Thunderstorm-Scale EnKF Analyses Verified with Dual-Polarization, Dual-Doppler Radar Data

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Ensemble Data Assimilation Workshop, 9 April 2010

Motivation

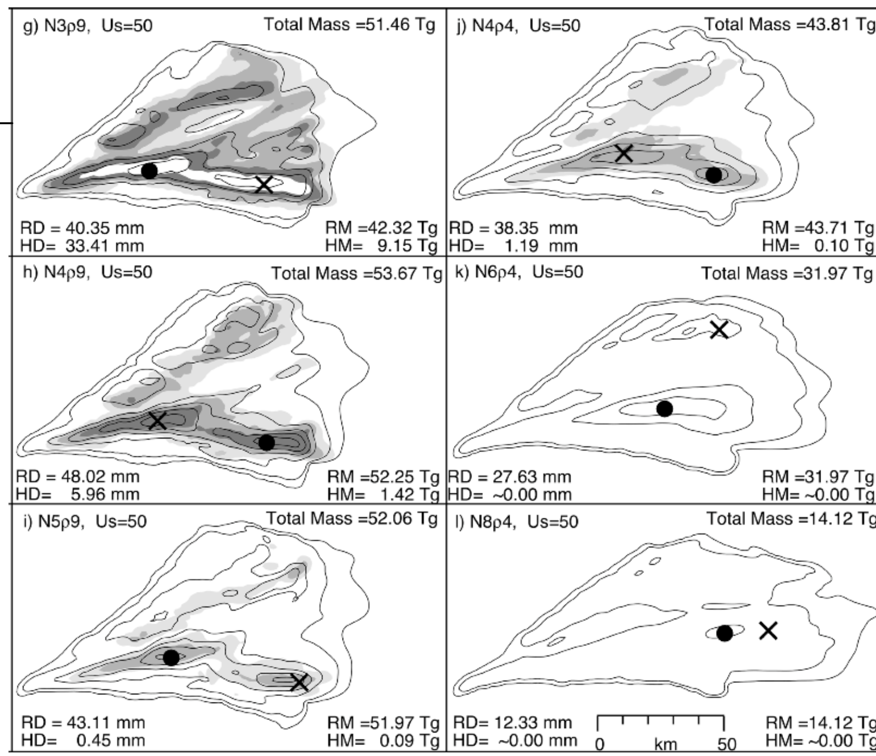
- Still much to learn from EnKF radar DA experiments for real convective storms for models with grid spacings ~1 km
- Encouraging results so far for assimilating Doppler velocity
  - Realistic storm structures, for a variety of convective storm types
  - Observation-space diagnostics
  - But, most state variables not observed on these scales
- Ongoing research
  - Opportunities to evaluate further the quality of EnKF storm-scale analyses: enhanced observations from field programs
  - Analysis and forecast sensitivity to model's precipitation-microphysics scheme *(previous and current presentation)*
  - Localization (how to handle isolated blobs of dense observations)
  - Reflectivity-data assimilation
  - Radar-data quality control and thinning
  - Radar DA in models with full mesoscale complexity
  - Model-error characterization and ensemble design

Motivation (continued)

- Gilmore et al. (2004): significant variability in simulated convective storm structure and accumulated precipitation obtained by varying graupel/hail density (ρ_h) and intercept parameter (N_{0h}) in a single-moment microphysics scheme

2-h hail accumulation (shading) and rain accumulation (contours)

fewer particles,
larger mean size,
higher density
"hail"

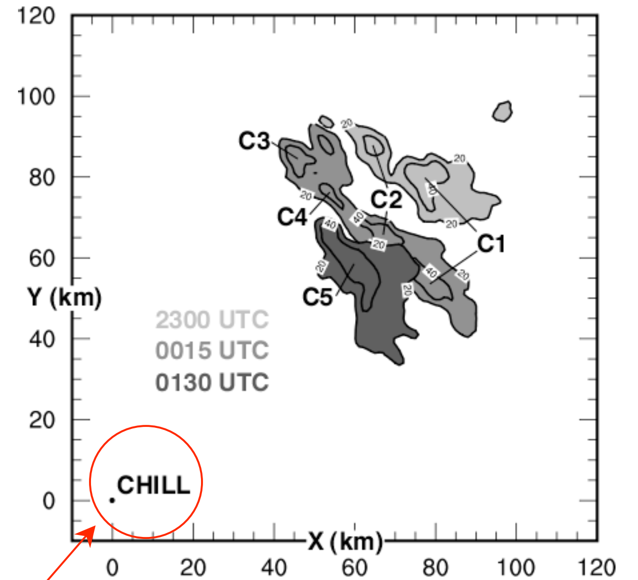


more particles,
smaller mean size,
lower density
"graupel"

