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

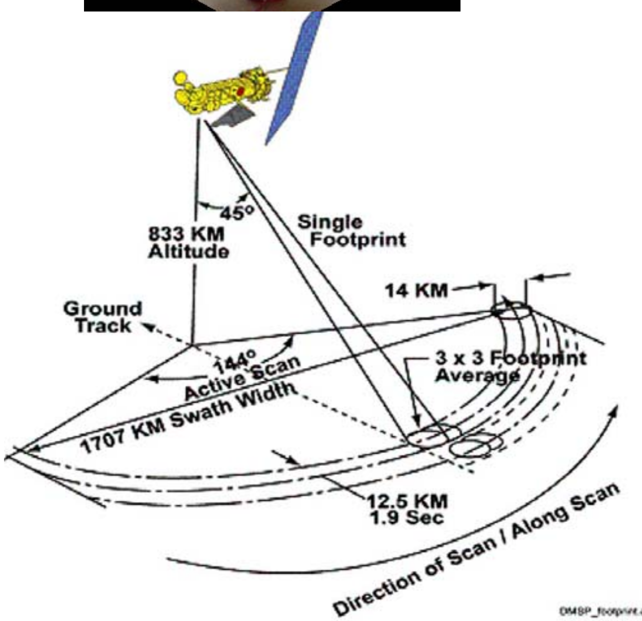
SSMIS Instrument

24 Channel Microwave Imager/Sounder

Conical Scan (53° Incidence Angle)

0.61 m Graphite Reflector (VDA/SiO_x)

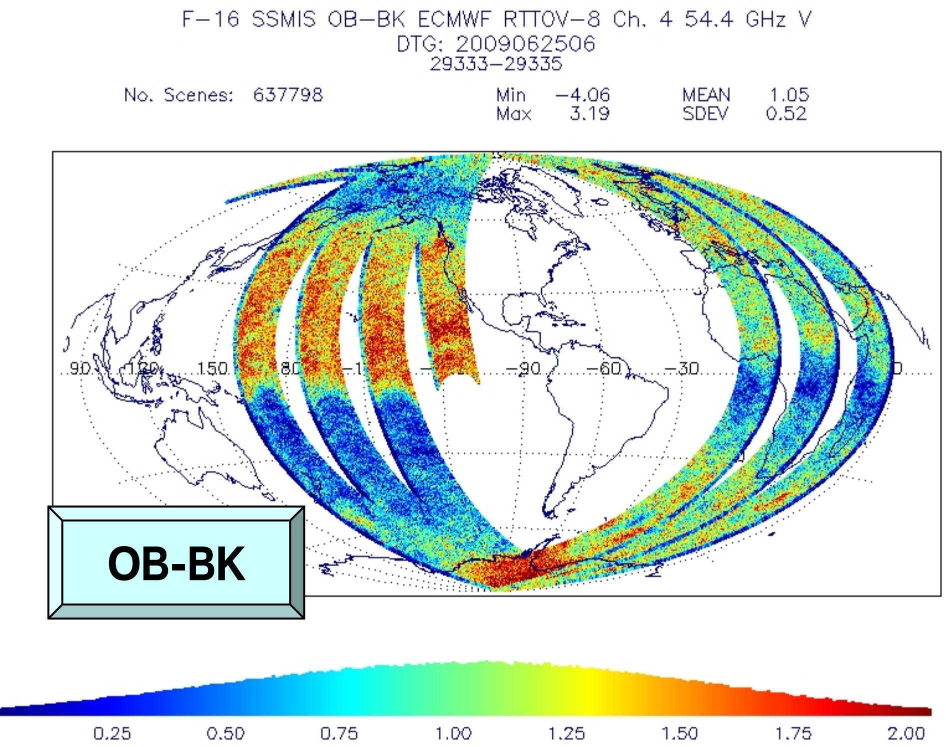
	Res. (km)	Freq. (GHz)
Imaging	12.5 km 25.0 km	91 - 183 (5) 19 – 37 (5)
LAS T	37.5 km	50 - 60 (8)
LAS Hum.	37.5 km	150, 183 (3)
UAS T	75.0 km	60-63 (5)



SSMIS Calibration Anomaly Detection

Launch Dates: F16 (10/2003), F17 (11/2006), F18 (10/2009)

- 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, 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

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, ε_{Rflct}
    - 1.5–2K OB-BK Jump at 50-60 GHz
    - 5-8K OB-BK Jump at 183 GHz

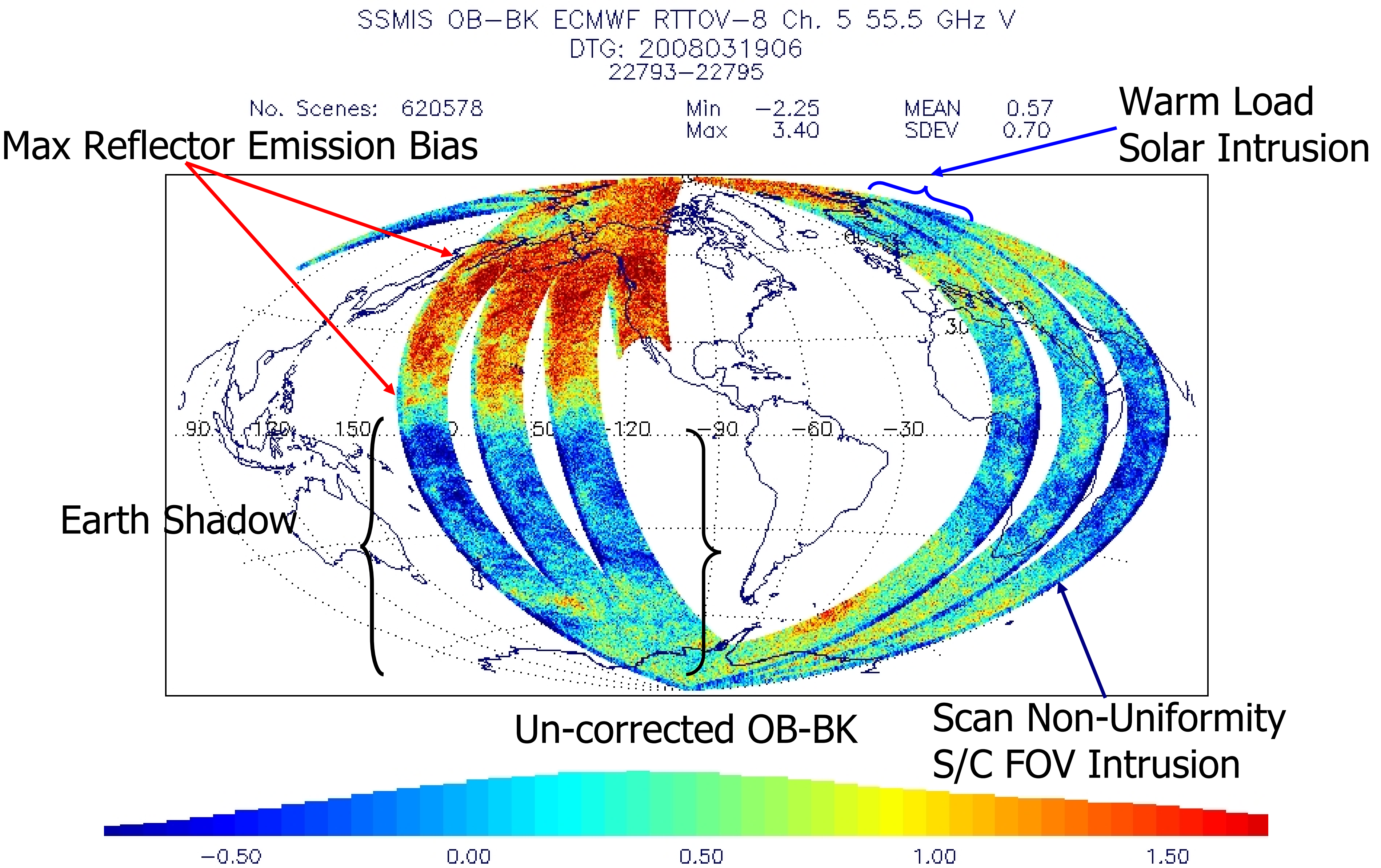
Warm Load Intrusions

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

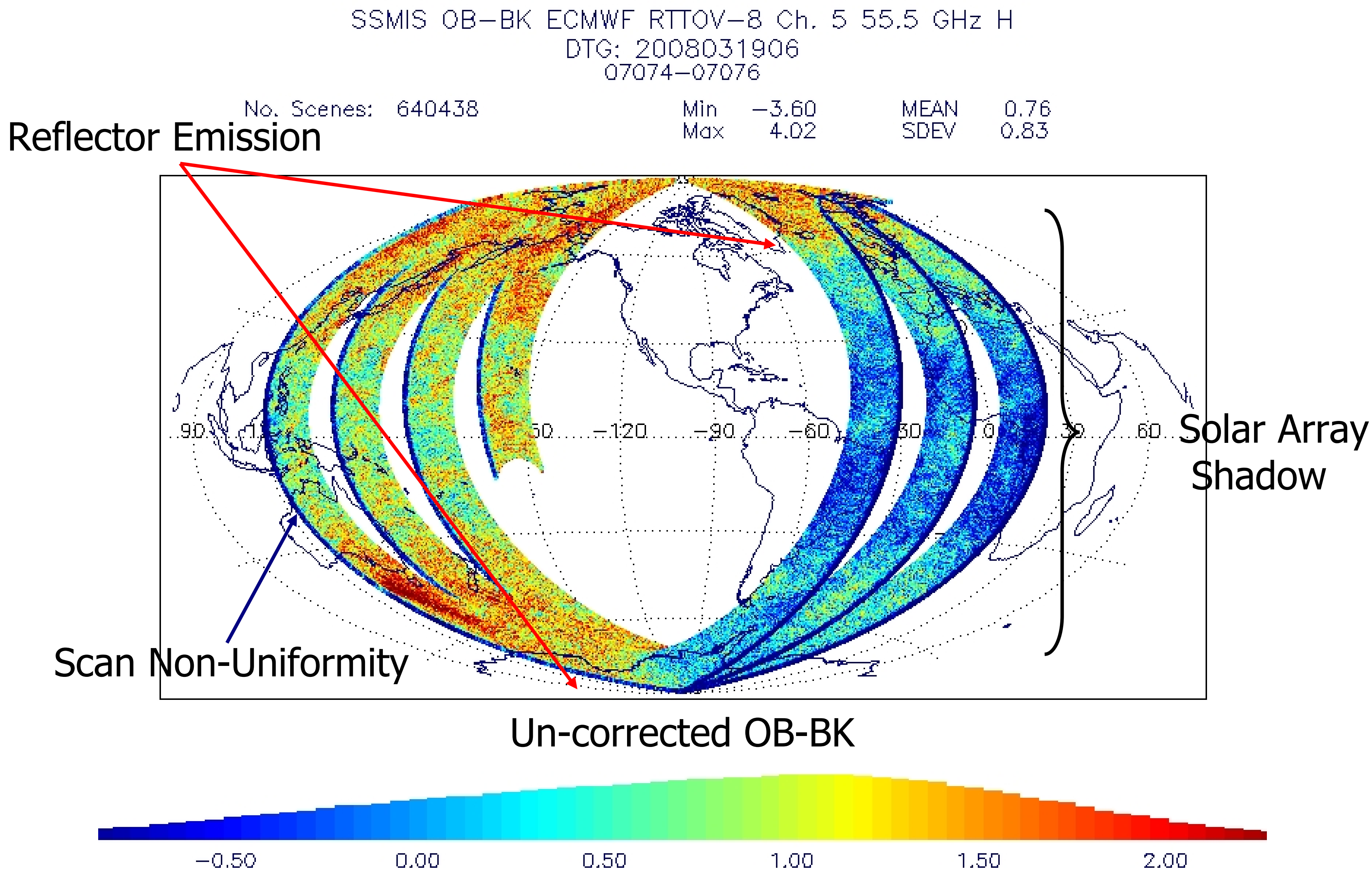
Residual Doppler Signature

- 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



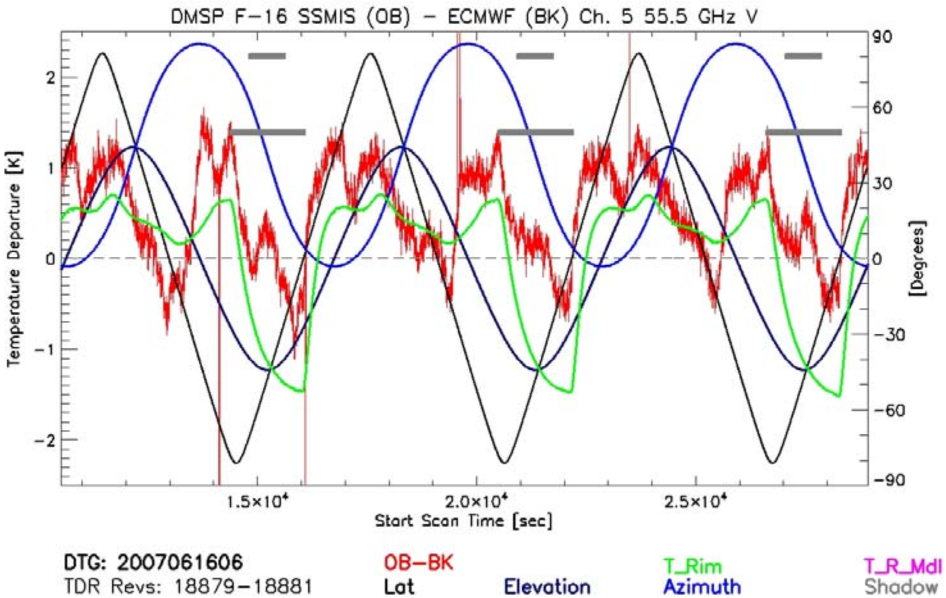
F17 SSMIS Calibration Anomalies

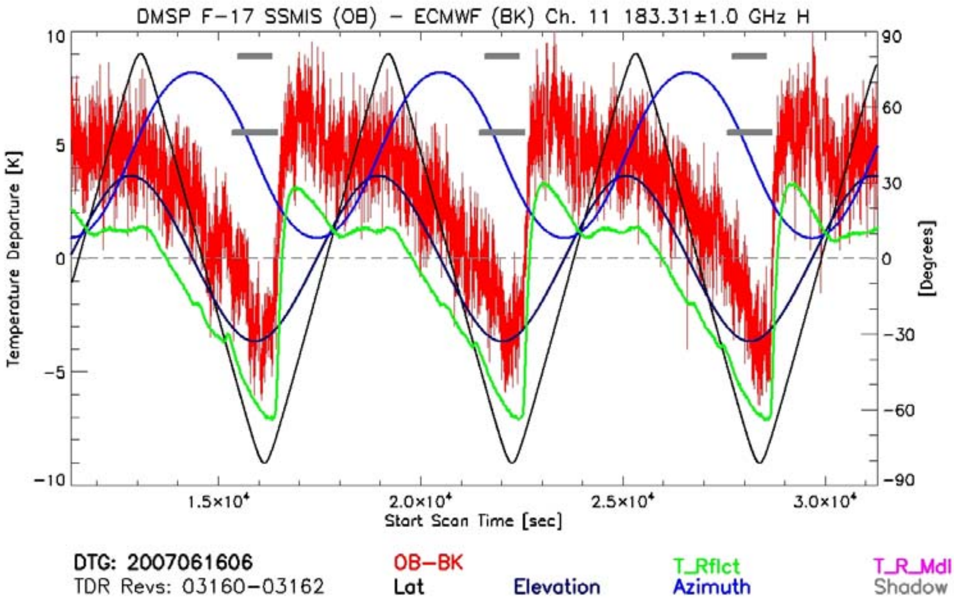


Frequency Dependence of the SSMIS Reflector Emission Bias

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

$\varepsilon(55.5)_{Rflct}$ ~ 0.015 - 0.02

F17 183 GHz Channel Shows 7 K Jump at emergence from Earth Shadow

$\varepsilon(183)_{Rflct}$ ~ 0.04 - 0.07

SSMIS Calibration Anomaly Mitigation
Unified Pre-Processor

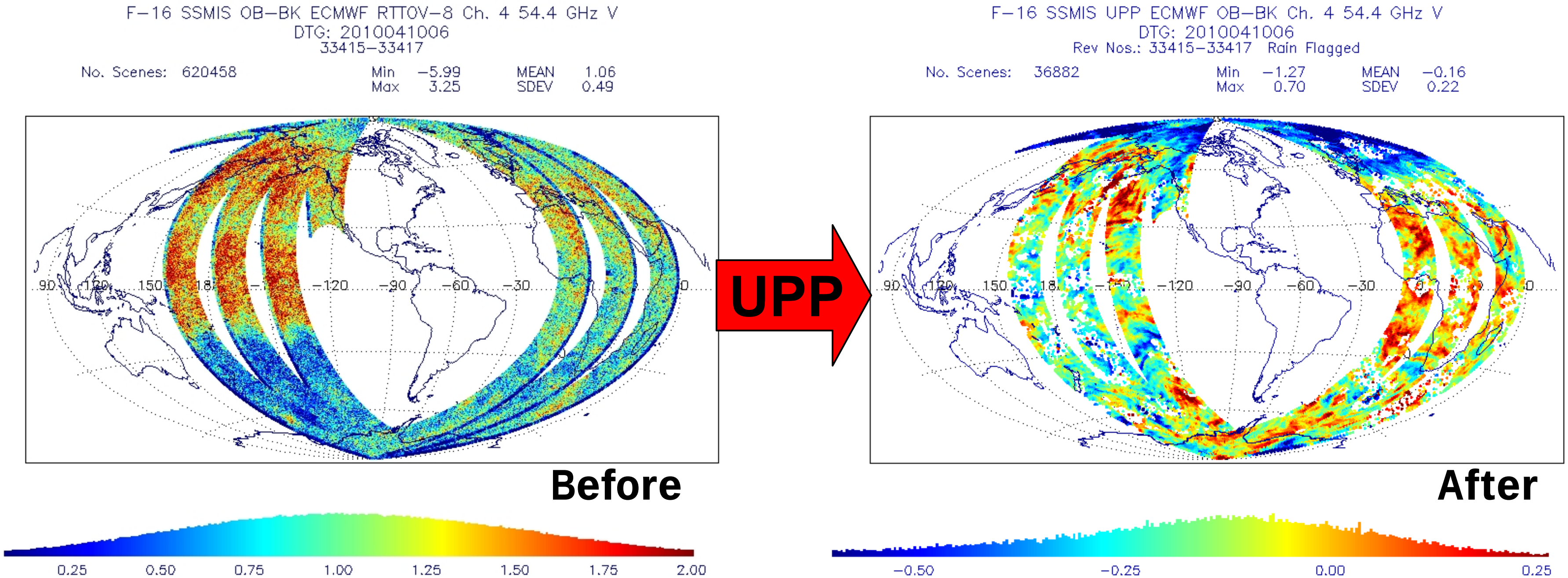
NRL and UK Met Office designed, developed and implemented a **Unified Pre-Processor (UPP)** to correct the F16 calibration anomalies

