

# Hybrid Variational-Ensemble Data Assimilation for Tropical Cyclone Forecasts: ongoing efforts and plans



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# Outline

**Introduction:** what and why hybrid?

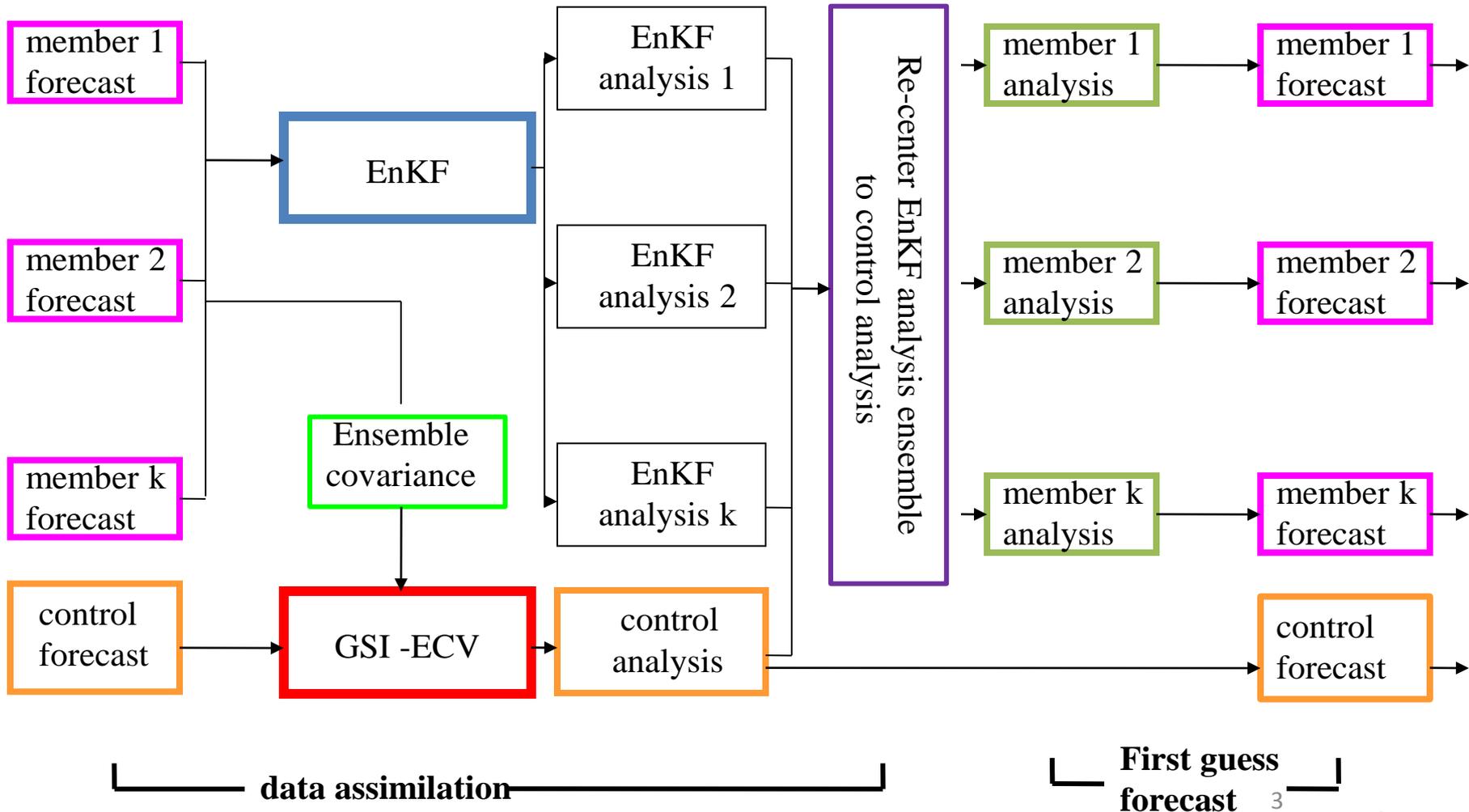
**Results of hybrid DA for**

- a). GFS Hurricane Track forecast 2010: ENS4DVAR vs. ENS3DVAR vs. GSI
- b). Diagnostics study on why hybrid provided better track forecast for Ike 2008
- c). High resolution radar data assimilation for hurricane Ike 2008
- d). Integration of global hybrid GSI-EnKF with regional: an encouraging story

**Plan for HWRF**



# Hybrid GSI-EnKF DA system





# Why Hybrid? “Best of both worlds”

	VAR (3D, 4D)	EnKF	hybrid	References (examples)
Benefit from use of flow dependent ensemble covariance instead of static B		x	x	Hamill and Snyder 2000; Wang et al. 2007b,2008ab, 2009b; Zhang et al. 2009; Buehner et al. 2010ab; Wang 2011;
Robust for small ensemble			x	Wang et al. 2007b, 2009b; Buehner et al. 2010b
Better localization for integrated measure, e.g. satellite radiance; radar with attenuation			x	Campbell et al. 2010
Easiness to add various constraints	x		x	
Outer loops	x		x	
More use of various existing capability in VAR	x		x	

Summarized in Wang 2010, MWR



# How to incorporate ensemble in GSI?

- Extended control variable method (Wang 2010, MWR):

$$\begin{aligned}
 J(\mathbf{x}'_1, \boldsymbol{\alpha}) &= \beta_1 J_1 + \beta_2 J_e + J_o \\
 &= \beta_1 \frac{1}{2} \mathbf{x}'_1{}^T \mathbf{B}^{-1} \mathbf{x}'_1 + \beta_2 \frac{1}{2} \boldsymbol{\alpha}^T \mathbf{C}^{-1} \boldsymbol{\alpha} + \frac{1}{2} (\mathbf{y}^{o'} - \mathbf{H}\mathbf{x}')^T \mathbf{R}^{-1} (\mathbf{y}^{o'} - \mathbf{H}\mathbf{x}')
 \end{aligned}$$

Extra term associated with extended control variable

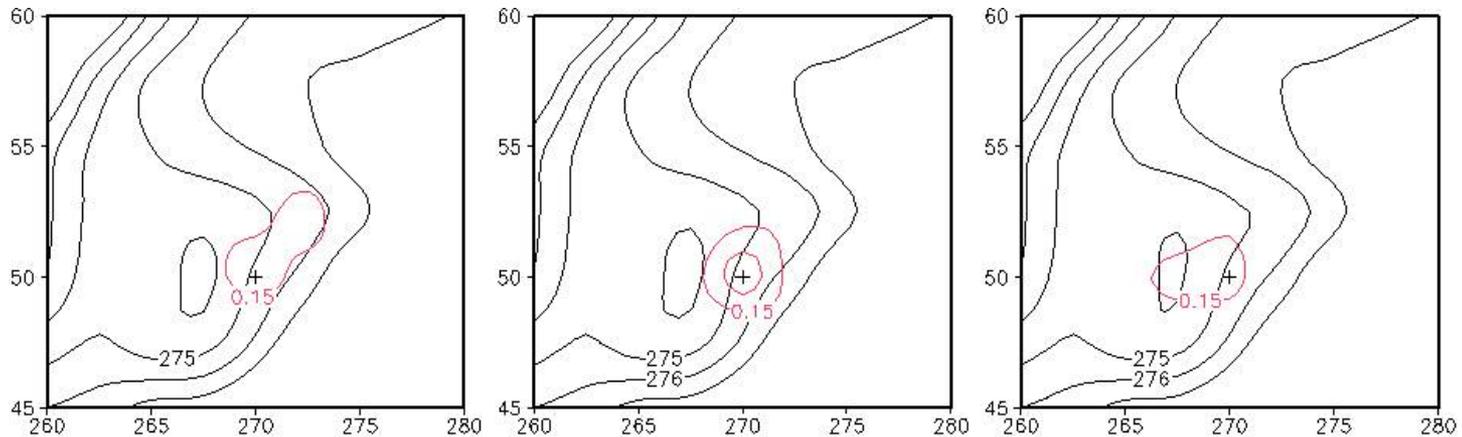
$$\mathbf{x}' = \mathbf{x}'_1 + \sum_{k=1}^K (\boldsymbol{\alpha}_k \circ \mathbf{x}_k^e)$$

Extra increment associated with ensemble

**B** 3DVAR static covariance; **R** observation error covariance;  $K$  ensemble size;  
**C** correlation matrix for ensemble covariance localization;  $\mathbf{x}_k^e$   $k$ th ensemble perturbation;  
 $\mathbf{x}'_1$  3DVAR increment;  $\mathbf{x}'$  total (hybrid) increment;  $\mathbf{y}^{o'}$  innovation vector;  
**H** linearized observation operator;  $\beta_1$  weighting coefficient for static covariance;  
 $\beta_2$  weighting coefficient for ensemble covariance;  $\boldsymbol{\alpha}$  extended control variable.

