SSMIS Calibration Anomalies

Observed F-16 and F-17 Anomalies Detailed Analysis of the Root Causes, and the Path Forward

Steve Swadley, Gene Poe and Nancy Baker (NRL Monterey)
Dave Kunkee and Don Boucher (The Aerospace Corp)
William Bell (The Met Office/ECMWF)
Shannon Brown and Ezra Long (NASA JPL)
Aluizio Prata (USC)

SSMIS Calibration Anomalies

- Description of the Calibration Anomalies
- Post-Launch Mitigation Strategies
- Analysis and Verification of Root Causes
- Path Forward for F-18 through F-20 SSMIS

Description of the SSMIS Calibration Anomalies

F-16 Calibration Issues

Reflector Emission

- Reflector Rim Temperature Cycle Dominated by Earth and Spacecraft Shadowing
- OB-BK Patterns Showed Frequency Dependent Reflector Emissivity, ε_{Rflct}
  - 1.5–2K OB-BK Jump at 50-60 GHz
  - 5-7K OB-BK Jump at 183 GHz

Warm Load Intrusions

- Direct and Reflected Solar Intrusions onto Warm Load Tines
- 1-1.5K Depression in TBs

- Field-of-View Obstructions
- Moon Intrusion into Cold Sky Reflector
- Random Noise Spikes

F-17 Calibration Issues

Reflector Emission

- Reflector Rim Thermistor moved to rear of graphite epoxy reflector shell
- Reflector Temperature Cycle Dominated by Solar Panel Shadowing for Most of Year, Some Earth and Spacecraft Shadowing
- Frequency Dependent Reflector Emissivity, ε_{Rflct}
  - 1.5–2K OB-BK Jump at 50-60 GHz
  - 5-7K OB-BK Jump at 183 GHz

Warm Load Intrusions

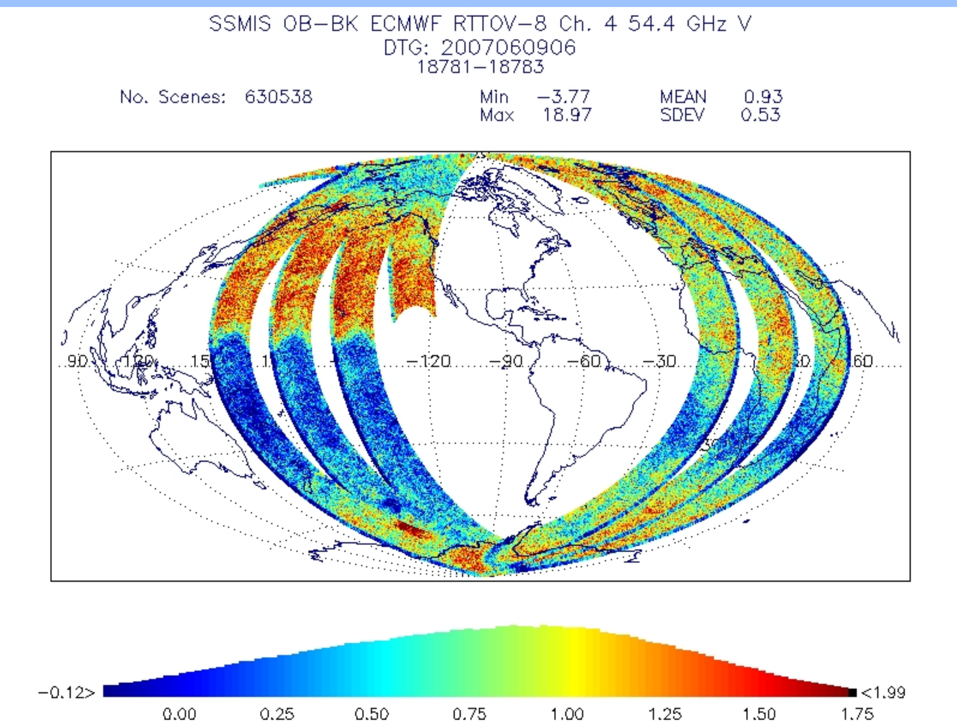
- Fence Successful in Mitigating Direct Solar Intrusions
- Reflected Solar Intrusions onto Warm Load Tines limited to High Solar Elevation angles

- Residual Doppler Signature
- Additional Noise due to Flight S/W Mods, Fewer Calibration Samples
- Field-of-View Obstructions
- Moon Intrusion into Cold Sky Reflector
- Random Noise Spikes

