NRL Satellite Assimilation Activities

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Monterey, CA

May 24-25, 2011
JCSDA Science Workshop

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 (~70 km)**
- 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 2.0 M observations per cycle
- **Adjoint developed for observation impact with real-time web monitoring capability, computed 4x/day**

Recent Highlights of Navy Data Assimilation NAVDAS-AR (4D-Var)

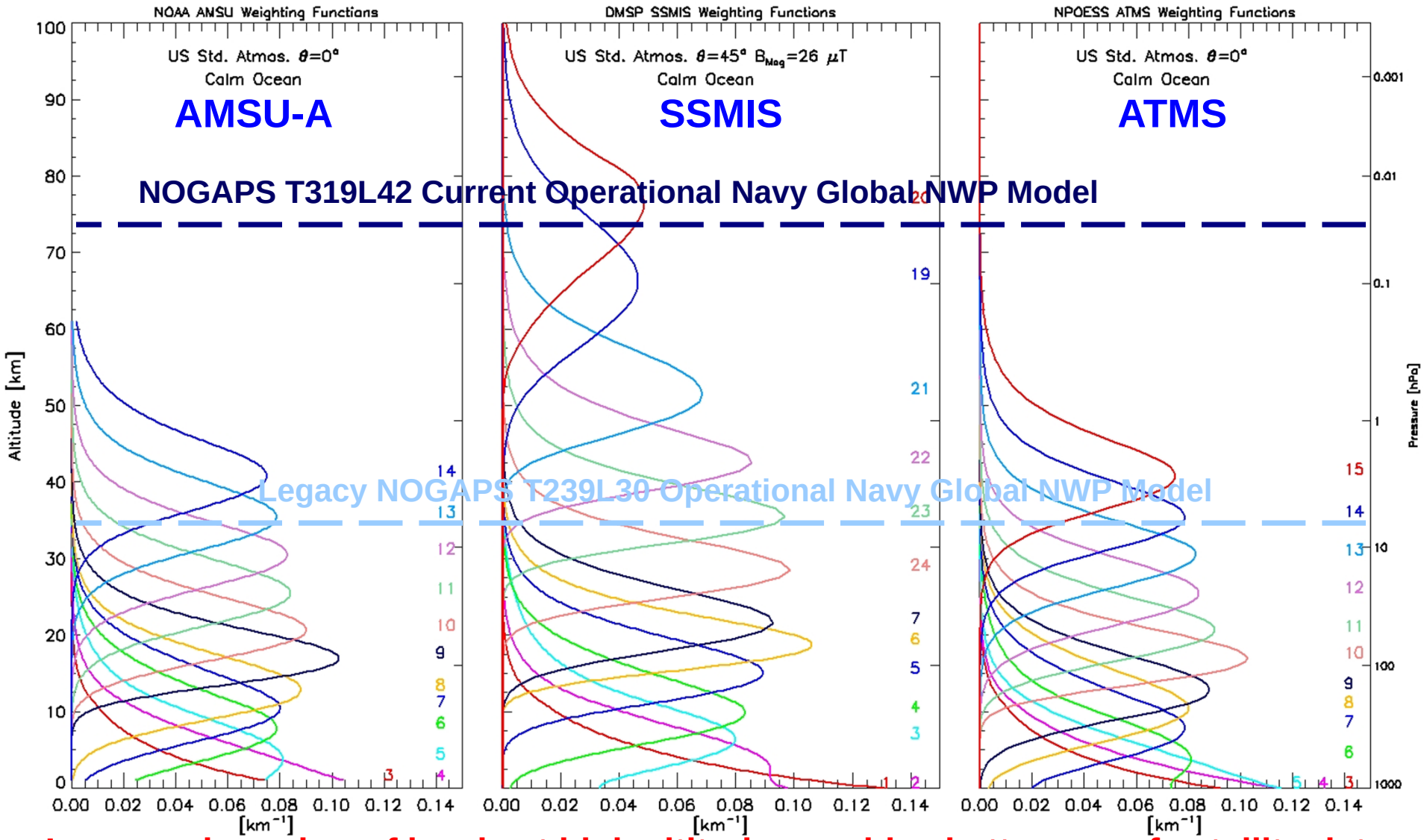
- **NAVDAS-AR *(strong constraint, CRTM)* Operational Sept, 2009**
- **New Satellite Data sources added or improved with NAVDAS-AR**
  - ✓ **IASI, AIRS assimilation added, *refined and skill improved*; NOAA-19 AMSU-A**
  - ✓ **DMSP F16, F17, F18 UPP operational; *Radiances, surface winds, TPW, ice***
  - ✓ **ASCAT, WindSAT *(winds and TPW)***
- **T319L42 NOGAPS/NAVDAS-AR Operational May, 2010**

NOGAPS

- **Subsequent sensors added to NAVDAS-AR**
  - ✓ **GPS RO bending angle Operational Sept, 2010***
    - **COSMIC, GRAS, GRACE-A, Terra SAR-X, SAC-C, C/NOFS**
  - ✓ **RARS ATOVS retransmission data Operational Sept, 2010***
  - ✓ **Combined LEO/GEO atmospheric motion vectors (AMV) Operational Nov, 2010***
  - ✓ **Hourly geostationary winds (AMV) from MTSAT, Meteosat & GOES-W Operational Dec, 2010***
  - ✓ **MHS and SSMIS 183 GHz channel assimilation Operational Jan, 2011**
- **Sensors and enhancements to be added to NAVGEM**
  - ➢ **Variational bias correction**
  - ➢ **SBU/V and MLS ozone, HIRS and Geostationary Clear-Sky Radiance**
  - ➢ **Aerosols, clouds, land surface**

Microwave Atmosphere Sounding Capabilities

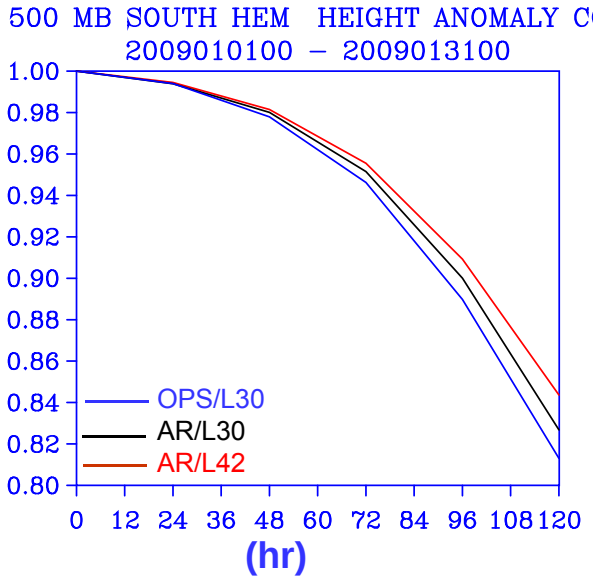
NOGAPS-ALPHA Navy Global NWP Model - Under Development (125 km Model Top)

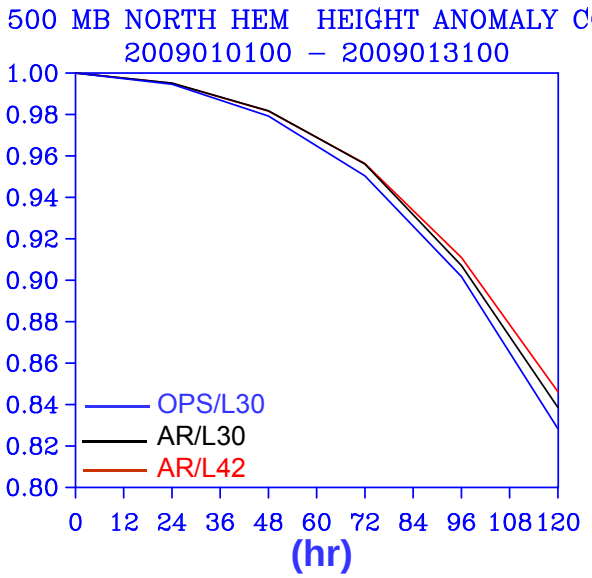


Increased number of levels at high altitudes enables better use of satellite data.

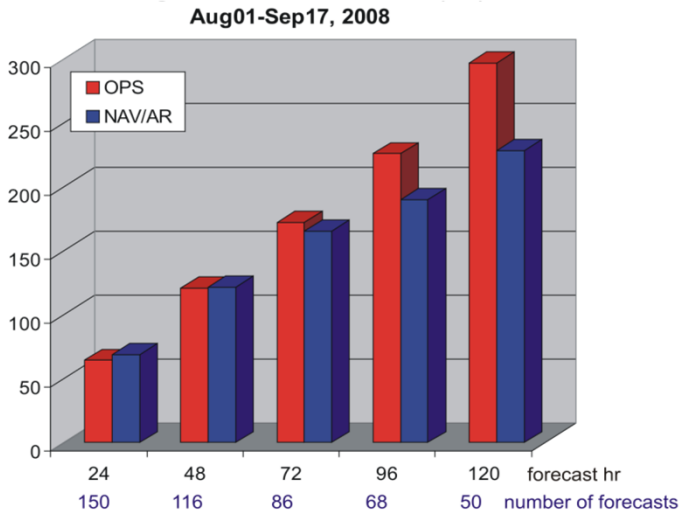
NAVDAS-AR: Operational 23 Sept 2009

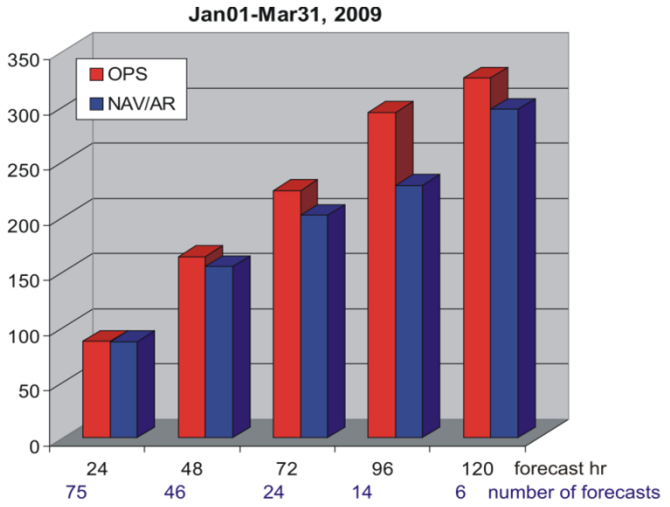
Improvements in both the mid-latitude anomaly correlations, and the Tropical Cyclone track forecasts





