Motivation: Tornado warning lead-times have stopped improving
Motivation: Tornado warning lead-times have stopped improving
Current Warning Process: “Warn on Detection”
Current Warning Process: “Warn on Detection”

Forecaster: Uses knowledge of environment to assess the potential tornado threat…
Current Warning Process: “Warn on Detection”
Current Warning Process: “Warn on Detection”
Current Warning Process: “Warn on Detection”

KTLX Radar 19:25 UTC 20 May 2013

KTLX Radar 19:39 UTC 20 May 2013

Forecaster: Considers his knowledge of environment with radar trends...

Developing circulation and hook echo
Current Warning Process: “Warn on Detection”

Forecaster: Combining the threat from the environment with radar trends crosses a threshold...

Tornado Warning Issued 19:40

Lead time for Moore storm: 16 min
Future Warning Process: “Warn on Forecast”
Future Warning Process: “Warn on Forecast”

Model forecasts developing circulation and hook echo

KTLX Radar 19:25 UTC 20 May 2013

Storm-Scale Forecast for 19:40 UTC
Future Warning Process: “Warn on Forecast”

“Probabilistic warnings enabled by combining observations with rapidly-updating, high-resolution storm-scale models”

Storm-Scale Forecast for 19:40 UTC

- WoF predicts storm for 19:40 by 19:27
- Forecaster “sees” evolution “ahead” of time
- Warning can be issued 13 minutes earlier
Future Warning Process: “Warn on Forecast”
“Probabilistic warnings enabled by combining observations with rapidly-updating, high-resolution storm-scale models”

Storm-Scale Forecast for 19:40 UTC

- WoF predicts storm at 19:40
- Forecaster “sees” the storm evolution “ahead” of time
- Warning can be issued 15 minutes earlier

Warnings will likely be very different...

- Warning is probabilistic (information rich)
- Warning is more focused (smaller area)
- Threat information will have temporal and spatial distributions (binary warning)

FACETS will be the delivery system for WoF-probabilistic warnings
Why NSSL?

- **Our Core Strengths**
  - Radar (Doppler, dual-Pol, MPAR)
  - Severe storms observations and dynamics
  - Storm-scale NWP and ensembles
    - NSSL has introduced these into SPC and OUN through HWT interactions
  - Warnings research and applications
    - NSSL has long history of R2O for NWS warning operations
Warn on Forecast Overview

- ~$2.6M annual budget

**Supports:**
- Internally
  - 9 PhD scientists currently
  - 4 post-docs / 2.5 staff support
  - 1-3 M.S./Ph.D. students supported on average
- Externally supports (~$800K)
  - funding goes to SPC, NWS OUN, GSD, CAPS, OU, PSU
  - Supports 4-5 more staff positions and several senior scientist months

**Other significant collaborations**
- CIMSS (Wisc.), NESDIS, NCEP/EMC
- NCAR Mesoscale Prediction Group & IMAGe

**Measures of Quality and Relevance and Progress (last 5 years)**
- ~100 peer-reviewed papers published in the last 5 years
- ~200 presentations at national or international conferences and workshops
- ~dozen regional WoF prediction test cases completed in last two years
WoF Science…

• Rest of presentation will focus on our scientific achievements…

  • Practical predictability of supercells and other severe weather threats?
  
  • Are the current prediction systems ACCURATE enough to predict these events reliably?
  
  • Could rapid-scan radar data (MPAR) improve storm-scale forecasts?
Practical Predictability of Supercells?


**Probability of Sig. Rotation Forecast after 7 radar Volumes**

Both radars located far away from storm (> 100 km)

**Probability of Sig. Rotation Forecast after 11 radar Volumes**

Red contour: Where “truth” storm has rotational velocity > 10 m s⁻¹

What is an Observing Systems Simulation Experiment (OSSE) study?

- Generate synthetic observations using “nature run” from a high-resolution prediction model
- Assimilate these synthetic observations back into your NWP system
- Because you know the “truth” from the “nature run” – you what the answer should be – can study…
  - Best assimilation methods / impact of new observations / needed obs resolution, etc.
  - Here: OSSE used to study radar location and its impact on forecasts
- Problem: **Hard** to create OSSEs that accurately represent real-world errors: Results are too optimistic!
Practical Predictability of Supercells?


**OSSE Study**
- Generate synthetic observations using model
- Assimilate observations back into model
- Determine potential impact and predictability

Probability of Sig. Rotation Forecast after 7 radar Volumes

Probability of Sig. Rotation Forecast after 11 radar Volumes

Red contour: Where “truth” storm has rotational velocity > 10 m s\(^{-1}\)

Truth Simulation

Both radars located far away from storm (> 100 km)

2\(^{nd}\) radar 50-60 km from storm
Are Models Accurate Enough?