# Ensemble 4DVAR (ENS4DVAR) for GSI

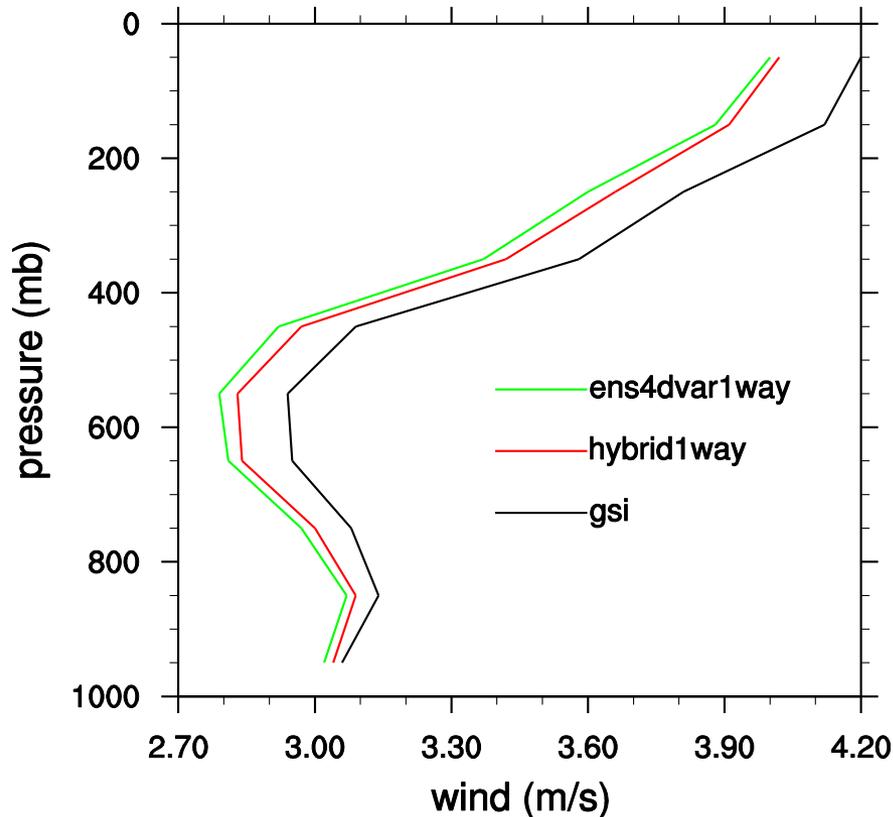
- Like traditional 4DVAR, 4D analyses are obtained by fitting observations spanning the assimilation window.
- Unlike traditional 4DVAR, ens4dvar does not need to develop the tangent linear and adjoint of the forecast model (Tian et al. 2008, Liu et al. 2008).



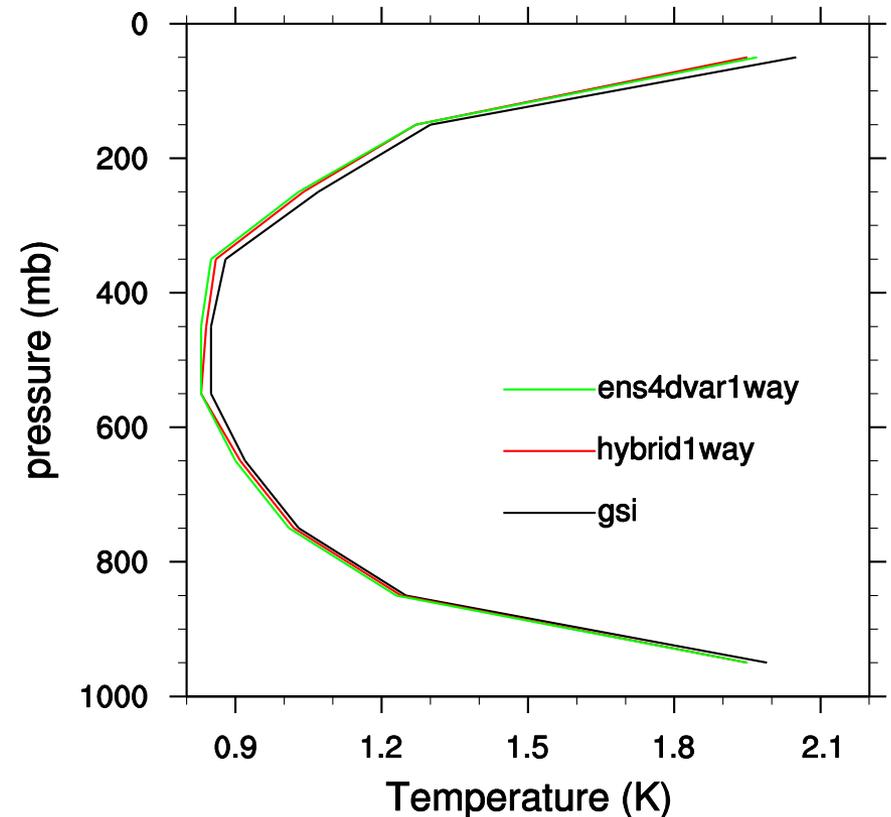


# RMSE of global forecasts by GFS

6h rms for wind global



6h rms for temp global



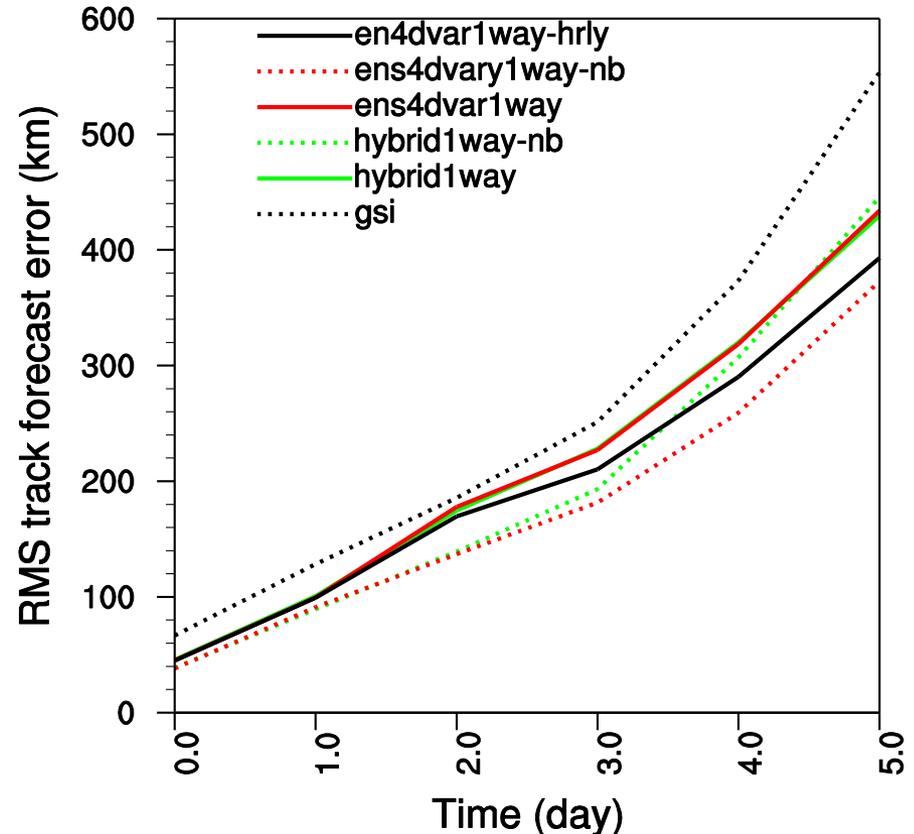
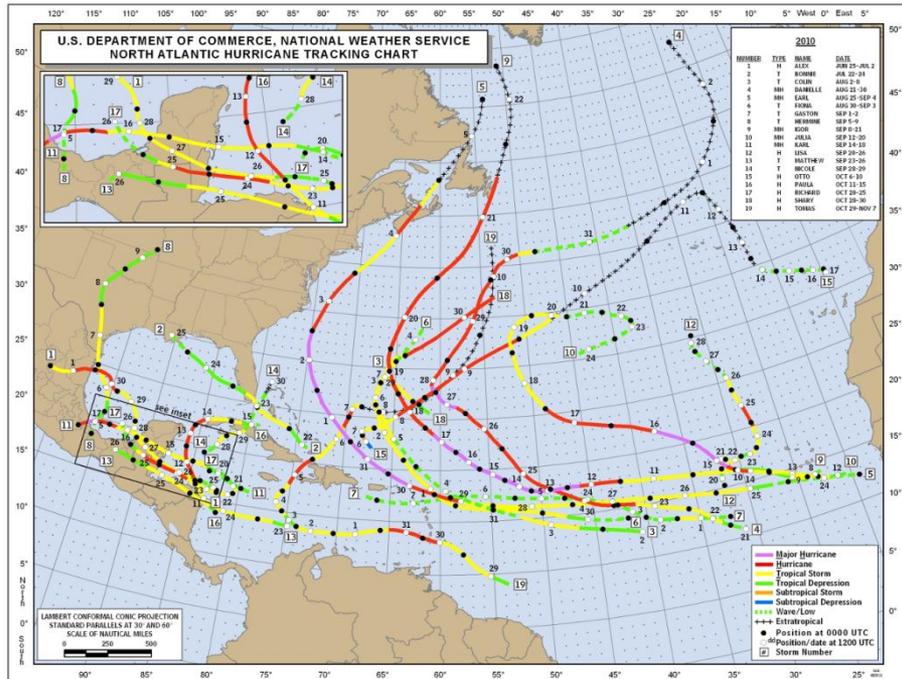
- Significant improvement of ens3dvar hybrid and ens4dvar hybrid over GSI
- ens4dvar showed further improvement over ens3dvar especially for wind



