Convective-scale Warn-on-Forecast

The Future of Severe Weather Warnings in the USA?

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Present Warning System: 2 March 2012

Warning is natural culmination of information distributed over previous days

3-day Outlook

2-day Outlook

1-day Outlook

Tornado Watch

Tornado Warning
How well are we doing?

Tornado Warning Statistics 1987-2011
Model Forecasts Used as Warning Guidance
Missing An Opportunity...
Warn-on-Forecast Vision

An ensemble of storm-scale NWP models predict the path of a potentially tornadic supercell during the next 1 hour. The ensemble is used to create probabilistic tornado guidance.

Stensrud et al. 2009 (October BAMS)
Warn-on-Forecast Vision

Radar and Initial Forecast at 2100 CST

Radar at 2130 CST: Accurate Forecast

An ensemble of storm-scale NWP models predict the path of a potentially tornadic supercell during the next 1 hour. The ensemble is used to create probabilistic tornado guidance.

Probabilistic tornado guidance: Forecast looks on track, storm circulation (hook echo) is tracking along centerline of highest tornadic probabilities

Stensrud et al. 2009 (October BAMS)
Two major research activities:

- Demonstrate value of a single *three-dimensional variational (3DVAR) analysis* for warning activities

Gao et al. (2013)
Smith et al. (2014)

- Research to make Warn-on-Forecast *forecast* vision a reality
Two major research activities:

- Demonstrate value of a single *three-dimensional variational (3DVAR) analysis* for warning activities

  Gao et al. (2013)  
  Smith et al. (2014)

- Research to make Warn-on-Forecast *forecast* vision a reality

  An ensemble of storm-scale RWP models predict the path of a potentially tornado supercell during the next 3 hours. The ensemble is used to create probabilistic tornado guidance.
Convective-scale Data Assimilation

- Convective-scale data assimilation is a **retrieval** problem:
  - Retrieval of the model state from mostly non-state observations
  - **STATE** (P, T, Qv, U, V, W, Qr, Qs, Qg, Qh, Qc, Qi) from **OBS** (dBZ, Vr, Zdr, Kdp)
  - This problem is very under-determined

- With *ensemble* data assimilation, the model matters:
  - We can fit the observations very well
  - The retrieved model state can be different depending upon model used
Model Details

• Numerical models
  – NCOMMAS (Lou Wicker)
    • Cloud-scale model with microphysics and turbulent mixing, homogeneous initial conditions
    • Good for fast turnaround – small wins
  – WRF/ARW
    • Full physics, non-homogeneous initial conditions
  – Grid spacing 1-3 km, 50 vertical levels
  – Not predicting tornadoes explicitly, looking at lowest model level vertical vorticity as proxy
Assimilation Details

• Data Assimilation
  – Ensemble Kalman filters
    • Square root (Whitaker and Hamill 2002)
    • Ensemble adjustment (Anderson 2001) via the Data Assimilation Research Testbed (DART) software
    • Local Ensemble Transform (Hunt et al. 2007)
  – Ensemble size of ~50 members
  – Physics diversity used in some of the ensemble; results generally encouraging
Pros and Cons

• Overall results similar between NCOMMAS and WRF/ARW and between the various data assimilation approaches

• Need to squeeze as much as possible out of assimilation method and balance accuracy with computational cost
Warn-on-Forecast: 4 May 2007
Greensburg, Kansas, Tornado

Dawson, Wicker, Mansell and Tanamachi, 2012 (MWR)
COMMAS model, 1 km horizontal grid spacing, 50 vertical levels,
Ensemble Kalman filter assimilation of WSR-88D observations, 30 ensemble members
Warn-on-Forecast: 8 May 2003
Oklahoma City Tornado

Yussouf, Mansell, Wicker, Wheatley and Stensrud 2013 (MWR)
WRF model, 2 km horizontal grid spacing, 50 vertical levels, DART ensemble
Kalman filter assimilation of WSR-88D observations, 45 ensemble members
Are cycled forecasts consistent and robust?

