The importance of error covariance in the core region of a hurricane for dynamically consistent vortex initialization: Can background error be approximated using an axisymmetric model?

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Introduction

A 1-2% per year increase in track forecasts has occurred over the last 3 decades (Franklin et al. 2009). In general, little progress has been made in terms of intensity prediction.

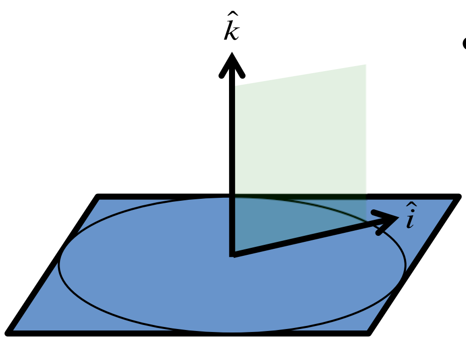
Why study covariance?

One deficiency in tropical cyclone prediction systems comes from the use of <u>isotropic</u>, <u>flow-independent</u> background statistics in operational data assimilation systems, which are ill-suited for the highly <u>flow-dependent</u> background error covariance associated with tropical cyclones. Estimating non-static background statistics is a computationally expensive process, but may be required for the next generation of tropical cyclone prediction systems.

Model Descriptions

Rotunno-Emanuel (1987) Axisymmetric Vortex Model (RE87)

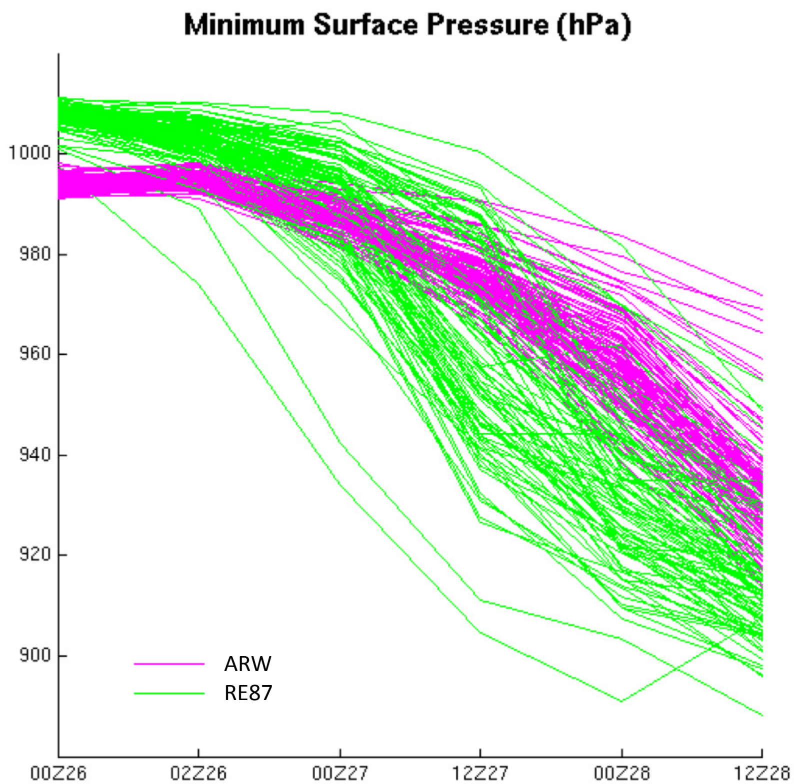
- Steady-state, axisymmetric hurricane Simulation
- Variables: Vt, u, v, w, dP, dT, Wz, q_l, and q_v
- Originally designed to study Maximum Potential Intensity (MPI) theory
- Nonhydrostatic, compressible dynamics, in cylindrical coordinates (r-z)
- Convection is accounted for explicitly
- Initialized with a finite-amplitude vortex
  - Rmax = 110 km, Vmax = 8 m/s
- Uses soundings from WRF Katrina members
- Ensemble size: 100
- 2-dimensional r-z plane interpolated to 3-Dimensions
- Reduced Domain:
  - 45 *x* 45 *x* 15 grid points
  - 9 km horizontal grid spacing
  - 1.2 km vertical grid spacing
  - ~ 400 km x 400 km x 18 km

