Advanced Radiance Transformation System (ARTS) For Space-borne Microwave Instruments

Hu(Tiger) Yang¹, Fuzhong Weng², Ninghai Sun²
Wanchun Chen², Lin Lin² , Miao Tian¹

1. Earth Science System Interdisciplinary Center, University of Maryland
2. NOAA Center for Satellite Applications and Research, USA

huyang@umd.edu
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NOAA request a full radiance based calibration algorithm for consistent calibration for historical, present and future microwave sounding instruments

- Weather forecast application require continuous improving for satellite instrument calibration accuracy
- Satellite climate study need to develop and implement a robust, sustainable and scientifically defensible calibration system to producing and preserving climate records from satellite data

Present microwave calibration system is derived in temperature space, which is not consistent with historical full radiance calibration system developed in NOAA

- R-J approximation corrected calibration algorithm will cause scene dependent calibration error
- New sciences established from solid study of SNPP ATMS are need to be included to improve the calibration accuracy

An Advanced Radiance Transformation System (ARTS) is developed for microwave sounding instruments in JPSS era

- Full radiance calibration system applicable to different sensors
- New science for improving the calibration accuracy
• Consistent calibration algorithm for different sensors

• Full radiance calibration system with improved two-point calibration algorithm

• Data resampling ability to generate TDR with different spatial resolutions
Quality Control in ARTS

Different level of Quality control with PCT as inputs makes system being sustainable

Granule Level

- Quadratic Correction (i.e., Nonlinearity)

Scan Level

- Instrument mode
- Health and status
- PRT conversion
- PRT temperature limit
- PRT temperature consistency
- Scan time/Data gap check

Channel Level

- Lunar contamination
- Gain error
- Insufficient warm target observations
- Insufficient cold space observations
- Calibration counts out of range
- Warm target view inconsistency check
- Supports both big and little endian platforms
- Comparable processing efficiency with IDPS

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Main ARTS Modules

- Satellite geolocation
- Full radiance calibration
- B-G resampling
- Coherent noise filtering
- Lunar contamination correction
- Geolocation module includes GPS based and TLE based algorithms
- Primary algorithm uses GPS measurements of satellite position/velocity
- TLE is used as backup when no GPS data or large data gap exists in raw data
- ATMS geolocation error relative to VIIRS is about 3-4km
Full Radiance Calibration

- Calibrated space view scene brightness temperatures from IDPS are not equal to the cosmic background temperature 2.73K
- Abnormal scan angle dependent feature existed in calibrated TDR products
Calibration Error in IDPS

- Normally, a scene temperature dependent term and a constant bias term are used in R-J calibration equation.
- However, after applying correction by them it will still have residual errors that are dependent to temperature and frequency in the corrected calibrated temperature.
- Especially, when the scene temperature is close to cosmic background temperature, large bias will present when applying the R-J calibration equation with Tc correction.

\[ T_s = \delta(T_h - T_c) + T_c + (\Delta T_c - \Delta T_s) \]
New Two-Point Calibration Model in ARTS

Antenna emission including near-field radiation effect is modeled as function of scan angle and included in the calibration. Cold space observations from pitch maneuver operation are clean and used to derive model parameters for different channels. Such new algorithm can only be delivered in full radiance calibration system.

Corrected Two Point Calibration Equation in ARTS

For Vertical Polarization Channels:

\[ R_s = \delta[(Rh - Rc) + \beta_1(sin^2\theta_h - sin^2\theta_c)] + Rc + \beta_1(sin^2\theta_s - sin^2\theta_c) \]

For Horizontal Polarization Channels:

\[ R_s = \delta[(Rh - Rc) + \beta_1(cos^2\theta_h - cos^2\theta_c)] + Rc + \beta_1(cos^2\theta_s - cos^2\theta_c) \]

- \( R_s \): Calibrated antenna radiance
- \( Rh \): Warm load radiance
- \( Rc \): Cold space radiance (equal to 2.73K)
- \( \theta_h \): Scan angles of warm load measurements
- \( \theta_c \): Scan angles of space view
- \( \theta_s \): Scan angles of Earth view (i.e., each FOV)
- \( \delta \): Defined as \((Cs - Cc)/(Ch - Cc)\), where \(Ch/Cc/Cs\) are receiver output counts of warm load, cold space and earth view, respectively
Space View BT Calibrated by ARTS
Scan Angle Dependent in TDR from ARTS

For space view BT corrected by ARTS: No scan angle dependent feature, and close to cosmic background 2.73K

Channel -1

Channel -2

Channel -14

Channel -18
Resolution Reduction Resolution Enhancement

- Explore the potential of the oversampling characteristic of ATMS observations and generate observations at different frequencies with consistent FOV size

- Backus-Gilbert observation reconstruction algorithm is used for remapping TDR to expected spatial resolution

- Remapping coefficients are tuned to ensure the remapped TDR products are in best balance between noise and spatial resolution
Coherent Noise Filtering

Based on frequency spectrum analysis of the receiver output calibration counts, a low-pass filter with sinc window function is developed to effectively remove the high-frequency components (rapid fluctuations) while keep the low-frequency components (gain variations) unchanged.

Sinc Window Function

Calibrated Tb with and without calibration counts noise filtering
Lunar Contamination Correction

Brightness temperature increment arising from lunar contamination is modeled as function of lunar solid angle, antenna response and radiation from the Moon

\[ \Delta T_{moon} = G \ast \Omega \ast T_{moon} \]

\( G \): Antenna response function

\( \Omega_{moon} \): Weights of the Moon in antenna pattern:

\( T_{moon} \): Brightness temperature of the Moon

- LI happens when \( \beta' = \beta - \alpha_l \leq 1.25 \cdot \theta_{3dB} \)
- Lunar contamination impacts to the four space view counts are different.
- The increased brightness temperature due to the lunar contamination can be accurately identified and quantified from the model.
Activities

- ATMS RDR dataset was re-processed using the latest ATMS SDR algorithm code and PCT to evaluate lunar intrusion (LI) detection and correction performance.
- The potential impact of current TDR with LI on NWP model was evaluated in GSI.
- New metrics and physical model was developed for LI identification and correction.
- Different approaches for LI correction was compared and tested in ARTS, optimal algorithm was selected and implemented in current operational calibration system.

Results

- Lunar intrusion was accurately identified and correctly flagged in SDR datasets.
- Data gap was removed after LI correction, residual correction error is below the instrument noise.
- New scheme for LI detection and correction was developed for future improvement of current IDPS.
TDR Products from ARTS

- TDR products are generated on the daily basis
- TB difference ARTS and IDPS is scene and frequency dependent.

TDR from ARTS   ATMS Channel-01   TDR from IDPS

ATMS Channel-17
Conclusions and Future Works

- ARTS is a full radiance calibration system designed for microwave sounding instruments. With new sciences developed from solid study of SNPP ATMS, the calibration accuracy of TDR products from future JPSS satellite will be improved.

- ARTS is designed as a robust, sustainable and scientifically defensible operational calibration system for future JPSS satellite, and also can be used as test bed for developing new algorithm.

- Future work will focus on reprocessing SNPP ATMS data using ARTS, generating 2.2° resolution TDR products for use in weather and climate study.
Pertinent Publications


- Fuzhong Weng, Xiaolei Zou, 2013, “Errors from Rayleigh-Jeans approximation in satellite microwave radiometer calibration systems”, 52 ( 3) PP. 505-508


- Xiaolei Zou, Fuzhong Weng, and Hu Yang, 2014, “Connection the Time Series of Microwave Sounding Observations from AMSU to ATMS for Long-Term Monitoring of Climate Change”, Journal of Climate, accepted for publication

ATMS Optimal Striping Filters

X. Zou¹, Y. Ma¹ and F. Weng²

¹Department of EOAS, Florida State University

²Center for Satellite Applications and Research, NOAA

May 13, 2014
Outline

• ATMS TDR/SDR Striping Issues
• User Complains
• Requirements for Characterization and Correction
• AMSU-A/MHS/AMSU-B
• ATMS Striping (TVAC, Pitchover Data, Earth Scene ...)
• De-striping Methodology
• Optimal Striping Filters for Radiances
• Optimal Striping Filters for Calibration Counts

PCA Decomposition for ATMS Channel 10

The ATMS data can then be expressed as in PCA:

\[ A = \sum_{j=1}^{96} r_j e_j u_j \]

PC mode \( A \)
PC coefficient \( r_j \)

\[ A = \begin{pmatrix} TB_{1,1} & TB_{1,2} & L & TB_{1,j} & L & TB_{1,K} \\ TB_{2,1} & TB_{2,2} & L & TB_{2,j} & L & TB_{2,K} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ TB_{k,1} & TB_{k,j} & \ddots & TB_{k,K} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ TB_{96,1} & & & & & TB_{96,K} \end{pmatrix} \]

- Total number of scanlines \( K \)

\( \mathbf{r}, \mathbf{e}, \mathbf{u} \) denote the principal components.
The First Three IMFs of ATMS Ch10 Obs.

The 1\textsuperscript{st} PC Component at Nadir

Scanline

$e_{48,1, u_{i,j}} \ (K)$

The 1\textsuperscript{st} IMF

Frequency (s\textsuperscript{-1})

Power Spectrum Density

Original data

After taking away the three IMFs

The 2\textsuperscript{nd} IMF

Scanline

The 3\textsuperscript{rd} IMF
The Optimal Striping Filters: Mathematical Formula

The first PC coefficient

\[ \{u_{1,k}\} (k = 1, 2, \ldots, K) \]

The filtered first PC coefficient

\[ \overline{u}_{1,k} = \sum_{n=-N}^{N} \alpha_n u_{1,k+n}, \quad \alpha_n = \alpha_{-n} \]

\[ u_{1,k} = \sum_{m=0}^{K-1} C_m e^{-i \frac{2\pi mk}{K}} \quad \overline{u}_{1,k} = \sum_{m=0}^{K-1} \overline{C}_m e^{-i \frac{2\pi mk}{K}} \]

\[ r_m = \sum_{n=0}^{N} \alpha_n \cos(2\pi f \Delta t) \]

\[ \overline{C}_m = r_m C_m, \quad f = \frac{m}{K \Delta t}, \quad \Delta t = \frac{8}{3} s \]

\[ \{ \min_{\alpha_n} J = \min_{k=1}^{K} \left( \sum_{n=-N}^{N} \alpha_n u_{1,k+n} - \overline{u}_{eemd}^{1, k} \right)^2 \]

\[ \sum_{n=-N}^{N} \alpha_n = 1, \quad \alpha_n = \alpha_{-n} \]

where \[ \overline{u}_{eemd}^{1, k} = u_{k,1} - \sum_{m=1}^{L} IMF_m(k) \]

\[ T_{\text{destriping}}^{b, k, i} = e_{1,i} \sum_{n=-N}^{N} \alpha_n u_{1,k+n} + \sum_{j=2}^{96} e_{j,i} u_{j,k} \]

\[ i \in 1, 2, \ldots, 96 \] represents scan position

\[ k \in 1, 2, \ldots, K \] represents scan line
Power Spectrum Density of the First Seven IMFs and Residuals of ATMS Brightness Temperatures

