Ensemble-based Data Assimilation for Tropical Cyclones: Current Status and Future Prospects

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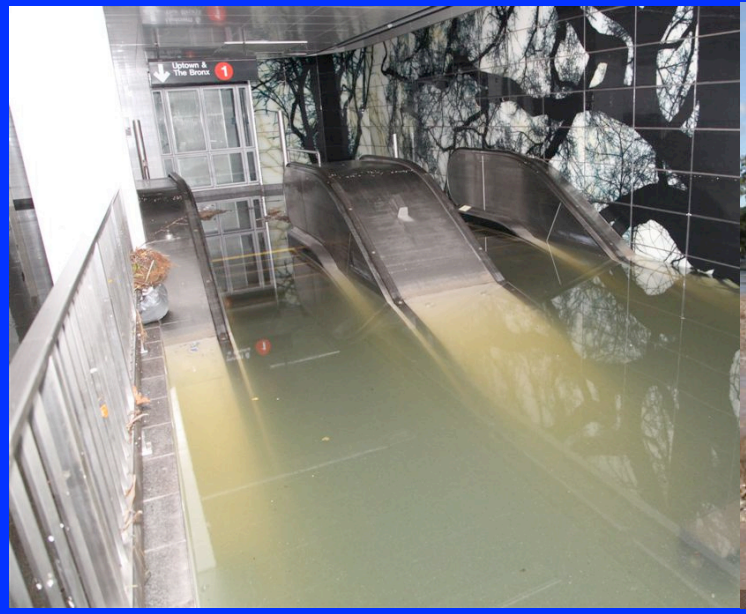
Frontiers in Ensemble Data Assimilation Workshop
5 August 2015
Boulder, CO

Outline

- Tropical Cyclone Overview
- Unique TC Observations
- Challenges with TCs
- Future prospects

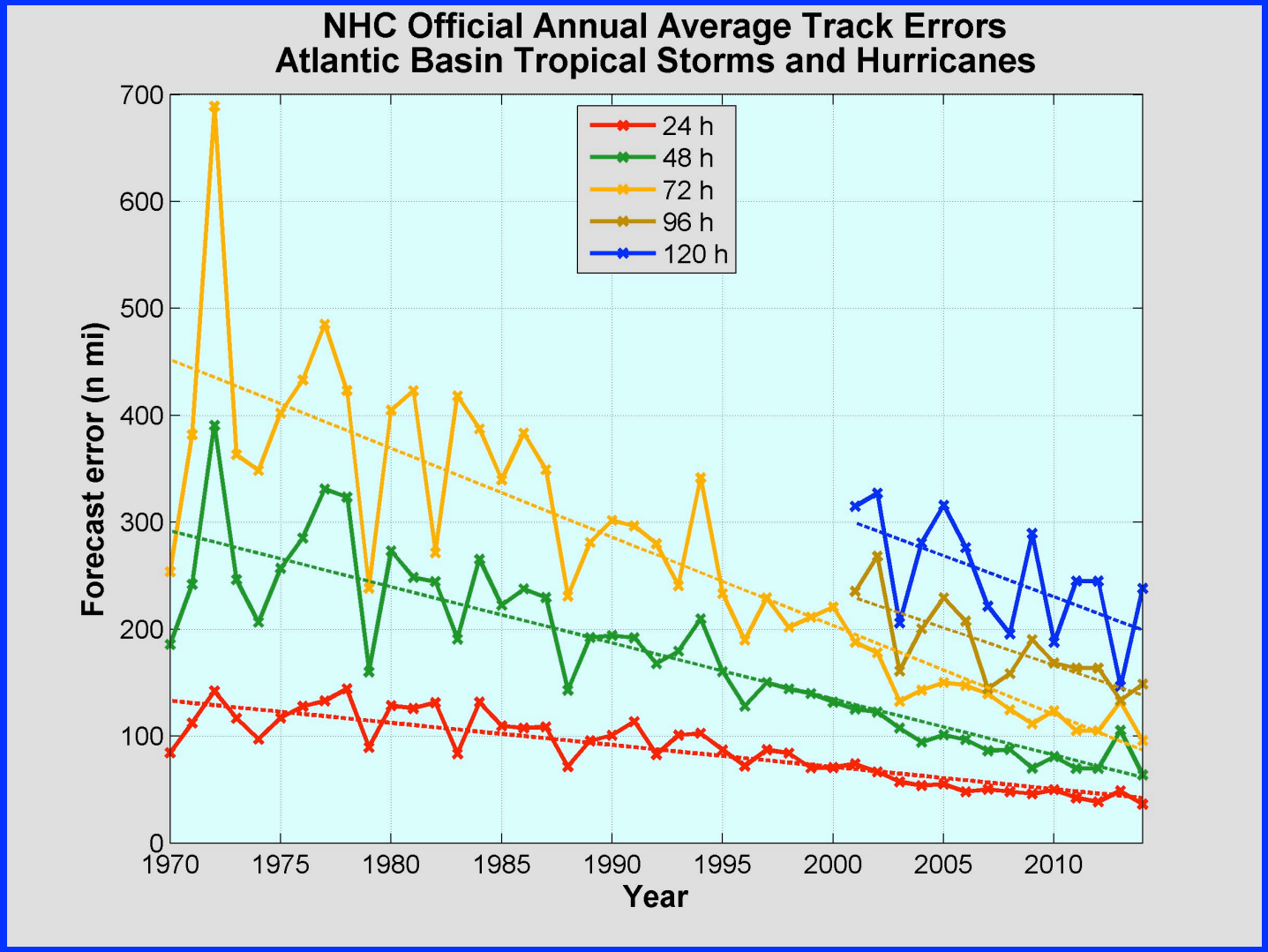
Source: Jim Brooks



Source: Metropolitan Transit Authority

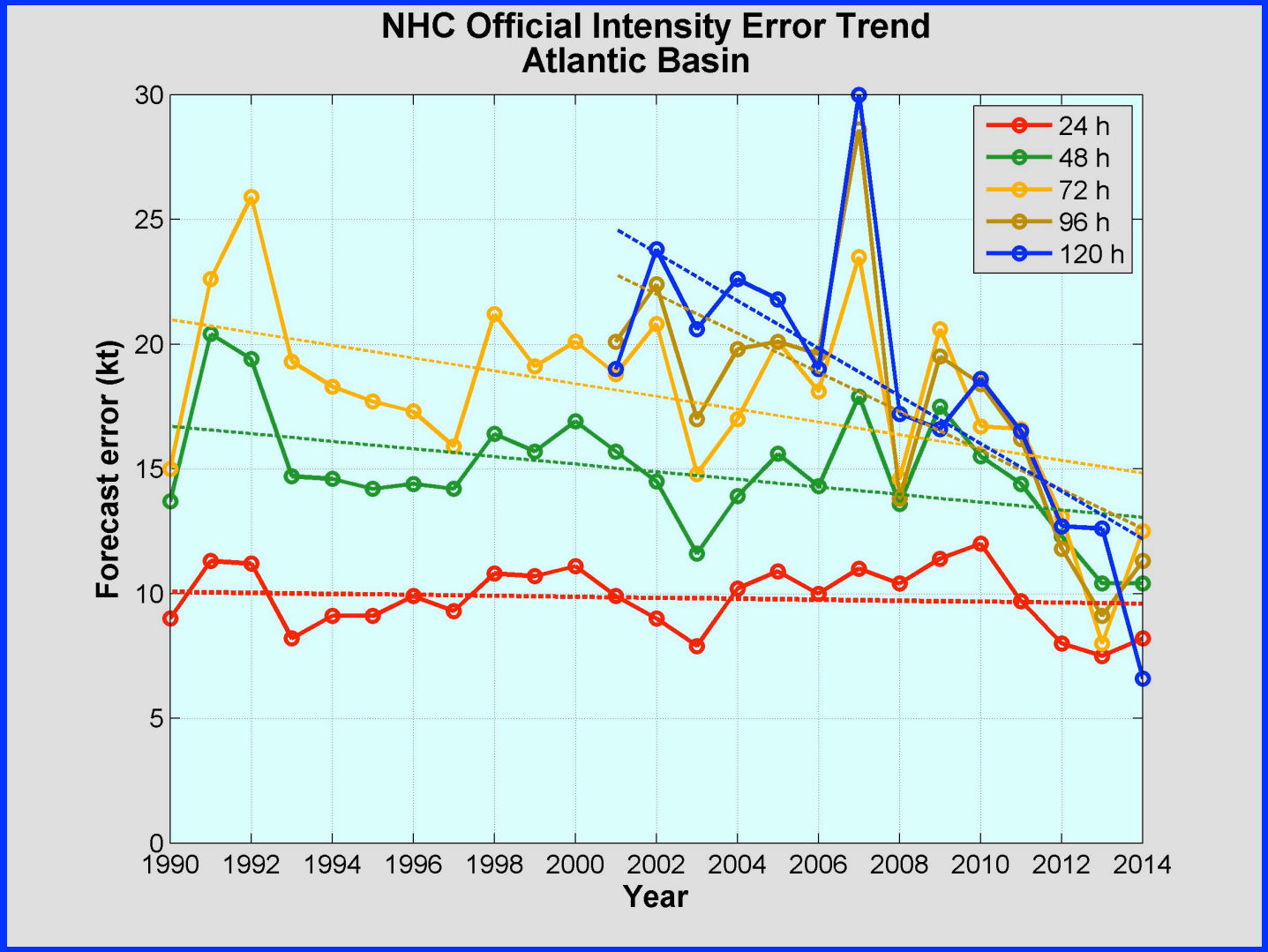
Source: AP

TC Track Errors



National Hurricane Center

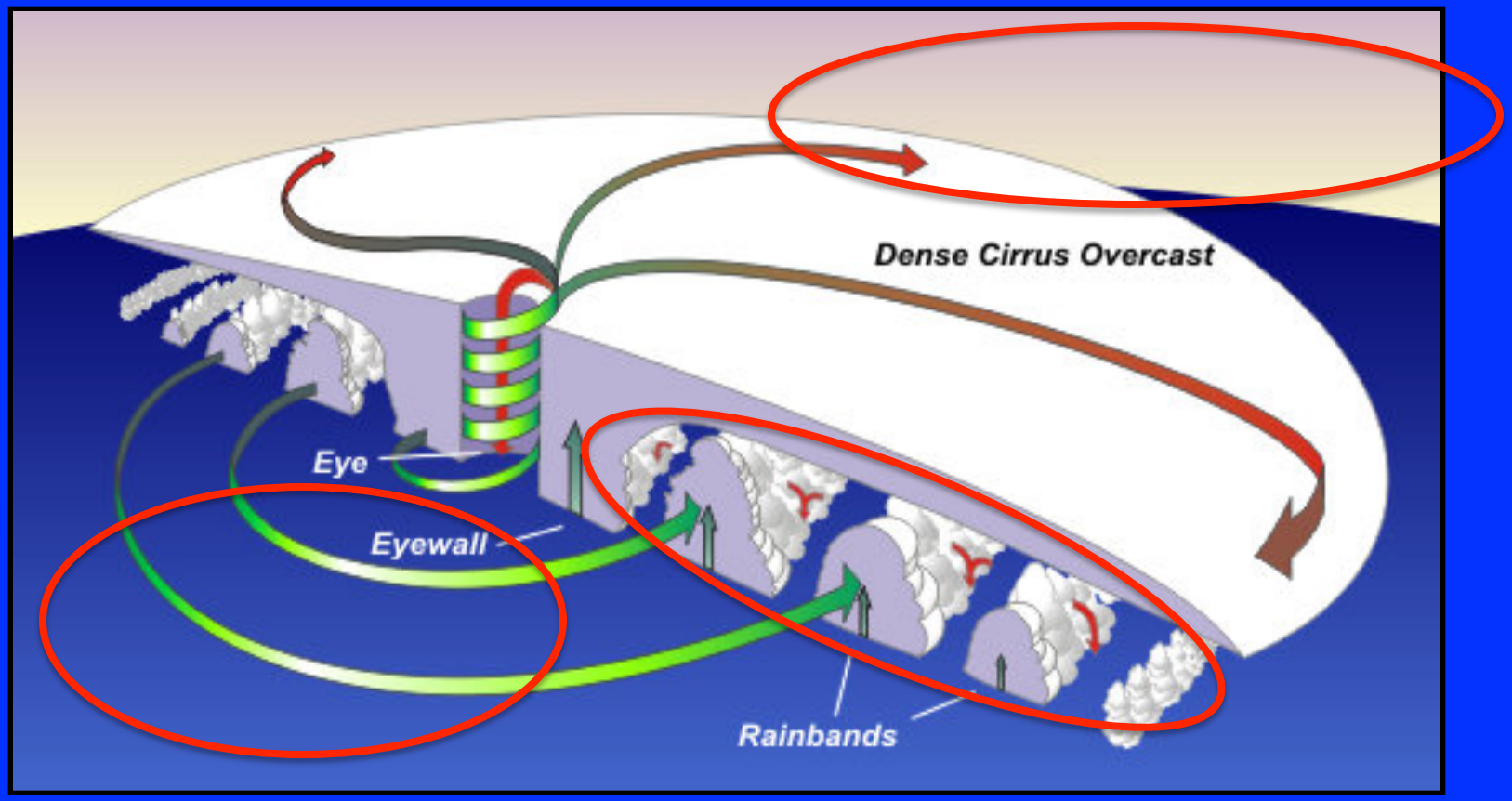
TC Intensity Errors



National Hurricane Center

Intensity Factors

TC Environment



Courtesy National Hurricane Center

Surface Boundary

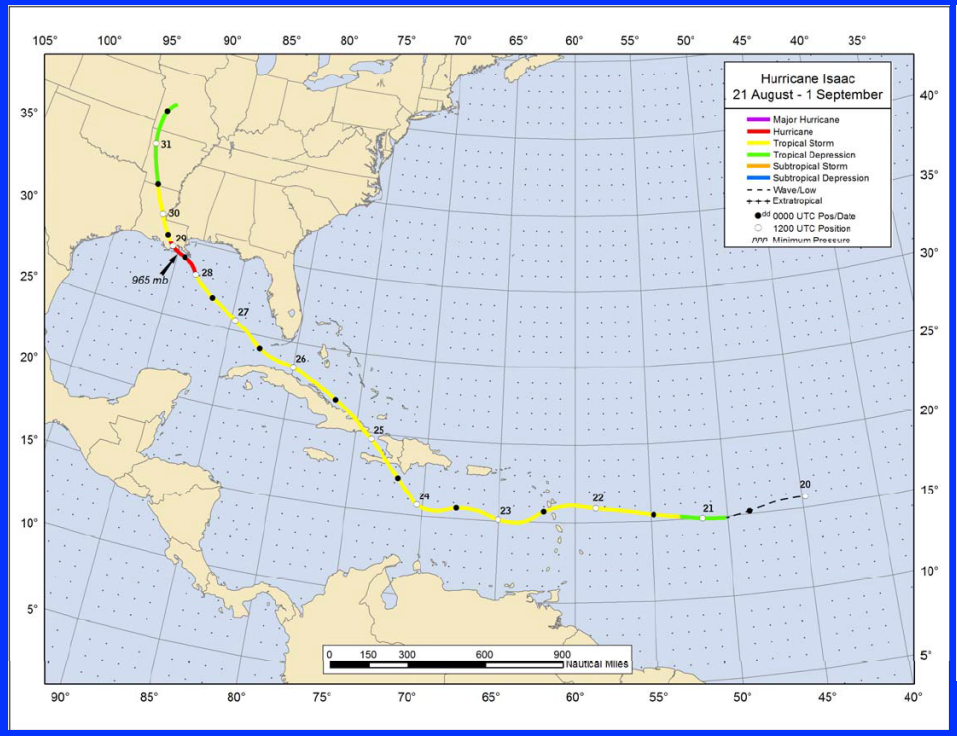
Internal Processes

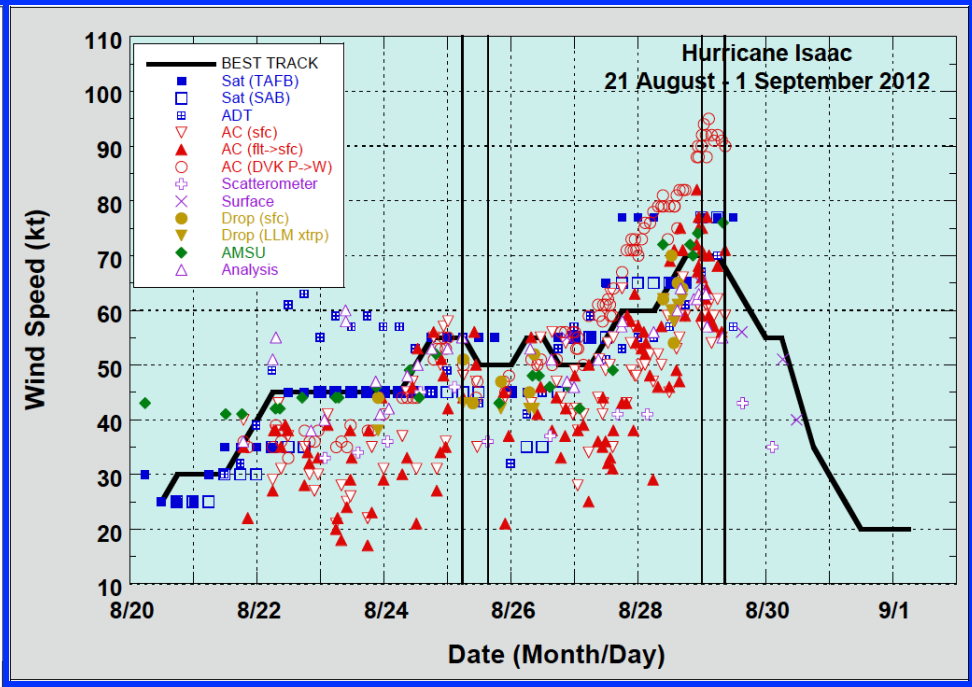
TC Observations

- One hypothesis for how to improve TC intensity forecasts is to assimilate more observations in their viscinity
- TCs have some unique datasets
  - TC “Vitals”
  - Aircraft Data
  - Satellite-derived wind vectors

TC “Vitals”

Hurricane Isaac (2012)

