REFLECTOR EMISSIVITY BIASES ON ATMS

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1. INTRODUCTION

The Suomi NPP spacecraft pitch-over maneuver revealed that the Advanced Technology Microwave Sounder (ATMS) [1,2] had a scan angle-dependent bias when viewing deep space, which could introduce errors up to 0.5 K in derived operational scene brightness temperatures. Two examples of this bias are shown in Figure 1, which plots the brightness temperature versus scan angle during this maneuver (orbit number 1637, descending, on February 20, 2012). In these plots, the value for each beam position is an average over 231 scans.

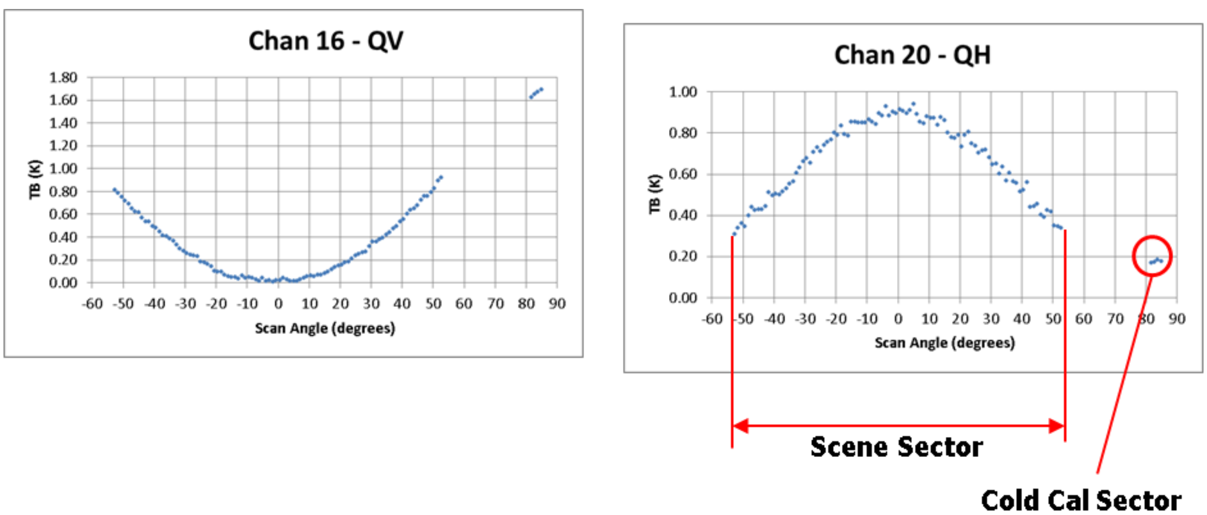

Figure 1 Scan bias observations during ATMS pitch maneuver

It was hypothesized that this bias was due to the polarized emissivity of the scanning reflector. For the ATMS configuration, the emissivity is polarization dependent, resulting in a scan-dependent bias, with the quasi-vertical channels having a different functional dependence than the quasi-horizontal channels. The normal-incidence emissivity of the scanning reflector was empirically estimated by fitting the theoretical model to the pitch-over maneuver data. Similarly, ground calibration data were used to estimate reflector emissivity of both the Suomi NPP and the JPSS-1 ATMS units. A special test was then performed on a spare reflector to make a direct measurement of its polarized emissivity. This paper presents the theoretical model, describes the special reflector emissivity test, and compares the results from the pitch maneuver, the ground calibrations and the special spare reflector test. A new calibration algorithm is then proposed as a means for correcting this scan-dependent bias.

2. EMISSIVITY MODEL

The ATMS scanning reflector is a gold-plated beryllium flat plate, oriented 45 degrees relative to the wavefront (see Figure 2).

