THE VALUE OF PERFORMANCE.

NORTHROP GRUMMAN

Reflector Emissivity Biases on ATMS

AMS 2015, Session J18.6

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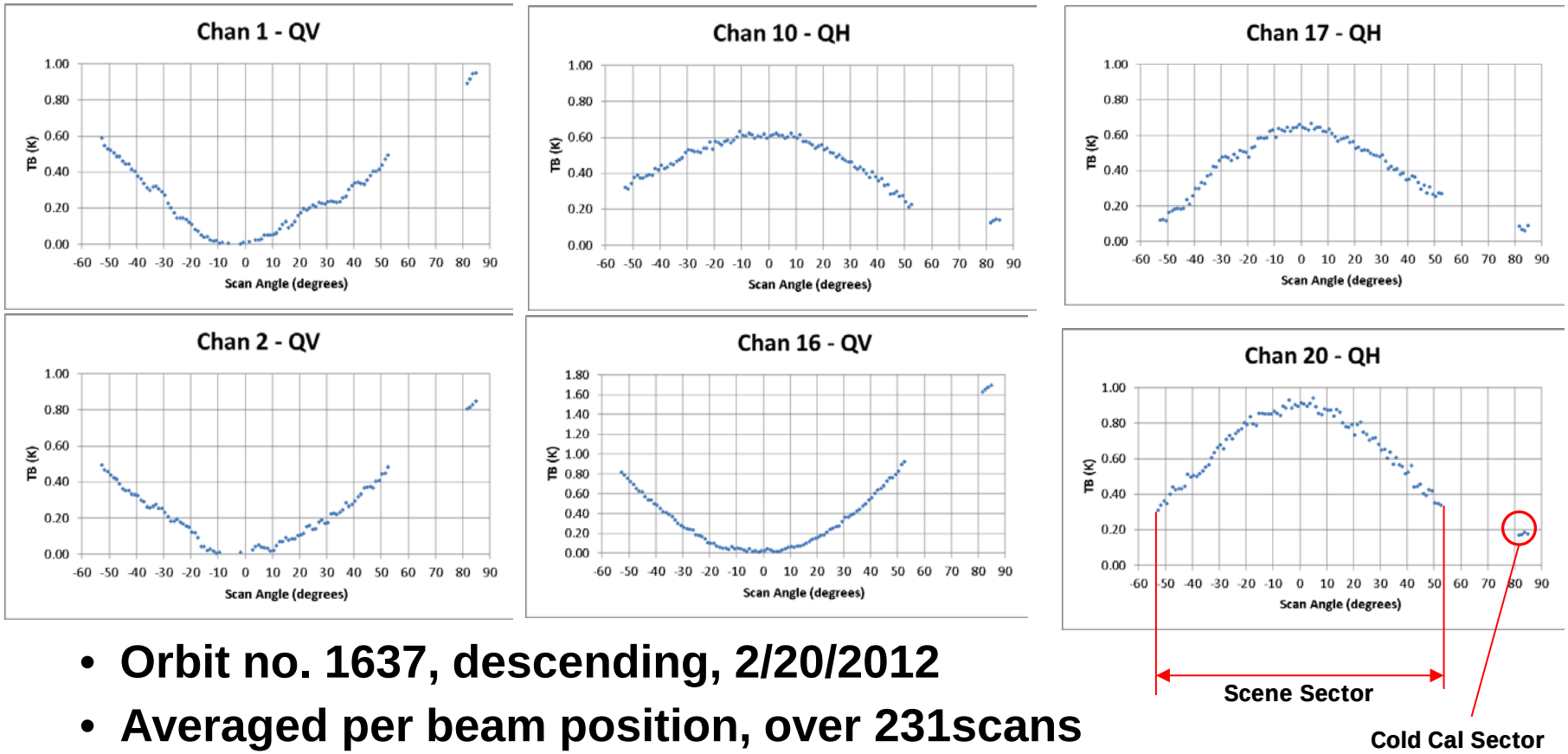
Outline

- **Scan-dependent Bias Observations on SNPP**
- **Theory of root cause: reflector emissivity**
- **Analysis of Pitch-maneuver data**
- **Analysis of ground calibration data**
- **Special reflector emissivity test**
- **Proposed correction algorithm, and residual error analysis**
- **Summary and Conclusions**

Acknowledgments: This work was carried out under a contract with the National Aeronautics and Space Administration.

