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Testing and Evaluation of GSI Hybrid Data Assimilation for Basin-scale HWRF: Lessons We Learned

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Special acknowledgement to HFIP

DTC Developmental Testbed Center

Mechanism for DTC Data Assimilation(DA) T&E

Operational GSI implementation and parallel test runs. Focus on evaluating the overall performance of GSI.

- Benchmark
- Parallel run config
- Archived data / background for retro runs

DTC real-time & retrospective GSI runs using functionally-similar operational environment: Focus on testing incremental changes.

- **Real-time**: "sync" testbed, uncover the issues
- **Short-term retrospective**: test individual changes, tackle the issues
- **Extensive retrospective**: impact study w/ SS, test research/developmental components

- Benchmark
- Developmental config (suggested from the DTC)

Pathway to "O"

DTC
Developmental Testbed Center

GSI 3D-Var/Hybrid Ensemble-3DVar Cost Functions

$$J_{3DVAR}(\mathbf{x}') = \frac{1}{2}(\mathbf{x}')^T \mathbf{B}_\mathbf{f}^{-1}(\mathbf{x}') + \frac{1}{2}(\mathbf{H}\mathbf{x}' - \mathbf{y}')^T \mathbf{R}^{-1}(\mathbf{H}\mathbf{x}' - \mathbf{y}')$$

Fit to background   Fit to observations

$$J'_{hybrid}(\mathbf{x}') = \frac{\beta}{2}(\mathbf{x}')^T \mathbf{B}_\mathbf{f}^{-1}(\mathbf{x}') + \frac{1-\beta}{2}(\mathbf{x}')^T \mathbf{B}_{ens}^{-1}(\mathbf{x}') + \frac{1}{2}(\mathbf{H}\mathbf{x}' - \mathbf{y}')^T \mathbf{R}^{-1}(\mathbf{H}\mathbf{x}' - \mathbf{y}')$$

$\mathbf{x}'$: Analysis increment $(\mathbf{x}^a - \mathbf{x}^b)$; where $\mathbf{x}^b$ is a background

$\mathbf{B}_\mathbf{f}$: (Fixed) Background error covariance (estimated offline)

$\mathbf{H}$: Observations (forward) operator

$\mathbf{B}_\mathbf{f}$: (Fixed) background error covariance (estimated offline)

$\mathbf{R}$: Observation error covariance (Instrument + representativeness)

$\mathbf{B}_{\mathbf{ens}}$: (Flow-dependent) background error covariance (estimated from ensemble)

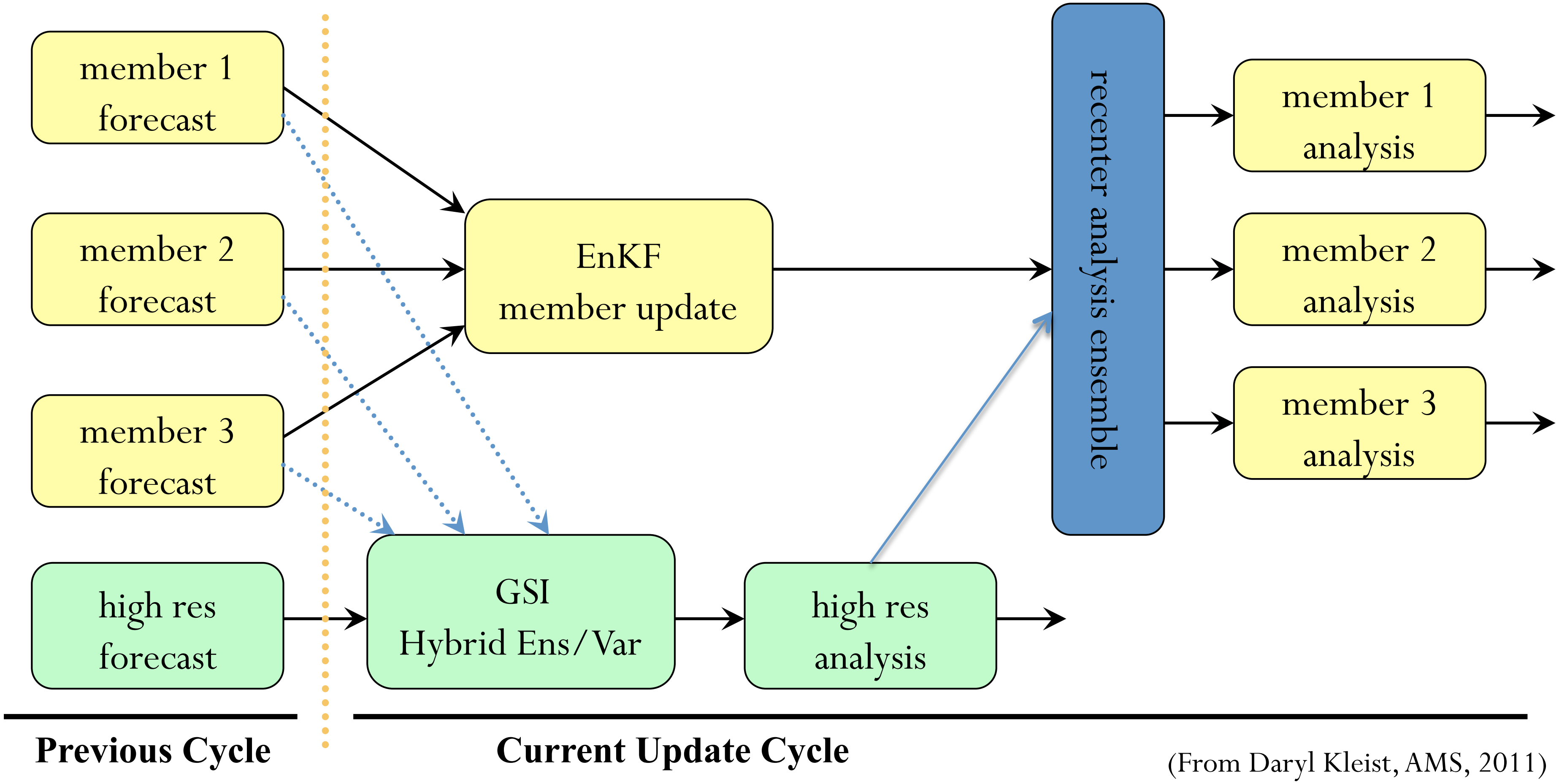
$\mathbf{y}' = \mathbf{y}^o - H\mathbf{x}^b$, where $\mathbf{y}^o$ are the observations

β: Weighting factor (0.25 means total **B** is ¾ ensemble).

Cost function (*J*) is minimized to find solution, $\mathbf{x}'$ [$\mathbf{x}^a = \mathbf{x}^b + \mathbf{x}'$]

(Courtesy from Jeff Whitaker, GSI Tutorial, 2012)

NCEP Dual-Res Global Coupled Hybrid



(From Daryl Kleist, AMS, 2011)

- Gets flow dependent background error covariance in 3(4)D-Var by using an ensemble estimate.
- Ensemble perturbations are incorporated directly into cost function using extended control variable approach

“Minimal” GSI-Hybrid System for Regional Applications

The minimal system was set up by NCEP/EMC in 2012:

- BE contributions: 25% (β) static (fixed) and 75% ensemble
- The ensemble input comes from NCEP’s Global Forecast System (GFS) ensemble.
- No feedback from deterministic analysis to ensemble analyses
- No extra computational cost due to ensemble generation

✓ Similar regional GSI-hybrid DA system has shown positive impacts in NCEP’s NAM applications.

✓ Would it be beneficial to TC forecasts? Issues? Limitations?

