The Impact of Satellite Atmospheric Motion Vectors in the U.S. Navy Global Data Assimilation System

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FIFTH WMO WORKSHOP ON

THE IMPACT OF VARIOUS OBSERVING SYSTEMS ON NWP

Sedona, Arizona, (USA), 22-25 May 2012

* Thanks to Ryan Maue, Ben Ruston, Tim Whitcomb, Steve Swadley, Randy Pauley and Glen Carl

Motivation

- Investigate why NRL/FNMOC appears to obtain more benefit from AMVs than other NWP centers
  - Superobbing vs. thinning
  - Assimilating geostationary winds from NESDIS/EUMETSAT/JMA, CIMSS and AFWA—three datasets for most satellite
  - Assimilating hourly winds where available
- Why does NRL seem to get less impact from MW/IR radiances?
  - NRL top 6: AMV, raob, aircraft, land surface, IASI, AMSU
  - GMAO top 6: AMSU, raob, aircraft, IASI, AMV, AQUA AIRS
- Participate in the International Winds Working Group NWP experiments
- This presentation focuses on the NHEM Summer case

Experiment Design

- Run with a configuration that closely matches OPS
- Forecast Model: NOGAPS
  - T319L42, model top 0.04 hPa (around 70 km), horizontal resolution ~ 42 km.
  - Eulerian forecast model, with Emanuel cumulus scheme
- Data Assimilation: NAVDAS-AR
  - 4D-Var solved using accelerated representer technique
  - T319 outer loop, T119 (~ 111 km) inner loop resolution,
  - Approximately 2.2 million obs/6 hrs (late data cut)
  - Radiance bias correction using offline two-predictor Harris and Kelly approach
  - Bias predictor coefficients are updated every 6-hr update cycle
  - Begin with zero bias coefficients 15 days prior to experiment start
- NHEM Summer case : 15 August - 30 September, 2010. Forecasts at 12 UTC

NAVDAS-AR: NRL Atmospheric Variational Data Assimilation System – Accelerated Representer
NOGAPS: Navy Operational Global Atmospheric Prediction System

NOGAPS/NAVDAS-AR Operational System

Conventional Data Types

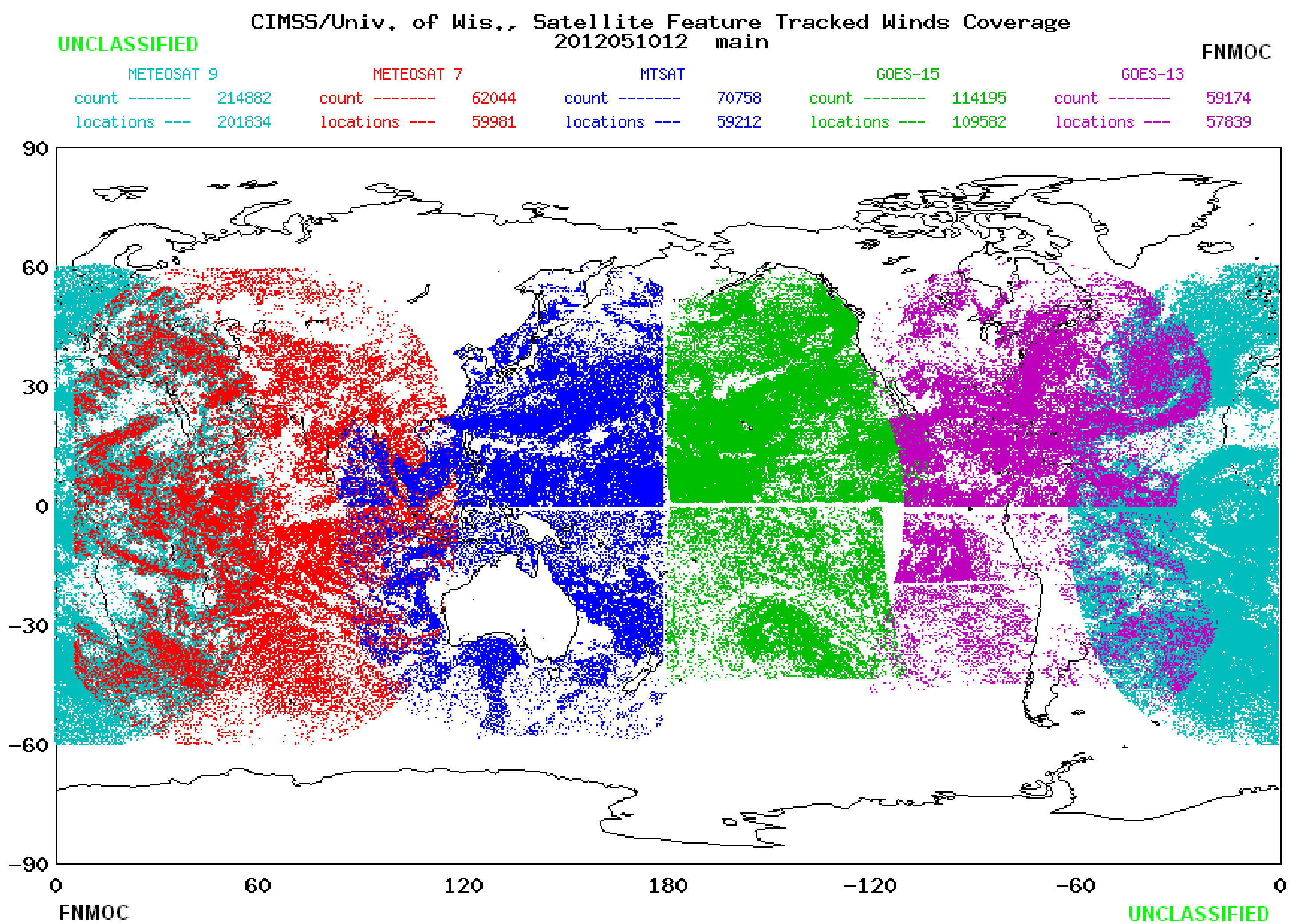
- Radiosondes and Pibals
- Dropsondes
- Driftsonde (Concordiasi)
- Land and Ship Surface Obs
- Aircraft Obs
  - AIREPS
  - AMDAR
  - MDCRS
- Synthetic Obs
  - TC Bogus

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, CORISS, C/NOFS, Terra SAR-X

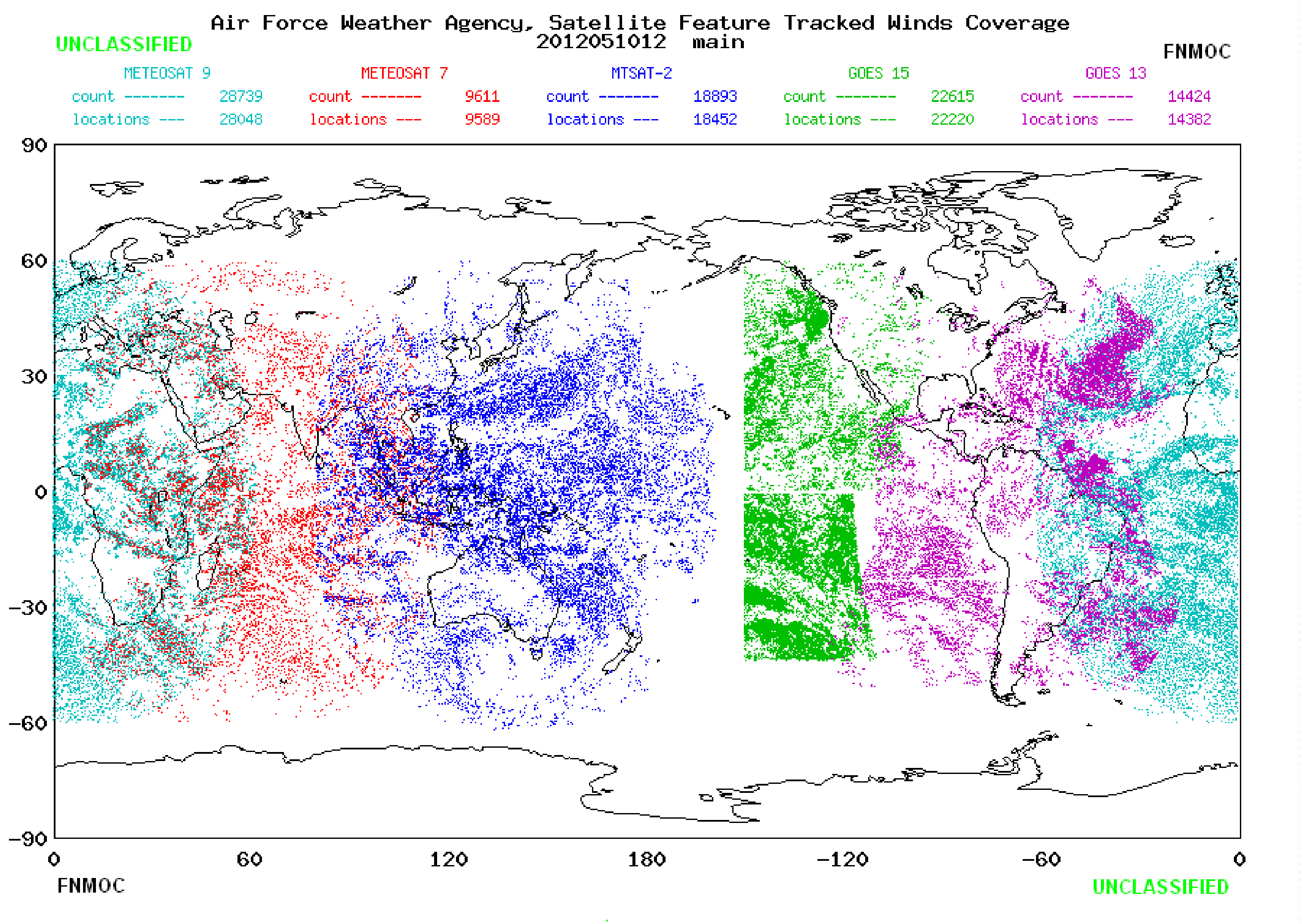
Satellite Data Types

- Surface Winds
  - Scatterometer, ASCAT and ERS-2
  - SSMI/SSMIS (4)
  - WindSat
- Feature Tracked Winds
  - Geostationary (5 satellites)
  - Polar Orbiters (AVHRR and MODIS)
  - Combined polar/geo winds (CIMSS)
- Total Water Vapor
  - SSMI/SSMIS TVAP (4)
  - WindSat TVAP
- GPS Bending Angle (11)
- IR Sounding Radiances
  - IASI and AIRS
- MW Sounding Radiances
  - AMSU-A (Ch 4-14) (6)
  - SSMIS (Ch 2-7, 22-24) (3)
  - SSMIS/MHS 183 GHz (4)