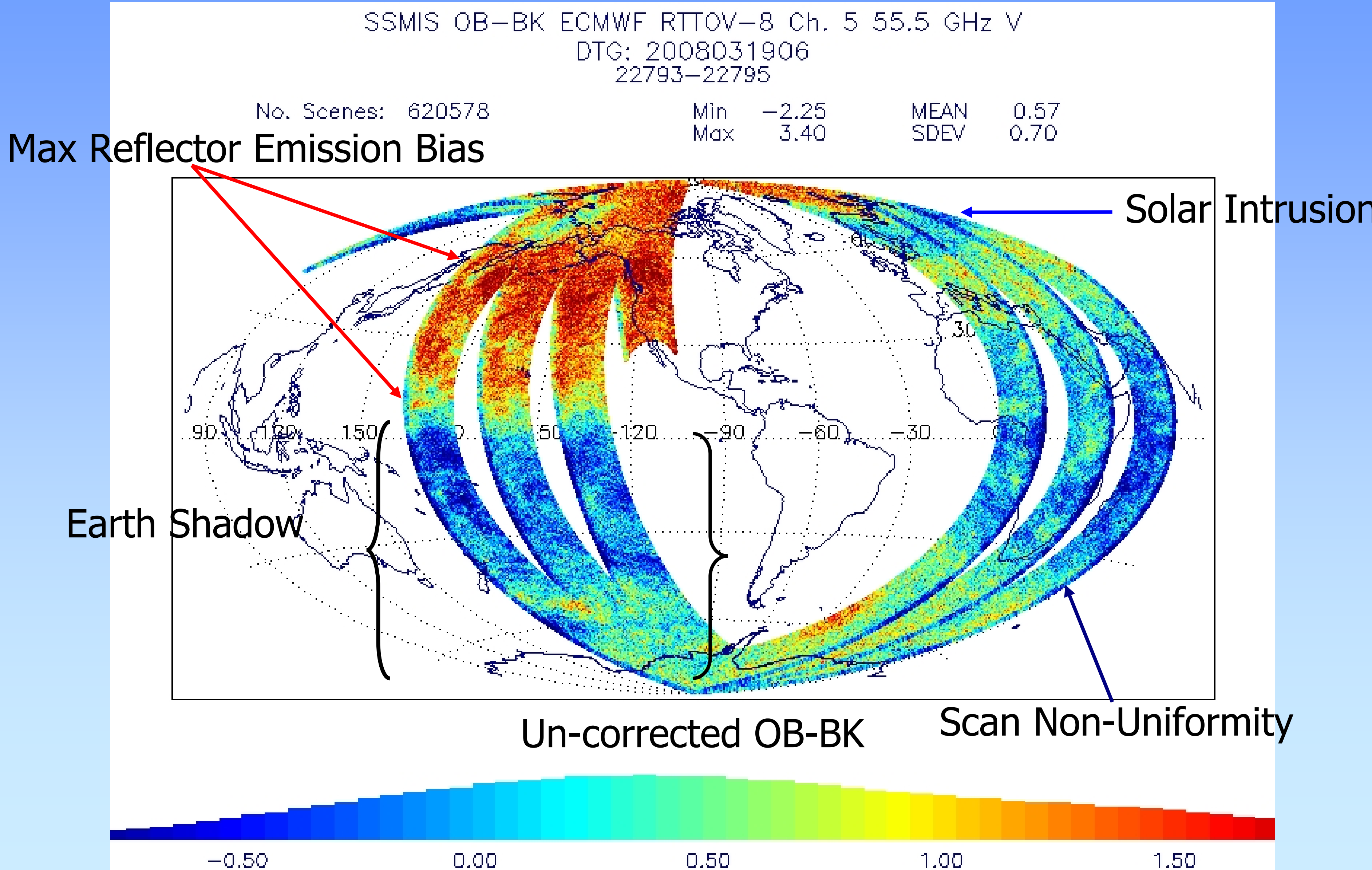
SSMIS Calibration Anomaly Detection

SSMIS Calibration Anomaly Detection

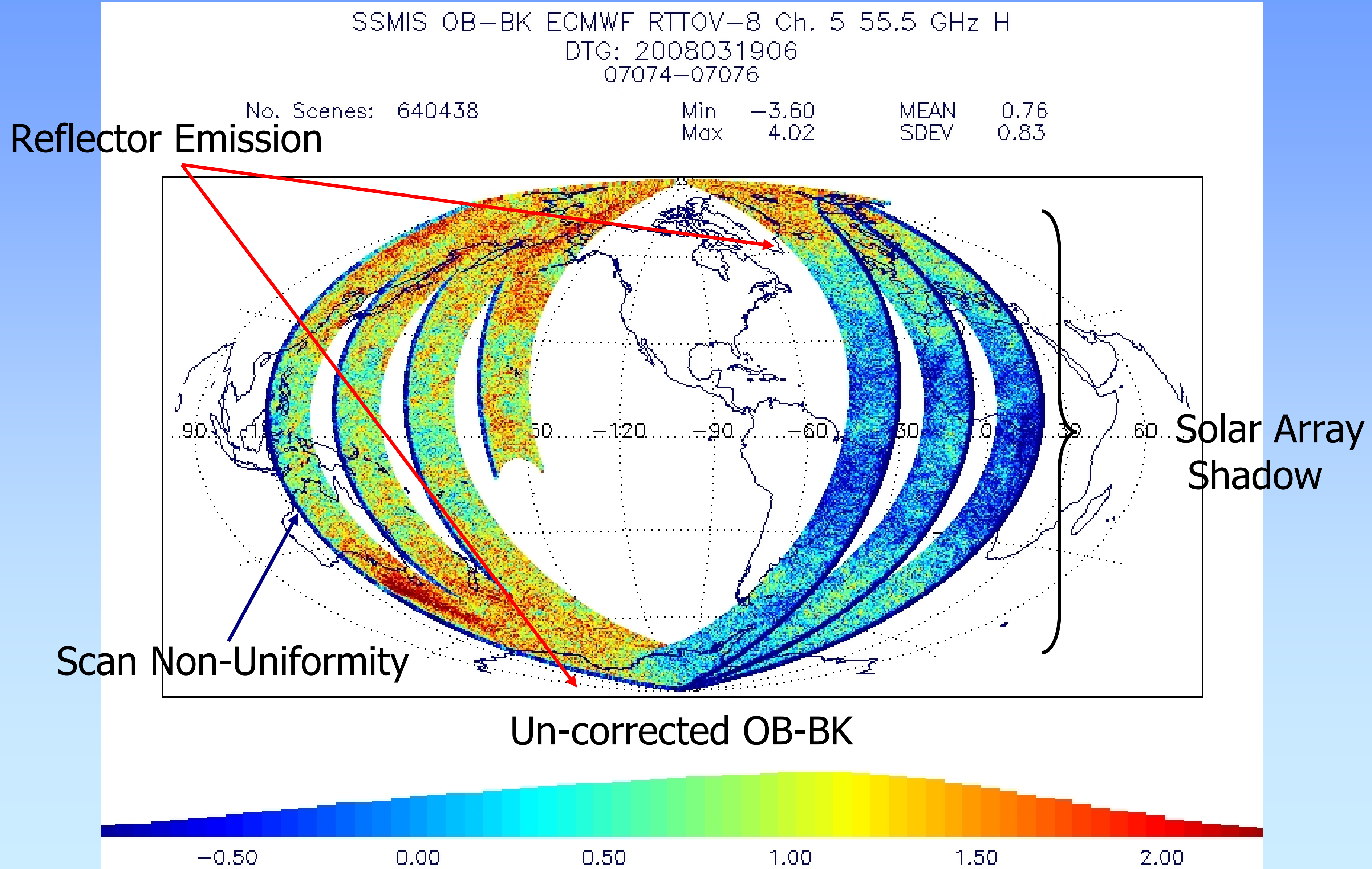
- Using OB-BK computed using ECWMF analyses and RTTOV-8 in combination with the DGS software package developed by Mike Werner (Aerospace), the SSMIS Cal/Val team was able to pinpoint the physical mechanisms causing the Calibration Anomalies



