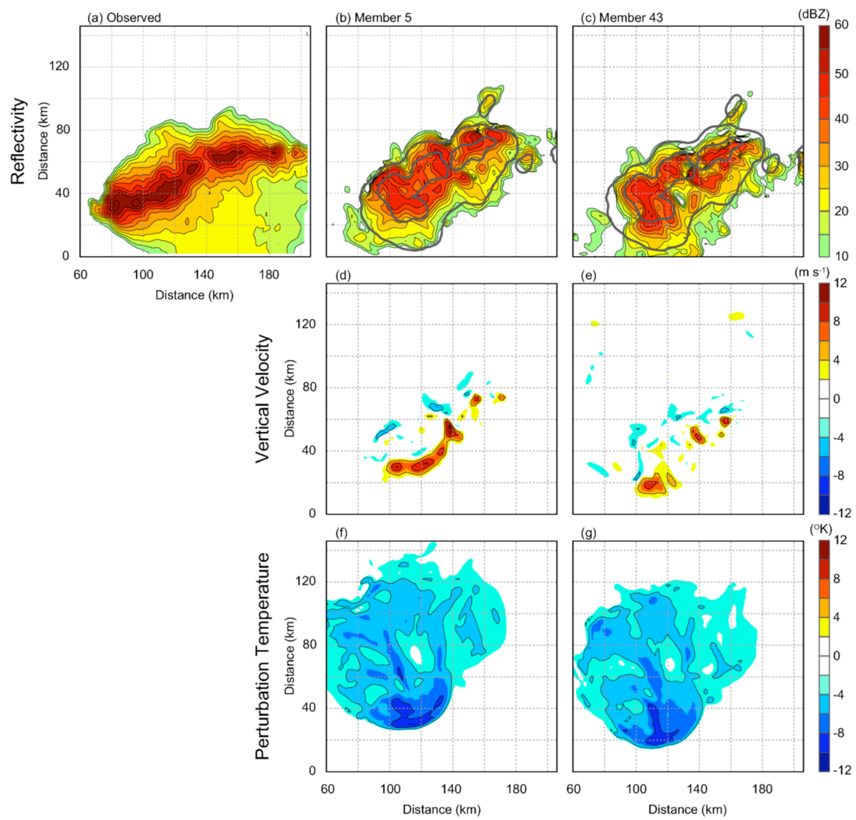
Mesoscale Ensemble Data Assimilation with WRF and the Data Assimilation Research Testbed



Chris Snyder (NCAR)

Mesoscale Ensemble Data Assimilation with WRF and the Data Assimilation Research Testbed

DART development: Jeff Anderson, Nancy Collins, Tim Hoar

Assimilation of surface obs: David Dowell, Soyoung Ha

Tropical cyclone results: Ryan Torn (SUNY Albany)

Assimilation of radar obs: Altug Aksoy (U Miami), David Dowell

Plus: Alain Caya (Environment Canada), Yongsheng Chen (York U), Josh Hacker, Hui Liu, Bill Skamarock

Challenges of Meso- and Convective-Scale DA

Dynamics are complex

- Mass-wind balances are limited or absent
- Strong role of parameterized, diabatic processes

Observations are incomplete

- E.g., single component or single level of ***v***

Forecasts are less skillful than at large scales

- 30 minutes is “medium range” at convective scale
- Models may have large deficiencies

The Ensemble Kalman Filter (EnKF)

Basics of the EnKF

- Estimate covariances at each analysis time from ensemble of short-range forecasts

Attractions for mesoscale applications

- Minimal assumptions about covariances; does not rely on large-scale balances
- Flexible to details of model, such as complex microphysical schemes
- Ease of implementation and parallelization

How the EnKF works

Suppose we wish to assimilate an observation of v_r
Consider how assimilation affects a model variable, say *w*.

Begin with:

- ensemble of short-range forecasts (of model variables)
- Observed value of v_r

How the EnKF works (cont.)

1. Compute v_r for each ensemble member

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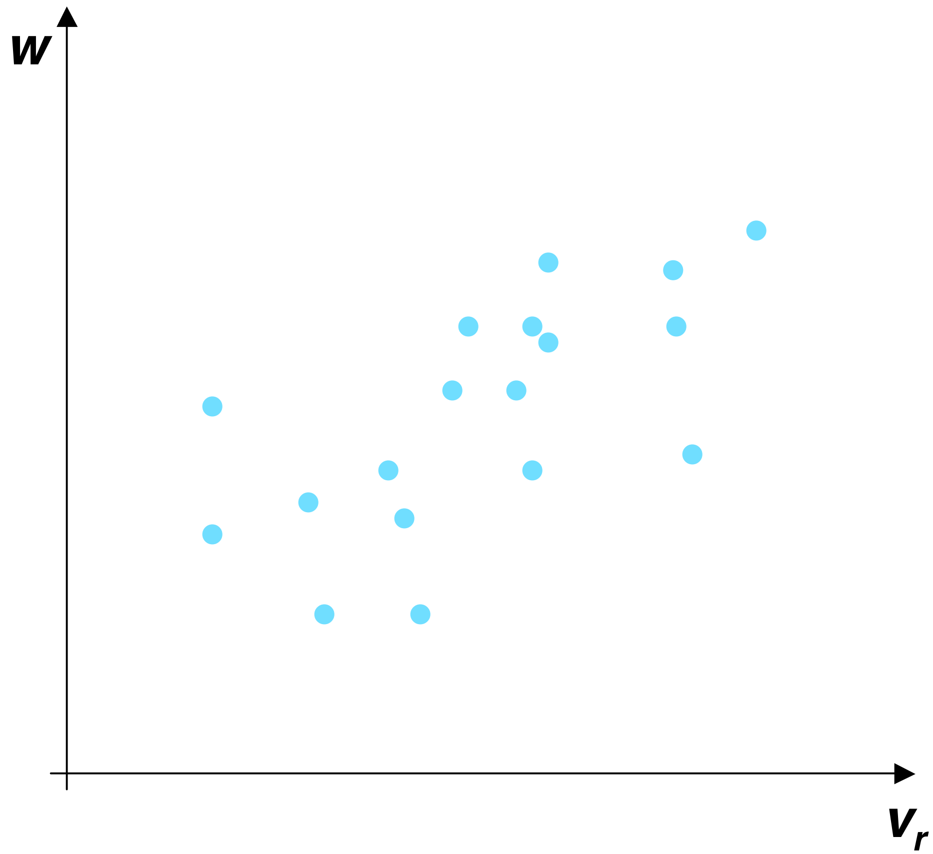