Homogeneous TC forecast track errors (nm)



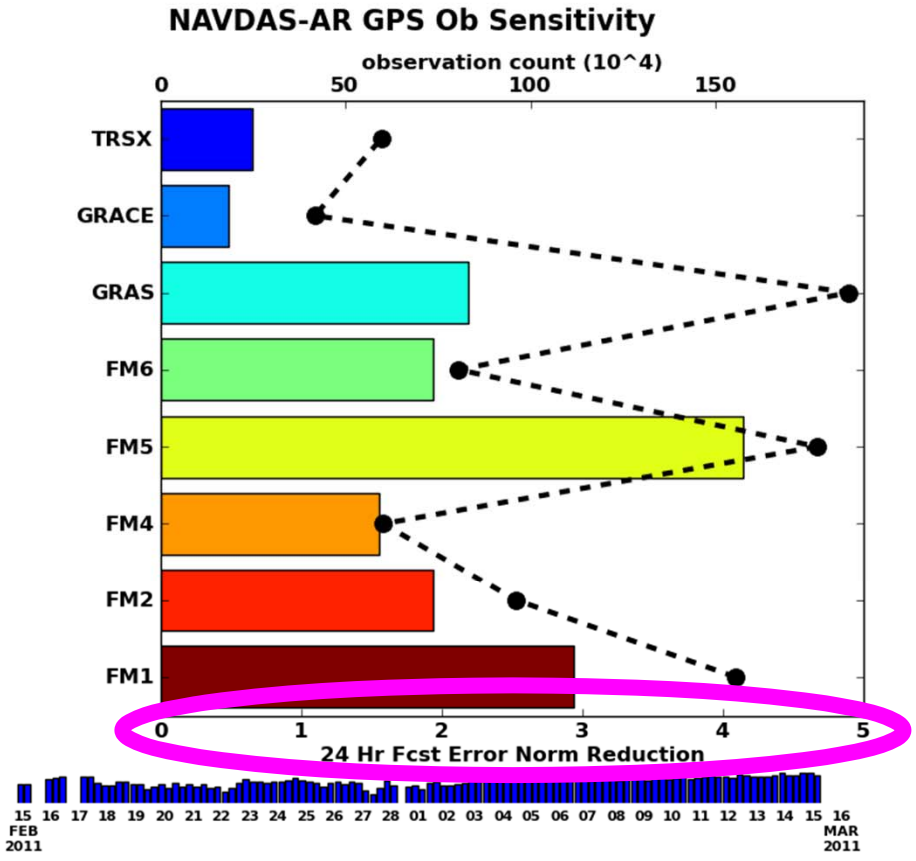


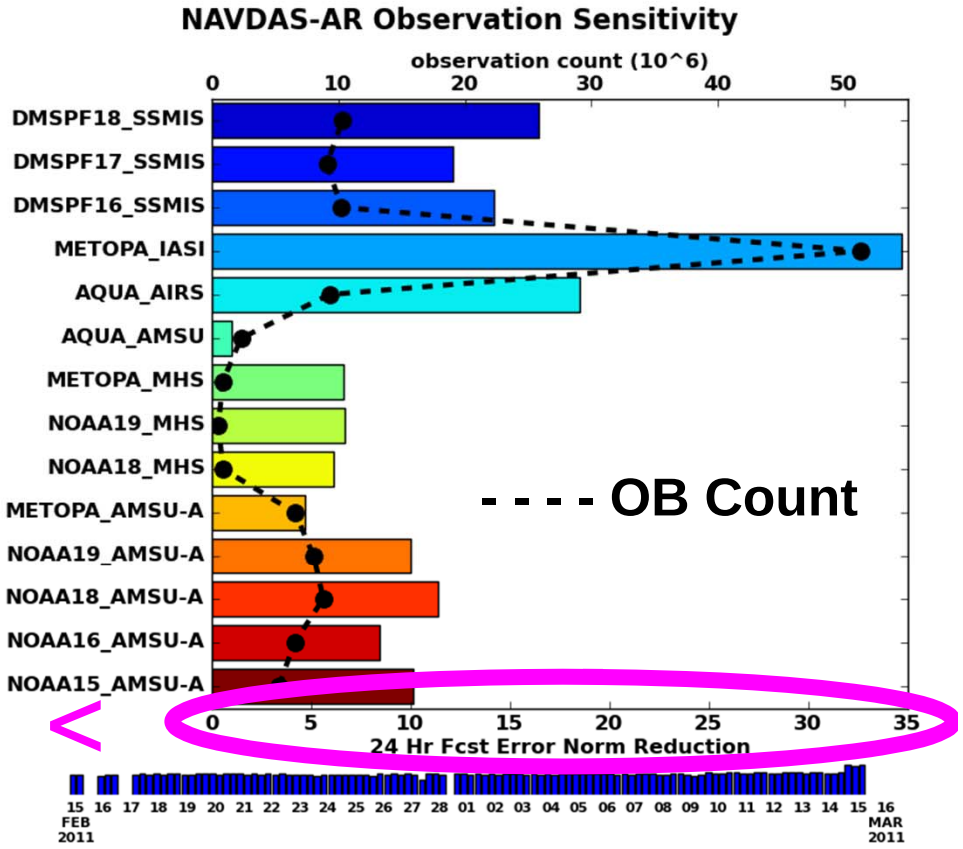
FNMOC OPS Upgrades
Sep 15, 2010

- Addition of GPS bending angle assimilation
  - no bias correction, very low error 8km – 30km
  - EUMETSAT GRAS-SAF Software Deliverable ROPP* version 4
    - *Radio Occultation Processing Package
  - COSMIC FM1-6; GRAS MetOp-A; GRACE-A; Terra SAR-X, SAC-C, and C/NOFS CORISS
- Additional IR/MW radiance for stratospheric channels:
  - 4 -- AMSU-A: ch 11-14
  - 3 -- SSMIS: ch 22-24
  - 10 -- IASI: 122, 128, 135, 141, 148, 154, 161, 173, 185, 187
- Assimilate 24 IASI channels over land/sea-ice
  - prior use of hyperspectral was over open ocean only
- Perform consistent antenna pattern correction for all AMSU-A
  - AVHRR and ATOVS Preprocessing Package (AAPP)
- Supplement real-time AMSU-A data feed with RARS
  - adds 10-15% more data to real-time OPS run

GPS Bending Angle Impacts

Impact of GPS on tropospheric moist error norm for a 24-hour forecast is less than typical for IR and MW sounders, but is consistently positive