F-16 SSMIS Calibration Anomalies

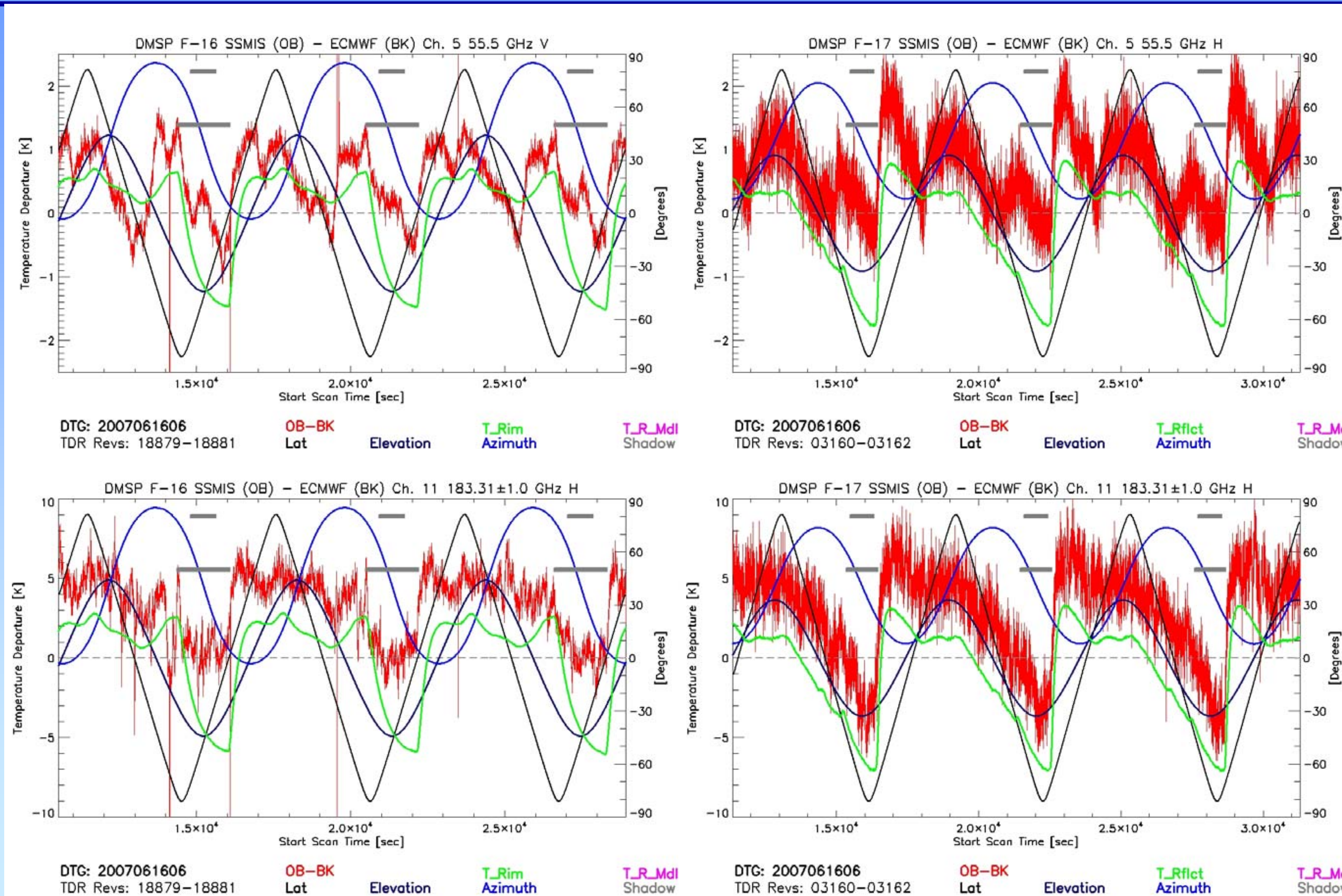


F-17 SSMIS Calibration Anomalies



Un-corrected OB-BK

Summary of the SSMIS Calibration Anomalies
F-16 versus F-17 Scan-to-Scan Noise Levels



Time series of Scan Averaged OB-BK for SSMIS Channels 5 and 11

Post-Launch Mitigation Strategies

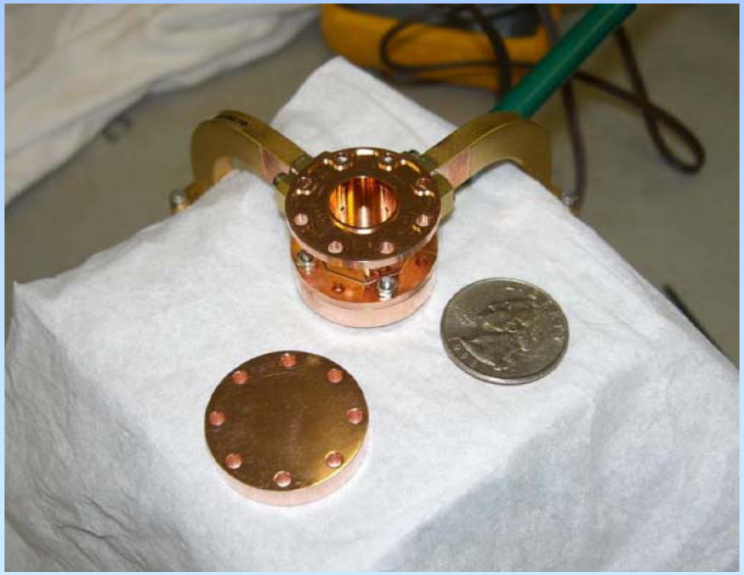
NRL/Met Office SSMIS
Unified Pre-Processor (UPP) Overview

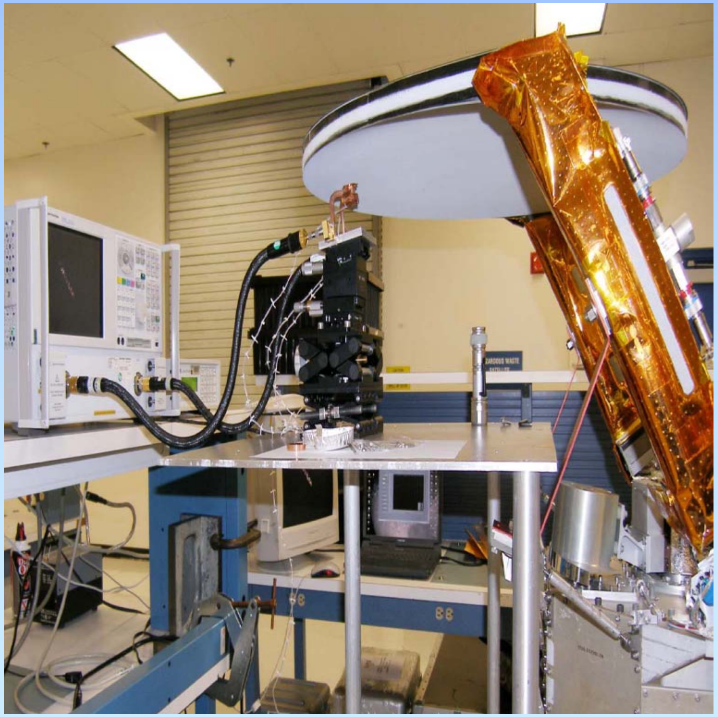
Unified Pre-Processor designed to mitigate the calibration anomalies uncovered during the SSMIS Cal/Val process and produce corrected SSMIS TDR files suitable for radiance assimilation at both global and regional scales.

