Q3FY16 GFS Upgrade

Data Assimilation Verification

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Objectives

- Describe some of the tools used by the data assimilation team for verification.
- Outline the data assimilation components for the Q3FY16 GFS/GDAS upgrade.
- Present verification for each component to ensure that they are implemented correctly.
  - A low resolution testing environment will be the primary means for showing this.
  - Results from clean tests will be shown for low resolution experiments.
  - Results from the GFSx will then be examined to see if we observe the same impacts.

Tools

- Standard VSDB Package
- Minimization Monitor
- Radiance Monitor

home

Analyses: Increments; RMSI
Ensemble: mean; spread
Forecast Maps
Upper Air: **anl d1 d2 d3**
Surface: **anl d1 d2 d3**
Fcst-Obs: **anl d1 d2 d3**

Anomaly Correlation
Height Go

Bias
Wind Speed Go

RMSE
Vector Wind Go

Murphy's MSE Skill Score
Vector Wind Go

Ratio of Standard Deviation
Vector Wind Go

RMSE from Mean Difference
Vector Wind Go

RMSE from Pattern Variation
Vector Wind Go

Pattern Correlation
Vector Wind Go

Sfc Regional Means
CAPE Go

Grid-To-Obs
00Z 06Z 12Z 18Z

ScoreCard
Hurricane Track
CONUS Precip Score
Fit-To-Obs
Radiance Monitoring
Minimization Monitoring

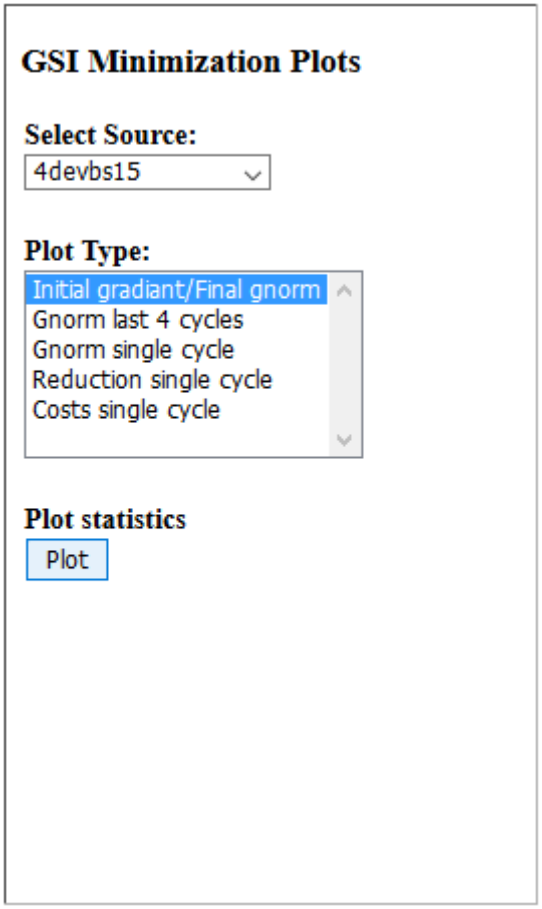
Global Climate and Weather Modeling Branch
Environmental Modeling Center
National Centers for Environmental Prediction

NCEP/EMC Global Model Experimental Forecast Performance Statistics

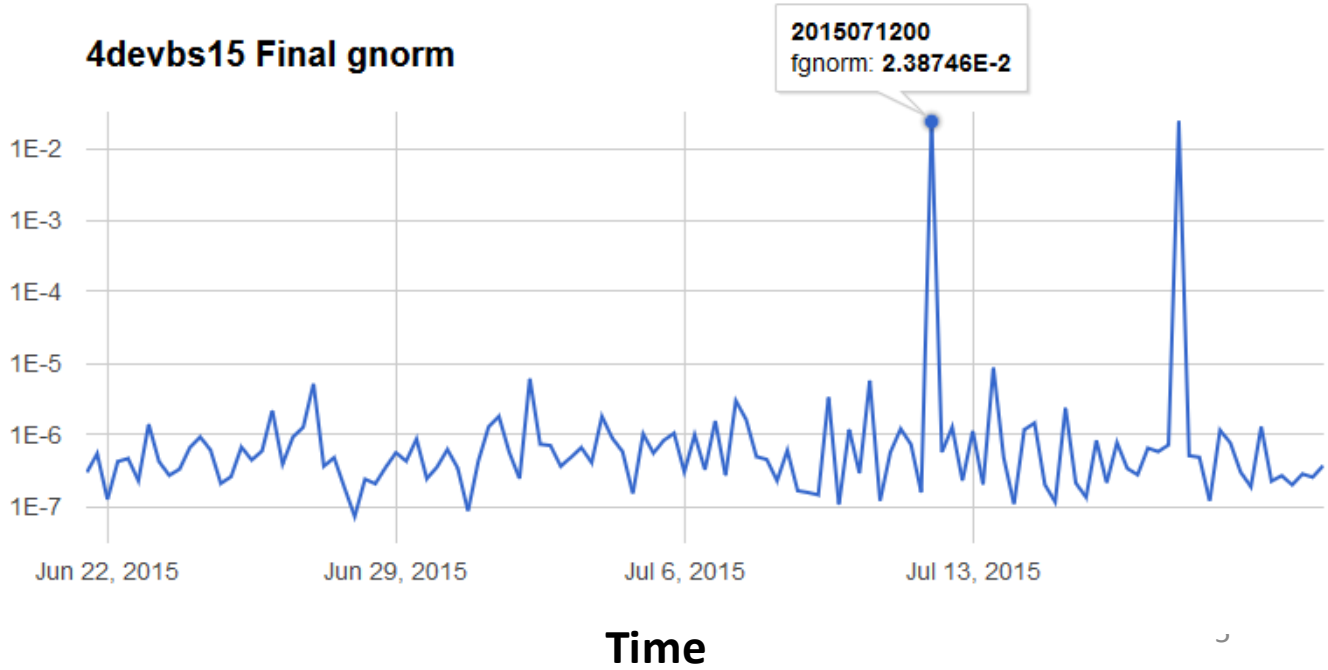
- The site displays verification statistics for global NWP forecasts. All data used are on the GRIB G2 (2.5x2.5 degree) grid.
- The regions referred to are: G2 (GLB): Globe NHX: 20N-80N SHX: 20S-80S TRO: 20S-20N PNA: Pacific North America, 180E-320E, 20N-75N N60: 60N-90N S60: 60S-90S NPO: N.Pacific SPO: S. Pacific NAO: N. Atlantic SAO: S. Atlantic CAM: Central America NSA: N. South America
- Pattern correlations for all NWP models are computed using anomalies respective to a 30-year (1959-1988) climatology of the NCEP/NCAR reanalysis.
- Please see this presentation for definitions of the various verification metrics.

Minimization Monitor

- Our variational data assimilation system minimizes a cost function to find the best analysis that fits both the previous model forecast and observations.

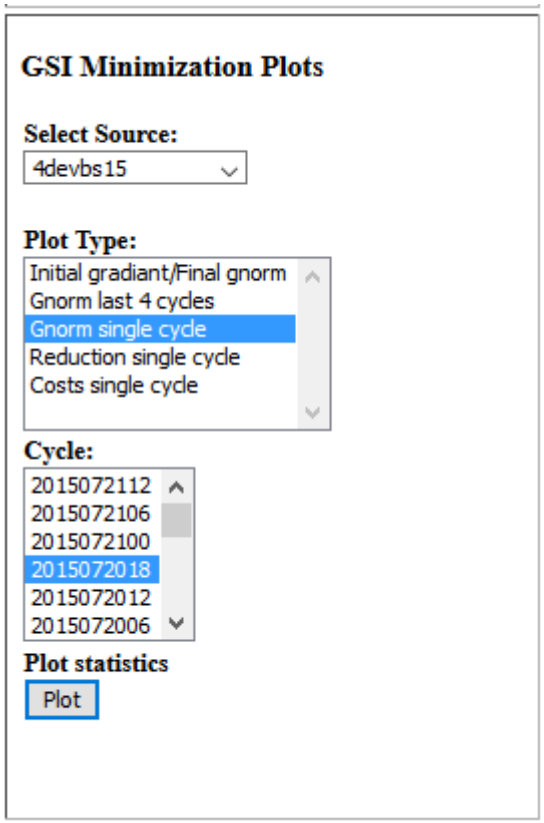


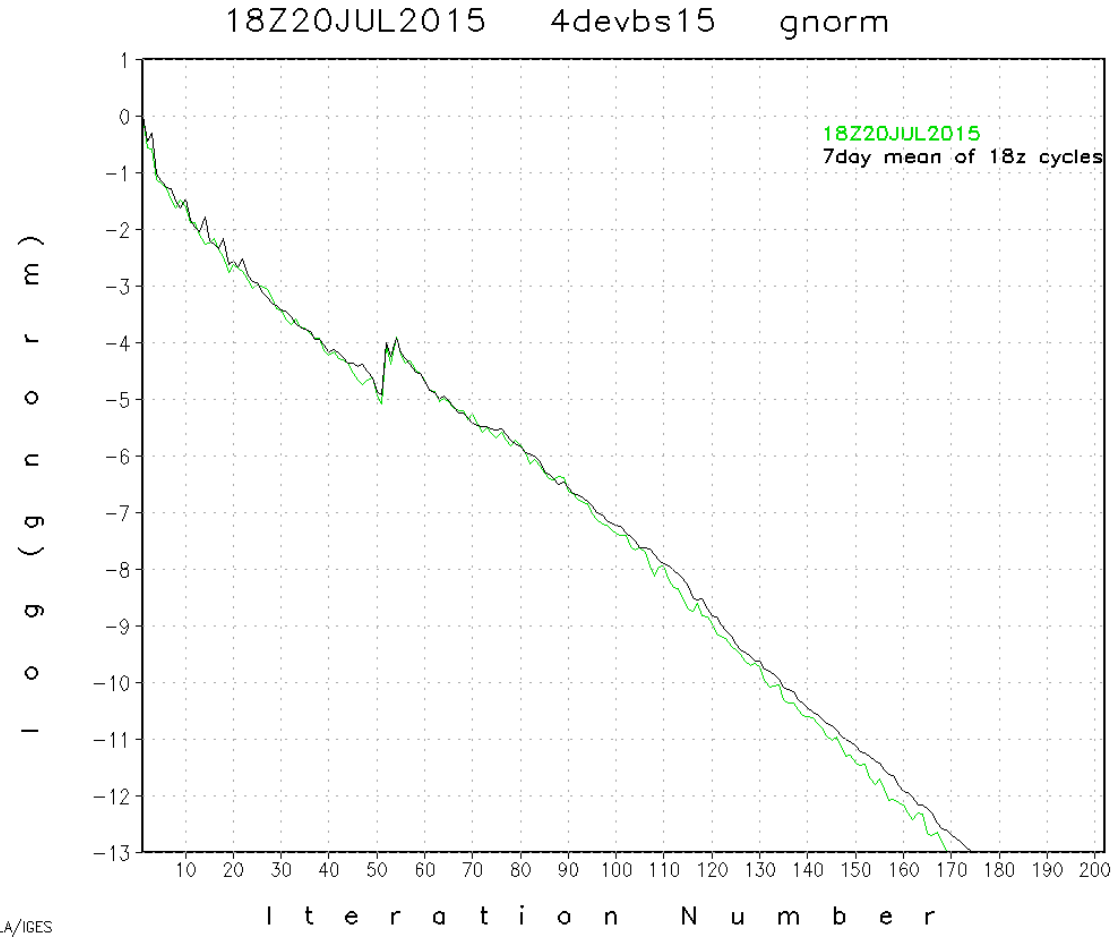
- The cost function is minimized iteratively, striving to get the gradient as close to zero as possible.
- Cycles with gradients much larger than zero did not minimize properly and should be examined in greater detail.



Minimization Monitor

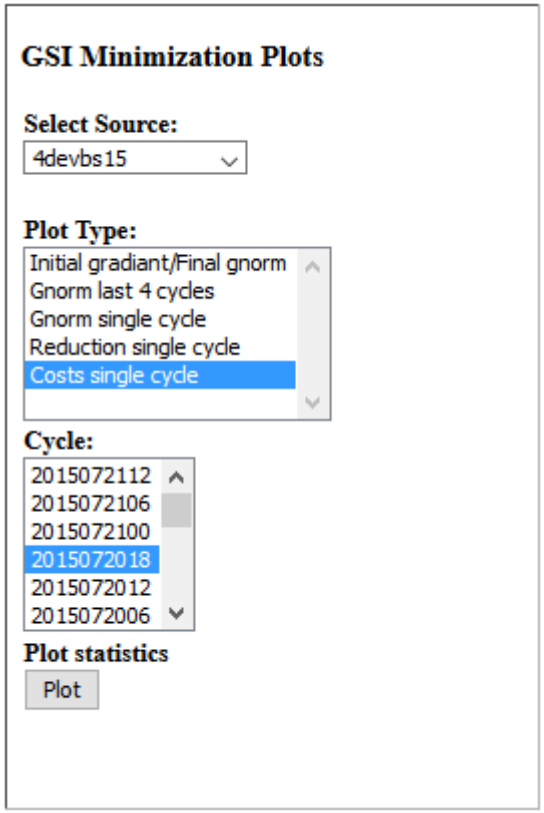
- The gradient for a single cycle can be plotted by iteration.
- We want to see a smooth decrease towards zero for the full amount of iterations.

