# Cloud-resolving Hurricane Analysis and Forecasting Assimilating Airborne Doppler Observations with EnKF

**Yonghui Weng and Fuqing Zhang**

**Penn State University**

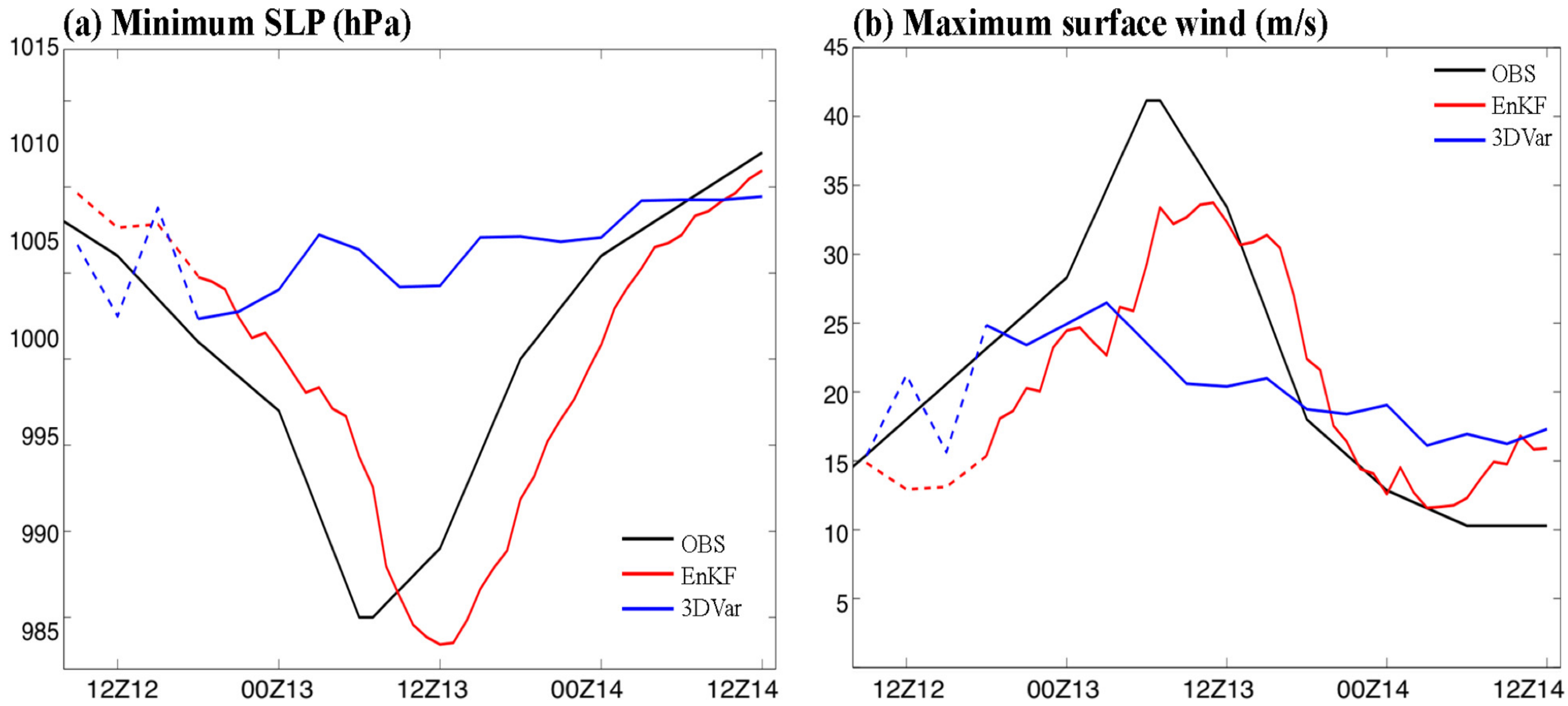
**Contributors: John Gamache and Frank Marks, NOAA/HRD**

**Special Acknowledgments: NOAA-P3 crews; TACC staff**

**Sponsors: NSF, ONR and NOAA**

# Assimilate W88D Doppler Vr for Humberto'05

*WRF/EnKF Forecast vs. Observations vs. 3DVAR*

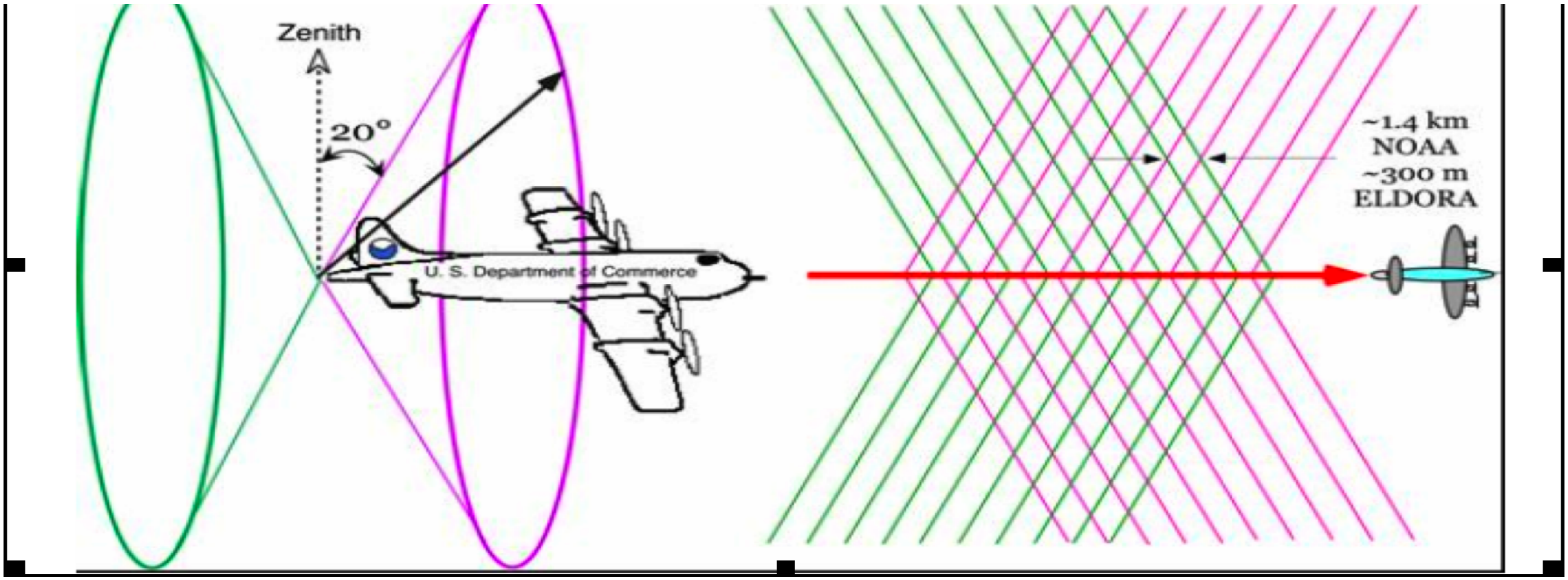



The WRF/3DVAR (as a surrogate of operational algorithm) assimilates the same radar data but without flow-dependent background error covariance, its forecast failed to develop the storm despite fit to the best-track observation better initially

**(Zhang et al. 2009 MWR)**

# Superobservation for Airborne Doppler Radar Winds

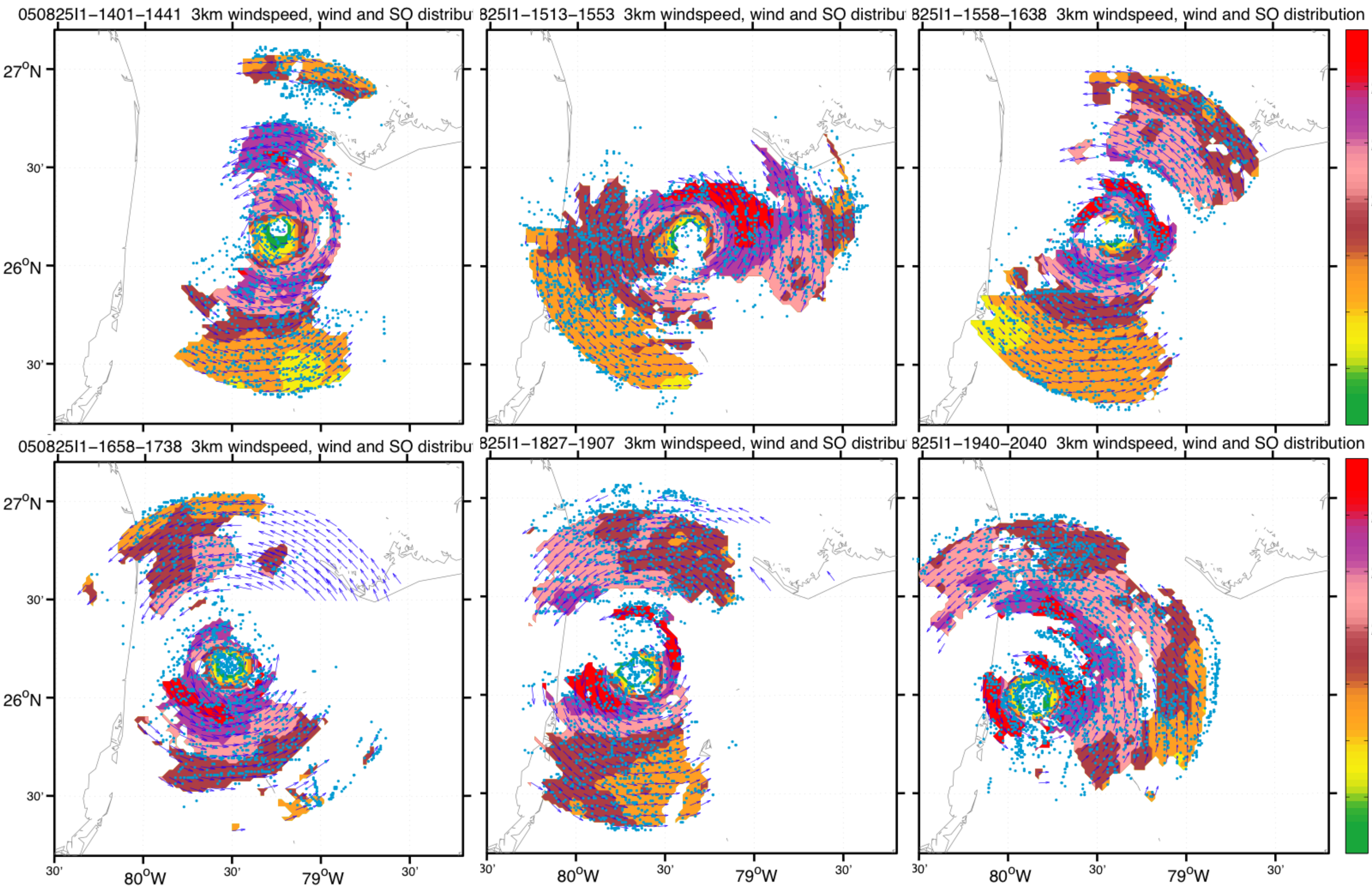
*Available for 20+ years but never used in operational models due to the lack of resolution and/or the lack of efficient data assimilation methods*