- UPP V1 included
  - Reflector Emission Corrections
  - Warm Load Solar Intrusion detection and flagging (Gain Anomalies)
  - Spatial Averaging to reduce NEΔT to the 0.1 K level
- UPP V2 includes
  - Uses Operational NGES Fourier Filtered Gain Files to Correct Gain Anomalies
  - Produces ASCII and BUFR TDR output files at reduced resolution
  - Performs Scan Non-uniformity corrections
- UPP V3 Plans
  - Perform Anomaly corrections and produce TDR file at native resolution
  - Allow end-users to define amount of spatial averaging
  - Additional F-17 Calibration Averaging to lower scene noise

PRECISE EFFECTIVE CONDUCTIVITY MEASUREMENTS OF REFLECTOR SURFACES USING CYLINDRICAL TE01 MODE RESONANT CAVITIES

Aluizio Prata, Jr. (USC)
Ezra M. Long and Shannon T. Brown (JPL)





Effective Conductivity and Thermal Emissivity

For Large Effective Conductivities, the approximate *v* and *h* polarized emissivities are:

$$\varepsilon_v \cong \sqrt{\frac{16\pi\upsilon\varepsilon_0}{\sigma}}\sec\theta_i$$

$$\varepsilon_h \cong \varepsilon_v \cos^2\theta_i$$

υ : Frequency [Hz]

ε_0 : Free-space permittivity [F/m]

θ_i : Surface Incidence angle

Effective Conductivity, σ [MS/m]

Example:

183 GHz Pure Al at 300 K
$\theta_i = 18°$
σ = 36.59 MS/m

$$\varepsilon_v = 0.00157$$

$$\varepsilon_h = 0.00142$$

Ideally, we want an ϵ_{Rflct} approaching that of Pure Al

Effective Conductivity and Thermal Emissivity

Resonant Cavity Measurements have been conducted at 7 and 32 GHz, for Reflector coupons from the following sensors

Mission	Test Coupon	Effective Conductivity [MS/m]	Emissivity at 32 GHz	Emissivity at 183 GHz*
JIMO⁺(Jupiter Icy Moons)	Coupon 1	32±1	0.0006	0.0014
CloudSat⁺	Flight Unit	2.11±0.03	0.0023	0.0056
JMR (Jason Microwave Radiometer)	Spare–Post rework Spare–Post rework Spare–Post rework Flight Unit	15.1±0.5 14.6±0.5 0.353±0.004 9±2	0.0008 0.0009 0.0057 0.0013	0.0021 0.0021 0.0137 0.0027
MLS	Flight Unit	4.3±0.1	0.0016	0.0039
AMR Advanced Microwave Radiometer OSTM Launch ~ June 2008	Original Coupons Prior to rework	0.2 1.4 3.4 9.1 16.5 31.	0.0076 0.0029 0.0185 0.0011 0.0008 0.0006	0.0183 0.0069 0.0044 0.0027 0.0020 0.0015

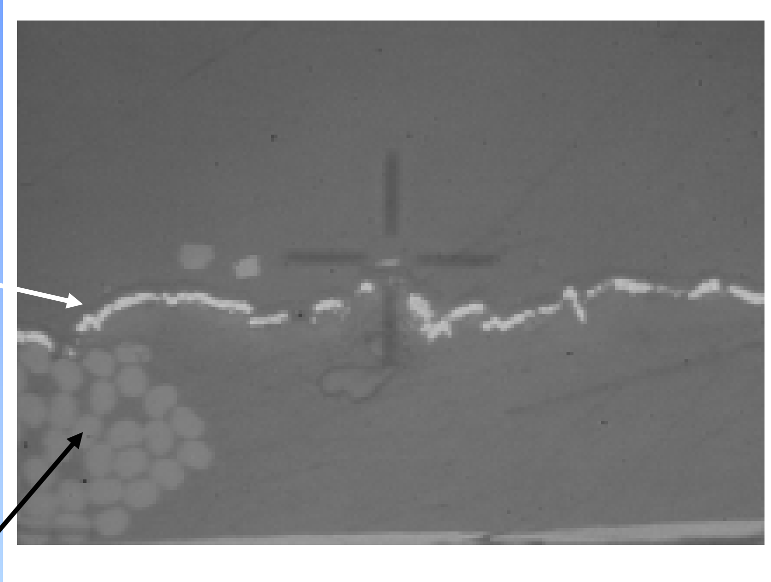
⁺ Active Radars

* Computed form the 32 GHz measurement

Analysis and Verification of Root Causes

VDA Applied to Aggressively Roughened Surface

VDA* Layer



Carbon Fibers of the Unidirectional Cross-Layered Tape (P75S/ERL1962) forming the Epoxy Shell

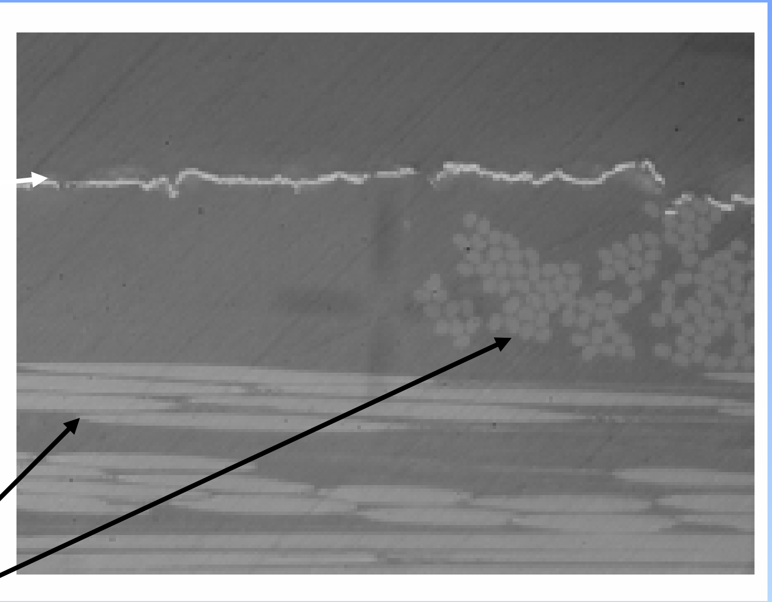
32 GHz σ_E = 3.4 MS/m

55 GHz ε = 0.0027

***VDA: Vapor Deposited Aluminum**

VDA Applied to Moderately Roughened Surface

VDA Layer



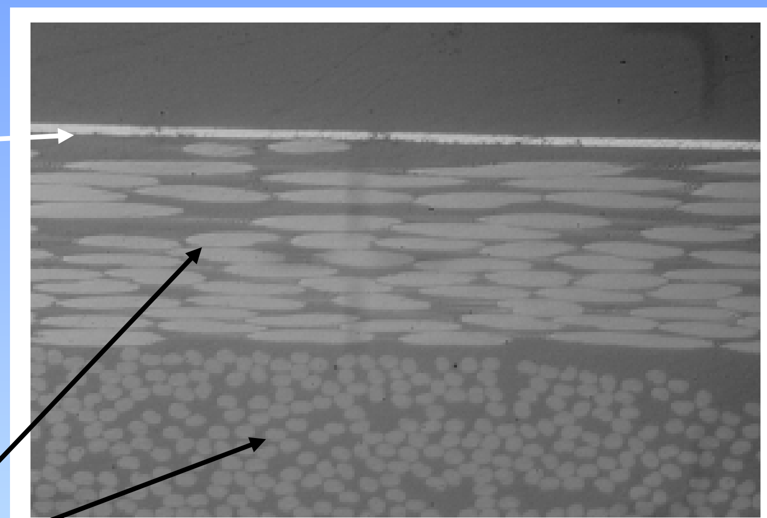
Carbon Fibers of the Unidirectional Cross-Layered Tape (P75S/ERL1962) forming the Epoxy Shell