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



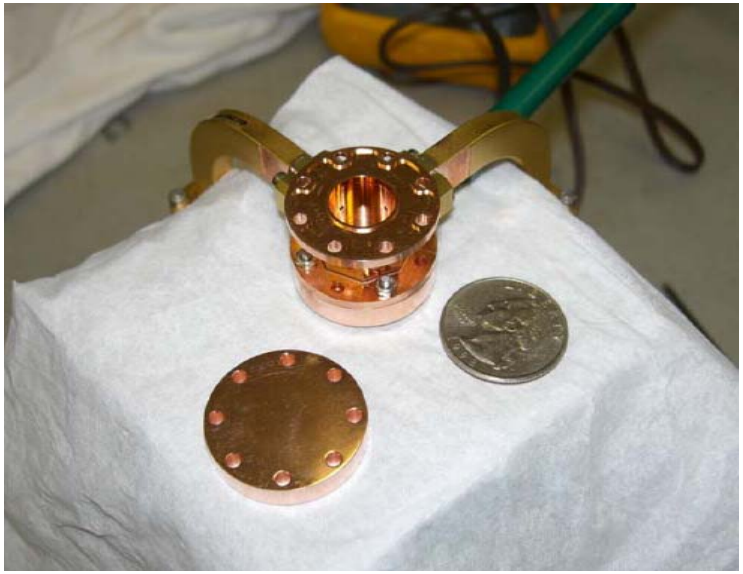
UPP V2 includes

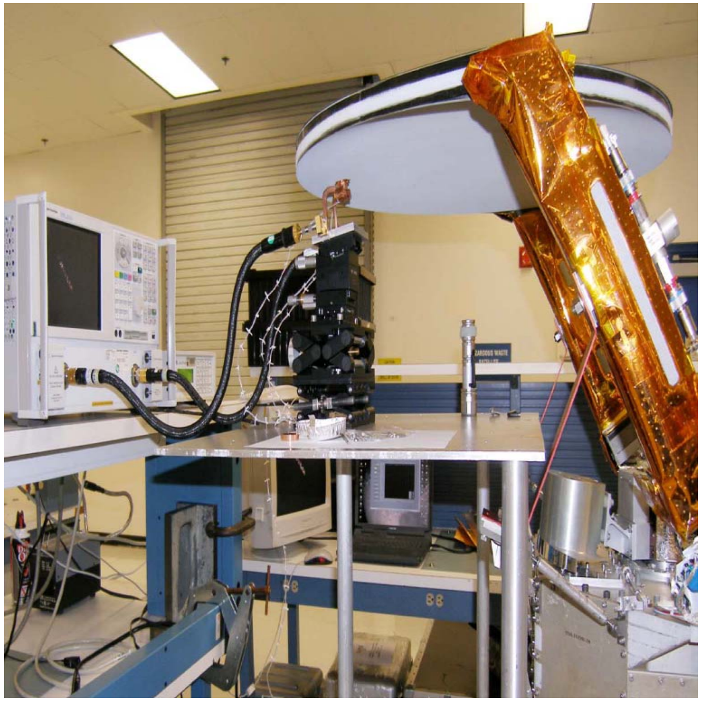
- Reflector Emission Corrections (F16 and F17)
- Spatial Averaging to reduce NEΔT to 0.15 - 0.25 K level (NRL only)
- Uses Operational NGES Fourier Filtered Gain Files to Correct Gain Anomalies
- Produces ASCII and BUFR TDR output files at full and/or filtered resolution
- Performs Scan Non-uniformity 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 *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
θ_i = 18°
σ = 36.59 MS/m