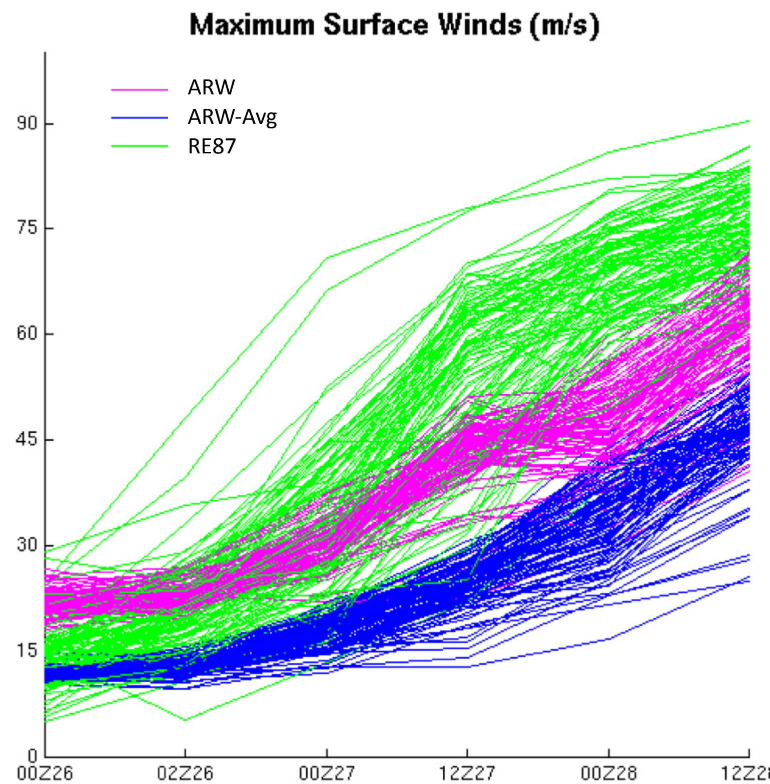


Advanced Research WRF (ARW)

- Fully compressible, nonhydrostatic, mesoscale model
- Variables: Vt, u, v, w, dP, dT, Wz, q_l, and q_v
- Nested vortex following domain:
  - 253 *x* 253 *x* 34
  - 4.5 km horizontal grid spacing
- Ensemble initialization: EnKF after assimilating hours of airborne Vr
- Ensemble size: 100
- Storms centered based on location of minimum surface pressure for Lagrangian case, and relocated based on the 12 hr ensemble forecast positions
- Two separate ARW experiments:
  - ARW-Avg: Variables averaged azimuthally
  - ARW: Non-averaged model output