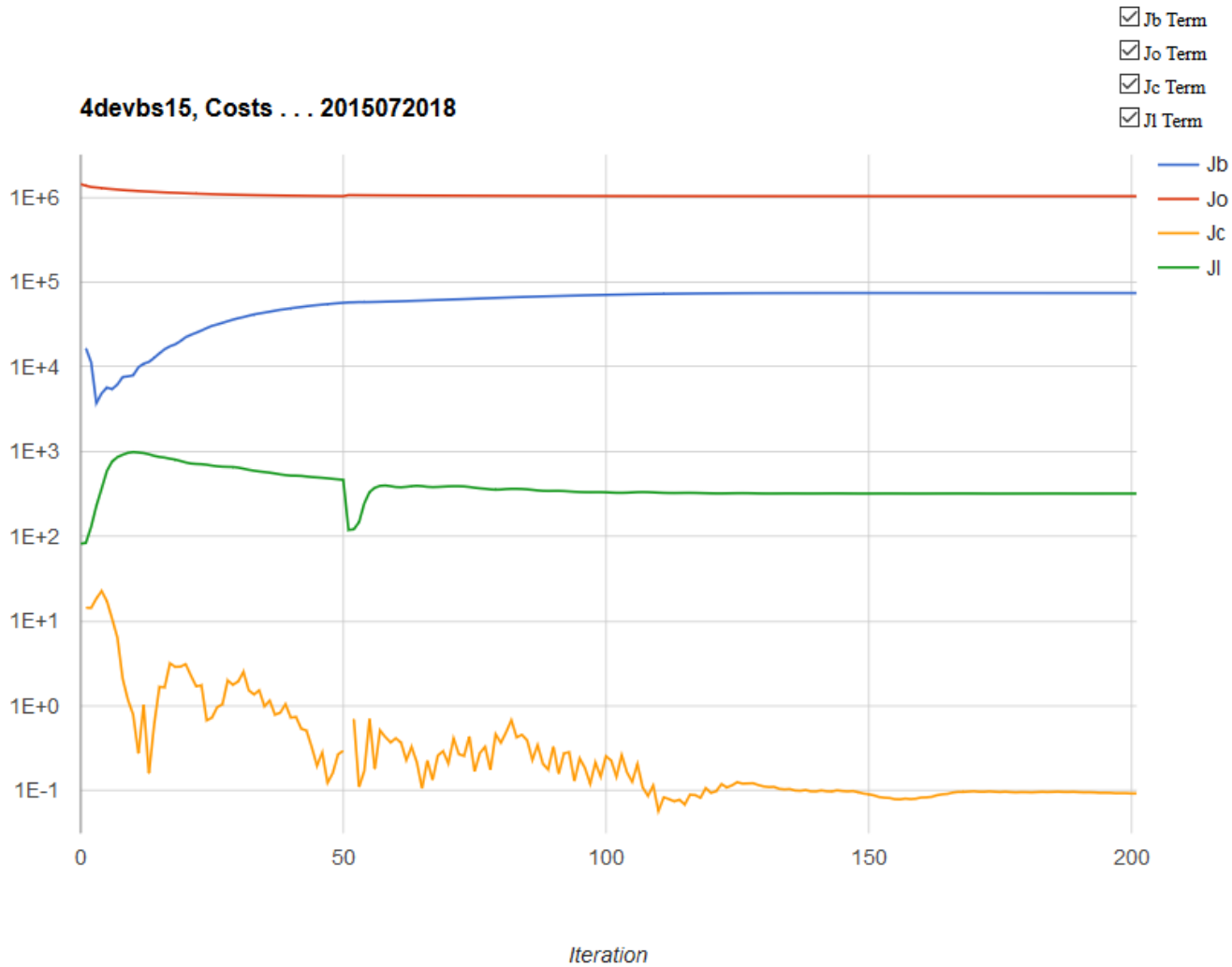




Minimization Monitor

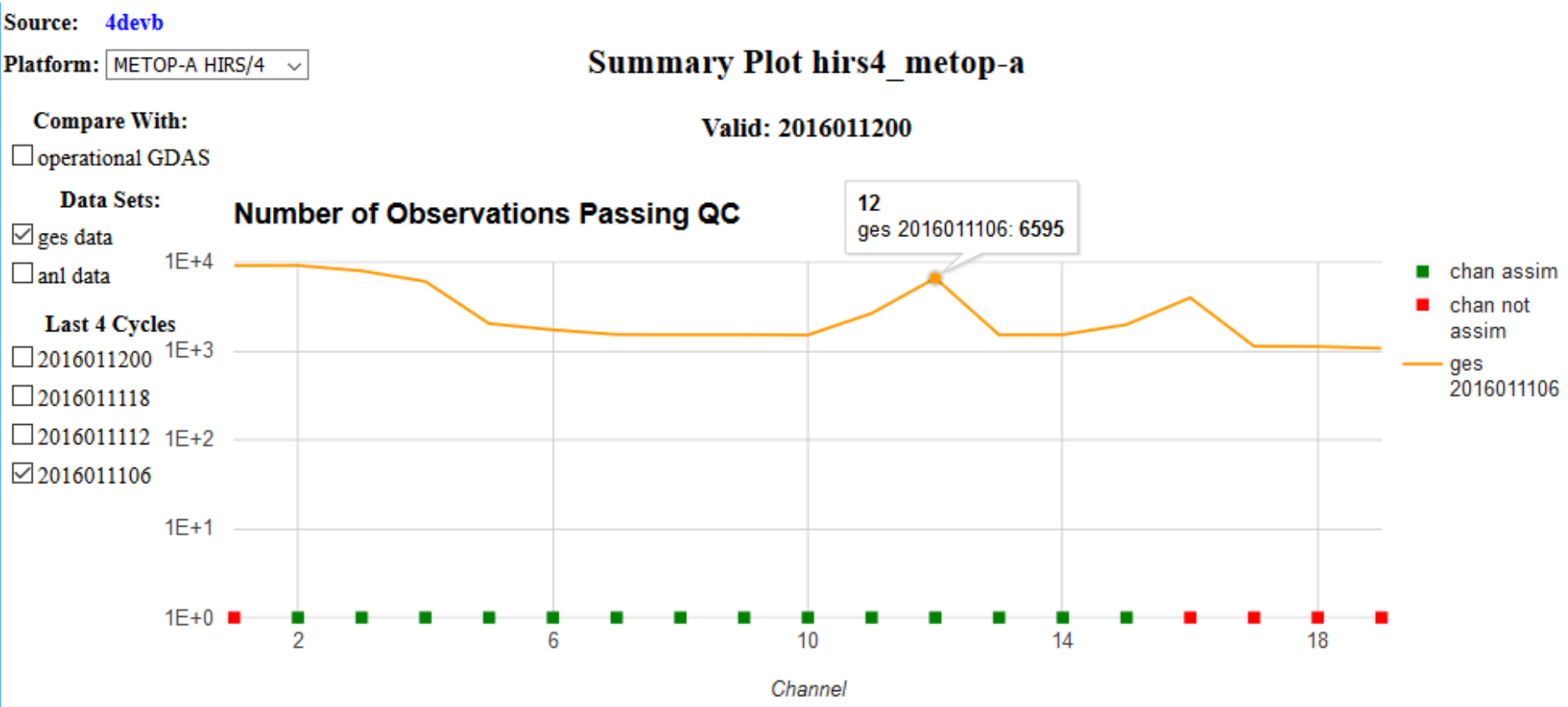
- Each component of the cost function can be examined for a single cycle, plotted by iteration.





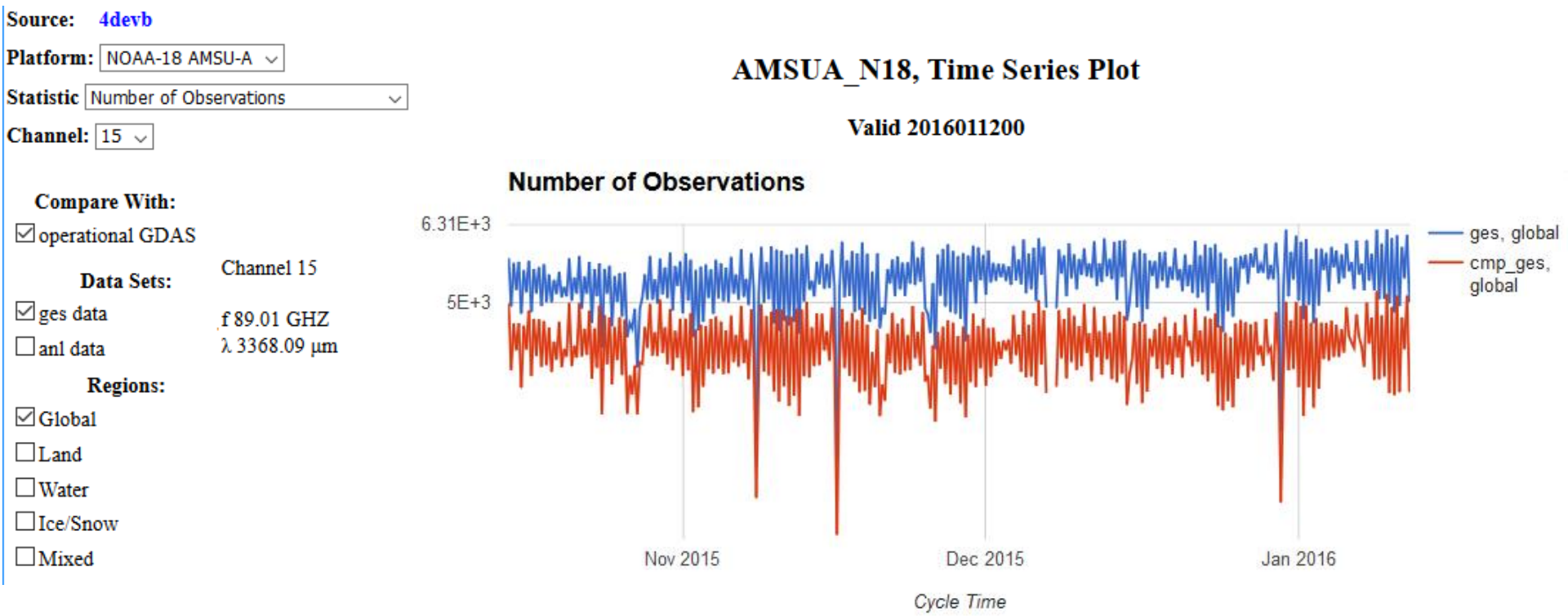
Radiance Monitor

- Summary statistics are available for each sensor.
- Can examine the guess vs analysis, the parallel vs operational, number of observations, bias correction coefficient, contribution to penalty...



Radiance Monitor

- Time series statistics are also available for each sensor.
- Can examine the same values as the summary statistics as well as individual correction terms and statistics by scan angle.



Q3FY16 Package
New Theoretical DA Components

- 3D to 4D ensemble covariances
- Increase in ensemble contribution from 75% to 87.5%
- Reduction of horizontal localization length scales in the troposphere
- Removal of additive inflation
- Code optimization
- Limit moisture perturbations for improved minimization
- Inclusion of ozone cross-covariances

Q3FY16 Package
New Observational DA Components

- Removal of time component for data selection
- 4D thinning of AMVs
- Aircraft temperature bias correction
- All sky microwave radiances
- CRTM upgrade

Ensemble-Variational Methods

- ***En-Var:*** background error covariance ($\mathbf{P^b}$, updated using EnKF and propagated through an ensemble, for e.g.) is used in the variational solver.

- ***3D-EnVar***: $\mathbf{P^b}$ is assumed to be constant through the assimilation window (current NCEP implementation).

- ***4D-EnVar***: $\mathbf{P^b}$ at every time in the assimilation window comes from ensemble estimate (no TLM needed).

- ***En-4DVar***: static $\mathbf{P^b}$ is replaced with ensemble estimate (or hybrid) at the beginning of the assimilation window, but propagated with tangent linear model (and its adjoint) within the window.

Courtesy: Jeff Whitaker

4D EnVar: The Way Forward?

- This upgrade is moving to the **Hybrid 4DEnVar**
- **Natural extension** to operational Hybrid 3DEnVar
  - Uses variational approach with already available 4D ensemble perturbations
- **No need** to develop or maintain **TLM and ADJ** models
  - Makes use of 4D ensemble to perform 4D analysis
  - Modular, usable across a wide variety of models (NGGPS dycore replacement)
- Highly **scalable** and computationally **inexpensive** (w.r.t. 4DVar)
  - Aligns with technological/computing advances
  - Estimates of improved efficiency e.g. at Env. Canada (6x faster than 4DVAR on half as many cpus)
- Combines best aspects of variational and ensemble DA algorithms
- Other centers exploring similar path forward for deterministic NWP
  - Canada (replaced 4DVAR), UKMO (potentially replace En4DVar)

Courtesy: Daryl Kleist

4D Hybrid, Low Resolution

	Current 3DHybrid	Proposed 4DHybrid
Static / Ensemble Weights	25% static ; 75% ensemble	12.5% static; 87.5% ensemble
Additive Inflation	5%	0%
Tropospheric localization length scales		½ of current 3D Hybrid

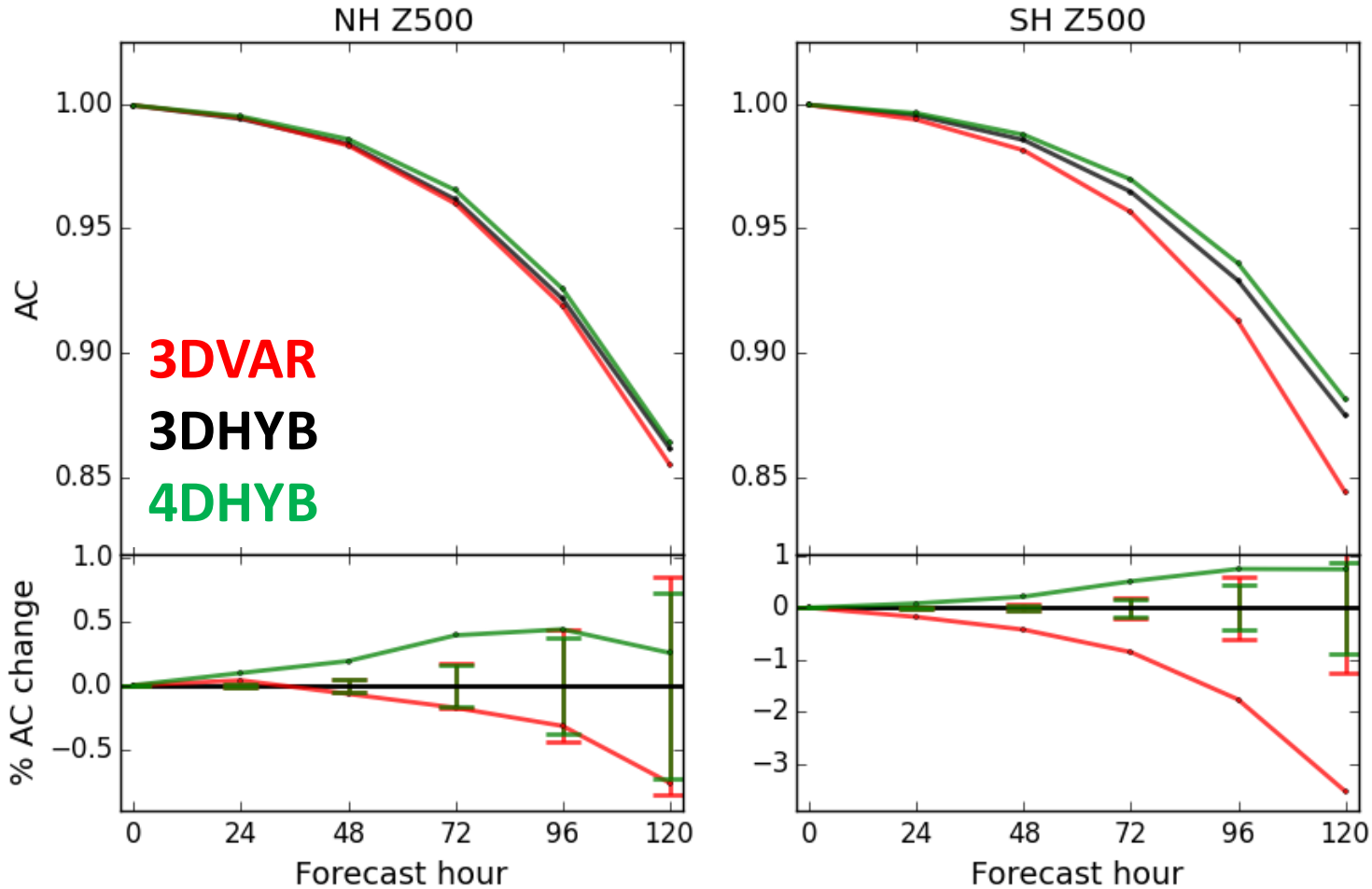
Test Configuration

- T670L64 deterministic GFS with 80 member T254L64 ensemble with fully coupled (two-way) EnKF
- Incremental normal mode initialization (TLNMC) on total increment
- Multiplicative inflation and stochastic physics for EnKF perturbations
- Full field digital filter

Courtesy: Rahul Mahajan

Courtesy: Rahul Mahajan

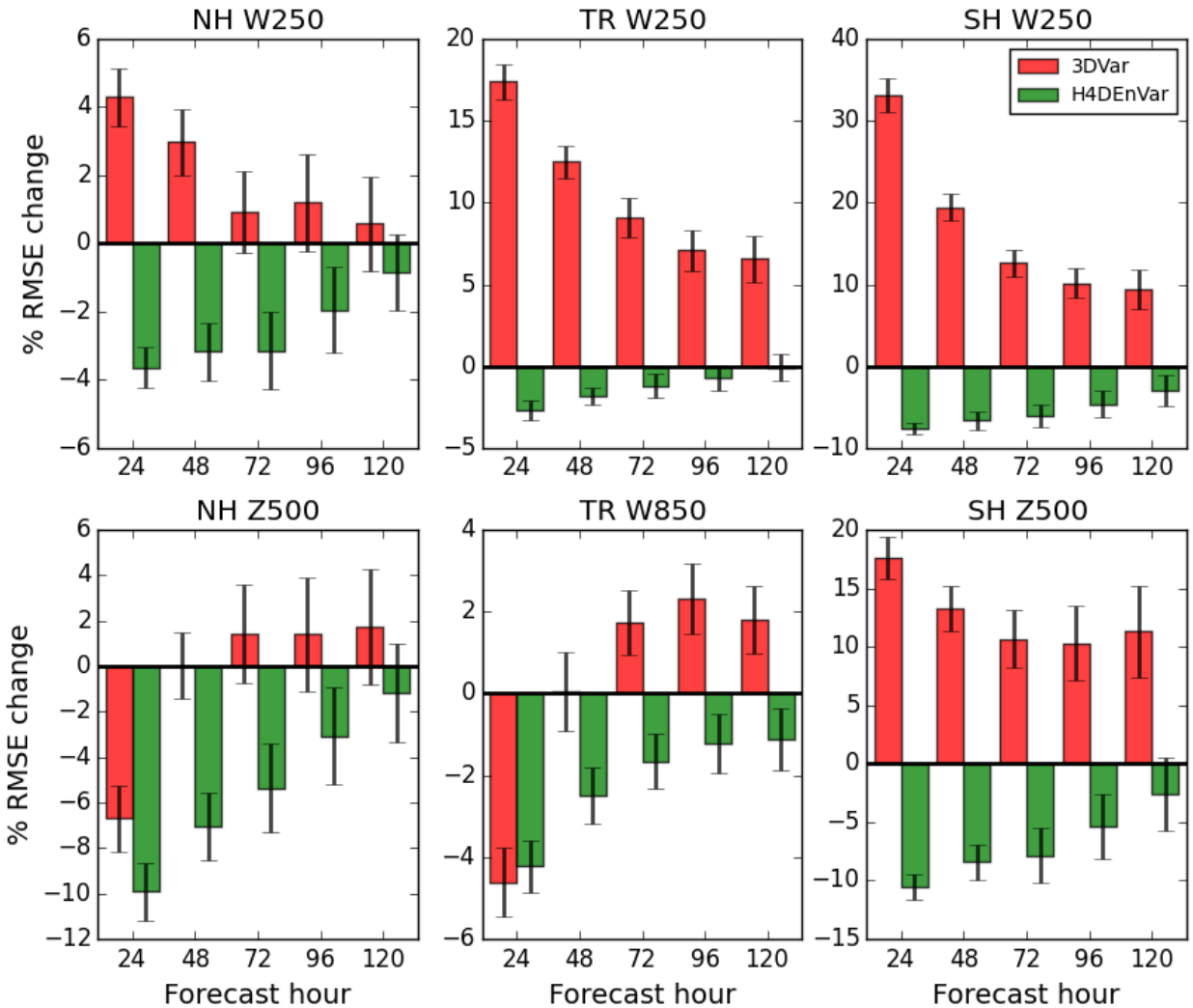
500 hPa Die Off Curves, Low Resolution



3D Hybrid (current operations) to Hybrid 4D-EnVar yields improvement that is about 75% in amplitude in comparison from going from 3DVar to 3D Hybrid