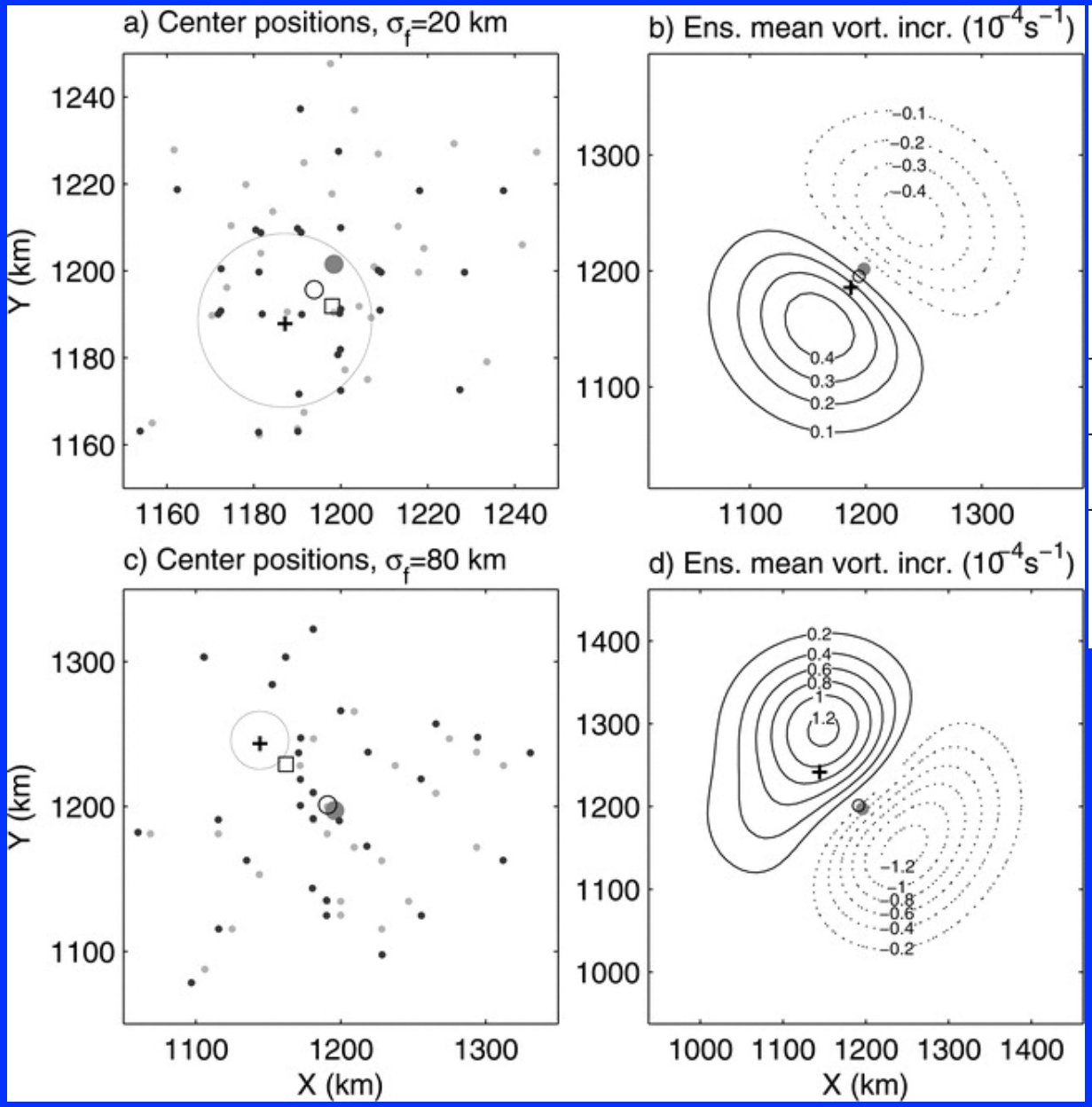


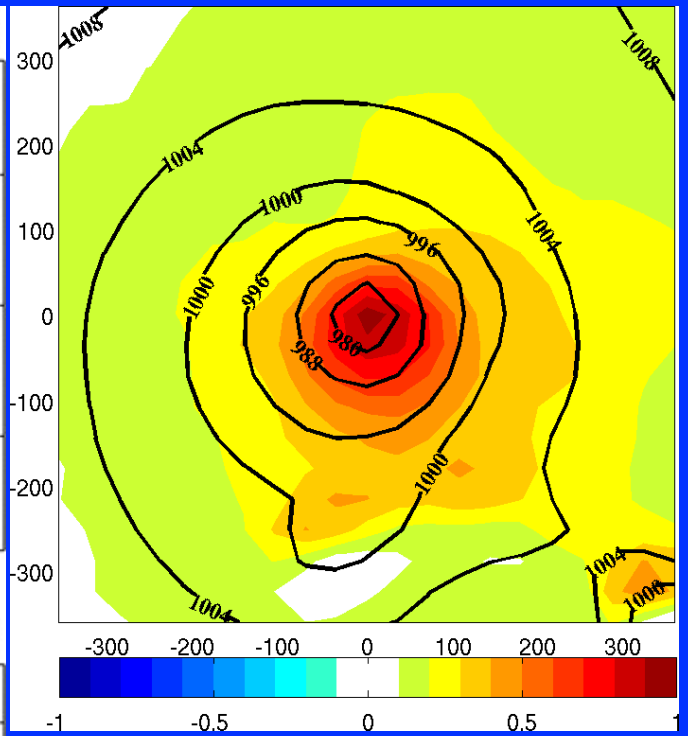


NHC 09L ISAAC 20120828 1200 278N 0882W 305 031 0976 1012 0556 31

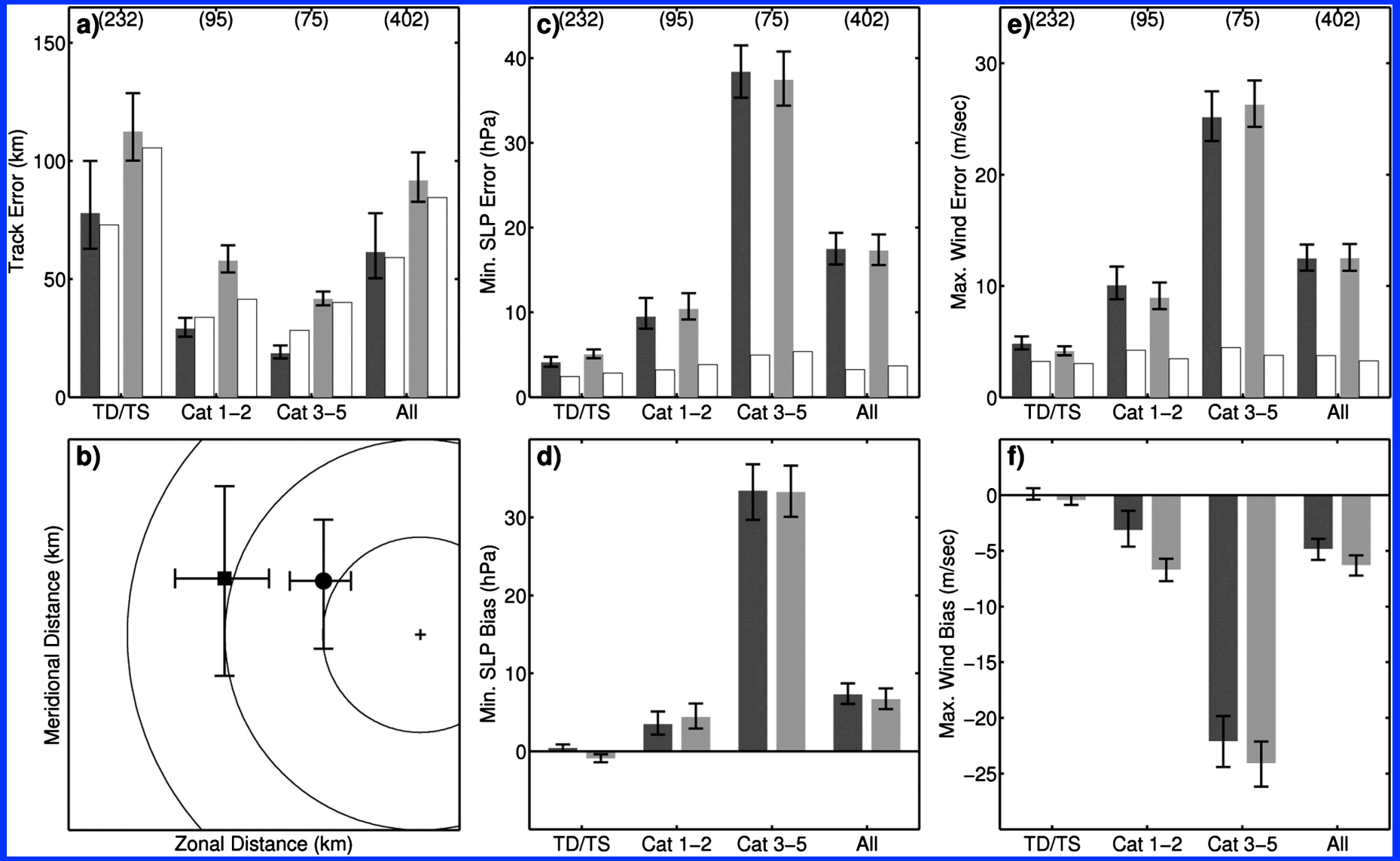
Position Assimilation

MSLP Assimilation





Chen and Snyder (2007) MWR



Torn 2010, MWR

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ZCZC MIATCMAT3 ALL
TTAA00 KNHC DDHHMM

HURRICANE SANDY FORECAST/ADVISORY NUMBER  17
NWS NATIONAL HURRICANE CENTER MIAMI FL       AL182012
1500 UTC FRI OCT 26 2012

CHANGES IN WATCHES AND WARNINGS WITH THIS ADVISORY...

THE GOVERNMENT OF THE BAHAMAS HAS DISCONTINUED THE TROPICAL STORM
WARNING FOR THE CENTRAL BAHAMAS...AND REPLACED THE HURRICANE
WARNING WITH A TROPICAL STORM WARNING FOR THE NORTHWEST BAHAMAS
EXCEPT FOR GREAT ABACO AND GRAND BAHAMA ISLANDS.

THE TROPICAL STORM WATCH FOR THE FLORIDA KEYS SOUTH OF OCEAN REEF TO
CRAIG KEY AND FOR FLORIDA BAY HAS BEEN DISCONTINUED.

HURRICANE CENTER LOCATED NEAR 26.7N  76.9W AT 26/1500Z
POSITION ACCURATE WITHIN  25 NM

PRESENT MOVEMENT TOWARD THE NORTH OR 360 DEGREES AT   5 KT
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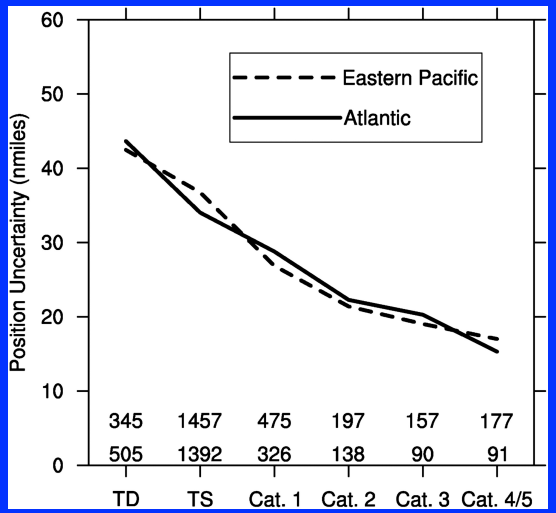
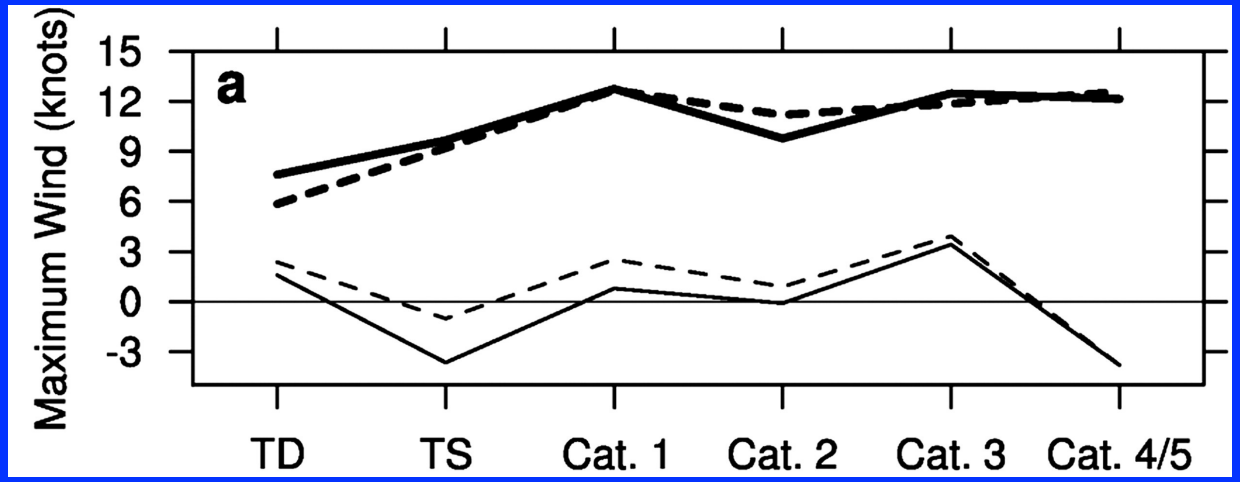




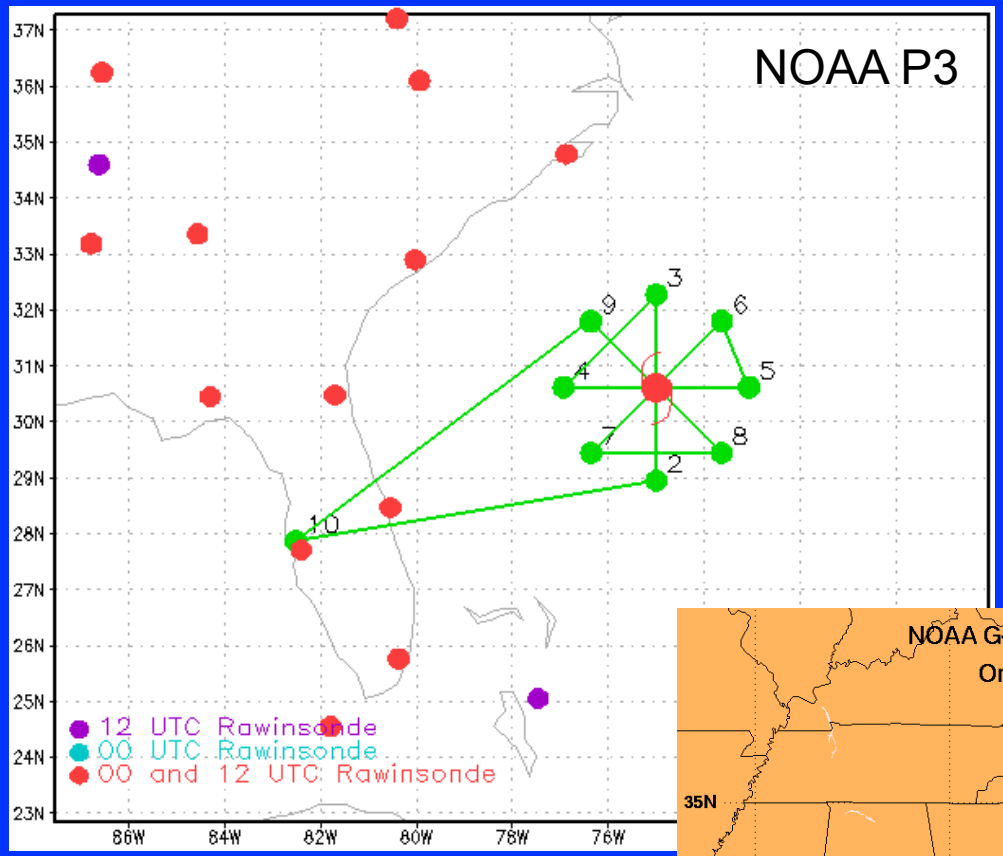
Torn and Snyder (2012), WAF

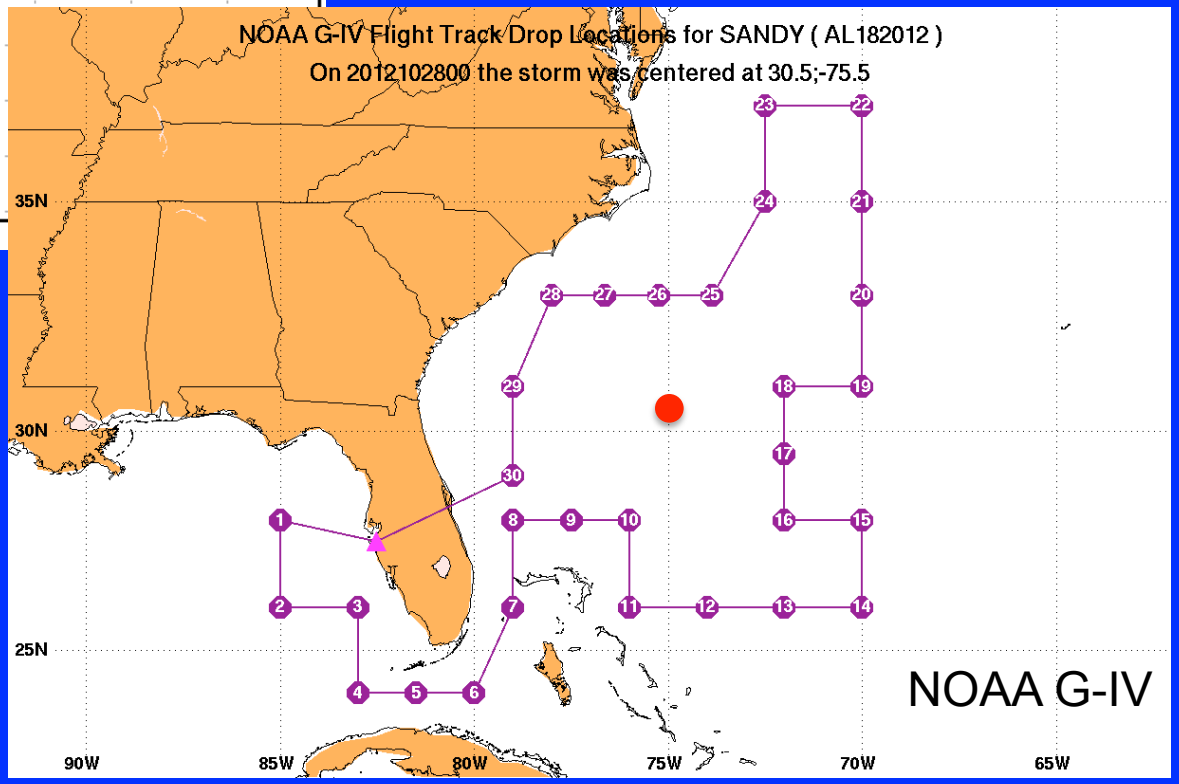
Aircraft Platforms

- Flight-level wind, temperature, moisture
- Dropsondes
- Tail-mounted Doppler Radar
- Stepped-Frequency Microwave Radiometer (SFMR; P3)

- Flight-level wind, temperature, moisture
- Dropsondes
- Stepped-Frequency Microwave Radiometer (SFMR)

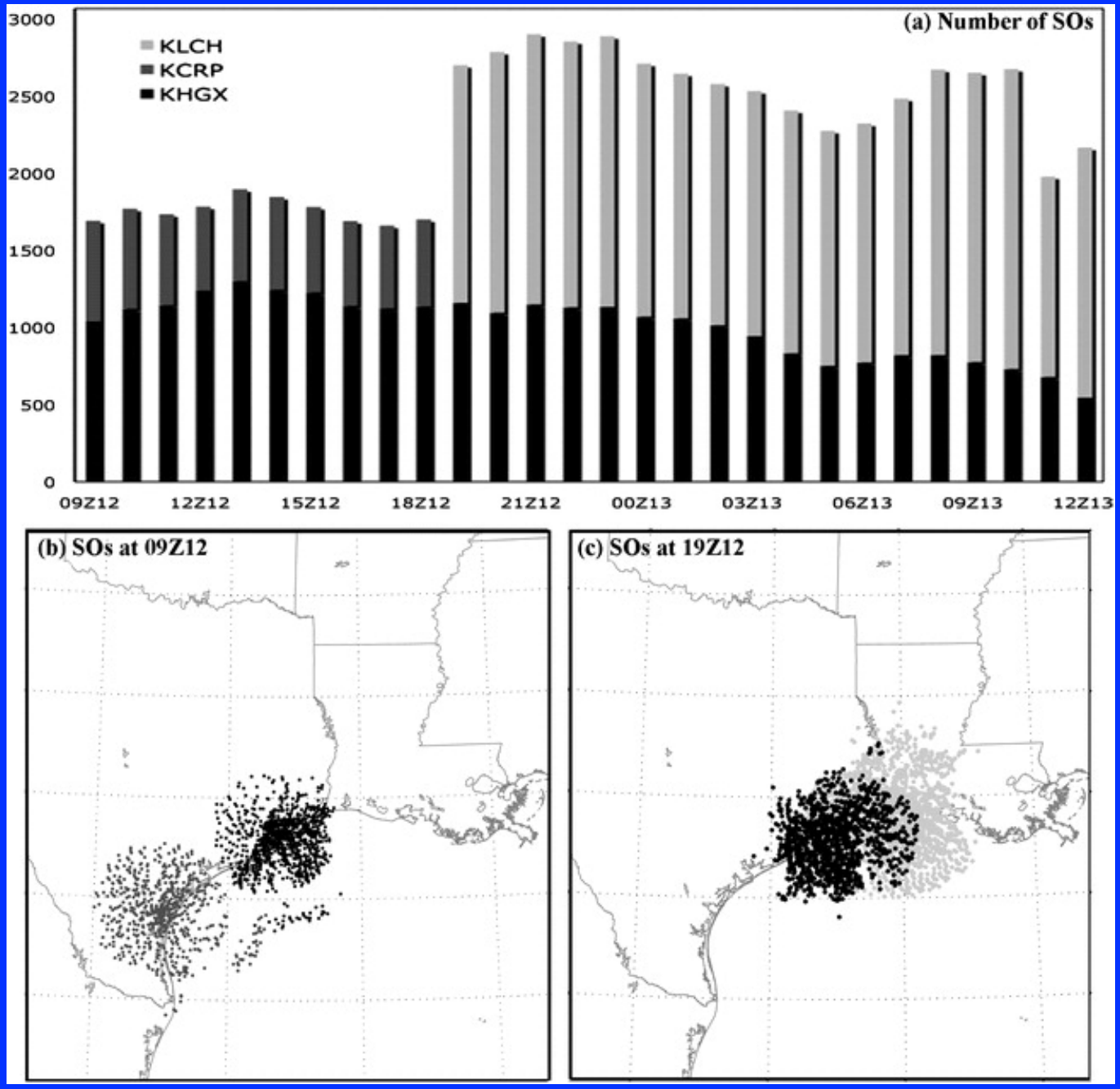
Hurricane Sandy
0000 UTC 28 October 2012



