Recovering longwave irradiance tainted with bad thermistor data

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Pyrgeometer case and dome temperatures need to be measured correctly and accurately.

\[ LW = \frac{\text{Thermopile voltage}}{C} + \sigma T_c^4 - k\sigma (T_d^4 - T_c^4) \]

- **Clear**: ~18% ~81% ~1%
- **Overcast**: ~7% ~93% < 1%
LW irradiance errors associated with bad up-looking pyrgeometer case temperatures

Goodwin Creek station, 11 Nov. 2015, 1822 UTC
Actual Downwelling IR irradiance is 365.33 Wm\(^{-2}\)
Actual case temp = 300.93 K
Actual dome temp = 300.36 K

<table>
<thead>
<tr>
<th>CaseT_ERR(K)</th>
<th>DomeT_ERR(K)</th>
<th>Rad ERR (Wm(^{-2}))</th>
<th>Rad_ERR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>+0.1</td>
<td>0.0</td>
<td>2.214</td>
<td>0.606</td>
</tr>
<tr>
<td>+0.2</td>
<td>0.0</td>
<td>4.430</td>
<td>1.213</td>
</tr>
<tr>
<td>+0.3</td>
<td>0.0</td>
<td>6.649</td>
<td>1.820</td>
</tr>
<tr>
<td>+0.4</td>
<td>0.0</td>
<td>8.869</td>
<td>2.428</td>
</tr>
<tr>
<td>+0.5</td>
<td>0.0</td>
<td>11.092</td>
<td>3.036</td>
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<tr>
<td>+0.6</td>
<td>0.0</td>
<td>13.317</td>
<td>3.645</td>
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<tr>
<td>+0.7</td>
<td>0.0</td>
<td>15.544</td>
<td>4.255</td>
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<tr>
<td>+0.8</td>
<td>0.0</td>
<td>17.774</td>
<td>4.865</td>
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<tr>
<td>+0.9</td>
<td>0.0</td>
<td>20.006</td>
<td>5.476</td>
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<tr>
<td>+1.0</td>
<td>0.0</td>
<td>22.240</td>
<td>6.088</td>
</tr>
</tbody>
</table>
LW irradiance errors associated with bad up-looking pyrgeometer dome temperatures

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Actual Downwelling IR irradiance is 365.33 Wm⁻²
Actual case temp = 300.93 K
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</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>+0.1</td>
<td>-1.587</td>
<td>-0.434</td>
</tr>
<tr>
<td>0.0</td>
<td>+0.2</td>
<td>-3.175</td>
<td>-0.869</td>
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<tr>
<td>0.0</td>
<td>+0.3</td>
<td>-4.765</td>
<td>-1.304</td>
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<tr>
<td>0.0</td>
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<td>-1.740</td>
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<td>-2.176</td>
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<td>-2.612</td>
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<td>+0.7</td>
<td>-11.139</td>
<td>-3.049</td>
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<tr>
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<td>-3.486</td>
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<tr>
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<td>+0.9</td>
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<td>-3.924</td>
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<tr>
<td>0.0</td>
<td>+1.0</td>
<td>-15.937</td>
<td>-4.362</td>
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</tbody>
</table>
Motivation

- Subtle pyrgeometer thermistor problems can go unnoticed for months.

- Problems persist when thermistor errors are typically small (< 1°C) and not readily perceptible in data QC.

- Small thermistor temperature errors can result in significant longwave irradiance errors.

- The ability to recover LW data tainted by bad thermistor measurements serves to preserve BSRN long term data records.
Normal pyrgeometer thermistor data

Desert Rock, Nevada, United States (DRA)
16 December 2015

Temperature (°C)

Hour of Day (UTC)
A strange reversal of the normal case - dome temperature order of the up-viewing pyrgeometer

Fort Peck 10 Dec. 2000

Which thermistor is bad?

