SUB-REGIONAL PYRANOMETER INTERCOMPARISON OF THE RA VI MEMBERS FROM SOUTH- EASTERN EUROPE
(Split, Croatia, 22 July - 6 August 2007)

by
K. Premec (Croatia)
This report presents the results from the Sub-Regional Pyranometer Intercomparison that was held for the Members of South-Eastern Europe at the kind invitation of Croatia.

The calibration and traceability of instruments to recognized standards is crucial for climate change monitoring and to determine the Earth’s radiation budget. In that context, the Fourteenth Session of the Commission for Instruments and Methods of Observations recognized that a successful determination of the radiation budget, which was fundamental to understanding the Earth’s climatic system, climate variability and climate change, was only possible with very homogeneous solar radiation data measured all over the world. The way to guarantee a desired level of quality of radiation data is to assure the traceability of solar radiation measurements to the World Radiometric Reference (WRR). This is achieved through the International Pyrheliometer Comparisons done in 5 years cycles and Regional Pyrheliometer Comparisons that should be organized in all WMO Regions.

Furthermore, the traceability chain to the WRR, needs to be implemented down to the level of the instruments that are routinely used in national observation networks. This intercomparison precisely addressed this step, as it used pyranometers that had been recently calibrated against the WRR as a reference and could provide calibration factors to instruments that had not been calibrated over a long period.

I wish to express my sincere appreciation for the efforts of the Meteorological and Hydrological Service of Croatia, and in particular to Mr Krunoslav Premec, for organizing this intercomparison.

(Dr J. Nash)

President
Commission for Instruments and Methods of Observation
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Acknowledgement

The organisation of the Intercomparison wouldn’t be possible without the support and very useful suggestions from WMO Secretariat, particularly from Dr. Miroslav Ondras, Dr. Dusan Hrcek and Dr. Igor Zahumensky.

Participation of the World Radiation Centre - PMOD Davos, and efforts made by Dr. W. Finsterle in assuring the reference value were very valuable.

Important and clear comments, and very helpful guidelines for the preparation of the Report, provided by the Expert Team on Meteorological Radiation and Atmospheric Composition Measurements, particularly Dr. Bruce Forgan, were highly appreciated and carefully implemented.

Persons responsible for the participating pyranometers were very cooperative and very successful in arranging all necessary work for participation in the Intercomparison.

I would like to express my deepest gratitude to all, and want to stress that it was my great pleasure to work with them.
1. INTRODUCTION

Following the WMO standards and recommendations regarding measurement, maintenance and calibration of instruments including their intercomparisons, as well as experiences from the outdoor comparison campaign of pyranometers and sunshine duration recorders in WMO RA VI held in Budapest, Hungary, in 1984 (WMO-TD-No. 146), Meteorological and Hydrological Service of Croatia (MHSC) hosted, with support from the WMO Secretariat, “The Sub-Regional Pyranometer Intercomparison for the South-Eastern Europe” in 2007.

1.1. Place and Date

The Intercomparison was held in Split, second largest town in Croatia with approximately 200,000 inhabitants, situated on the Adriatic coast (Figure 1). Pyranometers were installed on a flat roof of the Meteorological observatory (43° 38' N, 16° 26' E), designated by the red arrow in the smaller picture in Figure 1. Meteorological observatory is situated on the small hill, 122 m a msl, southwest from the town, approximately 1000 m air distance from the city centre (smaller picture in Figure 1). Surrounding mountains, less than 1000 m high and more than 5 km distant, lie on the North and the Northeast from the town. From the Northeast to the Northwest, clockwise, there is the sea, and there aren’t any obstacles.

![Figure 1. Map of the site where the intercomparison took place](image)

Based on climatological data and available resources, period from July 20 to August 6, 2007, was chosen as the most appropriate for the Intercomparison.

