ATMS Algorithm Verification and Improvements to Reduce Radiometric Biases


Kent Anderson (NGES)

2015 Annual Science Team Meeting

26 August 2015

College Park, MD

This work was sponsored by the National Oceanic and Atmospheric Administration under contract FA8721-05-C-0002. Opinions, interpretations, conclusions, and recommendations are those of the author and are not necessarily endorsed by the United States Government.
Outline

- Update on the Flat Reflector Emissivity
- Icelandic S-NPP Aircraft Cal/Val Campaign
- Radiometric Environment Characterization
- On-orbit Single Events Upsets
- Future Work
Pitchover Bias: Potential Explanations

- With the Earthview sector viewing deep space, the radiometric scene is a homogenous and unpolarized source that fills the entire field of view of ATMS.

- As an unpolarized scene, the polarization twist or cross-pol. impurity issues are not the primary explanation.

- Alignment/pointing errors are unlikely due to strict subsystem quasi-optical alignment requirements that were verified during assembly.

- Skimming or spillover is a possibility, but the bias symmetry is difficult to justify.

- The bias asymmetry in the response is explained by near-field emission from the satellite, but the ATMS is positioned on the edge of the spacecraft, which doesn’t justify the cosine or sine relationship.
Potential Explanation: Flat Reflector Emissivity Model

- ATMS scanning reflector is a gold-plated beryllium flat plate, oriented 45 degrees relative to the wavefront (a nickel layer bonds the two).
- Conductive gold surface is a thin layer composed of microcrystalline granules, the emissivity can exceed the theoretical (Hagen-Rubens) emissivity of a perfectly flat bulk material.
- The layered and rough surface is difficult to accurately model or simulate.
- Values of the two polarization components can be expressed in terms of the normal emissivity derived from the Fresnel equations for reflections from a plane interface.

Vertical and Horizontal brightness temperatures will be:

\[
T_{BV} = \rho_V T_{SV} + \varepsilon_V T_R \\
T_{BH} = \rho_H T_{SH} + \varepsilon_H T_R
\]

where:  
\( \rho_V = \) reflectivity of the reflector = 1-\( \varepsilon_V \),  
\( T_{SV,SH} = \) brightness temperature of the scene, viewed by the reflector  
\( T_R = \) physical temperature of the reflector  
SV = Scene Vertical Pol.  
SH = Scene Horiz. Pol.  

Kent Anderson (NGES)
Penetration Depth in Metal

Gold - Au

Nickel - Ni

Amplitude Reduction [Percent]

Distance [micron]

GHz

GHz
When the reflector scans to an angle $\phi$, the resulting Quasi-Vertical (QV) and Quasi-Horizontal (QH) outputs:

$$T_{QV} = T_{BV} \cos^2 \phi + T_{BH} \sin^2 \phi \quad \text{Substitute } T_{BV} \text{ and } T_{BH}$$

$$T_{QV} = T_{SV} \cos^2 \phi + T_{SH} \sin^2 \phi + \frac{E_N}{\sqrt{2}} [T_R + T_{SV} - 2T_{SH}] \sin^2 \phi + \frac{E_N}{\sqrt{2}} (T_R - T_{SV})$$

$$T_{QH} = T_{BV} \sin^2 \phi + T_{BH} \cos^2 \phi$$

$$T_{QH} = T_{SV} \sin^2 \phi + T_{SH} \cos^2 \phi + \frac{E_N}{\sqrt{2}} [T_R + T_{SV} - 2T_{SH}] \cos^2 \phi + \frac{E_N}{\sqrt{2}} (T_R - T_{SV})$$

For the case of an unpolarized ($T_{SH} = T_{SV} = T_{CS}$) scene, at $T_{CS}$:

$$T_{QV} = T_{CS} + \frac{E_N}{\sqrt{2}} [T_R - T_{CS}] \sin^2 \phi + \frac{E_N}{\sqrt{2}} (T_R - T_{CS})$$

$$T_{QH} = T_{CS} + \frac{E_N}{\sqrt{2}} [T_R - T_{CS}] \cos^2 \phi + \frac{E_N}{\sqrt{2}} (T_R - T_{CS})$$
Emissivity Correction Parameters

