Impact of NPP Satellite Assimilation in the US Navy Global Modeling System

Presented by Benjamin Ruston

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Monterey, CA

JCSDA Seminar
December 12, 2012

A few comments …

- Naval Research Laboratory (NRL)
  - Main lab is in Washington, DC
  - Marine Meteorology Division – Monterey, CA
  - Oceanography and Marine Geosciences – Stennis, MS

- NRL Monterey
  - Co-located with Fleet Numerical Meteorology and Oceanography Center (FNMOC)

Overview

- NRL data assimilation systems and summary
- NPP ATMS calibration activities
- NPP ATMS assimilation experiments and impacts

- Other reading on the topic:

Bormann N., A. Fouilloux, and W. Bell, 2012. Evaluation and assimilation of ATMS data in the ECMWF system. ECMWF tech memo #689.

Doherty, A., N. Atkison, W. Bell, B. Candy, S. Keogh, and C. Cooper, 2012. UK Met Office, Forecast R&T report #569.

Navy's Data Assimilation Tools

NCODA

NRL Coupled Ocean Data Assimilation System
Multivariate Analysis of ocean u,v,T,s,ice,SSH,SWH.
Global, Regional, Local Ocean Data Assimilation.

NAVDAS

NRL Atmospheric Variational Data Assimilation System
3D Variational Analysis, Observation Space.
Global, Regional, or Local Application.

NAVDAS-AR

NAVDAS Accelerated Representer
4D Variational Analysis, Weak Constraint, Model Space.
Global or Regional Application. High Altitude DA.

ADJOINTS

NAVDAS(–AR) Adjoints of 3D & 4D Data Assimilation Systems
NOGAPS TLM; Moist Adjoint
COAMPS®TLM; Moist Adjoint, ***including explicit moist physics***

NAVOBS

NAVDAS-Adjoint OBservation Monitoring System (web-based)
Real-time monitoring of all data assimilated.
Identification of observation quality problems.
Real-time data selection and data targeting.

Ensemble DA

Ensemble Kalman Filter Algorithm
Testing for COAMPS® using real observations.
EnKF/4DVAR Hybrid for the NAVDAS-AR framework.

NRL/FNMOC Global Analysis System

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

NRL Scientists developed and transitioned to FNMOC the first operational global 4D-Var in the United States: 23 September 2009

- Full 4D-Var algorithm solved in observation space using representer approach
- Weak constraint formulation allows inclusion of model error
- **T319L42, model top at 0.04 hPa (~70km) current operations at FNMOC**
  - **NAVGEM T359L50, model top at 0.04 hPa (~70 km) next target at FNMOC**
- More effective use of asynoptic and single-level data
- **More computationally efficient than NAVDAS (3D-Var) for large # of obs**
  - NAVDAS assimilated ~500K observations in each cycle
  - NAVDAS-AR assimilates ~2.2 M observations per cycle
- **Adjoint developed for observation impact with real-time web monitoring capability, computed 4x/day**

NOGAPS/NAVDAS-AR Operational System Observational Data Types Assimilated

Conventional Data Types

- Radiosondes and Pibals
- Dropsondes
- Driftsonde (Concordiasi)
- Land and Ship Surface Obs
- Aircraft Obs
  - AIREPS
  - AMDAR
  - MDCRS
- Synthetic Obs
  - TC Bogus

NOAA-15,16,18,19
METOP-A
AQUA, TERRA
GOES, MTSAT, METEOSAT
DMSP F15,16,17,18
WindSat
COSMIC 1-6, GRAS, GRACE-A,
SAC-C, CORIS, C/NOFS, Terra SAR-X

Satellite Data Types

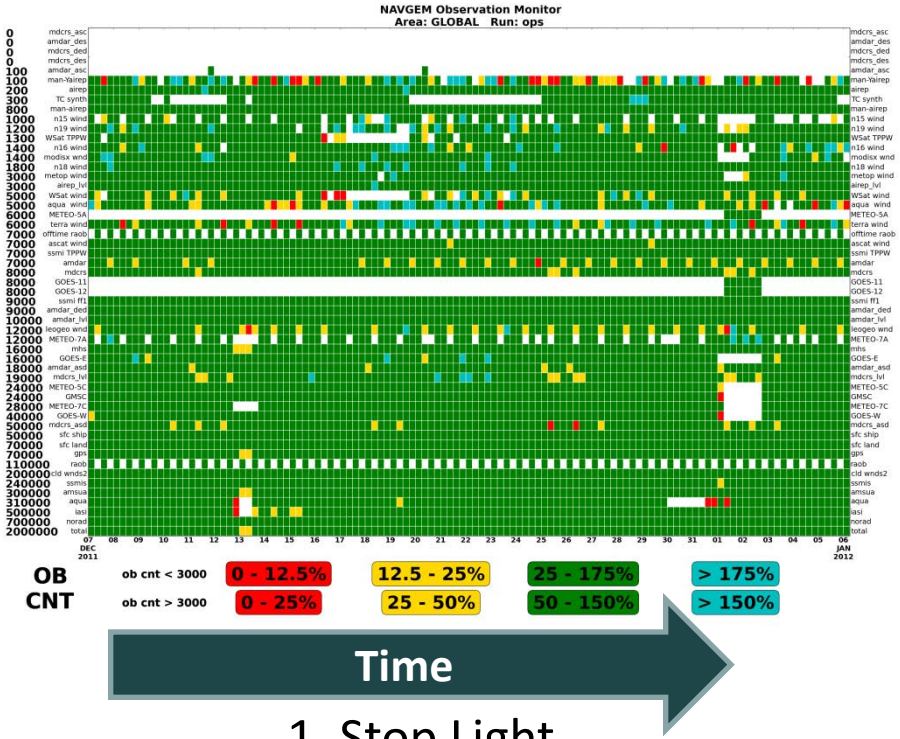
- Surface Winds
  - Scatterometer, ASCAT and ERS-2
  - SSMI/SSMIS
  - WindSat
- Feature Tracked Winds
  - Geostationary (6 satellites)
  - Polar Orbiters (AVHRR and MODIS)
  - Combined polar/geo winds (CIMSS)
- Total Water Vapor
  - SSMI/SSMIS TVAP
  - WindSat TVAP
- GPS Bending Angle
- IR Sounding Radiances
  - IASI and AIRS
- MW Sounding Radiances
  - 6 AMSU-A (Ch 4-14)
  - 3 SSMIS (Ch 2-7, 22-24)
  - 3 SSMIS/3 MHS 183 GHz