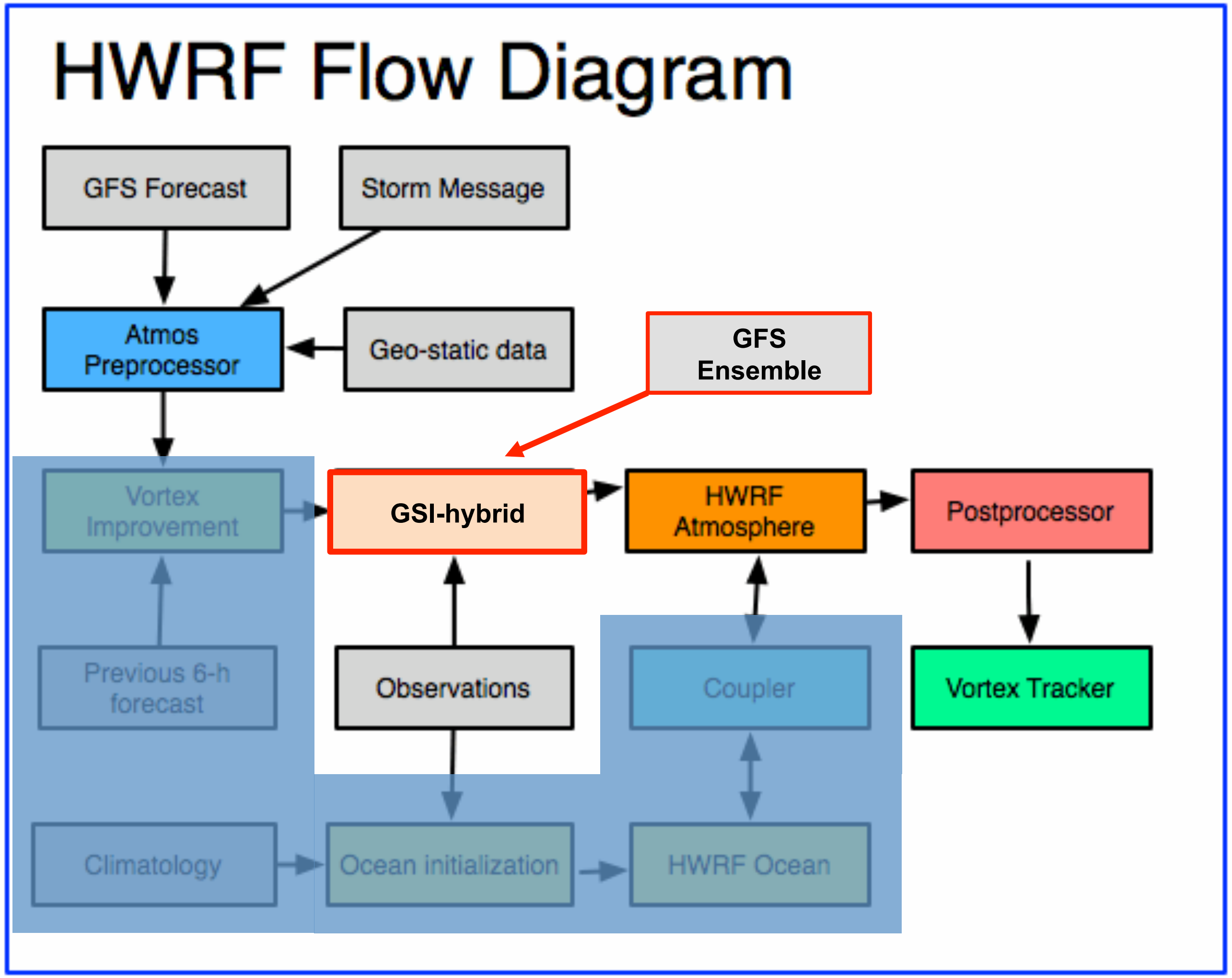
✓ What developmental direction should be taken for this specific scenario?

Objectives

In coordination with other regional GSI-hybrid DA development teams, the DTC

- Tests and evaluates the developmental GSI-hybrid DA model, currently the NCEP minimal regional GSI-hybrid, for Hurricane WRF (HWRF) applications.
  - Cross covariance of variables through hybrid/ensemble components
  - Sensitivity study of the weights for the static and ensemble BE statistics
  - Cycling schemes of the DA-forecast system.
- Develops develop user related interface.
  - Binary capability of the HWRF components
    - Reading big-endian files on little-endian platforms
- Leads the effort to make a code management plan for the GSI-hybrid code, including both variational and ensemble components.

Hurricane WRF components



HWRF Components

WRF model
Pre-Processor (WPS)
Vortex initialization
Data assimilation (GSI)
Coupler (NCEP)
Ocean (POM-TC)
Post-Processor (UPP)
Vortex Tracker (GFDL)

(Courtesy from Ligia Bernadet)

2012 HWRF Basin Scale T&E Configuration

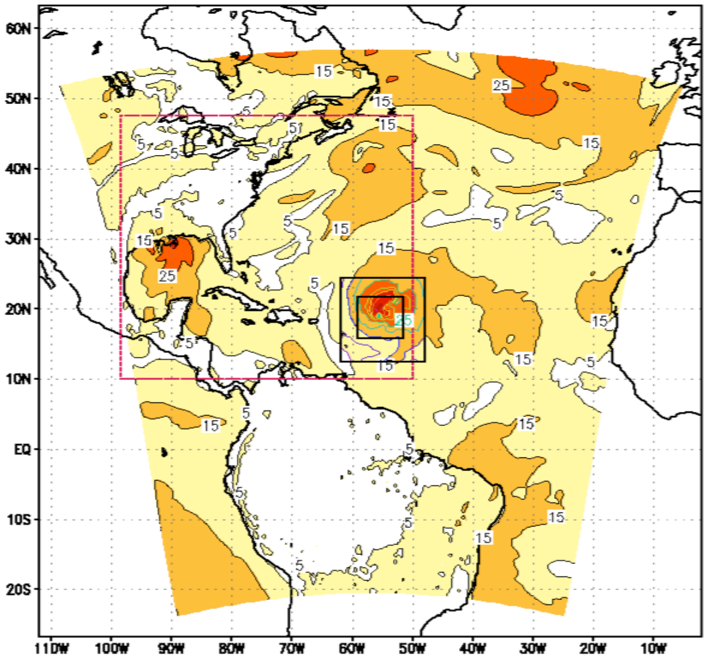
Operational HWRF atmospheric config:

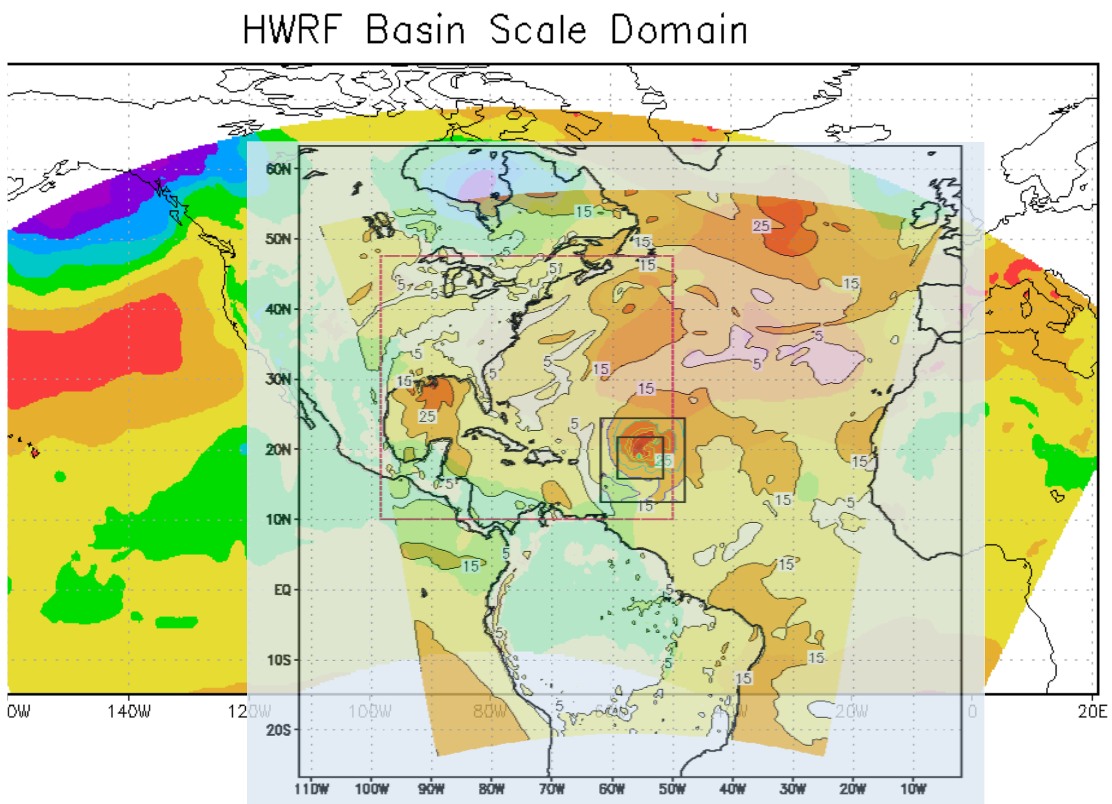
Horizontal grid spacing: 27, 9, 3 km

- Inner nests move to follow storm
- Domain location vary from run to run depending on storm location
- 42 vertical levels
- Model top 50 hPa

Exp. HWRF atmospheric config:

- Horizontal grid spacing: 27 km
- No inner nests yet
- Domain is fixed
- 61vertical levels
- Model top 2 hPa





Experimental Design

	Config. ID	% Static BE	% Ens. BE	ICs
Cycling experiment	CTL			GFS analysis
	COLD	25%	75%	Cold start with GFS forecasts
	CYC	25%	75%	1-day GSI cycling prior to analysis time
BE weighting experiments	Var00	0	100	Cold start with GFS forecasts
	Var10	10	90	Cold start with GFS forecasts
	Var25	25	75	Cold start with GFS forecasts
	Var50	50	50	Cold start with GFS forecasts
	Var75	75	25	Cold start with GFS forecasts

