SSMIS Radiance Assimilation, Calibration Anomaly Mitigation and Assimilation Results From F18

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Outline

- F16 and F17 SSMIS Calibration Anomalies
- Post-Launch Mitigation Strategies
- Analysis and Verification of Root Causes
- F16 and F17 SSMIS Assimilation Results
- F18 SSMIS Preliminary Results
  - Radiometric Performance
  - Assimilation Results
- Path Forward for F19 and F20 SSMIS
### SSMIS Instrument

<table>
<thead>
<tr>
<th>Mode</th>
<th>Resolution (km)</th>
<th>Frequency (GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imaging</td>
<td>12.5 km</td>
<td>91 - 183 (5)</td>
</tr>
<tr>
<td></td>
<td>25.0 km</td>
<td>19 – 37 (5)</td>
</tr>
<tr>
<td>LAS T</td>
<td>37.5 km</td>
<td>50 - 60 (8)</td>
</tr>
<tr>
<td>LAS Hum.</td>
<td>37.5 km</td>
<td>150, 183 (3)</td>
</tr>
<tr>
<td>UAS T</td>
<td>75.0 km</td>
<td>60-63 (5)</td>
</tr>
</tbody>
</table>

- **24 Channel Microwave Imager/Sounder**
- **Conical Scan (53° Incidence Angle)**
- **0.61 m Graphite Reflector (VDA/SiO₂)**

- FNMOC and ECMWF global NWP analyses with RTTOV-8/9 were used to produce OB-BK departures for TDR/SDR and EDR products
- Departures were analyzed in combination with the DGS software package developed by Mike Werner (Aerospace)
- SSMIS Cal/Val team using these tools was able to successfully pinpoint the physical mechanisms causing the calibration anomalies
F16 and F17 SSMIS Calibration Anomalies

F16 Calibration Anomalies

**Reflector Emission**
- Reflector Rim Temperature Cycle Dominated by Earth and Spacecraft Shadowing
- OB-BK Patterns Showed Frequency Dependent Reflector Emissivity, $\varepsilon_{\text{Rflct}}$
  - 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

F17 Calibration Anomalies

**Reflector Emission**
- Reflector Rim Thermistor moved to rear of graphite epoxy reflector shell (True for all remaining SSMIS)
- Reflector Temperature Cycle Dominated by Solar Panel Shadowing for Most of Year, Earth and Spacecraft Shadowing occur during annual cycle
- Frequency Dependent Reflector Emissivity, $\varepsilon_{\text{Rflct}}$
  - 1.5–2K OB-BK Jump at 50-60 GHz
  - 5-8K 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
F16 SSMIS Calibration Anomalies

Max Reflector Emission Bias

Earth Shadow

Warm Load
Solar Intrusion

Scan Non-Uniformity
S/C FOV Intrusion

Un-corrected OB-BK

SSMIS OB-BK ECMWF RTTOV-8 Ch. 5 55.5 GHz V
DTG: 2008031906
22793–22795

No. Scenes: 620578
Min -2.25
Max 3.40
MEAN 0.57
SDEV 0.70
F17 SSMIS Calibration Anomalies

SSMIS OB–BK ECMWF RTTOV–8 Ch. 5 55.5 GHz H
DTG: 2008031906
07074–07076

No. Scenes: 640438
Min -3.60
Max 4.02
Mean 0.76
SDEV 0.83

Reflector Emission
Scan Non-Uniformity
Solar Array Shadow

Un-corrected OB-BK
Frequency Dependence of the SSMIS Reflector Emission Bias

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

\[ \Delta T_{Emis} = T_{Obsvd} - T_{Scene} = \varepsilon(\nu)_{Rflct} \left( T_{Rflct} - T_{Scene} \right) \]

**F16 55.5 GHz Channel**

Shows 1.5 K Jump at emergence from Earth Shadow

\[ \varepsilon(55.5)_{Rflct} \sim 0.015 - 0.02 \]

**F17 183 GHz Channel**

Shows 7 K Jump at emergence from Earth Shadow

\[ \varepsilon(183)_{Rflct} \sim 0.04 - 0.07 \]
NRL and UK Met Office designed, developed and implemented a Unified Pre-Processor (UPP) to correct the F16 calibration anomalies.