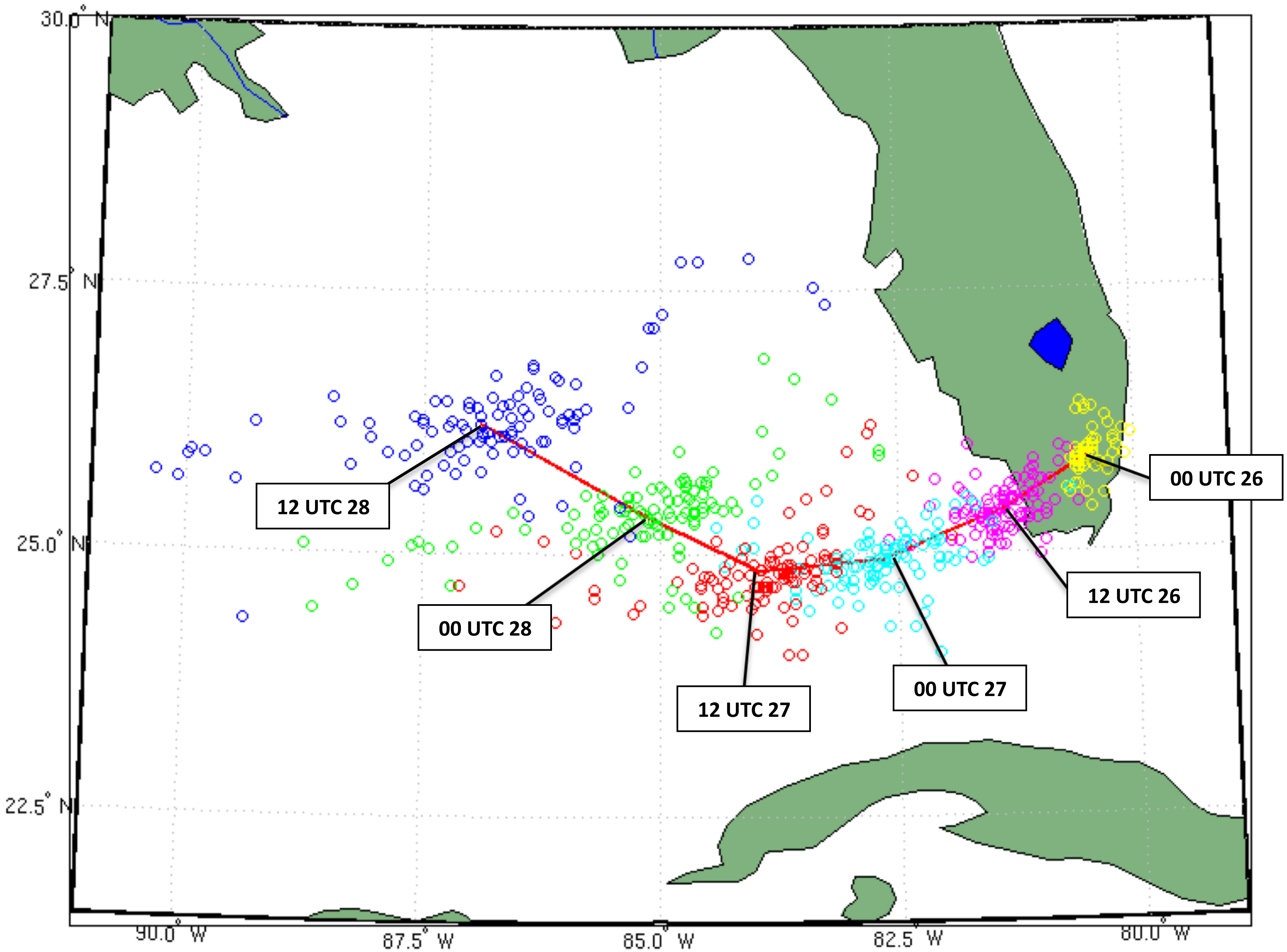
Ensemble Intensity Comparison for Hurricane Katrina