Gilmore et al. 2004

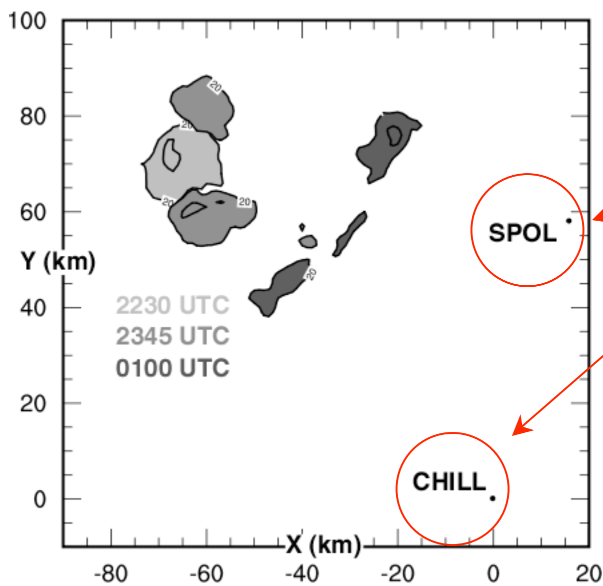
Three Cases of Isolated Thunderstorms

reflectivity at approx. 4 km AGL

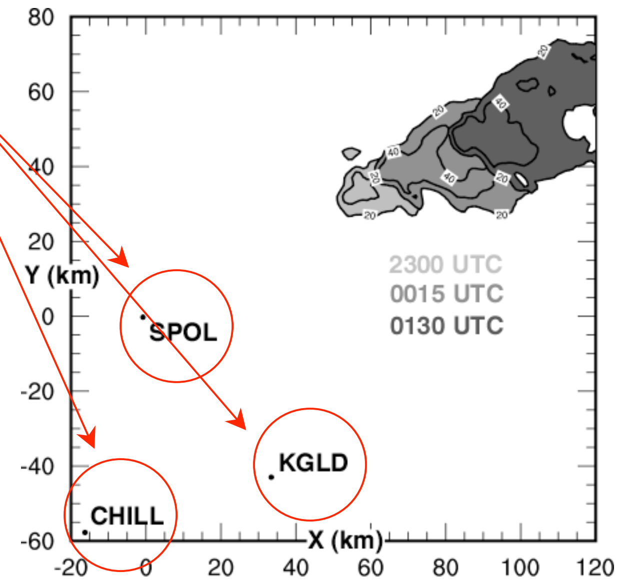


10 July 1996 (STERAO-A)
multicell

radars



6 June 2000 (STEPS)
ordinary storms

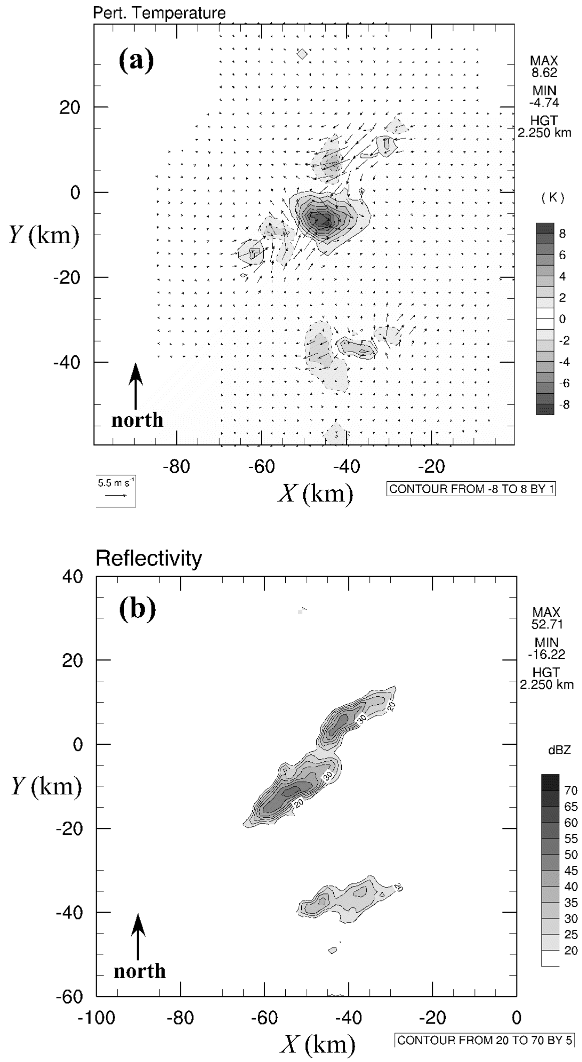


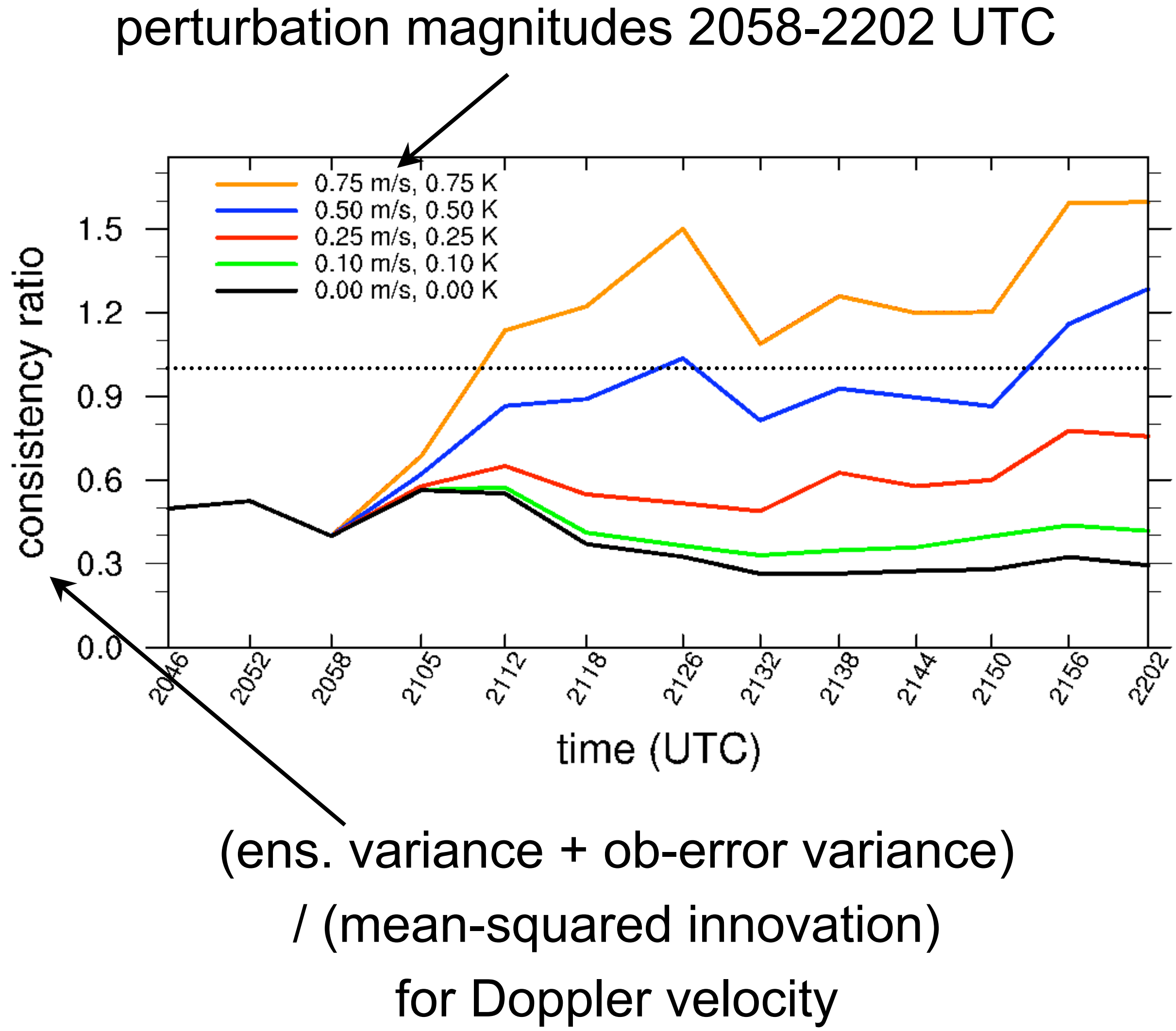
5 July 2000 (STEPS)
supercell

WRF Model Ensemble

- "Cloud model" configuration of WRF-ARW
  - Initial state horizontally homogeneous, initialized with sounding data
  - No terrain, no surface fluxes, no radiation, open lateral boundaries
- Domain 100-120 km wide, 20 km tall
- Grid spacing 1 or 2 km
- Lin et al. (1983) precipitation-microphysics scheme
  - single-moment cloud, rain, snow, ice crystals, graupel/hail
- Variability among 60 ensemble members
  - Random perturbations to base-state wind profiles (Aksoy et al. 2009)
    - Proxy for environmental variability
  - Random local perturbations ("additive noise") in wind, temperature, and water-vapor fields where convective precipitation is observed (Caya et al. 2005) added at regular intervals (~5 min) during the data-assimilation period (Dowell and Wicker 2009)

Additive Noise (Dowell and Wicker 2009)





Suggested improvement: adaptive perturbation magnitudes based on recent innovation statistics