How the EnKF works (cont.)

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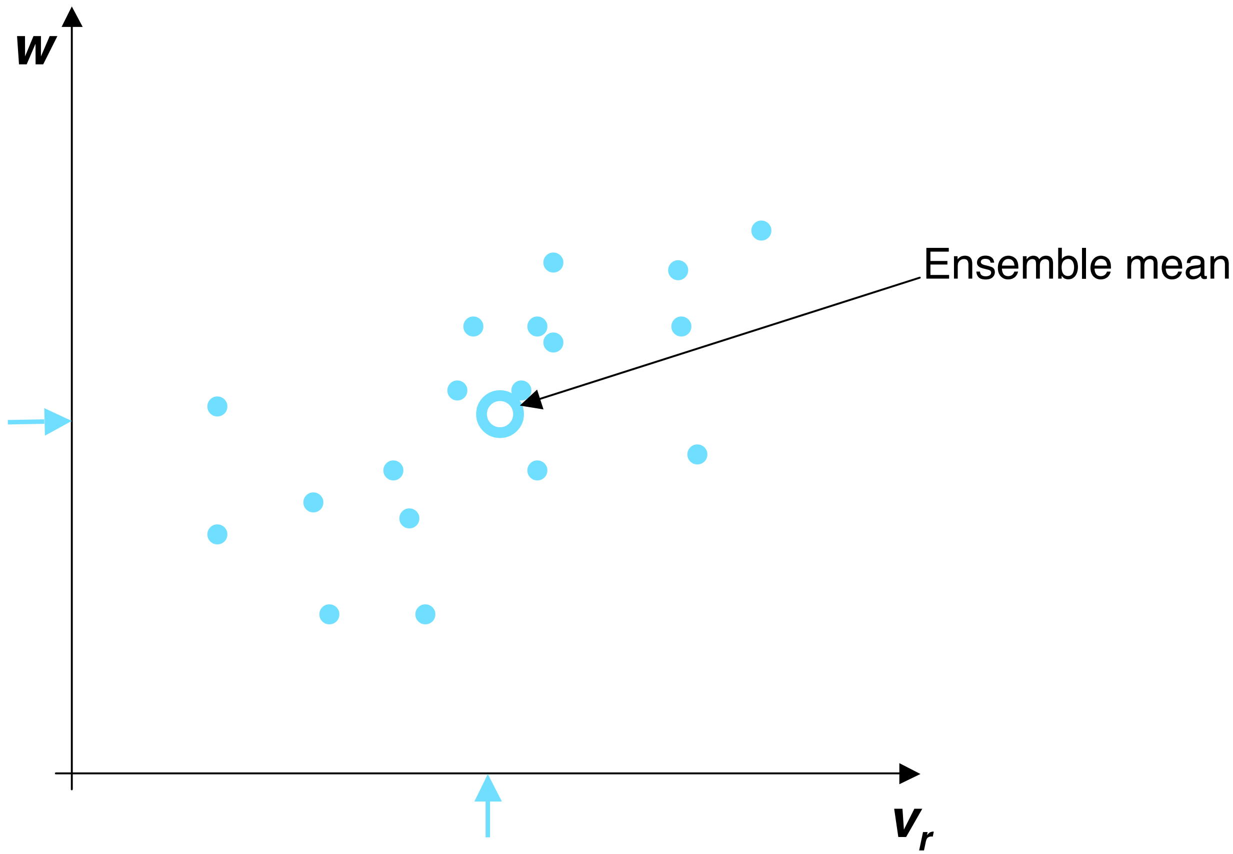