Observations, from pitch-maneuver



- **Orbit no. 1637, descending, 2/20/2012**
- **Averaged per beam position, over 231scans**
- **Channel 10 is representative of channels 3-15**
- **Channel 20 is representative of channels 18-22**
- **QV channels consistently “concave-up”; QH “concave-down”**

Theory

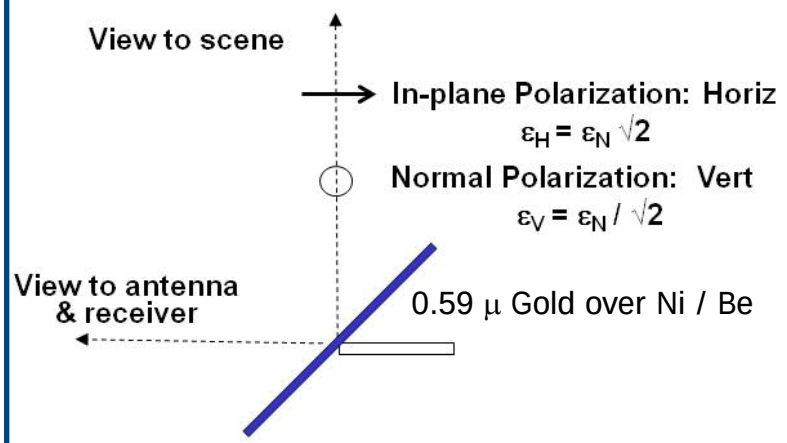
- **Vertical and Horizontal brightness temperatures will be:**

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

where : 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**

- **When the reflector scans to an angle ϕ, the resulting Quasi-Vertical (QV) and Quasi-Horizontal (QH) outputs:**

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

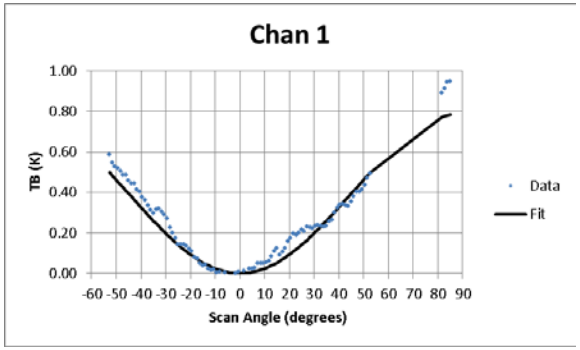


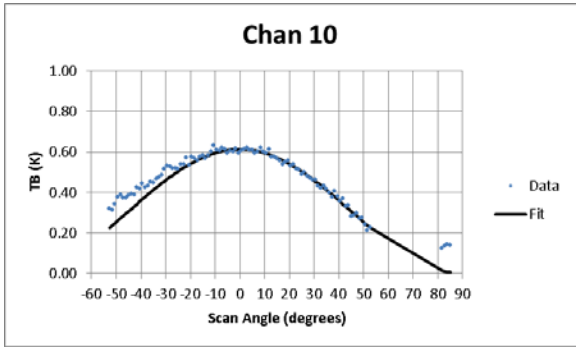
Scanning Reflector Geometry

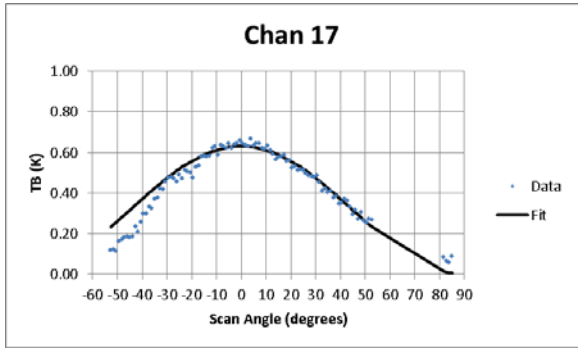
For the case of an unpolarized scene, at T_{CS}:

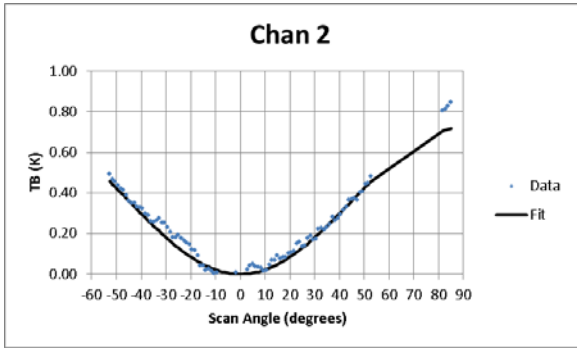
$$T_{QV} = T_{CS} + \frac{\varepsilon_N}{\sqrt{2}}[T_R - T_{CS}]\sin^2\phi + \frac{\varepsilon_N}{\sqrt{2}}(T_R - T_{CS})$$
$$T_{QH} = T_{CS} + \frac{\varepsilon_N}{\sqrt{2}}[T_R - T_{CS}]\cos^2\phi + \frac{\varepsilon_N}{\sqrt{2}}(T_R - T_{CS})$$

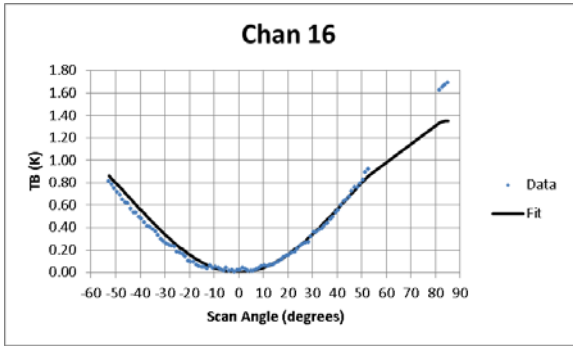
Analysis of Pitch Maneuver Data

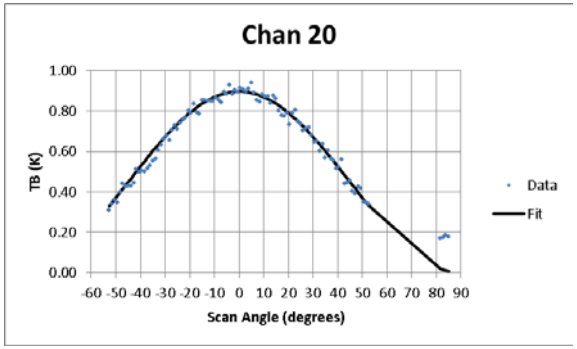












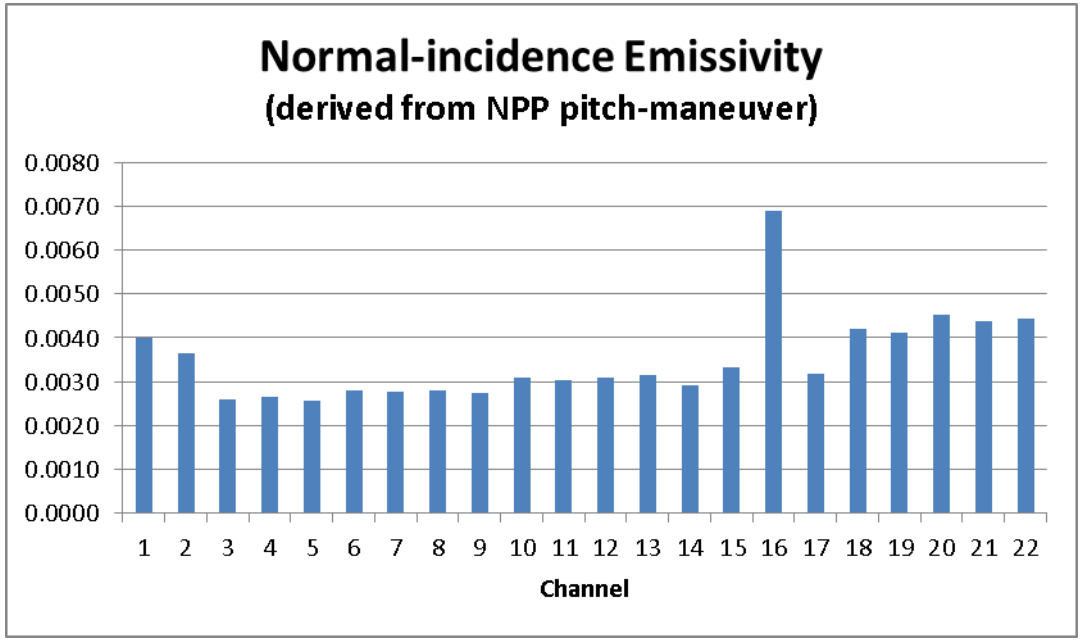
- **Curve-fitting of $\sin^2$ and $\cos^2$ functions to data over the anti-SC side of scene sector (0° to 53° scan angles)**
  - **Avoids asymmetric effect of SC interference for angles < 0°**
  - **Avoids cold-cal sector offset due to earth intercept**
- **Resulting amplitudes of $\sin^2$ and $\cos^2$ functions used to compute emissivity**