• First parameter is the physical temperature of the flat reflector
  – There is no temperature sensor on the reflector, but there is on the Scan Drive Motor (SDM) and NGES has a thermal model to adjust the SDM temp. to a reflector temp.
  – Calibration algorithm is fairly insensitive to the reflector temperature (i.e., temp. is multiplied by the emissivity), which was confirmed by a rough sensitivity study

• Second parameter is the normal emissivity for each band (or channel)
  – Difficult to model or derive a theoretical equation
  – Three empirical methods were used to derive emissivity:
    • Used pitchover maneuver to “fit” a normal emissivity value to each channel
    • Derived from two precision calibration targets at similar temperatures but different angles during TVAC calibration
    • Measured the emissivity of flight-like spares (NGES)
On-orbit Derivation of the Normal Emissivity

- Swept the normal emissivity in a emissivity-corrected calibration algorithm until the Earth View Sector during the pitchover was flat
- Top figure presents the radiometric EVS results of stepping the emissivity for Channel 1
  - Cyan: original uncorrected result
  - Blue: corrected results at various emissivity steps
  - Green: tuned emissivity that had the lowest EVS standard deviation metric
- Bottom plot gives the derived emissivity for each channel
  - K- and V-band flat reflector is on the left
  - W- and G-band flat reflector is on the right
  - Tuning method was not sensitive to emissivity steps less than 0.05%
- Derived emissivity explained TVAC calibration anomaly
The error of quasi-V channels moved close to zero at the two calibration points.

V-band quasi-H channels also moved closer to zero.
NGES Emissivity Measurement

• NOAA/NASA asked NGES to measure the emissivity of the flight spare flat reflector to confirm on-orbit measurements

• NGES measured the emissivity of three flat reflectors:
  – Spare flight reflector (Au/Ni/Be)
  – Bulk Aluminum (6061)
  – Stainless Steel (304)

• Setup and more details coming up:
  – Flight spare’s emissivity trend across bands (i.e., frequency) was verified
  – Absolute values were different than on-orbit measurements
  – Analytical (i.e., Hagen-Rubens) values did not match
A special test was performed using a spare flight reflector to make a direct measurement of its polarized emissivity.

- Reflector was heated to produce contrast between reflector emission and energy reflected from a blackbody shroud.
- Reflector rotated at constant rate (1 Hz) and data processing extracted the 2 Hz sinusoidal component due to emissivity.

Special Test for Reflector Emissivity

- Shroud (Semi-transparent for illustration)
- Feedhorn and mm-wave receiver
- Beryllium Reflector Oriented 45° to Wavefront
- Absorber
- Aluminum Reflector Shown (Shroud Removed)
- Servomotor & Rotary Stage

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NGES Test Results

Derived Normal Emissivity

Results:

- Flight trend matches on-orbit trend
- No freq. trend with Al or SS
- SS is higher than Al

- Hagen-Rubens expects 2.8 times the emissivity between K and G-band
  - Smooth bulk Al = 0.0005 to 0.0015
  - Smooth bulk SS = 0.0027 to 0.0076

- Hagen-Rubens expects 5 times the emissivity between SS and Al
Simulating the Normal Emissivity

- Non-resonant characterization method using rectangular waveguide
- Numerical computation via HFSS FEA modeling
- Scattering parameters are obtained for waveguide
- Application of Nicolson-Ross-Weir Algorithm is used on computed S-parameters to obtain reflection coefficient
- HFSS Huray roughness model had 10 μm nodule radius and 2.9 Hall-Huray surface ratio

Idahosa Osaretin (MIT LL)
## Simulated Emissivity Results for Aluminum and Stainless Steel (WIP)

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Still working on modeling surface roughness

Still working on modelling stainless steel

Before analyzing layered flight reflector, simulating Al, SS, and teflon to build confidence
What it means for J1 & J2?