Radar-Data Assimilation

- Algorithm: Data Assimilation Research Testbed (DART) EAKF
- Localization: Gaspari-Cohn, sphere, zero weight at radius 6 km
- Assimilated observations
  - Doppler velocity from one radar
- Verification observations
  - Reflectivity (note: reflectivity also used to determine regions for additive noise)
  - Updraft volume
  - Total graupel mass
  - Total rain mass

Storm dynamics strongly constrained by observations.
Cloud microphysics weakly constrained (covariances w/ Doppler velocity).

More About Verification of Storm-Scale EnKF Analyses

Radar reflectivity

Updraft volume

- Total volume where vertical velocity > 5 m s^{-1}
- Dual- and triple-Doppler wind syntheses

Total masses of (1) graupel and (2) rain

1) Particle ID (PID) algorithm (Vivekanandan et al. 1999) applied to polarimetric radar data to determine dominant hydrometeor type
2) Hydrometeor mass estimated at each grid point
   - Reflectivity - mass relationship specific to identified dominant hydrometeor type (Heymsfield and Palmer 1986; Heymsfield and Miller 1988)
3) Total mass for each hydrometeor type summed over whole storm
   - Graupel / small hail
   - Rain

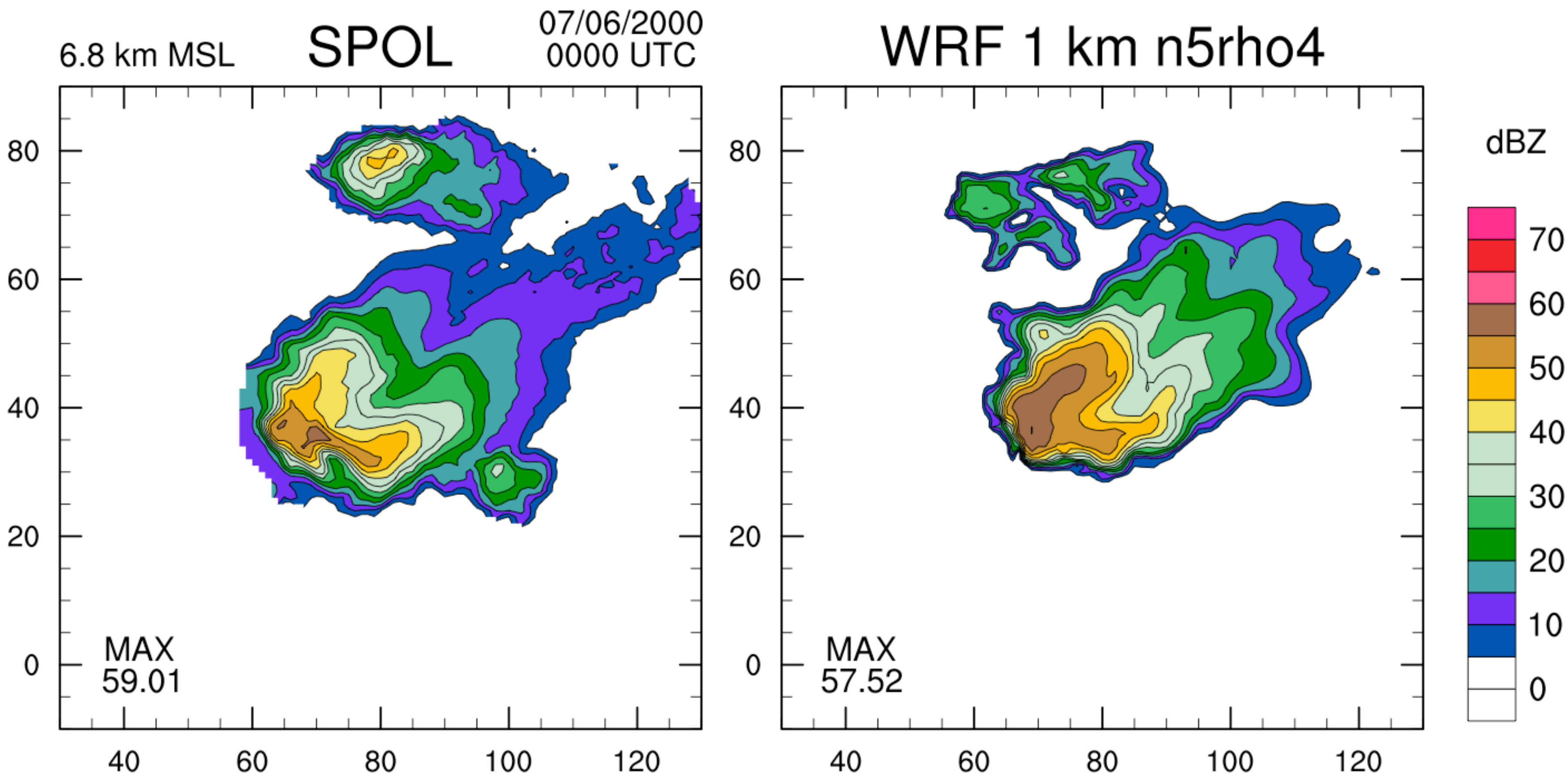
Note: large bias errors expected in these verification quantities derived from observations, so trends more relevant.