SOs: 1. Separate forward and backward scans; 2. removing data with vertical pointing angles greater than 45 degree; 3. treat every 3 adjacent full scans as one fixed-space radar (translation<5km); 4. thinning ---one bin for 5 km in radial distance and 5 degree in scanning angle; 5. use medium as SO after several additional QC criteria checking

*These SOs are generated on flight of NOAA P3's; transmitted to ground in realtime*

# Assimilate Airborne Doppler Vr for Katrina (2005)



# Assimilate Airborne Vr with EnKF for Katrina

- **WRF domains:** D1-D2-D3 grid sizes---40.5, 13.5, 4.5km (movable)
  - **Physics:** WSM 6-class microphysics; YSU PBL; Grell-Devenyi CPS

- **EnKF (Meng & Zhang 2008a,b; Zhang et al 2009):** - 30-member ensemble

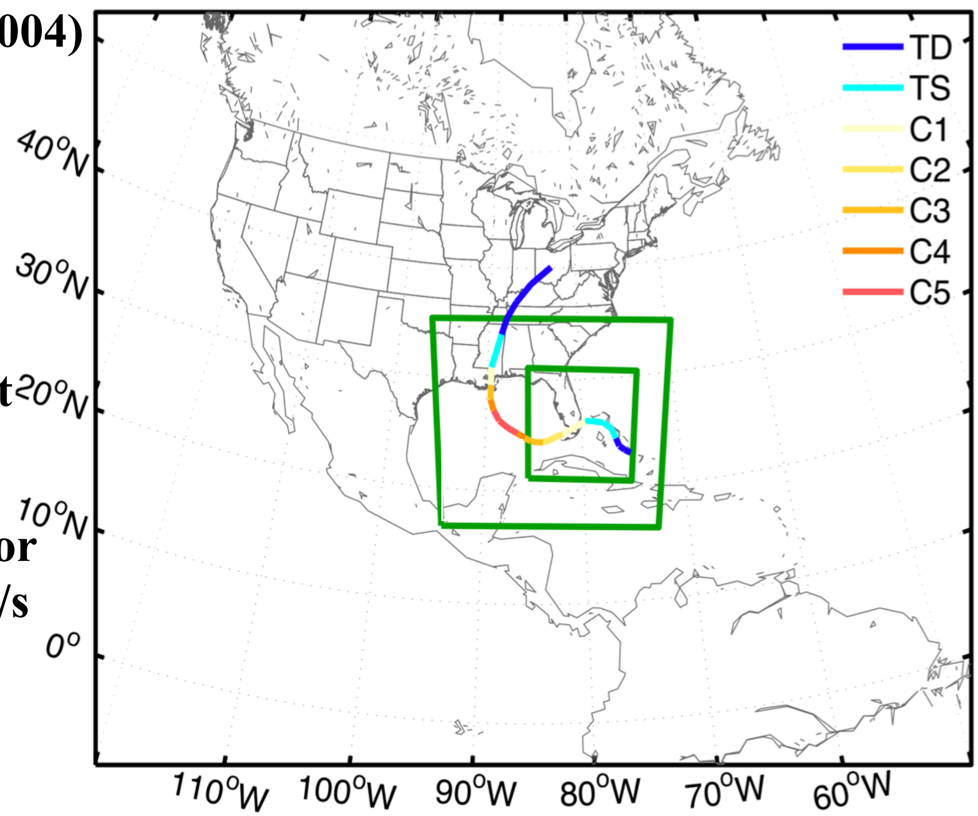
  - IC/BC perturbations: WRF3DVar background uncertainty (Barker et al. 2005)

  - Covariance localization: Gaspairi&Cohn (1999) but successively smaller

  - Covariance relaxation (Zhang et al 2004)

$$(\mathbf{x}^{a}_{new})' = (1 - \alpha)\,(\mathbf{x}^{a})' + \alpha\,(\mathbf{x}^{f})'$$

- **Data assimilated**
  - SOs from 6 flight legs at 1430, 1530 1630, 1730, 1900, 2000UTC 25 August
  - Data assimilation are performed for all domains but reduced density for D1 and D2; SO observation error 3m/s



# Successive Covariance Localization
## (Zhang et al. 2009)

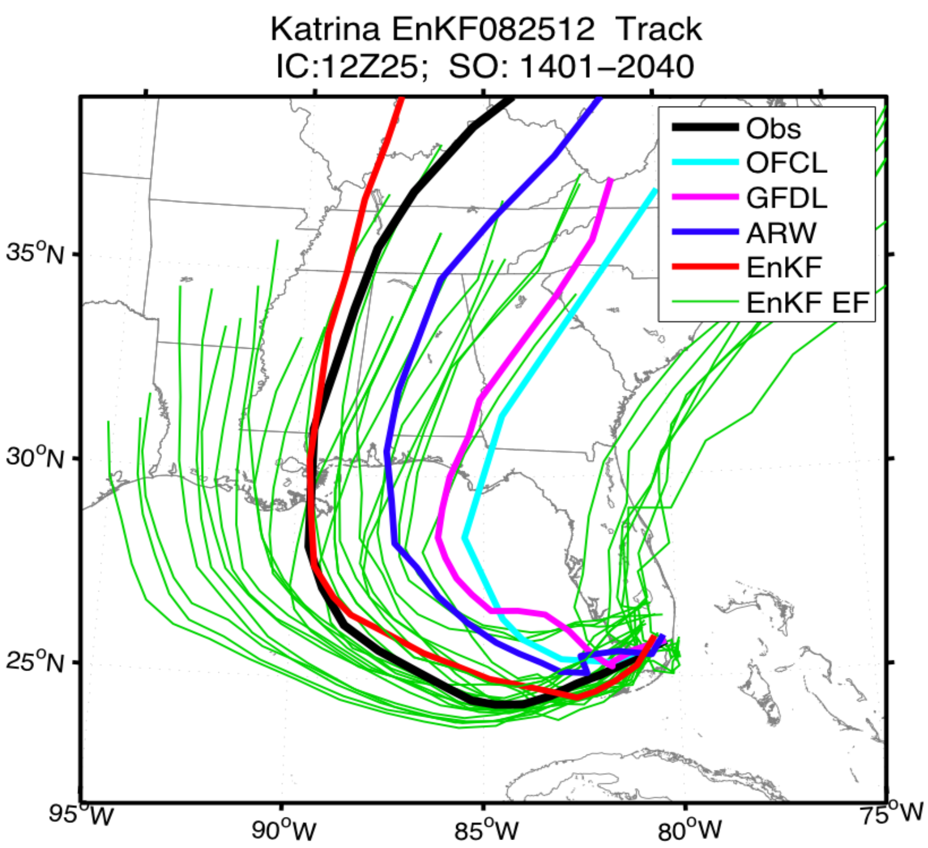
SCL is designed to assimilate dense observations that contain information about the state of the atmosphere at different scales, as is the case for hurricanes. It is also designed to reduce computation cost and sampling errors