NAVOBS – NAVDAS-AR Monitoring System

Continuous AR Monitoring Capability

- complementary to FNMOC scorecard
  verify/validate experiments against OPS

Stop Light

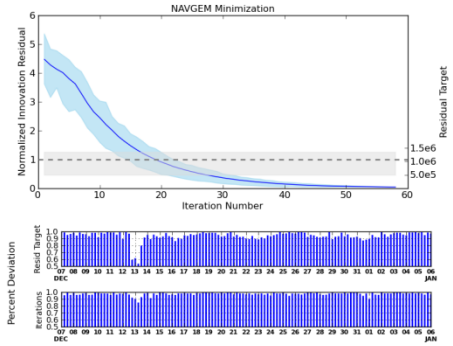


1. Stop Light

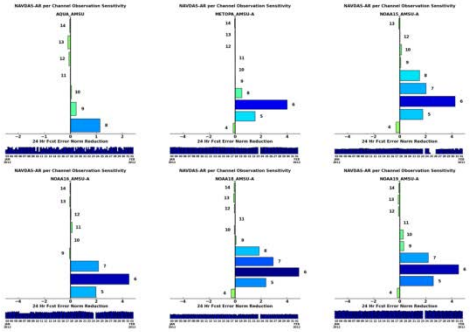
Verify data counts

2. AR Minimization

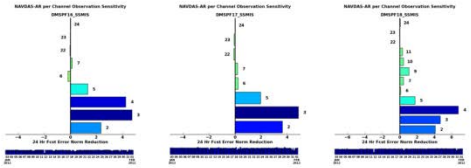
Convergence stability



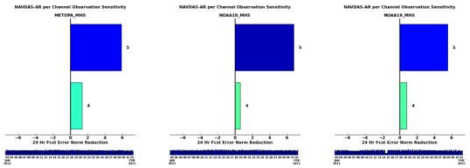
AMSU-A



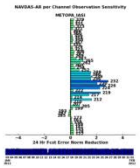
SSMIS



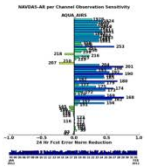
MHS



IASI



AIRS

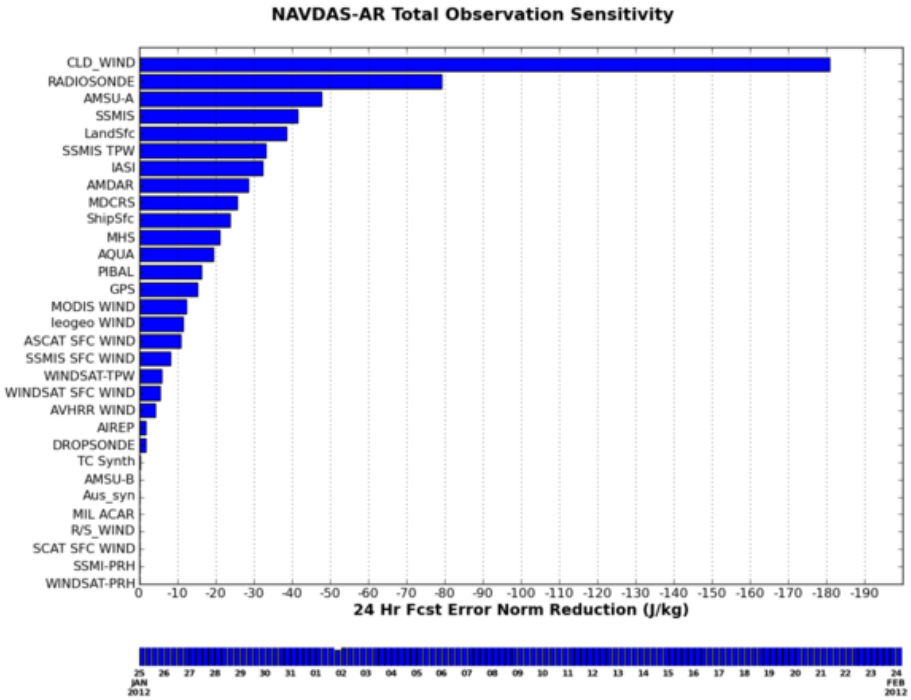


3. Observation Impact

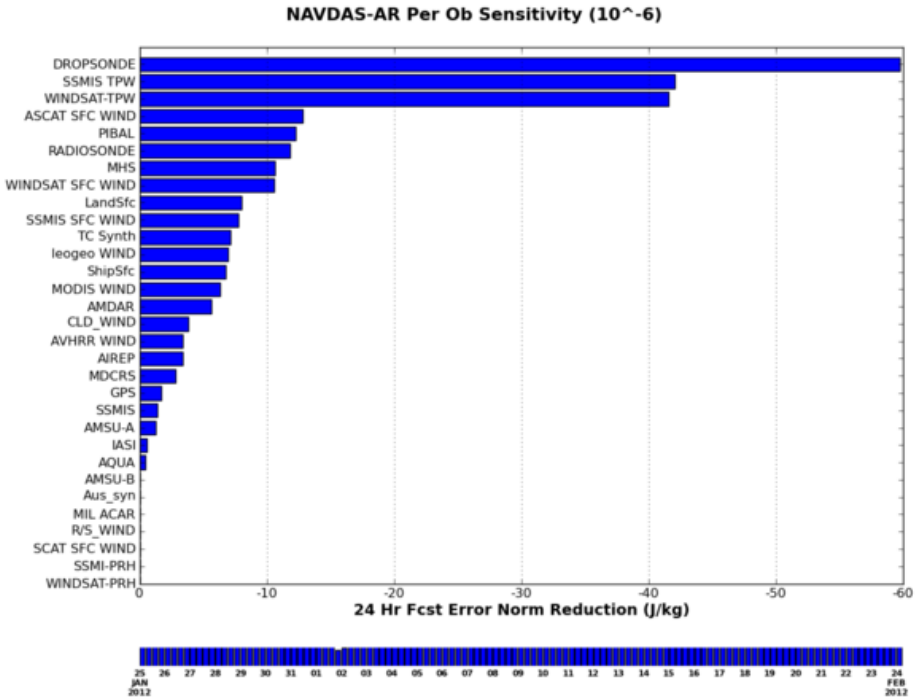
IR/MW data influence on forecast error

NAVDAS-AR Observation Impact

Total Impact



Per Ob



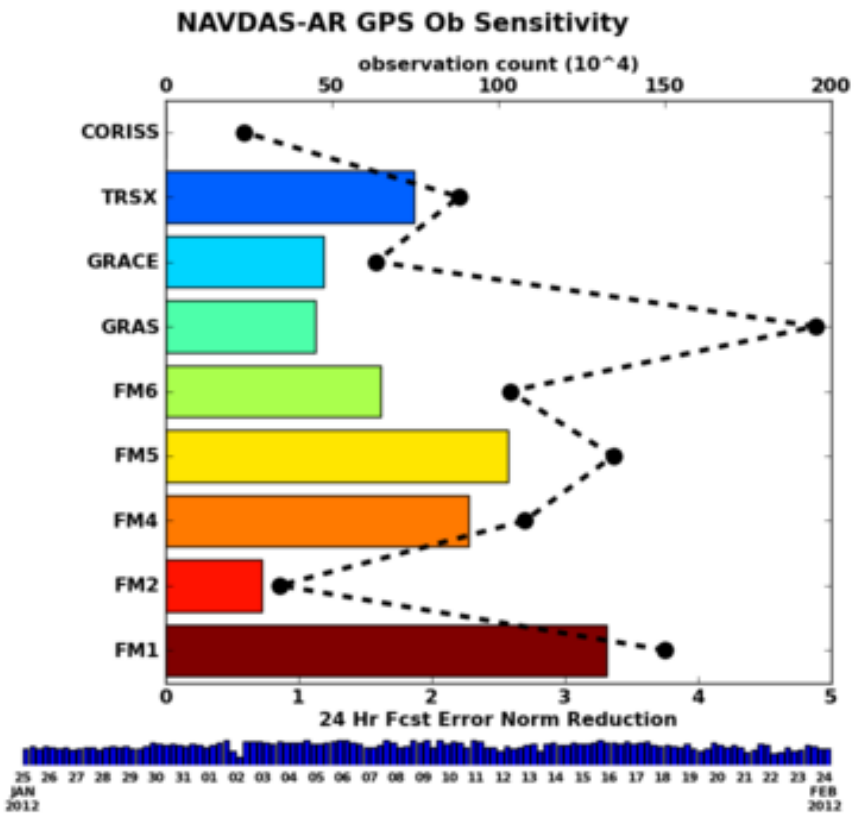
- Ability to rank sensors by total or per observation impact on error

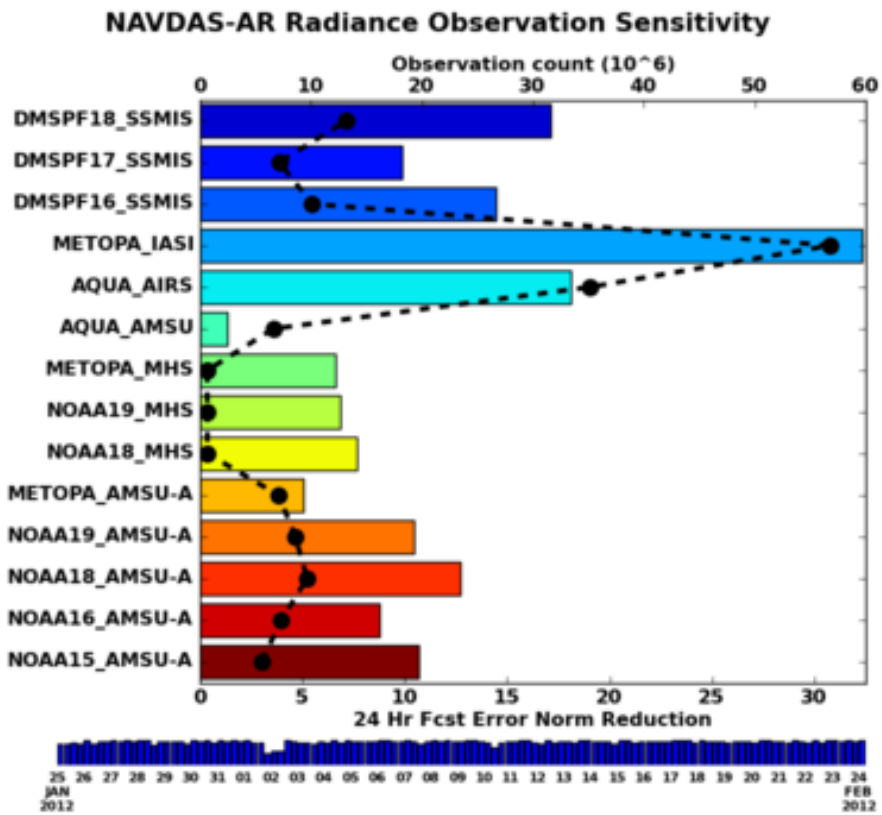
http://www.nrlmry.navy.mil/metoc/ar_monitor/

NAVDAS-AR Observation Impact

GPS sensors

IR and MW radiometers

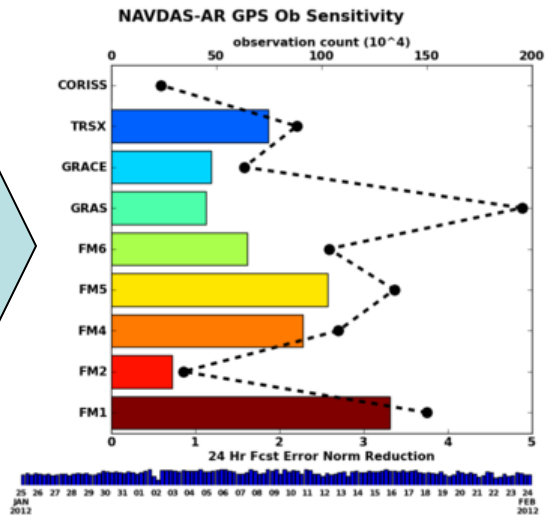


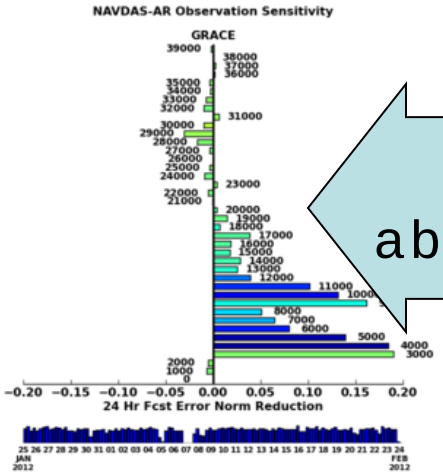


- GPS impact is almost an order of magnitude less than a radiometer
  - why? because this metric is weighted predominantly in the troposphere

