Coupling EnKF with 4DVar for mesoscale data assimilation

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Objective:

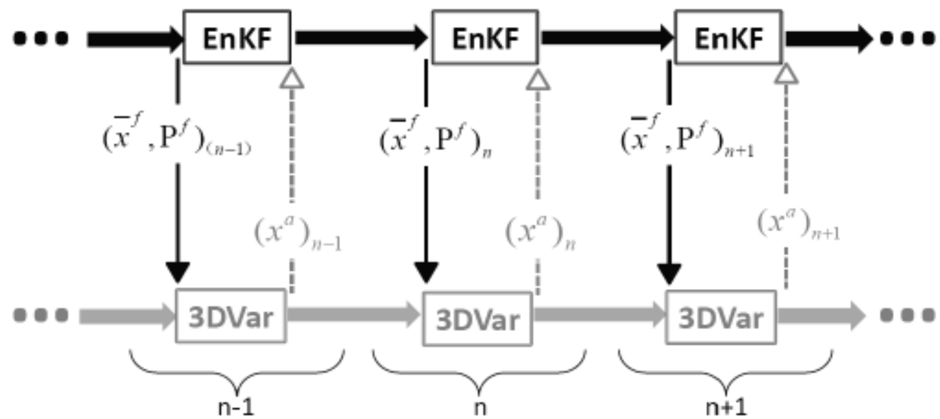
Couple version 3.4 of WRFDA with EnKF for the cloud-permitting analysis of mesoscale weather systems

Coupled EnKF-Var data assimilation

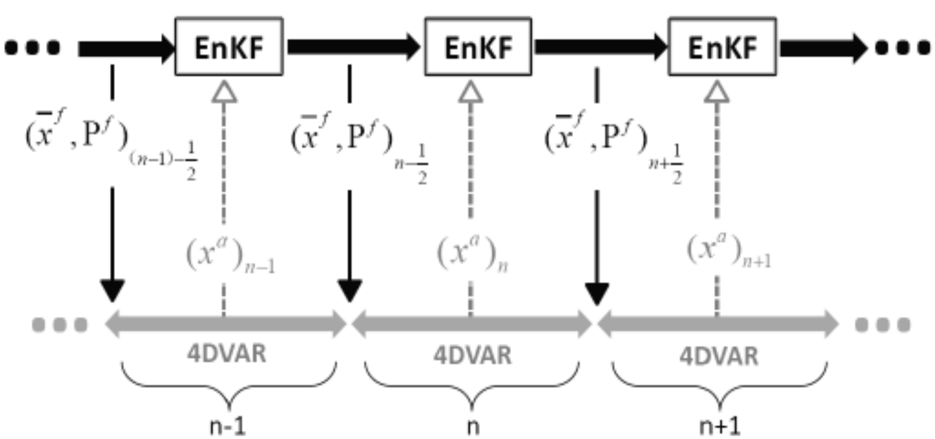
Variable Changes

- The forecast mean ($\overline{\mathbf{x}}^{\mathbf{f}}$) is used as first guess.
- Ensemble perturbations are introduced into WRFDA using extended control variables (Wang et al. 2008)
- The resulting variational analysis ($\overline{\mathbf{x}}^{\mathbf{a}}$) replaces the ensemble mean and the perturbations are updated by EnKF

E3DVAR: 3DVAR coupled with EnKF



E4DVAR: 4DVAR coupled with EnKF



Zhang et al. 2009 AAS; Zhang&Zhang 2011 MWR

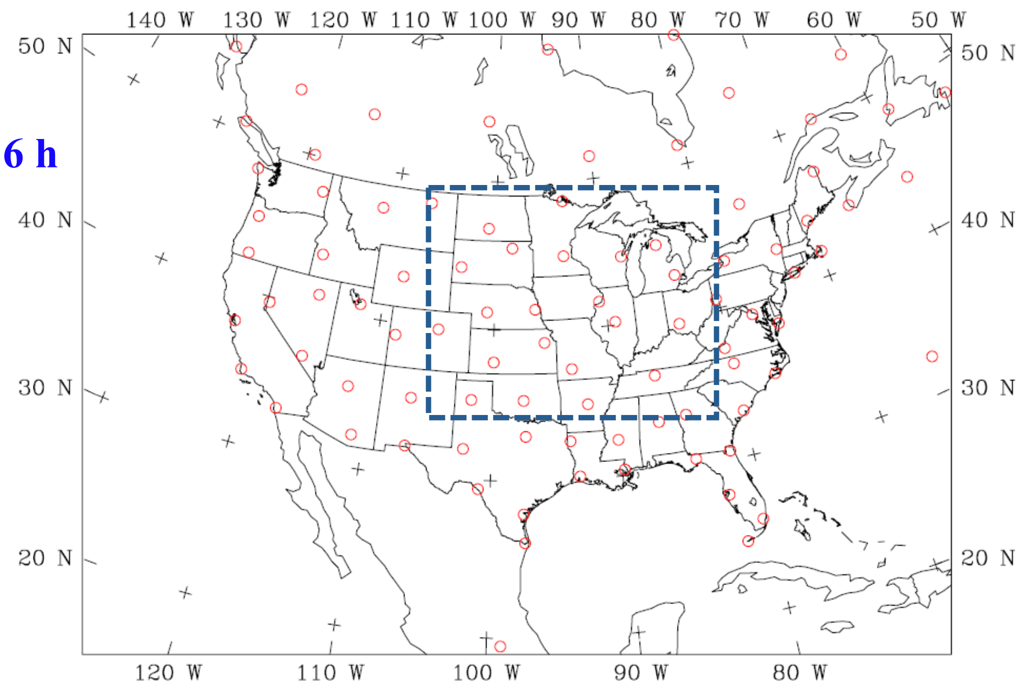
Month-long comparison of EnKF and 3/4DVar and hybrid systems

WRF-ARW V3.1 ***(****Skamarock et al. 2005****)***

-90-km grid covering North America
-27 vertical levels up to 50 hPa
-LBCs interpolated from FNL analysis every 6 h

EnKF ***(****Meng and Zhang 2008a,b****)***

-40-member ensemble
-Multi-physics parameterization
-1800-km influence radius for localization
-0.8 relaxation coefficient
-Initial ensembles are perturbed at 00Z June 1 2003, via CV5 option in WRF-Var
-Perturbed LBCs



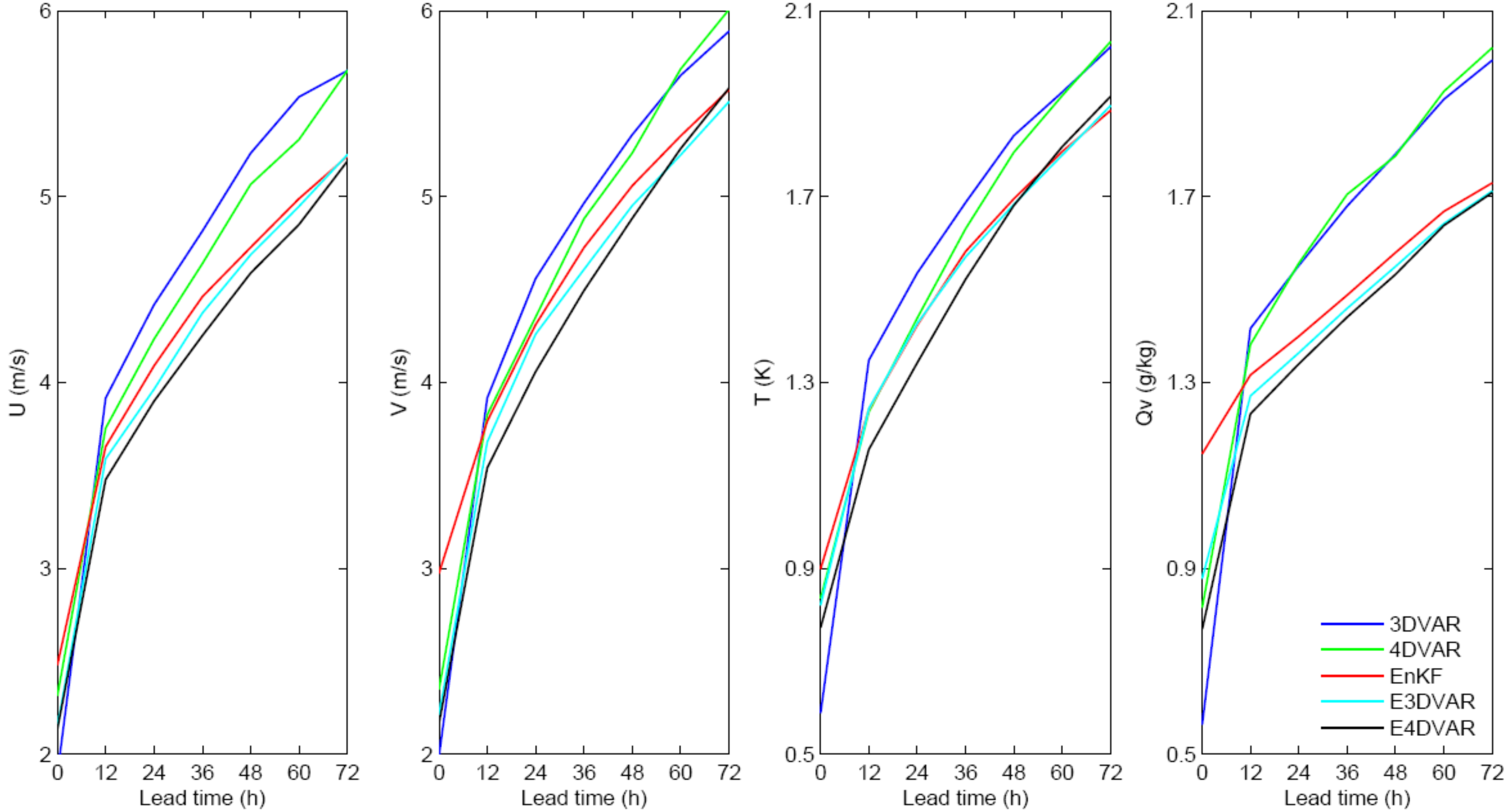
3D/4DVar of WRF-Var V3.1 ***(****Barker et al. 2004; Huang et al. 2009****)***

