The World Infrared Standard Group (WISG) of longwave radiometers: How can/should updated calibrations be transferred to BSRN records?

Stephan Nyeki, Stefan Wacker*, Julian Gröbner
PMOD/WRC, Davos, Switzerland

* Formerly at PMOD/WRC, now at ASIAQ, Nuuk, Greenland
World Infra-Red Standard Group (WISG)

- PMOD/WRC pyrgeo calibrations based on WISG
  Eppley PIR K&Z CG4

- WISG calibration based on …
  PIR 31463, CG4 FT004 calibs based on IPASRC-I, -II (1999, 2001)
  Agreement of pyrgeos, ASR, AERI, RTMs was ±2 W.m⁻².

- WISG
  Internal stability ±1 W.m⁻² since Jan. 2004
  Uncertainty ±2.5 W.m⁻²
Night average differences of DLR between the WISG pyrgeometers relative to their average. The thick lines represent a monthly running average.
World Infra-Red Standard Group (WISG)

- WISG is complemented by 2 pyrgeos without IWV dependence:
  - Since Feb. 2008, CG4 030669 (FT006 body, 030669 dome), unofficial “WISG₅”.
  - Since Nov. 2011, CGR4 110390 (no solar-blind filter), unofficial “WISG₆”.

- Observations in Gröbner et al. (JGR, 2015), suggest that the WISG may eventually need to be re-calibrated against other transfer standards (IRIS/ACP/others ...) due to:
  - IWV dependence of Eppley PIR and pre-2003 K&Z CG4 when IWV<~10 mm.
  - A scale offset (up to -5 W.m⁻²) of the WISG due to its calibration dating back to IPASRC-I and II.
How will these aspects potentially affect BSRN long-wave irradiance time-series?
### BSRN Pyrgeometer Statistics (Dec. 2015)

#### BSRN PYRGEOMETER INSTRUMENT TYPES

<table>
<thead>
<tr>
<th>Eppley</th>
<th>K&amp;Z</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>188</td>
<td>15</td>
<td>223</td>
</tr>
<tr>
<td>%</td>
<td>84.3</td>
<td>100</td>
</tr>
</tbody>
</table>

| CG4    |       |
| 20     | 100   |

| CGR4   |       |
| 20     | 100   |

#### BSRN PYRGEOS WITH DIRECT TRACEABILITY TO WISG (ie CALIBRATED AT PMOD/WRC)

<table>
<thead>
<tr>
<th>Eppley</th>
<th>K&amp;Z</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>188</td>
<td>35</td>
<td>223</td>
</tr>
<tr>
<td>%</td>
<td>84.3</td>
<td>100</td>
</tr>
</tbody>
</table>

| CG(R)4 |       |
| 47     | 25   |
| 58     | 26   |

#### BSRN PYRGEOS WITH INDIRECT TRACEABILITY TO WISG (ie CALIBRATED VIA A REF. PYRGEO)

<table>
<thead>
<tr>
<th>Eppley</th>
<th>K&amp;Z</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>188</td>
<td>35</td>
<td>223</td>
</tr>
<tr>
<td>%</td>
<td>84.3</td>
<td>100</td>
</tr>
</tbody>
</table>

| CG(R)4 |       |
| 40     | 21   |
| 61     | 29   |

#### BSRN PYRGEOS WITH IWV DEPENDENCY

<table>
<thead>
<tr>
<th>Eppley</th>
<th>K&amp;Z</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>188</td>
<td>35</td>
<td>223</td>
</tr>
<tr>
<td>%</td>
<td>84.3</td>
<td>100</td>
</tr>
</tbody>
</table>

| CG(R)4 |       |
| 47     | 11   |
| 58     | 26   |

#### BSRN PYRGEOS WITH IWV DEPENDENCY

<table>
<thead>
<tr>
<th>Eppley</th>
<th>K&amp;Z</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>188</td>
<td>35</td>
<td>223</td>
</tr>
<tr>
<td>%</td>
<td>84.3</td>
<td>100</td>
</tr>
</tbody>
</table>

| CG(R)4 |       |
| 47     | 11   |
| 58     | 26   |

Note: Data from PMOD Archive

Note: Percentages are definite and not upper or lower limits.