Results from Pitch-maneuver Data Analyses

- **Derived emissivities from the curve-fit $\sin^2$ and $\cos^2$ amplitudes, A:**

$$\varepsilon_N = \frac{\sqrt{2}A}{T_R - 3}$$

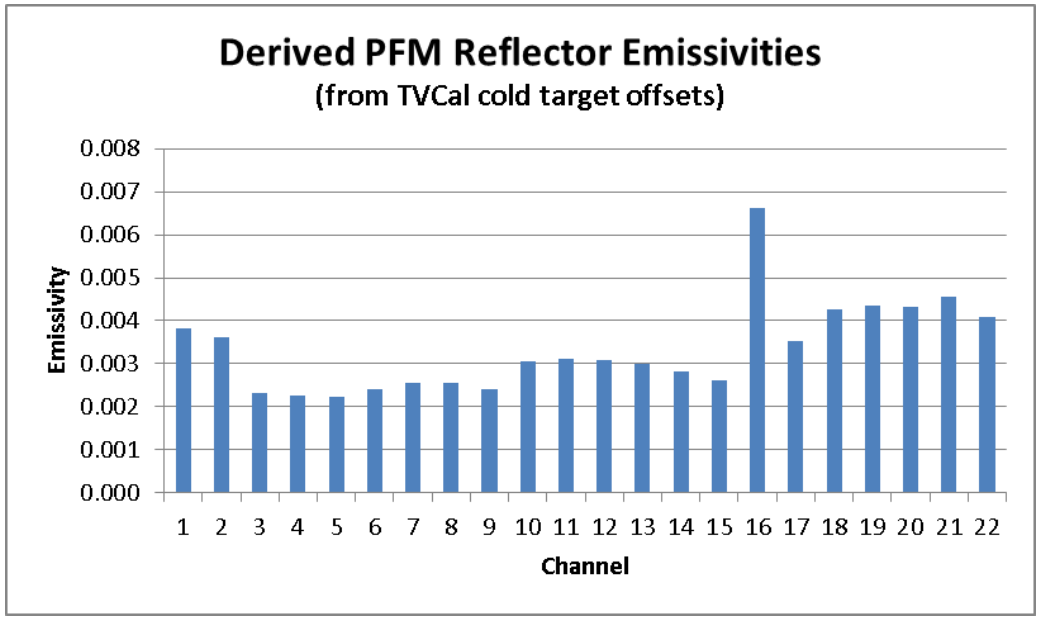
- **Reflector temperature determined from temperature telemetry and detailed thermal model: T_R = 283 K**



Chan	Emissivity
1	0.00399
2	0.00365
3	0.00260
4	0.00266
5	0.00255
6	0.00279
7	0.00278
8	0.00278
9	0.00274
10	0.00310
11	0.00302
12	0.00308
13	0.00315
14	0.00292
15	0.00333
16	0.00689
17	0.00318
18	0.00421
19	0.00411
20	0.00453
21	0.00439
22	0.00444

