CLARREO and IR Intercal

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CLARREO Science Meeting
Hampton, VA
6-9 July 2010
Outline

1. Overview of UW studies of CLARREO IR Intercal
2. Expected on-orbit radiometric calibration performance for NPP CrIS
3. AIRS / IASI Intercal: updated results
CLARREO Intercal Study;
Initial Question:

Given a candidate CLARREO mission optimized for producing the climate benchmark products, how well can we meet the CLARREO objective to serve as an inter-calibration reference for the operational IR sounders?

The goal is to be capable of performing the inter-calibration with uncertainty comparable to the CLARREO radiometric accuracy, for the benefit of the operational sounders for their (primarily weather driven) goals as well as their use to intercalibrate colocated imagers (e.g. AIRS/MODIS) and geo sensors (e.g. AIRS/GOES).
Study Approach:

A simulation study using real MODIS data.

Find Simultaneous Nadir Overpasses (SNOs) of CLARREO and EOS Aqua for 2006, and for each SNO use MODIS radiances to estimate the spatial and temporal sampling differences between CLARREO and CrIS/AIRS or IASI.

Opposed to actual inter-comparison studies involving two sensors, this approach removes the unknown sensor biases and allows spatial and temporal inter-calibration differences to be examined.
CLARREO/Aqua SNOs in 2006

Three 90-degree CLARREO orbits with right ascension separated by 120 degrees are “launched” on January 1st, and the SNOs for CLARREO and EOS Aqua are identified for the year of 2006.
Spatial Sampling Differences

“spatial difference” (K) = mean w/in CLARREO FOV minus mean w/in CrIS/IASI FOVs

“BT STDEV” (K) = Standard deviation w/in CLARREO FOV
Time Sampling Differences

“temporal difference” (K) = mean w/in CLARREO FOV minus mean w/in displaced FOV

11 µm MODIS BT (K)

(100 km FOVs every 16s)
Footprint Size

CLARREO

CrIS/AIRS

100 km

50 km

25 km
Sample Results

11 µm 1-sigma monthly intercal uncertainty vs. NEDT:

The results are generated using 30 sec sampling, 25 KM (diameter) FOV, and for each SNO allowing FOVs with less than 10 deg scan angles to be included in the intercal. The red curve is the monthly mean uncertainty for 2006, with each black curve representing the individual months.
Summary of CrIS FM1 (NPP) Radiometric Performance
Continuity of Polar Operational Satellite Programs

5/27/2010 POES Flyout Chart, NESDIS
CrIS Radiometric Uncertainty Spec

- **CrIS sensor Radiometric Specifications**
  Expressed as (1-sigma) percent radiance uncertainty with respect to Plank 287K radiance [i.e. $100 \cdot \Delta R/B(287K)$]:
  - Longwave: 0.45%
  - Midwave: 0.58%
  - Shortwave: 0.77%
  for $B(233K)$ to $B(287K)$
CrIS FM1 In-flight Radiometric Uncertainty

On-orbit radiometric calibration equation:

\[ R_{\text{Earth}} = Re\left\{ \frac{(C'_{\text{Earth}} - C'_{\text{Space}})}{(C'_{\text{ICT}} - C'_{\text{Space}})} \right\} (R_{\text{ICT}} - R_{\text{Space}}) + R_{\text{Space}} \]

with:

\[ R_{\text{ICT}} = \varepsilon_{\text{ICT}} B(T_{\text{ICT}}) + (1 - \varepsilon_{\text{ICT}}) R_{\text{ICT,Reflected}} \]
\[ R_{\text{Space}} = B(T_{\text{Space}}) \]
\[ C' = C (1 + 2 a_2 V_{DC}) \]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>1-(\sigma) uncertainty</th>
<th>3-(\sigma) uncertainty</th>
<th>Source/Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>(T_{\text{ICT}}) (K)</td>
<td>37.5 mK</td>
<td>112.5 mK</td>
<td>Bomem/ITT eng. estimate (w/o known readout issue)</td>
</tr>
<tr>
<td>(\varepsilon_{\text{ICT}}) ( )</td>
<td>0.01</td>
<td>0.03</td>
<td>Independent measurement (TSSR) at 2500 cm(^{-1}) plus Analysis</td>
</tr>
<tr>
<td>(T_{\text{refl,measured}}) (K)</td>
<td>0.5 K</td>
<td>1.5 K</td>
<td>Temperature monitored components (Frame, OMA, BS, ICT Baffle)</td>
</tr>
<tr>
<td>(T_{\text{refl,modelled}}) (K)</td>
<td>2 K</td>
<td>6 K</td>
<td>Worst case estimate of unmonitored SSM Baffle T variations</td>
</tr>
<tr>
<td>(a_2) (1/counts)</td>
<td>9.6% Longwave 15.5% Midwave</td>
<td>28.8% Longwave 46.5% Midwave</td>
<td>DM and ECT view analysis</td>
</tr>
</tbody>
</table>