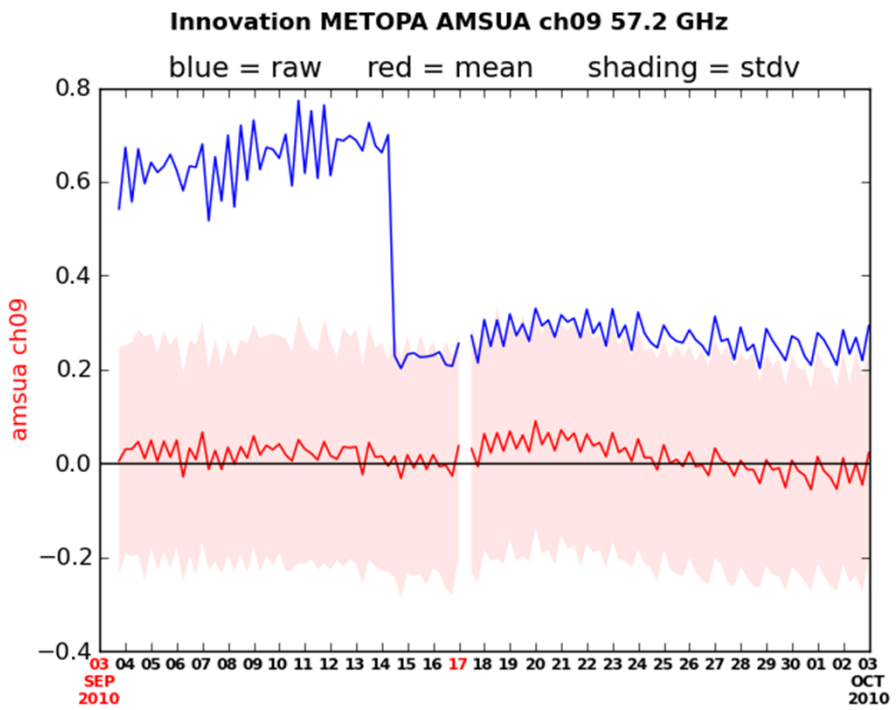
GPS Bending Angle Impacts

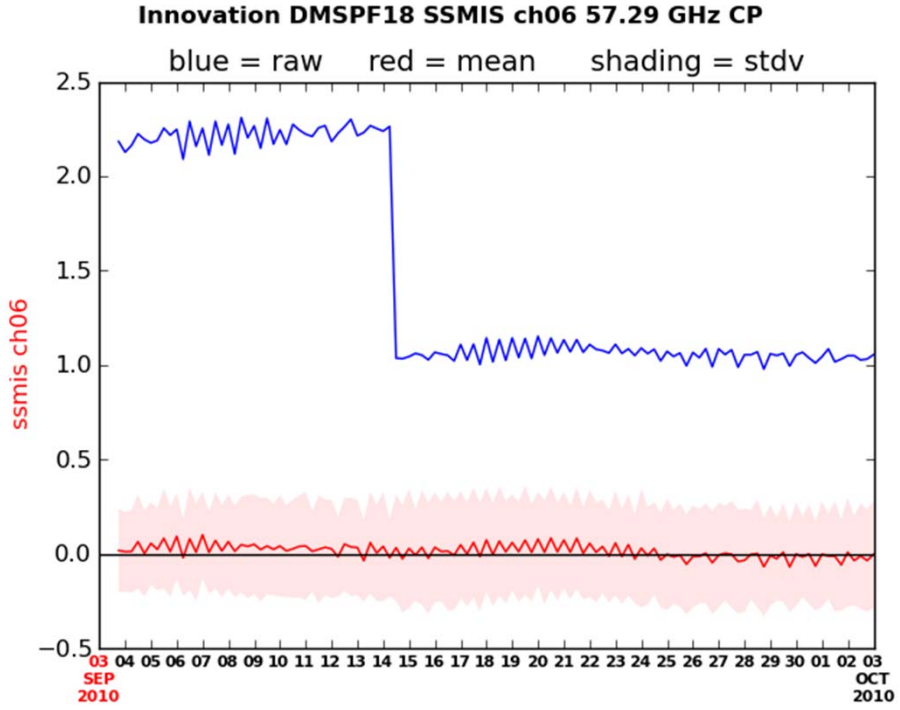
The assimilation of GPS reduced a stratospheric bias which dramatically improved the raw departures (observed – simulated) shown in blue

Due to the stratospheric improvements these channels were added to the operational assimilation system:

AMSU-A: ch 11-14 (5x: NOAA-15, -16, -18, -19 and MetOp-A)

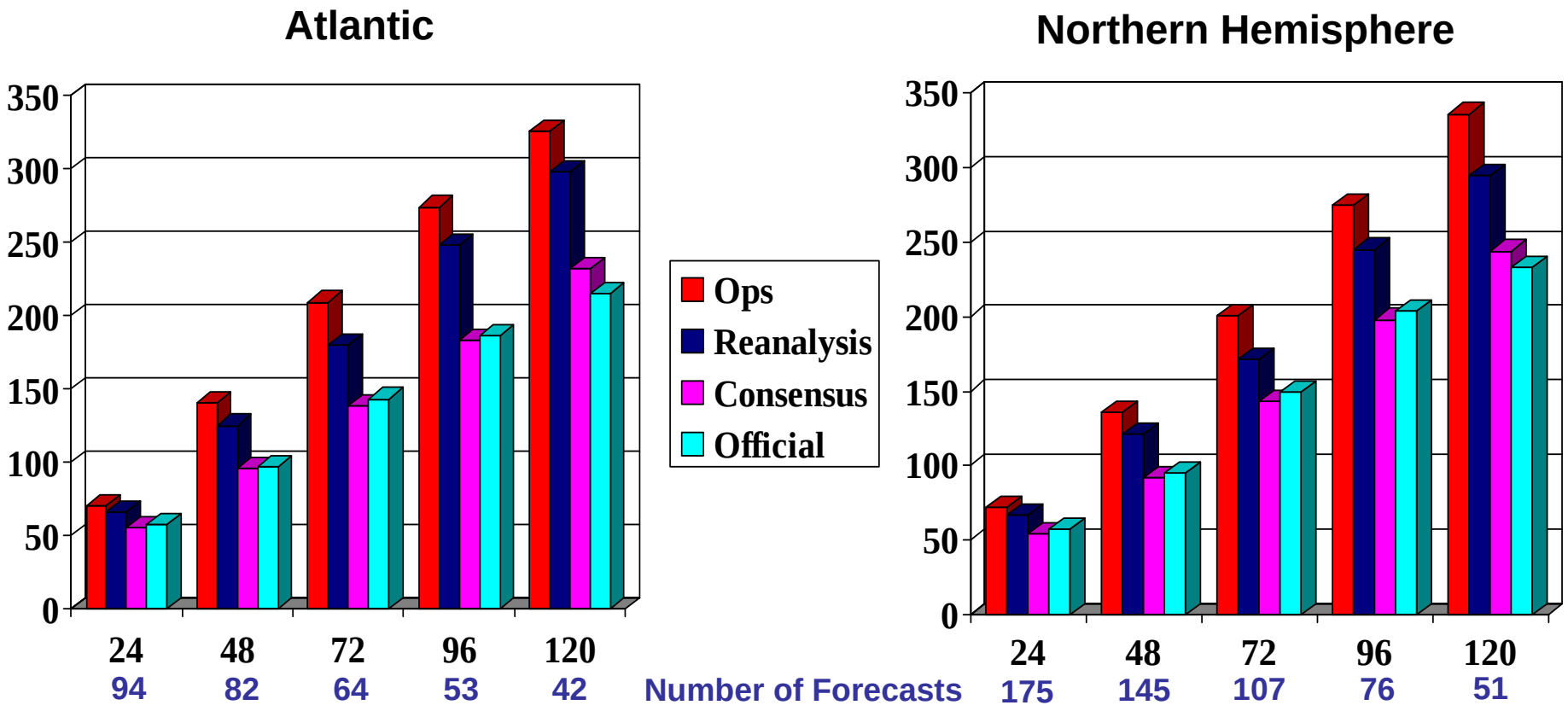
SSMIS: ch 22-24 (3x: DMSP F16, F17 and F18)





Impact of assimilation of GPS, additional IR/MW stratospheric channels, IASI channels over land/sea-ice

Tropical Cyclone Track Prediction



• Comparison of Operational NOGAPS, NOGAPS with update, Official, and leading consensus forecast guidance for July 1 – Sep. 6, 2010.

Recent Mesoscale NAVDAS (3D-Var) Improvements

New Satellite Data Sources added to NAVDAS

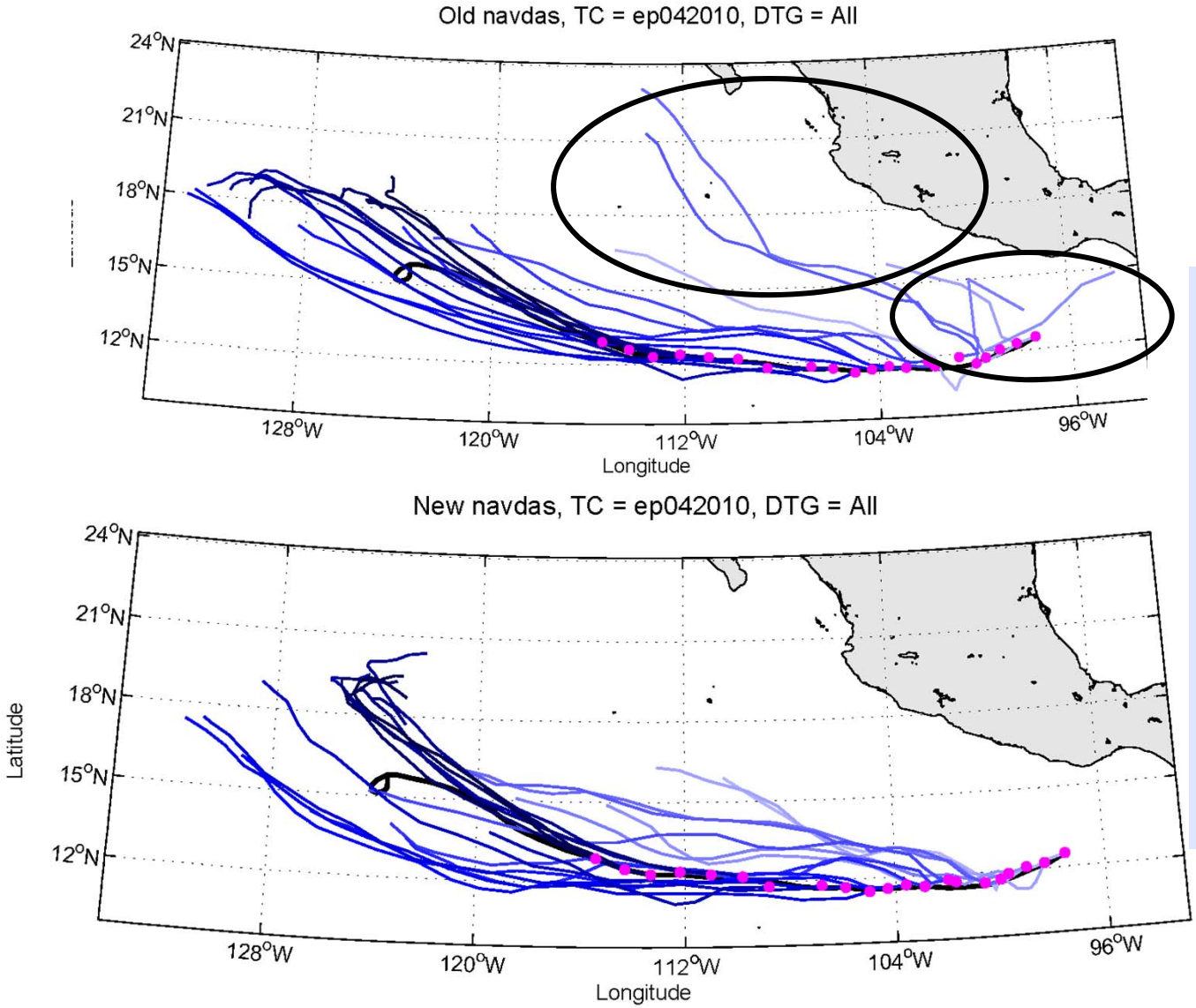
- ✓ ASCAT scatterometer
- ✓ WindSat wind vectors and TPW, new WindSat retrieval algorithm (NRL DC)
- ✓ Mid-level Geostationary winds
- ✓ MODIS and AVHRR polar winds
- ✓ Combined LEO/GEO winds
- ✓ AMSU-A Satellite Radiances, including RARS

