An Investigation of the Impact of Atmospheric Motion Vectors on NAVDAS-AR/NOGAPS

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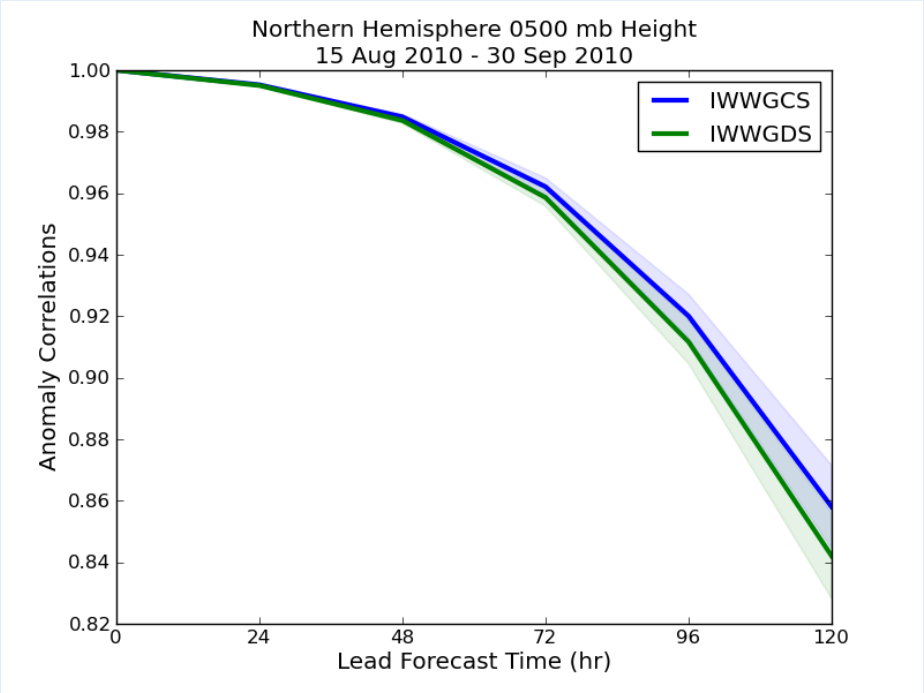
Experiment Design

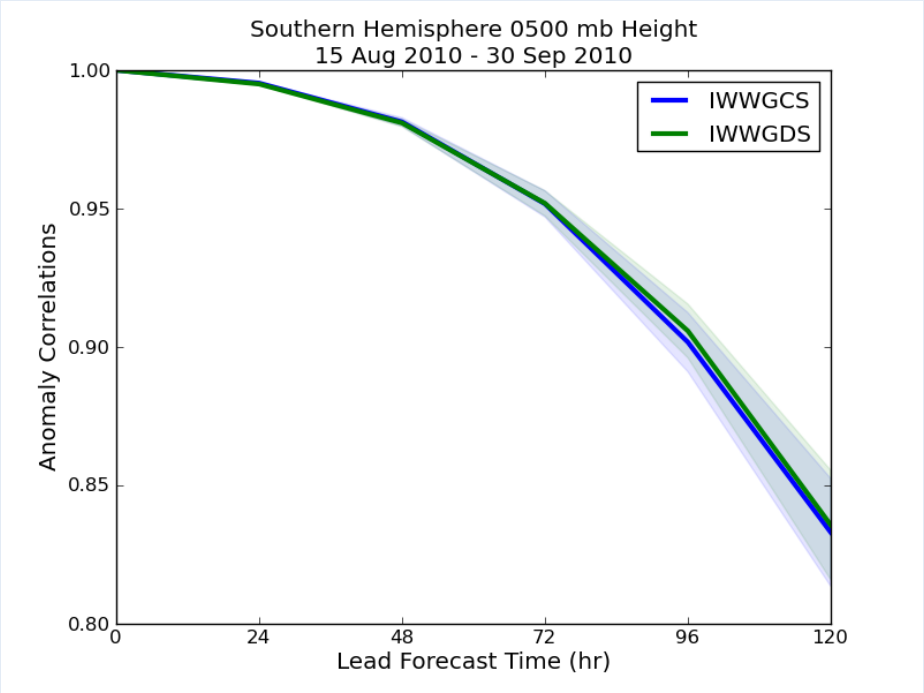
- Run with a configuration that closely matches OPS
  - NAVDAS-AR; 4D-Var solved using accelerated representer technique
  - T319 outer loop, T119 inner loop resolution, approximately 2.2 million obs/6 hrs (late data cut)
  - NOGAPS forecast model, T319L42, model top 0.01 hPa (around 72 km)
  - Eulerian forecast model, with Emanuel cumulus scheme
  - Radiance bias correction using offline two-predictor Harris and Kelly approach
  - Begin with zero bias coefficients 15 days prior to experiment start
- Experiments completed
  - NH Winter Case, observation impact ongoing
  - Polar winds denial (AQUA/TERRA MODIS, AVHRR, LEO/GEO)
  - NH Summer Case, observation impact completed
  - Wind vector super-ob vs. thinning case (Pat Pauley)

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

Model Verification
NH Summer Case

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



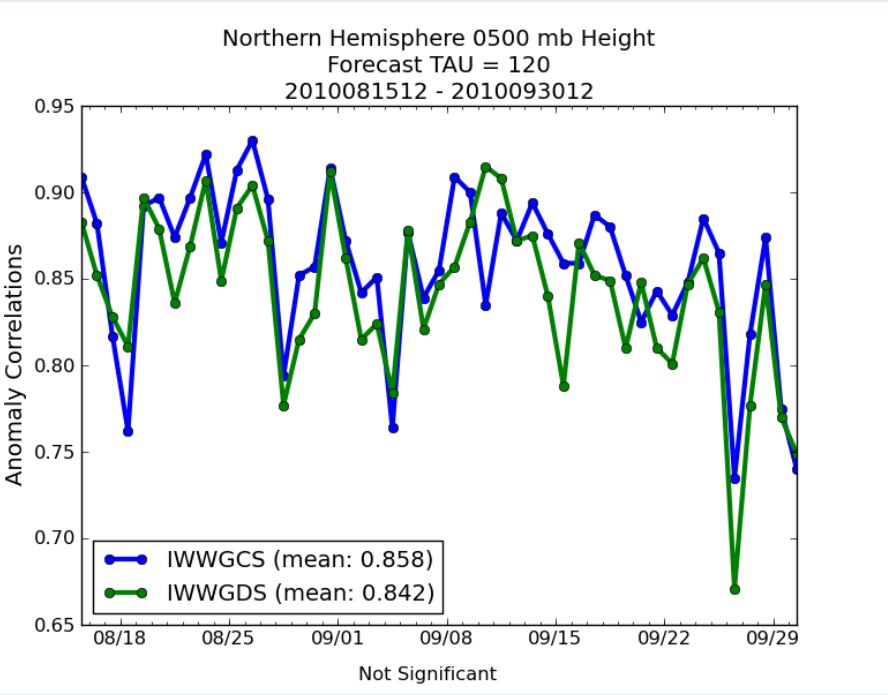


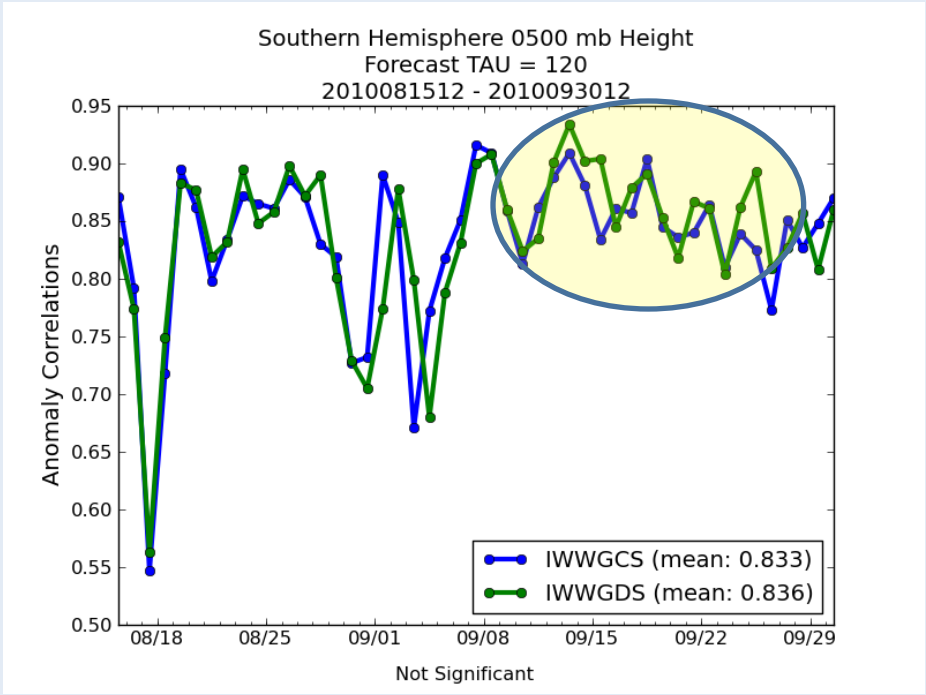
The summer hemisphere shows the most impact in terms of Z500 anomaly correlation. This trend holds for all cases examined.

Winter hemisphere shows occasional loss of skill with AMV assimilation (probably not significant, but nonetheless troubling).

Model Verification
NH Summer Case

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



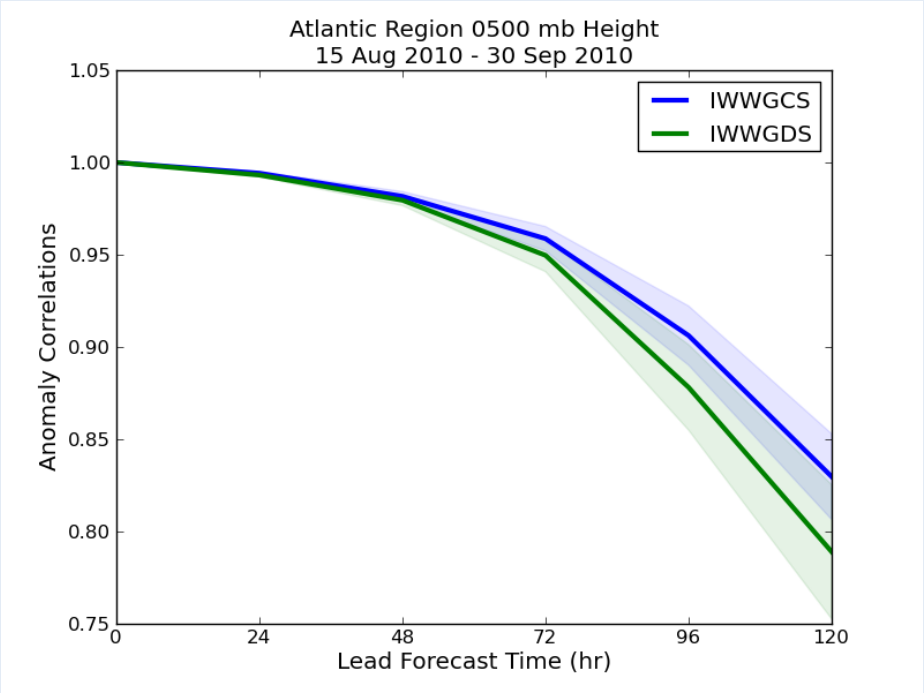


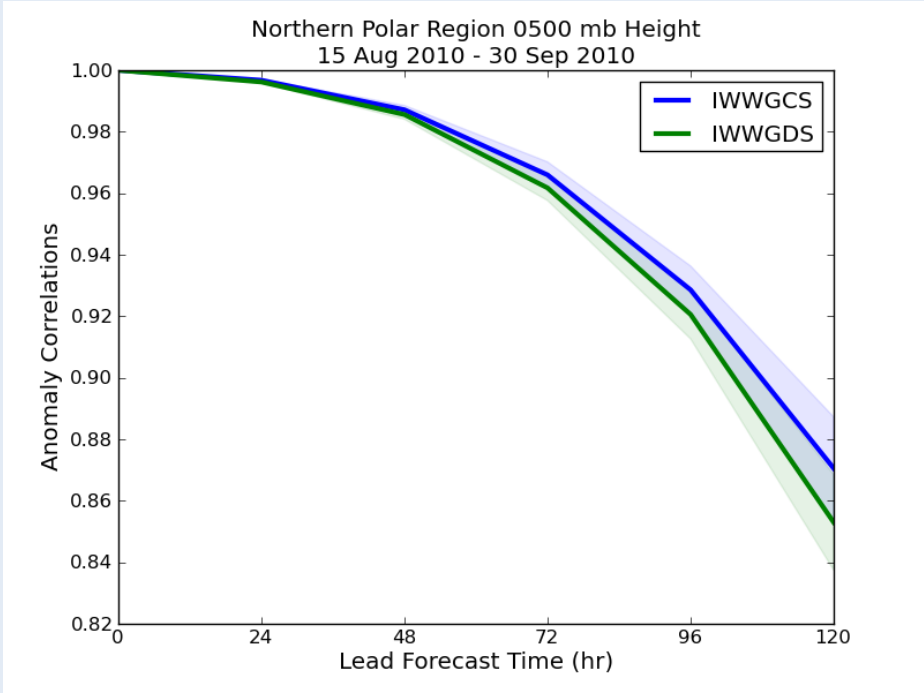
AMV wind assimilation produces better forecasts in general. There are a few notable exceptions that warrant further investigation

We want Blue Line to be higher (better skill)