*Assuming all PIR and pre-2003 CG4(<SN 030646) are affected.

"Supported" by numerous 1-season calibs wrt WISG.
BSRN Pyrgeometer Statistics (Dec. 2015)

Summary

- At least 55% BSRN pyrgeometers currently have calibrations directly/indirectly traceable to WISG.
- Hence, max of 45% BSRN pyrgeometers have calibrations traceable to BBs and other institutes.
- Users (those asked so far) have confirmed that WISG calibrations were implemented asap.
- Portions of BSRN time-series may still be based on BB calibrations.
- Note: Statistics refer to N of pyrgeometers and not data-months in BSRN archive.

<table>
<thead>
<tr>
<th>DIRECT AND INDIRECT TRACEABILITY TO WISG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eppley</td>
</tr>
<tr>
<td>PIR</td>
</tr>
<tr>
<td>188</td>
</tr>
<tr>
<td>N (total traceable)</td>
</tr>
<tr>
<td>87</td>
</tr>
<tr>
<td>%</td>
</tr>
<tr>
<td>CG(R)4</td>
</tr>
</tbody>
</table>
The number of pyrgeos (used for atmos meas) outside BSRN is potentially large:

- Currently 223 pyrgeos in BSRN archive since inauguration in 1992.
- PMOD/WRC has calibration records of ~220 pyrgeos (122 PIR, 98 K&Z) since 1993. Only 58 from BSRN.
- Worldwide number of Eppleys and K&Z currently in use for atmos meas?
## BSRN Pyrogeometer Statistics (Dec. 2015)

- Pyrogeometer calibration history of several stations analysed so far.
- Yellow = BB calibs directly/indirectly traceable to PMOD/WRC BB.
- Light orange = BB calibs to PMOD/WRC WISG.
- Dark orange = BB/outdoor calibs directly/indirectly traceable to PMOD/WRC WISG.
Closer Look at IWV Dependence and Scale Offset of Reference and BSRN Pyrgeos
IWV Dependence of Eppley Pyrgeos: Previous 3-Season Meas from PMOD/WRC Archive

PMOD/WRC
PIR 29434

Too few measurements for IWV>10 mm
IWV Dependence of Eppley Pyrgeos: Previous 3-Season Meas from PMOD/WRC Archive

PMOD/WRC
PIR 29434
Too few measurements for IWV>10 mm

NREL
PIR 31197
Too few measurements for IWV>10 mm
IWV Dependence of K&Z Pyrgeos: Previous 3-Season Meas from PMOD/WRC Archive

**DWD**
**CGR4 060028**
Too few measurements for IWV>5 mm

**NREL**
**CG4 060881**
Too few measurements for IWV>10 mm

**BOM**
**CG4 060921**
Too few measurements for IWV>10 mm

**WISG Calib**

**WISG₅ Calib**

**IRIS Calib**

**WISG₅ meas. only available after Feb. 2008**

**IRIS outdoor meas. only available after June 2008**
IWV Dependence of **K&Z Pyrgeos**: Previous 3-Season Meas from PMOD/WRC Archive

**K&Z Ref**
CG4 010536

- 2011 and 2015 periods combined
- New dome since 2005

**K&Z Ref**
CGR4 100280
IWV Dependence of K&Z Pyrgoeos: Previous 3-Season Meas from PMOD/WRC Archive

JMA CGR4 070037
WISG Calib

JMA CGR4 070038
WISG\textsubscript{5} Calib

JMA CGR4 070039
IRIS Calib

Too few measurements for the whole IWV range
IWV Dependence of K&Z Pyrgeos: Previous 3-Season Meas from PMOD/WRC Archive

**SMHI**
CGR4 110349

**SMHI**
CGR4 110350

**MCH**
CGR4 110355

BSRN pyrgeo at PAY

Measurements are ongoing at PMOD to obtain data for a full 3-season calibration. Graphs show status up to Feb. 2016.
IWV Dependence of Pyrgeos: Summary of 3-Season Meas at PMOD/WRC

<table>
<thead>
<tr>
<th></th>
<th>Meas &gt;90 days</th>
<th>Meas &gt;90 days AND Meas over IWV = 2 – 25 mm range</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIR</td>
<td>7</td>
<td>4&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>CG(R)4</td>
<td>21</td>
<td>14&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup> (1 Customer, 2 WISG, 1 PMOD/WRC), <sup>b</sup> (10 Customer, 2 WISG, "WISG5" and "WISG6")

- Autumn-Winter-Spring period long enough but very often too few valid data points to fully characterise IWV dependence of pyrgeos.