- For J1, Kent Anderson’s (NGES) initial evaluation of the emissivity from the May 2013 TVAC calibration indicated the emissivity was significantly smaller, but a J1 pitchover maneuver is a more reliable measurement because
  - It’s independent of potential Calibration Test Equipment issues
  - Gives multiple angles (i.e., more data) to derive the emissivity

- For J2, NGES and NASA added these changes:
  - Specifying 8 micro-inches profile arithmetic mean ($R_a$) surface roughness for the Be surface prior to nickel plating
  - Polish the nickel-plated surface to < 100 Angstroms surface quality
  - Thicker gold plating (increased from > 0.5 micron to > 1.3 micron)
Correction biases for an observed unpolarized brightness temperature $T_B$ are computed as below:

\[
\Delta T_{QV} = \frac{\varepsilon_N}{\sqrt{2}} [T_R - T_B] \sin^2 \phi + \frac{\varepsilon_N}{\sqrt{2}} (T_R - T_B) \\
\Delta T_{QH} = \frac{\varepsilon_N}{\sqrt{2}} [T_R - T_B] \cos^2 \phi + \frac{\varepsilon_N}{\sqrt{2}} (T_R - T_B)
\]

Algorithm steps:

1. Add the biases due to reflector emissivity to the cold and warm calibration brightness temperatures
   - Scan angles are at 83.3° and 195° respectively
   - Use $T_R$ derived from temperature telemetry
2. Add biases to correct for any other error sources
3. Compute gain and offset for the radiometric transfer function
4. Compute uncorrected scene temperatures, based on transfer function gain and offset
5. Add emissivity bias correction for each scene sample (function of scan angle and scene temperature)
Polarized Scenes

• Calibration targets and opaque channels use this scene correction term:

\[ \Delta T_{QV} = \frac{\varepsilon_N}{\sqrt{2}} \left[ T_R - T_B \right] \sin^2 \phi + \frac{\varepsilon_N}{\sqrt{2}} \left( T_R - T_B \right) \]

Use uncorrected \( T_B \)  
Use model-adjusted SDM temperature

• Channels sensitive to the surface (i.e., window channels) should use this scene correction term (Ch. 1, 2, 3, 4, 16 & 17):

\[ \Delta T_{QV} = \frac{\varepsilon_N}{\sqrt{2}} \left[ T_R + T_{SV} - 2T_{SH} \right] \sin^2 \phi + \frac{\varepsilon_N}{\sqrt{2}} \left( T_R - T_{SV} \right) \]

Need to model relationship between vertical and horizontal polarizations

• Implementing the surface correction for the window channels requires:
  – Ability to differentiate between sea and land (e.g., land/sea mask)
  – A model to estimate the brightness temperature difference between the vertical and horizontal polarization, which is a function of scan angle, surface wind speed, and sea surface temperature
  – May not be worth the effort
Status of Implementing Reflector Emissivity in IDPS

- Implementing the algorithm in IDPS requires making the Processing Coefficient Table (PCT) larger to hold the additional instrument-specific calibration parameters.

- Implementation requires a relatively minor code change to the TDR/SDR calibration algorithm.

- Plan to implement change in ADL, then compare the TDR scan bias against NWP and GPS-RO (Tiger NOAA STAR has implemented it in ARTS and have presentation available).

- The TDR-to-SDR conversion, i.e., the scan bias correction from antenna pattern measurements, will have to be reevaluated.
ATMS Calibration Validation Mission
March 2015

NAST-M
Dual-band, 15-channel microwave sounder similar to ATMS (54, 183) GHz

Mission
NASA ER-2 Aircraft

- Sorties from Keflavik, Iceland
- Greenland Summit weather station

http://www.nasa.gov/

Mike DiLiberto & Jason Meyer (MIT LL)
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 in the models
2015 Science Sorties Over Greenland

NAST-M has data from 7 flights ~41 hours

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Flight Time (H) | 5.92 | 4.58 | 6.23 | 4.12 | 7.45 | 7.35 | 6.08 |

Collected data from 9 S-NPP overflights
## 2013 Science Sorties Over the Pacific Next to Mexico

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

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**Collected data from 9 S-NPP overflights**
23 March ER-2 Flight Path and NPP Track

ER-2 flight path
NPP track

NAST-M Camera image from underpass

VIIRS Cloud Mask (blue is cloudy)

NAST-M and ATMS Coincident Measurements

NAST-M 7.5°
"pseudo nadir" ATMS 54 GHz 2.2°
"pseudo nadir" ATMS 18 GHz 1.1°
Examples of NAST-M TDR Bias