# Hurricane track forecasts by GFS

2010 Aug.-Sep.

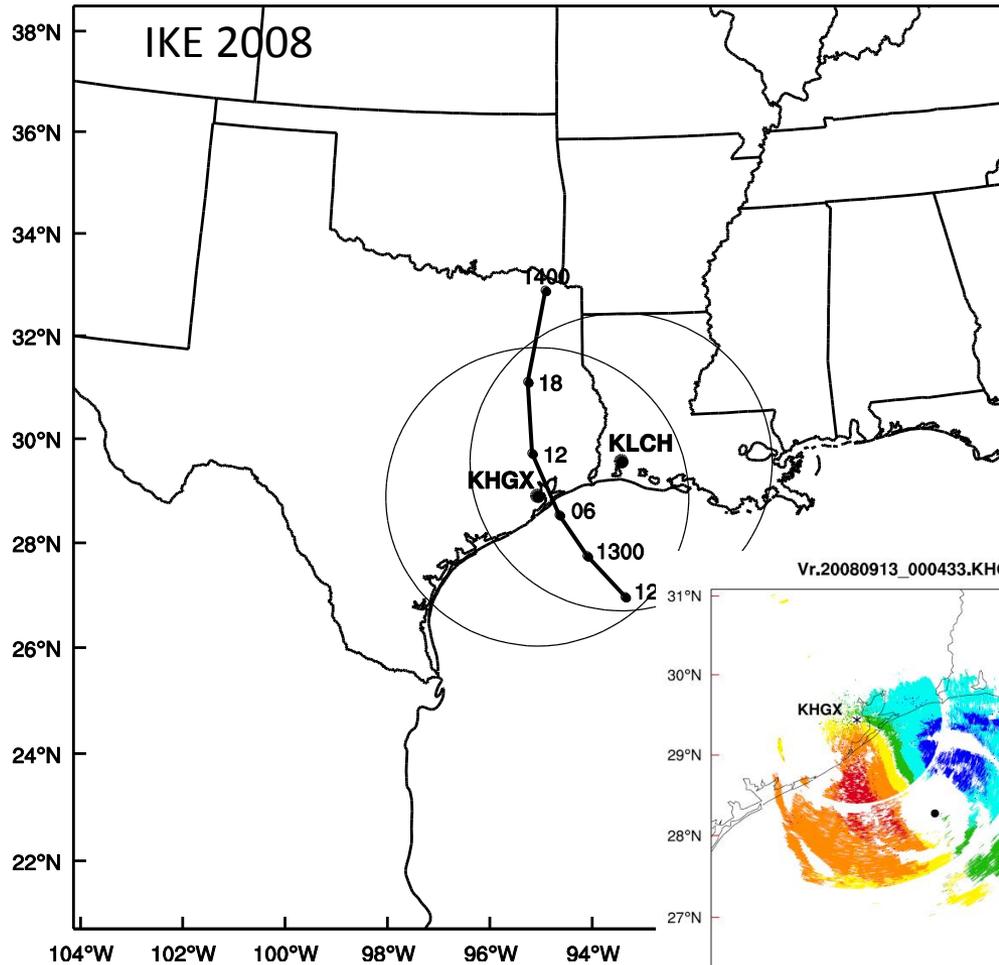
2010 hurricane



- Improvement of TC track forecasts by ens3dvar hybrid than GSI and further improvement by ens4dvar hybrid.
  - Balance constraint in GSI hurt TC forecast of hybrid.
- Lei, Wang et al. 2011

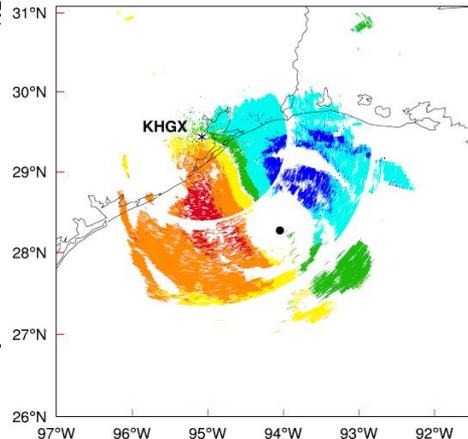


# Radar hybrid DA for hurricane

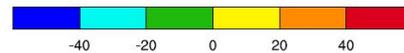
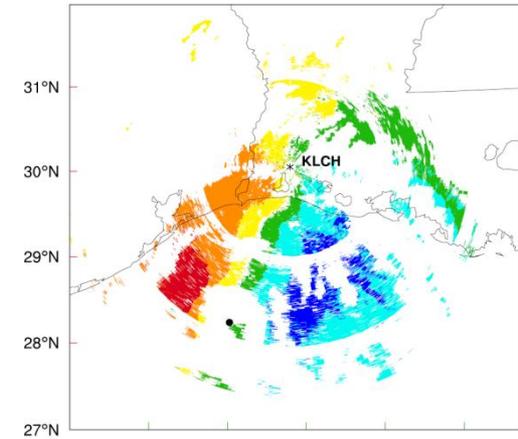


- **WRF:**  $\Delta x=5\text{km}$
- **Observations:** radial velocity from two WSR88D radars (KHGX, KLCH)