NH Winds at 850 hPa
NH Summer Case

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

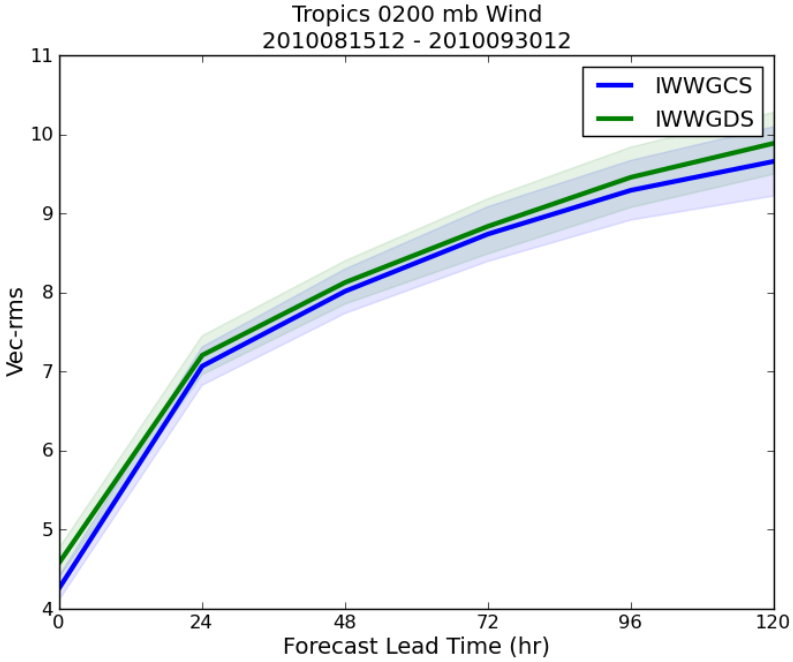


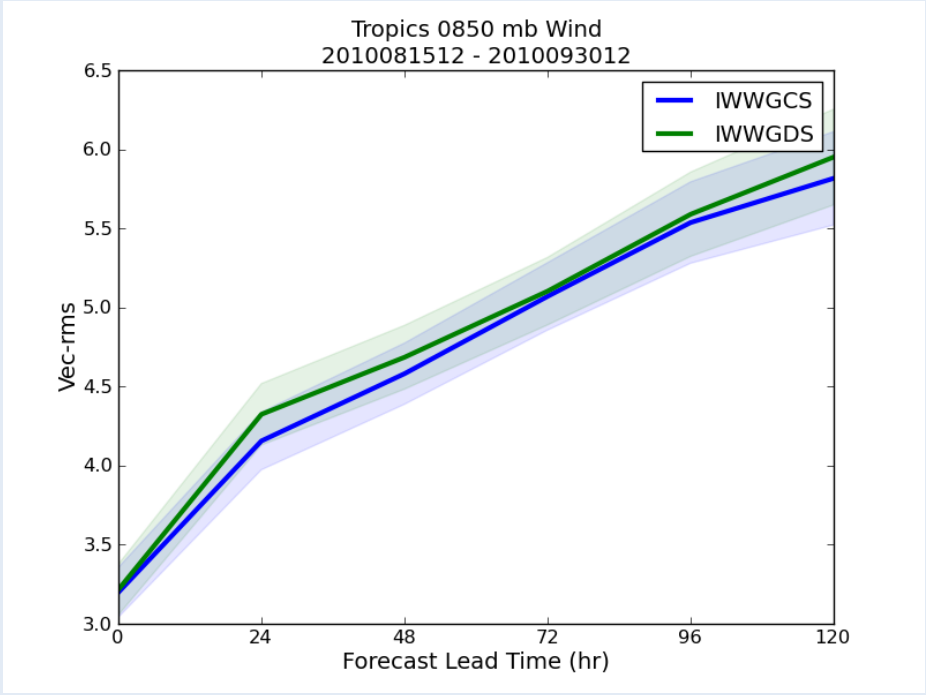


We want Blue Line to be higher (better skill)

Tropics Wind Vector RMSE
NH Summer Case, Raob Verification

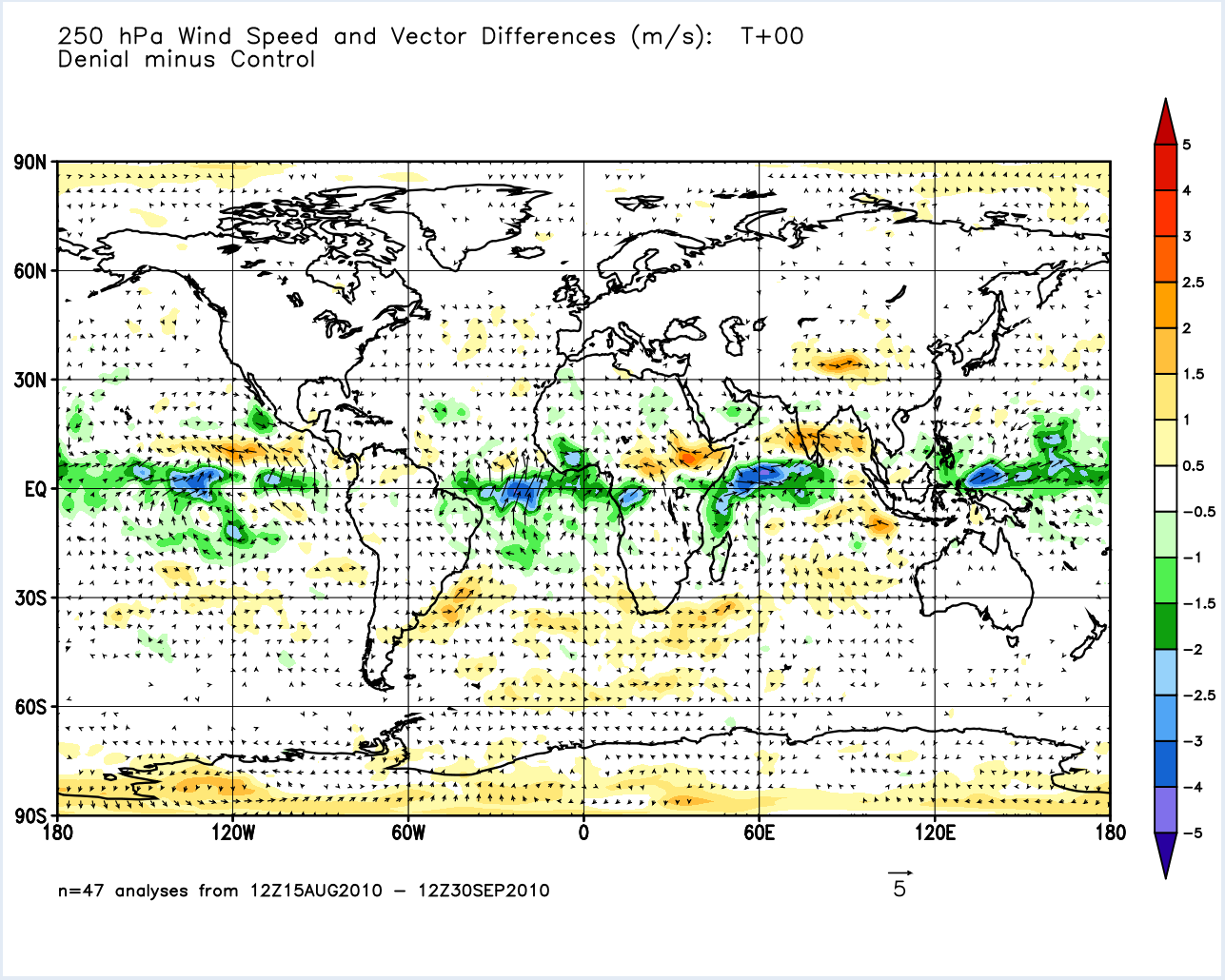
Blue line is the AMV assimilation run; green line is the wind denial run



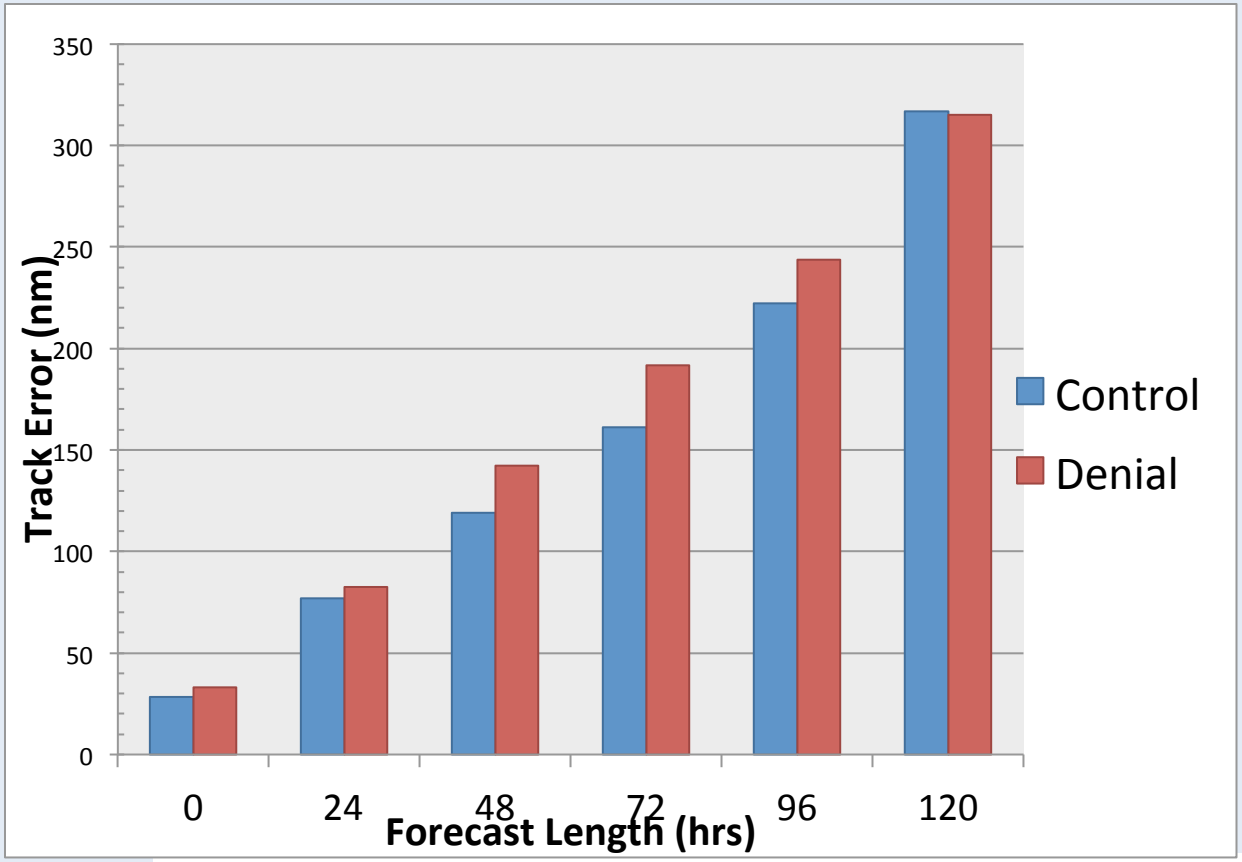


850 mb rmse vector wind impact is less, mean wind speed error is mixed at both levels. Similar story for 200 mb heights and winds, verified against self-analysis

NH Summer, Denial-control 250 hPa analyzed wind differences



Tropical Cyclone Track Verification

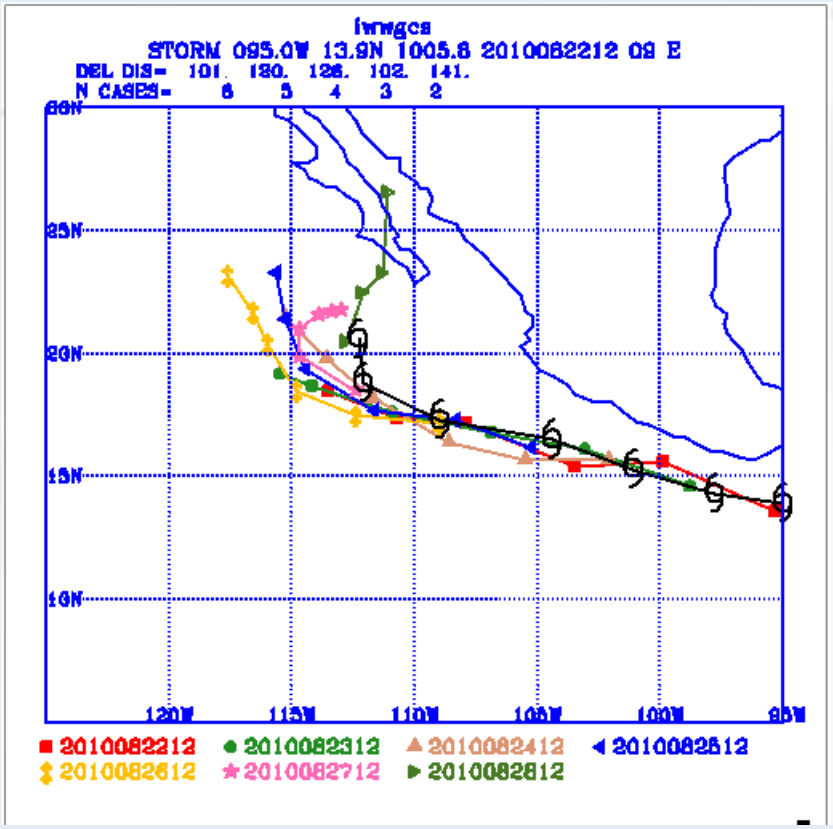


109	76	56	44	35	26	Number of storms

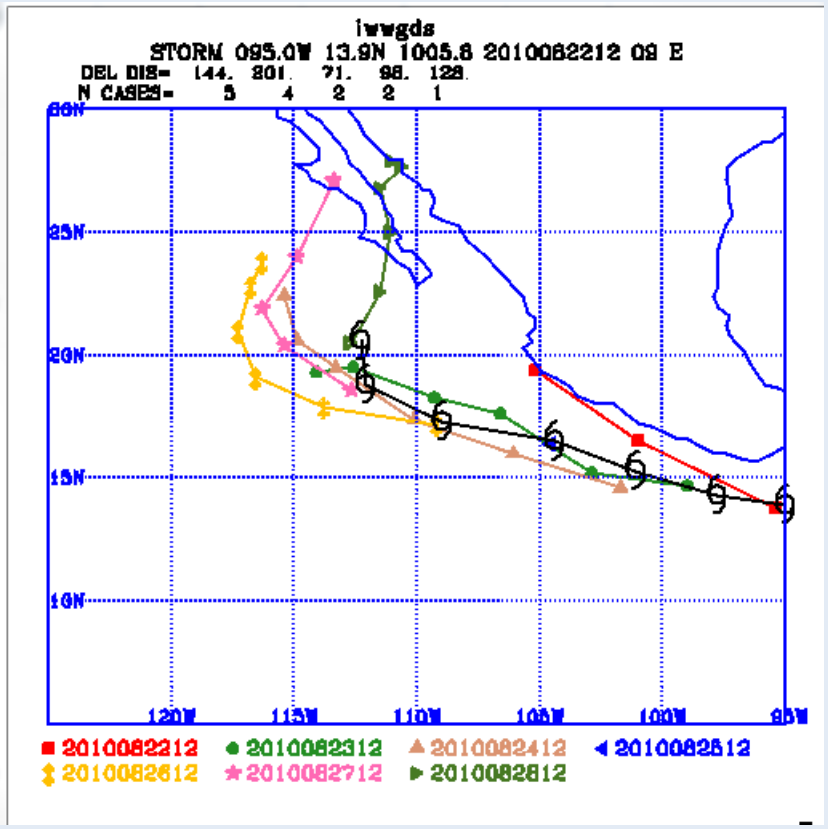
Significant for all forecast lengths to t+72 at the 99.0 – 99.5% confidence level

