Recalibrating HIRS Sensors to Produce a 30 year Record of Radiance Measurements Useful for Cloud and Moisture Trend Analysis

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Recalibrating HIRS
Accommodating Orbit Drift
TPW and UTH Trends
CTP Results

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HIRS Recalibration

Mitigating sensor to sensor differences

Recalibrating Metop HIRS using IASI

Recalibrating all prior HIRS using Metop HIRS or IASI as a reference
(at Simultaneous Nadir Overpasses adjust for radiance differences beyond those caused by known SRF differences)
### Measurements from 16 HIRS sensors in use for 30+ year cloud study

<table>
<thead>
<tr>
<th>Morning (8 am LST)</th>
<th>Desc Node Times</th>
<th>Night (2 am LST)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOAA 6 HIRS/2</td>
<td></td>
<td>NOAA 5 HIRS</td>
</tr>
<tr>
<td>NOAA 8 HIRS/2</td>
<td></td>
<td>NOAA 7 HIRS/2</td>
</tr>
<tr>
<td>NOAA 10 HIRS/2</td>
<td></td>
<td>NOAA 9 HIRS/2</td>
</tr>
<tr>
<td>NOAA 12 HIRS/2</td>
<td></td>
<td>NOAA 11 HIRS/2I *</td>
</tr>
<tr>
<td>NOAA 15 HIRS/3</td>
<td></td>
<td>NOAA 14 HIRS/2I *</td>
</tr>
<tr>
<td>NOAA 17 HIRS/3</td>
<td></td>
<td>NOAA 16 HIRS/3</td>
</tr>
<tr>
<td>METOP-A HIRS/4</td>
<td></td>
<td>NOAA 18 HIRS/4 +</td>
</tr>
<tr>
<td>METOP-B HIRS/4</td>
<td></td>
<td>NOAA 19 HIRS/4</td>
</tr>
</tbody>
</table>

Before HIRS/2I ch 10 is at 8.6 um, thereafter it is at 12.5 um. HIRS/3 improved S/N.

* indicates orbit drift from 14 UTC to 18 UTC over 5 years of operation. Before HIRS/4 FOV is 20 km FOV; thereafter it is 10 km. + indicates excessive noise in LW channels. Local Time of descending node equator crossing is shown below along with operational transfer dates.
Accuracy Requirements of the Climate Observing System

The length of time required to detect a climate trend caused by human activities is determined by:

- Natural variability
- The magnitude of human driven climate change
- The accuracy of the observing system
SRFs of CO2 channels for NOAA/Metop satellites
- SRF of HIRS ch12 for NOAA/MetOp satellites (left axis), an IASI spectra (right axis)
- Differences can be seen between HIRS/2, HIRS/3, and HIRS/4
Corrected of blackbody bias (0.14 K), SRFs (shifted -0.13, 0.09, -0.15 cm<sup>-1</sup> for Ch 4, 5, and 7), and calibration non-linearity term.

Validated with 16 months sampled MetOp data (the fifth orbit of each day)

Both mean bias and bias variation (both T- and non T-dependent) are significantly reduced ( < 0.1K )
Toward an Integrated System for Intersatellite Calibration of POES using the SNO Method

N15 & N16 (+) and N16 & N17 (X)
SNO locations from 2000 to 2003

SNO: Simultaneous Nadir Overpass
Impact of spectral shift on inter-satellite radiance (or BT) difference depends on atmospheric state at time of measurements.

IASI-simulated HIRS data are used to develop linear models to estimate impacts of SRF shifts (and differences) on inter-satellite radiance differences for various atmospheric conditions;

For channel $i$ and satellite $m$ a shift of $\Delta SRF$ will produce a radiance change $\Delta R_{im} = \Delta SRF \left[ \sum_j a_{ijm} R_{jm} + c_{im} \right]$ where $j$ sums the HIRS CO2 channels 2 – 7, IRW channel 8, and H2O channel 12 (these are used to estimate the atmospheric state for a given SNO).
Ch 5 original

Ch 5 after SRF shifts
IASI-simulated HIRS data are used to develop linear models to estimate impacts of SRF differences and shifts on inter-satellite radiance biases for various atmospheric conditions.

After accounting for pre-launch SRF differences, inter-satellite biases are recalculated.