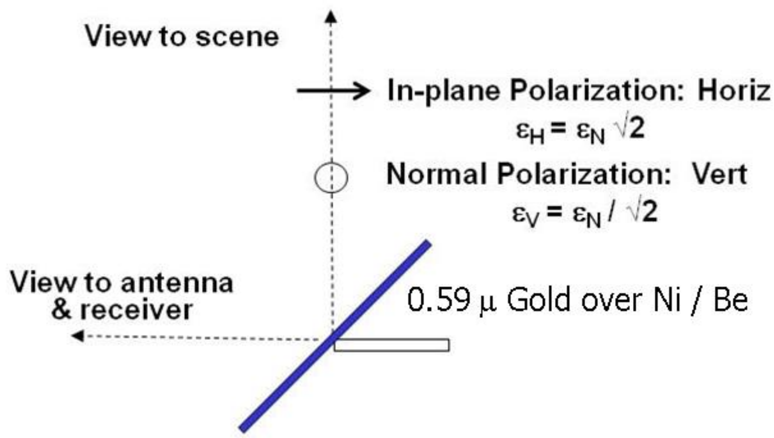

Figure 2 ATMS scanning reflector configuration

The effect of reflector emissivity is that the brightness temperature vertical and horizontal components viewed by the antenna feedhorn will be: $T_{BV} = \rho_V T_{SV} + \varepsilon_V T_R$ and $T_{BH} = \rho_H T_{SH} + \varepsilon_H T_R$,

where ρ_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

For a thin conductive layer, the emissivity can be expected to significantly exceed the theoretical (Hagen-Rubens) emissivity of a perfectly flat bulk material, and can only be determined experimentally. Based on the Fresnel equations for reflections from a plane interface, the emissivity for polarization in the plane of incidence will be twice the polarization component normal to the plane of incidence (for 45° incidence angle). When the reflector is scanned relative to a fixed linear polarization feed horn, the Quasi-Vertical (QV) and Quasi-Horizontal (QH) components of emissions therefore have a $\sin^2$ and $\cos^2$ scan angle dependence, respectively. The resulting antenna temperature, viewed by the feed horn, also exhibits this sinusoidal scan-dependency, with a magnitude proportional to the difference between the reflector physical temperature and the scene brightness temperature, as shown in the equations below.

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

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

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

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

For the case of an unpolarized scene, at T_{CS} (as in the pitch-over maneuver), this simplifies to the following:

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

$$T_{QH} = T_{CS} + \frac{\varepsilon_N}{\sqrt{2}}\left[T_R - T_{CS}\right]\cos^2\phi + \frac{\varepsilon_N}{\sqrt{2}}\left(T_R - T_{CS}\right)$$

3. PITCH-OVER MANEUVER

During the Suomi NPP pitch-over maneuver, brightness temperature data were collected while executing the normal operational scanning profile, which consists of 96 samples in an "Earth-view" sector that covers a ± 52.7° swath, plus a 4.4° cold-space view calibration sector and a 4.4° internal warm load calibration sector (see Figure 1). For the pitch-over orientation, the "Earth-view" swath was centered at the cold-space zenith orientation. The resulting data showed a very good fit to the $\sin^2$ and $\cos^2$ functions expected for the reflector polarized emissivity effect. There are, however, two kinds of small deviations from the sinusoidal functions: 1) higher than expected brightness temperature at the "cold-calibration" sector, and 2) asymmetry of the sun-side versus the anti-sun-side of the "Earth-view" sector. The former is explainable as a contribution from Earth intercept of the antenna sidelobes, and the latter as a contribution from spacecraft intercept. Therefore, to obtain a more accurate characterization of the reflector emissivity, the $\sin^2$ and $\cos^2$ curve fitting was applied only to the anti-sun half of the "Earth-view" sector. The results of this curve-fitting are illustrated in Figure 3.