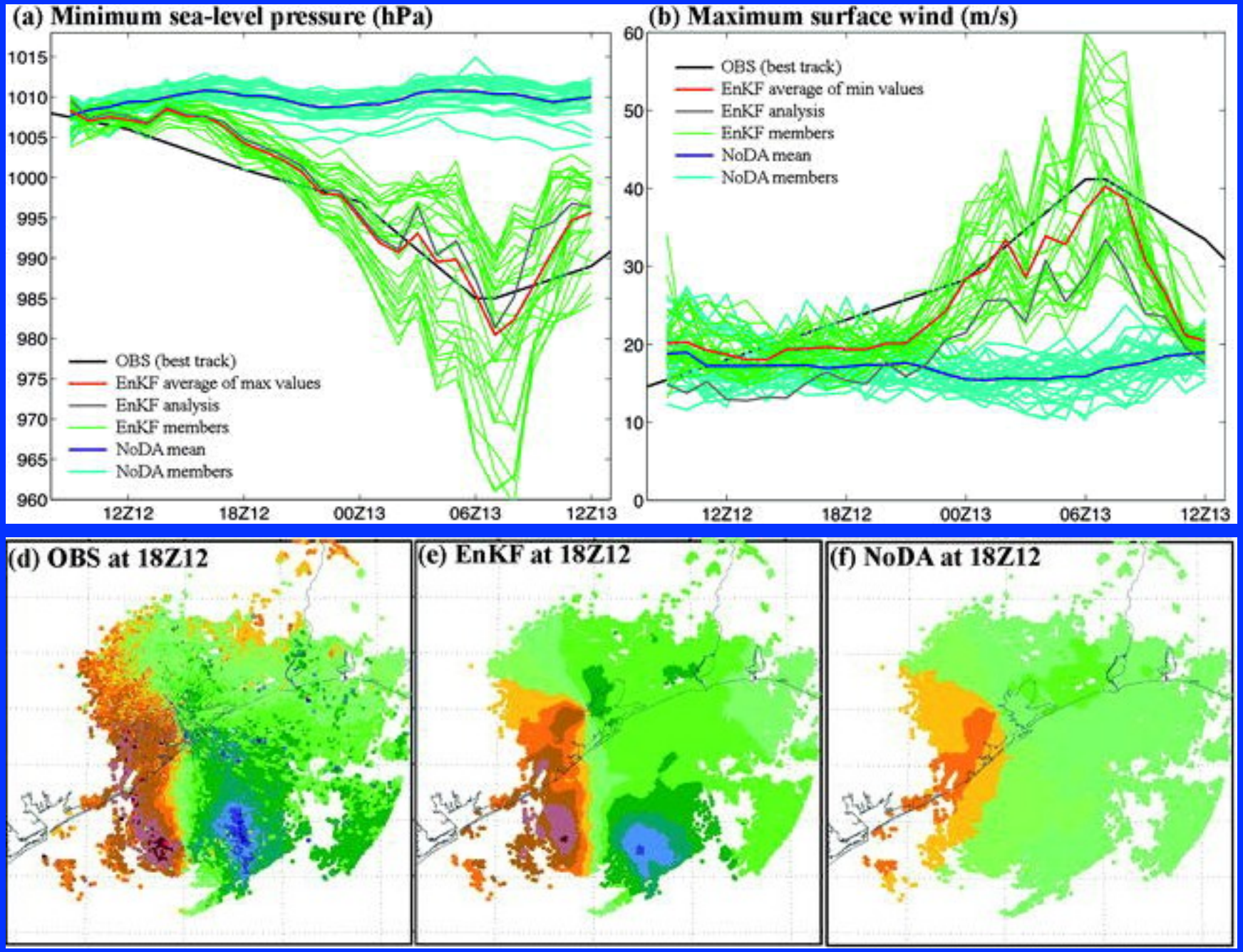


Radar Assimilation

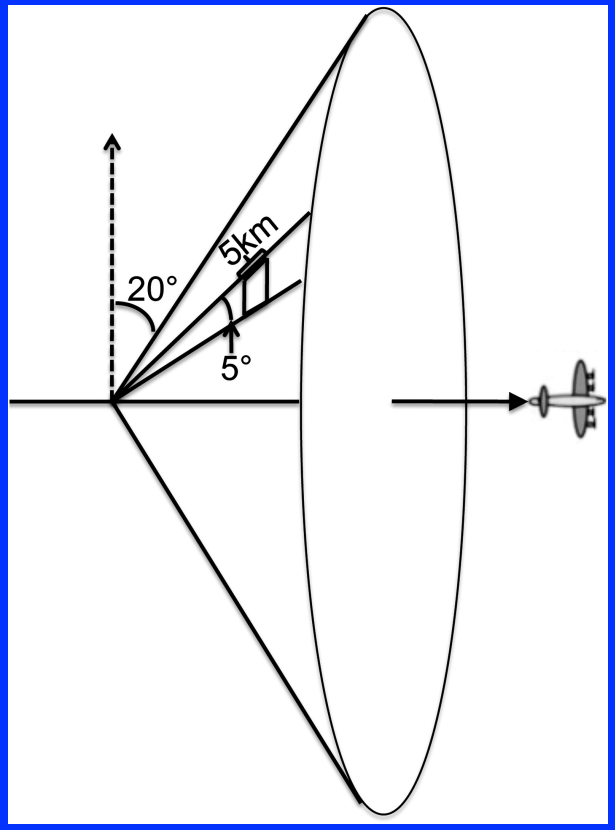
- Dropsonde and flight-level data assimilation is fairly straightforward to assimilate and is more complete
- Radar velocity assimilation considered potentially more valuable due to greater spatial coverage

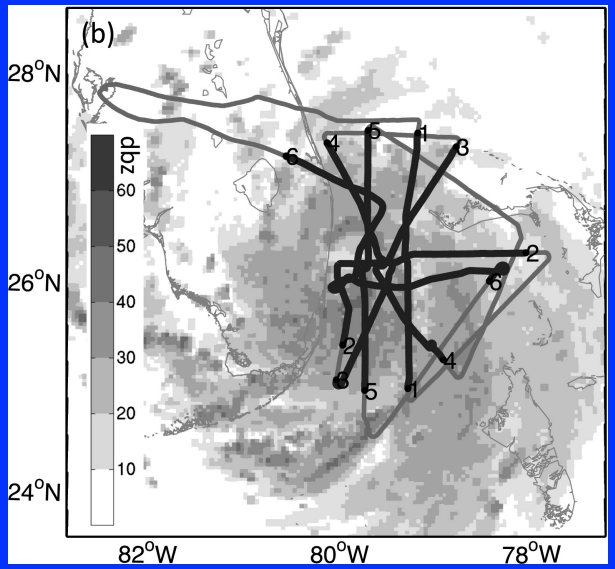


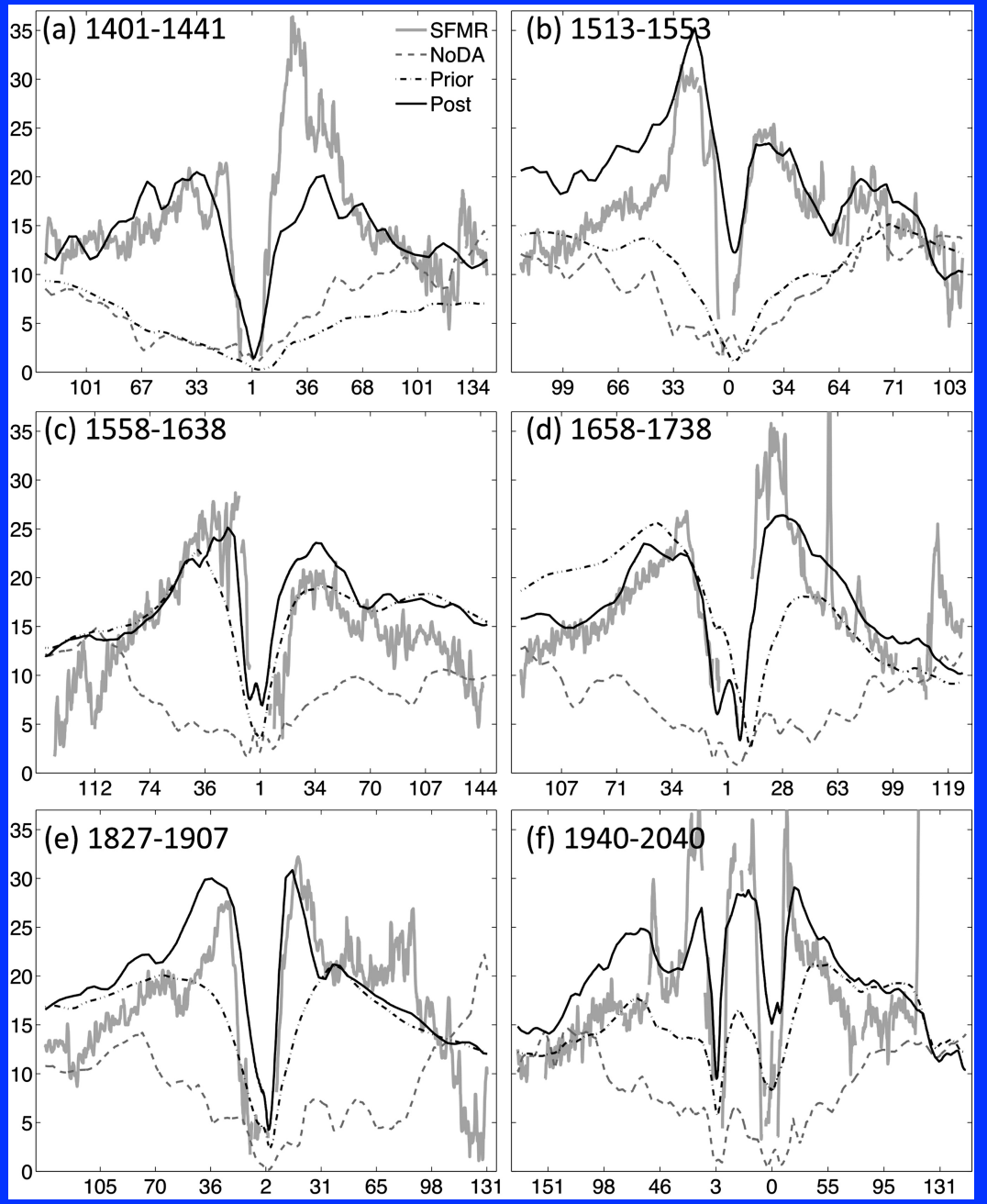
Zhang et al. (2009) MWR



Zhang et al. (2009) MWR







Wang and Zhang (2012), MWR

Comprehensive Recon. Tests

Atlantic Basin	Forecast Hour	0	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120
	HWCT-HWAR	-0.7	0	-3	-2.3	-1.8	-1.2	-1.3	-1.2	-3	-3.5	-4.3	-5.5	-5.8	-6.4	-6	-2.5	4	2.8	3	5.3	4.7
	Track	-8%	0%	-13%	-8%	-5%	-3%	-3%	-2%	-5%	-6%	-6%	-7%	-7%	-6%	-6%	-2%	3%	2%	2%	3%	2%
	Land/Water	0.803	0.018	0.99	0.899	0.693	0.465	0.465	0.445	0.817	0.8	0.819	0.88	0.919	0.892	0.768	0.36	0.504	0.318	0.3	0.429	0.321
	HWCT-HWAR	-5.3	-7.6	-5	-2.6	0.4	1.2	1.8	1.4	1.1	0.7	0.8	1	-0.1	1.1	0.2	1.1	-0.4	0.3	0	0.1	-0.1
	Intensity	-151%	-104%	-57%	-25%	3%	10%	16%	12%	9%	5%	6%	8%	-1%	8%	2%	8%	-3%	2%	0%	1%	-1%
	Land/Water	0.999	0.999	0.992	0.877	0.177	0.654	0.889	0.94	0.68	0.656	0.648	0.77	0.132	0.886	0.158	0.747	0.39	0.234	0.001	0.116	0.105
	HWCT-HWAR	-5.3	-8.2	-5.7	-3	0.8	1.6	2.1	1.8	1.3	0.4	1.3	0.5	0.2	-0.4	-1	-0.5	2	2.2	1.6	3.8	0
	Intensity	-153%	-115%	-65%	-29%	7%	13%	17%	14%	10%	3%	9%	4%	2%	-3%	-7%	-3%	12%	13%	10%	21%	0%
	Water Only	0.999	0.999	0.989	0.83	0.27	0.585	0.812	0.728	0.479	0.177	0.705	0.214	0.153	0.264	0.512	0.256	0.816				

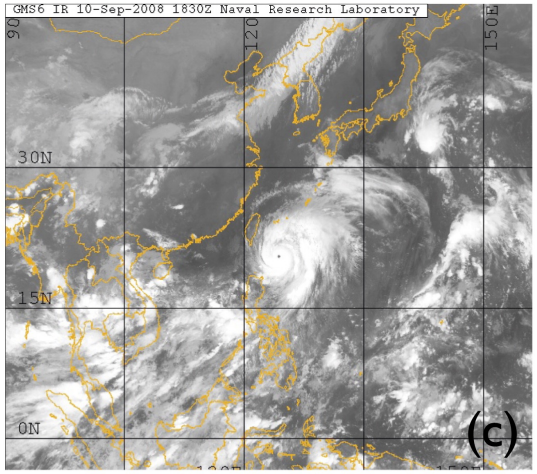
Atlantic Basin	Forecast Hour	0	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120
	APCT-APAR	8.3	5.7	5.2	7.9	7.7	8.4	8.4	8.6	13.3	15.7	21.1	24.9	30.8	29.5	14.1	17.8	8.8	9.9	13	21.3	32.8
	Track	33%	19%	15%	20%	17%	16%	15%	13%	17%	18%	21%	22%	24%	22%	12%	14%	8%	8%	9%	12%	16%
	Land/Water	0.999	0.985	0.98	0.999	0.998	0.982	0.921	0.82	0.863	0.917	0.893	0.758	0.482	0.548	0.923	0.867	0.79	0.773	0.805	0.934	0.967
	APCT-APAR	-2.4	-1.2	-0.5	0.3	0.7	1.6	1.5	0.7	1.8	1.7	1.5	1.4	0	0.2	0.6	-0.1	-1.1	0	-1	-0.8	-1
	Intensity	-23%	-12%	-5%	3%	6%	14%	12%	5%	14%	14%	12%	11%	0%	2%	5%	-1%	-10%	0%	-9%	-7%	-8%
	Land/Water	0.982	0.631	0.331	0.183	0.414	0.822	0.752	0.378	0.859	0.878	0.967	0.889	0.008	0.164	0.555	0.059	0.762	0.02	0.713	0.436	0.342
	APCT-APAR	-2.4	-1.5	-0.7	0.4	1	2.5	3.2	1.2	2.8	2	1.1	0.7	-0.9	-0.7	1	0	-0.6	-2.1	-1.2	0.8	-5.2
	Intensity	-23%	-15%	-6%	3%	8%	19%	23%	9%	21%	15%	9%	6%	-7%	-5%	7%	0%	-4%	-22%	-16%	9%	-62%
	Water Only	0.982	0.7	0.356	0.171	0.419	0.856	0.901	0.498	0.788	0.912	0.731	0.314	0.561	0.386	0.642	0.001					

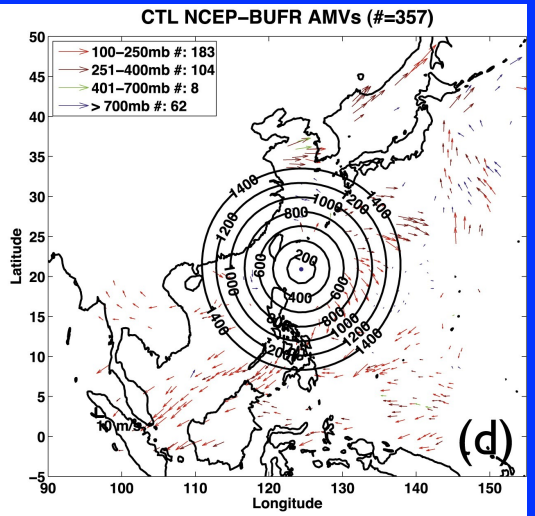
Atlantic Basin	Forecast Hour	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120
	HECT-HEAR	12.1	9.1	9.4	7.9	9.6	4.6	0.1	0.7	5.5	6.1	3.6	4	6.5	1.6	4.3	9.9	12.7	7.3	1.1	4
	Track	37%	21%	19%	14%	15%	7%	0%	1%	6%	6%	3%	3%	4%	1%	2%	5%	6%	3%	0%	2%
	Land/Water	0.991	0.99	0.996	0.968	0.98	0.73	0.018	0.173	0.89	0.89	0.635	0.664	0.807	0.234	0.558	0.881	0.923	0.735	0.119	
	HECT-HEAR	7	4.1	4.7	2.9	2.3	1.4	0.2	1.8	-0.4	0.4	-0.9	-0.3	-0.1	-1.7	-4.4	-2.6	-1.6	-0.1	1.8	-4.2
	Intensity	38%	24%	30%	20%	16%	9%	1%	12%	-3%	3%	-6%	-2%	-1%	-12%	-30%	-14%	-8%	0%	8%	-17%
	Land/Water	0.999	0.999	0.996	0.992	0.972	0.667	0.131	0.871	0.244	0.252	0.531	0.166	0.071	0.49	0.8	0.707	0.431	0.035	0.356	
	HECT-HEAR	7.1	4.6	5.4	3.2	2.6	1.6	-0.2	2.2	-0.8	0.9	-1.8	-2.4	-2.8	-5.9	-9.8	-8.8	-5.4	-3.9	-1.2	-2.6
	Intensity	38%	27%	32%	21%	17%	10%	-1%	13%	-4%	4%	-10%	-14%	-17%	-38%	-63%	-55%	-29%	-20%	-5%	-10%
	Water Only	0.999	0.999	0.996	0.987	0.953	0.466	0.1	0.776	0.253	0.289	0.546	0.65	0.796	0.932						