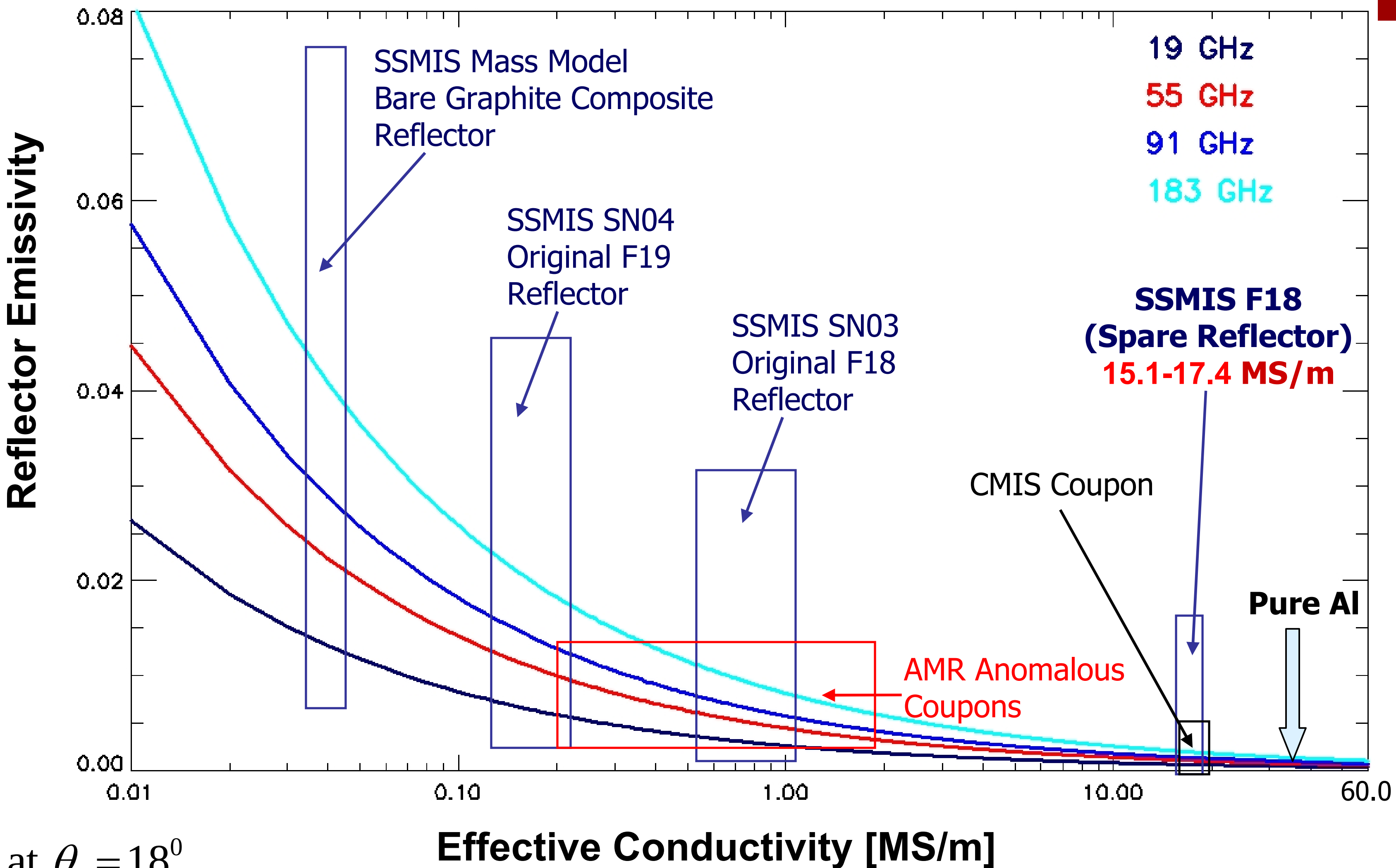
$$\varepsilon_v = 0.00157$$

$$\varepsilon_h = 0.00142$$

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

JPL/USC Effective Conductivity Measurements

Emissivity vs. Effective Conductivity

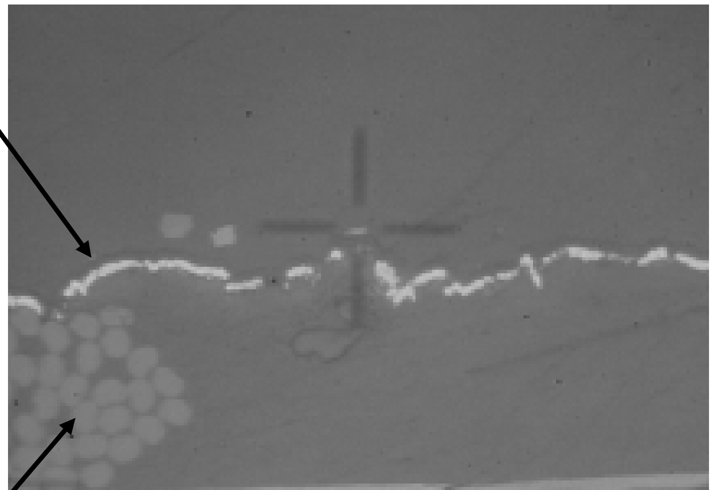


ε_h at $\theta_i = 18^0$

Analysis and Verification of Root Causes

VDA* Layer

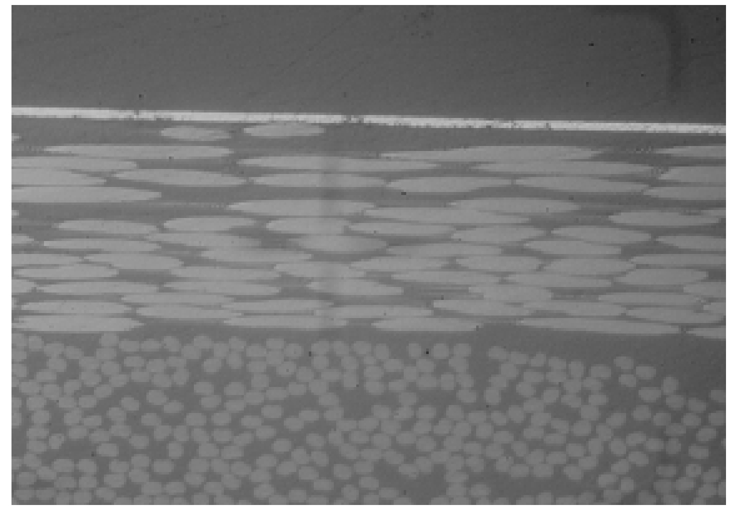
Roughened Surface



32 GHz σ_E = 3.4 MS/m

55 GHz ε = 0.0027

Smooth Surface



32 GHz σ_E = 33 MS/m

55 GHz ε = 0.0009

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

***VDA: Vapor Deposited Aluminum**

Analysis and Verification of Root Causes

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

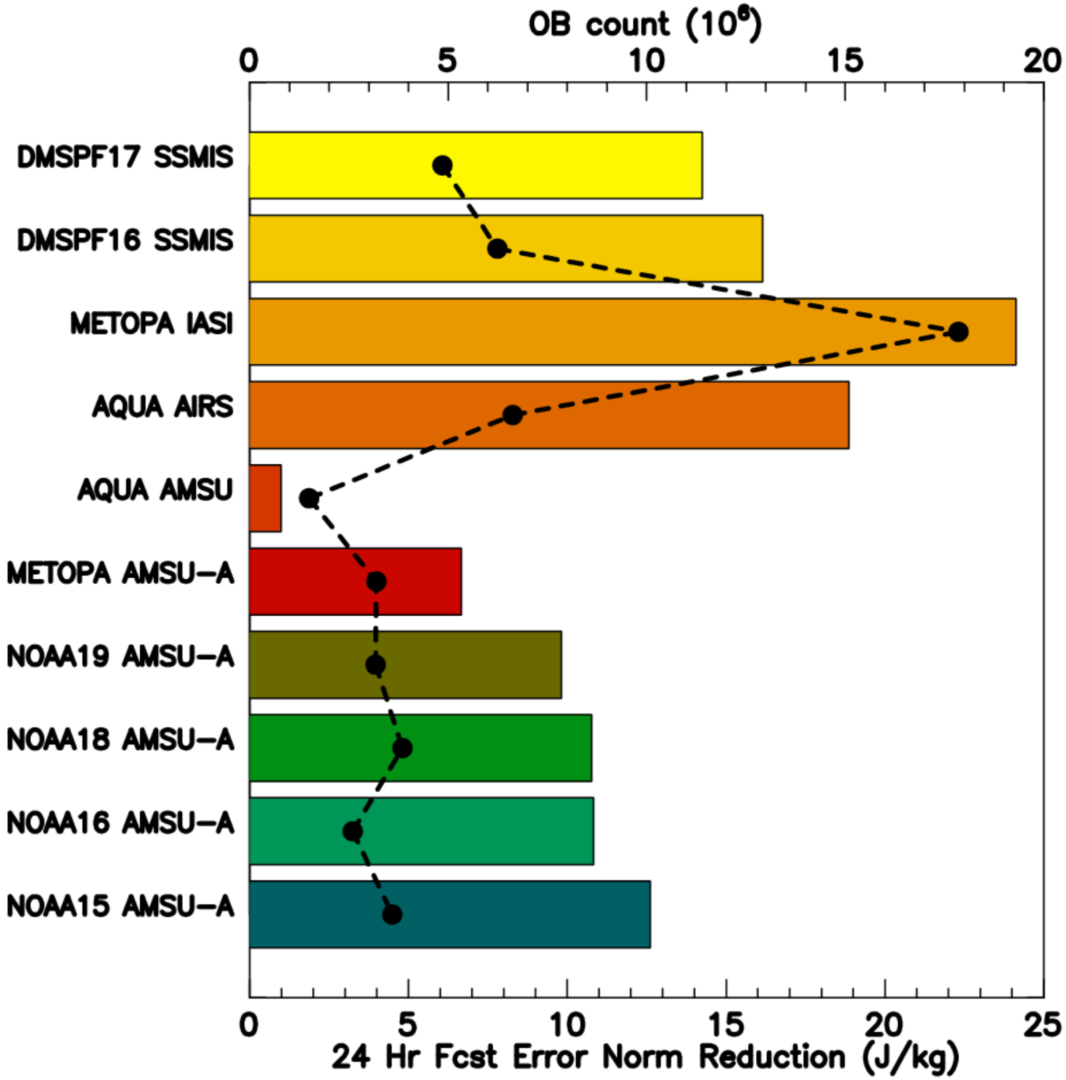
Assessing Impacts of Observing Systems

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

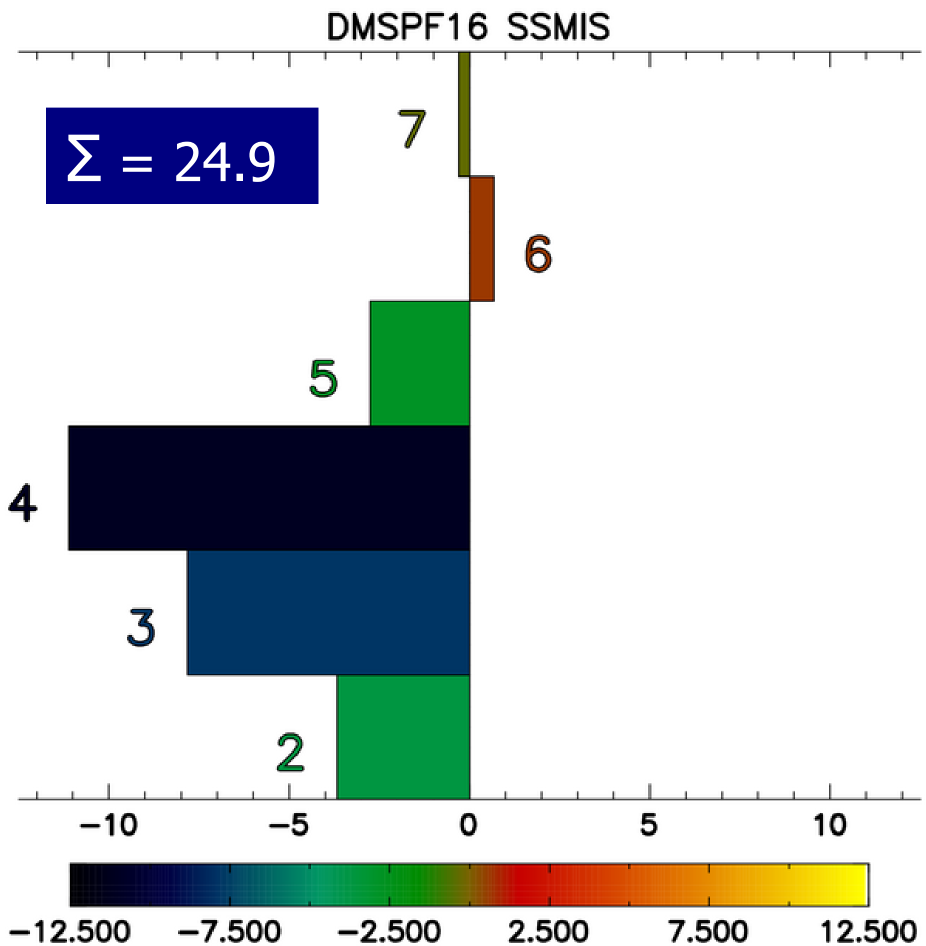


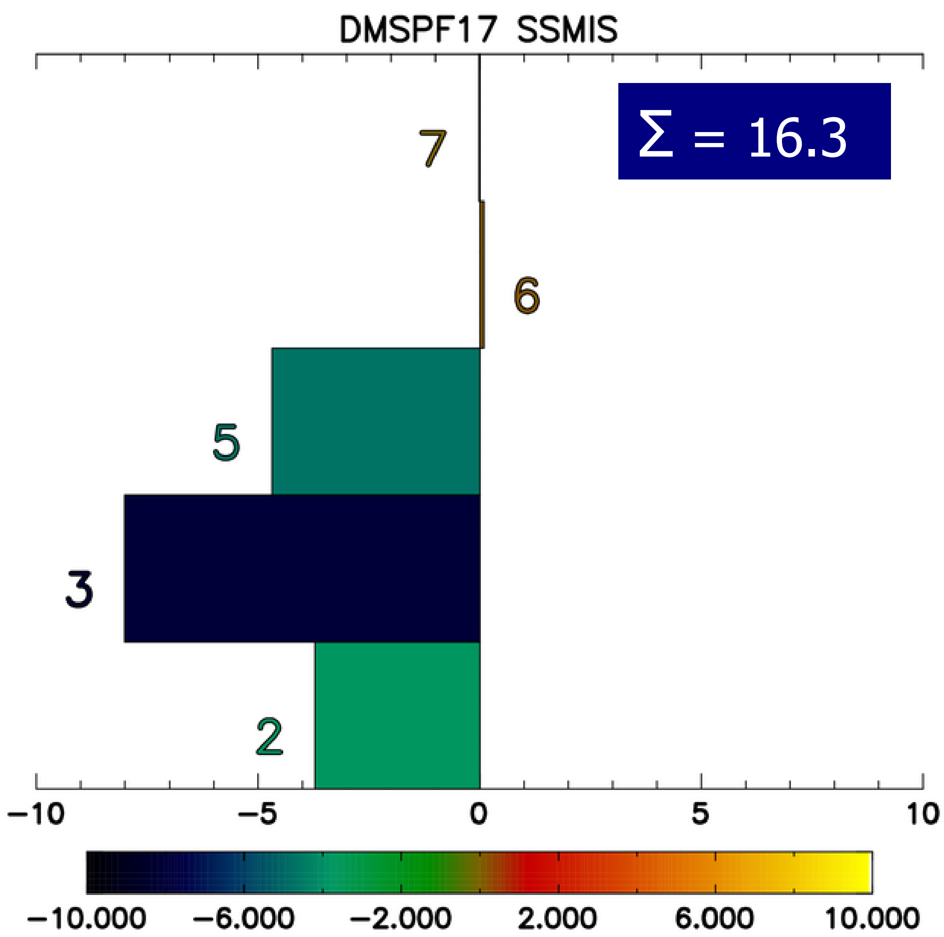
Adjoint Sensitivity Method

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

NAVDAS-AR Operational SSMIS Channel Specific Impacts



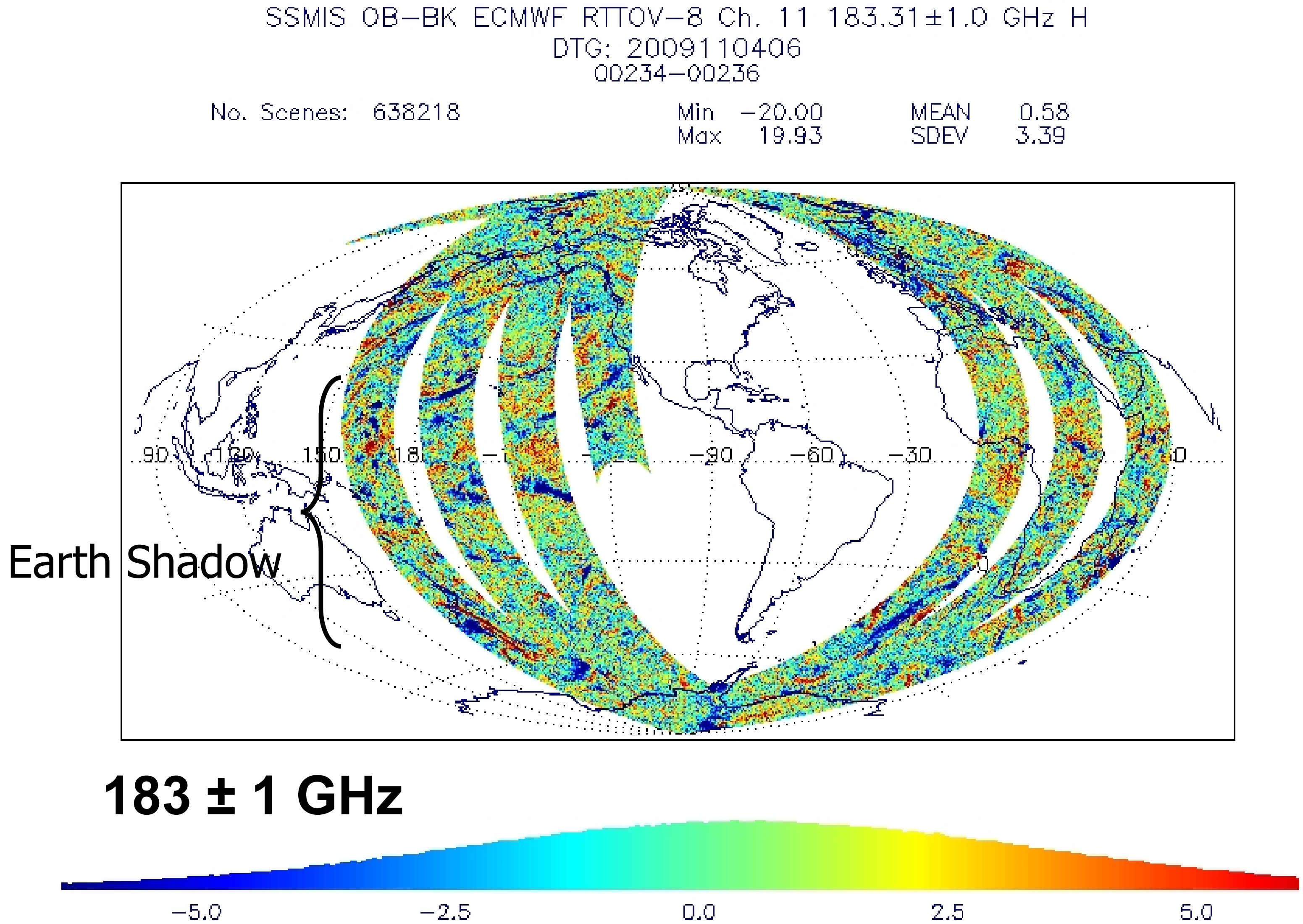


SSMIS UPP Data Impacts

Impact of F17 is lower due to the loss of Ch 4

DMSP F18 SSMIS Cal/Val Status

OB-BK Analysis



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) (Trec=305K)

Channel Grouping	Ch	F-16	F-17	F-18 (T/V**)	Spec.	Averaging
Lower Atmos. Sounding (LAS)	1	0.22	0.24	0.19 /0.19	0.40	3x3
	2	0.24	0.21	0.19 /0.19	0.40	
	3	0.21	0.22	0.21 /0.20	0.40	
	4	0.23	-	0.22 /0.22	0.40	
	5	0.24	0.22	0.23 /0.22	0.40	
	6	0.30	0.27	0.25 /0.24	0.50	
	7	0.36	0.30	0.24 /0.23	0.60	
	8	0.55	0.58	0.50 /0.47	0.88	
	9	0.66	0.74	0.68 /0.68	1.20	
	10	0.67	0.47	0.65 /0.60	1.00	
	11	0.81	0.66	0.80 /0.74	1.25	
Imaging (IMG)	12	0.40	0.33	0.34 /0.35	0.70	1x2
	13	0.42	0.36	0.32 /0.33	0.70	
	14	0.38	0.41	0.39 /0.39	0.70	
	15	0.44	0.26	0.32 /0.31	0.50	
	16	0.25	0.22	0.23 /0.25	0.50	
	17	0.21	0.19	0.18 /0.18	0.30	3x3
	18	0.43	0.29	0.22 /0.21	0.30	
Upper Atmos. Sounding (UAS)	19	1.64	1.40	1.20 /1.28	2.38	6x6
	20	1.46	1.35	1.10 /1.16	2.38	
	21	1.05	1.02	0.80 /0.84	1.75	
	22	0.74	0.73	0.55 /0.58	1.00	
	23	0.46	0.42	0.35 /0.36	0.60	
	24	0.23	0.22	0.20 /0.20	0.35	

Zeeman Affected (channels 19–21 highlighted)

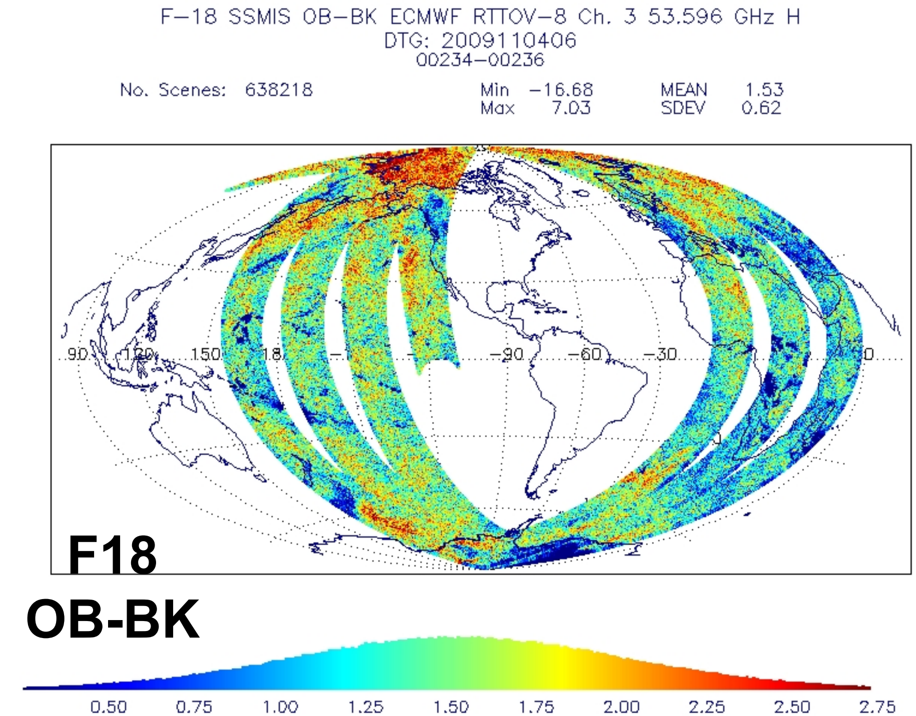
Averaging: Along Track by Along Scan

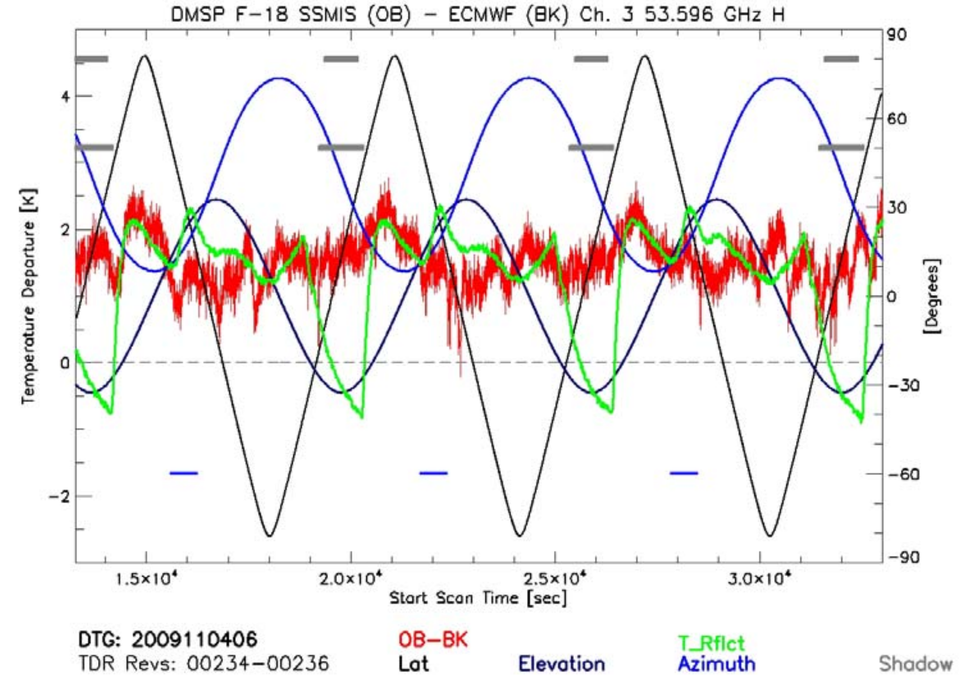
F18
OB-BK

F18
Scan-Averaged OB-BK
Time Series

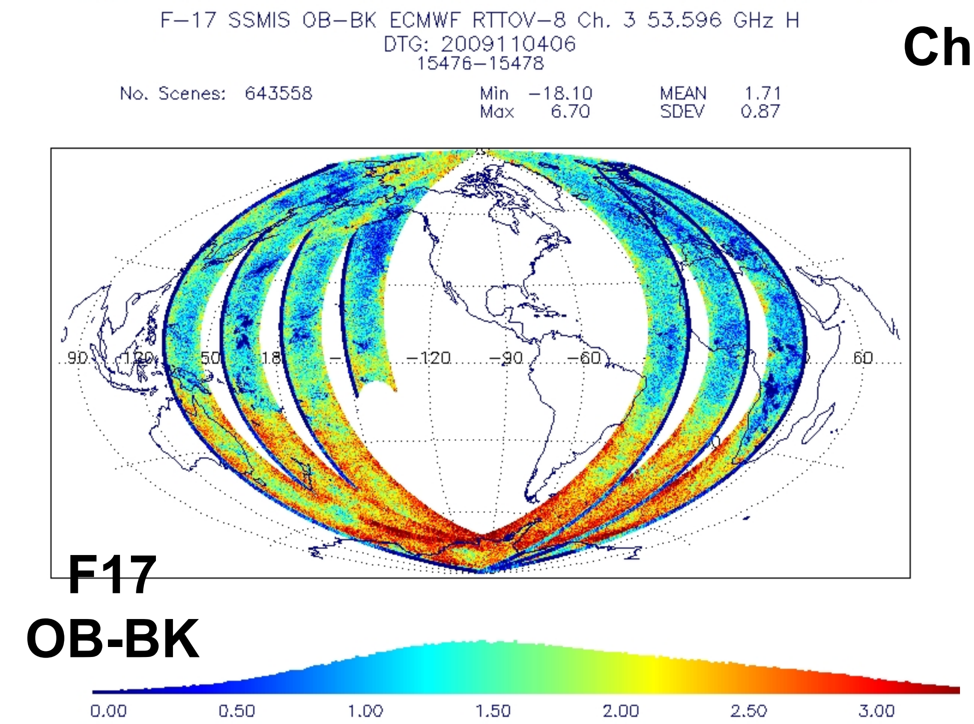
F17
OB-BK

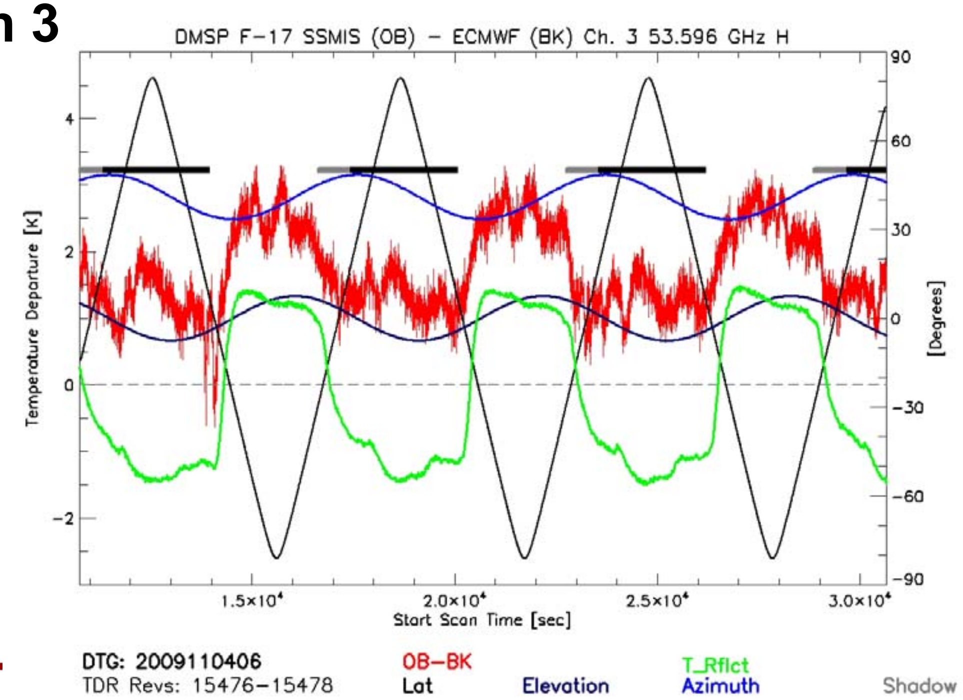
F17
Scan-Averaged OB-BK
Time Series

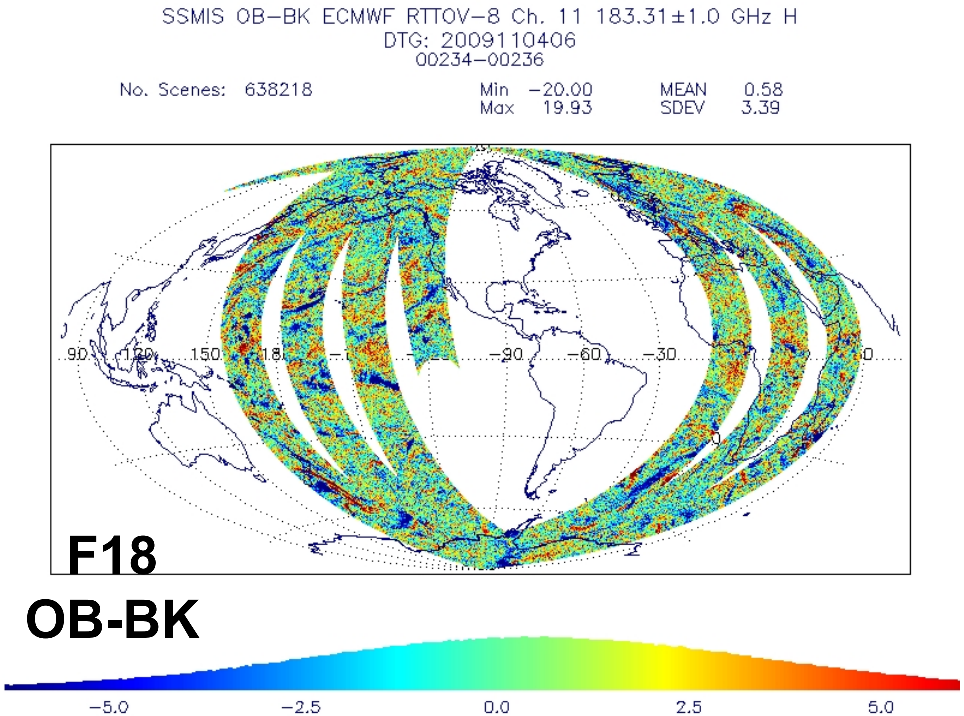

F−18 SSMIS OB−BK ECMWF RTTOV−8 Ch. 3 53.596 GHz H
DTG: 2009110406
00234−00236
No. Scenes: 638218
Min −16.68
Max 7.03
MEAN 1.53
SDEV 0.62
F18
OB-BK
0.50 0.75 1.00 1.25 1.50 1.75 2.00 2.25 2.50 2.75

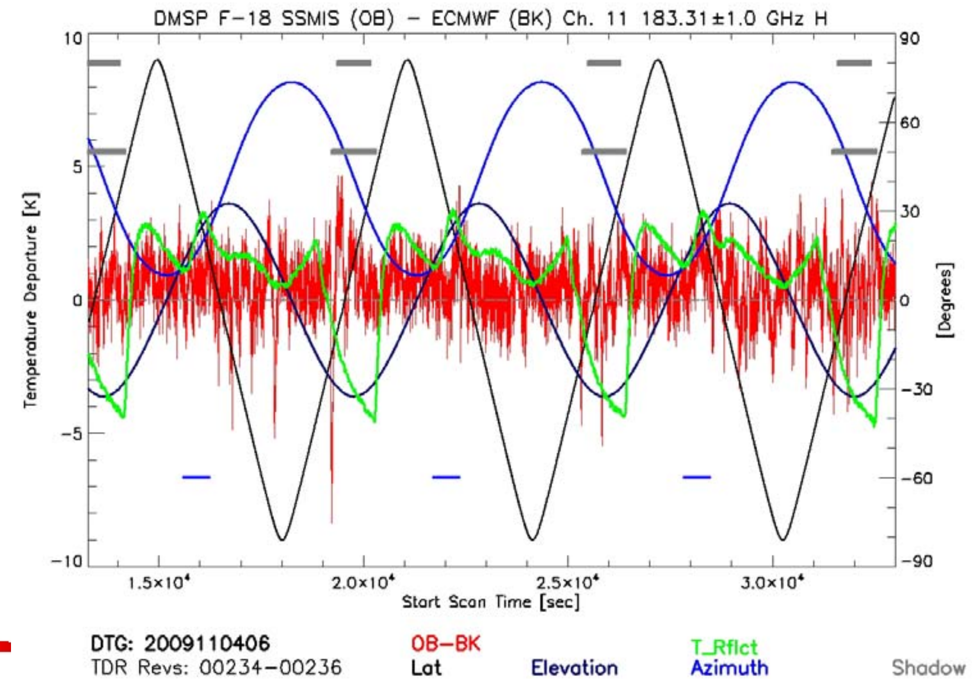

DMSP F-18 SSMIS (OB) − ECMWF (BK) Ch. 3 53.596 GHz H
Temperature Departure [K]
[Degrees]
Start Scan Time [sec]
DTG: 2009110406
TDR Revs: 00234−00236
OB−BK
Lat
Elevation
T_Rflct
Azimuth
Shadow