Ground Calibration Data Analysis - NPP

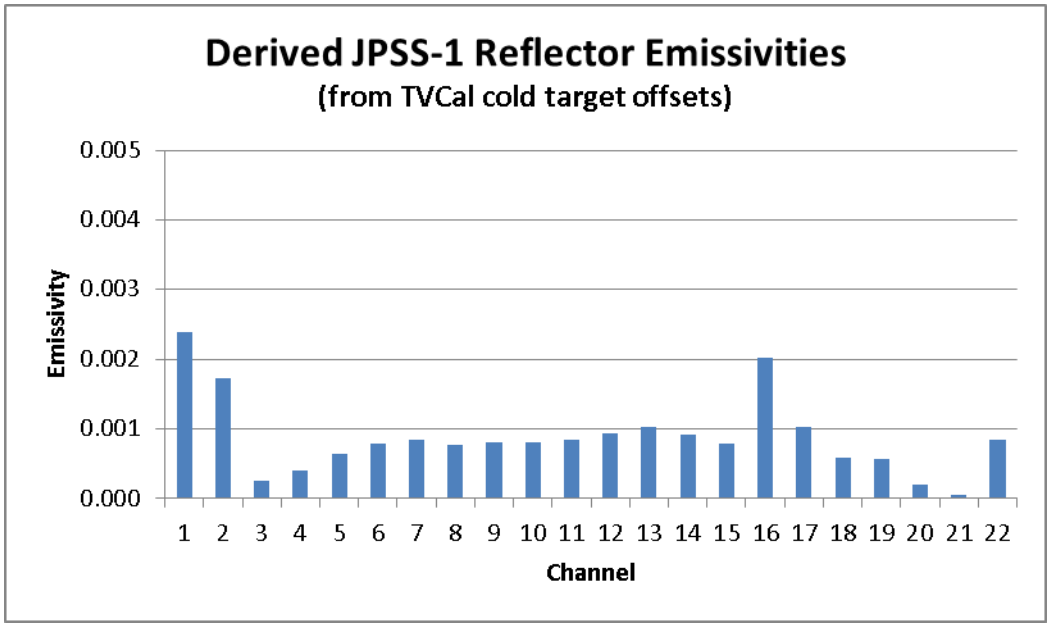
- In thermal vacuum calibration, a variable (scene) target and a fixed (cold-cal) target were observed
- When at the same physical temperature, the radiometric measurement deltas are due to two causes:
  - Temperature measurement errors of the targets
  - Polarized reflector emissivity, at two scan angle positions
- Reflector emissivity was derived, under the constraint that target temperature error is constant for all channels
- Results, below, are in substantial agreement with pitch-maneuver results



Chan	Emissivity
1	0.00381
2	0.00363
3	0.00231
4	0.00225
5	0.00224
6	0.00241
7	0.00255
8	0.00256
9	0.00240
10	0.00305
11	0.00310
12	0.00308
13	0.00300
14	0.00283
15	0.00262
16	0.00662
17	0.00354
18	0.00426
19	0.00434
20	0.00433
21	0.00457
22	0.00410