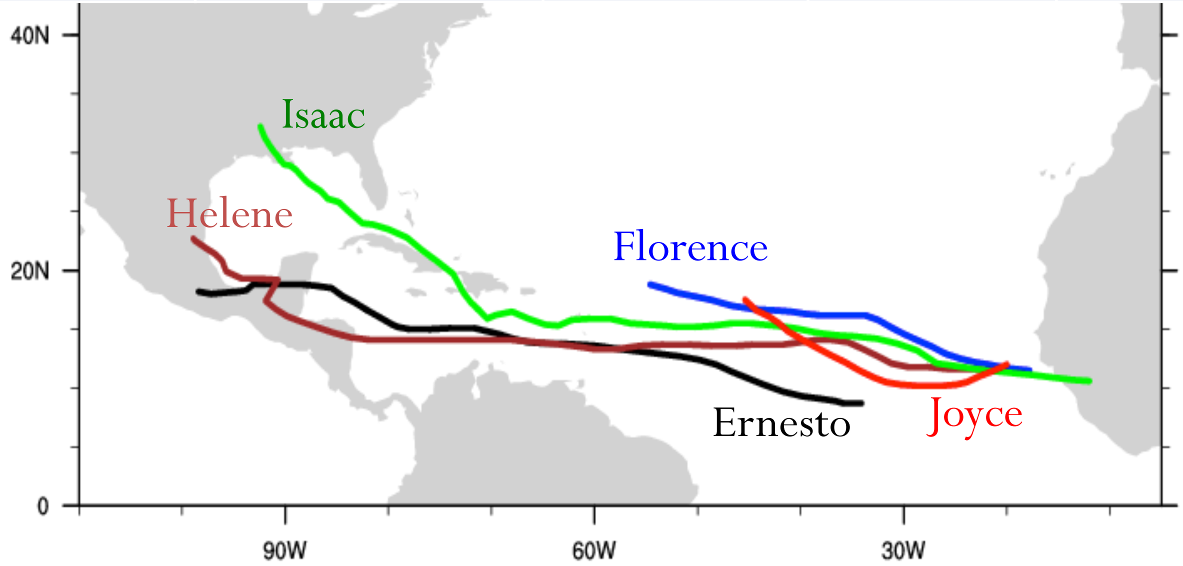
Only conventional observations and TCvital were assimilated.

Testing Period

Dates: Aug 1st 2012 – Aug 13; Aug 22nd – Aug 28th, 2012

Storms covered: Ernesto, Florence, Helene, Isaac, Joyce

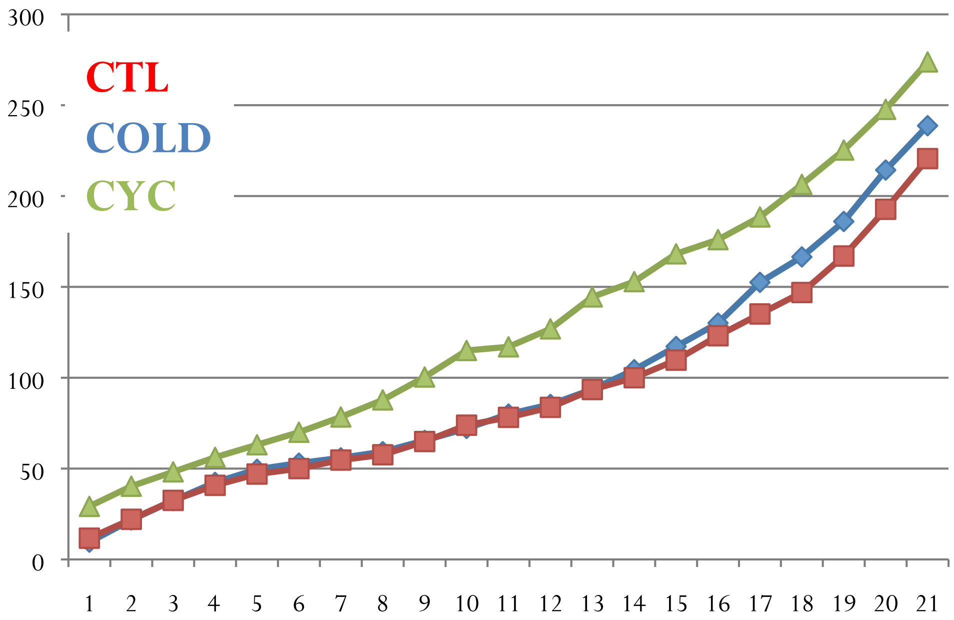
Type/ Cat	Name	Dates	Max Wind (mph)	Min Press (mb)	Deaths U.S.	Damage
H2	Ernesto	1 – 10 Aug	100	973	7	
TS	Florence	3 – 6 Aug	60	1002		
TS	Helene	15 – 20 Aug	110	965		
H1	Isaac	21 Aug – 1 Sep	80	965	34	$2.35B
TS	Joyce	22-24 Aug	40	1006		



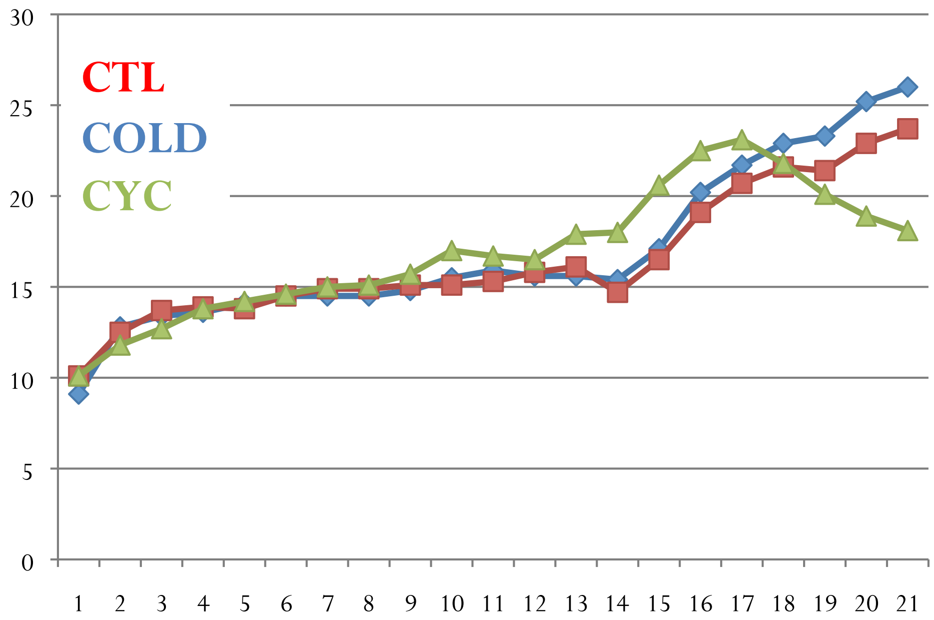
* Info from NWS National Hurricane Center webpage