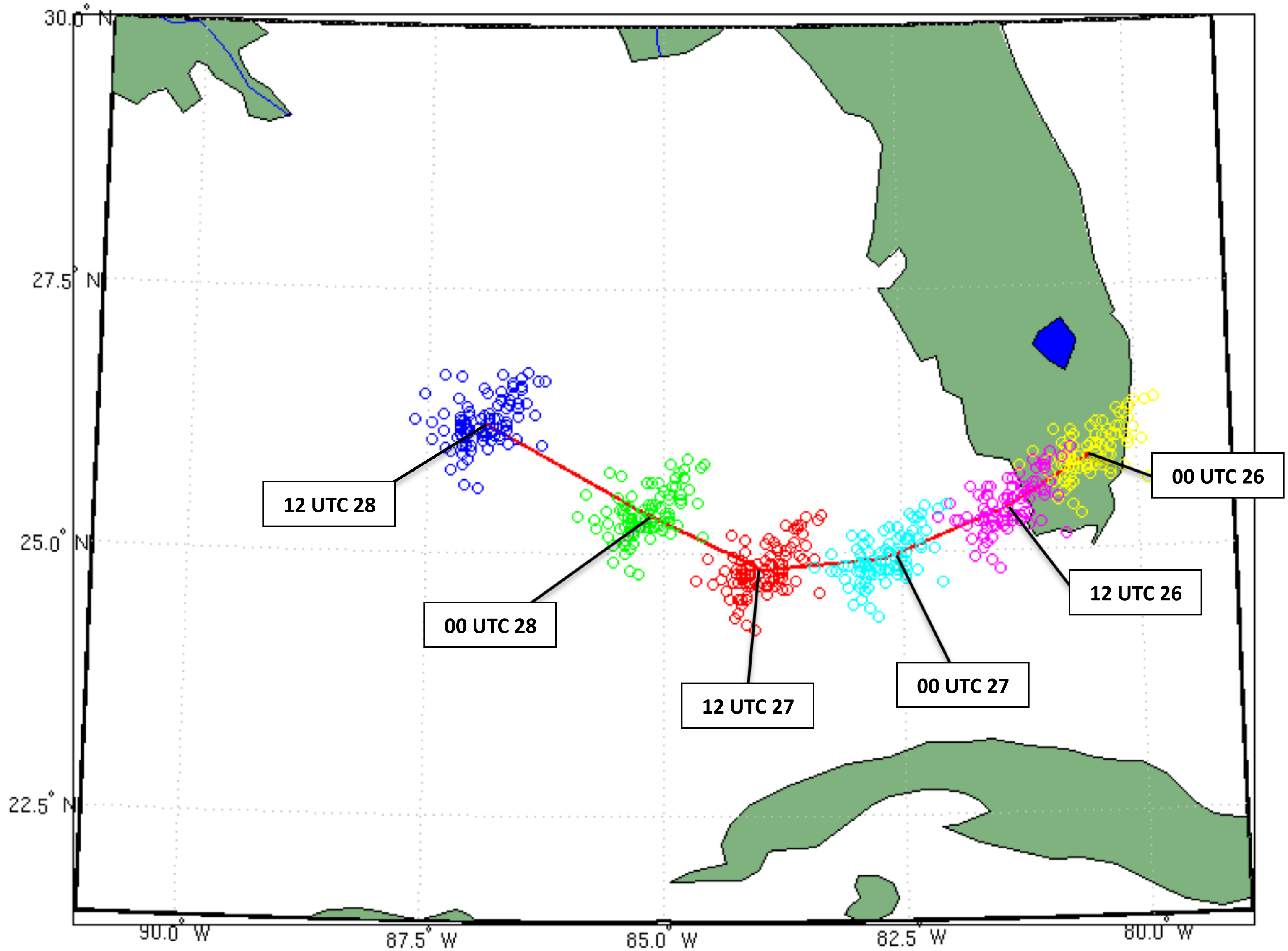


The time evolution of each member's minimum surface pressure and max surface wind speed are shown for Katrina (magenta and blue) and RE87 (green). Each time step for RE87 corresponds to 24 hrs (ranging from day 5 to day 10).