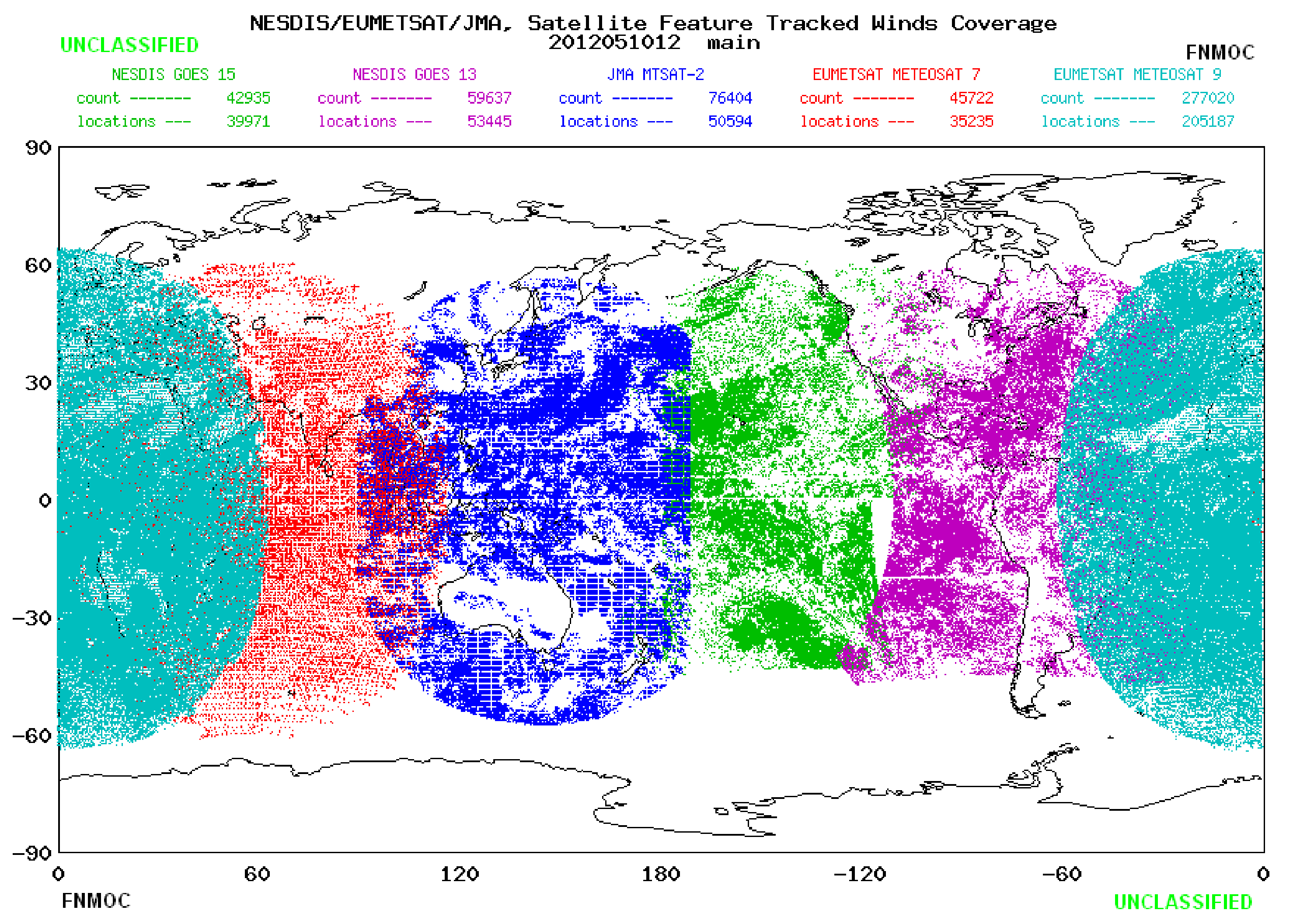
Data Overview—CIMSS/UW Winds



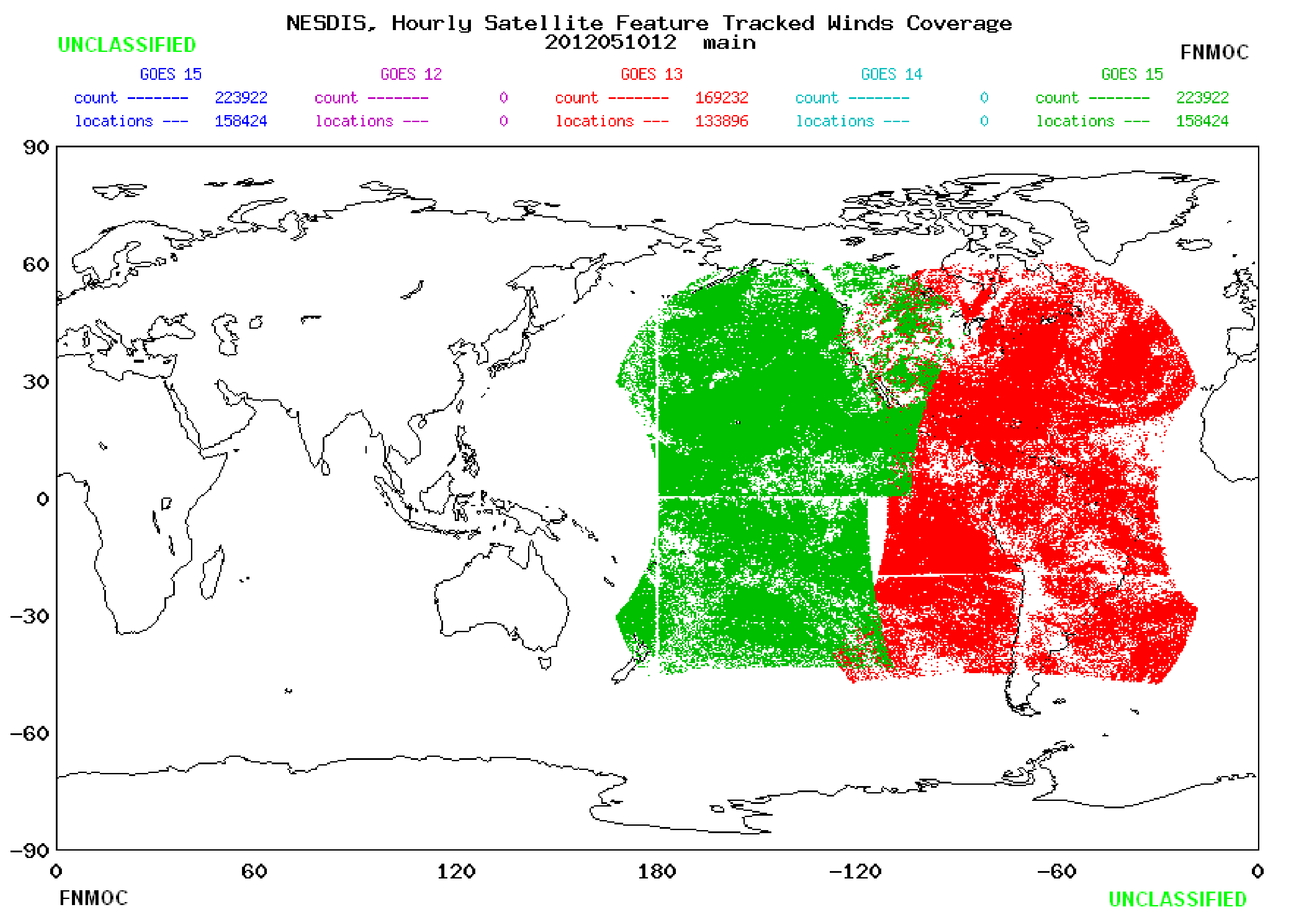
AFWA Winds


Air Force Weather Agency, Satellite Feature Tracked Winds Coverage
2012051012 main
UNCLASSIFIED
FNMOC
METEOSAT 9
count ------- 28739
locations --- 28048
METEOSAT 7
count ------- 9611
locations --- 9589
MTSAT-2
count ------- 18893
locations --- 18452
GOES 15
count ------- 22615
locations --- 22220
GOES 13
count ------- 14424
locations --- 14382
90
60
30
0
-30
-60
-90
0
60
120
180
-120
-60
0
FNMOC
UNCLASSIFIED

NESDIS/EUMETSAT/JMA Winds



NESDIS Hourly Winds

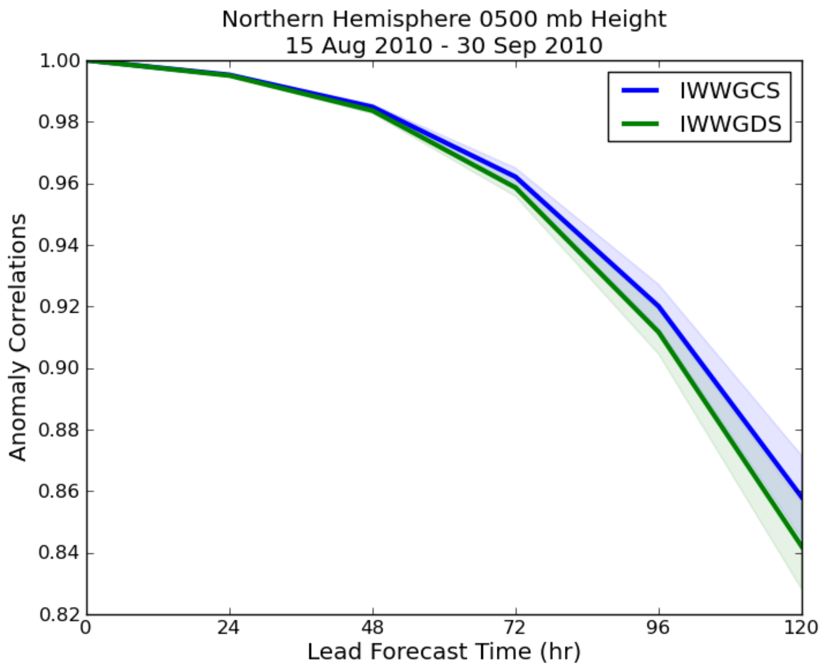


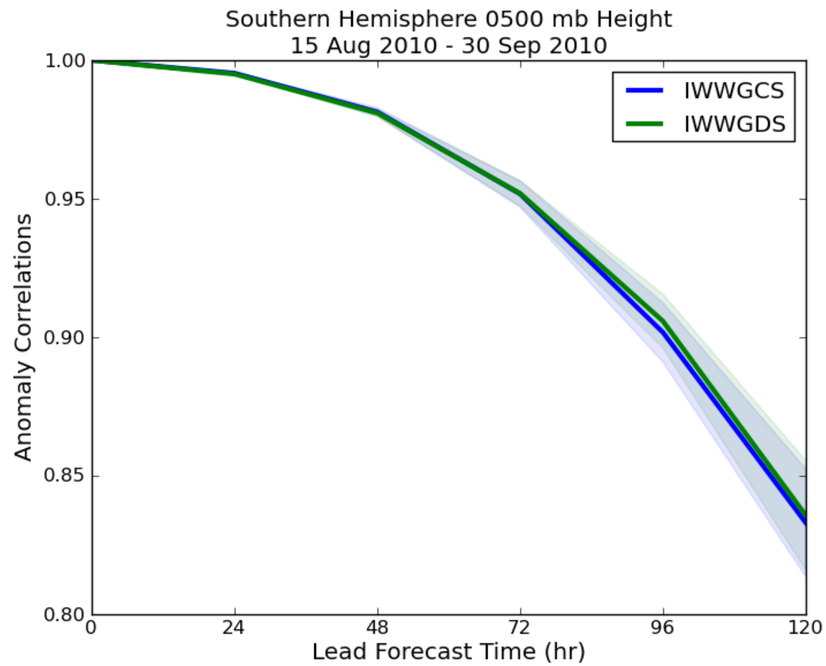
Results from AMV Denial Experiment NH summer

- Traditional metrics
- Observation Impact

NH Summer Model Verification

Blue line is the AMV assimilation control run; green line is the AMV denial run

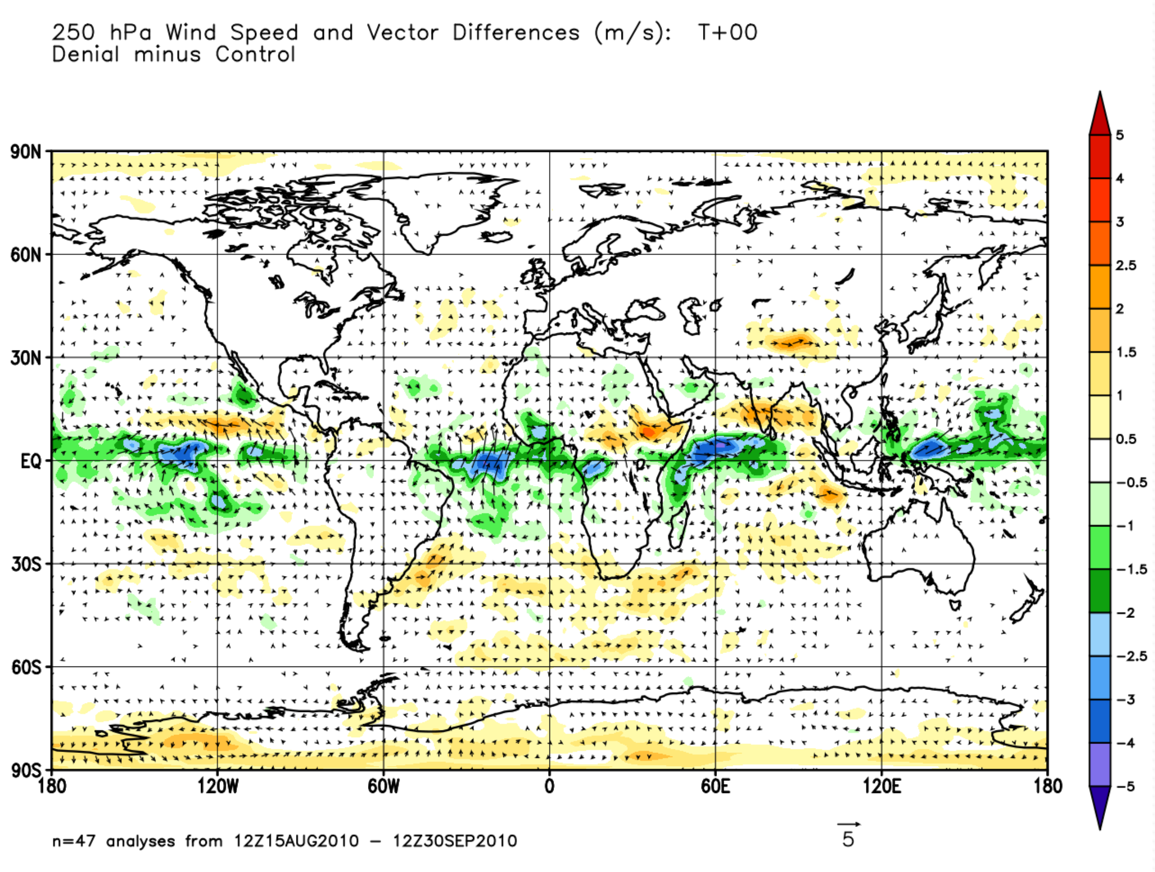




The summer hemisphere shows the most impact in terms of 500 hPa geopotential height anomaly correlation (AC). This trend holds for all cases examined.

