NRL Satellite Assimilation Activities

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Monterey, CA

JCSDA Summer Colloquium
July 16, 2009

A bit of history

- 40 years ago today, Apollo 11 launched (lunar landing July 20, 1969)
- First satellite Sputnik Oct 4, 1957
- First U.S. Satellite Explorer I, Jan 31, 1958 (provided evidence for the Van Allen radiation belt)
- Naval Research Laboratory-
  - First U.S. Satellite program – Vanguard (1955-1959)
  - NRL Constructed the first complete launch facility at Cape Canaveral in 1957
  - Vanguard I launched March 17, 1958 (temperature sensor; still in orbit)
  - Vanguard II, Feb 17, 1959 (mission to observe cloud cover; still in orbit)
  - Part of U.S. participation in the International Geophysical Year (July 1957- Dec 1958)
  - NASA formed July 29, 1958 – with 200 NRL scientists forming the core

Naval Research Laboratory (NRL)

- ***Monterey – Marine Meteorology Division***
  - **Research and development of global, mesoscale and shipboard atmospheric analysis and prediction systems**
  - **Coupled atmosphere-ocean modeling**
  - **Development of forecaster aids and automated weather interpretation system**
- ***Washington, D.C. – Remote Sensing and Space Sciences Divisions***
  - **Design and build satellites (POAM II/III, WindSat, MIS)**
  - **Stratospheric and mesospheric assimilation (GPS, ozone, MLS, SABER assimilation)**
  - **NOGAPS – ALPHA (Advanced Level Physics High Altitude)**
- ***Stennis Space Center, MS – Ocean Division***
  - **Ocean data assimilation and modeling**

Customers

- **Fleet Numerical Meteorology and Oceanography Command (FNMOC)**
  - Provides weather support for Navy and Marine Corps, Air Force and other DoD activities
  - Produces and distributes products from numerical prediction models of the ocean and atmosphere
  - Ocean modeling
- Other Customers
  - Navy and Marine Corps, Air Force and other DoD activities
  - Civilian - US Coast Guard search and rescue planners

NRL/FNMOC Forecast Suite

- NOGAPS - Navy Operational Global Atmospheric Prediction System
  - Spectral T239L42 with effective model top at 0.04 hPa
  - Provides input/boundary conditions for
    - mesoscale, ocean, wave and ice prediction models,
    - ensemble forecasting system (T119L30)
    - aircraft and ship routing programs
    - tropical cyclone forecast model (GFDN)
  - Used for basic research predictability studies, adjoint sensitivity studies, adaptive observation-targeting

- COAMPS®* - Coupled Ocean/ Atmosphere Mesoscale Prediction System
  - Nonhydrostatic; globally relocatable, nested grids; explicit prediction of moisture variables
  - Many different operational areas

NRL/FNMOC Analysis Systems

NAVDAS – NRL Atmospheric Variational Data Assimilation System

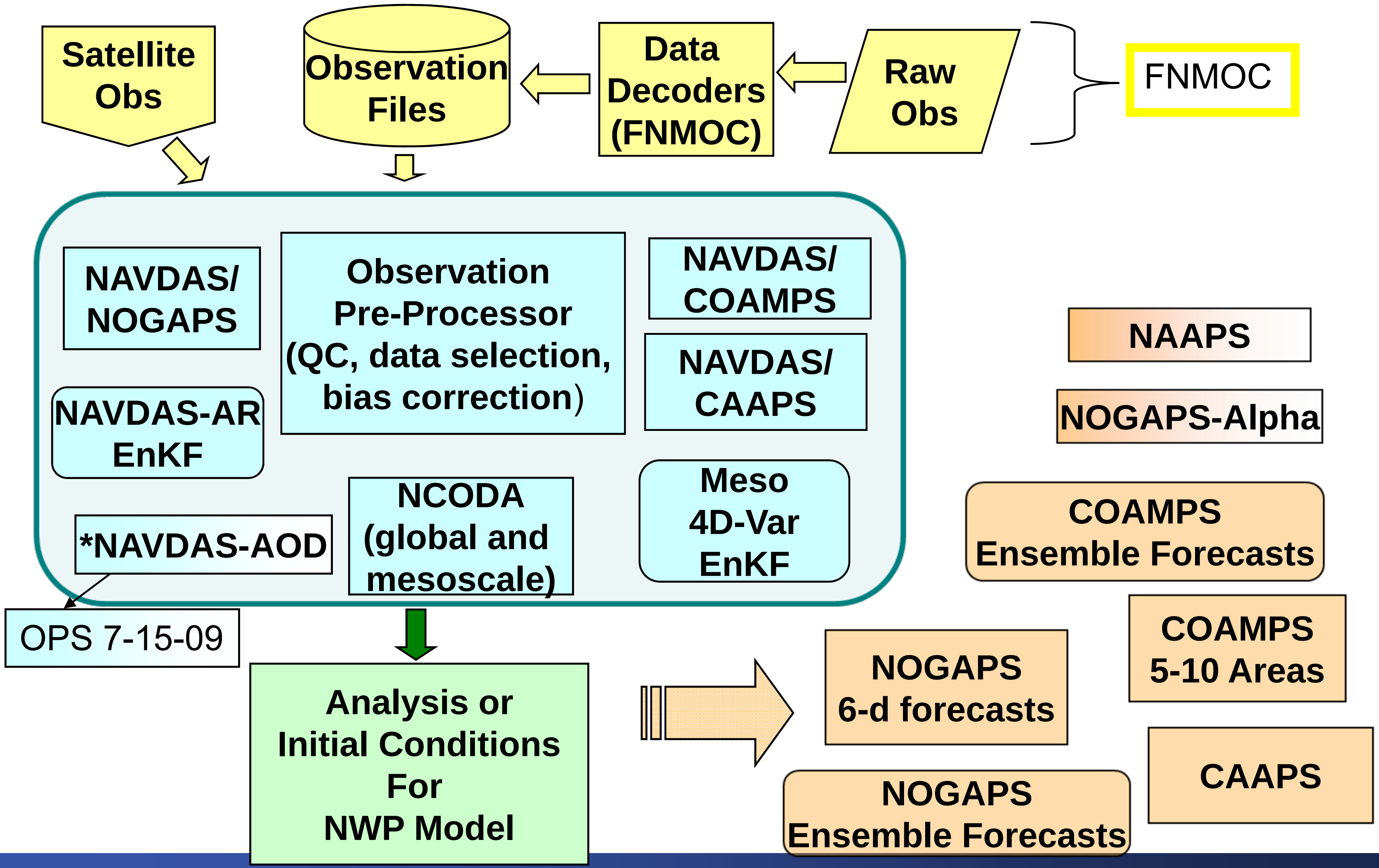
– 3DVAR observation space algorithm
– Unified code for both global and mesoscale NWP systems
  - *Operational for NOGAPS on October 1, 2003*
  - *Operational for COAMPS® December, 2006*
  - *Operational for COAMPS-OS® (CAAPS) October 15, 2008*
– Designed to be precursor for our 4D-Var system, NAVDAS-AR, an accelerated representer assimilation system
– Groundbreaking development of the adjoint of NAVDAS is used for cost effective observation impact studies

NRL/FNMOC Analysis Systems

NAVDAS-AR – NRL Atmospheric Variational Data Assimilation System-Accelerated Representer

- Full 4D-VAR algorithm solved in observation space using representer approach
- Weak constraint formulation allows inclusion of model error
- T239L42, model top at 0.04 hPa
- More effective use of asynoptic and single-level data
- More computationally efficient than NAVDAS for large # of obs
- Adjoint developed for observation impact with real-time web monitoring capability
- Targeted for operational implementation August 2009
  - *Currently in pre-operational testing for NOGAPS at FNMOC*

DA R&D and Operational Suite



NAVDAS-AR

- **Satellite Assimilation Upgrades**
  - ❖ METOP IASI/AMSU hyperspectral IR/MW sounders
  - ❖ AQUA AIRS/AMSU hyperspectral IR/MW sounders
  - ❖ DMSP F16 and F17 SSMIS microwave imager/sounder
  - METOP ASCAT scatterometer
  - GOES Rapid Scan Atmospheric Motion Vectors
  - WindSat ocean surface wind vectors and total precipitable water
  - NOAA-19 AMSU-A, AVHRR polar winds

- **Satellite Assimilation: Sensors to be added**
  - COSMIC GPS-RO
  - SBU/V and MLS ozone assimilation
  - AMSU-B/MHS

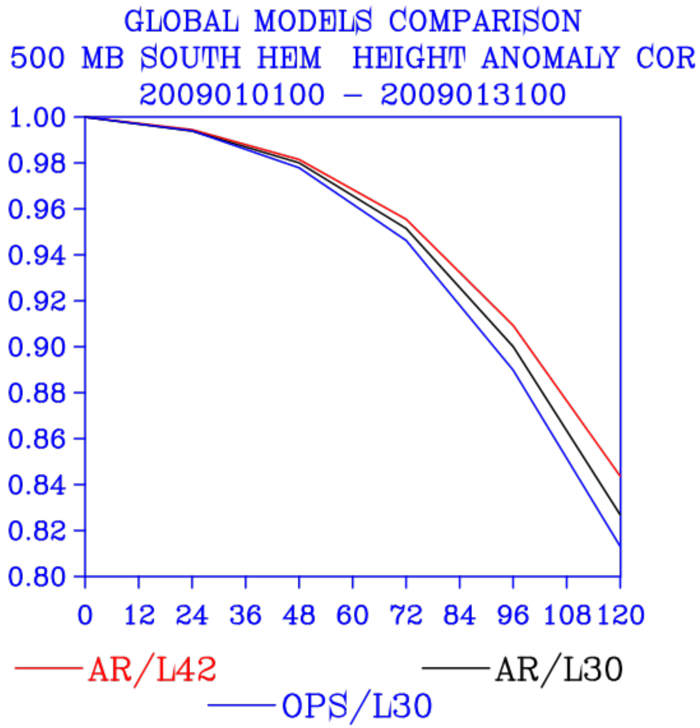
❖ Satellite Assimilation added to NAVDAS-AR only

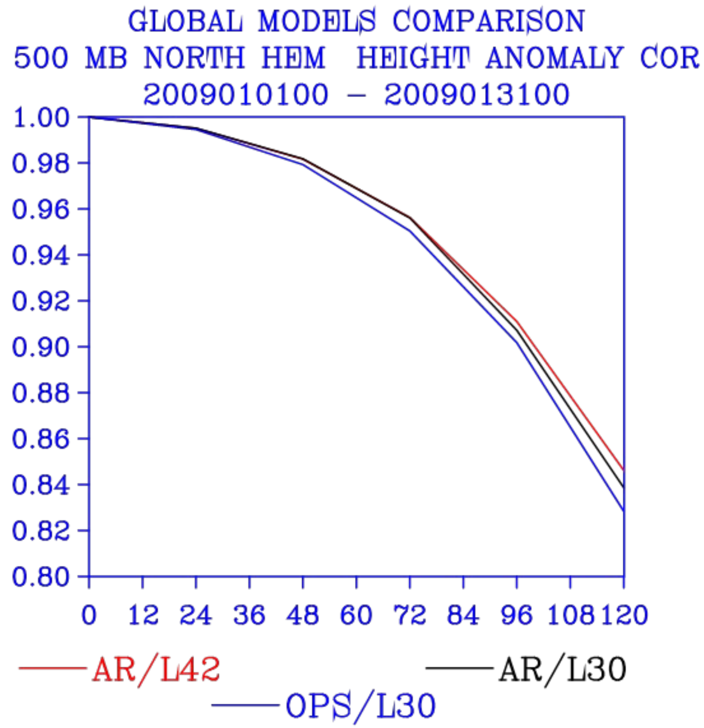
NAVDAS-AR

- **System Timing**
  - NAVDAS, 550K obs, 20 minutes for 60 processors
  - NAVDAS-AR, 800K obs, 35 minutes for 60 processors (< 30 minutes using 90 processors)

- **Enhancement of current capabilities**
  - Variational Bias Correction
  - Weak-constraint formulation
  - Second outer loop
  - Estimation of observation and background error variances (Desroziers et al.)
  - Update observation and background error covariances

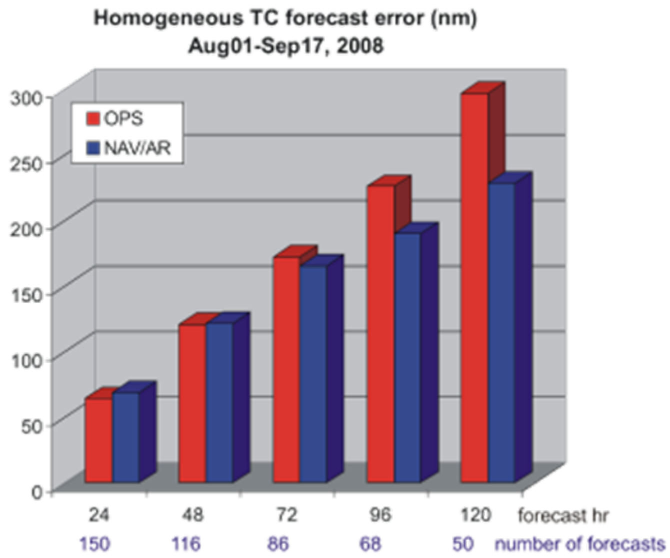
NAVDAS-AR
500 mb Height Anomaly Correlation

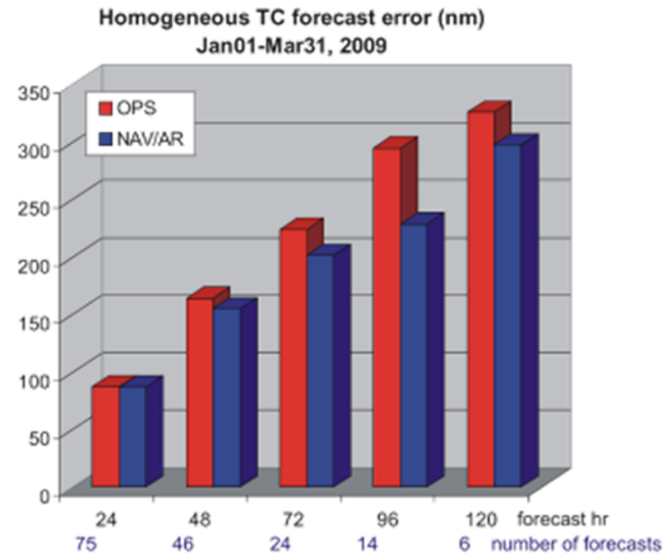




Comparison of NAVDAS (OPS/L30), NAVDAS-AR with 30 vertical levels (AR/L30) and NAVDAS-AR with 42 vertical levels and model top of 0.04 hPa