Courtesy: Rahul Mahajan

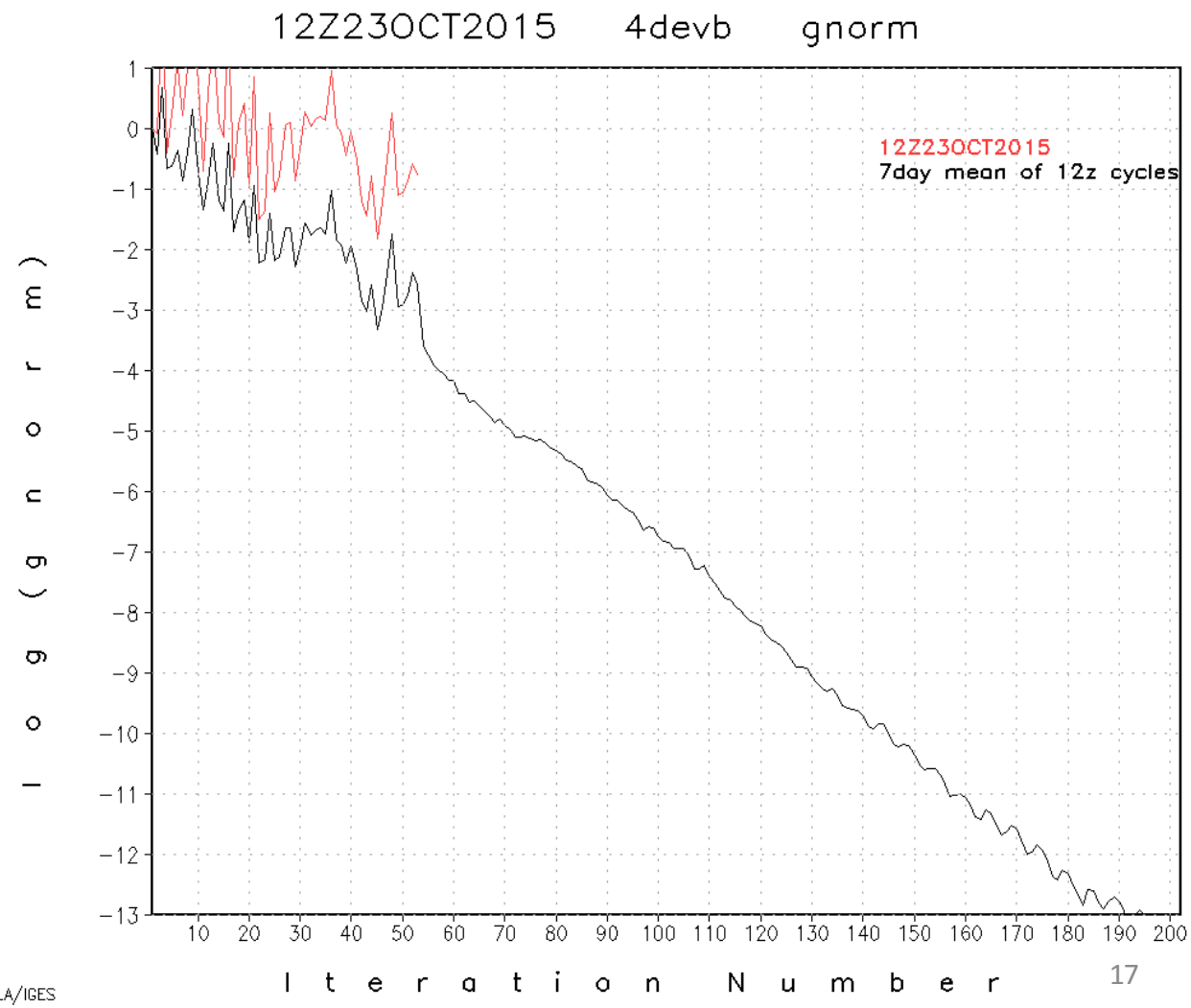
RMSE Summary, Low Resolution



3DVAR
3DHYB
4DHYB

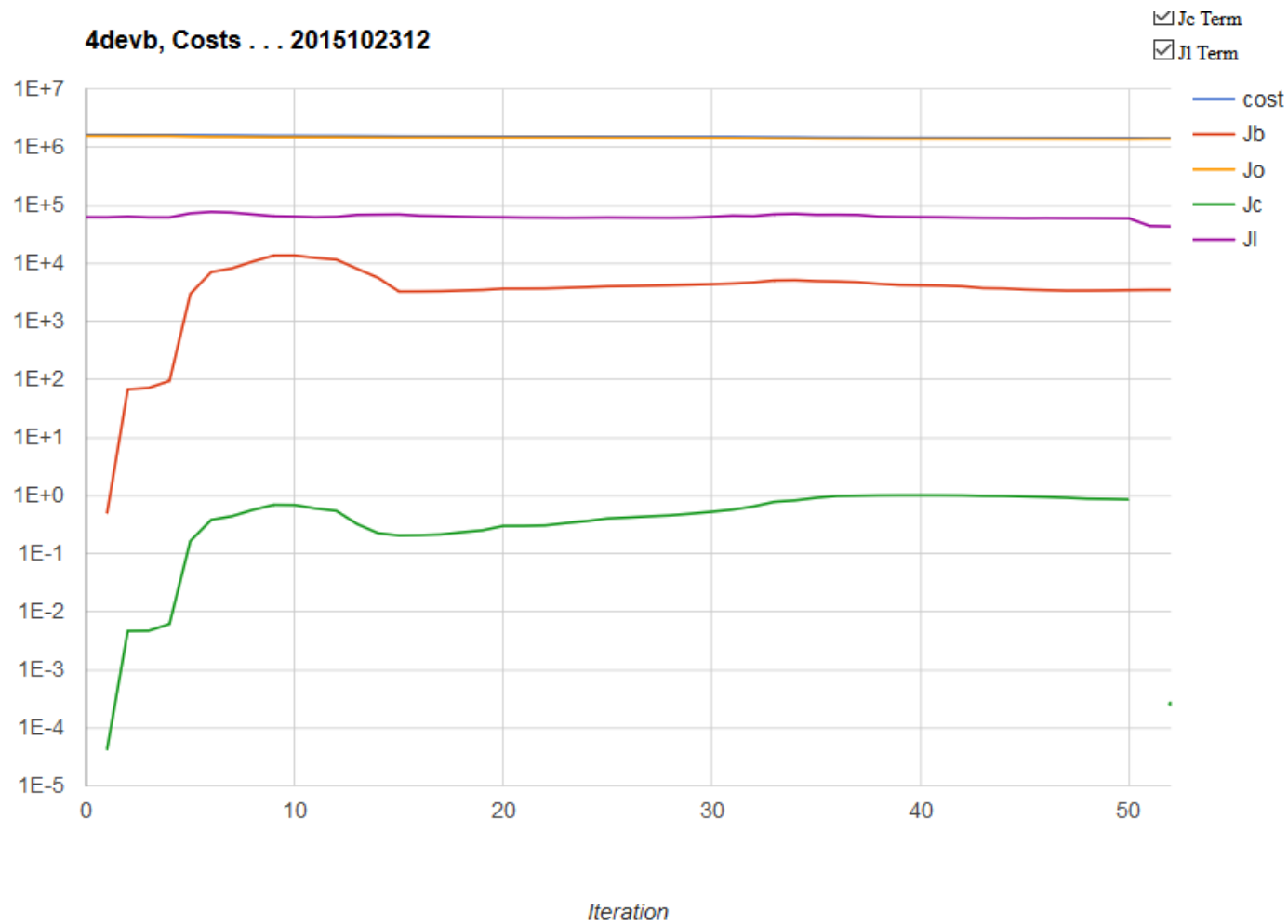
Minimization, GFSx

- In late October 2015, the GFSx had several consecutive cycles with minimization problems.
- Gradient norm was several orders of magnitude too large.
- Minimization algorithm was exiting early.



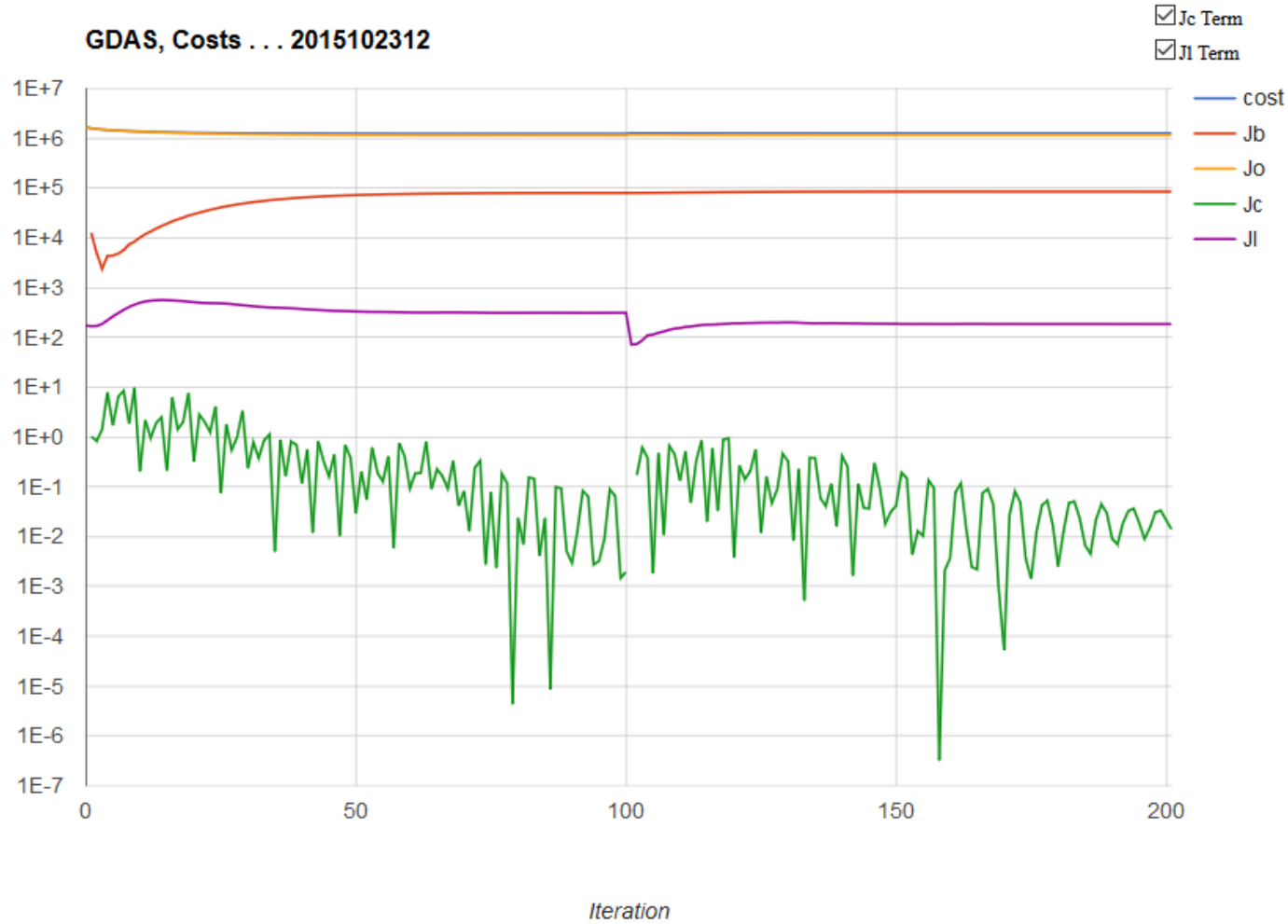
Minimization, GFSx

- We examined the components of the cost function for a single cycle.
- The negative/ excessive moisture constraint (purple) was several orders of magnitude larger than typically seen (compare to next slide).



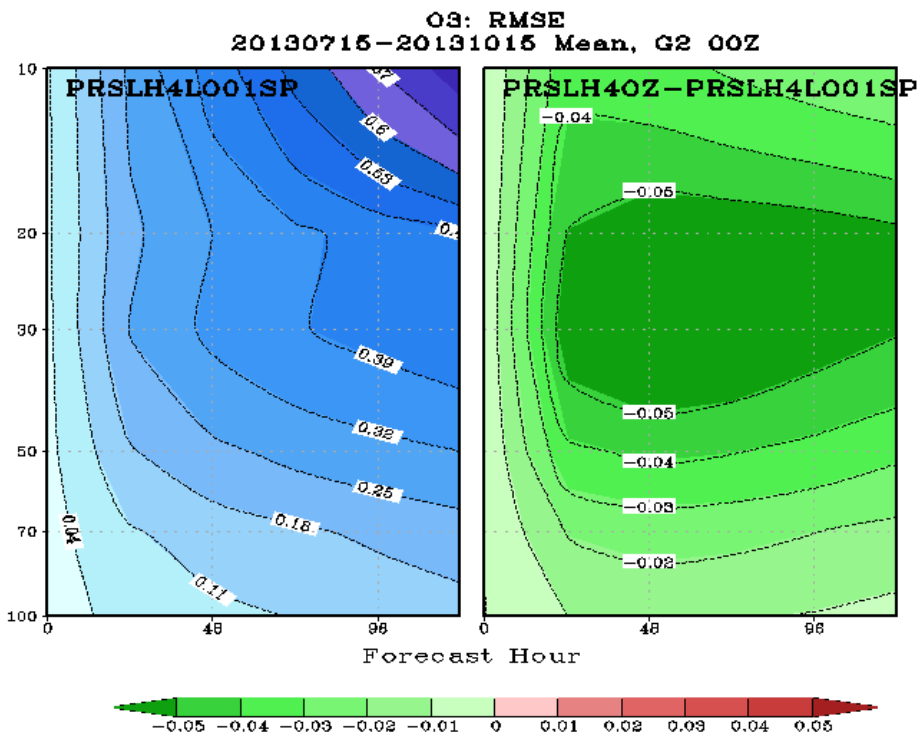
Minimization, GFS

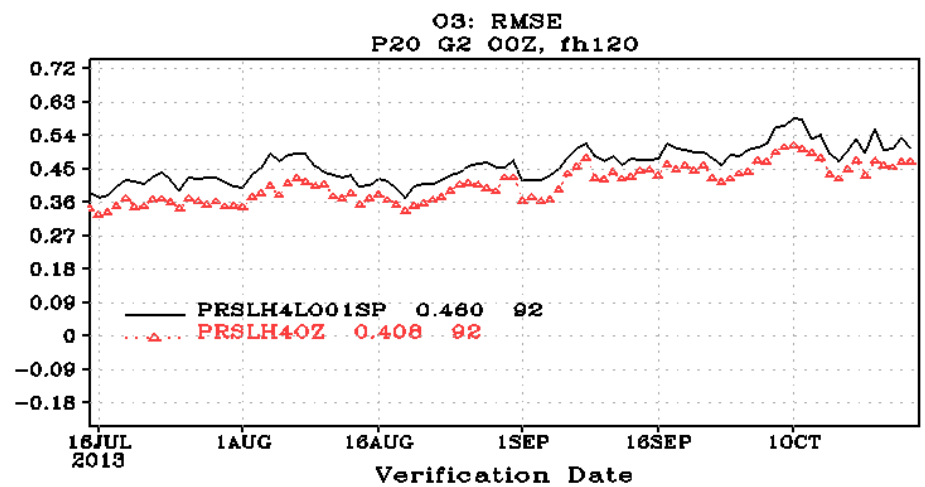
- Operational GFS did not suffer the same problem.
- In the GFSx, some moisture perturbations were being sent from the model that were beyond realistic bounds, >200%.
- A fix was included to limit the moisture perturbations to realistic values (±100%).



Multivariate Ozone, Low Resolution

- Ozone has previously been assimilated univariately.
- We now include the cross-covariances between ozone and the other variables.





Self-analysis verification

Multivariate Ozone, GFSx

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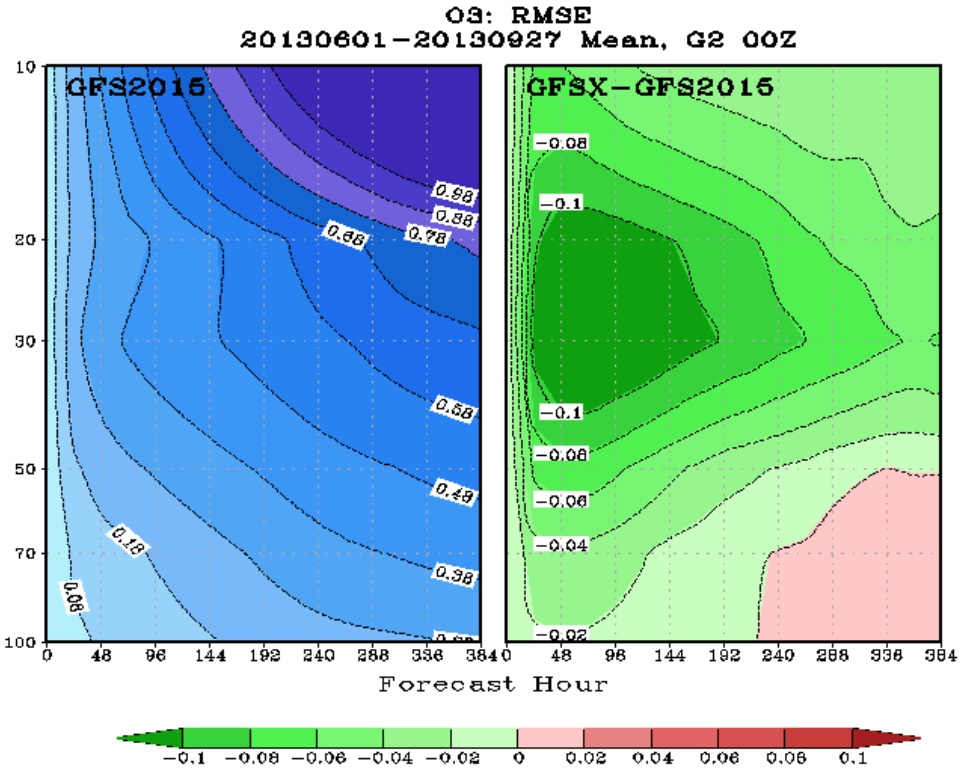
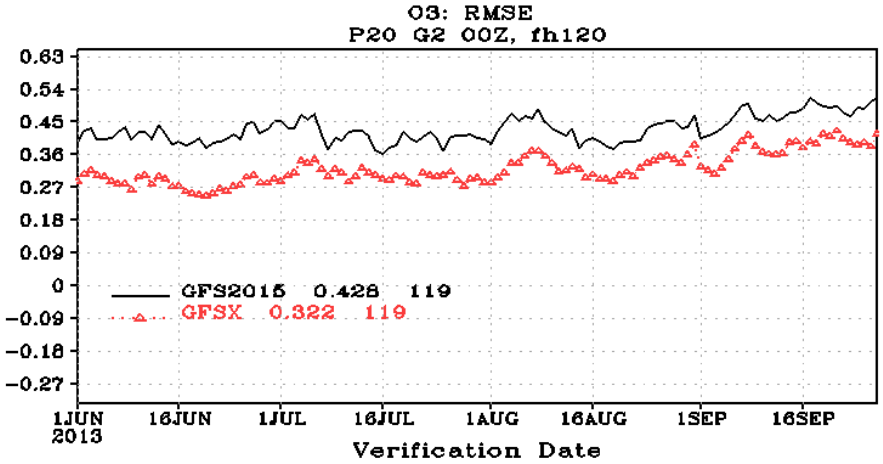
- We now include the cross-covariances between ozone and the other variables.