Vr.20080913\_000433.KHGX.0.5



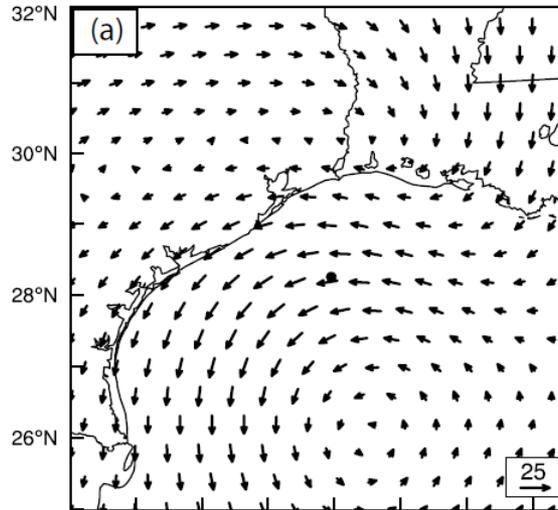
Vr.20080913\_000324.KLCH.0.5



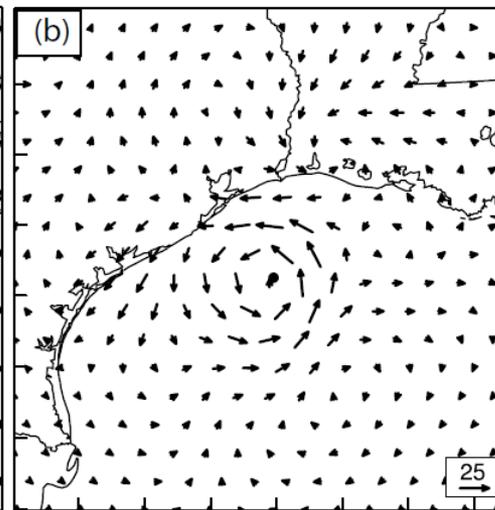


# Wind increment

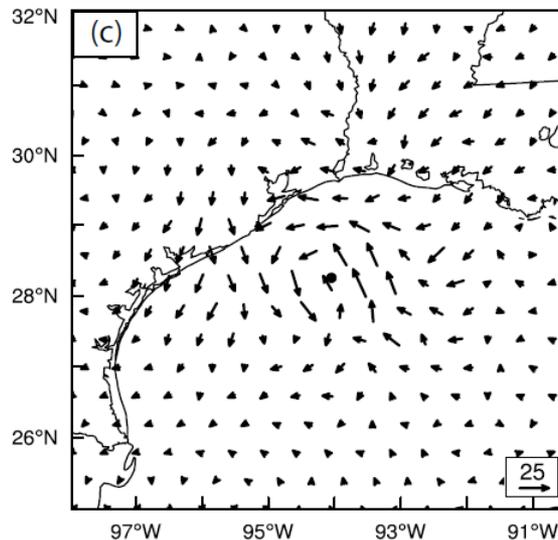
3DVAR with un-tuned static covariance (3DVARa)



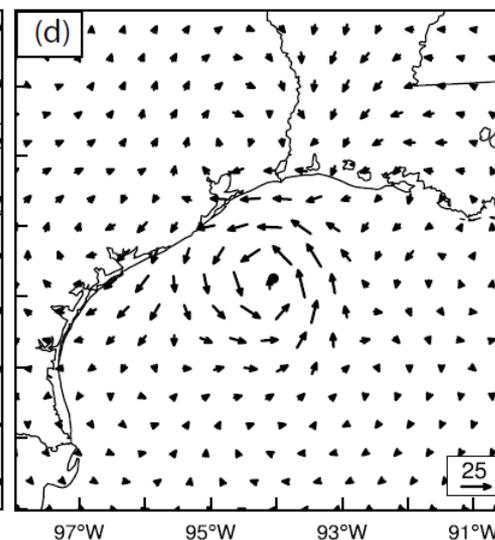
3DVAR with tuned static covariance (3DVARb)



Hybrid with full ensemble covariance (hybrid1)



Hybrid with half ensemble covariance and half static covariance (hybrid.5)