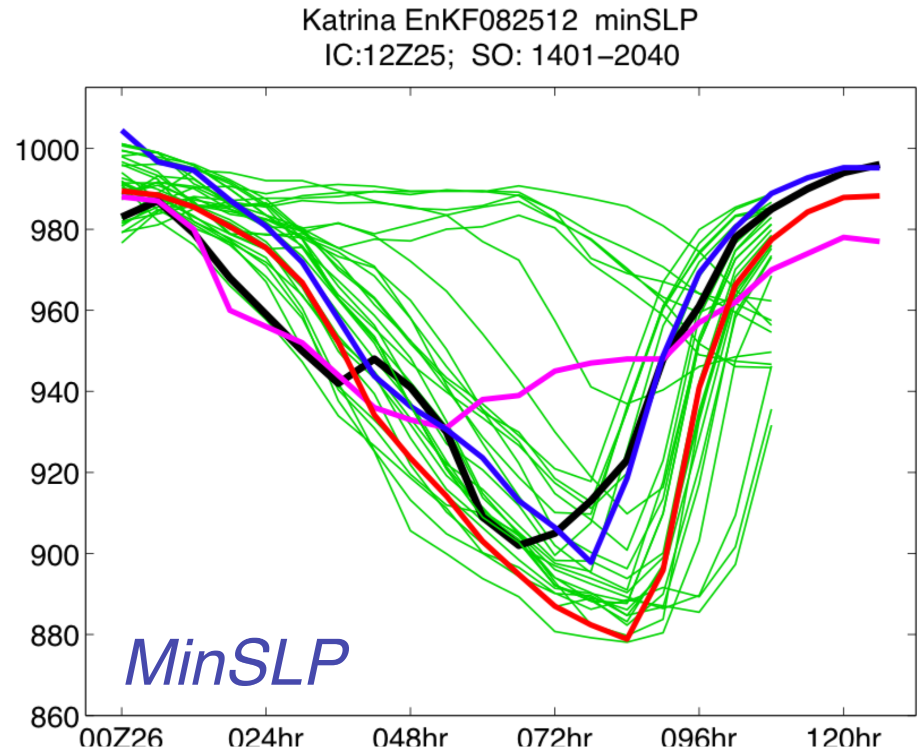
Rationale: Assuming larger-scale errors will have larger correlation length scales and smaller-scale errors have much smaller correlation length scales, fewer observations with larger radii of influence (ROIs) are needed to constrain large-scale errors, and a larger number of observations are needed to constrain small-scale errors

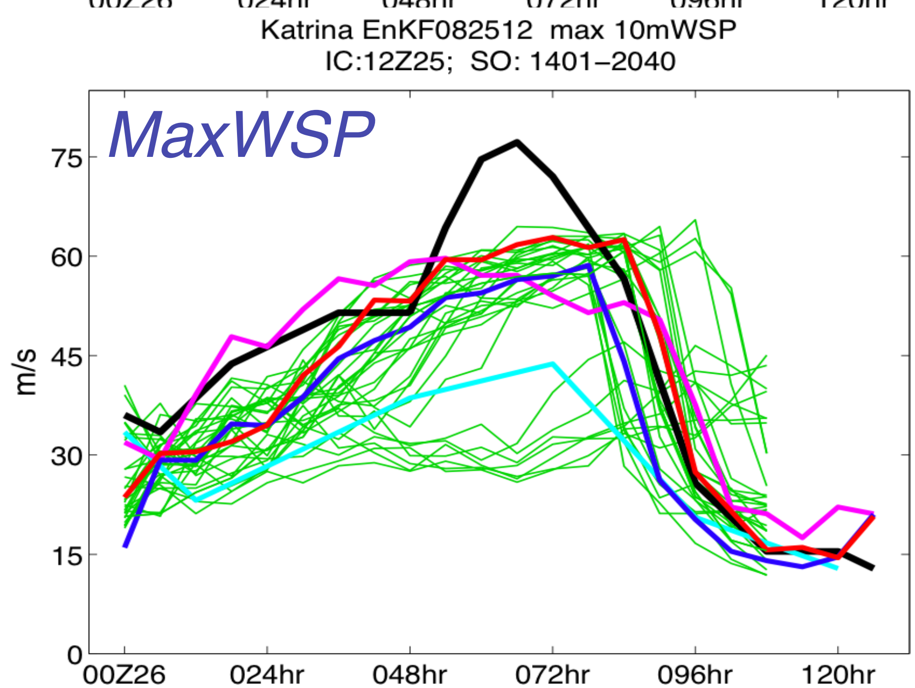
CNTL experiments: SCL with different radii of influence (ROIs): 1200km (1/18 of SOs) characteristic scale for large-scale flow; 400km (1/9 of SOs) for subsynoptic or TC storm scale; 135km (1/3 of SOs) for mesoscale to convective-scale details; other ½ not used now

# WRF/EnKF Performance With airborne Vr obs

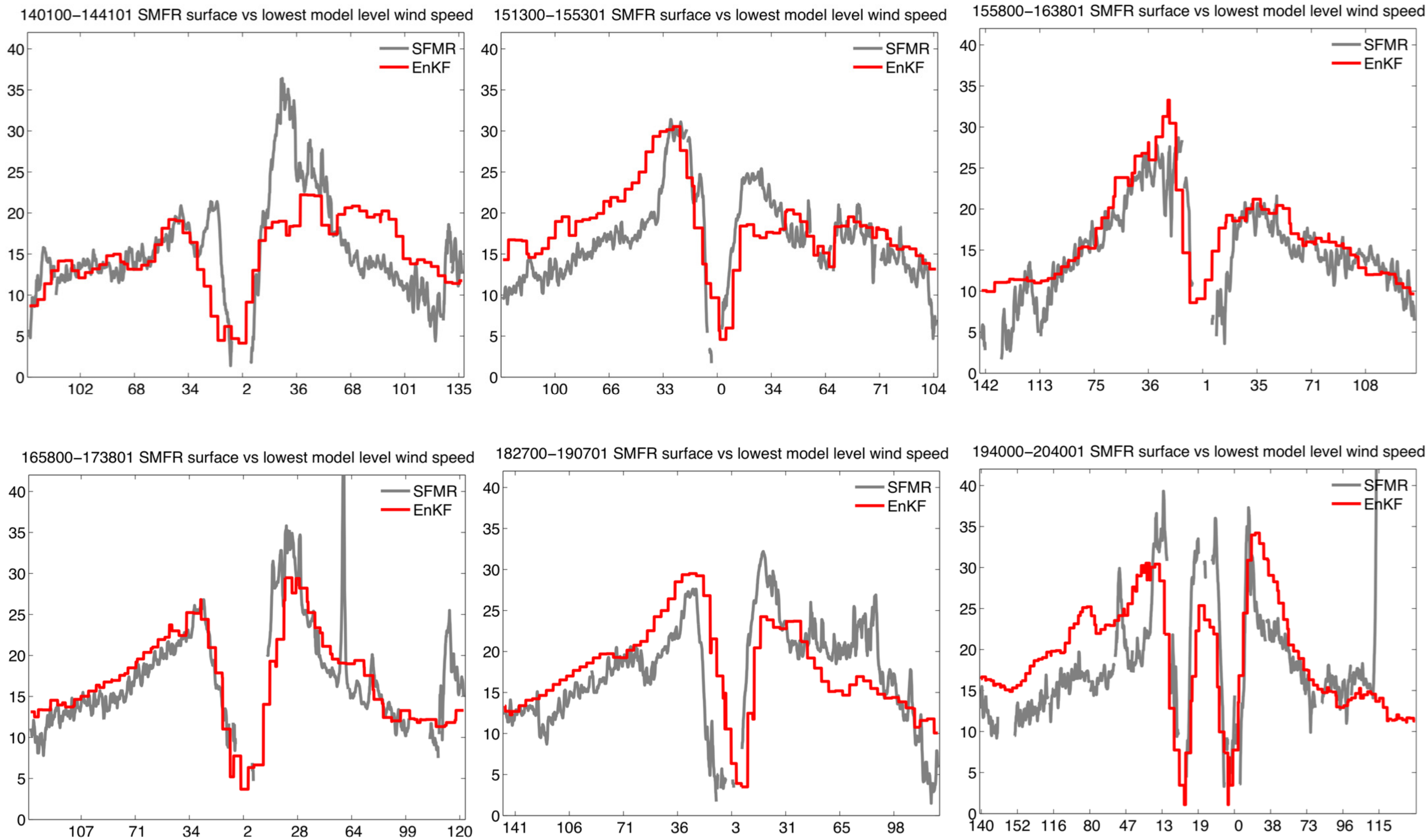
*30-member ensemble forecast from EnKF posterior uncertainty*