NAVDAS-AR
Tropical Cyclone Track Verification





Consistently better hurricane forecast tracks; additional testing underway

Assessing the Value of Observations

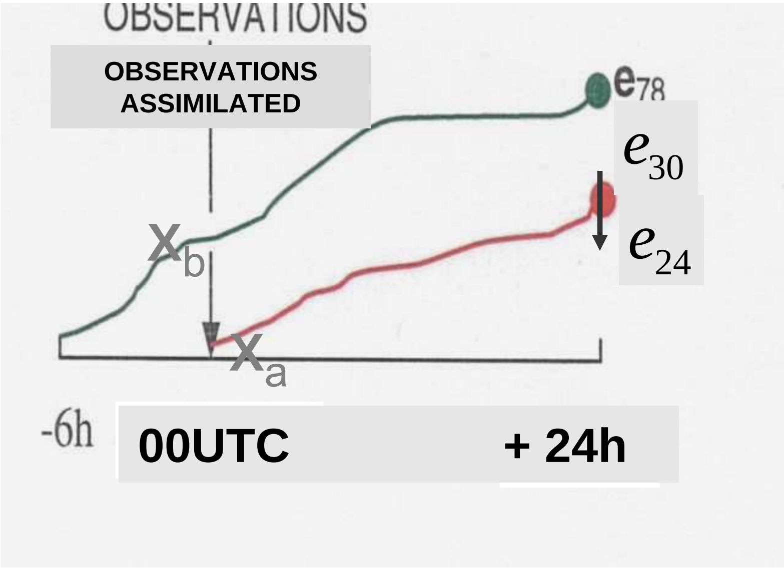
Adjoint Techniques

Observation Impact Methodology

- New mathematical technique using NAVDAS and NOGAPS adjoint models (outgrowth of PhD research at NPS by Langland (1996) and Baker (2000))
- Observation impact products generated daily at 00 & 12 UTC
- Uses operational analysis fields and operational innovation vectors from NAVDAS / NOGAPS (NAVDAS-AR/NOGAPS)
- Results are used to
  - evaluate observation quality
  - tune observation reject lists
  - modify assimilation procedures
  - select satellite channels for assimilation

Baker and Daley (QJRMS, 2000)
Langland and Baker (Tellus, 2004)

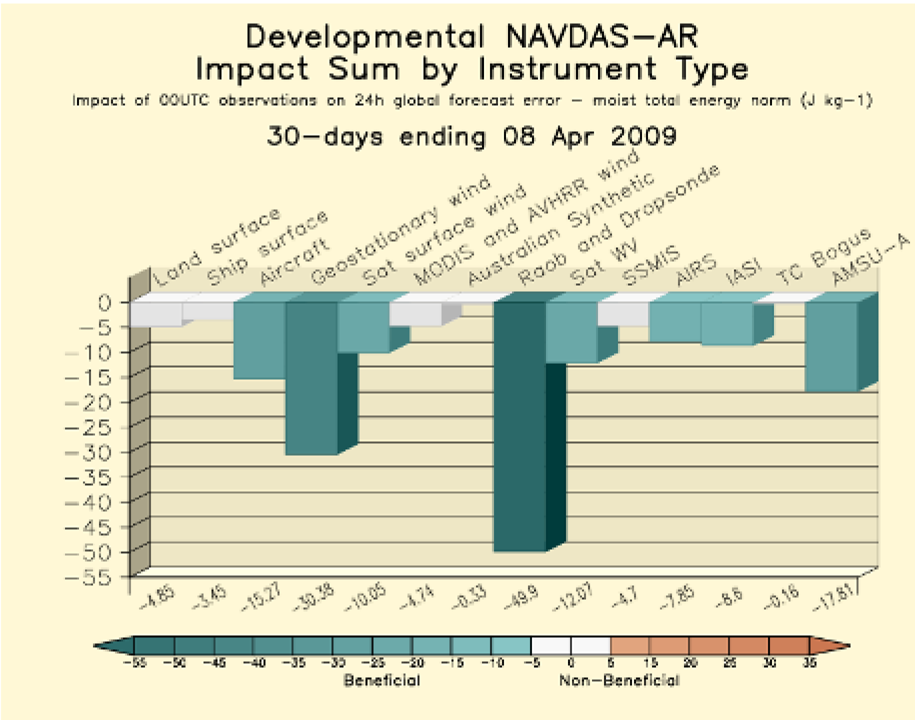
Observations, model trajectories & forecast error

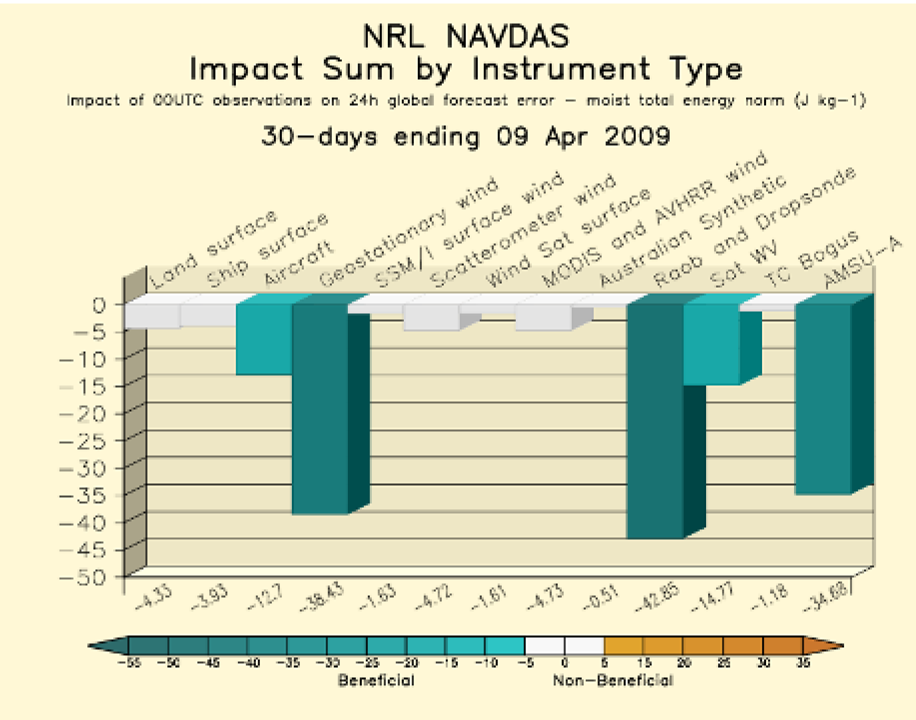


Observations move the model state from the "background" trajectory to the new "analysis" trajectory

The forecast error difference, $e_{24} - e_{30}$, is due to the combined impact of all observations assimilated at 00UTC

NAVDAS-AR & NAVDAS Observation Impact





NAVDAS-AR

NAVDAS

New satellites: SSMIS, AIRS, IASI

The Role of Data Assimilation and NWP in Sensor Calibration and Validation

Steve Swadley, Nancy Baker, Gene Poe and Ben Ruston
NRL Monterey

William Bell
The Met Office/ECMWF

Importance of NWP in Satellite Cal/Val

- The Importance of the Sensor Cal/Val Process

- The Role of NWP, Data Assimilation and Radiance Monitoring in the Cal/Val Process

- Routine Radiance Monitoring Tools

- SSMIS Cal/Val Experience
  - Uncovering the Calibration Anomalies
  - Analysis and Verification of Root Causes

- Radiance Pre-processing tailored for NWP Data Assimilation

- Path Forward for Future Sensor Systems

Importance of the Sensor Cal/Val Process

Purpose: To verify the end-to-end instrument radiometric performance including long- and short-term stability, NEDT (NEDN), and the absolute calibration accuracy

- Validation of the Sensor Data Records (SDR)
  - Early Orbit evaluation
  - Initial Assessments
  - System Calibration
  - Anomaly Detection

- Validation of the Environmental Data Records (EDR)
  - Detection of systematic biases
  - Error Characterization
  - Algorithm Improvements

Radiance Assimilation Monitoring Tools

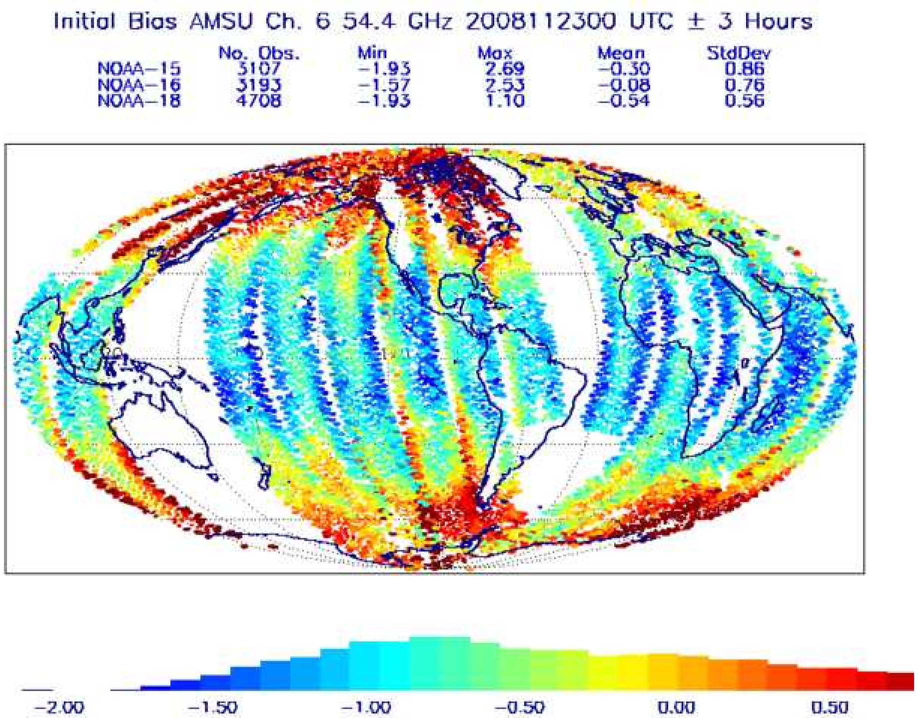
Graphical tools to monitor departures between the observed (OB) radiance (or Tb), and the background (BK) computed radiances using forward model

- For Cal/Val Purposes, examine initial OB-BK, without bias corrections applied
- For Radiance Assimilation, a channel dependent bias correction procedure is applied offline, or within minimization step (VarBC)

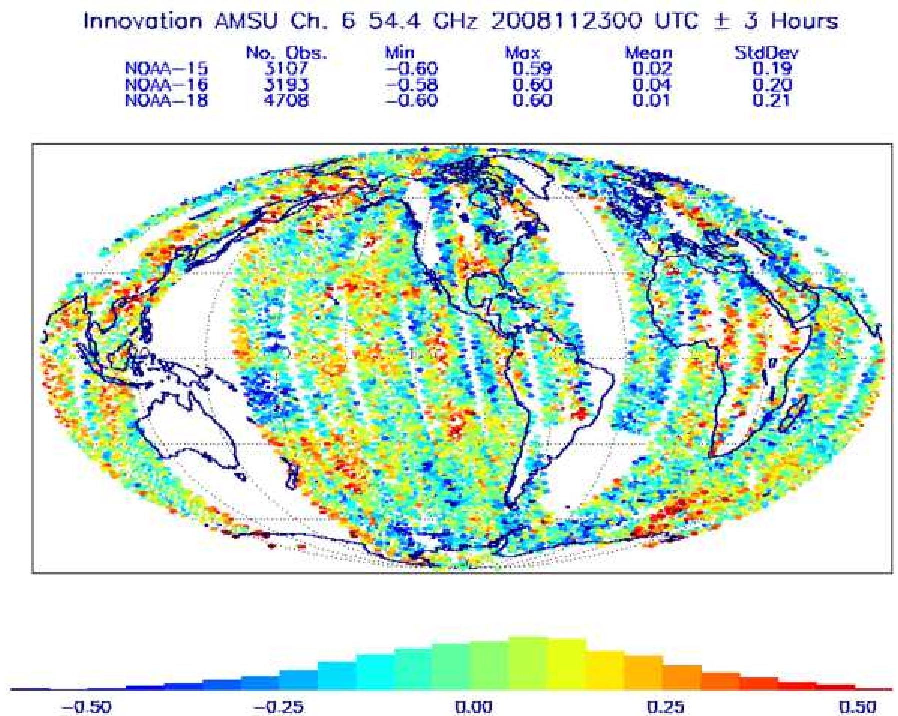
- **Examples include**
  - Departure coverage plots
  - “Radgrams” (departure time series)
  - Scan bias plots
  - Scan-averaged departure time series (conical systems)
  - Hovmoeller time series, “DNA” plots
  - Observation impact using adjoint techniques