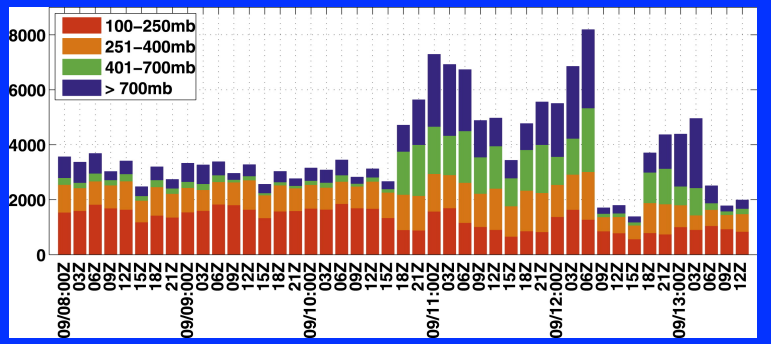
Nance et al. (2013) Report

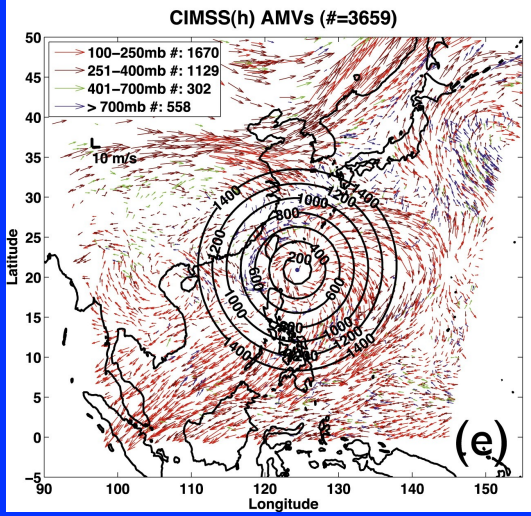
- 101 cases over 5 different seasons
- 3 Different groups, two different models
  - NCEP Environmental Modeling Center (HW*)
  - Penn State University (AP*)
  - NOAA Hurricane Research Division (HE*)

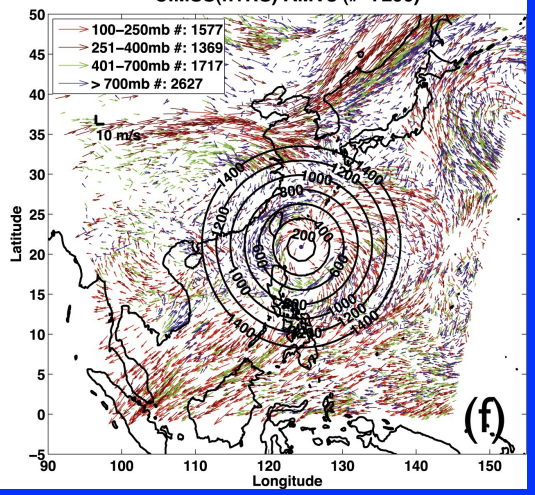
Atmospheric Motion Vectors

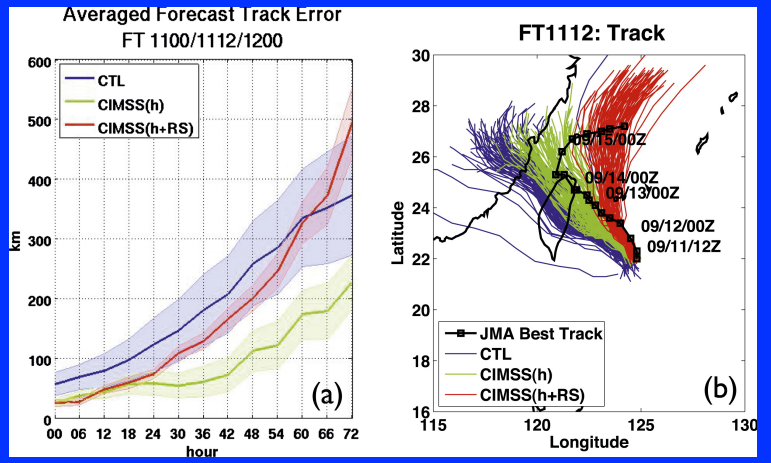










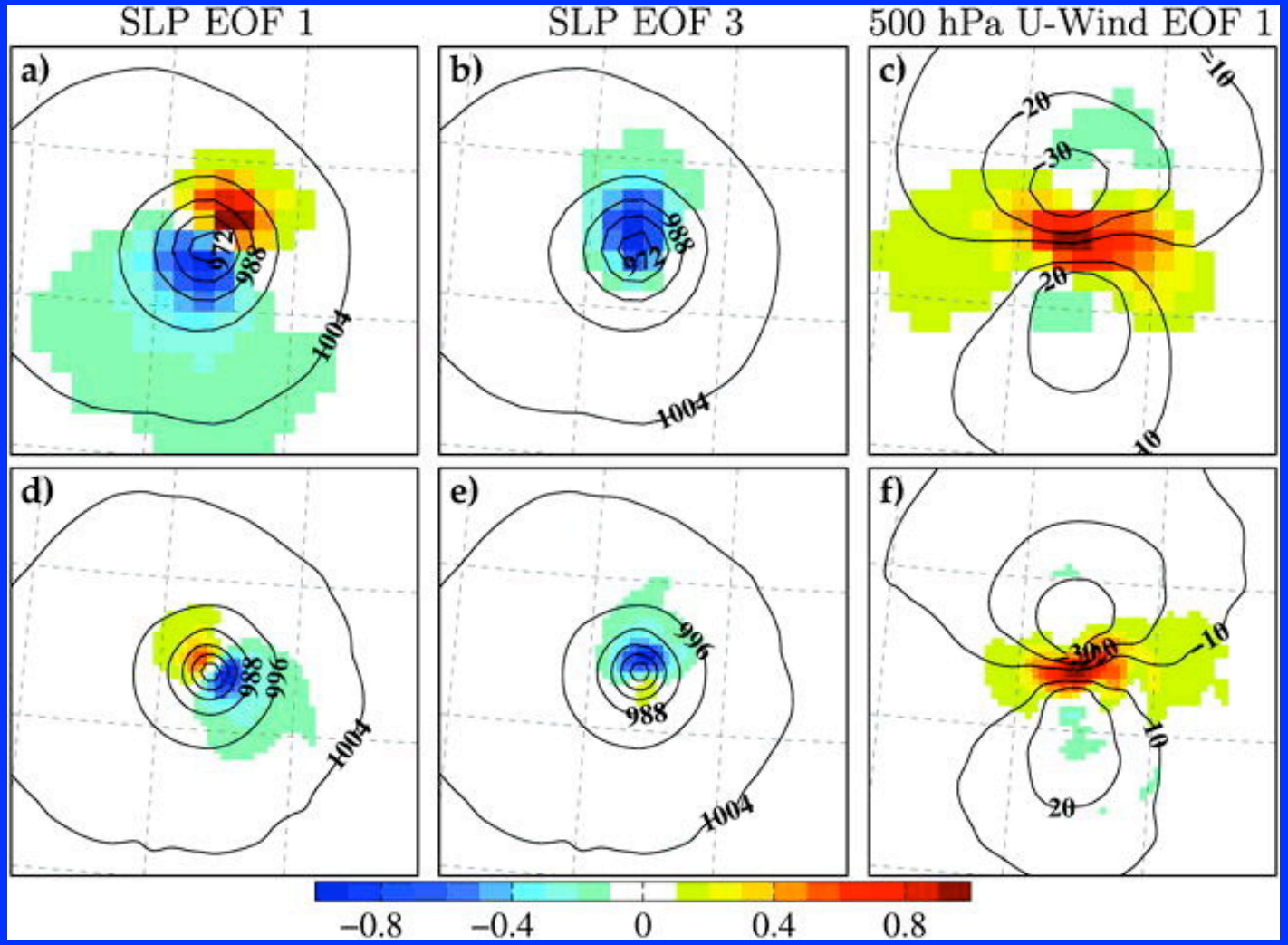


Wu et al. (2014), MWR

Challenges

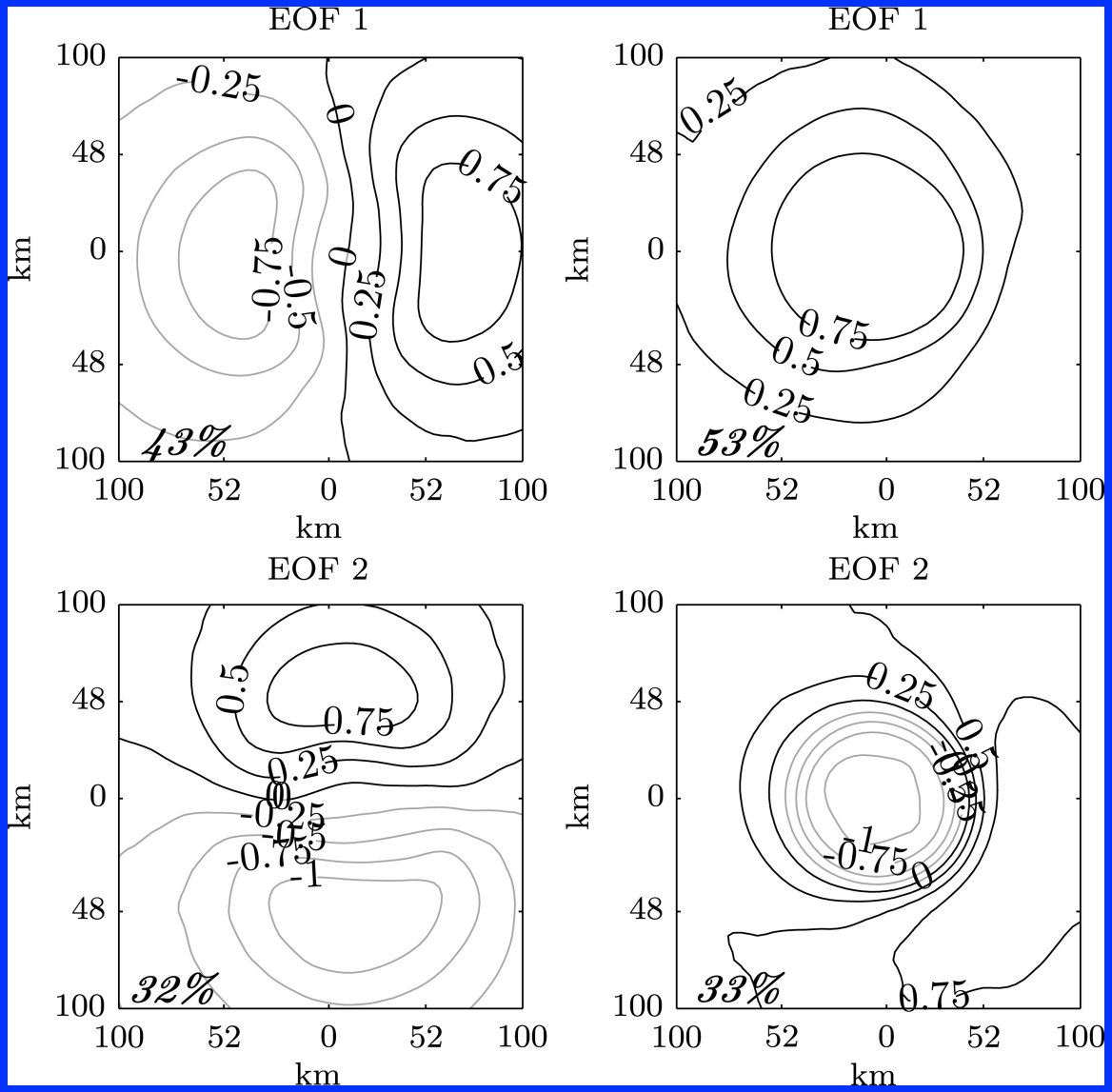
- TC data assimilation has a number of challenges, some of which are unique to the application
  - Modes of variability
  - Impact of sampling errors
  - Representativeness
  - Variable observation densities
  - Model biases
  - Domain sizes

Tropical Cyclone Variability



Torn & Hakim (2009), MWR

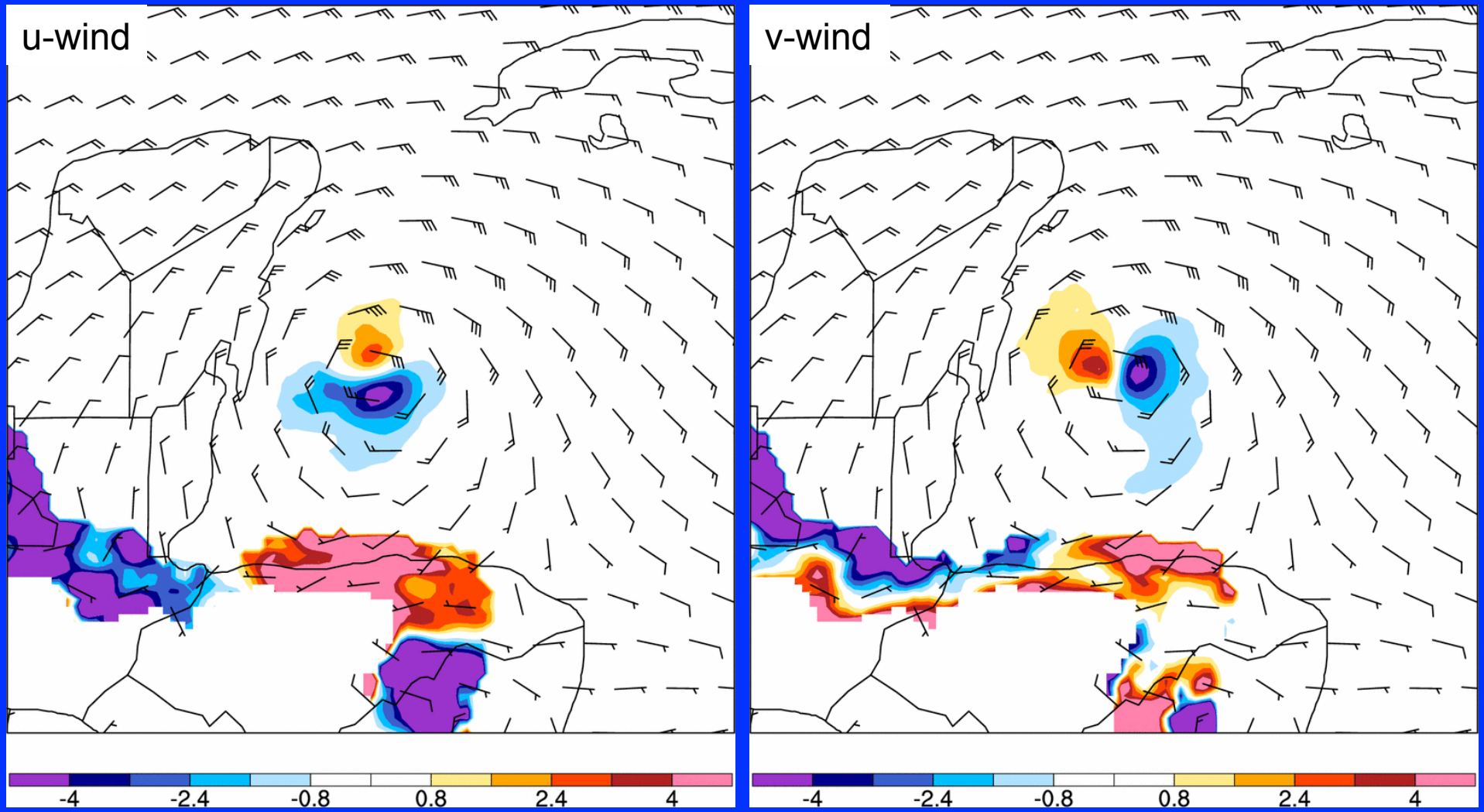
Tropical Cyclone Variability



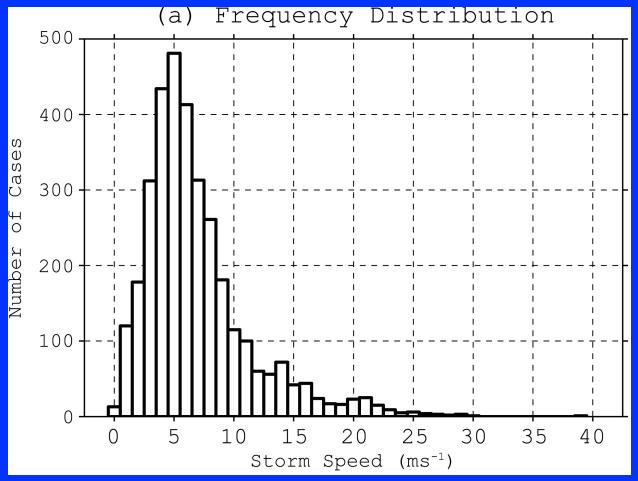
Navarro & Hakim (2013) QJRMS

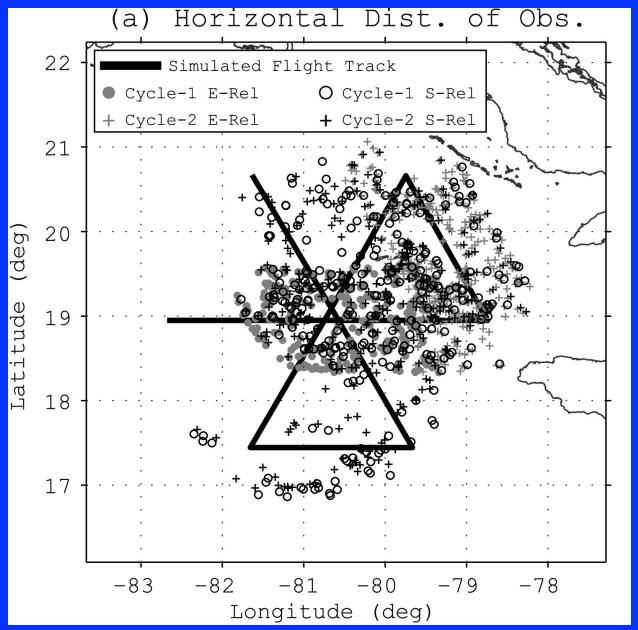
Storm-centered Assimilation

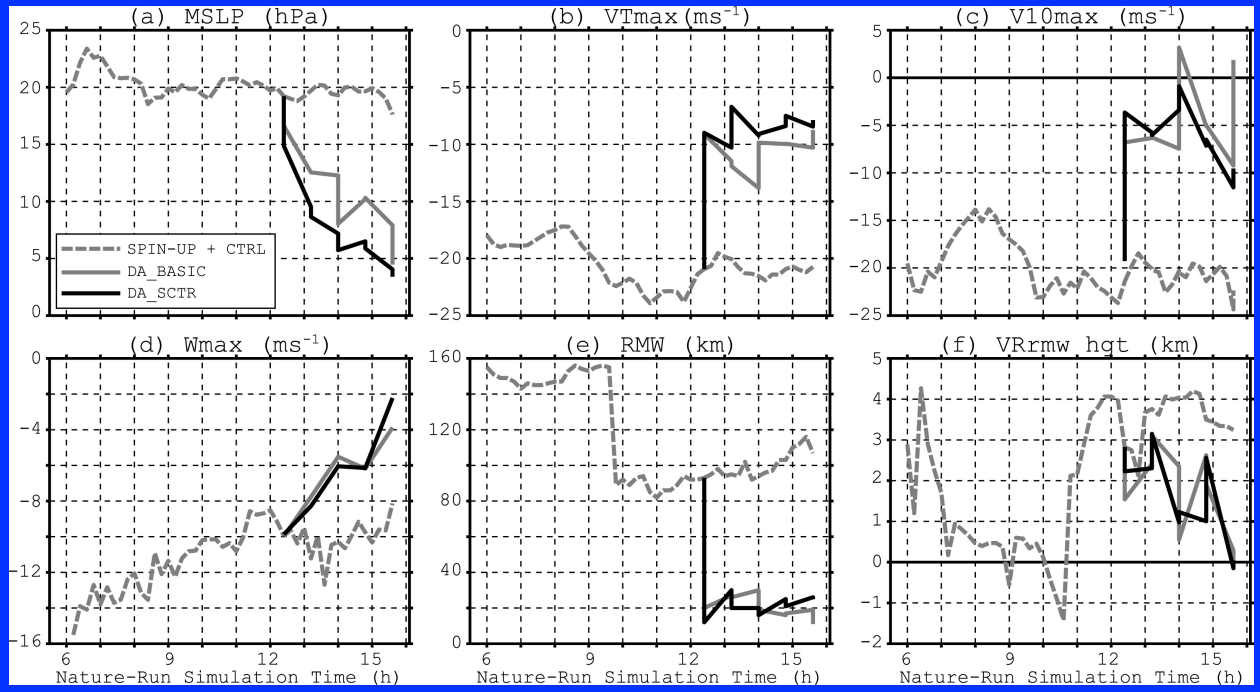
Regression Between TC sea-level pressure and 950 hPa wind



Storm-relative Obs.