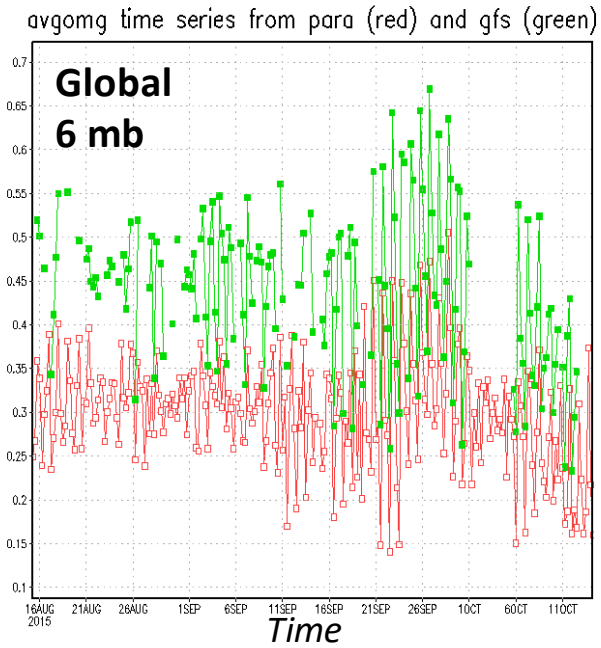
Self-analysis verification

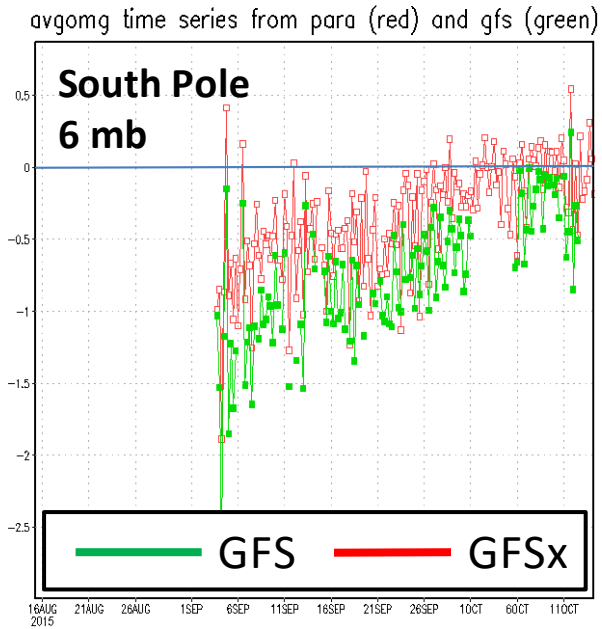
Multivariate Ozone, GFSx

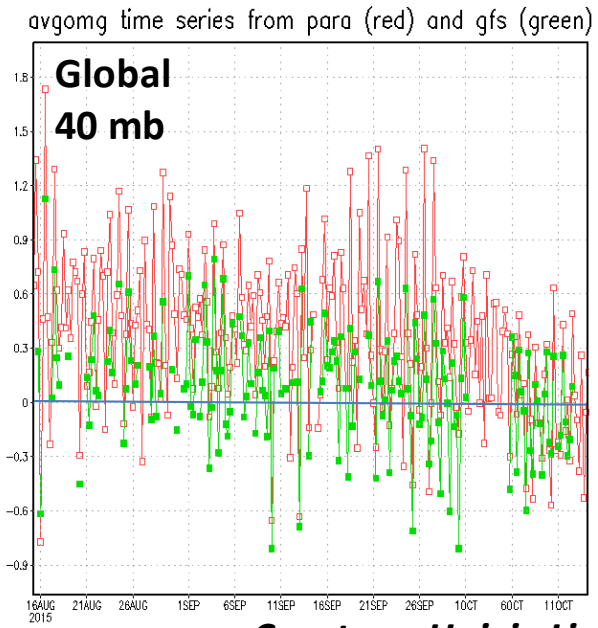
- Ozone in the GFSx was compared with observations
- Shown for SBUV/2
- Aug 15 – Oct 15, 2015
- Overall neutral to positive impact

Some levels showed a large positive impact.

A couple levels showed a negative impact.



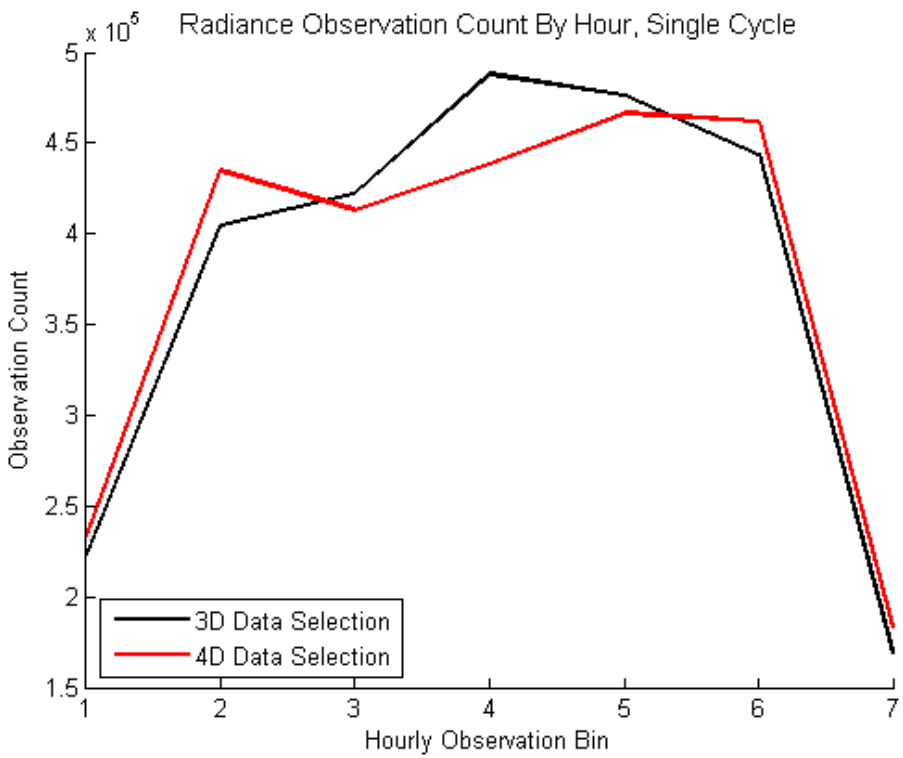


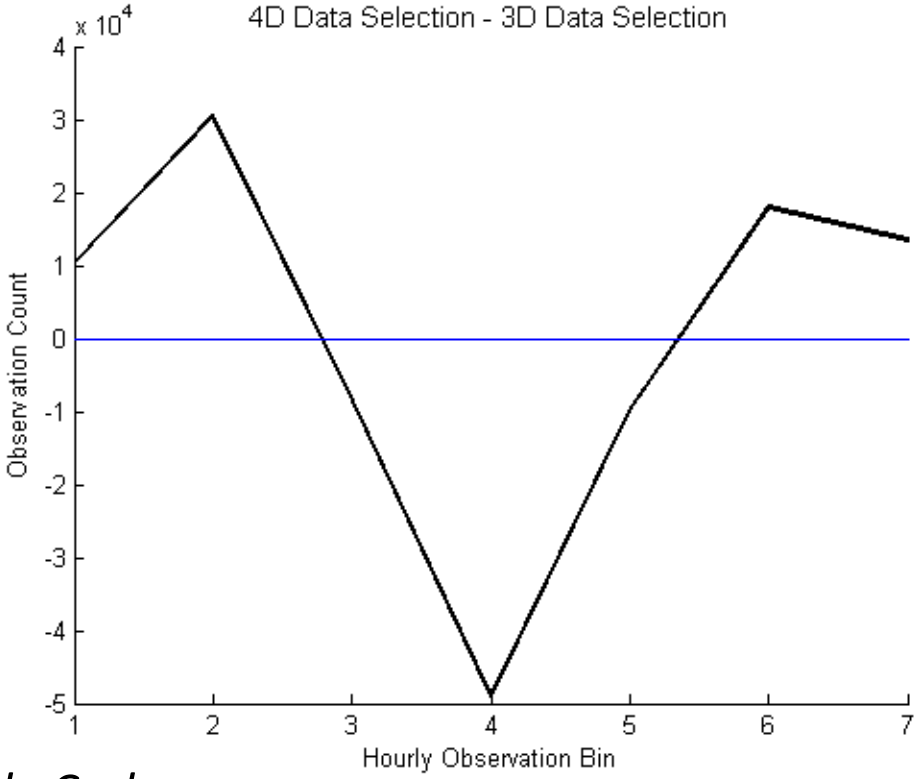


Courtesy: Haixia Liu

Data Selection in 4D, Low Resolution

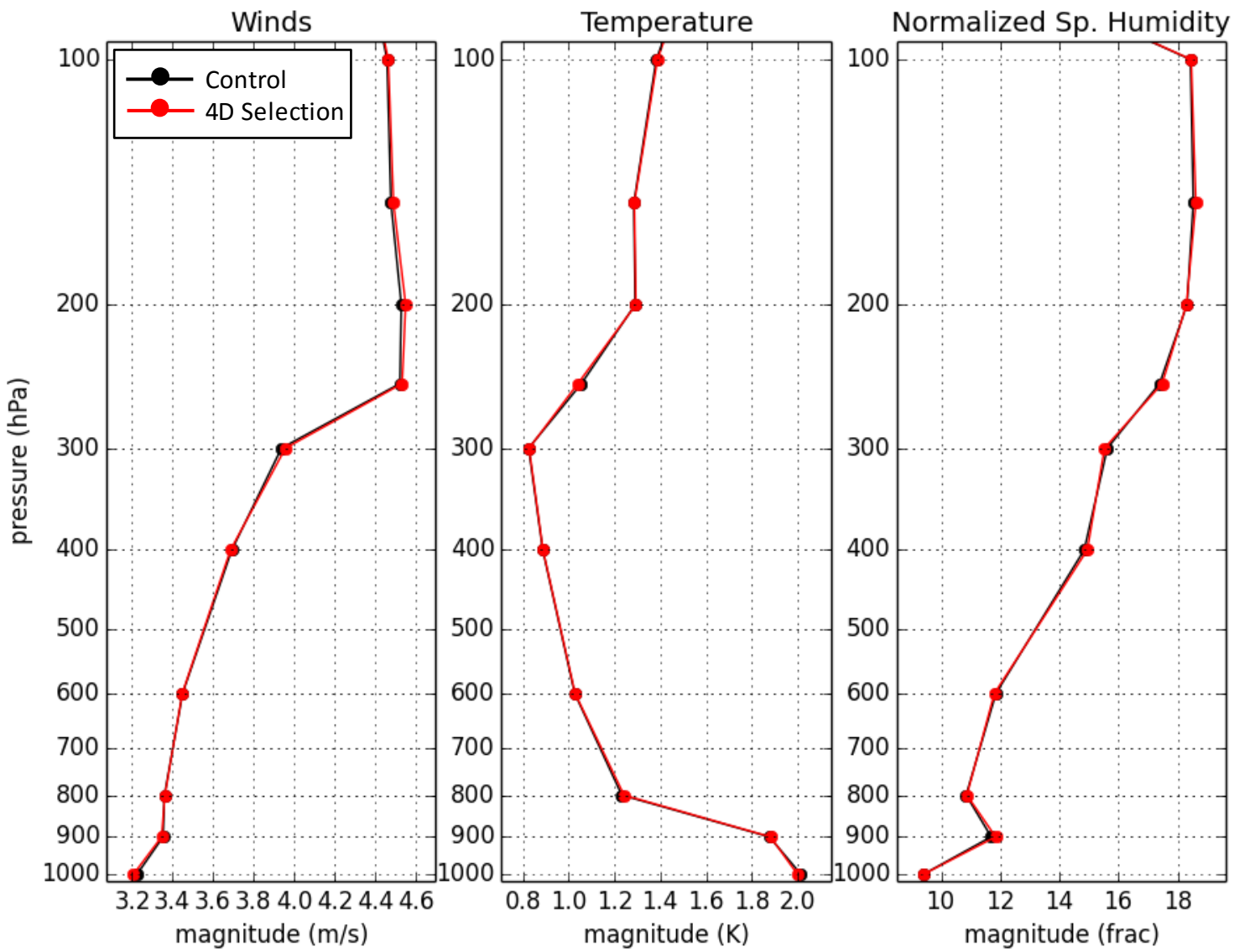
- In the 3D context, data towards the analysis time was preferentially chosen.
- With the background ensemble at each hour, this is no longer necessary.
- The time component of the data selection procedure has been removed.
- Data is more evenly distributed across the window.





Single Cycle

Low Resolution Experiments



Not expected to have a large impact globally. First step towards 4D thinning.

Data Selection in 4D, GFSx

- In the 3D context, data towards the analysis time was preferentially chosen.
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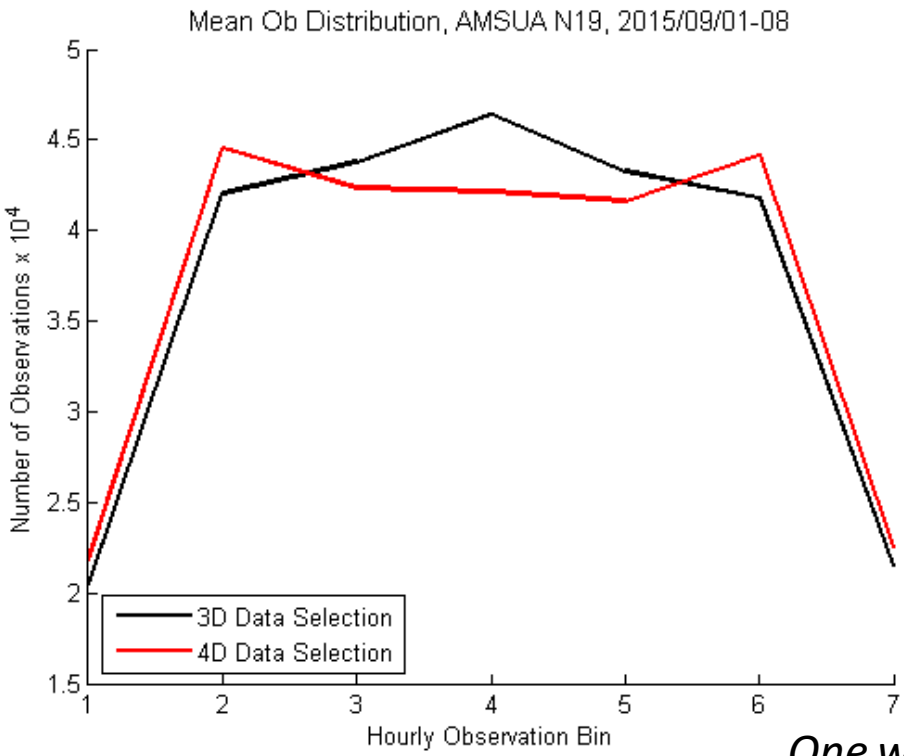
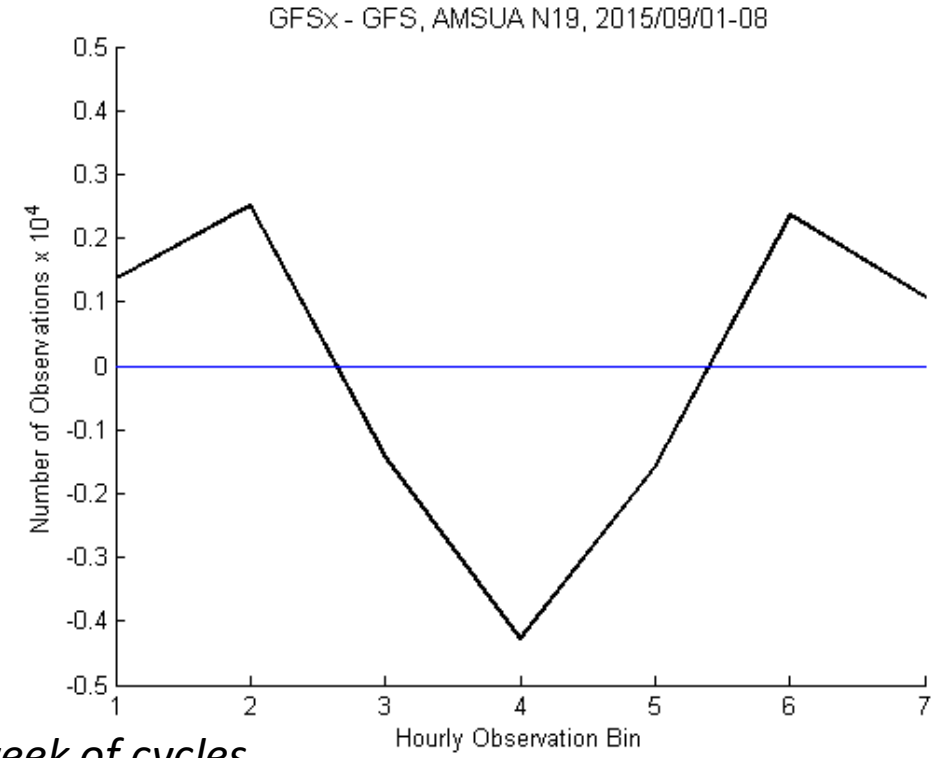




One week of cycles

4D Thinning of Hourly AMVs

- Hourly products replaced 3-hourly products at EUMETSAT and JMA.
- Current 3D algorithm would not take advantage of the additional information in time.
- We can extract information on the time evolution from hourly observations.
- New 4D thinning configuration has 2-hour observation bins.