Katrina Mean Track and Member Locations

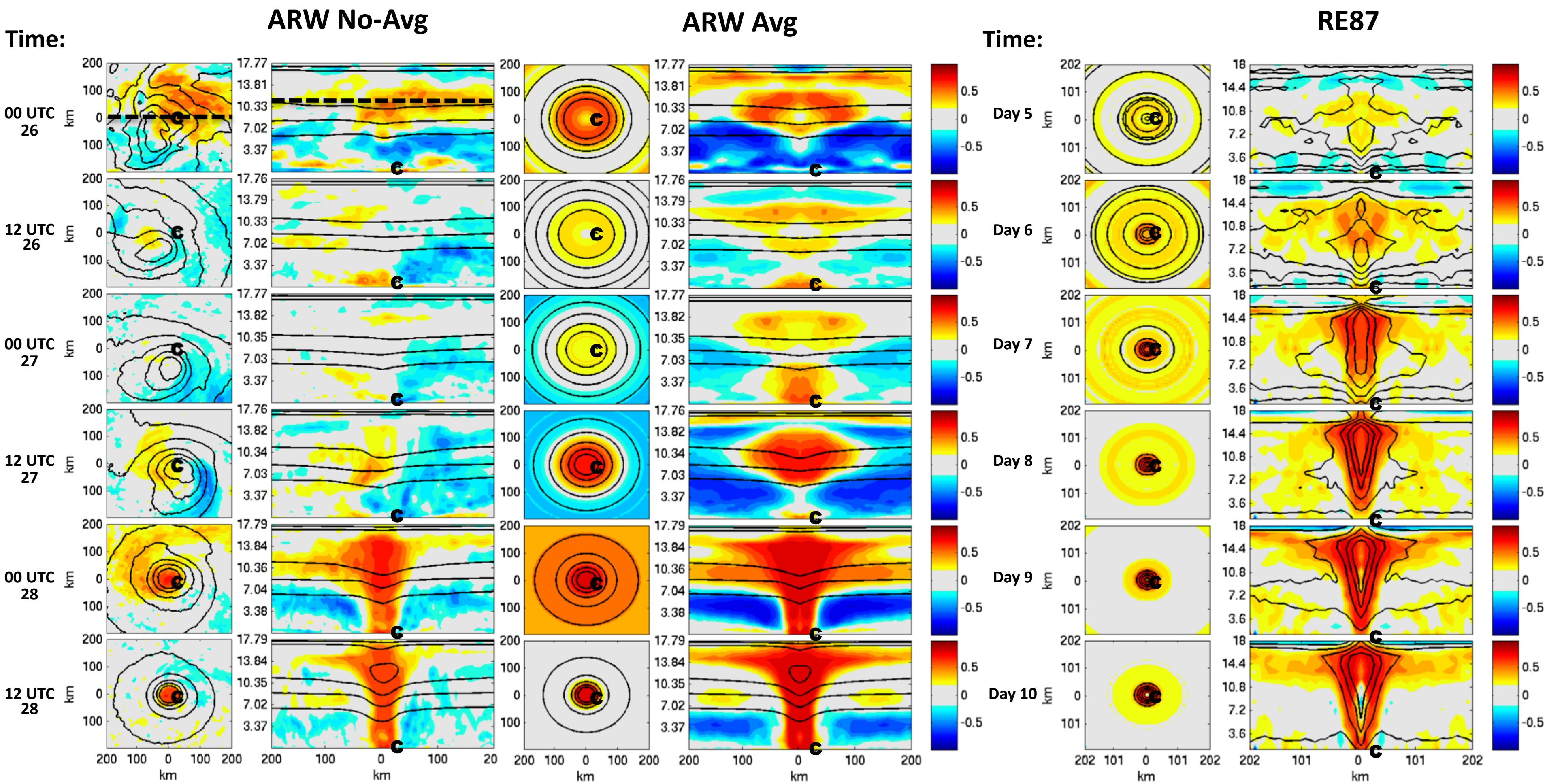


Katrina Mean Track and Relocated Members: New positions are based on 12-hr ensemble position error