NH Summer, Denial-control

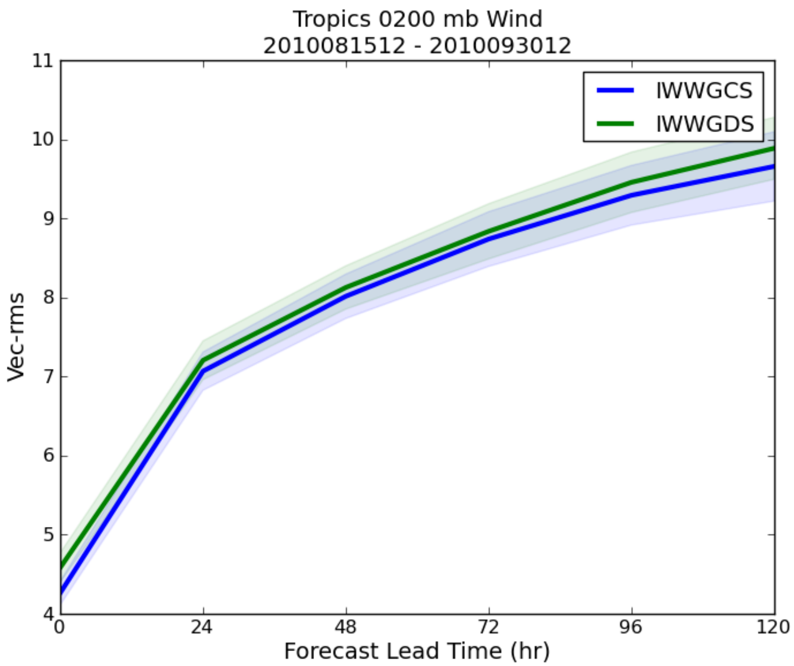
250 hPa analyzed wind differences

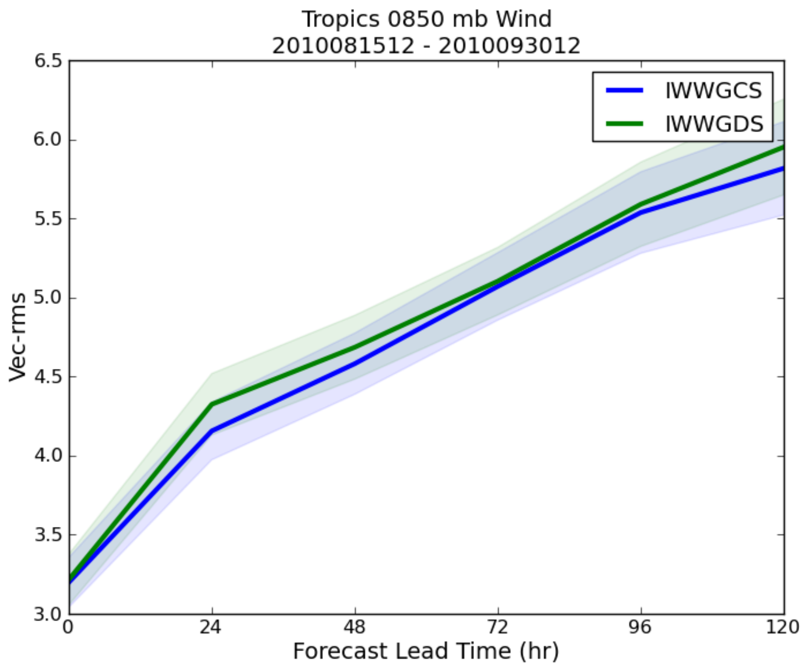


Most of the AMV impact on the analyses is in the tropics and SH (increases winds along the equator).

Tropics Wind Vector RMSE
NH Summer Case, Raob Verification

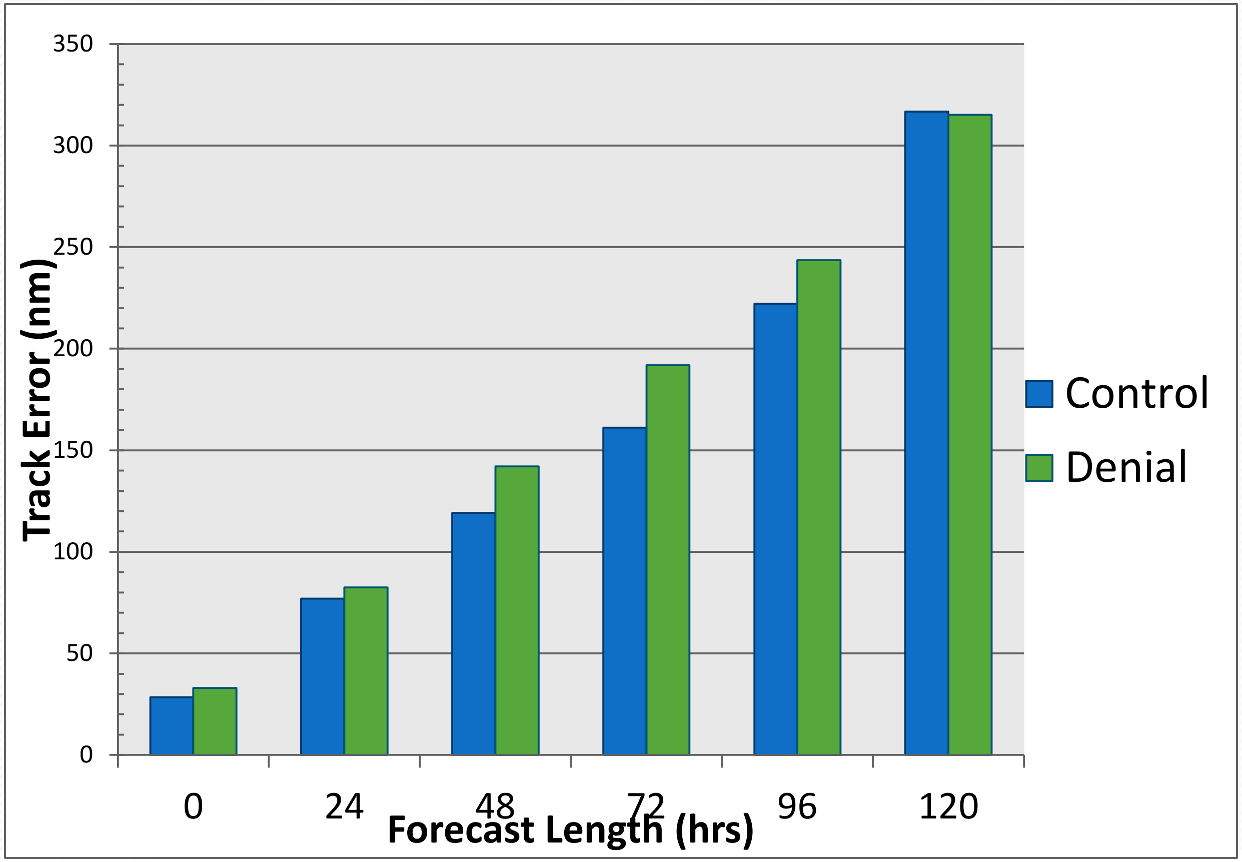
Blue line is the AMV assimilation run; green line is the wind denial run





The raob verification w.r.t. 200/850 hPa geopotential heights is consistent, e.g. assimilation of winds reduce the geopotential height errors.

Tropical Cyclone Track Verification

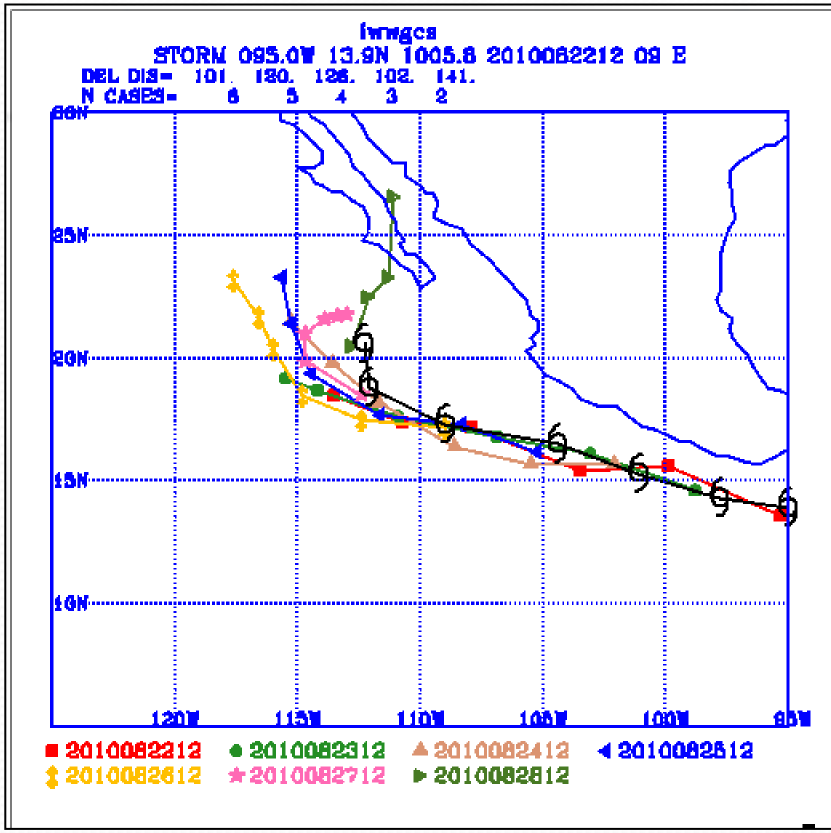


109	76	56	44	35	26	Number of storms

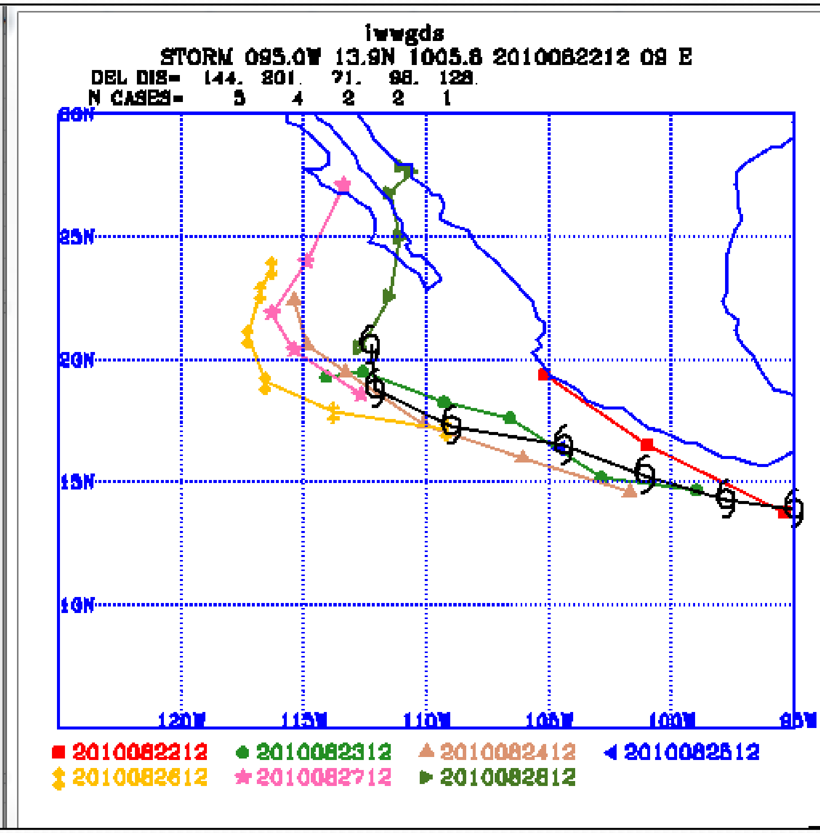
Significant for all forecast lengths to t+72 at the 99.0 – 99.5% confidence level