Radiance Assimilation Monitoring Tools

Departure Coverage Diagrams



Un-Corrected Departures

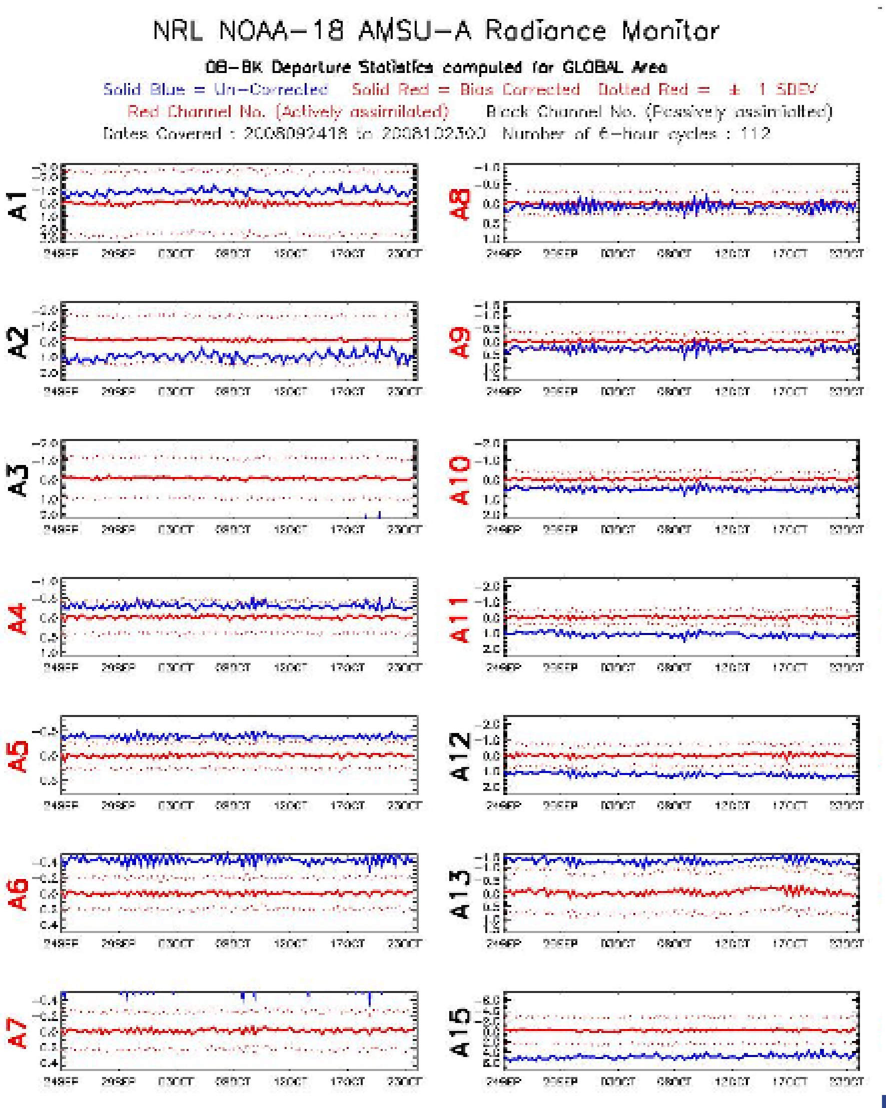


Bias Corrected Departures

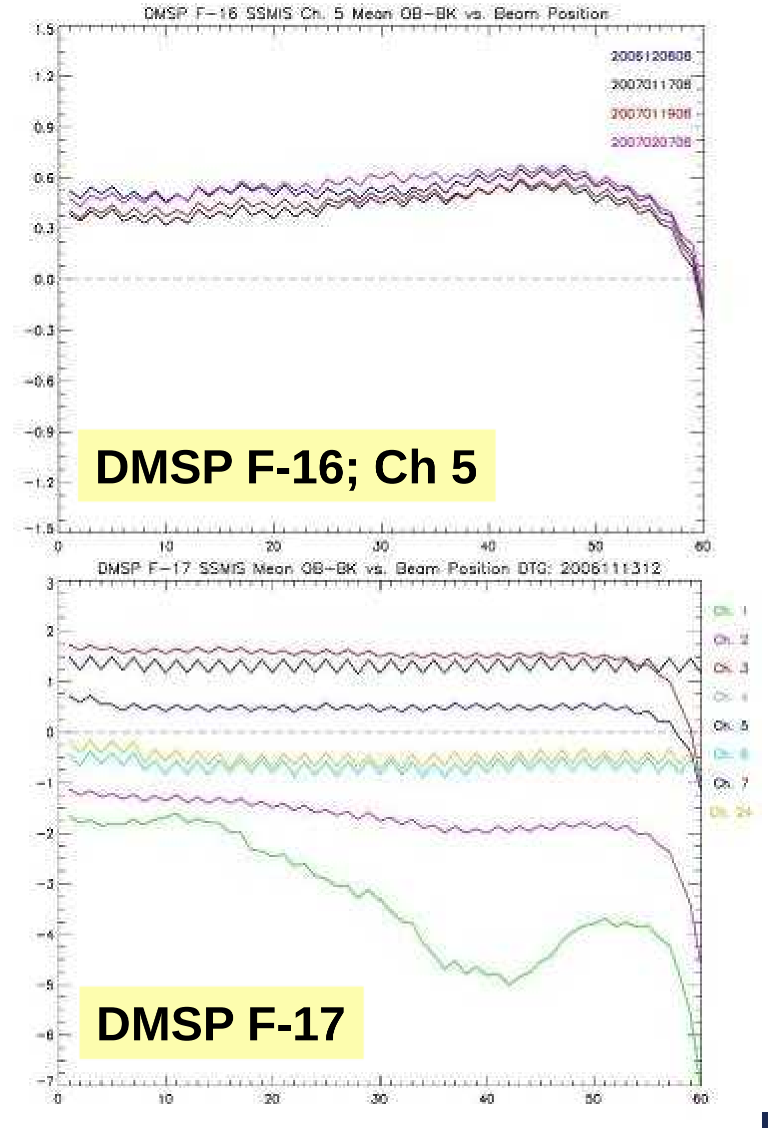
NOAA AMSU-A Ch 6

Radiance Assimilation Monitoring Tools

Radgrams

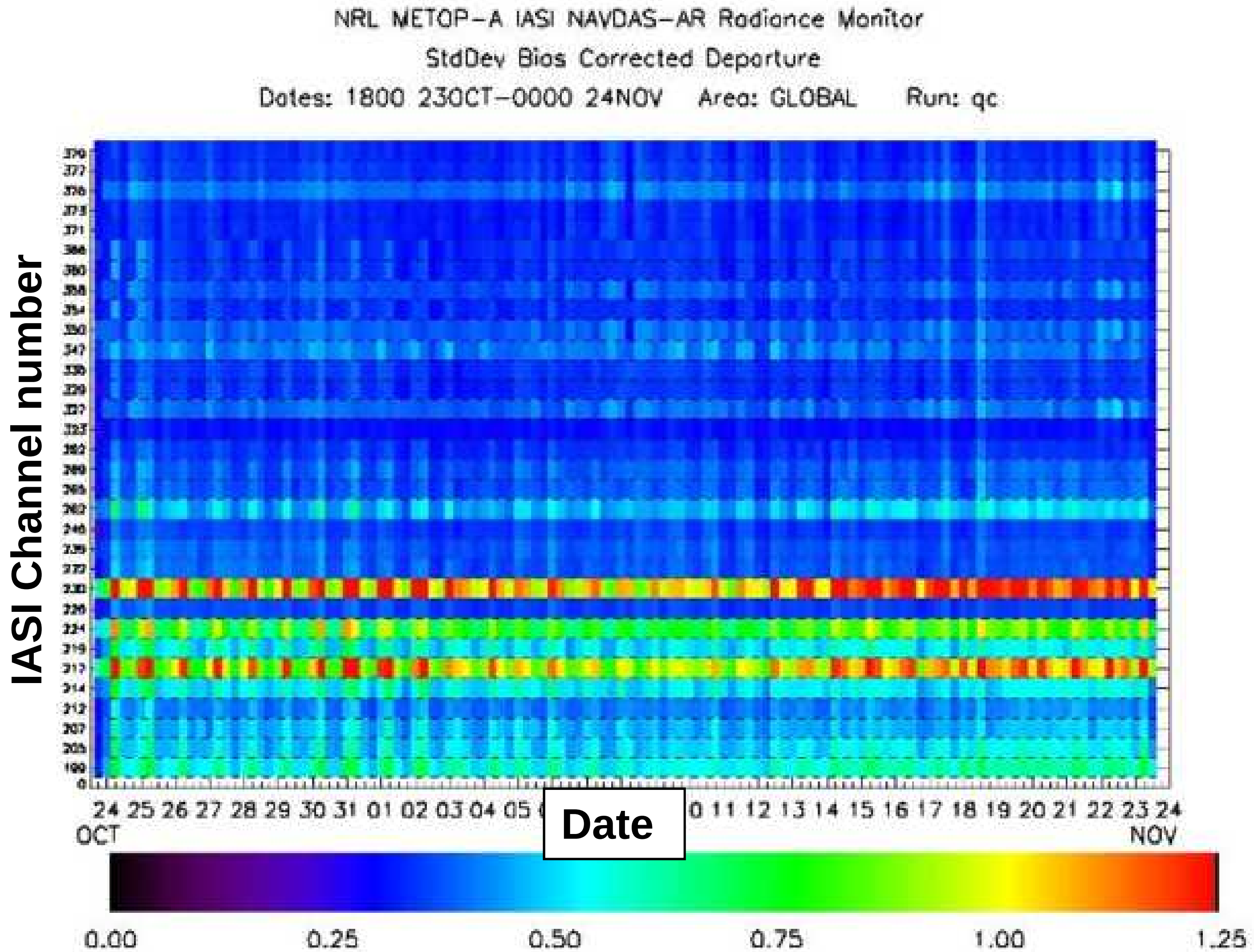


Scan Bias Plots

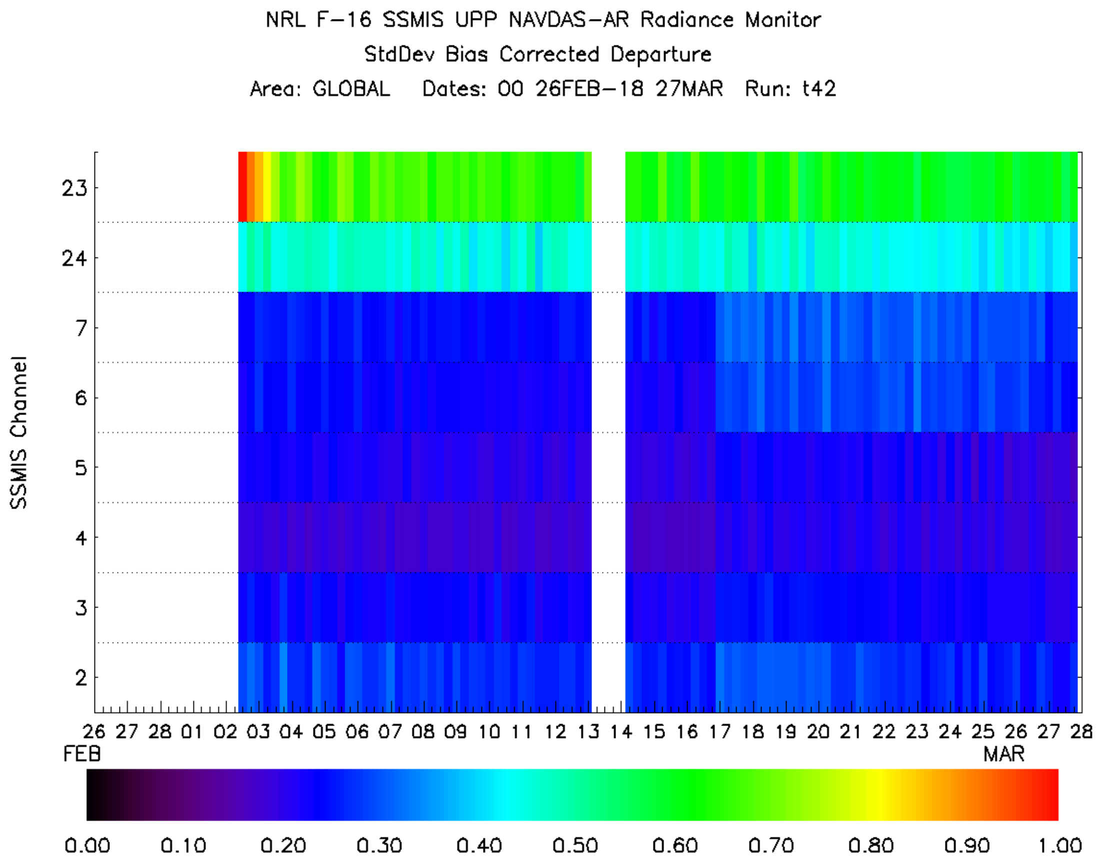


Radiance Assimilation Monitoring Tools

Hovmoeller Diagrams

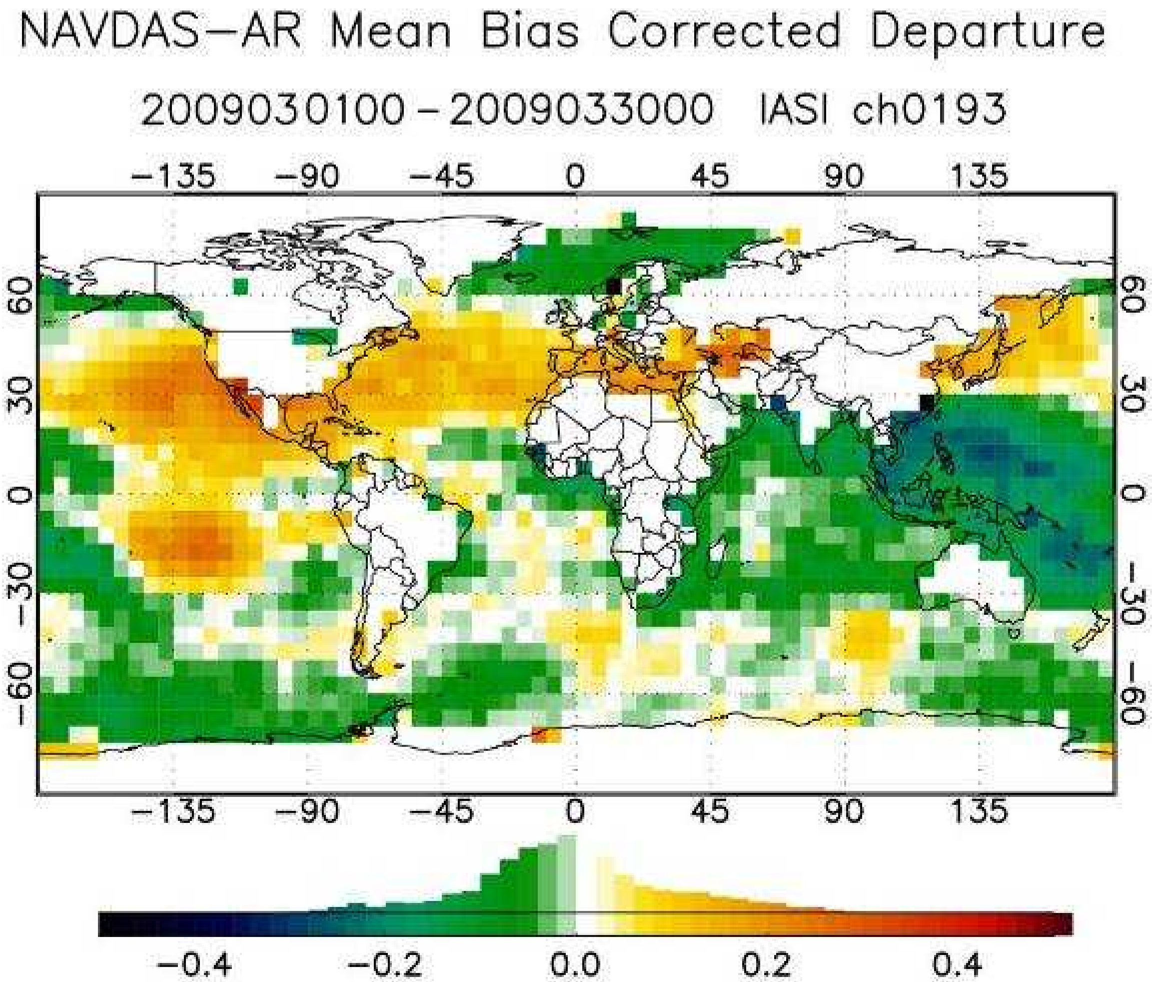


Monitoring Tools



A Hovmöller diagram of the standard deviation of the SSMIS Bias Corrected observation minus background for the previous 30 days of the NOGAPS/NAVDAS-AR. Bias corrected standard deviations for channels 23 and 24 are running in the 0.6 K and 0.4 K range, respectively. SSMIS channel 23 was added to the assimilation run with bias correction coefficients set to zero on 2 February.