COAMPS®

Sensors still to be added to NAVDAS

- ✓ IASI, AIRS and SSMIS radiances
- ✓ MHS and SSMIS 183 GHz channel assimilation

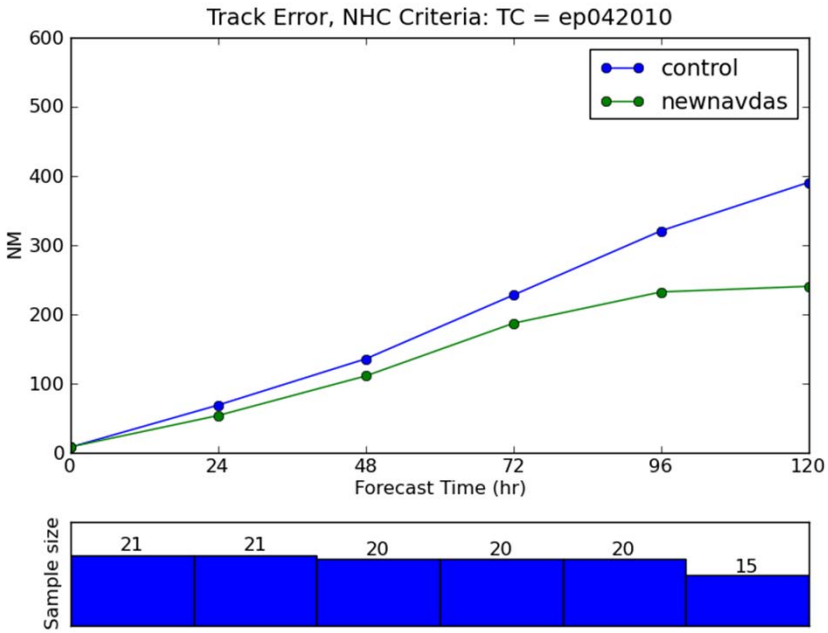
TC Celia track with COAMPS-TC



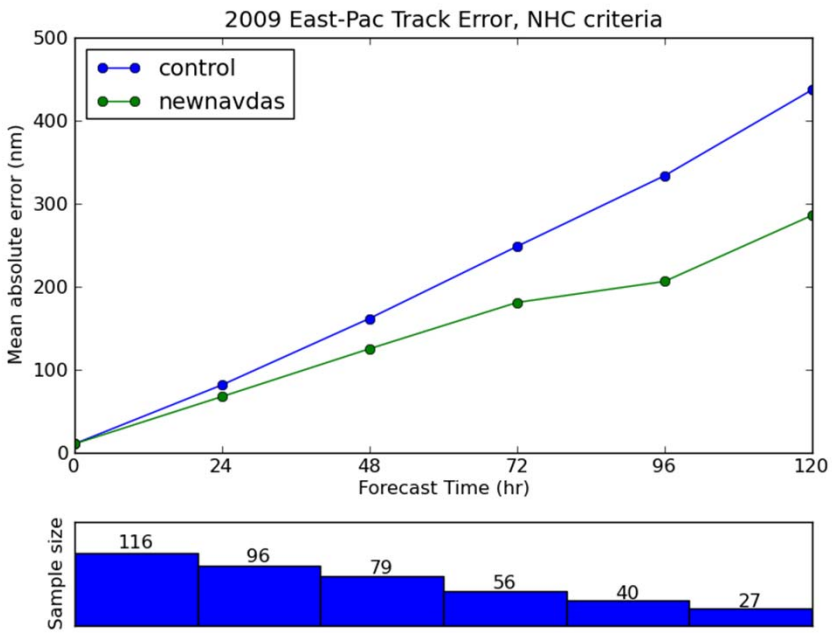
Assimilating superobs of atmospheric motion vectors (AMV), scatterometer and WINDSAT winds and integrated water vapor retrievals improve track for COAMPS tropical cyclone forecasts.

TC tracks with COAMPS-TC

Tropical East-Pac case: Celia



2009 Tropical East-Pac summary



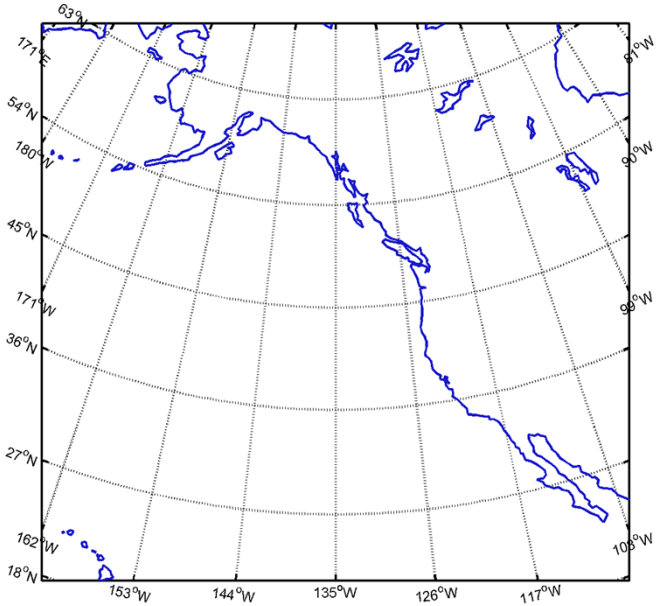
Assimilating superobs of AMV, scatterometer and WINDSAT winds and IWV improve track for COAMPS tropical cyclone forecasts (left). Similar track improvement found by COAMPS-TC group with 2008-2009 retrospective runs (right).

New data sources incorporated into NAVDAS for all "real-time" Hurricane Forecast Improvement Project (HFIP) runs after 12Z 29 August 2010

COAMPS®
AMSU-A Radiance Assimilation

- **Control run** is standard **30-level** COAMPS with satellite and geostationary winds plus all conventional data, plus the NESDIS **ATOVS retrievals**
  - 30 levels, model top near 35 km & most of the resolution below 15 km.
- Exp. 1: **ATOVS retrievals** with **45-level** COAMPS (increased vertical resolution above 15 km).
- Exp. 2: **AMSU-A radiances** with **30-level** COAMPS, fixed bias coefficients from global NAVDAS-AR
- Exp. 3: **AMSU-A radiances** with **45-level** COAMPS and fixed bias coefficients
- Exp. 4: **AMSU-A radiances** with **45-level** COAMPS, fixed bias coefficients updated with mesoscale bias statistics.