Ch 3

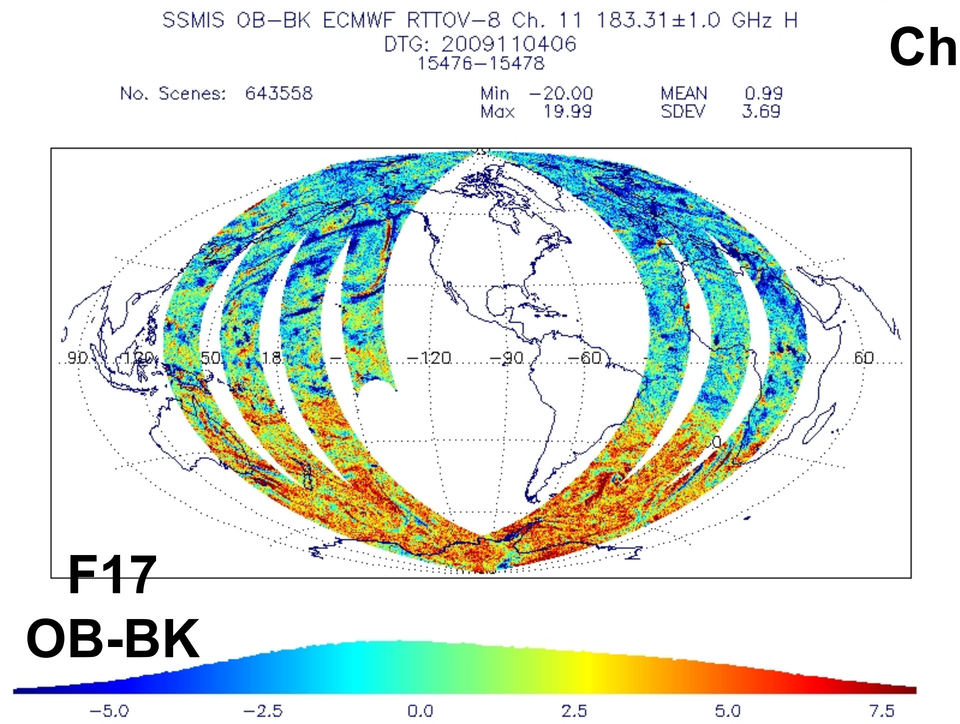

F−17 SSMIS OB−BK ECMWF RTTOV−8 Ch. 3 53.596 GHz H
DTG: 2009110406
15476−15478
No. Scenes: 643558
Min −18.10
Max 6.70
MEAN 1.71
SDEV 0.87
F17
OB-BK
0.00 0.50 1.00 1.50 2.00 2.50 3.00

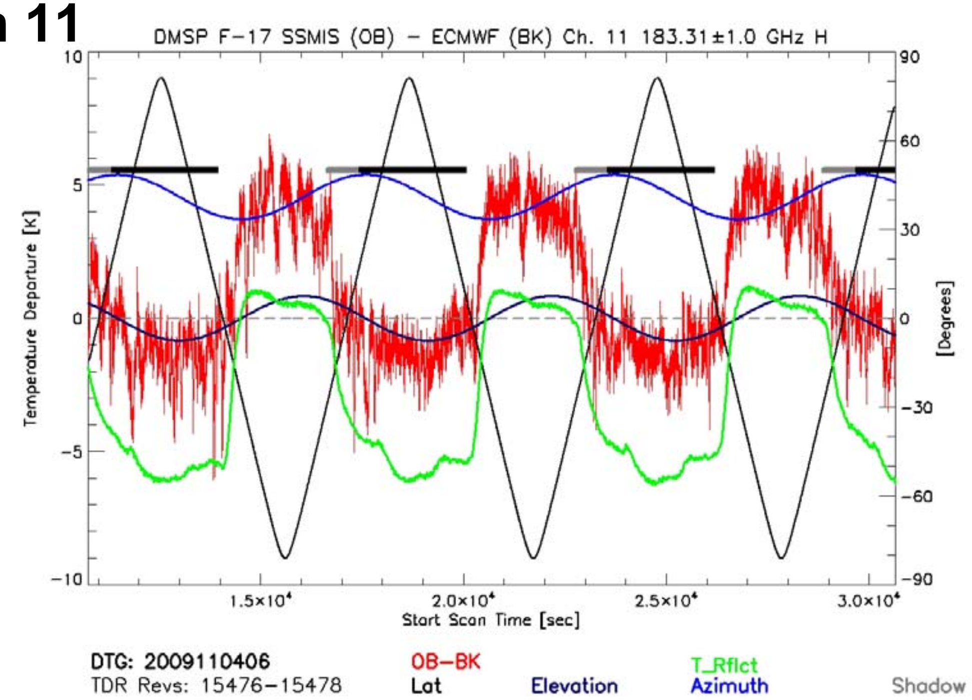

DMSP F-17 SSMIS (OB) − ECMWF (BK) Ch. 3 53.596 GHz H
Temperature Departure [K]
[Degrees]
Start Scan Time [sec]
DTG: 2009110406
TDR Revs: 15476−15478
OB−BK
Lat
Elevation
T_Rflct
Azimuth
Shadow


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
F18
OB-BK
−5.0
−2.5
0.0
2.5
5.0


DMSP F−18 SSMIS (OB) − ECMWF (BK) Ch. 11 183.31±1.0 GHz H
Temperature Departure [K]
[Degrees]
Start Scan Time [sec]
DTG: 2009110406
TDR Revs: 00234−00236
OB−BK
Lat
Elevation
T_Rflct
Azimuth
Shadow

Ch 11


SSMIS OB−BK ECMWF RTTOV−8 Ch. 11 183.31±1.0 GHz H
DTG: 2009110406
15476−15478
No. Scenes: 643558
Min −20.00
Max 19.99
MEAN 0.99
SDEV 3.69
F17
OB-BK
−5.0
−2.5
0.0
2.5
5.0
7.5


DMSP F−17 SSMIS (OB) − ECMWF (BK) Ch. 11 183.31±1.0 GHz H
Temperature Departure [K]
[Degrees]
Start Scan Time [sec]
DTG: 2009110406
TDR Revs: 15476−15478
OB−BK
Lat
Elevation
T_Rflct
Azimuth
Shadow

Reflector Emission Model

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

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

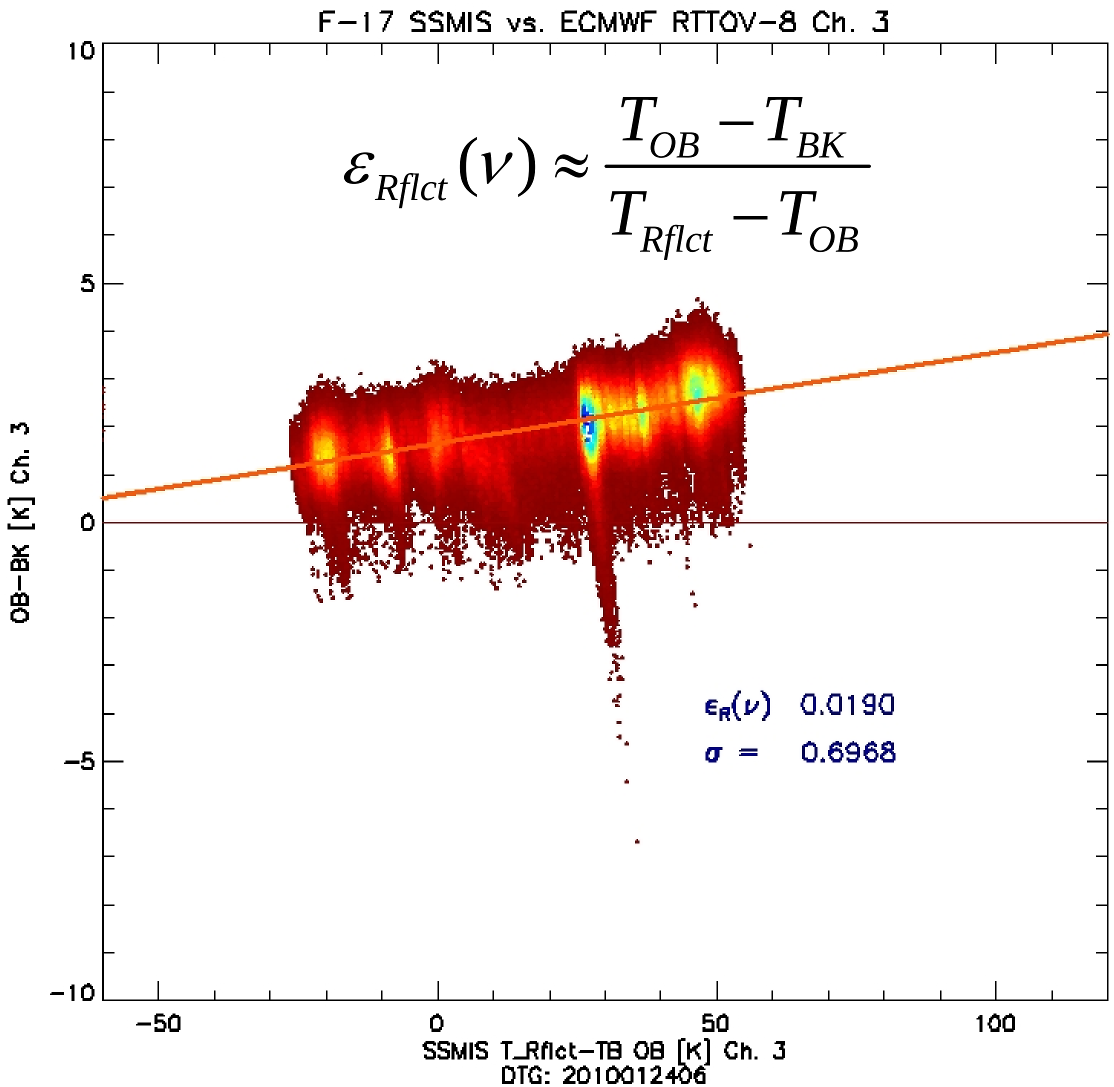
$$\left[T_{Rflct} - T_{OB}\right] \text{ versus } \left[T_{OB} - T_{BK}\right]$$

$$\varepsilon_{Rflct}(\nu) \approx \frac{T_{OB} - T_{BK}}{T_{Rflct} - T_{OB}}$$

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

F17
Ch. 3

$$\varepsilon_{Rflct}(\nu) \approx \frac{T_{OB} - T_{BK}}{T_{Rflct} - T_{OB}}$$



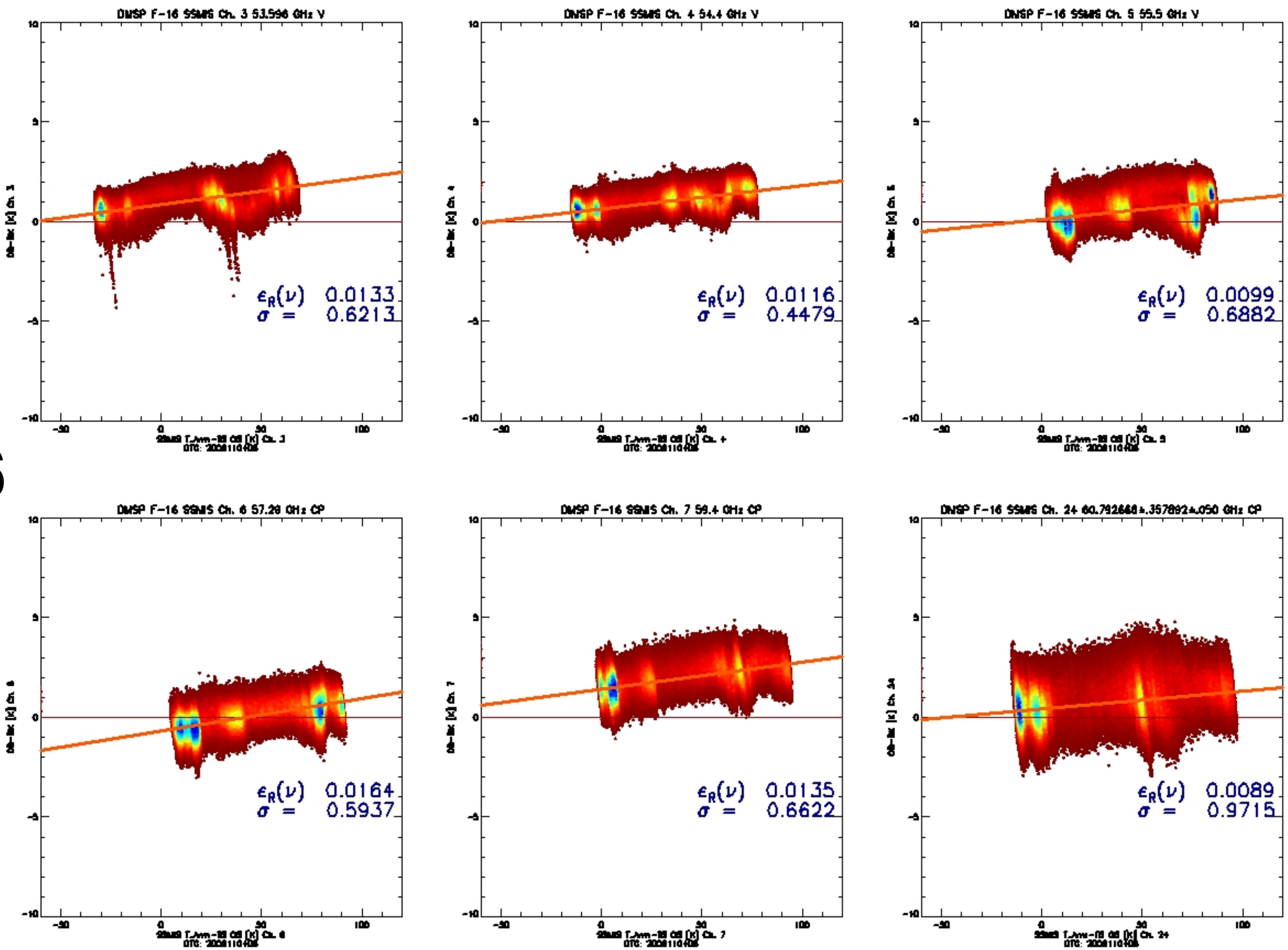
OB-BK

ε_{Rflct} ~ 0.019

T_{Rflct}-OB

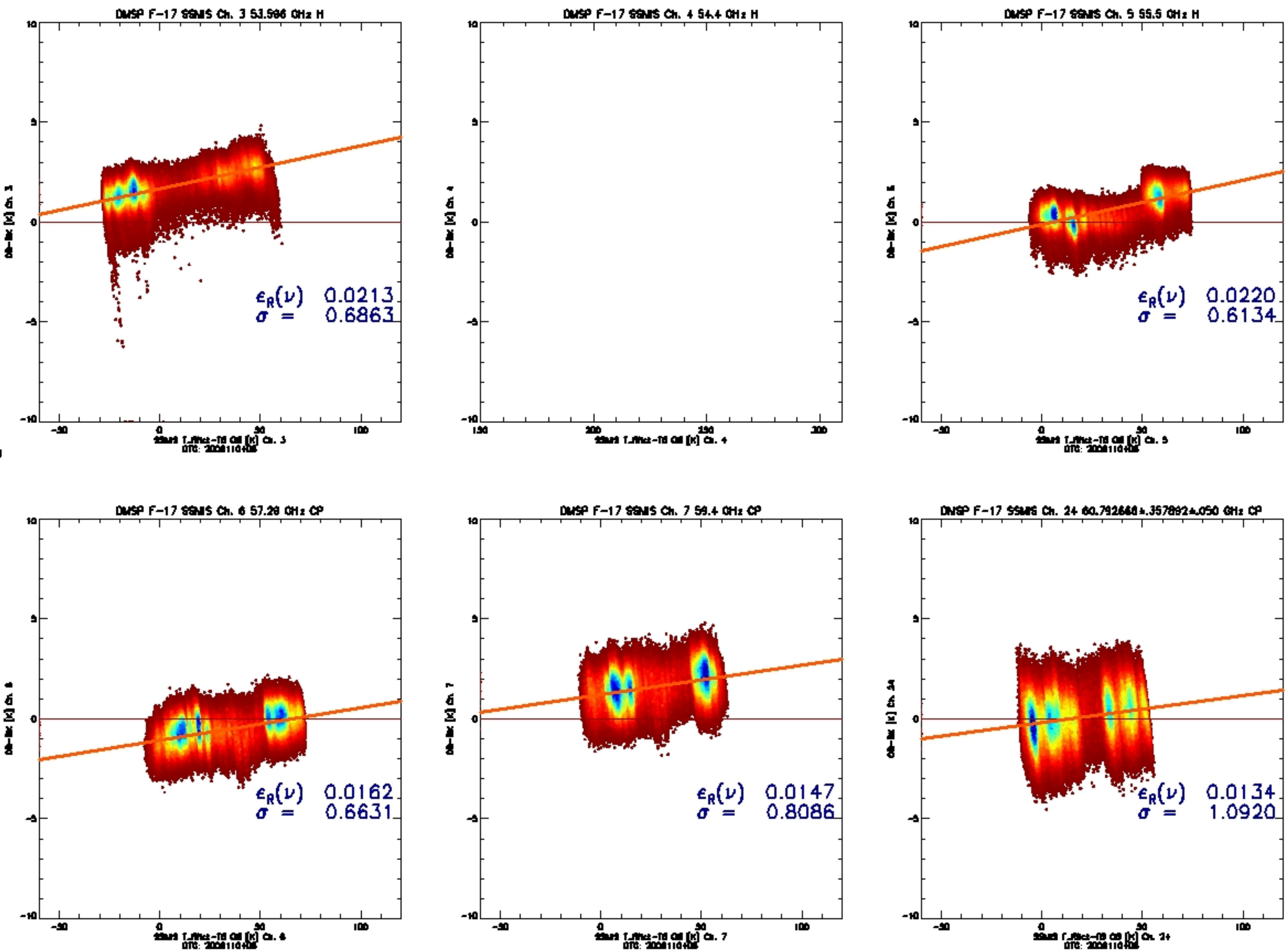
F16 Reflector Emissivity Estimates
LAS Channels 3-7, 24, DTG:2009110406