Monitoring Tools



A 5X5º plot of the mean bias corrected innovation (observation – simulated) for 30 days of March 2009. Channel 193 of IASI is a longwave channel corresponding to 693 cm-1 (14.43 µm).

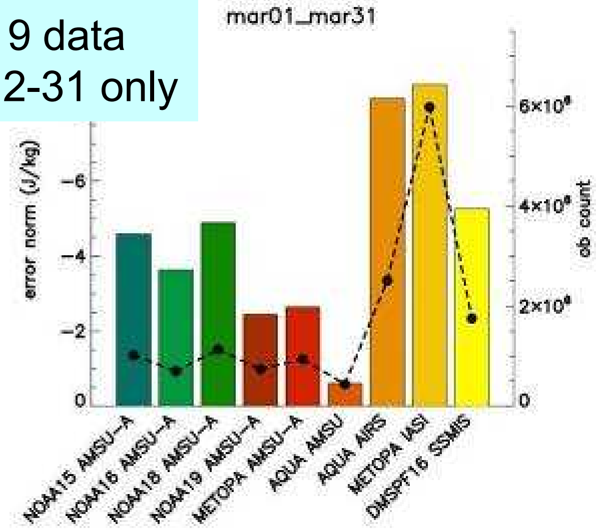
Advanced Sounders

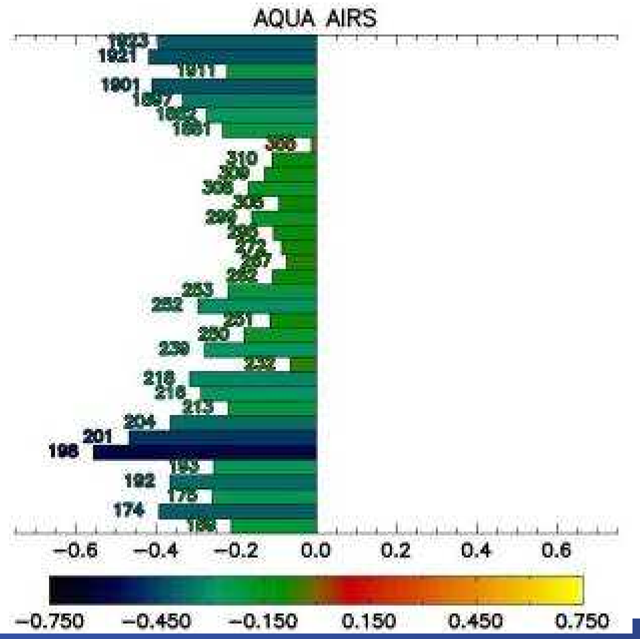
Observation Sensitivity

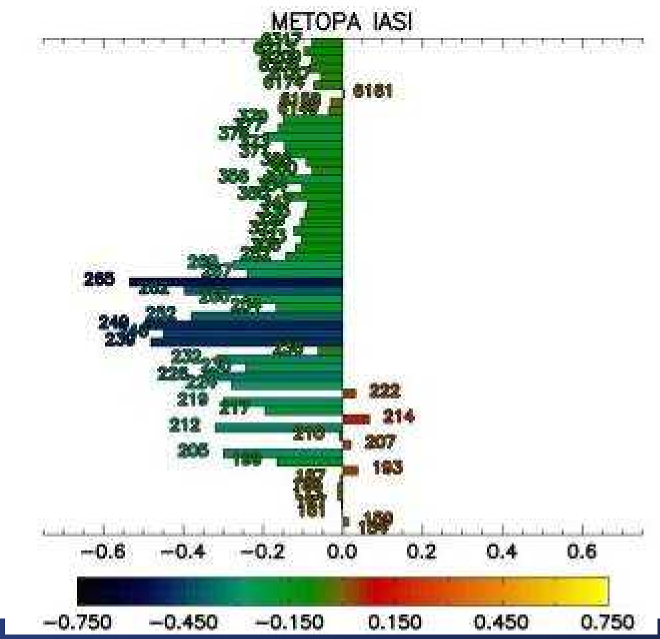
Hyperspectral sounders contribute:
- large volume of data
- large reduction in forecast error norm

Complex channel interactions; ob-sensitivity powerful tool discriminating impacts of additional channels

NOAA-19 data
March 12-31 only

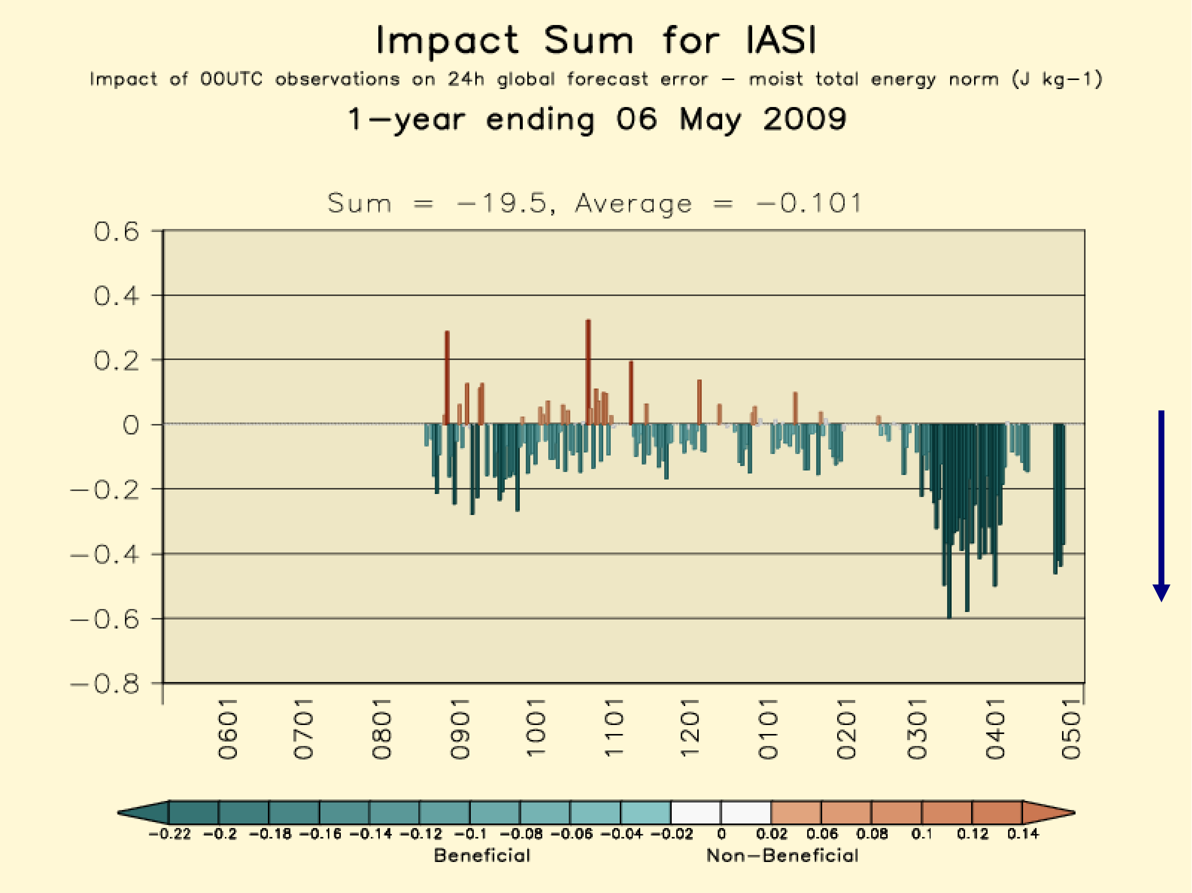






Satellite Data Impact (JCSDA)

Improved impact of IASI radiance data from channel selection diagnostics and other changes



Reduction of 24h forecast error

www.nrlmry.navy.mil/obsens/dev/obsens_main_od.html

SSMIS Unified Pre-Processor (UPP)

The first two SSMIS were launched in October 2004 (F16), and November 2006 (F17). The Cal/Val program uncovered several radiometric calibration anomalies which affected more than 40% of the observations, and made the radiances unusable for NWP.

NRL scientists and collaborators developed and implemented a Unified Pre-processor to correct these calibration anomalies, and produce radiances of sufficient quality for NWP.

<u> Findings have important implications for NPOESS MIS (and other sensors)</u>**
<u> SSMIS important sensor the Navy for NPOESS gap mitigation</u>**

Met Office

THE AEROSPACE CORPORATION

Jet Propulsion Laboratory
California Institute of Technology

ECMWF

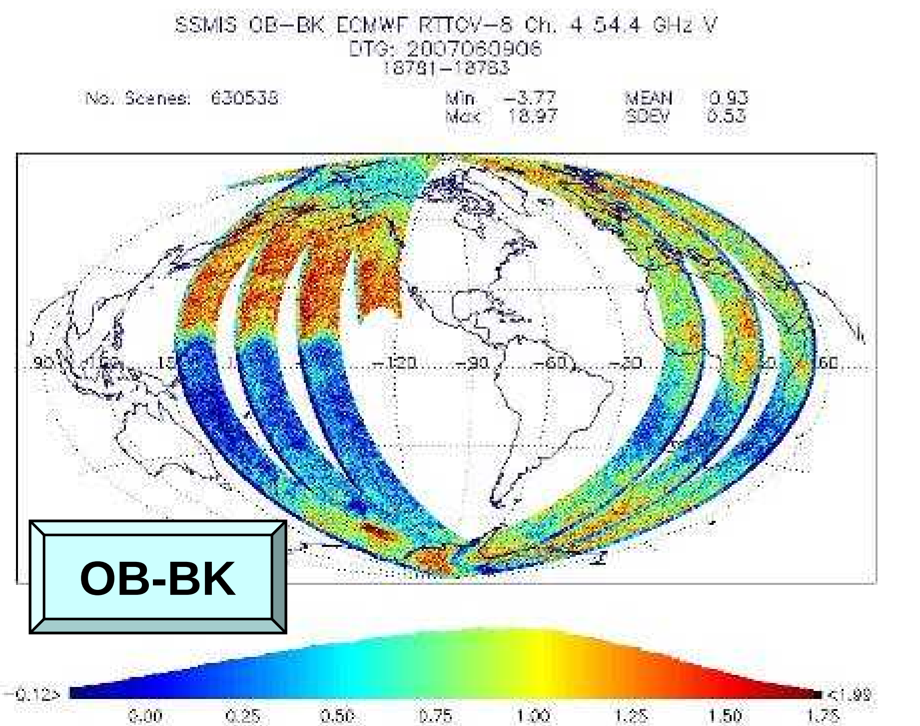
USC

Contributors: Steve Swadley, Gene Poe, Nancy Baker and Ben Ruston (NRL-Monterey), Dave Kunkee, Ye Hong, Mike Werner and Don Boucher (Aerospace), William Bell and Sana Mahmood (The Met Office/ECMWF), 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

