Ensemble Statistics and Error Covariance in a Rapidly Intensifying Hurricane

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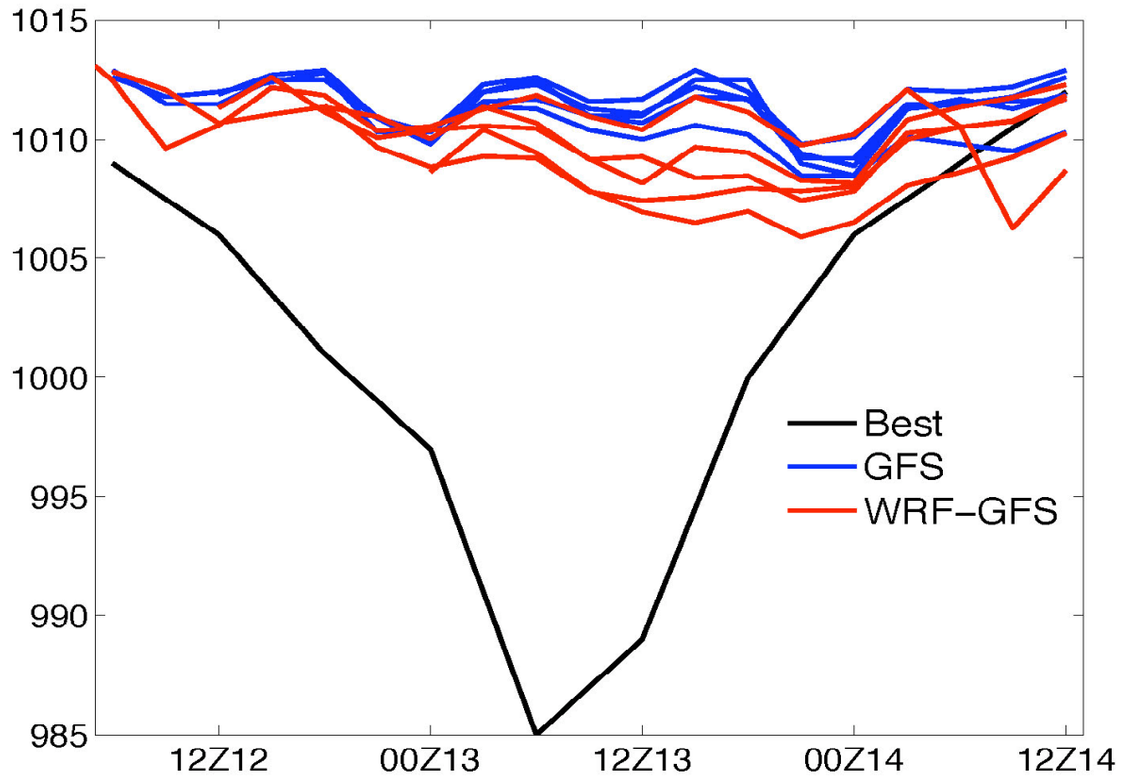
Motivation

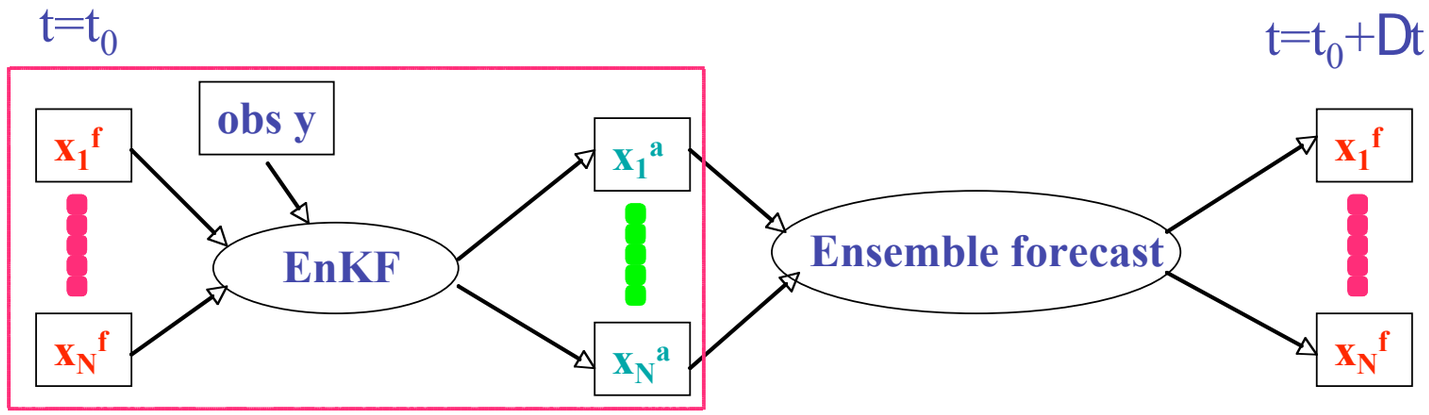
- Forecasting genesis and intensification of tropical cyclones remains challenging
  - Track forecasts vastly improved (Franklin, 2007), skill of forecasting intensity static
  - Improvements made in forecasts of other systems (Hawlblitzel et al, 2007)
- Data assimilation as a solution
  - Combines all available information optimally to best estimate state of atmosphere
  - Past studies (Zhang, 2005) indicate initial condition accuracy one key to capturing small, mesoscale features



*GFS (**blue**) & 4.5-km WRF (**red**) forecast: No forecast initialized with GFS FNL analysis ev 6hr from 00Z 12 to 00Z 13 predicts rapid formation*

Ensemble Kalman Filter

- Based on linear statistical assumptions
  - All errors assumed to be Gaussian
  - Lack of computing power prevents full solution of non-linear systems



- EnKF equations

(1) $\mathbf{x}_a = \mathbf{x}_b + \mathbf{K}[\mathbf{y}_0 - \mathbf{H}(\mathbf{x}_b)]$ *Estimate of analysis*