Forecasts out to 2300 UTC generated by rapidly updated analyses from 2145 UTC to 2227 UTC

Tornado on the ground from 2210 to 2238 UTC

Yussouf et al. (2013)
Warn-on-Forecast: 24 May 2011
El Reno, Oklahoma, Tornado

Vorticity swaths shown to improve when using 1-minute Doppler observations from a phased array radar

Photo courtesy Jeff Snyder

Courtesy Chris Karstens, CIMMS and Louis Wicker, NSSL
Early Convection on May 24 2011: 1915 UTC
4 km Reflectivity (ensemble mean)

- **CWP** and **RADP** slow to develop high radar reflectivity compared to observations
- **RADP** generates larger area of low reflectivity corresponding to spurious **CWP** seen previously
- **RADCWP** locates convection correctly and generates higher magnitude reflectivity values consistent with observations
- **Assimilation of both radar and satellite data allows for a faster storm spin-up within the model**

Jones et al. (2015)
27 April 2011 Supercell Tornado Outbreak

Roughly 300 tornadoes

348 fatalities from tornadoes and other thunderstorm hazards

Results from this event courtesy Nusrat Yussouf from CIMMS at the University of Oklahoma
Forecast Probability of Reflectivity

Observed 40-dBZ Reflectivity Contour at 1.5 km MSL

Prob. of reflectivity >= 40 dBZ at 1.5 km MSL

10 20 30 40 50 60 70 80 90 %
1 hr Forecast Probability of Vorticity from every 15-min analyses

1930 -2030 UTC

1945 - 2045 UTC

2000 - 2100 UTC

2015 - 2115 UTC

WDSS-II Rotation Track (s⁻¹)

0-1 hr Prob. of Vorticity >= 0.004 s⁻¹ at 1 km AGL

% 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95

Hackleburg tornado on the ground : 2005 - 2220 UTC
Duration: 2 hrs and 15 mins

Cullman tornado on the ground : 1940 - 2038 UTC
Duration: ~1 hr

Hackleburg EF-5 Tornado
72 fatalities
Duration: 2005 – 2220 UTC (2 hrs. 15 mins.)
Distance Traveled: 212 km
Extended Hour Forecast Probability of Vorticity out to 2315 UTC

Tornado on the ground: 2143 - 2314 UTC
Duration: 1 hr 30 mins
Tuscaloosa to Birmingham EF-4 Tornado
65 fatalities, 1500 injuries
Duration: 2143 – 2214 UTC (1 hr. 30 mins.)
Distance Traveled: 130 km
Cordova EF-4 Tornado

Duration: 2040 – 2250 UTC (2 hr. 10 mins.)
Distance Traveled: 205 km
13 Fatalities

1-hr Forecast Probability of Vorticity from every 15-min analyses

0-1 hr Prob. of Vorticity $\geq 0.004 \text{ s}^{-1}$ at 1 km AGL

Tornado on the ground: 2040 to 2250 UTC
Duration: 2 hrs 10 mins

Cordova EF-4 Tornado
Duration: 2040 – 2250 UTC (2 hr. 10 mins.)
Distance Traveled: 205 km
13 Fatalities
0-1 hr Forecast Probability of Vorticity every 15-mins
Communication and Use of Information

Provide high-quality weather warning information to allow people to make the best decisions for their families.
Challenges

• Accurate mesoscale environment
  – Including cold pool structure(s)

• Accurate storm-scale model
  – Treatment of microphysics and boundary layer

• Assimilation of radar and satellite data
  – Data quality control
  – Best assimilation methods (EnKF, 3DVAR, 4DEnKF, LETKF, Hybrid)

• Use of ensemble output by forecasters
  – FACETs: How to use these data and interpret them for end users
The Road Ahead

• Value of single analysis in warning operations
• Robust probabilistic ensemble forecasts of high-impact weather events
• Testing in Hazardous Weather Testbed
• Learning how to use probabilistic information in warning operations (FACETs)
• Need for computers to get faster and more affordable
Thanks to everyone on the Warn-on-Forecast team for their hard work and dedication!

http://nssl.noaa.gov/projects/wof/
Multiscale Ensemble DA and Forecast System

- IC/BC from Global Ensemble Forecast System (GEFS) at 0000 UTC 27 April 2011
- Ensemble Adjusted Kalman Filter (EAKF) from DART software
- Observation platforms: METAR, Radiosonde, Maritime, Automated Aircraft, Satellite Derived Winds
- No radar data assimilation on 15-km grid

Mesoscale
- WRF ARW version 3.4.1
- A 36-member multi-physics ensemble
- 51 vertical levels
- Mesoscale at 15 km and
- Storm-scale at 3 km horizontal grid spacing
Radar Data Assimilation in Storm-scale 5-min Update System

• Radar DA starts at 1800 UTC in the nested 3-km domain
• WSR-88D radar observations from KDGX, KGWX, KBMX and KHTX
• Radar reflectivity, radial velocity, mesonet other conventional observations
• Radar observations objectively analyzed at 6 km using OPAWS software
• Every 5 min from 1800 UTC – 0000 UTC
• Launch 1-h storm-scale ensemble forecasts every 15 min

• Sources of ensemble spread for storm-scale data assimilation
  • GEFS
  • Multi-physics
  • Adaptive inflation
  • Additive noise (Dowell and Wicker, 2009)