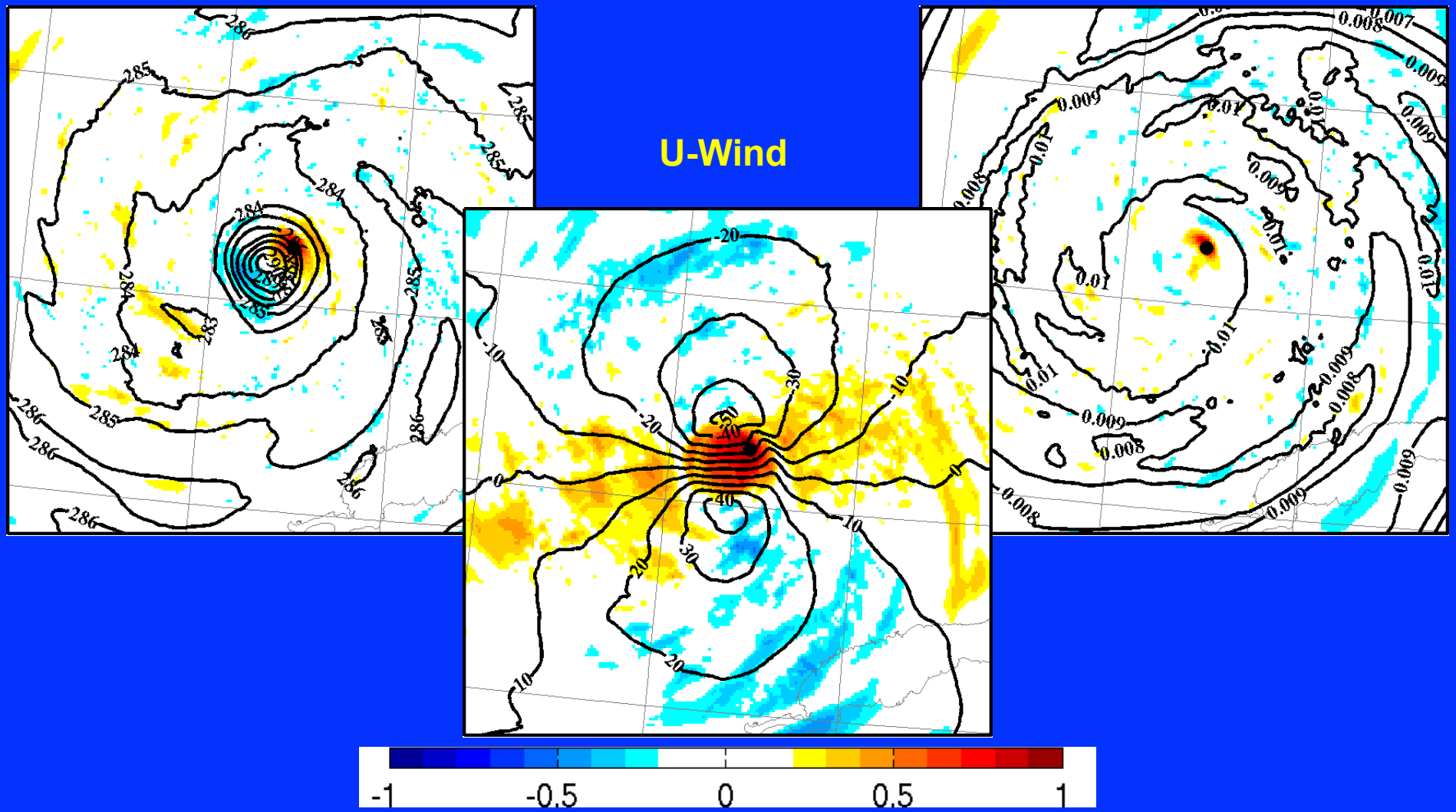
Aksoy (2013) MWR

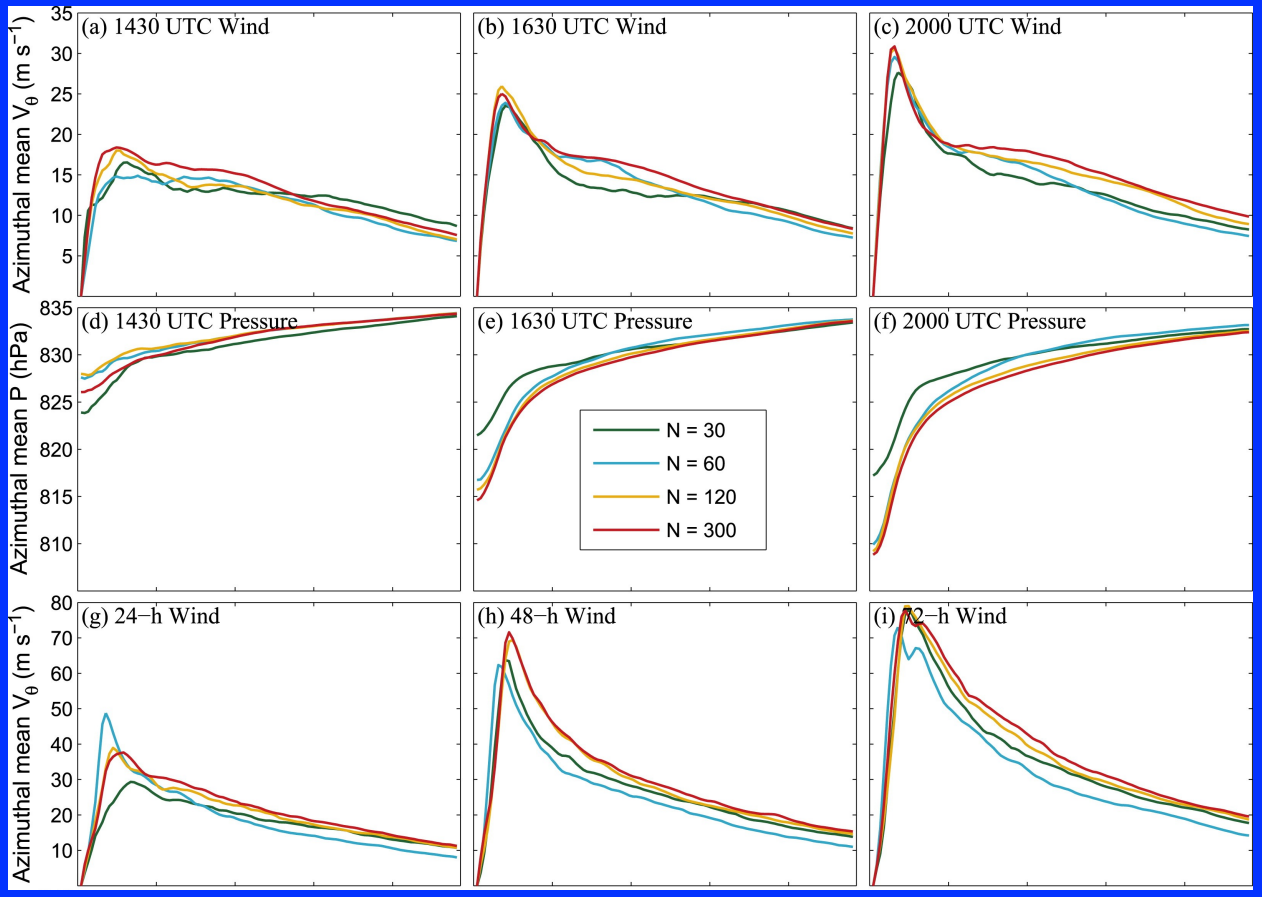
Covariances

Temperature

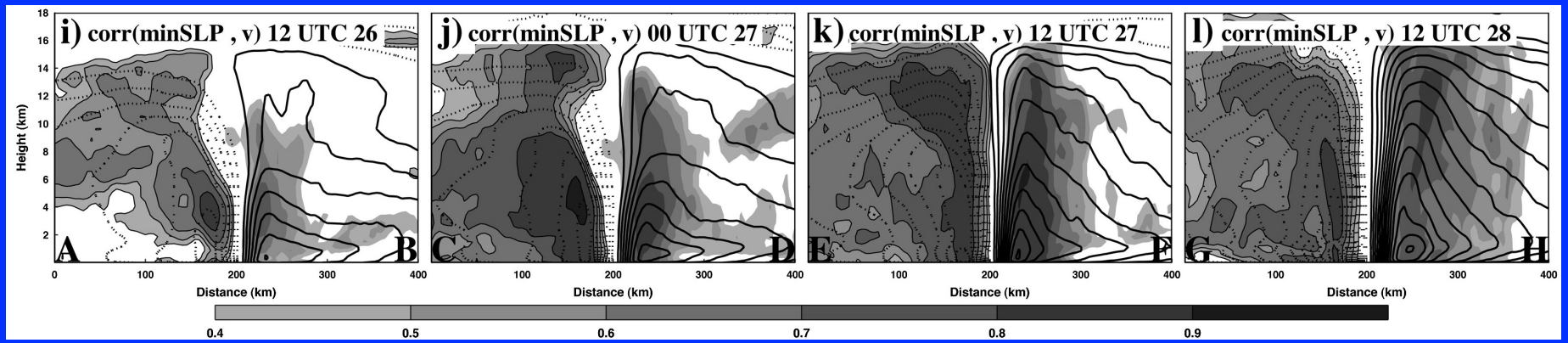
U-Wind

Mixing Ratio



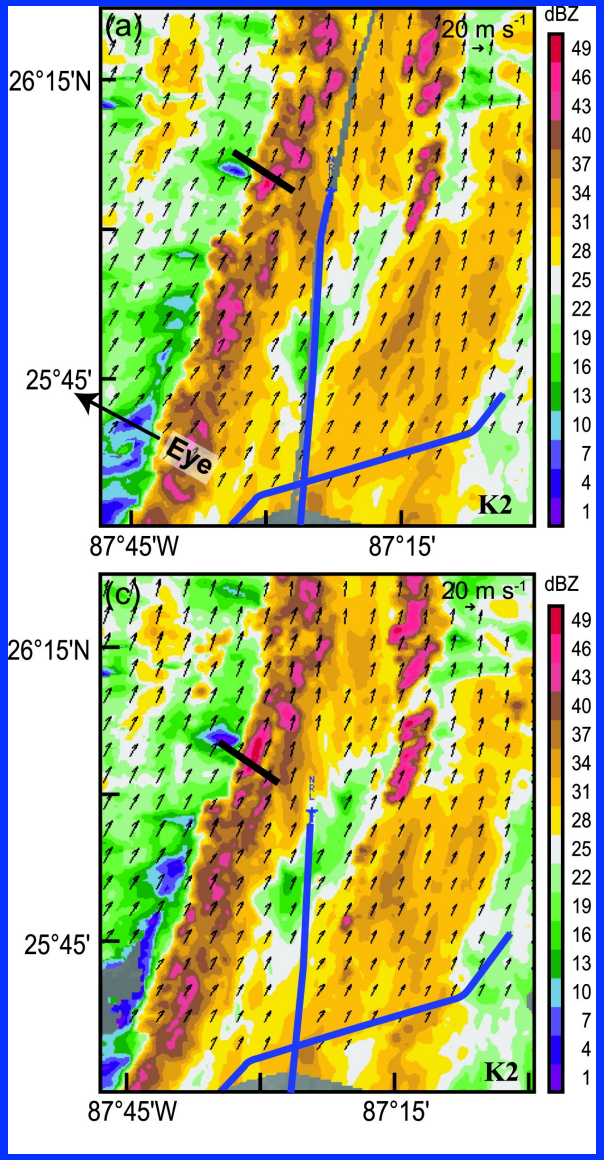


Poterjoy et al. (2014), MWR

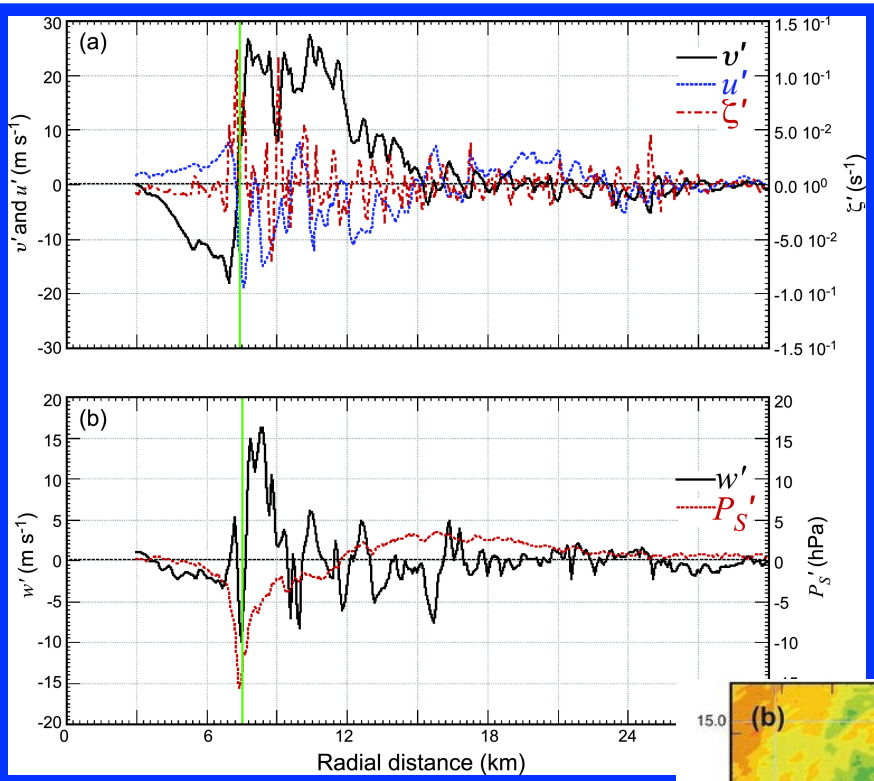


Poterjoy and Zhang (2011), MWR

Representativeness

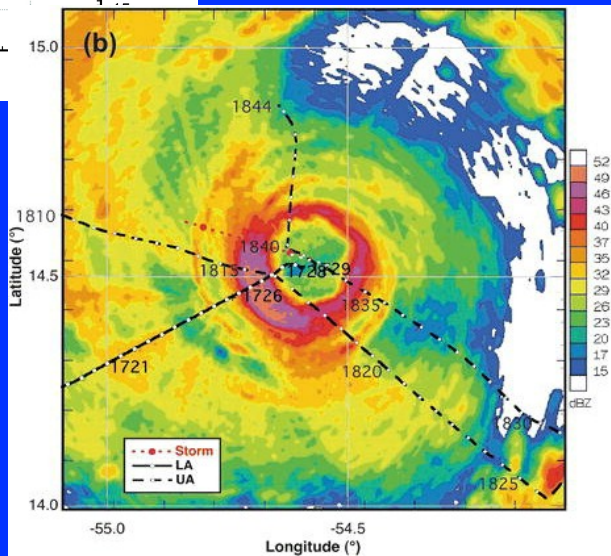


Hence & Houze (2008), MWR

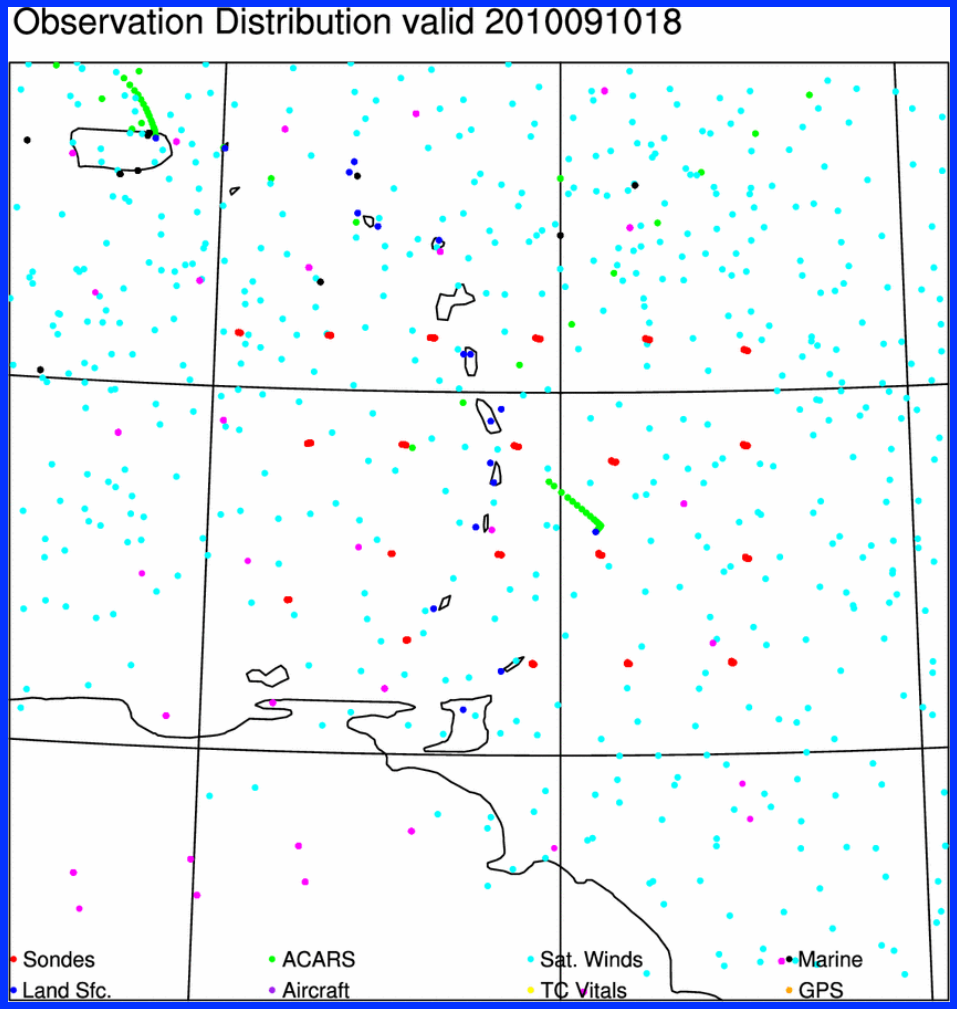


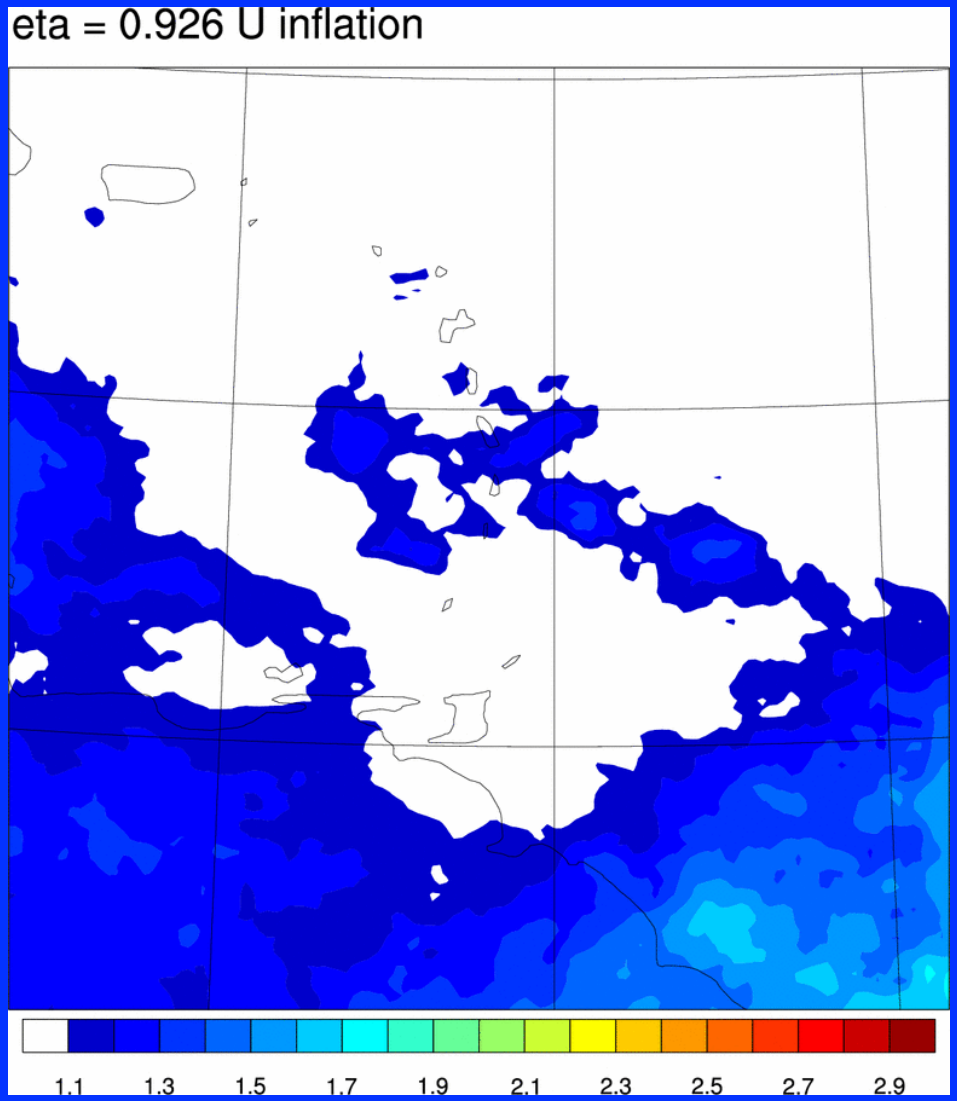
Hurricane Hugo (1989)