UPP SSMIS provides radiances of sufficient quality for NWP assimilation.

SSMIS now plays larger role in the NPOESS gap mitigation.

Contributors:
- Steve Swadley (NRL) and William Bell (Met Office), Gene Poe, Nancy Baker and Ben Ruston (NRL), Dave Kunkee, Ye Hong, Mike Werner and Don Boucher (Aerospace), Sana Mahmood (Met Office), Yiping Wang, Randy Pauley and Jeff Tesmer (FNMOC), Karl Hoppel (NRL DC), Yong Han (JCSDA), Shannon Brown and Ezra Long (NASA JPL), Aluizio Prata (USC), and ECMWF.
DMSP SSMIS UPP Update

UPP V2 includes

- Reflector Emission Corrections (F16 and F17)
- Spatial Averaging to reduce $\Delta T$ to 0.15 - 0.25 K level (NRL only)
- Uses Operational NGES Fourier Filtered Gain Files to Correct Gain Anomalies
- Produces ASCII and BUFR TDR output files at full and/or filtered resolution
- Performs Scan Non-uniformity corrections
- SSMIS UPP V2 Operational at FNMOC (F1607/2008, F17 – 04/2009, F18 – Apr '09)
- FNMOC distributes UPP data to NESDIS for use by the NWP Community
Analysis and Verification of Root Causes

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 $\nu$ and $h$ polarized emissivities are:

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

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

- $\nu$: Frequency [Hz]
- $\varepsilon_0$: Free-space permittivity [F/m]
- $\theta_i$: Surface Incidence angle

Effective Conductivity, $\sigma$ [MS/m]

Example:

183 GHz  Pure Al at 300 K
$\theta_i = 18^\circ$
$\sigma = 36.59$ MS/m

$\varepsilon_v = 0.00157$
$\varepsilon_h = 0.00142$

Ideally, we want an $\varepsilon_{Rfct}$ approaching that of Pure Al
Emissivity vs. Effective Conductivity

$\varepsilon_\parallel$ at $\theta_i = 18^0$
Analysis and Verification of Root Causes

VDA* Layer

Roughened Surface

32 GHz $\sigma_E = 3.4$ MS/m
55 GHz $\varepsilon = 0.0027$

Smooth Surface

32 GHz $\sigma_E = 33$ MS/m
55 GHz $\varepsilon = 0.0009$

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

*VDA: Vapor Deposited Aluminum
Reflector Emission Anomaly Summary

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

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

- High Reflector Emissivity Traced to the VDA Coating Process

- F18 Reflector replaced with spare (15-17 MS/m)

- Verification of Pre-Flight measurement using on-orbit F18 data
NRL
Adjoint Observation Sensitivity Tools

Assessing Impacts of Observing Systems

The Good News

SSMIS UPP Data Providing Positive Operational Impacts with Navy 4D-Var Analysis System
NAVDAS-AR Operational Radiance Observation Impacts

Observation Impacts
14 Mar – 13 Apr 2010

Adjoint Sensitivity Method

Shows the impact an individual observing system, sensor or select channel had in reducing the 24 hour global forecast error as measured by a moist energy norm integrated over the troposphere and lower stratosphere (1000–150 hPa)

- - - - OB Count
SSMIS UPP Data Impacts

Impact of F17 is lower due to the loss of Ch 4
OB-BK Analysis

SSMIS OB-BK ECMWF RTTOV-8 Ch. 11 183.31±1.0 GHz H
DTG: 2009110406
00234-00236

No. Scenes: 638218
Min: -20.00
Max: 19.93
MEAN: 0.58
SDEV: 3.39

Earth Shadow

183 ± 1 GHz
DMSP F-18 SSMIS Cal/Val Status
Preliminary Results

Results derived using OB-BK departures from both ECMWF and NOGAPS/NAVDAS-AR Analyses

• Scan Non-Uniformity (FOV) Edge of Scan biases present
• Residual Doppler Signature is small compared to F17
• Results indicate a Very Low-Emissive Reflector
• Minor Warm Load Solar Intrusions are occurring
## DMSP F-18 SSMIS Cal/Val Status