Supercell Case

after 80 minutes of Doppler velocity data assimilation

Reflectivity at 7 km MSL

Observations WRF-DART Ensemble Mean

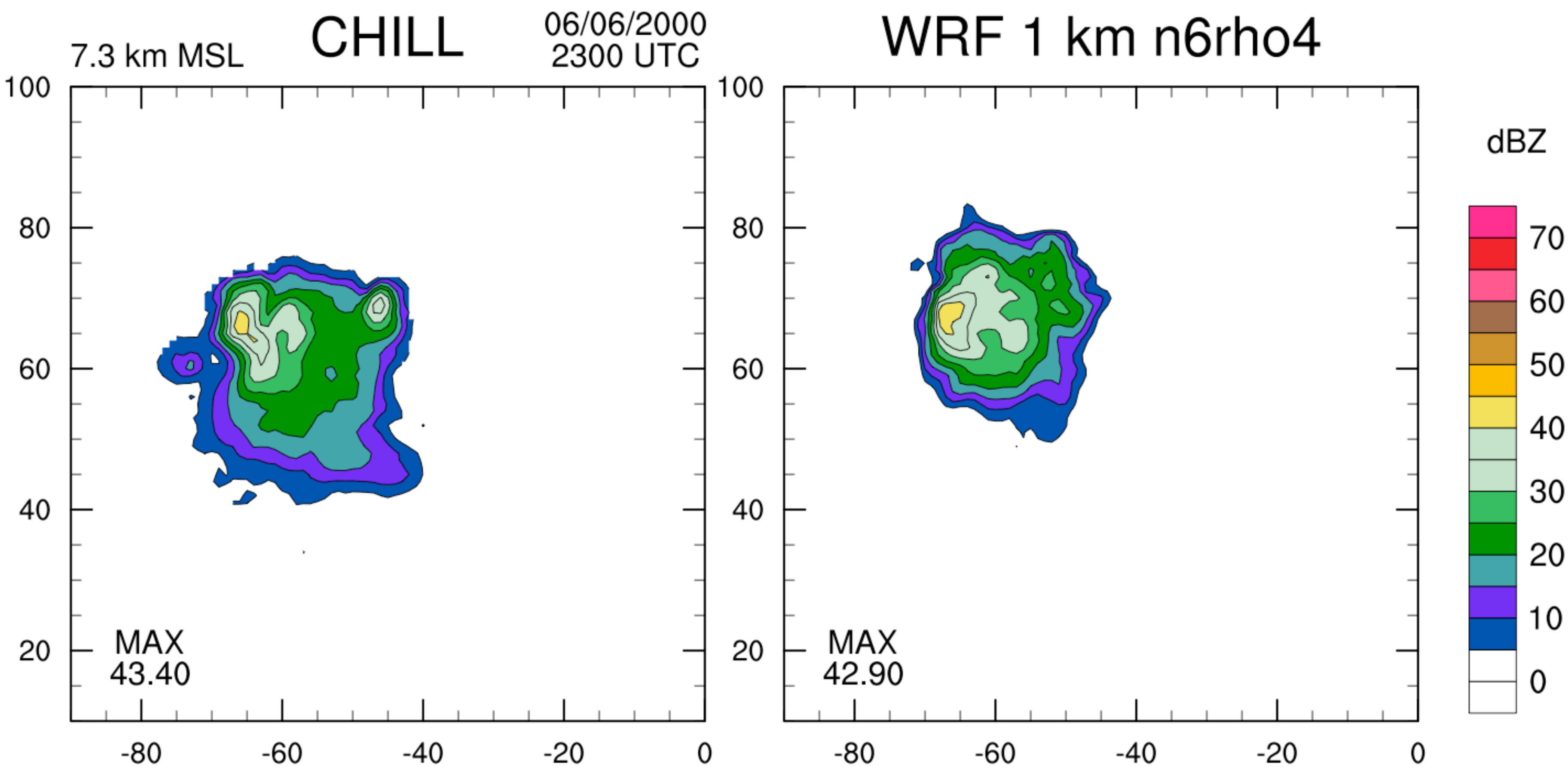


Ordinary Cell Case

after 80 minutes of Doppler velocity data assimilation

Reflectivity at 7 km MSL

Observations WRF-DART Ensemble Mean