Surface Tangential Velocity

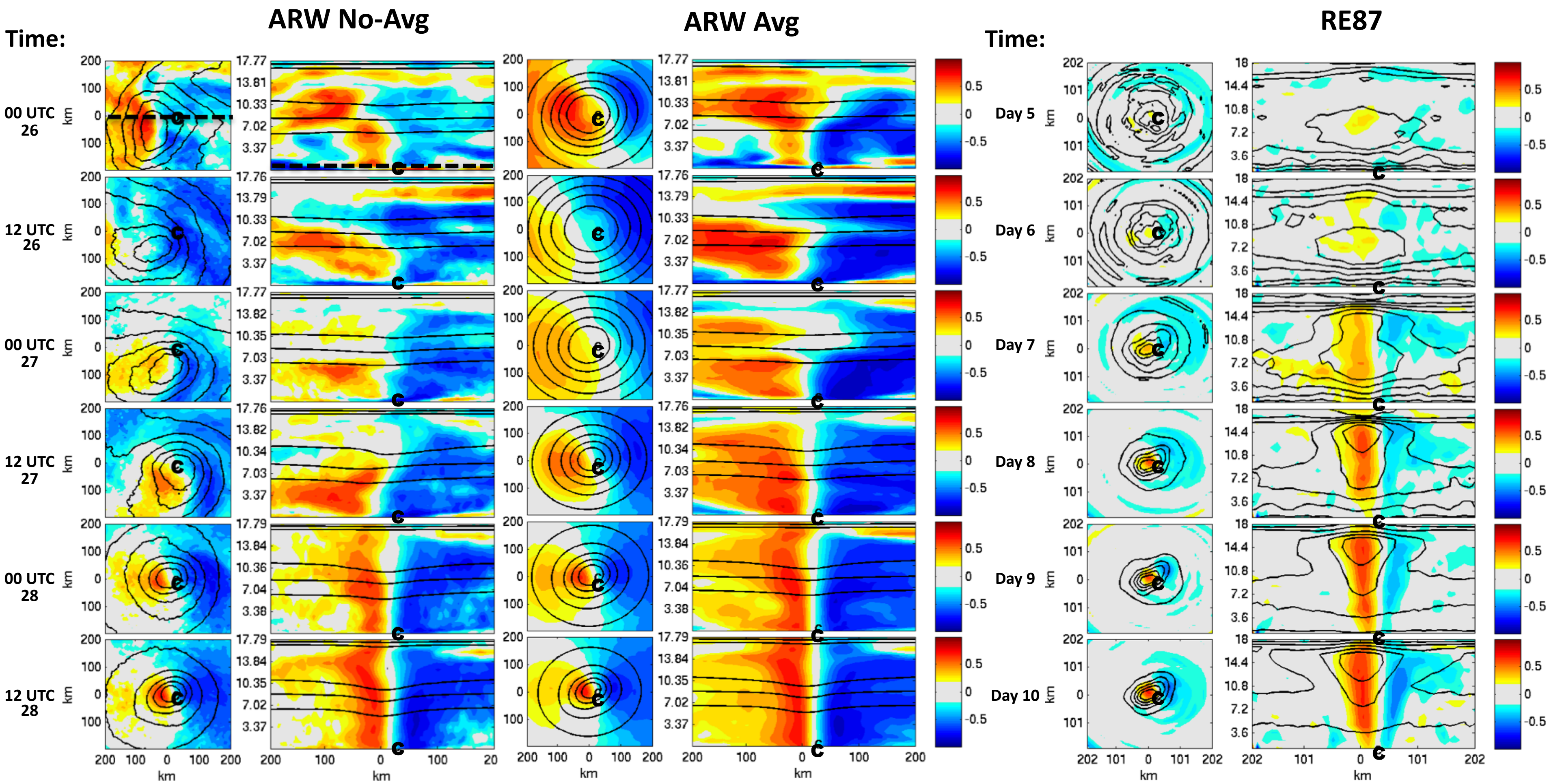
Lagrangian reference frame: Vt-dT Cross-Spatial Correlations



A hypothetical situation in which a surface velocity measurement (~36 km from the storm center) is used to correct the temperature field is demonstrated using the three model experiments.