Other contributions, such as scan mirror polarization and stray light, are not included here. Other studies, by ITT, show these do not contribute significantly to the total RU.
FM1 ICT emissivity

UW analysis of CrIS PQH@315K dataset to derive ICT emissivity and uncertainty:

ICT emissivity retrieval uncertainty simulation
$T_{ECT} = T_{ICT} = 310K, T_{BG} = 318K, T_{ST} = 107K$

- $dT_{ECT} = 0.05K$
- $dT_{ICT} = 0.05K$
- $dT_{BG} = 1K$
- $dT_{ST} = 3K$
- RSS

1%

- FM1 ICT emissivity
- TSSR (0.976 +/- 0.006)
Reflected Component of Predicted ICT Radiance

The predicted ICT Radiance, used in the calibration equation, is:

\[ R_{ICT} = \varepsilon_{ICT} B(T_{ICT}) + (1 - \varepsilon_{ICT}) R_{ICT,Reflected} \]

where \((1 - \varepsilon_{ICT}) R_{ICT,Reflected}\) is the reflected term. Contributions to \(R_{ICT,Reflected}\) fall into three groups:

1. Ambient temperature components with active temperature sensors, accounting for \(~47.5\%\) view factor.
2. Near ambient temperature components without representative temperature monitoring, accounting for \(~50.8\%\) view factor. ITT thermal modeling predicts orbital variation of \(~5.5K\) peak-to-peak variation in this component.
3. Cold view components, accounting for \(~1.8\%\) view factor.

We put the full range of this expected variation into the uncertainty budget, even though the SDR algorithm will include orbital/thermal model estimates.
Summary of non-linearity correction coefficients, $a_2$

1-sigma uncertainty is computed from the variability of the various estimates: 9.6% for LW, 15.5% for MW.
CrIS FM1 In-flight Radiometric Uncertainty: Examples for FOVs 7 and 9 for ECT@287K
CrIS FM1 In-flight Radiometric Uncertainty: 
versus scene temperature for all FOVs for ~mid-band spectral channels
CrIS FM1 TVAC Testing Radiometric Uncertainty

TVAC calibration equation for ECT view:
\[
R_{ECT} = Re\{(C'_{ECT} - C'_{ST})/(C'_{ICT} - C'_{ST})\}(R_{ICT} - R_{ST}) + R_{ST}
\]

with:
\[
\begin{align*}
R_{ST} &= \varepsilon_{ST} B(T_{ST}) + (1-\varepsilon_{ST}) B(T_{ST,Reflected}) \\
R_{ICT} &= \varepsilon_{ICT} B(T_{ICT}) + (1-\varepsilon_{ICT}) R_{ICT,Reflected} \\
C' &= C (1+2a_2V_{DC})
\end{align*}
\]

TVAC “truth”: ECT view predicted:
\[
R_{ECT} = \varepsilon_{ECT} B(T_{ECT}) + (1-\varepsilon_{ECT}) B(T_{ECT,Reflected})
\]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>1-\sigma uncertainty</th>
<th>3-\sigma uncertainty</th>
<th>Source/Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>(T_{ECT}) (K)</td>
<td>200-310 K</td>
<td>29.7 mK</td>
<td>89.1 mK</td>
<td>Bomem/ITT estimate recent new Hart/UW absolute cal info, and without spatial gradients</td>
</tr>
<tr>
<td>(\varepsilon_{ECT})</td>
<td>0.9995</td>
<td>0.0003</td>
<td>0.0009</td>
<td>Bomem report</td>
</tr>
<tr>
<td>(T_{ECT,Reflected}) (K)</td>
<td>(T_{ICT})</td>
<td>3 K</td>
<td>9 K</td>
<td>Conservative estimate</td>
</tr>
<tr>
<td>(T_{ST}) (K)</td>
<td>105 K</td>
<td>2 K</td>
<td>6 K</td>
<td>Conservative estimate</td>
</tr>
<tr>
<td>(\varepsilon_{ST})</td>
<td>0.9995</td>
<td>0.0003</td>
<td>0.0009</td>
<td>Bomem report</td>
</tr>
<tr>
<td>(T_{ST,Reflected}) (K)</td>
<td>(T_{ICT})</td>
<td>3 K</td>
<td>9 K</td>
<td>Conservative estimate</td>
</tr>
</tbody>
</table>
CrIS FM1 TVAC Testing Radiometric Uncertainty