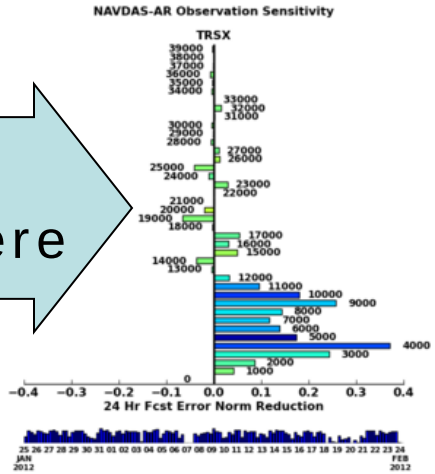
NAVDAS-AR Observation Impact

GPS sensors

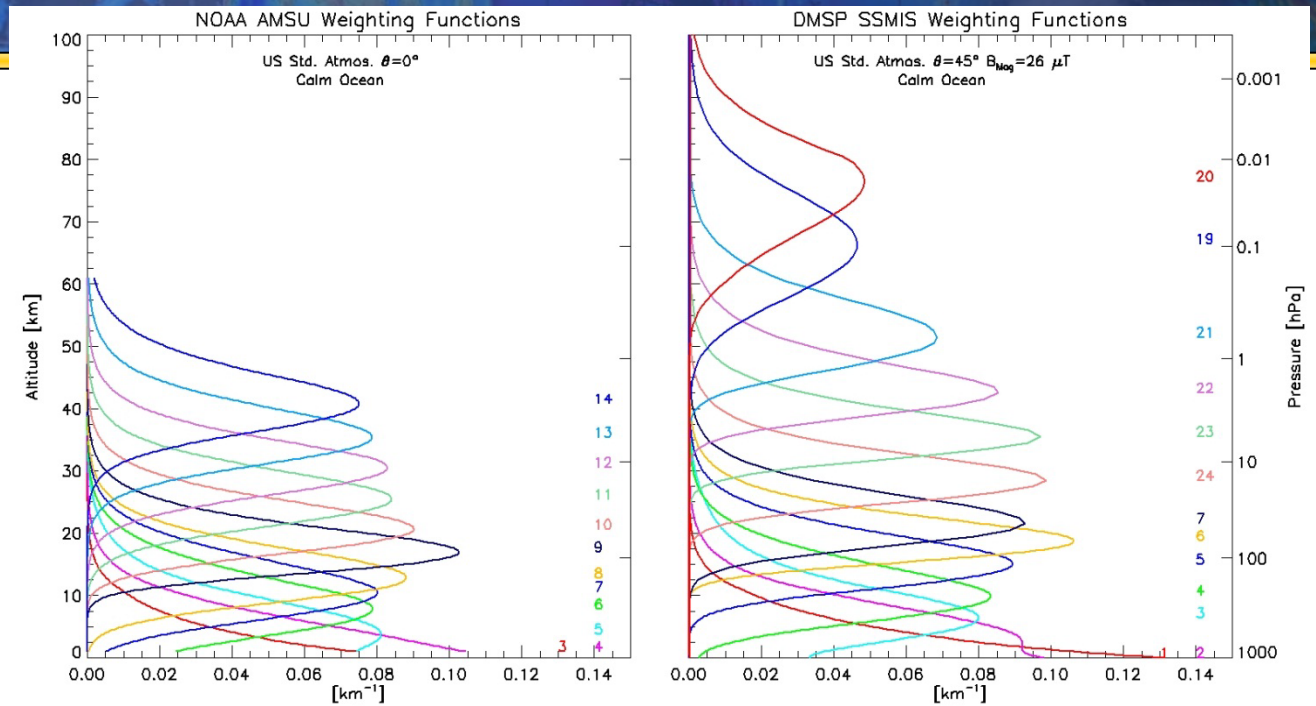


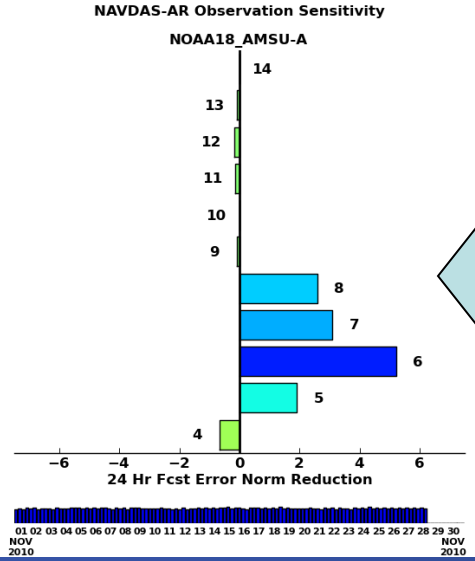


Impact reduced above the troposphere

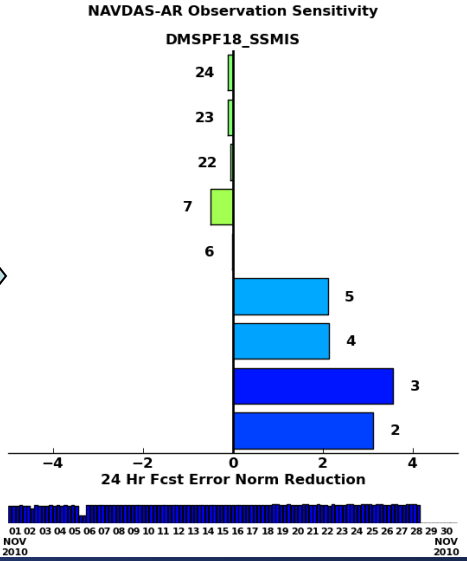


NAVDAS-AR Observation Impact





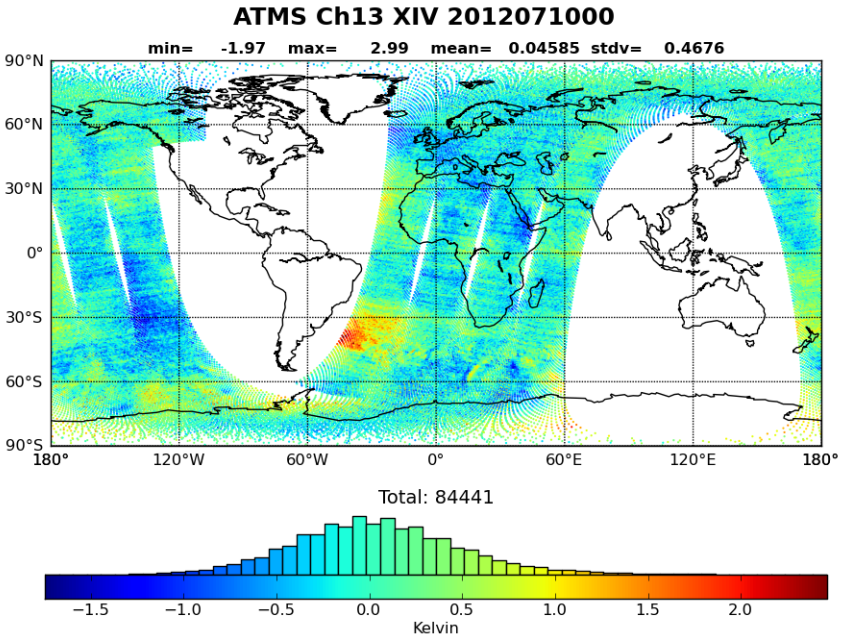
Impact reduced above troposphere



NPP ATMS Calibration

A few slides on NRL's involvement in calibration/validation of the NPP ATMS sensor

- "striping" noise inherent in the sensor
  - Both a roll maneuver and a re-examination of the pre-launch thermal vacuum tests have verified the presence of the "striping" noise
- Seen most easily with full-resolution un-averaged data
- Various levels of scene averaging have shown limited ability to mitigate striping noise



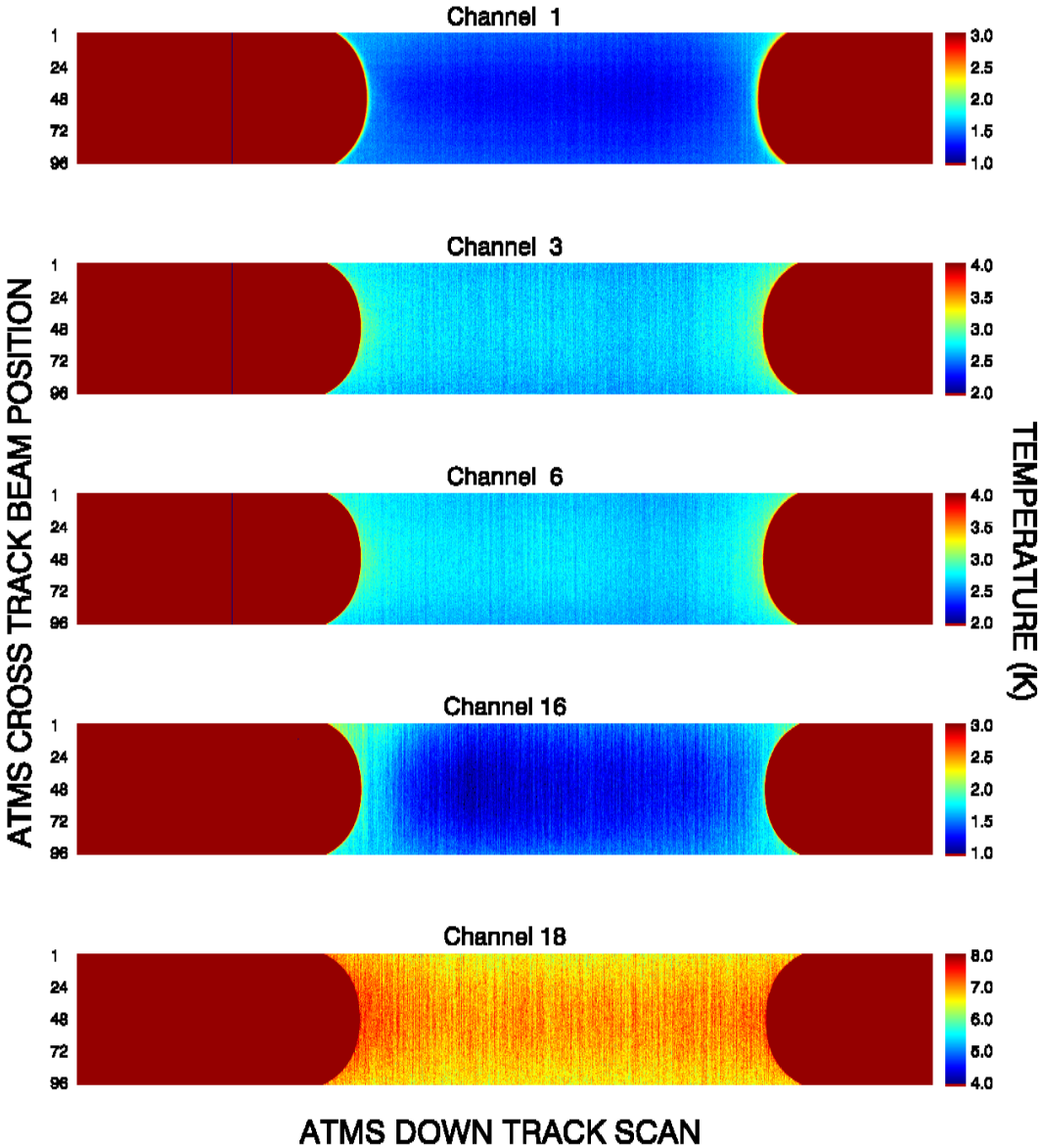
NPP ATMS Calibration

NPP Roll Maneuver 20 Feb 2012

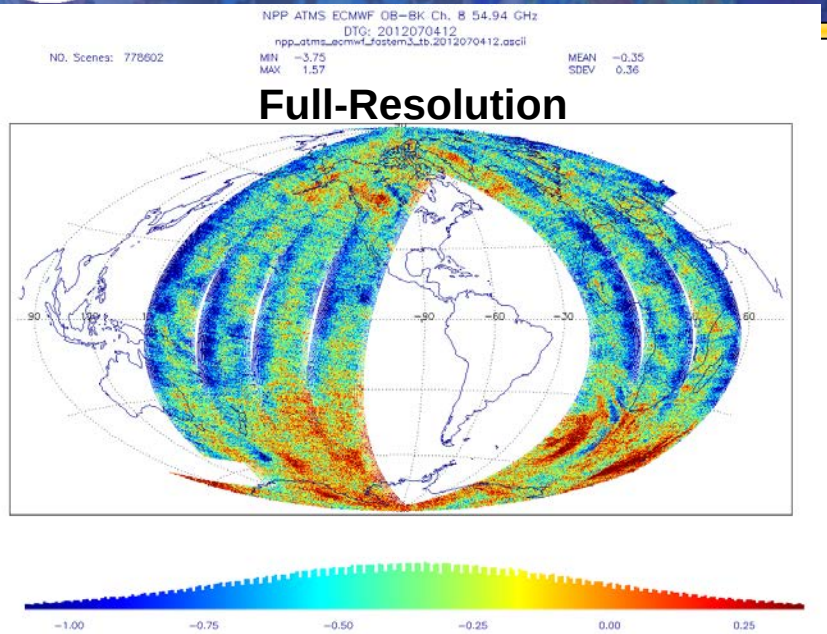
ATMS Scan Striping Observed in Cold Space View