F16



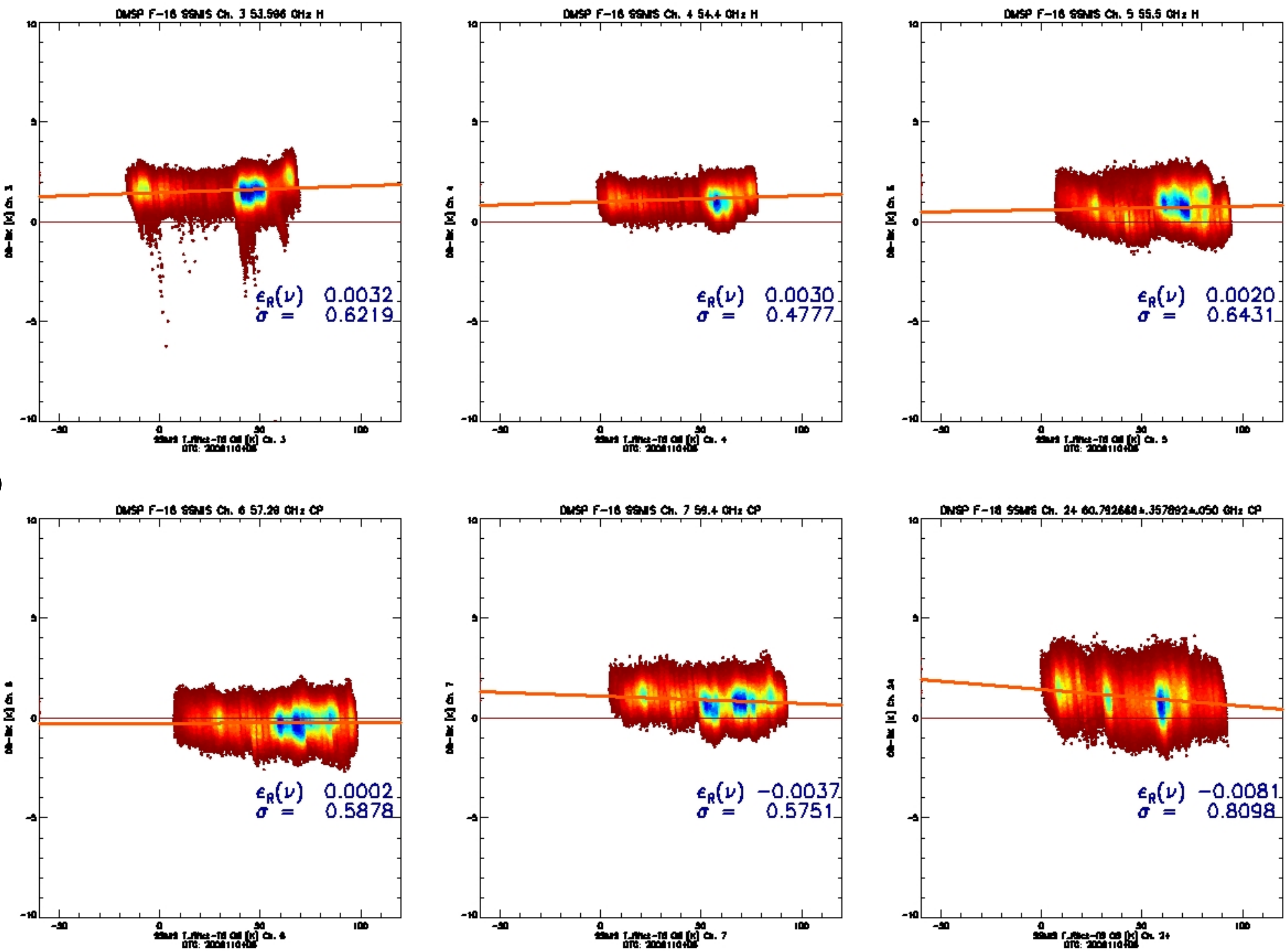
F17 Reflector Emissivity Estimates
LAS Channels 3-7, 24, DTG:2009110406

F17



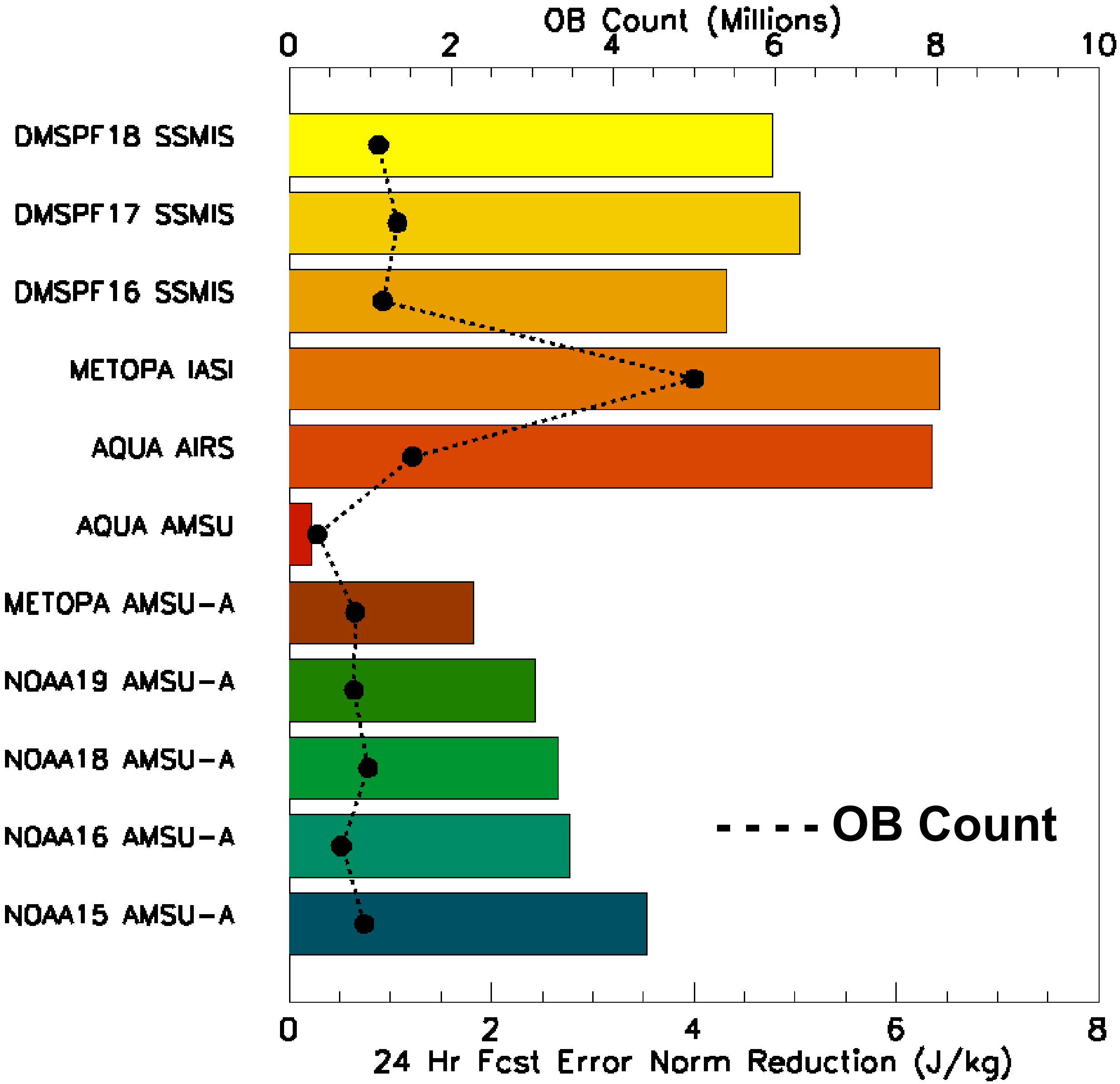
F18 Reflector Emissivity Estimates
LAS Channels 3-7, 24, DTG:2009110406
Verifies Pre-Flight Conductivity Measurements

F18



F18 SSMIS LAS Assimilation Results

Beta OPS 05-12 April 2010

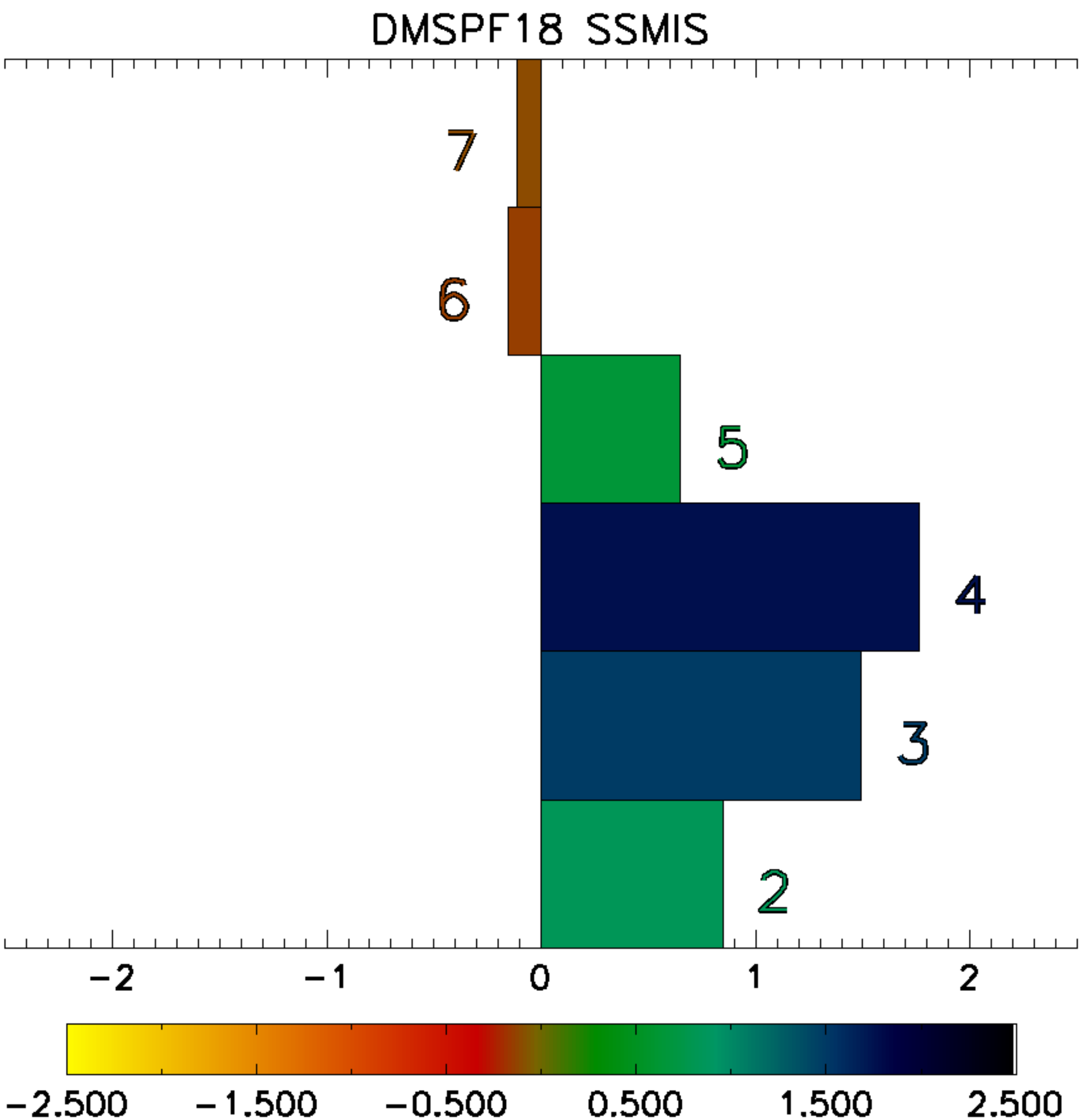


Adjoint Sensitivity Impacts for each Sensor Summed over First 8 days of the Beta OPS NAVDAS-AR Run at FNMOC

F18 UPP Transitioned to FNMOC OPS NAVDAS-AR:

14 April 2010

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

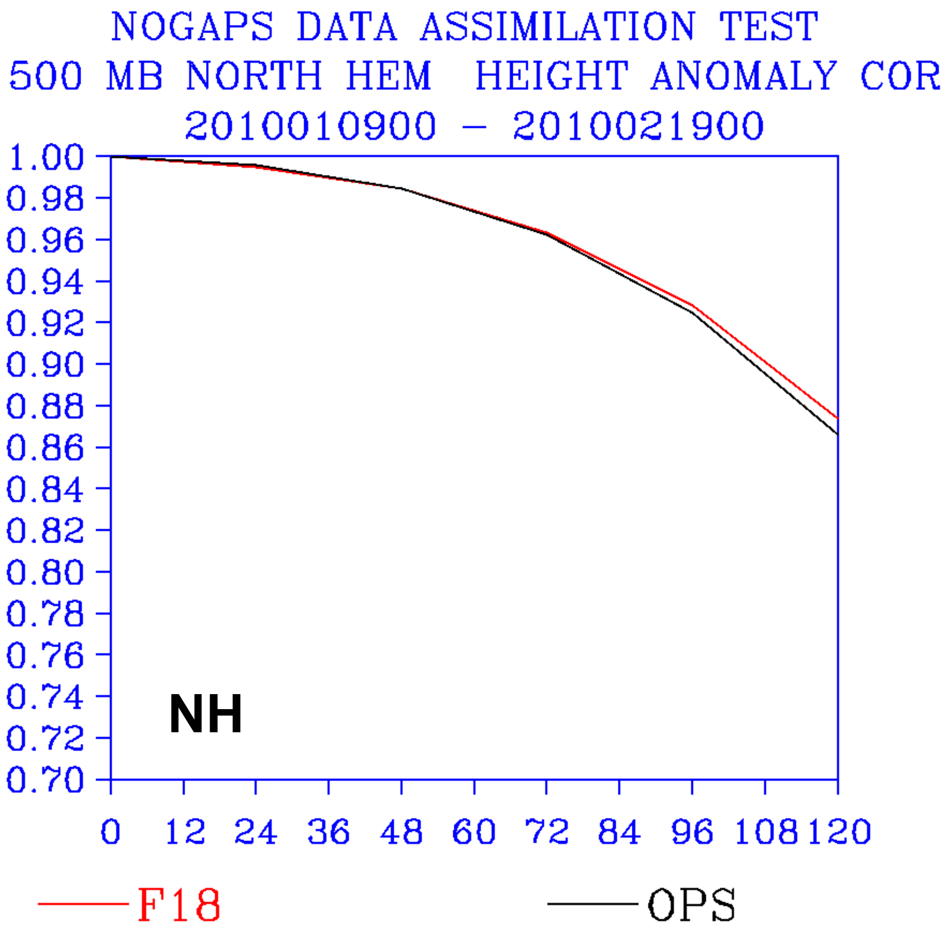


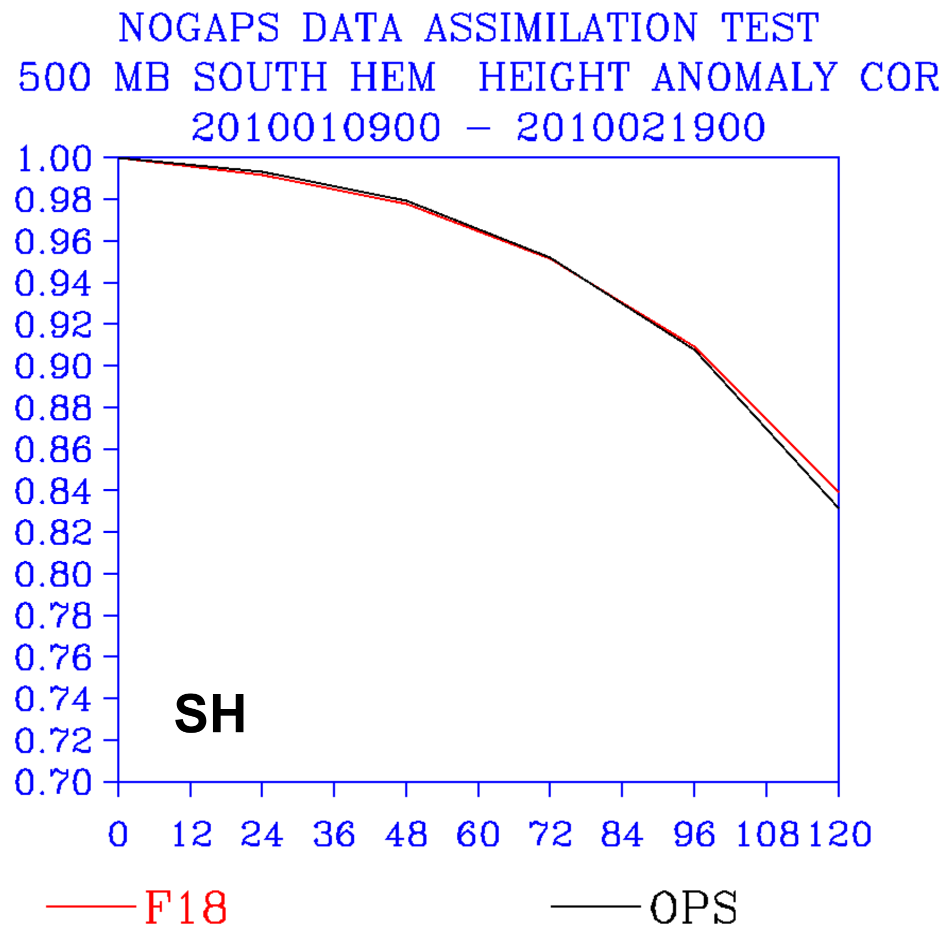
Adjoint Sensitivity Impacts for each F18 Channel assimilated Summed over First 8 days of the Beta OPS NAVDAS-AR Run at FNMOC

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





Path Forward for SSMIS F-19 and F-20

- 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)

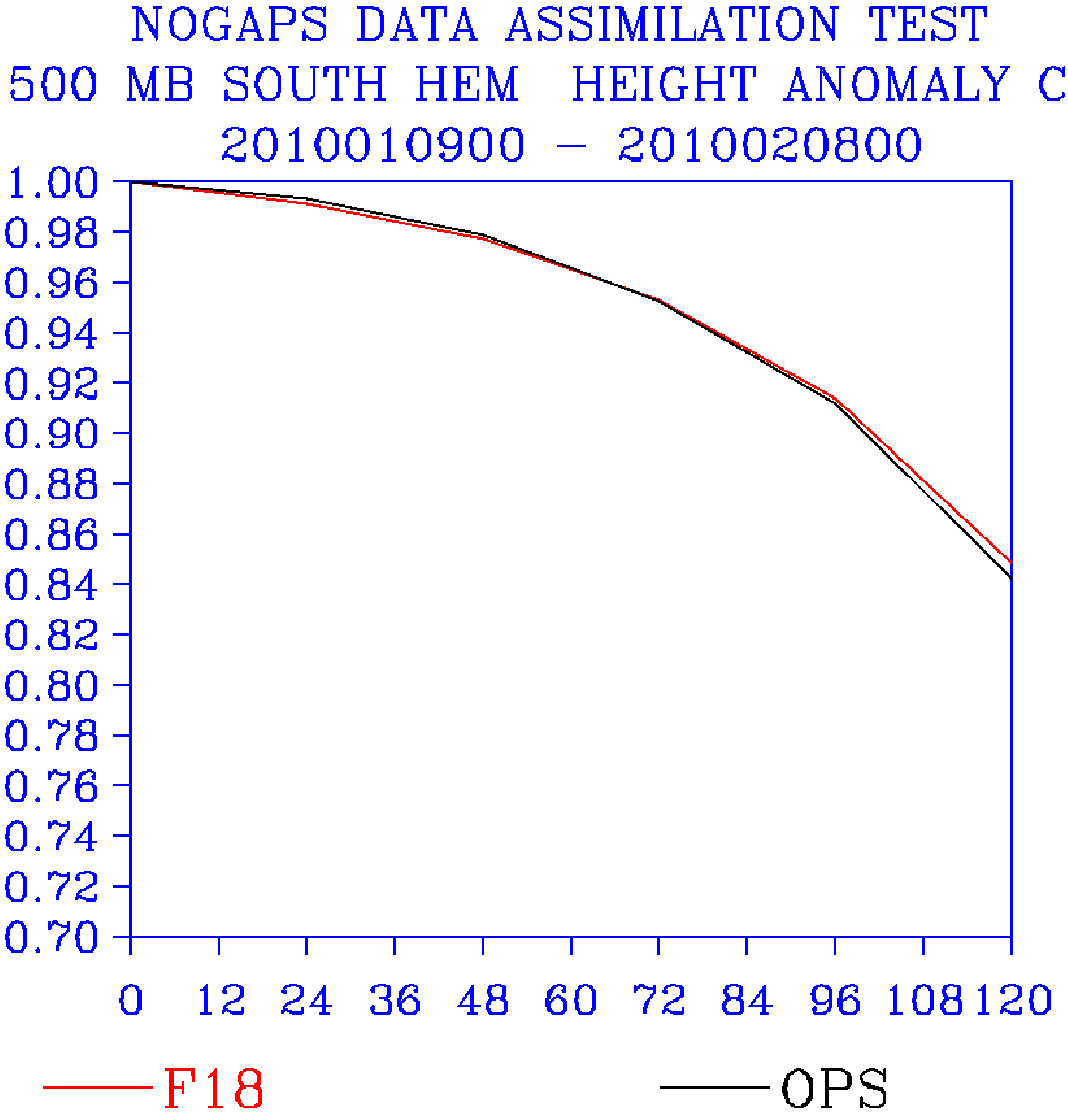
- NWP Forecast Accuracies are very sensitive to key aspects of sensor data records:
  - Number of Channels
  - Vertical Sensitivity Distributions
  - Noise Levels for each channel

- Precise Calibration Remains the Technical Challenge

Thank You

Questions ?