Ch. 8: 54.94 GHz

STAR ICVS GPS-RO TDR bias

Ch. 19: 183 +/- 4.5 GHz

STAR ICVS CRTM/ECMWF TDR bias
S-NPP Radiometric Environmental Characterization

Resulted from S-NPP ATMS Scan Reversal, which has contiguous sampling

Diagnostic mode in continuous sampling gives 2.43° spacing (360/148)
Scatter Plots: SV Spot 97 Cnts vs EV 48 Tb

- Plots above indicate a correlation between EV Tb and SV counts
- Disclosure: Tb calibrated using all 8 calibration measurement (4 SV & 4 HC)
- Channels affected seem to be the quasi-V polarized channels (Ch. 1, 2, & 16)
- May be some correlation in V-band window channel (Ch. 3).
- Spot 100 of the SVS had similar response
- Correlation coefficient about the same for all SVS spot 97 (between 0.4 to 0.55)
Potential to Move Space View Sector

SVS4 SVS1

Selected as “optimal” SVS1

Potentially move SVS toward S/C
Two types of SEU have been identified.

One type of event impacts the radiometric counts.

Another type of event impacts the Scan Drive Motor & resolver.

All events found are either in or near the South Atlantic Anomaly or near the polar regions.

ATMS recovers very quickly with minimum number of pixels impacted, but TDR/SDR Quality Flags (QFs) were not tripped.

Team should investigate altering QF to inform user of these events.
Radiometric SEU

- NGAS Sept. 8, 2014 investigation showed “random” positive and negative spike pattern per V-band Channels

Only V Band Channels Are Affected and the Anomaly can be both Positive and Negative

Positive Spikes: Channels 3, 6, 7, 9, 12, 13, 14, 15

Negative Spikes: Channels 4, 5, 8, 10

Undetermined: Channel 11

Initially characterized by Sung-Yung Lee (NASA JPL)

Degui Gu & Alex Foo (NGAS)
Section of ATMS Flow Diagram
NGAS SEU Characterization of Radiometric Event

Spatial Characteristics

Location

Latitude

Longitude

SAA

Time and Beam Position

Beam Position

Year of Anomaly

Degui Gu and Alex Foo (NGAS)
Reconstructed scan angles during event does seem to indicate that the SDM continues toward nadir, but starts to react to the zero resolver values (i.e., goes in reverse) before correcting itself.
Radiance & Geolocation (SDR) Data Products

Radiance “fill” values also had latitude and longitude fill values (-999.5)

8 Apr 2015
S-NPP Location at Start of SDM Event

About one or two SDM SEUs occur per month
Future Work

• Flat reflector emissivity
  – Continue to investigate emissivity with modeling
  – Implement the emissivity correction in IDPS and add coefficients to the ATMS SDR PCT
  – Get user and science community sign off

• NAST-M
  – Return to 2013 campaign to increase the data set
  – Continue with NAST-M upgrade that will add K & Ka channels

• Advocate for J1 spacecraft maneuvers and radiometric environment characterization in the PLT

• Investigate developing data product quality flags for ATMS Single Event Upsets
Backup Slides
### Comparison to Previous ATMS Emissivity Study Results