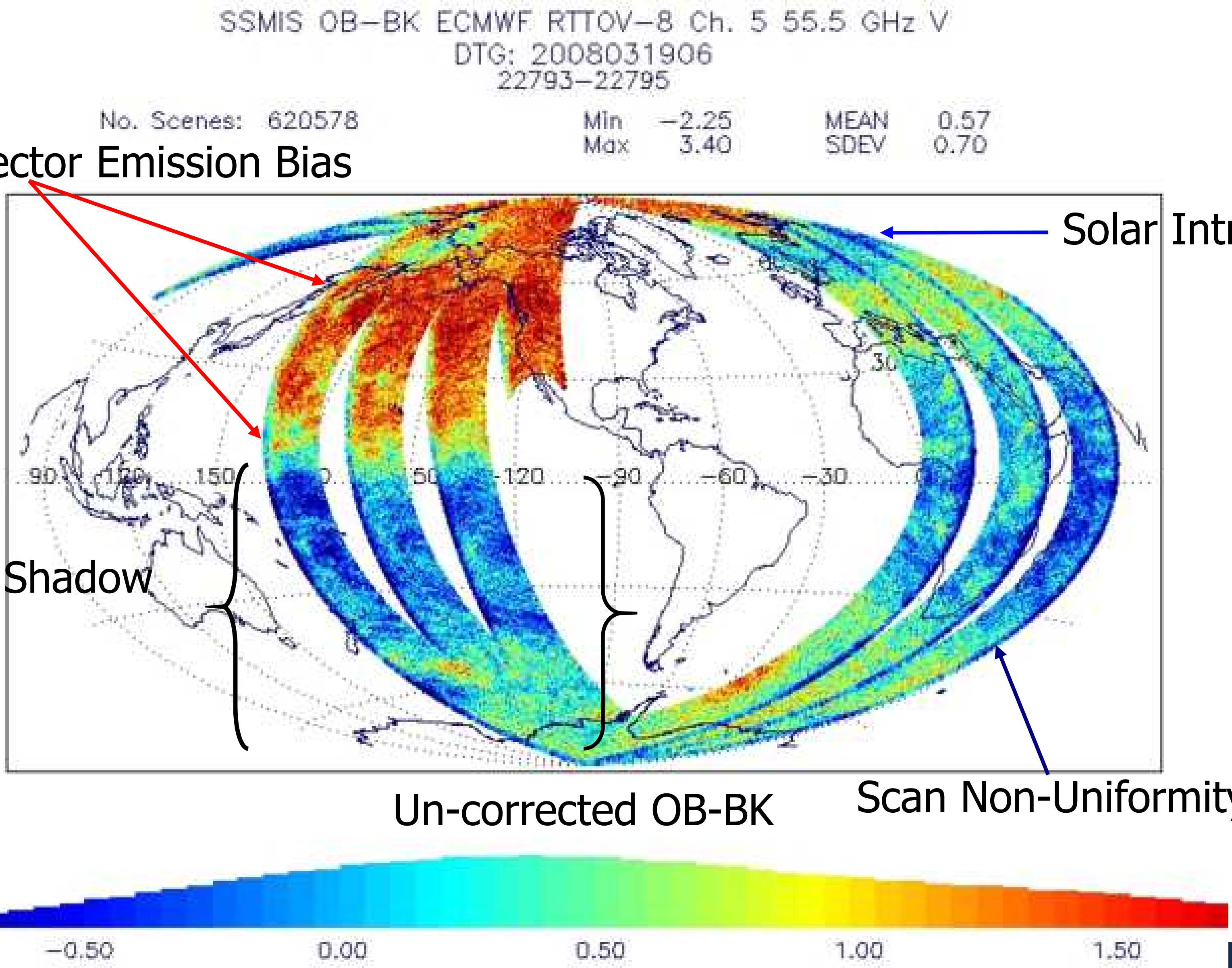
SSMIS Calibration Anomaly Detection

DMSP F-16 launched 18 October 2003

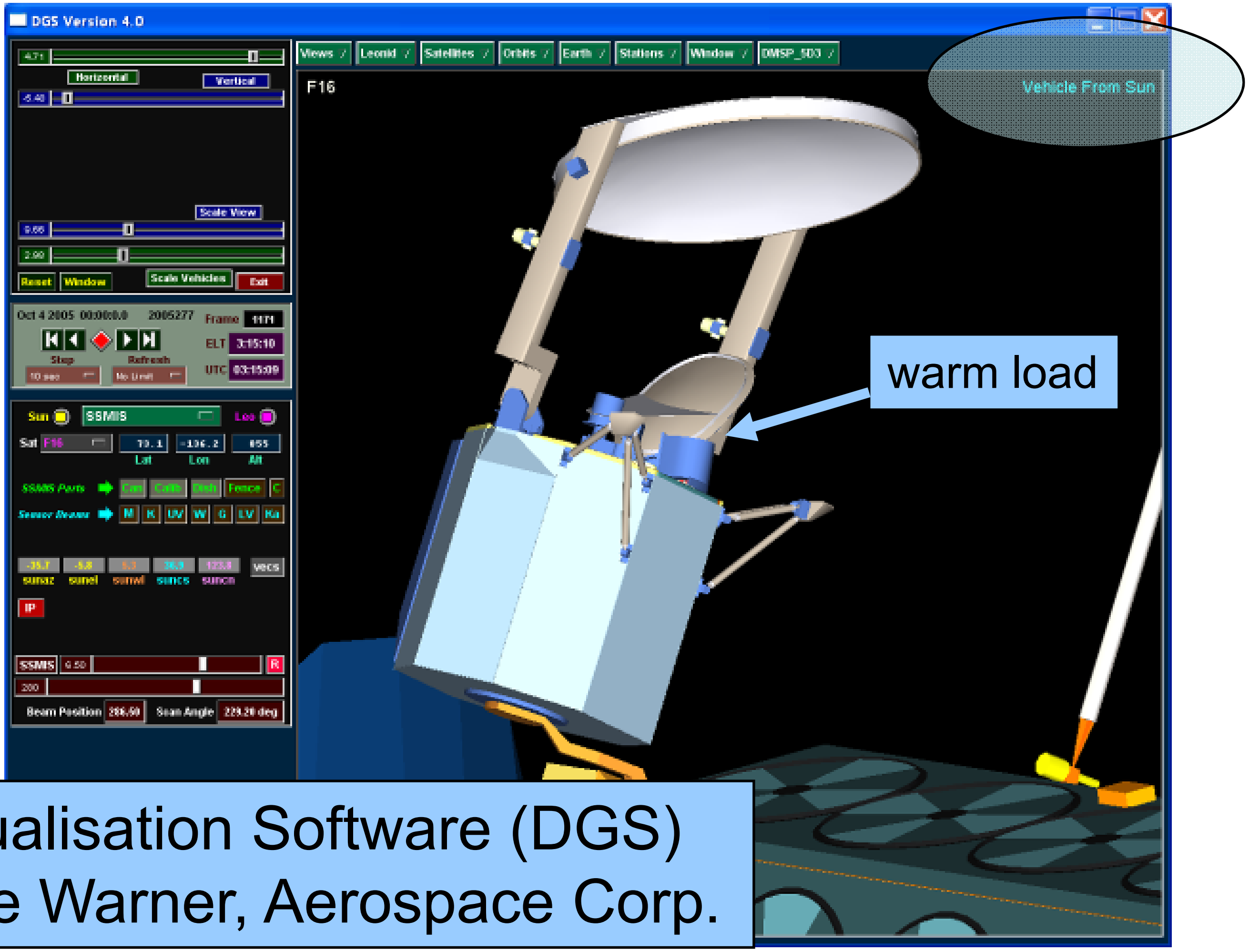
- FNMOC and ECMWF global NWP analyses with RTTOV-8 were used to produce OB-BK departures for TDR/SDR and EDR products
- Departures were analyzed in combination with the DGS software package developed by Mike Werner (Aerospace)
- SSMIS Cal/Val team was able to successfully pinpoint the physical mechanisms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



F-16 SSMIS Calibration Anomalies



NWP in Cal/Val:
Example 1: SSMIS Calibration Anomalies



Visualisation Software (DGS)
Mike Warner, Aerospace Corp.

Description of the F16 SSMIS Calibration Anomalies

F-16 Calibration Issues

Reflector Emission

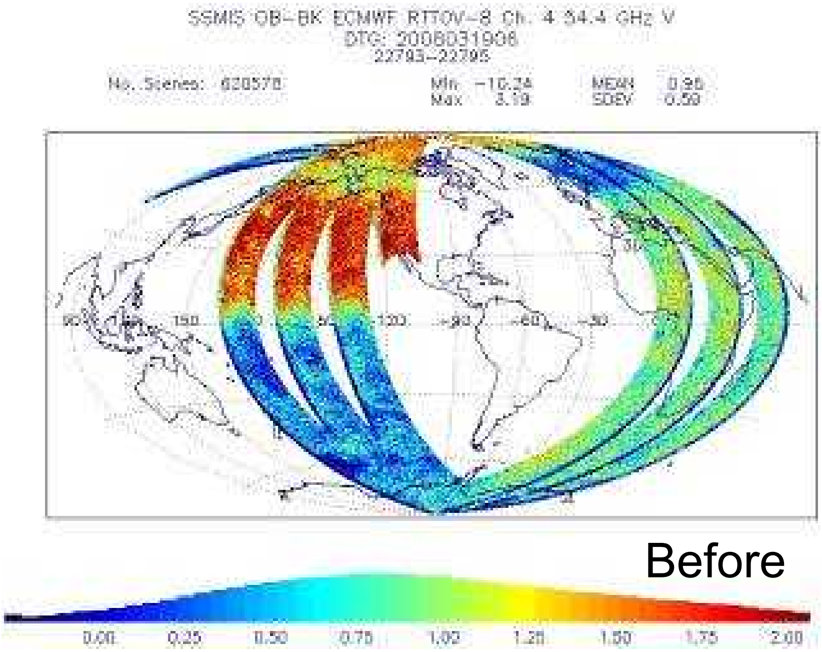
- Reflector Rim Temperature Cycle Dominated by Earth and Spacecraft Shadowing
- OB-BK Patterns Showed Frequency Dependent Reflector Emissivity, ε_{Rflct}
  - 1.5–2K OB-BK Jump at 50-60 GHz
  - 5-7K OB-BK Jump at 183 GHz

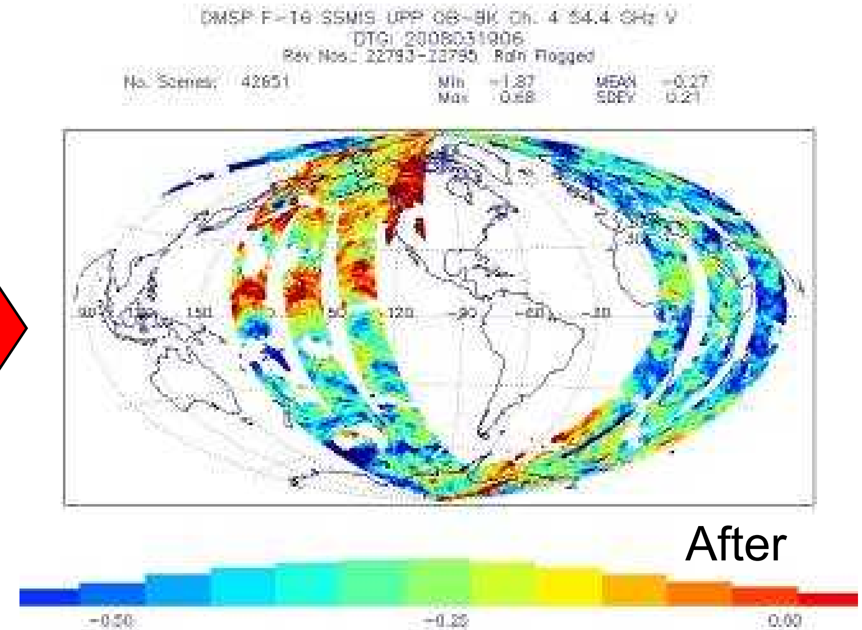
Warm Load Intrusions

- 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

SSMIS Unified Pre-Processor *Updated*





UPP V2 includes

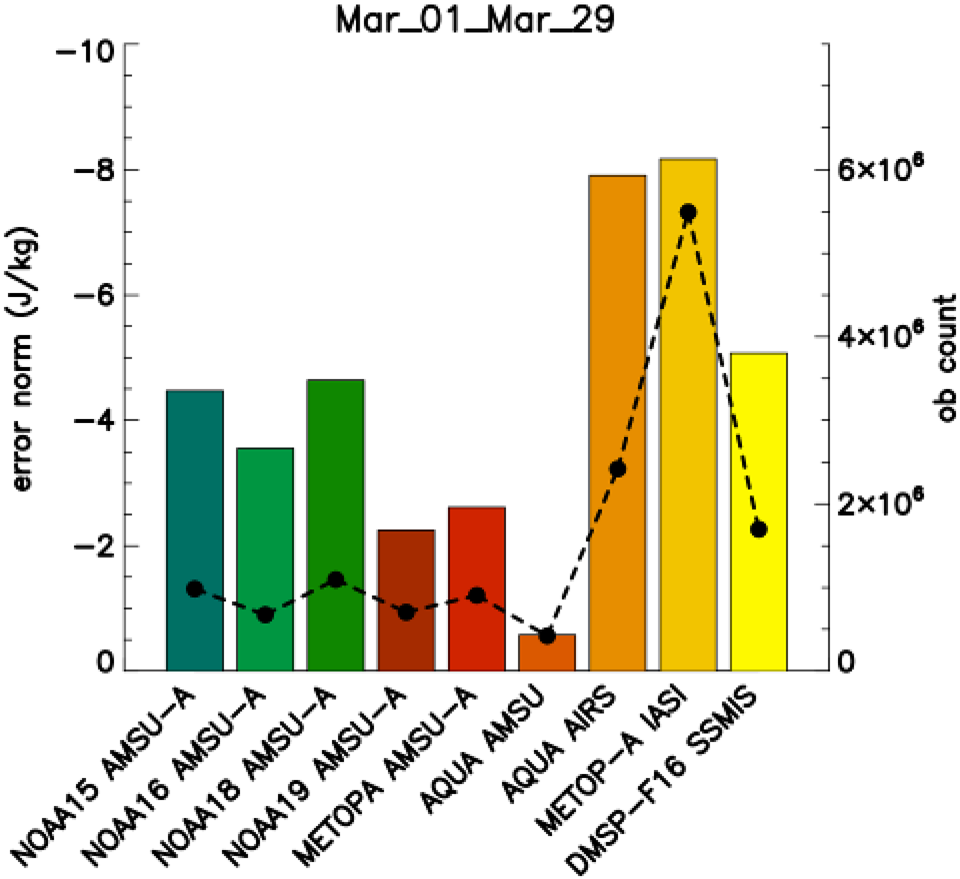
- Reflector Emission Corrections
- Spatial Averaging to reduce NEΔT to 0.1 K level
- Uses Operational NGES Fourier Filtered Gain Files to Correct Gain Anomalies
- Produces ASCII and BUFR TDR output files at reduced resolution
- Performs Scan Non-uniformity corrections
- SSMIS UPP V2 Operational at FNMOC July 2008 for F16
- F17 UPP changes in OPS at FNMOC April 23, 2009
- FNMOC distributes UPP data to NESDIS for use by the NWP Community

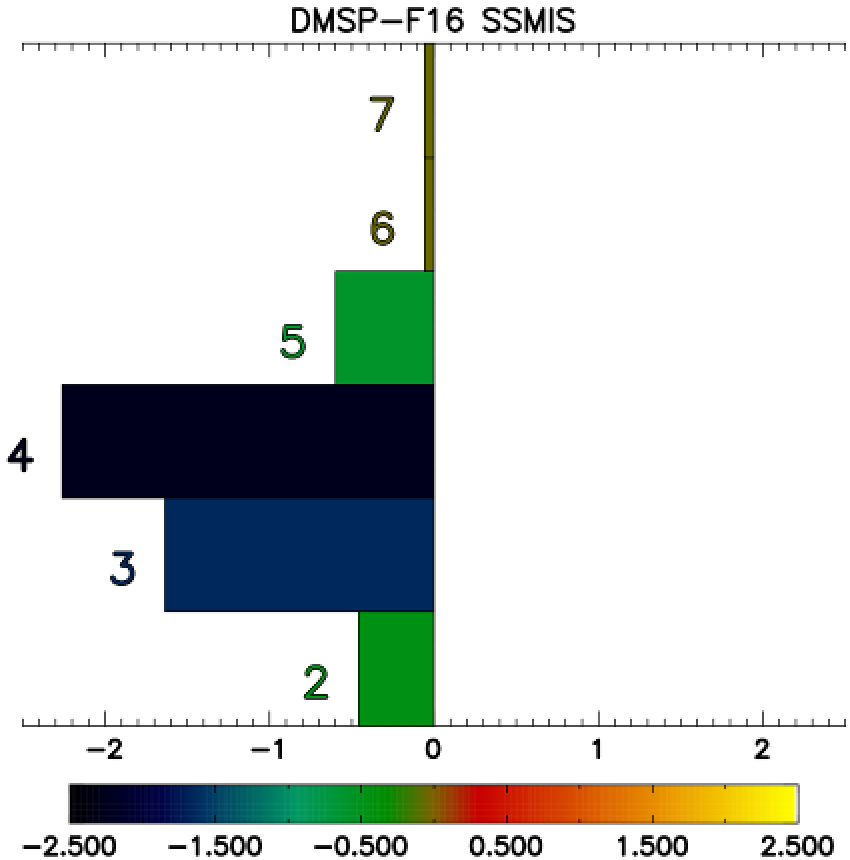
Operational at FNMOC, UKMO, ECMWF; Testing underway at AFWA and NCEP.