TC Track Forecasts, TC Frank

AMV control



AMV denial



Not many TCs during study period

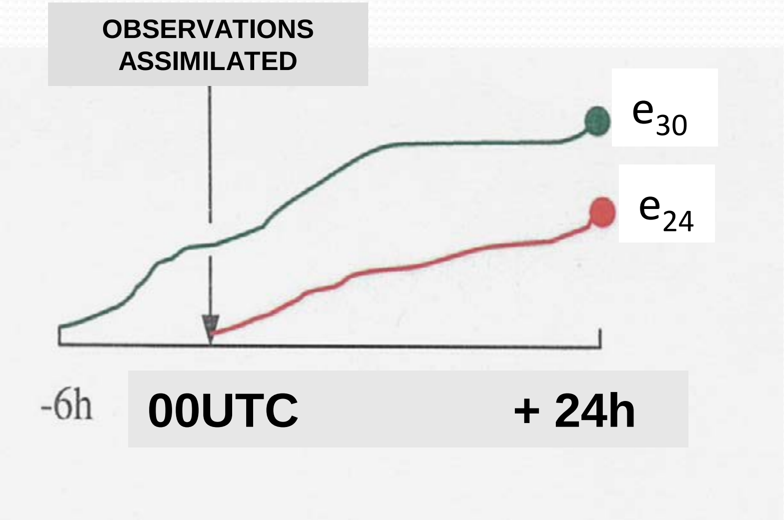
AMV wind assimilation helps with initial storm motion

Summary of NH Summer AMV Results

- In terms of 500 hPa anomaly correlation, the greatest benefit from the AMV winds is in the summer (NH) hemisphere (+0.016)
  - Wind analysis differences at 250 hPa are small
- Most of the AMV impact on the 250 hPa wind analyses is in the tropics and SH.
- Tropical cyclone predicted tracks are significantly better out to 3 days (>= 99%)
- How do these results compare with the observation impact statistics?

Observation Impact Methodology

- Mathematical technique using NAVDAS-AR and NOGAPS adjoint models
- Use a moist total energy error norm
- Observation impact products generated operationally 4x per day
- Results are used to refine observation usage
  - evaluate observation quality, satellite channel selection and tune observation reject lists



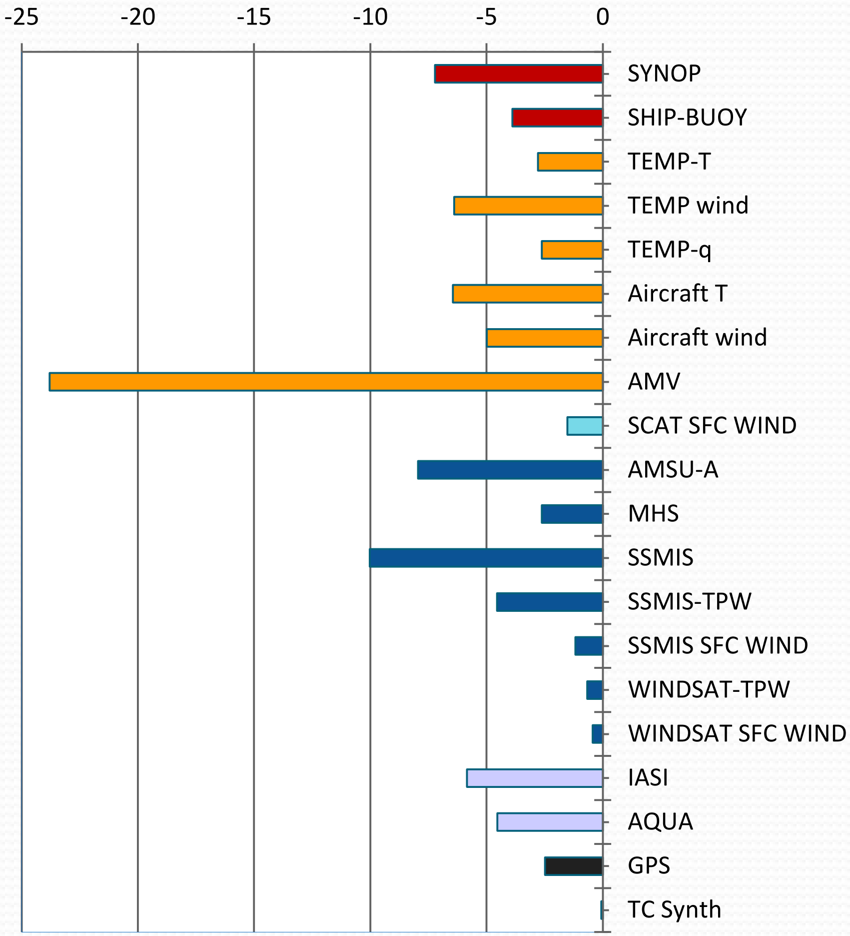
Observations move the model state from the "**background**" trajectory to the new "**analysis**" trajectory

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

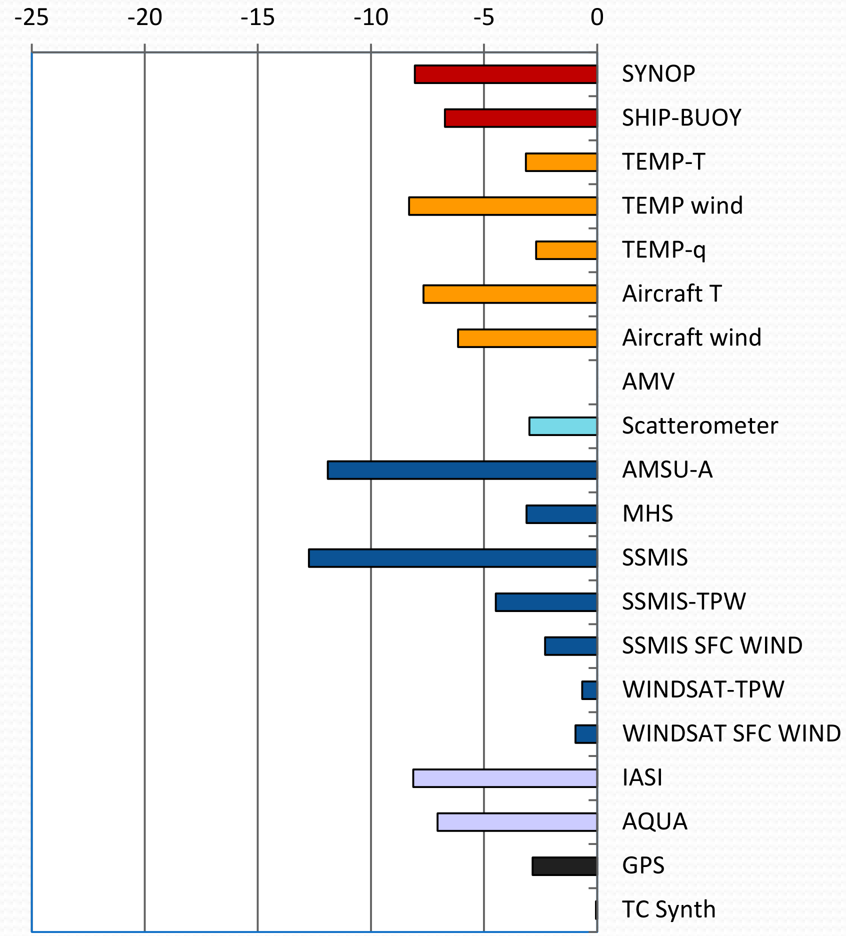
Baker and Daley (QJRMS, 2000); Langland and Baker (Tellus, 2004)

Aug 15th, 12 UTC through Sept. 30th, 12 UTC
Percent Reduction in Moist Error Norm
Observation impacts computed every 6 hrs

AMV wind control



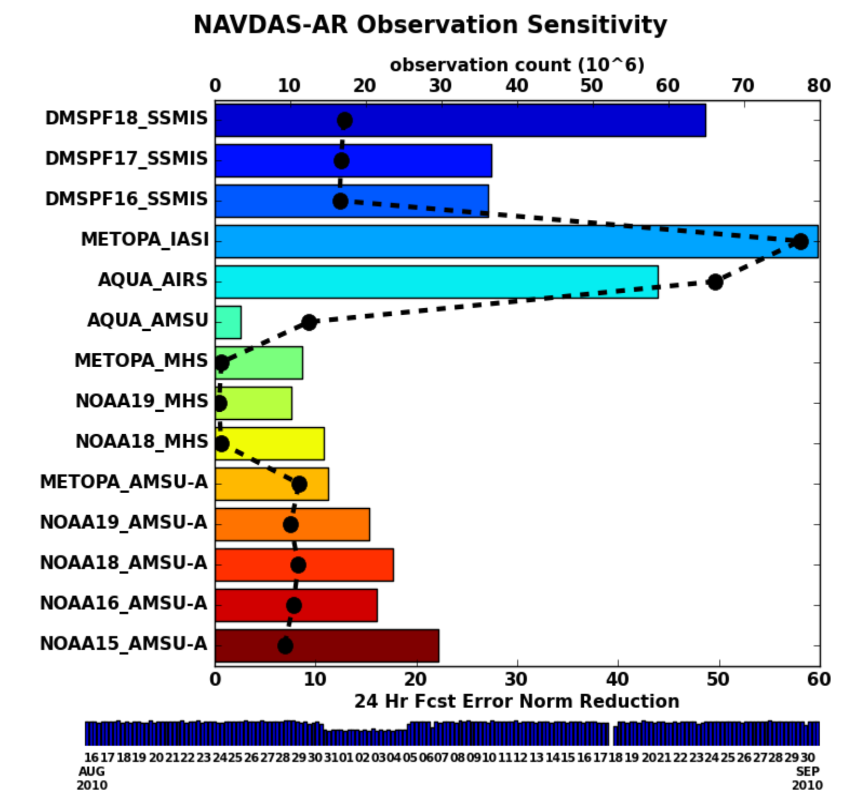
AMV wind denial



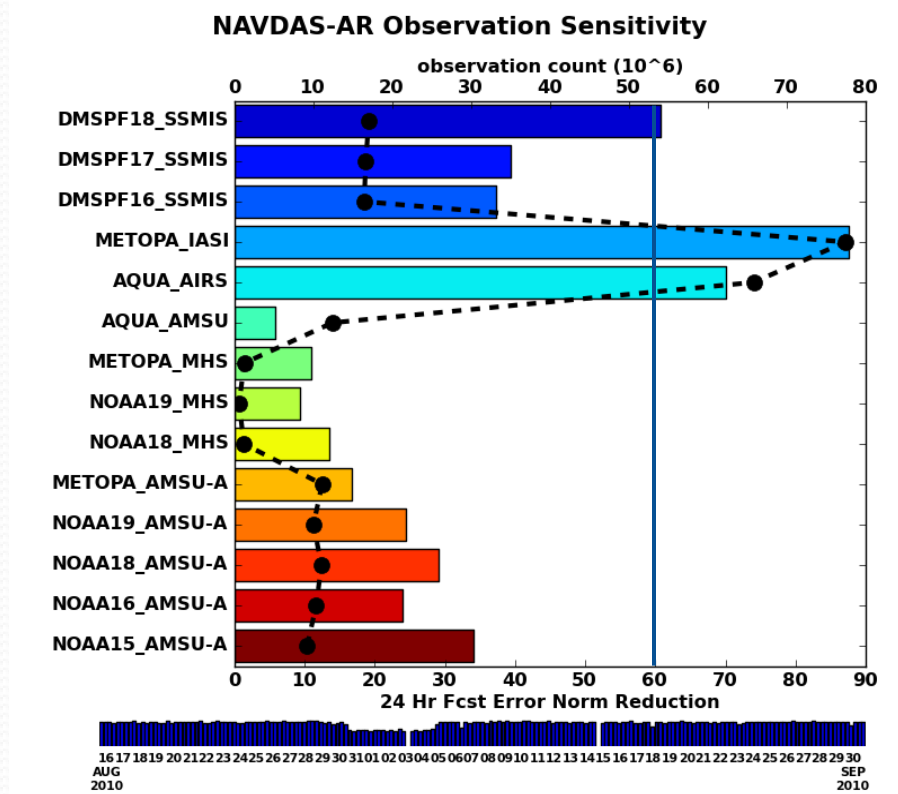
Other observing platforms apparently compensate for denial of AMV