TC Track Stats

AMV control



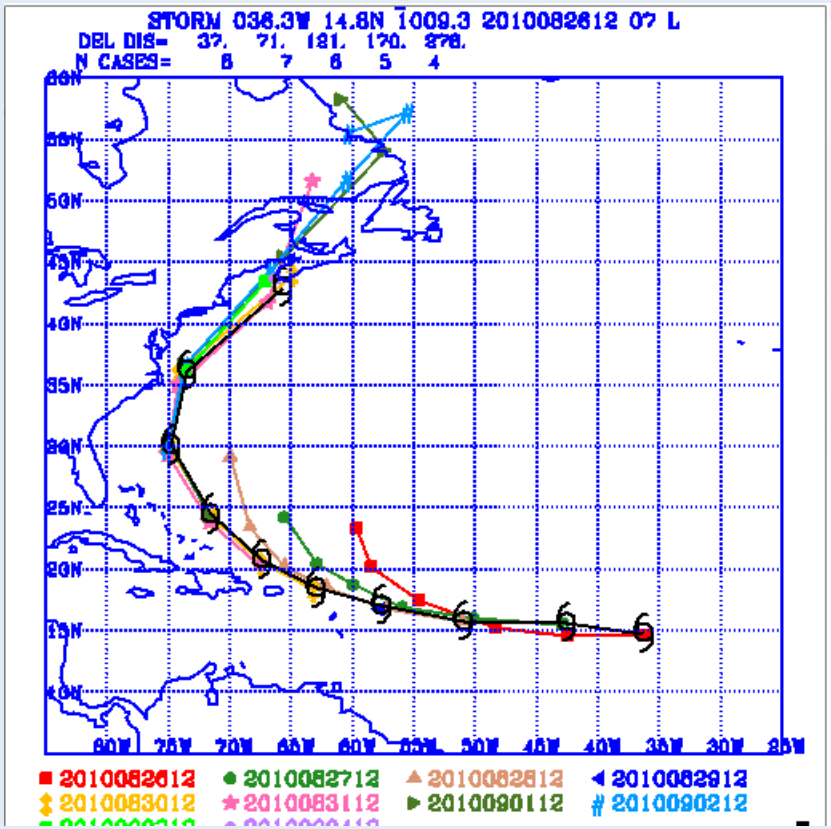
AMV denial



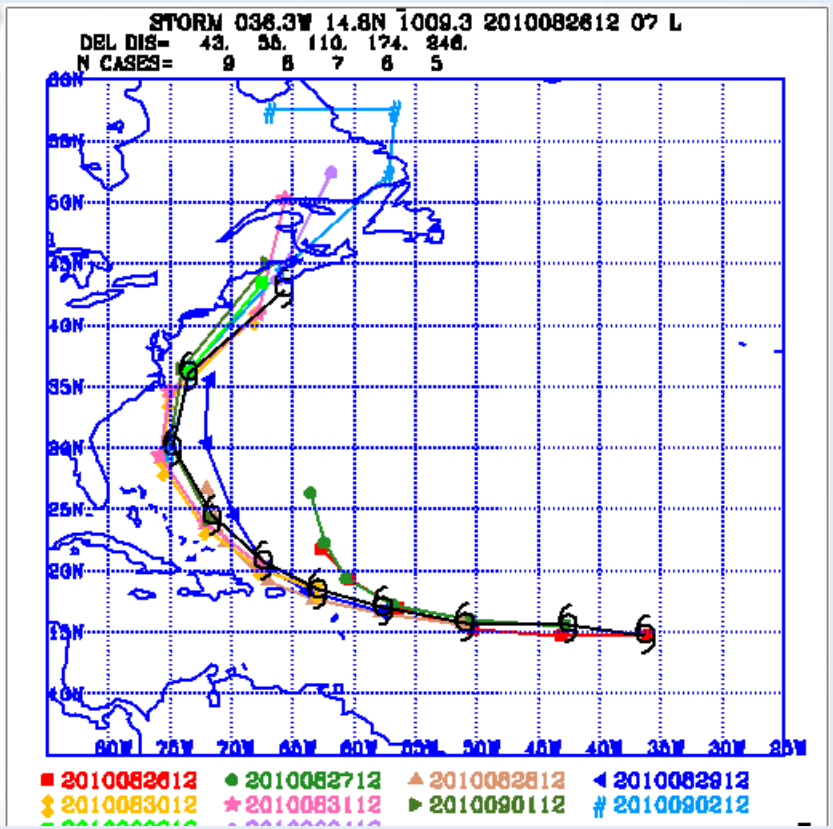
AMV wind assimilation helps with initial storm motion

TC Track Stats

AMV control



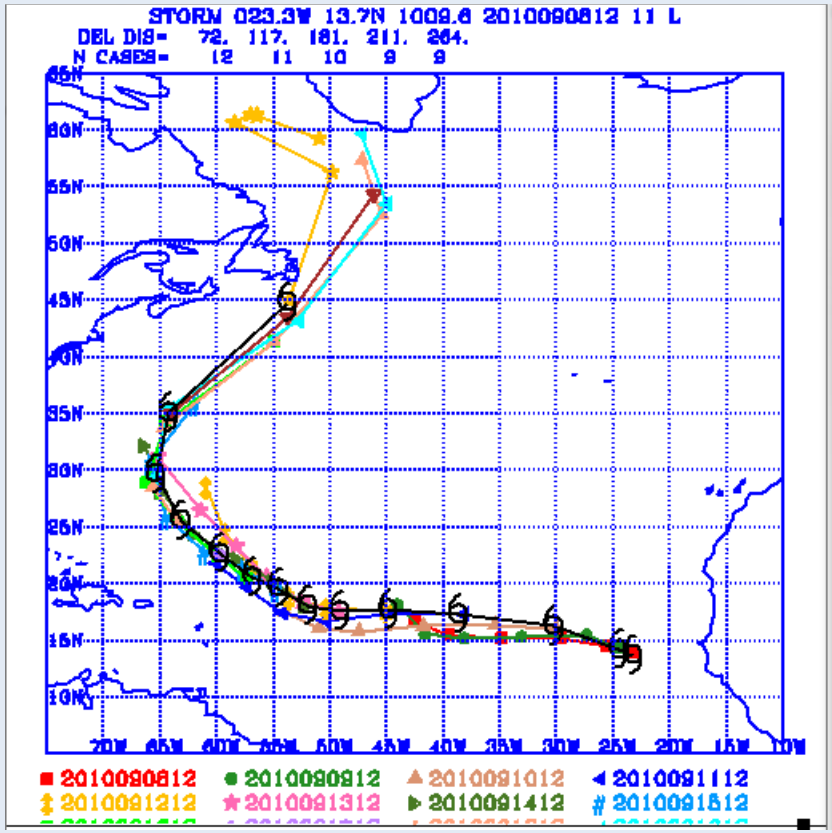
AMV denial



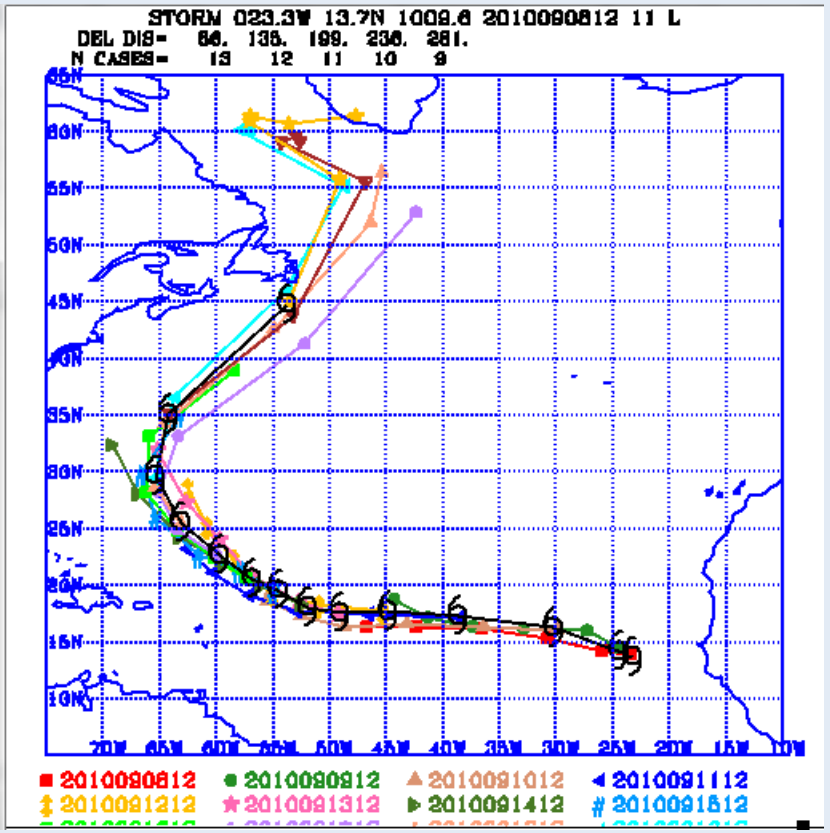
AMV wind assimilation helps with initial storm motion – most of the time
But not in this case either.

TC Track Stats

AMV control



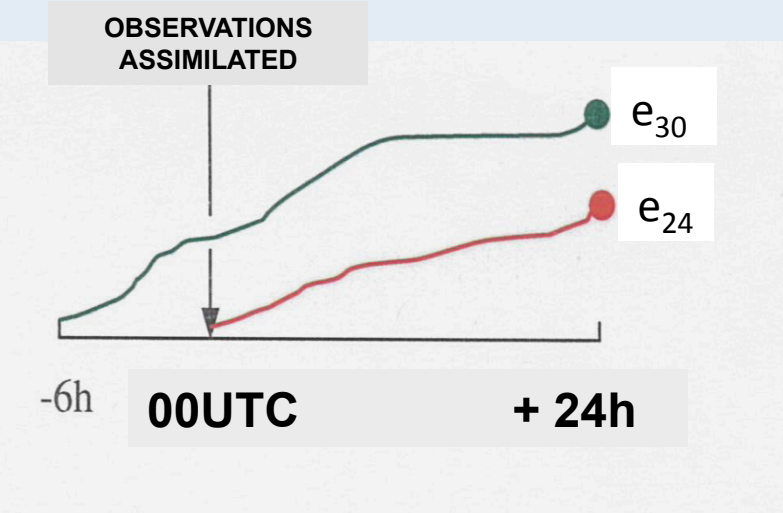
AMV denial



AMV winds seem help with recurving storms and extra-tropical transition

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
  - evaluate observation quality and tune observation reject lists
  - select satellite channels for assimilation

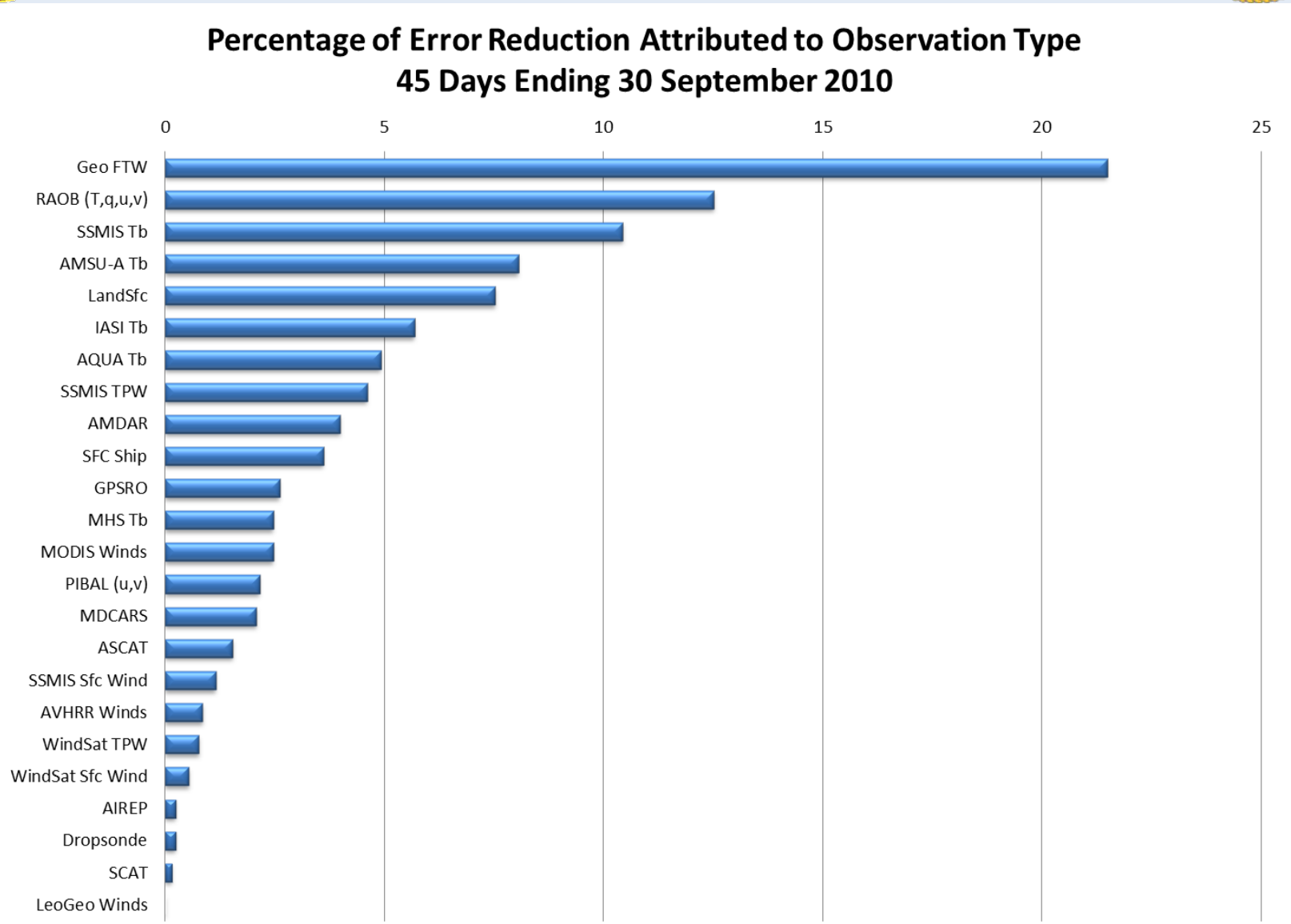


Observations move the model state from the "**background**" trajectory to the new "**analysis**" trajectory