All instruments were fixed on the same horizontal flat plate and levelled properly (Figure 2). Emerging leads were pointed to the North.
1.2. Participation

The idea for the Intercomparison was suggested by MHSC and accepted by WMO Secretariat in early 2007. With joint efforts of WMO and MHSC, all member countries from south-eastern part of WMO RA VI were invited to participate in the Intercomparison, as well as manufacturers of solar radiation equipment. Great support has been got from World Radiation Centre which enabled calibration of two reference pyranometers and which sent their own pyranometer for the Intercomparison.

Altogether 11 pyranometers, from National Meteorological Services of Bosnia and Herzegovina, Croatia, Israel, Macedonia, Slovenia, from the World Radiation Centre – Davos Switzerland, and from two manufacturers: Davis Instruments from United States of America, and Delta-T from United Kingdom, participated in the Intercomparison (Table 1).

Each participating pyranometer can be identified by the number P from the Table 1, which denotes the position of the pyranometer in Figure 2 (from left to right).

Transportation of the instruments to Croatia was arranged by participating institutes/services via different shipping companies.

All instruments were checked in a laboratory under an artificial light source before and after the Intercomparison. Zero-offsets found in a laboratory were taken into account before calibration factor calculations.

On site, the instruments were fixed on a same aluminium platform at the flat roof of Meteorological observatory Split-Marjan and levelled properly. As there was no presence of participants, the staff of Meteorological laboratory of MHSC performed regular and permanent inspection and control of pyranometers, as well as of the whole system, during the Intercomparison.

On the opening ceremony, on July 23, the Intercomparison was visited by two experts from WMO Regional Instrument Centre Ljubljana, Slovenia.

Figure 2. Pyranometer mounting platform at the roof of Meteorological observatory Split-Marjan
1.3. Data Acquisition System

Signals from pyranometers were acquired by the 12-channel analogue data acquisition system developed by Tritonel-Multimedia (Croatian company specified for meteorological and electronic equipment production). The system was based on amplifiers in front of the AD 12 bits converters and EPROMs, based on 1 second sampling rate. Developed software support assured acquisition of 1-second, 1-minute and 10-minute records on a hard disk of a laptop. The system was calibrated before and checked after the Intercomparison with a calibrated millivolt source 404S Time Electronics Ltd and a digital multimeter Fluke 8841. No drift was found.

The pyranometers were connected to the system with supplied cables that were less than 10 meters long. All Kipp&Zonen pyranometers were connected directly to the data acquisition system with 2 wire connections. For Davis Inc. pyranometers stable 3V DC, and for Delta-T pyranometer, stable 12V DC supplies were used respectively, according to instruction manuals. All pyranometers were grounded according to the manufacturer’s instructions. Only the pyranometer from Switzerland (CM21, 970401) was ventilated.