Summer 2010
Aug 15th, 12 UTC through Sept. 30th, 12 UTC
Total Reduction in the Moist Error Norm
Observation impacts computed every 6 hrs

AMV wind control

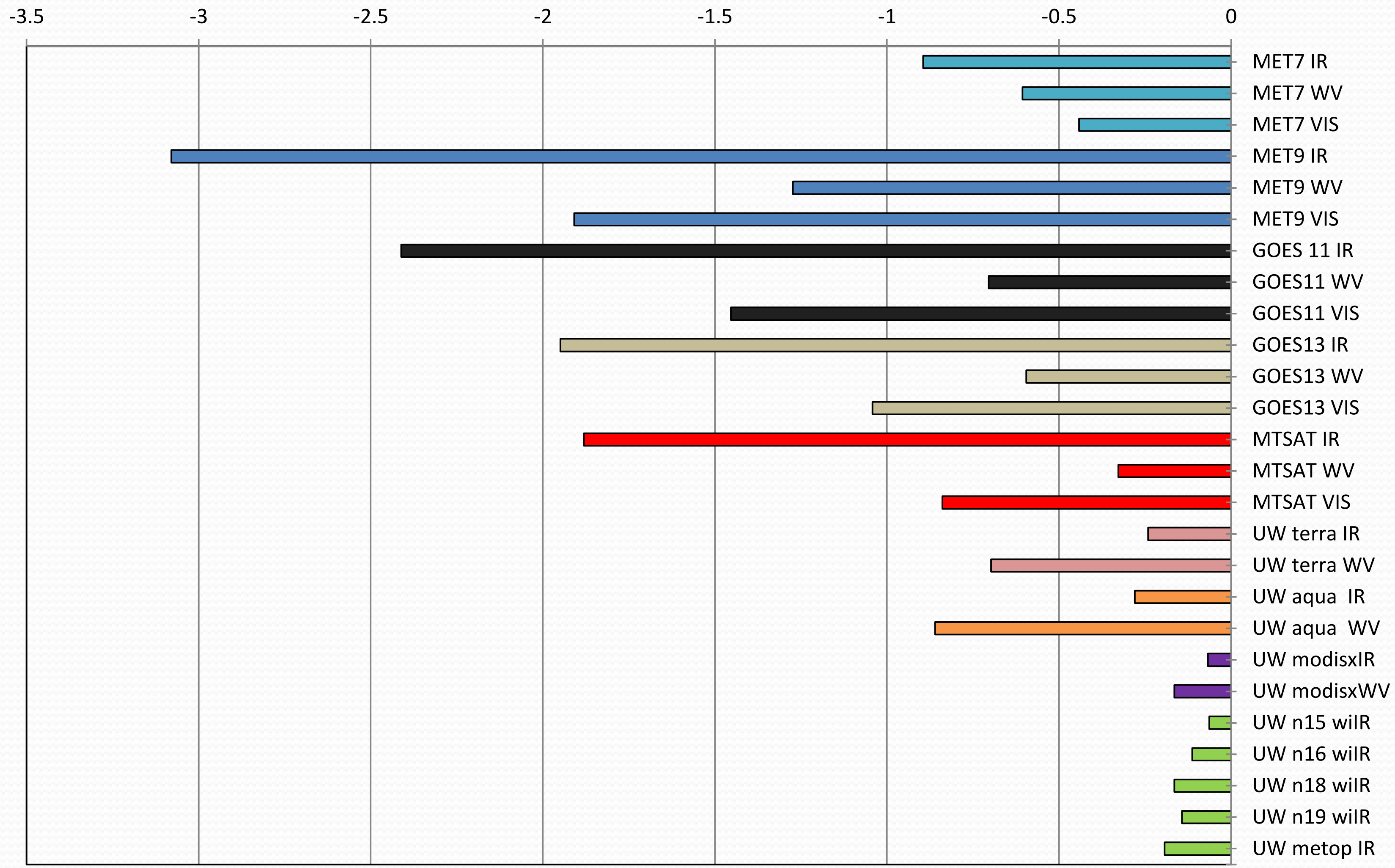


AMV wind denial



MW and IR satellite sounders have greater impact when AMV winds are denied

Aug 15th, 12 UTC through Sept. 30th, 12 UTC
Percent Reduction in Moist Error Norm
AMV control



Most impact from IR winds, however VIS winds have greater impact that WV winds!

NRL Observation Impact Assessment

- The ob impact results show that AMVs produce large forecast error reduction (e24-e30) for the total moist energy norm.
- However, reducing total error (e24) is not the same as changing (e24-e30), which is what the adjoint ob impact measures.
  - Examine the 24-hr moist total energy error norm for the control and denial cases
- Denying all satellite AMV is a large change to the NRL global analysis/forecast system
- We assume that the control analyses (with AMVs) are more accurate than the analyses produced without AMV winds

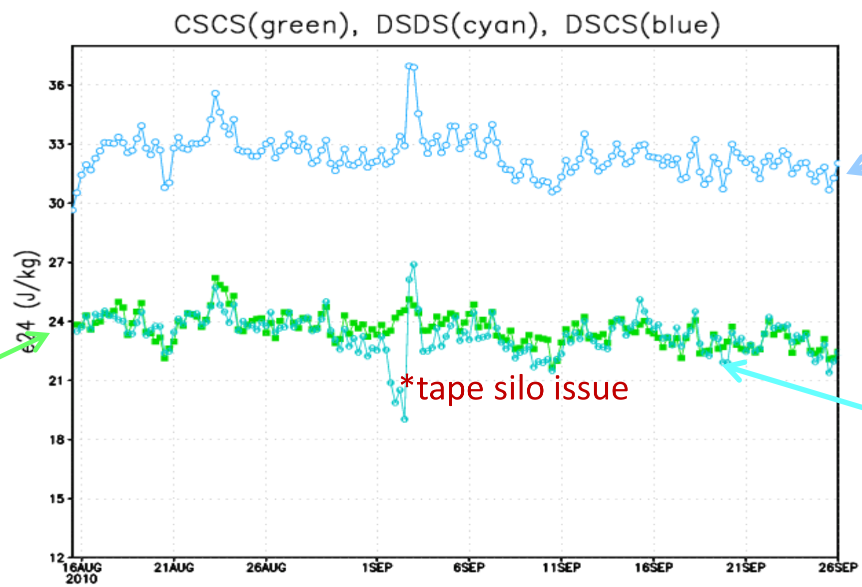
24-hr moist total energy error norms

- **CS=control run with AMVs, DS=AMV-denial run; self-verification**
- **Lower (smaller) 24-hr moist enorm values are color-coded, Red (CS) or Blue (DS)**

AVG VALUES	Total		Vorticity		Divergence		Temperature		Humidity	
	CS	DS	CS	DS	CS	DS	CS	DS	CS	DS
GLOBAL	23.257	22.976	7.469	7.647	1.673	1.604	2.028	2.001	12.024	11.658
NHEM (20-80)	8.587	8.844	2.322	2.509	0.432	0.441	0.713	0.718	5.101	5.157
SHEM (20-80)	6.264	6.377	3.097	3.248	0.530	0.530	0.900	0.902	1.703	1.661
TROPICS (20-20)	8.387	7.678	1.959	1.755	0.706	0.626	0.393	0.352	5.319	4.936

- **Global:** AMVs reduce vorticity error but increase temperature, divergence and humidity component of the error norm.
- **NHEM** (summer): AMVs primarily reduce vorticity error. Consistent with AC scores.
- **SHEM** (winter): AMVs reduce vorticity error and slightly increase humidity error
- **TROPICS** : AMVs increase all components of the error norm, including vorticity. AMVs cause a significant increase in tropics humidity forecast error. **Inconsistent!**

24-h moist energy error norms

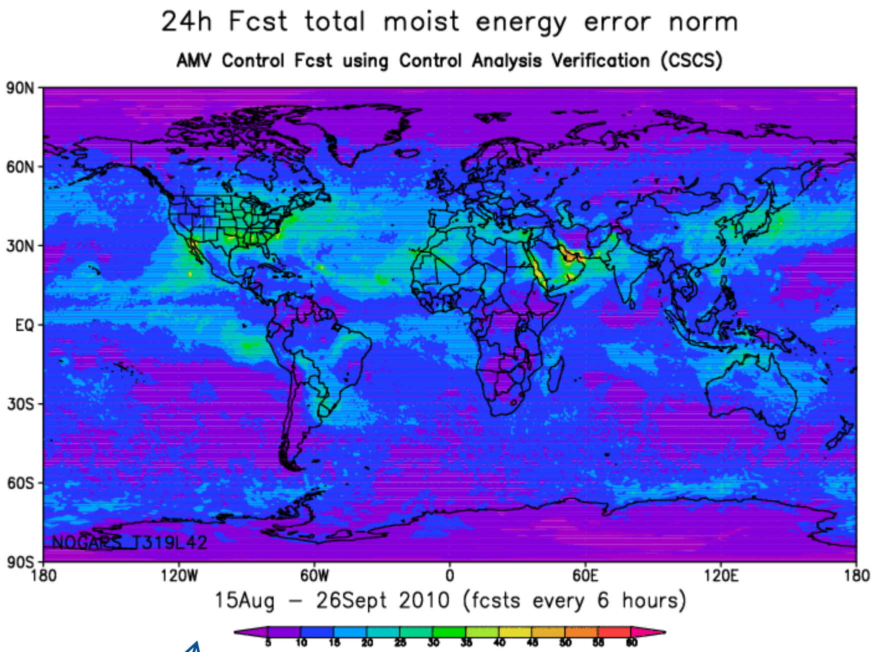


Blue line DSCS Denial verified against control

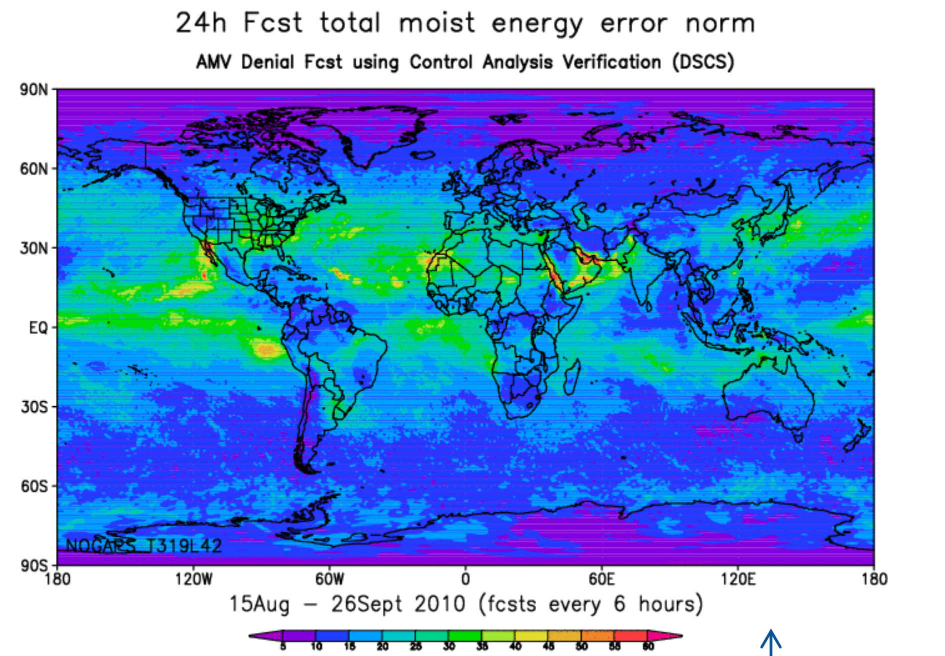
Green line CSCS Control verified against control

Cyan line DSDS Denial verified against denial

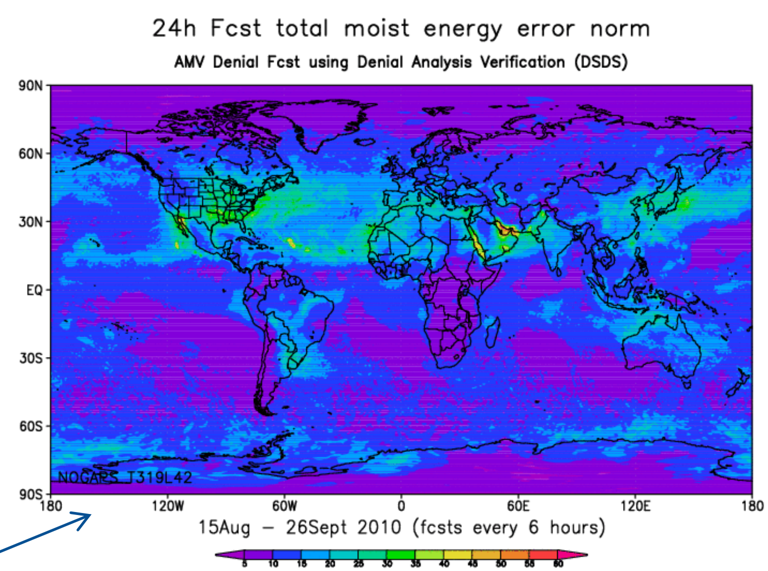
- When verified against self-analyses, the control and denial runs have similar 24-hr moist energy error norms
- When verified against the control analyses:
  - Denial forecasts (DSCS) have much larger 24h errors using the total energy error norm
  - All components of the error norm (vorticity, divergence, temperature, humidity) are larger when AMVs are excluded from the assimilation.