-NMC background error covariance (B), derived from previous month
-CV5 option with 3.0 variance scale and 1.0 length scale
-6-h assimilation window (covering -3 to +3 h at every analysis time)

(Zhang et al. 2011 MWR)

Month-long comparison of 3DVAR, 4DVAR, EnKF, E3DVAR & E4DVAR over CONUS (June 2003)

0-72hr U, V, T & Q RMS forecast error



(Zhang et al. 2012 MWR; Zhang and Zhang 2011 MWR)

Sampling in an ensemble hurricane data assimilation system

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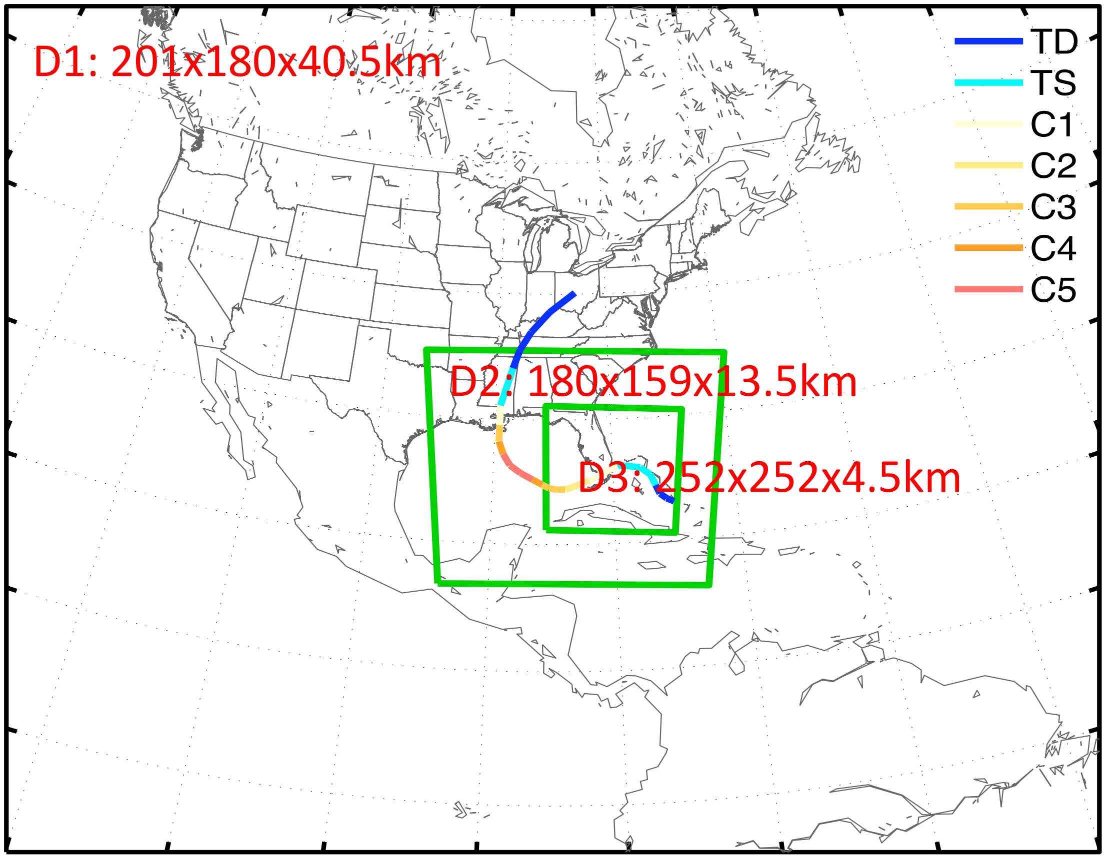
Penn State University

Objective:

Investigate the role of ensemble size and covariance relaxation in assimilating airborne Doppler radar observations for Hurricane Katrina (2005)

Poterjoy and Zhang 2011 JAS; 2012 in prep

Model Configuration



Katrina NHC best track and model domain configuration on 25 August 2005. The inner domains follow the vortex after 12 h of integration.

- WRF V3.1
- 35 vertical levels
- Two-way nested, vortex following inner domains
- WSM 6-class microphysics
- YSU PBL scheme
- Grell-Devenyi convection scheme (D1 only)

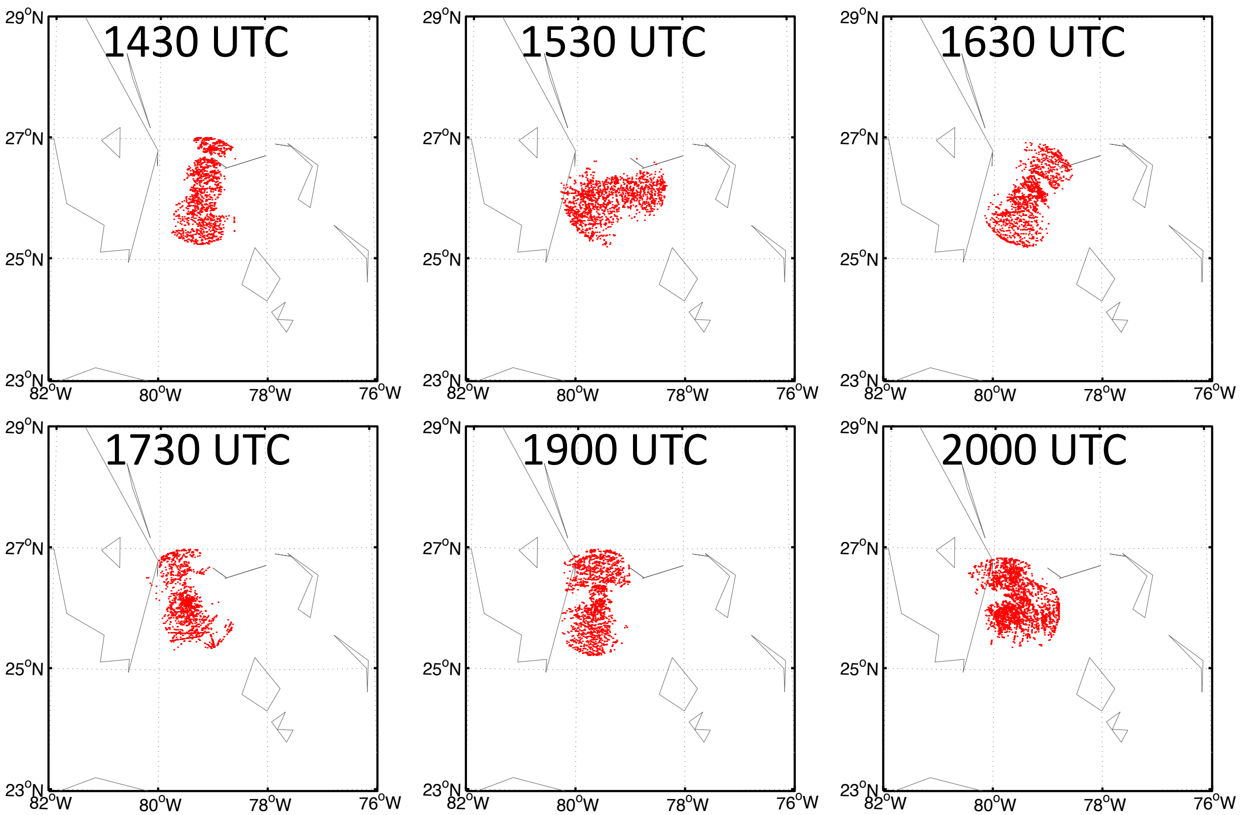
ICs: GFS analysis

BCs: GFS forecast

Perturbations: WRFDA V3

(Weng and Zhang 2012)

Data Assimilation



Radar observations from all six flight legs on August 25, 2005

- Airborne Doppler radar observations are assimilated at each flight time.
- The localization radius of influence ranges from 1215 – 135 km, depending on domain.
- A 14.5 h free-running ensemble forecast is used at the first update time.