Surface Tangential Velocity

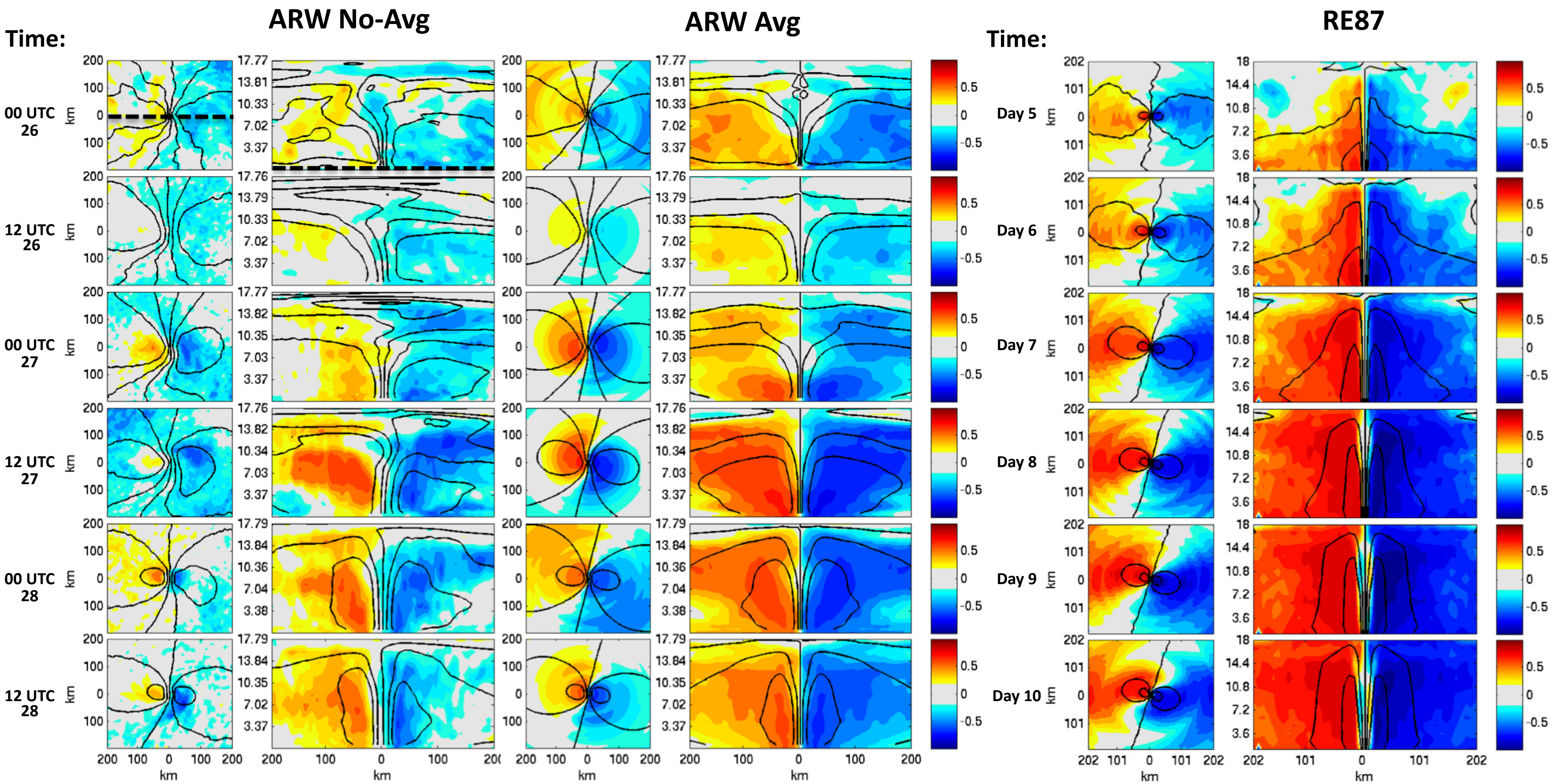
Eulerian reference frame: Vt-dT Cross-Spatial Correlations



Results from all experiments show Eulerian correlations to be dependent on storm intensity and location. Non-Gaussian errors associated with the 12-hr ensemble position spread produces a dipole in cross-correlations for this case.

