Performance of the NSSL Experimental Warn-on-Forecast System in Varying Mesoscale Environments

Patrick S. Skinner\textsuperscript{1,2}, Dustan M. Wheatley\textsuperscript{1,2}, Kent H. Knopfmeier\textsuperscript{1,2}, Thomas A. Jones\textsuperscript{1,2}, David C. Dowell\textsuperscript{3}, Therese T. Ladwig\textsuperscript{3}, Curtis R. Alexander\textsuperscript{3}, Ryan A. Sobash\textsuperscript{4}, Gerald J. Creager\textsuperscript{1,2}, Corey K. Potvin\textsuperscript{1,2}, and Louis J. Wicker\textsuperscript{1}

\textsuperscript{1} - Cooperative Institute for Mesoscale Meteorological Studies, University of Oklahoma
\textsuperscript{2} - NOAA/OAR/National Severe Storms Laboratory
\textsuperscript{3} - NOAA/OAR/Earth System Research Laboratory
\textsuperscript{4} - National Center for Atmospheric Research

International Symposium on Data Assimilation 2016
NOAA’s Warn-on-Forecast project aims to use ensembles of convection-allowing models to produce probabilistic forecasts of short-term, $O(1\text{hr})$, thunderstorm hazards
Motivation:

- EnKF-based assimilation of Doppler radar, and recently satellite data, have reliably produced accurate analyses and short-term rotation forecasts for high-impact events from the springs of 2013 - 2016 (e.g. Wheatley et al. 2015; Yussouf et al. 2015; Jones et al. 2016)
- These forecasts have typically been performed for discrete supercells in strongly favorable environments for tornado development

- Less is known about forecast accuracy for tornadoes with greater storm coverage and marginally favorable environments
Spring 2016: Demonstration of Prototype Warn-on-Forecast System for VORTEX-Southeast Field Project

- High-Resolution Rapid Refresh Ensemble (HRRRE) run at NOAA/ESRL
- Hourly-updated storm-scale ensemble for a fixed domain
- NSSL Experimental Warn-on-Forecast System for ensembles (NEWS-e)
- 15-min updated storm-scale ensemble with radar and satellite assimilation run for an event-dependent domain
- Forecasts for VORTEX-SE designed to test system performance for marginal tornado environments
## System Configuration:

<table>
<thead>
<tr>
<th></th>
<th>HRRRE</th>
<th>NEWS-e</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model Version</td>
<td>WRF-ARW v3.6+</td>
<td>WRF-ARW v3.6+</td>
</tr>
<tr>
<td>Grid Points</td>
<td>$415 \times 325 \times 50 / 650 \times 550 \times 50$</td>
<td>$250 \times 250 \times 50$</td>
</tr>
<tr>
<td>Grid Spacing</td>
<td>15 km / 3 km</td>
<td>3 km (1 km in research)</td>
</tr>
<tr>
<td>EnKF Cycling</td>
<td>20-40 mem w/ GSI-EnKF every 1 h</td>
<td>36 mem w/ DART every 15 min</td>
</tr>
<tr>
<td>Observations</td>
<td>conventional obs only: $T, q_v, u, v,$ and $p$ from rawinsonde, aircraft, surface (land and marine), profiler</td>
<td>Doppler velocity from ~20 WSR-88D sites; MRMS radar reflectivity; cloud-water path</td>
</tr>
<tr>
<td>Radiation LW/SW</td>
<td>RRTMG/RRTMG</td>
<td>Dudhia/RRTM or RRTMG/RRTMG</td>
</tr>
<tr>
<td>Microphysics</td>
<td>Thompson (aerosol aware)</td>
<td>Thompson</td>
</tr>
<tr>
<td>Cumulus Param.</td>
<td>GF + shallow / none</td>
<td>none</td>
</tr>
<tr>
<td>PBL</td>
<td>MYNN</td>
<td>YSU, MYJ, or MYNN</td>
</tr>
<tr>
<td>LSM</td>
<td>RUC (Smirnova)</td>
<td>RUC (Smirnova)</td>
</tr>
</tbody>
</table>

Courtesy David Dowell, 2016
System Workflow:

NEWS-e Forecasts:

<table>
<thead>
<tr>
<th>Time (UTC)</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>1900</td>
<td>180</td>
</tr>
<tr>
<td>1930</td>
<td>90</td>
</tr>
<tr>
<td>2000</td>
<td>180</td>
</tr>
<tr>
<td>2030</td>
<td>90</td>
</tr>
<tr>
<td>2100</td>
<td>180</td>
</tr>
<tr>
<td>2130</td>
<td>90</td>
</tr>
<tr>
<td>2200</td>
<td>180</td>
</tr>
<tr>
<td>2230</td>
<td>90</td>
</tr>
<tr>
<td>2300</td>
<td>180</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