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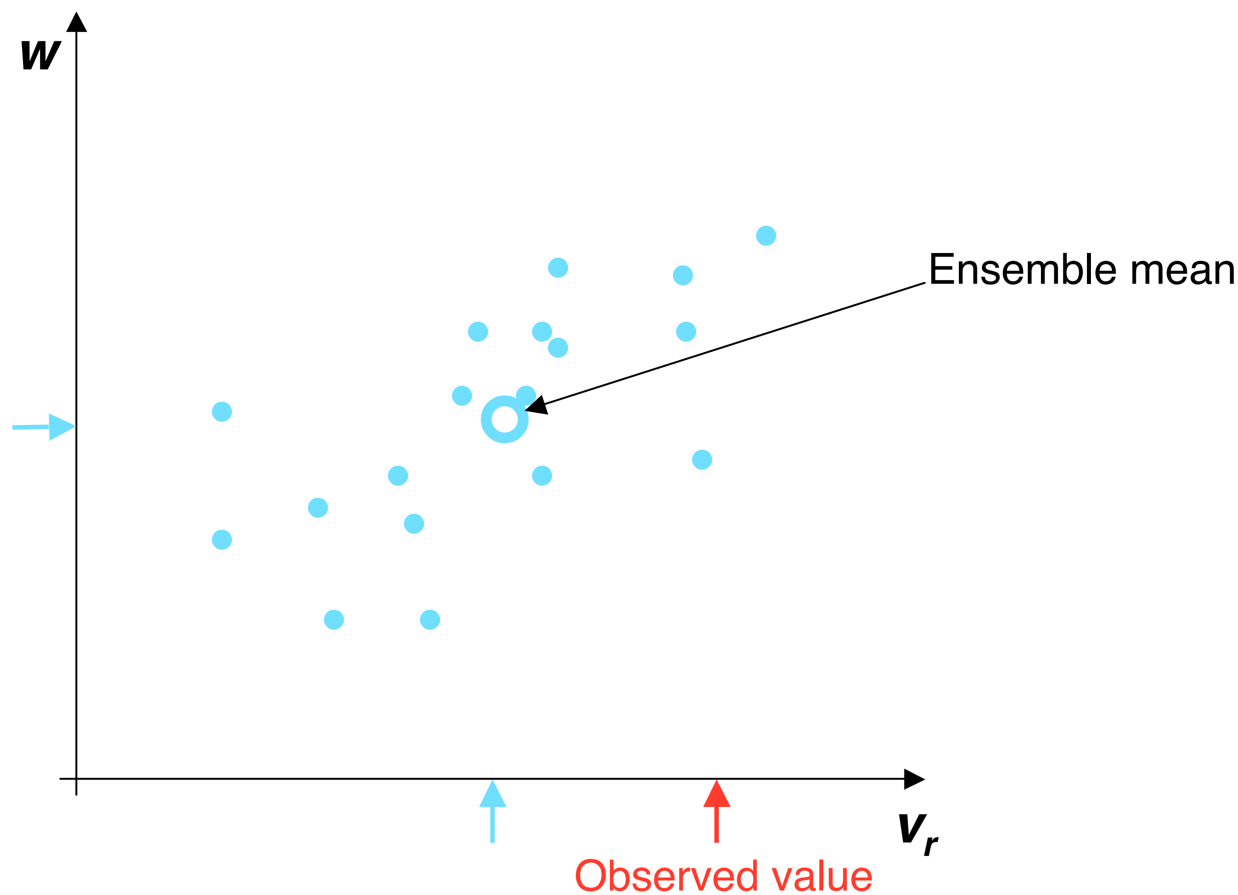
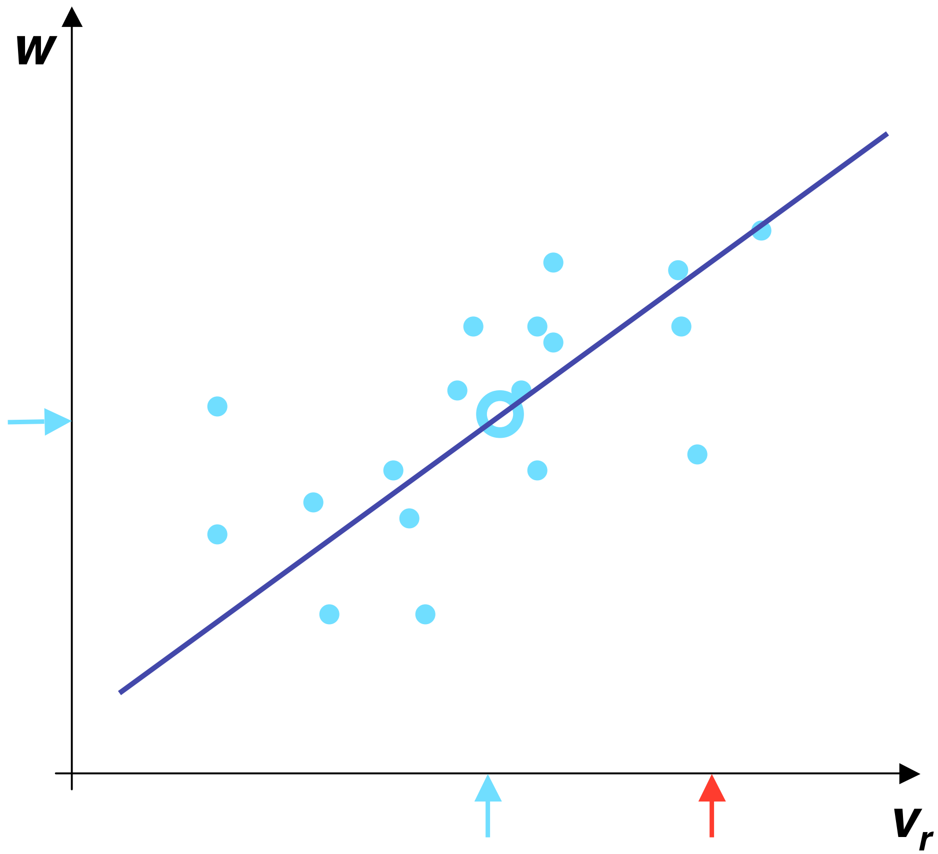