The total number of IMFs removed are two for channels 1-2 and three for channels 3-22.
The Optimal Striping Filters: Numerical Results

This is a set of optimal filters for ATMS radiances designed to smooth out the striping noise but not to alter lower frequency weather signals.

\[ J = \sum_{k=1}^{K} \left( \sum_{n=-N}^{N} \alpha_n u_{1,k+n} - \bar{u}_{1,k}^{eemd} \right)^2 \]

\[ r_m = \sum_{n=0}^{N} \alpha_n \cos(2\pi f \Delta t) \]
Variation of Cost Function $J$ with Filter Span

\[
J = \sum_{k=1}^{K} \left( \sum_{n=-N}^{N} \alpha_n u_{1,k+n} - \bar{u}_{1,k}^{eemd} \right)^2
\]
Optimal Weighting Coefficients

\[ J = \sum_{k=1}^{K} \left( \sum_{n=-N}^{N} \alpha_n u_{1,k+n} - \overline{u}_{1,k}^{eemd} \right)^2 \]
Response Functions of the Optimal Striping Filters

\[ r_m = \sum_{n=0}^{N} \alpha_n \cos(2\pi f \Delta t) \]
Striping noise Spectrum removed by the optimal striping filters

Global O-B Spectrum with and without Applying the Optimal Striping Filter
Global O-B Distributions of ATMS Channel 8

Before

After

Before minus After

Striping noise
Pitch-Over Maneuver Data with and without Optimal Filtering

ATMS Channel 1

ATMS Channel 9
Striping Index (SI)

\[ SI = \frac{V_{\text{along}}}{V_{\text{cross}}} \]

Along-track variance

\[ V_{\text{along}} = \frac{1}{N} \sum_{j=1}^{N} \left( \frac{1}{M} \sum_{k=1}^{M} \left( T_b(k, j) - \frac{1}{M} \sum_{k=1}^{M} T_b(k, j) \right)^2 \right) \]

Cross-track variance

\[ V_{\text{cross}} = \frac{1}{M} \sum_{k=1}^{M} \left( \frac{1}{N} \sum_{j=1}^{N} \left( T_b(k, j) - \frac{1}{N} \sum_{j=1}^{N} T_b(k, j) \right)^2 \right) \]
Striping Index (SI) of Pitch-Over Maneuver Data

Variance of down-track (VDT), variance of cross-track (VCT), and striping index (SI) before (red) and after (blue) applying the optimal striping filter.

SI is significantly reduced to one for ATMS all channels.
Summary

• Twenty two optimal striping filters are developed for 22 ATMS channels

• Two months of de-striping ATMS data are being produced for NWP impact test
Future Plan

Similar optimal striping filters will be developed for calibration counts, and impact of striping noise on NEDT will be quantified.
Towards Establishing A Benchmark Instrument for Microwave Sounders

Lin Lin\textsuperscript{1, 2}, Fuzhong Weng\textsuperscript{3} and Xiaolei Zou\textsuperscript{4}

\textsuperscript{1} Joint Center for Satellite Data Assimilation, College Park, Maryland, USA
\textsuperscript{2} I. M. Systems Group, Inc., Rockville, Maryland, USA
\textsuperscript{3} National Environmental Satellite, Data, & Information Service, National Oceanic and Atmospheric Administration, Washington, D. C., USA
\textsuperscript{4} Department of Earth, Ocean and Atmospheric Sciences, Florida State University, USA
1. Introduction
2. A Brief Description of GPS RO Data
3. GPS RO Derived Scan Bias and Bias Correction
4. MonoRTM Simulations Using Measured and Boxcar SRF
5. Long Term Monitoring of ATMS Bias Characterization Using Collocated COSMIC RO Data
6. Summary
• For both NWP and climate applications, it is important to know the satellite instrument’s on-orbit accuracy. However, lack of on-orbit truth measurement makes it challenging.

• The Global Positioning System (GPS) Radio Occultation (RO) data have high accuracy and precision on atmospheric temperature, and also have high vertical resolution under all weather conditions.

• Current radiative transfer (RT) models are accurate for ATMS temperature sounding channels since the $O_2$ absorption coefficient for frequency between 50-70 GHz is accurately derived in lab.

• This research presents a method of using the GPS RO data and atmospheric RT models, such as the U.S. Joint Center of Satellite Data Assimilation (JCSDA) Community Radiative Transfer Model (CRTM) and the line-by-line RT model, to assess ATMS on-orbit accuracy.
A Brief Description of GPS RO

1. High vertical resolution
2. No contamination from clouds
3. No system calibration required
4. High accuracy and precision:
   a. The global mean differences between COSMIC and high-quality reanalyses is \(~0.65K\) between 8 and 30km (Kishore et al. 2008)
   b. The precision of COSMIC GPS RO soundings is \(~0.05K\) in the upper troposphere and lower stratosphere (Anthes et al. 2008)
Collocation of GPS and ATMS

Temporal difference $\leq \pm 3$ hrs
Spatial distance $\leq 50$ km

Use COSMIC geolocation at the altitude of maximum WF for spatial collocation

Channel- and FOV- Dependent
Distribution of Matchups


Channel 6:
16,701 in total

Similar patterns for other channels 5, 7-13.

Latitudinal Distribution

Most collocated data are located in subtropical in Northern Hemisphere and middle latitudes in Southern Hemisphere.
ATMS Observation and GPS Simulation

Ch5
Corr. Coef. = 0.993

Ch6
Corr. Coef. = 0.986

Ch7
Corr. Coef. = 0.997

Ch8
Corr. Coef. = 0.996

Ch9
Corr. Coef. = 0.995

Ch10
Corr. Coef. = 0.995

Ch11
Corr. Coef. = 0.984

Ch12
Corr. Coef. = 0.968

Ch13
Corr. Coef. = 0.961
GPS RO Derived Scan Bias
Bias Before/After Scan Bias Correction

Before:

Ch 7

Ch 8

Ch 9

After:

Ch 7

Ch 8

Ch 9
Bias Before/After Scan Bias Correction (Cntd’)

Before:

Ch 10

Ch 11

Ch 12

After:

Ch 10

Ch 11

Ch 12
Different channels have different biases (i.e., in PDF).

After calibrated using GPS RO data, biases of all channels are very close to normal distribution.

More, magnitudes of these calibrated biases are about an order smaller than the original TDR data.
MonoRTM

- A line-by-line (LBL) radiative transfer calculation
- Accurate atmospheric spectroscopy data base
- Only gaseous absorption
- Vertical stratification

For microwave sounding channels at 50-60 GHz, the O₂ absorption band can be best simulated under a cloud-free atmosphere using the LBL calculation.
To save computational time, the SRF is truncated at -20dB to keep the 99% of the maximum SRF for each band of each channel.

Compared to 256 lines for Boxcar SRF, the number of lines for truncated measured SRF is at least tripled for each channel.

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<th>ATMS Channel Number</th>
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<td>13</td>
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SRFs after the -20dB Truncation for CP at 20°C
Data from January 2012

The mean difference is within ± 0.2K.
The Std. Dev. is within 0.2K.
Long Term Monitoring of ATMS Bias Characterization
Using Collocated COSMIC RO Data


Mean

Std. Dev.
Daily Mean and Std. Dev. of O-B^{COSMIC}


Ch 7

Mean

Std. Dev.
Daily Mean and Std. Dev. of O-B\textsuperscript{COSMIC}


Ch 8

Mean

Std. Dev.
Daily Mean and Std. Dev. of O-B^{COSMIC}


Ch 9

Mean

Std. Dev.

Ch 10

Mean

Std. Dev.
Daily Mean and Std. Dev. of O-B\textsuperscript{COSMIC}


Mean

Std. Dev.
Daily Mean and Std. Dev. of O-B<sub>COSMIC</sub> Clear-sky, over ocean, 60°S ~ 60°N, Dec. 10, 2011 ~ Dec. 31, 2013

Ch 12

Mean

Std. Dev.
Daily Mean and Std. Dev. of O-B\textsuperscript{COSMIC}

Clear-sky, over ocean, 60\textdegree S \sim 60\textdegree N, Dec. 10, 2011 \sim Dec. 31, 2013

Ch 13

Mean

Std. Dev.
Monthly Mean of O-B^{COSMIC}


Channels 6 to 11 show consistently stable mean O-B and standard deviation.
Monitoring of ATMS Bias Characterization

O-B for ATMS Ch.7 54.4 GHz 2014-05-11 (clear-sky, over ocean, 60°S-60°N)

O-B for ATMS Ch.9 55.5 GHz 2014-05-11 (clear-sky, over ocean, 60°S-60°N)

O-B for ATMS Ch.11 57.29034±0.217 GHz 2014-05-11 (clear-sky, over ocean, 60°S-60°N)

O-B for ATMS Ch.13 57.29034±0.3222±0.022 GHz 2014-05-11 (clear-sky, over ocean, 60°S-60°N)
• Since Dec. 2012, COSMIC RO data are collocated with ATMS observations for channels 5-13. Clear-sky conditions over ocean within 60°S~60°N are examined.

• ATMS global BT biases for channels 5-13 derived from GPS RO are asymmetric to scan angle and within ±0.7K. After scan bias correction, the biases become Gaussian, and the magnitudes are one order smaller.

• The SRF comparison presents biases less than ±0.2K. It suggests that forward RTM should either use the measured SRFs or remove the model biases introduced by the Boxcar SRFs that currently used in CRTM.

• Moreover, the biases and standard deviations of channels 6-11 are stable and consistent with each other; but for channels 12 and 13 their biases increase since July 2012.