Northrup Grumman claims the striping is due to 1/f noise, but this has not been verified

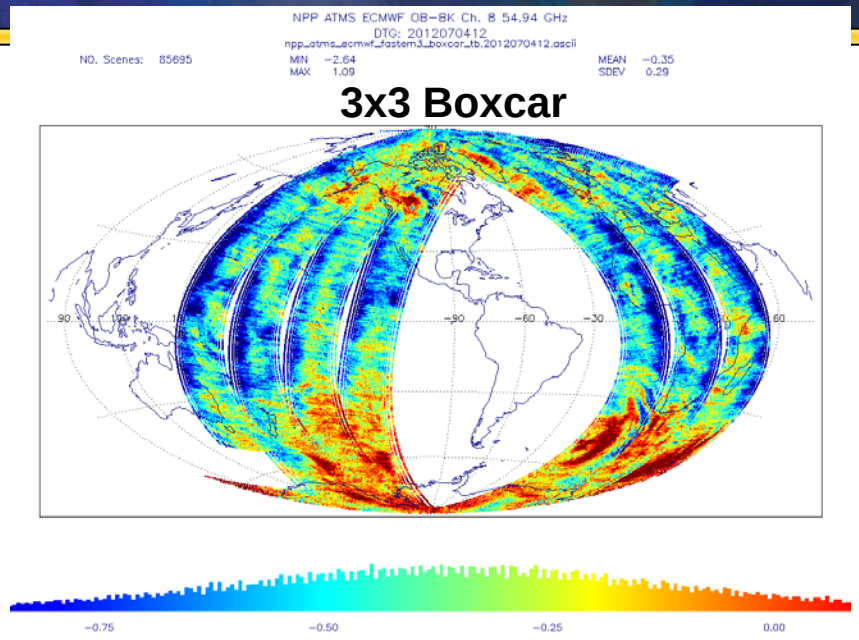
AMSU-A/MHS do not exhibit this 1/f type noise



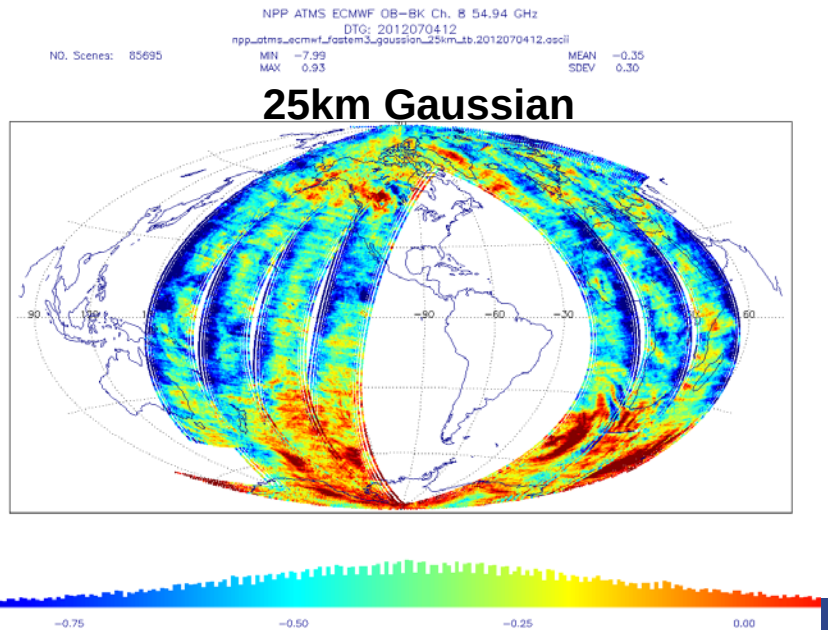
NPP ATMS Calibration



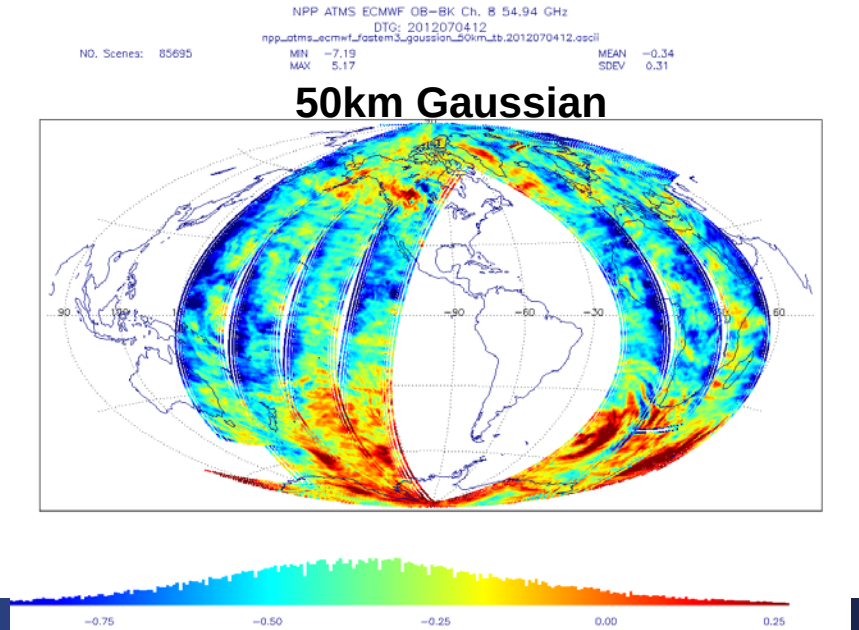
Full-Resolution



3x3 Boxcar



25km Gaussian



50km Gaussian

NPP ATMS Calibration

ATMS Spatial Smoothing Effects on OB-BK Std. Dev.

DTG: 2012070412

Channel	Full Res	3x3 Boxcar	Gaussian σ=25km	Gaussian σ=36km	Gaussian σ=50km
7	0.43	0.37	0.36	0.36	0.37
8	0.36	0.29	0.30	0.30	0.31
9	0.45	0.38	0.38	0.38	0.39
10	0.46	0.32	0.33	0.32	0.34
11	0.56	0.33	0.33	0.32	0.33
12	0.64	0.43	0.43	0.42	0.43
13	0.90	0.56	0.54	0.52	0.52
14	1.24	0.72	0.69	0.66	0.65
15	2.04	1.18	1.12	1.06	1.04

Boxcar Average

$$\tilde{T}_B(s,b) = \frac{1}{9}\sum_{i=-1}^{i=1}\sum_{j=-1}^{j=1} T_B(s_i, b_j)$$

s: Scan Position, *b*: Beam position

Gaussian Average

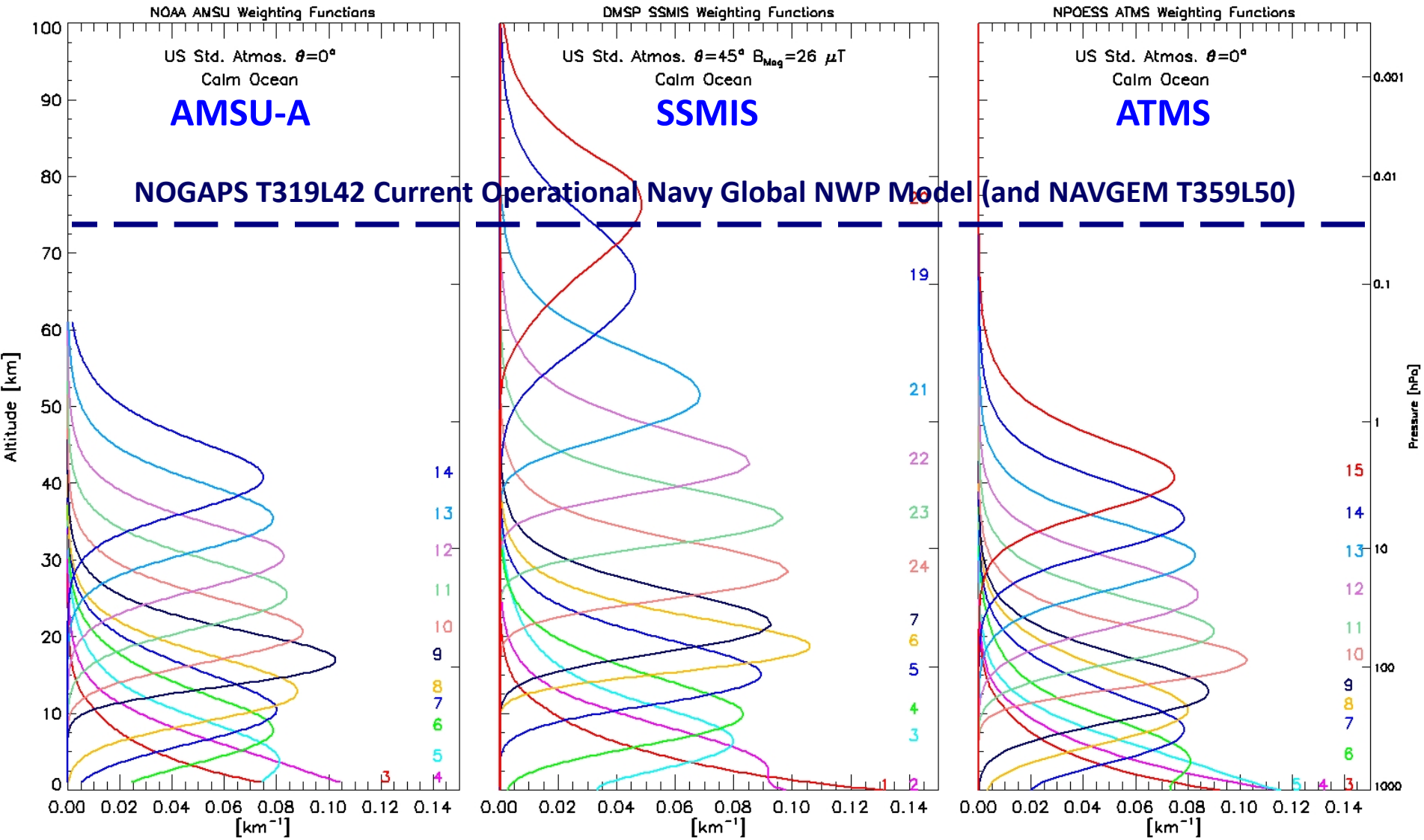
$$\hat{T}_B(s,b) = \sum_{i=1}^{N} w_i(p) T_B(\delta s_i, \delta b_i)$$

$$w_i(p) = \exp\left(\frac{-r_i^2}{2\sigma^2}\right)$$

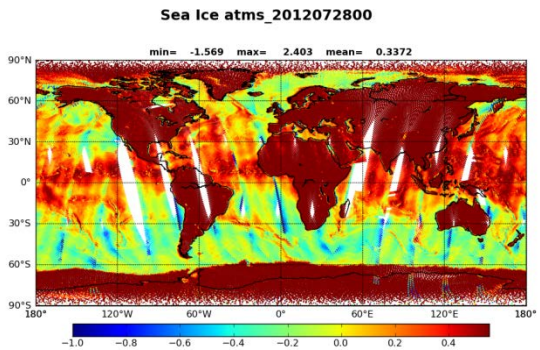
$$r_i = \left\|(s,b),(s+\delta s_i, b+\delta b_i)\right\|$$