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

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

Summer 2010
Aug 15th, 12 UTC through Sept. 30th, 00 UTC
Observation impacts computed every 6 hrs



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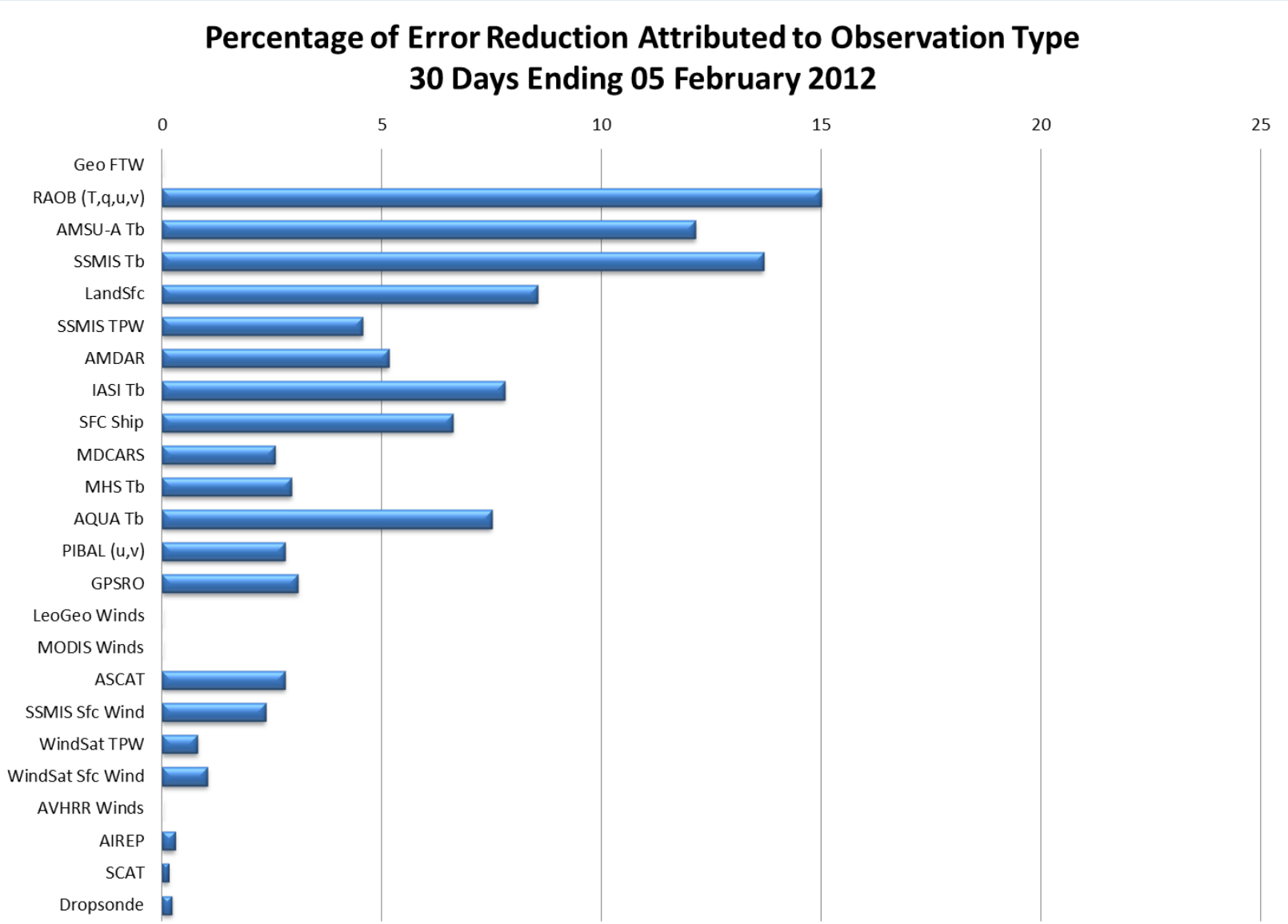
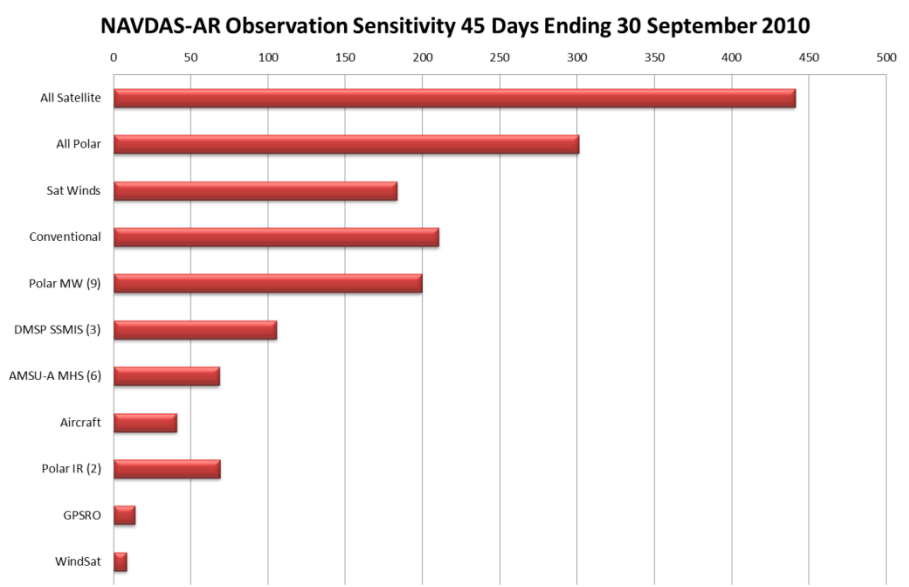
Observation impacts computed every 6 hrs



Summer 2010
Aug 15th, 12 UTC through Sept. 30th, 00 UTC

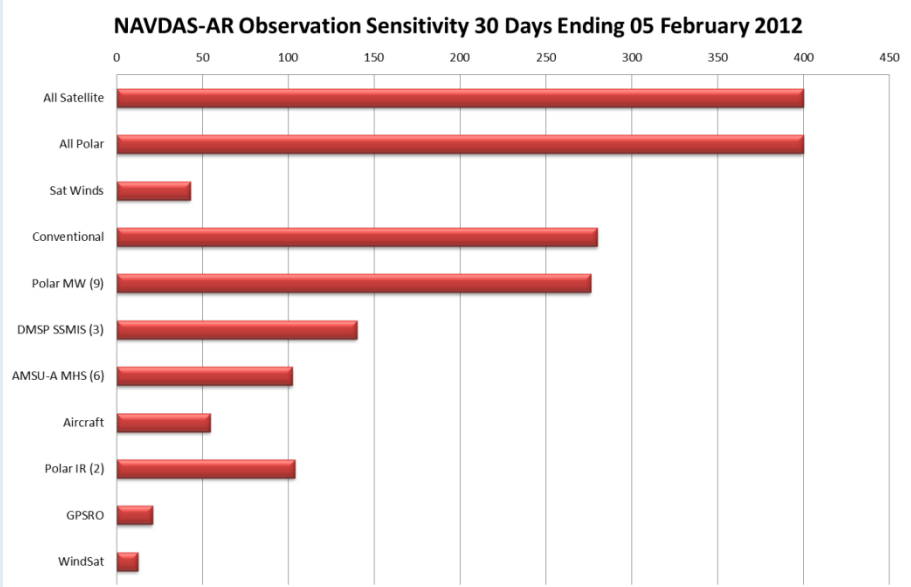
Observation impacts computed every 6 hrs

AMV wind control



	WindSat	GPSRO	Polar IR (2)	Aircraft	AMSU-A MHS (6)	DMSP SSMIS (3)	Polar MW (9)	Conventional	Sat Winds	All Polar	All Satellite
Ob Impact	8.50	14.00	69	41	68.5	105.5	199.5	210.5	183.5	301	441

AMV wind denial

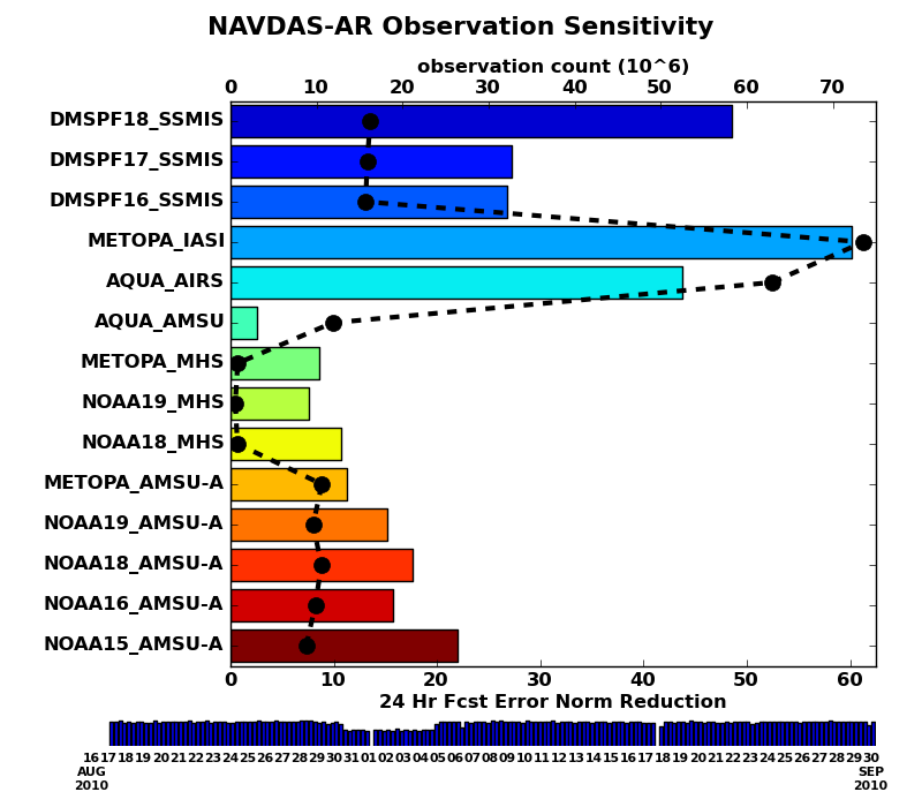


	WindSat	GPSRO	Polar IR (2)	Aircraft	AMSU-A MHS (6)	DMSP SSMIS (3)	Polar MW (9)	Conventional	Sat Winds	All Polar	All Satellite
Ob Impact	12.50	21.00	104	54.5	102.5	140	276	280	43	400	400

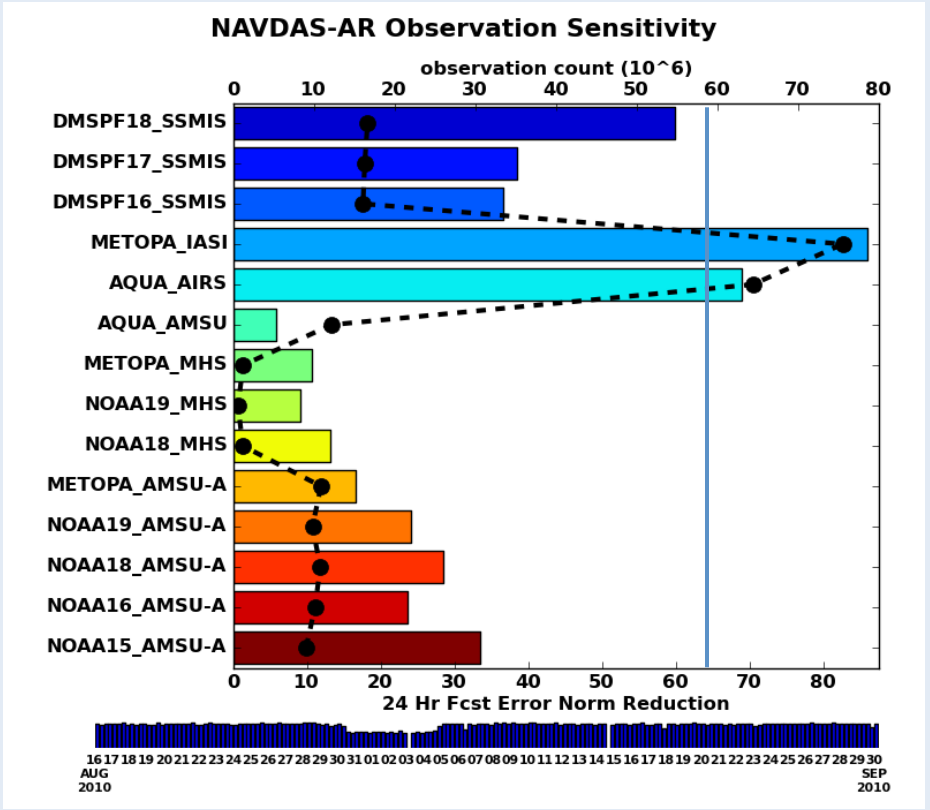
Summer 2010
Aug 15th, 12 UTC through Sept. 30th, 00 UTC

Observation impacts computed every 6 hrs

AMV wind control



AMV wind denial



NRL Observation Impact Assessment

- The ob impact results show that AMVs produce large forecast error reduction (e24-e30) for the total moist energy norm.

- We next examine the 24-hr moist total energy error norm for the control and denial cases
  - However, reducing total error (e24) is not the same as changing (e24-e30), which is what the adjoint ob impact measures.