• To deduce a long-term climate trend with high accuracy, precision, stability, and consistency, this study can significantly contribute to a better refined post-launch calibration of ATMS, and future integration of ATMS data into long-term satellite climate data records (CDRs).
ATMS Airborne SDR Validation, Spectral Analysis, & Correlation Analysis

Vince Leslie, Bill Blackwell, Mike DiLiberto, Idahosa Osaretin, Erik Thompson, and Mark Tolman

STAR JPSS Annual Meeting

13 May 2014

LINCOLN LABORATORY
Massachusetts Institute of Technology
Outline

• NAST-M cross-validation from S-NPP Field Campaign

• S-NPP and J1 ATMS Spectral Analysis

• S-NPP and J1 ATMS Correlation Coefficients Analysis
Radiance Versus Modeling Verification

Radiance to Radiance Comparisons

• Separate sensors measuring nearly the same point at the same time
• Examples include Simultaneous Nadir Observations (SNO) or aircraft underflights
• Pros: same atmosphere and surface conditions with similar instrumentation
• Cons: Different spectral or spatial characteristics and small data sets

Radiance to Model Comparisons

• Model the sensor and the atmosphere
• Examples include using state-of-the-art NWP, radiative transfer, and surface models
• Pros: large amounts of data
• Cons: Idealized or measured spectral or spatial characteristics and modeling errors
Airborne Validation Status

• Calibrated NAST-M (V-band & upper G-band) in altitude chamber using precision microwave calibration target from 100-325 K at the instrument’s high-altitude operating temperature

• NAST-M calibrated to these residual errors:
  – V-band: <0.25 K from 200-325 K
  – G-band: <0.30 K from 200-325 K

• Compared S-NPP ATMS measurements against NAST-M for the 10May2013 sortie
S-NPP Mission Cal/Val Campaign

10 May 2013 Sortie over Gulf of CA

ATMS spot center points

NAST-M spot center points

Red: NAST-M
Green: ATMS V-band
Blue: ATMS G-band

ATMS Nadir Footprints (Spots 48 & 49)

NAST-M calibration at MIT LL in altitude chamber

Calibration Target
### Science Sorties During S-NPP Mission

**NAST-M has data from 12 flights  ~81 hours**

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<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
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</table>

**Overpass**

<table>
<thead>
<tr>
<th>NPP</th>
<th>Aqua</th>
<th>Metop-A</th>
<th>Metop-B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</table>

**Conditions**

<table>
<thead>
<tr>
<th>Time Of Day</th>
<th>Day</th>
<th>Day</th>
<th>Day</th>
<th>Day</th>
<th>Day</th>
<th>Day</th>
<th>Day</th>
<th>Day</th>
<th>Night</th>
<th>Night</th>
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</thead>
</table>

<table>
<thead>
<tr>
<th>Surface type</th>
<th>Ocean</th>
<th>Mixed</th>
<th>Mixed</th>
<th>Mixed</th>
<th>Land</th>
<th>Land</th>
<th>Land</th>
<th>Land</th>
<th>Ocean</th>
<th>Land</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Weather</th>
<th>Cloudy</th>
<th>Clear</th>
<th>Clear</th>
<th>Scattered</th>
<th>Thin Cirrus</th>
<th>Scattered</th>
<th>Clear</th>
<th>Cloudy</th>
<th>Scattered</th>
<th>Scattered</th>
<th>Clear</th>
</tr>
</thead>
</table>

| Flight Time (H) | 6.35 | 5.98 | 7.63 | 8.13 | 6.25 | 8.47 | 9.2 | 6.58 | 8.03 | 6.22 | 8.18 | 0     |

**Collected data from 9 S-NPP overflights**
NAST-M Calibration Accuracy: 54 GHz Band
NAST-M Calibration Accuracy: 183 GHz Band

![Graphs showing accuracy vs scene temperature for different frequency bands](image-url)
Calibrated NAST-M Brightness Temperatures

Calibrated ATMS Brightness Temperatures

Limb Correction

Co-location Spatial and temporal

Average NAST-M Pixels

Altitude Correction

Green boxes need one of these:
1) Radiosonde or dropsonde (Most desirable)
2) Simulated model output (e.g., ECMWF)
3) Retrieved profile from a different instrument

Satellite $T_b$

Avg. NAST-M $T_b$

Compare
Altitude-Corrected Aircraft Brightness Temperature ($T_b$)

Use Simulated Brightness Temperatures

$$T_b^{\text{SAT}} \approx T_b^{\text{NWP}} \left( \text{sim} \uparrow \downarrow_{\text{Surface}} \right)$$

$$T_b^{\text{AC}} = T_b^{\text{NWP}} \left( \text{sim} \uparrow \downarrow_{\text{AC}} \right)$$

Radiative Transfer Model

$$T_b^{\text{Alt-Corrected}} = T_b^{\text{AC}} \left( \text{meas} \uparrow \downarrow_{\text{Surface}} \right) + T_b^\Delta$$

$T_b^\Delta = T_b^{\text{SAT}} - T_b^{\text{AC}}$

$\approx 0.1 \leftrightarrow 1\,\text{K}(54\,\text{GHz})$

$\approx 0.01 \leftrightarrow 0.1\,\text{K}(183\,\text{GHz})$
Residual Error between ATMS measurements and NAST-M (ATMS – NAST-M) at nadir

### Lower V-Band ATMS Channels

<table>
<thead>
<tr>
<th>ATMS</th>
<th>Ch. 3</th>
<th>Ch. 4</th>
<th>Ch. 5</th>
<th>Ch. 6</th>
<th>Ch. 7</th>
<th>Ch. 8</th>
<th>Ch. 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDR</td>
<td>0.95</td>
<td>-0.22</td>
<td>-1.6</td>
<td>0.59</td>
<td>-0.07</td>
<td>0.00</td>
<td>-0.36</td>
</tr>
<tr>
<td>SDR</td>
<td>1.38</td>
<td>0.34</td>
<td>-0.89</td>
<td>1.04</td>
<td>0.41</td>
<td>0.35</td>
<td>-0.19</td>
</tr>
</tbody>
</table>

### Upper G-Band ATMS Channels

<table>
<thead>
<tr>
<th>ATMS</th>
<th>Ch. 18</th>
<th>Ch. 19</th>
<th>Ch. 20</th>
<th>Ch. 21</th>
<th>Ch. 22</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDR</td>
<td>-2.52</td>
<td>-2.11</td>
<td>-2.23</td>
<td>-1.24</td>
<td>1.58</td>
</tr>
<tr>
<td>SDR</td>
<td>-3.38</td>
<td>-2.93</td>
<td>-3.08</td>
<td>-2.11</td>
<td>0.62</td>
</tr>
</tbody>
</table>

TDR = Temperature Data Record or antenna temperature
SDR = Sensor Data Record or brightness temperature (scan bias corrected)
ATMS Residuals of SDR and TDR against ECMWF/CRTM for May 24, 2013 over ocean and under clear skies from STAR

* NAST-M Result from 10 May 2013; clear skies over ocean with limited # of high quality matchups
TDR-to-SDR Results: Upper Air Sounding

* NAST-M Result from 10 May 2013; clear skies over ocean
TDR-to-SDR Results for W/G Band

NAST-M Result from 10 May 2013; clear skies over ocean with limited # of high quality matchups
Example Power Spectral Densities

- PSD show the 1/f noise on the left and the thermal noise to the right
- The red vertical line is the calibration frequency (scan period) and the calibration algorithm effectively applies a highpass filter to the spectrum
Brightness Temperature Correlation

Figure 6. Estimates of interchannel error correlations based on the Desroziers diagnostics for ATMS. Statistics are based on used data over sea for 1–31 July 2012 (only scenes for which all considered channels are assimilated).

S-NPP Brightness temperature correlation coefficient matrix from pre-launch TVAC calibration

Bormann et al., “Evaluation and assimilation of ATMS data in ECMWF” JGR-A Vol. 118 12,970-12,980
Correlation and the Calibration Algorithm

- Pre-launch TVAC
- Two external targets and internal target
- Correlation matrix calculated for eleven scene temperatures
- Correlation matrices averaged after Fisher transform
- DN cold is the averaged four Space View measurements
- Gain uses eight scans in calculation

\[ T_b = \text{gain} \times \left( D_{\text{scene}} - D_{\text{cold target}} \right) + T_{\text{cold target}} \]
J1 ATMS Results

J1 RC = 1 CPT = 7.7 °C

DN Cold

Gain

DN Scene

Scene $T_b$
• Successful airborne campaign, but need to finish processing all sorties and investigate ATMS bias

• J1 ATMS 1/f noise and correlation is lower than S-NPP ATMS

• Need to analyze how the J1 & S-NPP spectra and correlation matrices impact data products and instrumentation
JPSS1 ATMS Thermal Vacuum Calibration Early Results

2014 STAR JPSS Science Team Meeting

Kent Anderson, Edward Kim, and Otto Bruegman

with contributions from Joseph Lyu, Vince Leslie, and Hemanshu Patel

13 May, 2014
JPSS1 ATMS Instrument Calibration Test Profiles

- Testing performed for 4 redundancy configurations at each calibration step
- For each calibration step, 278 scans of data processed to yield 271 scans of derived accuracy data

**Scene Temperature**

- 330 K
- 305 K
- 280 K
- 255 K
- 230 K
- 205 K
- 180 K
- 155 K
- 130 K
- 105 K
- 95 K

**Gain Fluctuation Test**
- 305 K
- 280 K
- 255 K
- 230 K
- 205 K
- 180 K
- 155 K
- 130 K
- 105 K
- 95 K

**Hysteresis Test** (repetition of 305 K and 130K levels, after downward transition)
- 330 K
- 305 K
- 280 K
- 255 K
- 230 K
- 205 K
- 180 K
- 155 K
- 130 K
- 105 K
- 95 K

**Baseplate Temperature:**

- **Mid**
  - V-shelf at +16.6° C
  - Cold Plate at +7.7° C
- **High**
  - V-shelf at +26.9° C
  - Cold Plate at +18.5° C
- **Low**
  - V-shelf at +6.2° C
  - Cold Plate at -3.1° C
JPSS1 ATMS NEDT Performance

- Worst Case of 4 Redundancy Configurations
- Scene temperature at 300 K

- Waiver request will be submitted for Channel 17 NEDT
- All other channels compliant
JPSS1 ATMS NEDT Performance

- Worst Case of 4 Redundancy Configurations
- Scene temperature interpolated to 300 K
JPSS1 ATMS On-Orbit Accuracy

- Worst Case of 4 Redundancy Configurations
- All channels compliant
Radiometric Transfer Functions

Channel 1 Accuracy vs Scene Temperature, +7.7°C Coldplate

- RC1 Accur
- RC2 Accur
- RC5 Accur
- RC6 Accur
- RC1 Accur Hyst.
- RC2 Accur Hyst.
- RC5 Accur Hyst
- RC6 Accur Hyst
- Poly. (RC1 Accur)
- Poly. (RC2 Accur)
- Poly. (RC5 Accur)
- Poly. (RC6 Accur)

Channel 2 Accuracy vs Scene Temperature, +7.7°C Coldplate

- RC1 Accur
- RC2 Accur
- RC5 Accur
- RC6 Accur
- RC1 Accur Hyst.
- RC2 Accur Hyst.
- RC5 Accur Hyst
- RC6 Accur Hyst
- Poly. (RC1 Accur)
- Poly. (RC2 Accur)
- Poly. (RC5 Accur)
- Poly. (RC6 Accur)

Channel 3 Accuracy vs Scene Temperature, +7.7°C Coldplate

- RC1 Accur
- RC2 Accur
- RC5 Accur
- RC6 Accur
- RC1 Accur Hyst.
- RC2 Accur Hyst.
- RC5 Accur Hyst
- RC6 Accur Hyst
- Poly. (RC1 Accur)
- Poly. (RC2 Accur)
- Poly. (RC5 Accur)
- Poly. (RC6 Accur)

Channel 4 Accuracy vs Scene Temperature, +7.7°C Coldplate

- RC1 Accur
- RC2 Accur
- RC5 Accur
- RC6 Accur
- RC1 Accur Hyst.
- RC2 Accur Hyst.
- RC5 Accur Hyst
- RC6 Accur Hyst
- Poly. (RC1 Accur)
- Poly. (RC2 Accur)
Radiometric Transfer Functions (cont.)