Data Assimilation

Ensemble size experiment

- Examine the sensitivity of ensemble size, using ensembles of 30, 60, 90, 120, and 300 members
- Prior perturbations are centered on the same mean at 1430 UTC
- Covariance is inflated by relaxing 80% (α = 0.8) of posterior perturbations back to prior after each analysis: Zhang et al. 2004 MWR

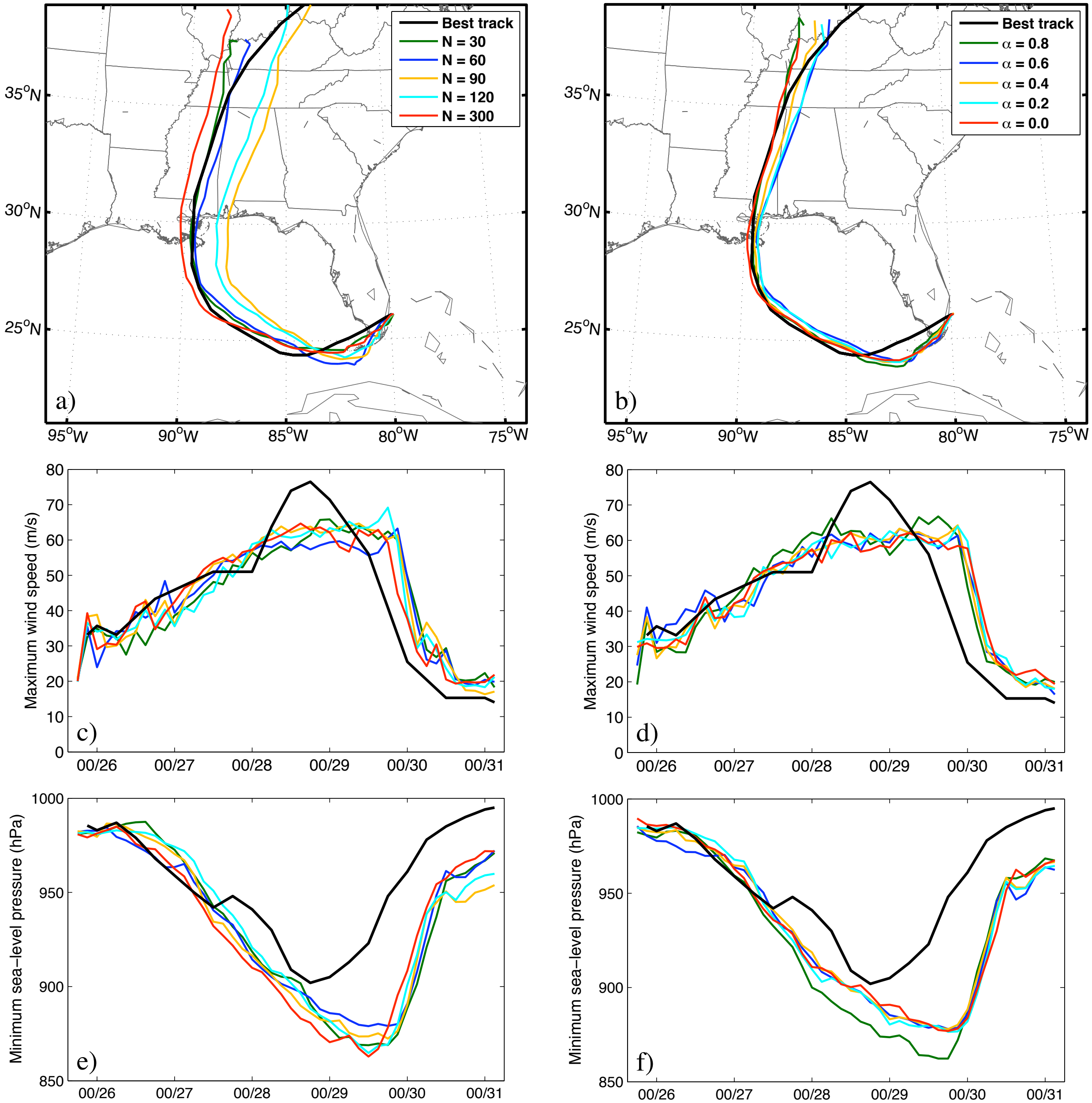
$$x'_a \rightarrow (1-\alpha)x'_a + \alpha x'_f$$

Relaxation experiment

- An ensemble size of 60 is used
- Examine the sensitivity to covariance relaxation by using relaxation coefficients (α) of 0.0, 0.2, 0.4, 0.6, and 0.8
- Cycling runs start from same prior ensemble at 1430 UTC

Forecast Results

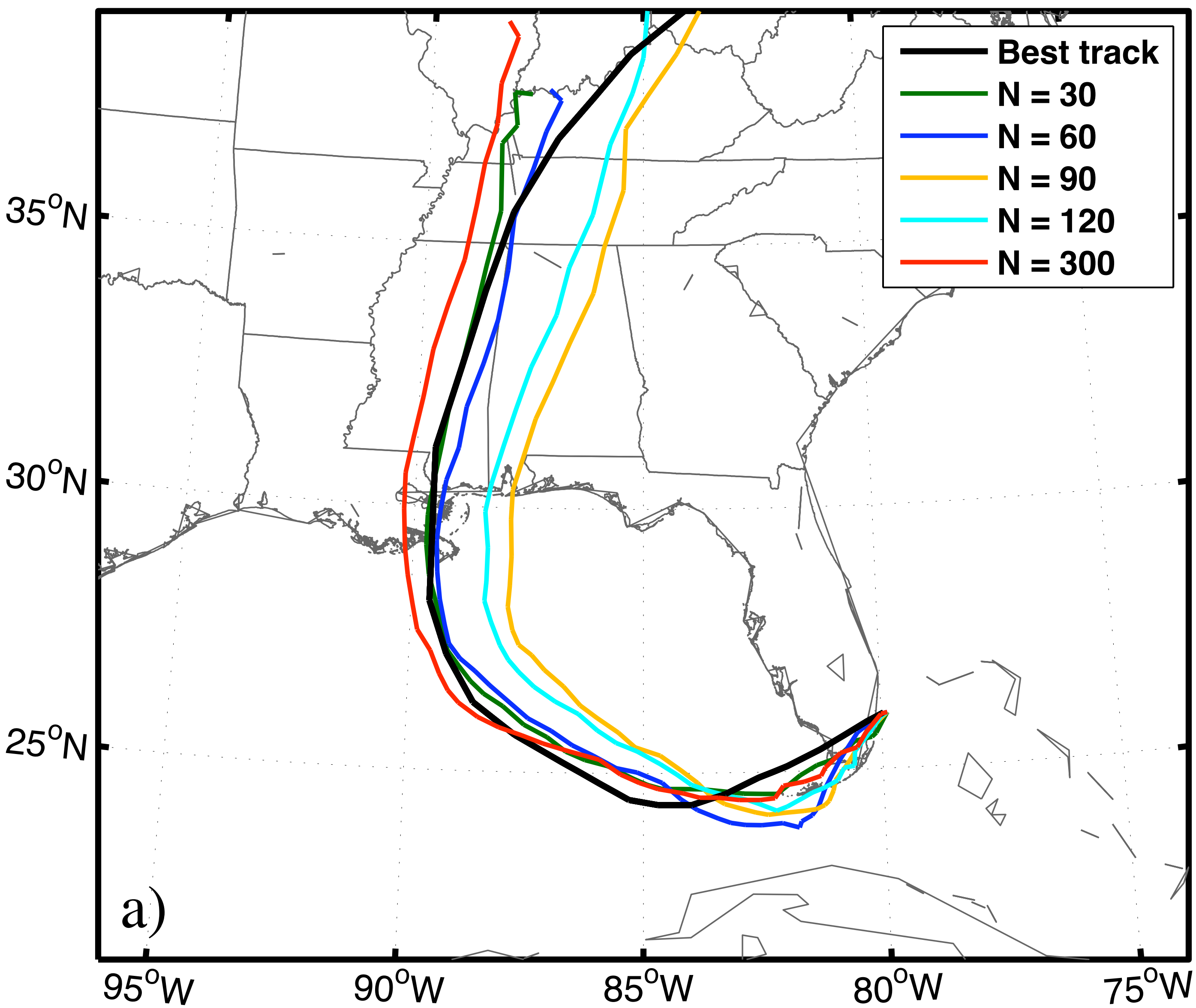
Ensemble size experiment | **Relaxation experiment**