Development

“Minimal” GSI-hybrid Versus GFS



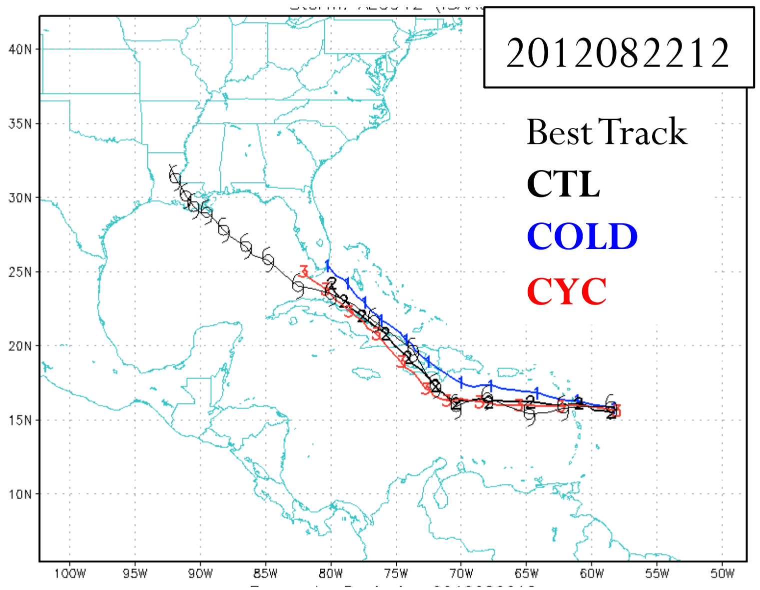
Aggregated track errors

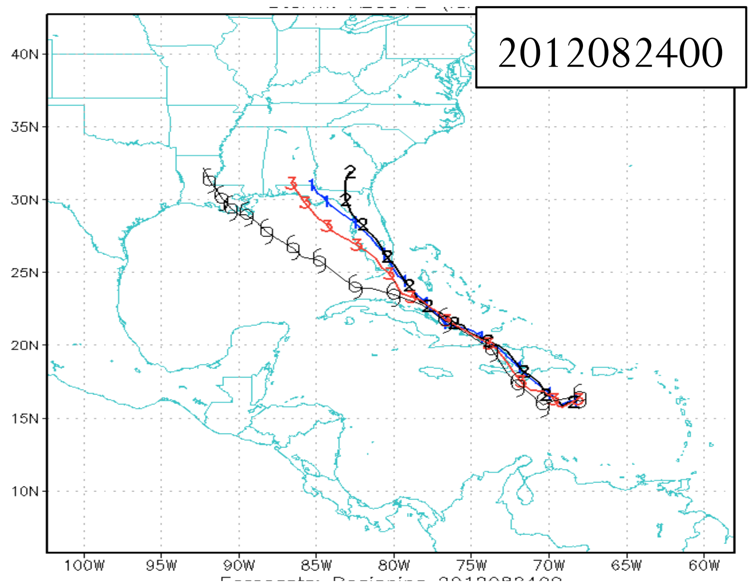


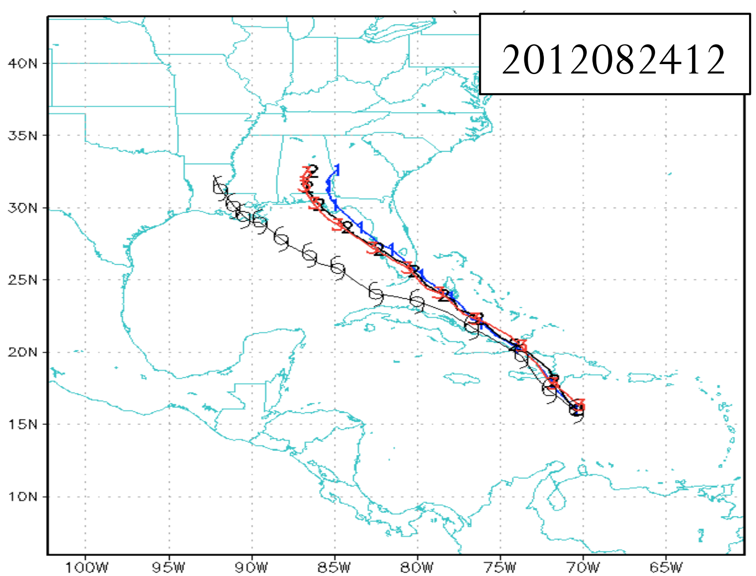
Aggregated intensity abs. errors

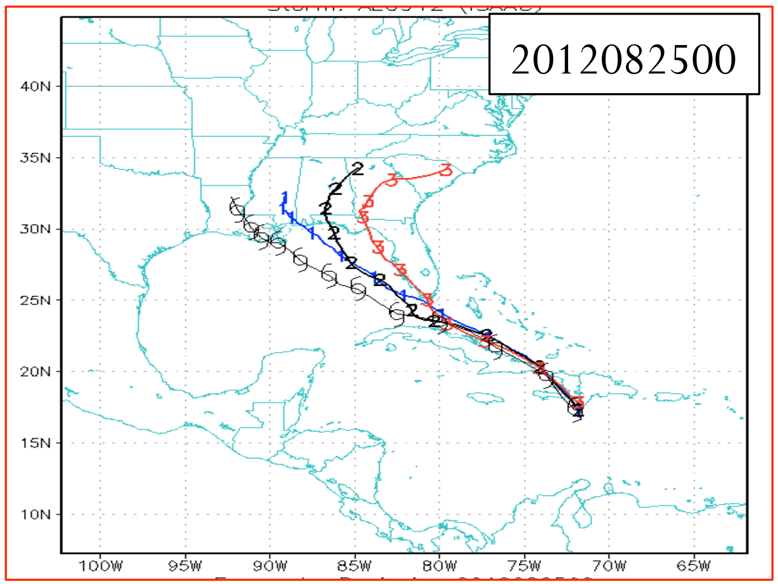
# of cases: 84 81 79 75 71 67 64 61 58 55 50 48 46 43 41 39 35 33 31 29 28