**Channel 5 Accuracy vs Scene Temperature, +7.7C Coldplate**

- RC1 Accur
- RC2 Accur
- RC5 Accur
- RC6 Accur
- RC1 Accur Hyst.
- RC2 Accur Hyst.
- RC5 Accur Hyst
- RC6 Accur Hyst
- Poly. (RC1 Accur)
- Poly. (RC2 Accur)
- Poly. (RC5 Accur)
- Poly. (RC6 Accur)

**Channel 6 Accuracy vs Scene Temperature, +7.7C Coldplate**

- RC1 Accur
- RC2 Accur
- RC5 Accur
- RC6 Accur
- RC1 Accur Hyst.
- RC2 Accur Hyst.
- RC5 Accur Hyst
- RC6 Accur Hyst
- Poly. (RC1 Accur)
- Poly. (RC2 Accur)
- Poly. (RC5 Accur)
- Poly. (RC6 Accur)

**Channel 7 Accuracy vs Scene Temperature, +7.7C Coldplate**

- RC1 Accur
- RC2 Accur
- RC5 Accur
- RC6 Accur
- RC1 Accur Hyst.
- RC2 Accur Hyst.
- RC5 Accur Hyst
- RC6 Accur Hyst
- Poly. (RC1 Accur)
- Poly. (RC2 Accur)
- Poly. (RC5 Accur)
- Poly. (RC6 Accur)

**Channel 8 Accuracy vs Scene Temperature, +7.7C Coldplate**

- RC1 Accur
- RC2 Accur
- RC5 Accur
- RC6 Accur
- RC1 Accur Hyst.
- RC2 Accur Hyst.
- RC5 Accur Hyst
- RC6 Accur Hyst
- Poly. (RC1 Accur)
- Poly. (RC2 Accur)
- Poly. (RC5 Accur)
- Poly. (RC6 Accur)
Radiometric Transfer Functions (cont.)

Channel 9 Accuracy vs Scene Temperature, +7.7°C Coldplate

Channel 10 Accuracy vs Scene Temperature, +7.7°C Cold Plate

Channel 11 Accuracy vs Scene Temperature, +7.7°C Coldplate

Channel 12 Accuracy vs Scene Temperature, +7.7°C Coldplate
Radiometric Transfer Functions (cont.)

Channel 13 Accuracy vs Scene Temperature, +7.7C Coldplate

Channel 14 Accuracy vs Scene Temperature, +7.7C Coldplate

Channel 15 Accuracy vs Scene Temperature, +7.7C Coldplate

Channel 16 Accuracy vs Scene Temperature, +7.7C Coldplate
Radiometric Transfer Functions (cont.)

Channel 17 Accuracy vs Scene Temperature, +7.7C Coldplate

- RC1 Accur
- RC2 Accur
- RC5 Accur
- RC6 Accur
- RC1 Accur Hyst.
- RC2 Accur Hyst.
- RC5 Accur Hyst
- RC6 Accur Hyst
- Poly. (RC1 Accur)
- Poly. (RC2 Accur)
- Poly. (RC5 Accur)
- Poly. (RC6 Accur)

Channel 18 Accuracy vs Scene Temperature, +7.7C Coldplate

- RC1 Accur
- RC2 Accur
- RC5 Accur
- RC6 Accur
- RC1 Accur Hyst.
- RC2 Accur Hyst.
- RC5 Accur Hyst
- RC6 Accur Hyst
- Poly. (RC1 Accur)
- Poly. (RC2 Accur)
- Poly. (RC5 Accur)
- Poly. (RC6 Accur)

Channel 19 Accuracy vs Scene Temperature, +7.7C Coldplate

- RC1 Accur
- RC2 Accur
- RC5 Accur
- RC6 Accur
- RC1 Accur Hyst.
- RC2 Accur Hyst.
- RC5 Accur Hyst
- RC6 Accur Hyst
- Poly. (RC1 Accur)
- Poly. (RC2 Accur)
- Poly. (RC5 Accur)
- Poly. (RC6 Accur)

Channel 20 Accuracy vs Scene Temperature, +7.7C Coldplate

- RC1 Accur
- RC2 Accur
- RC5 Accur
- RC6 Accur
- RC1 Accur Hyst.
- RC2 Accur Hyst.
- RC5 Accur Hyst
- RC6 Accur Hyst
- Poly. (RC1 Accur)
- Poly. (RC2 Accur)
- Poly. (RC5 Accur)
- Poly. (RC6 Accur)
• Consistency between 4 redundancy configurations
  • Indicator of measurement repeatability
  • Feasible to use one set of curves for all 4 redundancy cases
Lunar Intrusion Alternate Scheme

Get actual cold space obs by changing to an uncontaminated scan profile (SP #1 -> #4) during LI. Example LI case below. The data outside the yellow ticks are good SV data. The dashed line is treated as previously good SV, which is adopted to replace the contaminated SV data. **Note the TB offset that could result unless gain variations can be predicted.**

All 4 Ch 1 SV pixels are LI contaminated between yellow tick lines. Note that the SV counts did not return to the level prior to LI (due to random gain changes).
Remarks on Alternate LI Mitigation

- Switching scan profiles has already been done on orbit with S-NPP, and can be done over polar regions to minimize impact.
- Losing a few scans over the polar region is better than the worst LI correction cases, which could last for 25 min or longer.
- Since contaminated obs are replaced by un-contaminated actual obs, there should be no additional error.
- During commissioning, after switching between SP #1 and #4, no bias was found.
- This LI mitigation approach by switching between different SPs should work for all ATMS 22 channels. Namely, with proper SP selection (when applicable), there should be sufficient number of SV pixels that can be used for producing the SDR product uncontaminated by LI.
Inter-channel Correlation Coefficients

Correlation Coefficients of (left) AMSU-A1 and (right) ATMS Channel Gains.
NEDT for J-1 and NPP at Mid Cold Plate
Temp Interpolated to 300K
“Striping”

- All microwave imagers exhibit striping at some level—e.g., evidence is now being found of striping on AMSU, MHS, etc.—yet no NWP users saw striping-related issues with forecasts that used AMSU, MHS, etc data.

- The striping observed with S-NPP ATMS is not exceeding any hardware specs.

- Even so, ground processing changes (averaging) are being considered to somewhat reduce the existing striping. Such changes can be applied to S-NPP & J1-J3 ATMS without requiring any hardware changes.

- NWP users must therefore demonstrate the quantitative impact on forecasts from ATMS striping before any hardware changes can be considered. Even then the timeframe would be J4+. 
NGAS Support to ATMS SDR CalVal

Degui Gu

May 13, 2014
Outline

• NGAS activities in support to ATMS SDR Cal/Val
• Lunar intrusion correction update and assessment of residual errors
• Striping error assessment and mitigation
• J-1 ATMS Channel 16 gain dropout waveform reconstruction
• Summary and future plan
NGAS Activities in Supporting ATMS CalVal

- Validation of ATMS SDR and Remap SDR data product quality performance
  - ATMS calibration accuracy and scan dependent biases
  - Remap SDR quality (B-G approach)
  - Geolocation
- DR investigations
- ATMS SDR algorithm code and LUT updates
  - Lunar intrusion detection and correction
  - G-ADA processing and testing
- Striping noise assessment, root cause analysis, and mitigation
- Support to J-1 sensor performance test and characterization
  - NEdT
  - Striping (gain stability)
  - Nonlinearity
  - Calibration accuracy
  - Anomaly identification and characterization
Lunar Intrusion Correction
Code and LUT Update
Lunar Intrusion: Cold Counts Contaminated by Moon in Space View

Lunar intrusion event April 8-10, 2014. Channel 3

Mostly affected beam position

Minimum TB delta (K)

Scans with all four samples contaminated

0.2K
ATMS Lunar Intrusion Issues Before Code Updates

- NGAS found a coding error in ATMS operational algorithm software that caused the algorithm fail to correct for lunar intrusion, resulting up to ~1K errors in the affected ATMS SDR data products.
- NGAS found the antenna beam size values in the PCT file are incorrect, causing lunar intrusion quality flags being triggered more extensive than needed to be.
- ATMS SDR data gap could be produced if more than one space view samples are affected and the total number of “good” space view samples are less than 3.
- Some other minor issues such as errors in NEdT calculation during lunar intrusion.
Updated ATMS SDR Algorithm to Improve Lunar Intrusion Detection and Correction

- Fixed the software coding errors so that the lunar intrusion corrected space view counts are used to produce calibrated brightness temperatures

- Modified the algorithm to replace LI-contaminated space view samples with the uncontaminated good counts to avoid data gaps during lunar intrusion
  - If all four space views are affected by LI, good space view counts from the previous most recent scan are used

- Updated PCT file to use correct beam size values

- Code Update was implemented in MX8.3
  - Updated PCT implemented at a later time
Impact on ATMS SDR Data Product (1)
Impact on ATMS SDR Data Product (2)

**Before Update**

2011-12-05, NPP ATMS SDR, Brightness Temperature, CH: 21

**After Update**

2011-12-05, NPP ATMS SDR, Brightness Temperature, CH: 21

**Difference**
Assessment of Residual LI Correction Errors

- Residual LI correction errors can arise due to:
  - Uncorrected LI intrusion
    - LI affected cold counts not corrected if predicted TB increase < threshold of 0.2K (tunable)
  - Errors in the moon model
    - Simplified model for predicting space view temperature increases due to lunar intrusion
    - Moon position error (e.g., IDPS recently discovered code error)
  - Errors in the corrected cold counts
    - “Natural” changes in cold counts from last known uncontaminated sample to the current scan when all four samples are affected (due to gain instability, orbital phase variation, etc.)
    - Reduced number of samples per scan (noisier calibration data)
On-orbit Cold Counts Variability

Estimated cold counts variability from autocorrelation analysis

- CH3-9
- CH10-15
- CH16-22

Elapsed times (scans)

Standard deviation of cold counts differences (K)
Estimated Residual LI Correction Errors due to Natural Cold Counts Variability

- Residual LI correction Errors will result only when all four space view samples are contaminated.