32 GHz σ_E = 9.1 MS/m

55 GHz ε = 0.0016

VDA Applied to Smooth Surface

VDA Layer

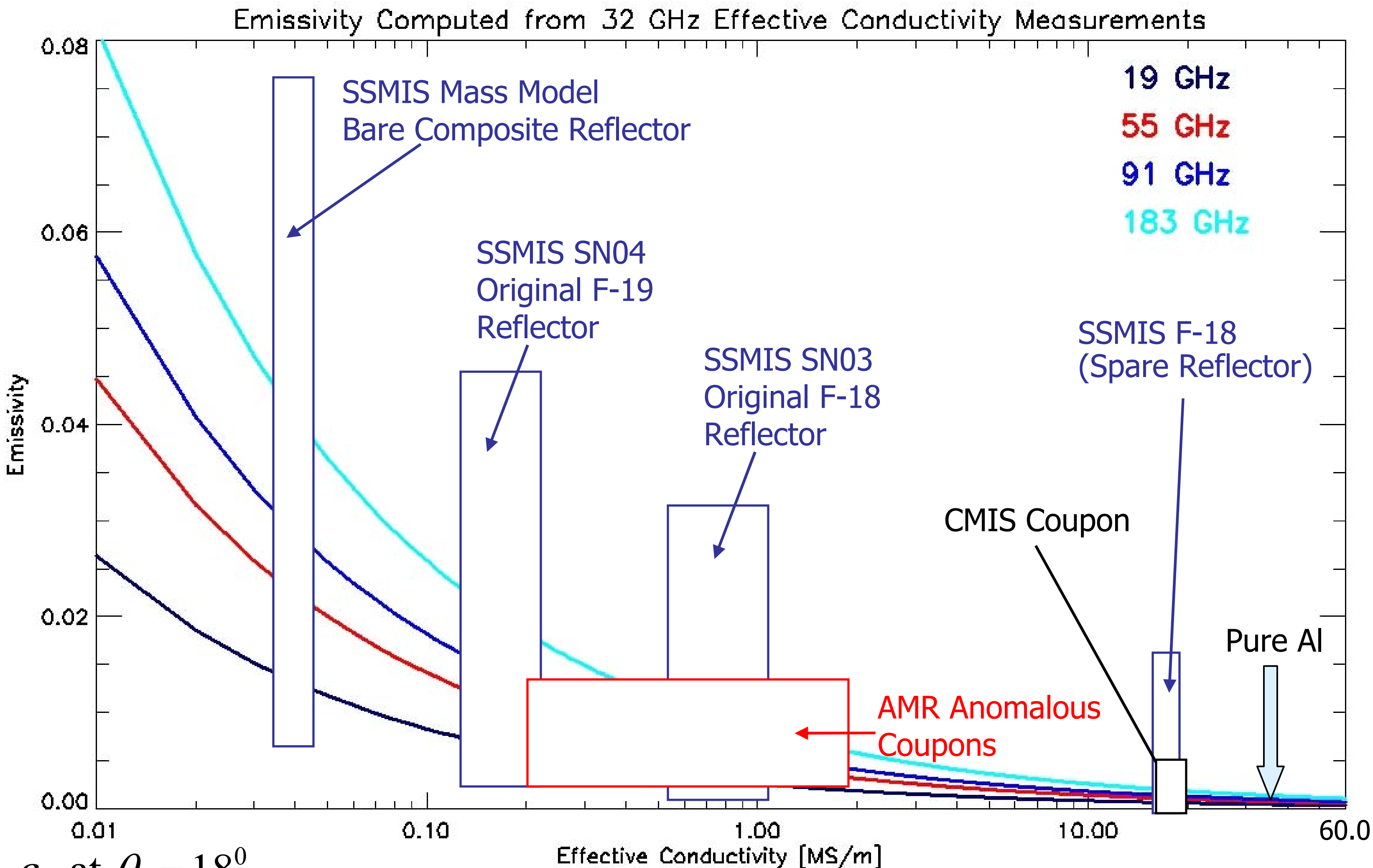


Carbon Fibers of the Unidirectional Cross-Layered Tape (P75S/ERL1962) forming the Epoxy Shell

32 GHz σ_E = 33 MS/m

55 GHz ε = 0.0009

Summary of Effective Conductivity Measurements



ε_h at $\theta_i = 18^0$

SSMIS Anomalies - Summary

- NWP and visualisation tools key to understanding and mitigating instrument calibration anomalies

- Pre-processing (UPP) required to meet stringent requirements of NWP radiance assimilation users for temperature sounding

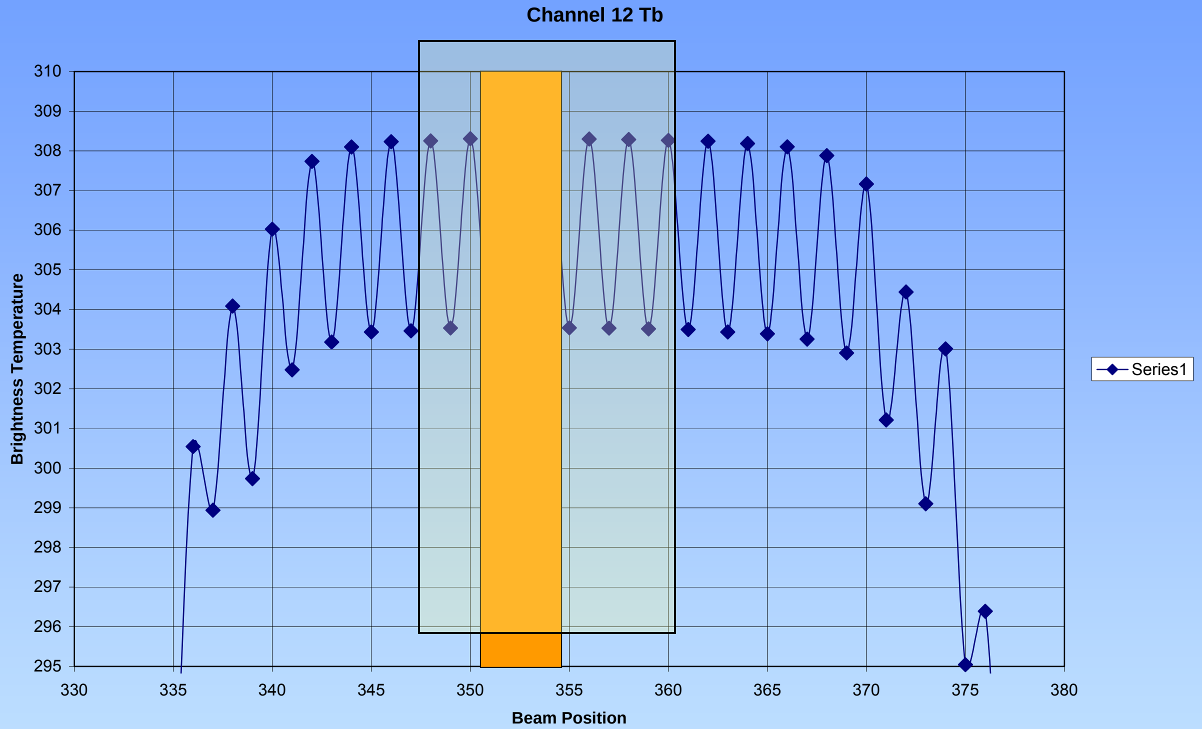
- New measurement techniques have been developed for pre-launch characterisation of reflectors, and should reduce risk for future radiometers