Forecast output available ~30 min following initialization
NEWS-e Experiments for VORTEX-SE:

- 23 December 2015:
  - Tornado outbreak across northern Mississippi and southern Tennessee
  - Well-defined risk area ahead of stationary front, with moderate CAPE (>1500 J kg\(^{-1}\)) and strong 0 - 1 km shear (>15 m s\(^{-1}\))
- 31 March 2016 (V-SE IOP):
  - Tornadoes in northwestern Alabama and southern Tennessee
  - Localized region of moderate CAPE and strong wind shear, but greater storm coverage
- 29 April 2016 (V-SE IOP):
  - QLCS with mesovortices in northern Alabama but no tornado reports
- 10 May 2016:
  - Tornado outbreak in western Kentucky
Example of a ‘Good’ Low-Level Rotation Forecast:

Developing Convection (<40 dBZ)

Probability of $\zeta > 0.003 \text{ s}^{-1}$
Example of a ‘Good’ Low-Level Rotation Forecast:

Ensemble Gridpoint 90th percentile $\zeta (s^{-1})$

Probability of $\zeta > 0.003 s^{-1}$
Example of a ‘Good’ Low-Level Rotation Forecast:

Ensemble Gridpoint 90th percentile $\zeta \ (s^{-1})$

High 90th percentile values indicates possibility of intense low-level mesocyclone.
Example of a ‘Good’ Low-Level Rotation Forecast:

- **Ensemble Gridpoint 90th percentile $\zeta (s^{-1})$**
  - High 90th percentile values indicate the possibility of intense low-level mesocyclone.

- **Probability of $\zeta > 0.003 \text{ s}^{-1}$**
  - Moderate (40-50%) probabilities of strong low-level rotation.
23 December 2015: 2130 Forecast

Low probabilities of intense rotation along track of strongest tornado ~40 min in advance

False alarms, storms present but with weak rotation

Early event missed
Rising, but still low, probabilities along track of strongest storm (10-min prior to tornado genesis)

False alarms signals weakening
Identifies high probabilities of intense rotation along ongoing long-track tornado

23 December 2015: 2230 Forecast

Increasing probabilities along track of trailing storm
23 December 2015: Poor 2130 Forecast

**Storm-Scale Challenge:**
Relatively small storms size and dense coverage

**Mesoscale Challenge:**
Storms remain behind CAPE axis for majority of forecast

Gray Shading: Observed 40 dBZ Contour
Colored Shading: Individual Member 40 dBZ Contours
31 March 2016: 2230 Forecast

**Storm-Scale Challenge:**
- Gray Shading: Observed AZ shear objects
- Colored Shading: Individual Member vertical vorticity objects
- First in series of short-lived, tornadic supercell in northern AL

**Mesoscale Challenge:**
- Axis of enhanced CAPE
- Embedded supercells moving into stable environment
- Cold pool from prior convection

**Ensemble Mean 75 hPa MLCAPE (J kg⁻¹)**
- Probability Matched Mean - Composite Reflectivity (dBZ)

Init: 2016-03-31, 2230 UTC
Valid: 2016-03-31, 2230 UTC
31 March 2016: 2230 Forecast

**Storm-Scale Challenge:**

Gray Shading: Observed AZ shear objects
Colored Shading: Individual Member vertical vorticity objects

**Mesoscale Challenge:**

Axis of enhanced 0-1 SRH

First in series of short-lived, tornadic supercell in northern AL
23 December 2015: 2230 Forecast

Missed storm-scale forecast

Tornado warns, but nontornadic storms
23 December 2015: 2330 Forecast

- Low probabilities of intense rotation for tornado storm, but misses storm decay and intensification of northern storm.

- Tornado-warned, but nontornadic storms.

- Severe, but nontornadic storms.
Summary:

- A prototype Warn-on-Forecast system has been demonstrated for the Spring of 2016

- Accurate low-level rotation forecasts have been produced across a variety of mesoscale environments; however, both storm and mesoscale challenges in accurately analyzing and forecasting individual thunderstorms remain

- Storm-scale Challenges:
  - Dense storm coverage can lead to unrealistic storm and cold-pool interactions
  - Small or shallow storms limit the number of radar observations assimilated, slowing spin-up
  - *May be mitigated by increasing storm and observation resolution (i.e. 1-km horizontal grid spacing) and utilizing multi-moment microphysics*

- Mesoscale Challenges:
  - Lack of observations for characterizing mesoscale environment
  - Model error
  - *Improved accuracy in forecasting the storm environment will result in similar improvements in storm-scale forecasts*
Future Work:

• Need quantitative verification of NEWS-e forecasts:
  • Model climatology of storm properties (i.e. 0-2 km vertical vorticity)
  • Object-based verification of storms
  • Near-storm environment characterization