SSMIS Radiance Assimilation

Observation impact (adjoint approach)

Reduction of 24-hr global forecast error due to the observations



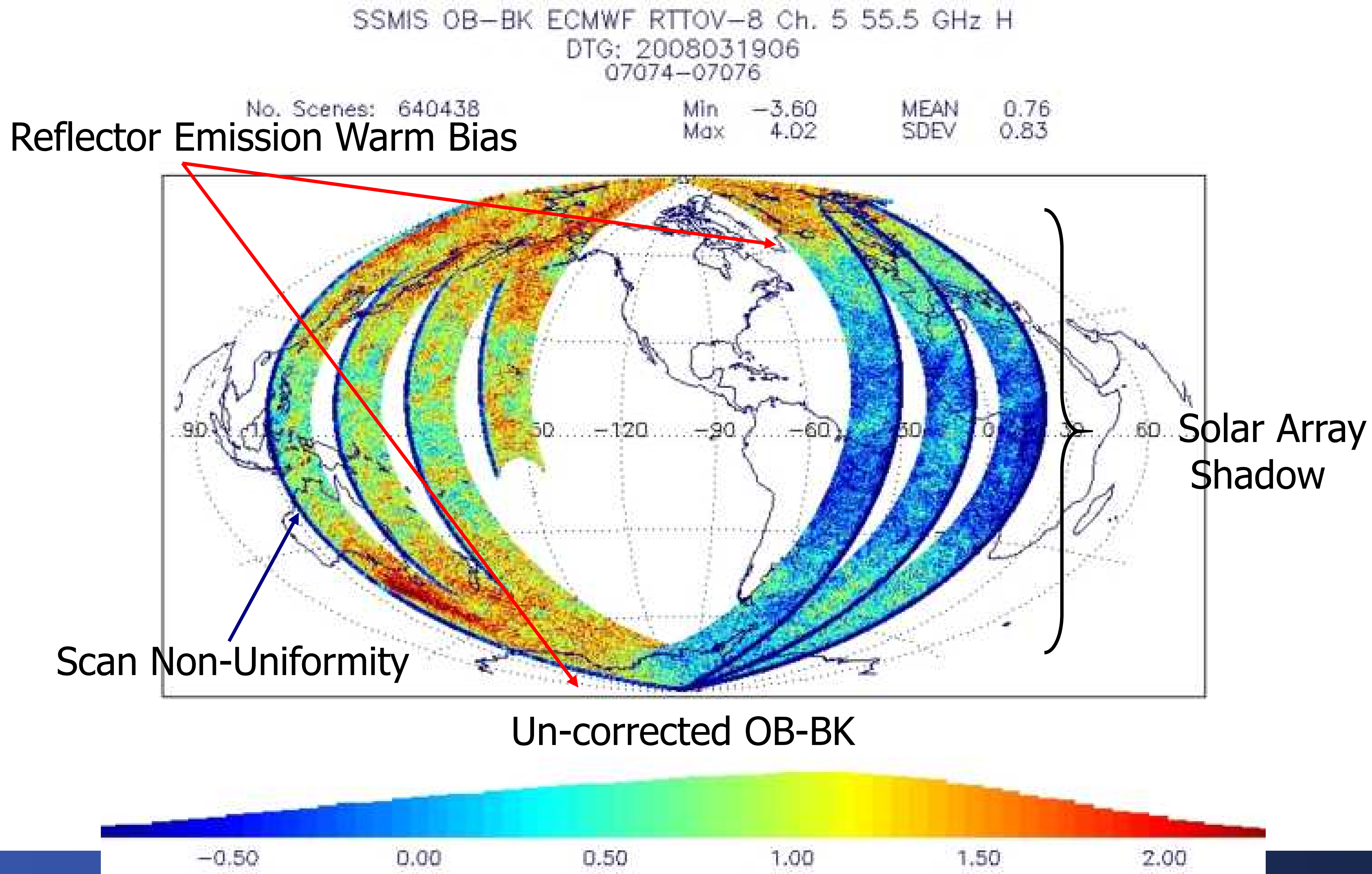


SSMIS F-17 Cal/Val Experience

DMSP F-17 launched 4 November 2006

- With the tools from the F-16 Cal/Val developed and in-place, the cal-val team was able to rapidly confirm
  - status of the SSMIS calibration
  - channel polarizations
  - channel noise levels
  - transient calibration anomalies

F-17 SSMIS Calibration Anomalies



Description of the F17 SSMIS Calibration Anomalies

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

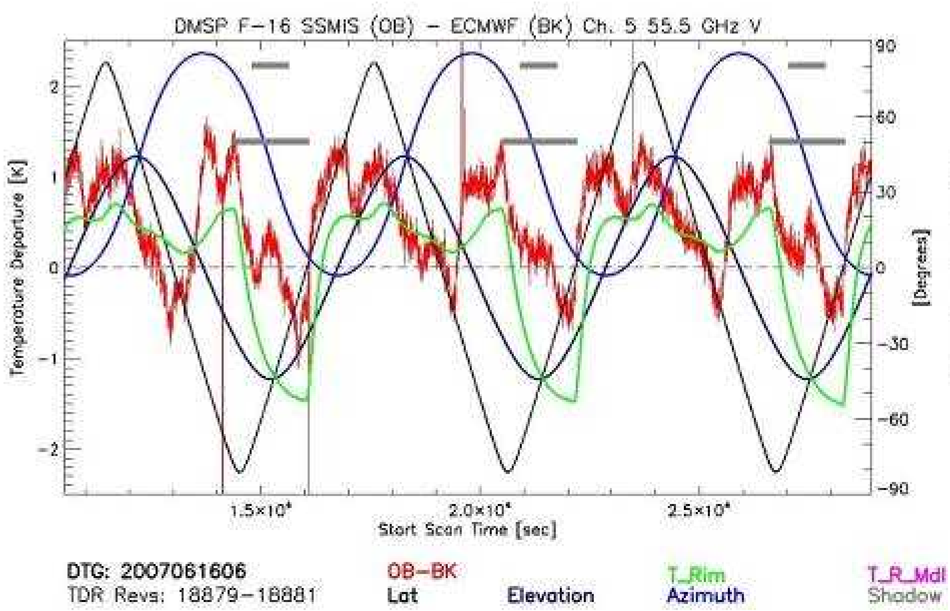
Warm Load Intrusions

- 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

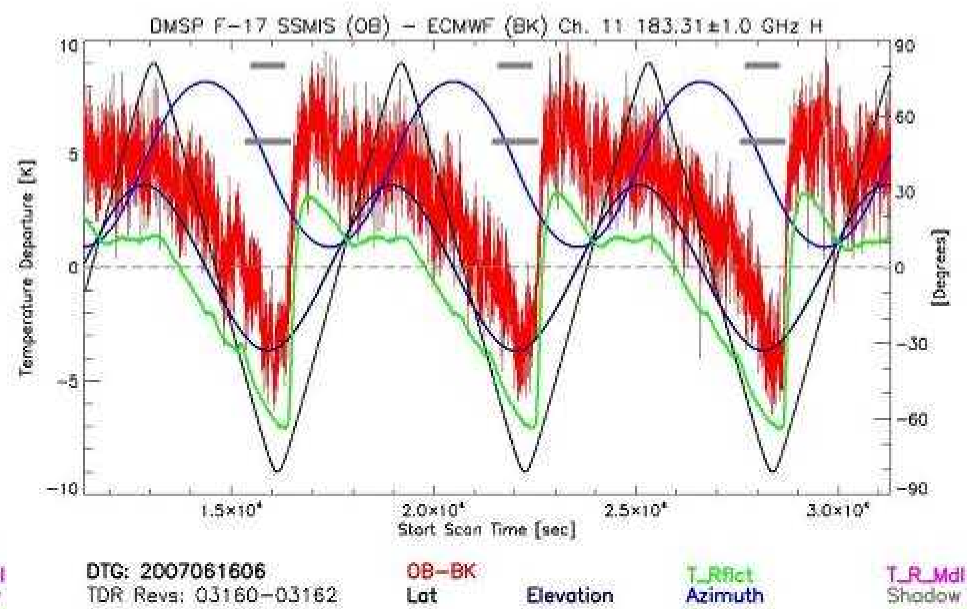
Frequency Dependence of the SSMIS Reflector Emission Bias

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



55.5 GHz Channel shows 1.5 K Jump at emergence from Earth Shadow

DMSP F-16



183 GHz Channel shows 7 K Jump at emergence from Earth Shadow

DMSP F-17

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

DSMP F-17 SSMIS Update

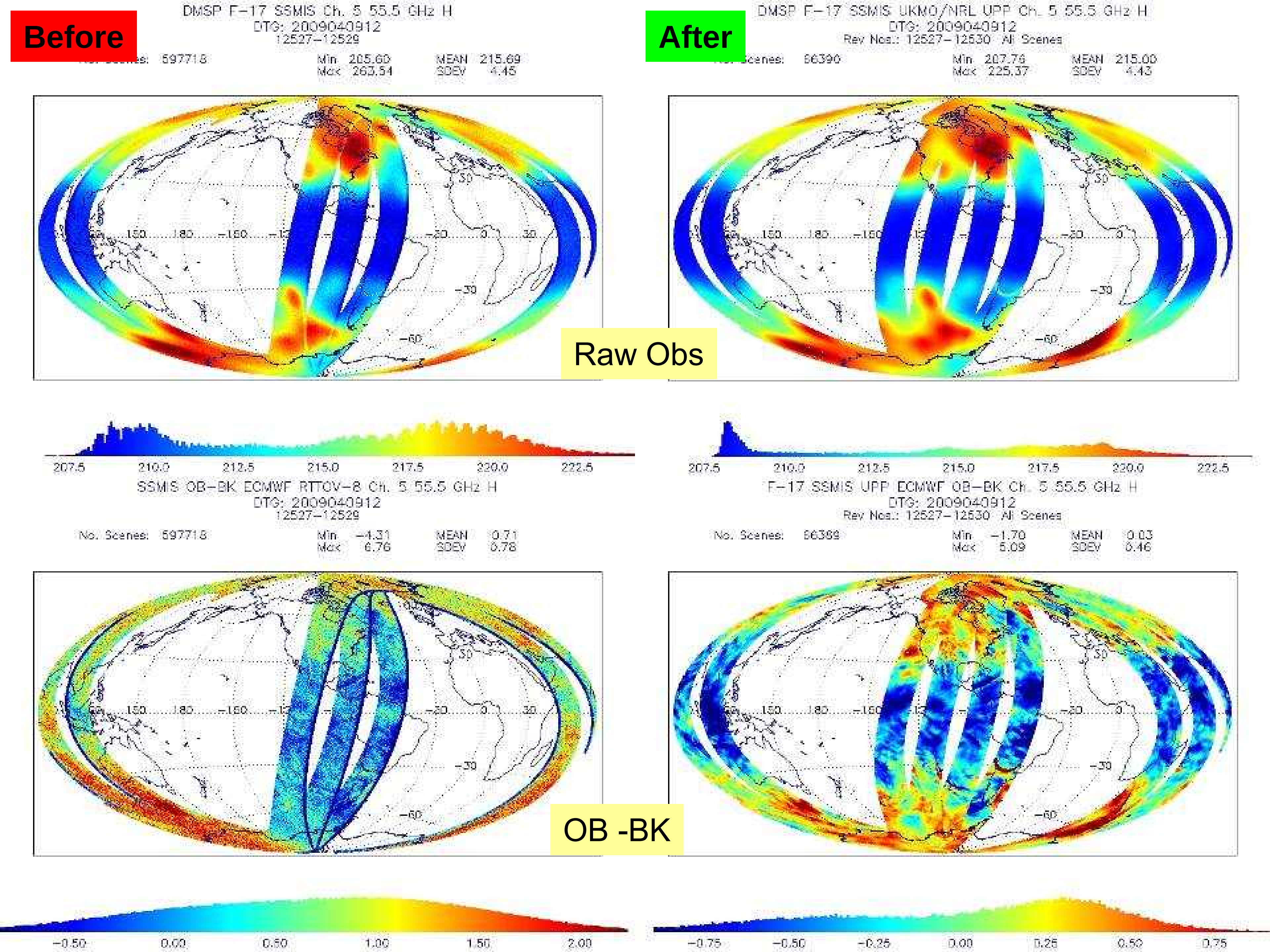
•Elevated Noise Levels from using two within-scan warm and cold cal scenes for calibration (Nscenes=2)