(2) $\mathbf{K} = \mathbf{B}\mathbf{H}^T(\mathbf{H}\mathbf{B}\mathbf{H}^T + \mathbf{R})^{-1}$ *Kalman gain matrix*

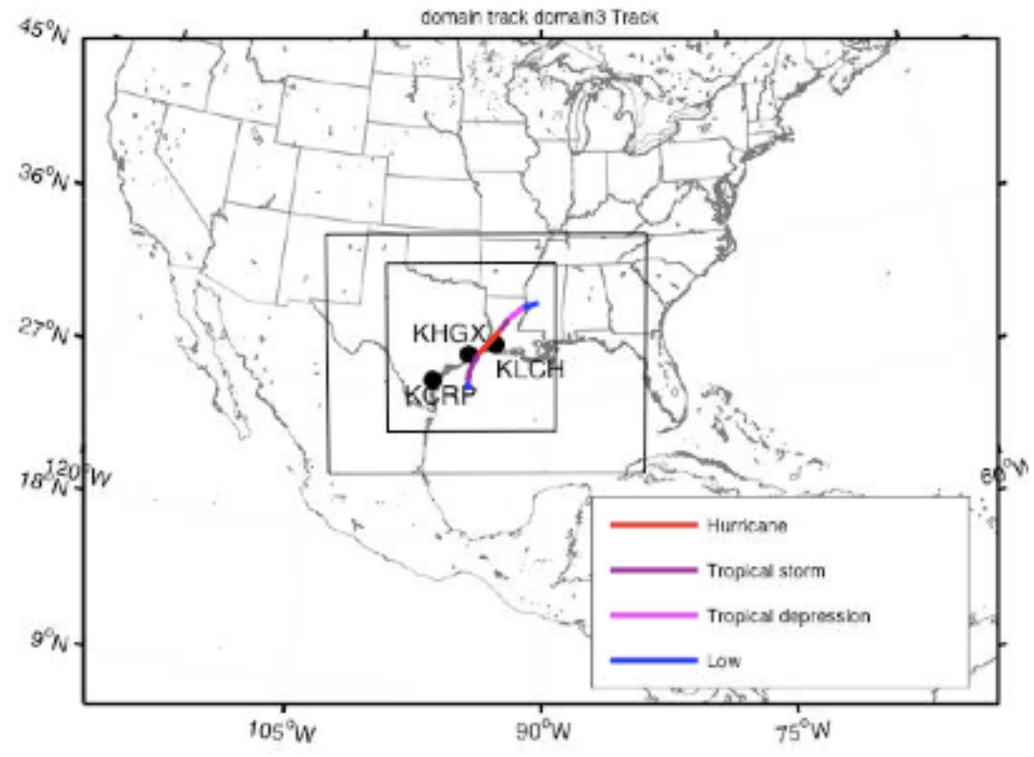
(3) $\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})(y_i - \bar{y})$ *Covariance calculation*

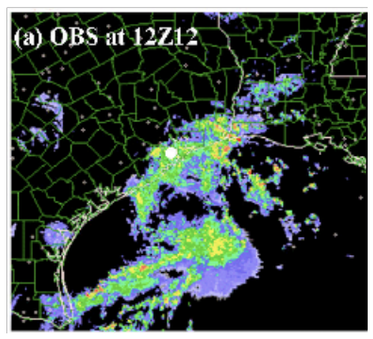
Why the EnKF?

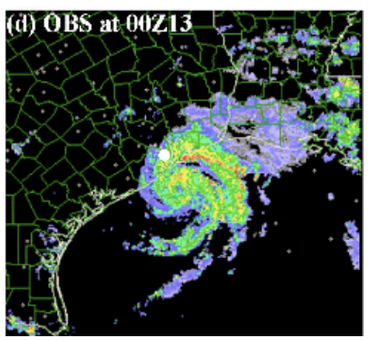
- 3DVAR (used at NCEP)
  - Uses a mostly static, isotropic background error covariance function
- 4DVAR (used for the ECMWF)
  - Equivalent to EnKF for linear cases
- Ensemble Kalman filter
  - No adjoint model necessary (computationally efficient)
  - Dynamic background covariance
    - Background covariances estimated directly from ensemble and can capture non-linear dynamics
    - Covariance structures evolve anisotropically according to dynamics of system
      - Coherent structures most prominent in areas of moist convection, strong PV gradients (Zhang, 2005)

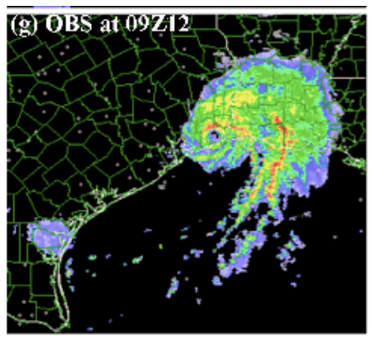
Model Setup

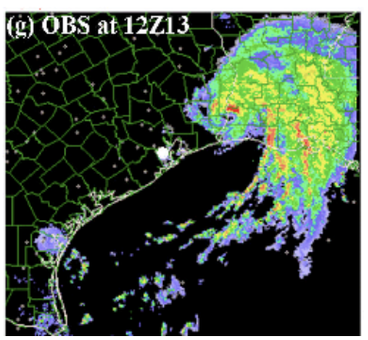
- WRF model used in study of Hurricane Humberto
- 3 model domains with two way nesting
- 00UTC 12 September GFS operational analysis used to create initial boundary conditions
- Ensemble size set at 30 members