**Sensor Performance - NEΔT**

### SSMIS Radiometer Warm-load NEDT* (K) (T_{rec}=305K)

<table>
<thead>
<tr>
<th>Channel Grouping</th>
<th>Lower Atmos. Sounding (LAS)</th>
<th>Imaging (IMG)</th>
<th>Upper Atmos. Sounding (UAS)</th>
<th>Zeeman Affected</th>
</tr>
</thead>
</table>

### Channel Grouping

<table>
<thead>
<tr>
<th>Ch</th>
<th>F-16</th>
<th>F-17</th>
<th>F-18 (T/V**)</th>
<th>Spec.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.22</td>
<td>0.24</td>
<td>0.19 /0.19</td>
<td>0.40</td>
</tr>
<tr>
<td>2</td>
<td>0.24</td>
<td>0.21</td>
<td>0.19 /0.19</td>
<td>0.40</td>
</tr>
<tr>
<td>3</td>
<td>0.21</td>
<td>0.22</td>
<td>0.21 /0.20</td>
<td>0.40</td>
</tr>
<tr>
<td>4</td>
<td>0.23</td>
<td>-</td>
<td>0.22 /0.22</td>
<td>0.40</td>
</tr>
<tr>
<td>5</td>
<td>0.24</td>
<td>0.22</td>
<td>0.23 /0.22</td>
<td>0.40</td>
</tr>
<tr>
<td>6</td>
<td>0.30</td>
<td>0.27</td>
<td>0.25 /0.24</td>
<td>0.50</td>
</tr>
<tr>
<td>7</td>
<td>0.36</td>
<td>0.30</td>
<td>0.24 /0.23</td>
<td>0.60</td>
</tr>
<tr>
<td>8</td>
<td>0.55</td>
<td>0.58</td>
<td>0.50 /0.47</td>
<td>0.88</td>
</tr>
<tr>
<td>9</td>
<td>0.66</td>
<td>0.74</td>
<td>0.68 /0.68</td>
<td>1.20</td>
</tr>
<tr>
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<td>0.67</td>
<td>0.47</td>
<td>0.65 /0.60</td>
<td>1.00</td>
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<tr>
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<td>0.81</td>
<td>0.66</td>
<td>0.80 /0.74</td>
<td>1.25</td>
</tr>
<tr>
<td>12</td>
<td>0.40</td>
<td>0.33</td>
<td>0.34 /0.35</td>
<td>0.70</td>
</tr>
<tr>
<td>13</td>
<td>0.42</td>
<td>0.36</td>
<td>0.32 /0.33</td>
<td>0.70</td>
</tr>
<tr>
<td>14</td>
<td>0.38</td>
<td>0.41</td>
<td>0.39 /0.39</td>
<td>0.70</td>
</tr>
<tr>
<td>15</td>
<td>0.44</td>
<td>0.26</td>
<td>0.32 /0.31</td>
<td>0.50</td>
</tr>
<tr>
<td>16</td>
<td>0.25</td>
<td>0.22</td>
<td>0.23 /0.25</td>
<td>0.50</td>
</tr>
<tr>
<td>17</td>
<td>0.21</td>
<td>0.19</td>
<td>0.18 /0.18</td>
<td>0.30</td>
</tr>
<tr>
<td>18</td>
<td>0.43</td>
<td>0.29</td>
<td>0.22 /0.21</td>
<td>0.30</td>
</tr>
<tr>
<td>19</td>
<td>1.64</td>
<td>1.40</td>
<td>1.20 /1.28</td>
<td>2.38</td>
</tr>
<tr>
<td>20</td>
<td>1.46</td>
<td>1.35</td>
<td>1.10 /1.16</td>
<td>2.38</td>
</tr>
<tr>
<td>21</td>
<td>1.05</td>
<td>1.02</td>
<td>0.80 /0.84</td>
<td>1.75</td>
</tr>
<tr>
<td>22</td>
<td>0.74</td>
<td>0.73</td>
<td>0.55 /0.58</td>
<td>1.00</td>
</tr>
<tr>
<td>23</td>
<td>0.46</td>
<td>0.42</td>
<td>0.35 /0.36</td>
<td>0.60</td>
</tr>
<tr>
<td>24</td>
<td>0.23</td>
<td>0.22</td>
<td>0.20 /0.20</td>
<td>0.35</td>
</tr>
</tbody>
</table>

