Results of Calibration/Validation efforts for the Cross-track Infrared Sounder (CrIS) on Suomi-NPP

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Hyères Les Palmiers, France
LEO (& Aircraft) Sounders

1978-
HIRS (20 ch)

1986-
HIRS, S-HIS, NAST-I

1990/91
ITS (~CrIS) UW/EUMETSAT Design Study

2002-
AIRS (2378 ch)

2006-
IASI (8461 ch)

2011-
CrIS (2211 ch)

1330 Suomi-NPP

0930 METOP-A

1330 Aqua

1986-
1990/91

1978-
**Spectral Coverage and Resolution Comparison**

- **AIRS:** 2002-
- **IASI:** 2006-
- **CrIS:** 2012-
- **CrIS:** 6/2013- Full Resolution

- AIRS: 2002-
- IASI: 2006-
- CrIS: 2012-
- CrIS: 6/2013-

**Legend:**
- L1B: > 1200 Resolving Power
  9 FOV/50km square
- L1C: ±2 cm OPD
  Gaussian apodized
  4 FOV/50km square
- ±0.8, 0.4, 0.2 cm OPD unapodized
  9 FOV/50km square
- ±0.8 cm OPD unapodized
  9 FOV/50 km square

**Wavenumber:**
- 600
- 800
- 1000
- 1200
- 1400
- 1600
- 1800
- 2000
- 2200
- 2400
- 2600
- 2800

**Resolutions:**
- Full Resolution
  ±0.8 cm OPD unapodized
  9 FOV/50 km square
**CrIS Radiometric Uncertainty Specification**

- **CrIS Radiometric Uncertainty specification**
  (circa 1990) is primarily driven by NWP applications. Expressed as 1-sigma percent radiance uncertainty with respect to Planck 287K radiance [i.e. $100\cdot \frac{dR}{B(287K)}$]:
  - Longwave: 0.45%
  - Midwave: 0.58%
  - Shortwave: 0.77%
  for $B(233K)$ to $B(287K)$

- **Climate (and NWP) Applications**
  typically require better accuracy

![CrIS Radiometric Uncertainty spec, expressed as 1 and 3 sigma brightness temperature differences](image-url)
Pre-Launch Radiometric Uncertainty Budget with component uncertainties based on pre-launch analysis/testing

On-orbit calibration equation:

\[
R_{\text{Earth}}(v_{\text{user}}) = SRA \left[ SA^{-1} \left( \text{Re} \left\{ \frac{C'_{\text{Earth}}(v_{\text{sensor}}) - <C'_{\text{Space}}(v_{\text{sensor}}) >}{<C'_{\text{ICT}}(v_{\text{sensor}}) > - <C'_{\text{Space}}(v_{\text{sensor}}) >} \right\} R_{\text{ICT}}(v_{\text{sensor}}) \right) \right]
\]

with \( R_{\text{ICT}} = e_{\text{ICT}} B(T_{\text{ICT}}) + (1-e_{\text{ICT}}) R_{\text{ICT,Reflected}} \) and \( C' = C / (1 - a_2 V_{DC}) \)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>1-σ uncertainty</th>
<th>3-σ 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>( e_{\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/Exelis, show these do not contribute significantly to the total RU.
ICT Predicted Radiance

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

**ICT Emissivity**

- Prediction includes a modeled component of the reflected radiance which varies with orbit phase.
- Effect is expected to be small, but largest for warm scenes in SW band and edge of MW band.

**ICT Emissivity Uncertainty**

- T \_\text{refl}, modeled

**\( T \_\text{refl}, \text{modeled} \)**

- Delta T Between ICT View of Baffle Average and Temperature Sensor Location

- Delta T (K)

- Orbit time (sec)
Non-Linearity Corrections

• The CrIS RU budget and SDR algorithm did not originally include NL contributions; Significant quadratic NL was realized for LW and MW (PV MCT) bands and characterized only with system level TVAC testing. SW band (InSb) is linear.

• The correction is FOV#, band, wavenumber, and scene dependent

• The NL magnitude was observed to change between TVAC cycles, particularly for certain MW FOVs.

• A post-launch strategy to refine the on-orbit NL was developed using out-of-band harmonic analysis of ICT and Space views and FOV-2-FOV consistency of Earth views.

Corrected Raw Complex Spectrum = Raw Complex Spectrum \times (1 + 2 a_2 V)
where V is DC level voltage at 1st stage of preamplifier

**Correction Coefficient, a_2**

**Example corrections**

![Correction Coefficient Graph](image)

![Example corrections Graph](image)
Schedule Overview

◆ Suomi-NPP launched on 28 October 2011
◆ CrIS powered on and first light data on 20 Jan 2012

◆ April 2012:
  ◆ v33 Engineering Packet upload and NF fix
  ◆ First valid spectra from the operational processing system
  ◆ SDR (aka L1B) “Beta” status

◆ CrIS SDR “Provisional” status in October 2012

◆ June 2013:
  ◆ Full resolution mode
  ◆ “Final” refinements to calibration coefficients
  ◆ CrIS SDR “Validated” status
Sample “1st Light” spectra (20 January 2012)

Overlays for a uniform 3x3 FOR
Water Vapor Map from CrIS

24 February 2012, 1580 cm$^{-1}$ BT
On-orbit Spectral Calibration Summary

- Small FOV position adjustments were made to produce inter-FOV spectral calibration agreement of a few tenths ppm, which is very stable with time.