CSCS
Control verified against control



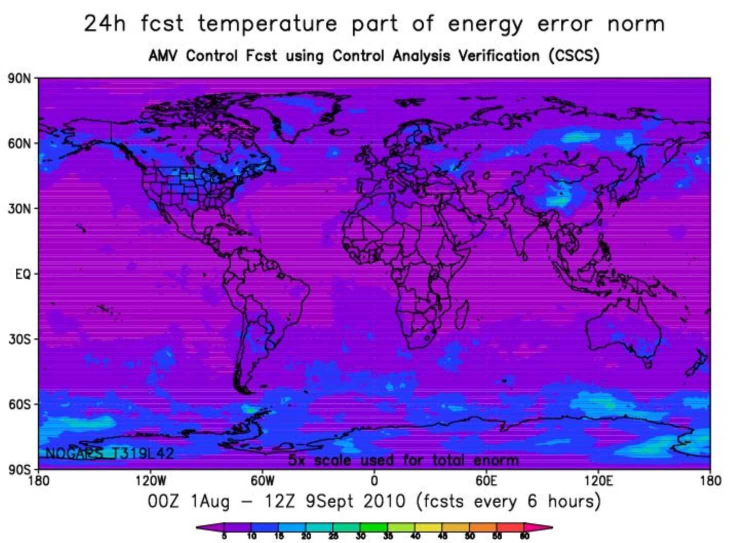
DSCS
Denial verified against control



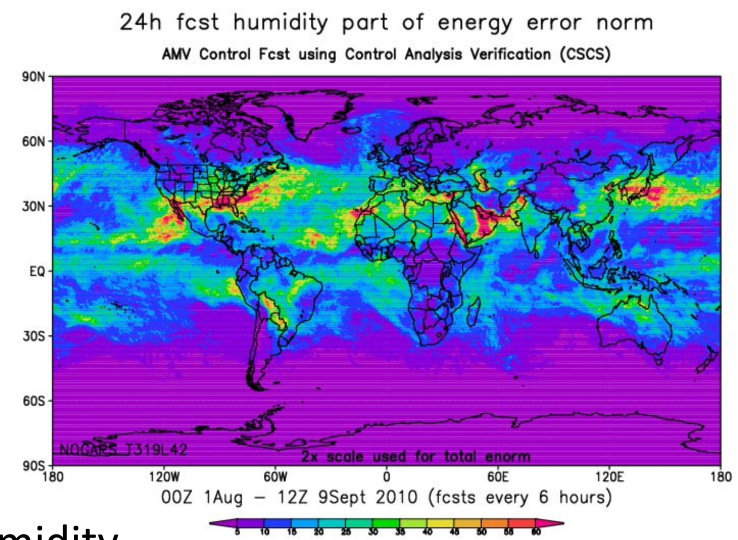
DSCS
Denial verified against denial

Removal of AMVs results in a large departure from the control state in the tropics.

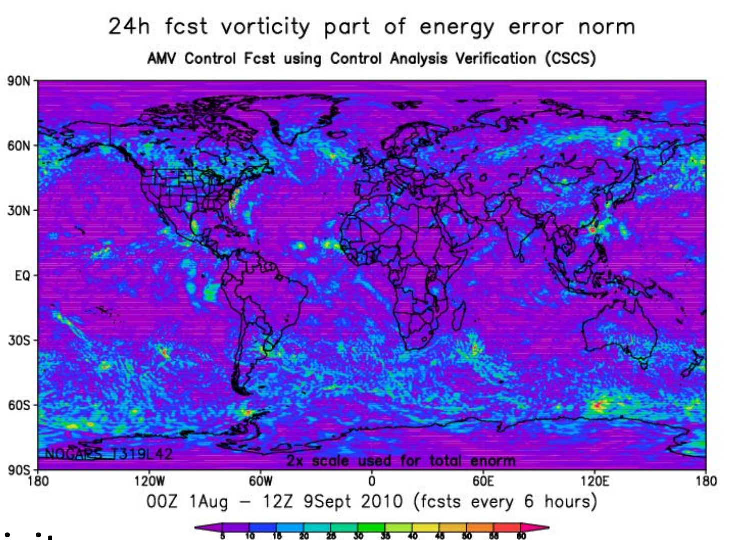
Components of the 24-hr energy error norm



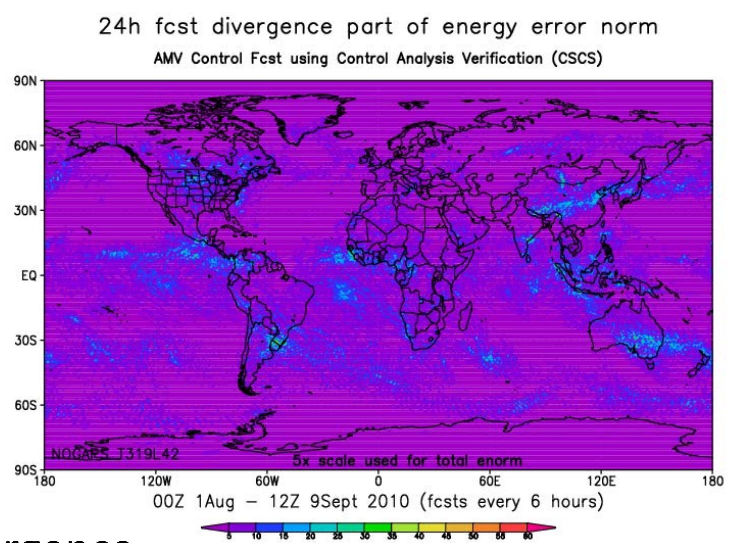
temperature



humidity

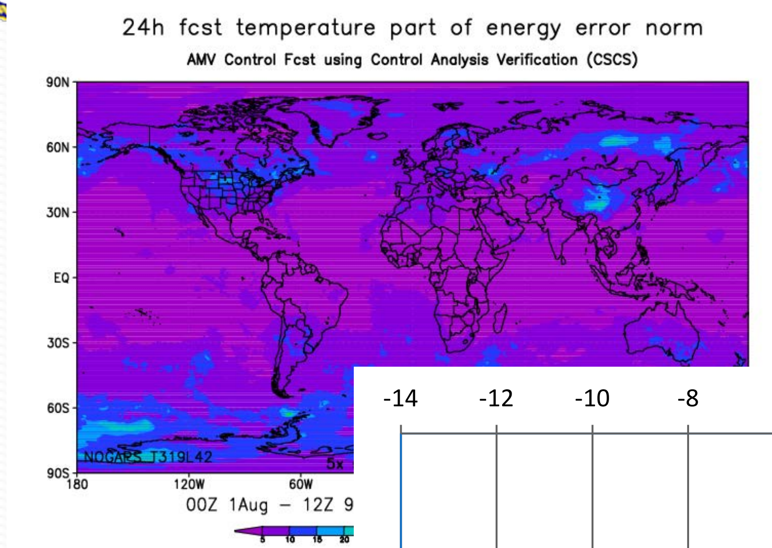


vorticity

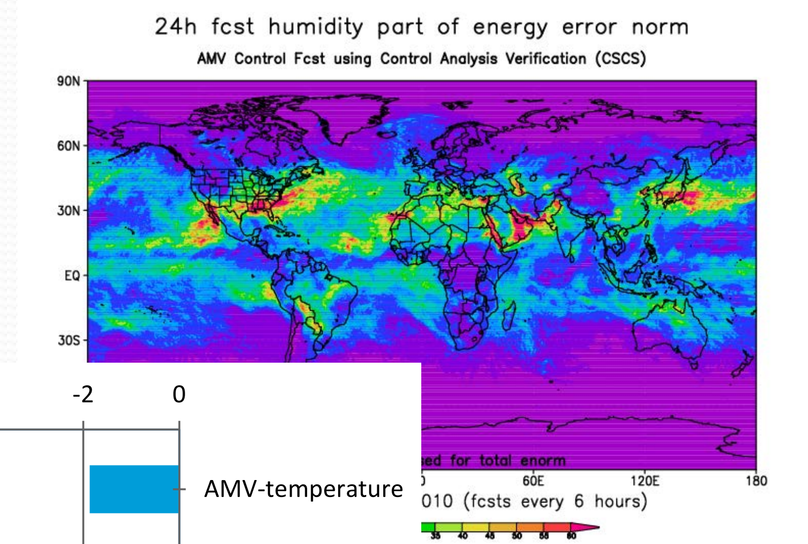


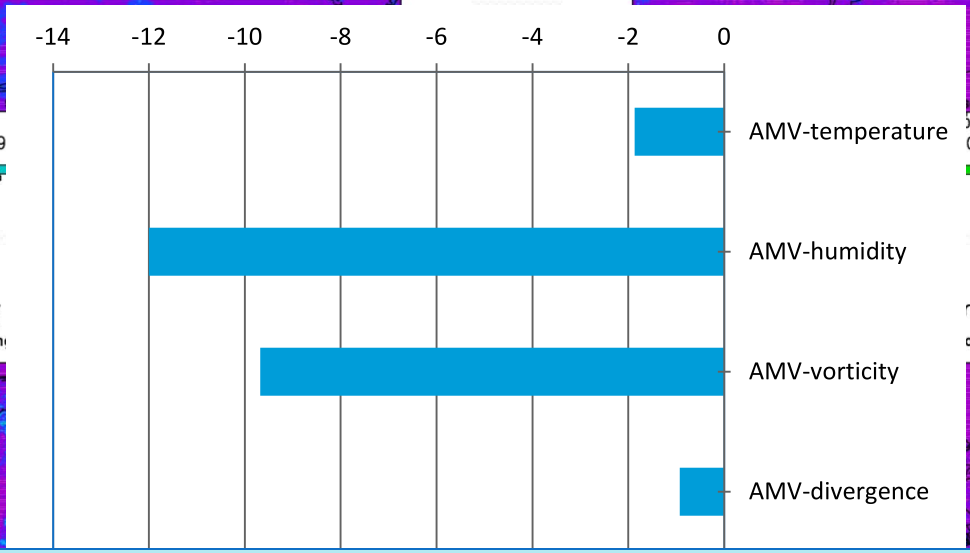
divergence

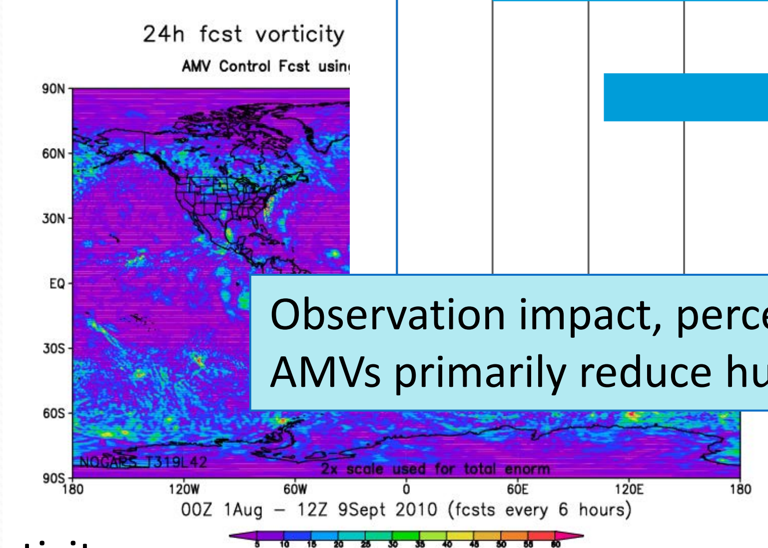
Components of the 24-hr energy error norm