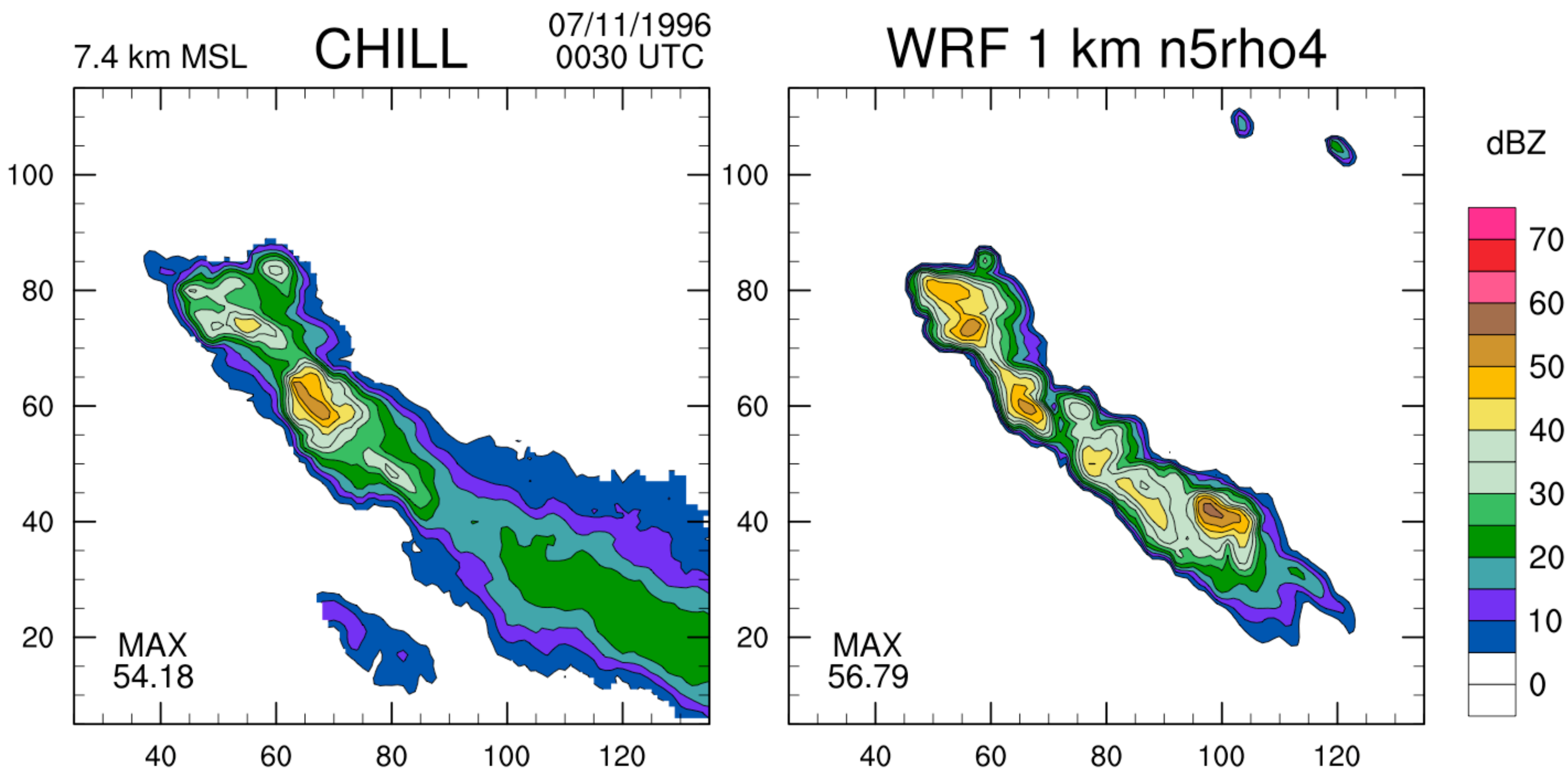


Multicell Case

after 180 minutes of Doppler velocity data assimilation

Reflectivity at 7 km MSL

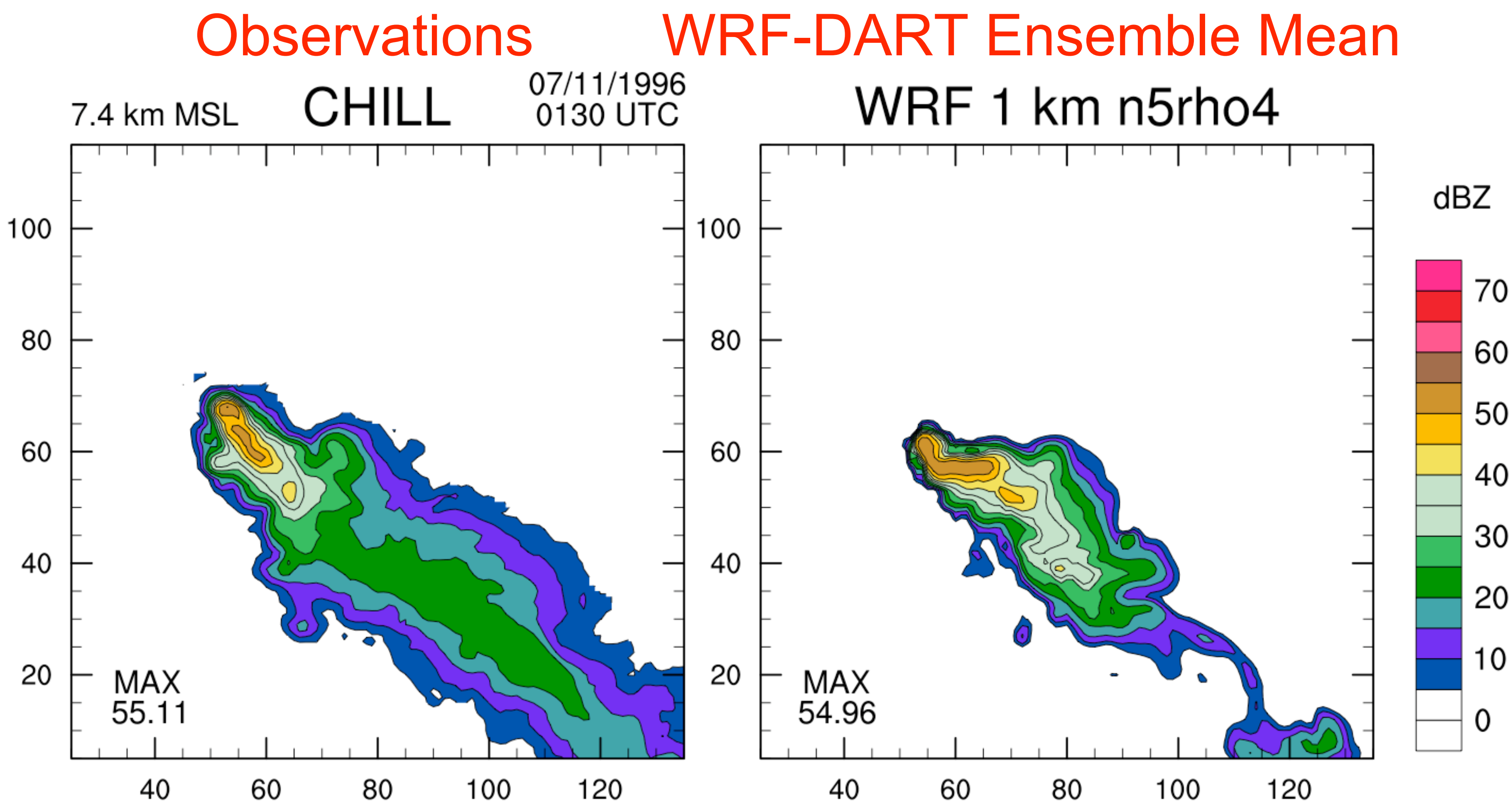
Observations | WRF-DART Ensemble Mean



Multicell Case

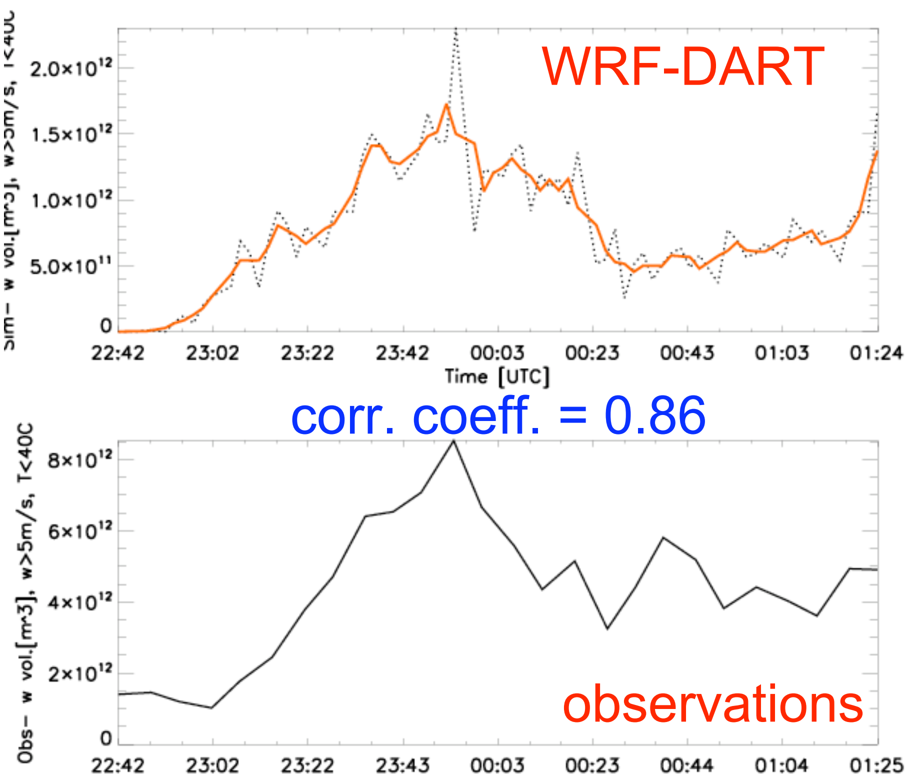
after 240 minutes of Doppler velocity data assimilation

