Calibration Anomalies and Radiance Assimilation Correction Strategies for the Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave Imager Sounder (SSMIS)

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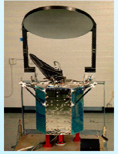
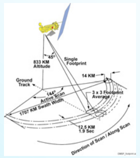
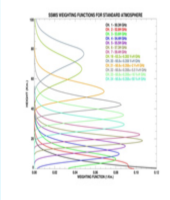
Introduction

The Defense Meteorological Satellite Program (DMSP) launched the first (F-16) in a series of five spacecraft carrying Special Sensor Microwave Imager Sounders (SSMIS) on October 18, 2003. The SSMIS is a 24 channel conically scanning microwave radiometer, with frequencies ranging from 19 to 183 GHz. During the comprehensive SSMIS Calibration and Validation (Cal/Val) efforts, unexpected calibration anomalies were discovered in the radiometric data [1]. Two principal anomalies were detected: an intermittent solar intrusion to the warm load calibration target; and reflector emission due to solar heating of the reflector face itself. Data assimilation systems for numerical weather prediction typically demand less than 0.4 K uncertainty in the 50-60 GHz oxygen absorption channels, and require that such observed biases be removed prior to assimilation.





Ch. No.	Center Frequency [GHz]	1st IF [MHz]	2nd IF [MHz]	Bandwidth [MHz]	Pol	Peak [hPa]	
1	50.3	0.	0.	400.	V	1000	AMSU-A
2	52.8	0.	0.	400.	V	700	
3	53.596	0.	0.	400.	V	400	
4	54.40	0.	0.	400.	V	200	
5	55.50	0.	0.	400.	V	100	
6	57.29	0.	0.	350.	LCP	60	
7	59.4	0.	0.	250.	LCP	30	
8	150.0	1250.	0.	1500.	H		AMSU-B
9	183.31	6600.	0.	1500.	H		
10	183.31	3000.	0.	1000.	H		
11	183.31	1000.	0.	400.	H		
12	19.35	0.	0.	400.	H		SSM/I
13	19.35	0.	0.	400.	V		
14	22.235	0.	0.	500.	V		
15	37.0	0.	0.	1500.	H		
16	37.0	0.	0.	1500.	V		
17	91.655	900.	0.	1500.	V		
18	91.655	900.	0.	1500.	H		
19	63.283248	±285.271	0.	1.5	LCP	0.02	MESO
20	60.792668	±357.892	0.	1.5	LCP	0.05	
21	60.792668	±357.892	±2.	1.5	LCP	0.7	
22	60.792668	±357.892	±5.5	3.0	LCP	2	AMSU-A
23	60.792668	±357.892	±16.	8.0	LCP	7	
24	60.792668	±357.892	±50.	30.0	LCP	15	



SSMIS Calibration

Radiometric calibration for the SSMIS is performed by a two-point method in which the radiometer feedhorns are passed under a warm load target and a cold space reflector. The warm load target consists of an array of pyramidal tines coated with highly emissive paint. The key assumption in this calibration method are 1) the relationship between antenna temperatures and raw radiometric counts is linear between the warm and cold calibration points, and 2) the warm load and cold space temperatures are representative of the respective calibration targets.

Linear Calibration Equation

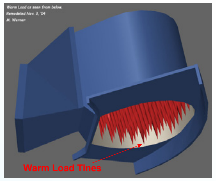
$$T_{Ai} = Tc + \frac{\overline{Tw} - Tc}{\overline{Cw} - \overline{Cc}}\left(C_i - \overline{Cc}\right) = Tc + \frac{C_i - \overline{Cc}}{G}$$

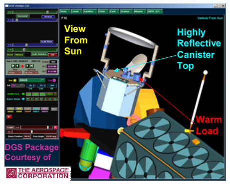
T_{Ai} = Antenna Temperature
Tc = Cosmic Background Temperature
$\overline{Cc}$ = Mean Cold Space Reflector Count
$\overline{Tw}$ = Mean Warm Load Temperature
$\overline{Cw}$ = Mean Warm Load Count
C_i = Scene Count

$$G = \frac{\overline{Cw} - \overline{Cc}}{\overline{Tw} - Tc} = \text{Radiometer Gain}$$