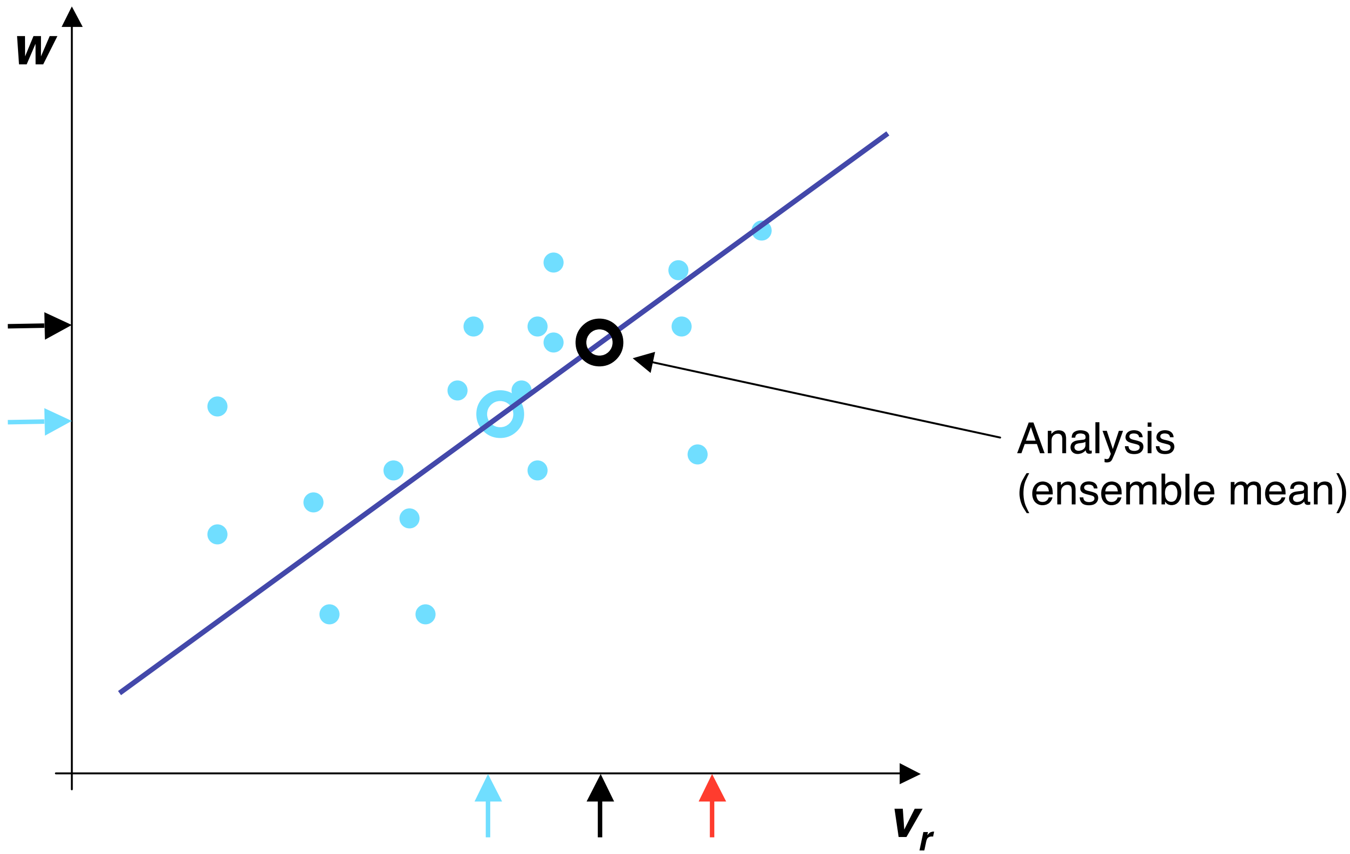
How the EnKF works (cont.)

2. Compute best-fit line that relates v_r and w



How the EnKF works (cont.)