- Nominal number of scans when all four space view samples are contaminated (dependent of FOV size):
  - 500 scans for CH1-2
  - 200 scans for V and W bands CH3-16
  - Not yet encountered for G band channels

- Estimated cold counts error from using history data:
  - CH1-2: \(~0.2K\)
  - CH3-15: \(~0.15K\)
  - Ch16: \(~0.35K\)
  - CH17-22: N/A

- When history data is used, the cold calibration data can be noisier due to fewer samples being averaged, causing additional (sometimes dominant) calibration errors (e.g., channel 15)
Residual LI Correction Errors due to Cold Counts Noises

Channel 15 cold counts variability and effect of averaging

- All 4 SV samples
- 4-sample averages
- 10-scan moving averages
Channel 1 Residual Error Estimates

Before LI Correction:
Worst cold count error: 1.2K
Median scene temp: 210K
Residual TB errors: 0.3K
Ocean: 180K, 0.45K

After LI Correction:
Worst cold count error: 0.5K
Median scene temp: 210K
Residual TB errors: 0.13K
Ocean: 180K, 0.18K

Blue: No LI correction
Red: After LI correction
Green: All four samples contaminated and history data used
Channel 10 Residual Error Estimates

Before LI Correction:
- Worst cold count error: 3.5K
- Median scene temp: 210K
- Residual TB errors: 0.9K

After LI Correction:
- Worst cold count error: 0.5K
- Median scene temp: 210K
- Residual TB errors: 0.13K

Blue: No LI correction
Red: After LI correction
Green: All four samples contaminated and history data used
Channel 15 Residual Error Estimates

Blue: No LI correction
Red: After LI correction
Green: All four samples contaminated and history data used

Before LI Correction:
Worst cold count error: 4K
Median scene temp: 250K
Residual TB errors: 0.43K

After LI Correction:
Worst cold count error: 1.5K
Median scene temp: 250K
Residual TB errors: 0.17K
Channel 16 Residual Error Estimates

Before LI Correction:
- Worst cold count error: 3.5K
- Median scene temp: 230K
- Residual TB errors: 0.63K

After LI Correction:
- Worst cold count error: 0.5K
- Median scene temp: 230K
- Residual TB errors: 0.1K
Channel 17 Residual Error Estimates

Before LI Correction:
Worst cold count error: 8K
Median scene temp: 250K
Residual TB errors: 0.85K

After LI Correction:
Worst cold count error: 0.5K
Median scene temp: 250K
Residual TB errors: 0.05K

Blue: No LI correction
Red: After LI correction
Green: All four samples contaminated and history data used
Assessment of Residual LI Correction Errors

- With MX8.3 code update and the PCT update, brightness temperature errors due to lunar intrusion have been reduced by a factor of 5-10 for most channels, except for channels 1, 2, and 15 which see reductions between 2-3 times.

- Worst case residual errors are estimated to be ~0.2K for K/Ka/V band channels, ~0.1 K for the W band, and ~0.05K for the G band channels.
  - Based on the analysis of April 8-10, 2014 lunar intrusion event.

- Standard deviation of lunar intrusion correction residual errors should be much lower, estimated to be <0.1K for all channels.
Striping Noise Assessment and Mitigation
Striping in S-NPP and J-1 Sensor Raw Data

Composite Image of normalized counts

J-1 TVAC Data (RC2, 230K)

S-NPP TVAC Data (RC1, 230K)

Striping on SNPP image, significantly reduced on J-1 image, except for channels 16 and 17.
Residual Striping in S-NPP and J-1 Calibrated Brightness Temperatures

Composite Image of calibrated brightness temperatures

J-1 TVAC Data (RC2, 230K)

SNPP TVAC Data (RC1, 230K)

Striping on SNPP image, significantly reduced on J-1 image, except for channel 17
Striping Index to Quantify Striping Noise

Striping Index (SI) is defined as the ratio of along-track variance to cross-track variance of the observed brightness temperatures

$$SI = \frac{V_{AT}}{V_{CT}}$$

If this index is significantly larger than 1, it indicates additional scan-to-scan variability (striping).

This index can be used to inflate O-B error covariance for NWP assimilation to prevent over fit of data.

This index can be computed using ground TVAC test data to verify sensor hardware performance before launch.

More precise estimate of SI can be obtained by averaging along-track variance over multiple FOVs and cross-track variance over multiple scans.
Estimated J-1 Residual Striping Errors

Estimated J-1 striping noises (Cold Plate Temp MID)

- Large and variable striping in Ch 17; also Ch 16 in some of the tests.
- Slightly elevated and variable striping in channels 4-6 in some of the tests.

Channel 16

- Minimum Striping Index vs. Calibration scene temperatures (K)

Channel 17

- Minimum Striping Index vs. Calibration scene temperatures (K)
Comparison of J-1 and S-NPP Striping Noises

- **J-1 Sensor**
  - Minimum SI
  - ATMS Channels

- **NPP Sensor**
  - Minimum SI
  - Channel
Estimated J-1 Sensor Gain Variability (1-sigma)

Channels 1-2

Channels 3-9

Channels 10-15

Channels 16-22

Elapsed Times (second)
Gain Variability Data Analysis Results: CH 16

- Time series of counts
- Autocorrelation analysis
- Spectral analysis
- Power spectrum density

Datasets
Samples
Frequency (Hz)
Power spectrum density
STDV of count differences
Time differences (second)
Gain Variability Data Analysis Results: CH 17

- **Time series of counts**
  - Samples vs Datasets
  - Color map: Counts x 10^4

- **Autocorrelation analysis**
  - STDV of count differences vs Time differences (seconds)

- **Spectral analysis**
  - Frequency (Hz) vs Datasets
  - Color map: Frequency

- **Power spectrum density**
  - PSD vs Frequency (Hz)
Gain Variability Data Analysis Results: CH 18

- Time series of counts
- Autocorrelation analysis
- Spectral analysis
- Datasets
- Samples
- Frequency (Hz)
- Power spectrum density

![Graphs showing time series, autocorrelation, spectral analysis, and power spectrum density.](image-url)
Mitigation of Striping Errors: PCA-EEMD Verification

• Simulated ATMS SDRs by adding random noise and striping noise to evaluate effectiveness of PCA-EEMD method in detecting and quantifying striping noises
  – Random noise added based on the simulated scene temperatures
  – Striping noise added based on scene temperatures and are correlated across scans
  – Magnitudes of random noise and striping noise are derived from previous analyses

• Performed PCA on simulated noisy brightness temperature images (200 scans)

• Extracted the EM’s in the first PC scores using the EMD method
  – Special treatment at the edges to minimize ringing

• Assessment:
  – Reconstructed brightness temperature images with the striping-induced EM’s removed to visually evaluate the effectiveness
  – Compared the estimated striping errors to the simulated errors to evaluate absolute accuracy
ECMWF Simulated SDR Channel 12

Simulated TB

Noised TB

Simulated Striping

1st EM

1st EM Removed

1st 3 EM's Removed

First 2 EM's

First 3 EM's

First 4 EM's

PC Scores

Scans

EM's

Estimated Striping (K)

Simulated Striping (K)
J-1 Channel 16 Gain Dropout
Waveform Construction
Observed J-1 Sensor Channel 16 Gain Dropouts During Transition from CP LOW to CP MID

Normalized raw counts from selected beam positions (03-23-2014)

Increasing cold plate temperatures
J-1 Channel 16 Gain Dropouts in Scan Data

Raw counts of all beam positions

Raw counts of calibration target (beam positions 9-22)
Reconstruction of Gain Dropouts from Thermal Cycle Test Datasets

Measured counts

Expected counts

Gain drop: ratio of measured counts to expected counts

Counts and local maximum

UTC Time of Day (hours)
Reconstructed Gain Dropout Waveforms During Transition

Reconstructed channel 16 gain dropout waveforms

UTC Time of Day (hours)

Increasing cold plate temperatures
Reconstructed Gain Dropout Waveforms at Different Instrument Temperatures

Reconstructed gain dropout waveforms as cold plate temperature increases during transition from Cold #7 to Hot #8 at selected time windows. 2014-04-24 01:03-03:12 (UTC)

Continuous dropouts that takes ~3-4 scans to recover at Cold CP temp

Frequent dropouts that recovers in ~2 scans at transitional CP temp

Occasional dropouts that recovers in ~1 scan at near MID CP temp

(Degui Gu and Alex Foo, NGAS)
Verification of Reconstructed Waveforms against the Observed Waveforms

- **Color**: reconstructed from TB2 data (2014-03-12)
- **Black**: observed average from gain stability test data (2014-04-25)

**Maximum drop**: 0.7% or 175 counts or 5.7K

**Half Peak Width**: 0.8s

(Degui Gu and Alex Foo, NGAS)
Summary and Future Work

• NGAS ATMS team will continue to support S-NPP ATMS SDR CalVal activities as the focus transitioning to LTM

• We plan to continue to support J-1 ATMS sensor testing and characterization
  – Support to sensor sell off
  – Support to J-1 algorithm development and improvement
  – Support to J-1 algorithm LUT/PCT coefficients derivation and verification
    • Calibration coefficients and nonlinearity correction
    • Beam efficiency correction coefficients
    • Striping noise mitigation by filtering
    • Geolocation LUT (sensor pointing and mounting data verification)
STAR Independent Assessment of J1 ATMS
Thermal Vacuum Test
CP-Mid and CP-High Data Analysis

STAR ATMS SDR Team
May 13, 2014
Analyzing TVAC calibration data provides instrument performance assessment:

• Calibration Accuracy
• Nonlinearity
• Sensitivity (i.e., NEΔT)
• Dynamic Range
• Striping

**J1 ATMS TVAC Test**
- Data is updated till May 9, 2014
- TVAC calibration: ST95, 105, 130, 155, 180, 205, 230, 255, 280, 305, 330 in CP_Mid and CP_High

**Software**
- Log file reader is provided by MIT-LL (version 1.7)
- Programs mainly prepared for TVAC calibration test

**Date:** May 13, 2014
### J1 ATMS TVAC Redundancy Configuration

**Diagram:**
- **28V A**
  - SPA PS A
  - RCVR A
  - SDE A
- **28V B**
  - SPA PS B
  - RCVR B
  - SDE B
- **SPA A**
- **SPA B**
- **SAW A**
- **SAW B**

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Cold Plate Temperature at CP_Mid ST-330

Mean: 7.8152K ; Std. Dev: 0.0189K
NEΔT at CP_Mid

Ch.01

Ch.02

Ch.03

Ch.04

NEDT (K)
Scene Temperature (K)

NEDT (K)
Scene Temperature (K)

NEDT (K)
Scene Temperature (K)

NEDT (K)
Scene Temperature (K)

Spec.  RC01  RC02  RC05  RC06
NEΔT at CP_Mid

Ch.09

NEDT (K)

Scene Temperature (K)

Ch.10

NEDT (K)

Scene Temperature (K)

Ch.11

NEDT (K)

Scene Temperature (K)

Ch.12

NEDT (K)

Scene Temperature (K)

Spec. RC01 RC02 RC05 RC06
NEΔT at CP_Mid

Ch.13

Ch.14

Ch.15

Ch.16

NEDT (K)

Scene Temperature (K)

NEDT (K)

Scene Temperature (K)

NEDT (K)

Scene Temperature (K)

NEDT (K)

Scene Temperature (K)

Spec.  RC01  RC02  RC05  RC06
NEΔT at CP_Mid

Ch.17

Ch.18

Ch.19

Ch.20

Scene Temperature (K)

Scene Temperature (K)

Scene Temperature (K)

Scene Temperature (K)

NEDT (K)

NEDT (K)

NEDT (K)

NEDT (K)

Spec. RC01 RC02 RC05 RC06
NEΔT at CP_Mid

Ch. 21

Ch. 22

Scene Temperature (K)

Scene Temperature (K)

NEDT (K)

NEDT (K)