### Averaging

- **3x3**
- **1x2**
- **3x3**
- **6x6**

Averaging: Along Track by Along Scan
Reflector Emission Model

\[ T_{\text{Scene}} = T_{OB} - \varepsilon_{\text{Rflct}}(\nu) \left[ T_{\text{Rflct}} - T_{\text{Scene}} \right] \]

Assume Reflector Emissivity can be estimated by the slope of an ensemble of:

\[ \left[ T_{\text{Rflct}} - T_{OB} \right] \text{ versus } \left[ T_{OB} - T_{BK} \right] \]

\[ \varepsilon_{\text{Rflct}}(\nu) \approx \frac{T_{OB} - T_{BK}}{T_{\text{Rflct}} - T_{OB}} \]
\[
\begin{bmatrix}
T_{\text{Rflct}} - T_{OB}
\end{bmatrix}
\text{ versus }
\begin{bmatrix}
T_{OB} - T_{BK}
\end{bmatrix}
\]

\[
\varepsilon_{\text{Rflct}}(\nu) \approx \frac{T_{OB} - T_{BK}}{T_{\text{Rflct}} - T_{OB}}
\]

\(\varepsilon_{\text{Rflct}} \sim 0.019\)
F16 Reflector Emissivity Estimates  
LAS Channels 3-7, 24, DTG:2009110406
F17 Reflector Emissivity Estimates
LAS Channels 3-7, 24, DTG:2009110406

F17
F18 Reflector Emissivity Estimates
LAS Channels 3-7, 24, DTG:2009110406
Verifies Pre-Flight Conductivity Measurements
Adjoint Sensitivity Impacts for each Sensor Summed over First 8 days of the Beta OPS NAVDAS-AR Run at FNMOC

F18 UPP Transitioned to FNMOC OPS NAVDAS-AR:

14 April 2010
F18 SSMIS LAS Assimilation Results
Beta OPS 05-12 April 2010

Adjoint Sensitivity Impacts for each F18 Channel assimilated Summed over First 8 days of the Beta OPS NAVDAS-AR Run at FNMOC

FNMOC and NESDIS Coordinating the Operational Transfer of F18 SSMIS UPP Data

F18 UPP to be made Available possibly as early as next week
F-18 SSMIS LAS Assimilation Results
Assimilation Trials: 09 Jan – 19 Feb 2010

NOGAPS DATA ASSIMILATION TEST
500 MB NORTH HEM HEIGHT ANOMALY COR
2010010900 – 2010021900

--- F18 --- OPS

--- F18 --- OPS
• Effective Conductivity Measurements have been Verified on Orbit for F18 Reflector

• F19 and F20 SSMIS Reflectors have been Re-Coated. Measured Effective Conductivities ~ 34-35 MS/m

• Effective Conductivity Measurements Should be a Required Pre-Flight Process for MW Reflectors

• Lessons Learned Advantageous to future MW Imager/Sounder Programs

• SSMIS will continue to play Large Role in MW Imaging and Sounding for the next 10 Years
Path Forward for SSMIS F-19 and F-20

- There are great, but yet to be fully exploited advantages, in having the sounding and imaging channels in the same geometry

- Conical Imager/Sounders with constant resolution across scan provide self-consistent T, q and hydrometeor information (RR, CLW, TVAP)

- NWP Forecast Accuracies are very sensitive to key aspects of sensor data records:
  - Number of Channels
  - Vertical Sensitivity Distributions
  - Noise Levels for each channel

- Precise Calibration Remains the Technical Challenge
Thank You

Questions ?
Backup Slides
NOGAPS DATA ASSIMILATION TEST
500 MB SOUTH HEM HEIGHT ANOMALY COR
2010010900 - 2010020800

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F18

OPS
DSMP F-18 SSMIS UPP Update

F-18 SSMIS UPP OB-BK Ch. 4 54.4 GHz V
DTG: 2009110406
ssmis_stats_2009110406

No. Scenes: 51559

Min  -1.50
Max   1.68
MEAN  0.16
SDEV  0.30
NCAR WRF Radiance Assimilation Impacts