Backup Slides



NOGAPS DATA ASSIMILATION TEST
500 MB SOUTH HEM HEIGHT ANOMALY COR
2010010900 – 2010020800
1.00
0.98
0.96
0.94
0.92
0.90
0.88
0.86
0.84
0.82
0.80
0.78
0.76
0.74
0.72
0.70
0
12
24
36
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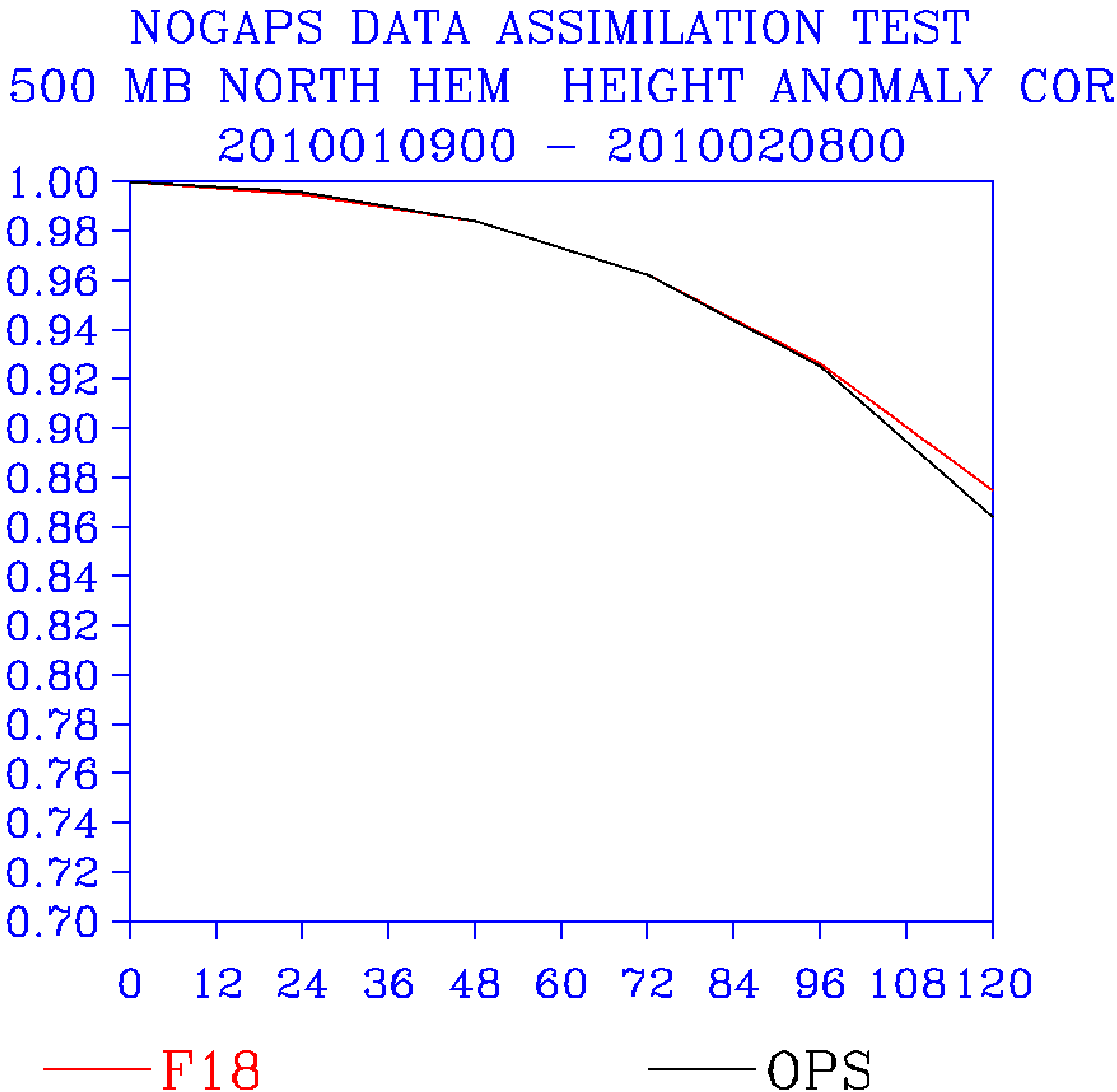
72
84
96
108
120
F18
OPS


NOGAPS DATA ASSIMILATION TEST
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0.94
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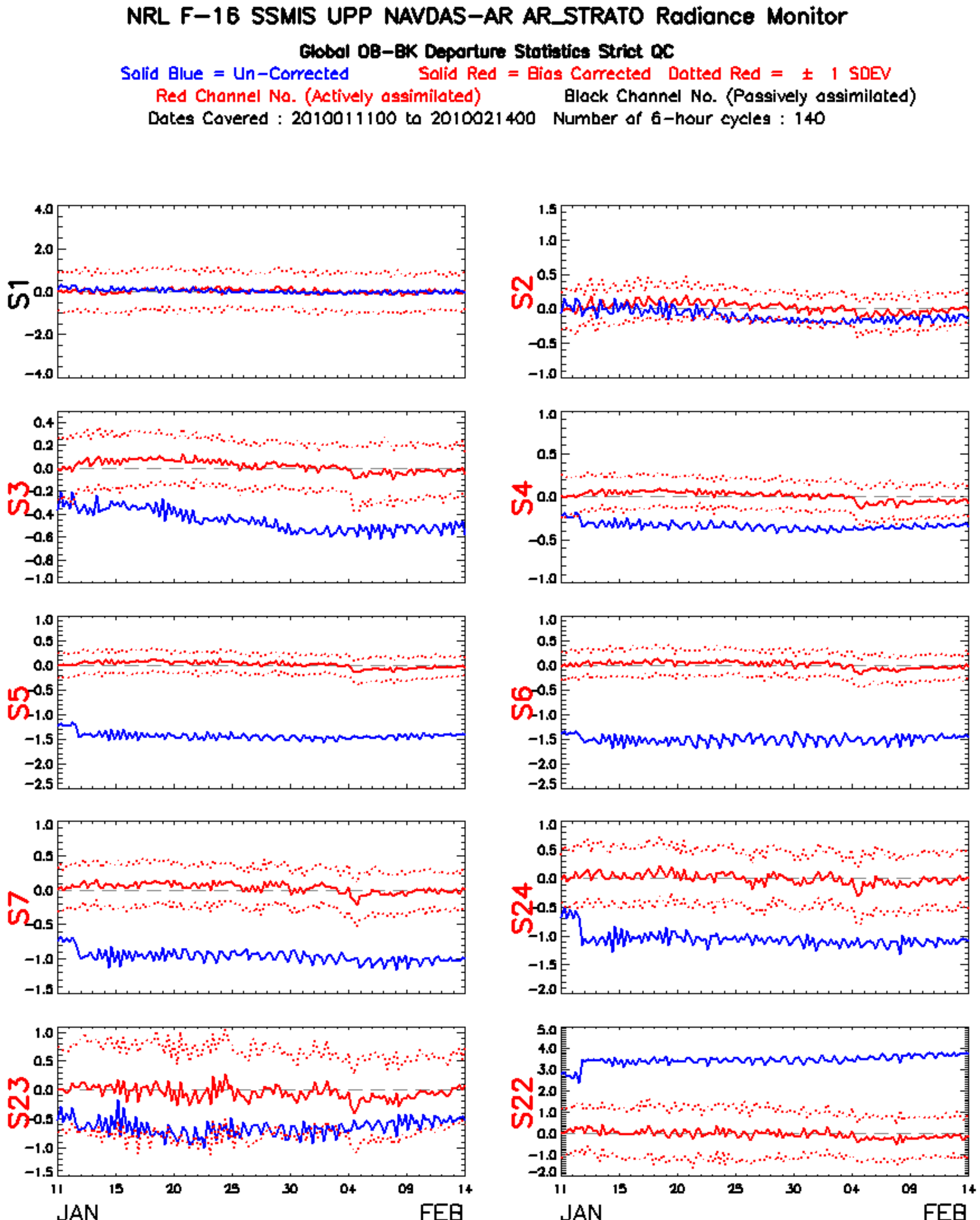
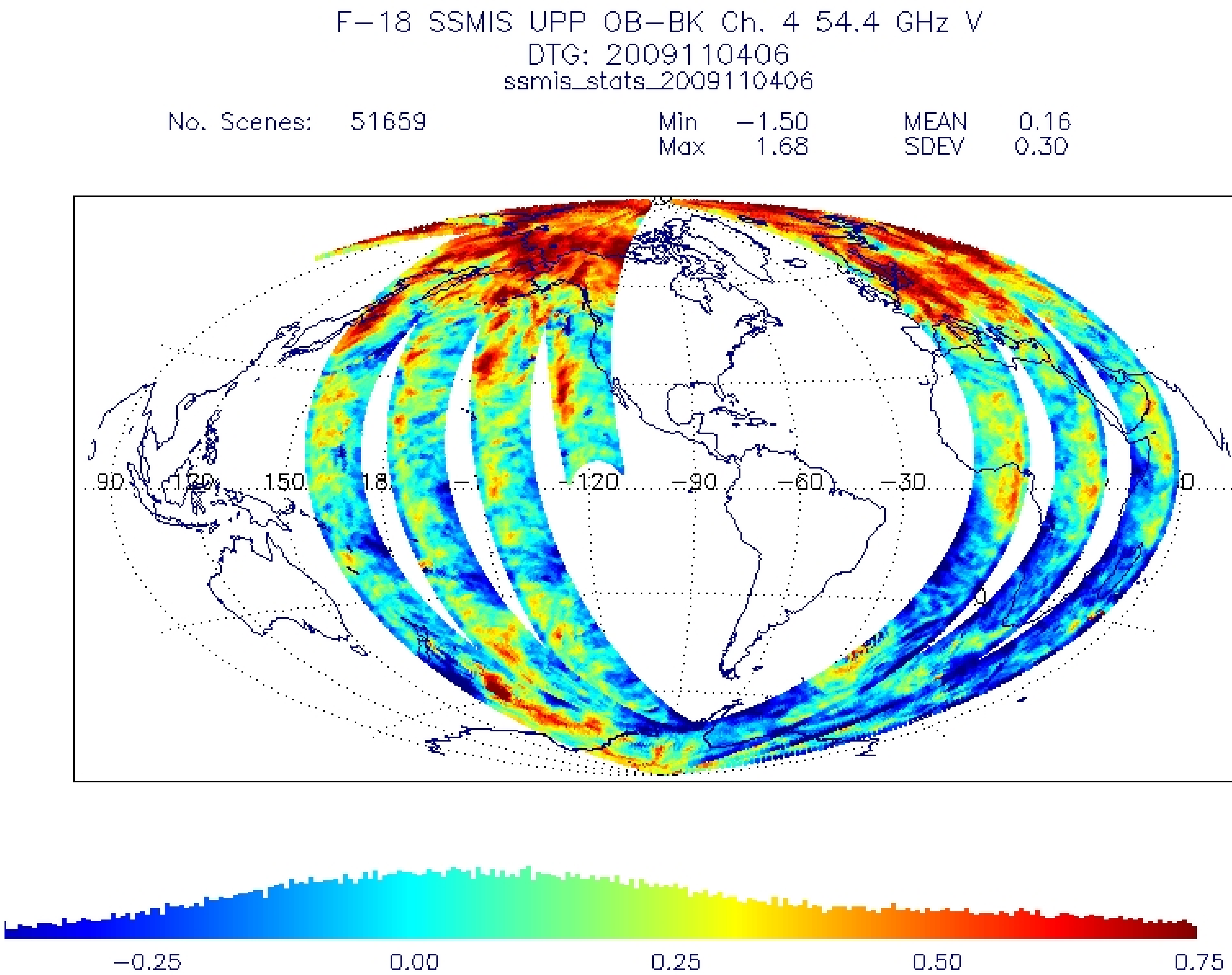
0.90
0.88
0.86
0.84
0.82
0.80
0.78
0.76
0.74
0.72
0.70
0 12 24 36 48 60 72 84 96 108 120
F18
OPS

F-18 SSMIS LAS Assimilation Results



DSMP F-18 SSMIS UPP Update



NCAR WRF Radiance Assimilation Impacts

WRF Observation Impact

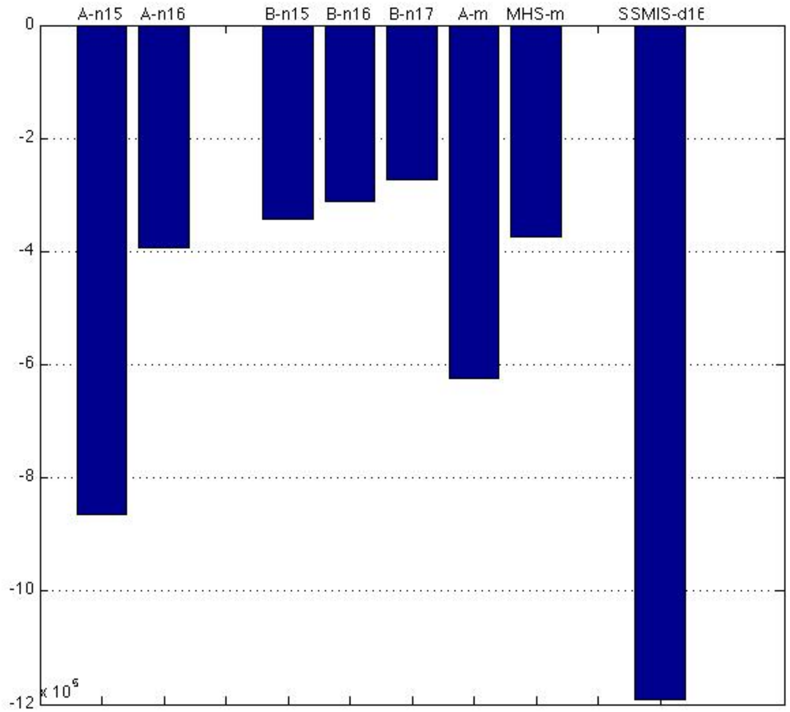
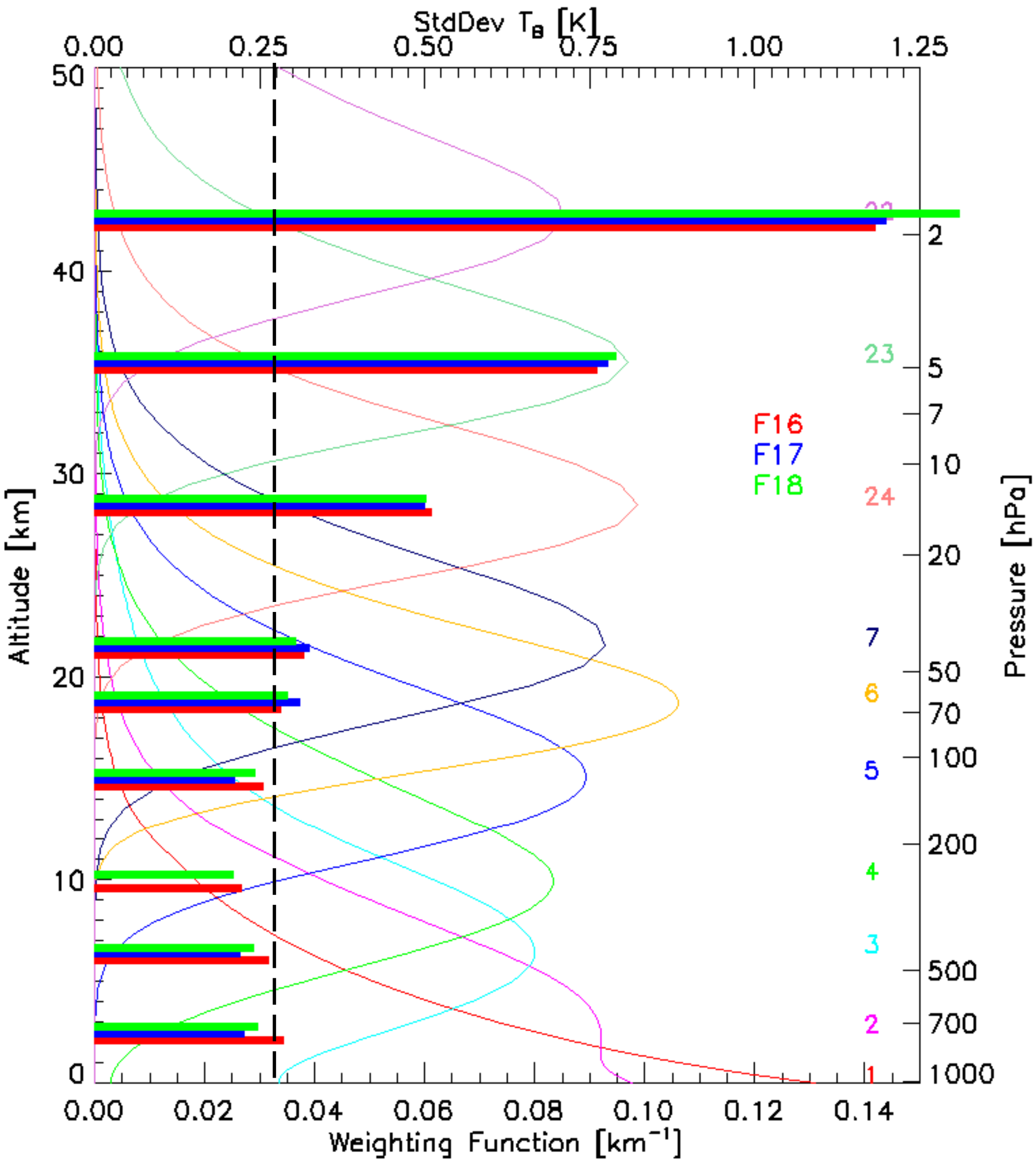


Image Courtesy of Tom Auligné (NCAR)

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)