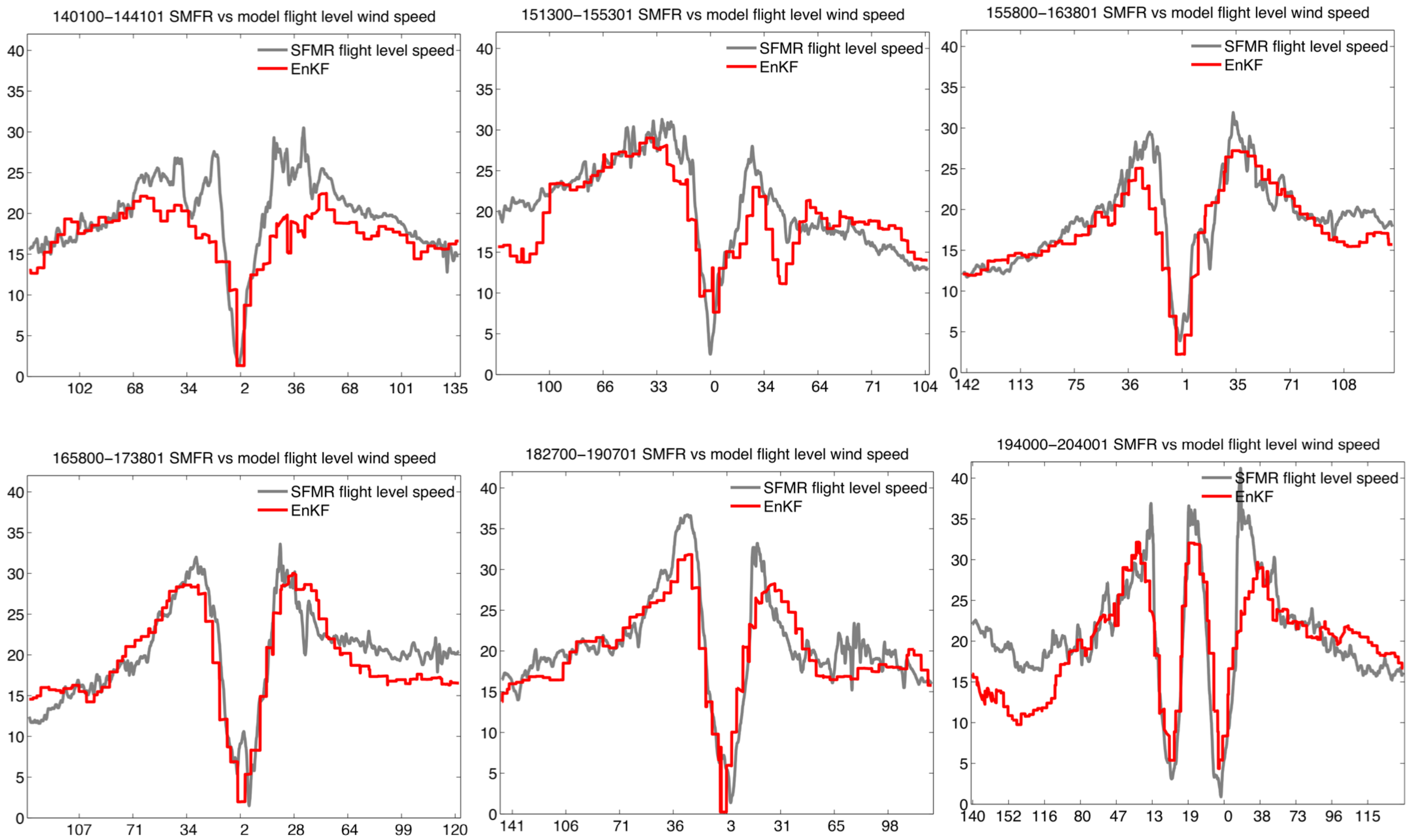



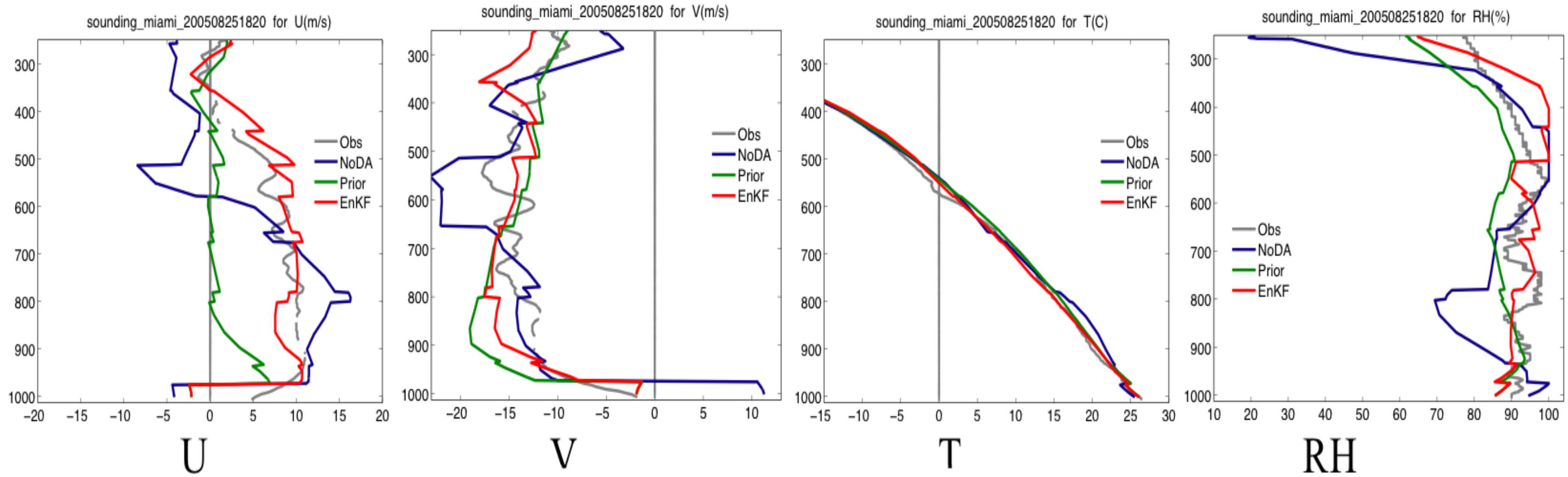
# Verification: SFMR wind obs vs. EnKF sfc analysis