Courtesy: Xiujuan Su

Data Count Change by Data Type

2013102300-2013120218

- 242(MTSAT VIS): 69488/338366=21%
- 252(MTSAT IR) 395046/2436233=16%
- 250(MTSAT WV) 275144/1529824=18%
- 243(METEOSAT-7 VIS) 96543/376100=26%
- 243(METEOSAT-10 VIS) 406730/340972=119%
- 253(METEOSAT-7 IR) 269414/426286=63%
- 253 (METEOSAT-10 IR) 843564/554759=152%
- 254 (METEOSAT-7 WV) 456858/1320300=35%
- 254(METEOSAT-10 WV) 760661/473751=161%

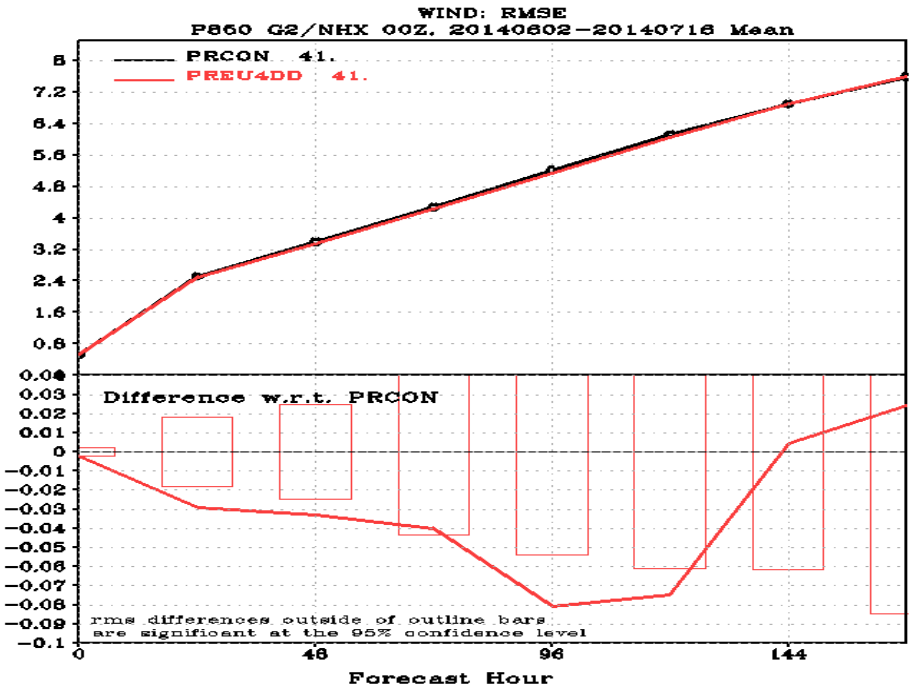
MTSAT and METEOSAT-7 were not previously thinned. → Decrease in data count
METEOSAT-10 was previously thinned but in 3D. → Increase in data count

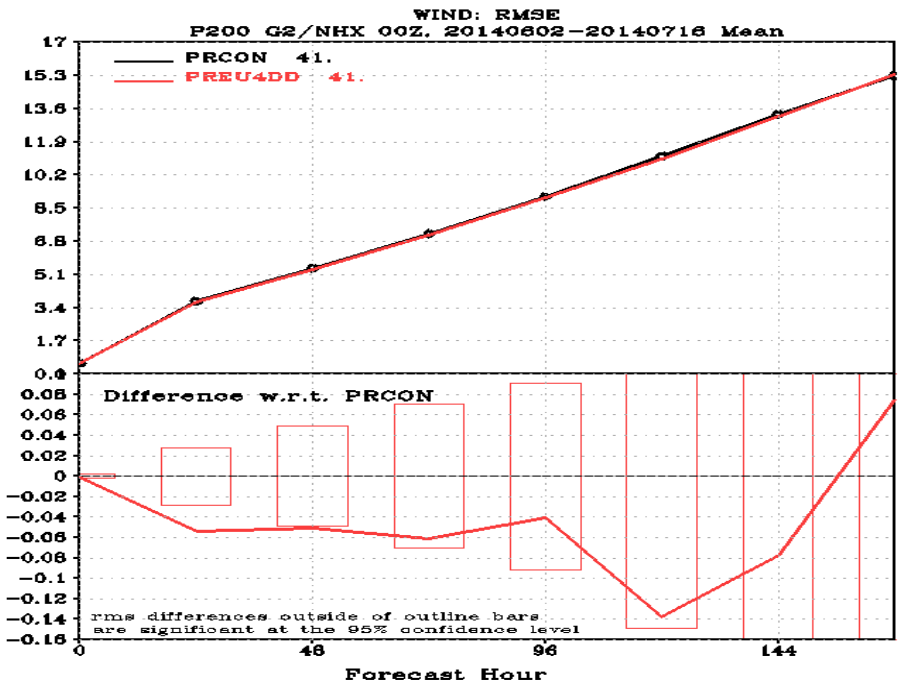
Courtesy: Xiujuan Su

4D Thinning of Hourly AMVs

- Low Resolution Experiment
- 2 Seasons: 2013102200 to 20131205, 20140601 to 20140716
- Results consistent between seasons, only summer shown
- Improvement in winds, other variables are neutral

Wind RMS at 850mb and 200mb in the northern hemisphere





Courtesy: Xiujuan Su

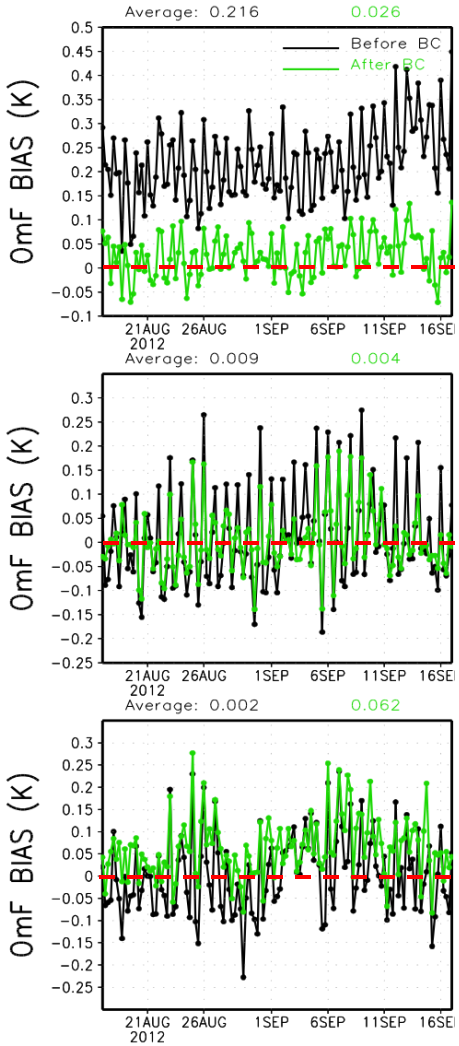
Aircraft Bias Correction

- Several studies have noted that the aircraft data contains a warm bias at around 200 hPa.
- Follows the variational radiance bias correction (Derber and Wu 1998, Zhu et al 2013) and the aircraft bias correction of ECMWF (Isaksen et al 2012).
- Aircraft temperature bias correction is conducted simultaneously inside the analysis system as the analysis is produced.
- Bias coefficients are aircraft tail number dependent for AMDAR data, but one single bias coefficient for AIREP data.
- Tensioned spline method is used to calculate aircraft vertical velocity (Purser et al 2014), used in defining bias predictors, which mitigates missing time information.

Courtesy: Yanqiu Zhu

Aircraft Bias Correction, Low Res.

OmF Bias



Before BC
After BC

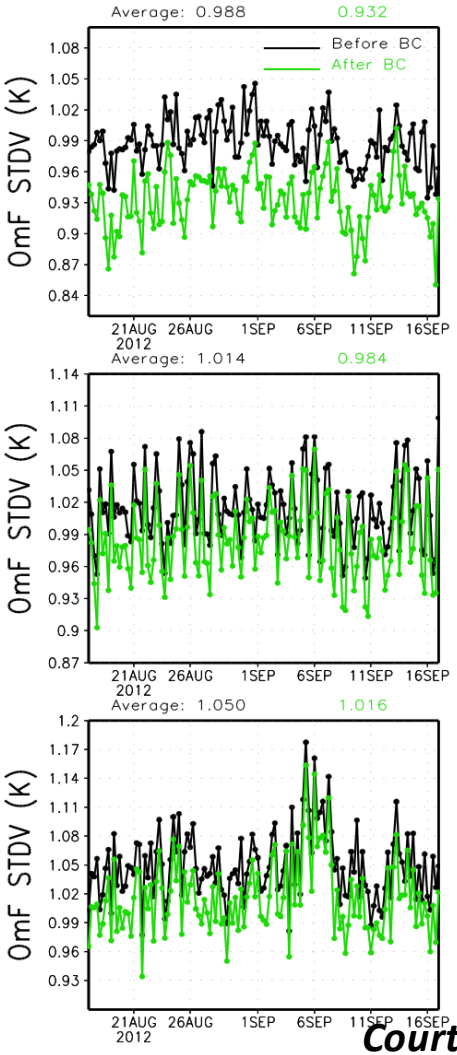
Cruise Level

Ascending

Descending

OmF = Observation minus forecast

OmF Std Dev



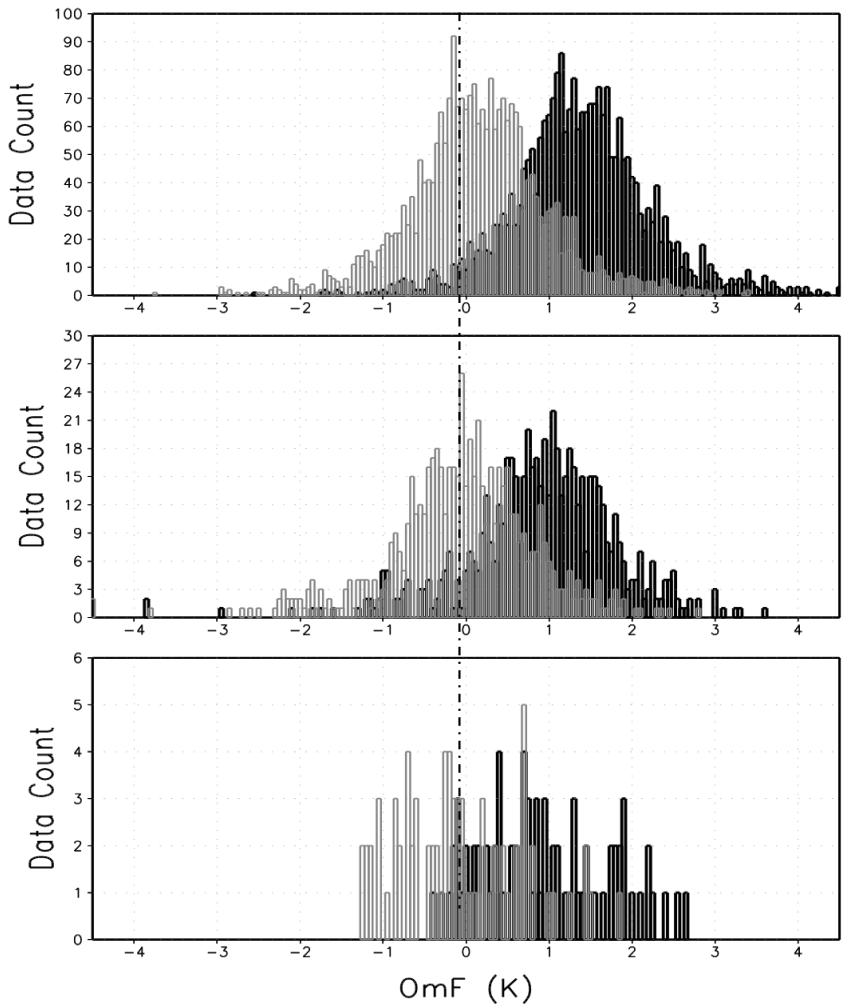
Courtesy: Yanqiu Zhu

Aircraft Bias Correction, Low Res.

Before BC
After BC

Aug 17-Sept 17, 2012
NUS-AMDAR
Aircraft EU6900

Observation Minus Forecast (OmF)



Cruise Level

Ascending

Descending

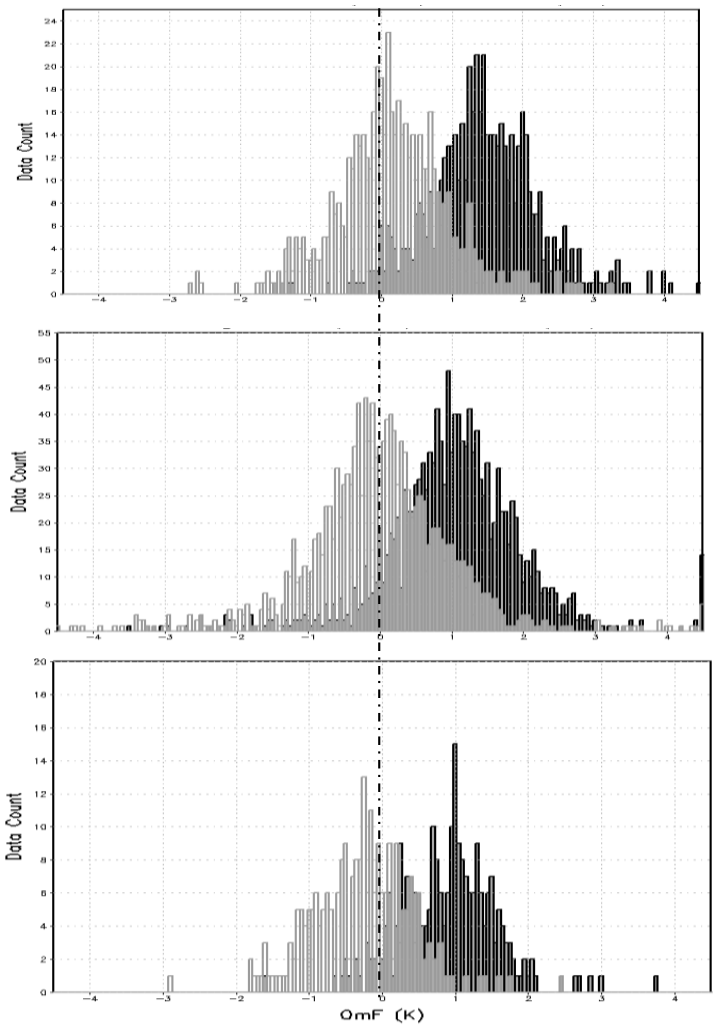
Courtesy: Yanqiu Zhu

Aircraft Bias Correction, GFSx

Before BC
After BC

Sept 1 – Oct 31, 2015
NUS-AMDAR
Aircraft EU6900

Observation Minus Forecast (OmF)