F-18 SSMIS LAS Assimilation Results



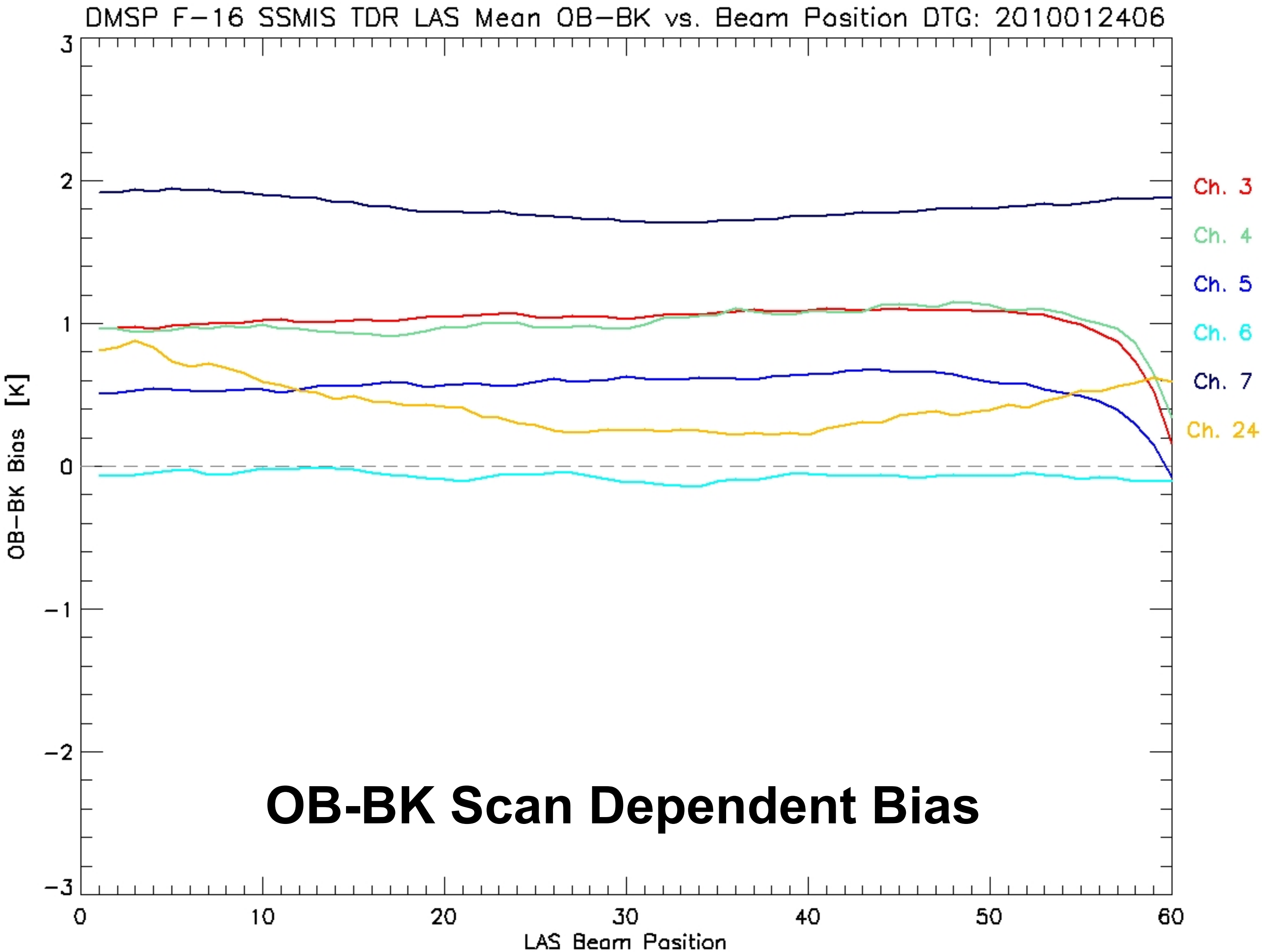
NAVDAS-AR
F-18 Assimilation Trials
SSMIS OB-BK StdDevs

SSMIS

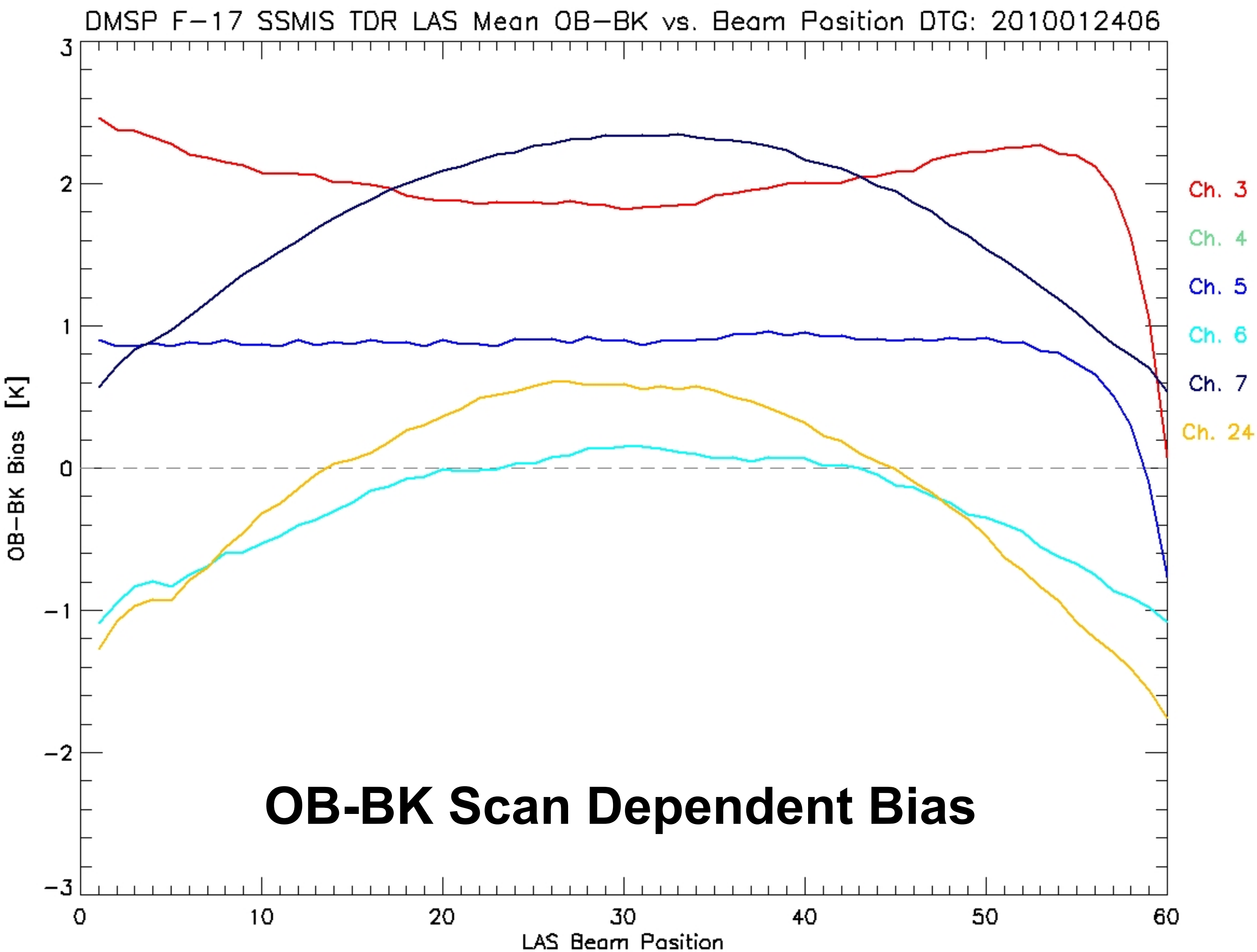
LAS Scan Dependence

OB-BK (ECMWF)