- Original F-18 Reflector has been replaced with Spare Reflector (15-18 MS/m)

- DMSP SPO plans to either Strip and Recoat the F-19 and F-20 Reflectors or manufacture new reflectors

Backup Slides

SSMIS Warm Load Calibration Samples Early Orbit Mode Data

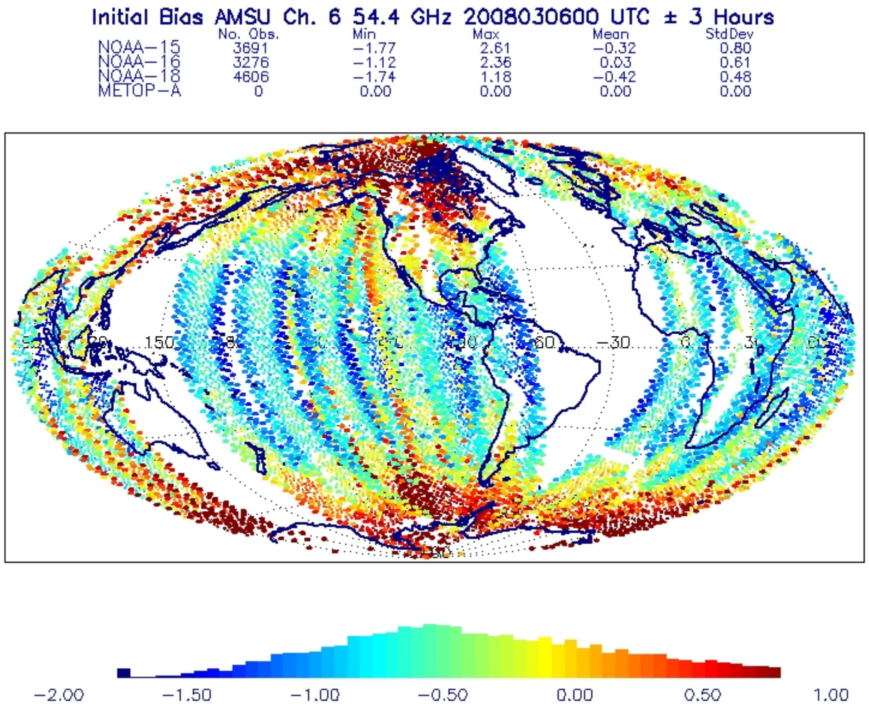


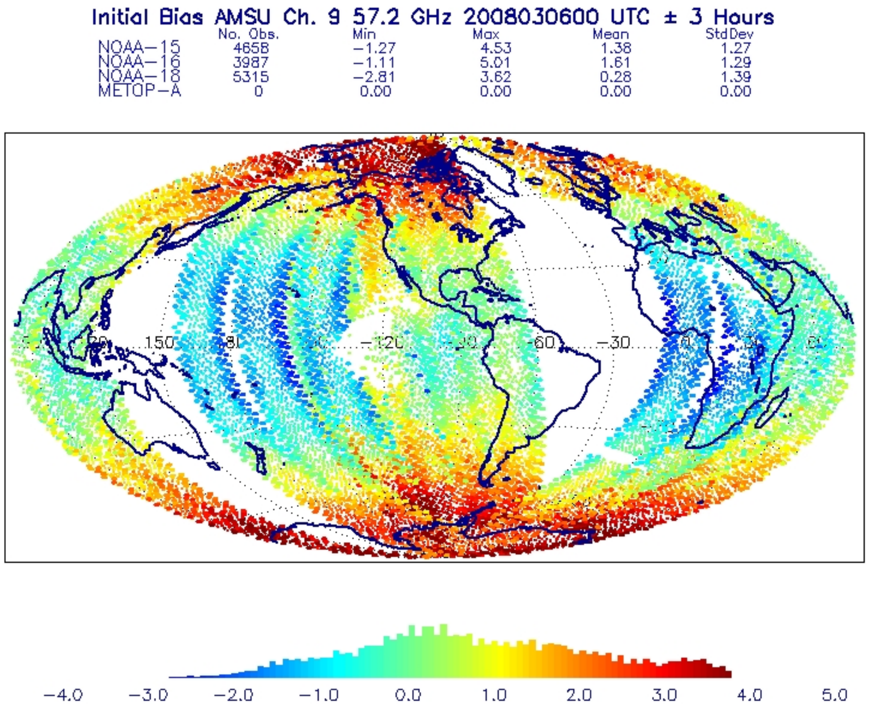
- Saw-tooth pattern is the result of the A/B Integrator
- Original Flight S/W averaged 4 warm load samples
- F-17 Flight S/W changes now use only 2 warm load samples
- Additional warm load samples (8-12) would lower noise
- Lower noise is crucial to NWP radiance assimilation

EO-2 Mode Imagery, courtesy of Dave Kunkee, Aerospace

AMSU OB-BK Biases

Un-corrected OB-BK





AMSU also contains biases, which must be removed prior to assimilation. AMSU OB-BK biases are dominated by scan angle effects and air mass biases in the RTM. Biases are also sensor specific.