Table 1. Participating instruments

<table>
<thead>
<tr>
<th>P</th>
<th>Country</th>
<th>Institute/ Service</th>
<th>Producer</th>
<th>Model</th>
<th>Instrument s/n</th>
<th>Contact person</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Bosnia and Herzegovina</td>
<td>Federal Meteorological Institute</td>
<td>Kipp&amp;Zonen</td>
<td>CM 6B</td>
<td>057520</td>
<td>Kemal Sehbarjaktarevic</td>
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<tr>
<td>1</td>
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<td>Meteorological Service</td>
<td>Kipp&amp;Zonen</td>
<td>CMP 11</td>
<td>060100</td>
<td>Alexander Baskis</td>
</tr>
<tr>
<td>2</td>
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<td>Hydrometeorological Service</td>
<td>Kipp&amp;Zonen</td>
<td>CM 11</td>
<td>892422</td>
<td>Vesna Pavlovska</td>
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<td>4</td>
<td>Slovenia</td>
<td>Environmental Agency</td>
<td>Kipp&amp;Zonen</td>
<td>CM 11</td>
<td>861547</td>
<td>Drago Groselj</td>
</tr>
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<td>10</td>
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<td>Environmental Agency</td>
<td>Kipp&amp;Zonen</td>
<td>CM 11</td>
<td>861350</td>
<td>Drago Groselj</td>
</tr>
<tr>
<td>11</td>
<td>Switzerland</td>
<td>World Radiation Centre - PMOD</td>
<td>Kipp&amp;Zonen</td>
<td>CM 21</td>
<td>970401</td>
<td>Wolfgang Finsterle</td>
</tr>
<tr>
<td>3</td>
<td>UK</td>
<td>Delta-T</td>
<td>Delta-T</td>
<td>SPN 1</td>
<td>A-149</td>
<td>Tony Peloe</td>
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<td>Davis Inst.</td>
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<td>ML98000008</td>
<td>Jason Karvelot</td>
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<td>Jason Karvelot</td>
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<td>Meteorological and Hydrological Service</td>
<td>Kipp&amp;Zonen</td>
<td>CM 11</td>
<td>027750</td>
<td>Krunoslav Premec</td>
</tr>
<tr>
<td>8</td>
<td>Croatia</td>
<td>Meteorological and Hydrological Service</td>
<td>Kipp&amp;Zonen</td>
<td>CM 21</td>
<td>950238</td>
<td>Krunoslav Premec</td>
</tr>
</tbody>
</table>

P – denotes a position of the pyranometer at Figure 2 (from left to right).
1.4. **Auxiliary Data**

During the Intercomparison auxiliary data were also collected.

The meteorological parameters (wind speed and direction, air temperature, relative humidity, atmospheric pressure) as well as global and diffuse solar radiation were measured by the automatic weather station (AWS), located at the Split Marjan observatory, as 10-minute records.

Cloudiness and visibility were observed manually, by an observer at the Observatory.

Additionally, manual measurement of direct solar radiation was performed every day one hour before and one hour after solar noon with Kipp&Zonen CH1 pyrheliometer that participated in the IPC-X in 2005, in Davos (WMO/TD No. 1320). In the same way, aerosol optical depth (AOD) was determined by the Solar Light Co. MICROTOPS II Sunphotometer at the 5 wavelengths: 340 nm, 380 nm, 440nm, 500 nm, 675 nm.

1.5. **Malfunctions**

Due to unknown reasons, on the first day of the Intercomparison, malfunctions were found with Davis Inc. pyranometer s/n ML98000009, and the agreement about excluding this pyranometer from the intercomparison was achieved with the contact person responsible for the pyranometer.

Instrument Kipp&Zonen, s/n 057520, from Bosnia and Herzegovina arrived on July 26, and was included in the intercomparison immediately. Due to the late arrival there was a lack of data of 6 days.
2. MEASUREMENTS AND RESULTS

Although there were almost 60000 data per day per each participating instrument, to avoid the cosine effect, only the data between 9 AM and 3 PM (local time = GMT+1) were used for calculations. Based on the response time, i.e. thermal relaxation time, all 1-second data were summed over the period of 20 seconds, and for further calculations 20-second sums were used.

All pyranometers were checked in a laboratory (according to Kipp&Zonen Calibration procedure) under the artificial light source, metal-halide high pressure gas discharge lamp, before and after the Intercomparison. Zero-offsets found in a laboratory were as follows:

$Z_0(CM21-970401)=0.000 \ \mu V$, $Z_0(CM21-950238)=0.014 \ \mu V$, $Z_0(CM11-027750)=0.012 \ \mu V$, $Z_0(CM6B-057520)=0.008 \ \mu V$, $Z_0(CMP11-060100)=0.018 \ \mu V$, $Z_0(CM11-892422)=0.009 \ \mu V$, $Z_0(CM11-861547)=0.011 \ \mu V$, $Z_0(CM11-861350)=0.003 \ \mu V$, $Z_0(SPN1-A149)=4.5 \ \mu V$, $Z_0(PRO6450-ML9800009)=1.1 \ \mu V$.