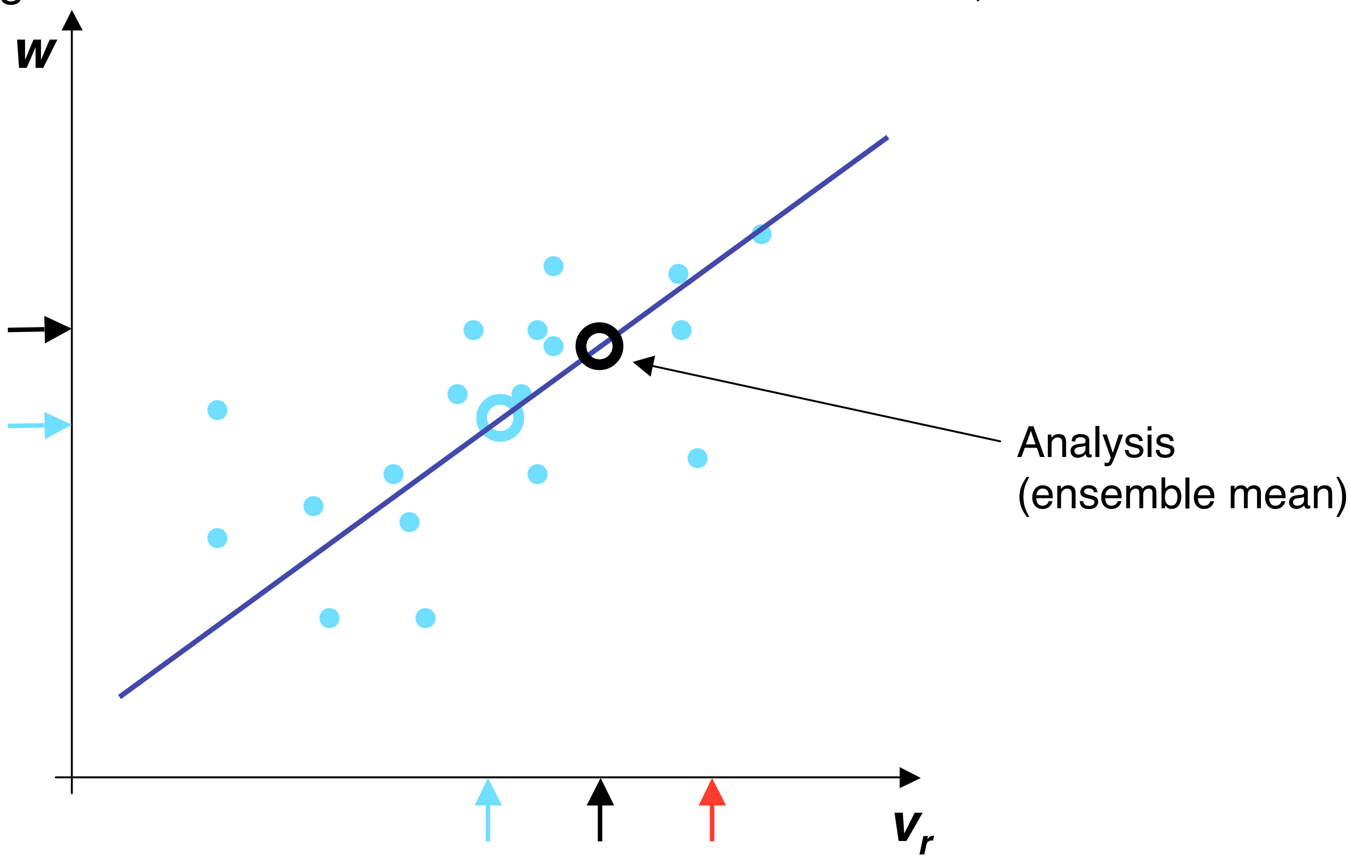
3. Analysis moves toward observed value of v_r and along best-fit line



How the EnKF works (cont.)

3. Analysis moves toward observed value of v_r and along best-fit line

… have gained information about unobserved variable, *w*



How the EnKF works (cont.)

4. Update deviation of each ensemble member about the mean as well.

Yields initial conditions for ensemble forecast to time of next observation.

Data Assimilation Research Testbed (DART)

Provides general, model-independent algorithms for ensemble filtering

Numerous DART-compliant models

- ARW, CAM, COAMPS, …

Parallel analysis scheme that scales well to 100's of processors

See http://www.image.ucar.edu/DAReS/DART/

WRF/DART

Interfaces for WRF in DART

- WRF variables on model grid $\leftrightarrow$ DART state vector
- Distance between any two elements of state vector

Suite of observation operators

- Includes Doppler radar and various GPS; no radiances

Scripts for advancing WRF under DART control

EnKF Details

"Deterministic, square-root, serial"

Between 50 and 100 ensemble members

Covariance localization

- Single observation influences analysis only within specified radius

Ensemble of lateral BCs, to account for their uncertainty

Explicitly account for model uncertainty only in surface-obs experiments

Assimilation of Surface Observations

60-km resolution, CONUS domain

Ensemble covariances localized within radius of ~500 km.

6-hourly analyses

- Assimilate radiosondes, ACARS, satellite winds
- Test with and without 2-m T, T_d and 10-m u,v