NH Summer AMV Denial Experiments
24-hr moist total energy error norms

- CS=control run with AMVs, DS=AMV-denial run
- 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
TROPICS (20-20)	8.387	7.678	1.959	1.755	0.706	0.626	0.393	0.352	5.319	4.936
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
GLOBAL	23.257	22.976	7.469	7.647	1.673	1.604	2.028	2.001	12.024	11.658

- NHEM (summer hemisphere) AMVs primarily reduce vorticity error
- SHEM (winter hemisphere) AMVs reduce vorticity error and sl. increase humidity error
- TROPICS (20S-20N), AMVs increase all components of the error norm, including vorticity. AMVs cause a significant increase in tropics humidity forecast error – we don't know why
- Global domain, AMVs (CS) reduce vorticity error but increase temperature, divergence and particularly the humidity component of the error norm.

Conclusions

- Overall, we see good benefit from AMVs
- Most of the impact is in the summer hemisphere and subtropics (TC forecasts)
- 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. The small impact of AMVs on temperature error may explain why there is also relatively small impact on 500mb height anomaly correlation.

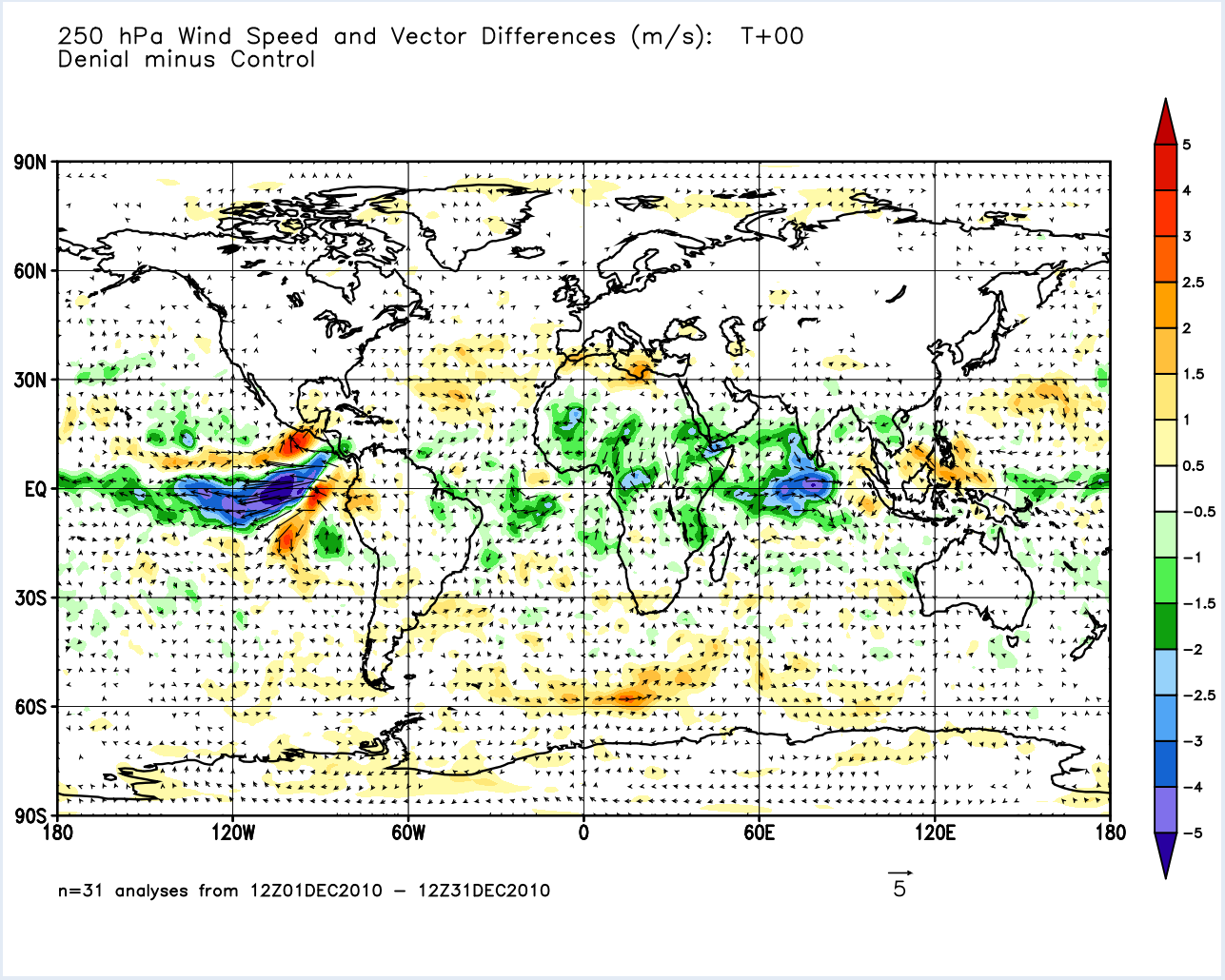
Future Plans

- Complete diagnostics for the various runs
- Determine what is happening in the deep tropics
- The mixed results in certain regions hint that revision of the initial background error covariances would help NAVDAS-AR extract additional information from the AMV winds
  - Our background temperature error variances are too small, and our radiance ob errors are proportionately too large
  - The wind background and observation errors are overall in better balance
- Define the energy norm as vorticity only and re-compute sensitivities and ob impacts for the control forecasts
- Repeat for the divergence, temperature and humidity components of the error norm
- This would allow us to see which error component accounts for the large role of AMVs in terms of e24-e30.

Summary of NH Winter AMV Denial and Polar AMV Denial

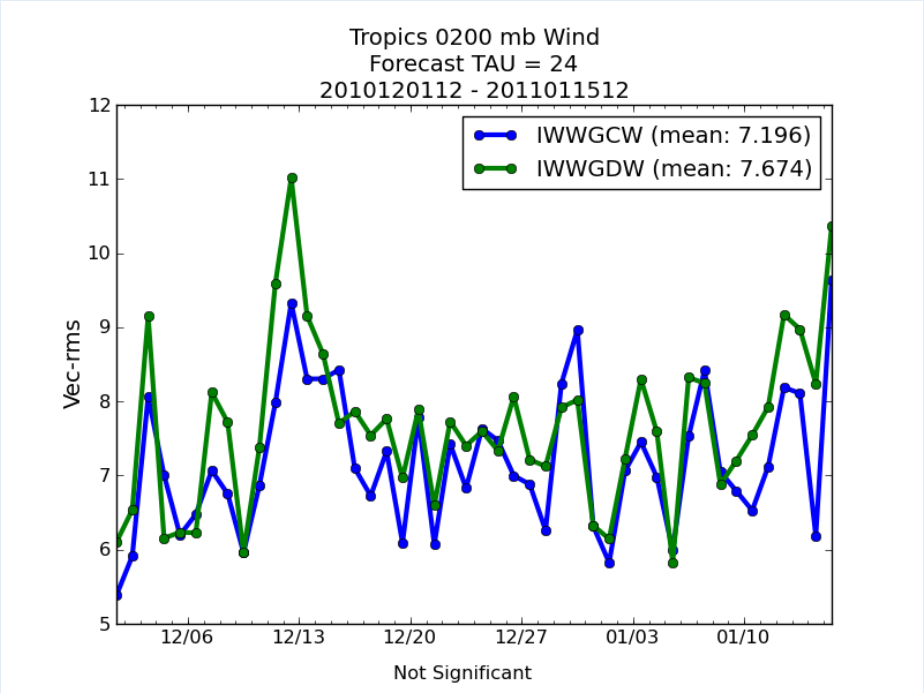
- In terms of 500 hPa anomaly correlation, the greatest benefit from the winds is in the summer (SH) hemisphere (+0.01)
  - Occasional lower AC scores for AMVs decrease NH benefit, resulting in neutral impact
- Polar winds: for 500 hPa, most of the benefit is in the summer (SH) hemisphere (+0.01)
  - AC scores are lower in Northern Polar and WPAC regions with Polar AMV

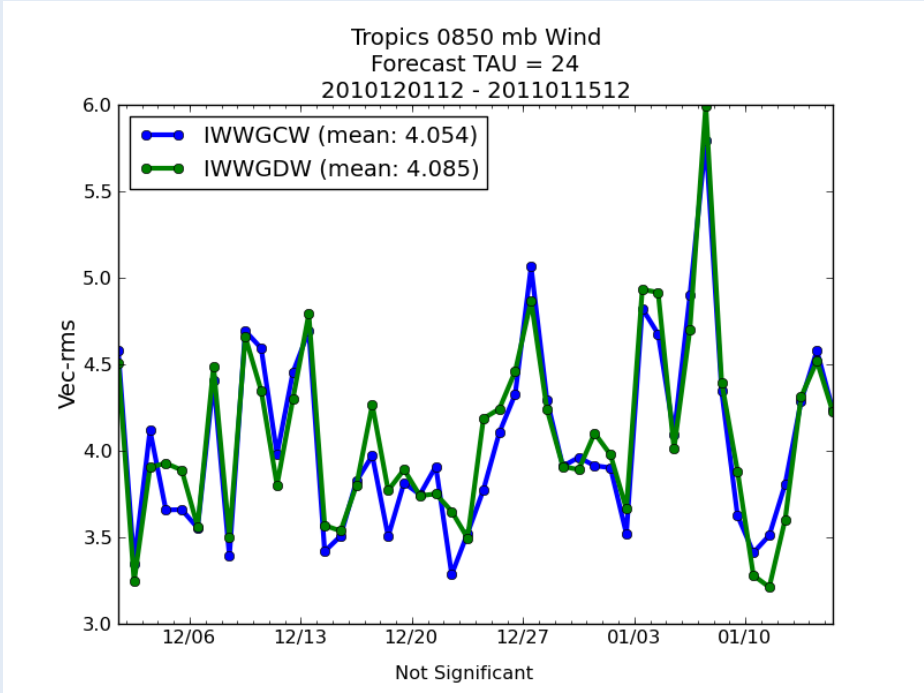
NH Winter, denial – control, T+00 250 hPa analyzed wind differences



Model Verification
NH Winter Case - Raobs

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



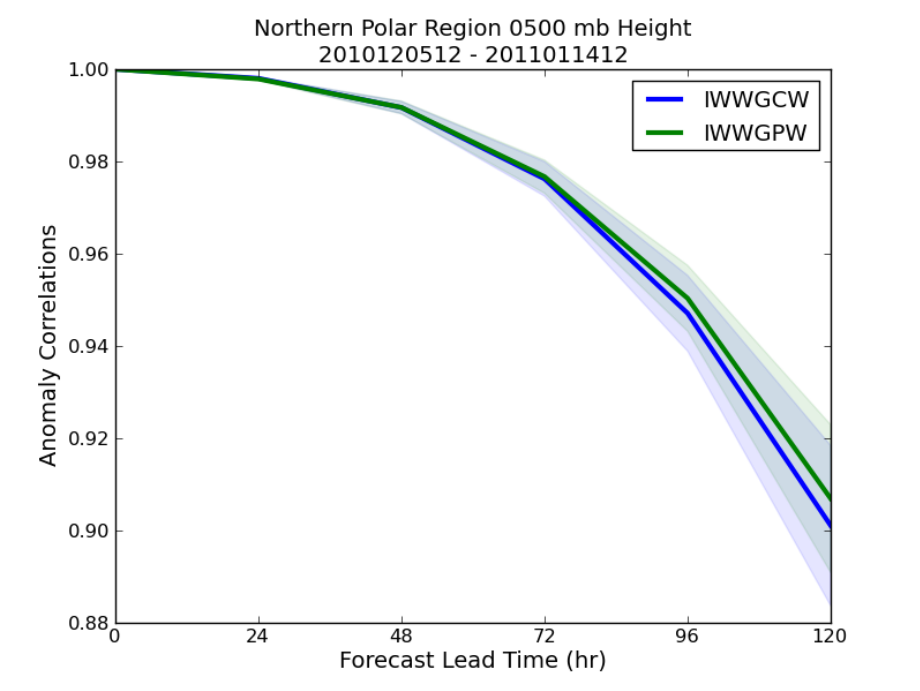


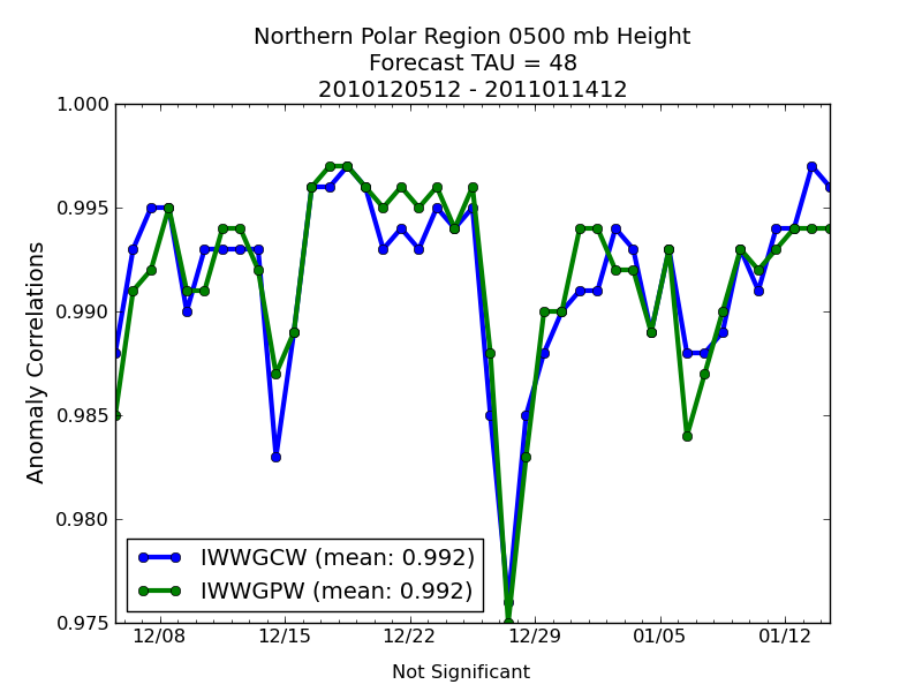
AMV assimilation reduces the 200 hPa vector wind RMS error, as verified against self-analysis
At 200/850 mb, wind speed errors worse with AMV, wind vector RMSE better with AMV
Decreased wind vector RME reflected in geopotential height error RMSE

We want Blue Line to be lower (smaller error)

Polar AMV Wind Denial

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





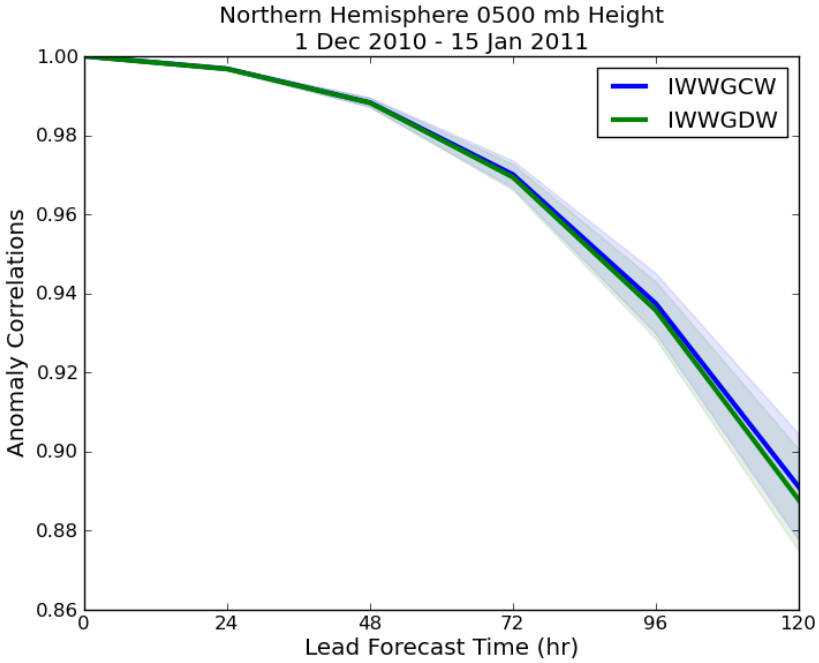
However, most NH areas show improvement with AMV wind assimilation, except Northern Polar Region. Why is that?