All zero-offsets were taken into account for measuring signals before calibration factor calculations.

2.1. Reference Value

For every time interval (20-second sum) the reference value was calculated as the average of 3 Kipp&Zonen instruments using the sensitivity factors achieved by the calibration in Davos in May and July, 2007 (Table 2).

<table>
<thead>
<tr>
<th>Model</th>
<th>Instrument s/n</th>
<th>Sensitivity (µV/W/m²)</th>
<th>Calibration factor</th>
<th>STDEV (ppm)</th>
<th>N used</th>
<th>N total</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM 21</td>
<td>970401</td>
<td>11.15</td>
<td>1.001049</td>
<td>1755</td>
<td>14904</td>
<td>19436</td>
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<td>CM 21</td>
<td>950238</td>
<td>8.64</td>
<td>0.998379</td>
<td>1029</td>
<td>15388</td>
<td>19436</td>
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<tr>
<td>CM 11</td>
<td>027750</td>
<td>5.03</td>
<td>1.000674</td>
<td>1897</td>
<td>16713</td>
<td>19436</td>
</tr>
</tbody>
</table>

STDEV designates standard deviation in parts per million - ppm, N used – number of data used for the calculations, N total – total number of available data.

In the first iteration the reference radiant exposure (20-second sum) was calculated from the all available data:

$$REFRE(t) = \langle RE_1(t), RE_2(t), RE_3(t) \rangle$$

where:

$REFRE(t)$ – reference radiant exposure at time t
$RE_1(t)$ – radiant exposure of pyranometer CM21, s/n 970401 at time t
$RE_2(t)$ – radiant exposure of pyranometer CM21, s/n 950238 at time t
$RE_3(t)$ – radiant exposure of pyranometer CM21, s/n 27750 at time t

$\langle \rangle$ – denotes average

t – time (20-second interval)
then calibration factor \( CF_i(t) \) was calculated as follows:

\[
CF_i(t) = \frac{REFRE_i(t)}{RE_i(t)}, \quad i = (1, 2, 3)
\]

In the second iteration all data lying out of \( \pm 2\sigma \) interval around the average were rejected, and the calculations were repeated for reference radiant exposure, as well as for calibration factors according to the formulas above.

The final calibration factors were calculated as:

\[
CF_i = \langle CF_i(t) \rangle, \quad i = (1, 2, 3)
\]

where \( \langle \rangle \) - denotes average over all data remained after first iteration.

\( CF_1 \) – calibration factor of pyranometer CM21, s/n 970401
\( CF_2 \) – calibration factor of pyranometer CM21, s/n 950238
\( CF_3 \) – calibration factor of pyranometer CM11, s/n 027750.

These calibration factors (listed in Table 2) were used for the final reference radiant exposure calculation.

### 2.2. Participating Instruments Results

For the calculations of calibration factors for participating instruments, so called \( TREFRE(t) \) was used.

\( TREFRE(t) \) represents true reference radiant exposure obtained as the average of:

\[
TREFRE(t) = \langle CF_1 \cdot RE_1(t), CF_2 \cdot RE_2(t), CF_3 \cdot RE_3(t) \rangle
\]

Then the calibration factors were calculated:

\[
CF_i(t) = \frac{TREFRE(t)}{RE_i(t)}, \quad i = (4, 5, 6, 7, 8, 9, 10)
\]

where \( i \) – stays for pyranometers other then those used for \( TREFRE(t) \) calculations.

In the second iteration all data lying out of \( \pm 2\sigma \) interval around the average were rejected and the calculations for the \( CF_i(t) \) were repeated.

The final calibration factors were calculated as:

\[
CF_i = \langle CF_i(t) \rangle, \quad i = (4, 5, 6, 7, 8, 9, 10)
\]

where \( \langle \rangle \) - denotes average over all data remained after first iteration.