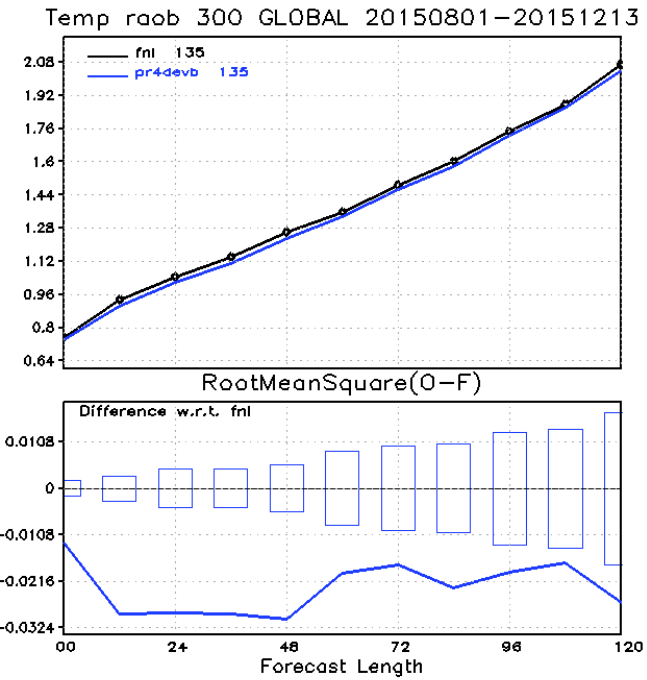


Cruise Level

Ascending

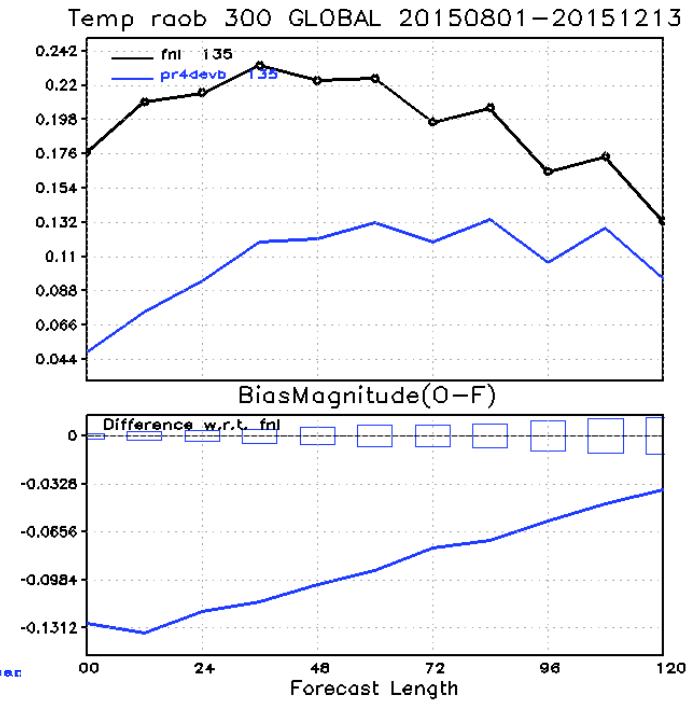
Descending

Aircraft Bias Correction, GFSx

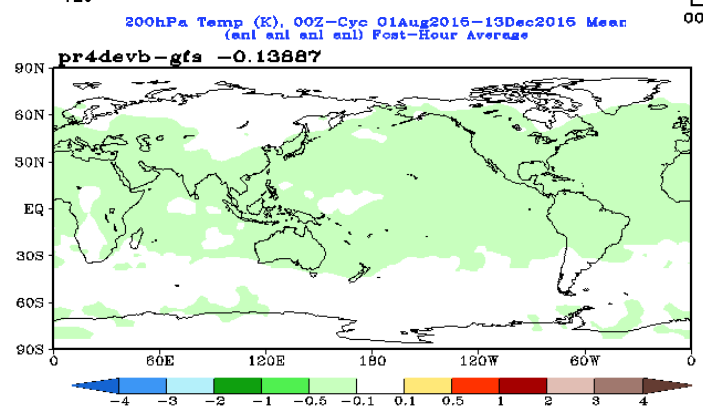


Fit to Radiosondes
T at 300 hPa

RMS OmF (left)
Bias OmF (right)



T at 200 hPa
GFSx - GFS



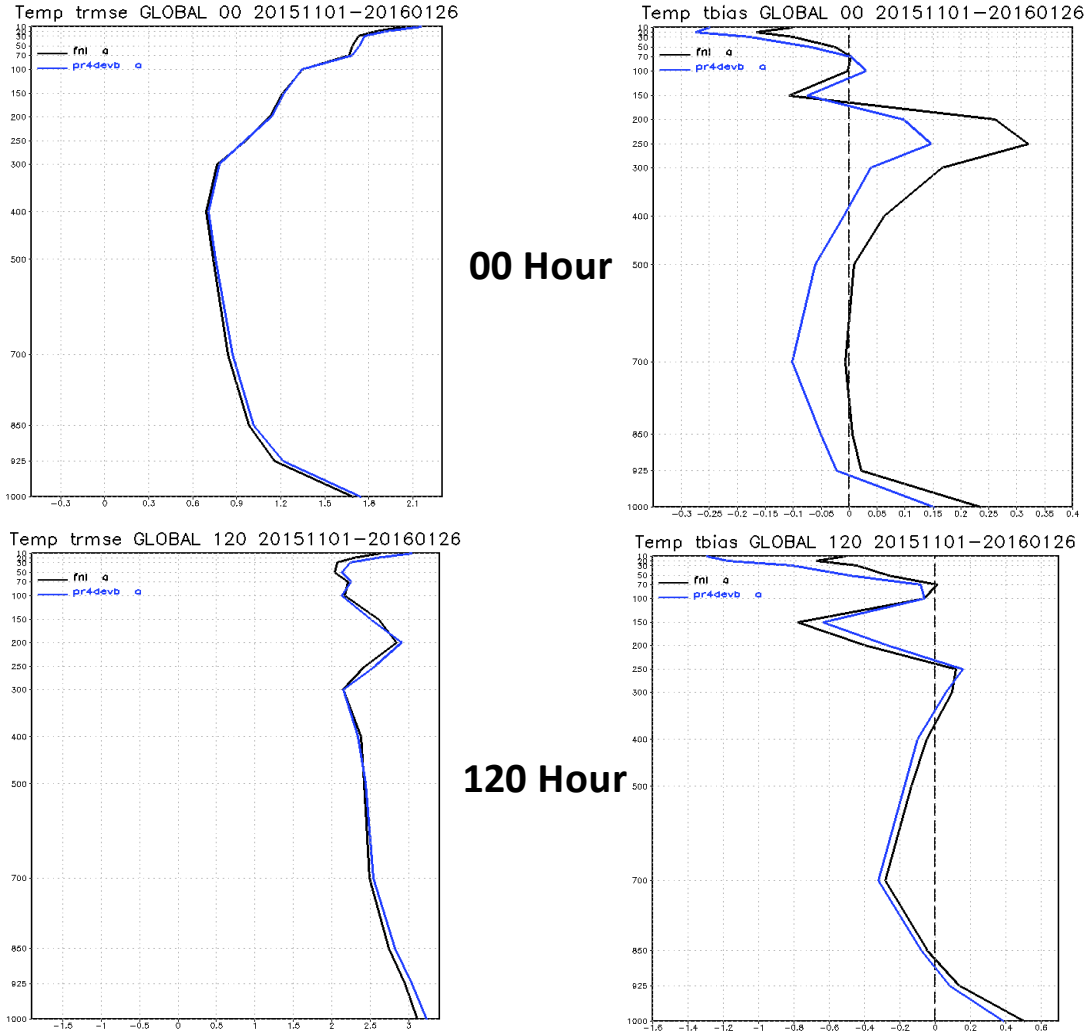
Large amount of cooling found at levels of greatest warm bias.

Column Cooling Concern

Real Time GFSx
11/01/2015 – 01/26/2016

- It was noted that the GFSx had a cooler troposphere with forecast degradation when compared to raobs through 120 hours.
- Is this due to the cooling of the aircraft bias correction?

RMSE **Bias**



00 Hour

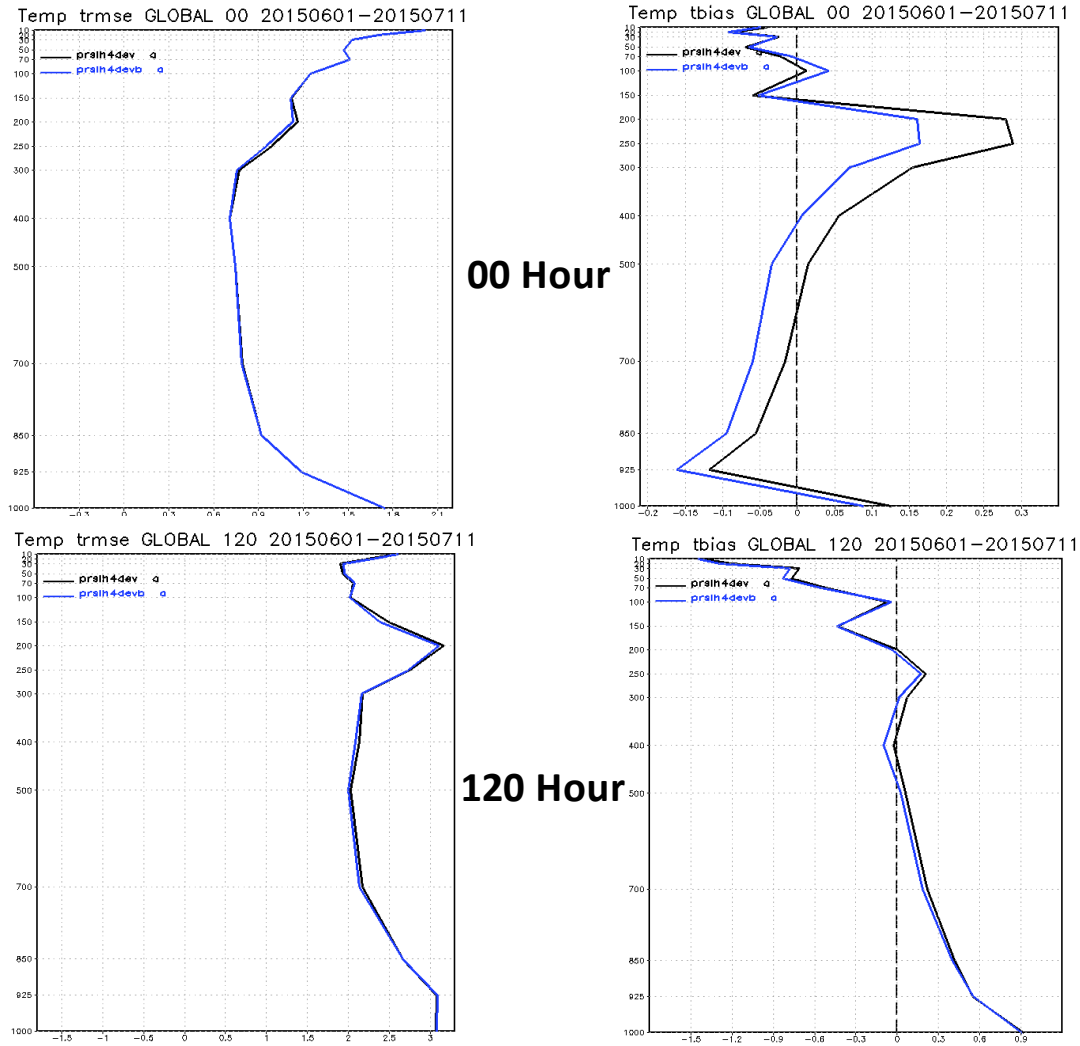
120 Hour

Column Cooling Concern

Low Resolution
06/01/2015 – 07/11/2015

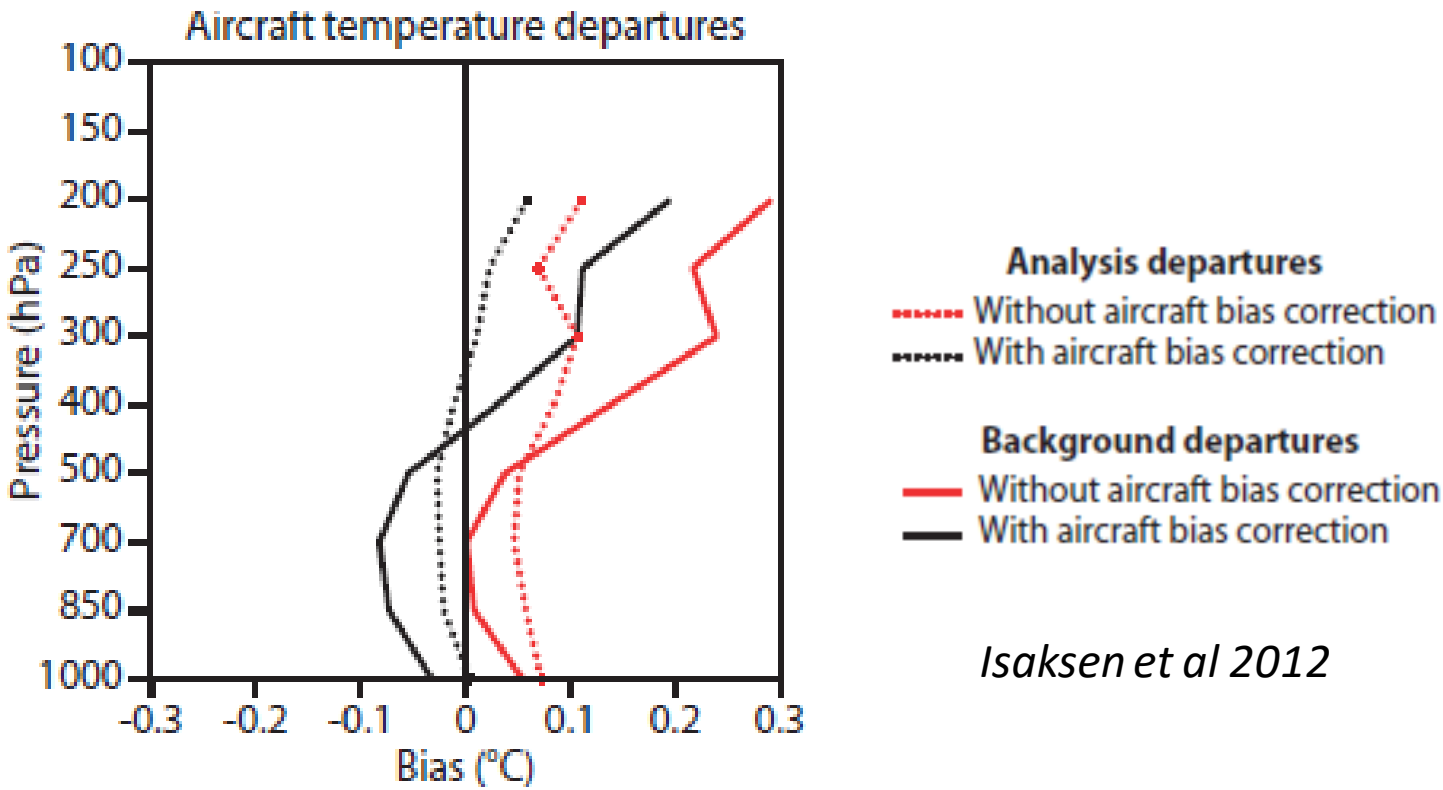
- Previous clean low resolution experiments show substantial cooling where the largest warm bias occurs but the cooling extends throughout the column at the 00 hour.
- Amount of cruise level data overwhelms the rest.
- However, forecast skill is not degraded and the cool bias is significantly reduced by 120 hours.

RMSE **Bias**



Column Cooling Concern

- This type of aircraft bias correction was initially implemented at ECMWF.
- Their results showed similar column cooling.
- Our implementation seems to be correct.



Isaksen et al 2012

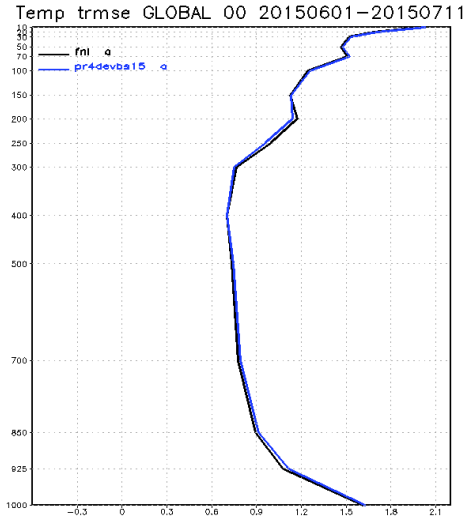
Column Cooling Concern

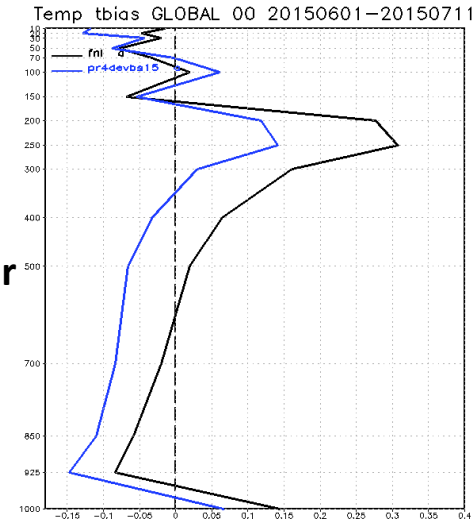
Retrospective GFSx
06/01/2015 – 07/11/2015

- Low resolution results are not directly comparable to real time GFSx figures due to potential seasonality
- Looked at the GFSx retrospective for same period as our low resolution test
- We see additional cooling at the surface that was not present in our test.
- Due to the land surface change?