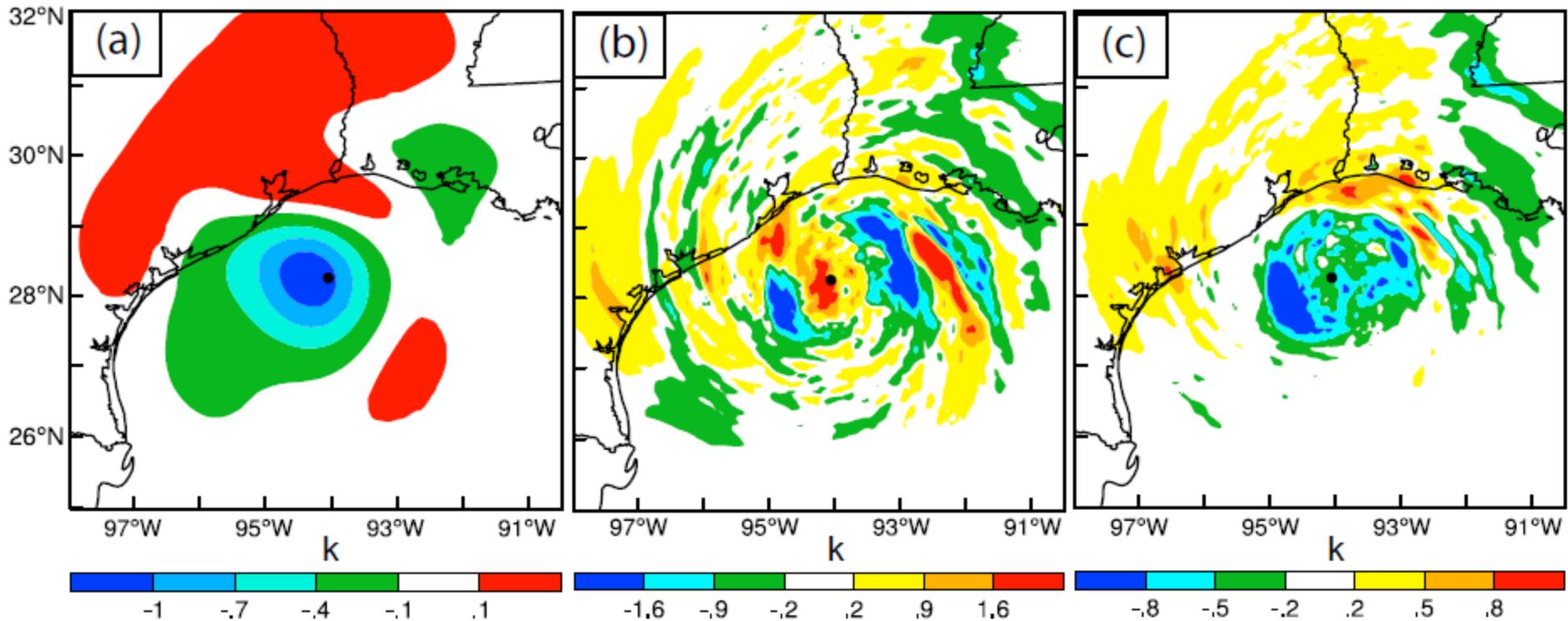


# Temperature increment

3DVARb

Hybrid1

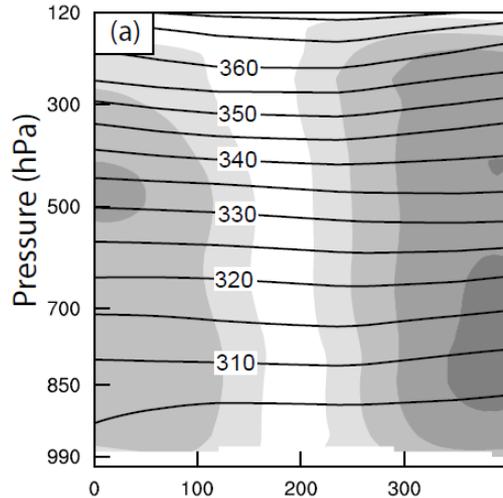
Hybrid.5



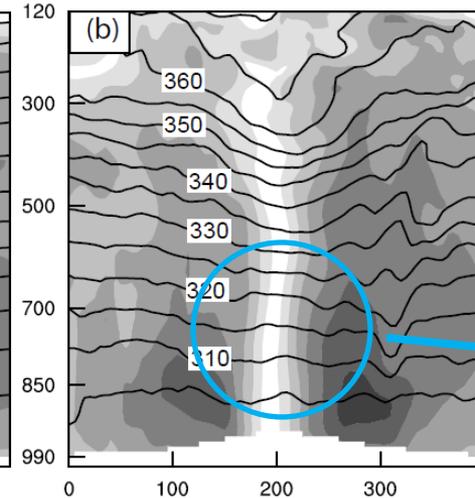


# Wind and pot. temperature analyses

No Radar DA

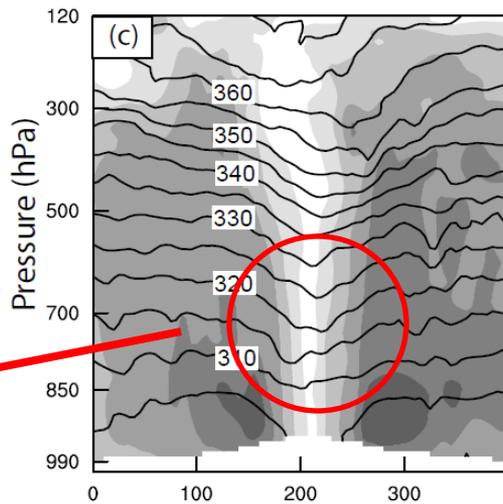


3DVARb



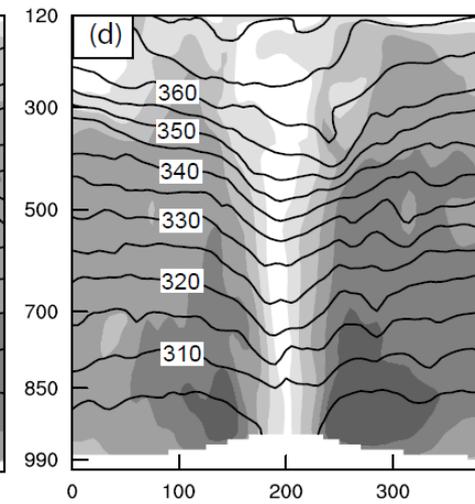
Cold core

Hybrid1



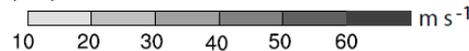
Warm core

Hybrid.5



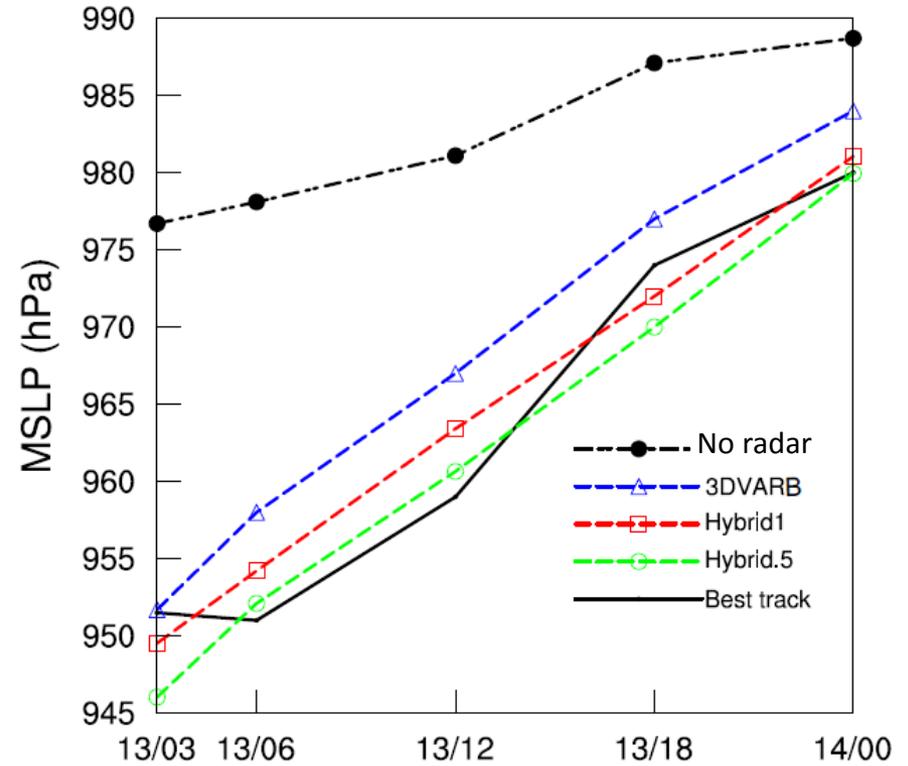
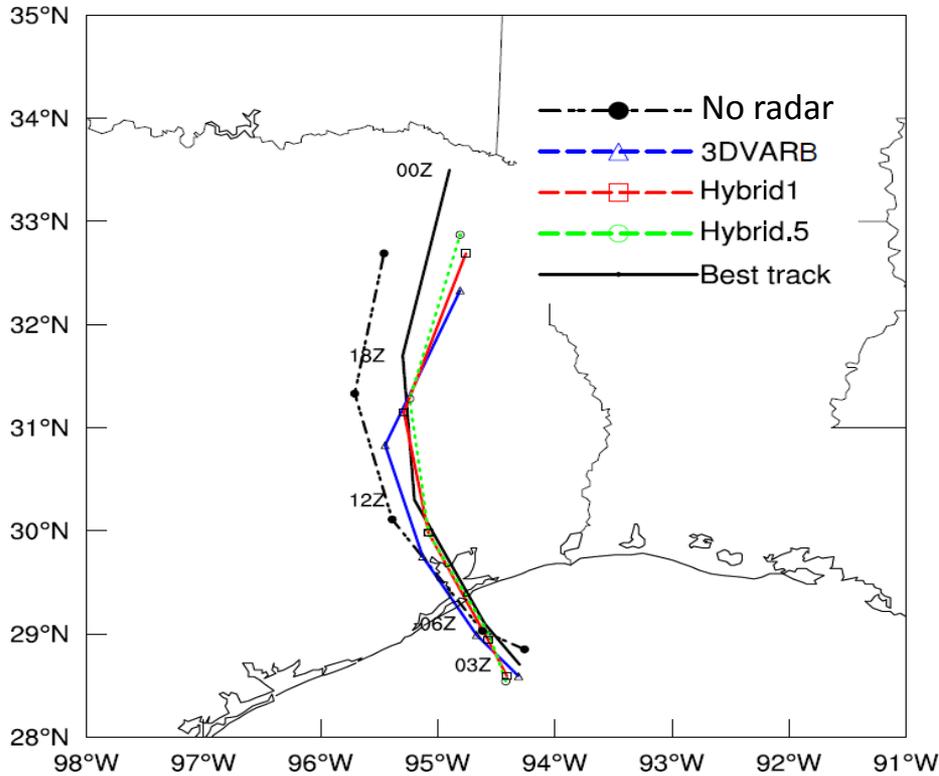
Distance (km)

Distance (km)