Summary of the SSMIS Calibration Anomalies

Both F-16 and F-17 SSMIS Exhibit Calibration Anomalies which are unique to the each sensor and orbit geometry

Over 40% of F-16 SSMIS Data are Affected by the Calibration Anomalies

- Reflector Emission Biases
- Warm Load Intrusions

All of F-17 SSMIS Data are Affected by the Calibration Anomalies/Issues

- Reflector Emission Biases
- Increased Noise due to Calibration Flight S/W Mods
- Warm Load Intrusions Limited to High Solar Elevation periods
- Channel 4 Cold Cal Count Problem (Synthetic Cold Cal a possibility)

Preprocessing of SSMIS Radiance Data for Operational NWP DAS for the Temperature and Humidity sensitive channels is a Requirement

NRL/Met Office SSMIS
UPP V2 Planned User Community

F-16 UPP V2 is Operational at FNMOC and is being Distributed to NESDIS

UPP V2 includes the required BUFR Format modification Option

- NRL has Transitioned F-16 SSMIS UPP to FNMOC for Radiance Assimilation

- F-17 UPP Modifications Underway

- AFWA currently conducting WRF Radiance Assimilation Trials using the UPP V2 data in for the Southeast Asia window corresponding to the FNMOC/AFWA JEFS/JME demonstration project this past Summer

- EMC conducting GFS Radiance Assimilation Trials using the UPP V2

- Met Office is Operational with SSMIS Met Office PP, and plans to wait for operational distribution of UPP by FNMOC

- EMC, ECMWF, MeteoFrance, and MSC plan on using data from the SSMIS UPP V2 as soon as its available

NRL/Met Office SSMIS UPP
Summary and Future Developments

SSMIS Unified Preprocessor Developed to Meet NWP DA Needs

The UPP Produces SSMIS data that Meet the Stringent NWP Radiance Assimilation Accuracy Requirements for Temperature Sounding Channels

Plans are to allow for user specified Averaging to meet specific application requirements. i.e. Mesoscale NWP

SSMIS UAS Radiance Assimilation will also Require Pre-Processed SSMIS TDR data with the required Geomagnetic Parameters

F-17 SSMIS Data Present an New Challenge for the Radiance Assimilation Community to Produce TDR Data meeting the NWP DA Requirements

Analysis and Verification of Root Causes

SSMIS Reflector Emission Bias, ΔT_{Emis}

$$T_{Obsvd} = \left(1 - \varepsilon_{Rflct}\right) T_{Scene} + \varepsilon_{Rflct} T_{Rflct}$$

$$T_{Scene} = T_{Obsvd} - \varepsilon_{Rflct}\left(T_{Rflct} - T_{Scene}\right)$$

$$\Delta T_{Emis} = T_{Obsvd} - T_{Scene} = \varepsilon_{Rflct}\left(T_{Rflct} - T_{Scene}\right)$$

- Caused by a frequency dependent reflector emissivity, ϵ_{Rflct} that is much larger than expected based upon pre-flight assumptions regarding a graphite epoxy reflector shell coated with a multiple layers of VDA Al and SiO_x.

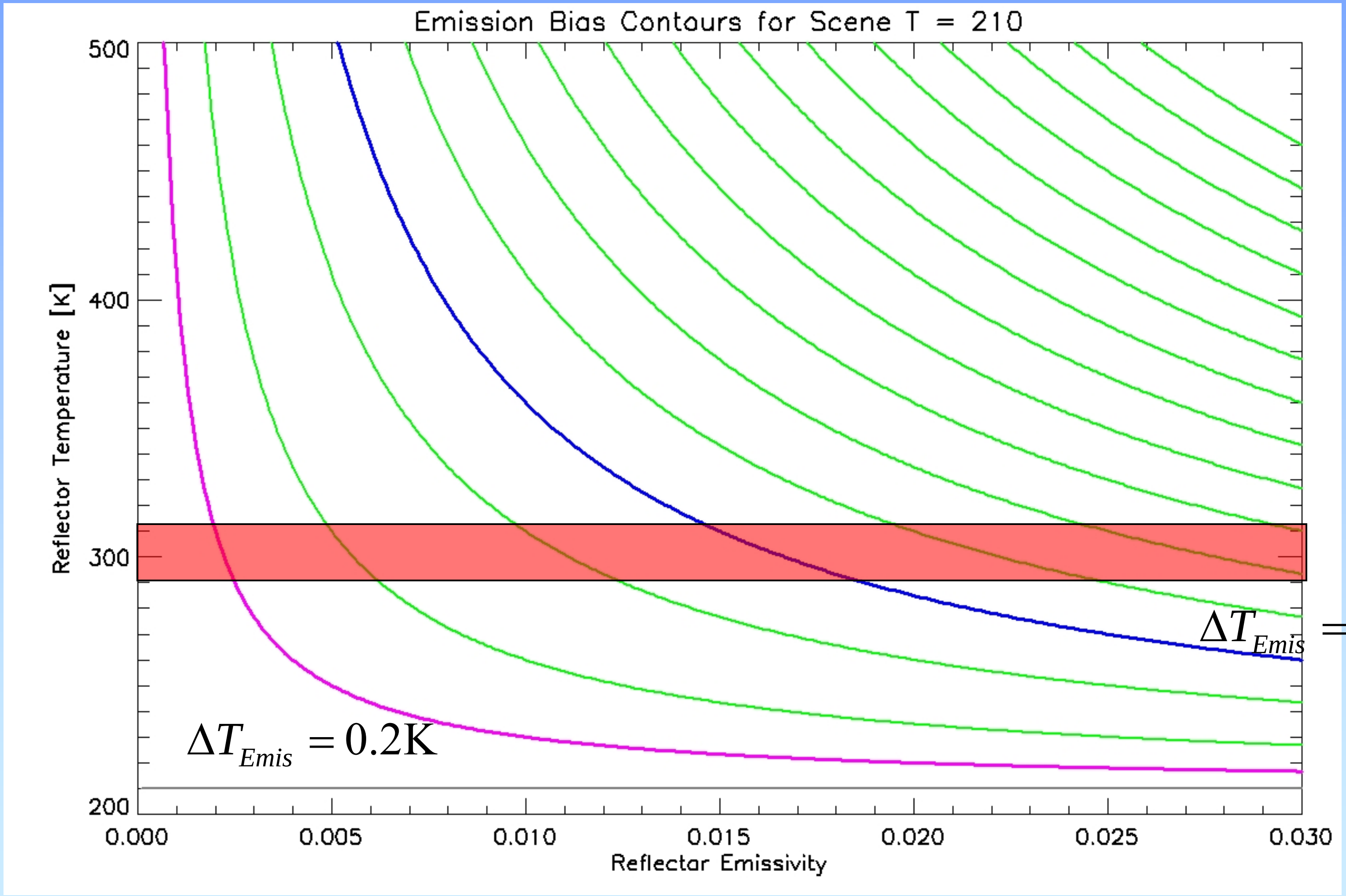
- Post-Launch analysis of OB-BK signatures indicate the peak Emission Bias is of the order 1.5-2 K for the 50-60 GHz channels and 5-7 K for the 183 GHz channels

- Provided the reflector temperature T_{Rflct} and ϵ_{Rflct} are known, a Reflector emission correction can be applied