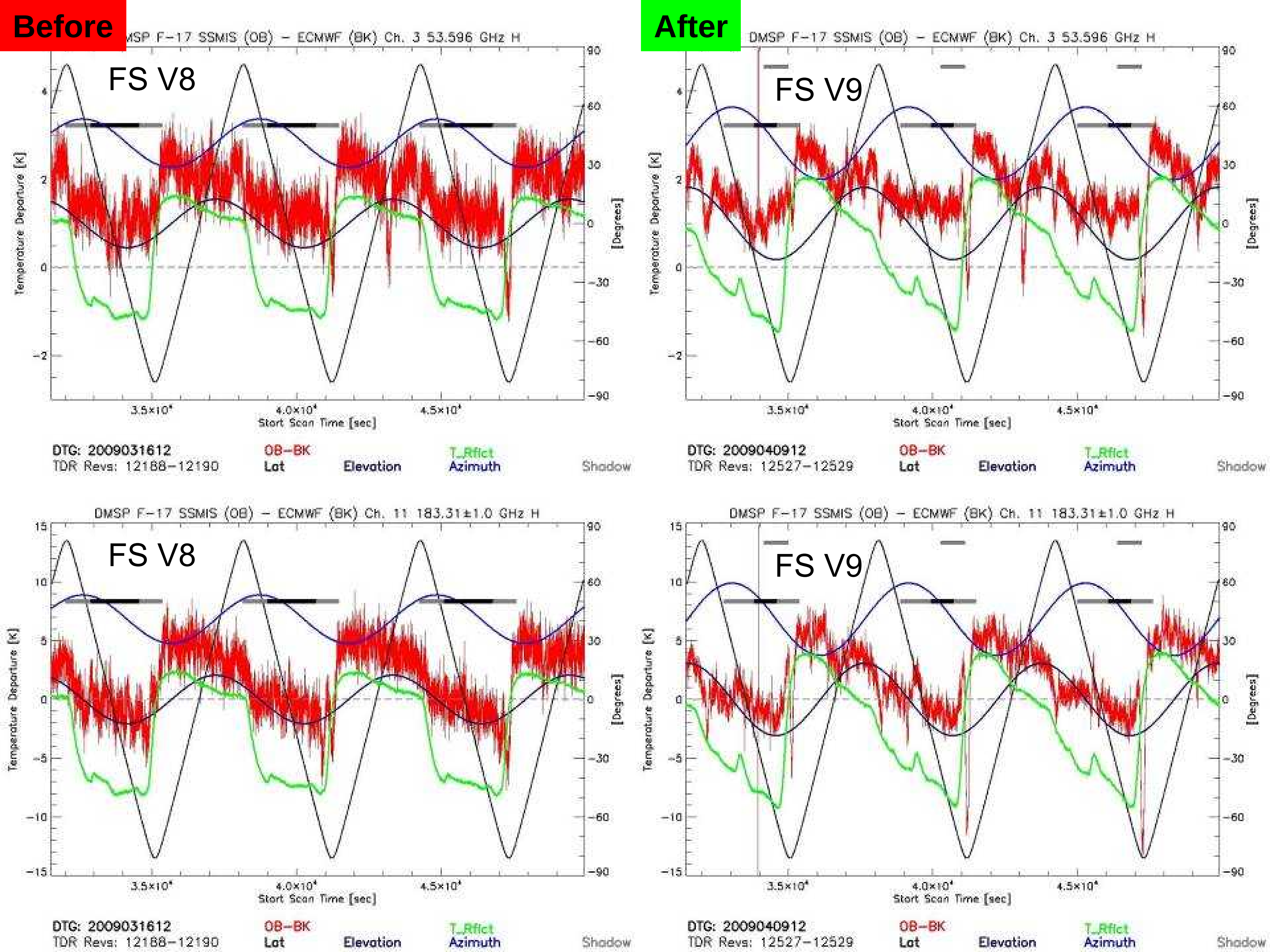
•Successful SSMIS F-17 Flight Software Upgrade (V9) 19 March 2009

•NRL Cal/Val team, Aerospace and NOAA SOCC commanded and monitored multiple calibration averaging schemes and Early Orbit (EO) modes during the 3 days of implementation and verification

•Noise levels were reduced by a factor of 1.5–2. (Nscenes=8)

•SSMIS Flight Software V10 plans: include NRL optimal beam positions and Nscenes=16


Before
After
DMSP F-17 SSMIS Ch. 5 55.5 GHz H
DTG: 2009040912
12527-12529
Scenes: 597718
Min 205.60
Max 263.54
MEAN 215.69
SDEV 4.45
DMSP F-17 SSMIS UKMO/NRL UPP Ch. 5 55.5 GHz H
DTG: 2009040912
Rev Nos.: 12527-12530 All Scenes
Scenes: 56390
Min 207.76
Max 225.37
MEAN 215.00
SDEV 4.43
Raw Obs
207.5
210.0
212.5
215.0
217.5
220.0
222.5
SSMIS OB-BK ECMWF RTTOV-8 Ch. 5 55.5 GHz H
DTG: 2009040912
12527-12529
No. Scenes: 597718
Min -4.31
Max 6.76
MEAN 0.71
SDEV 0.78
F-17 SSMIS UPP ECMWF OB-BK Ch. 5 55.5 GHz H
DTG: 2009040912
Rev Nos.: 12527-12530 All Scenes
No. Scenes: 56369
Min -1.70
Max 5.09
MEAN 0.03
SDEV 0.46
OB -BK
-0.50
0.00
0.50
1.00
1.50
2.00
-0.75
-0.50
-0.25
0.00
0.25
0.50
0.75


Before
After
DMSP F-17 SSMIS (OB) - ECMWF (BK) Ch. 3 53.596 GHz H
FS V8
FS V9
DMSP F-17 SSMIS (OB) - ECMWF (BK) Ch. 11 183.31±1.0 GHz H
Temperature Departure [K]
[Degrees]
Start Scan Time [sec]
3.5×10⁴
4.0×10⁴
4.5×10⁴
DTG: 2009031612
TDR Revs: 12188-12190
DTG: 2009040912
TDR Revs: 12527-12529
OB-BK
Lat
Elevation
T_Rflct
Azimuth
Shadow

DSMP F-17 SSMIS UPP Update

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

- Spatially averaged BUFR files distributed to NOAA by FNMOC

- UPP V2.1 developed by Bill Bell (Met Office/ECMWF) and Steve Swadley (NRL)

- 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 require WMO BUFR code table changes

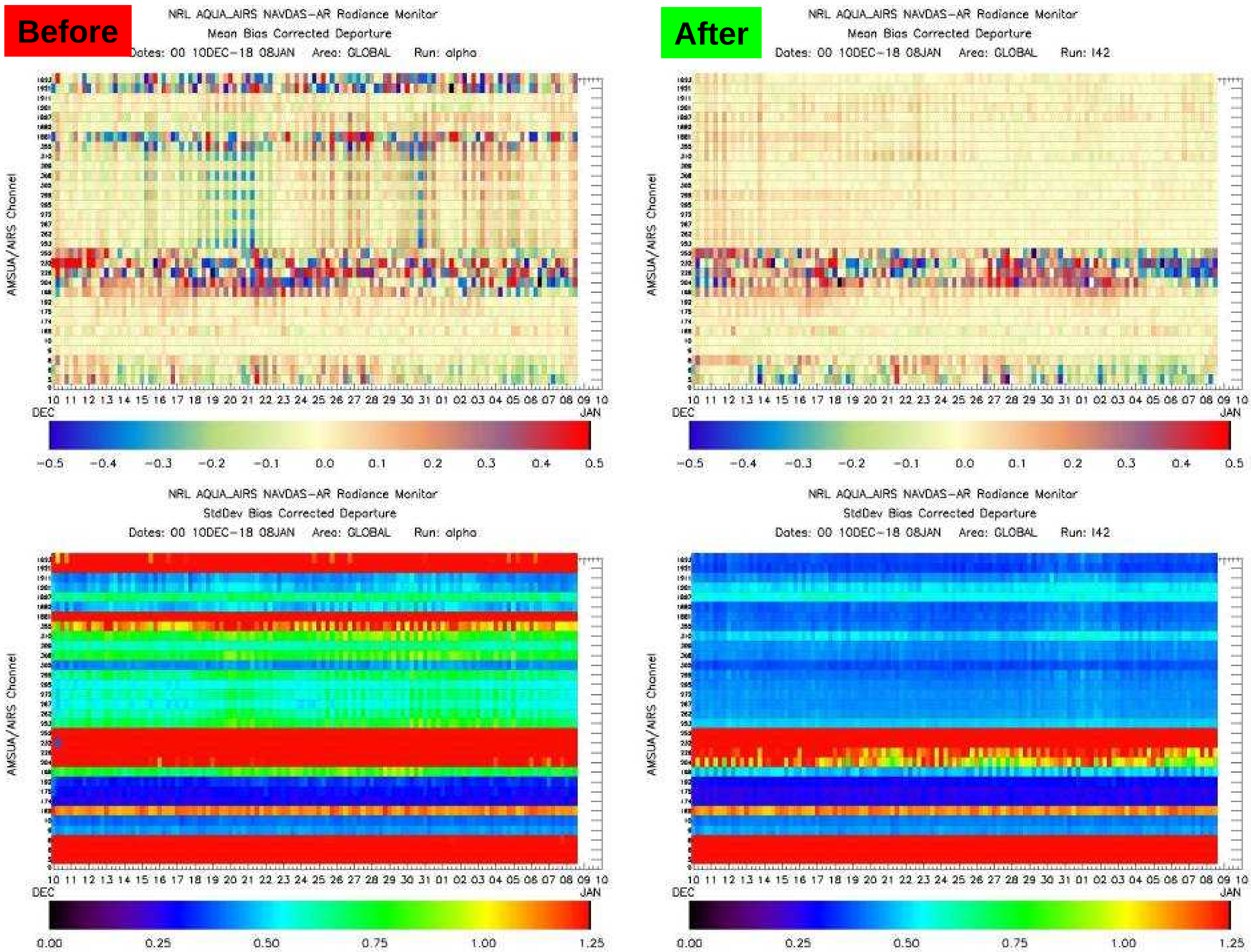
Path Forward for Future Sensor Systems

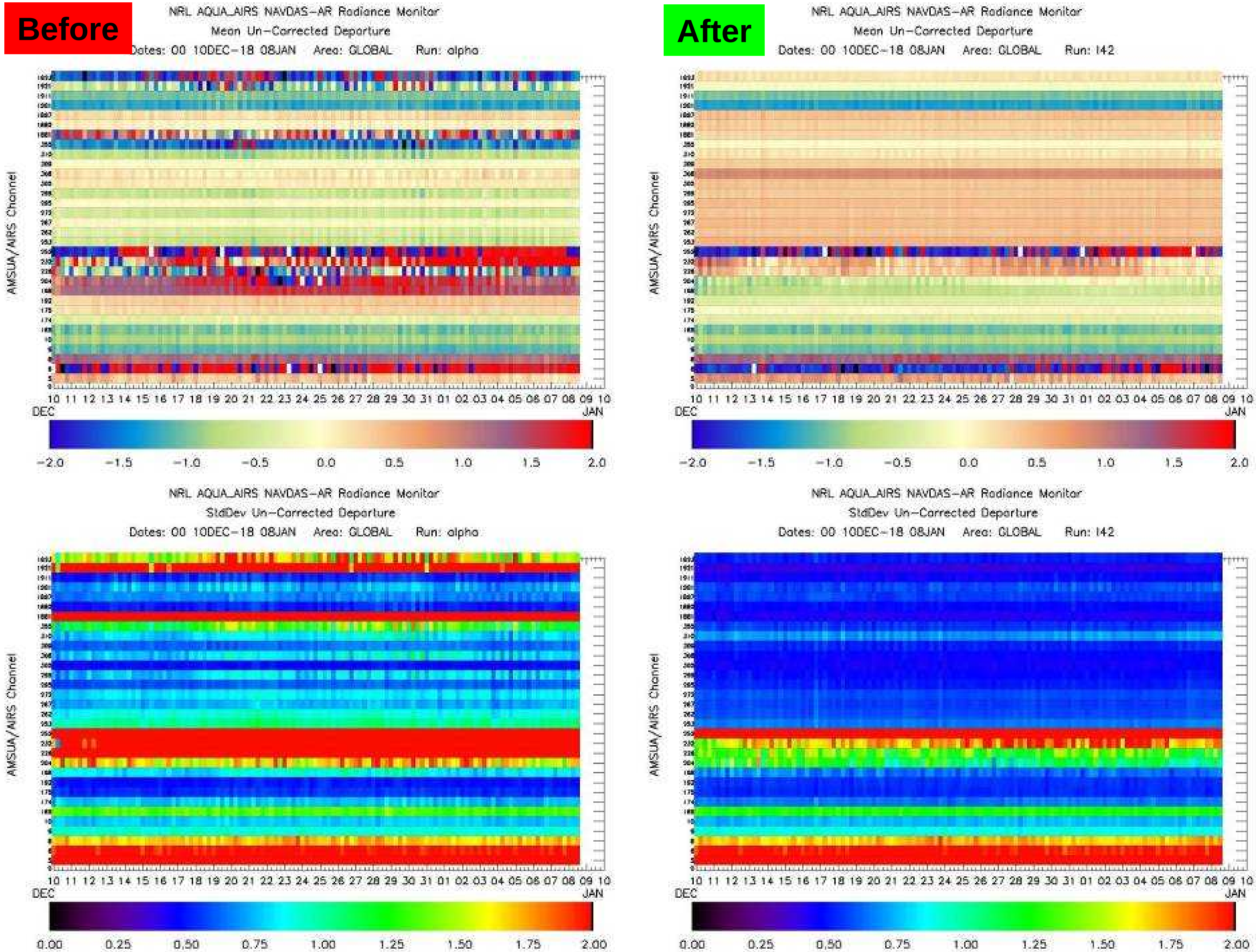
Operational NWP centers have the radiance monitoring tools, processing infrastructure and experience in place to perform the necessary sensor checkout

These assets should be heavily relied upon in order to transition the sensor data into operations as rapidly as possible

T239L30 vs. T239L42

- New model top around 71 km (0.04 hPa)
- The advantage of a higher model top
  - Complex interactions between weighting functions and background error covariances (temperature correlations in the vertical)
  - Higher-peaking channels can have a significant impact lower down
  - Truncation errors become important