Hurricane Isaac Tracks



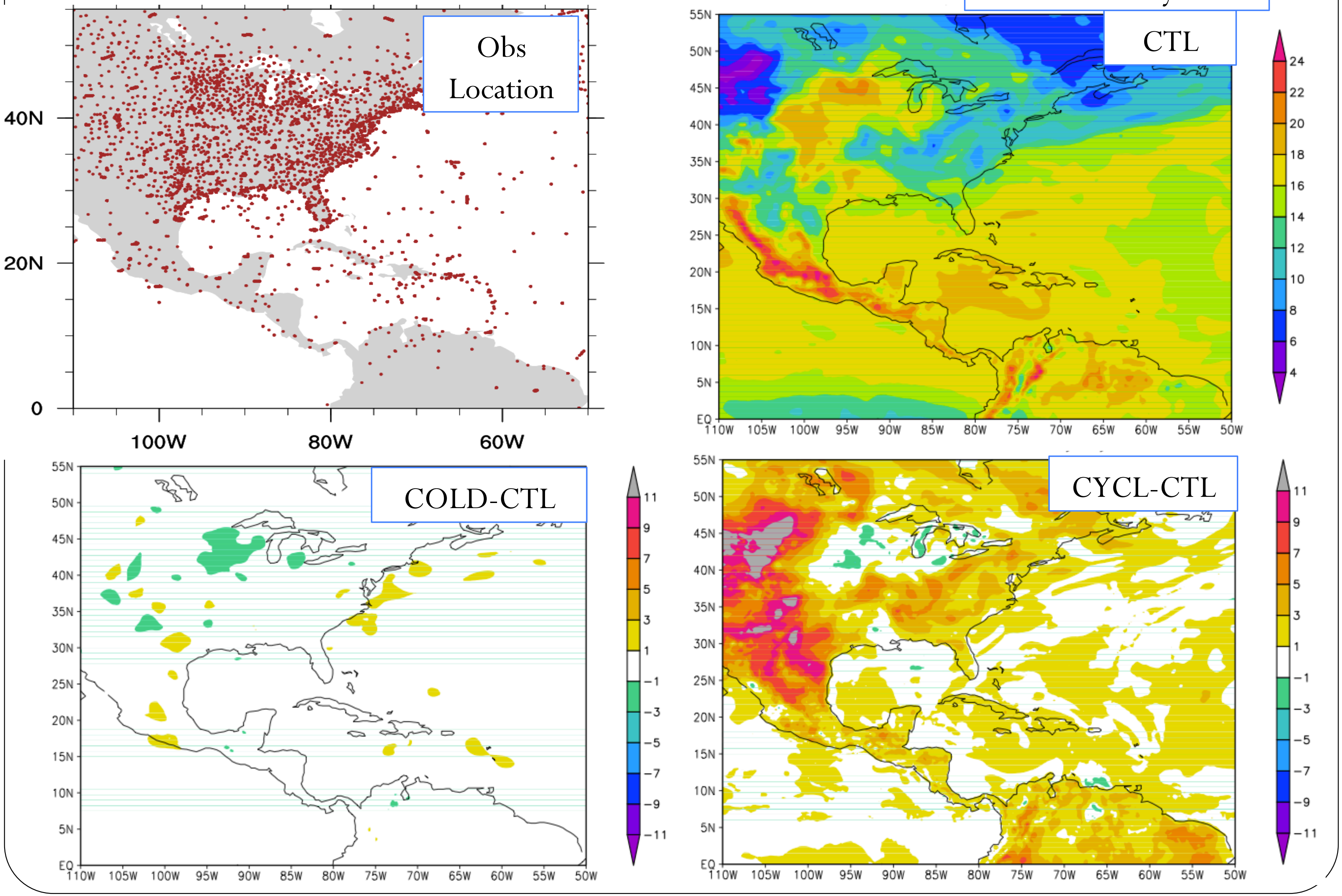






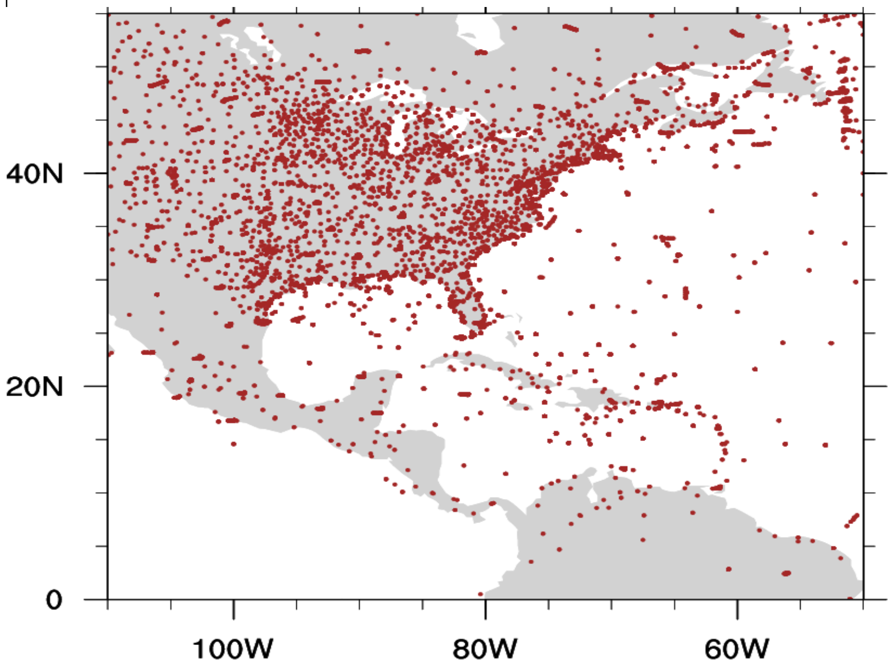
Isaac Analysis Initiated at 2012082500

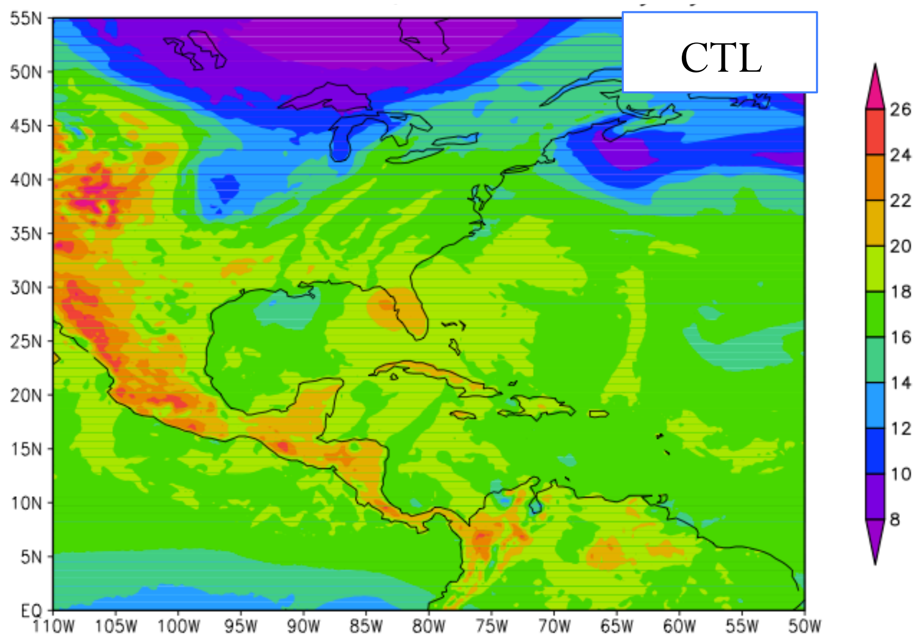
1000 hPa Specific Humidity

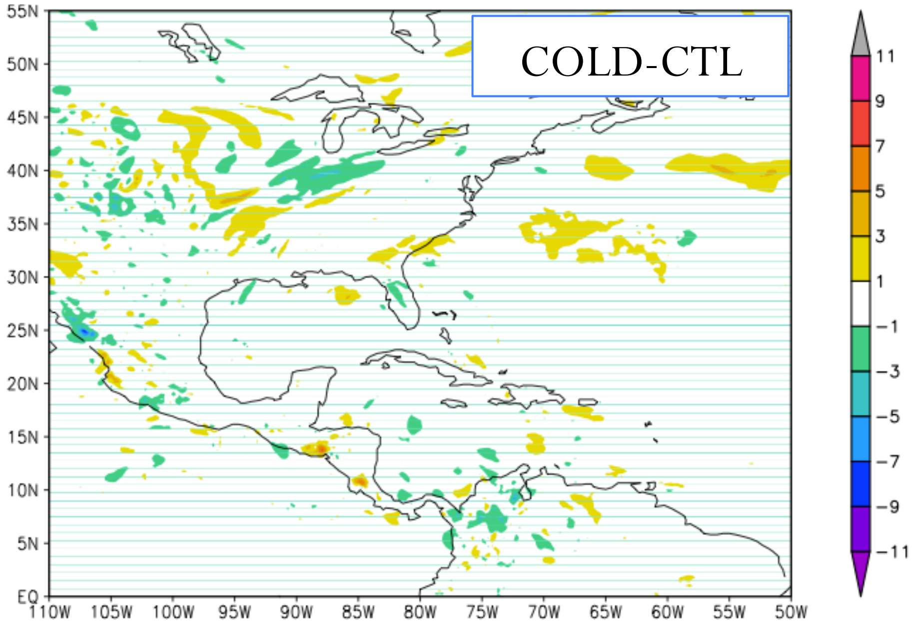


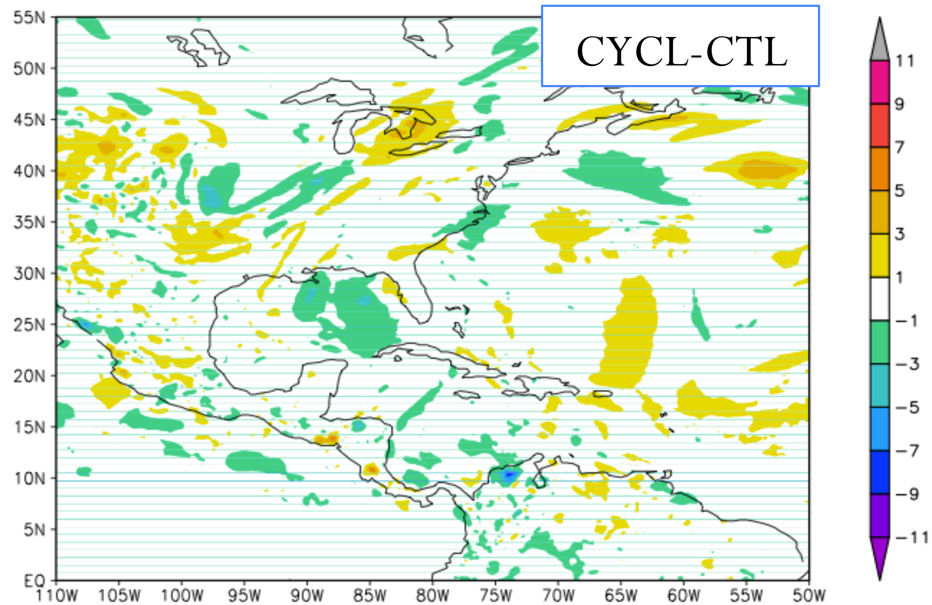
Isaac 72hr Forecasts Initiated at 2012082500