Marks et al. (2008)



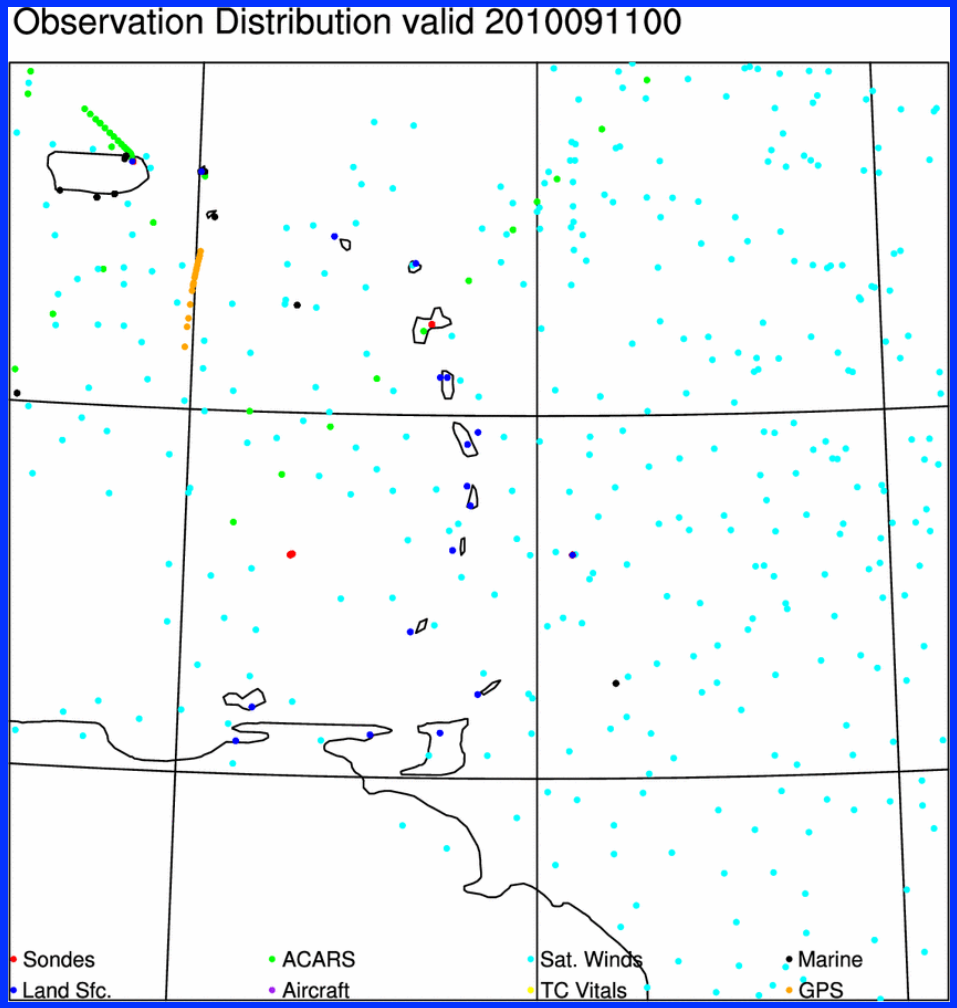
Observation Variability

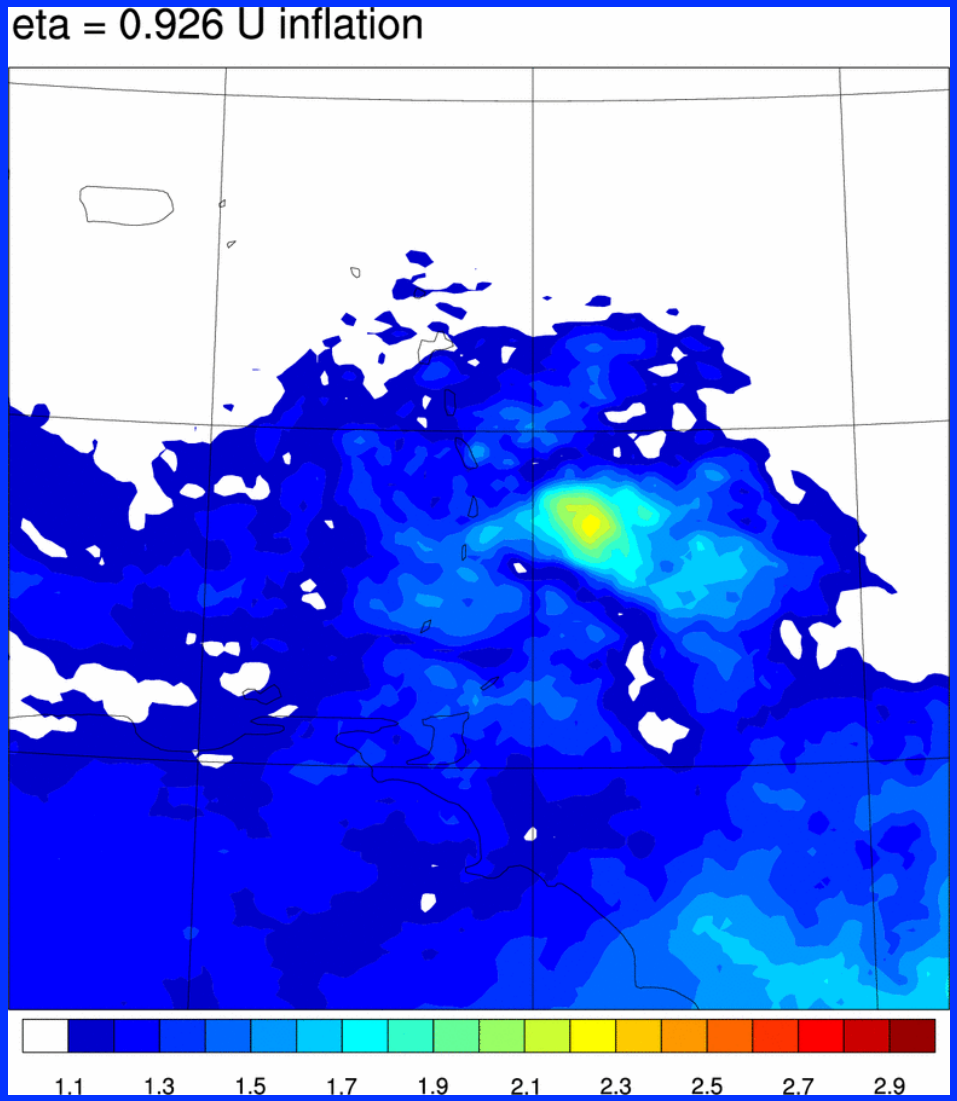




1800 UTC 10 September 2010

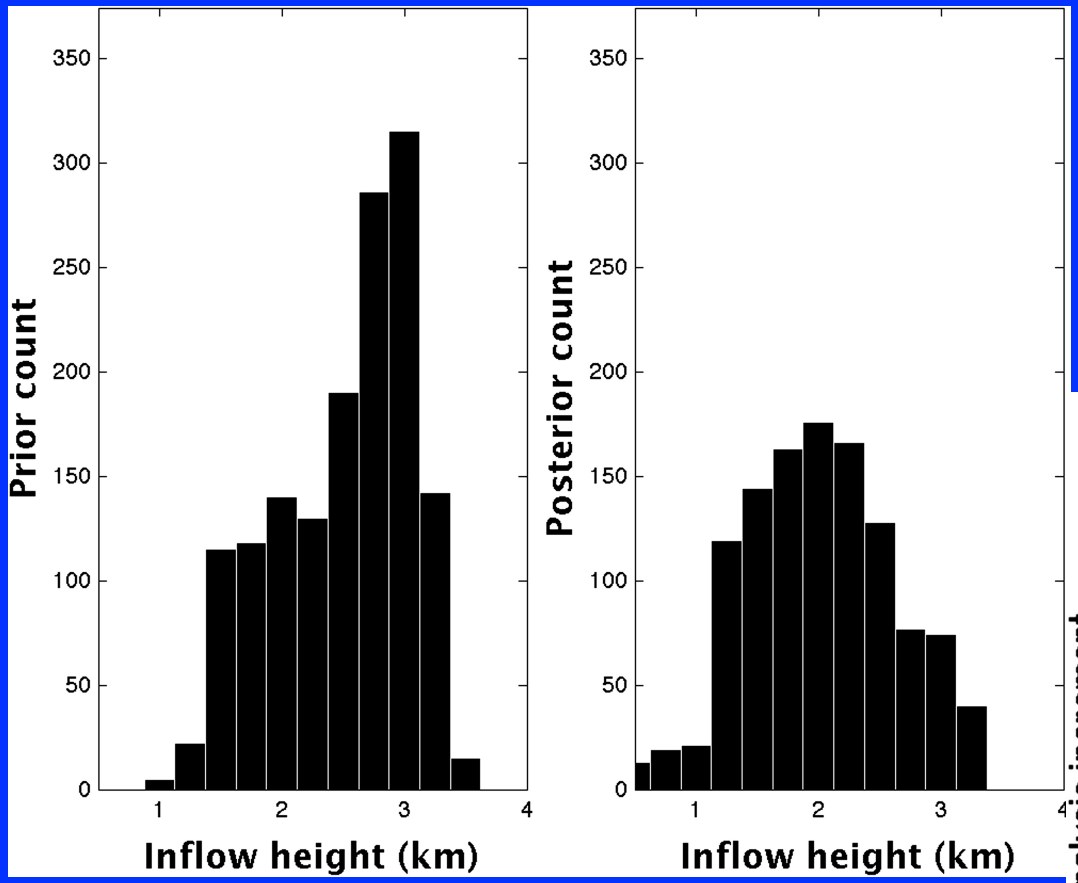
Observation Variability

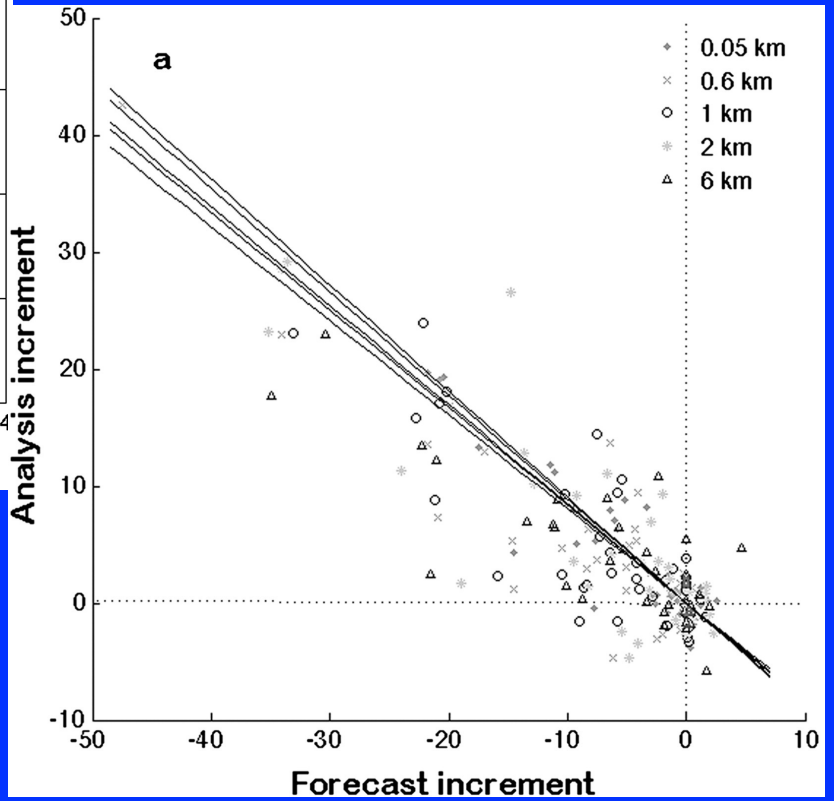




0000 UTC 11 September 2010

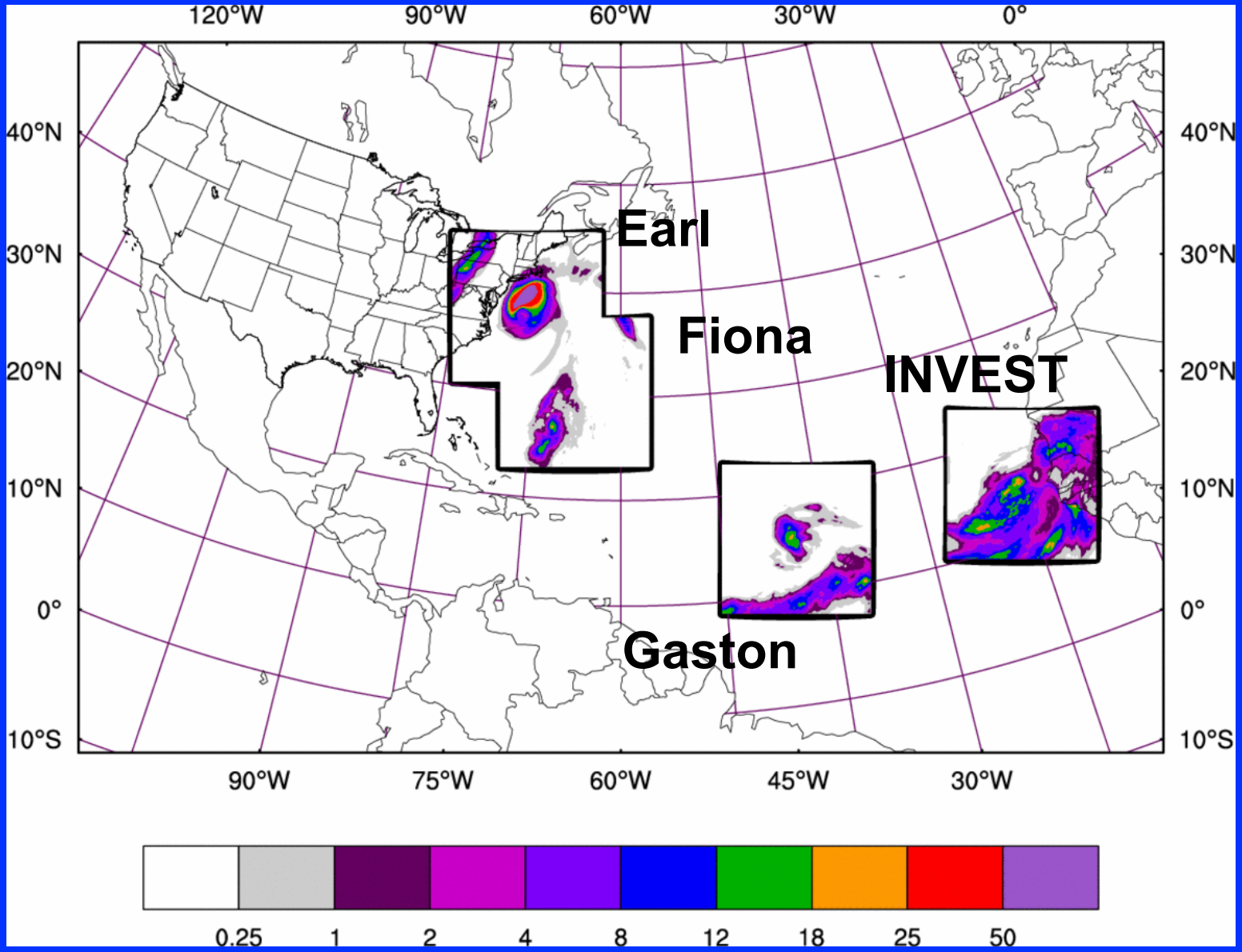
Model Biases



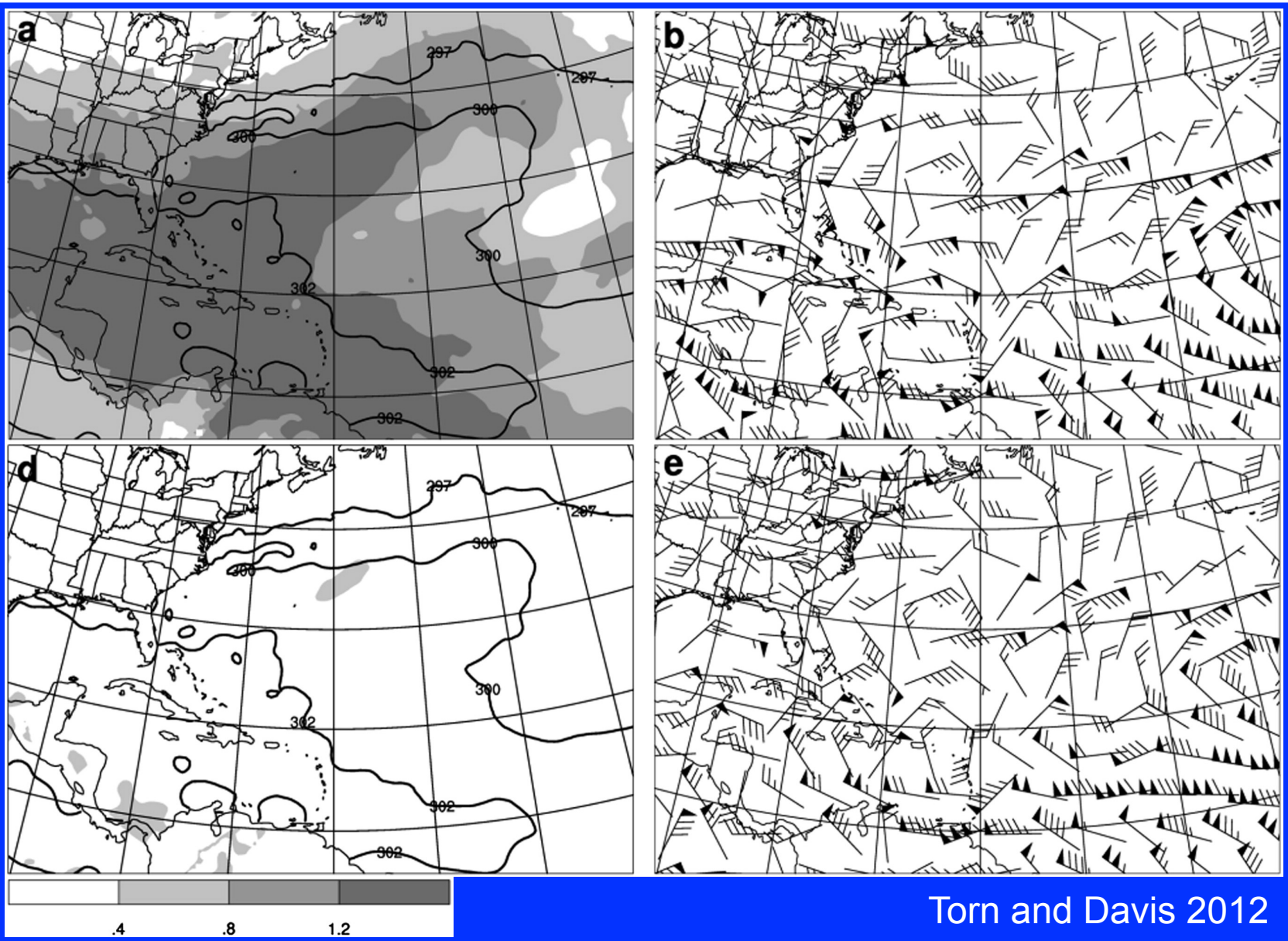


Vucevick et al. (2013), MWR

Interaction & Basin-Scale Models



Prior Biases

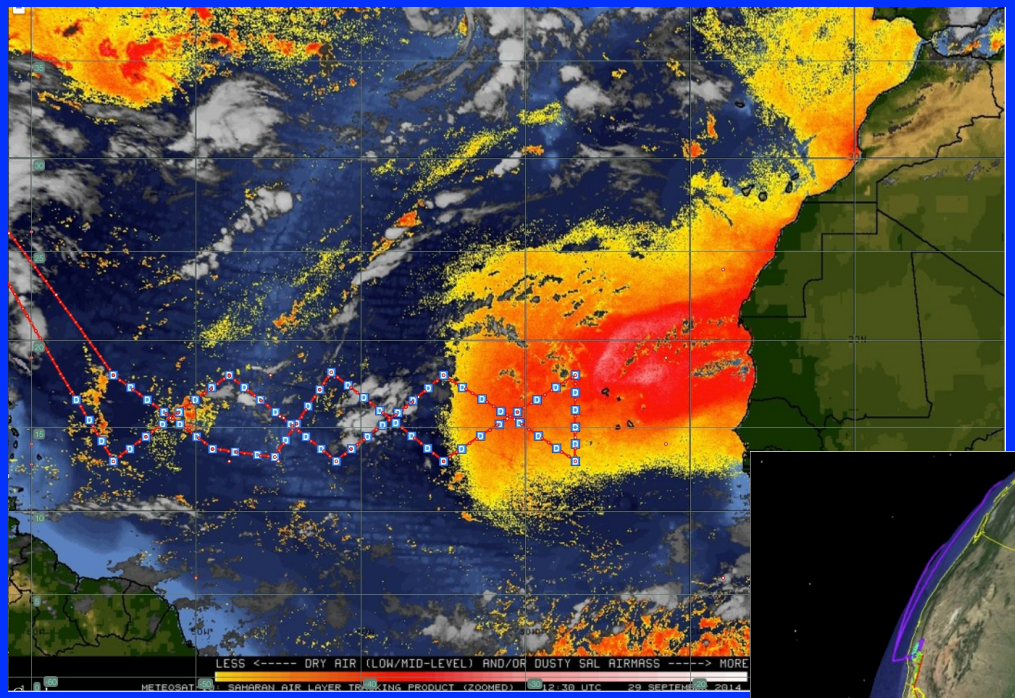


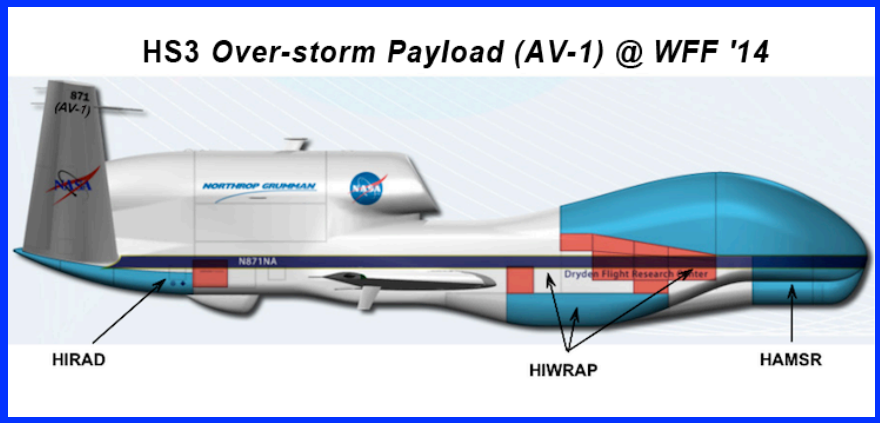
Torn and Davis 2012