N = 200 pre-computed closest points

ATMS Assimilation Experiment



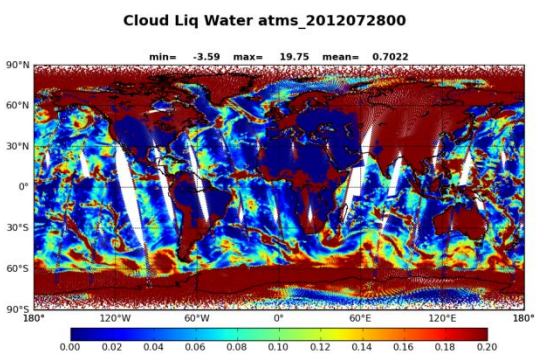
NPP ATMS Quality Control



Sea Ice

>0.55 for lower tropospheric and water vapor channels (ch1-6, ch16-20)

$$Sea\ Ice = 2.85 + 0.020 * T_{B(23GHz)} - 0.028 * T_{B(50GHz)}$$



Cloud Liquid Water (clw)

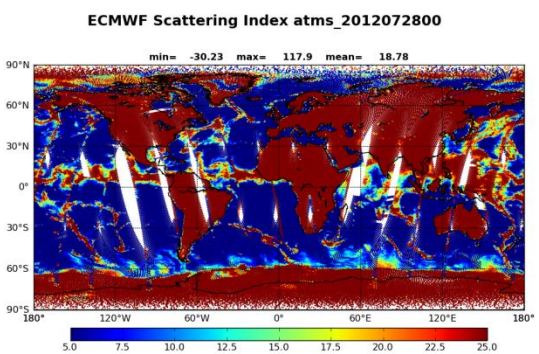
> 0.175 for lower tropospheric and water vapor channels (ch1-6, ch16-20)

> 0.2 for upper tropospheric and water vapor channels (ch7-8, ch21-22)

$$aa = 8.240 - (2.622 - 1.846\mu) * \mu$$

$$\mu = cos(sat\ zenith)$$

$$\mathrm{clw} = \mathrm{aa} + 0.754 * \ln\left(285.0 - T_{B(23GHz)}\right) - 2.265 * \ln\left(285.0 - T_{B(31GHz)}\right)$$



Scattering Index (si)

> 9 for lower tropospheric and all water vapor channels (ch1-6, ch16-22)

> 18 for upper tropospheric (ch7-8)

$$si_{ecmwf} = T_{B(si)} - (-46.94 + 0.248 * \theta)$$

$$si_{bennartz-grody} = T_{B(si)} - (-39.201 + 0.1104 * \theta)$$

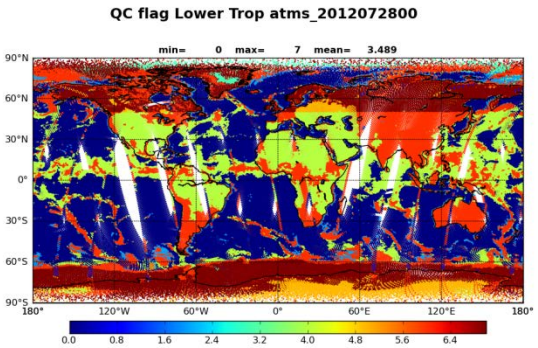
$$\Delta T_{B(si)} = T_{B(89GHz)} - T_{B(165GHz)}$$

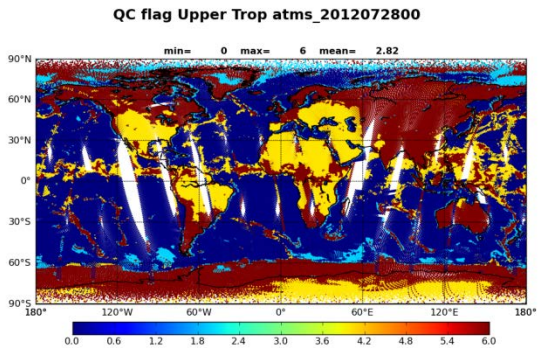
$$\theta = sat\ zenith$$

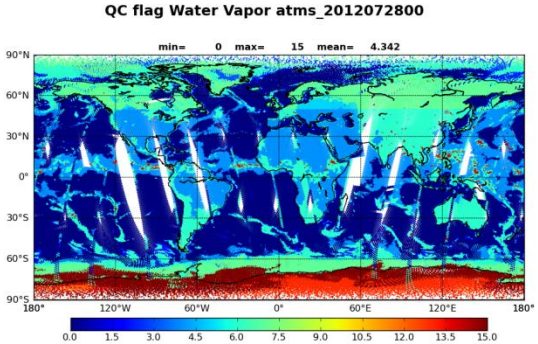
Mean 183 GHz *(not shown)*

< 240 for all water vapor channels (ch18-22)

NPP ATMS Quality Control







Sea Ice
Flag Value += 1 (2**0)

Cloud Liq Water
Flag Value += 2 (2**1)

Scattering Index
Flag Value += 4 (2**2)

Mean 183 GHz
Flag Value += 8 (2**3)

These checks do not affect ch10-15

Final check for all assimilated channels on innovation

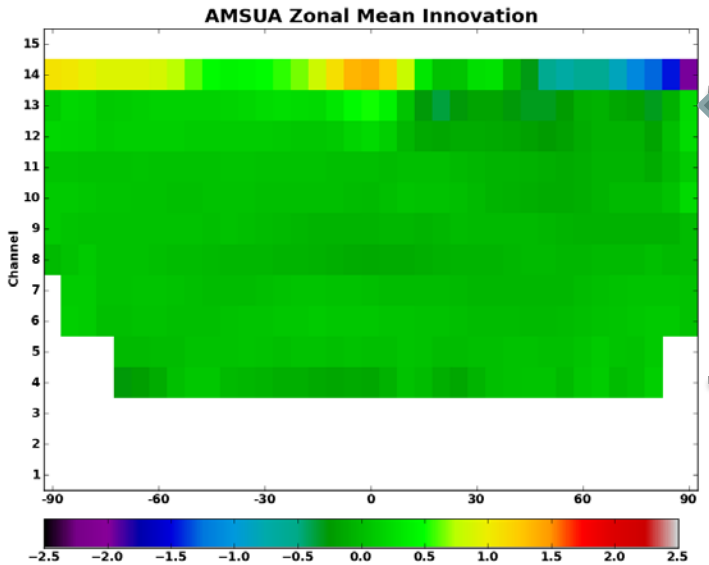
- Normalized currently by observation error
- Being replaced by normalization with square root of the sum of observation and background error

ATMS Assimilation Experiment

- Two global models used:
  - Current OPS configuration
    - NOGAPS T319L42
    - ZZtop - Harris and Kelly (2001) type off-line bias correction
  - Next-generation configuration
    - NAVGEM T359L50
    - varBC – variational bias correction
- Experiments both:
  - Start from the same initial conditions
  - Spin-up (zero bias correction at the beginning)
    - Variational bias correction typically longer spin-up times
  - Both bias correction schemes contain
    - Offset
    - Scan position predictor
    - Two airmass predictors 850-300 hPa, 200-50hPa
    - Satellite radiances are bias corrected while radiosondes and GNSS-RO bending angle are not