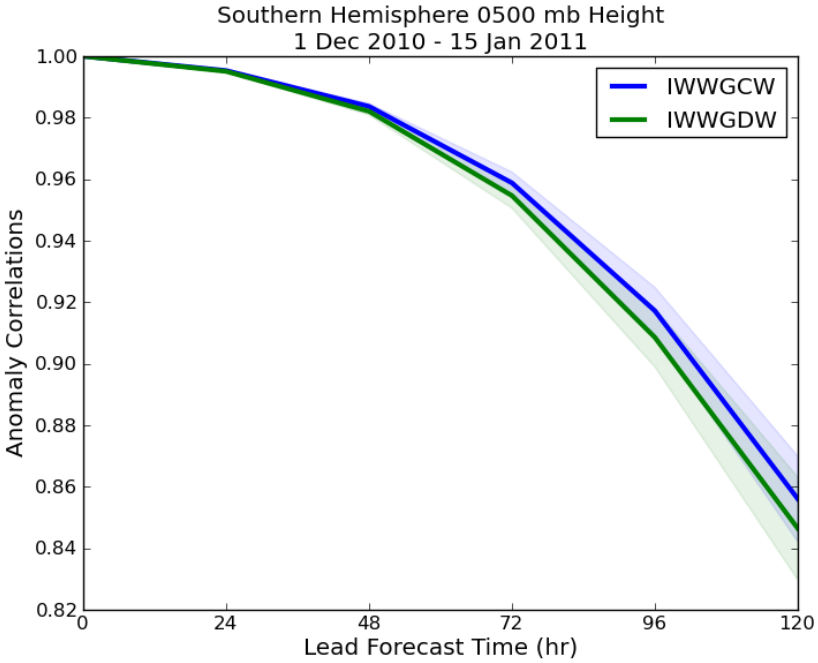
We want Green Line to be higher (better skill)

RESULTS FROM AMV WIND DENIAL NH WINTER

Model Verification
NH Winter Case

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

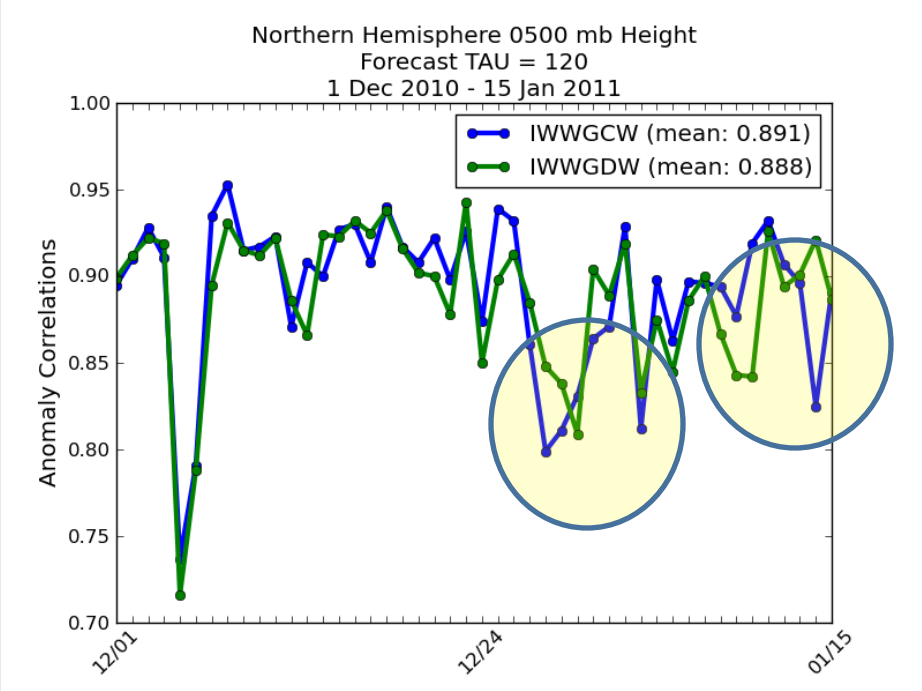


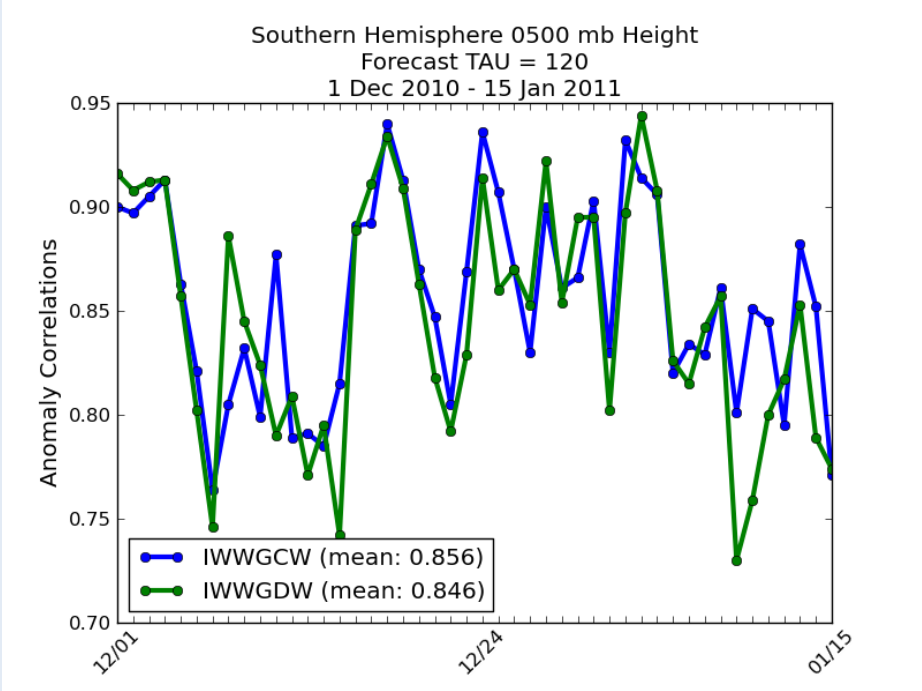


The impact is greatest in the summer hemisphere – this is a trend that holds for these experiments

Model Verification
NH Winter Case

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





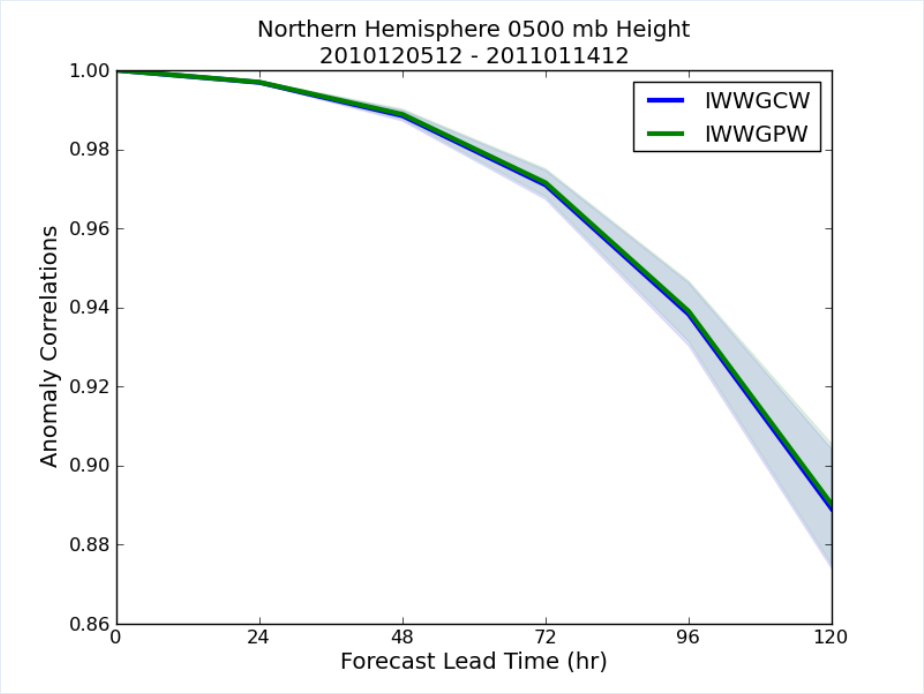
AMV assimilation reduces dropouts most, but not all, of the time.

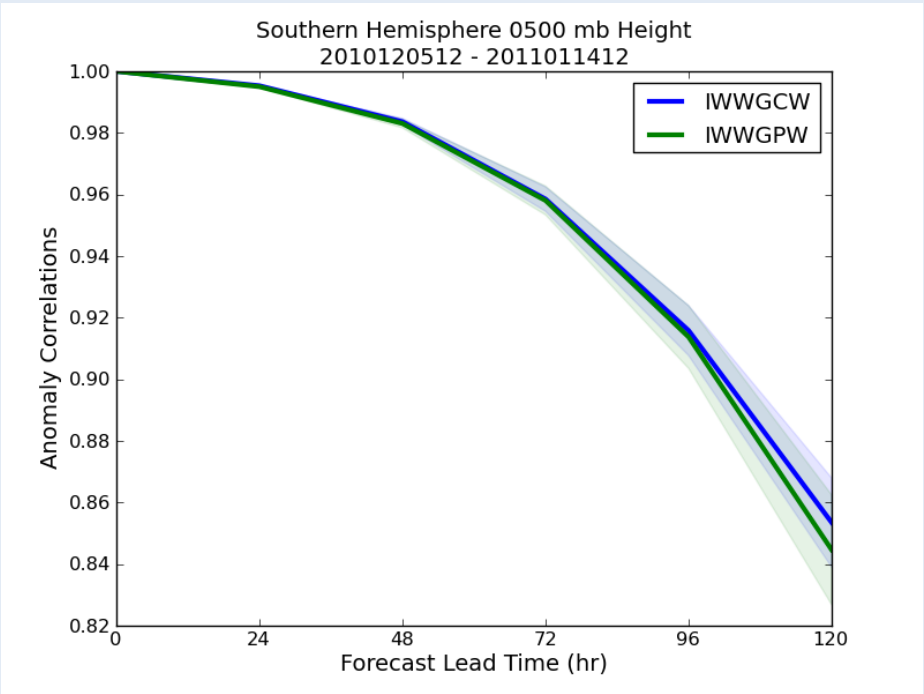
We want Blue Line to be higher (better skill)