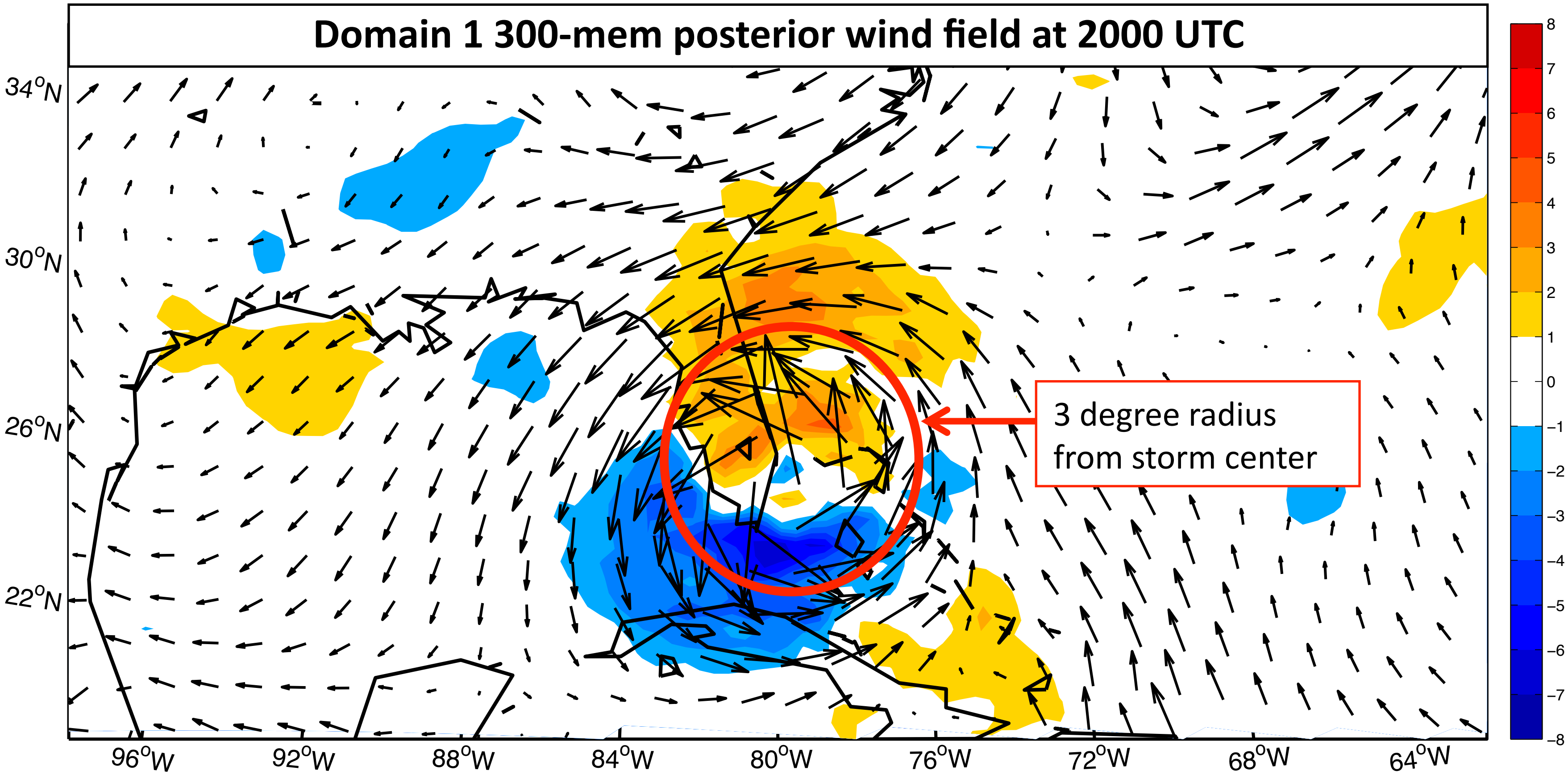
- This particular case (and verification metrics) is not sensitive to relaxation.
- The forecast track is highly sensitive to the number of ensemble members.