Spec.  RC01  RC02  RC05  RC06
Ch. 16 and 17 NEΔT at CP_Mid & CP_High

Graphs showing the NEΔT (K) for Scene Temperature (K) at CP_Mid for Ch. 16 and Ch. 17, and at CP_High for Ch. 16 and Ch. 17. The NEΔT values are represented for different scene temperatures ranging from 95 to 330 K, with different colors indicating different radiances (Spec., RC01, RC02, RC05, RC06).
NE∆T at 300K CP_Mid vs. CP_High

![Graph showing temperature in K versus channels for NE∆T at 300K CP_Mid vs. CP_High](image)

**Channels**

- Spec.
- CP-Mid RC1
- CP-Mid RC2
- CP-Mid RC5
- CP-Mid RC6
- CP-High RC1
- CP-High RC2
- CP-High RC5
- CP-High RC6
### NEΔT at 300K S-NPP vs. J1

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<th>RC 05</th>
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NEΔT vs. Allan Variance at 300K (CP_Mid)
Radiometric Accuracy at CP_Mid ST-95

Note: Accuracy is computed by subtracting the inferred scene brightness temperature using two-point linear calibration equation with corresponding measured scene brightness temperature. FOV# 9 to 22 are used.
Radiometric Accuracy at CP_Mid ST-105

Temperature (K) vs Channels

Channels: 1 to 22

Temperature (K) ranges from -0.30 to 0.20

Legend:
- RC01
- RC02
- RC05
- RC06
Radiometric Accuracy at CP_Mid ST-130

![Bar chart showing temperature differences across different channels.
Channels 1 to 22 are plotted along the x-axis.
Temperature (K) values range from -0.3 to 0.3.
Legend includes four colors representing different channels: RC01, RC02, RC05, and RC06.
]
Radiometric Accuracy at CP_Mid ST-155

Temperature (K) vs. Channels

- RC01
- RC02
- RC05
- RC06
Radiometric Accuracy at CP_Mid ST-180

![Bar chart showing temperature (K) across channels for different categories]

- RC01
- RC02
- RC05
- RC06

Channels: 1 to 22

Temperature (K): -0.2 to 0.4
Radiometric Accuracy at CP_Mid ST-205
Radiometric Accuracy at CP_Mid ST-255

Temperature (K)

Channels

RC01  RC02  RC05  RC06
Radiometric Accuracy at CP_Mid ST-280
Radiometric Accuracy at CP_Mid ST-305

Temperature (K)

Channels

Temperature (K)

Channels

RC01  RC02  RC05  RC06
Radiometric Accuracy at CP_Mid ST-330

The diagram shows the temperature (K) across different channels for RC01, RC02, RC05, and RC06. The channels range from 1 to 22, and the temperature varies from approximately -0.7 to 0.0 K.
Radiometric Accuracy at CP_Mid RC1

Scene Target Temperature (K)

Channels

J1 ATMS CP_Mid RC1
Nonlinearity Fitting for CP_Mid RC1 vs. S-NPP

Black – NPP; Red – J1 RC1
Nonlinearity Fitting for CP_Mid RC1 vs. S-NPP

Ch.05

Ch.06

Ch.07

Ch.08
Nonlinearity Fitting for CP_Mid RC1 vs. S-NPP

Ch.09

Ch.10

Ch.11

Ch.12
Nonlinearity Fitting for CP_Mid RC1 vs. S-NPP

Ch. 13

Accuracy (K) vs. Scene Temperature (K)

Ch. 14

Accuracy (K) vs. Scene Temperature (K)

Ch. 15

Accuracy (K) vs. Scene Temperature (K)

Ch. 16

Accuracy (K) vs. Scene Temperature (K)
Nonlinearity Fitting for CP_Mid RC1 vs. S-NPP

Ch. 17

Ch. 18

Ch. 19

Ch. 20
Nonlinearity Fitting for CP_Mid RC1 vs. S-NPP

Ch. 21

Ch. 22
Peak Nonlinearity CP_Mid vs. CP_High vs. S-NPP

Channels

Peak Nonlinearity (K)

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22

Spec. CP-Mid RC1 CP-Mid RC2 CP-Mid RC5 CP-Mid RC6
CP-High RC1 CP-High RC2 CP-High RC5 CP-High RC6
Peak Nonlinearity CP_Mid vs. CP_High vs. S-NPP

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<th>RC 05</th>
<th>RC 06</th>
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Striping in RC1 at CP_Mid ST-95 vs. ST-330
Striping Index at CP_Mid ST-330

RC1

Striping Index

Channels

RC2

Striping Index

Channels

RC5

Striping Index

Channels

RC6

Striping Index

Channels

Blue: Scene Count; Red: Scene BT
Striping Index at ST-230 CP_Mid vs. CP_High

Channels

Striping Index

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22

CP-Mid RC1 CP-Mid RC2 CP-Mid RC5 CP-Mid RC6
CP-High RC1 CP-High RC2 CP-High RC5 CP-High RC6
Striping Index at ST-255 CP_Mid vs. CP_High
Striping Index at ST-280 CP_Mid vs. CP_High
Striping Index at ST-305 CP_Mid vs. CP_High

- Channels
- Striping Index

Graph showing striping index against channels for CP_Mid and CP_High with different labels for each channel.
Striping Index at ST-330 CP_Mid vs. CP_High

Channels

Striping Index

1  2  3  4  5  6  7  8  9  10  11  12  13  14  15  16  17  18  19  20  21  22

CP-Mid RC1  CP-Mid RC2  CP-Mid RC5  CP-Mid RC6
CP-High RC1  CP-High RC2  CP-High RC5  CP-High RC6
Ch.15 Counts Anomaly at CP_Mid ST-180

Ch.15 RC1

Ch.15 RC2

Ch.15 RC5

Ch.15 RC6
Ch. 15 Counts Anomaly at CP_Mid ST-180

Ch. 15 RC1

Ch. 15 RC5

Ch. 15 RC2

Ch. 15 RC6

Data Records
Summary

- J1 ATMS all channels’ NEΔT, except channel 17, meet the mission requirements

- Channel 16 demonstrates large temperature dependent noise

- Radiometric accuracy at channel 4 to 6 present reversed pattern compared to S-NPP

- Radiometric accuracy residuals exist at ST-95 and large difference is found between S-NPP and J1

- Several V-band channels’ peak nonlinearity are out of specifications

- SDR algorithm introduces additional striping affects
CrIS Radiometric Uncertainty (RU) Estimates

Dave Tobin, Hank Revercomb, Joe Taylor, Bob Knuteson, Dan DeSlover, Lori Borg, Graeme Martin
Space Science and Engineering Center, University of Wisconsin-Madison

2014 JPSS Science Teams Annual Meeting
NOAA Center for Weather and Climate Prediction, College Park, MD
13 May 2014

RU estimates are useful for understanding the size and dependencies of the primary contributors to the CrIS SDR uncertainties, for calibration improvements, and for weather, process, trend, and inter-calibration applications.

1. Perturbation of Calibration Equation and Parameter uncertainties
2. On-orbit RU estimates for Suomi-NPP CrIS
3. Changes for JPSS-1 (2017 launch), JPSS-2 (2022 launch) and CrIS-NG (TBD ~2027)
RU estimates for AIRS, IASI, and CrIS

• A) Observation intercomparisons and other Cal/Val approaches versus B) RU estimation via calibration equation perturbation. Synergy between these two.

• RU estimates for AIRS, IASI, and CrIS:
  – Standard RU methodology and terminology needed
  – IASI: CNES team is currently working to produce RU estimates for IASI-A and IASI-B.
Achieving Climate Change Absolute Accuracy in Orbit
Wielicki et al., BAMS, 2013

- CLARREO prototypes developed and performance recently demonstrated, but mission TBD.

- Emphasizes the benefit of characterizing AIRS/IASI/CrIS as well as possible, and improving if possible.
Suomi-NPP CrIS Radiometric Uncertainty Estimates

Simplified On-Orbit Radiometric Calibration Equation:

\[ R_{\text{scene}} = Re \left\{ \frac{(C'_{\text{scene}} - C'_{\text{SP}})}{(C'_{\text{ICT}} - C'_{\text{SP}})} \right\} R_{\text{ICT}} \]  

with:

Nonlinearity Correction:  \( C' = C \cdot (1 + 2 \cdot a_2 \cdot V_{\text{DC}}) \)

ICT Predicted Radiance:  \( R_{\text{ICT}} = \varepsilon_{\text{ICT}} B(T_{\text{ICT}}) + (1-\varepsilon_{\text{ICT}}) \left[ 0.5 B(T_{\text{ICT, Refl, Measured}}) + 0.5 B(T_{\text{ICT, Refl, Modeled}}) \right] \)

Parameter Uncertainties:

<table>
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<tr>
<th>Parameter</th>
<th>Nominal Values</th>
<th>3-(\sigma) Uncertainty</th>
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<tr>
<td>( T_{\text{ICT}} )</td>
<td>280K</td>
<td>112.5 mK*</td>
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<tr>
<td>( \varepsilon_{\text{ICT}} )</td>
<td>0.974-0.996</td>
<td>0.03</td>
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<td>( T_{\text{ICT, Refl, Measured}} )</td>
<td>280K</td>
<td>1.5 K</td>
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<td>( T_{\text{ICT, Refl, Modeled}} )</td>
<td>280K</td>
<td>3 K</td>
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<tr>
<td>( A_2 ) LW band</td>
<td>0.01 – 0.03 V^{-1}</td>
<td>0.00403 V^{-1}</td>
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<tr>
<td>( A_2 ) MW band</td>
<td>0.001 – 0.12 V^{-1}</td>
<td>0.00128 – 0.00168 V^{-1}</td>
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</table>

*Exelis at-launch estimate
Suomi-NPP CrIS, example 3-sigma RU estimates

For a typical warm, ~clear sky spectrum
Suomi-NPP CrIS, example 3-sigma RU estimates

For a cold, high cloud spectrum

![Graph showing 3-sigma RU estimates for different wavenumber ranges and BT values.](image)
ICT Emissivity and Reflected terms

• Despite relatively low ICT emissivity and greater sensitivity to the reflected terms, cal/val has not shown radiometric artifacts related to these contributions. This is not unexpected due to the ambient temperature design of CrIS and the relative size of these RU contributions compared to other terms.

• The redesigned ICT for J1 and J2 CrIS has emissivity requirements of >0.995 emissivity and uncertainty <0.0015 1-sigma. Modeling and testing to date shows the expected performance meets these requirements and the corresponding RU contributions should be much smaller (~negligible) compared to those for Suomi-NPP.
ICT Temperature

• Suomi-NPP CrIS has BOL uncertainty of 112 mK 3-sigma, and significant BOL to EOL contributions.

• J1 CrIS has BOL uncertainties similar to Suomi-NPP CrIS but reduced BOL to EOL contributions.

• Phase change cells on the ICT are being considered for J2 CrIS which would further reduce BOL to EOL contributions and allow performance to be verified on-orbit.
Nonlinearity

• On-orbit Nonlinearity RU contributions for J1 CrIS should be similar to those for Suomi-NPP.
  – Preliminary DM results for J1 are qualitatively similar to FM1 (SW is linear, some linear MW FOVs, all LW FOVs are nonlinear) and the same type of NL correction and TVAC and on-orbit $a_2$ analysis techniques will be needed for J1.
  – Compared to S-NPP, the J1 LW FOVs are more linear (except FOV5), and 8 of the J1 MW FOVs are very linear.