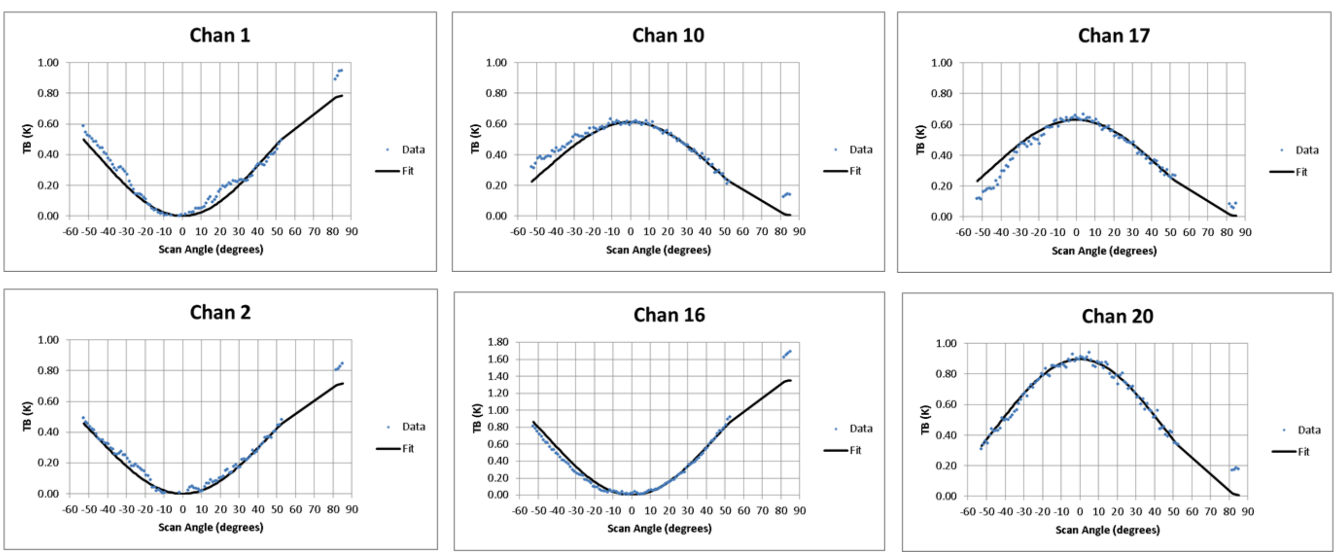

Figure 3 Curve-fitting to the pitch-maneuver data

Based on an estimated reflector physical temperature of 283 K, a value of normalized emissivity was derived for each channel by minimizing mean-squared errors of computed brightness temperature. The resulting emissivities are shown in Figure 4.

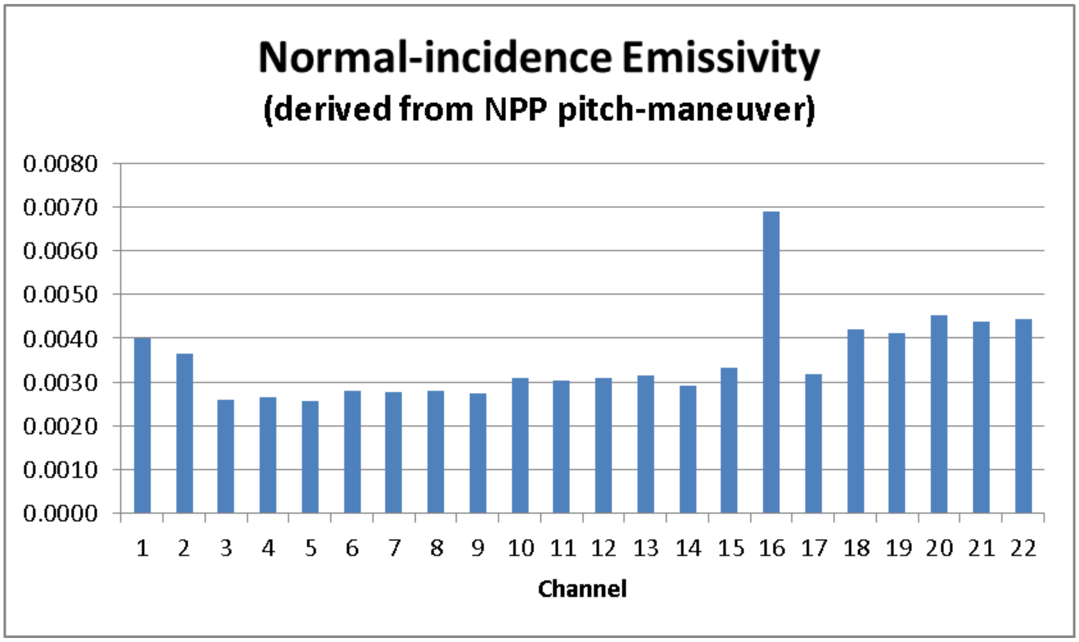

Figure 4 Reflector emissivities derived from pitch-maneuver data

4. GROUND CALIBRATION

In thermal vacuum ground calibration, the ATMS executes the normal operational scanning profile, observing a cold target at the cold-calibration sector and a variable scene-target for a portion of the Earth-view sector. When the scene target is at the same physical temperature as the cold-calibration-view target, any difference between the inferred scene brightness temperature and the calibration temperature is generally attributed to relative bias errors in the targets. Such an offset is expected to be nearly constant across all the channels covered by a set of targets. However, since the scene and calibration target views are at different scan angles, there will also be an error contribution due to the polarized emissivity of the scanning reflector. In particular, this error component will be significantly different for the QV and the QH channels. This effect has been consistently observed in the ground calibration data, and it is therefore possible to use this data to estimate the reflector emissivity. The results of this analysis for the Suomi NPP instrument calibration are shown in Figure 5, which is consistent with the observations from the pitch-over maneuver.