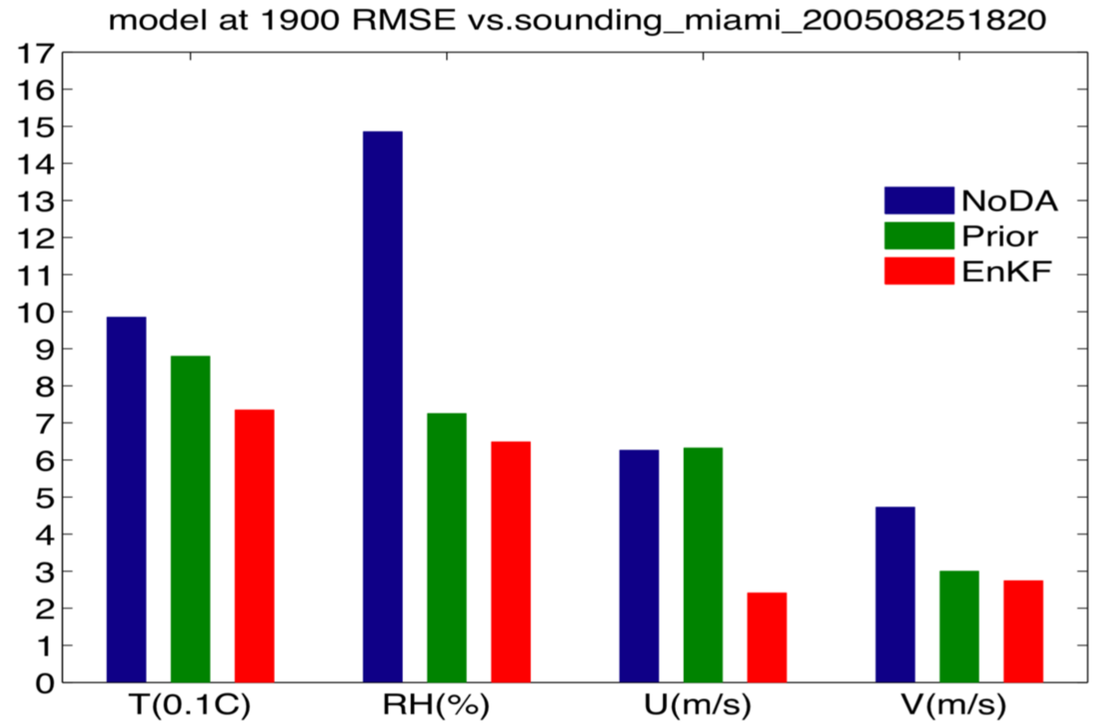


# Verification: P3 flight-level wind vs. EnKF analysis

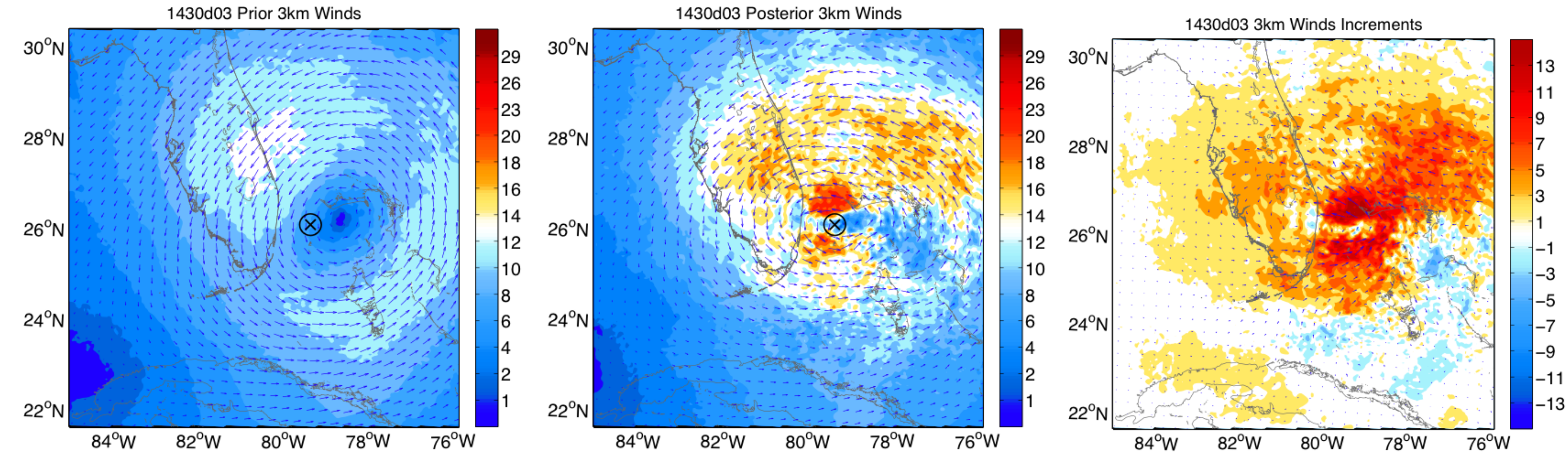


# Verification: Miami Sounding 1820Z vs. EnKF analysis 19Z

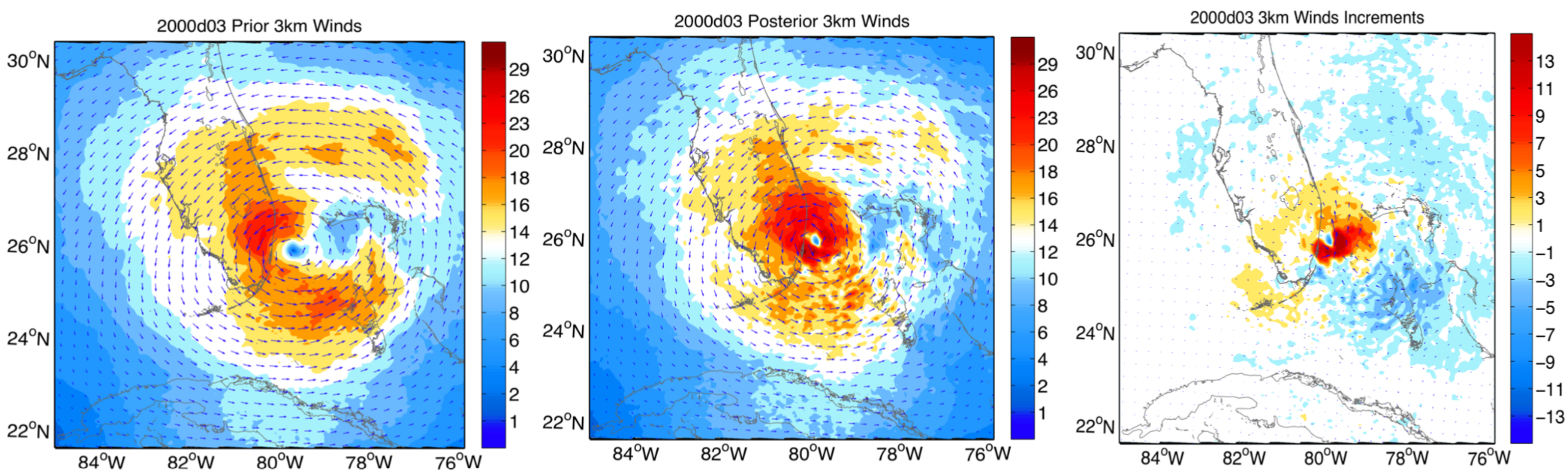


# WSP prior, posterior and increments 1st and last leg

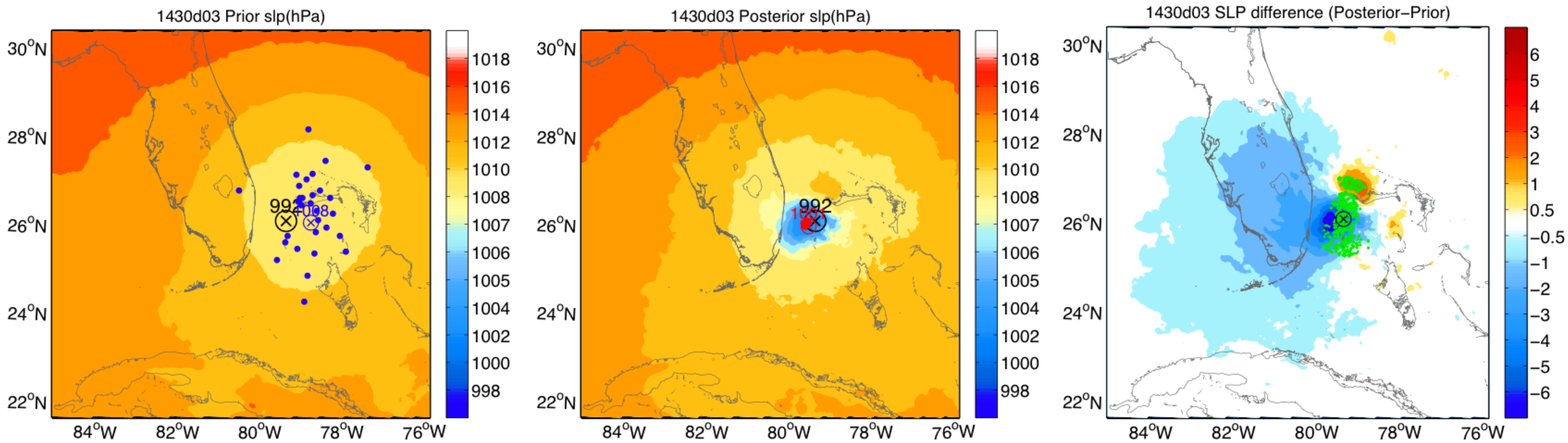



14:30 D03 (4.5km)

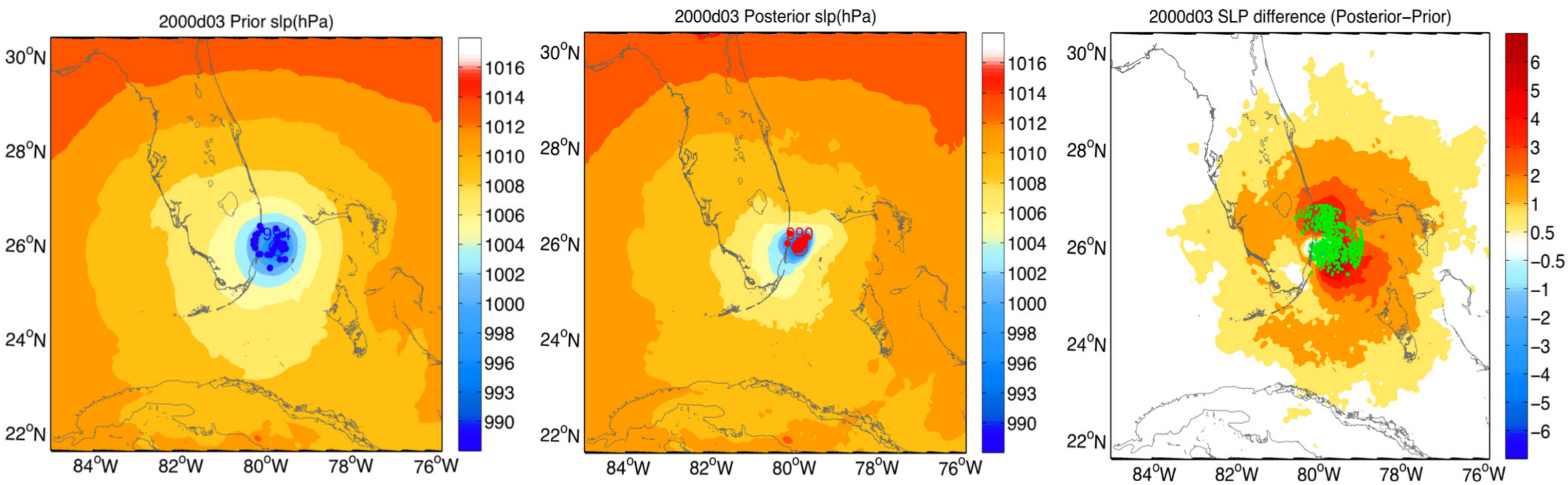



20:00 D03 (4.5km)

# SLP prior, posterior and increments 1st and last leg

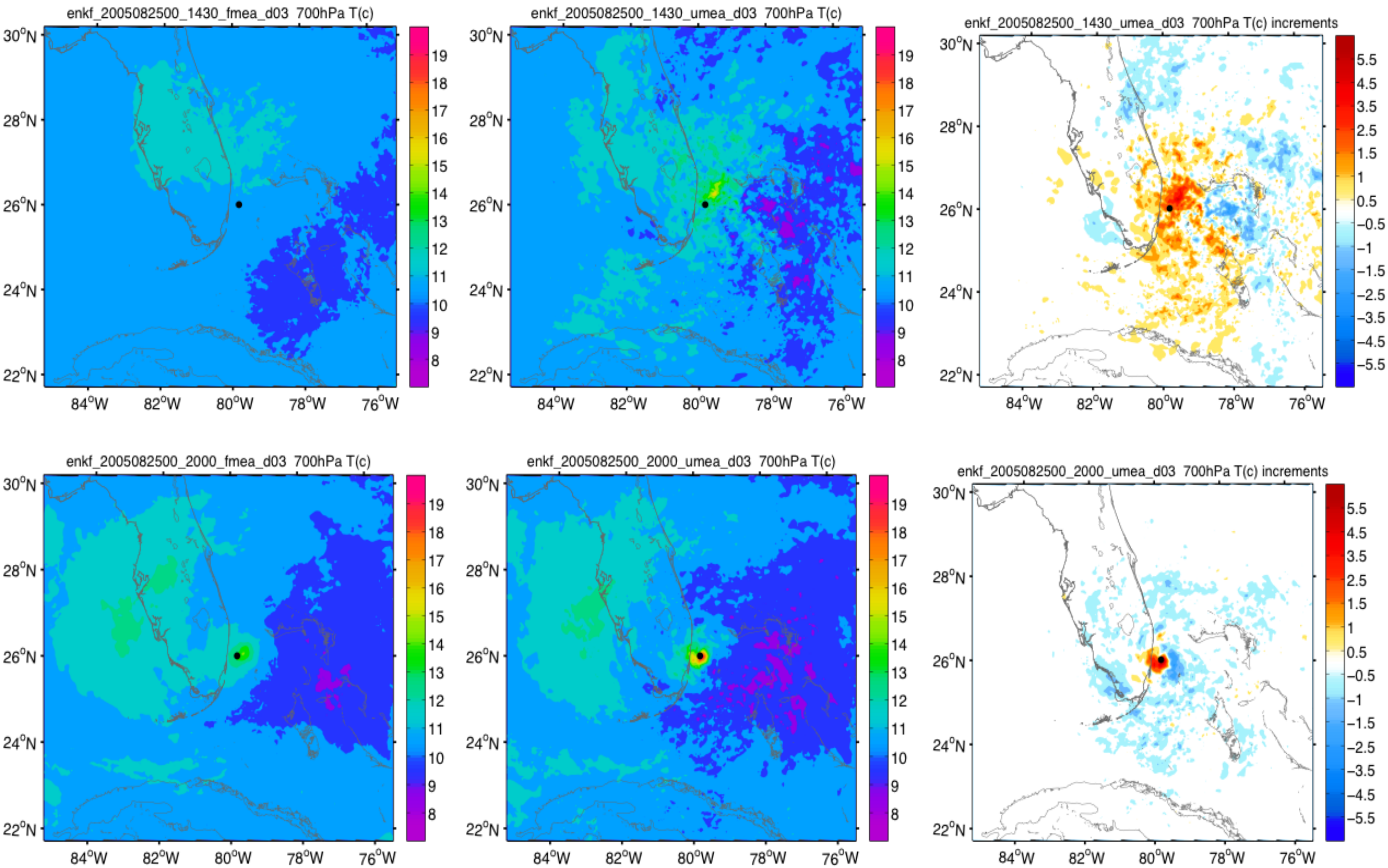



14:30 D03 (4.5km)