Reflectivity at 7 km MSL



Supercell Case: Volume of Updraft > 5 m s^{-1}

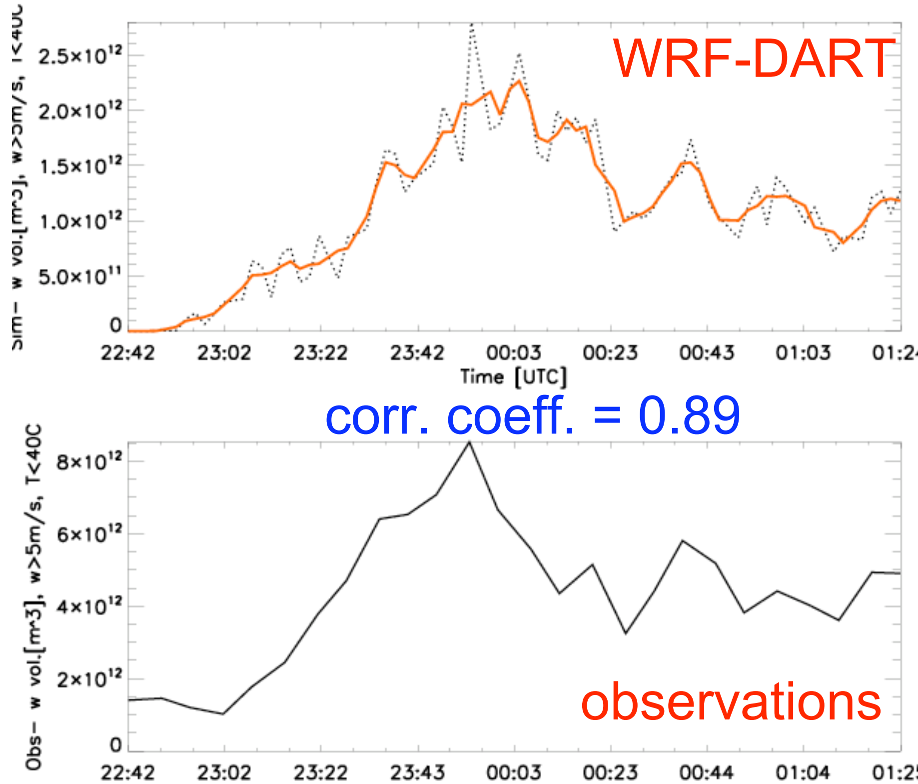
N3rho9 (hail-like distribution)



Time (UTC)

← 160 minutes →

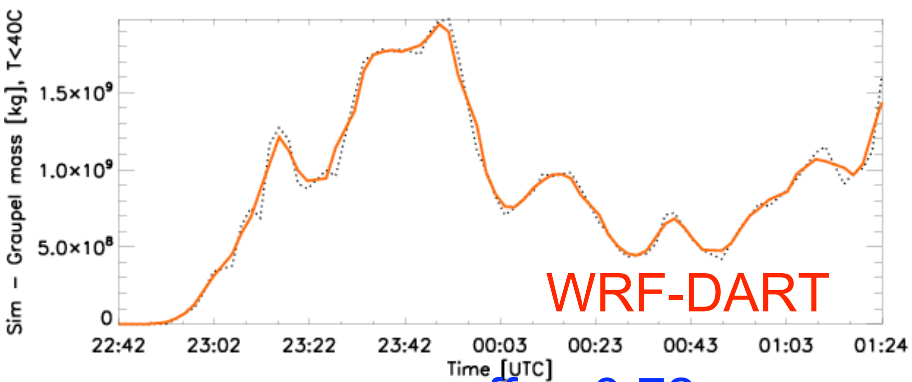
N5rho4 (graupel-like distribution)



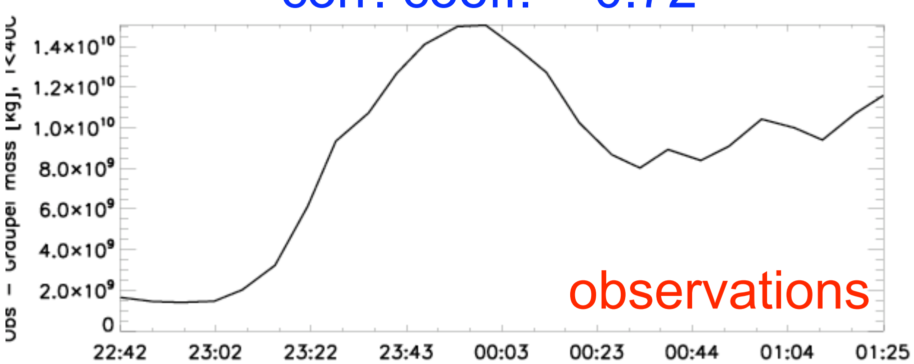
Time (UTC)