Forecast Results

Ensemble size experiment

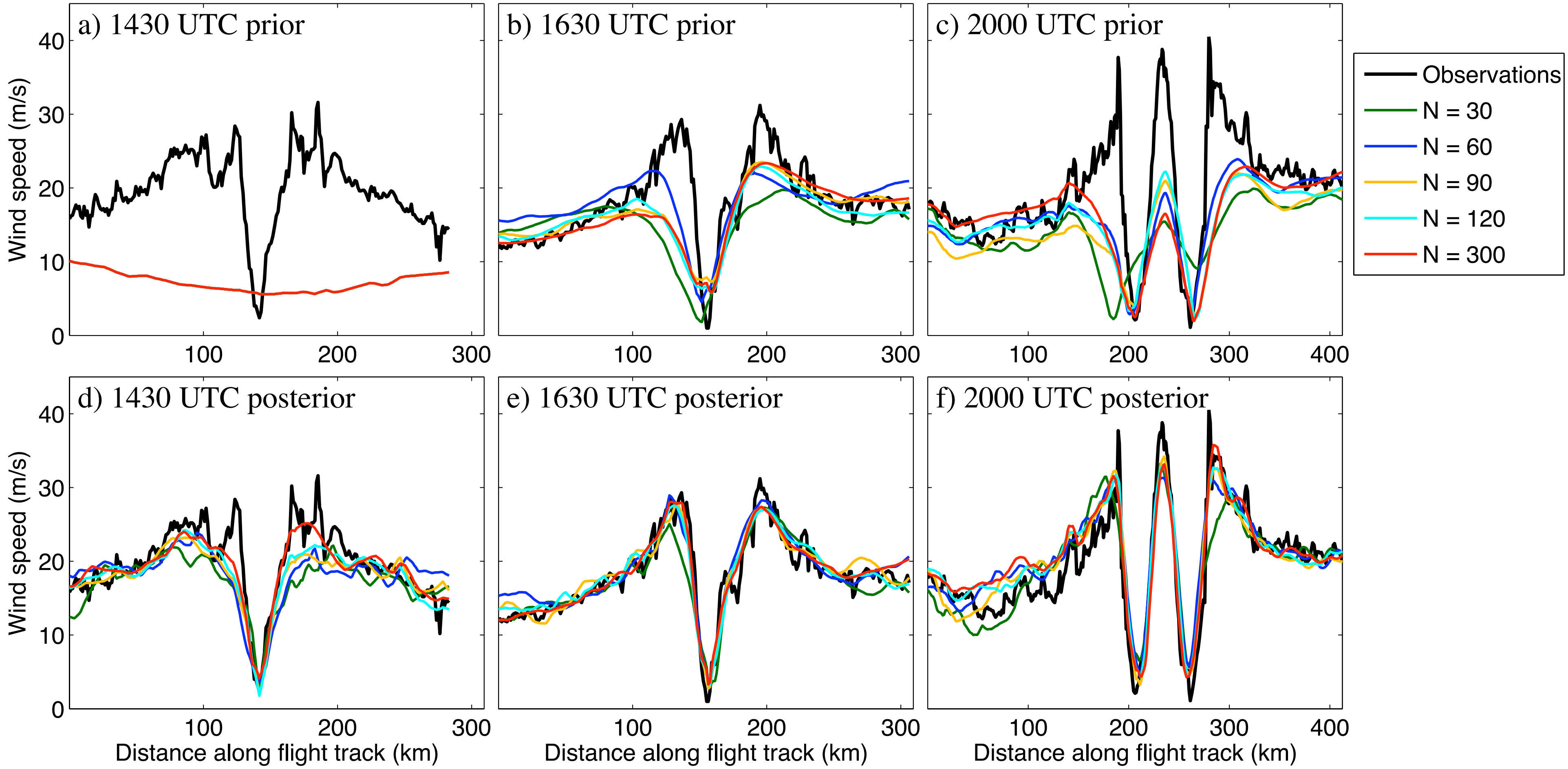


Posterior differences at last update time



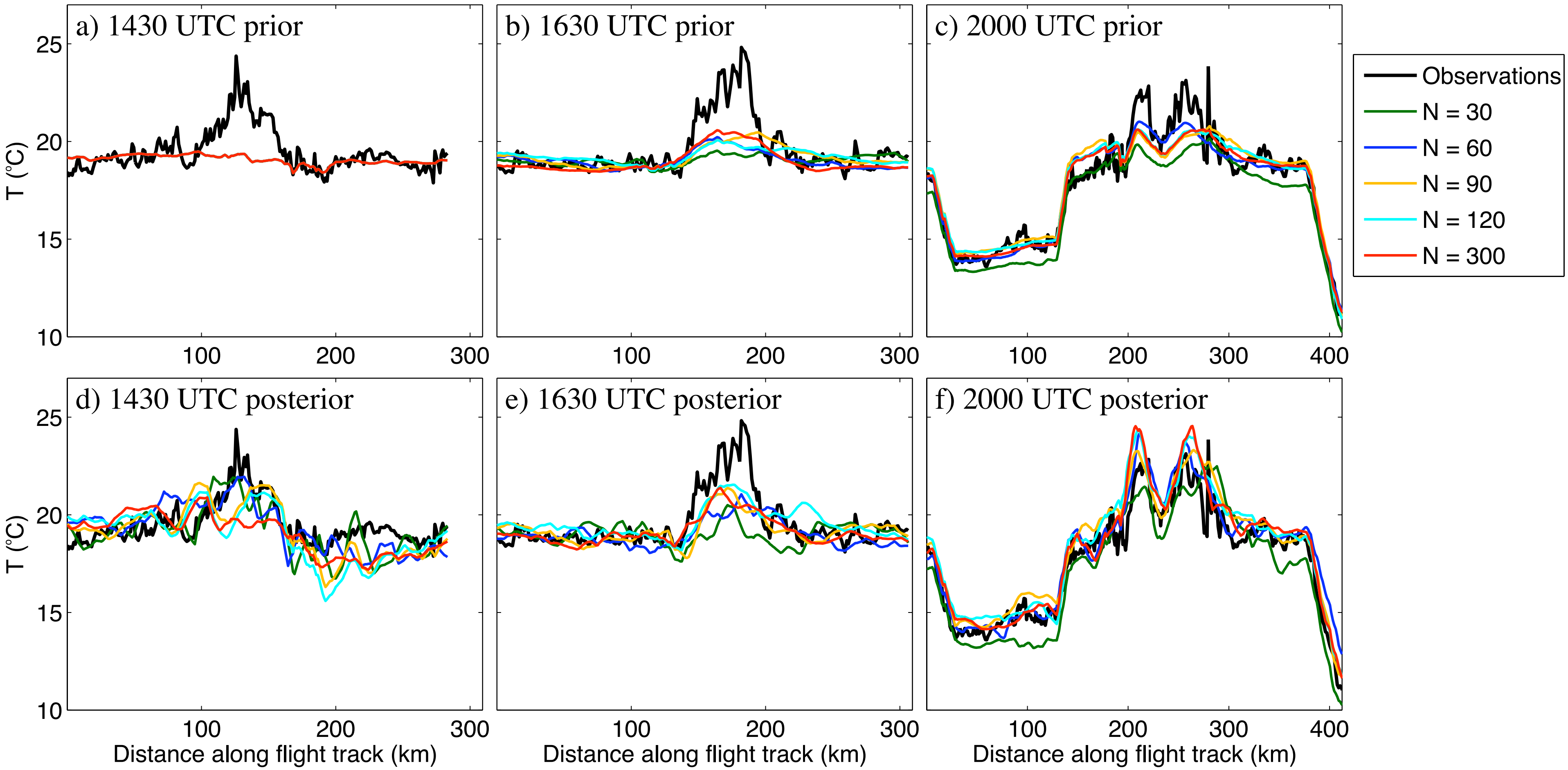
- Differences between 300- and 90-member posterior u-wind are shaded every 1 m s^{-1}.
- Observations are assimilated with a 1215 km localization radius for D1
- Significant differences only occur within 3-5 degrees from the storm center, so changes in storm track must be caused by differences within this region.

Prior/posterior verification in storm core



- Prior and posterior winds are compared with Stepped Frequency Microwave Radiometer (SFMR) data at flight level (about 1500 m)
- The different ensemble sizes produce similar analyses of the inner-core wind field

Prior/posterior verification in storm core

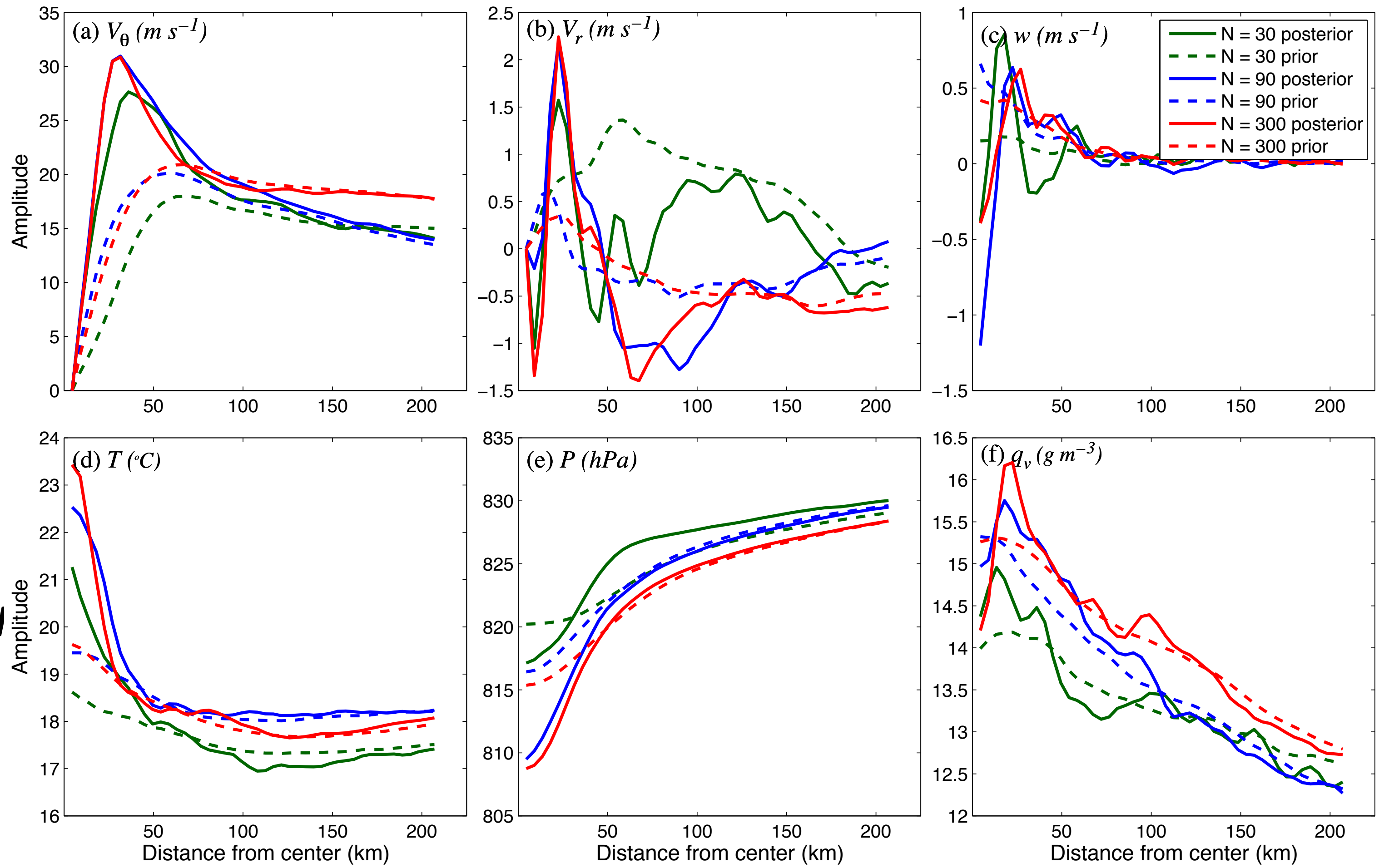


- Prior and posterior temperature is compared with SFMR data
- 30-member ensemble is the only noticeable outlier