• LW and MW detectors are being selected for J2 CrIS. An accurate measure of nonlinearity should be assessed as part of this selection, with an FTS for example.
Other RU Terms

Smaller contributors not currently accounted for in the calibration algorithm or included in current RU estimates:

• Spectral Ringing
  ➢ Polarization
  ➢ Possible SW Nonlinearity
• Other smaller/negligible terms:
  – Detector temperature changes, Changes in DA Bias tilt over 4 minutes, Changes in optical flatness, OPD sample rate drift over 4 minutes, Electronic gain drift over 4 minutes, Electronic delay drift over 4 minutes, FOV to FOV crosstalk in same band, FOV to FOV crosstalk between bands, Stray light, Optics temperature change during cal, Changes in channel spectra
Error from Scene Mirror Induced Polarization

- CrIS uses a 45° gold scene mirror that provides low sensitivity to polarization; no correction is included in the SDR algorithm/processing.
- However, it seems almost certain that CrIS should have polarization effects of ~50 mK for especially warm and cold brightness temperatures in some spectral regions.
- Radiance error dependence \( \sim 2p_r p_t (N - B_{ICT}) \)
- A correction should be developed based on CrIS characterization tests yet to be conducted (measurements of scene mirror degree of polarization, \( p_r \), and interferometer polarization sensitivity, \( p_t \)).
SW Band Biases

- FOV-2-FOV analyses and differences with respect to other sensors suggest small artifacts in the SW band, both in Mean biases and FOV-2-FOV differences. E.g. Differences with respect to IASI

- Mechanisms investigated:
  - Spectral shift
  - Thermal SP view contamination
  - Solar SP view contamination
  - Polarization
  - Low level Nonlinearity
    - Displays FOV dependent behavior
    - Has plausible spectral and scene level dependencies
  - Low SNR Radiometric Calibration
Other Potential Changes for CrIS

1. Remove spectral gaps
   – J2 baseline design does not remove gaps, but a cost study is underway and if successful will be proposed to NOAA as a design mod.

2. Smaller and more numerous footprints
   – Not included in J1 or J2 design

• There are compelling scientific reasons for both, and feasible concepts presented for implementing both.
• Both require efforts/funding to perform further design/costing studies, and both likely require higher data rate for DB downlink.
Summary

J1: RU should be similar to S-NPP CrIS

J2: Possibly reduced RU pending detector selection and associated nonlinearity behavior, and addition of ICT phase change cells.

Polarization measurements

Additional changes (remove spectral gaps, smaller footprints) require efforts/funding to perform further design/costing studies, and both likely require higher data rate for DB downlink.

• Need clear and efficient communication between users, Flight and JPSS project offices, and DB users in order to make progress.
SDR algorithm testing

TOA Radiance Spectrum

Simulated CrIS Truth Spectra

Simulated CrIS Measured Interferograms

Calibrated CrIS Spectra

Calibration Algorithm
backup slides
Intercomparison of IASI-A, IASI-B, and CrIS
Intercomparison of CrIS and VIIRS; Daily Mean Differences

With mean biases subtracted off.
Figure 9a (left). Residual Differences (retrieved vs LABB measured) for ABopt Linearity test at 40 degree scan angle. Red curves are predicted temperature error from the radiometric uncertainty model for each LABB temperature. Figure 9b (right) Average residual error over all tests by module for each of the different polarization coefficient types (legend). Residual errors are similar for most coefficient types.

**VIIRS**−**CrIS** BT (K)

**CrIS/VIIRS Daily Mean Differences**

- **Mar**
- **Apr**
- **May**
- **Jun**
- **Jul**
- **Aug**
- **Sep**
- **Oct**
- **Nov**
- **Dec**
- **Jan**
- **Feb**
- **Mar**
- **Apr**
- **May**
- **Jun**
- **Jul**
- **Aug**
- **Sep**
- **Oct**
- **Nov**
- **Dec**
- **Jan**
- **Feb**
- **Mar**
- **Apr**
- **May**

**M13, 4um**
**M15, 10.8um**
**M16, 12um**
QA & Latency Trending, IDPS
QA & Latency Trending, CSPP
Low SNR Radiometric Calibration

• Rowe et al., 2011: A responsivity-based criterion for accurate calibration of FTIR emission spectra: Theoretical development and bandwidth estimation, Optics Express, 19(7), 5930-5941.
• Rowe et al., 2011: A responsivity-based criterion for accurate calibration of FTIR emission spectra: Identification of in-band low-responsivity wavenumbers, Optics Express, 19(6), 5451-5463.
CrIS Spectral Calibration

L. Larrabee Strow, Howard Motteler, Chris Hepplewhite, Sergio De-Souza Machado, and Breno Imbiriba

Department of Physics, JCET
University of Maryland Baltimore County (UMBC)

STAR JPSS Science Team Annual Meeting
May 2014
College Park, MD
Overview

- Spectral calibration performance: Neon stability
- High-resolution spectral improvements: Period Sinc basis
- Full spectral comparison with AIRS via SNOs
Data using IDPS long-wave SDRs; Very few updates due to 2 ppm threshold
- SDR’s exhibit ~3 ppm variability
- Correct operation of CMO generation started in Nov. 2013
Question: Is any of this drift due to the Neon lamp? Original plans were to update the Neon calibration via up-welling radiances 1/month.

Difficult to use IDPS SDR record for this since Neon cal used in IDPS uncertain until Nov. 2013.
Reprocess 2 years of SDRs with CCAST using metrology laser that follows Neon calibration exactly.

Normal ν-cal compares observed to NWP simulated radiances: not yet finished.

Here: compare (via cross-correlation) April 2012 scene radiances to time series of a small clear subset of CCAST output.

Regression of drift over 2 years: -0.07 ppm ± 0.54 ppm

Excellent long-term stability

This approach introduces noise, we will soon finish matching 2-years of CCAST output to NWP (ECMWF) and will have a much lower noise Neon calibration to determine if it is drifting and needs any updates.

The results shown here suggest no long-term drifts, but possibly a small seasonal drift with solar heating of the instrument.
CCAST SDR Cal Approach for This Work

\[ r_{\text{OBS}} = F \cdot r_{\text{ICT}} \cdot f \cdot S A^{-1} \cdot f \cdot \frac{\text{ES} - \text{SP}}{\text{IT} - \text{SP}} \]

- \( r_{\text{OBS}} \) is calibrated radiance at the user grid
- \( F \) is Fourier interpolation from sensor to user grid
- \( f \) is a raised-cosine bandpass filter
- \( r_{\text{ICT}} \) is expected ICT radiance at the sensor grid
- \( S A^{-1} \) is the inverse of the ILS matrix
- \( \text{ES} \) is earth-scene count spectra
- \( \text{IT} \) is calibration target count spectra
- \( \text{SP} \) is space-look count spectra
Periodic Sinc Applied to High-Resolution Spectra

- Periodic sinc (psinc) is the correct basis for the instrument line shape (ILS)
- Thanks to Dan Mooney, see next talk
- IDPS and previously CCAST used sinc, not psinc

Two metrics for spectral performance

- Observed - Computed (NWP)
  - 100 Clear Ocean Scenes

- Standard Deviation of FOV5-FOVn
  - Large global dataset FORS=15,16

![Graphs showing spectral performance metrics](image-url)
Periodic Sinc: Details

Bias Psinc/sinc - Bias Hamming
A clean metric for excess ringing

- This is a major improvement to the high-resolution short-wave data
- Periodic sinc mostly improves corner FOVS, where the self-apodization correction is largest, SA matrix is more poorly conditioned.
- Should help improve absolute spectral calibration once CrIS is in high-resolution mode
FOV7 Non-Linearity in High-Resolution Data

- High-res mid-wave water vapor line centers very cold
- Below: Std. Dev. of FOV5-FOVn for global data set. IDPS non-linear coefficients (Feb. 20, 2014 +).
- FOV7 non-linearity may need a more refined correction
Periodic Sinc Applied to Normal Resolution SDRs

- Periodic sinc only clearly better at high wavenumber end of mid-wave band and most of short-wave band.
- Other contributors to non-sinc ringing dominate
CrIS/AIRS SNOs using Native CrIS ILS

- Intercalibration of AIRS and CrIS can only be done with L1b data in winow regions.
- ILS (Instrument Line Shape) differences cause large (4+K) differences between AIRS and CrIS for.
- We convert AIRS (L1c) radiances using a deconvolution, reconvolution approach.
- The AIRS→CrIS data may provide the best approach for building a seamless AIRS + CrIS L2 time series.
AIRS L1c: Mismatch due to ILS Differences

Sampling of AIRS vs CrIS ILS

B(T) error using just $\nu$ interpolation
AIRS $\rightarrow$ CrIS Conversion

This topic is beyond the scope of this talk, so just a summary.

**Basic methodology**

Let $S_a$ be a matrix whose rows are AIRS SRFs on a 0.1 cm$^{-1}$ grid, $c$ AIRS channel radiances, and $r$ radiances on the same 0.1 cm$^{-1}$ grid. Then we can write

$$c = S_a r,$$

expressing the channel radiances as the convolution of observed radiance. In practice we have $c$ and don’t know $r$, but we can approximate it by taking the pseudo-inverse $S_a^{-1}$ and applying it to $c$,

$$r = S_a^{-1} c.$$

This is the deconvolution. This regularly spaced $r$ can then be convolved to CrIS radiances at the user grid, taking into account band differences. The key in practice is that the L1c channel set gives a relatively well-conditioned $S_a$. 
Example of De-convolved AIRS Spectrum
Example of AIRS L1c and Conversion to CrIS
Example of AIRS L1c and Conversion to CrIS
Example of AIRS L1c and Conversion to CrIS

\[ \text{L1b} + \text{L1c} + \text{L1c} \to \text{CrIS} \]

![Graph showing the conversion of AIRS L1c to CrIS](image-url)
Example of AIRS L1c and Conversion to CrIS

$L1b + L1c + L1c \rightarrow CrIS + CrIS$
Example of AIRS L1c and Conversion to CrIS

L1c → CrIS + CrIS

B(T) in K vs. Wavenumber (cm$^{-1}$)
Full Spectrum Differences (Pre-Feb. 2014 Non-Linearity)

Hamming Apodization

Long/Mid Wave Spectrum

Longwave Zoom

0.2K “ringing” may be due to lack of frequency calibration

The standard error is extremely small. ±50°latitude SNOs, 2 million+ samples.
Differences between CrIS vs AIRS day/night larger than statistical errors

Thermal issues on one of these instruments?

NWP day vs night biases similar for AIRS, CrIS in 650-700 cm\(^{-1}\) region, but very different for water vapor due to sampling differences

AIRS “ringing” due to me not doing AIRS frequency calibration before forming SNOs. TBD.
CrIS Radiometric Stability
Relative to SST, CO₂

- Tropical ocean clear
- 1-Year differences far below 0.1K. Red curve is smoothed time series.