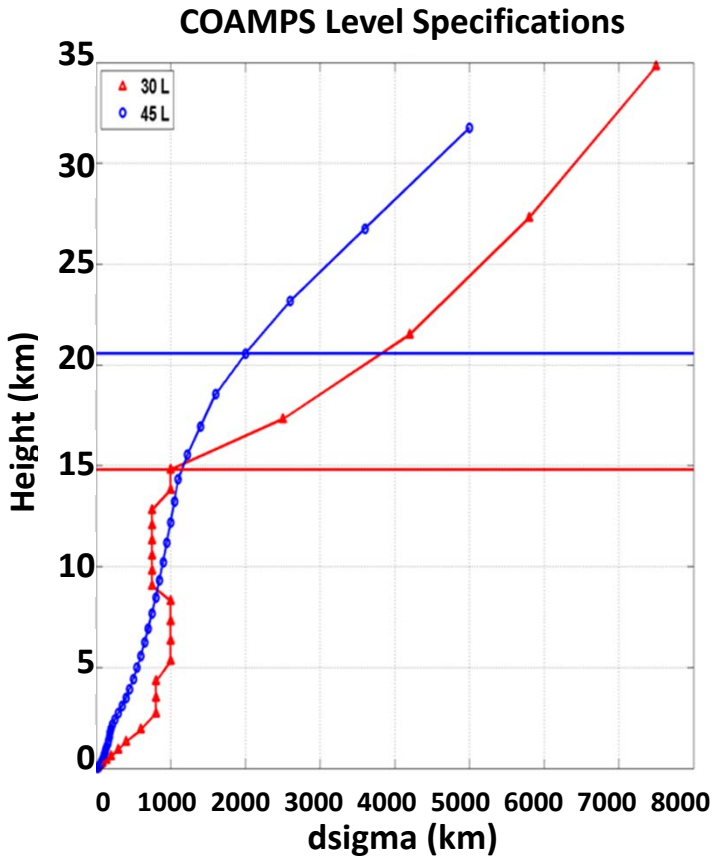
COAMPS EastPac Region

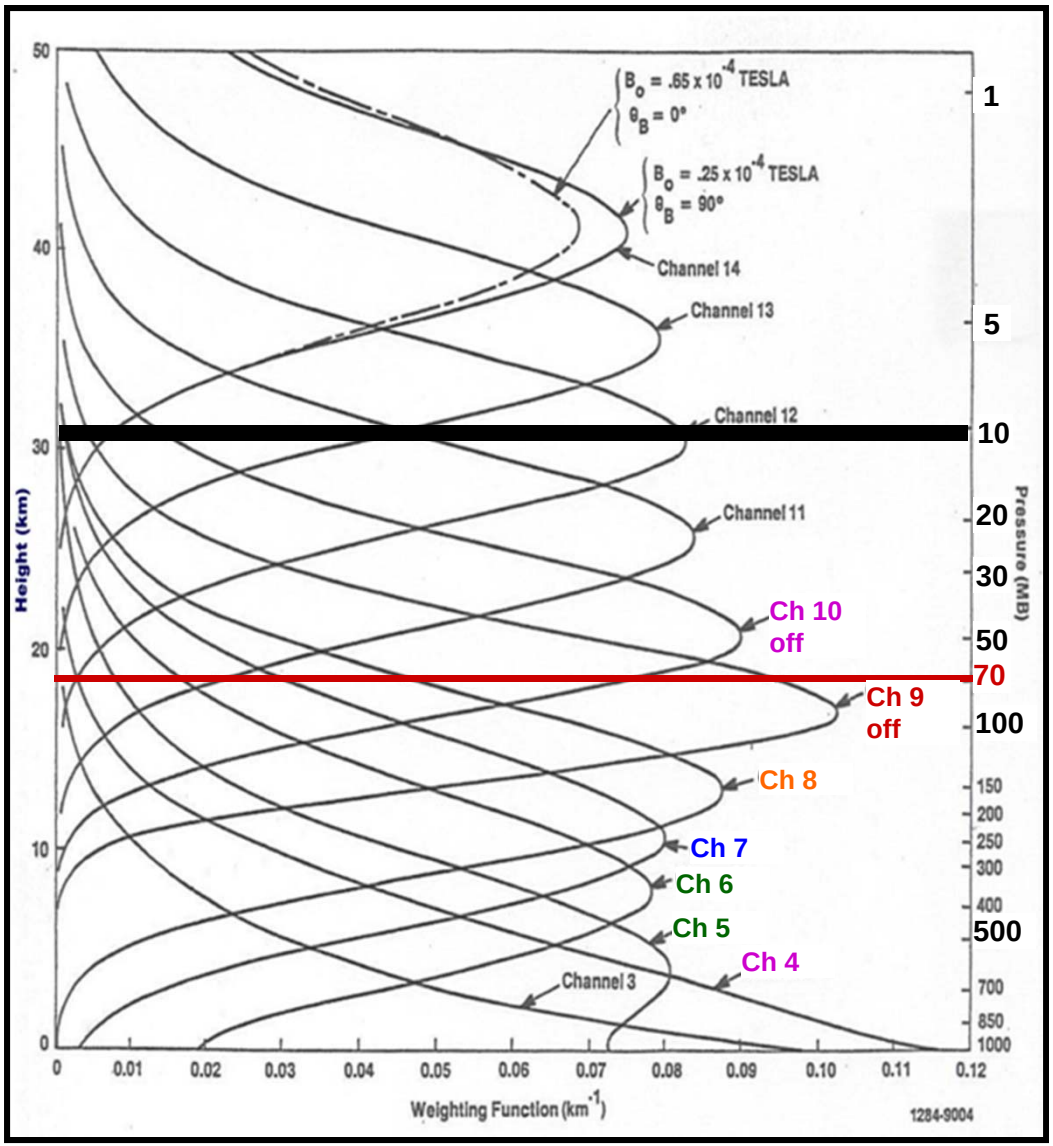


COAMPS was run **doubly nested over the EastPac** region; **inner 27-km nest** covers most of the domain **3-week Dec. 2009 run.**

AMSU-A
Weighting Functions

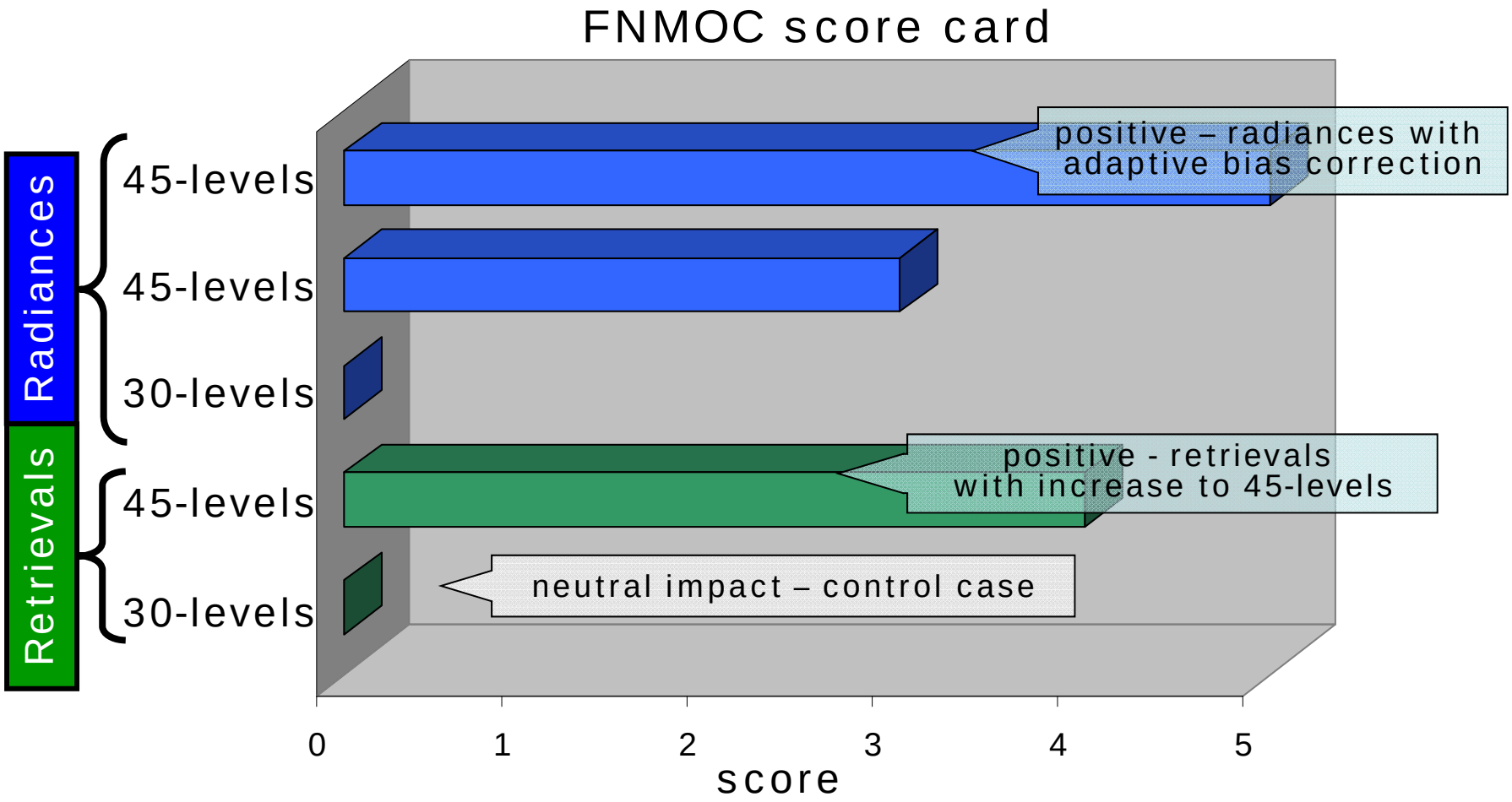
COAMPS 30 and 45 Level Configurations





AMSU-A Radiance Assimilation

NAVDAS/COAMPS®



Operational : Retrievals 30-level (15km effective model top)

Experimental : Radiances 45-level (21km effective model top) ← shown above

Proposed : Radiances 60-level (40km effective model top)

Mesoscale Radiance Assimilation
Conclusions

- **A sufficiently high model top is essential for positive impact from atmospheric sounders such as AMSU-A**
- **Bias correction using coefficients from a global model *with the same underlying radiative transfer model* performs well (at least for EastPac), which is a big advantage when spinning up a new limited area model**
- **There may be some advantage to blending the global bias correction coefficients and those derived from a COAMPS run**
- **With the caveats above, radiance assimilation is a net positive versus retrieval assimilation in mesoscale models**

