATA ACQUISITION AND PROCESSING SYSTEM FOR PYRANOMETERS
Pyranometer Comparison
during the First Regional Pyrheliometer Comparison (RPC) of RA-IV

The Pyranometers were compared in the same way as described the "WMO GUIDE TO METEOROLOGICAL INSTRUMENTS AND METHODS OF OBSERVATION: 9.4.1.3 By reference to a standard pyrheliometer".

1) The comparison of pyranometer was carried out parallel at the same place (see Appendix E) and during the same period as the RPC.

2) The participating pyranometer was installed and maintained by the staff of the host country.

3) The pyranometer was leveled horizontally to measure global radiation G.

4) All data were acquired, processed and evaluated by the data acquisition system of the RPC (see 2.5.2 and 2.5.3).

5) Data reports are included as Appendix K.
CALCULATION OF DIRECT SOLAR IRRADIANCES

With the following notations:

- $I$: direct solar irradiance
- $V_{\text{th}}$: output of thermopile
- $U_h$ or $U_r$: voltage across heater ($U_h$) or standard resistor ($U_r$)
- $i_h$: current through heater
- $R_n$: standard resistor
- $K$: calibration factor
- $R_l$: resistance of heater leads

1. THE (IRRADIANCE) ABSOLUTE RADIOMETERS OF PACRAD TYPE ARE CALCULATED ACCORDING TO:

An irradiance measurement consists of the reading of the thermopile output $V_{\text{th}}$ (irrad.) produced by the irradiated receiver. During the calibration period the shaded cavity is heated electrically and the voltage $U_h$ across the heater, the voltage $U_r$ across a standard resistor $R_n$ and the corresponding thermopile output $V_{\text{th}}$ (cal.) are measured. Further, the null of the thermopile $V_{\text{th}}$ (null) is determined with the detector shaded and with no electrical power. The irradiance is determined by the following equation:

$$I = K \cdot \frac{V_{\text{th}} \text{ (irrad)} - V_{\text{th}} \text{ (null)}}{V_{\text{th}} \text{ (cal)} - V_{\text{th}} \text{ (null)}} \cdot \frac{U_r}{R_n} \cdot \left(\frac{U_h}{R_n} - \frac{U_r}{R_n} \cdot R_l\right)$$

Formula A

The TMI are calibrated directly by the user, so that only one value is --
read which is scaled and zeroed during the calibration period in such a way, that a 100 mV reading corresponds to 100 mWcm$^{-2}$, hence the irradiance formula is very simple:

$$I = K \cdot U$$  \hspace{1cm} \text{Formula B}

with:

$$K = 10,000 \text{Wm}^{-2} \text{V}^{-1}$$

2. **ACTIVE ABSOLUTE RADIOMETERS**

These radiometers are operated actively, which means that the temperature difference across the thermal resistor is maintained constant by heating the cavity electrically. During the shutter open period, the electrical power is diminished by the amount of radiative power absorbed by the cavity. The intensity is calculated according to the following formulas, depending on how the electrical power is measured:

$$I = K \cdot [P(\text{closed}) - P(\text{open})]$$  \hspace{1cm} \text{Formula C}

with:

$$P = U_h \cdot i_h$$  \hspace{1cm} \text{Formula D}

$$P = U_h \cdot \frac{U_v}{R_n}$$  \hspace{1cm} \text{Formula E}
P(close) is linearly interpolated for the instant of the open reading from the closed values before and after the open reading.

3. **ANGSTROM PYRHELIOMETERS**

The current through the left or right strip of the Ångström pyrheliometer is measured as voltage drop across a standard resistor. The irradiance is calculated by the formula:

\[
I = K \cdot \frac{U_r(\text{right}) \cdot U_r(\text{left})}{R^2_n} \quad \text{Formula F}
\]

As this irradiance is the geometric mean between the irradiance prevailing at the time of the left and right reading respectively, the ratio to the reference is calculated using the geometric mean of the corresponding reference irradiances.
## Summary of Daily Irradiance Values

**Fecha: 04-22-1989**  
**Instrumento: Eppley H-F No. 18747**  
**Constante de Instrumento: 1**  
**Terminal No. 01 (1)**

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**Fecha: 04-22-1989**  
**Instrumento: MK-VI No. 67502**  
**Constante de Instrumento: 1**  
**Terminal No. 02 (1)**

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**Fecha: 04-22-1989**  
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**Terminal No. 02 (2)**

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## Summary of Daily Irradiance Values (Continued)

**Fecha: 04-22-1989**  
**Instrumento: MK-VI No. 67401**  
**Constante de Instrumento: 1**  
**Terminal No. 03 (1)**

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**Terminal No. 89 [11]**

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### Summary of Daily Irradiance Values

#### Ensenada, B. C., Mexico

#### Appendix H.2

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**APPENDIX H.2**

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APPENDIX I

SUMMARY OF REGIONAL REFERENCE VALUES
FIRST WMO REGIONAL PYRHELIOMETER COMPARISON
OF RA-IV
ENSENADA, MEXICO 1989

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1
# List of WRR Reduction Factors and New Calibration Factors Recommended for Pyrheliometers

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*APPENDIX J*
LIST OF NEW CALIBRATION FACTOR
RECOMMENDED FOR PYRANOMETERS

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* MEXICAN NATIONAL REFERENCE PYRANOMETER COMPARED AGAINST EPPLEY A-18587
+ MEAN RATIO = MEAN [PYRAN. IRRADIANT./REFERENCE PYRAN. IRRADIANT.]
### SUMMARY OF METEOROLOGICAL DATA

**FIRST WMO REGIONAL PYRHELIOMETER COMPARISON OF RA-IV**

**ENSENADA, MEXICO 1989**

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