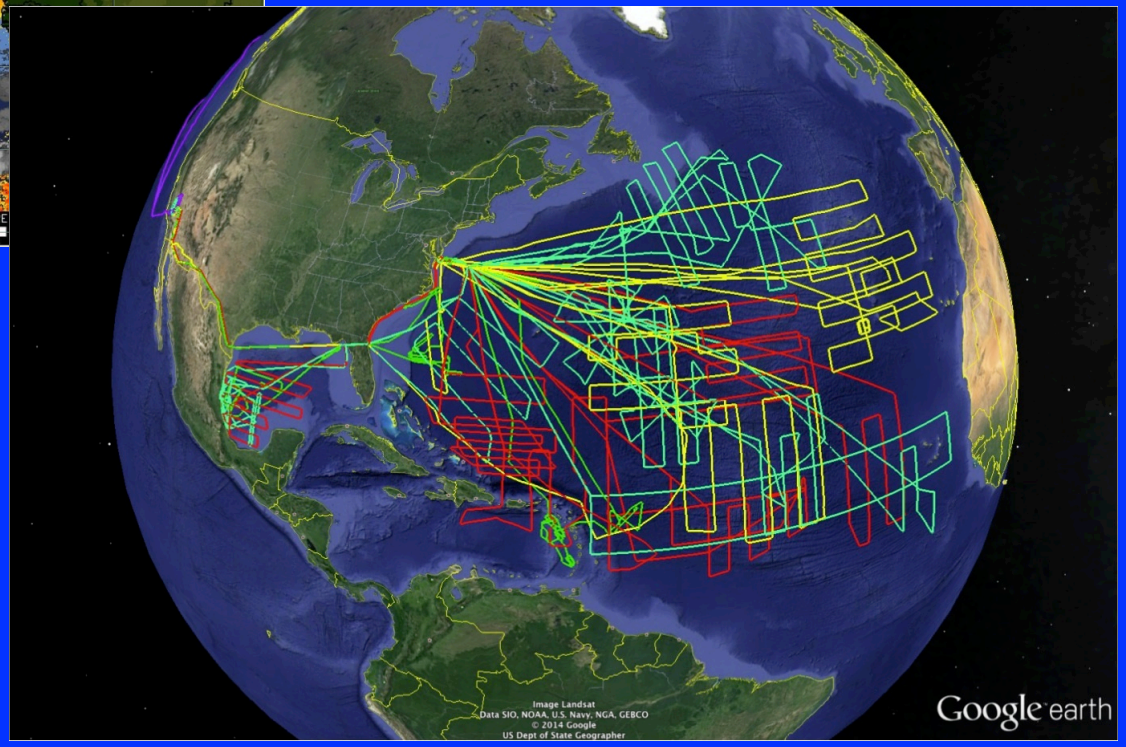
New Directions

- Most of the above issues can be addressed with more development & computing
- New observation platforms are becoming available that will provide better coverage
- New methods of determining where to direct scarce observation resources

Unmanned Vehicles



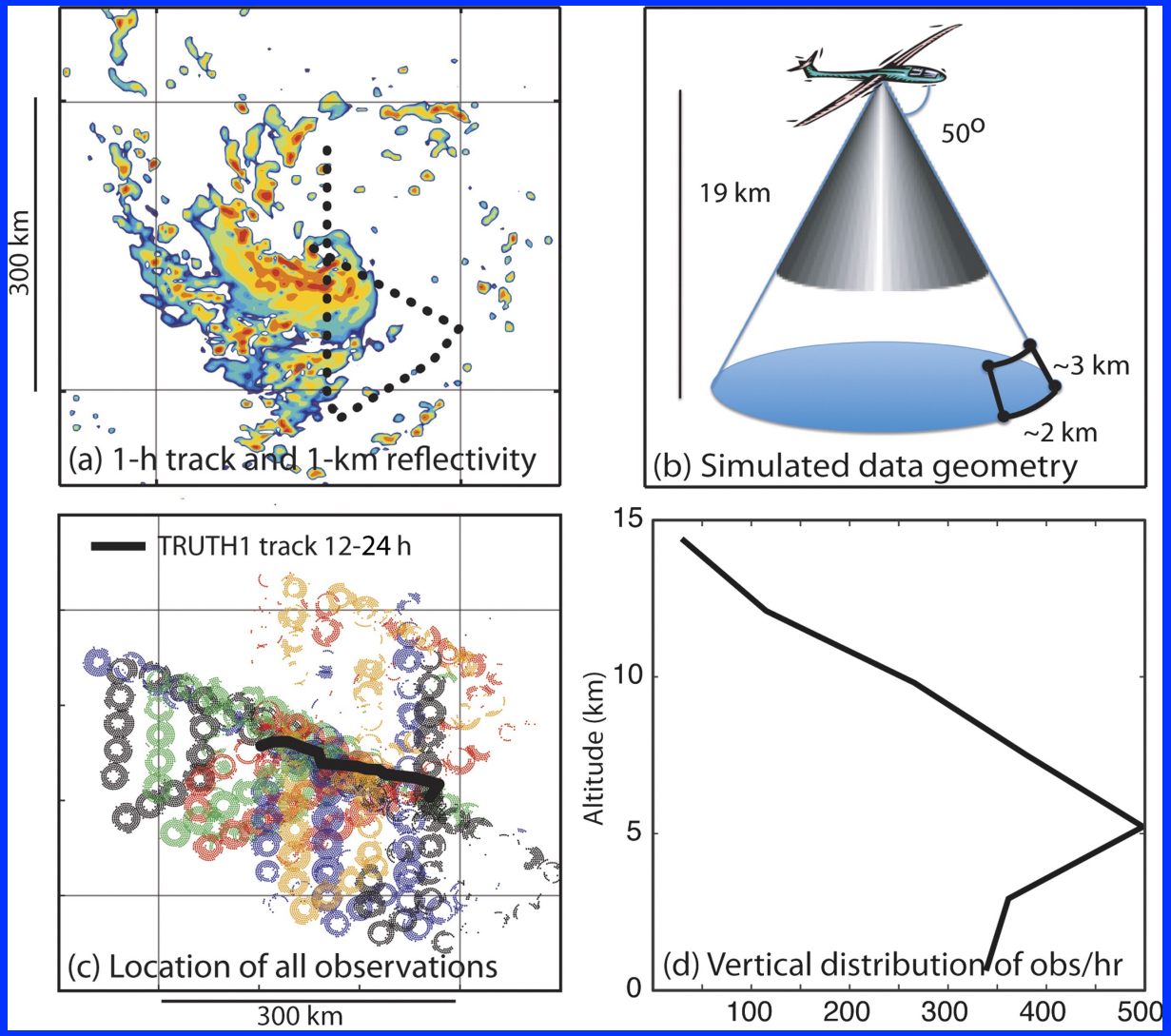


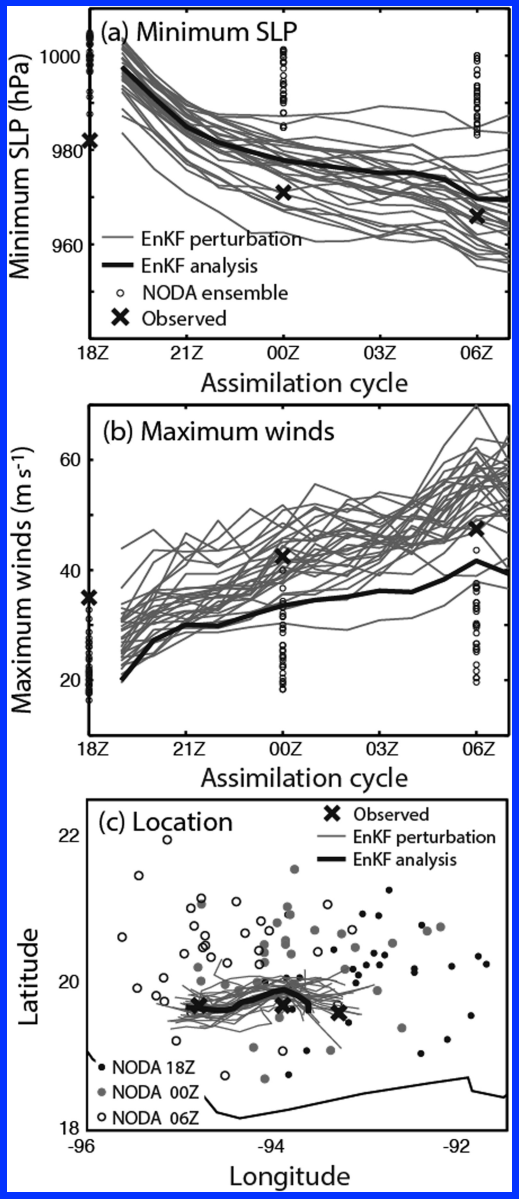


NASA Global Hawk

- Has similar observation capability to manned aircraft (including radar)
- Long duration flights (> 20 h)
- Used in Hurricane Sentinel (HS3) project