Storm structure at last analysis time (2000 UTC)

n = 0 amplitude within 200 km of storm center at 1500 m

Center is determined from posterior wind field

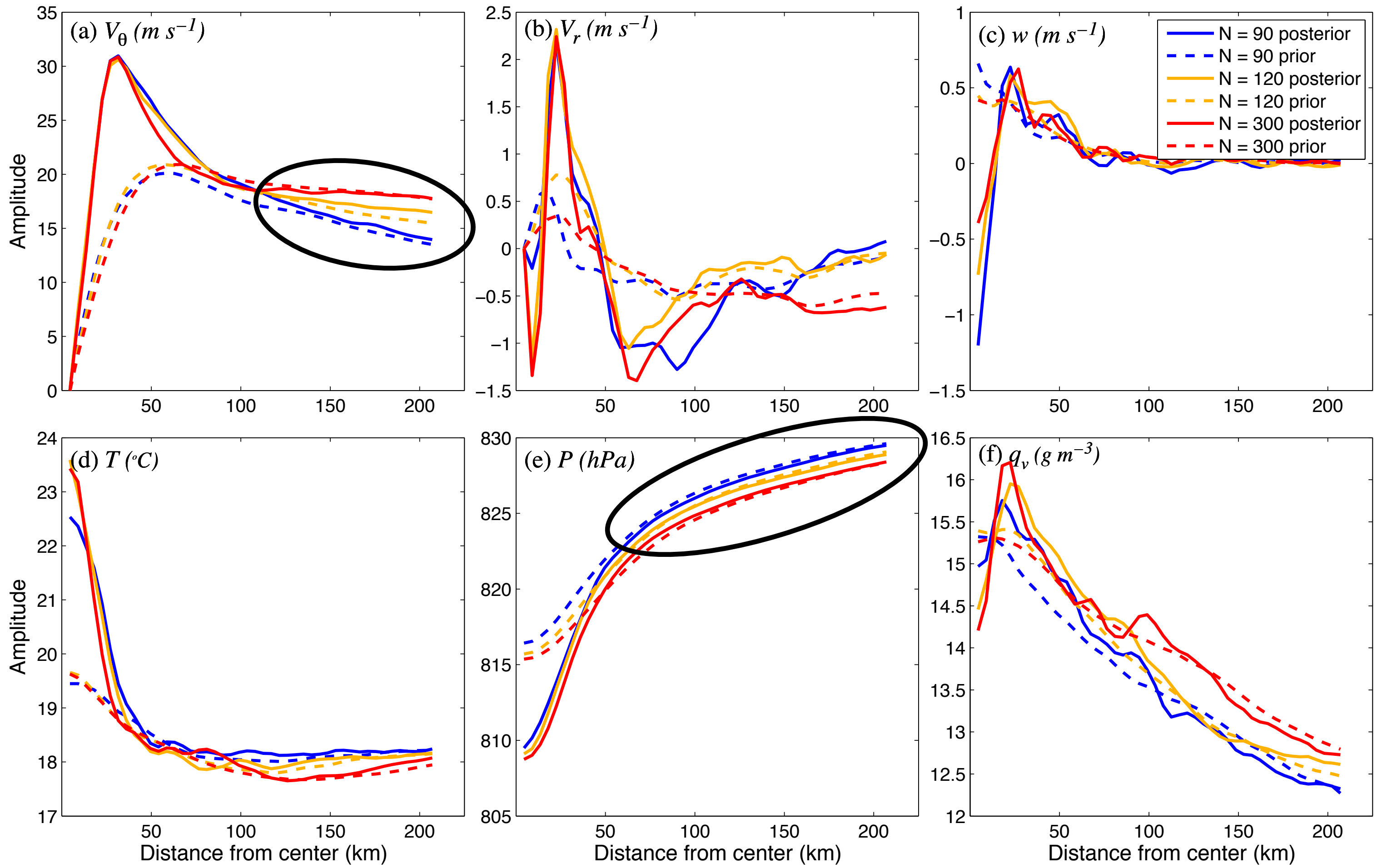


- The larger ensembles produce a more well-defined warm core, lower pressure and stronger winds inside 50 km.
- The 300-member ensemble produces a stronger circulation and a lower pressure field outside of 100 km.

Storm structure at last analysis time (2000 UTC)

n = 0 amplitude within 200 km of storm center at 1500 m

Center is determined from posterior wind field

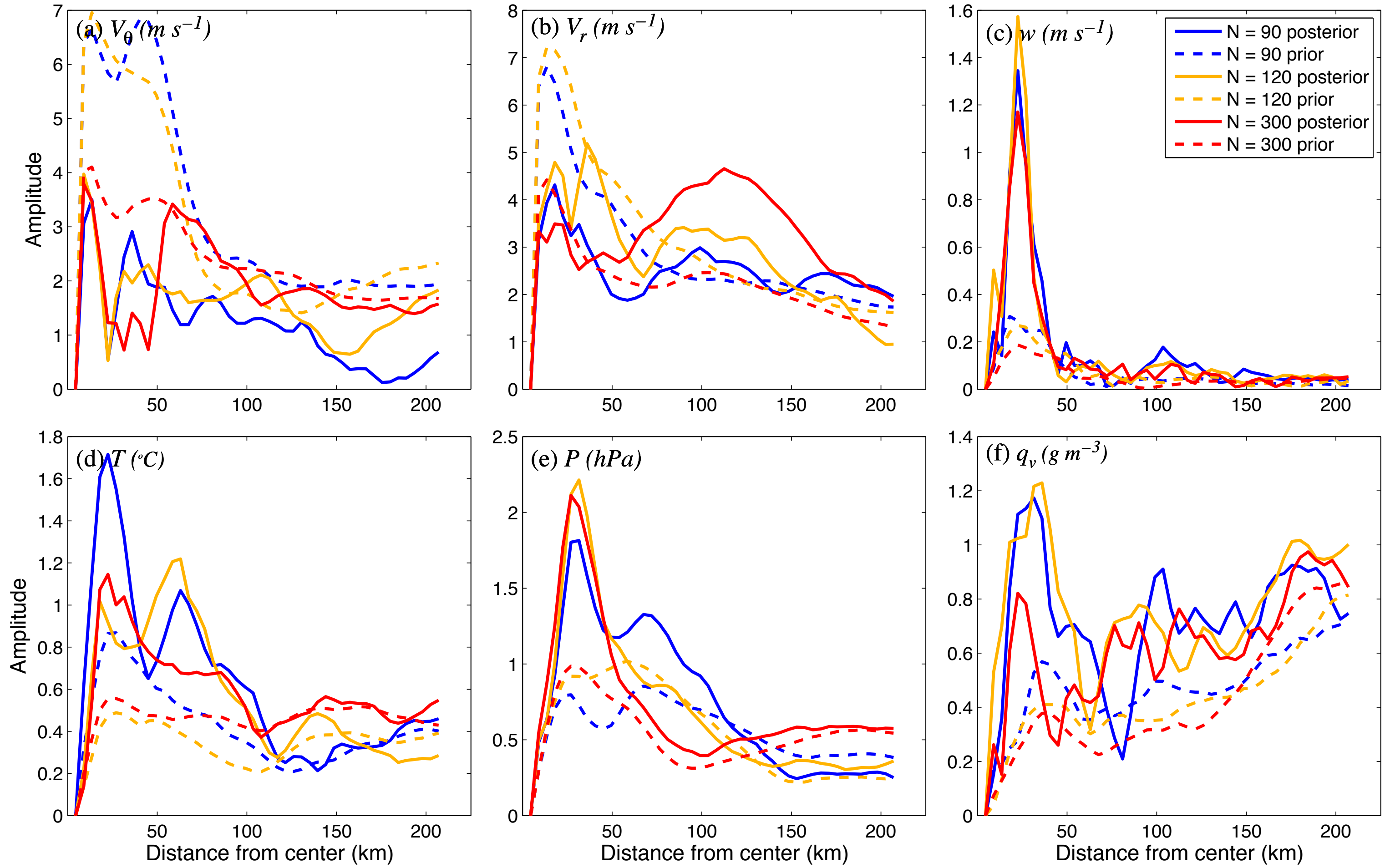


- Increasing the number of members from 90 to 300 produces a stronger circulation and lower pressure outside 100 km.
- 300- and 120-member analyses produce stronger temperature gradients between eyewall and warm core