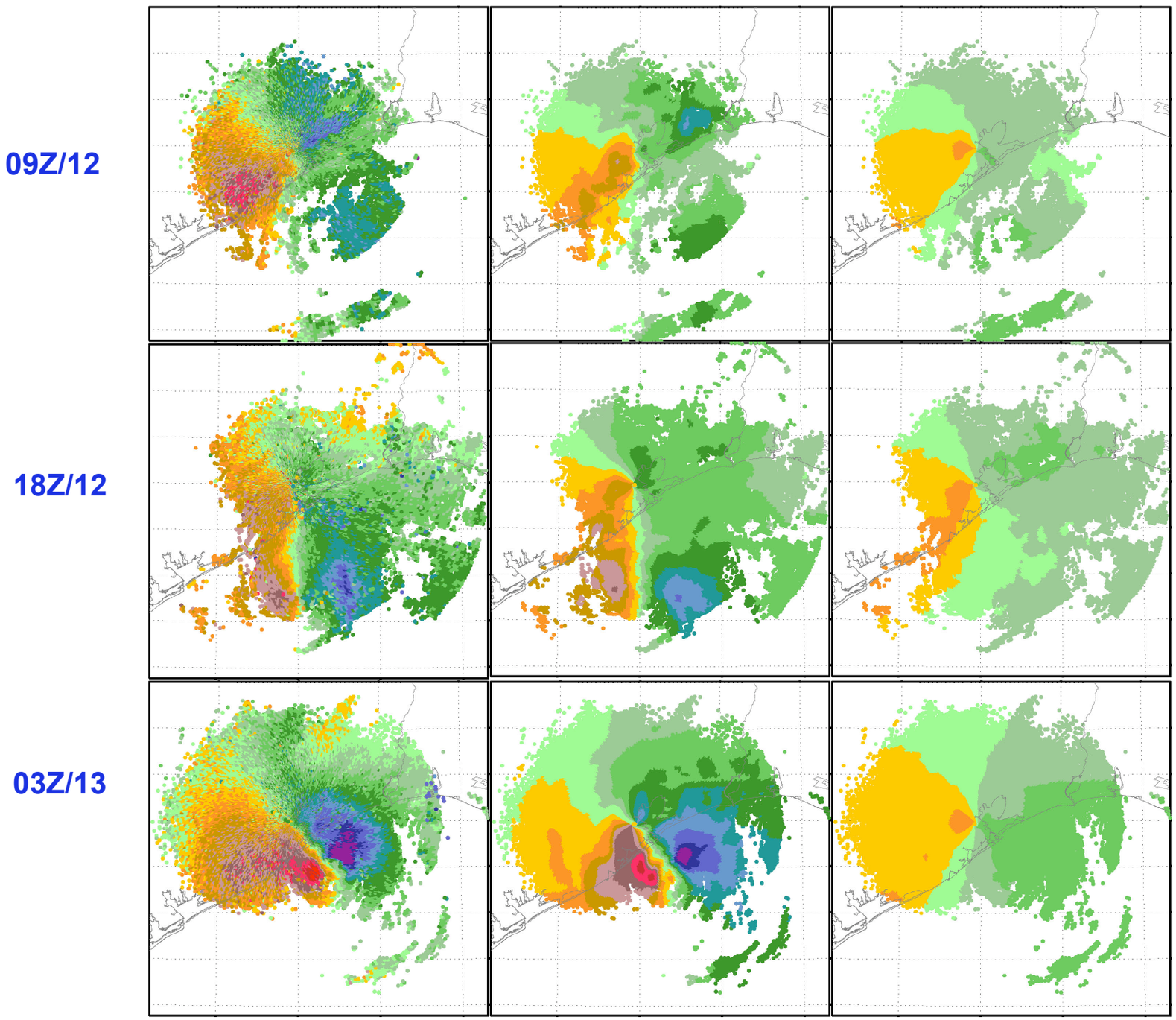






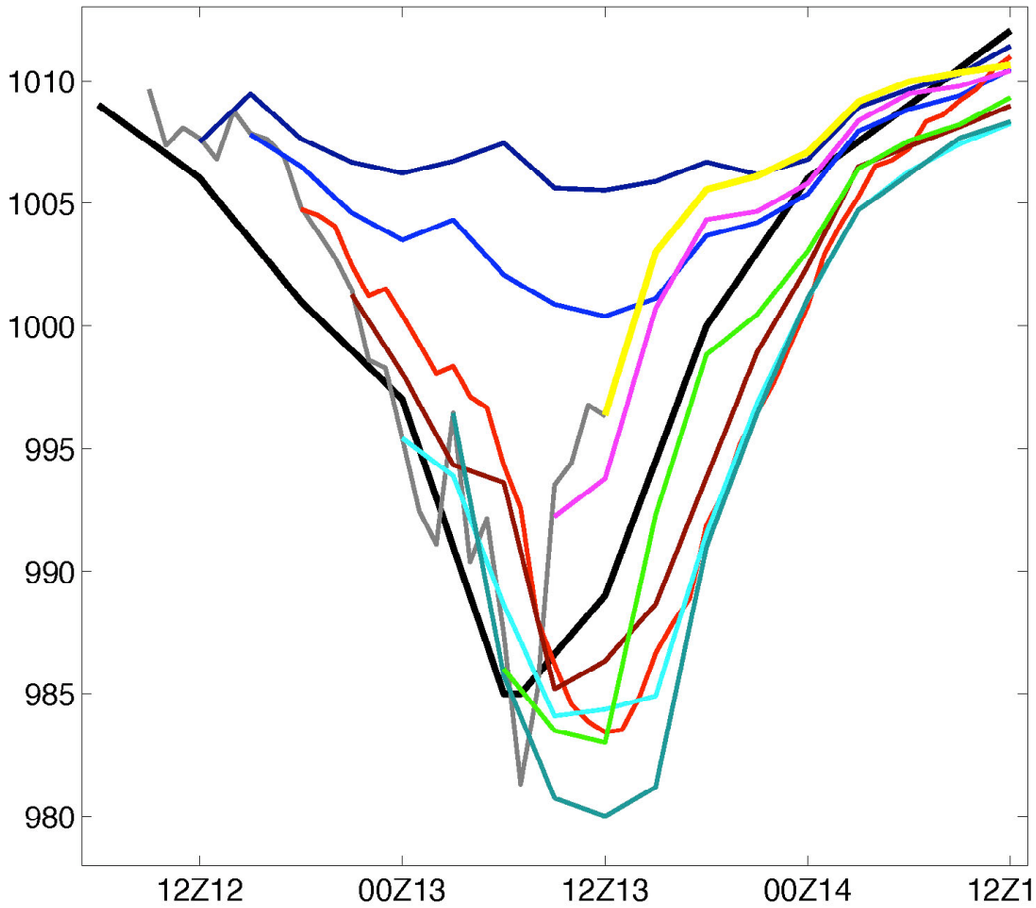


Radar Obs Assimilation

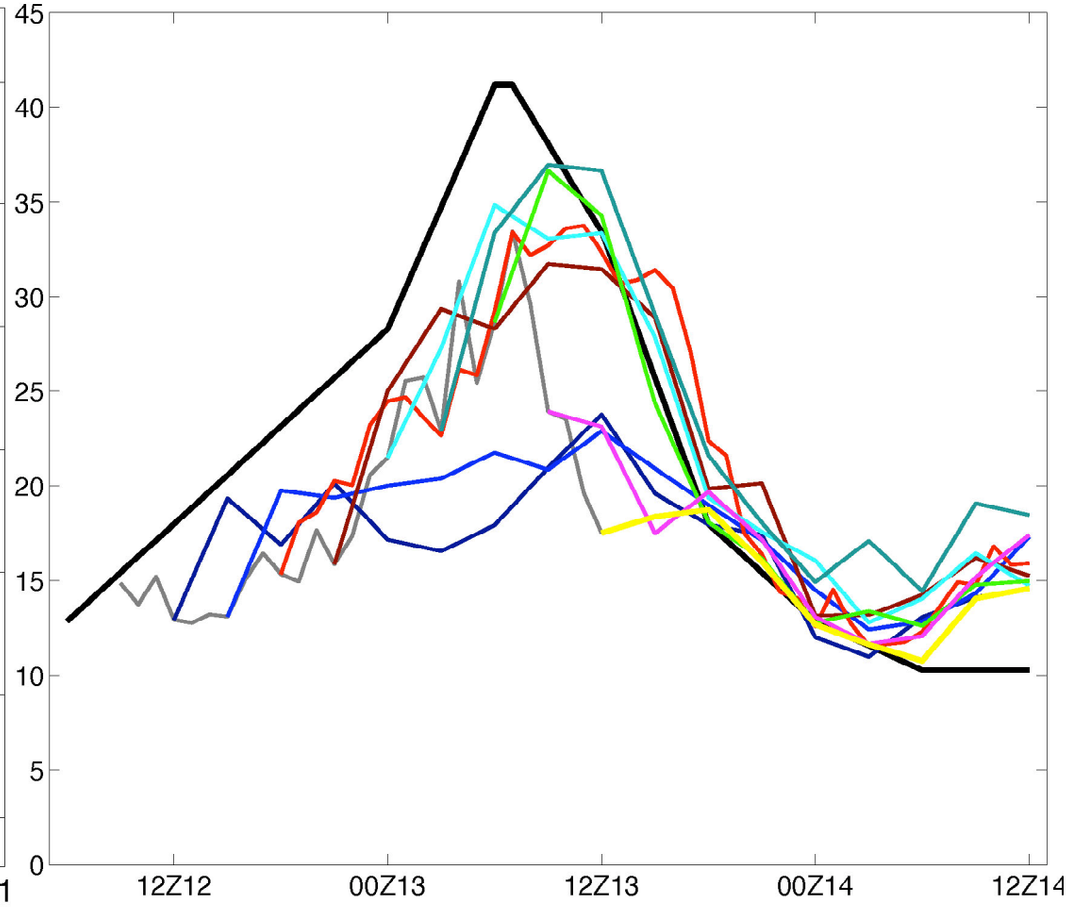