NPP ATMS Assimilation

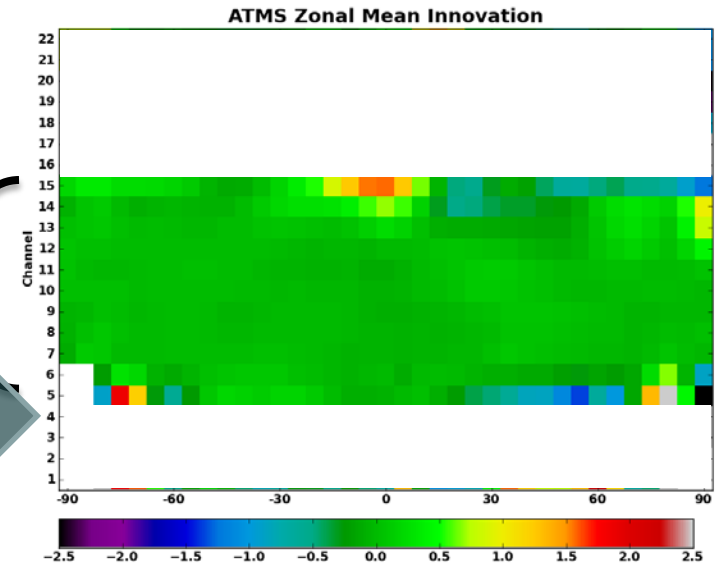
NPP ATMS mean Zonal innovation

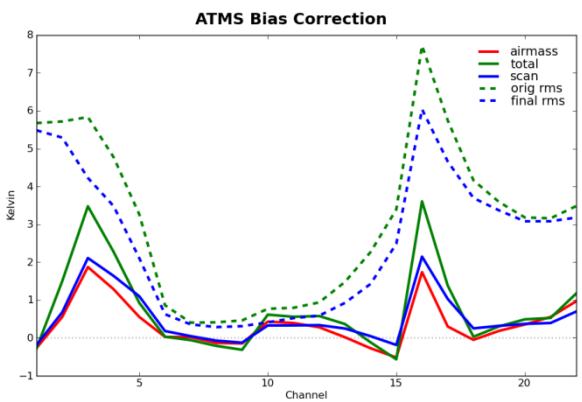


AMSUA ch4-14

≈

ATMS ch5-15



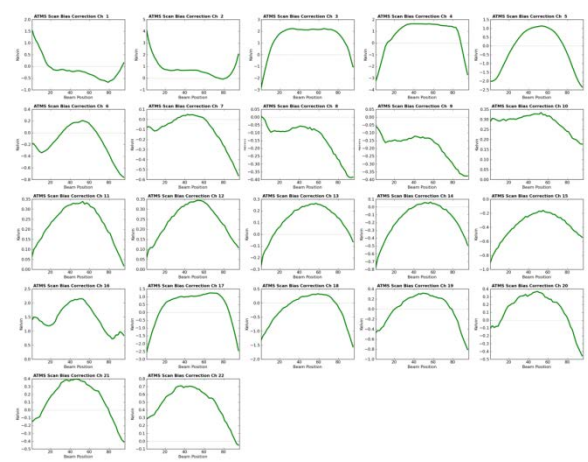


Bias Corrections

←airmass

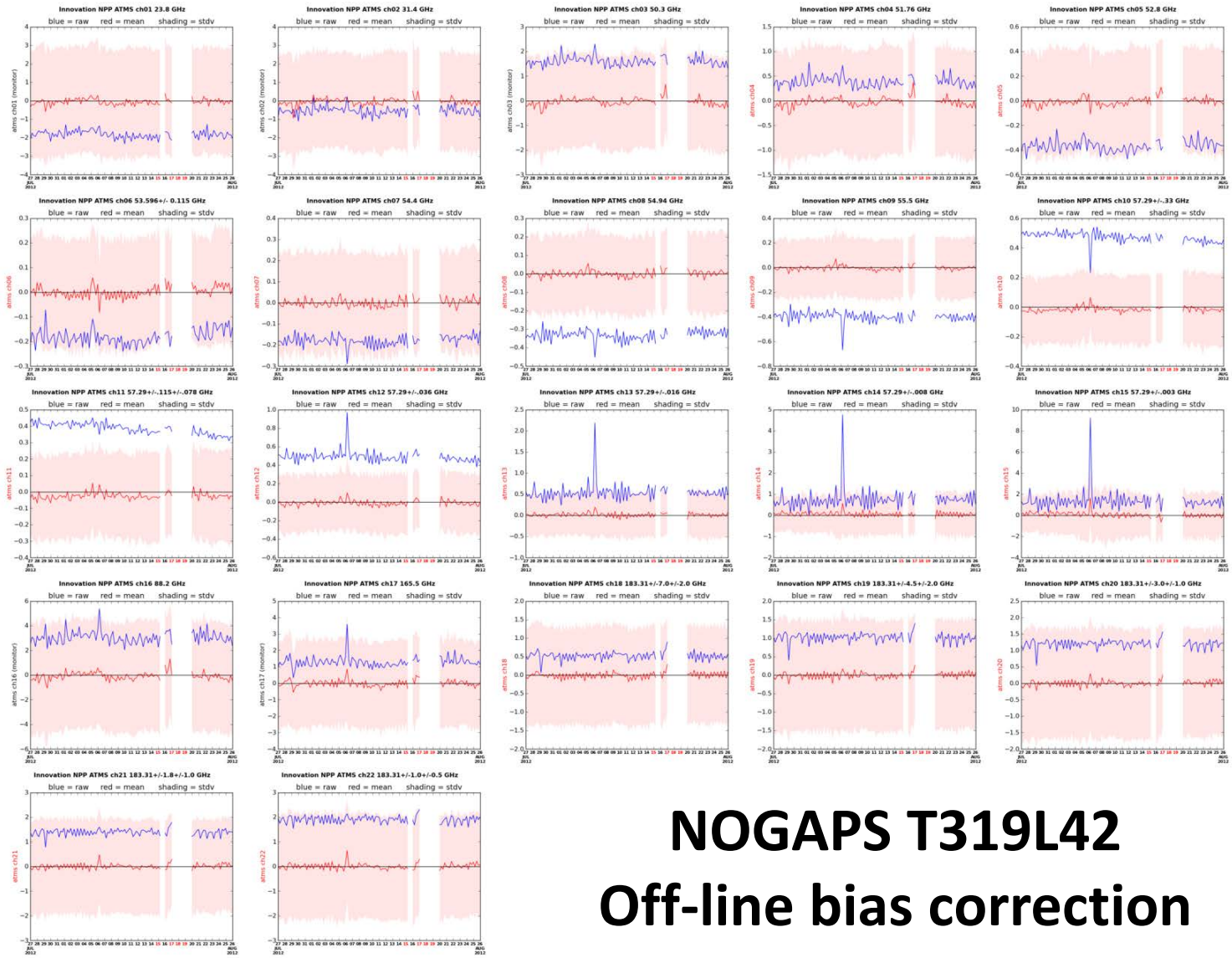
- and -

residual scan→



NPP ATMS Assimilation

ATMS

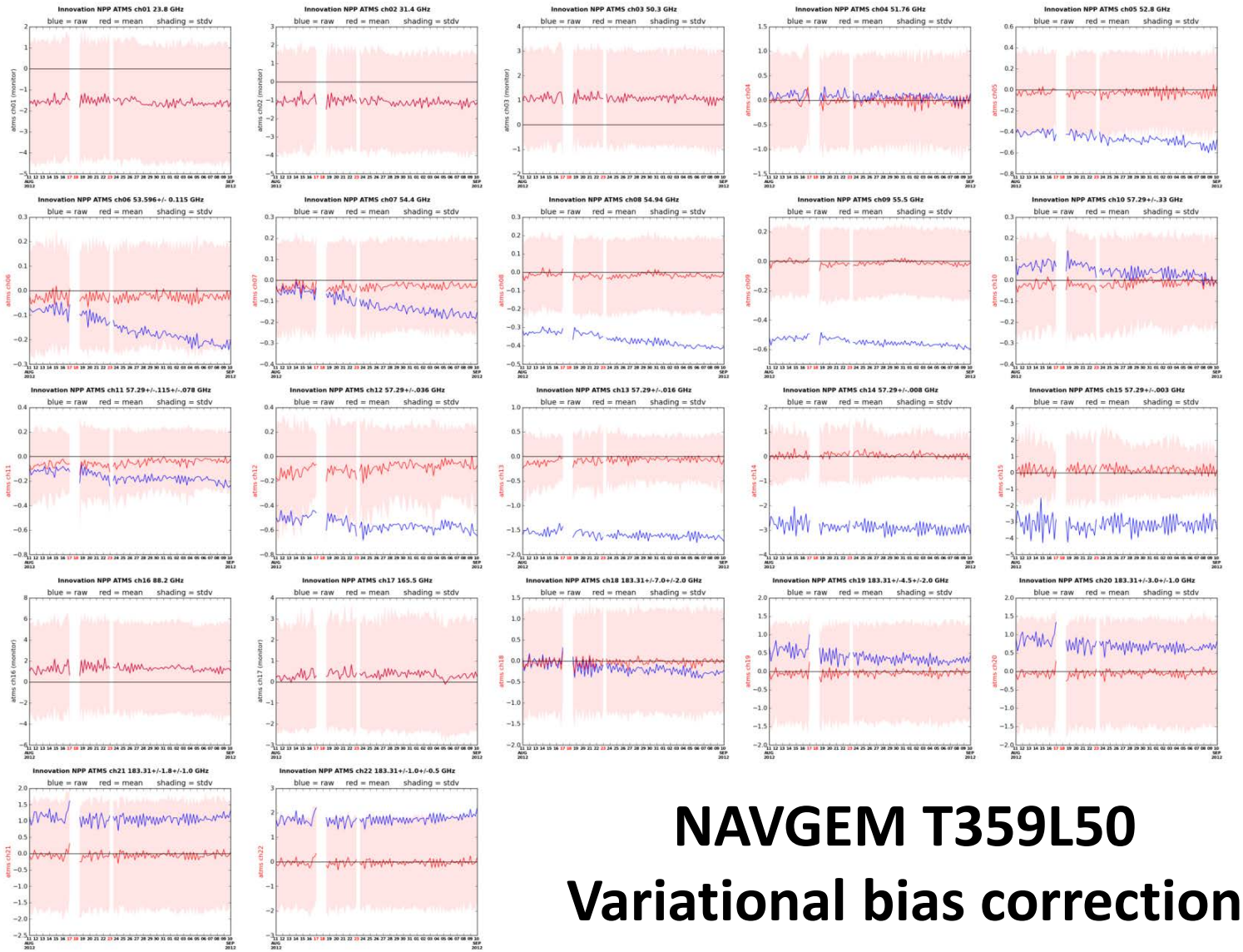


NOGAPS T319L42

Off-line bias correction

NPP ATMS Assimilation

ATMS

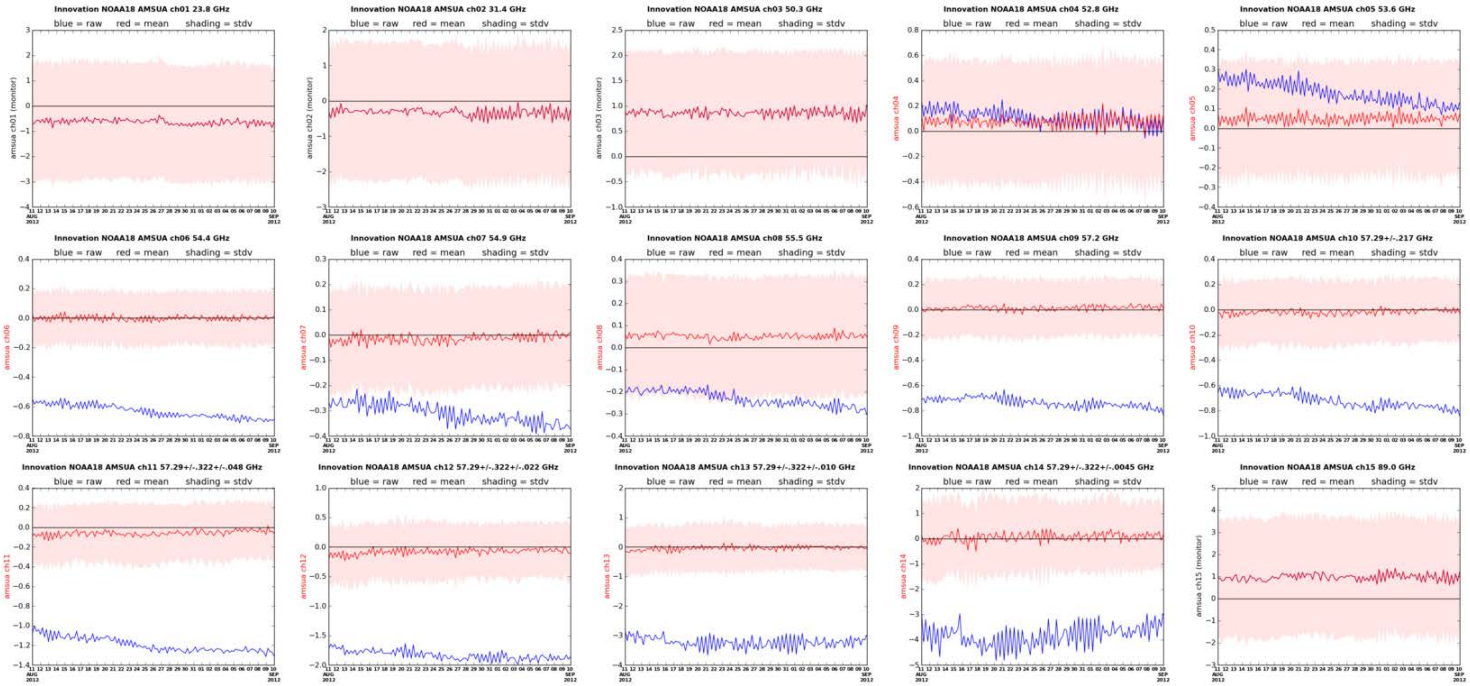


NAVGEM T359L50

Variational bias correction

NPP ATMS Assimilation