Storm structure at last analysis time (2000 UTC)

n = 1 amplitude within 200 km of storm center at 1500 m

Center is determined from posterior wind field

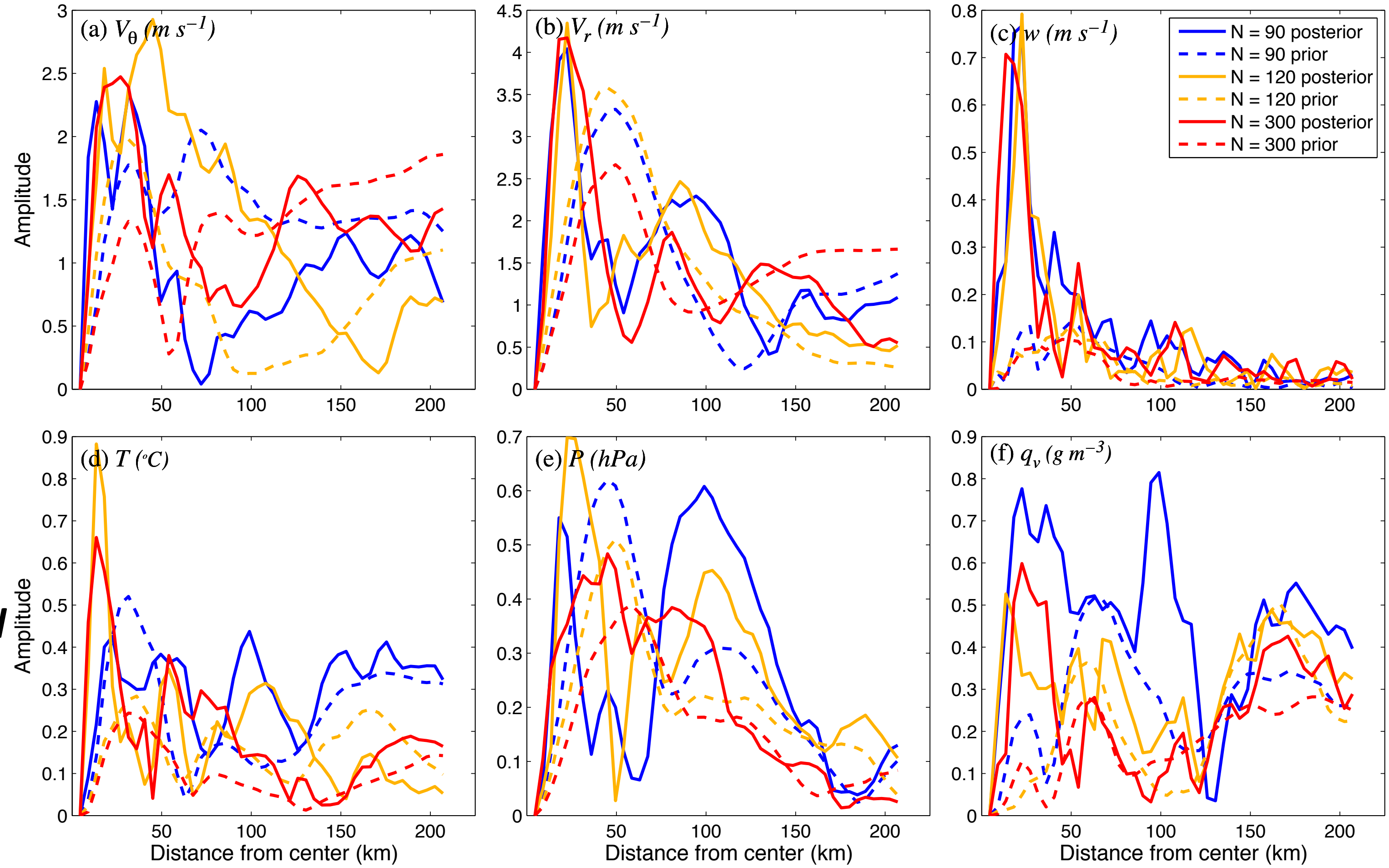


- Large n = 1 asymmetry in prior wind field for 90- and 120-member cases show a larger position correction taking place
- 300-member posterior has a larger asymmetry in both horizontal components of wind outside of 50 km

Storm structure at last analysis time (2000 UTC)

n = 2 amplitude within 200 km of storm center at 1500 m

Center is determined from posterior wind field



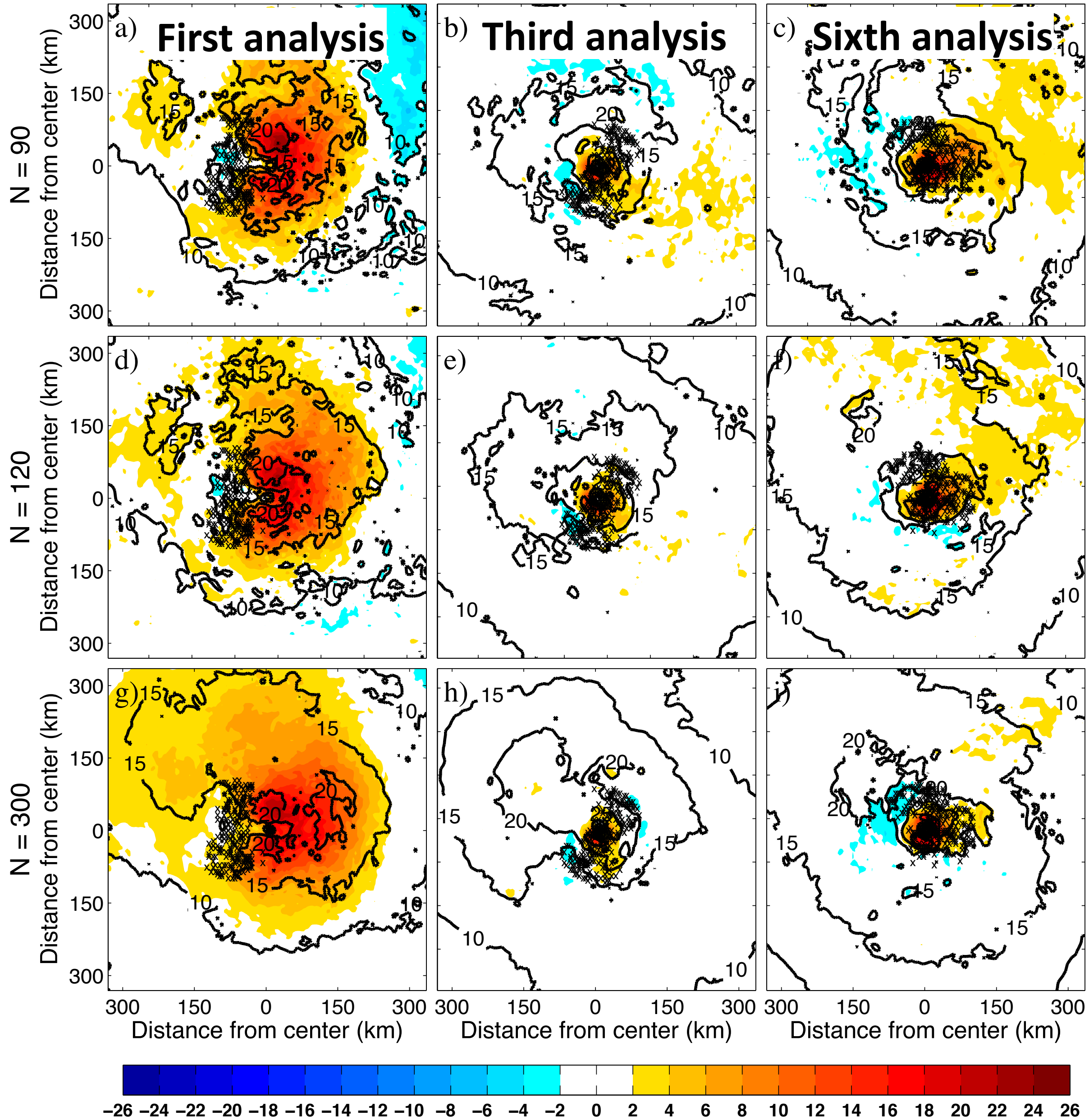
- All three cases have qualitatively similar n = 2 secondary circulations
- The cumulative effects of sampling begin to cause differences at all radii