Radial velocities: Blues indicate winds toward the radar, reds indicate winds away from the radar

Radar Obs Assimilation



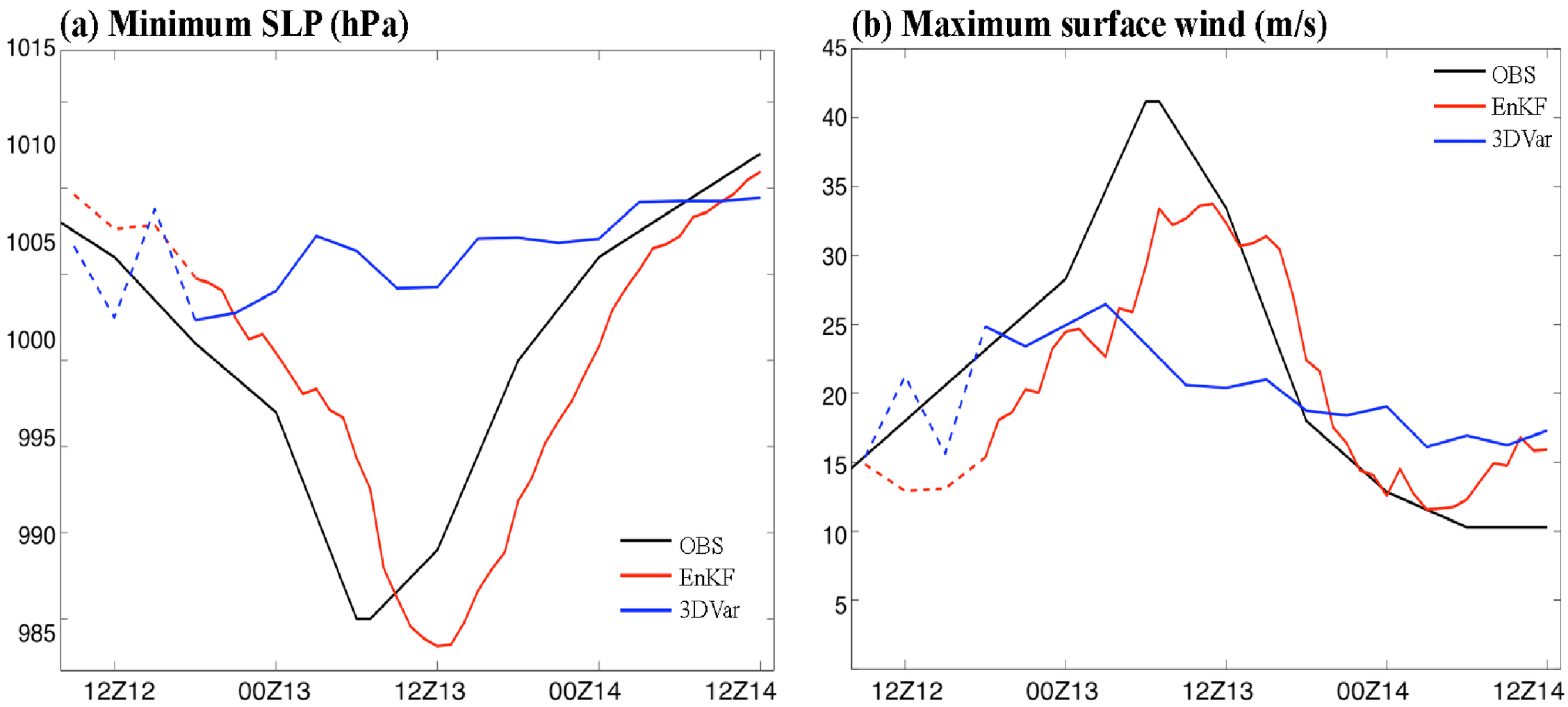
Min SLP (hPa)