This problem persisted for seven months
Premise of the correction method:

Pyrgeometer case – dome temperature difference is correlated with the thermopile signal.

Very cold atmosphere
Thermopile signal largely negative
$T_{\text{dome}} < T_{\text{case}}$

Cool cloud base
Thermopile signal negative but small
$T_{\text{dome}} \sim T_{\text{case}}$
Up-looking pyrgeometer case-dome temperature difference versus the thermopile signal


$T_c - T_d = -0.0055$ (thermopile signal) - 0.02541

$T_c - T_d = -0.00078$ (thermopile signal) + 0.3096

$T_c - T_d = -0.02311$ (thermopile signal) - 0.14146

Wet mode:
$T_c - T_{sky_{BB}} < 6^\circ K$

Wet:
$RH > 80%$
Bad dome temperatures in both pyrgeometers

26–Oct–2015
SURFRAD Goodwin Creek
LW signals before correction

26–Oct–2015
SURFRAD Goodwin Creek
Up-looking pyrgeometer case-dome temperature difference versus the thermopile signal

Goodwin Creek 2 Jul – 29 Aug 2015

\[ T_c - T_d = -0.0092 \text{ (thermopile signal)} - 0.37445 \]

\[ T_c - T_d = -0.00373 \text{ (thermopile signal)} + 0.14578 \]

\[ T_c - T_d = -0.01305 \text{ (thermopile signal)} + 0.10503 \]
Down-looking pyrgeometer case-dome temperature difference versus the thermopile signal

Goodwin Creek 2 Jul – 29 Aug 2015

\[ T_c - T_d = -0.00514 \text{ (thermopile signal)} - 0.07414 \]

\[ T_c - T_d = -0.00622 \text{ (thermopile signal)} - 0.11997 \]

\[ T_c - T_d = -0.00656 \text{ (thermopile signal)} - 0.11488 \]
Corrected dome temperatures

26–Oct–2015

SURFRAD Goodwin Creek
LW signals after correction

26–Oct–2015
SURFRAD Goodwin Creek

Watts/m²

Hour (UTC)

0000 0200 0400 0600 0800 1000 1200 1400 1600 1800 2000 2200 0000

Downwelling infrared
Upwelling infrared
Error assessment of correction method

Up-looking pyrgeometer
Bondville, period used: 1-June to 15 July 2005

\[
T_c - T_d = -0.00643 \text{ (thermopile signal)} - 0.38277
\]

\[
T_c - T_d = -0.00234 \text{ (thermopile signal)} + 0.10492
\]

\[
T_c - T_d = -0.01678 \text{ (thermopile signal)} - 0.07217
\]
Errors associated with predicted case and dome temperatures for a up-looking pyrgeometer

Bondville 24-Jul-2005

Mean LW error (new $T_d$) = 0.63% ± 0.6%
Mean LW error (new $T_c$) = 0.87% ± 0.8%
Error assessment of correction method for a down-looking pyrgeometer

Bondville, period used: 1-June to 15 July 2005

$T_c - T_d = -0.00463$ (thermopile signal) – 0.06774

$T_c - T_d = -0.00947$ (thermopile signal) – 0.15388

$T_c - T_d = -0.00672$ (thermopile signal) – 0.05825
Errors associated with predicted case and dome temperatures for a down-looking pyrgeometer

Bondville 24-Jul-2005

Mean T_d error = -0.125% ±0.6% (2σ)
Mean LW error (new T_d) = -0.13% ±0.6%
Mean LW error (new T_c) = -0.17% ±0.9%
Summary of method

- Determine which pyrgeometer thermistor is bad

- Use a period of good operation to develop relationship between the case-dome temperature difference and the thermopile signal (relationships are site and instrument dependent)

- Develop linear models of the case-dome temperature difference versus the thermopile signal separately for clear mode, cloudy mode, and wet mode

- Reprocess the pyrgeometer data substituting the predicted case or dome temperature for the bad measurements
Thank You

Questions?