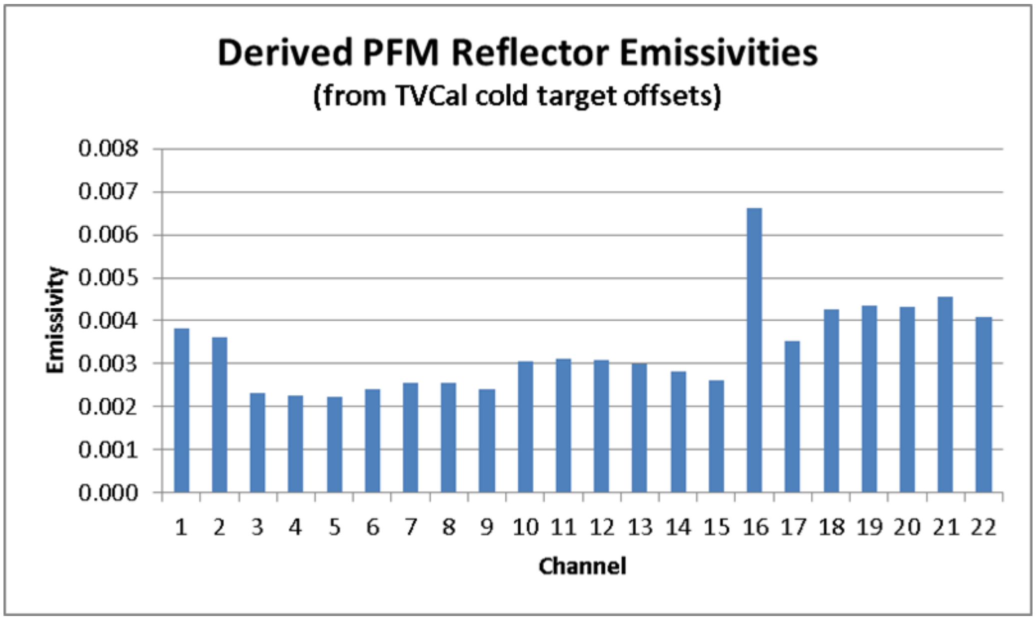

Figure 5 ATMS S-NPP (PFM) reflector emissivities derived from ground calibration test data

Estimates of reflector emissivity are also shown in Figure 6 for the JPSS-1 reflector, based on it's ground calibration test.

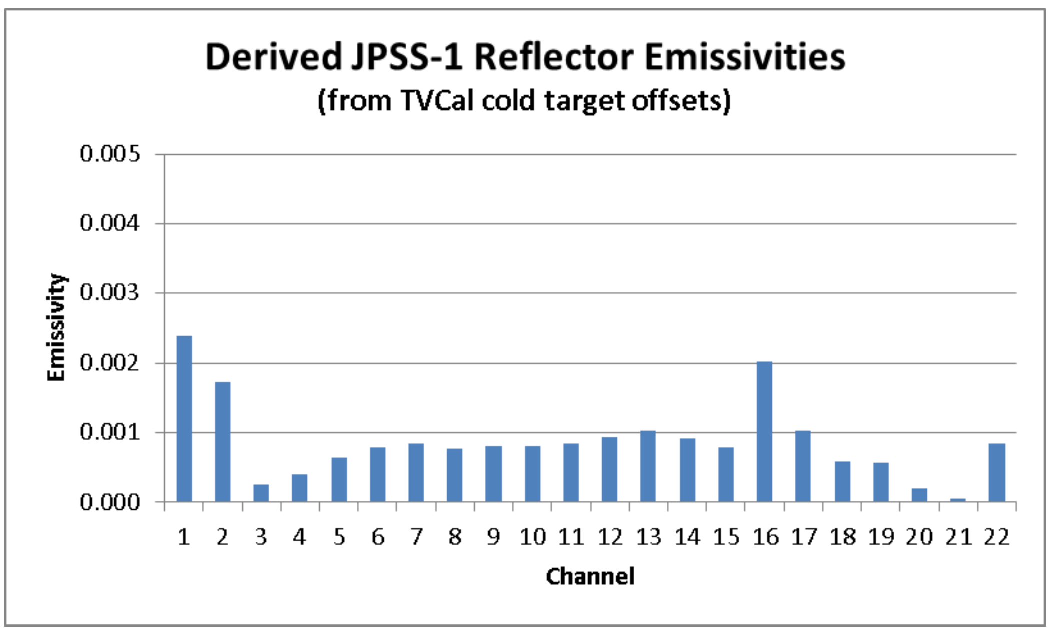

Figure 6 ATMS JPSS-1 reflector emissivities derived from ground calibration test data