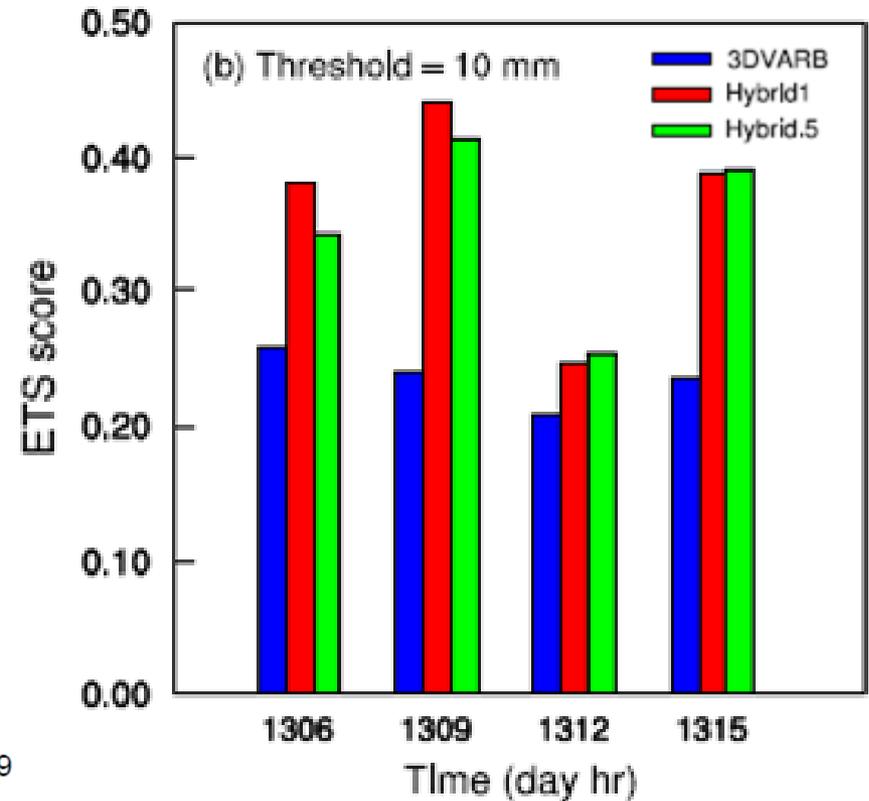
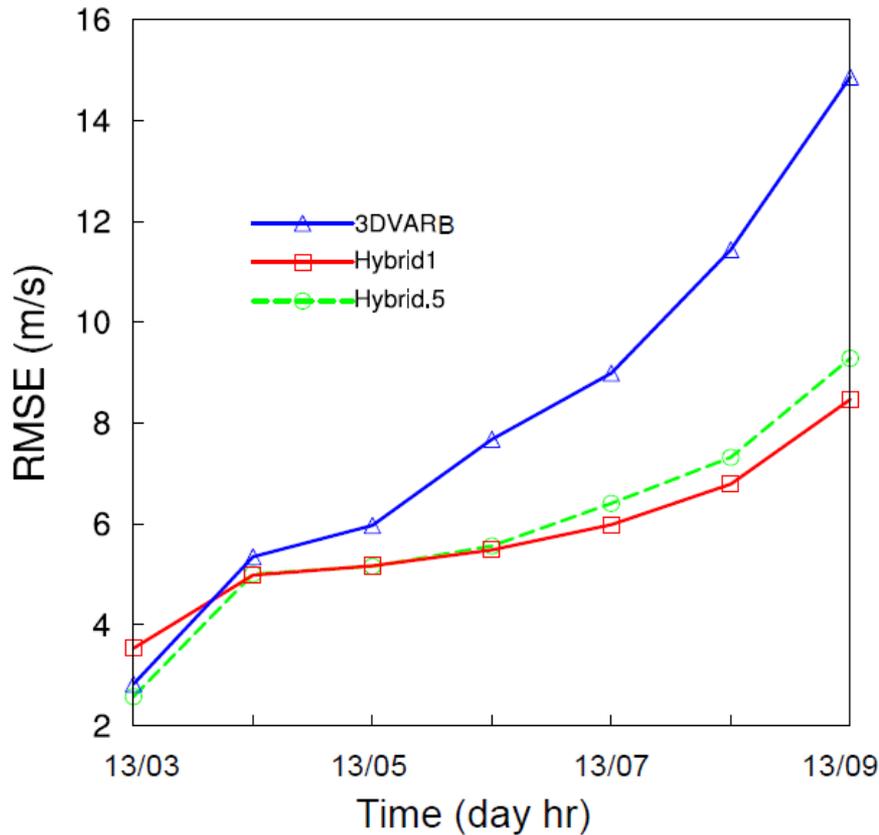


# Track and intensity forecasts



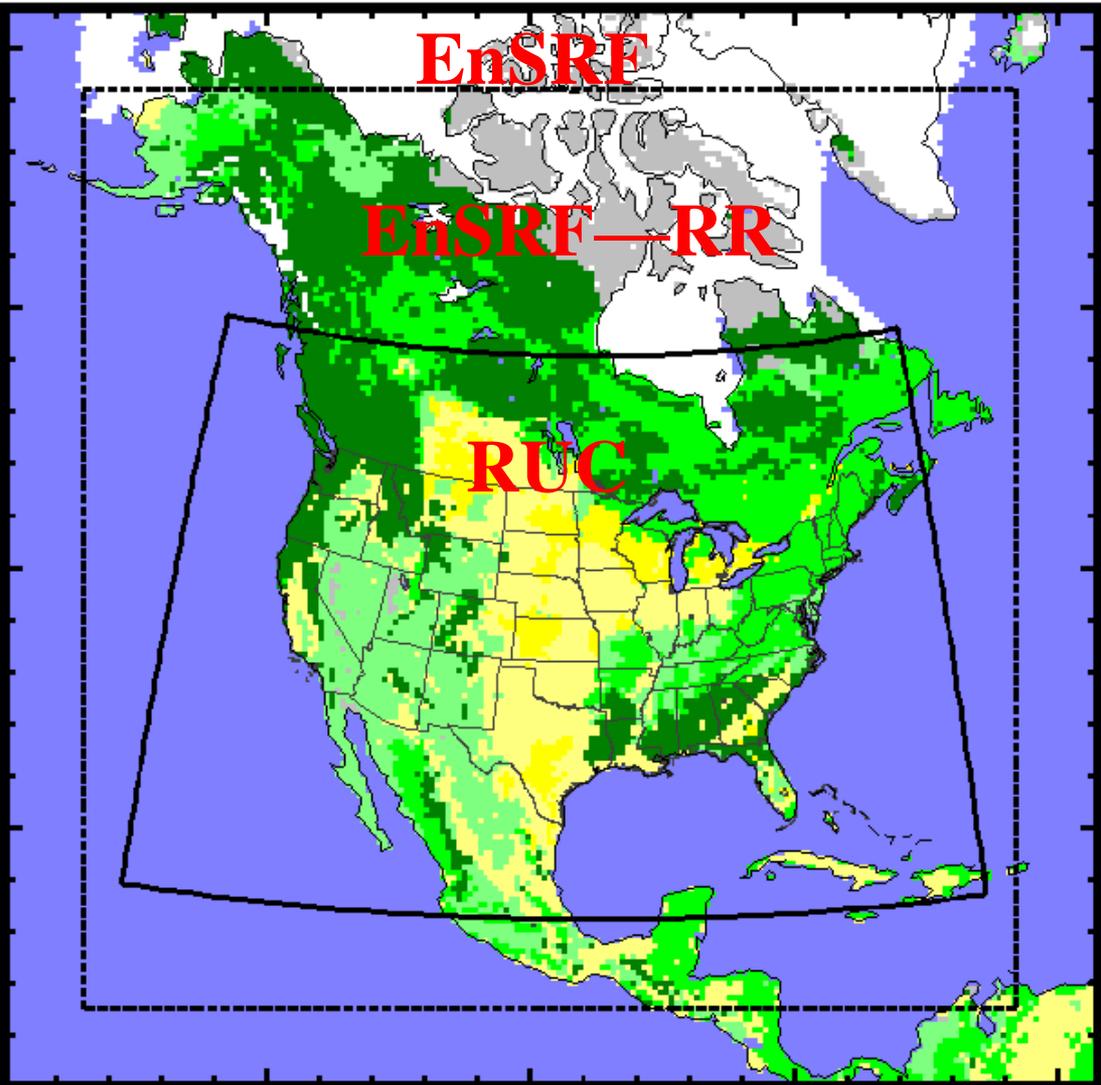


# Wind and Precipitation forecasts





# Integration of the global hybrid to the regional



**Model:** WRF ARW,

**Ensemble size:** 40

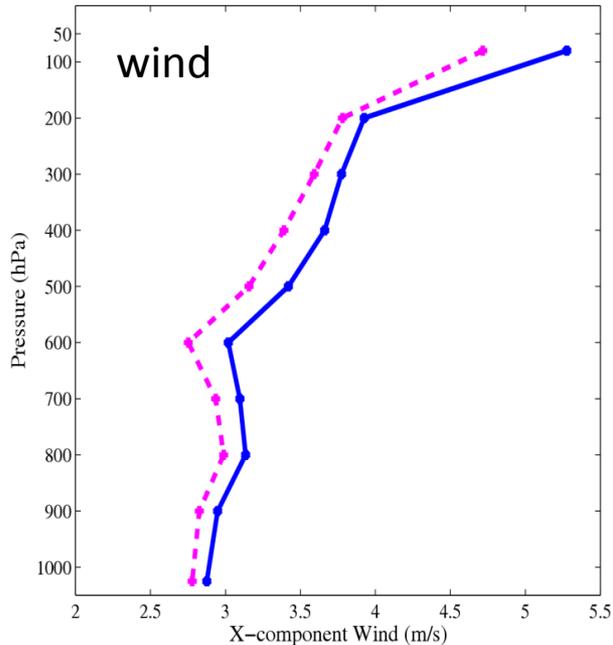
**Observations:**  
operational data except  
satellite radiances