Ongoing and Future Work

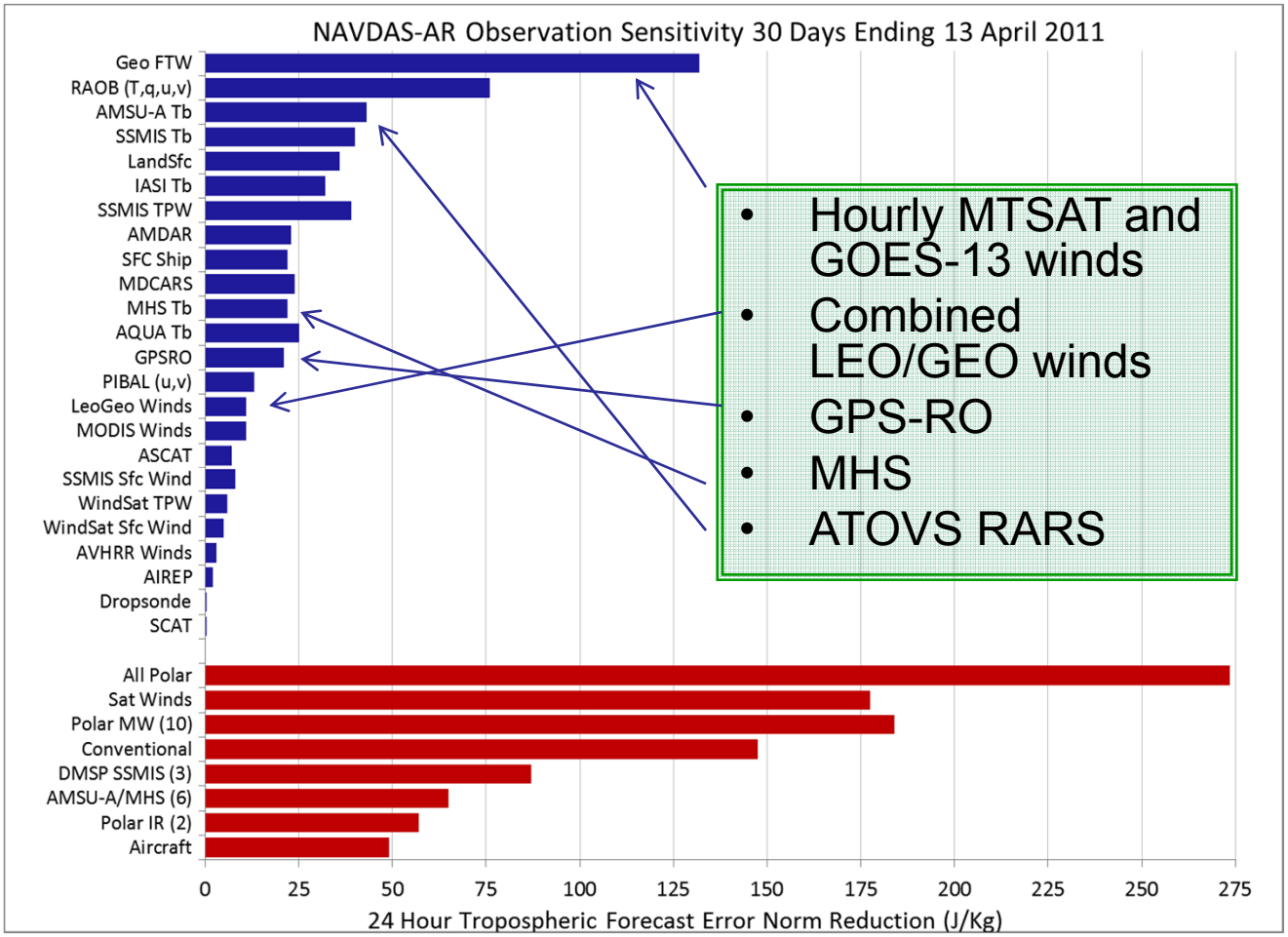
1. **Complete preparations for day 1 DA monitoring of NPP radiances**

2. **Improve ob use and implement new observation sources**
   - Revisit surface ob QC and data use
   - BUFR raobs (3-D location)
   - Aircraft humidity obs
   - HDOB
   - Wind profilers
   - GPS-MET TPW

3. **Mesoscale Data Assimilation for COAMPS**
   - NAVDAS upgrade for COAMPS-TC and hourly analyses
   - Evaluate EnKF for COAMPS (and COAMPS ensemble)
   - Coupled ocean/atmosphere data assimilation
   - NAVDAS-AR with options for hybrid 4D-DA

4. **Global NAVDAS-AR enhanced capabilities → NAVGEM**
   - Updated observation and situation-dependent background error variances
   - Additional physics in TLM/Adjoint for AR
   - Second outer loop (for nonlinearity)
   - Weak-constraint to allow for model error
   - Hybrid 4D-DA (variational + ensemble techniques); several options available in NAVDAS-AR

Observation Impact Summary



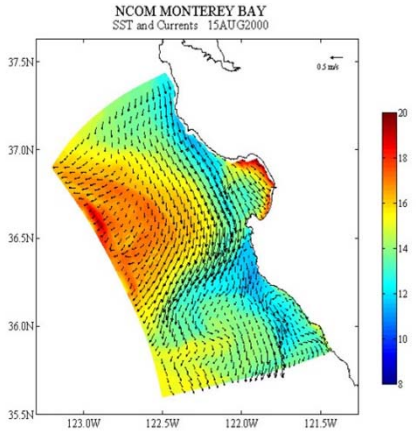
The observation impact of all data assimilated by NAVDAS-AR, ranked by impact. The data is binned into broader categories of interest (red bars at bottom of plot).

Satellite Aerosol Data Assimilation

Satellite Ocean Data Assimilation

Aerosol DA Accomplishments

- Transition of MODIS Over-Land QA/QC and DA into operational NAVDAS-AOD *(in alpha-testing at FNMOC)*
- FLAMBE v1.2 Tuned smoke source based on regional V&V, transition 4Q2011
  FLAMBE v2.0 Global geostationary inputs, robust coverage, cloud correction 2011
- Products used by joint DOD command responsible for forecasting for Southwest Asia
- Reanalysis included MODIS both over water and over land; by end of summer, will include MISR, CALIOP, MODIS deep blue
- Research team working on AVHRR, OMI



Ocean DA Accomplishments

- NCODA (NRL Coupled Ocean Data Assimilation) **3DVAR system v3.0 transitioned** to FNMOC for beta-test for global and coupled mesoscale application.
  - ➢ Assimilates SSH from altimeter ; SWH from altimeter, buoys; ice conc. from F13—F18, AMSR-E; SST from NOAA, METOP (GAC/LAC), GOES, MSG, AATSR, AMSR-E, ship/buoy; Profile T/S from XBT, CTD, floats, fix/drift buoys, gliders, [synthetic obs]; Velocity from HF radar, ADCP, Argo trajectories, drifters, gliders
- Progress toward assimilating physical skin SST retrieval
  - ✓ Implemented CRTM forward model with real-time NOGAPS and satellite radiances at FNMOC
  - ✓ Developed and validated CRTM inverse model for calculation of physical skin SST
  - ✓ Completed bulk-to-skin SST model for ship and buoy data in skin SST assimilation
  - ✓ Performed idealized runs of CRTM aerosol module using NAAPS