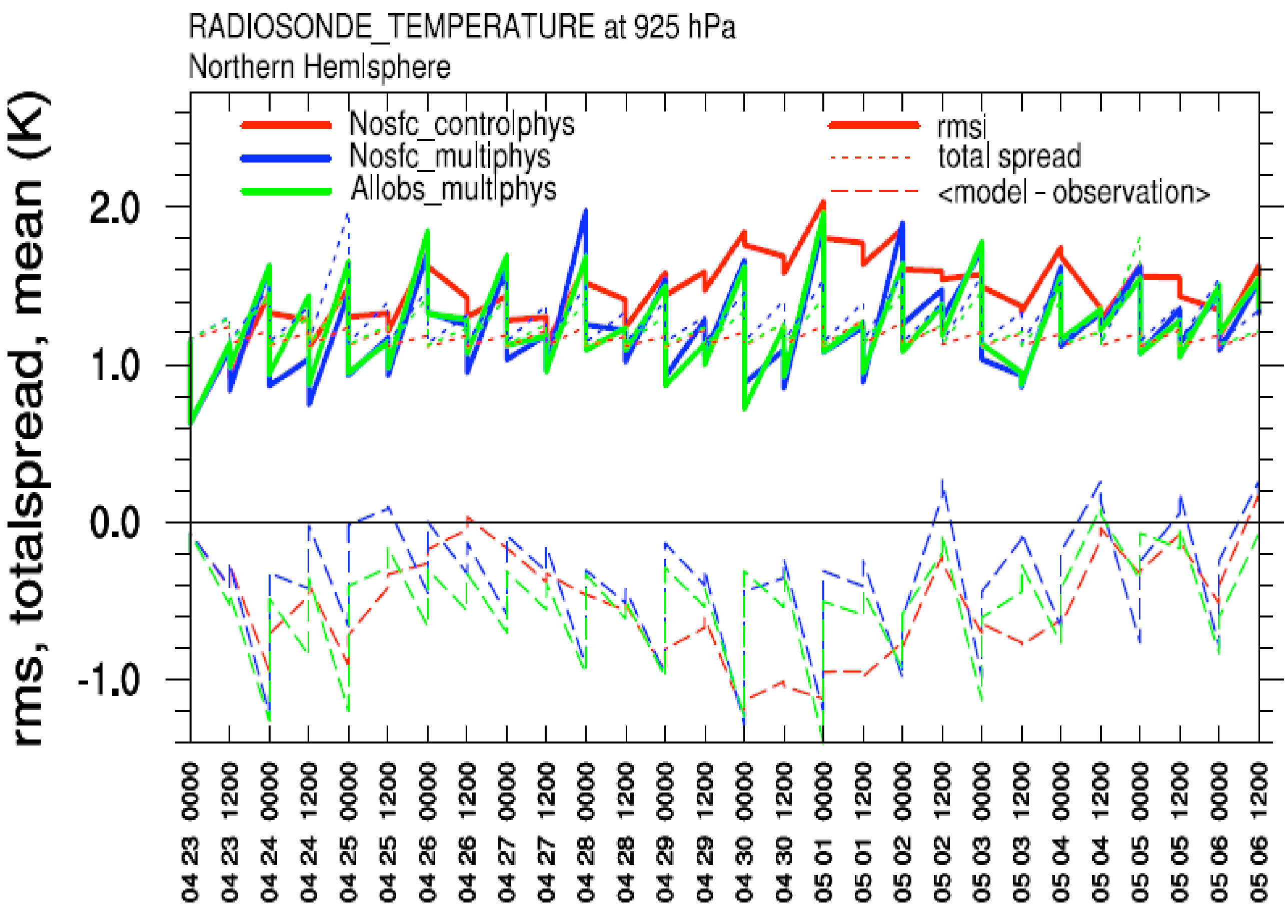
"Multi-physics" ensemble

- Each member uses distinct configuration of WRF
- Choose from 3 PBL, 3 cumulus, 2 shortwave radiation
- Hope to capture, at least partially, uncertainty of forecast model

Assimilation of Surface Observations (cont.)

Comparison against radiosonde temperature

Control physics, multi-physics, multi-physics with surface obs



Assimilation of Surface Observations (cont.)

Comparison against radiosonde temperature at 925 hPa
Control physics, multi-physics, multi-physics with surface obs

Representing model error in EnKF significantly improves results for T

… but effect is neutral for wind and above PBL.

Assimilation for Tropical Cyclones

Courtesy R. Torn (SUNY Albany)

Assimilation for Tropical Cyclones (cont.)

36-km resolution, CONUS + W Atlantic + Caribbean domain

Ensemble covariances localized within 2000-km radius

10 HFIP cases

6-hourly analyses, beginning 4 days prior to depression

- Radiosondes, ACARS, satellite winds, surface pressure
- Also TC position and “synoptic” dropsondes

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36-km resolution, CONUS + W Atlantic + Caribbean domain

Ensemble covariances localized within 2000-km radius

10 HFIP cases

6-hourly analyses, beginning 4 days prior to depression

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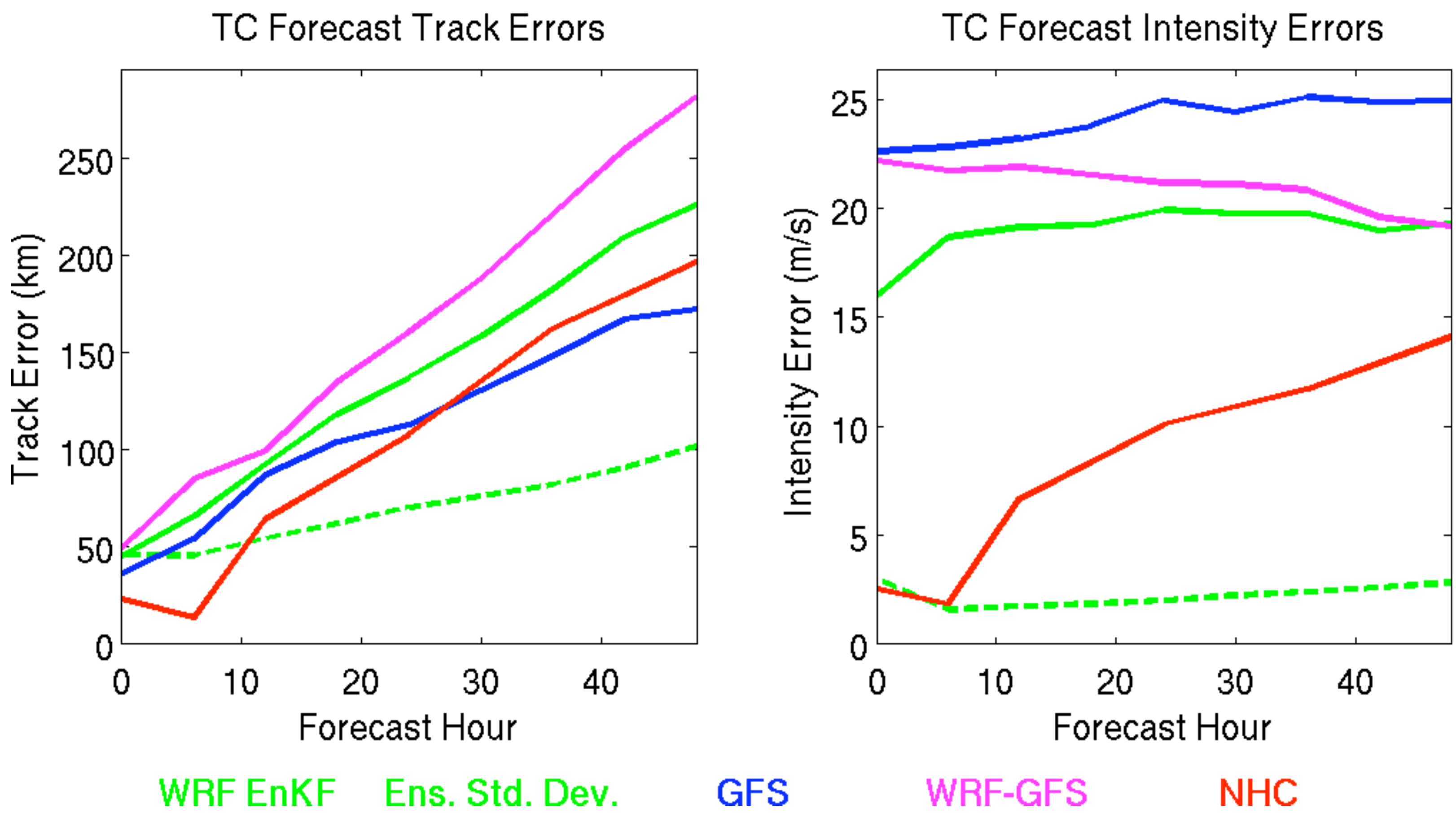
- Also TC position and “synoptic” dropsondes