Calculated calibration factors were presented in Table 3.
### Table 3. Calculated calibration factors for participating instruments

<table>
<thead>
<tr>
<th>Country</th>
<th>Instrument s/n</th>
<th>Previous sensitivity (µV/W/m²)</th>
<th>Calibration factor</th>
<th>STDEV (ppm)</th>
<th>N Used</th>
<th>N total</th>
<th>Recommended new sensitivity (µV/W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bosnia and Herzegovina</td>
<td>057520</td>
<td>11,88</td>
<td>1,007024</td>
<td>11400</td>
<td>11912</td>
<td>12509</td>
<td>11,80</td>
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<tr>
<td>Israel</td>
<td>060100</td>
<td>10,20</td>
<td>1,027011</td>
<td>778</td>
<td>12088</td>
<td>19436</td>
<td>9,93</td>
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<td>Macedonia</td>
<td>892422</td>
<td>4,53</td>
<td>1,013365</td>
<td>794</td>
<td>8789</td>
<td>19436</td>
<td>4,47</td>
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<td>Slovenia</td>
<td>861547</td>
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<td>9290</td>
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<td>10915</td>
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<td>1682,03</td>
</tr>
</tbody>
</table>

STDEV - designates standard deviation in parts per million - ppm, N used – number of data used for the calculations, N total – total number of available data.

Recommended new sensitivity was calculated multiplying previous sensitivity by reciprocal value of the calibration factor.
2.3. Environmental parameters

Some important environmental parameters for the calculations of the calibration factors, were measured or observed either by an AWS or an observer during the intercomparison. These parameters were expressed via extreme values in Table 3 and variations, through the period used for the calculation, in Figures 4.1. to 4.10.

Solar zenith angle varied between 22.95° and 46.48° during observed period, with daily variations around 20°.

Air temperature has changed less than 5 °C on all days except on July 31, when the largest daily variation, 7.4 °C, was measured. During the intercomparison, the air temperature changed between 20.9 °C and 36.7°C. Relative humidity and atmospheric pressure daily variations were less than 20%, and less than 5 hPa, respectively.

The sky was almost clear on the majority of days, and cloudiness more than a 5 tenth was observed only at some hours on the following days: July 30, 31, and August 3, and 5. On these days also greater values and greater variability were found for a diffuse radiant exposure. Visibility was greater than 20 km on all days, except July 24, when the lowest direct solar irradiance and quite high AOD were measured.

<table>
<thead>
<tr>
<th>Date</th>
<th>Solar Zenith Angle (°)</th>
<th>Air temperature (°C)</th>
<th>Relative humidity (%)</th>
<th>Atmospheric pressure (hPa)</th>
<th>Cloudiness (1/10)</th>
<th>Visibility (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>Max</td>
<td>Min</td>
<td>Max</td>
<td>Min</td>
<td>Max</td>
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<td>34.8</td>
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<tr>
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<td>46.48</td>
<td>20.9</td>
<td>36.7</td>
<td>20</td>
<td>60</td>
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</tbody>
</table>
2.4. Conclusions

With the great support of WMO Secretariat and World Radiation Centre, MHSC has conducted the first international pyranometer intercomparison in the south-eastern part of Europe. Favourable, sunny weather enabled acquiring a large amount of data for a reasonable evaluation of the pyranometers participated in the Intercomparison.

Reference value obtained by three recently calibrated pyranometers represented a reliable basis for further calculations.

Large number of data used for statistics assured reasonable confidence in the calculated calibration factors. Available auxiliary data could be linked to the calibration factors and considered during future comparisons of the calibration factors for similar conditions.

Generally, slight underestimation of the global solar radiation by the participating instruments could be addressed also to the degradation of their sensitivity (some of them haven’t been calibrated for more than 15 years) or to different type of sensors. Further detailed analyses with the use of available auxiliary data and comparison with previous calibrations and corresponding condition could enable better understanding of calibration factors behaviour.