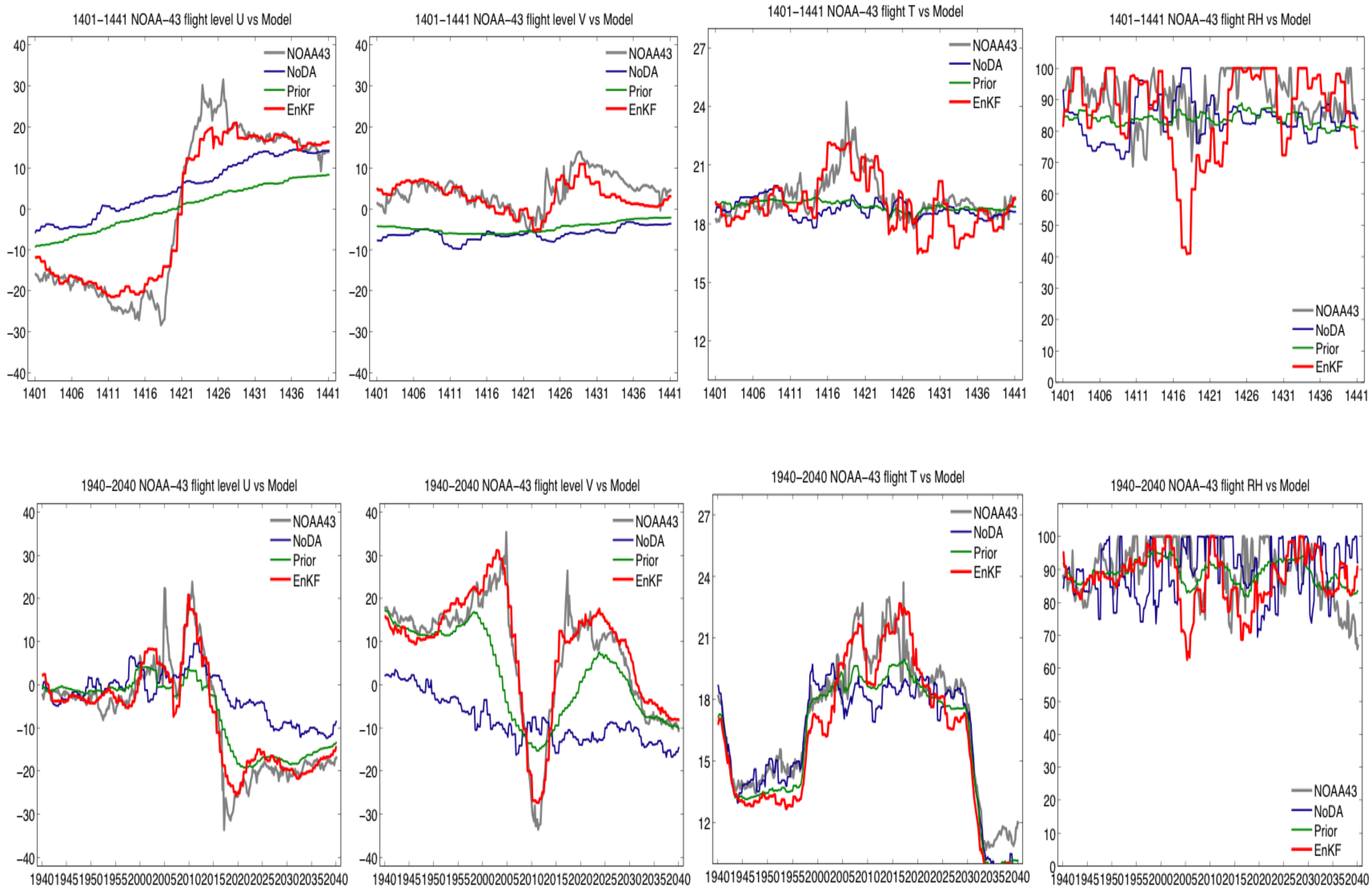

20:00 D03 (4.5km)

# T(700mb), posterior and increments 1st and last leg

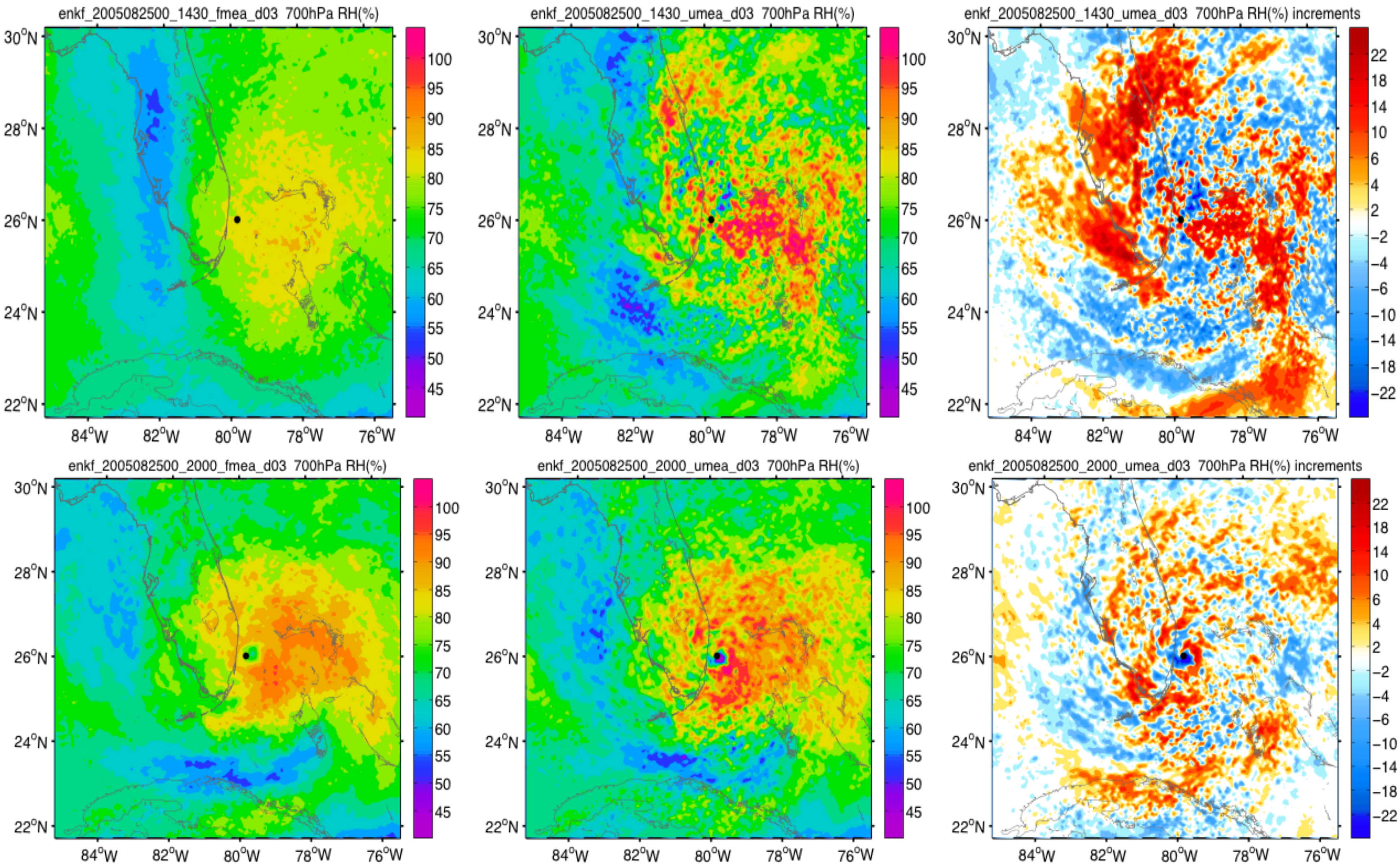



20:00 D03 (4.5km)