Max WSP (m/s)

Forecasts initialized with EnKF analyses captured rapid cyclone deepening

WRF/3DVAR vs. WRF/EnKF

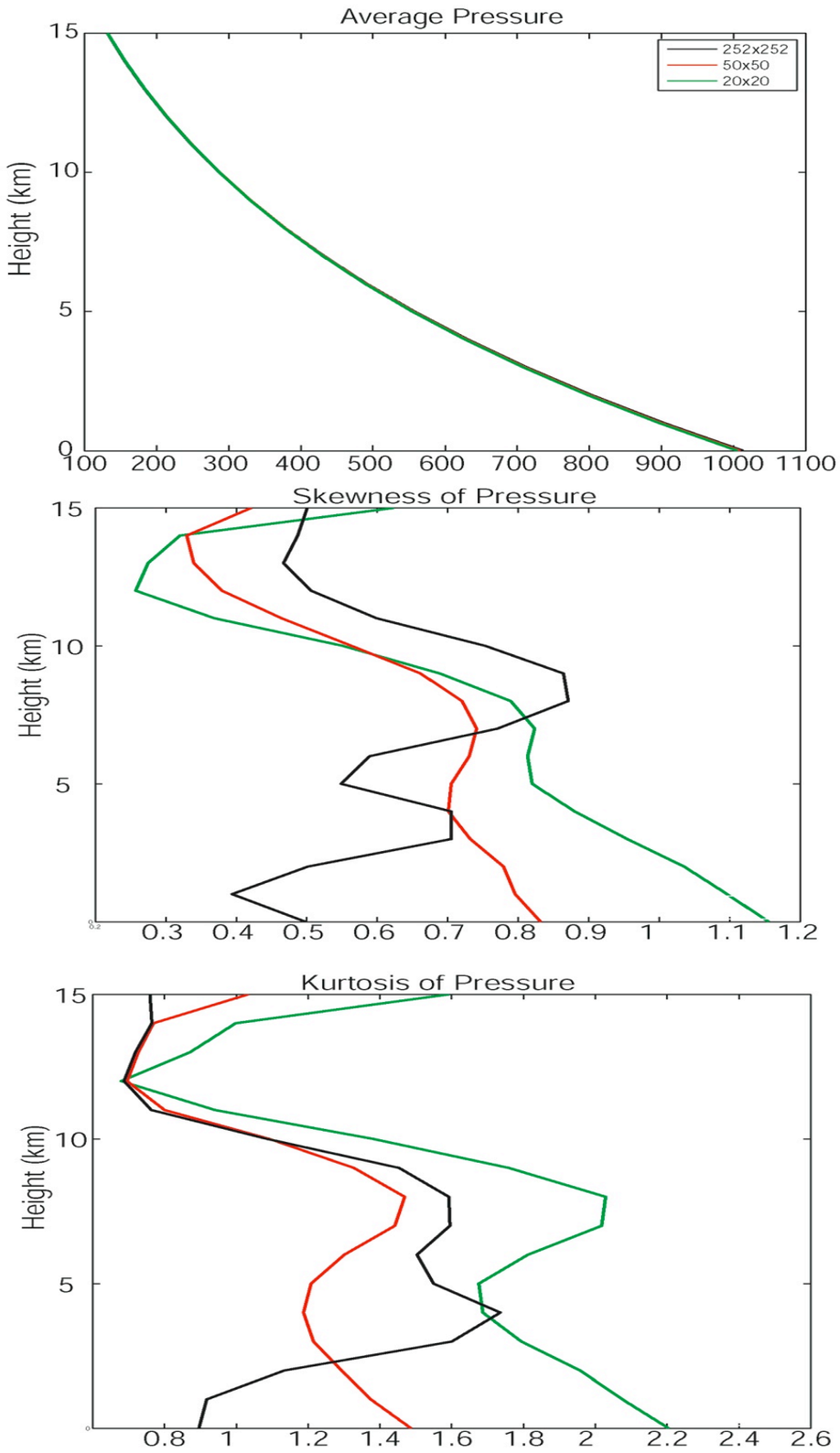


WRF/3DVAR fails to capture rapid intensification of tropical cyclone

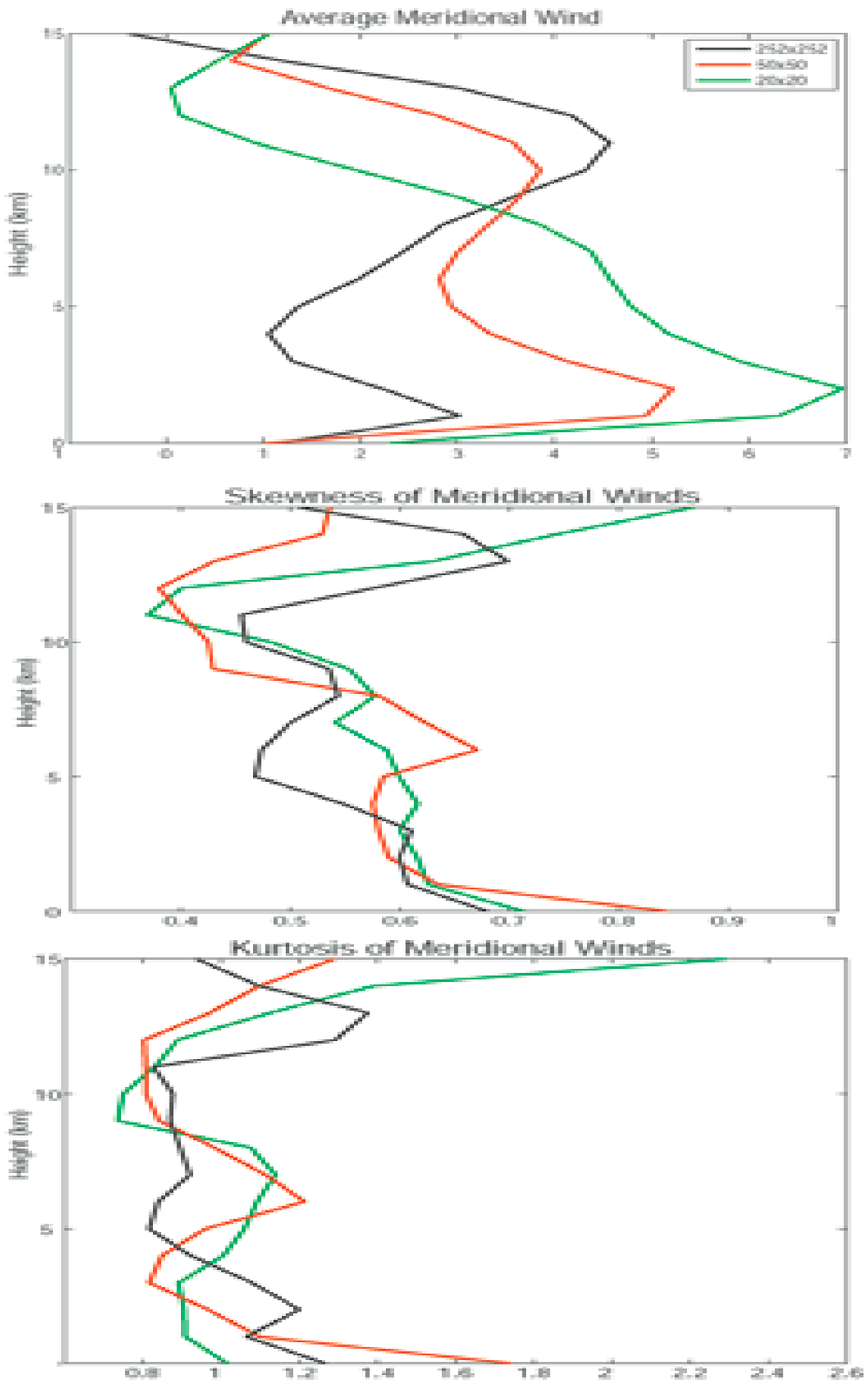
Methods

- Analysis performed at 0900 UTC on September 13 (at the time of landfall calculated by WRF ensemble)
- Statistical moments averaged across spatial domains
  - Three domains (252x252, 51x51,21x21)
  - Average taken at each vertical layer of domain (1 through 15 km)
- Will quantify non-Gaussianity of distribution and determine whether it affects performance of EnKF
- Superobs' effectiveness in reducing non-Gaussianity explored