Supercell Case: Storm-Total Graupel/Hail Mass

N3rho9 (hail-like distribution)



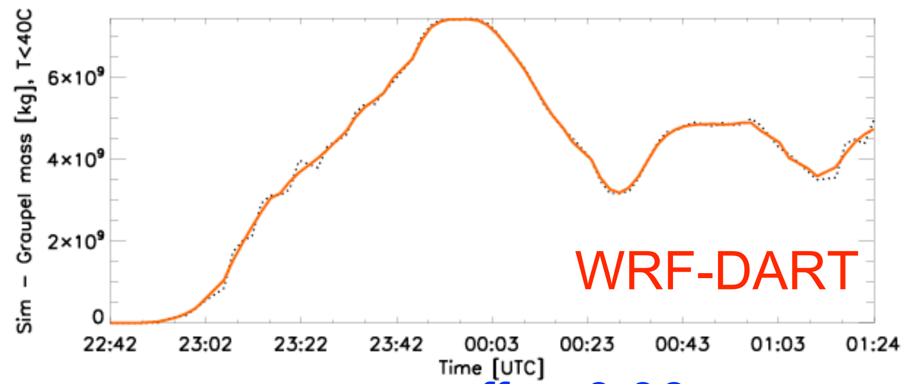
corr. coeff. = 0.72



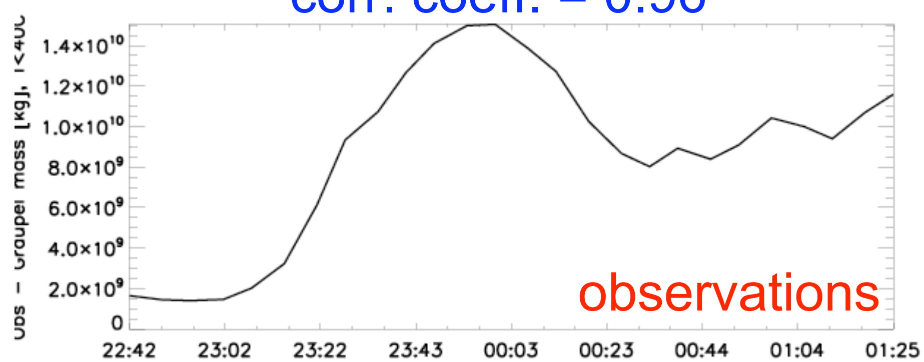
Time (UTC)

← 160 minutes →

N5rho4 (graupel-like distribution)



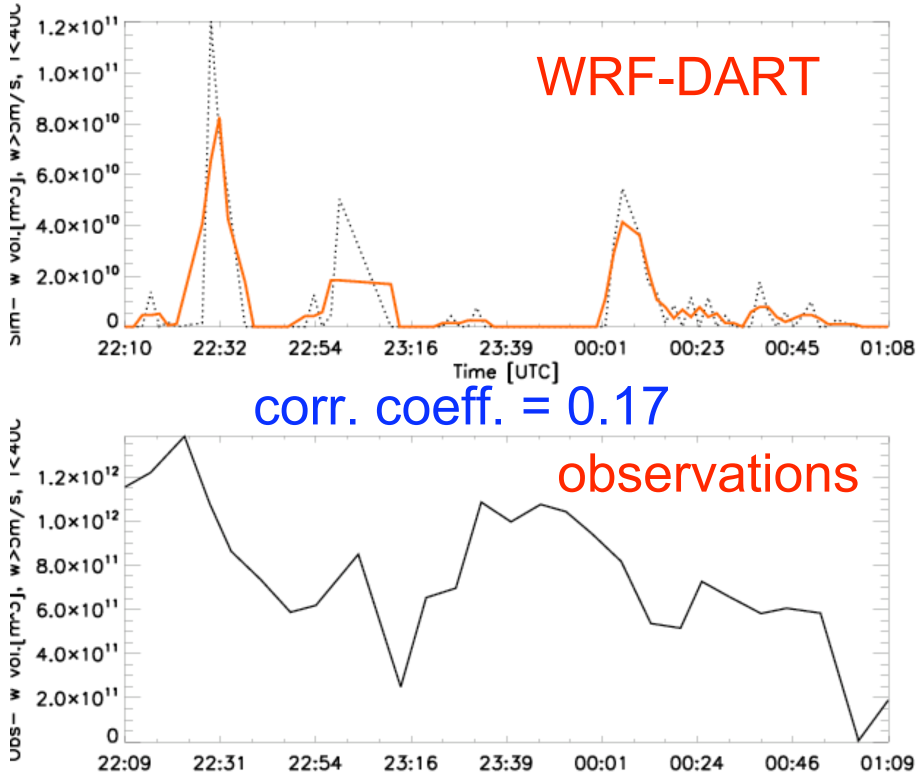
corr. coeff. = 0.96



Time (UTC)