Optimized SRF shifts (as large as 4 cm⁻¹) minimize RMS of biases to less than 1%.
## CO2 and H2O HIRS spectral shifts

<table>
<thead>
<tr>
<th></th>
<th>Ch4(14.2)</th>
<th>Ch5(13.9)</th>
<th>Ch7(13.3)</th>
<th>Ch12(6.7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hirs2n06 V</td>
<td>0.31</td>
<td>0.7</td>
<td>0.7</td>
<td>1.1</td>
</tr>
<tr>
<td>Hirs2n07 V</td>
<td>-0.18</td>
<td>0.1</td>
<td>1.2</td>
<td>-0.46</td>
</tr>
<tr>
<td>Hirs2n09 H</td>
<td>0.43</td>
<td>2.66</td>
<td>-0.48</td>
<td>1.1</td>
</tr>
<tr>
<td>Hirs2n10 H</td>
<td>0.95</td>
<td>1.56</td>
<td>-0.93</td>
<td>3.0</td>
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<tr>
<td>Hirs2n11 H</td>
<td>1.72</td>
<td>2.05</td>
<td>0.15</td>
<td>4.2</td>
</tr>
<tr>
<td>Hirs2n12 H</td>
<td>0.47</td>
<td>2.23</td>
<td>-2.06</td>
<td>4.1</td>
</tr>
<tr>
<td>Hirs2n14 H</td>
<td>1.97</td>
<td>3.13</td>
<td>1.22</td>
<td>4.1</td>
</tr>
<tr>
<td>Hirs3n15 I</td>
<td>-0.21</td>
<td>0.27</td>
<td>1.01</td>
<td>0.6</td>
</tr>
<tr>
<td>Hirs3n16 I</td>
<td>0.22</td>
<td>0.62</td>
<td>0.47</td>
<td>0.8</td>
</tr>
<tr>
<td>Hirs3n17 I</td>
<td>0.54</td>
<td>0.72</td>
<td>0.44</td>
<td>-0.3</td>
</tr>
<tr>
<td>Hirs4n18 I</td>
<td>-0.71</td>
<td>-0.37</td>
<td>-0.49</td>
<td>3.3</td>
</tr>
<tr>
<td>Hirs4n19 I</td>
<td>-0.00</td>
<td>-0.12</td>
<td>0.10</td>
<td>0.7</td>
</tr>
<tr>
<td>Hirs4moa I</td>
<td>-0.15</td>
<td>0.10</td>
<td>-0.15</td>
<td>2.2</td>
</tr>
<tr>
<td>Hirs4mob I</td>
<td>-1.21</td>
<td>-0.43</td>
<td>-0.54</td>
<td>0.0</td>
</tr>
</tbody>
</table>

V indicates intercal with VAS, H with later HIRS, and I with IASI directly.
Accommodating Orbit Drift

Dividing the day into four segments
(with sunlight before and after noon; without sunlight before and after midnight)
Equatorial Crossing Times / Operational Transfer Dates for NOAA

Operational Transfer Dates

Updated on 12/03/2013 09:49
Dividing the Day into 4 Time Periods

Morning $\text{SZA} \leq 85^\circ$ and Local Time Before Noon
Afternoon $\text{SZA} \leq 85^\circ$ and Local Time After Noon
Evening $\text{SZA} > 85^\circ$ and Local Time Before Midnight
Night $\text{SZA} > 85^\circ$ and Local Time After Midnight

Accounting for and taking advantage of orbit drift
NOAA CDR of monthly mean TPW; 2009 January, morning (0–12h)
NOAA CDR of monthly mean TPW; 2009 January, evening (12–24h)
NOAA CDR of monthly mean TPW; 2009 January, night (0–12h)

Total Precipitable Water [mm]

Data Min = 0.0, Max = 103.9, Mean = 23.2
Upper Tropospheric/Lower Stratospheric (UTLS) Cloud Frequency

UTLS Frequency in Percent

Morning June 2006
SZA <= 85° and Local Time Before Noon
Spatial Resolution is 0.5° Equal Angle
Upper Tropospheric/Lower Stratospheric (UTLS) Cloud Frequency

UTLS Frequency in Percent
Afternoon June 2006
SZA <= 85° and Local Time After Noon
Spatial Resolution is 0.5° Equal Angle
Upper Tropospheric/Lower Stratospheric (UTLS) Cloud Frequency

UTLS Frequency in Percent

Evening June 2006
SZA > 85° and Local Time Before Midnight
Spatial Resolution is 0.5° Equal Angle
Upper Tropospheric/Lower Stratospheric (UTLS) Cloud Frequency

UTLS Frequency in Percent

Night June 2006

SZA > 85° and Local Time After Midnight
Spatial Resolution is 0.5° Equal Angle
HIRS High Cloud Detection Trends

