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

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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 ($\rho_h$) 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

6 June 2000 (STEPS)
ordinary storms

5 July 2000 (STEPS)
supercell

10 July 1996 (STERAO-A)
multicell

reflectivity at approx. 4 km AGL
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

**perturbation magnitudes 2058-2202 UTC**

(ens. variance + ob-error variance) / (mean-squared innovation)

for Doppler velocity
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

SPOL 07/06/2000 0000 UTC

MAX 59.01

MAX 57.52

6.8 km MSL

WRF 1 km n5rho4

dBZ
Ordinary Cell Case
after 80 minutes of Doppler velocity data assimilation

Reflectivity at 7 km MSL

Observations
WRF-DART Ensemble Mean

CHILL 06/06/2000 2300 UTC

WRF 1 km n6rho4

MAX 43.40
MAX 42.90

dBZ

7.3 km MSL
Multicell Case
after 180 minutes of Doppler velocity data assimilation

Reflectivity at 7 km MSL

Observations  WRF-DART Ensemble Mean

CHILL  07/11/1996 0030 UTC

WRF 1 km n5rho4

MAX 54.18
MAX 56.79

dBZ
Multicell Case
after 240 minutes of Doppler velocity data assimilation

Reflectivity at 7 km MSL

Observations  WRF-DART Ensemble Mean

CHILL  07/11/1996 0130 UTC  WRF 1 km n5rho4

MAX 55.11  MAX 54.96

7.4 km MSL

dBZ

0  10  20  30  40  50  60  70
Supercell Case: Volume of Updraft $> 5 \text{ m s}^{-1}$

N3rho9 (hail-like distribution)  
WRF-DART  
corr. coeff. = 0.86  
observations

N5rho4 (graupel-like distribution)  
WRF-DART  
corr. coeff. = 0.89  
observations

160 minutes
Supercell Case: Storm-Total Graupel/Hail Mass

N3rho9 (hail-like distribution)

WRF-DART

corr. coeff. = 0.72

observations

160 minutes

N5rho4 (graupel-like distribution)

WRF-DART

corr. coeff. = 0.96

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

N3rho9 (hail-like distribution)

WRF-DART

corr. coeff. = 0.17

observations

N6rho4 (graupel-like distribution)

WRF-DART

corr. coeff. = 0.55

observations

180 minutes
Ordinary Cell Case: Storm-Total Graupel/Hail Mass

N3rho9 (hail-like distribution)

N6rho4 (graupel-like distribution)

WRF-DART

corr. coeff. = 0.43

observations

WRF-DART

corr. coeff. = 0.65

observations

180 minutes
Corr (obs total graupel, ens mean total graupel)

<table>
<thead>
<tr>
<th>case</th>
<th>hail-like distribution</th>
<th>graupel-like distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supercell</td>
<td>0.72</td>
<td>0.96</td>
</tr>
<tr>
<td>Ordinary Cell</td>
<td>0.43</td>
<td>0.65</td>
</tr>
<tr>
<td>Multicell</td>
<td>0.54</td>
<td>0.71</td>
</tr>
</tbody>
</table>

Corr (obs total rain, ens mean total rain)

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<td>0.78</td>
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</tbody>
</table>
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!