This data indicates that there can be significant unit-to-unit variations in reflector emissivity, and that the JPSS-1 unit can be expected to have notably less scan bias than the S-NPP unit.

5. SPECIAL EMISSIVITY TEST

A special test was performed using an ATMS spare flat-plate reflector and engineering models of the ATMS radiometric receivers and feedhorns. The measurements were conducted at five frequency bands: the ATMS K, Ka, V, W and G bands. The reflector was rotated by a servo drive motor and the radiation was measured by a linear-polarized feed horn and receiver assembly. This test produced the expected sinusoidal scan angle variations, at a frequency of twice the rotation rate. The test results, shown in Figure 7, indicate conclusively that the reflector emissivity effect is present for the flight spare reflector. The emissivity values are larger than for the Suomi NPP flight unit, confirming the previous observation of unit-to-unit variability, but the results show the same general relative magnitudes between the frequency bands.

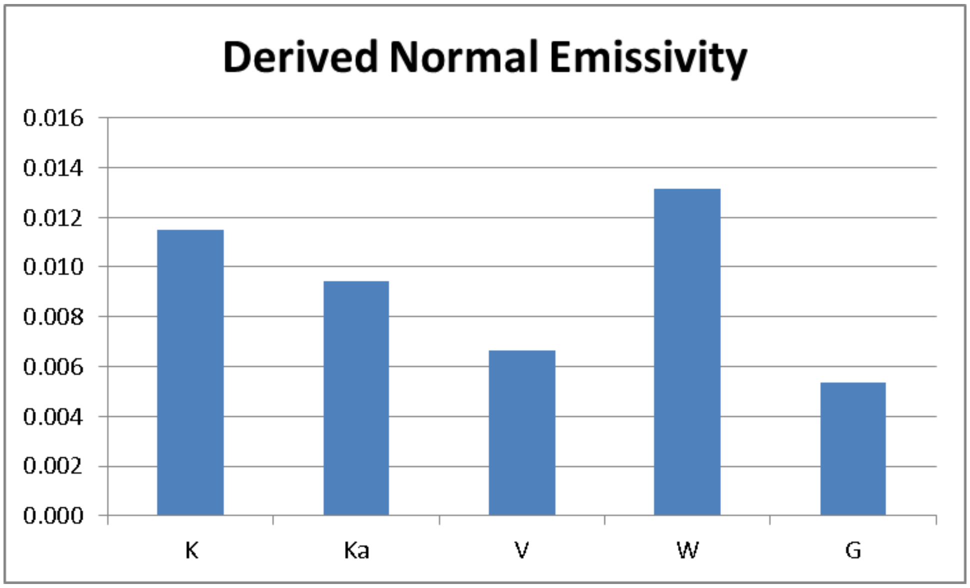

Figure 7 Emissivity of spare reflector, derived from special ground test

8. PROPOSED CALIBRATION ALGORITHM

A new radiometric calibration algorithm is proposed, which will correct for this scan-angle dependent polarized emissivity effect. The correction terms, shown below, are a function of scene temperature and reflector physical temperature, and should be used to correct for biases introduced in the calibration sectors as well as for the scene sector.

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

where TB is the initial estimate of scene brightness temperature, prior to performing this correction. An error analysis was also performed, indicating that a residual correction term uncertainty of < 0.10 K can be achieved if the reflector temperature is known to within 10°C and the reflector emissivity is known to within 0.001. Based on the fidelity of the ATMS thermal model, and the quality of data obtainable from a pitch maneuver, this level of performance is achievable.

9. REFERENCES

[1] C. Muth, *et al.,* "Advanced Technology Microwave Sounder on the National Polar-orbiting Operational Environmental Satellite System," *IGARSS 2005 Proceedings*, July 2005

[2] F. Weng, et al., "On Convertibility From Antenna to Sensor Brightness Temperature for ATMS," IEEE Geoscience and Remote Sensing Letters, preprint