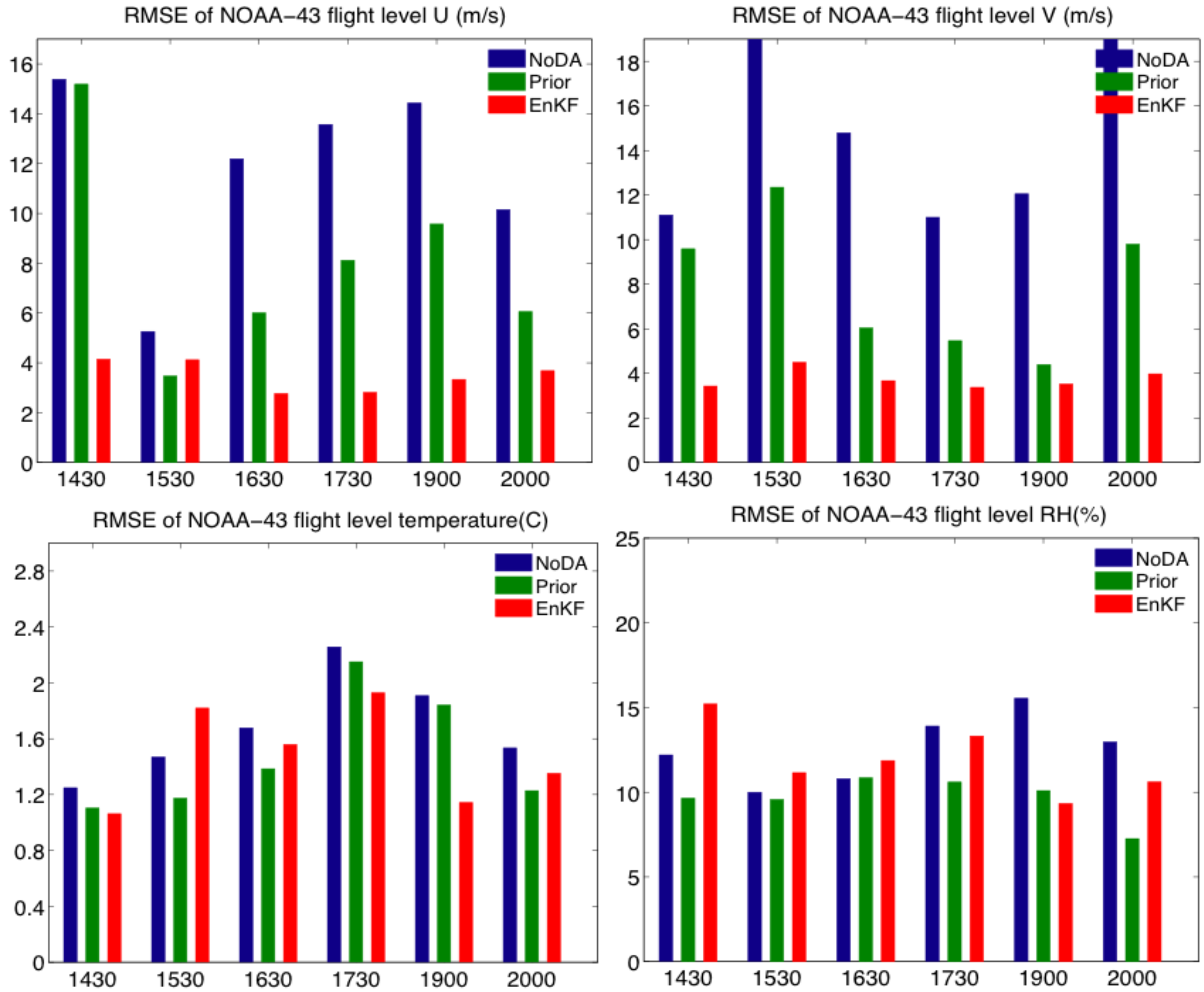
# Verification: Flight-level obs vs. EnKF analysis



# 700mb RH7, posterior and increments 1st and last lag



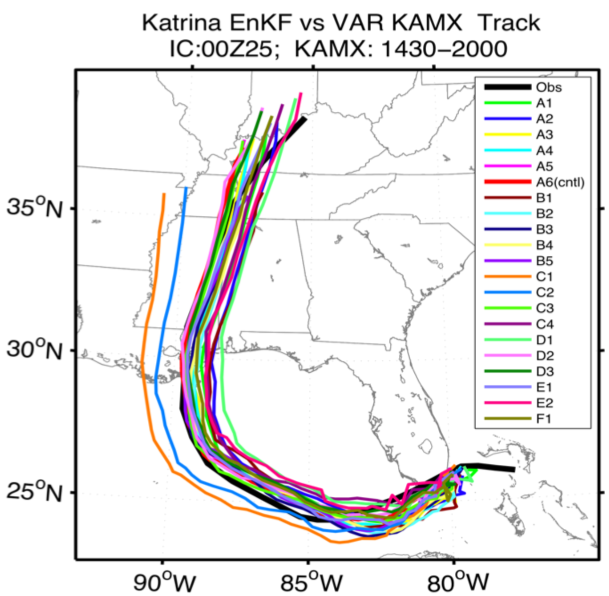
# Verification: Flight-level obs vs. EnKF analysis

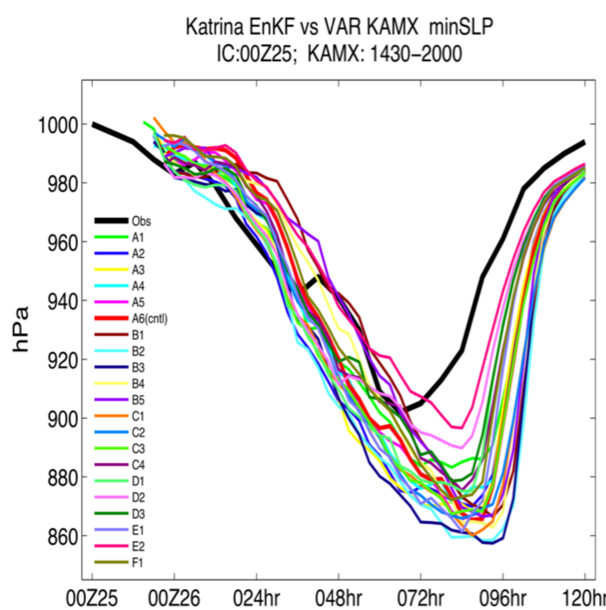


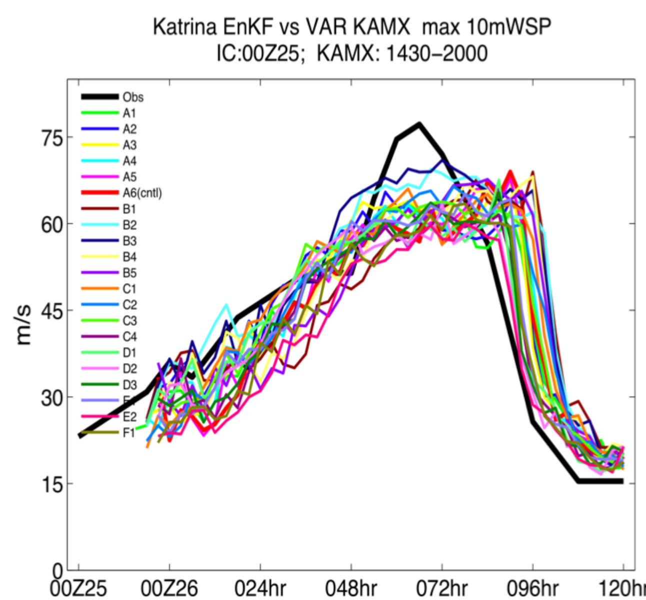
# How many legs of Airborne Vr are needed?

*Sensitivity to number of flight legs observations simulated*

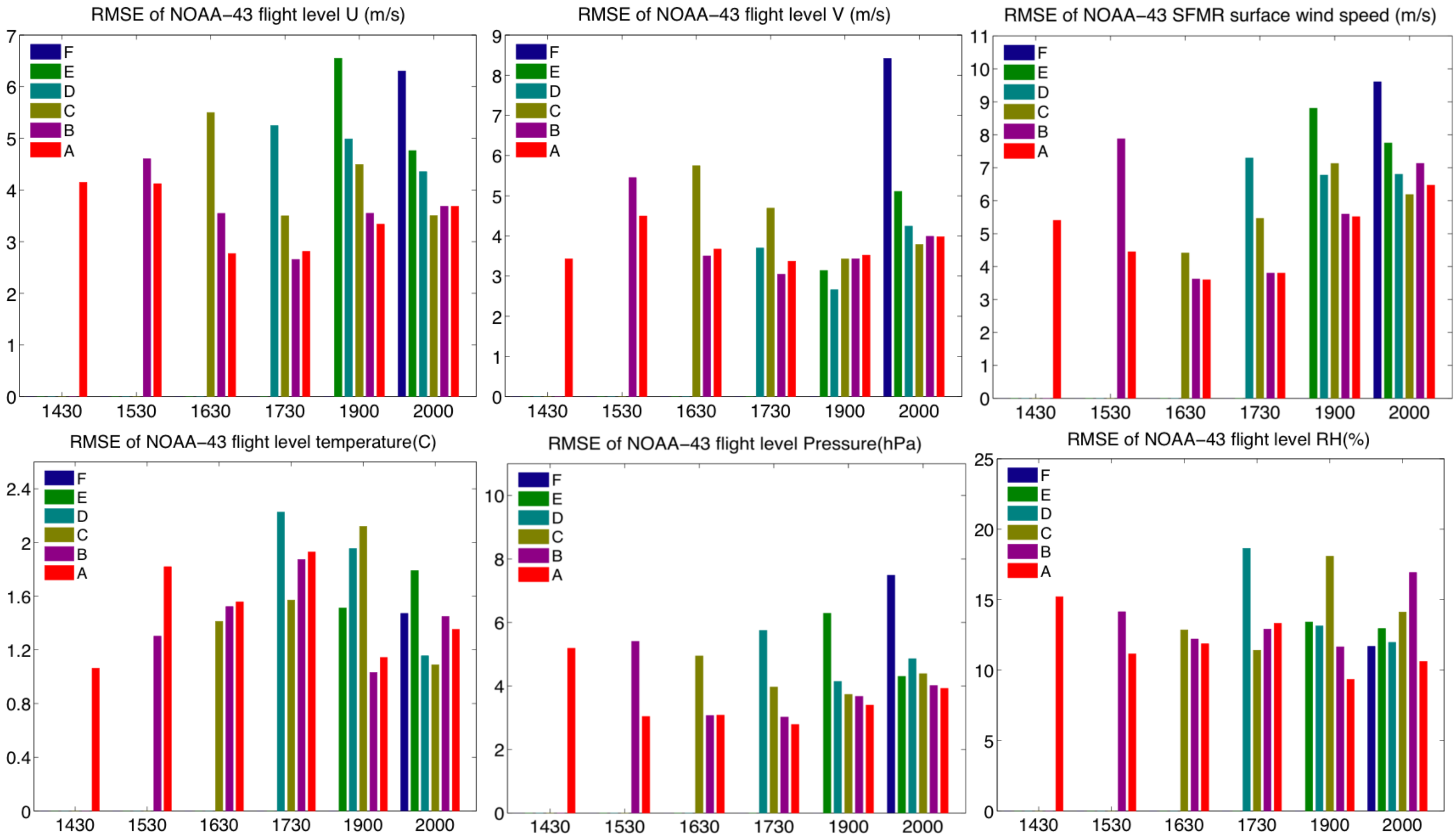
| Experiment Name | | End of EnKF, hence forecast | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1430 | 1530 | 1630 | 1730 | 1900 | 2000 |
| Start P3 assimilation | 1430 | A1 | A2 | A3 | A4 | A5 | A6 (cntl) |
| | 1530 | | B1 | B2 | B3 | B4 | B5 |
| | 1630 | | | C1 | C2 | C3 | C4 |
| | 1730 | | | | D1 | D2 | D3 |
| | 1900 | | | | | E1 | E2 |
| | 2000 | | | | | | F1 |