- CO₂ from ECMWF bias (791.5 cm⁻¹) - 0.27*bias(790 cm⁻¹).
- Second term removes any SST, H₂O variability.
- Oct 2012 through Oct 2013 shows 2.5 ppm growth rate (0.06K).
Conclusions

- CrIS spectral calibration continues to be stable and accurate.
- UMBC will complete full analysis of Neon stability in the near future using CCAST.
- CrIS high-resolution short-wave SDRs improved using period sinc basis function for apodization corrections.
- FOV-7 improvements needed for high-spectral resolution mode.
- AIRS/CrIS SNOs exhibit $\sim \pm 0.1$K agreement on a channel-by-channel basis with AIRS ($\sim 1080$ channels).
- AIRS/CrIS comparisons will improve once AIRS SNOs are frequency calibration (by UMBC).
- AIRS $\to$ CrIS conversion will make a combined AIRS, CrIS radiance climate data set possible, now at 11+ years length.
CrIS Calibration Equation

D. L. Mooney

Session 4b

STAR JPSS Annual Science Team Meeting

May 13 2014
The differences among processing approaches are small
Difference IDPS-Ref and low Pass filtered difference

LW mean real (SDR-REF), GranuleID=NPP000748812352 2, 6 2, 3

Corrected for gain and du shift

Envelope of the ripple

center  edges  corners

mW/m²-str-cm⁻¹

Wavenumber
Determine gain and wavenumber shift

![Graph showing the relationship between gain and wavenumber shift.](image)
Corrected for gain and wavenumber shift

LW mean real (SDR-REF), GranuleID=NPP000748812352 2, 6 2, 3 first interferogram IET=1772900476984108, 2014-03-07 16:21:16.984

Corrected for gain and du shift

~3 mK RMS noise for one to one spectra comparison
- We will use the envelope of ripple difference for comparing different calibration approaches
- Envelope by multiplying by \([1,-1,1,-1,\ldots]\)
Examine a Range of spectra for different FOR

LW spectra 16 LLNew - REF GranuleID=NPP000748812352

IET=1772900476984108, IET=2014-03-07 16:21:16.984 2, 1 2, 3
Ripple envelopes change with different FORs especially near the edges.

LW spectra 16 LLNew - REF GranuleID=NPP000748812352
IET=1772900476984108, IET=2014-03-07 16:21:16.984 2, 1 2, 3
## Calibration options

<table>
<thead>
<tr>
<th>Item</th>
<th>Member</th>
<th>Calibration</th>
<th>CMO Principals</th>
<th>Calibration Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>IDPS</td>
<td>$N = \left( S_A^{-1} \cdot F_{s \rightarrow u} \cdot F_{ATBD} \right) \cdot \left( \frac{S_E - S_{SP}}{S_{ICT} - S_{SP}} \cdot ICT(T, u_{sensor} \cdot \delta) \right)$</td>
<td>$S_A^{-1} \cdot F_{s \rightarrow u}$</td>
<td>Calibration first, then CMO</td>
</tr>
<tr>
<td>2</td>
<td>ADL/CSPP</td>
<td>$N = \left( S_A^{-1} \cdot F_{s \rightarrow u} \cdot F_{ATBD} \right) \cdot \left( \frac{S_E - S_{SP}}{S_{ICT} - S_{SP}} \cdot ICT(T, u_{sensor} \cdot \delta) \right)$</td>
<td>$S_A^{-1} \cdot F_{s \rightarrow u}$</td>
<td>Calibration first, then CMO</td>
</tr>
<tr>
<td>3</td>
<td>Exelis (old)</td>
<td>$N = \left( S_A^{-1} \cdot F_{s \rightarrow u} \cdot F_{ATBD} \right) \cdot \left( \frac{S_E - S_{SP}}{S_{ICT} - S_{SP}} \cdot f_{BT} \cdot \left[ S_A^{-1} \cdot F_{s \rightarrow u} \right] \cdot ICT(T, u_{sensor}) \right)$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>UMBC/UW**</td>
<td>$N = F_{s \rightarrow u} \cdot \left( S_A^{-1} \cdot f \cdot \left( \frac{FIR^{-1} \cdot (S_E - S_{SP})}{FIR^{-1} \cdot (S_{ICT} - S_{SP})} \cdot ICT(T, u_{sensor} \cdot \delta) \right) \right)$</td>
<td></td>
<td>Calibration first, then CMO</td>
</tr>
<tr>
<td>5</td>
<td>CCAST Cal mode 1</td>
<td>$N = F_{s \rightarrow u} \cdot \left( S_A^{-1} \cdot \left( \frac{FIR^{-1} \cdot (S_E - S_{SP})}{FIR^{-1} \cdot (S_{ICT} - S_{SP})} \cdot ICT(T, u_{sensor} \cdot \delta) \right) \right)$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>UMBC/UW**</td>
<td>$N = F_{s \rightarrow u} \cdot \left( S_A^{-1} \cdot \left( \frac{FIR^{-1} \cdot (S_E - S_{SP})}{FIR^{-1} \cdot (S_{ICT} - S_{SP})} \cdot ICT(T, u_{sensor} \cdot \delta) \right) \right)$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>CCAST Cal mode 2</td>
<td>$N = F_{s \rightarrow u} \cdot \left( S_A^{-1} \cdot \left( \frac{FIR^{-1} \cdot (S_E - S_{SP})}{FIR^{-1} \cdot (S_{ICT} - S_{SP})} \cdot ICT(T, u_{sensor} \cdot \delta) \right) \right)$</td>
<td></td>
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</tr>
<tr>
<td>8</td>
<td>LL(old)*</td>
<td>$N = \left{ \frac{M \cdot (FIR^{-1} \cdot (S_E - S_{SP}))}{M \cdot (FIR^{-1} \cdot (S_{ICT} - S_{SP}))} \right} \cdot ICT(T, u_{sensor})$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>LL(new)</td>
<td>$N = \left{ \frac{F_{s \rightarrow u} \cdot S_A^{-1} \cdot (FIR^{-1} \cdot (S_E - S_{SP}))}{F_{s \rightarrow u} \cdot S_A^{-1} \cdot (FIR^{-1} \cdot (S_{ICT} - S_{SP}))} \right} \cdot ICT(T, u_{sensor})$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Proposed(1)</td>
<td>$N = F_{s \rightarrow u} \cdot \left( S_A^{-1} \cdot \left( \frac{FIR^{-1} \cdot (S_E - S_{SP})}{S_A^{-1} \cdot (FIR^{-1} \cdot (S_{ICT} - S_{SP}))} \cdot ICT(T, u_{sensor}) \right) \right)$</td>
<td></td>
<td>CMO first, then Calibration</td>
</tr>
<tr>
<td>11</td>
<td>Proposed(2)</td>
<td>$N = ICT(T, u_{sensor}) \cdot \left{ \frac{F_{s \rightarrow u} \cdot S_A^{-1} \cdot (FIR^{-1} \cdot (S_E - S_{SP}))}{F_{s \rightarrow u} \cdot S_A^{-1} \cdot (FIR^{-1} \cdot (S_{ICT} - S_{SP}))} \right} \cdot ICT(T, u_{sensor})$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Exelis(new)</td>
<td>$N = \left{ \frac{S_A^{-1} \cdot F_{s \rightarrow u} \cdot (S_E - S_{SP})}{S_A^{-1} \cdot (S_{ICT} - S_{SP})} \right} \cdot ICT(T, u_{sensor})$</td>
<td>$S_A^{-1} \cdot F_{s \rightarrow u}$</td>
<td></td>
</tr>
</tbody>
</table>

*Note: The equations and calculations are presented in a tabular format, with each item corresponding to a specific calibration method or approach. The table is designed to illustrate the different calibration options and their associated equations for comparison and analysis.*
Calibration first then “CMO”
“CMO” first then calibration

- LW ripple envelope (LLNew-REF), GranuleID=NPP000748812352 2, 1 2, 3
  Corrected for gain and du shift
  Ripple envelopes FOR=16

- LW ripple envelope (LW ripple envelope (Prop2-REF), GranuleID=NPP000748812352 2, 1 2, 3
  Corrected for gain and du shift
  Ripple envelopes FOR=16

- LW ripple envelope (ExelisNew-Ref), GranuleID=NPP000562002667 2, 1 2, 0
  first interferogram IET=1754219500984117, 2013-08-03 11:11:40.984
  Corrected for gain and du shift
  Ripple envelopes FOR=2
Doing the interpolation before/after the calibration ratio makes a difference (LW)

\[ N = ICT(T, u_{\text{user}}) \cdot \left\{ \frac{F_{\text{S}	o\text{SP}} \cdot SA_1 \cdot \left( FIR^{-1} \cdot (S_E - S_{SP}) \right)}{F_{\text{S}	o\text{SP}} \cdot SA_1 \cdot \left( FIR^{-1} \cdot (S_{ICT} - S_{SP}) \right)} \right\} \]

\[ N = F_{\text{S}	o\text{SP}} \cdot f \cdot SA_1 \cdot \left\{ \frac{FIR^{-1} \cdot (S_E - S_{SP})}{FIR^{-1} \cdot (S_{ICT} - S_{SP})} \cdot ICT(T, u_{\text{sensor, off_axis}}) \right\} \]

Ratio after interpolation & ISA

LLnew - Ref

Ratio before interpolation

Prop1 - Ref

Ratio before interpolation & ISA

Option A - Ref

Ref= Prop2

Note: Ref does interpolation before ratio
Doing the interpolation before/after the calibration ratio makes a difference (SW)

\[ N = \text{ICT}(T, u_{\text{user}}) \cdot \left\{ \frac{M \cdot \left( \text{FIR}^{-1} \cdot (S_E - S_{SP}) \right)}{M \cdot \left( \text{FIR}^{-1} \cdot (S_{ICT} - S_{SP}) \right)} \right\} \]

\[ N = F_{s \rightarrow a} \cdot f \cdot S_{A}^{-1} \cdot \left\{ \frac{\text{FIR}^{-1} \cdot (S_E - S_{SP})}{\text{FIR}^{-1} \cdot (S_{ICT} - S_{SP})} \right\} \cdot \text{ICT}(T, u_{\text{sensor}_{\text{off-axis}}}) \]

Ratio after interpolation & ISA

Ratio before interpolation

Note: Ref does interpolation before ratio
Conclusions

- Doing interpolation after calibration ratio gives a different result than interpolation & ISA before calibration ratio.
- Difference is entirely a modulated ringing at the Nyquist.
- Effective comparison of calibration results can be done by comparing ringing envelope.
- There are two distinct classes of calibration algorithms:
  - Interpolation (and ILS correction) before calibration ratio.
  - Interpolation (and ILS correction) after calibration ratio.
- Definition of ISA matrix is only consistent with Interpolation & ISA before calibration ratio.
- Further analysis is ongoing to produce optimal extended resolution spectra with correct calibration equation.