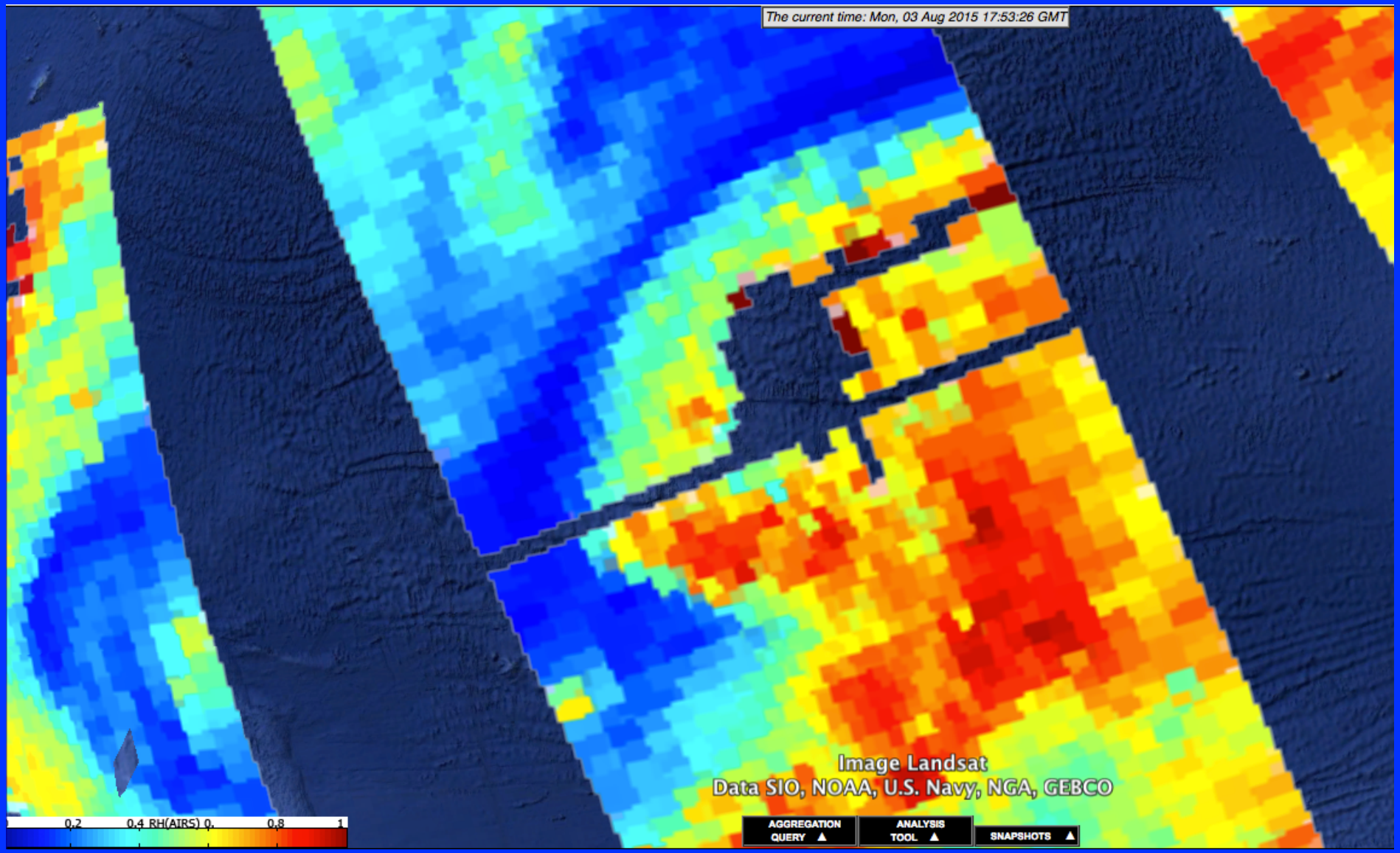
HIWRAP Assimilation



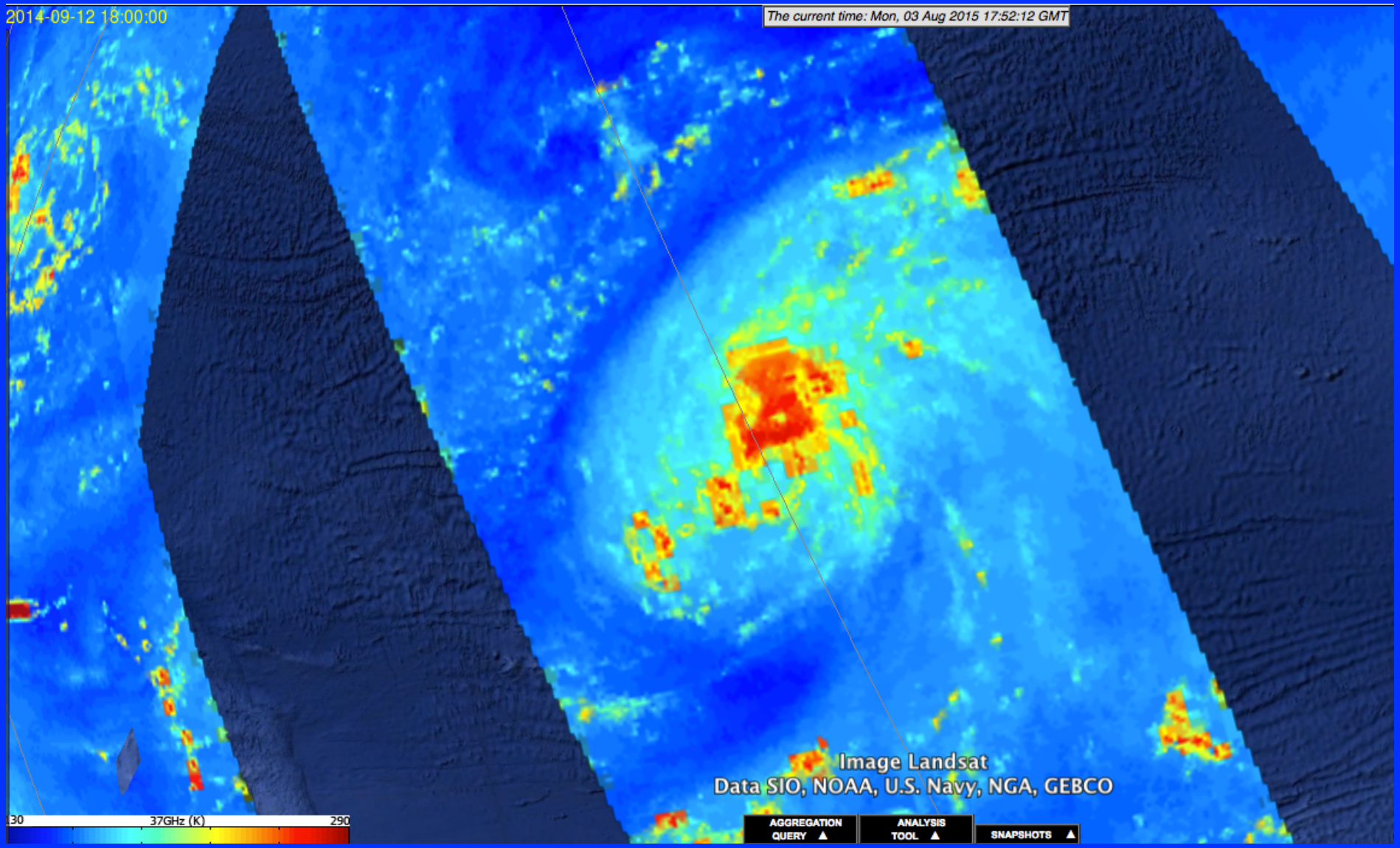


Sippel et al. (2013) and Sippel et al. (2014), MWR

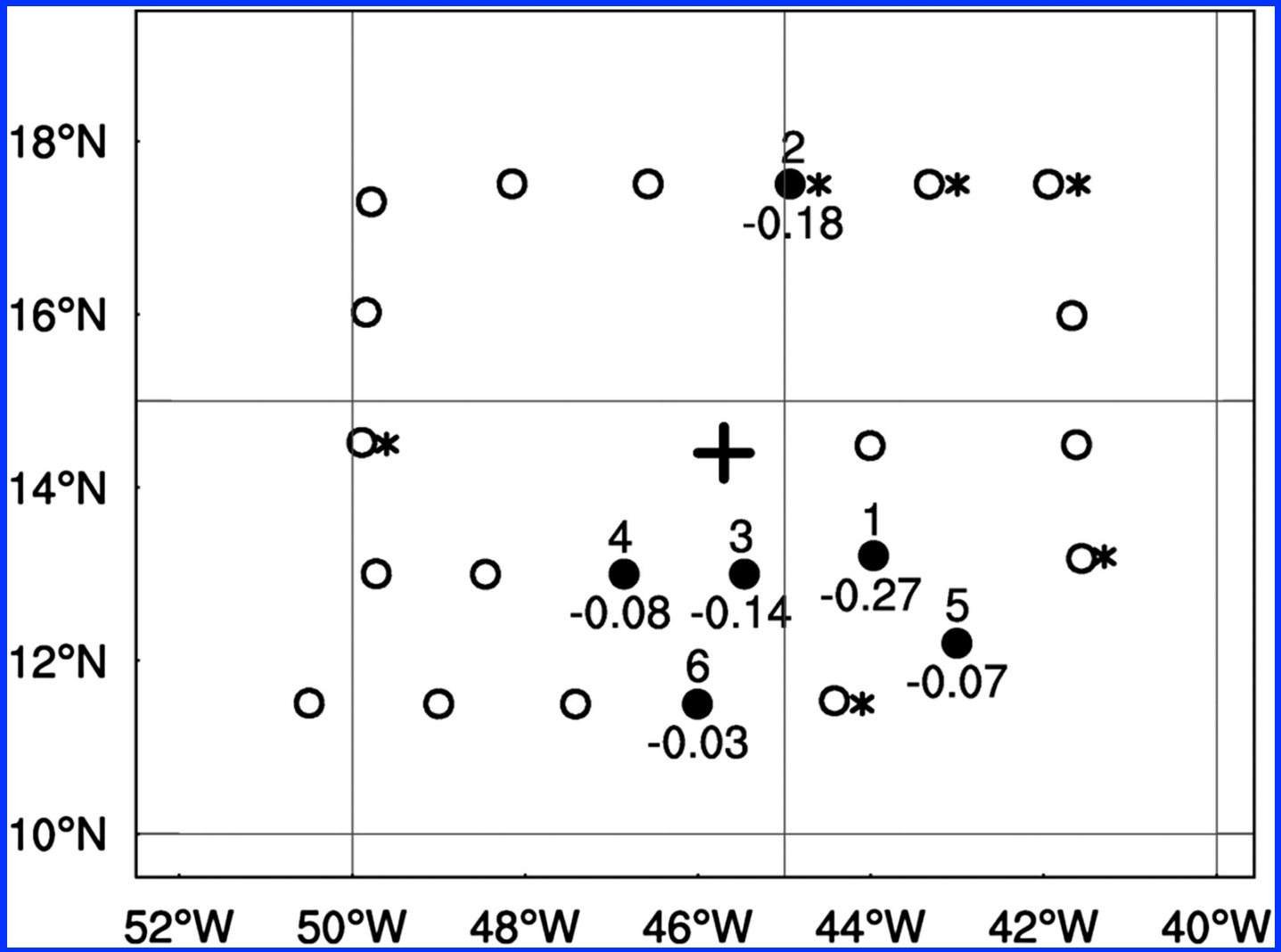
Satellite Data



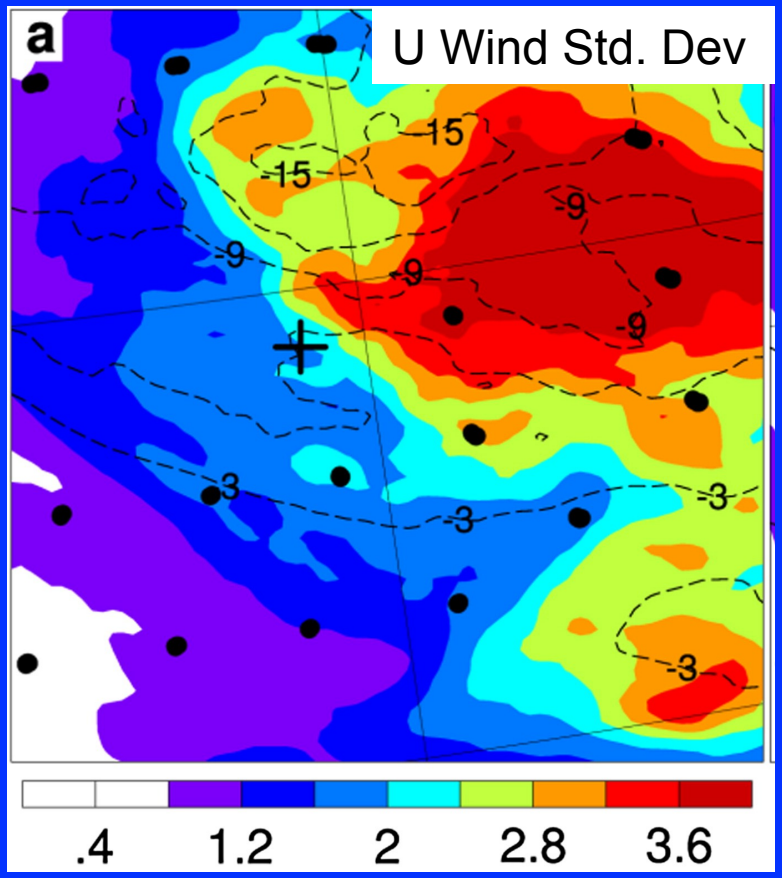
Satellite Data

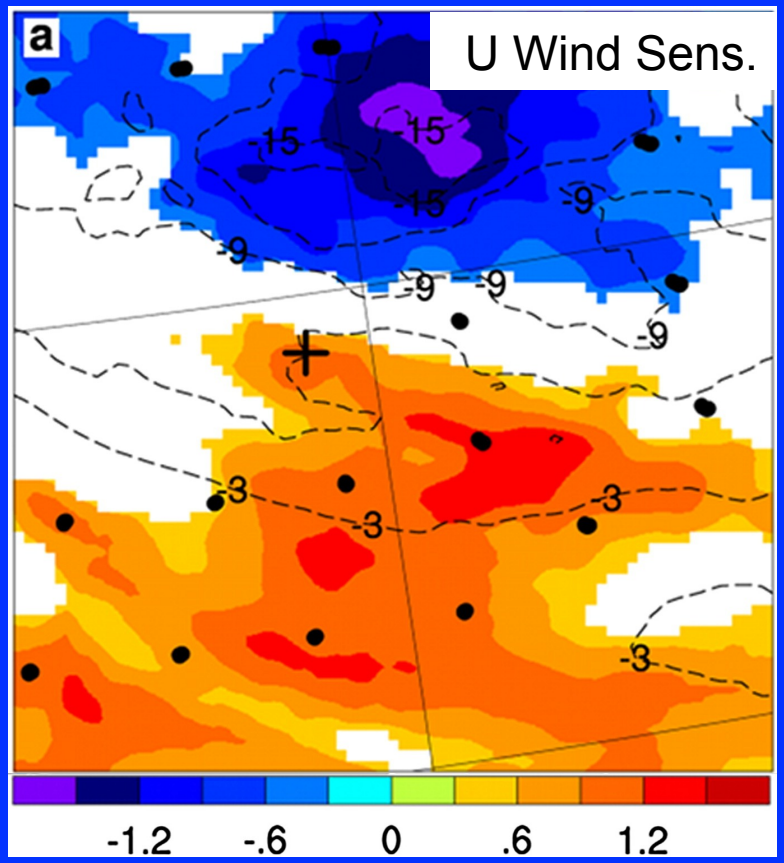


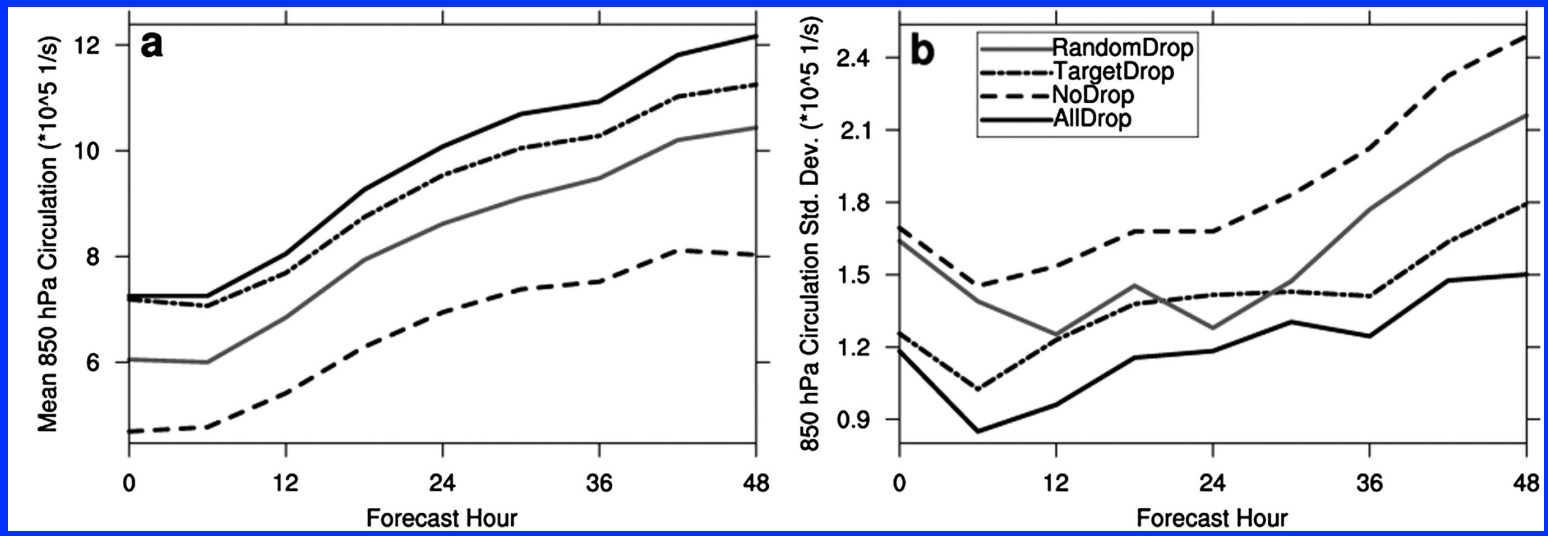
Targeting



Torn (2014) MWR

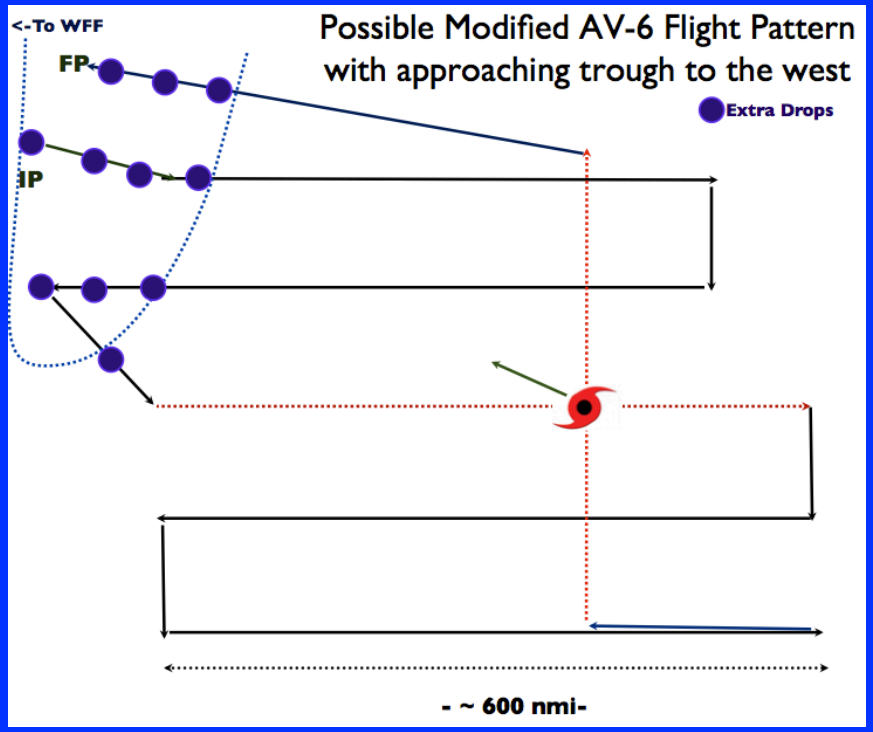

a
U Wind Std. Dev
-15
-9
-3
.4
1.2
2
2.8
3.6

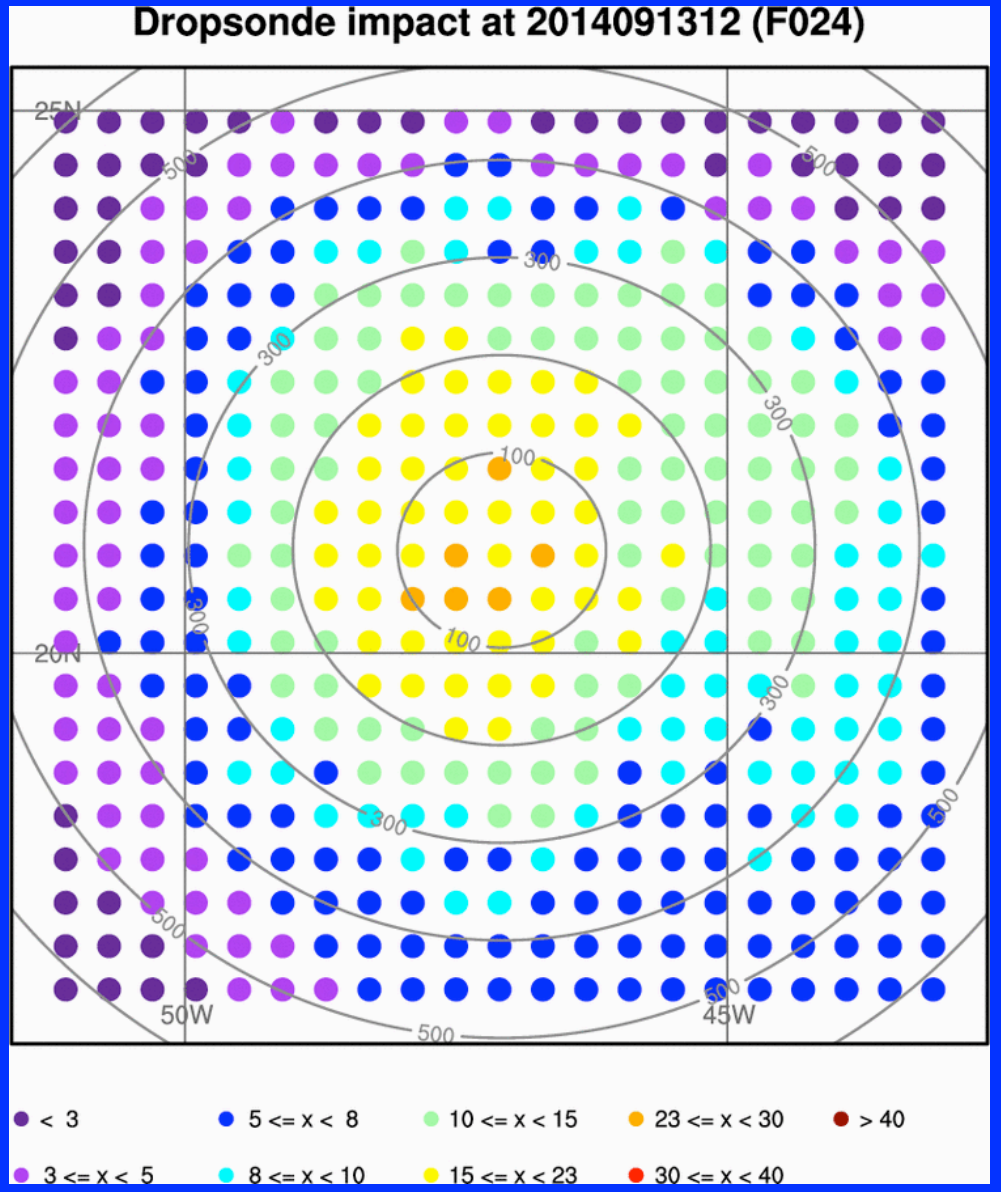

a
U Wind Sens.
-15
-9
-3
-1.2
-.6
0
.6
1.2


a
Mean 850 hPa Circulation (*10^5 1/s)
12
10
8
6
0
12
24
36
48
Forecast Hour
b
850 hPa Circulation Std. Dev. (*10^5 1/s)
2.4
2.1
1.8
1.5
1.2
0.9
RandomDrop
TargetDrop
NoDrop
AllDrop
0
12
24
36
48
Forecast Hour

SHOUT


SENSING HAZARDS WITH OPERATIONAL UNMANNED
SHOUT
TECHNOLOGY


<-To WFF
FP
IP
Possible Modified AV-6 Flight Pattern
with approaching trough to the west
Extra Drops
- ~ 600 nmi-


Dropsonde impact at 2014091312 (F024)
25N
20N
50W
45W
500
300
100
< 3
3 <= x < 5
5 <= x < 8
8 <= x < 10
10 <= x < 15
15 <= x < 23
23 <= x < 30
30 <= x < 40
> 40

Summary

- Greatest challenges in TC data assimilation due to multi-scale nature
  - Needs more intelligent methods of dealing with sampling errors
  - Must remove position variability
- Aircraft data is useful for assimilation, but impact has been limited. Likely that UAVs will provide better coverage in next 10-20 years
- Satellites hold promise to provide frequent coverage, but forward operators are problem
- Biggest improvement to assimilation likely to come from model itself. DA systems are too stressed by bias and representativeness problems
- Need to focus forecast metrics away from wind
  - Storm surge & Precipitation