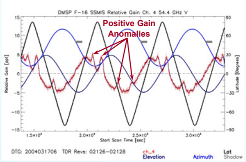
SSMIS Warm Load Solar Intrusion

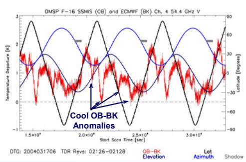
The orbit of the DMSP F-16 and the design of the SSMIS warm load and reflective canister top result in 4 distinct geometric scenarios where solar radiation can impinge upon the surfaces of the warm load tines. Two direct impingements and two reflections off of the canister top can occur per orbit. This in turn causes rapid heating of the tines that is not sensed by the 3 thermistors embedded on the deep inside the substrate of the warm load resulting in anomalous radiometer gains and subsequent calibration errors.





The solar intrusion anomaly is readily evident in the time series of the individual channel radiometer gains and match the cool anomalies in the Scan Averaged OB-BK time series.



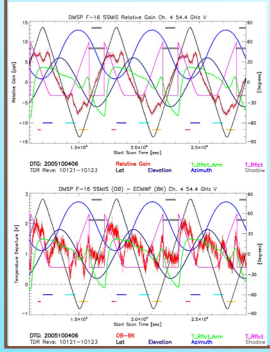


Mitigation Strategy

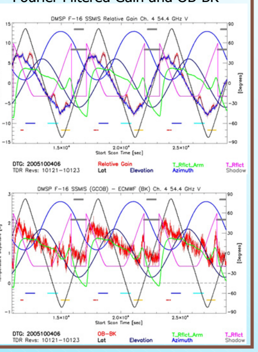
The solar intrusion anomaly can result in as much a 1.5 K peak depression in the observed scene temperatures near the center of the intrusion period. The duration and shape of the intrusion is channel dependent as the feedhorns view different warm load tines. A Fourier based filtering mitigation strategy has been implemented to perform the gain filtering in the SSMIS processing software for the sensor data records (SDRs). NRL has applied a Gain Ratio correction to TDR files used for radiance assimilation as follows: The Original Gain, G_o to Filtered Gain, G_f Ratio should be equal to 1.0 and have values greater than unity only where the intrusions occur. So the corrected TB_c is,

$$TB_c = T_{Cosmic} + \left(TB_o - T_{Cosmic}\right)\left(G_o / G_f\right)$$

Un-Filtered Gain and OB-BK

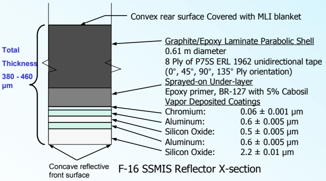


Fourier Filtered Gain and OB-BK



SSMIS Reflector Emission

The SSMIS reflector was designed to be non-emissive at microwave frequencies, and was specifically coated with SiOx to minimize such effects.



F-16 SSMIS Reflector X-section

Pre-launch tests of the main reflector showed a reflectivity > 0.9999. The F-16 SSMIS is equipped with a thermistor placed upon the rim of the reflector that observes an solar induced thermal cycle ranging from 220 - 300 K.

On orbit the F-16 SSMIS reflector appears to show a frequency dependent emissive behavior. Warm OB-BK biases of 1-2.5 K in the 50-60 GHz channels and ~ 5 K in the high frequency channels are observed. The maximum reflector emission anomaly occurs just after the spacecraft emerges from earth and/or spacecraft shadow, and the reflector face is directly illuminated by the sun. A simple physical model governs the reflector emission and resulting scene temperature bias.

$$T_{OB} = \left[1 - \varepsilon_R(\nu)\right]T_{Scene} + \varepsilon_R(\nu)T_R$$

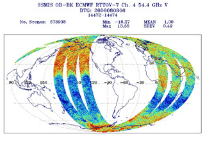
$$\Delta T_{R\_Emis} = T_{OB} - T_{Scene} = \varepsilon_R(\nu)\left[T_R - T_{Scene}\right]$$

The goal of applying the SSMIS Reflector Emission Correction is to remove the effect of the reflector emissions from the observed brightness temperature and produce an improved scene temperature.