- Both the internal Neon lamp views and Earth view analyses show overall spectral calibration variations (in the operational processing) with a range of ~1.5 ppm to date.

- Non-uniform scene effects on the ILS behave as expected (based on prior IASI experience). Mean spectra of large ensembles are unbiased due to this effect.

- Additional Gibbs effect artifacts present in the unapodized spectra, largest at edges of spectral bands, are currently under investigation.
v32 (Pre-launch) and v33 (In-flight) ILS parameters

**FOV Radii:** 8403 µrad

**v33 FOV5 offsets from FTS axis:** LW: 393 µrad, MW: 419 µrad, SW: 345 µrad

**Ratio of v32 off-axis angles to v33 off-axis angles:**

<table>
<thead>
<tr>
<th></th>
<th>FOV</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>LW</td>
<td></td>
<td>0.9999</td>
<td>1.0033</td>
<td>1.0055</td>
<td>0.9986</td>
<td>1.3008</td>
<td>1.0106</td>
<td>1.0005</td>
<td>1.0054</td>
<td>1.0097</td>
</tr>
<tr>
<td>MW</td>
<td></td>
<td>1.0013</td>
<td>1.0070</td>
<td>1.0058</td>
<td>0.9974</td>
<td>1.2923</td>
<td>1.0119</td>
<td>1.0018</td>
<td>1.0079</td>
<td>1.0107</td>
</tr>
<tr>
<td>SW</td>
<td></td>
<td>1.0058</td>
<td>1.0073</td>
<td>1.0066</td>
<td>1.0067</td>
<td>1.1620</td>
<td>1.0127</td>
<td>1.0040</td>
<td>1.0093</td>
<td>1.0100</td>
</tr>
</tbody>
</table>
**Inter-FOV Spectral Calibration Assessment**

Shifts wrt FOV5 derived from spectral correlation analysis:

- **Longwave band, 730-740 cm\(^{-1}\)**
  - April to October

- **Midwave band, 1350-1380 cm\(^{-1}\)**
  - April to October

- **Shortwave band, 2200-2250 cm\(^{-1}\)**
  - April to October
Inter-FOV Spectral Calibration Assessment

Inter-FOV Spectral Cal w/r/t FOV5;
Mean values over last 6 months:

- **FOV 1**
  - LW: 0.03
  - MW: −0.32
  - SW: −0.55

- **FOV 2**
  - LW: 0.04
  - MW: −0.03
  - SW: 0.12

- **FOV 3**
  - LW: −0.00
  - MW: −0.24
  - SW: −0.04

- **FOV 4**
  - LW: 0.05
  - MW: −0.11
  - SW: −0.30

- **FOV 5**
  - LW: 0.11
  - MW: 0.10
  - SW: −0.68

- **FOV 6**
  - LW: 0.19
  - MW: −0.22
  - SW: 0.13

- **FOV 7**
  - LW: 0.14
  - MW: 0.16
  - SW: 0.04

- **FOV 8**
  - LW: 0.14
  - MW: 0.00
  - SW: 0.32

- **FOV 9**
  - LW: 0.14
  - MW: 0.00
  - SW: 0.32
Metrology laser wavelength deviations, derived from Neon lamp views and laser temperature monitoring

Range is 1.6 ppm to date.
(Operational processing should update for ∆ of 2ppm threshold and processing re-start)

c/o NOAA STAR Cal/Val system
On-orbit Radiometric Calibration Summary

- Not finding artifacts due to the lower ICT emissivity and ICT reflected temperature variations over an orbit.
- Longwave and Midwave band nonlinearity $a_2$ coefficients were refined using in-flight Diagnostic mode (un-decimated) and Earth view data.
- **Overall Radiometric Uncertainty** estimates are generally less than 0.2K 3-sigma.
- Agreement with IASI and AIRS is generally less than a few tenths K; Larger differences are observed in the Shortwave band for cold scene radiances.
Radiometric Nonlinearity Coefficient Adjustments

v32 (Pre-Lauch, yellow) and v33 (In-orbit, orange) a2 values

**Longwave**

**Midwave**
Out-of-Band Harmonic Analysis

Example Longwave Band “Diagnostic Mode” spectrum:

- Quadratic Nonlinearity observed for CrIS Longwave and Midwave detectors.
- For the CrIS bandpasses, the nonlinearity correction simplifies to $C' = C + 2a_2 V C$, where $V$ is DC level voltage at 1st stage of preamplifier and $a_2$ is the magnitude of the quadratic nonlinearity.
- $\text{FFT(IFG}^2)/\text{FFT(IFG)}$ in the low wavenumber region (~50 to 200 cm$^{-1}$) provides an estimate of $a_2$. 
Nonlinearity Refinement using FOV-2-FOV consistency analysis