- Characteristics of IWV dependence:
  - Range<sup>c</sup> of IWV dependence: IWV < ~10 mm
  - Slope of IWV dependence (IWV < 10 mm): -0.5 W.m⁻².mm⁻¹ (IWV)

- IWV dependence related to pyrgeo dome, but comprehensive explanation still missing. Spectral dome transmission? Dome coating?

<sup>c</sup> The range IWV < 2 mm not observed at PMOD/WRC. Is linear or exponential behavior expected? No BSRN station with simultaneous PIR/pre-2003 CG4 and CG4(R)4 and with low potential IWV found so far.
More pyrgeos, especially PIR, should have longer meas (preferably >2 years) to better characterise/confirm IWV dependence. Other stations* may have simultaneous PIR/pre-2003 CG4 and post-2004 CG(R)4 meas?

Is a "general" correction for IWV dependence possible?

We believe so, despite some variability.

Unlikely that BSRN pyrgeos will be sent to PMOD/WRC for a 3-season calib → general IWV correction is only realistic option.

All 188 PIR and 10 CG4 BSRN pyrgeos are most prob. affected.

* Following have submitted PIR and CG4 to BSRN but presently unknown whether meass were simultaneous (CAR, LAU, LER, PAY, SYO, TAT).
Scale Offset of Pyrgeos: WISG and IRIS Long-Term Measurements

- PIR and pre-2003 CG4
  Up to +4 W.m\(^{-2}\) too high when IWV >10 mm
  (latest 2011-2015 data)

- IRIS and post-2003 CG4
  Results to within ±1 W.m\(^{-2}\)

- Necessary to keep WISG as a transfer standard as:
  IRIS/ACP/… are not "all-weather" radiometers.

**Gröbner et al. (JGR, 2015)**

**Table 2. Summary of the Dependence of the WISG Pyrgeometers With Respect to IRIS4 obtained From Measurements Spanning the Period August 2011 to December 2013**

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Offset (IWV &gt;10 mm) (W m(^{-2}))</th>
<th>Slope (IWV &lt;10 mm) (W m(^{-2})IWV(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>WISG 1</td>
<td>-6.1</td>
<td>-0.52</td>
</tr>
<tr>
<td>WISG 2</td>
<td>-4.7</td>
<td>-0.21</td>
</tr>
<tr>
<td>WISG 3</td>
<td>-5.5</td>
<td>-0.45</td>
</tr>
<tr>
<td>WISG 4</td>
<td>-4.5</td>
<td>-0.55</td>
</tr>
<tr>
<td>WISG</td>
<td>-5.1</td>
<td>-0.42</td>
</tr>
</tbody>
</table>

**Table 3. Operational and Suggested Sensitivities of the WISG Pyrgeometers as Retrieved for the Period August 2011 to December 2013 With Respect to IRIS4**

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Operational Sensitivity (µV W(^{-1}) m(^{-2}))</th>
<th>Offset IWV &gt;10 mm cm IWV</th>
<th>Slope/1 cm IWV</th>
<th>Maximal Relative Change in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>WISG 1</td>
<td>3.53</td>
<td>-0.25</td>
<td>-5.3</td>
<td></td>
</tr>
<tr>
<td>WISG 2</td>
<td>3.28</td>
<td>-0.14</td>
<td>-3.0</td>
<td></td>
</tr>
<tr>
<td>WISG 3</td>
<td>12.3</td>
<td>-1.0</td>
<td>-6.1</td>
<td></td>
</tr>
<tr>
<td>WISG 4</td>
<td>9.59</td>
<td>-0.75</td>
<td>-5.9</td>
<td></td>
</tr>
</tbody>
</table>

*The slope of the new sensitivities are given per 10 mm IWV, while the relative changes are calculated for the lowest observed IWV at Daros of 2 mm.*
Scale Offset of Pyrgeos: Conclusions wrt BSRN