RESULTS FROM POLAR AMV WIND DENIAL
NH SUMMER

Polar AMV Wind Denial

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



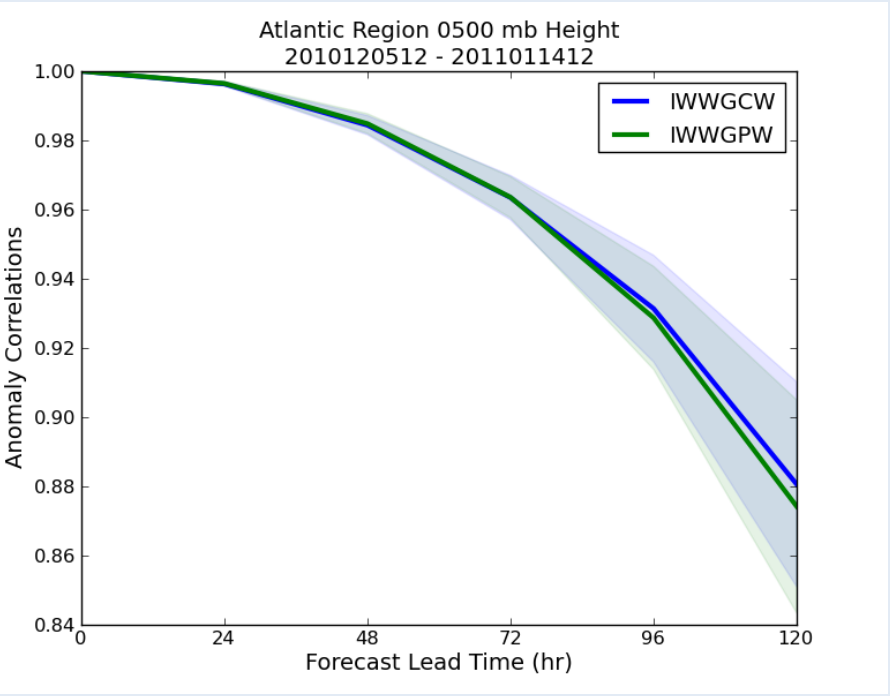


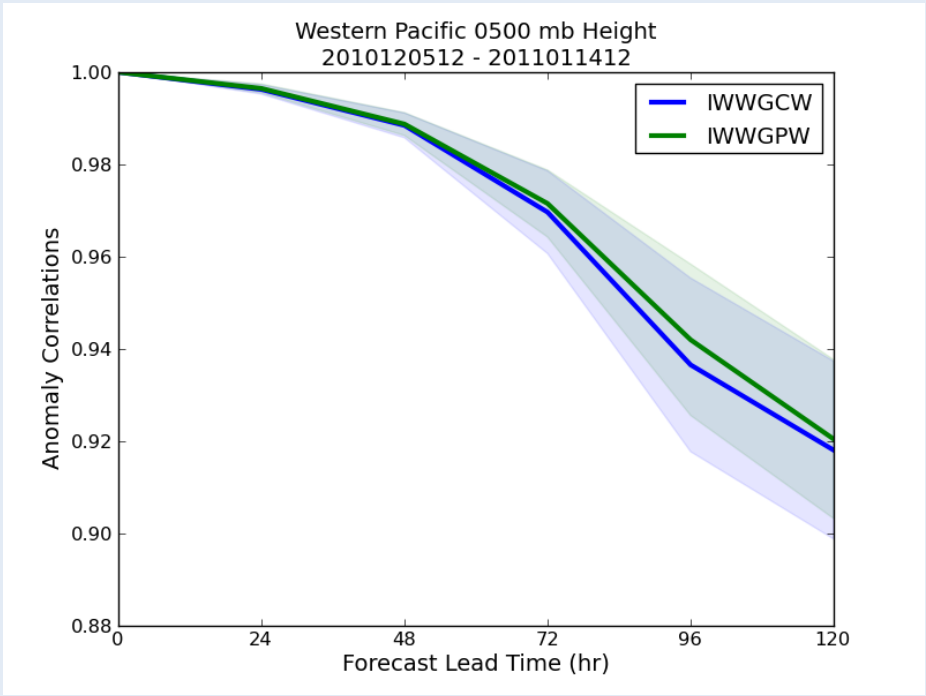
Again, most improvement is in the SH summer hemisphere, stats cover 20-80S

We want Blue Line to be higher (better skill)

Polar AMV Wind Denial

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





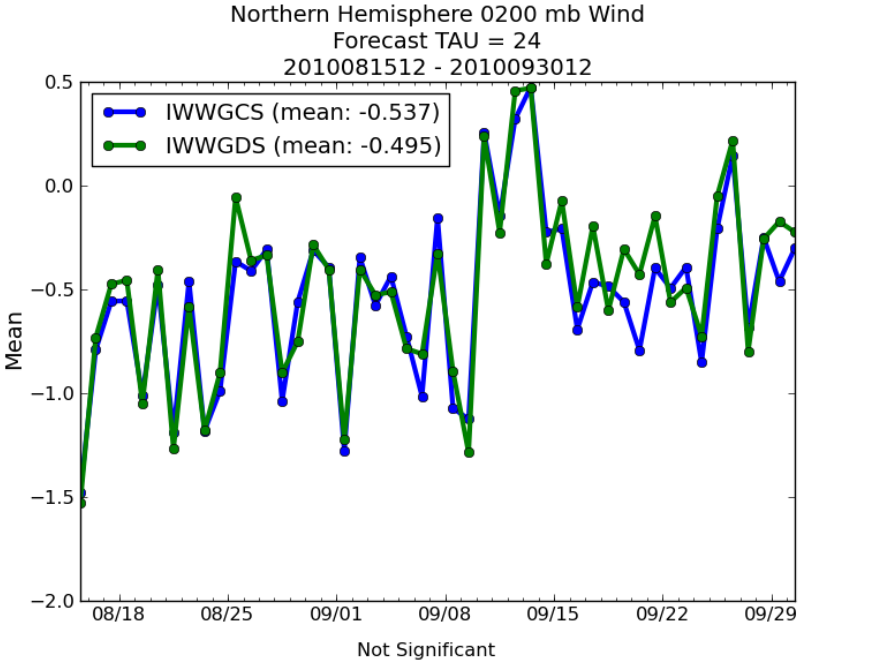
However, most NH areas show improvement with AMV wind assimilation, except WPAC. Why is that?

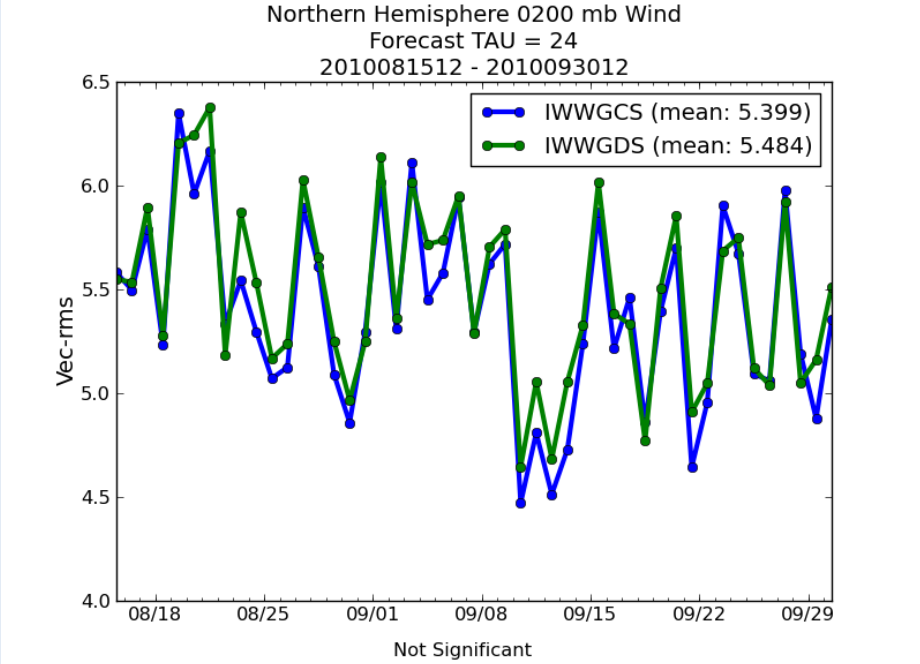
We want Green Line to be higher (better skill)

RESULTS FROM AMV WIND DENIAL NH SUMMER

NH Winds at 200 hPa
NH Summer Case - Raobs

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

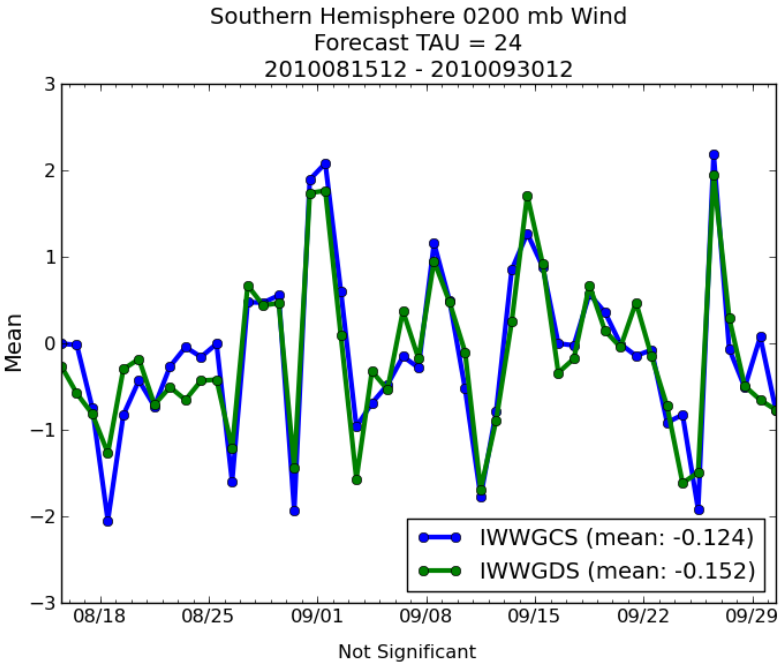


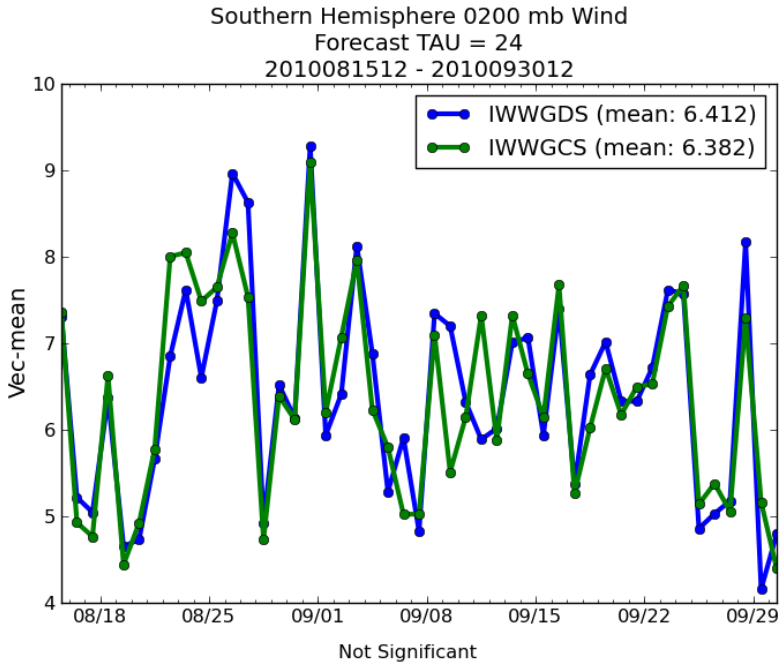


Summer (NH) 200 hPa mean wind speed is larger, but vector RMSE is less with AMV assimilation

NH Winds at 200 hPa
NH Summer Case - Raobs

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

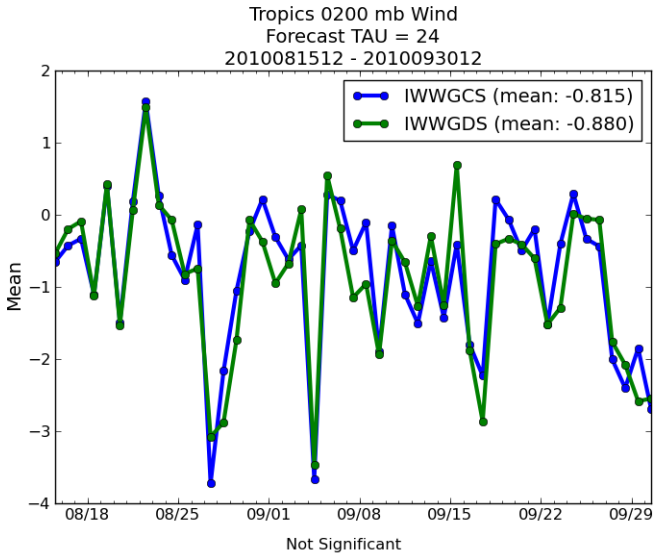


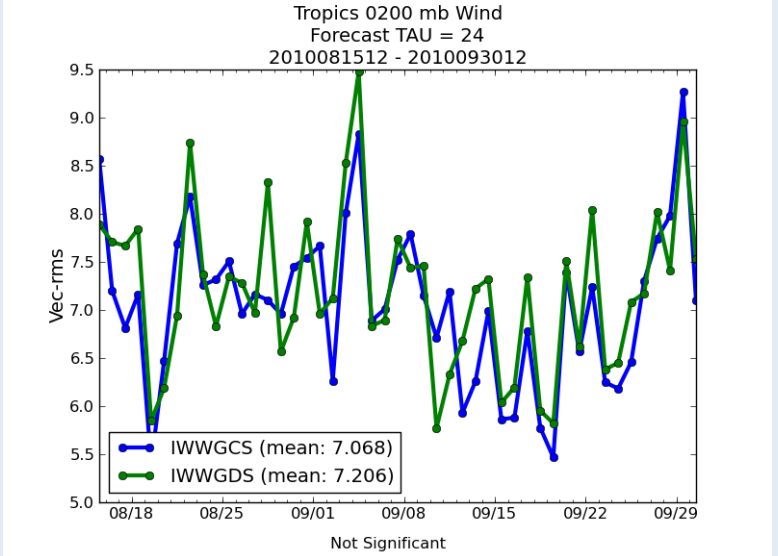


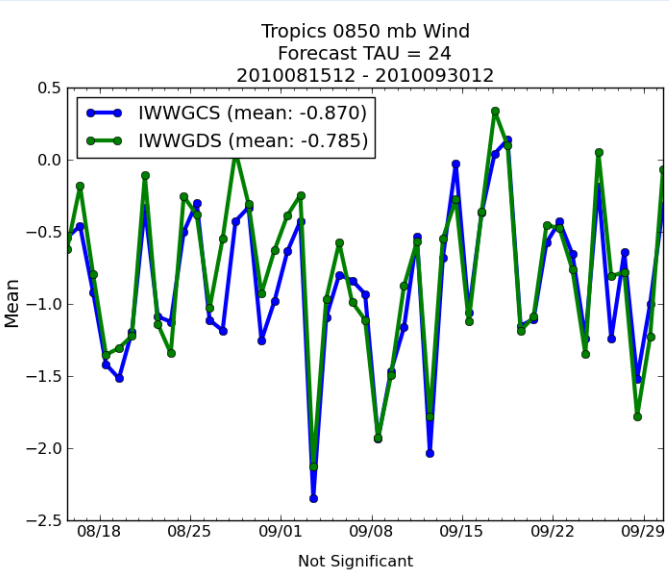
Winter (SH) 200 hPa mean wind speed and vector RMSE are less with AMV assimilation