Comparing N11 and N14
Different ratios reveal cloud properties at different levels

hi - 14.2/13.9  
mid - 13.9/13.6  
low - 13.6/13.3

Meas          Calc

\[
\begin{align*}
(p_c - I_{\lambda_1} - I_{\lambda_1}^{\text{clr}}) &= \frac{\eta \varepsilon_{\lambda_1} \int \tau_{\lambda_1} \, d\lambda_{\lambda_1}}{p_s} \\
\text{-----------------} &= \text{-----------------} \\
(p_c - I_{\lambda_2} - I_{\lambda_2}^{\text{clr}}) &= \frac{\eta \varepsilon_{\lambda_2} \int \tau_{\lambda_2} \, d\lambda_{\lambda_2}}{p_s} \\
\end{align*}
\]

if \((I_\lambda^{\text{clr}} - I_\lambda) < \Delta\) then IRW is used
High Cloud Frequencies from HIRS Observations

Morning Tropics (30S-30N Latitude)

Afternoon Tropics (30S-30N Latitude)

Evening Tropics (30S-30N Latitude)

Nighttime Tropics (30S-30N Latitude)

morning

afternoon

evening

night

30 S – 30 N
High Cloud Frequencies from HIRS Observations
Morning Northern Mid-Latitudes (30N–60N Latitude)

High Cloud Frequencies from HIRS Observations
Afternoon Northern Mid-Latitudes (30N–60N Latitude)

High Cloud Frequencies from HIRS Observations
Evening Northern Mid-Latitudes (30N–60N Latitude)

High Cloud Frequencies from HIRS Observations
Nighttime Northern Mid-Latitudes (30N–60N Latitude)

morning
afternoon
evening
night
HIRS TPW and UTH Trends

Comparing with Aqua MODIS
HIRS TPW and UTH is a statistical regression developed from the SeeBor data base (Borbas et al. 2005) that consists of geographically and seasonally distributed radiosonde, ozonesonde, and ECMWF ReAnalysis data. TPW are determined for clear sky radiances measured by HIRS over land and ocean both day and night. The retrieval approach is borrowed from MODIS (Seemann et al. 2003, Seemann et al. 2008). There is strong reliance on radiances from 6.5, 11, 12 μm.
<table>
<thead>
<tr>
<th>Time of Day</th>
<th>N11</th>
<th>N14</th>
<th>N16</th>
<th>N18</th>
<th>N19</th>
</tr>
</thead>
<tbody>
<tr>
<td>Night</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Morning</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Afternoon</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Evening</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Time series of TPW for Northern Mid-latitudes 1989 - 2010
Timeseries of N17/HIRS IWV high, middle and low over Daytime

HIRS IWV high over Daytime

HIRS IWV middle over Daytime

HIRS IWV low over Daytime

Red line: HIRS 30-60 S Latitude
Green line: HIRS 30-60 N Latitude
Blue line: HIRS -30-+30 Latitude
Timeseries of MYD07 IWV high, middle and low over Daytime

MYD07 IWV high over Daytime

MYD07 IWV middle over Daytime

MYD07 IWV low over Daytime

Legend:
- MODIS 30-60 S Latitude
- MODIS 30-60 N Latitude
- MODIS -30 - +30 Latitude
2008 La Nina Water Vapor 10 yr Anomaly
Conclusions

Regarding Recalibration
* Metop HIRS recalibration using IASI offers best HIRS reference
* Recalibration against reference HIRS mitigates but does not eliminate sensor to sensor differences
* Dividing the day into 4 time periods mitigates but does not eliminate effects of orbit drift

Regarding High Cloud Trends
* HIRS radiance data is being processed with MODIS CO2-slicing algorithm
* Afternoon cloud trends are affected by orbit drift
* Frequency of night time cloud is greater than that in afternoon (cloud mask issue??)
* 10 km FOV (HIRS4) sees fewer clouds than 20 km FOV (HIRS3 & HIRS2)
* N15 remains out of family
* Most HIRS to HIRS comparisons are in good agreement

Regarding H2O Trends
* Seasonal TPW cycle is strongest in northern mid-latitudes and weakest in tropics
* Seasonal TPW cycle is stronger in the afternoon than at night
* La Nina decrease in tropical TPW is evident
* Recalibrating IR split window needed to mitigate sensor to sensor TPW issues
* Decrease in TPW from 2002 to 2008 and increase after 2008 is suggested

Overall
* Processing whole HIRS record from 1978 onwards will reveal trends better
HIRS Northern Mid latitude (30N-60N)

Aqua/MODIS Northern Mid latitude (30N-60N - green)

S-NPP/VIIRS Northern Mid latitude (30N-60N – green)