Ensemble Statistics of a Tropical Cyclone

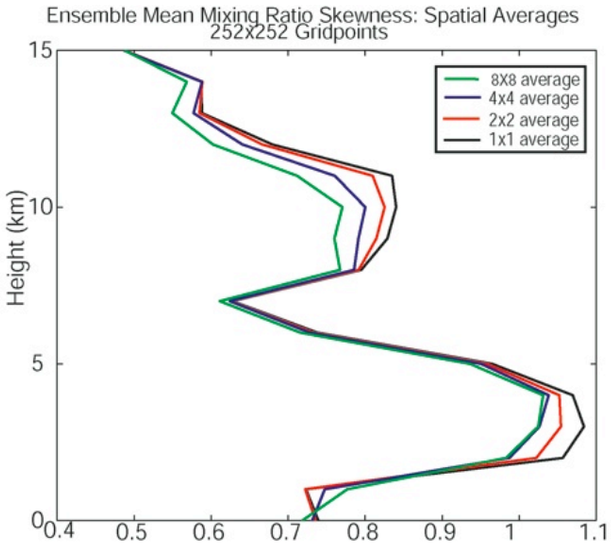


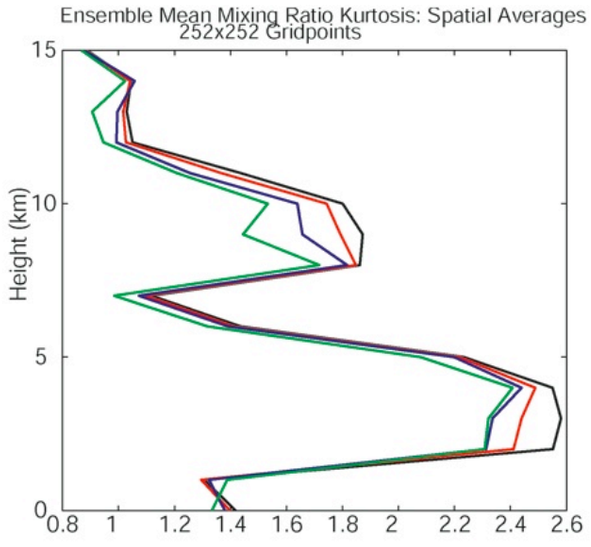
Skewness and Kurtosis of Pressure

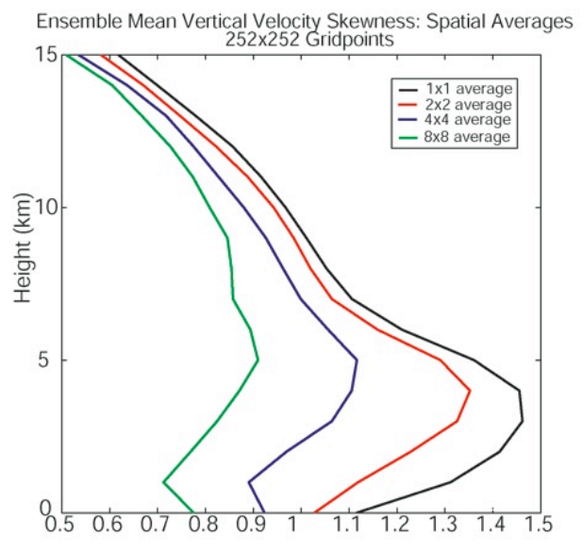


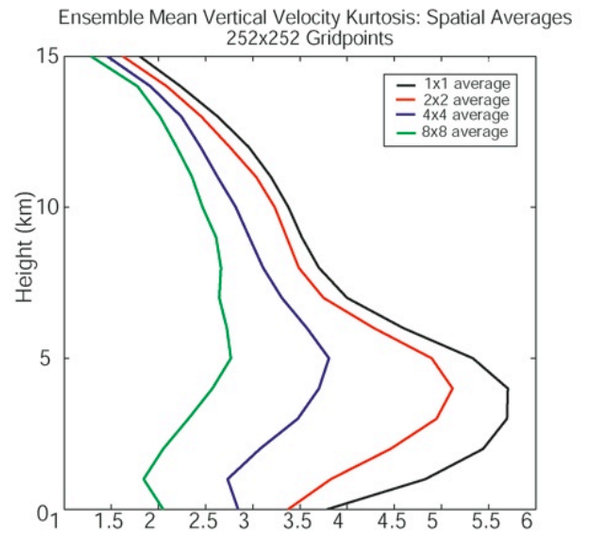
Skewness and Kurtosis of Meridional Wind