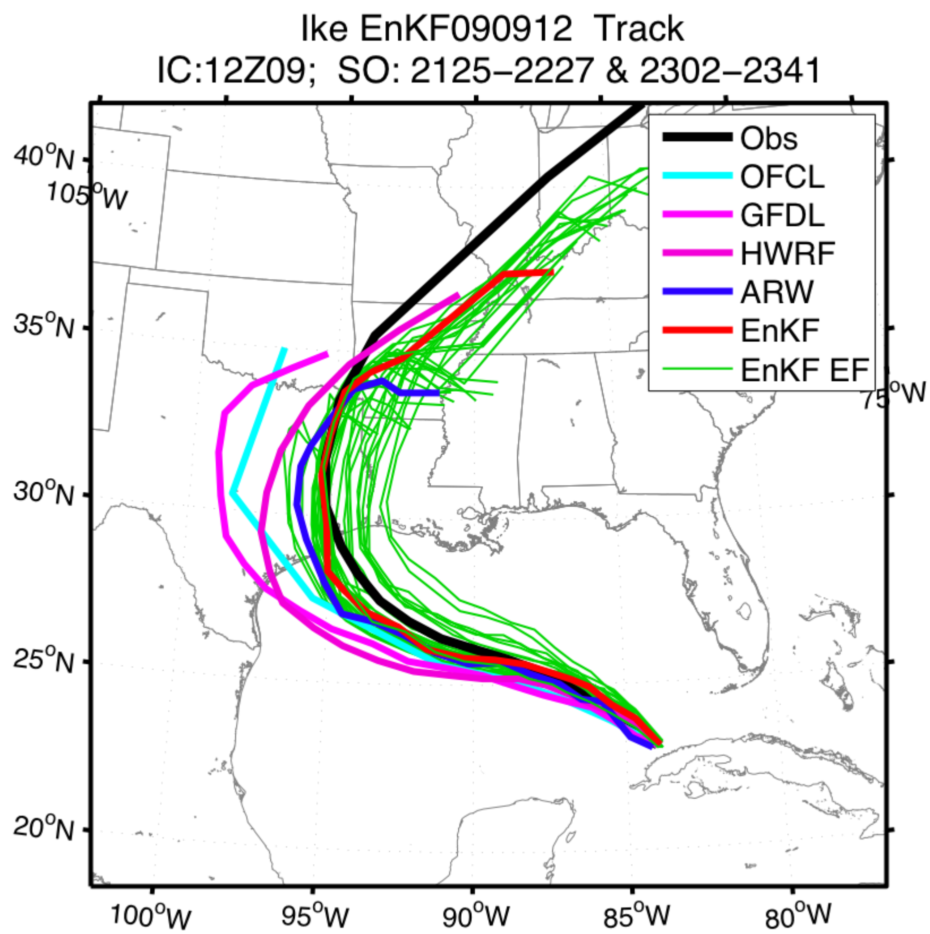



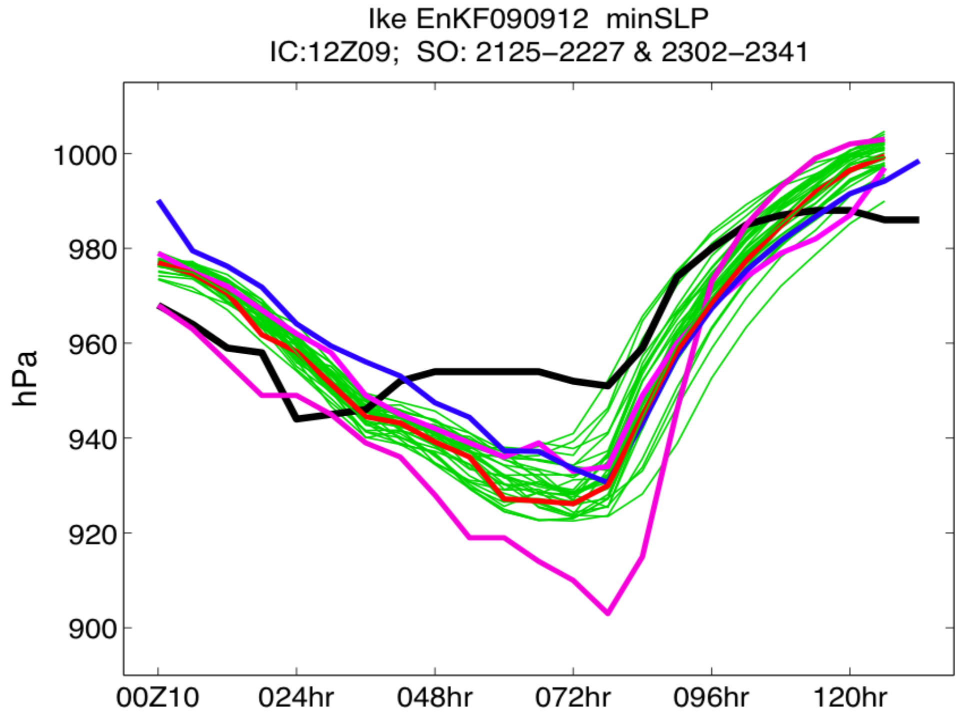
# How many legs of Airborne Vr are needed?

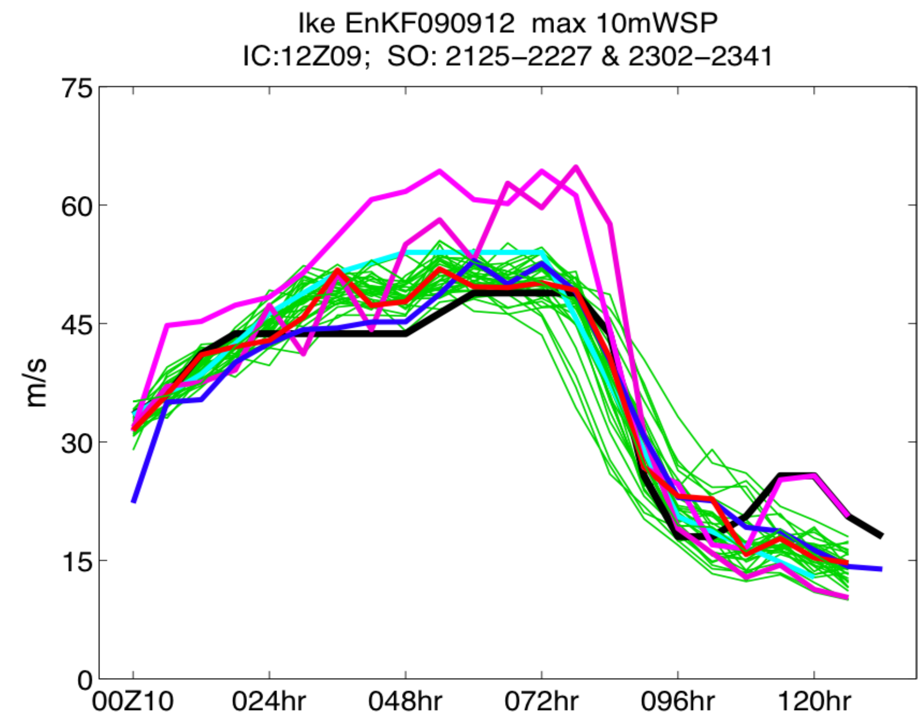


# Hurricane IKE (2008)

## *Realtime EnKF assimilation of airborne Doppler winds*



# Concluding Remarks

- EnKF assimilation of airborne Doppler radar observations into cloud-resolving mesoscale models is promising for convective-resolving hurricane analysis and initialization, deterministic and probabilistic forecasts; impact similar to WSR88D

- Promising for realtime 4D hurricane analysis beyond Hwind*

- Successive covariance localization (SCL) and covariance relaxation again simple but useful for multiscale complex flows; it has the benefits of reducing sampling errors and computation

- Realtime convective-permitting realtime ensemble analysis and forecasts for 2008/2009 Atlantic season quite successful; sample size still limited

- Our proof-of-concept realtime success is continuing on this year