May 8-16, 2010

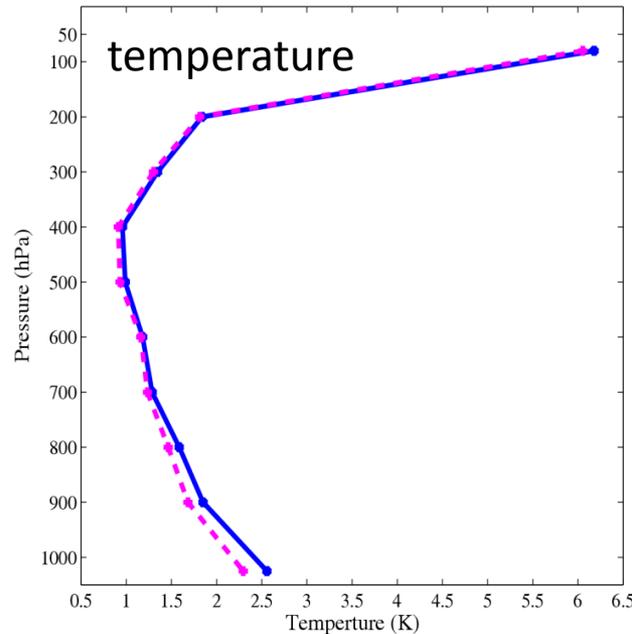


# Successful integration

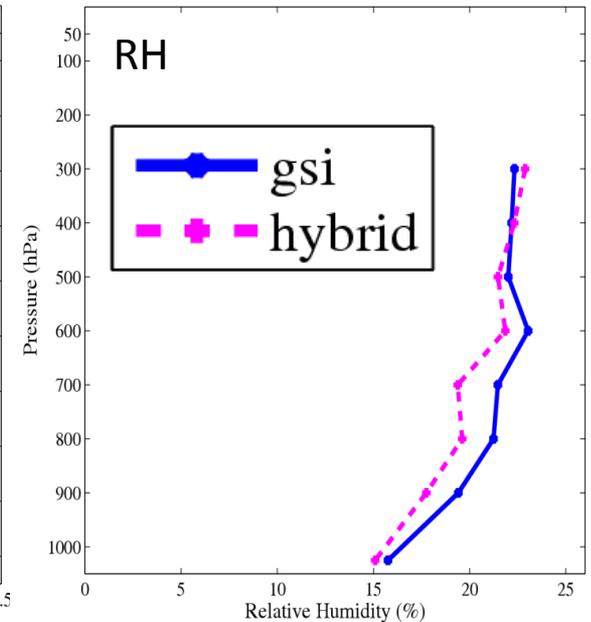
UGRDADPUPA,f3



TMPADPUPA,f3



RHADPUPA,f3



- The global hybrid GSI-EnKF system is successfully integrated with the regional WRF ARW model for operational Rapid Refresh system.
- Experience gained will help conduct the same integration and test for HWRF.



# Summary

- Ensemble-4DVAR (no tangent linear and adjoint needed) was developed for GSI and tested for GFS. Ensemble-4DVAR further improved upon the ENS3DVAR hybrid for TC track forecasts. Balance constraint in GSI hurt TC forecasts using hybrid.
- Plan on quasi real time demo of ens4dvar for the global system 2012 with ESRL. Apply ens4dvar for the regional.
- The hybrid was also implemented for high resolution radar data assimilation for TC forecast and showed improvement over 3DVAR.
- The global hybrid system was successfully integrated with the regional WRF ARW model for operational RR system.

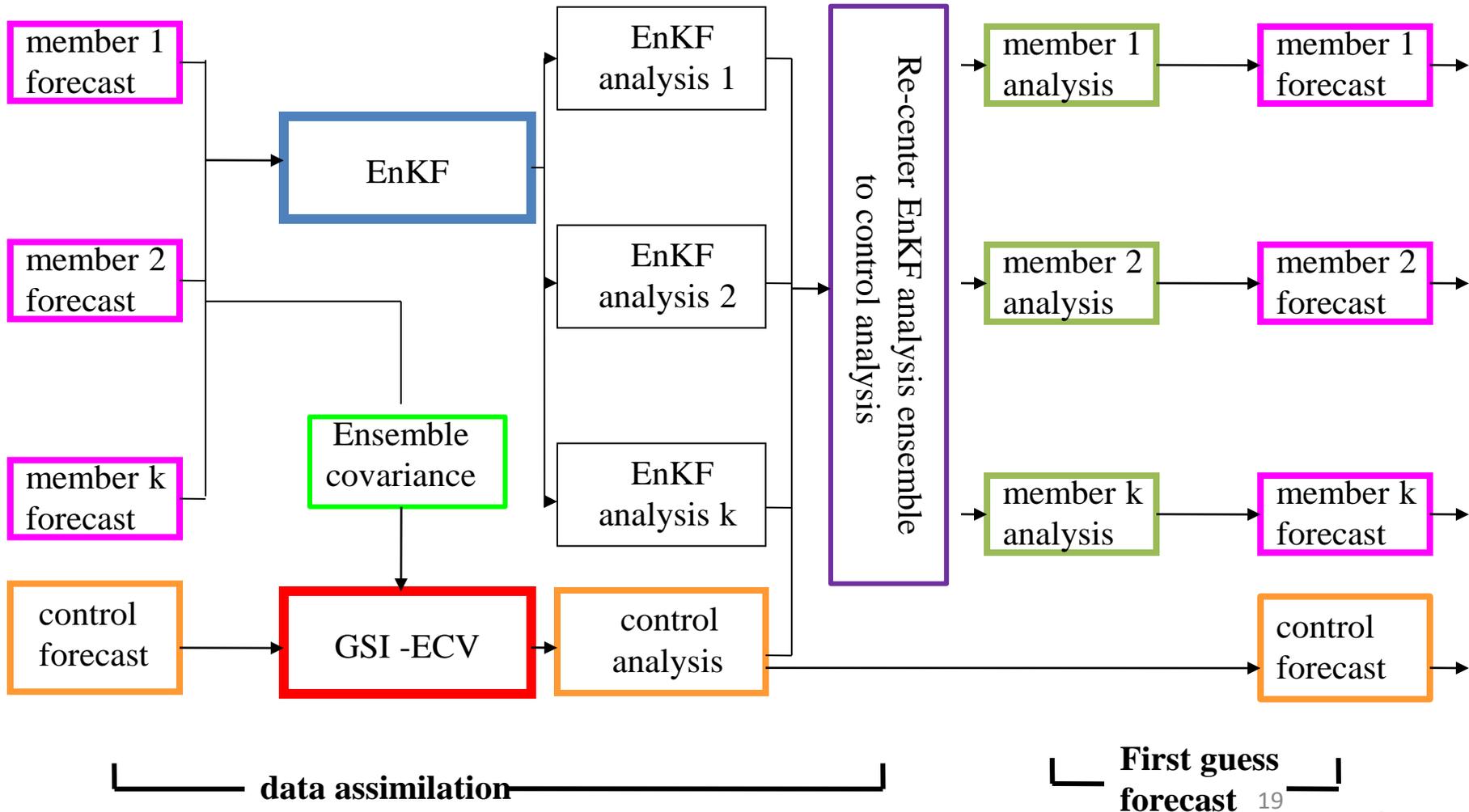


# A proposal to HFIP

- “Improving High-Resolution Tropical Cyclone Prediction Using a Unified GSI-based Hybrid Ensemble-Variational Data Assimilation System for HWRF” by Xuguang Wang (PI) and Ming Xue (co-PI), University of Oklahoma**
- The extension, application and extensive testing of GSI-based hybrid DA for the HWRF modeling system, at high resolutions, and including both environmental and inner-core observations, is the primary goal of this proposal.**
- Specific approaches, execution plan, milestones, deliverables, collaboration with EMC, AOML, ESRL, DTC were proposed.**



# Hybrid GSI-EnKF DA system





# Plans

- ❑ Leverage and contribute to the efforts by ESRL and AOML to interface and test the global EnKF with HWRF, and to add inner core data assimilation capability.
- ❑ Leveraging the framework from EMC, further extend and add various new capabilities of GSI-ECV for HWRF (hydrometeors, ENS4DVAR, balance weak constraint etc). 9 km domain was planned to be bigger than EMC to have less frequent domain changes.
- ❑ Select a retrospective case with airborne Doppler radar, ground-based radar and other inner-core observations available (with EMC and AOML).
- ❑ Extensive testing, tuning of the outer HWRF domain nested within the global hybrid (prepare global hybrid with ESRL and EMC).
- ❑ For the 3 km domain DA, we will gradually increase its degree of sophistication before reaching its own fully cycled hybrid DA.