- Given a Solar Absorptivity/IR emissivity (α/ϵ) ratio = 0.8 for SiO_x ,
  Maximum T_{Rflct} should be ~O(300 K)

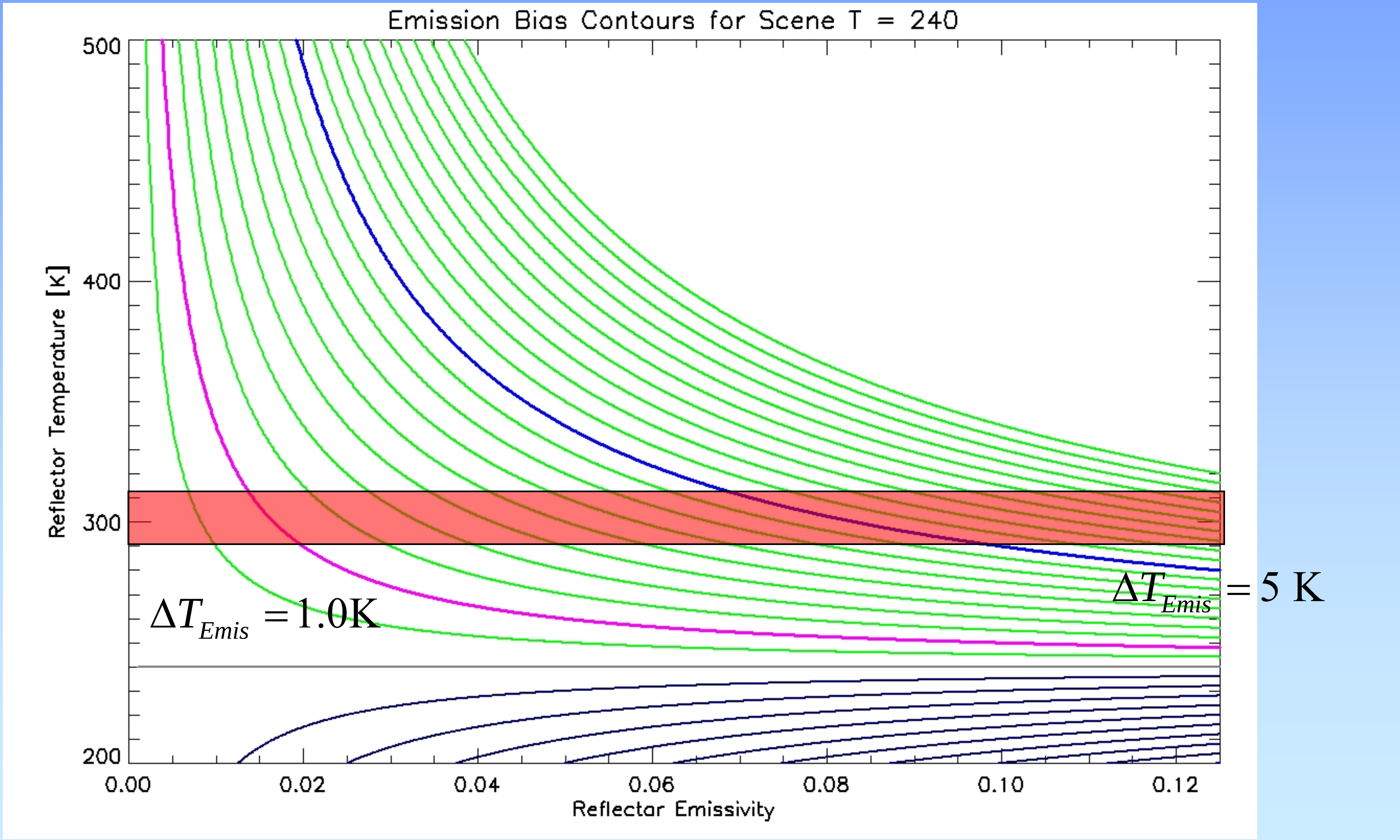
Typical SSMIS Ch 5 55.5 GHz ΔT = 1.5K at Shadow Emergence with a T_{Scene} = 210K

$$\Delta T_{Emis} = \varepsilon_{Rflct}\left(T_{Rflct} - T_{Scene}\right) = \varepsilon_{Rflct}\left(T_{Rflct} - 210\right)$$



Typical SSMIS Ch 11 183.3±1 GHz ΔT_{Emis} = 5 K at Shadow Emergence with T_{Scene}= 240K

$$\Delta T_{Emis} = \varepsilon_{Rflct}\left(T_{Rflct} - T_{Scene}\right) = \varepsilon_{Rflct}\left(T_{Rflct} - 240\right)$$



Analysis and Verification of Root Causes

AMR and SSMIS Conductivity Measurements

- Measured Effective Conductivities were anomalously low compared to Pure Al (37.7 MS/m) for additional coupons measured from previous AMR developments and other instruments

- Parallel materials investigation indicated a correlation between poor RF performance and level of surface roughening applied to composite layer

- AMR investigation coupled with SSMIS investigation indicates that a reliable coating process needs to be defined and verified

- Current VDA surface coating process produces RF surfaces guaranteed to perform somewhere between that of pure aluminum and bare graphite epoxy composite

- Clearly, a more precise and repeatable reflector coating process is required for space based precision microwave radiometers

Effective Conductivity and Thermal Emissivity

Resonant Cavity Measurements have been conducted at 32 GHz, for SSMIS and Re-Worked AMR Reflector coupons

Mission	Test Coupon	Effective Conductivity [MS/m]	Emissivity at 32 GHz	Emissivity at 183 GHz+
Re-Worked AMR Coupons	4 Coupons with Minor Surface Abrasion	18 – 20	0.00076- 0.0008	0.0019
	4 Coupons with No Surface Abrasion	19-20	0.00078-0.0008	0.0018-0.0019
SSMIS	Mass Model (Bare Graphite Epoxy)	0.0394-0.044	0.016-0.017	0.039-0.041
	SN03	0.54 – 1.119	0.0032-0.0046	0.0077-0.011
	SN04	0.144 – 0.231	0.0071-0.009	0.017-0.022
	Spare Reflector*	15.1-17.4	0.0008-0.0009	0.0019-0.0021
	CSR	2.7-3.4	0.0018-0.0021	0.0044-0.005

* SSMIS Spare Reflector manufactured by Composite Optics, but with Grit Blast vice Cabosil Primer to enhance VDA adhesion

+ The Emissivity at 183 GHz does not include surface roughness effects, and should be considered a lower bound on the 183 GHz emissivity

International TOVS Study Conference, 16th, ITSC-16, Angra dos Reis, Brazil, 7-13 May 2008. Madison, WI, University of Wisconsin-Madison, Space Science and Engineering Center, Cooperative Institute for Meteorological Satellite Studies, 2008.