900 cm\(^{-1}\)

1500 cm\(^{-1}\)

2350 cm\(^{-1}\)

\(3\sigma\) BT RU (K)

BT (K)

CrIS In-flight RU

TVAC RU
Evaluation of IASI and AIRS Spectral Radiances using Simultaneous Nadir Overpasses
**SNOs**

- “Simultaneous” “Nadir” Overpasses of AIRS and IASI
- SNOs based on the intersections of nadir ground tracks of METOP-A and Aqua (i.e. exact SNO locations)
- IASI and AIRS FOV selections for each SNO:
  - Time window: +/- 20 min from SNO time
  - Spatial window: 60 km from Nadir track intersection point to center of IASI/AIRS FOVs
- Resulting in:
  - ~45 AIRS FOVs, ~16 IASI FOVs per SNO
  - ~32 SNOs every ~3 days (16 North, 16 South)
  - 8102 SNOs in this study, covering May 2007 to Nov 2009
SNO characteristics

locations

+73.94°

-73.94°

timing

lat

day

07/01
07/08

seasons

Solar zenith angle

Northern SNOs

Southern SNOs

year

2007
2008
2009
2010
Sample SNO

Nadir track intersection location and 60 km radius

AIRS FOVs (L1B v5.0.0.0)

IASI FOVs
Mean Spectra

BT (K)

wavenumber

AIRS

BT (K)

wavenumber

IASI

 BT (K)
Sample spectral channel, 900.3 cm$^{-1}$

- AIRS
- IASI

IASI - AIRS
Spatial Sampling Differences

MODIS Band 31@11\textmu m; 100km CLARREO FOVs every 14s; CrIS/AIRS

Yes, Gaussian.
Analysis Approach

- For each SNO, the AIRS FOVs within 60 km of the SNO location are identified and the mean (MN) and standard deviation (SD) radiance spectra are computed. The same is done for IASI.
- For each SNO, the spectra are processed to have common spectral resolution and sampling and the difference between AIRS and IASI is computed
  \[ \delta_i = \text{MN}'_{\text{AIRS},i} - \text{MN}'_{\text{IASI},i} \]
- The resulting primary source of comparison error for each SNO case is due to the difference in the sparse sampling of the scene radiance provided by AIRS (nearly contiguous 3x3 FOVs) and IASI (non-contiguous 2x2 FOVs). The 1-sigma uncertainty for each SNO case is therefore computed as
  \[ \sigma_i = \sqrt{\text{SD}'_{\text{IASI},i}^2 + \text{SD}'_{\text{AIRS},i}^2} \]
- For ensembles of SNOs, the spatial sampling differences are found to be random from case to case. The mean differences between AIRS and IASI and their uncertainties are computed using weighted mean differences using the spatial standard deviations to compute the weights for each case:
  - Weights: \[ \omega_i = 1/\sigma_i^2 \]
  - Mean Difference: \[ \Delta = \sigma_\Delta^2 \left[ \sum_{i=1:N} \omega_i \delta_i \right] \]
  - Uncertainty: \[ \sigma_\Delta = \left[ \sum_{i=1:N} \omega_i \right]^{-\frac{1}{2}} \]
Sample SNO, #48

48 SNO_20070526_0513.hdf

Mean spectra

Standard deviation

wavenumber (cm\(^{-1}\))
Sample SNO, #157

Mean spectra

Standard deviation

wavenumber (cm\(^{-1}\))
Sample SNO, #180

Mean spectra

Standard deviation

wavenumber (cm$^{-1}$)
Mean difference is 150 mK (!)

Slope is 0.9 +/- 5.6 (1 sigma) mK/year (!!)
Mean Spectral Residuals

North SNOs

South SNOs
Mean Spectral Residuals

North SNOs

South SNOs
Summary

Radiometric accuracy and stability is important for operational IR sounder applications.

The radiometric calibration performance of today’s high spectral resolution IR sounders is very good (better than requirement), yet there is room for improvement.

CLARREO has the potential to improve upon this by serving as a reference for intercalibration.