# Plans (continued)

- ❑ Conduct comprehensive evaluations and verifications for this case.
- ❑ Repeat with other cases and select the best configuration for HWRF hybrid DA based on these results.
- ❑ Prepare and run the system in (quasi) real time (stream 2) for 2012 season.
- ❑ Conduct tests with more retrospective cases and use the evaluation metrics from NHC to conduct extensive evaluation of retrospective cases in preparation for stream 1.5 testing.
- ❑ Prepare the system for real time runs (stream 1.5) for the 2013 season.
- ❑ Make the system available to DTC and help DTC to conduct further testing.

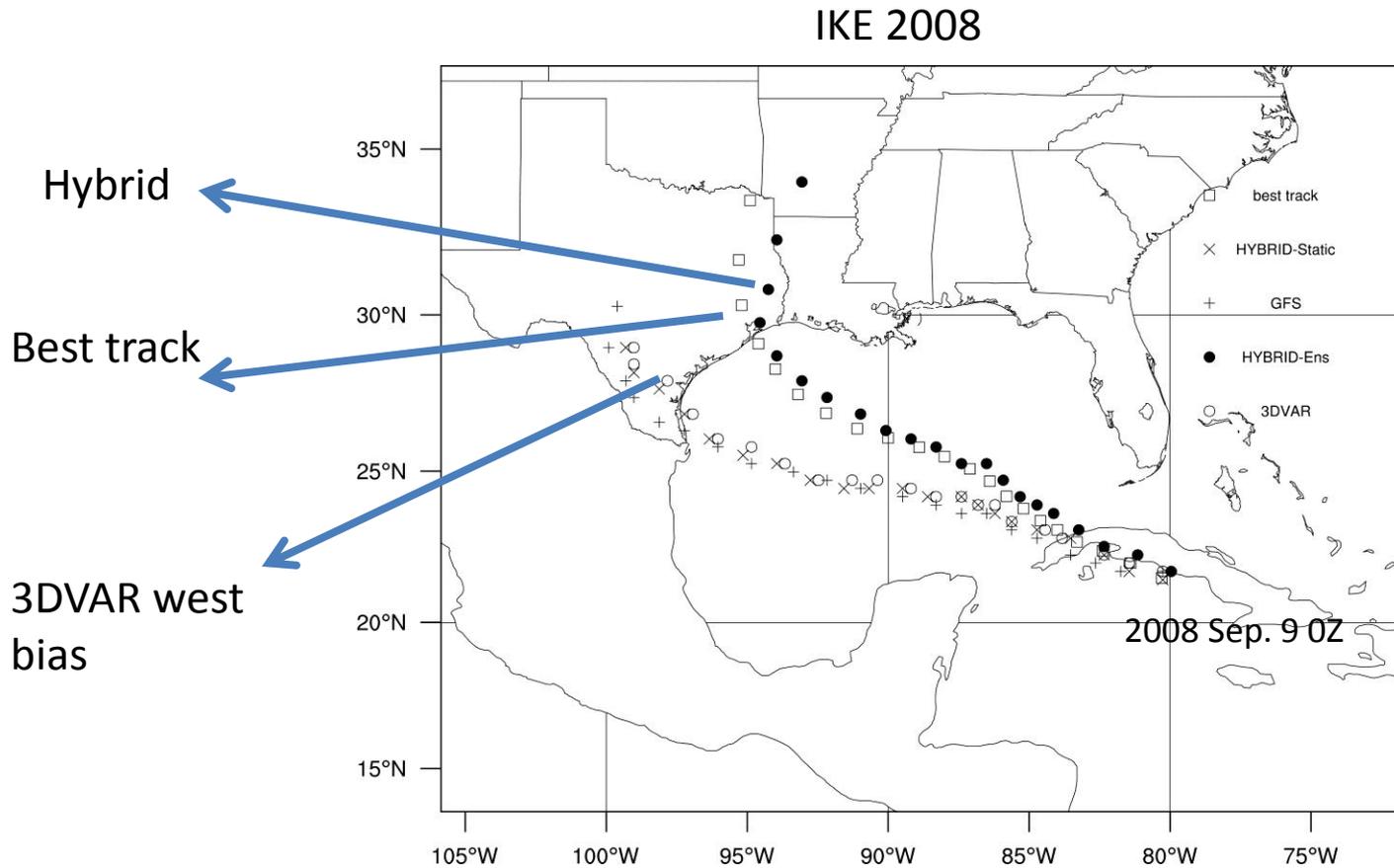


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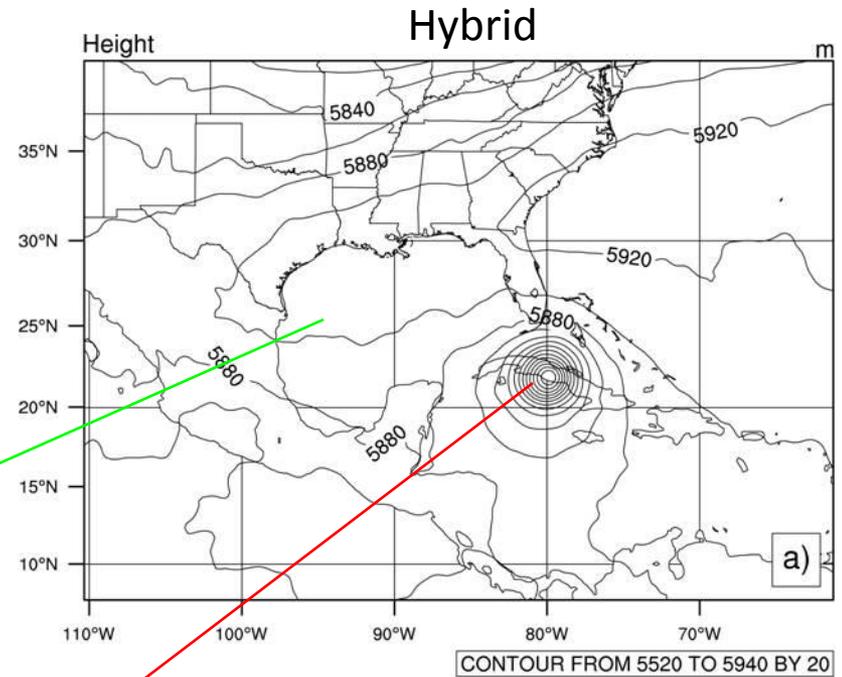
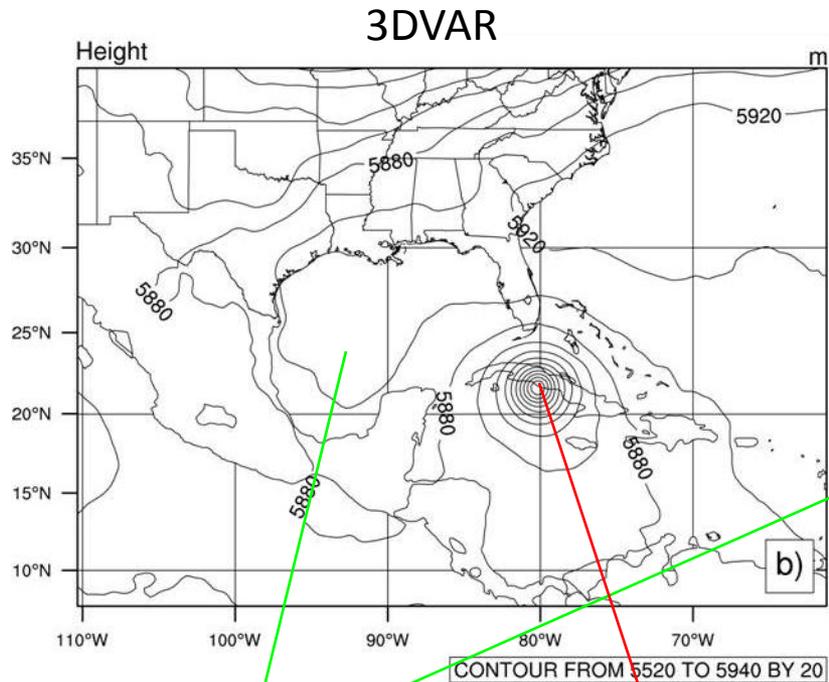


# Why hybrid produced better track forecast?





# Initial analyses: 500mb height



- The subtropical high in the 3DVAR analysis extended more to the south in the southwest quadrant of Gulf of Mexico than HYBRID.
- Weaker and smaller IKE estimated by 3DVAR.



# Analysis increment difference