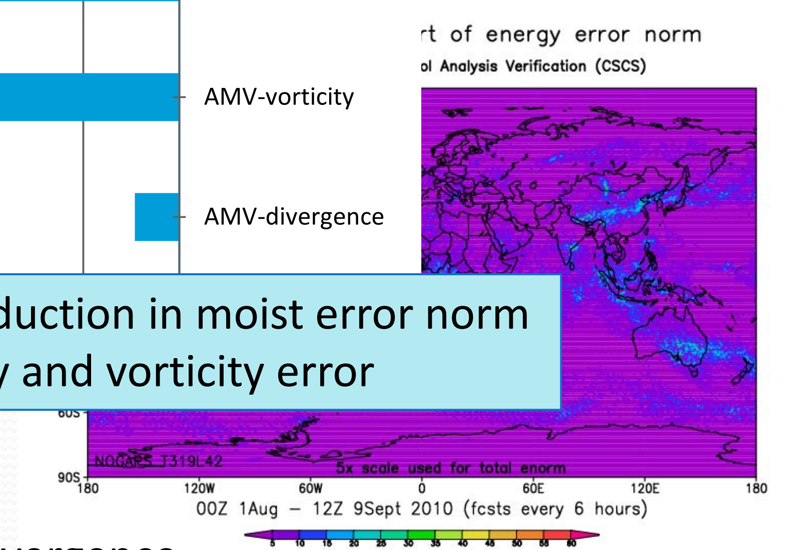
temperature







vorticity

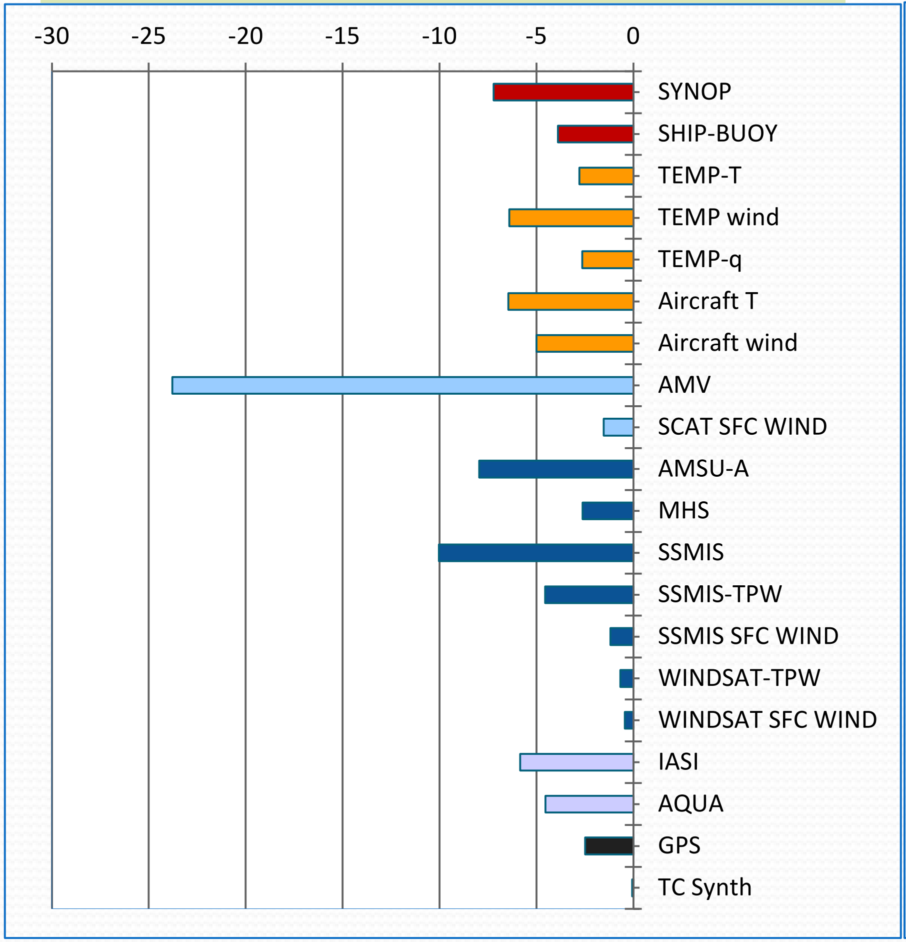


divergence

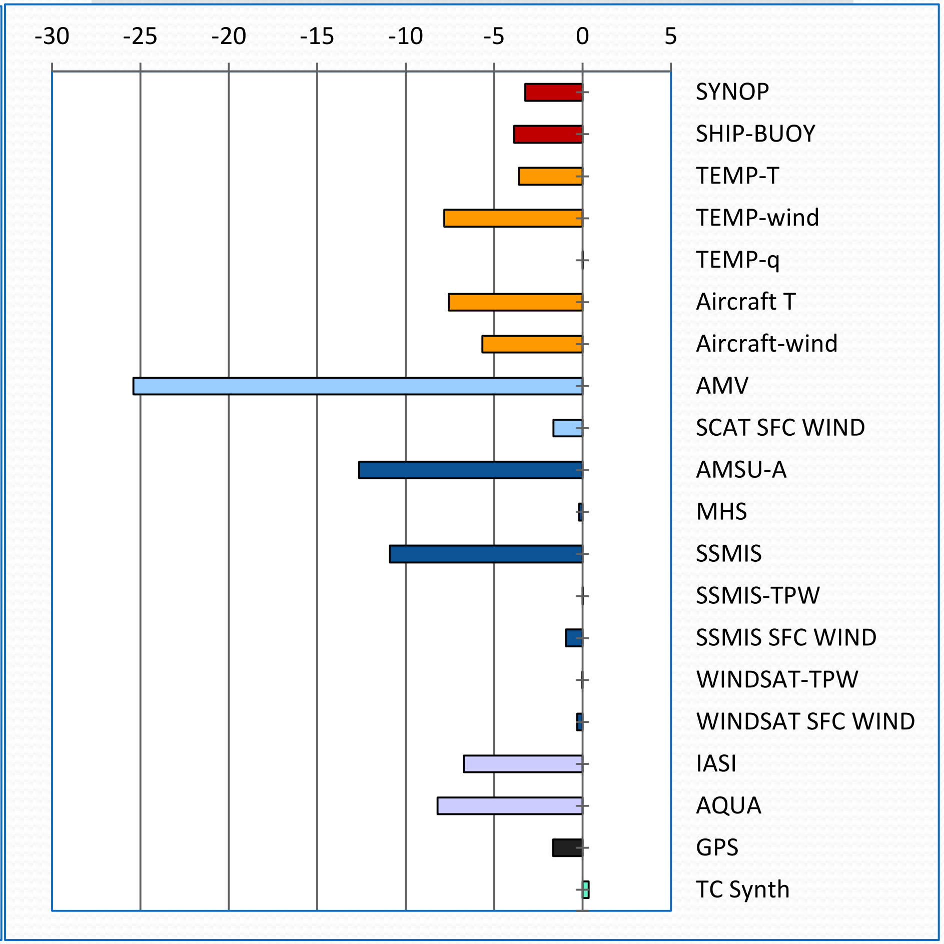
Observation impact, percent reduction in moist error norm
AMVs primarily reduce humidity and vorticity error

Summer 2010
Aug 15th, 12 UTC through Sept. 30th, 12 UTC

AMV wind control
Percent Reduction in Moist Error Norm



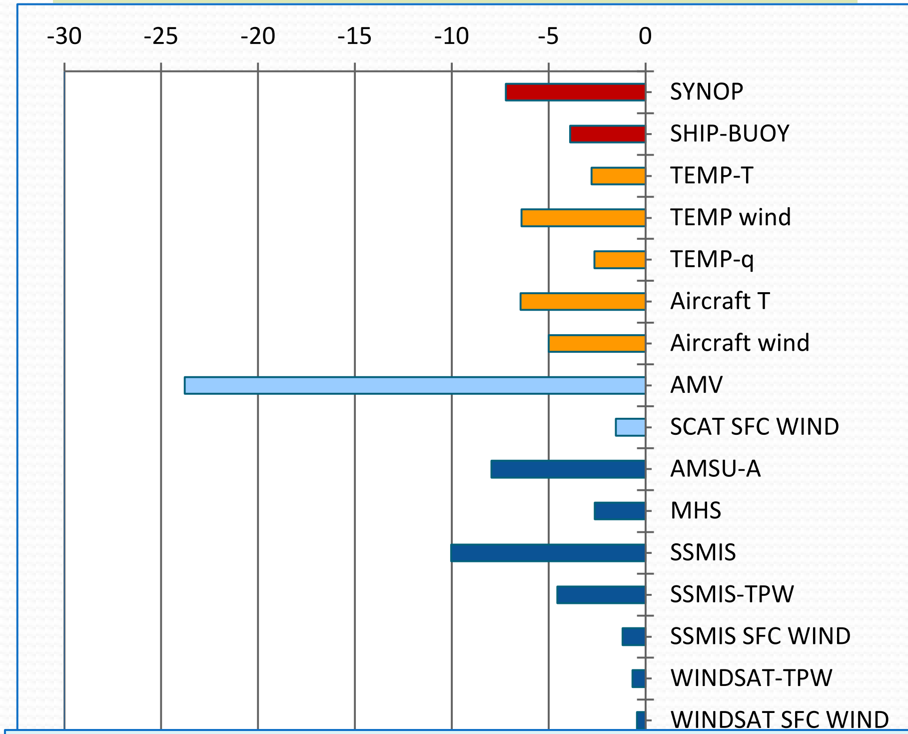
AMV wind control
Percent Reduction in Dry Error Norm



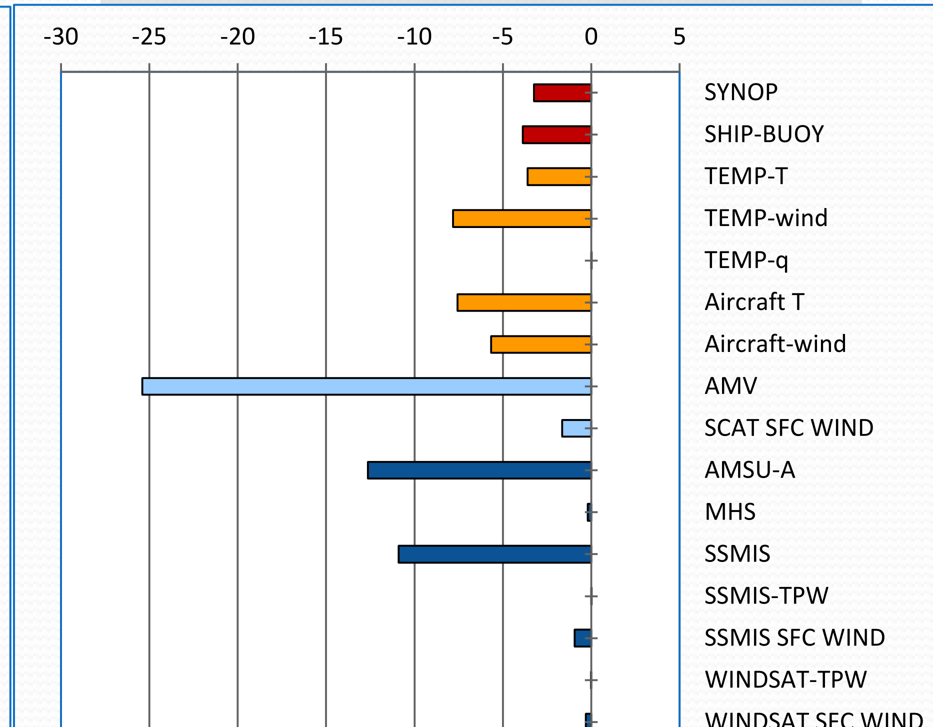
The results are qualitatively the same for moist and dry error norms, except for moisture obs