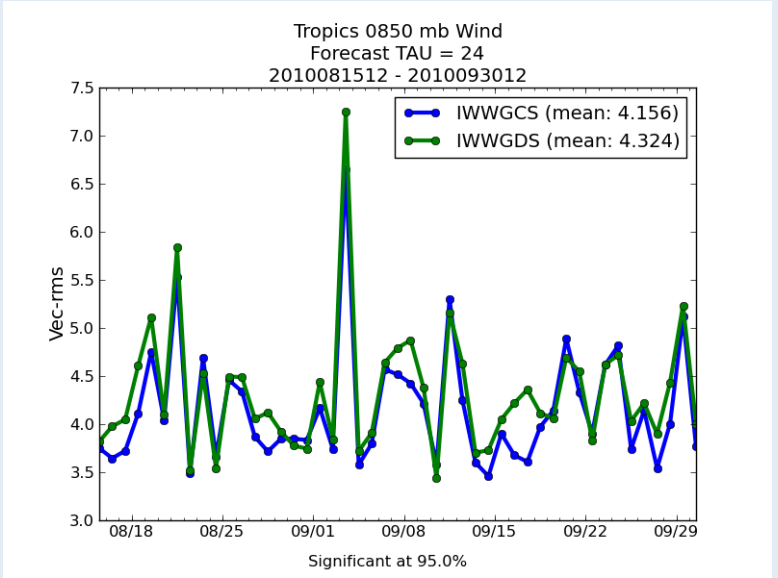
Blue line is the AMV assimilation run; green line is the wind denial run

NH Winds at 200 hPa
NH Summer Case - Raobs

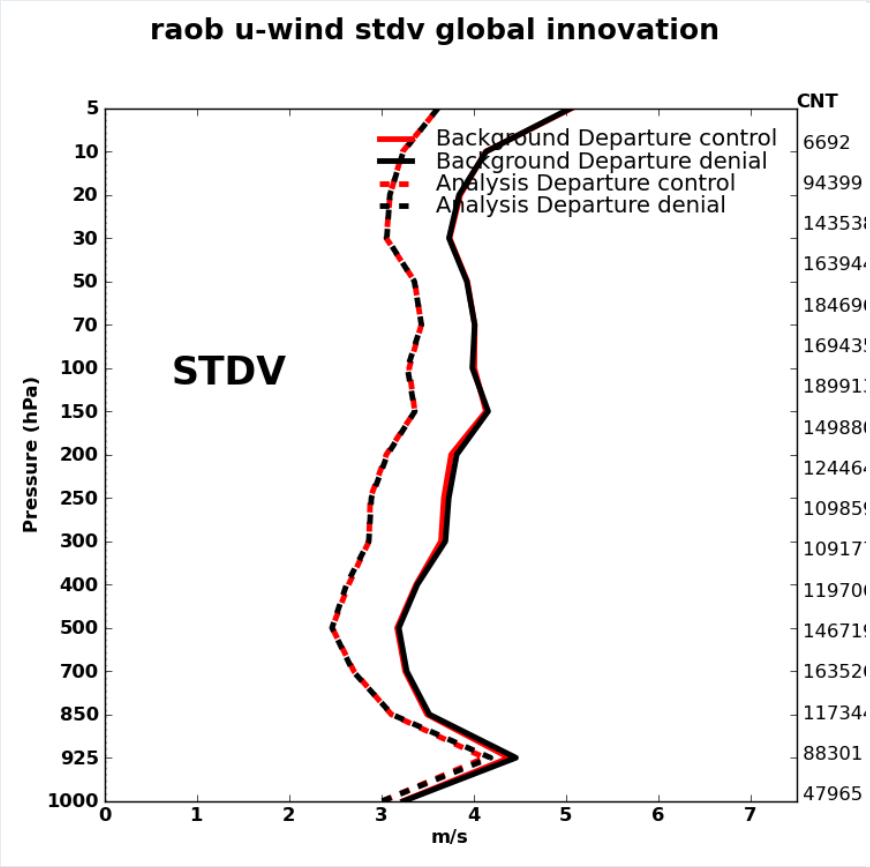


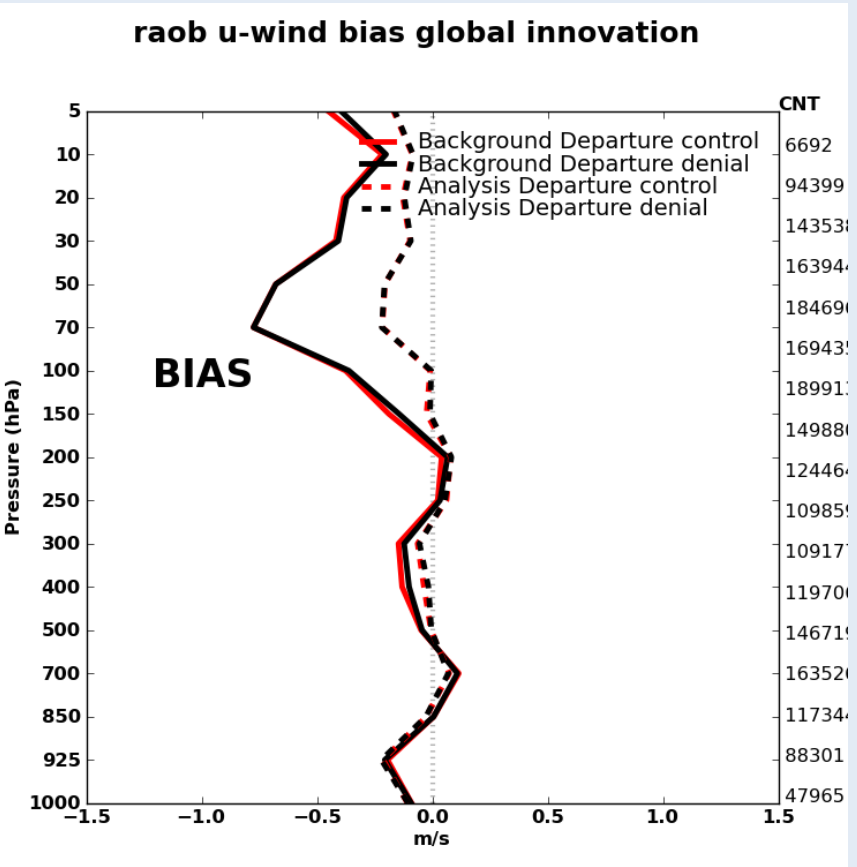




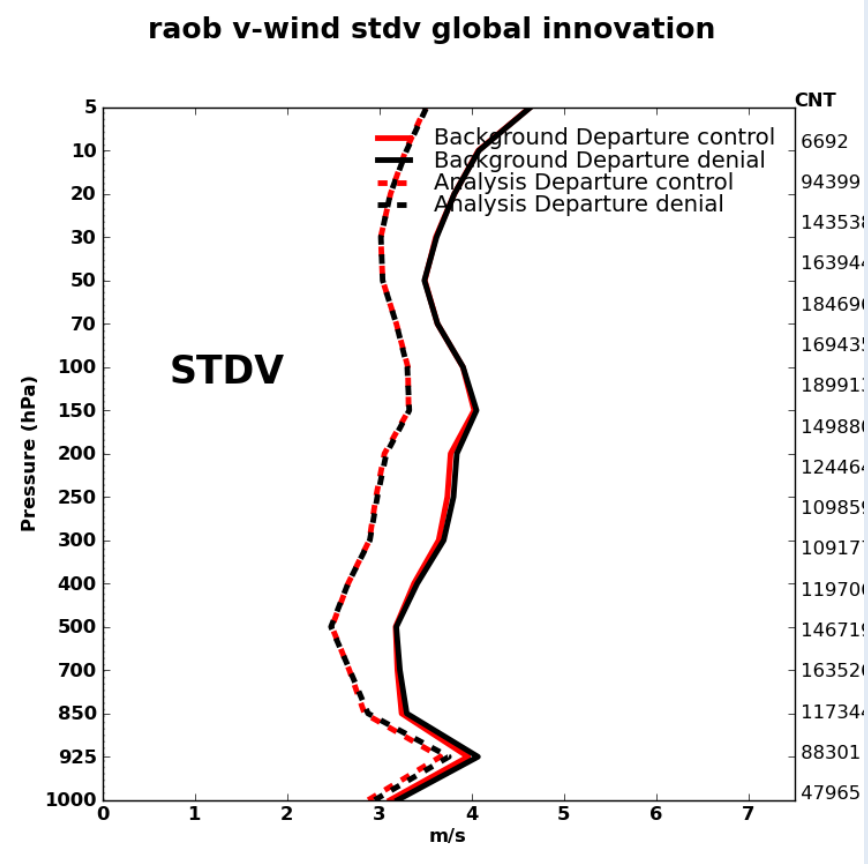


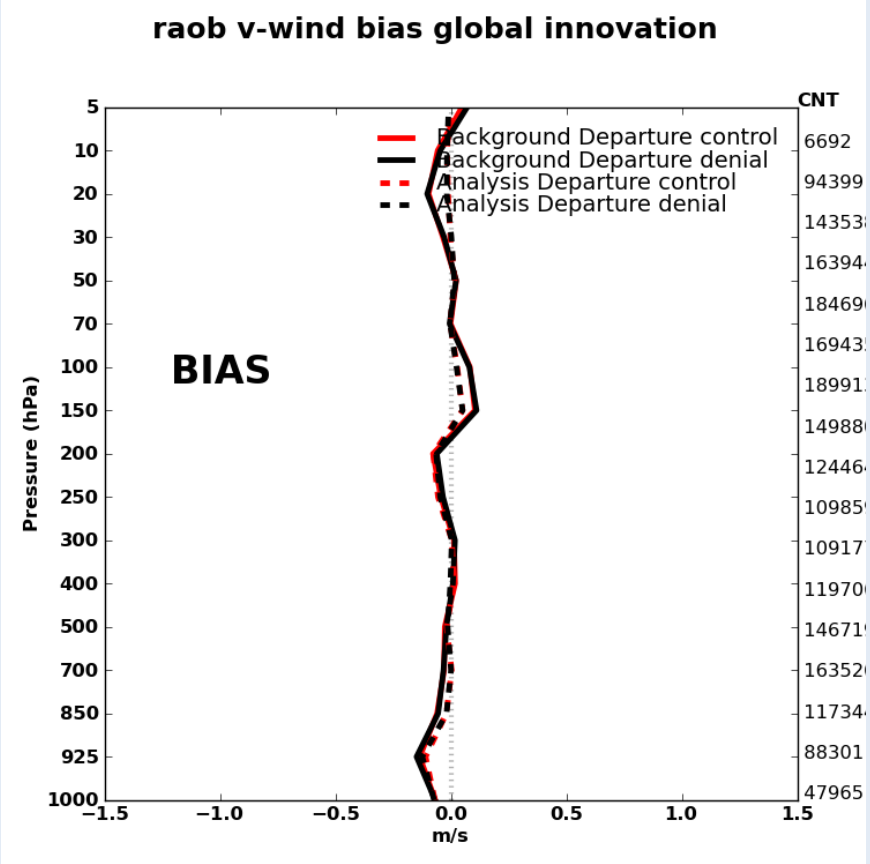
NH Summer Case, global





NH Summer Case, global





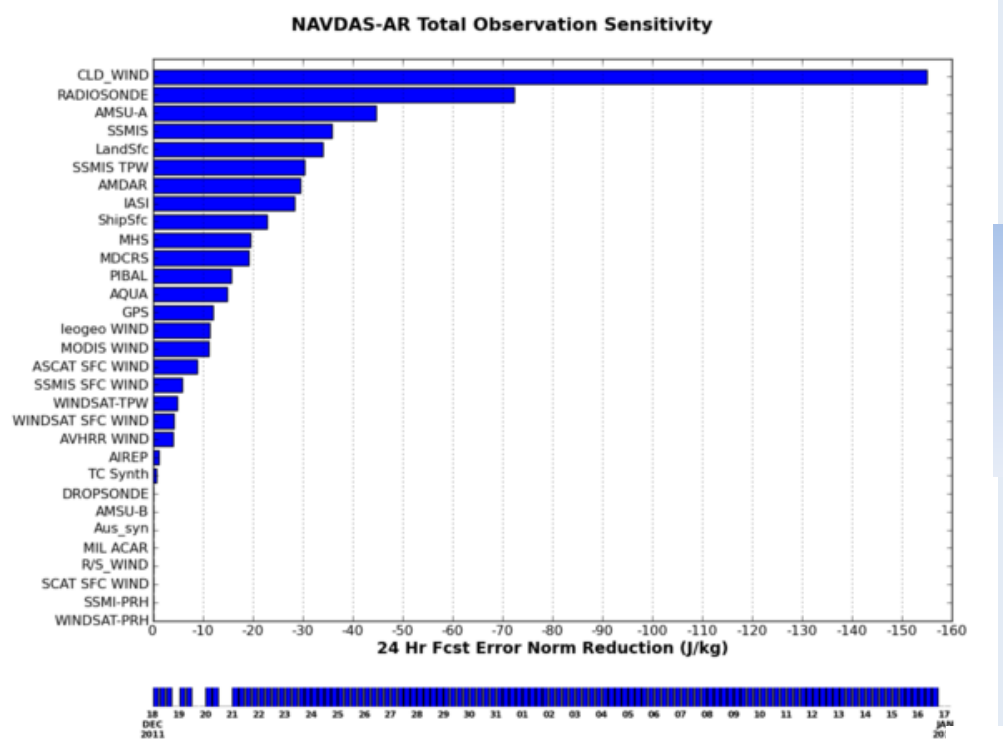
Summary of NH Summer AMV Results

- In terms of 500 hPa anomaly correlation, the greatest benefit from the winds is in the summer (NH) hemisphere (+0.016)
  - Occasional lower AC scores for AMVs decrease NH benefit, resulting in neutral impact
- Tropical cyclone predicted tracks are significantly better out to 3 days (>= 99%)
- Tropics: low level wind speed bias

Requested Verification

- Latitude bands
  - Northern Hemisphere: north of 20N
    - Our NH anomaly correlation stats are from 20N-80N; raob stats 20N-90N
    - Our N Polar anomaly correlation and raob stats are from 60N-90N
  - Tropics: 20S to 20N
  - Southern Hemisphere: south of 20S
    - Our SH stats are from 20S-80S; raob stats from 20S-90S
    - Our S Polar anomaly correlation and raob stats are from 60S-90S
- Navy's traditional verification metrics and diagnostic plots are different from the requested figures*
- Anomaly correlation and tropical cyclone track are not requested verification metrics

* Special thanks for diagnostic assistance from Ryan Maue, Ben Ruston, Tim Whitcomb, Steve Swadley, and Glen Carl



Additional Studies

One often-asked question is why does the Navy to get more impact out of the geostationary AMV winds that other NWP centers?

- Super-ob procedure?
- Quality control
- More winds?
- NAVDAS-AR is able to extract wind information more effectively than temperature information