Ground Calibration Data Analysis – JPSS-1

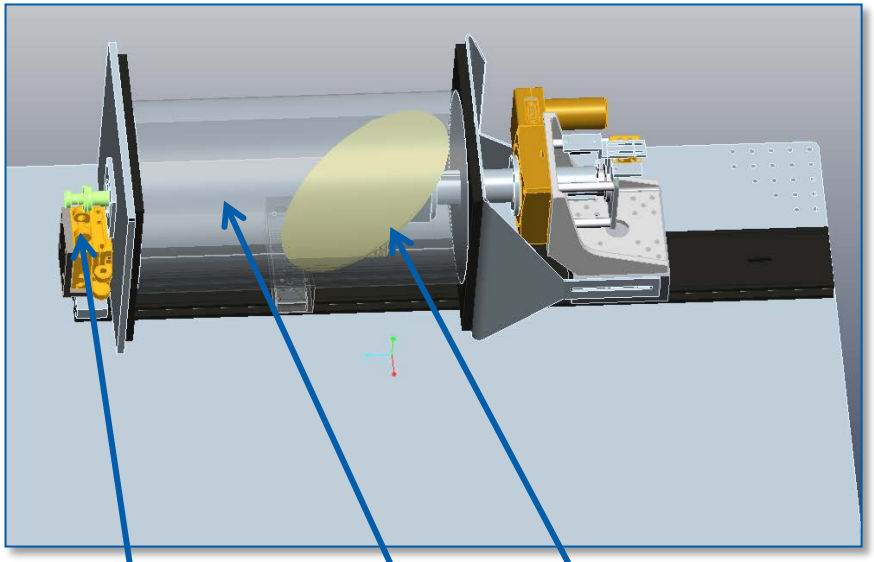
- Estimates from initial JPSS-1 calibration indicate:
  - Similar channel/frequency dependence
  - Overall substantially lower emissivity
- Subject to uncertainties due to unknown target errors
- Evidence of significant unit-to-unit variability

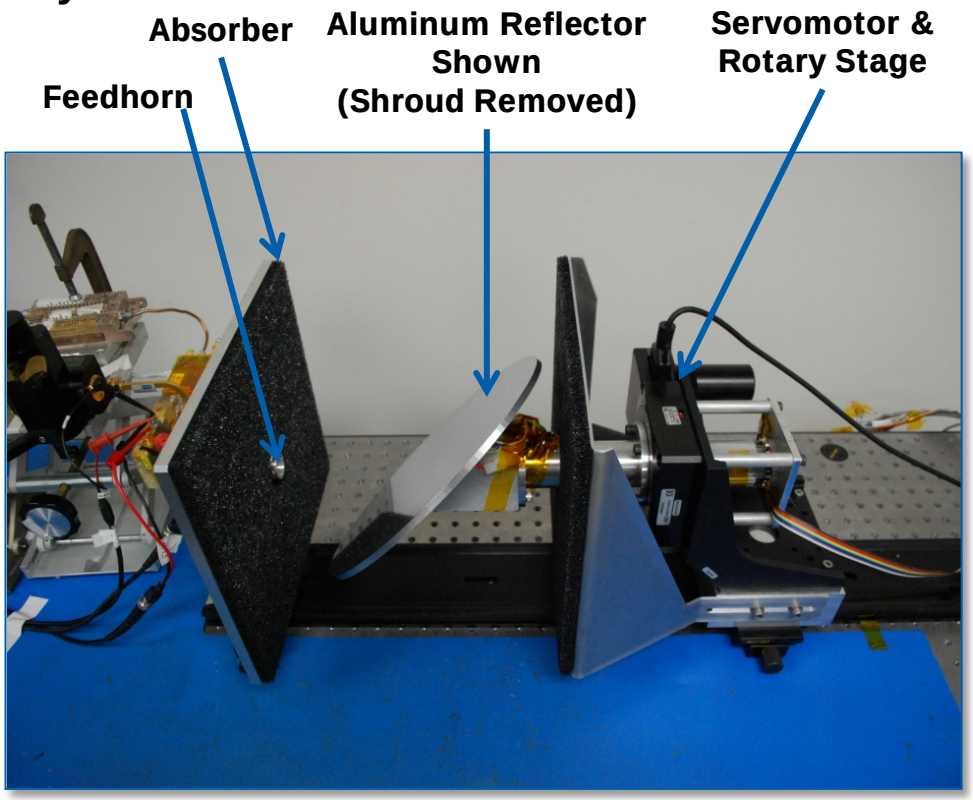


Chan	Emissivity
1	0.00240
2	0.00173
3	0.00026
4	0.00041
5	0.00064
6	0.00080
7	0.00084
8	0.00078
9	0.00081
10	0.00081
11	0.00084
12	0.00093
13	0.00102
14	0.00092
15	0.00078
16	0.00202
17	0.00102
18	0.00060
19	0.00057
20	0.00020
21	0.00005
22	0.00085