Analysis V_θ increments

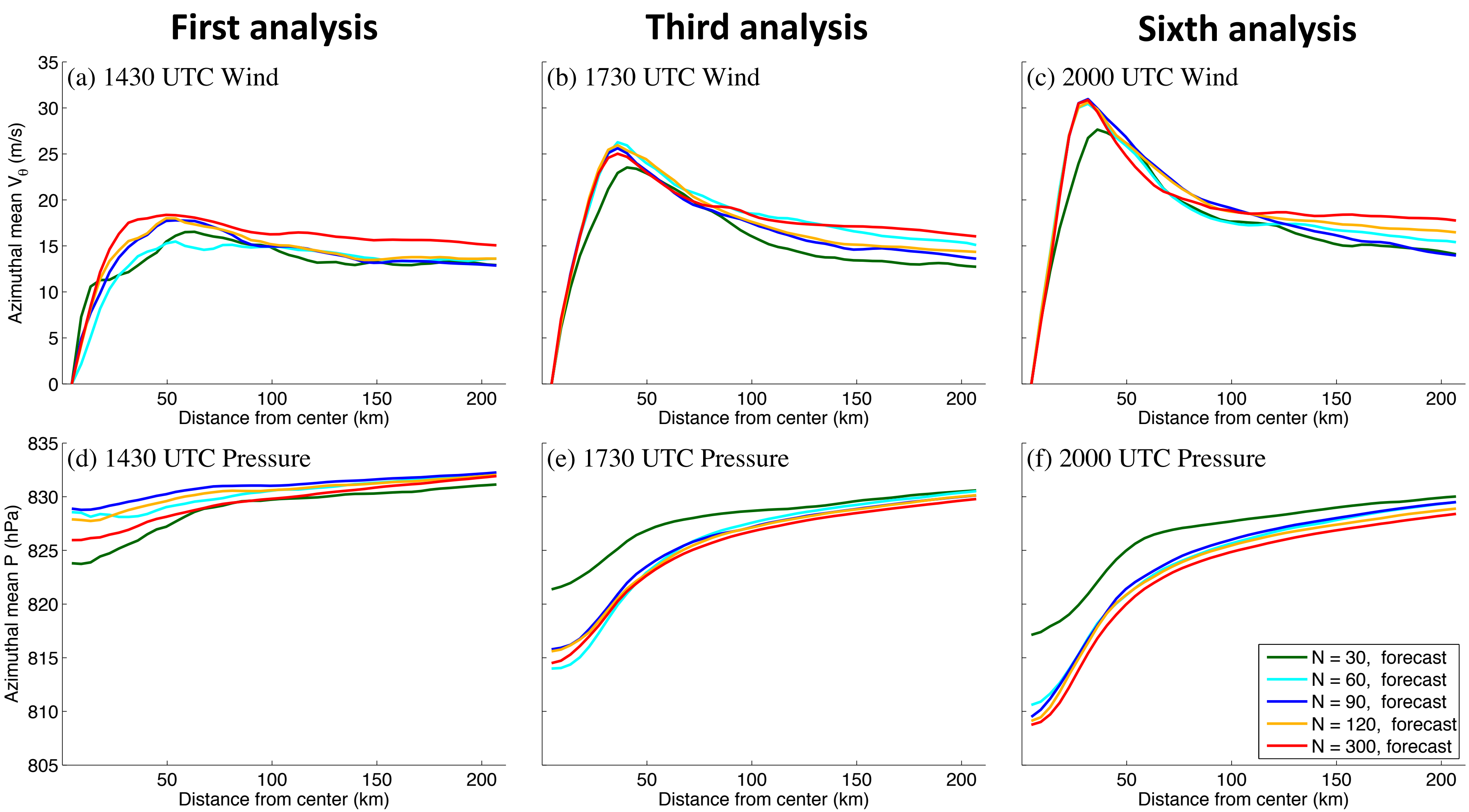
Posterior V_ϑ is contoured in black every 5 m s^{-1}

V_ϑ increments are shaded every 2 m s^{-1}

- The largest difference in increments occurs at the first analysis time.
- The 120-member posterior winds outside 100 km begin to resemble the 300-member posteriors by the last cycle

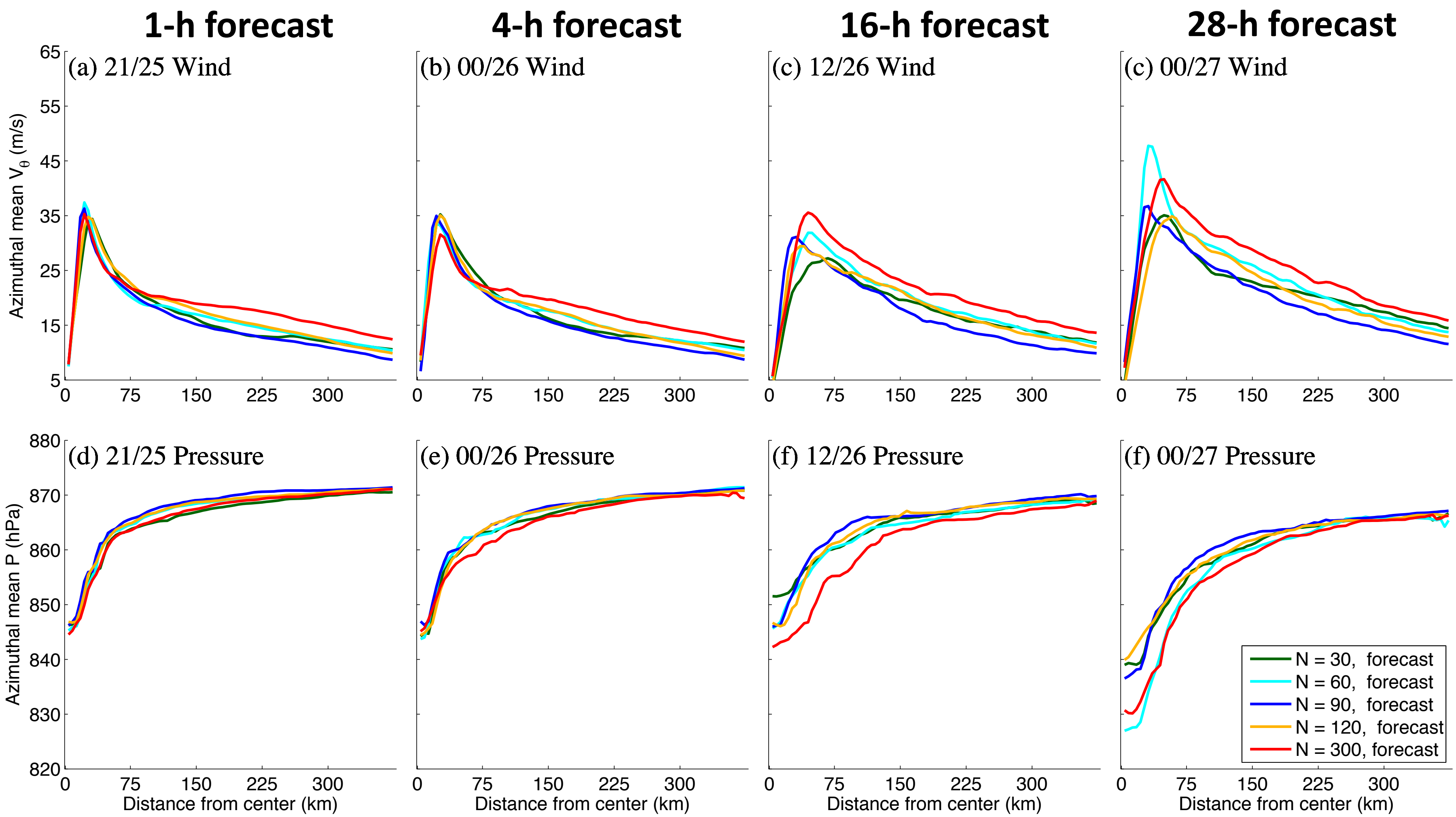


Azimuthal mean pressure and wind



- By the third assimilation cycle, cases with 60 or more members converged to a similar axisymmetric wind and pressure field inside 50 km, but clear differences are present outside the inner core

Storm structure after initialization



- The deterministic forecast from the 300-member posterior retains the strong circulation outside 150 km by 28 h

Summary

- Covariance relaxation had little impact on the track and intensity forecasts, but ensemble size had a large impact

- Increasing the ensemble size from 60 to 300 members led to small changes in wavenumber 0 – 2 storm structure inside 50 km

- The larger ensemble sizes produced a stronger circulation in the posterior outside 100 km by the last analysis time, which led to the different track forecasts

- Increments made to the large scale circulation at the first analysis time have a large impact on the posterior at the last update time, because all observations are close to the center of the vortex

- Short-term (1-28 h) forecasts show changes in storm strength and size that may be caused by differences in storm structure at initialization