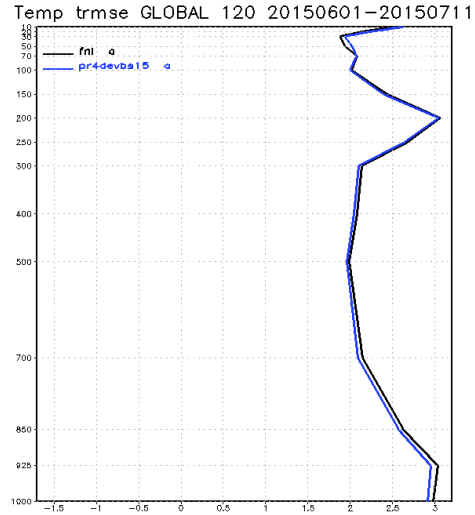
RMSE **Bias**

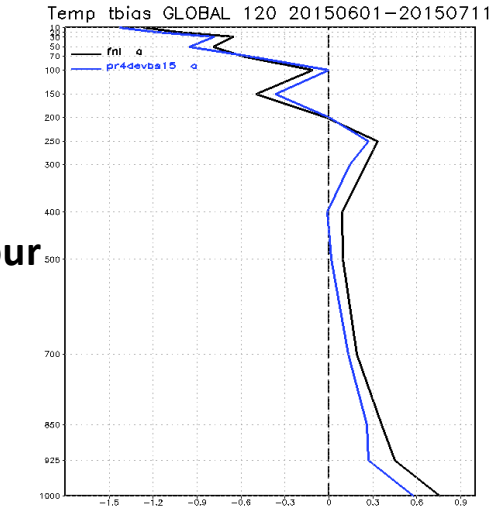
00 Hour





120 Hour



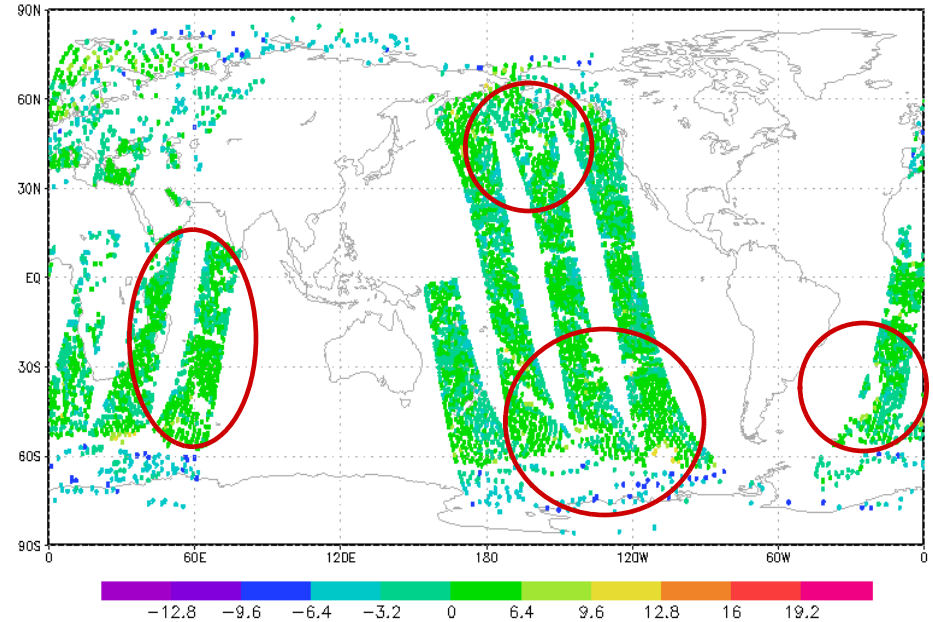


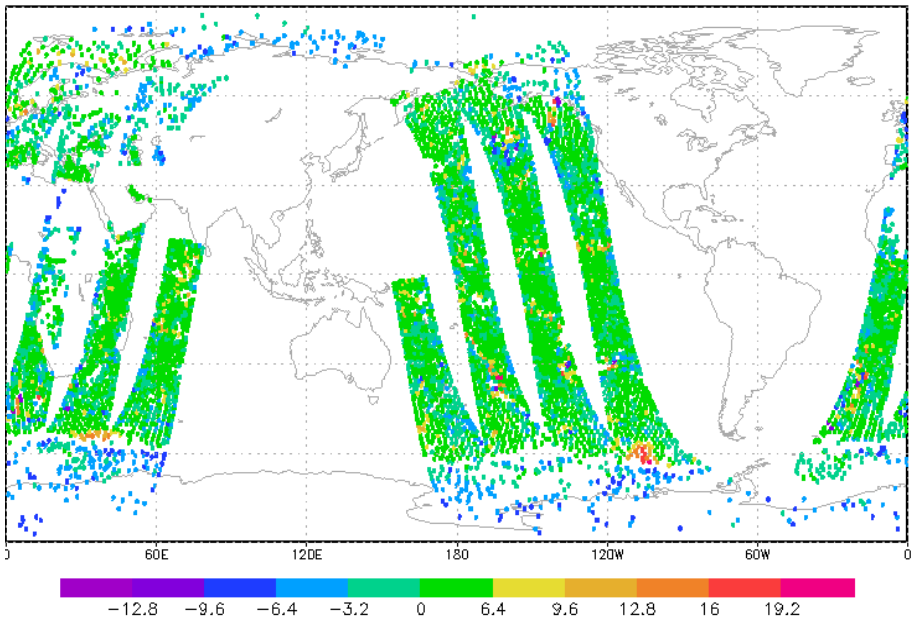
All Sky Microwave Assimilation

- Previously, clear sky data and radiances affected by thin clouds only were used
- The all sky approach includes the addition of microwave radiances affected by thick, non-precipitating clouds
- AMSU-A channels 1-5, 15
- New all-sky radiance bias correction strategy (Zhu et al 2014)
- Situation-dependent observation error inflation
- AMSU-A observation error re-tuned
- Symmetric observation error assignment (Geer et al 2011)
- Normalized cloud water control variable and new static background variance
- Individual hydrometeors as state variables

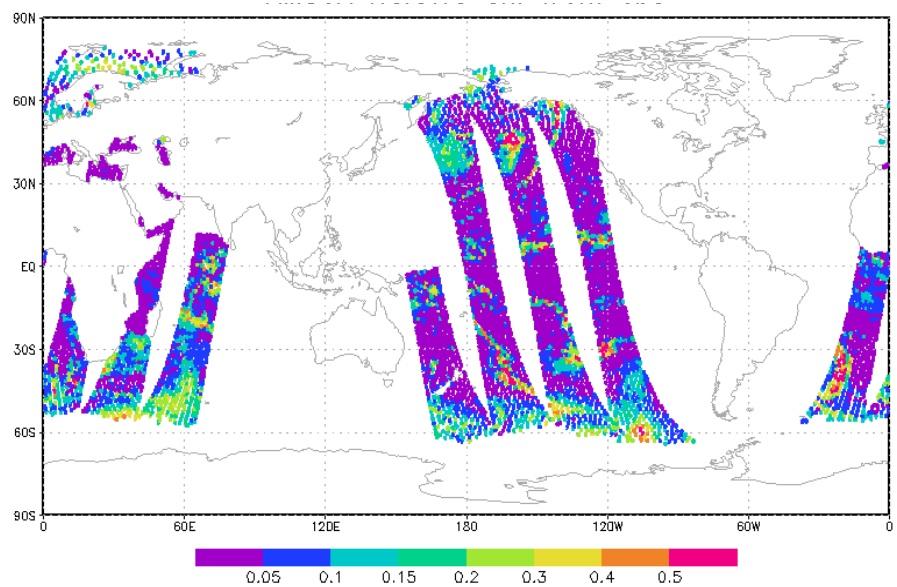
Courtesy : Yanqiu Zhu

Clear-sky OmF vs. All-sky OmF





Cloud Water

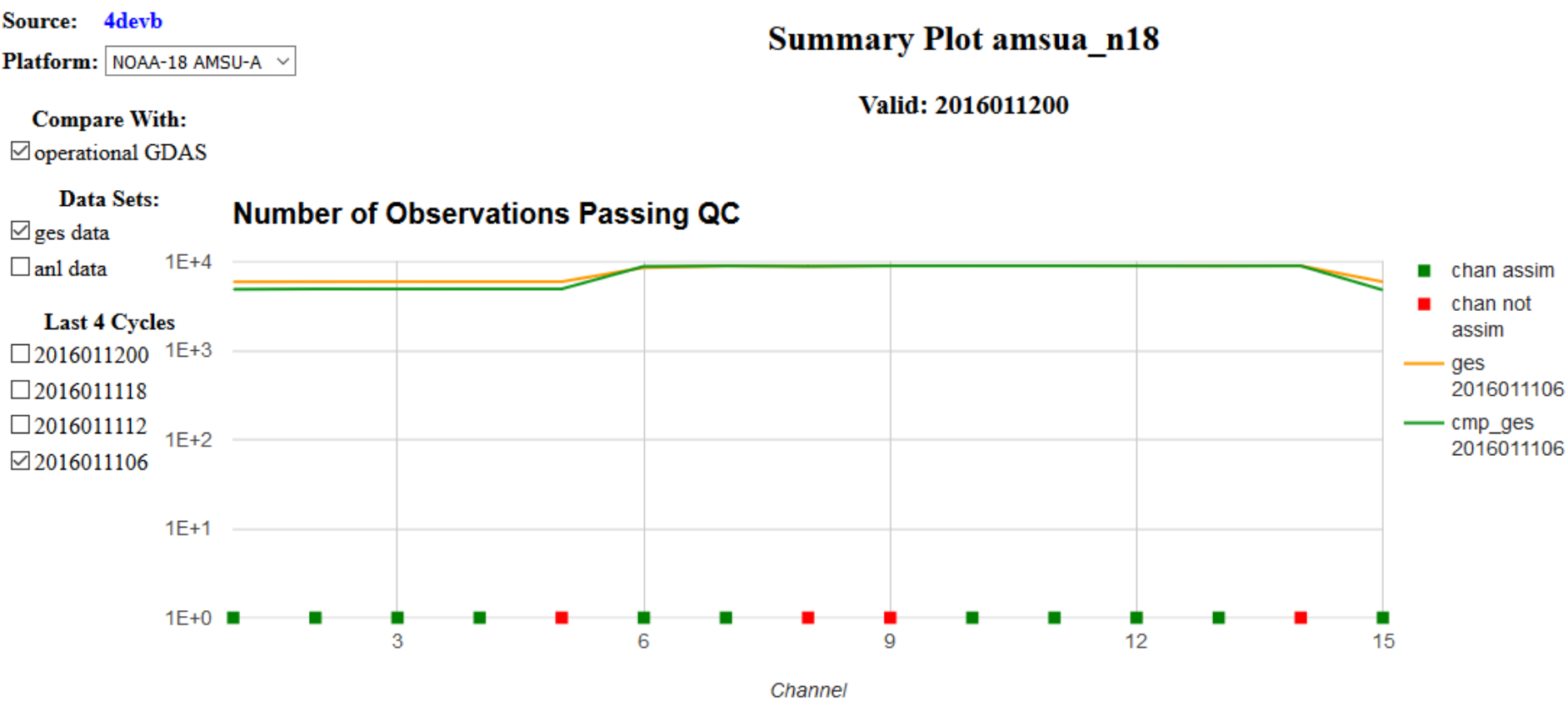


- More data coverage: Thick clouds that are excluded from clear-sky assimilation are now assimilated under all-sky condition
- Rainy spots are excluded from both conditions

AMSUA NOAA19 CH1 00Z 20131029

Courtesy : Yanqiu Zhu

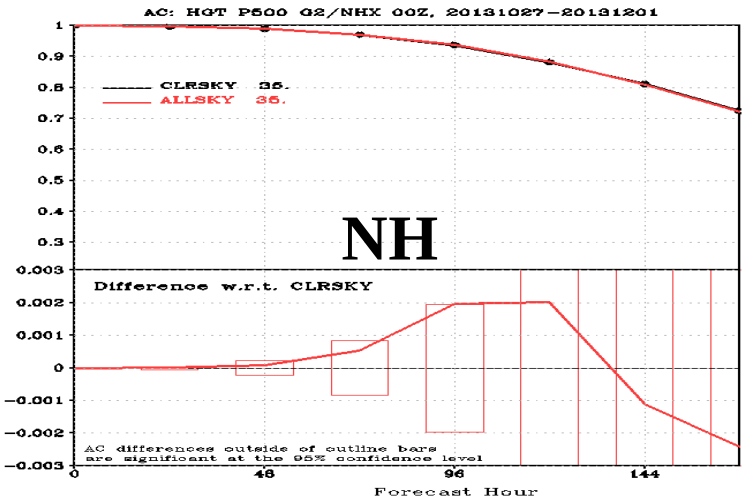
All Sky Assimilation, GFSx

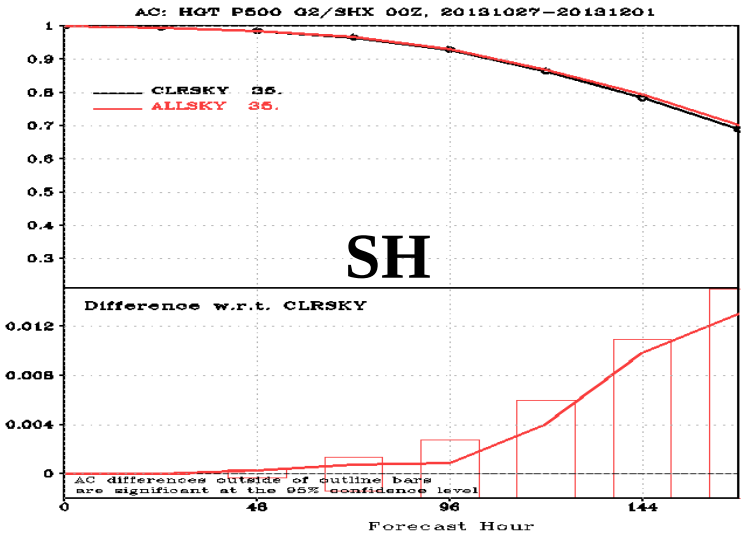


More observations are assimilated from the channels that now allow cloudy radiances.

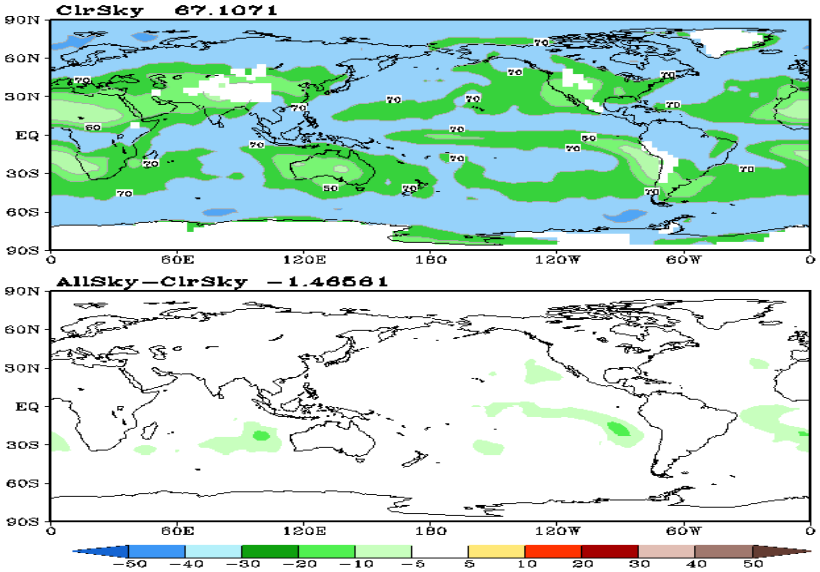
T670/T254 All-sky Microwave Radiance Assimilation in 3D EnVar