No TC bogussing or bogus observations

Assimilation for Tropical Cyclones (cont.)

RMS track and intensity errors, averaged over 10 cases



Radar Assimilation for Convective Storms

See earlier talk by D. Dowell

2-km resolution, local domains of ~300 km x 300 km, open lateral BCs

Ensemble covariances localized within 5-km radius

Analyses every 2 min

- Radial velocity and reflectivity from single radar
- Each elevation scan assimilated separately
- Automated velocity unfolding within EnKF

Nearby radiosonde provides “environment”

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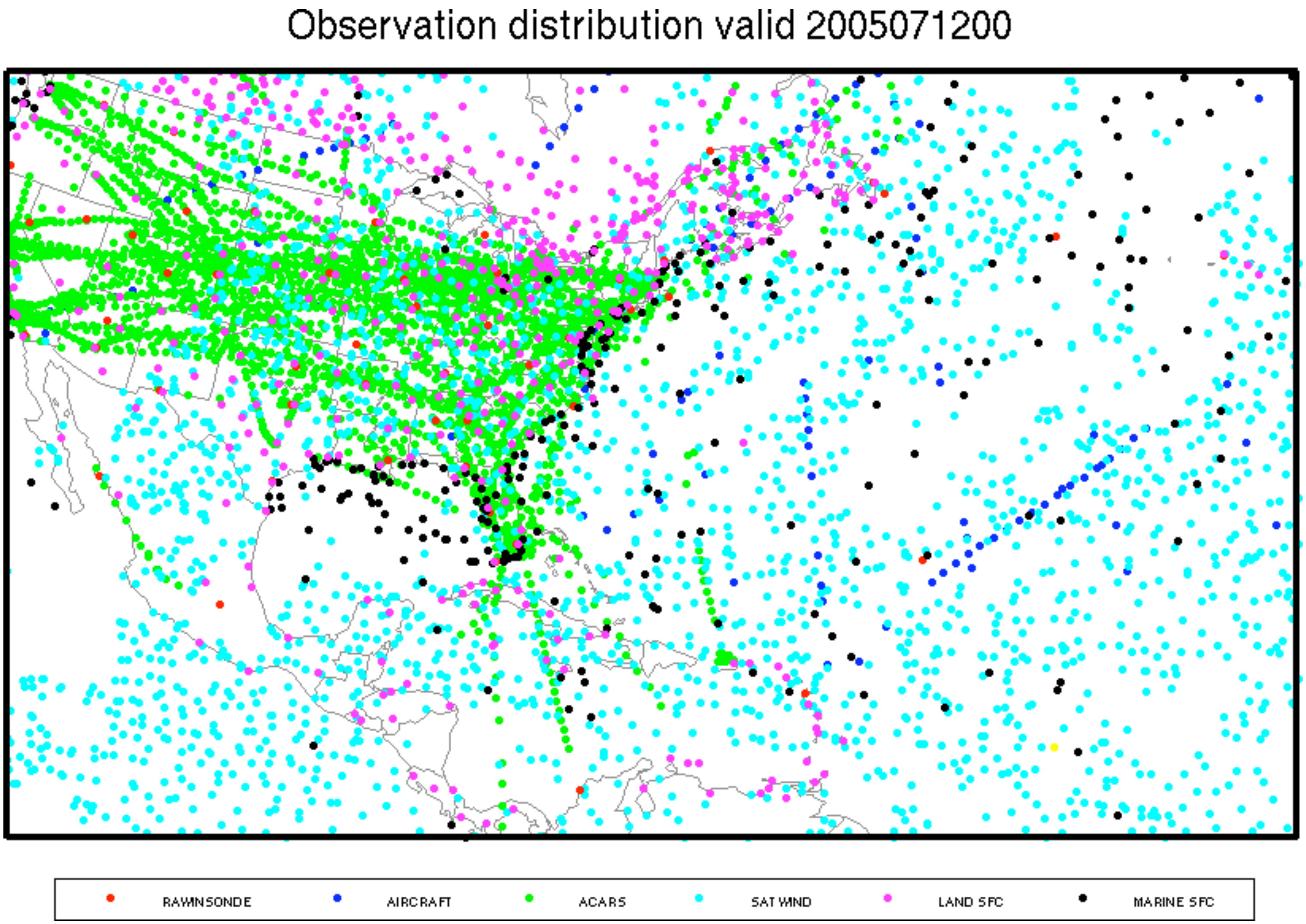
Status and Future Directions