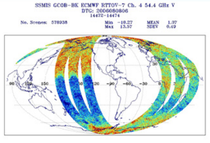
$$T_{Scene} = T_{OB} - \Delta T_{R\_Emis} = T_{OB} - \varepsilon_R(\nu)\left[T_R - \hat{T}_{Scene}\right]$$

However, this requires accurate knowledge of three parameters:

T_R the True Reflector Temperature
$\varepsilon_R(\nu)$ the Frequency Dependent Reflector Emissivity
$\hat{T}_{Scene}$ is the best estimate of the True Scene Brightness Temperature



Un-corrected OB-BK



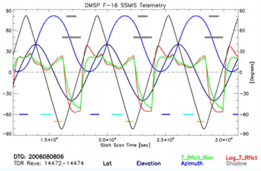
Gain corrected OB-BK

Mitigation Strategy

It is assumed that an estimate of the true reflector face temperature can be made from a lag filtered time rate of change of the observed SSMIS reflector rim temperature, as follows [2]:

$$T_{rflct} = T_{rim} + c_F \int_0^P e^{(-\tau/\sigma)} \frac{dT_{rim}}{dt}(t-\tau)\,d\tau$$

where,
σ is the lagged filter width
P is the lag period
c_F is correction factor constant



The NRL method has selected the following values for the filter constants: C_F = 250., P =120 s, τ = 32 s, σ = 320 s. Initial analysis of the OB-BK and emission correction patterns indicated that the reflector rim may undergo greater cooling than that of the reflector face in earth shadow. The reflector always "sees" the earth, whereas the rim does not. While in shadow the an OLR correction is also applied. The reflector face appears to heat up much faster upon exiting shadow than the rim. Reflector emissivities were chosen to be 0.02 for the 50-60 GHz channels and 0.07 for the 150-183 GHz channels, based upon the NRL antenna model for a graphite epoxy shell.

Results

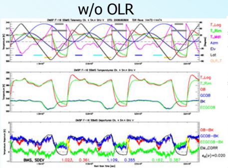
The SSMIS Fourier filtered Gain corrections have been applied to the TDR files and an estimate of the reflector face temperature have been made available for NRL radiance assimilation. Results of using these files in radiance assimilation trials are being presented in a companion paper. The following observations have been made regarding the SSMIS reflector emission corrections:

1) Scene temperatures immediately upon emergence from shadow are still not adequately emission corrected, but can be QC'd using magnitude of dT_{Arm}/dt

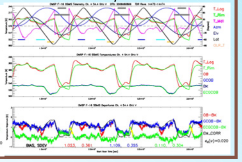
2) Channels 10 and 11 show that the mean monthly OLR values mimic the effect of the clouds as apparent in the scene temperatures, i.e. the double hump feature in near the minimum in the Arm temperature

3) Channel 5 OB-BK characteristics and to a lesser degree Channel 6, seem to point to an O_2 absorption RTM error,. i.e. the Gamma correction as the bias appears to be airmass dependent with negative biases in the tropics

Gain and Emission Corrections w/o OLR



Gain and Emission Corrections w/ OLR



Conclusions

An NRL SSMIS preprocessor has been developed that creates a new TDR file that contains the Gain corrected antenna temperatures, and an estimate of the reflector face temperature, T_R. The estimated T_R can then be used in the application of the emission correction. Further refinements to the lagged reflector temperature estimator are planned. Hardware modifications are planned for DMSP F-17 and beyond to mitigate these calibration anomalies at the source [3]. F-17 Hardware modifications include building a fence to eliminate the direct warm load solar intrusions and converting channels 1-5 to horizontal polarizations as originally intended in the design of the SSMIS.

References

[1] Poe, G. and Coauthors, 2005: Defense Meteorological Satellite Program Special Sensor Microwave Imager Sounder (F-16) Calibration/Validation Final Report. November 2005

[2] Bell, W., S. English, B. Candy, F. Hilton, S. Swadley, G. Kelly, 2006: An Initial Evaluation of SSMIS Radiances for Radiance Assimilation Applications. MicroRad '06, San Juan, PR.

[3] Kunkee, D., D. Boucher, G. Poe and S. Swadley, 2006: Evaluation of the Defense Meteorological Satellite Program Special Sensor Microwave Imager Sounder (SSMIS). IGARSS '06, Denver CO.

Acknowledgements

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