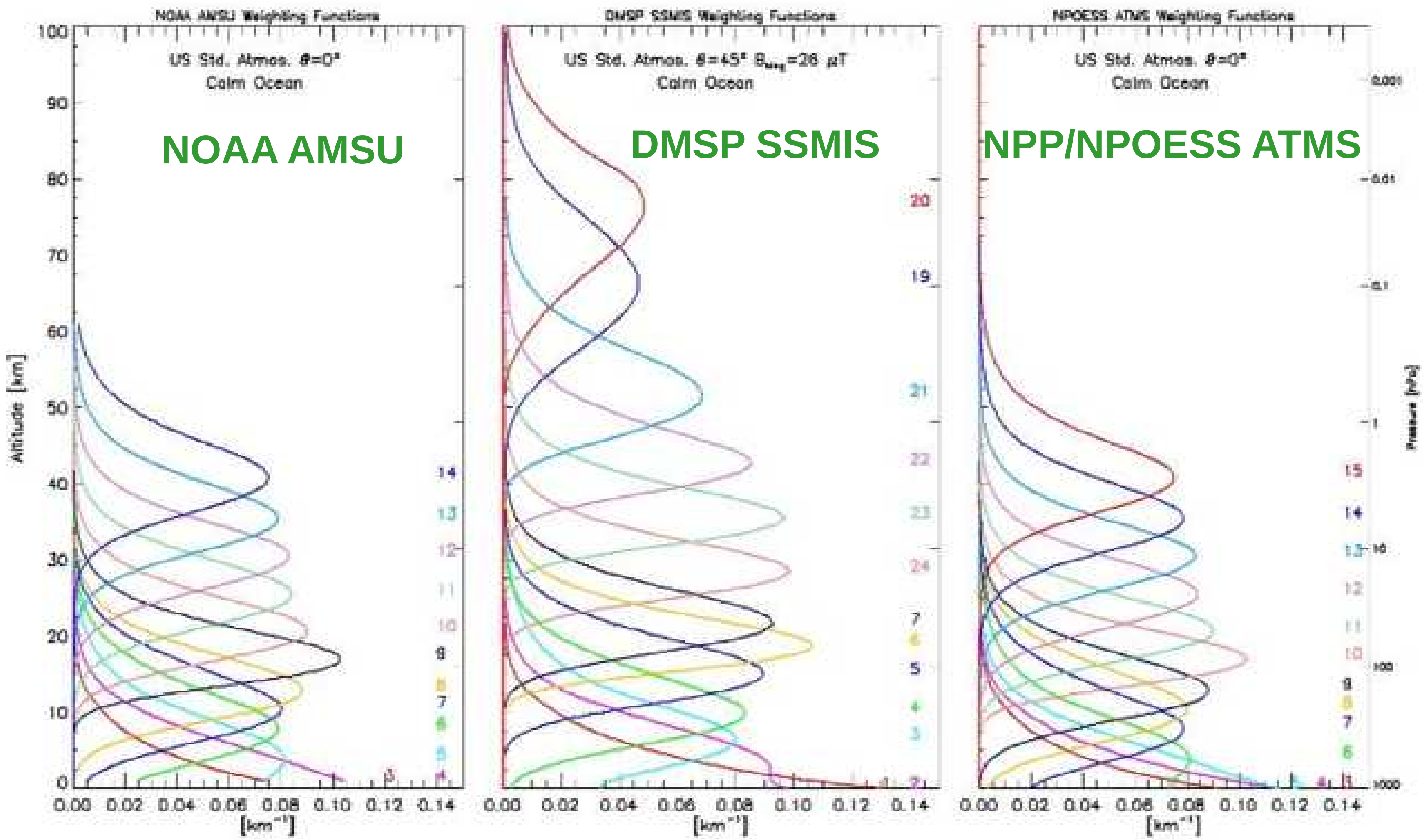

Before
NRL AQUA_AIRS NAVDAS-AR Radiance Monitor
Mean Bias Corrected Departure
Dates: 00 10DEC-18 08JAN Area: GLOBAL Run: alpha
AMSUA/AIRS Channel
10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 01 02 03 04 05 06 07 08 09 10
DEC
JAN
-0.5 -0.4 -0.3 -0.2 -0.1 0.0 0.1 0.2 0.3 0.4 0.5
After
NRL AQUA_AIRS NAVDAS-AR Radiance Monitor
Mean Bias Corrected Departure
Dates: 00 10DEC-18 08JAN Area: GLOBAL Run: I42
AMSUA/AIRS Channel
10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 01 02 03 04 05 06 07 08 09 10
DEC
JAN
-0.5 -0.4 -0.3 -0.2 -0.1 0.0 0.1 0.2 0.3 0.4 0.5
NRL AQUA_AIRS NAVDAS-AR Radiance Monitor
StdDev Bias Corrected Departure
Dates: 00 10DEC-18 08JAN Area: GLOBAL Run: alpha
AMSUA/AIRS Channel
10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 01 02 03 04 05 06 07 08 09 10
DEC
JAN
0.00 0.25 0.50 0.75 1.00 1.25
NRL AQUA_AIRS NAVDAS-AR Radiance Monitor
StdDev Bias Corrected Departure
Dates: 00 10DEC-18 08JAN Area: GLOBAL Run: I42
AMSUA/AIRS Channel
10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 01 02 03 04 05 06 07 08 09 10
DEC
JAN
0.00 0.25 0.50 0.75 1.00 1.25



Before
NRL AQUA_AIRS NAVDAS-AR Radiance Monitor
Mean Un-Corrected Departure
Dates: 00 10DEC-18 08JAN Area: GLOBAL Run: alpha
AMSUA/AIRS Channel
10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 01 02 03 04 05 06 07 08 09 10
DEC
JAN
-2.0 -1.5 -1.0 -0.5 0.0 0.5 1.0 1.5 2.0
After
NRL AQUA_AIRS NAVDAS-AR Radiance Monitor
Mean Un-Corrected Departure
Dates: 00 10DEC-18 08JAN Area: GLOBAL Run: I42
AMSUA/AIRS Channel
10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 01 02 03 04 05 06 07 08 09 10
DEC
JAN
-2.0 -1.5 -1.0 -0.5 0.0 0.5 1.0 1.5 2.0
NRL AQUA_AIRS NAVDAS-AR Radiance Monitor
StdDev Un-Corrected Departure
Dates: 00 10DEC-18 08JAN Area: GLOBAL Run: alpha
AMSUA/AIRS Channel
10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 01 02 03 04 05 06 07 08 09 10
DEC
JAN
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00
NRL AQUA_AIRS NAVDAS-AR Radiance Monitor
StdDev Un-Corrected Departure
Dates: 00 10DEC-18 08JAN Area: GLOBAL Run: I42
AMSUA/AIRS Channel
10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 01 02 03 04 05 06 07 08 09 10
DEC
JAN
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00

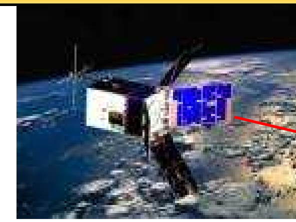
NWP, DAS and Radiance Assimilation

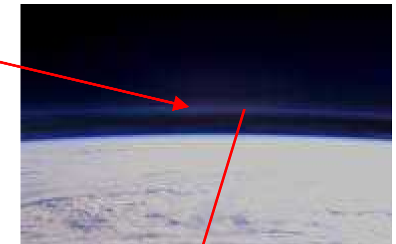
MW Weighting Functions: $K_\nu(z) = \left[\dfrac{d\tau(\nu)}{dz}\right]$

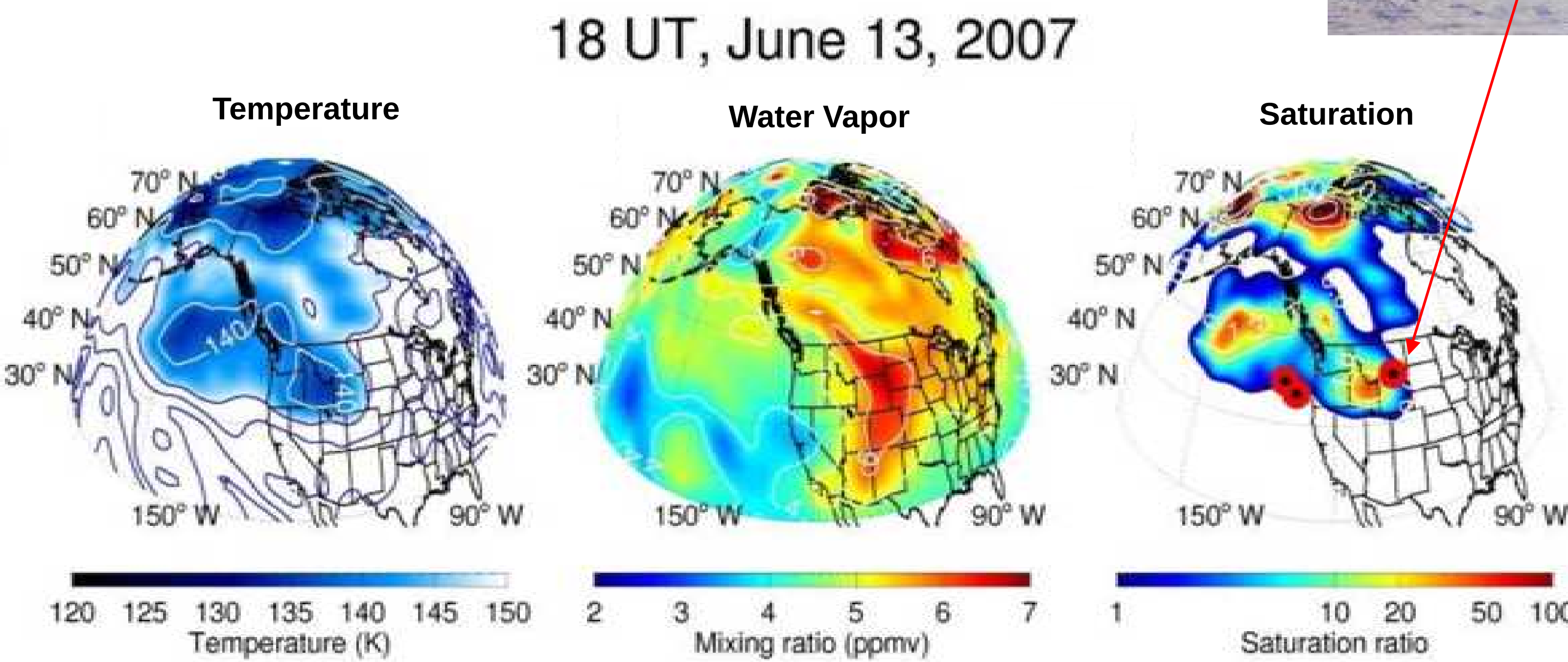


MLS/SABER Assimilation for Mesospheric Science

A cold pool moves over Pacific NW at <u>82 km altitude.</u>
Ice clouds (PMCs) predicted and observed
by NRL SHIMMER instrument (on STPSat-1).

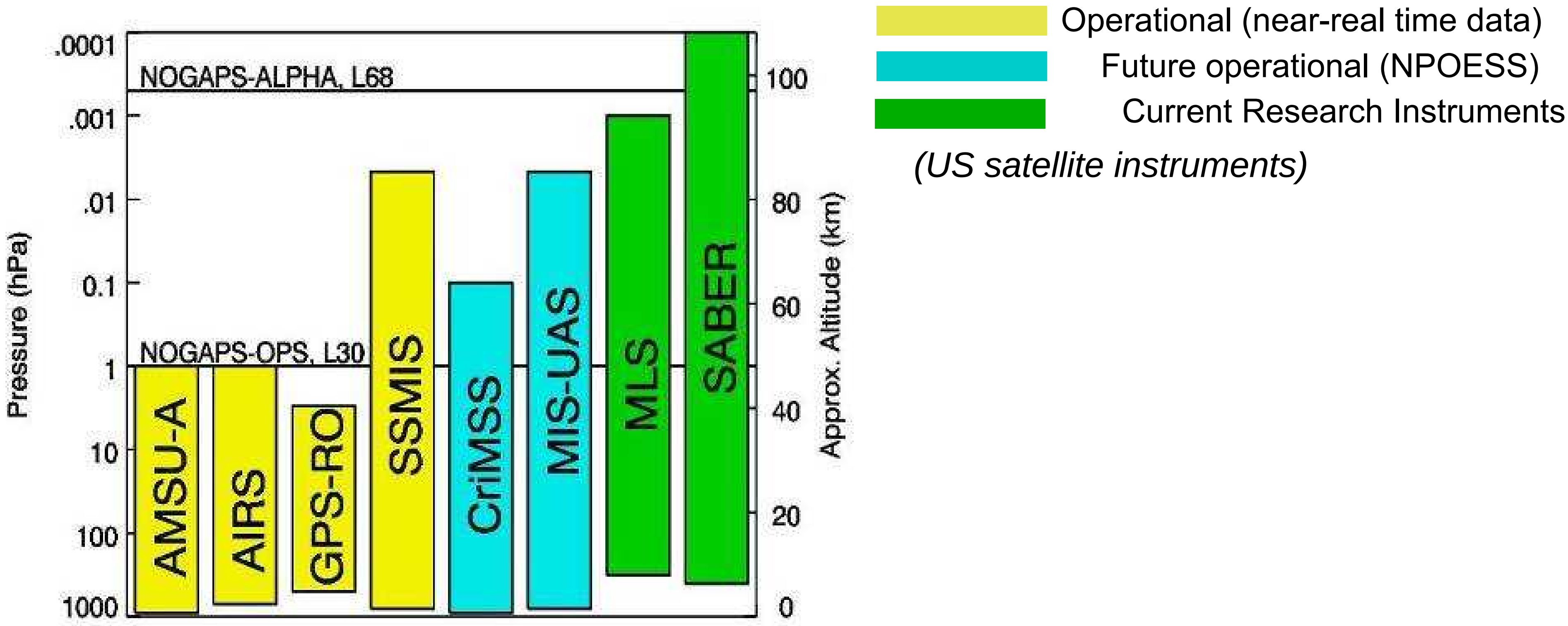






From Eckermann et al., "High-altitude data assimilation system experiments for the northern summer mesosphere season of 2007", *J. Atmos. Sol.-Terr. Physics* (in press)

High Altitude Data Assimilation
Available Temperature Measurements



AMSU-A: Advanced Microwave Sounding Unit
AIRS: Atmospheric Infrared Sounder
GPS-RO: GPS Radio Occultation from the COSMIC constellation of receivers
SSMIS: Special Sensor Microwave Imager/Sounder
CriMSS: Cross-track Infrared Sounder + Advanced Technology Microwave Sounder
MIS-UAS Microwave Imager/Sounder with Upper Air Sounding
MLS: Microwave Limb Sounder on the AURA spacecraft
SABER: Sounding of the Atmosphere using Broadband Emission Radiometry

New Physics, Dynamics & Chemistry

Support DA for the Mesosphere & Lower Thermosphere (MLT)

- Longwave radiation extended to *p*<0.01hPa using Fomichev parameterization of non-LTE CO_2 cooling
- Near-IR CO_2 heating corrected for non-LTE
- Fully prognostic ozone and water vapor
  - 3D initialization & spectral advection
  - Add ozone, stratospheric water vapor, trace gases to NAVDAS-AR
  - Linearized odd-oxygen and water vapor photochemistry schemes (former also transitioned to NCEP GFS August 2006)
  - Prognostic ozone and water feed into radiation to modify radiative heating/cooling (fully interactive)
  - “Cold tracer” for PSC (or PMC) formation and heterogeneous ozone loss
- prognostic CH_4 and N_2O capabilities added, via initialization, advection & parameterized chemistry
- new MLT parameterizations of non-orographic gravity wave drag and diffusion
- and <u>many</u> other additions too…..

NRL participation in JCSDA Activities

- JCSDA Associate Director (Navy): Pat Phoebus
- Chair, Science Steering Committee: Craig Bishop
- Technical Liaison: Nancy Baker
- Microwave Working Group co-chair: Steve Swadley
- Infrared Working Group: Ben Ruston
- CRTM Working Group: Ben Ruston

External Activities

- IPO Soundings Operational Algorithm Team (SOAT): Steve Swadley
- IPO Microwave OAT: Gene Poe, Steve Swadley
- AMS Satellite Meteorology and Oceanography Committee member: Nancy Baker
- 2nd Surface Properties Workshop Co-Chair: Ben Ruston
- NRL-MRY is the local host for the 17th International TOVS Study Conference, April 14-20, 2009.

Questions?