NOGAPS/NAVDAS-AR Operational System Observational Data Types Assimilated

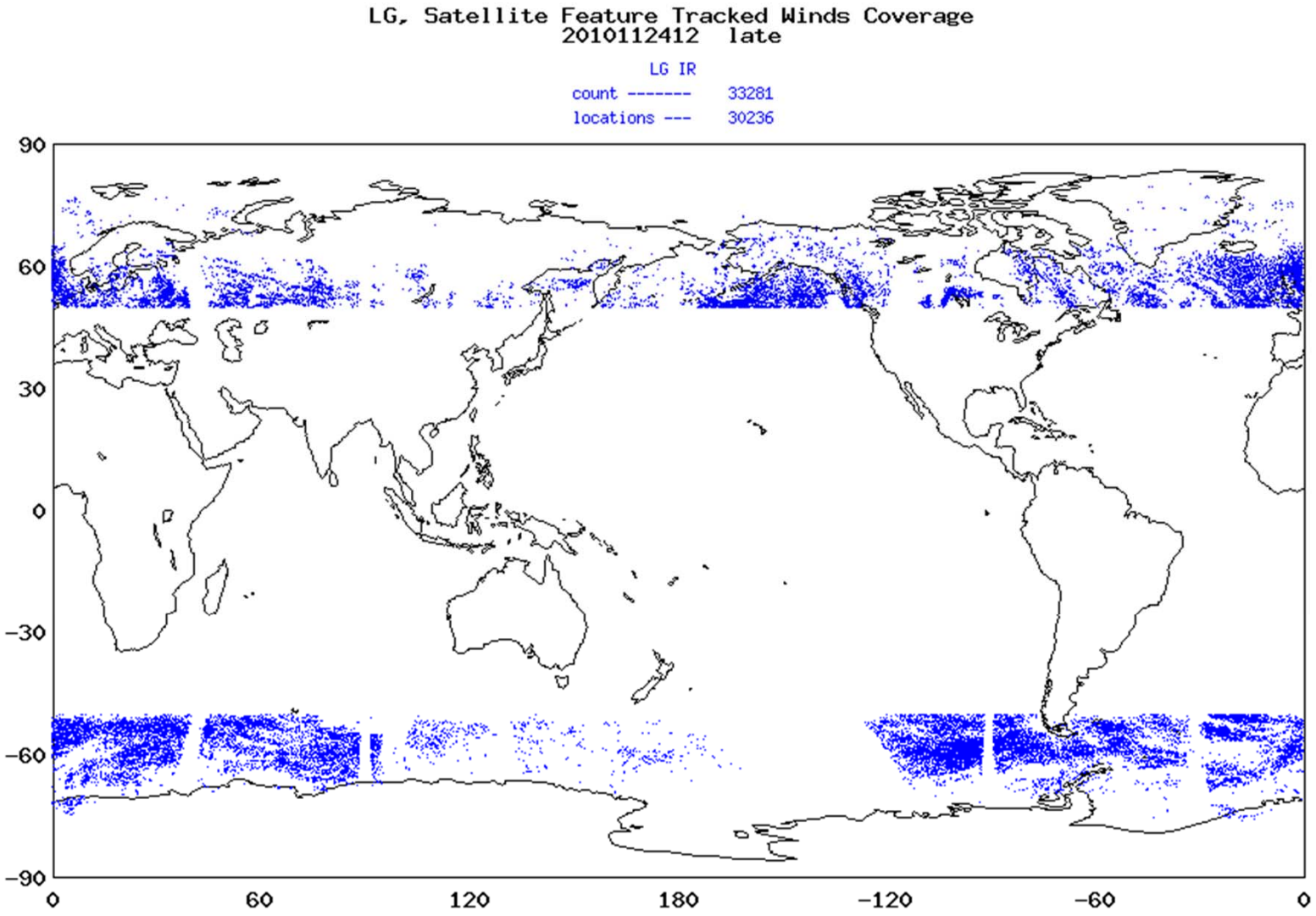
Conventional Data Types

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

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)
  - SSMIS/MHS 183 GHz

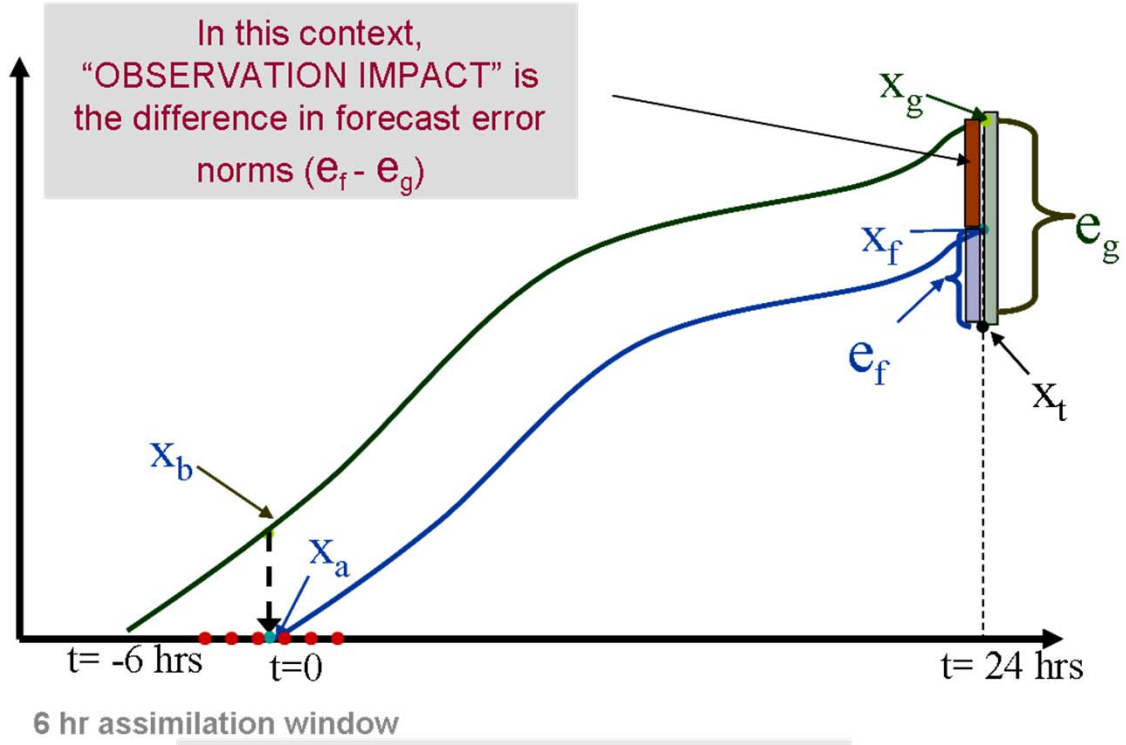
Operational Assimilation of LEO/GEO Winds from Wisconsin (17 November)



NRL
Adjoint Observation Sensitivity Tools

- Adjoint Methods allow for the real-time Assessment of the Impacts of Observing Systems
- Allows for fine-tuning of the satellite radiance assimilation, channel selection, rejection, etc.

Observations move the forecast from the **background trajectory** to the **trajectory starting from the new analysis**



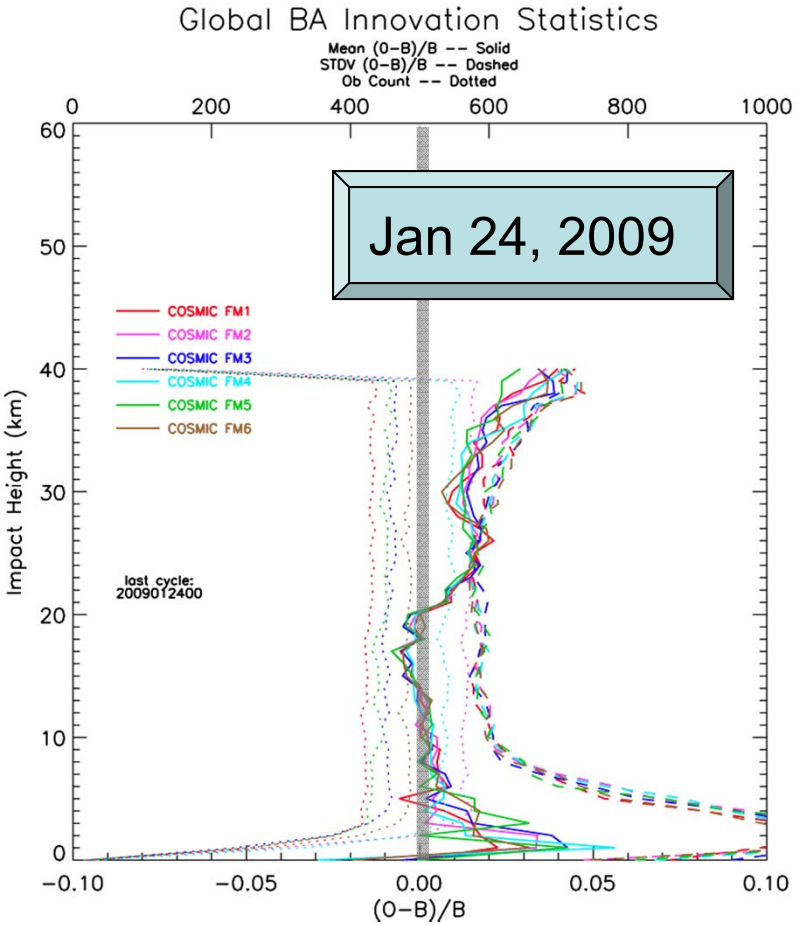
Langland and Baker (Tellus, 2004)

Forecast error as measured by a moist energy norm integrated over the troposphere and lower stratosphere (1000–150 hPa)