1000 hPa Specific Humidity



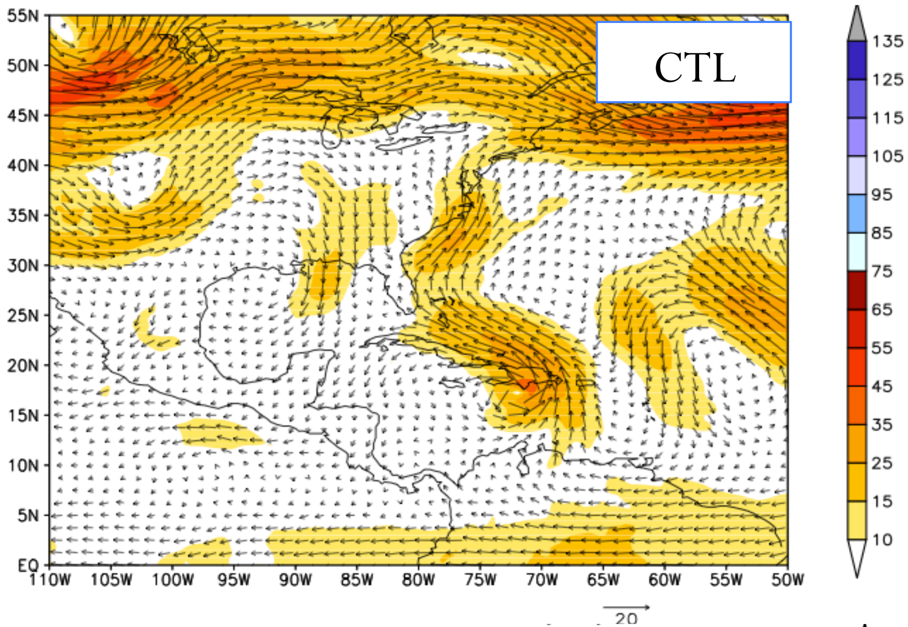


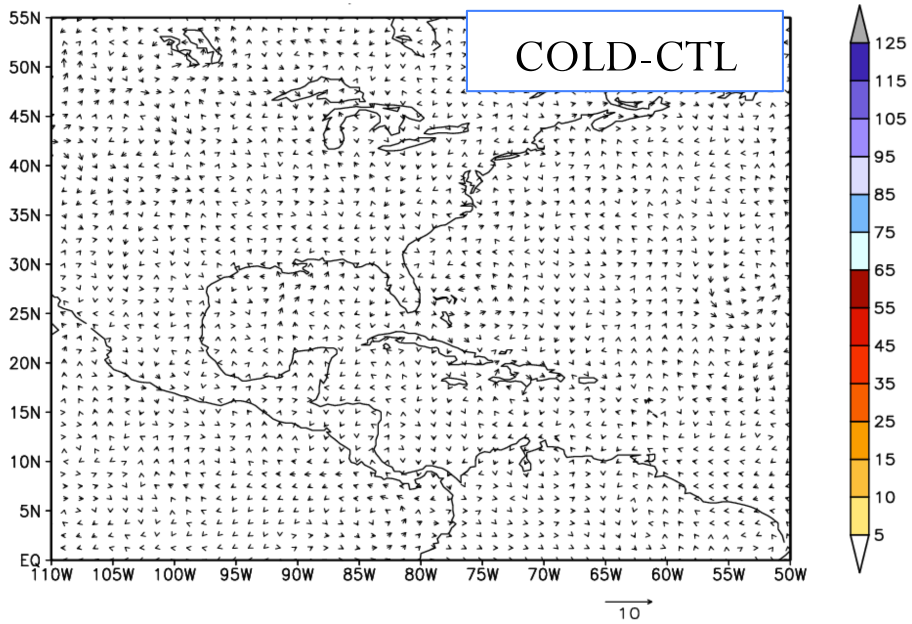


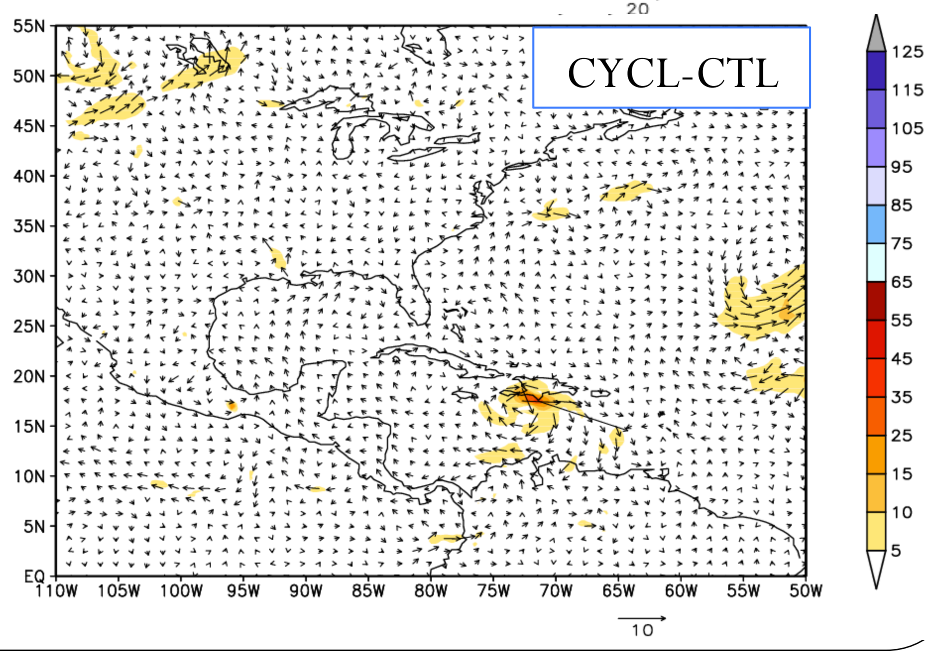


Isaac Analysis Initiated at 2012082500

Tropospheric deep-layer mean (DLM) wind vector and speed (kts)

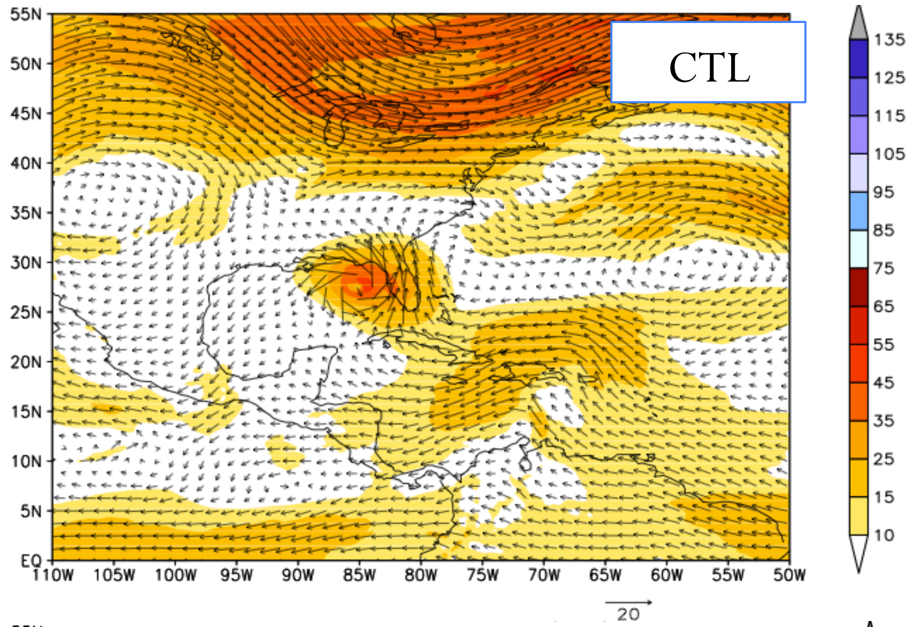


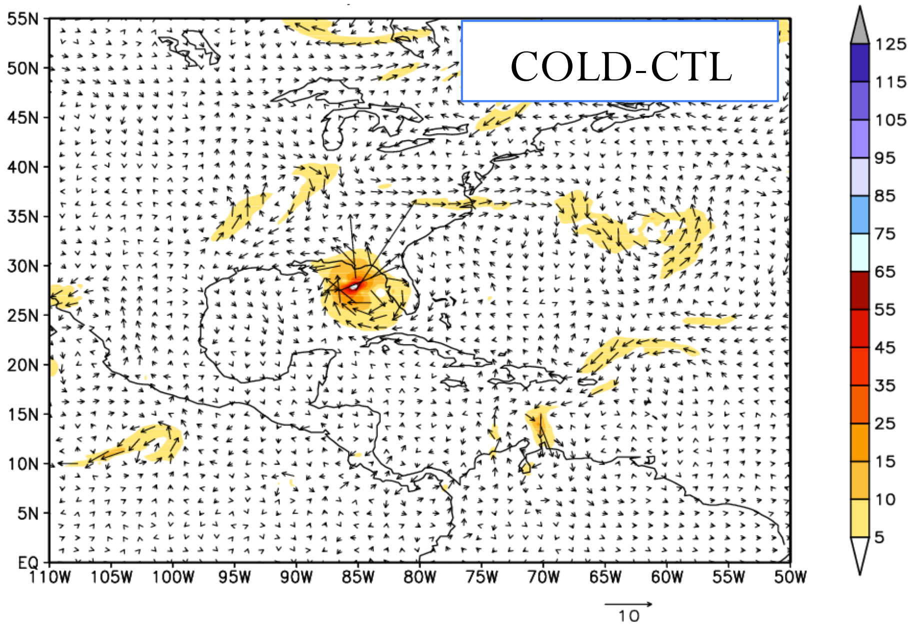


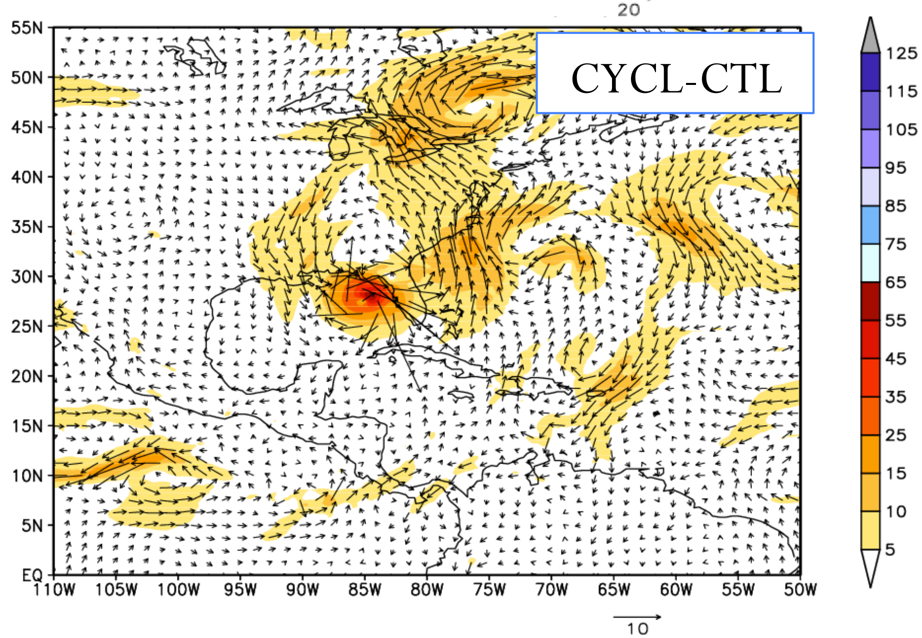


Isaac 72hr Forecast Initiated at 2012082500

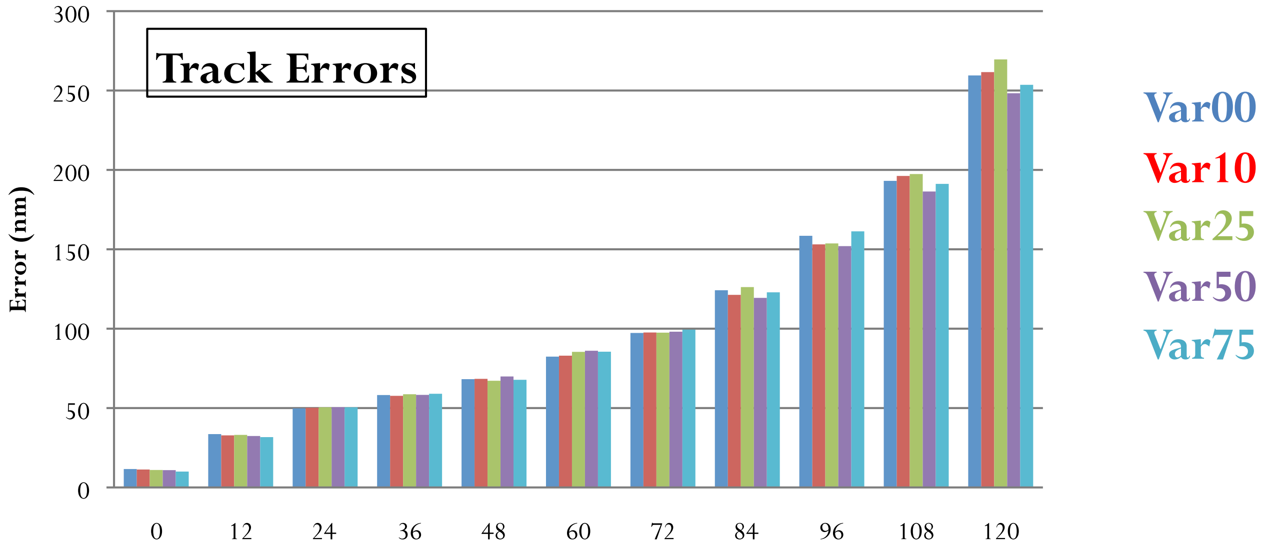
Tropospheric deep-layer mean (DLM) wind vector and speed (kts)