Storm-scale Predictions from 27 April 2011 Super Outbreak

~300 tornadoes
348 fatalities from tornadoes and other thunderstorm hazards

SPC Storm Reports for 04/27/11
Map updated at 1211Z on 05/07/11

Tuscaloosa, AL tornado
Rotation track prediction for Tuscaloosa-Birmingham storm
Valid: 2100-2315 UTC (135 min forecast)
Two storms are near MS border.

Pre-Tuscaloosa-Birmingham cells
Cordova Supercell

Tornado Track
Tornado starts: 2143 UTC
Tornado ends: 2314 UTC

FCST track initially dominated by northern cell

Are Models Accurate Enough?

Model Reflectivity Analysis
Valid: 2100 UTC

Probability

NSSL Lab Review Feb 25–27, 2015
Model Reflectivity Analysis
Valid: 2130 UTC

- Original cell merges with a new storm along its southwestern side.
- Result is the Tuscaloosa-Birmingham supercell and long-track tornado.

30 Minutes Later: Rotation Track Prediction
Valid: 2130-2315 UTC (105 min forecast)

- Southwestern cell becomes dominant..
- Maximum rotation probabilities shift SE onto dominant storm cell.
- Prediction system is capable of representing the details of storm-storm interactions...

Tornado starts: 2143 UTC
Tornado ends: 2314 UTC

Are Models Accurate Enough?
Impact from Rapid-Scan Radar (MPAR) on Storm-scale NWP

Mean forecasts after 30 min of data assimilation

WSR88D
6 Volumes Assimilated

Observations
0130 UTC

MPAR
31 Volumes Assimilated

30 min forecast Valid 0130 UTC

Cheng, J. and N. Yussouf
Mon. Wea. Rev., 2016?
Impact from Rapid-Scan Radar (MPAR) on Storm-scale NWP

Mean forecasts after 30 min of data assimilation

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Impact from Rapid-Scan Radar (MPAR) on Storm-scale NWP

Mean forecasts after 30 min of data assimilation

WSR88D 6 Volumes Assimilated

Observations 0130 UTC

MPAR 31 Volumes Assimilated

30 min forecast Valid 0130 UTC

Cheng, J. and N. Yussouf
Mon. Wea. Rev., 2016?
Impact from Rapid-Scan Radar (MPAR) on Storm-scale NWP

One hour ensemble forecasts after 30 min of data assimilation

Ensemble Probability of Strong Low-level Rotation ($z > 0.002 \text{ s}^{-1}$)

**Forecast Period: 0100-0200 UTC**

- **WSR88D**
  - 6 Volumes Assimilated

- **MPAR**
  - 31 Volumes Assimilated

Gray contours are the WDSS-II rotation locations
Tornado is from 0119-0141 UTC

Cheng, J. and N. Yussouf
How will forecasters use a storm-scale prediction system?

- **NSSL experimental WoF System-enKF (NeWS-e) experiment (May 2015)**
  - Prototype WoF system at 3 km resolution over relocatable 700 km² domain
  - Storm-scale ensemble analysis every 15 min / 90-min forecast every hour
  - Output evaluated using the Probabilistic Hazard Information (PHI) tool

**PHI is a FACETS Application**

Probabilistic Hazard Information (PHI) tool display with WoF ensemble prediction for a tornadic storm in 2011
Summary

• WoF project has demonstrated skill predicting storm tracks and rotational intensities for 0-2 hours for real-data case studies.

• Improved forecasts from assimilation of MPAR data relative to 88D data

• NSSL experimental WoF System tests of EnKF, cycled 3DVAR, hybrid all on the way…

• QRP for last 5 years:
  • ~100 peer-reviewed / ~200 presentations / ~ dozen case studies / real time system development
Summary (continued..)

Future Work

• Improve balance in storm-scale analyses from remotely-sensed observations.
  • Use of dual-polarization radar data in storm-scale analysis systems?
  • Incorporation of dynamical constraints in analysis and reduction in model errors

• Understanding how WoF output could/would be used by operational forecasters
  • How to post-process ensemble data output into probabilistic forecasts: “FACETS”
  • How can forecasters feedback guide our research emphasis? O2R!

• For WoF to reach its full potential requires a more accurate measurement of the storm-scale environment than the current observational network permits.
  • Vertical profiles of temperature, humidity and wind in boundary layer needed for CONUS. Ground-based thermodynamic and Doppler lidar profilers?
  • More radar observations are needed for CONUS in lowest 2 km!
Questions?