A larger standard deviation of few pyranometers was a consequence of the larger dispersion of the measurements.

Although there were some unexpected organisational and infrastructural irregularities, generally it is believed that the Intercomparison could provide some useful experiences and results for the participants, as well as the community involved in this issue from the sub-region, especially in the field of improving accuracy and assuring traceability of the global solar radiation measurement.
3. GRAPHICAL REPRESENTATION OF THE RESULTS

The following figures show the calibration factor (absolute value) variations of the reference and participating pyranometers. The horizontal solid red lines represent average±2σ values used as the upper and lower limits for final calibration factor calculations, respectively. On the top of each figure, the pyranometer serial number, the calibration factor, its standard deviation, and the number of used data are stated.

3.1. Reference Instruments

![Figure 3.1. CM21-970401 pyranometer calibration factor variations](image)

Figure 3.1. CM21-970401 pyranometer calibration factor variations
Figure 3.2. CM21-950238 pyranometer calibration factor variations

Figure 3.3. CM11-027750 pyranometer calibration factor variations
3.2. Participating Instruments

**CM6B-057520**, \( \text{CF}=1.007024, \text{STDEV}=11400 \text{ ppm}, \text{N-used}=12509 \)

![Figure 3.4. CM6B-057520 pyranometer calibration factor variations](image)

**CMP11-060100**, \( \text{CF}=1.02701, \text{STDEV}=778 \text{ ppm}, \text{N-used}=12088 \)

![Figure 3.5. CMP11-060100 pyranometer calibration factor variations](image)
Figure 3.6. CM11-892422 pyranometer calibration factor variations

Figure 3.7. CM11-861547 pyranometer calibration factor variations
Figure 3.8. CM11-861350 pyranometer calibration factor variations

Figure 3.9. SPN1-A149 pyranometer calibration factor variations
PRO6450-ML98000009, CF=0.992848, STDEV=2535 ppm, N-used=10915

Figure 3.10. PRO6450-ML98000009 pyranometer calibration factor variations
4. AUXILIARY DATA

4.1. Solar radiation

Figure 4.1. Direct solar irradiance measured by Kipp&Zonen, CH 1 pyrheliometer, manually, every day from 11 AM through 1 PM

Figure 4.2. Global radiant exposure (10-minute sums) measured by CM11 connected to the AWS (daily from 9 AM through 3 PM)
Figure 4.3. Diffuse radiant exposure (10-minute sums) measured by CM11 shaded by shadow ring, Kipp&Zonen, connected to the AWS (daily from 9 AM through 3 PM)

Figure 4.4. Sunshine duration (1-hour sums) obtained from heliograph (daily from 9 AM through 3 PM)
Figure 4.5. Aerosol Optical Depth measured by Solar Light Co. MICROTOPS II Sunphotometer at 5 wavelengths (340 nm, 380 nm, 440 nm, 500 nm, 675 nm), manually, every day from 11 AM through 1 PM.
4.2. Meteorological Data

Air temperature from AWS

![Graph of air temperature from AWS](image1)

Figure 4.6. Air temperature (10-minute averages) obtained from AWS (daily from 9 AM through 3 PM)

Relative humidity from AWS

![Graph of relative humidity from AWS](image2)

Figure 4.7. Relative humidity (10-minute averages) obtained from AWS (daily from 9 AM through 3 PM)
Figure 4.8. Atmospheric pressure (10-minute averages) obtained from AWS (daily from 9 AM through 3 PM)

Figure 4.9. Cloudiness (hourly values) estimated by observer (daily from 9 AM through 3 PM)
Figure 4.10. Visibility (hourly values) estimated by observer (daily from 9 AM through 3 PM)
5. LITERATURE


2. ISO 9059:1990 - Solar energy - Calibration of field pyranometers by comparison to a reference pyranometer.


8. Delta-T Devices Ltd: SPN 1 Sunshine Pyranometer

9. Davis Instruments: Solar Radiation Sensor