WRF Observation Impact

Adjoint Sensitivity Method

Shows the impact an individual observing system, sensor or select channel had in reducing the 24 hour forecast error as measured by a moist energy norm integrated over the troposphere and lower stratosphere (1000–150 hPa)

Image Courtesy of Tom Auligné (NCAR)
F-18 SSMIS LAS Assimilation Results

NAVDAS-AR
F-18 Assimilation Trials
SSMIS OB-BK StdDevs
SSMIS
LAS Scan Dependence

OB-BK (ECMWF)
F-16 SSMIS LAS Scan Dependence

OB-BK Scan Dependent Bias

OB-BK Bias [K]

LAS Beam Position

Ch. 3
Ch. 4
Ch. 5
Ch. 6
Ch. 7
Ch. 24
F-18 SSMIS LAS Scan Dependence

OB-BK Scan Dependent Bias

OB-BK Bias [K]

LAS Beam Position

Ch. 3
Ch. 4
Ch. 5
Ch. 6
Ch. 7
Ch. 24
DMSP SSMIS UPP Update

- SSMIS Unified Pre-Processor Version 2.1 now running operationally at FNMOC for both F-16 and F-17

- SSMIS UPP Software Maintained by NRL

- Un-Averaged BUFR files distributed to NOAA by FNMOC

- UPP V2.1 includes:
  - Reflector Emission Corrections, with sensor and channel dependent reflector emissivities
  - Sensor dependent Reflector Temperature model
  - Level of Spatial Averaging controlled at the script level
  - Full resolution BUFR files now being distributed by FNMOC

- Code modifications in place for F-18 SSMIS
  - Ready for Distribution once Scan Non-Uniformity Corrections are finalized
DMSP SSMIS UPP Update

Before After

UPP V2 includes

• Reflector Emission Corrections (F-16 and F-17)
• Spatial Averaging to reduce NEΔT to 0.15 - 0.25 K level
• Uses Operational NGES Fourier Filtered Gain Files to Correct Gain Anomalies
• Produces ASCII and BUFR TDR output files at full and/or filtered resolution
• Performs Scan Non-uniformity corrections
• SSMIS UPP V2 Operational at FNMOC (F16 - Jul ’08, F17 - Apr ’09, F18 – Apr ’09)
• FNMOC distributes UPP data to NESDIS for use by the NWP Community
F-18 SSMIS LAS Assimilation Results

NOGAPS DATA ASSIMILATION TEST
500 MB NORTH HEM HEIGHT ANOMALY COR
2010010900 – 2010013100

--- F18 ---

--- OPS ---

--- F18 ---

--- OPS ---
NAVDAS-AR Operational Radiance Observation Impacts

Observation Impacts
13 Dec – 13 Jan 2010

Adjoint Sensitivity Method

Shows the impact an individual observing system, sensor or select channel had in reducing the 24 hour global forecast error as measured by a moist energy norm integrated over the troposphere and lower stratosphere (1000–150 hPa).
F-18 SSMIS Assimilation Trials

Ch 3

NRL SSMIS Ch. 3 UPP NAVDAS–AR AR STRATO Radiance Monitor
Global OB–BK Departure Statistics Strict QC

Blue = F16    Red = F17    Green = F18
Un–Corrected (Dashed)  Bias Corrected (Solid)  Dotted = SDEV

Dates Covered: 2010011100 to 2010021400  Number of 6-hour cycles: 140
F-18 SSMIS LAS Assimilation Results

NRL SSMIS Ch. 4 UPP NAVDAS–AR AR STRATO Radiance Monitor
Global OB–BK Departure Statistics Strict QC

Blue = F16    Red = F17    Green = F18
Un-Corrected (Dashed)  Bias Corrected (Solid)  Dotted = SDEV

Dates Covered: 2010011100 to 2010021400  Number of 6-hour cycles: 140
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 $\sigma_E = 3.4$ MS/m
55 GHz $\varepsilon = 0.0027$

*VDA: Vapor Deposited Aluminum
Analysis and Verification of Root Causes

VDA Applied to Smooth Surface

VDA Layer

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

32 GHz $\sigma_E = 33$ MS/m

55 GHz $\varepsilon = 0.0009$