Midwave 1580 cm\(^{-1}\) Differences wrt FOV 9 as a function of NL coefficient, \(a_2\):

[Graphs showing the relationship between BT difference (K) and \(a_2\) scale factor for different FOVs (1 to 9).]
CrIS/IASI Northern SNOs, by FOV, prior to Apr 12 (v32 Eng Packet)

Weighted Mean (FOV i) minus Weighted Mean (all FOVs)

Weighted Mean Uncertainty
CrIS/IASI Northern SNOs, by FOV, post Apr 12 (v33 Eng Packet)

Weighted Mean (FOV i) minus Weighted Mean (all FOVs)

Weighted Mean Uncertainty
CrIS/AIRS Inter-comparison dataset

- 598,083 “big circle” samples, 25 Feb to 18 Dec
- Scan angles ≤ 30°; Scan angle difference ≤ 3°; Time Diff <= 20 min
- AIRS data is L1B v5; CrIS data is ADL (CSPP v1.1) with native Eng. Packets
- Daily processing c/o UW PEATE
CrIS/AIRS comparisons for Sample Wavenumber Regions

**LW window**
830-840 cm\(^{-1}\)

**Upper Trop H\(_2\)O**
1580-1595 cm\(^{-1}\)

**SW window**
2510-2520 cm\(^{-1}\)

- **BT Distributions**
  - **LW window**
    - CrIS
    - AIRS
  - **Upper Trop H\(_2\)O**
  - **SW window**

- **BT Difference Distributions**
  - **LW window**
    - 0.020 ± 0.004 K
  - **Upper Trop H\(_2\)O**
    - -0.067 ± 0.002 K
  - **SW window**
    - -0.058 ± 0.003 K
CrIS/AIRS comparisons for Sample Wavenumber Regions

LW window
835 cm$^{-1}$

Upper Trop H$_2$O
1592 cm$^{-1}$

SW window
2510 cm$^{-1}$

BT Difference Distributions

CrIS/AIRS comparisons for Sample Wavenumber Regions
Mean SNO differences, CrIS/IASI/AIRS

Northern SNOs

Southern SNOs

BT (K)

BT Diff (K)

wavenumber (cm⁻¹)
**Other On-orbit Performance Notes:**

*(what did *not* happen)*

- Interferometric noise (spectrally correlated) is exceptionally small—therefore, the vibration isolation stage was not deployed

- Radiation/particle induced Spikes are essentially non-existent—only 2 detected since launch

- No interferometer fringe count errors to date

- No signs of transmittance reduction from Ice buildup

- ILS effects on climate mean spectra from non-uniform scenes are very small (demonstrated by difference of corner and center FOV means)
**In-Flight Radiometric Uncertainty (RU) Estimates for a typical ~clear sky scene**

- **Longwave**
- **Midwave**
- **Shortwave**

**3σ uncertainties:**
- $a_2$ (30% LW, 15% MW)
- ICT Temp (112.5 mK)
- ICT emis (0.03)
- ICT Refl $T_{mod}$ (6K)
- ICT Refl $T_{meas}$ (1.5K)
- RSS/Total RU

* Not including Shortwave cold scene and Gibbs ringing artifacts
Current Leins, Areas of Investigation

- **Shortwave band, cold BT artifacts**
  - As seen in comparisons with AIRS, IASI, and Obs/Calcs
  - Well below spec, but still needs to be addressed

- **Gibbs effect, Spectral ringing**
  - Largest at band edges
  - Investigating source and possible fixes

- **Refinements to ILS and NLC coefficients**
  - Considering sub-tenth ppm adjustments to FOV positions and adjustments to LW NLC a2 coefficients, in June time frame.

- **“Repair Granules” in operational processing**
  - See next slides; users should use QA flags
Example QC plots for 2012.06.19, IDPS/CLASS products:

1. Aggregated RCRIS created at +2 hrs
2. RCRIS repair granules created at +4-5 hrs
3. Aggregated SCRIS files created at +6 hrs
What’s Next?

◆ **Suomi-NPP CrIS**
  - “Validated” status expected mid 2013, including small refinements to ILS and NLC calibration coefficients
  - Plan to go into full resolution mode (0.625 cm\(^{-1}\) unapodized resolution in all 3 bands) in June 2013. Full interferograms will be downloaded; operational SDR product will remain at truncated resolution.
  - NOAA/NASA currently determining plans/organization for reprocessing to produce a climate quality radiance dataset.

◆ **JPSS-1 CrIS**
  - Very similar to NPP CrIS but with a re-designed and higher emissivity ICT
  - Bench level and Thermal Vac testing to begin May/June of this year
  - Launch now scheduled for early 2017

◆ **JPSS-2 CrIS**
  - Smaller footprints; 3x3 FOVs (14km) replaced with effective 12x12 (~3.5km)
  - Spectral gaps removed
  - Launch in 2020/1
Thank You