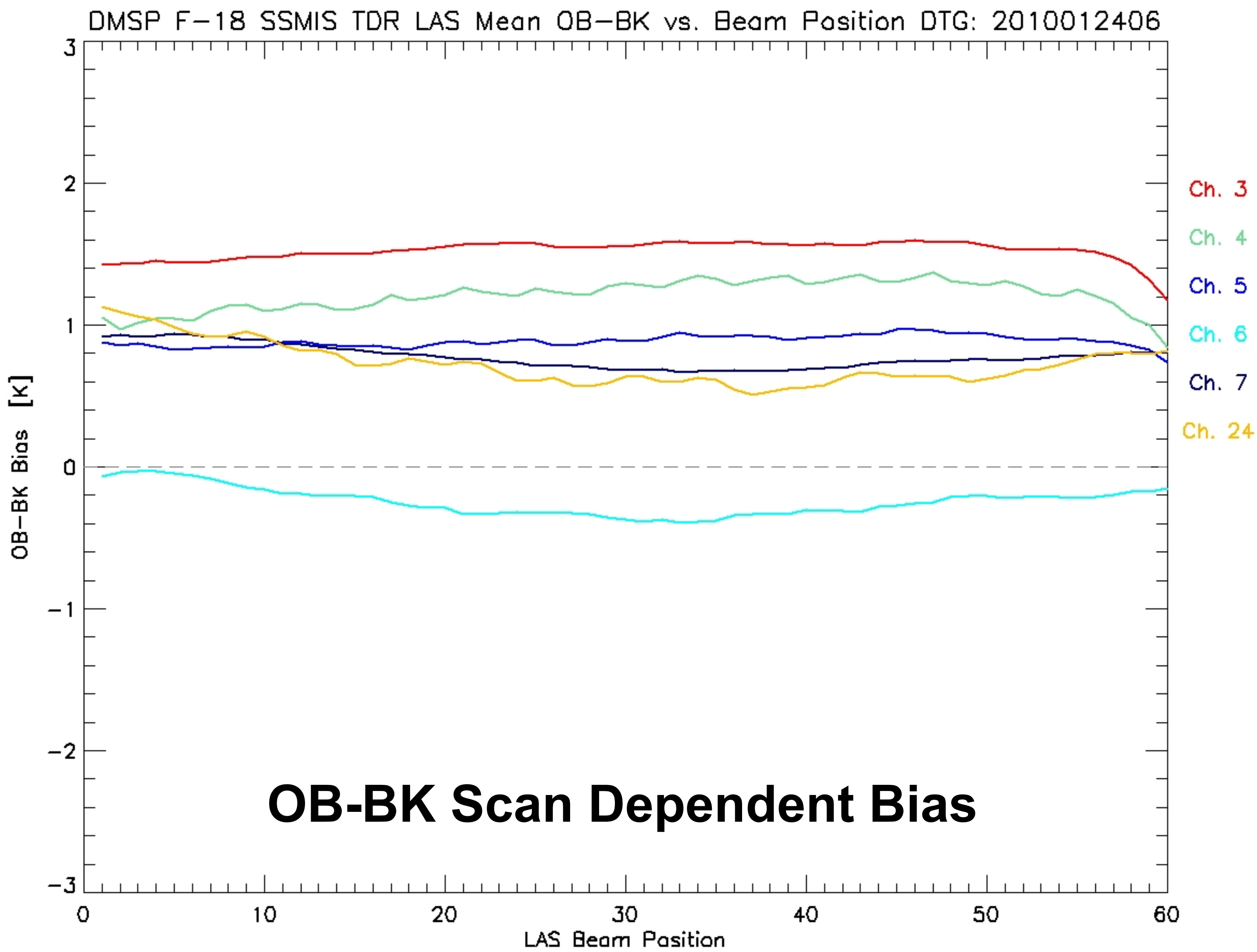
F-16 SSMIS LAS Scan Dependence



F-17 SSMIS LAS Scan Dependence



F-18 SSMIS LAS Scan Dependence



DMSP SSMIS UPP Update

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

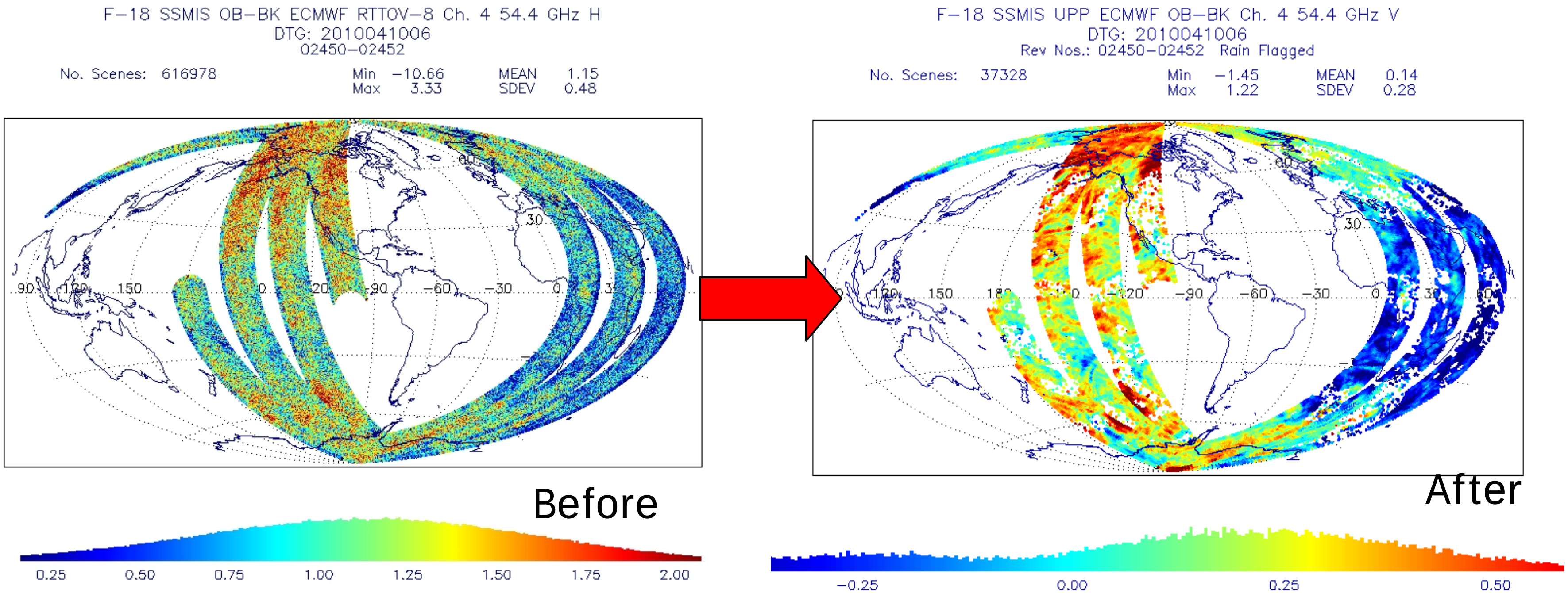
- SSMIS UPP Software Maintained by NRL

- 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

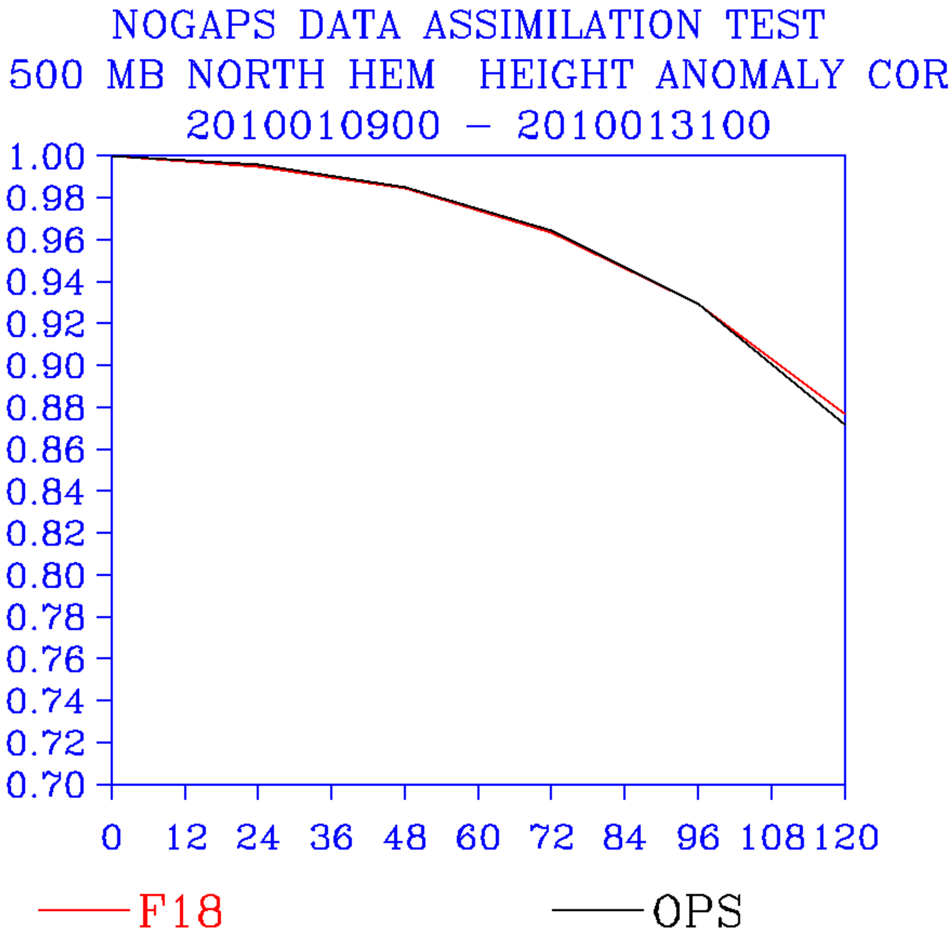
DMSP SSMIS UPP Update

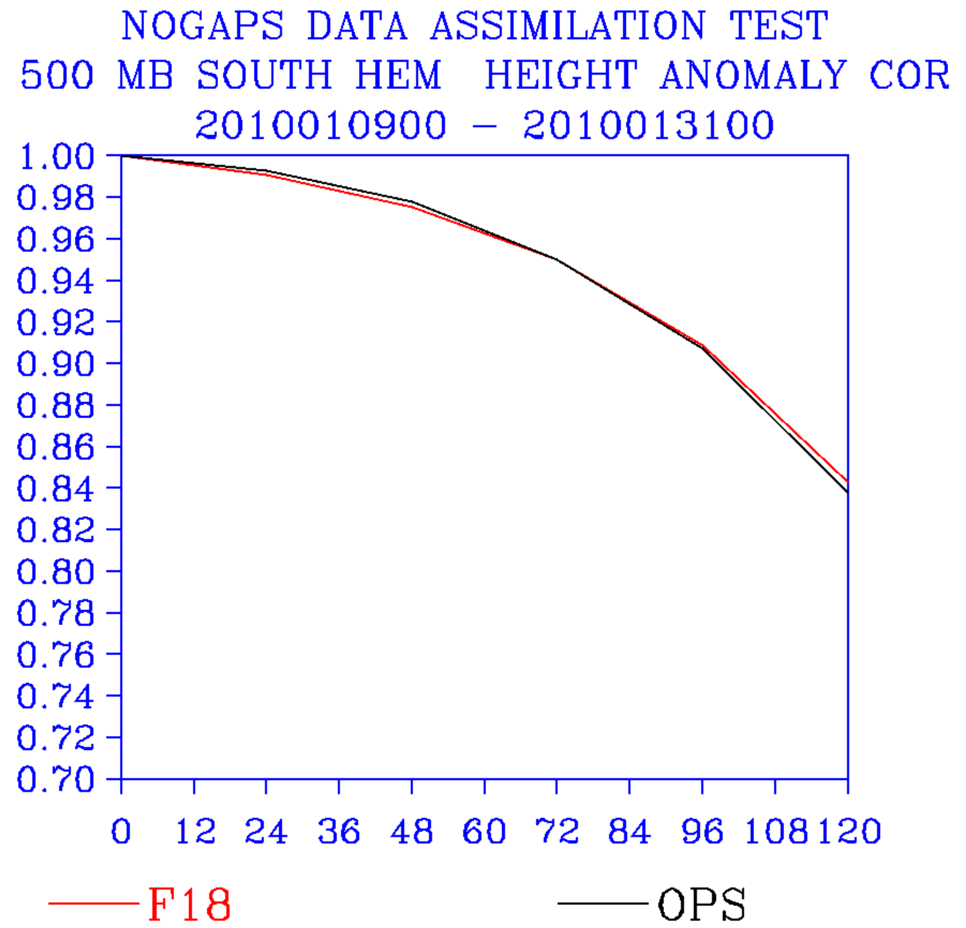


UPP V2 includes

- **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**

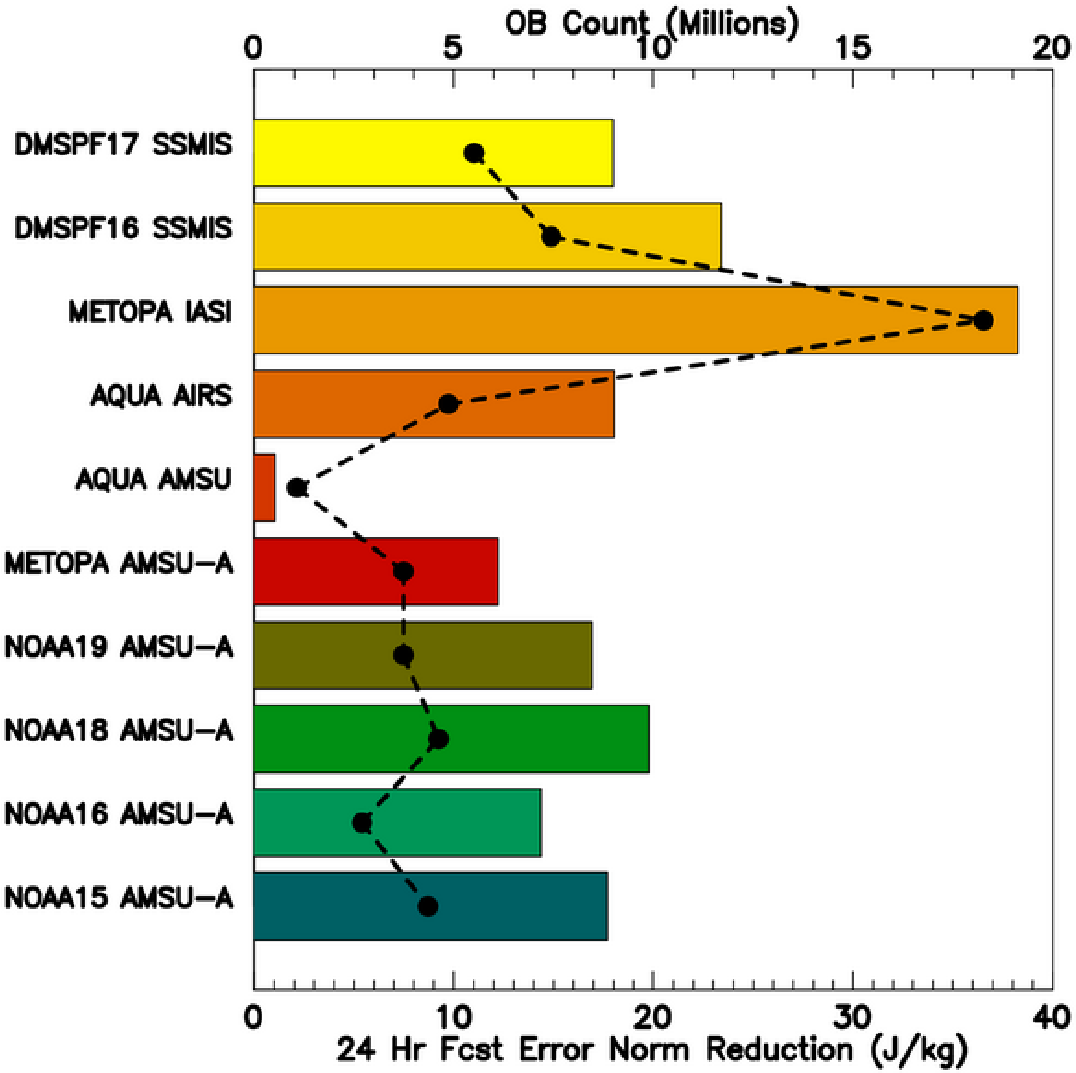
F-18 SSMIS LAS Assimilation Results





NAVDAS-AR Operational Radiance Observation Impacts

Observation Impacts
13 Dec – 13 Jan 2010

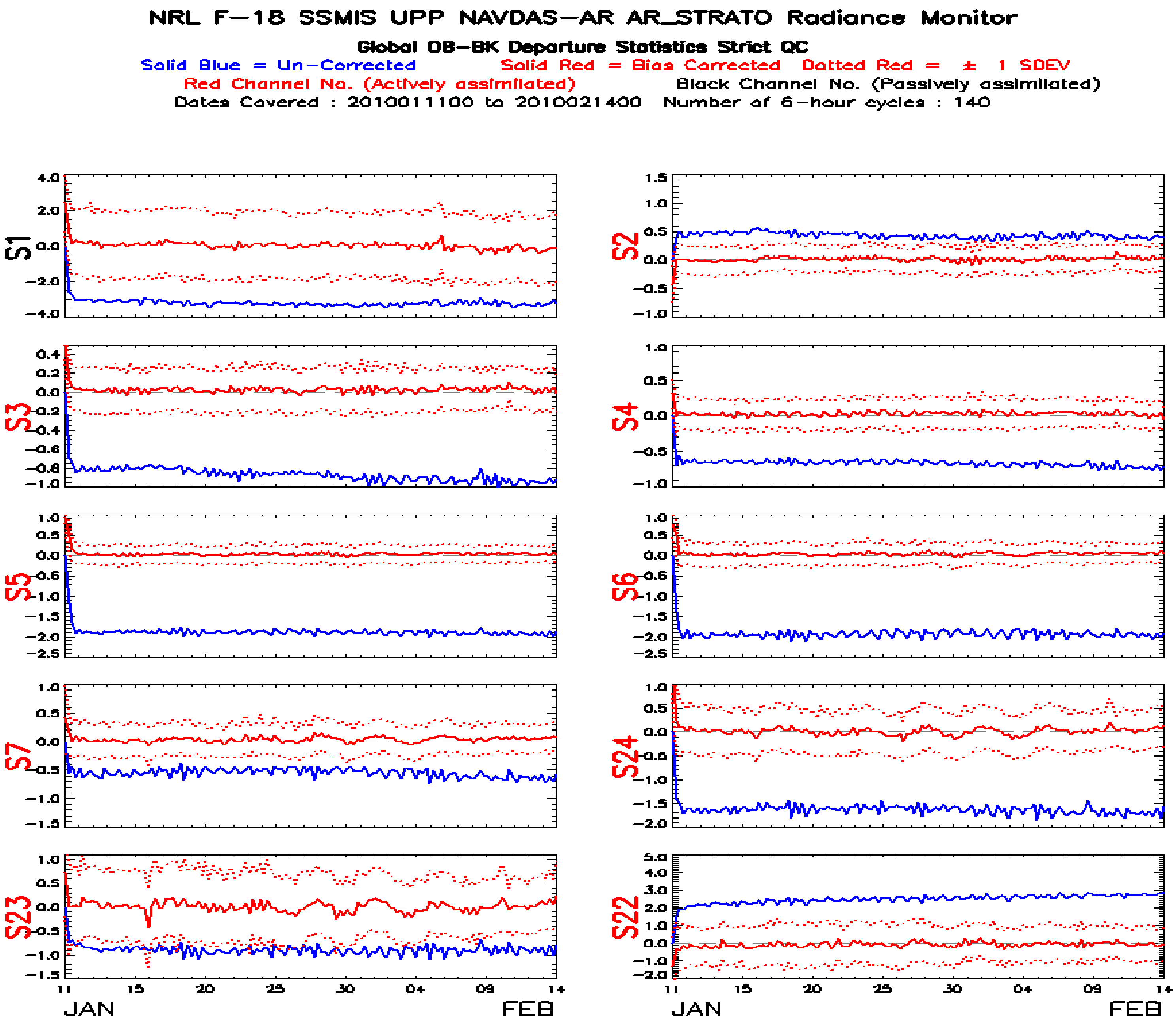


Adjoint Sensitivity Method

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)

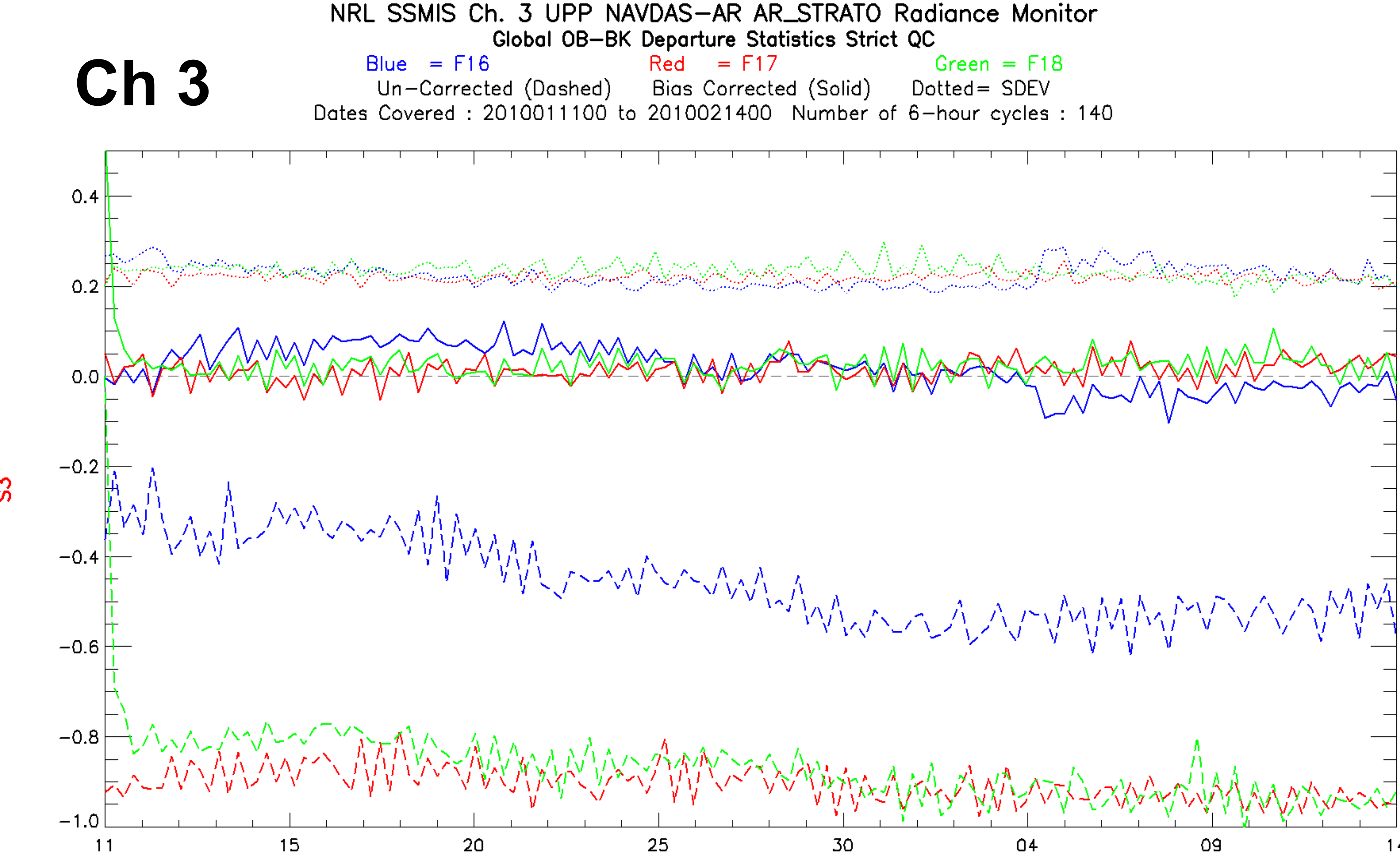
- - - - OB Count

F-18 SSMIS Assimilation Trials



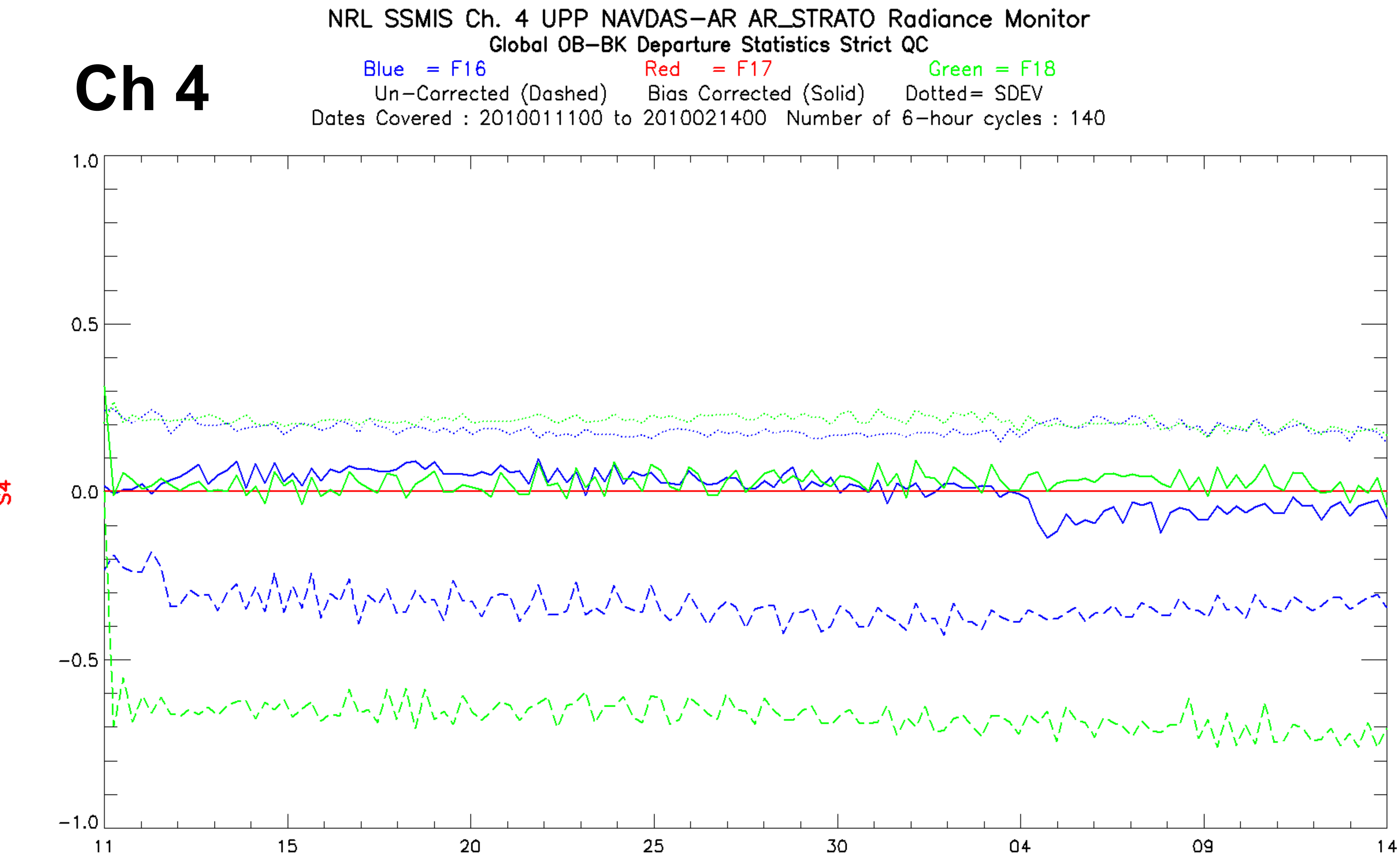
F-18 SSMIS Assimilation Trials

Ch 3



F-18 SSMIS LAS Assimilation Results

Ch 4

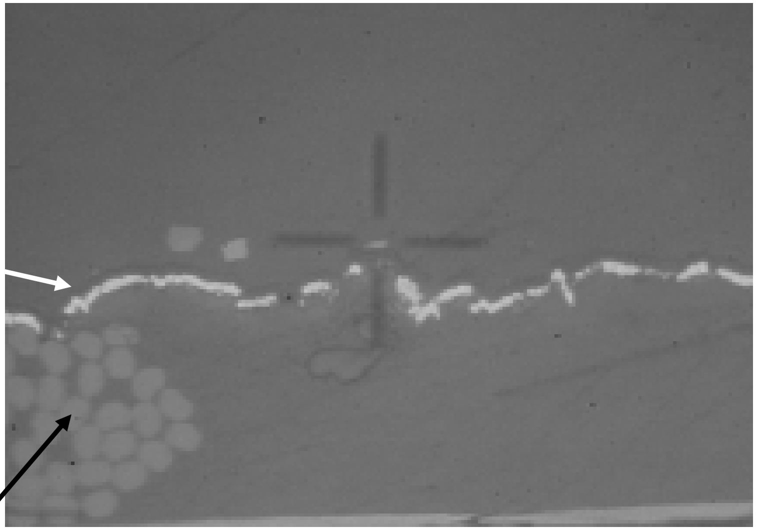


Analysis and Verification of Root Causes

VDA Applied to Aggressively Roughened Surface

VDA* Layer

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

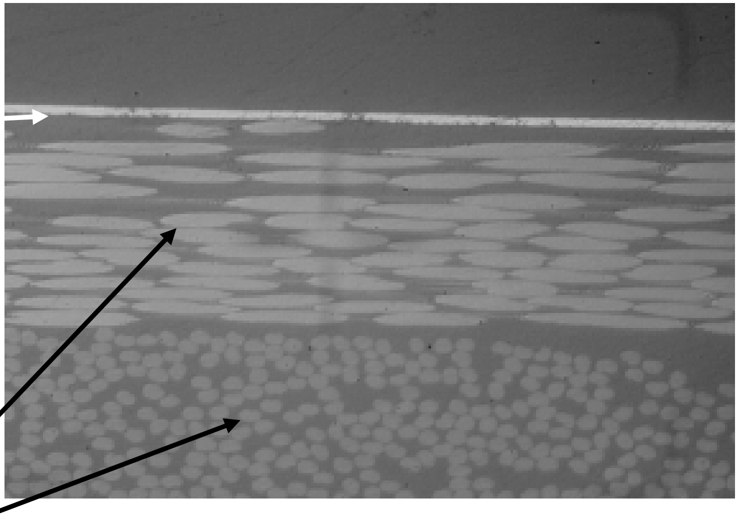


32 GHz σ_E = 3.4 MS/m

55 GHz ε = 0.0027

***VDA: Vapor Deposited Aluminum**

VDA Applied to 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

International TOVS Study Conference, 17th, ITSC-17, Monterey, CA, 14-20 April 2010. Madison, WI, University of Wisconsin-Madison, Space Science and Engineering Center, Cooperative Institute for Meteorological Satellite Studies, 2011.