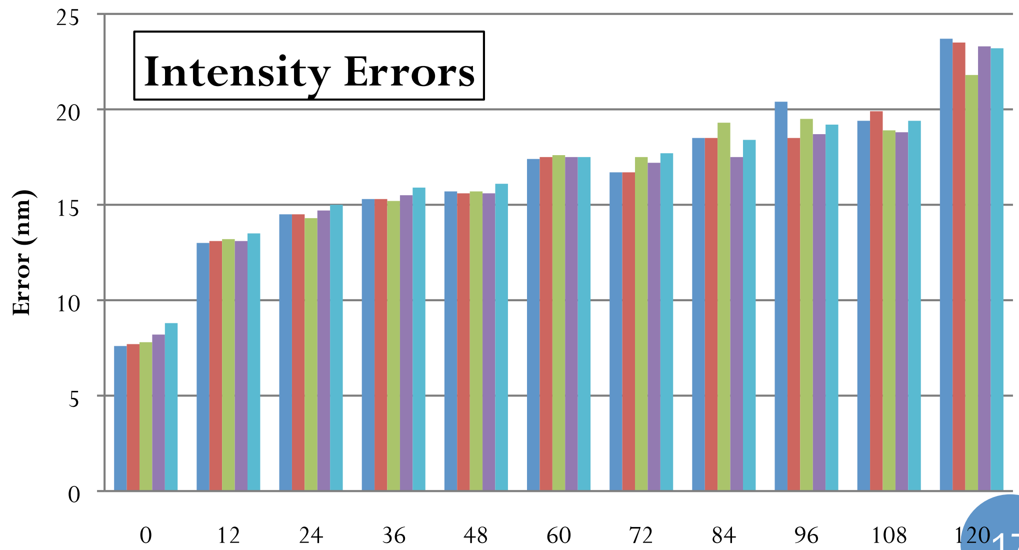






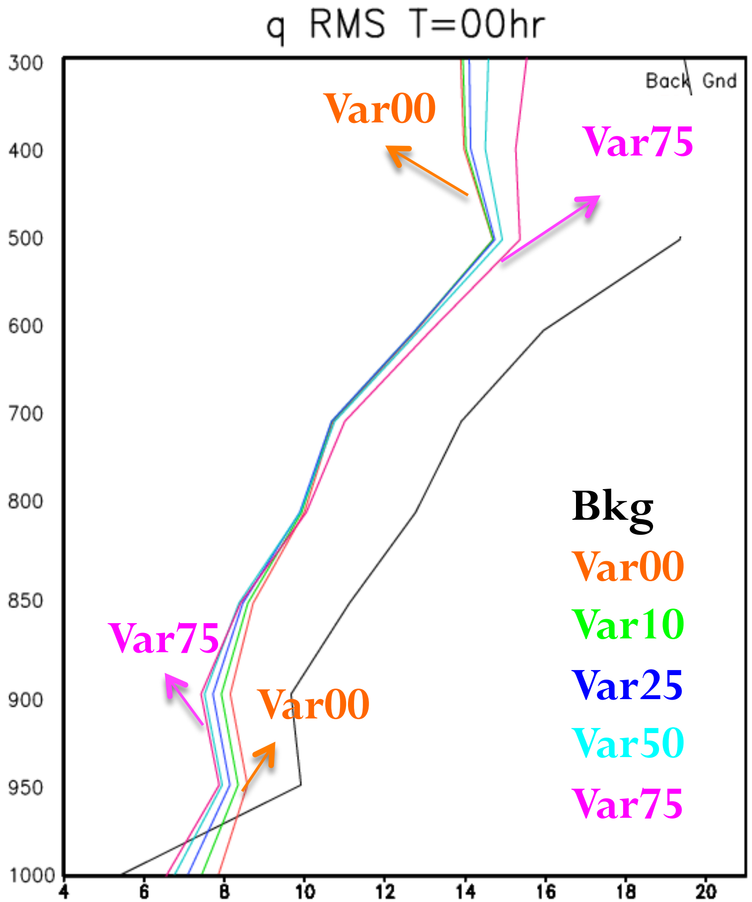
Varying Weights of Static and Ensemble BE

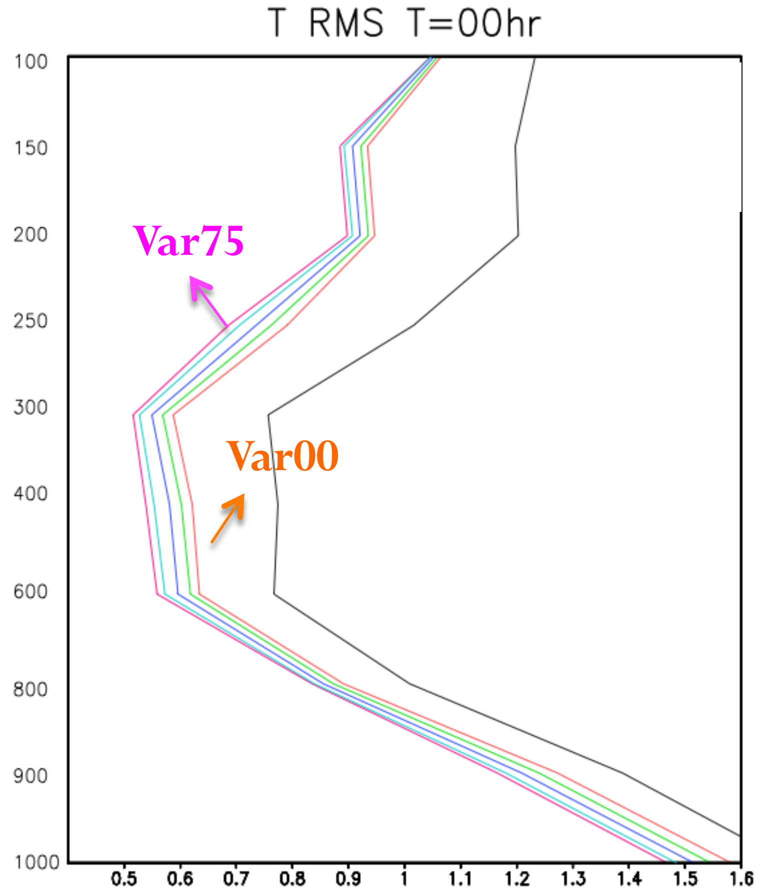




* Var 25: 25% Static BE and 75% ensemble BE

Isaac: Vertical profiles of RMSEs for q and T Analyses





Ensemble contributions degrade analysis of T at most levels and q at low levels. Similar results were found in biases and for Ernesto.

*Var 25: 25% Static BE and 75% ensemble BE

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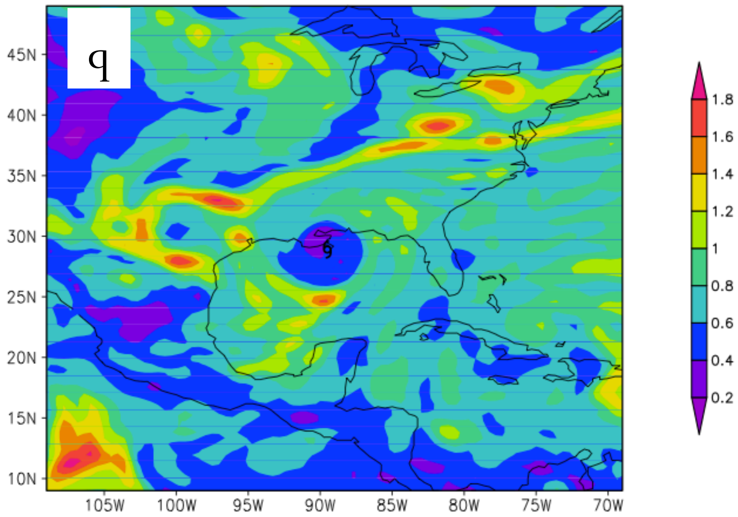
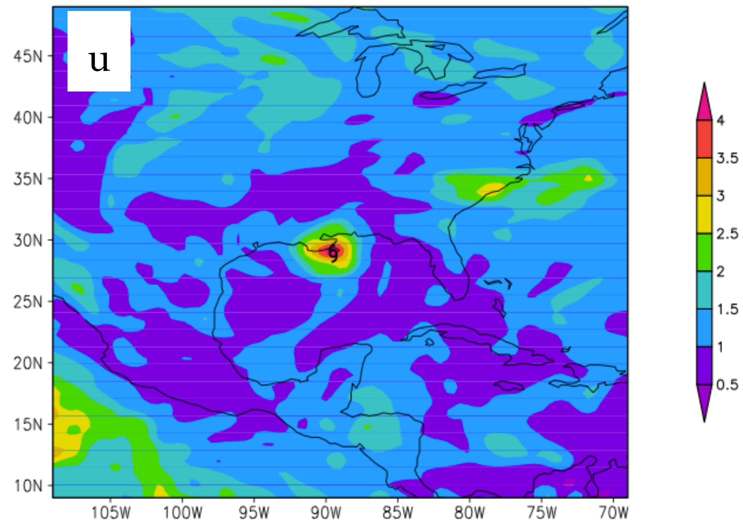
Ensemble spread 2012082900 (Isaac)