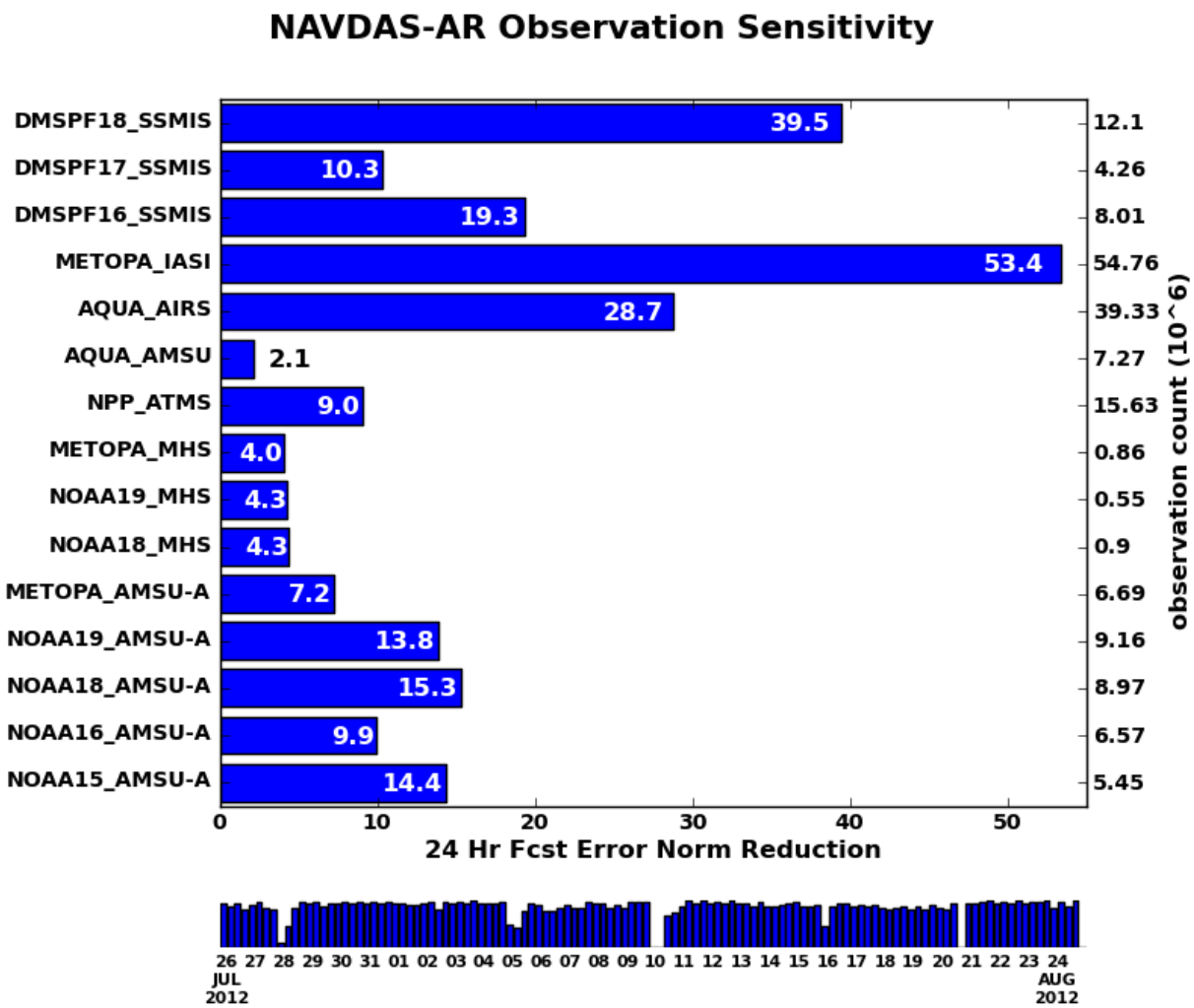
AMSU-A



NAVGEM T359L50

Variational bias correction

NPP ATMS Assimilation

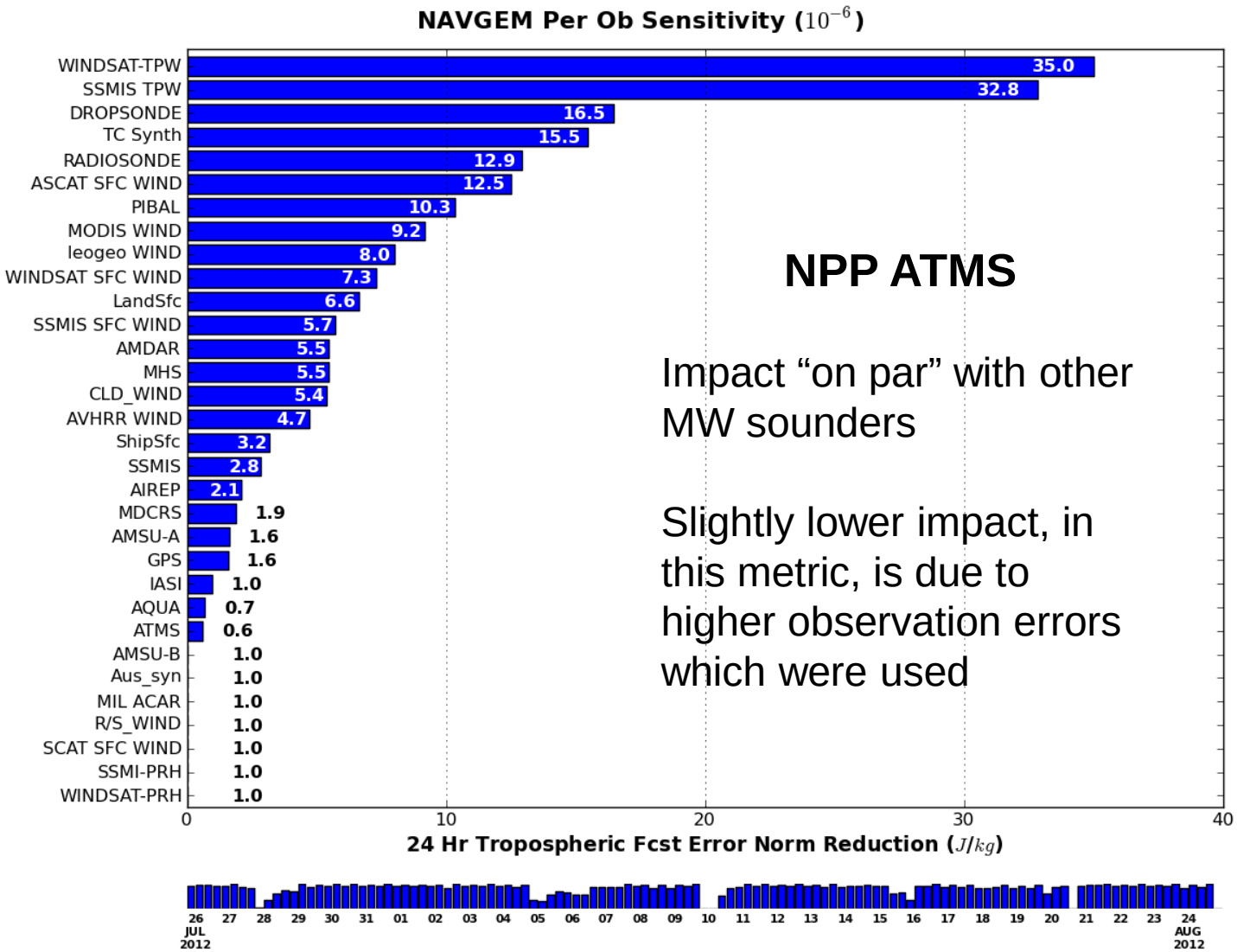


NPP ATMS

Impact “on par” with other MW sounders

Slightly lower impact, in this metric, is due to higher observation errors which were used

NPP ATMS Assimilation

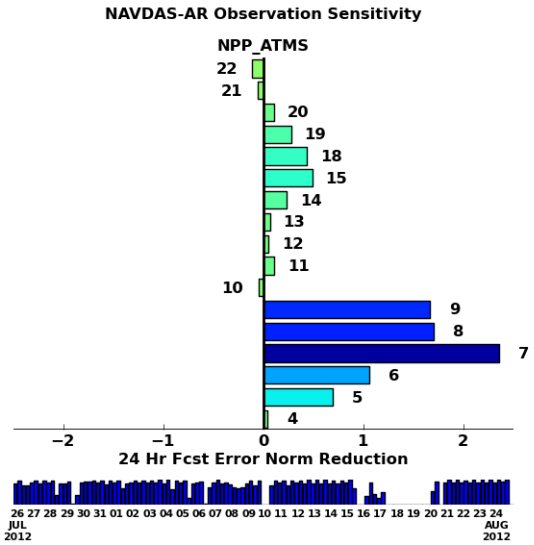


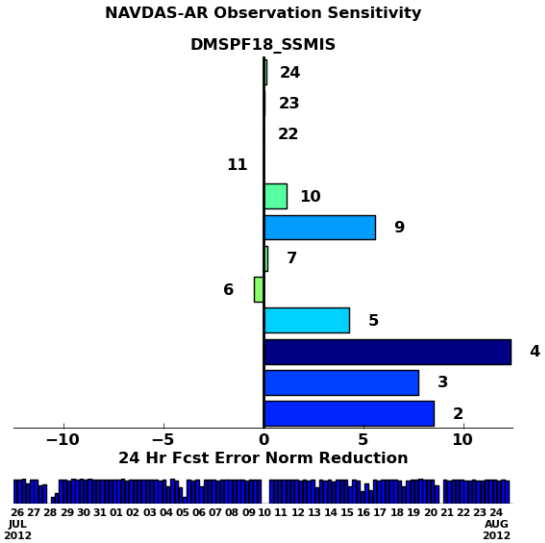
NPP ATMS

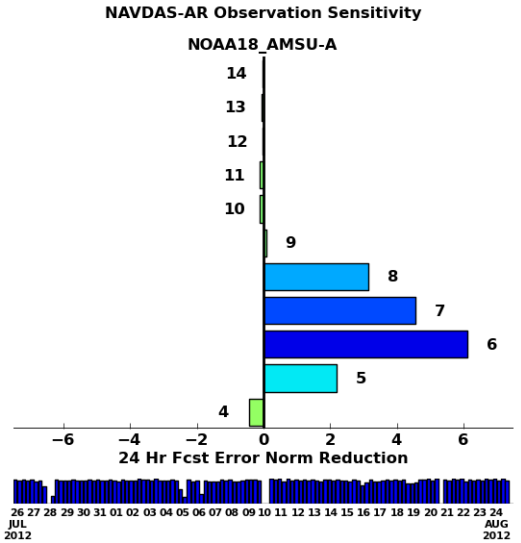
Impact “on par” with other MW sounders

Slightly lower impact, in this metric, is due to higher observation errors which were used