WRF/DART is a research-ready system applicable across a range of scales and phenomena

Ongoing activities

- Combining mesoscale analyses with high-resolution assimilation of Doppler radar
- Techniques to account for model error: multi-physics, multi-parameter, stochastic backscatter, adaptive inflation
- Application to WRF-Chem and PlanetWRF
- Assimilation of radiance observations

HFIP domain + snap-shot of observations



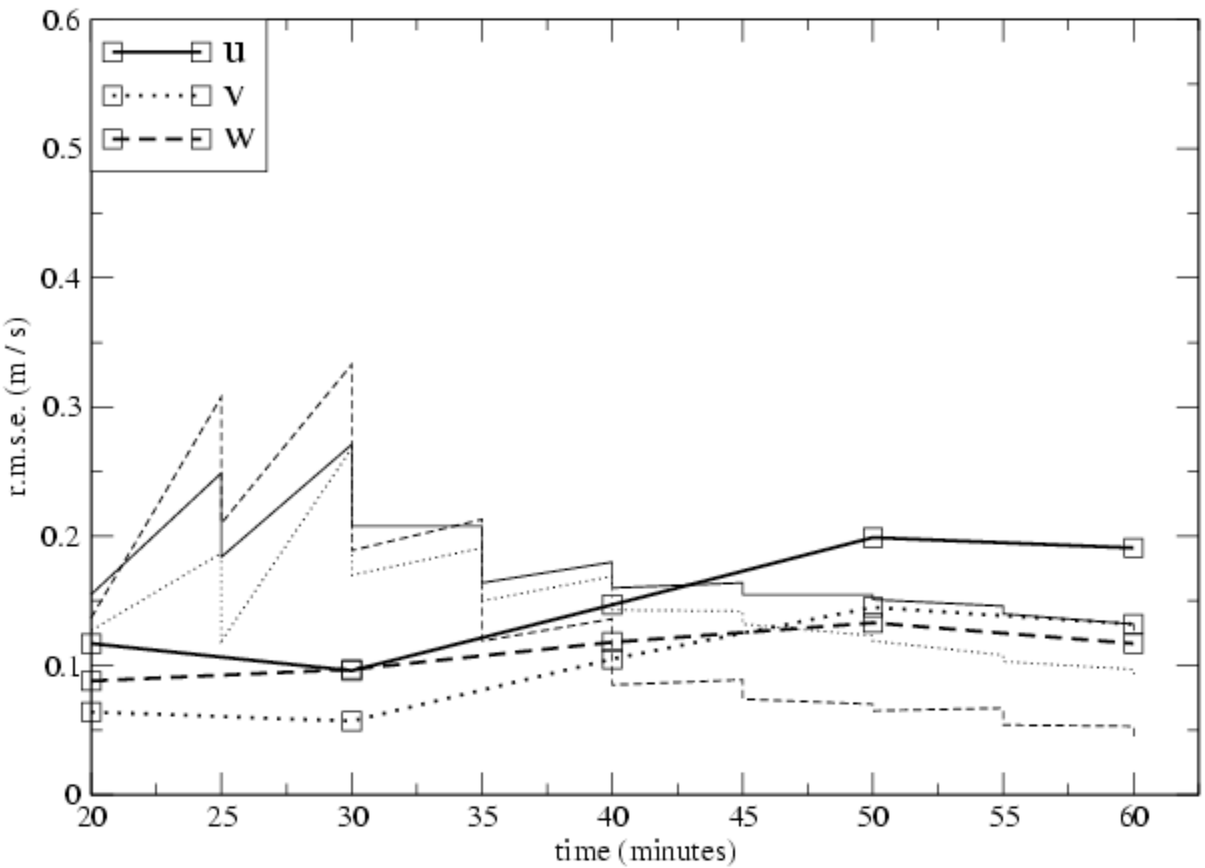
Comparison of EnKF and 4DVar

- **Simulated** observations of radial velocity and reflectivity for supercell storm (perfect model), available every 5 min
- 4DVar: full fields (not incremental), mesoscale background, simple covariance model, 10-min window
- EnKF: 100 members, initialized with noise in T where first scan shows reflectivity

Caya, A., J. Sun and C. Snyder, 2005: A comparison between the 4D-Var and the ensemble Kalman filter techniques for radar data assimilation. *Mon. Wea. Rev.*, **133**, 3081--3094.

Comparison with 4DVar

- rms errors over entire domain; obs of both v_r and reflectivity
- EnKF (thin) and 4DVar (thick w/ boxes)



Comparison of EnKF and 4DVar

Kalman filter/smoother and 4DVar are mathematically equivalent for linear, Gaussian systems

- Result also assumes both use same P, R, etc.

Overall, EnKF and 4DVar perform comparably in this case

After multiple cycles (30-40 min), EnKF beats 4DVar

- EnKF propagates information from previous obs through cycling of P^f
- In principle, updating of P could be included in 4DVar too

Given only obs over limited period (10-20 min), 4DVar beats EnKF

- Estimation errors large with limited obs, so nonlinear effect more important and 4DVar has advantage?