Ordinary Cell Case: Volume of Updraft > 5 m s^{-1}

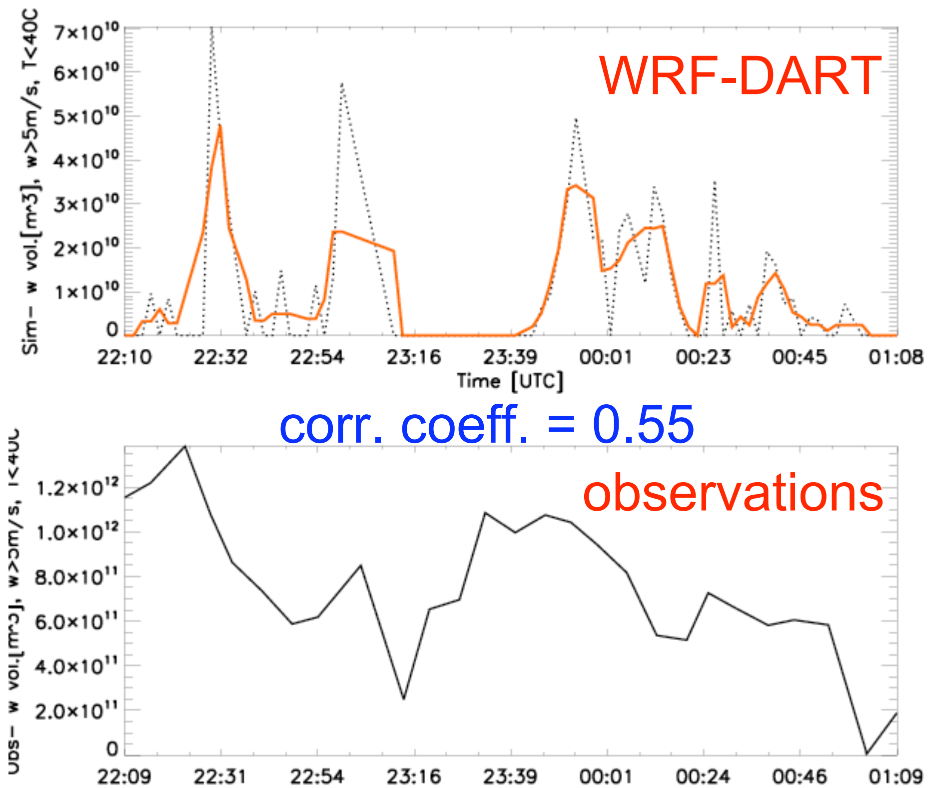
N3rho9 (hail-like distribution)



Time (UTC)

← 180 minutes →

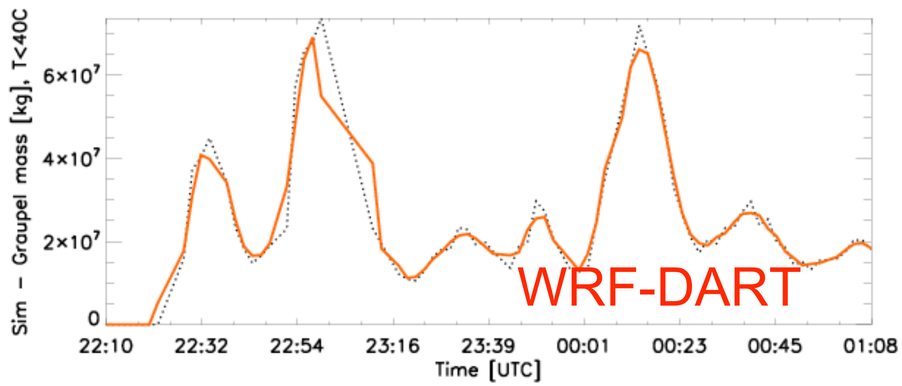
N6rho4 (graupel-like distribution)



Time (UTC)

Ordinary Cell Case: Storm-Total Graupel/Hail Mass

N3rho9 (hail-like distribution)

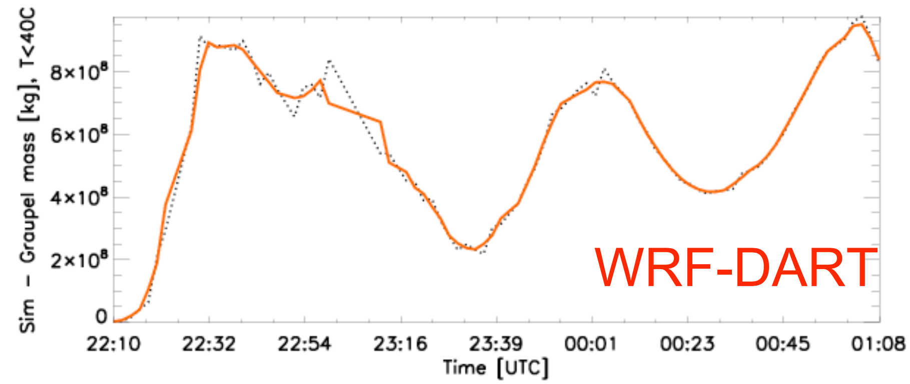


corr. coeff. = 0.43

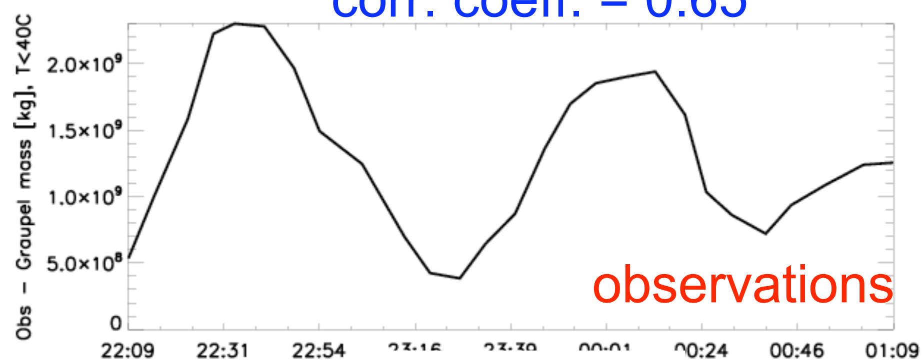
Time (UTC)

⟵ 180 minutes ⟶

N6rho4 (graupel-like distribution)



corr. coeff. = 0.65



Time (UTC)

Corr (obs total graupel, ens mean total graupel)

case	hail-like distribution	graupel-like distribution
Supercell	0.72	0.96
Ordinary Cell	0.43	0.65
Multicell	0.54	0.71

Corr (obs total rain, ens mean total rain)

case	hail-like distribution	graupel-like distribution
Supercell	0.54	0.71
Ordinary Cell	0.55	0.64
Multicell	0.67	0.78

Conclusions

- Results suggest that through Doppler-velocity DA, the ensemble mean is capturing cycles of storm growth and decay on times scales of a few 10’s of minutes.

- Even with strong constraints on storm dynamics / kinematics provided by velocity observations, EnKF analyses are still very sensitive to model’s precipitation microphysics scheme.
  - Updraft volume
  - Total graupel and rain masses
  - Cold pools (not shown)

- Much more work is needed to determine the nature of model errors on the convective storm scale…

VORTEX2 (Verification of the Origins of Rotation in Tornadoes Experiment 2)

- Spring 2009 and 2010
- Detailed radar and in situ observations in severe convective storms
- Opportunities to learn more about what model errors look like on these scales
- Real-time and retrospective storm-scale DA and NWP at NCAR, CAPS, NSSL, OU, PSU, TTU; others invited to participate!