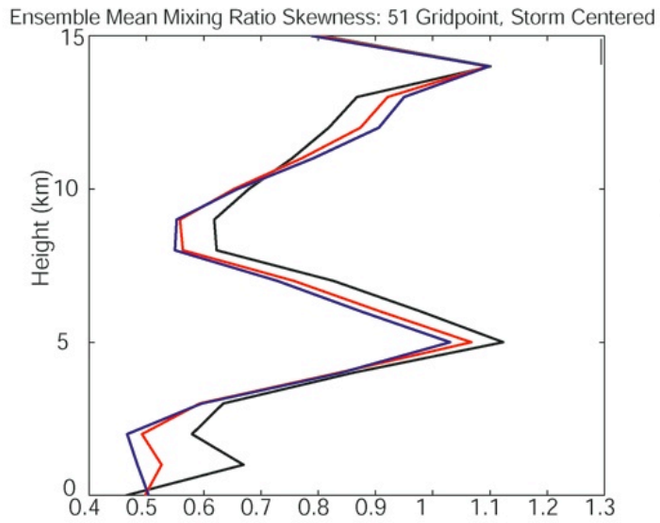
Effect of superobbing

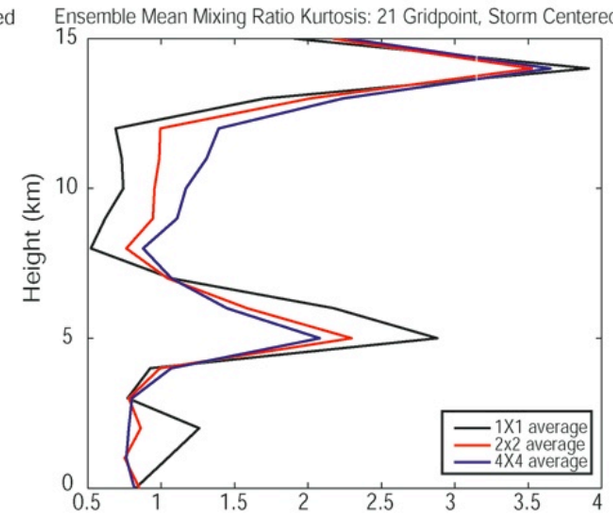


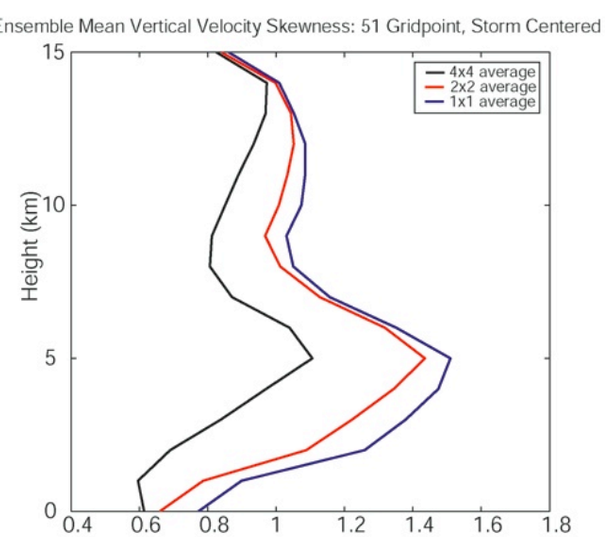


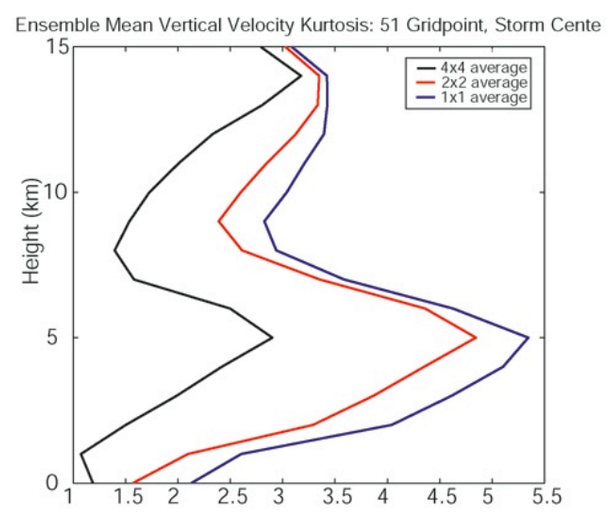


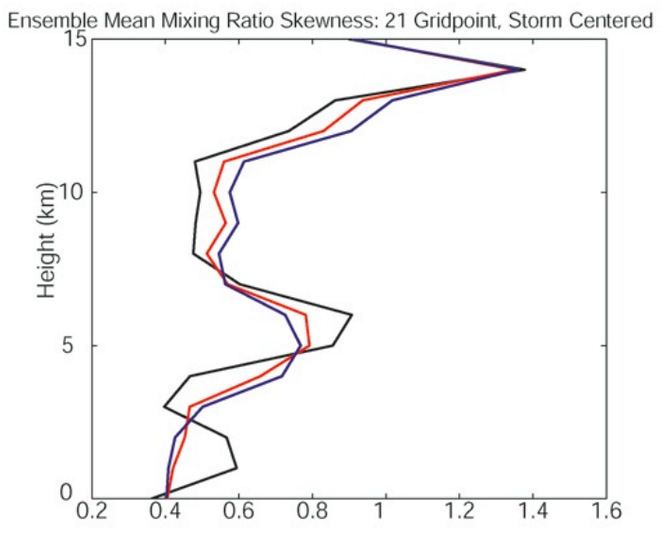


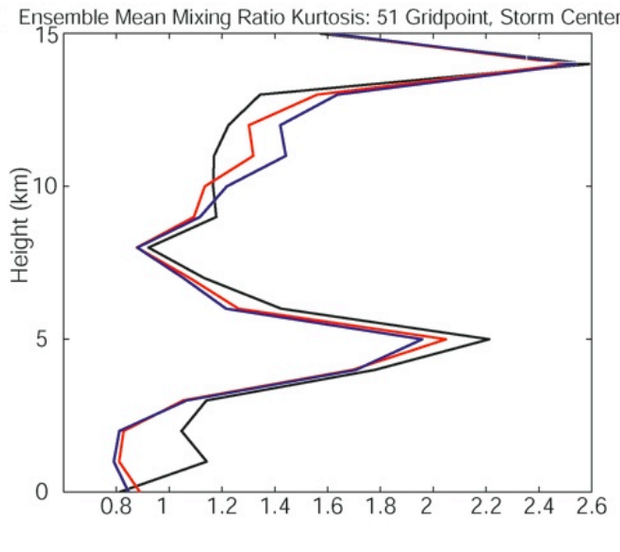


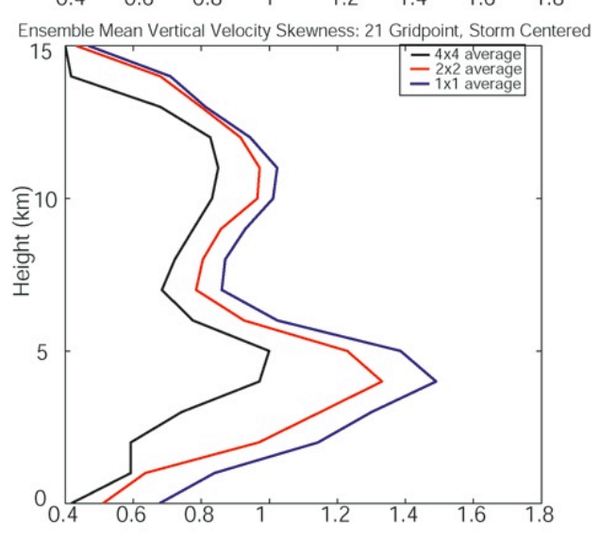


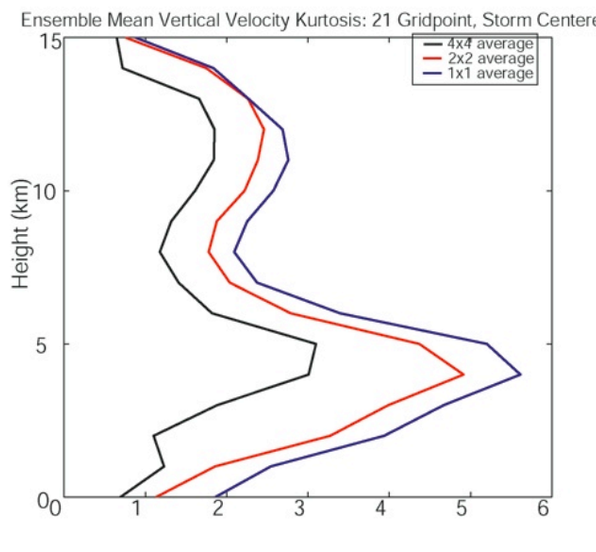












Summary and Conclusions

- Current numerical models often fail to capture rapid genesis of extreme weather events
- EnKF allows flow dependent covariance calculations
- EnKF analysis and deterministic forecasts able to capture some of Humberto's rapid intensification
- Non-Gaussianity has potential to degrade EnKF updates
  - Non-Gaussianity shown to be most severe in areas of moist dynamics and intense convection
- Superobbing shows potential to perform well operationally and reduce non-Gaussianity
- Storm-centered assimilation schemes provide potential for better representation of intense mesoscale events
  - Covariances better able to be calculated near storm center