Summer 2010
Aug 15th, 12 UTC through Sept. 30th, 12 UTC

AMV wind control
Percent Reduction in Moist Error Norm

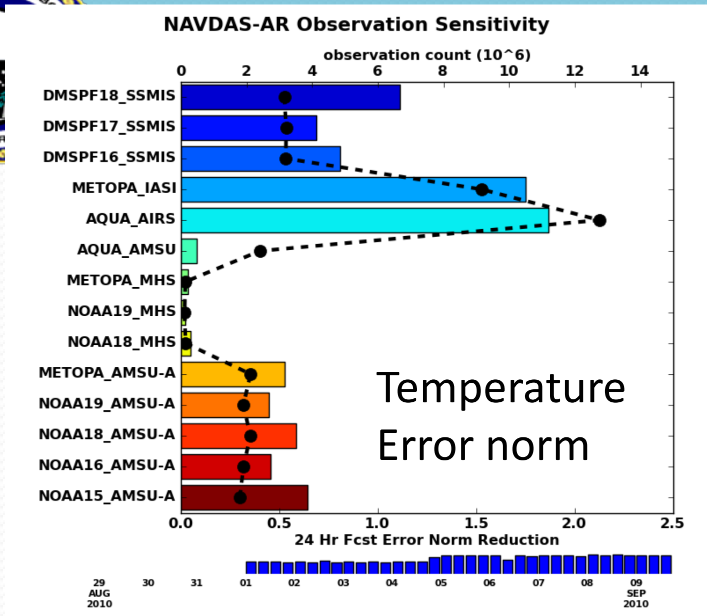


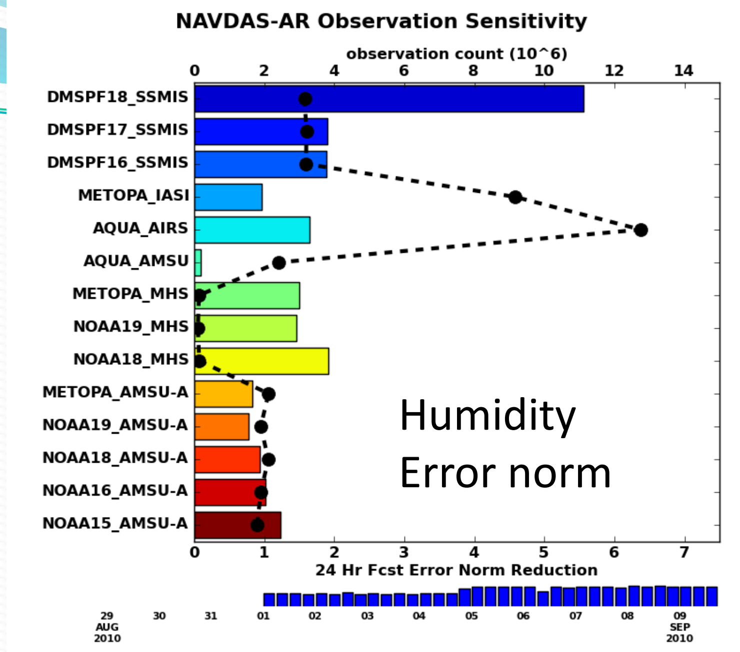
AMV wind control
Percent Reduction in Dry Error Norm



Moist Error Norm: NRL top 6: AMV, raob, aircraft, land surface, IASI, AMSU
Dry Error Norm: NRL top 6: AMV, aircraft, AMSU, raob, SSMIS, AQUA AIRS
Dry Error Norm: GMAO top 6: AMSU, raob, aircraft, IASI, AMV, AQUA AIRS

The results are qualitatively the same for moist and dry error norms, except for moisture obs


NAVDAS-AR Observation Sensitivity
observation count (10^6)
DMSPF18_SSMIS
DMSPF17_SSMIS
DMSPF16_SSMIS
METOPA_IASI
AQUA_AIRS
AQUA_AMSU
METOPA_MHS
NOAA19_MHS
NOAA18_MHS
METOPA_AMSU-A
NOAA19_AMSU-A
NOAA18_AMSU-A
NOAA16_AMSU-A
NOAA15_AMSU-A
Temperature
Error norm
24 Hr Fcst Error Norm Reduction
29 AUG 2010
09 SEP 2010


NAVDAS-AR Observation Sensitivity
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NOAA15_AMSU-A
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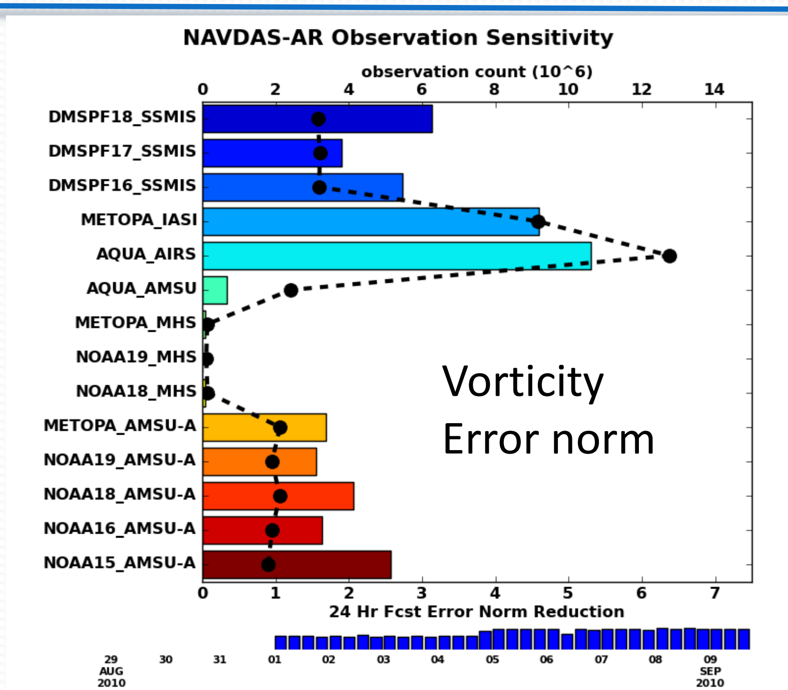
Error norm
24 Hr Fcst Error Norm Reduction
29 AUG 2010
09 SEP 2010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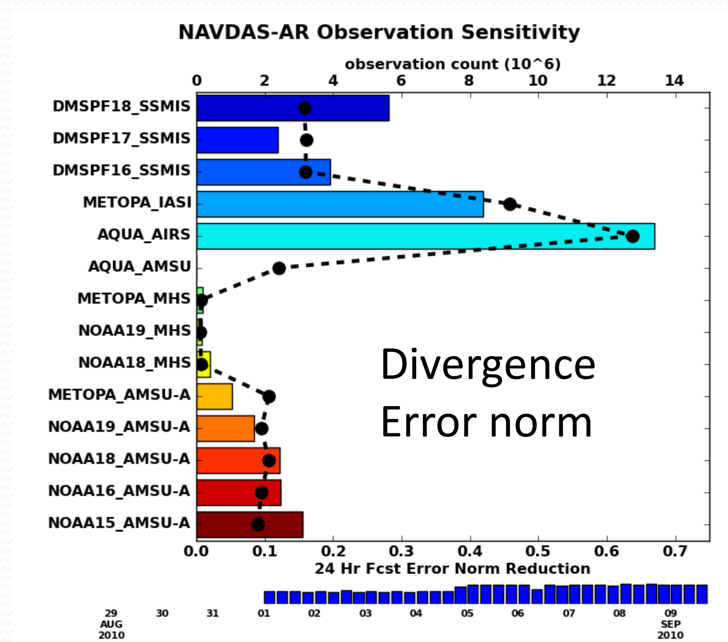

NAVDAS-AR Observation Sensitivity
observation count (10^6)
DMSPF18_SSMIS
DMSPF17_SSMIS
DMSPF16_SSMIS
METOPA_IASI
AQUA_AIRS
AQUA_AMSU
METOPA_MHS
NOAA19_MHS
NOAA18_MHS
METOPA_AMSU-A
NOAA19_AMSU-A
NOAA18_AMSU-A
NOAA16_AMSU-A
NOAA15_AMSU-A
Divergence
Error norm
24 Hr Fcst Error Norm Reduction
29 AUG 2010
09 SEP 2010

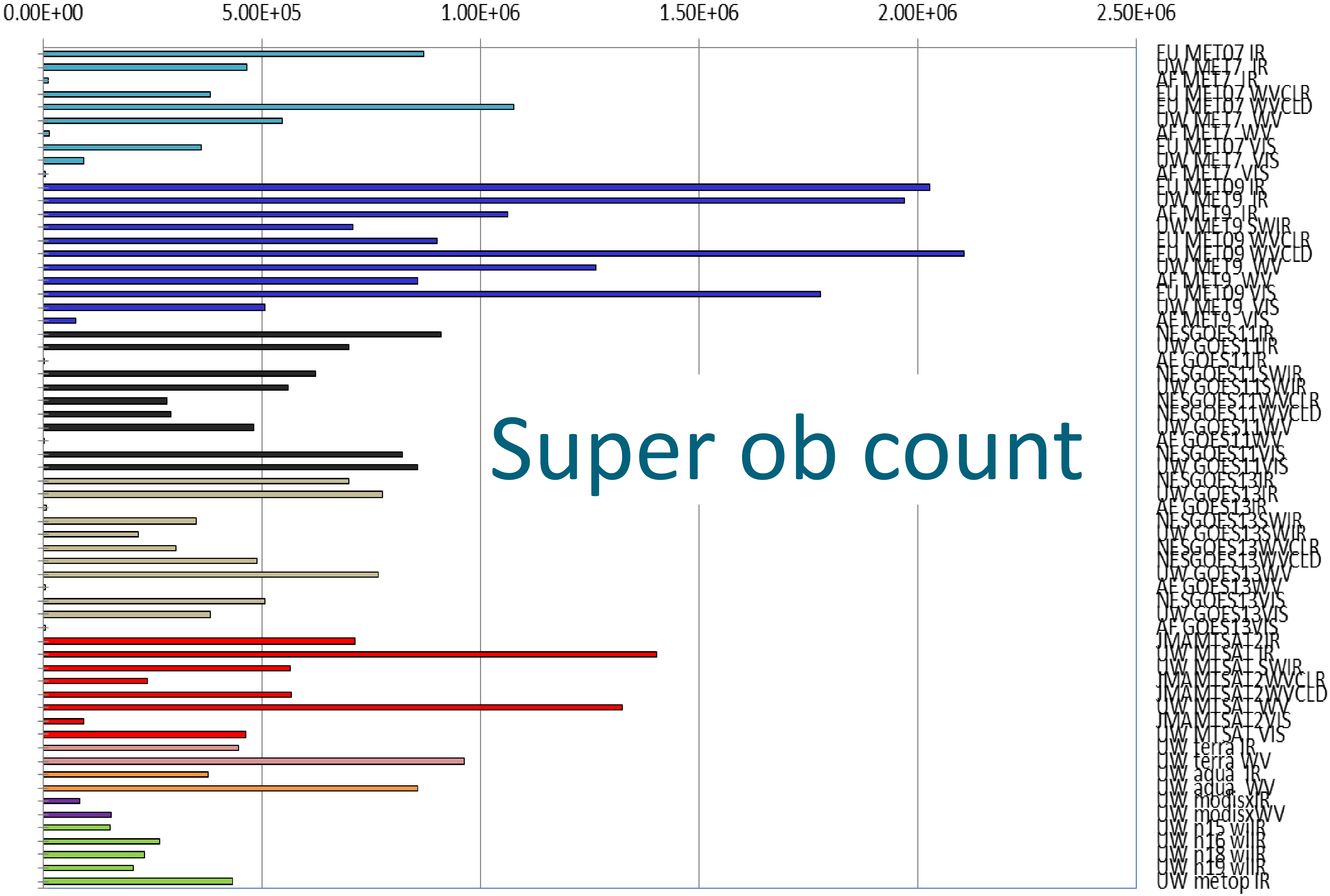
Conclusions and Future Work

- Overall, we see good benefit from AMVs
  - Most of the impact is in the tropics and summer hemisphere
  - AMVs reduce the total error norm in both NHEM and SHEM mid-latitudes, with greater error reduction in the summer hemisphere (NHEM).
  - The effects on temperature and divergence error are relatively small.

- Verification against self-analysis becomes problematic for large changes to the observing system

- The large impact from AMV in the Navy system is largely due to
  - Large number of winds assimilated
  - Super-ob assimilation gives slightly better forecast skill; examination of analysis differences would be more enlightening
  - AMVs likely "borrow" impact from satellite sounders

Super ob count



Acknowledgements

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