<table>
<thead>
<tr>
<th>Channel</th>
<th>Frequency</th>
<th>Analytical Emissivity (Bulk Ni Layer)</th>
<th>Numerical Emissivity</th>
<th>Analytical Emissivity (Bulk Au Layer)</th>
<th>PFM Pitch-Over Derived Emissivity LL</th>
<th>PFM Ground Calibration Derived Emissivity (NGES)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (QV)</td>
<td>23.8 GHz</td>
<td>0.0008545</td>
<td>0.0007060</td>
<td>0.0005083</td>
<td>0.004</td>
<td>0.0038</td>
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<tr>
<td>2 (QV)</td>
<td>31.4 GHz</td>
<td>0.0009815</td>
<td>0.0024944</td>
<td>0.0005838</td>
<td>0.0035</td>
<td>0.00363</td>
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<tr>
<td>3 (QH)</td>
<td>50.3 GHz</td>
<td>0.0012422</td>
<td>0.0004398</td>
<td>0.0007389</td>
<td>0.002</td>
<td>0.0025</td>
</tr>
<tr>
<td>6 (QH)</td>
<td>53.596 GHz</td>
<td>0.0012830</td>
<td>0.0004143</td>
<td>0.0007627</td>
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<td></td>
</tr>
<tr>
<td>7 (QH)</td>
<td>54.4 GHz</td>
<td>0.0012919</td>
<td>0.0004438</td>
<td>0.0007684</td>
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<td></td>
</tr>
<tr>
<td>10 (QH)</td>
<td>57.29 GHz</td>
<td>0.0013257</td>
<td>0.0005008</td>
<td>0.0007885</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16 (AV)</td>
<td>88.2 GHz</td>
<td>0.0016450</td>
<td>0.0014246</td>
<td>0.0009784</td>
<td>0.0065</td>
<td>0.00662</td>
</tr>
<tr>
<td>17 (QH)</td>
<td>165 GHz</td>
<td>0.0022533</td>
<td>0.0008428</td>
<td>0.0013403</td>
<td>0.004</td>
<td>0.00354</td>
</tr>
<tr>
<td>18 min (QH)</td>
<td>176.3 GHz</td>
<td>0.0023257</td>
<td>0.0008060</td>
<td>0.0013833</td>
<td>0.0045</td>
<td>0.0043</td>
</tr>
<tr>
<td>18 center (QH)</td>
<td>183.3 GHz</td>
<td>0.0023714</td>
<td>0.0006445</td>
<td>0.0014105</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18 max (QH)</td>
<td>190.3 GHz</td>
<td>0.0024163</td>
<td>0.0011150</td>
<td>0.0014372</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Calibration Algorithm Correction

Correction impacts three parts of the calibration equation:

\[ T_{\text{measured}} = g \times (C_{\text{scene}} - C_{\text{sv}}) + T_{\text{sv}} \]  \hspace{1cm} (Eq. 3)

1. The deep space radiometric counts are corrupted by the reflector’s physical temperature and must be corrected in the deep space brightness temperature:

\[ T_{\text{sv}} = \rho \times T_{\text{DS}} + \varepsilon_{\text{SV}} \times T_{\text{refl}} = T_{\text{DS}} + \frac{\varepsilon_n}{\sqrt{2}} \times \sin^2(\phi_{\text{SV}}) \times (T_{\text{refl}} - T_{\text{DS}}) \]  \hspace{1cm} (Eq. 4)

2. Since the hot and cold calibration views are at different angles, the gain must be corrected for the reflector emissivity contribution:

\[ g = \frac{T_{\text{HC}} + \varepsilon_{\text{HC}} \times (T_{\text{refl}} - T_{\text{HC}}) - T_{\text{DS}} - \varepsilon_{\text{SV}} \times (T_{\text{refl}} - T_{\text{DS}})}{C_{\text{HC}} - C_{\text{SV}}} \]  \hspace{1cm} (Eq. 5)

HC = Hot Cal (i.e., ambient)

3. Finally, the scene brightness temperature is corrupted and this correction must be applied:

\[ T_{\text{scene}} = \frac{T_{\text{measured}} - \varepsilon_x \times T_{\text{refl}}}{1 - \varepsilon_x} \]  \hspace{1cm} (Eq. 6)

\( \varepsilon_x \) is the quasi-V (QV) or quasi-H (QH) emissivity
Once the scan angle returns (see left), the scan angle value is in approximately the same location as it left off.

The Loop Integral Error changes before the resolver (i.e., scan angle) returns to correct values.
S-NPP Pitchover ATMS Scan Angle Bias

**Channel 1**
- QV 23.8 GHz

**Channel 16**
- QV 89 GHz

**Channel 3**
- QH 50.3 GHz

**Channel 4**
- QH 53.596 GHz
NOAA-14 MSU Deep Space Scan Bias

MSU Ch. 1 50.36 GHz

MSU Ch. 2 53.74 GHz

MSU Ch. 3 54.96 GHz

MSU Ch. 4 57.95 GHz

NOAA-14 Pitch Over Maneuver

"ATMS Ch. 3"

"ATMS Ch. 6"

"ATMS Ch. 8"

"ATMS Ch. 10"
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

Nadir Footprints (Spots 48 & 49)

NAST-M calibration at MIT LL

Calibration Target