- Only WISG$_{1-4}$ and WISG$_{5-6}$ have long-term measurements wrt IRIS.
- A scale correction can be applied by using the WISG as a re-calibrated transfer standard wrt IRIS/ACP/XYZ (WISG$_{IRIS}$).
- Calculate new sensitivity $C$ using raw data from previous PMOD/WRC calibrations.
- All 188 BSRN PIR pyrgeos are assumed to be affected.
- All 35 BSRN CG(R)4 pyrgeos are assumed to be affected.
Pyrgeo Stability and Traceability
Pyrgeo Calib Stability from PMOD/WRC Archives:
Sensitivity C Calculated with Albrecht Eq

- Albrecht eq \((k1=0, k2=1, k3=\text{constant for PIR})\). Vertical bars = uncert. (3.5%).

- Ref pyrgeos or those with a long calibration history are shown. Others include:

  **AWI Potsdam**
  - PIR 28858, 28859, 28895, 28897

  **SURFRAD**
  - PIR 29255, 29257, 29258

  **WISG**
  - PIR 31463, 31464
  - CG4 FT004, CG4 010535

  **K&Z**
  - CG4 010536

- Ref pyrgeos from large institutes calib at PMOD/WRC on a regular basis ie 1 – 3 yrs.

- However, most pyrgeos calibrated every 2 – 5 yrs or on sporadic basis.
How Good has Transfer of WISG Calibration been to Commercial Pyrgeometers?

An estimate for CG(R)4 by comparing original K&Z with first WISG calibration.

- Calib procedures? … Not really.
  - PMOD/WRC: clear sky/partially cloudy night-time.
  - K&Z: night-time, clear (net LR > -40 W.m⁻²).
- Sensor degredation? Not really.
  - WISG CG4s illustrate drift «1%/year
- Scale changes before WISG established?
- IWV issues during any part of the "traceability chain".
- Recent improvements (now +/- 1.5%) due to:
  - Intro of IWV criterion at PMOD/WRC since Apr. 2012.
  - K&Z intro of stricter QC procedures has helped reduce the standard deviation.

* Eppley ref and WISG comparison conducted during IPCs but lack of new Eppley PIR calibrated at PMOD/WRC prevents a more comprehensive overview.

NOTE: Only WISG calibs CG4 and CGR4s (N=17, 42; no multiple entries) within 3 years of orig. K&Z calib incl. using Albrecht eq (ie \(k_1=0, k_2=1\)). Only 4 pyrgeos are in BSRN.

NOTE: 3-season = calibration period during autumn-winter-spring
Updating BSRN Long-Wave Time-Series
BSRN Long-Wave Radiation Archives: Possible Procedure to Update Time-Series

- If BSRN pyrgeos not traceable to WISG then correction not possible.

- If BSRN pyrgeos are traceable:
  - PMOD/WRC re-determines pyrgeometer sensitivity $C$ wrt $WISG_{IRIS}$, using previous calibration data.
  - BSRN Users re-calculate long-wave time-series using new sensitivity $C$ based on $WISG_{IRIS}$.
  - If pyrgeos have an IWV dependence, then apply correction to long-wave time-series based on IWV time-series.

- Submit corrected time-series to BSRN, and adhere to the BSRN archiving guidelines … Easy/difficult … probably controversial ???

- However, at this early stage, emphasis on procedures rather than application of corrections.
Outlook for Current Project (Finish Dec. 2016)

- Publish findings and present report to CIMO Task Group.
- Feedback from the BSRN community is very welcome !!!

Thanks for your attention
Extra Slides
What are the Consequences of Adopting the IRIS/ACP/XYZ as new Transfer Standards?

Global Radiation Budget

- DLR would potentially increase by +4.0 W.m\(^{-2}\) (clear-sky, IWV>10 mm) but cloudiness occurs at almost all stations except perhaps at eg Alice Springs(!)

- Next Task: Obtain raw data and IWV climatology for several representative stations, and re-calculate DLR time-series.

- Final Task: Possibly see if Martin Wild could run a preliminary Surface Budget experiment to see the effect (if any).
What are the Consequences of Adopting the IRIS/ACP/XYZ as new Transfer Standards?

Global Radiation Budget

[Figure from IPCC 2013].