Anomaly Correlation at 500 hPa

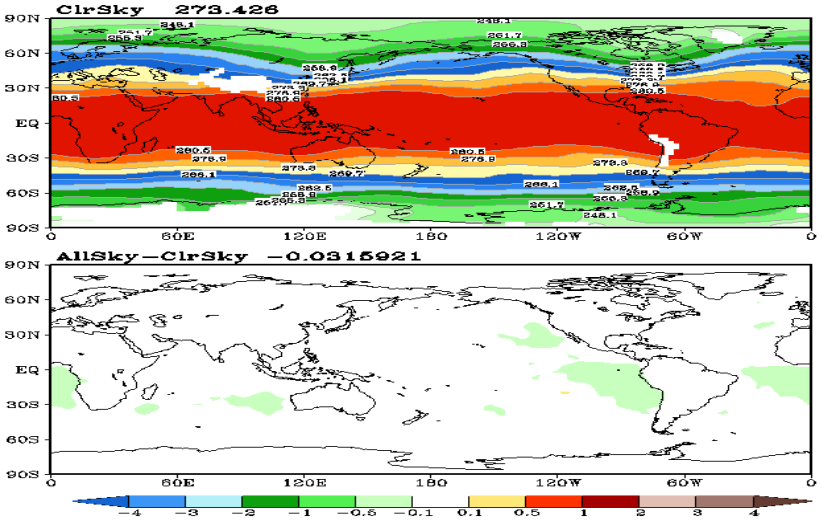




Impact on RH at 850hPa

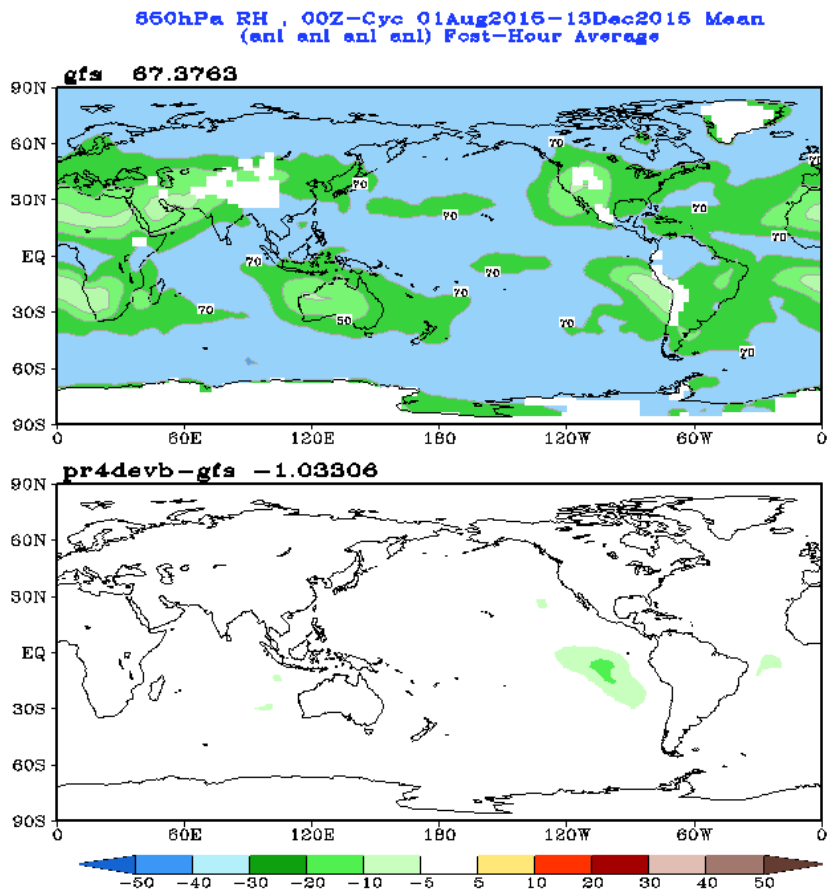


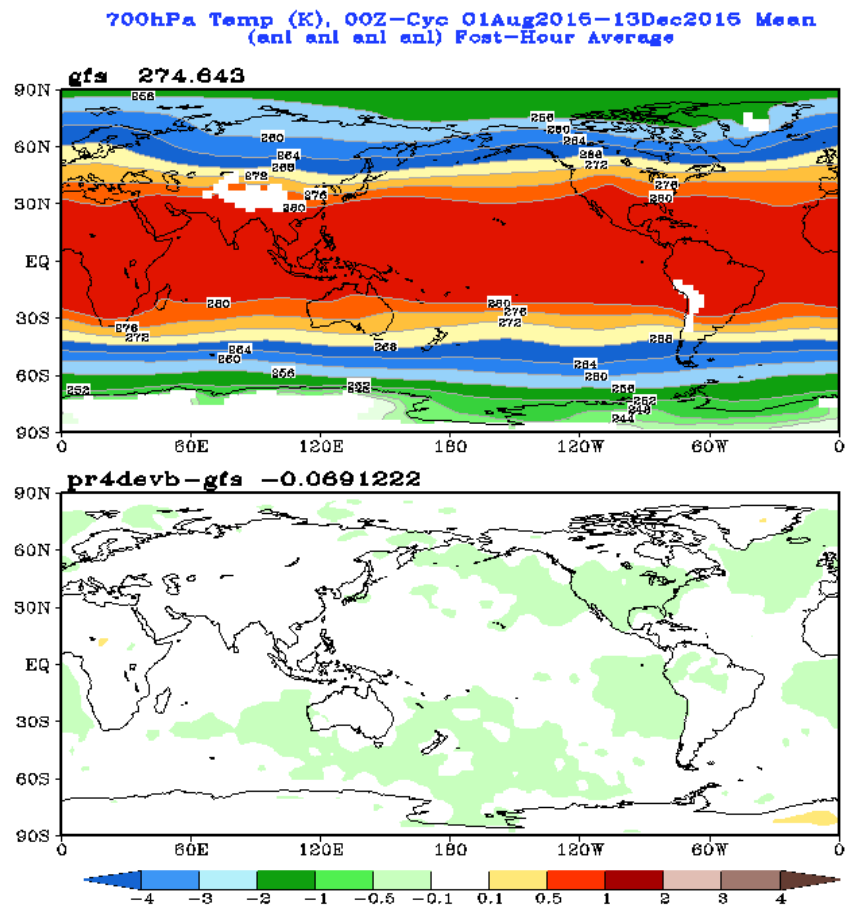
Impact on T at 700hPa



Courtesy: Yanqiu Zhu

All Sky Assimilation, GFSx



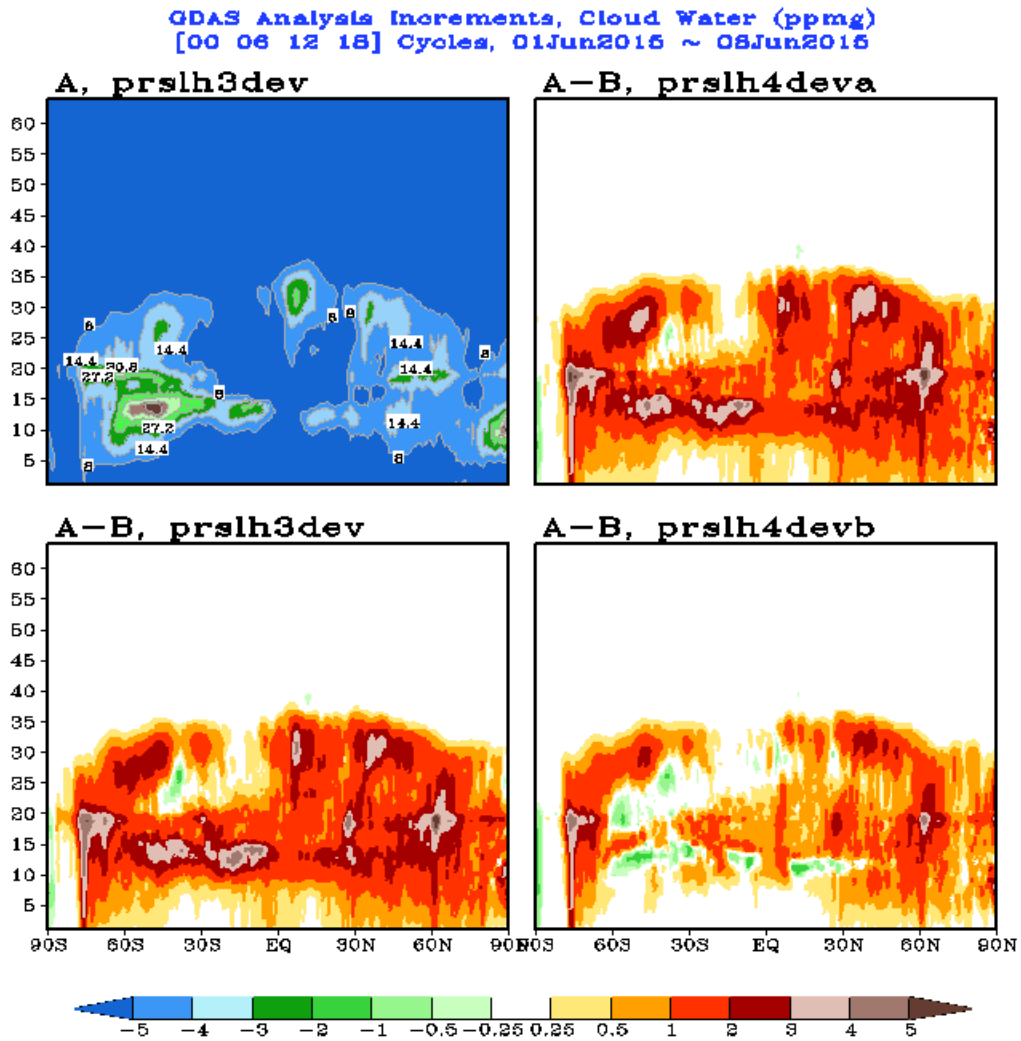


All Sky Assimilation, Low Resolution

Bottom left: Equivalent to OPS

Top right: 4D package with clear sky

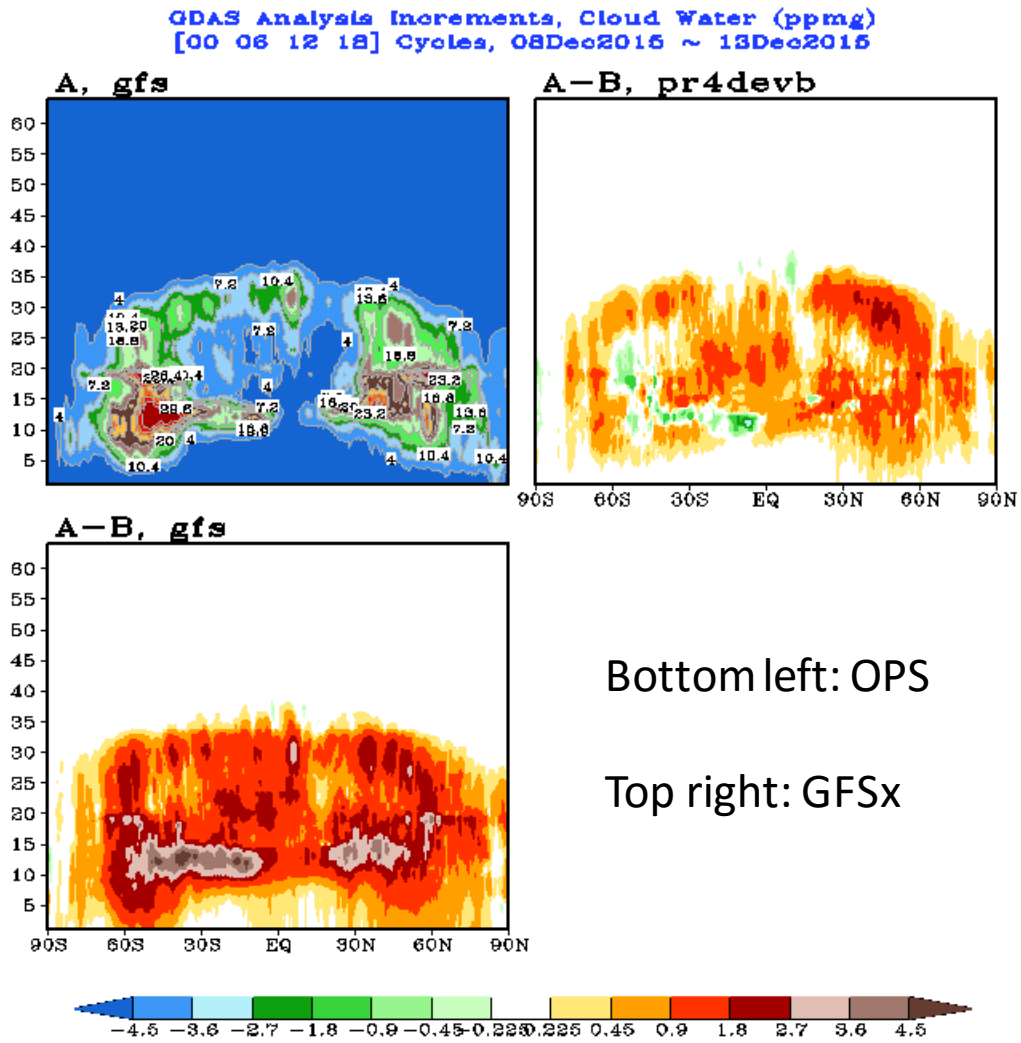
Bottom right: 4D package with all sky



Previous system had a positive bias for the cloud water increments.

The All-Sky Package reduces this bias.

All Sky Assimilation, GFSx



Bottom left: OPS

Top right: GFSx

CRTM

- Community Radiative Transfer Model
- Diffuse surface reflection added for non-precipitating clouds
- CRTM input wind direction bug fix
- Updated surface emissivity component from FASTEM-5 to FASTEM-6
- Minor changes to the interfacing

A series of tests were performed to validate the CRTM. Another radiative transfer model, RTTOV, was incorporated into the GFS for direct comparison. This allowed for some bugs to be discovered and corrected.

FASTEM Reflection Correction

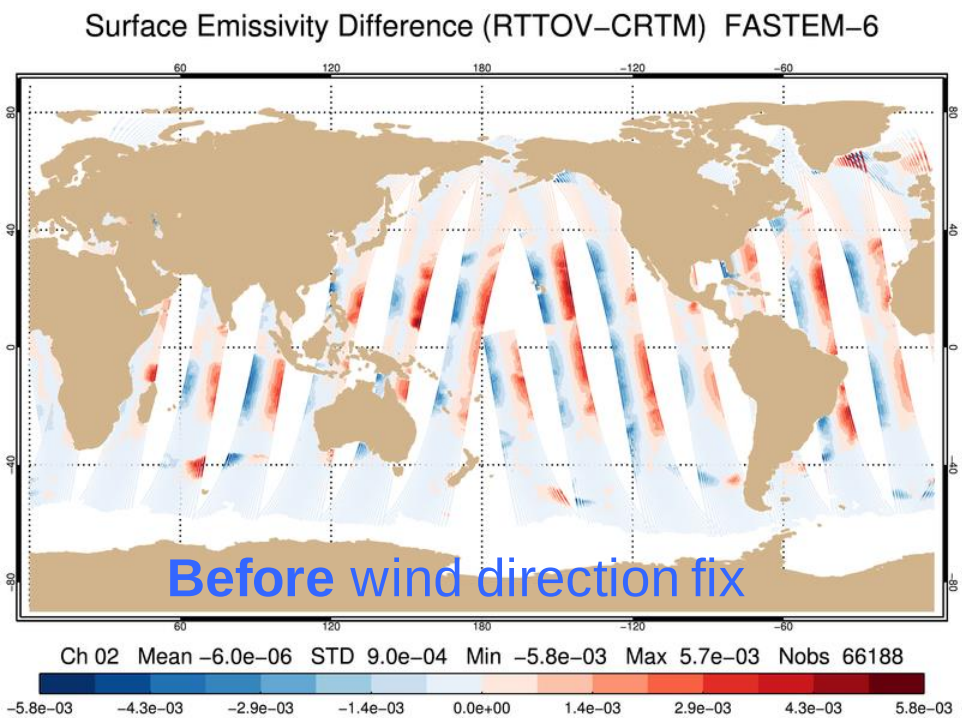
- Emily Liu provided plots that indicated a cold bias in simulations when applying the CRTM for non-precipitating cloudy atmospheres

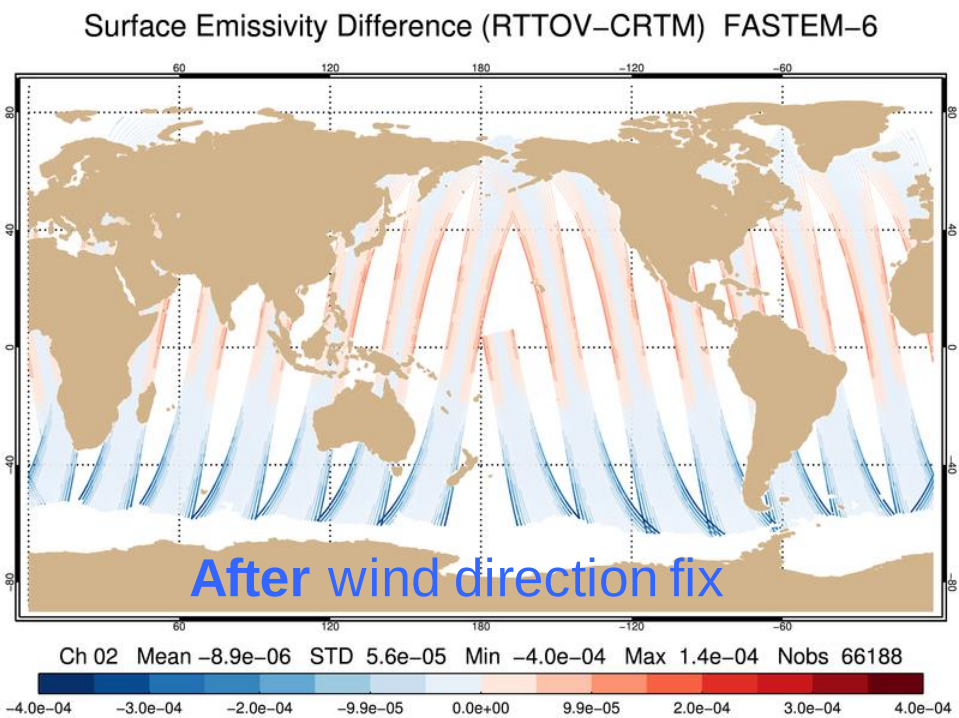
- The CRTM team identified that the source of this bias was due to the absence of a downwelling diffuse surface reflection contribution for non-precipitating cloudy atmospheres

- The diffuse surface reflection component for non-precipitating cloudy atmospheres was turned on for CRTM 2.2.X releases. Emily Liu confirmed that this removed the CRTM cold bias for simulations of AMSU-A surface sensitive channels.

Courtesy: David Groff

CRTM: Wind Direction Fix





- Input wind direction to the CRTM in the GSI's CRTM interface was incorrect. Westerly and easterly winds were previously input to the CRTM as having the same direction.

Courtesy: David Groff and Emily Liu

Points of Contact

Topic	Point of Contact
Monitoring Tools	Ed Safford
4D	Rahul Mahajan
Optimization/Minimization	John Derber
Multivariate Ozone	Cathy Thomas
4D Data Selection	Cathy Thomas
AMVs	Xiujuan Su
Aircraft Bias Correction	Yanqiu Zhu
All Sky Assimilation	Yanqiu Zhu
CRTM	Paul van Delst