Special Test for Reflector Emissivity

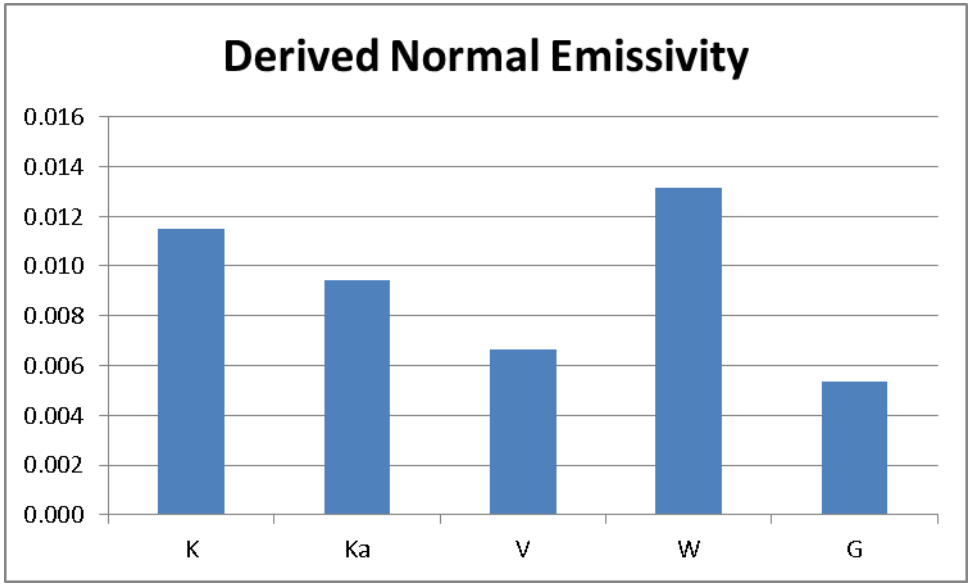
- **A special test was performed using a spare flight reflector to make a direct measurement of its polarized emissivity**
  - **Reflector was heated to produce contrast between reflector emission and energy reflected from a blackbody shroud**
  - **Reflector rotated at constant rate (1 Hz) and data processing extracted the 2 Hz sinusoidal component due to emissivity**





Results of Reflector Emissivity Tests

- The test produced the expected sinusoidal scan angle variations at a frequency of twice the reflector rotation rate, conclusively demonstrating the effect of polarized emissivity
- The derived emissivity for each frequency band is shown below
  - Magnitudes significantly larger than for SNPP, indicating unit-to-unit variability
  - Relative magnitudes between frequency bands are consistent with the SNPP data



Proposed Correction Algorithm

- **Correction biases for an observed brightness temperature T_B are computed as below:**

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

- **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)**

Assessment of Residual Errors

- **Based on the equation for bias correction,**

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

Bias estimation errors due to uncertainty in reflector temperature, ΔT_R, will be on the order of $\varepsilon_N \bullet \Delta T_R$

For ε_N in range of 0.002 to 0.006, and a reflector temperature error of ΔT_R = 10°C, the bias correction residual error will be 0.02 to 0.06 K

Bias estimation errors due to uncertainty in emissivity, $\Delta\varepsilon_N$, will be on the order of $(T_R - T_B)\,\Delta\varepsilon_N$

For $(T_R - T_B)$ = 100K, and an emissivity error of $\Delta\varepsilon_N$ = 0.001, the bias correction residual error will be 0.10 K

- **Conclusion is that thermal model estimates of reflector temperature, and pitch-maneuver estimates of emissivity, are adequate to provide high-quality corrections**

Summary and Conclusions

- ATMS scan-dependent biases, observed during the SNPP pitch maneuver, can produce radiometric errors up to 0.5 to 1.0 K
- Physical basis of the phenomenon is scanning reflector emissivity, which has been demonstrated by special tests
- Values for emissivity were derived from the SNPP pitch-maneuver data, and are in excellent agreement with values derived from ground calibration test data
- Emissivity values obtained from ground tests on a spare reflector, and values derived from JPSS-1 calibration, show significant unit-to-unit variation, but very similar trends relative to channels
- A correction algorithm is proposed, based on reflector and scene temperatures
- Error analysis supports viability of the algorithm, provided that pitch-maneuvers are repeated for each flight unit

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