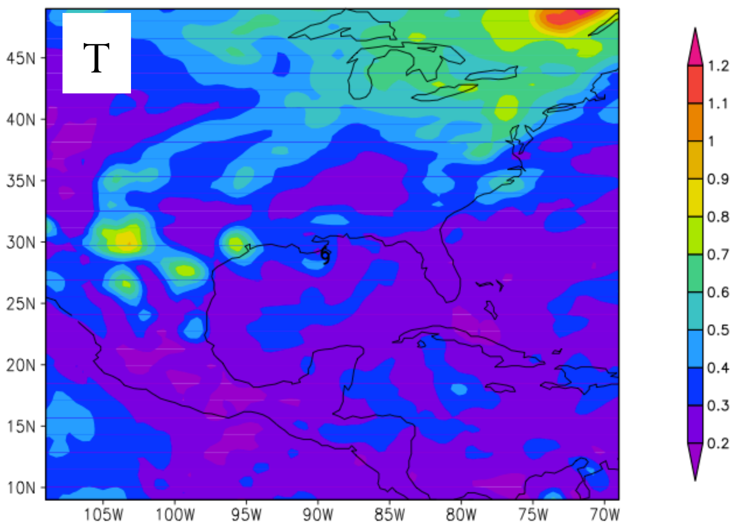
Z=18 specific humidity (g/kg) ens. spread
2012082900



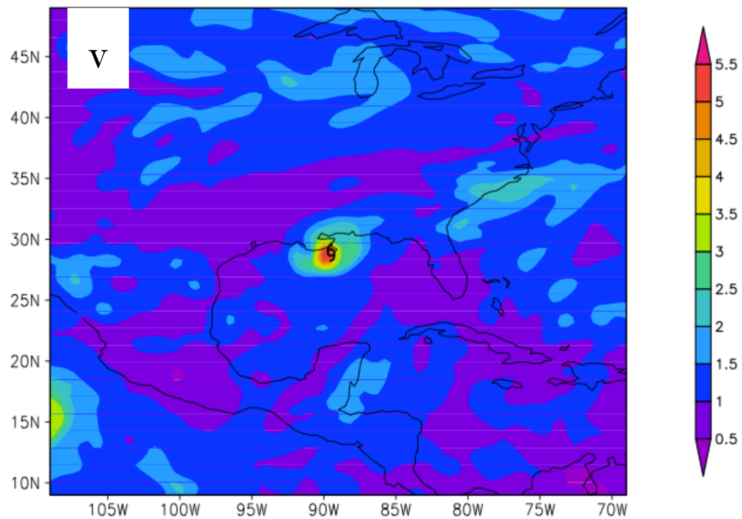
Z=18 u-wind ens. spread
2012082900



Z=18 temperature ens. spread
2012082900



Z=18 v-wind ens. spread
2012082900



Summary and Conclusions

- DTC built and configured a testing environment similar to NCEP/EMC (Same system, script, input data, different linux machines).
- The current GSI-hybrid system for basin-scale HWRF shows minimal or no improvement on TC intensity and track compared with GFS analysis initiated forecasts.
- Cycling the minimal GSI-hybrid system shows negative impacts on TC tracks and intensity by average. These impacts might be related to limitation of the DA in ocean areas? Further study is needed.
- No significant impacts on TC track and intensity from changing the relative weights of the static and ensemble BE statistics.
- For the case study, increased weighting of ensemble BEs gives more degradation to the biases and RMSEs of T at most levels and q at lower levels. However, ensemble contributions help the q bias at higher levels. The GFS ensemble used here should be further examined for representing regional errors?

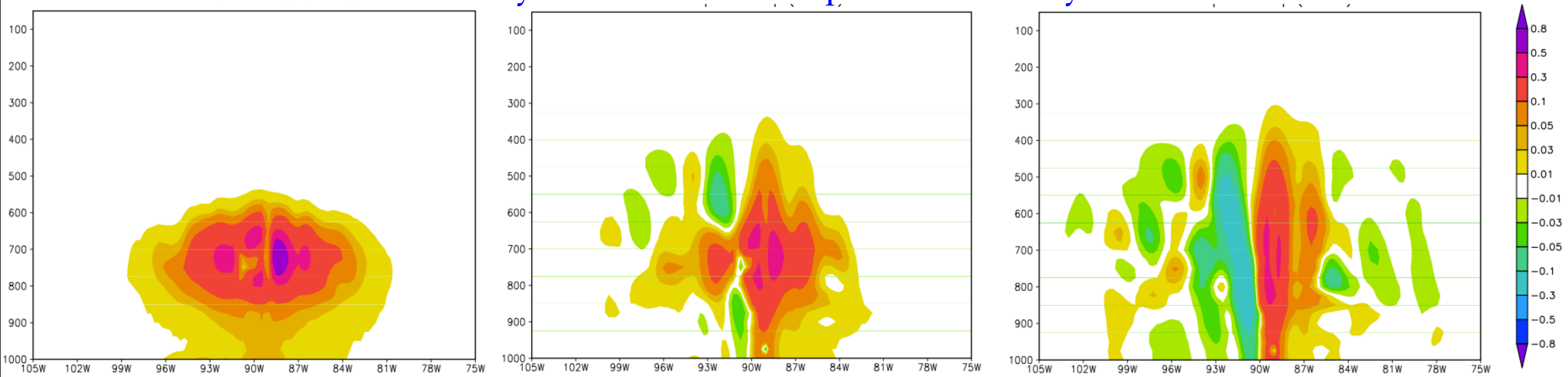
Future Work

- Regional ensemble versus global ensemble
  - Ongoing effort over NOAA/PSD on developing regional EnKF for regional ensemble update
- Radiance/Cloudy radiance DA
  - NCEP EMC added new bias correction scheme for regional radiance DA
  - Ongoing effort on cloudy radiance over NCEP/EMC and other development teams
- Moving nests/high resolution DA
- Observation impact study for TC forecasts

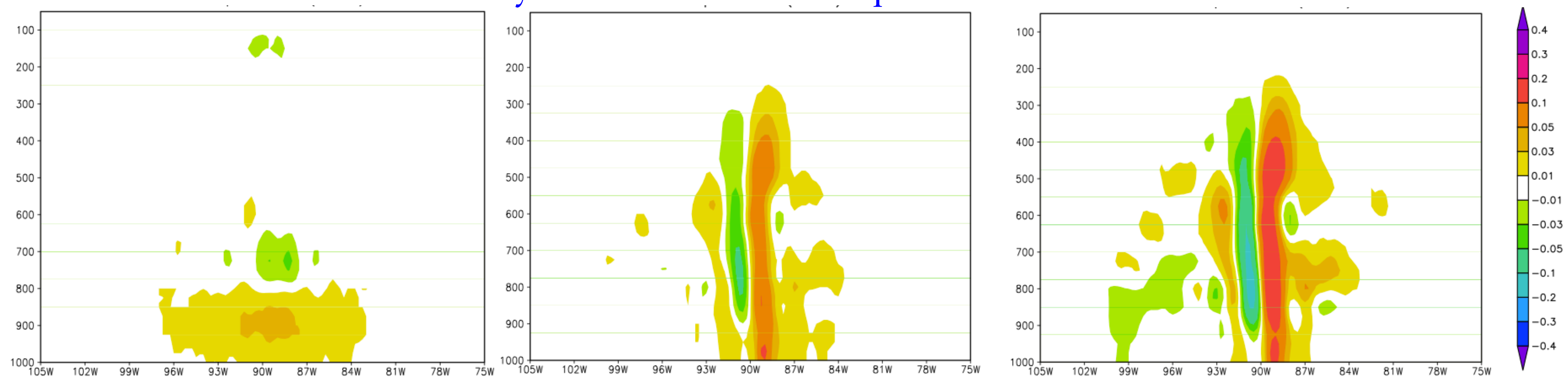
Pseudo-single Obs Test

q=1g/kg at 700mb at 28.9N, 270.5E (Isaac center)

Analysis increments of specific humidity



Analysis increments of temperature



3DVAR | Hybrid (0.25) | Ensemble

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Real Obs Test AMSU-A radiance channels at 272E, 25.12N