NPP ATMS Assimilation



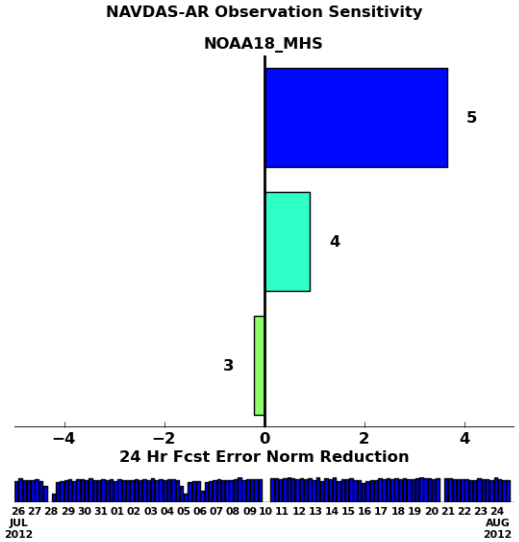




MW Sounders

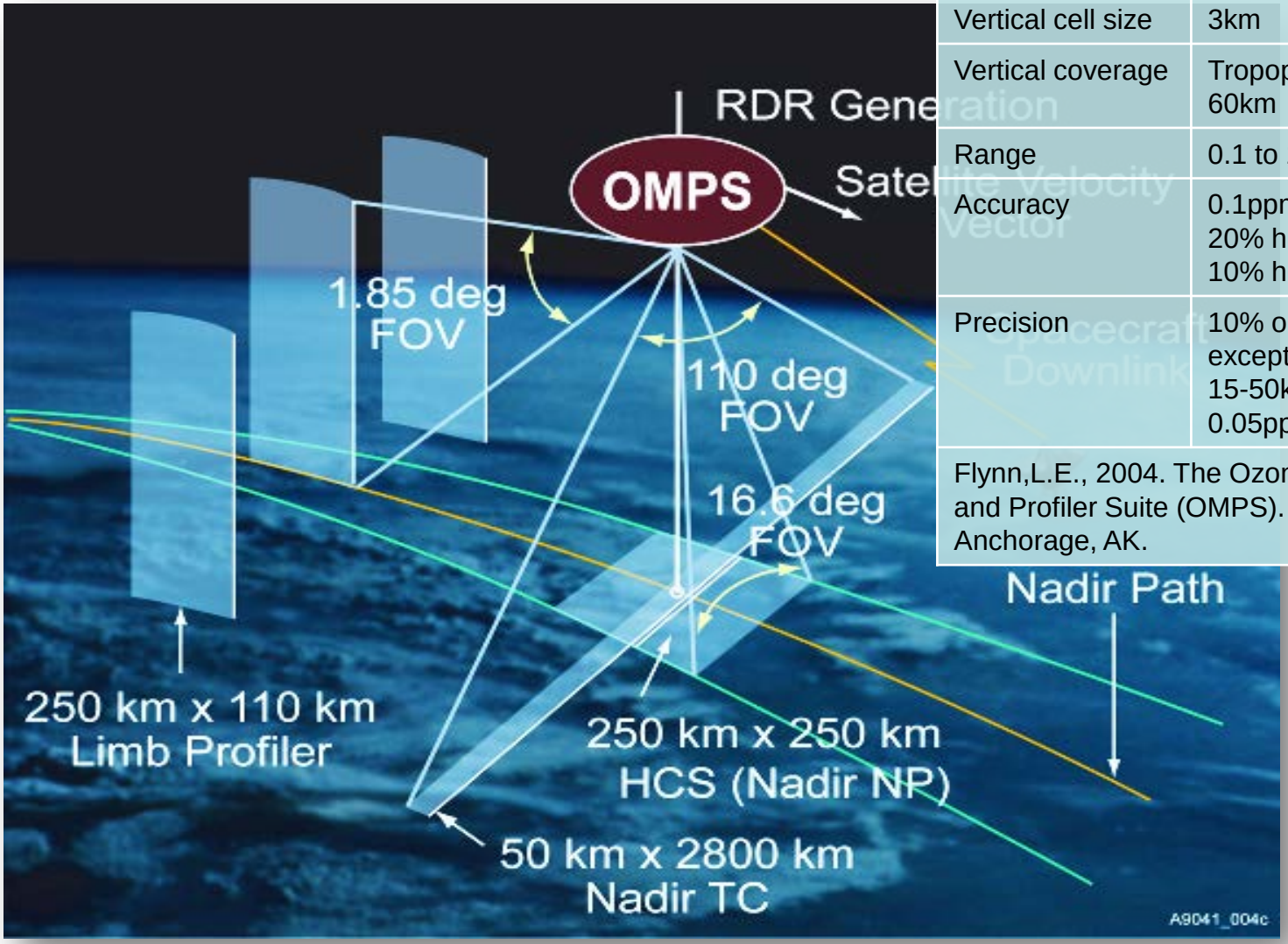
Using this metric, channels with weighting function peaks between 200 – 600 hPa give the biggest reduction of the 24-hour error norm.

For the humidity sounding channels the lowest peaking water vapor channels show the largest reduction.



NPP OMPS Assimilation

OMPS Nadir-Profiler



Property	Performance
Horizontal cell size	250km
Vertical cell size	3km
Vertical coverage	Tropopause to 60km
Range	0.1 to 15 ppmv
Accuracy	0.1ppmv or 20% h<15km; 10% h>15km
Precision	10% or 0.1ppmv; except between 15-50km 3% or 0.05ppmv

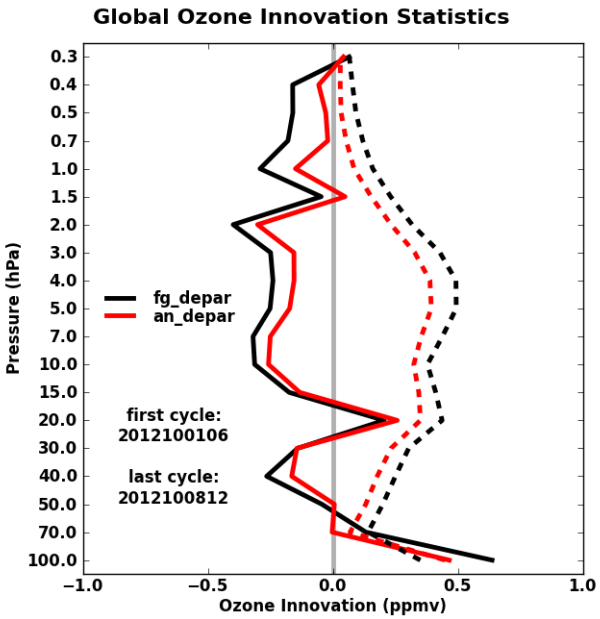
Flynn,L.E., 2004. The Ozone Mapping and Profiler Suite (OMPS). IGARSS, Anchorage, AK.

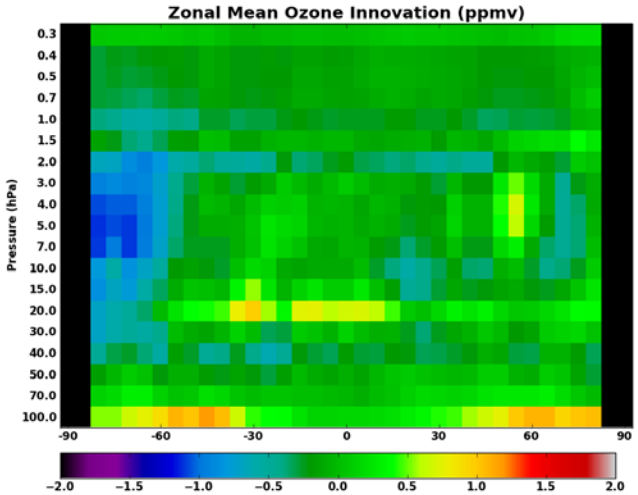
NPP OMPS Assimilation
OMPS Nadir-Profiler

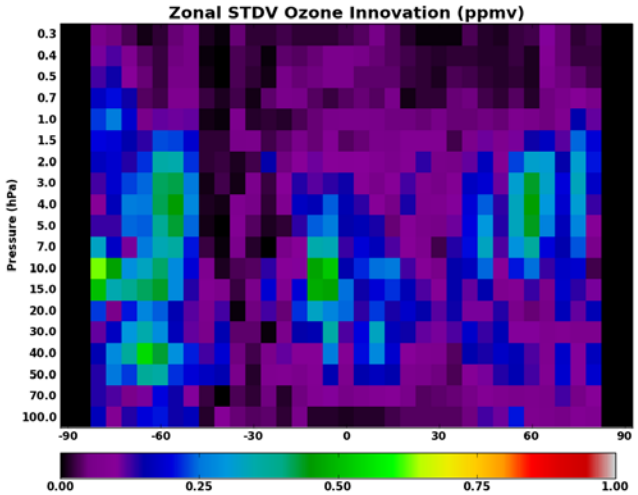
NAVGEM T359L50
With Ozone assimilation from NPP-OMPS

Right: Global innovation relative to background (fg_depar) and analysis (an_depar)

Below: Zonal mean and stdv Innovation (ob-bk)







NRL Student Opportunities

Paid Summer Internships

- Naval Research Enterprise Internship Program (all disciplines)
  - 10-week research program under guidance of a mentor at a Navy Lab;
  - Available to Jr./Sr. or Graduate Students at participating universities;
  - Must be a U.S. Citizen/perm. resident and pass a background check;
  - Stipends are $7,880 for Jr. and Sr.; $10,500 for Graduate Students;
  - Applications typically due around first of January.
  - http://nreip.asee.org or go to ONR.navy.mil under Outreach programs.

Postdoctoral Fellowships

- National Research Council (NRC) Cooperative Research Associateship
  - Applicants must be U.S. citizens/perm. resident/clear background;
  - Applications are reviewed in Feb, May, and August;
  - Appointments are made for one year, with renewal possible;
  - Stipends are $74,872 with a $3,000 travel allotment.
  - http://sites.nationalacademies.org/pga/rap/ , click on sponsors.

- American Society for Engineering Education (ASEE) Postdoctoral Fellowship
  - Similar terms to NRC Postdoc, but with rolling admission dates;
  - May be some differences in stipends, benefits, travel allotments;
  - http://www.asee.org/fellowship-programs/post-doctoral

Conclusions & Future Work

- ATMS is performing well and gives comparable impacts to AMSU-A or SSMIS

- ATMS striping noise is a fact-of-life issue which is hardware driven and only partially mitigated in post-processing. However, ATMS sensors yet to be constructed could use different components and remedy this issue.

- Forecast scores show neutral impact due to the addition of ATMS, this is due to the large redundancy currently enjoyed at this time. However, this sensor overlap will be decreasing rapidly over the next decade.

- ATMS striping noise does not preclude positive impacts from the sensor; however, it will increase the lower bound possible in observation error and consequently lessen the impact which can be derived from the sensor

- Near-term: additional “fine-tuning” of the ATMS quality control
- Longer-term: add Zeeman effect for highest peaking channels