Minimum Surface Pressure

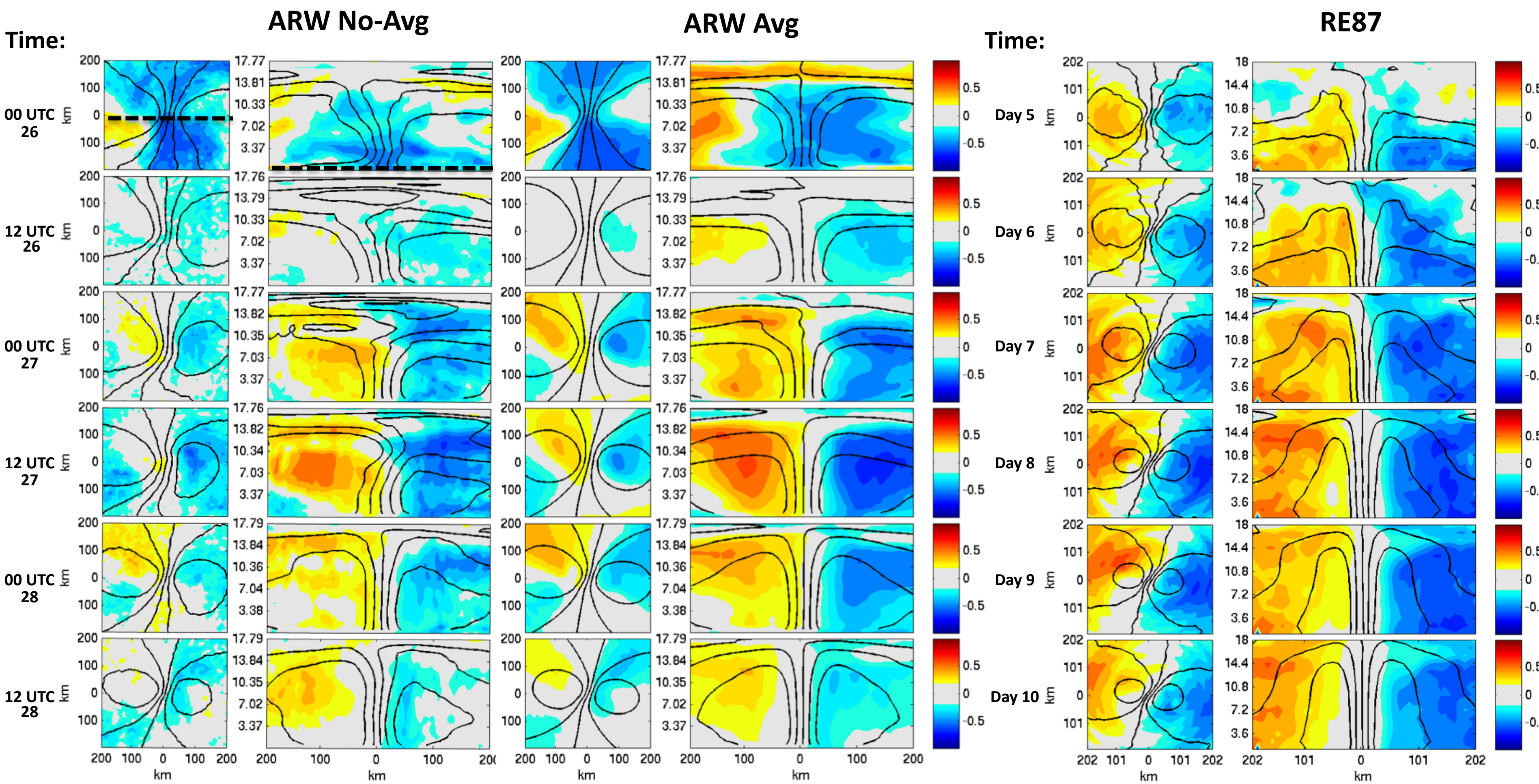
Lagrangian reference frame: Min SLP - Vt Cross-Spatial Correlations



Hurricane observations that are not regularly assimilated (e.g. maximum surface winds, radius of maximum winds, minimum sea level pressure, etc.) can be easily ingested using ensemble data assimilation methods, if significant correlations exist between the respective measurement and state variables.

Minimum Surface Pressure

Eulerian reference frame: Min SLP - Vt Cross-Spatial Correlations



Since wind speed and direction are largely determined by pressure gradients, broad regions of strong positive and negative values exist throughout the inner- and outer-core region. As a result, Eulerian correlations resemble values calculated in the Lagrangian reference frame, but with fewer significant values near the vortex center.

Summary and Conclusion

We examined the flow-dependent structure of ensemble correlations using a progression of simple to complex models:

Rankine vortex (not shown) ⟶ *Rotunno-Emanuel MPI model* ⟶ *ARW Katrina*

- Spatial correlations calculated from an ARW ensemble of Hurricane Katrina at six time steps were largely dependent on storm size, strength, and rate of intensification.

- For time steps at which Katrina maintained a category 3 or higher intensity, flow-dependent correlation structures were comparable to values calculated from a low-order, axisymmetric vortex model.

- Katrina members at early time steps demonstrated large degrees of tilt and asymmetry, resulting in large discrepancies in forecast error for the two models.

- Results from this study support the notion that covariance parameterization may be used for assimilating observations into an intense (category 3 or greater) hurricane using a simplified vortex model.

A possible hybrid method in which flow-dependent forecast error calculated from an ensemble of axisymmetric vortices is integrated into a variational data assimilation method may be developed.