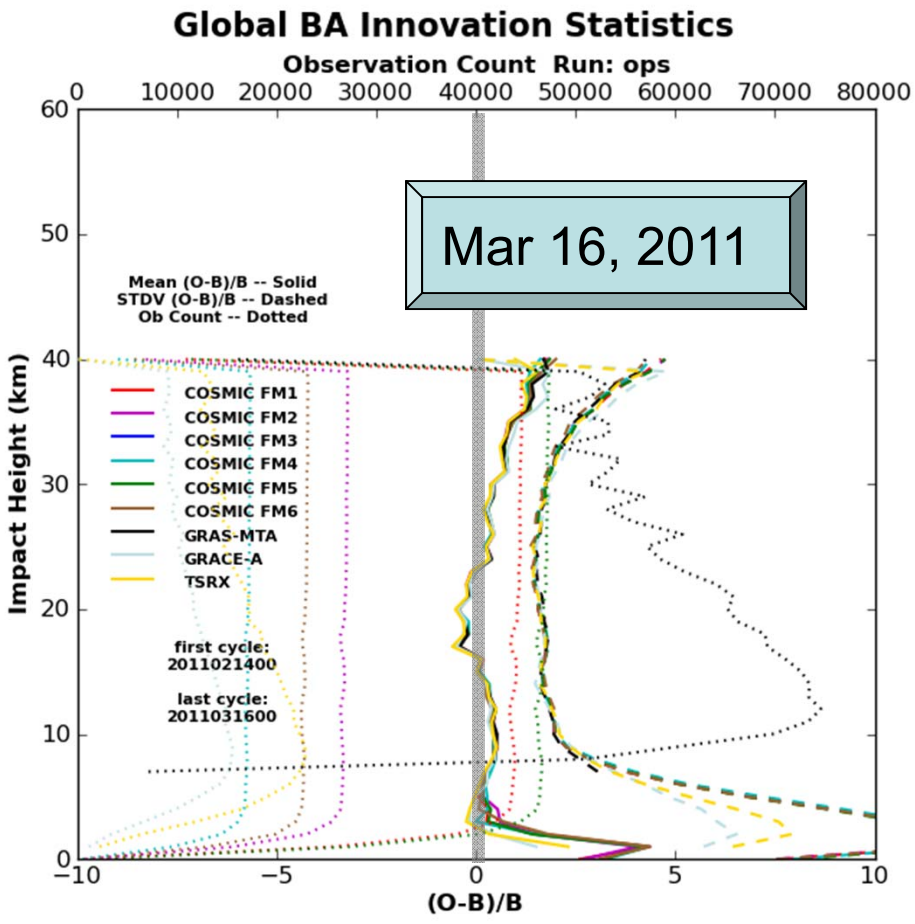
GPS Bending Angle Monitoring

Normalized Bending Angle Innovation (O-B)/B

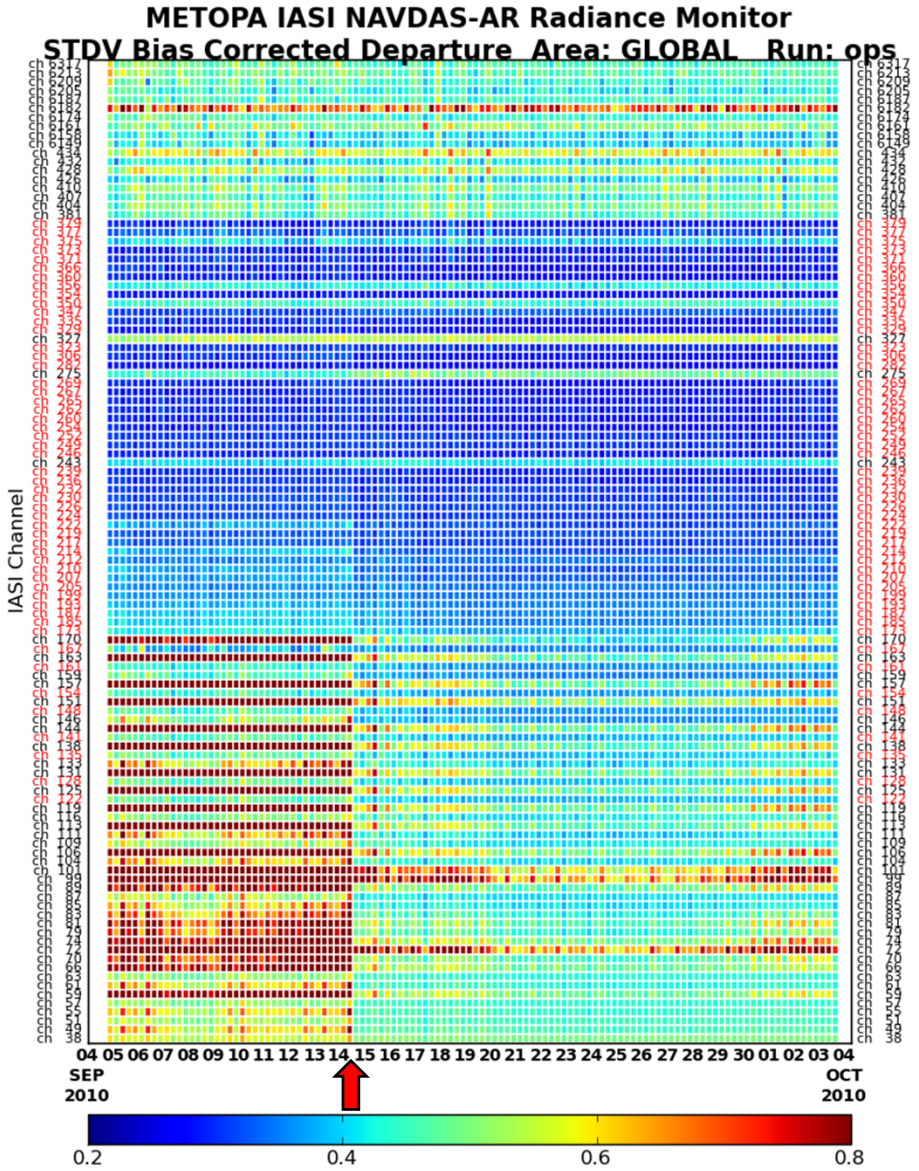
Before GPS assimilation



After GPS assimilation



GPS Bending Angle Impacts



Similarly, the improved stratosphere due to GPS impacted the standard deviation (STDV) of the bias corrected departures (observed – simulated) for IASI *shown on left*

As a result additional channels were added for both the IASI and AIRS hyperspectral IR sounders:

- 10 additional for IASI
- 31 additional for AIRS

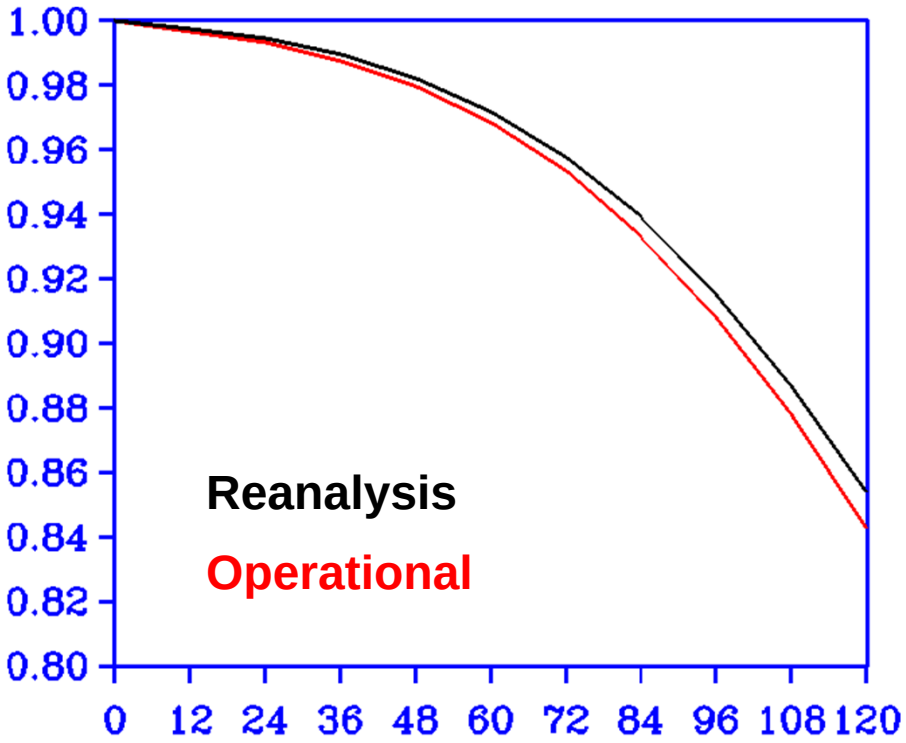
Operational Assimilation of GPS implemented 14 September 2010

Impact of assimilation of GPS, additional IR/MW stratospheric channels, IASI channels over land/sea-ice

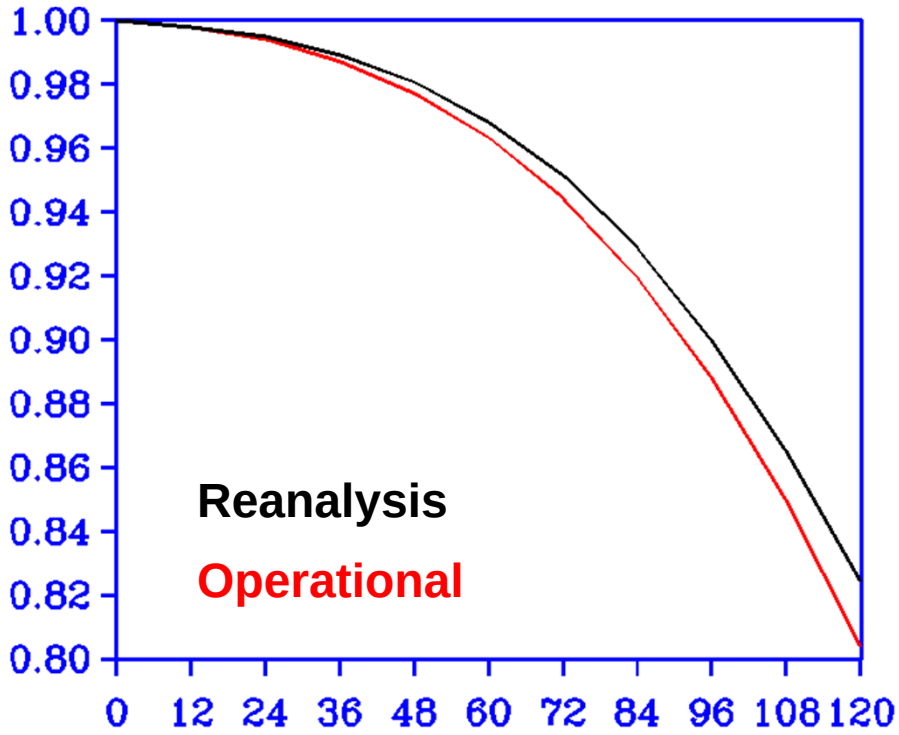
500 mb Height Anomaly Correlation

July 1-September 6 2010

Northern Hemisphere



Southern Hemisphere



Reanalysis Experiment over 2010 NH summer

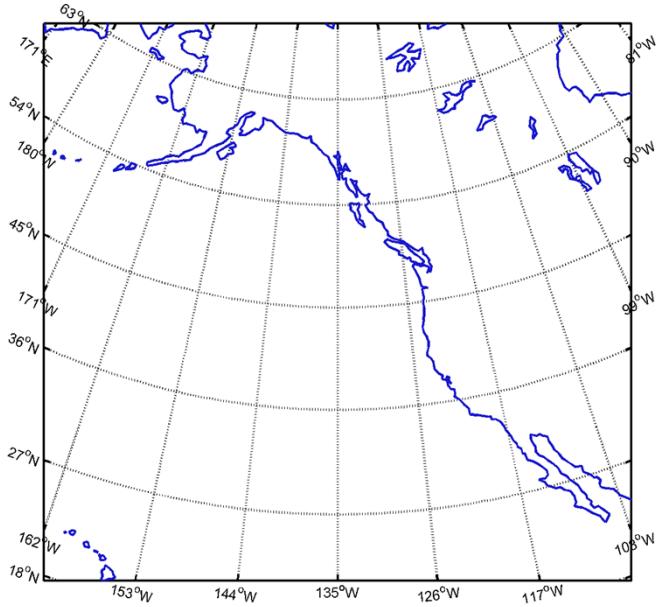
'OPS' -- operational configuration without GPS bending angle assimilation

'REANAL' -- current ops system with GPS & additional MW/IR sounding channels

COAMPS®
AMSU-A Radiance Assimilation

- COAMPS is a nonhydrostatic, fully compressible nested grid model with a sigma-z vertical coordinate
- COAMPS was run **doubly nested over the EastPac** region, with the **inner nest** covering most of the domain with **27 km resolution**
- **Control run** is standard COAMPS with satellite and geostationary winds plus all conventional data, plus the NESDIS **ATOVS retrievals**
- The lateral boundary conditions are provided by NOGAPS running with NAVDAS-AR
- Experiments were run from 12/9/2009 through 12/31/2009 with 3D-Var cycling data assimilation (NAVDAS) and **fixed bias coefficients**

COAMPS EastPac Region



NRL/FNMOC
Mesoscale 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*
- NAVDAS adjoint is used for cost effective observation impact studies
- Ongoing development for COAMPS-TC, and hourly analysis capability
- Moving to 4D-Var (with ensemble components)
- Coupled ocean/atmosphere data assimilation