ENSEMBLE SENSITIVITY ANALYSIS FOR TARGETED OBSERVATIONS OF SUPERCCELL THUNDERSTORMS
Acknowledgements

Nebraska Research Council's Maude Hammond Fling Faculty Research Fellowship
Air Force Office of Scientific Research grant FA9550-12-1-0412
National Science Foundation grant IIS-1527113
Introduction

Observed supercell thunderstorms developing in “similar” environments exhibit radically different evolutions
Introduction

Sources of uncertainty:

- Unresolved environmental heterogeneity
- Differences in the mechanisms of initiation
- Stochastic internal dynamics

All of these are likely to manifest in coherent (mesoscale) structures/patterns that are statistically significant indicators of future storm strength and tornado potential.
Introduction

How/where could observations be collected in proximity to supercell thunderstorms to enable improved predictability?

- Advance basic understanding of supercell and tornado dynamics
- Initiate a larger examination of the viability of targeted surveillance of supercell thunderstorms
Ensemble Sensitivity Analysis

Ensemble sensitivity analysis (ESA): Estimate the sensitivity of a dynamical model to observations at a location by statistically relating perturbations at the location to the forecast response (Ancell and Hakim 2007)
Ensemble Sensitivity Analysis

Sensitivity of maximum vertical velocity (in response area) to 700 hPa temperature (Hill et al. 2014)
Methodology

Numerical model configuration

- WRF
- $\Delta x, \Delta y = 1000\text{m}, \Delta z = 100-500\text{m}$
- Morrison double moment (with hail) microphysics
- Free slip lower boundary condition
- No surface fluxes of heat and moisture
- Storm initialized with 4K warm bubble

CAPE=2500 J/kg

0-6 BWD=35 m/s
0-3 SRH=338.9 m$^2$/ s$^2$
0-1 SRH=218.6 m$^2$/ s$^2$
Methodology

Numerical model configuration
Methodology

Ensemble configuration

- 51 members (control + 50)
- Perturbation method
  1. Three-mode sinusoidal perturbations (Aksoy et al. 2009) to $\theta$, $q_w$, $u$, and $v$
  2. Random adjustment to warm bubble $\delta x$ & $\delta y$ (10 km +/- 25)
  3. Random adjustment to the warm bubble $\theta$ (4 K +/- 25%)
  4. Random t=0 grid point perturbations to $\theta$ of +/-0.25 K
Methodology

ESA variables

- Perturbation variables: $\theta$, $p$, $q_v$, $u$, $v$, $w$
- Forecast response variables
  - Max 2-5 km updraft helicity $\left( \int_{z_0}^{z_1} w \, \zeta \, dz \right)$ (Kain et al. 2008)
  - Max composite reflectivity
  - Max $q_{\text{graupe}}$ (z=0)
  - Max $|\mathbf{V}|$ (z=0)
  - Min $p$ (z=0)
  - Max $\zeta$ (z=0)
Methodology

Procedure

1. Perturbations calculated at 0:45-1:55 at 5 min intervals

2. Correlate perturbations across all ensemble members at each analysis time with forecast response at all available future states

   \[ \Delta \tau = t_{\text{forecast}} - t_{\text{analysis}} \]

   ⇒ Absolute value of Spearman’s ranked correlation: \( |r|_{i,f} \)

3. Average \( |r|_{i,f} \) over all forecast-analysis pairs for a given \( \Delta \tau \) ⇒ \( \langle |r|_i \rangle_{\Delta \tau} \)

4. Average over all grid points in a given region of interest: \( \langle |r| \rangle_{\Delta \tau}^R \)
Methodology

Procedure

\[ \langle |r| \rangle_{\Delta \tau}^R \]
Results

- Evaluated $\langle |r| \rangle_{\Delta \tau}^R$ for each variable, each response, 6 heights (0.5-3 km), and each $\Delta \tau$ (lead time)

- Compared to the distribution of $|r|_{rand}$ for a random distribution of rankings

![Graph showing comparison between $\langle |r| \rangle_{\Delta \tau}^R$ and $|r|_{rand}$]
Results

Strong Supercell – Updraft Helicity – 500 meters

- Rear Flank Downdraft
- Forward Flank Gust Front
- Rear Flank Gust Front
- Precipitation Core
- Mesocyclone
- Storm Environment

**Potential Temperature**

**Pressure**

**Water Vapor Mixing Ratio**

**U Component of Wind**

**V Component of Wind**

**W Component of Wind**

[Graphs showing various meteorological parameters over lead time]
Results

Strong Supercell – Low Level Wind Speed – 500 meters

Rear Flank Downdraft
Forward Flank Gust Front
Rear Flank Gust Front
Precipitation Core
Mesocyclone
Storm Environment

Potential Temperature
Pressure
Water Vapor Mixing Ratio

U Component of Wind
V Component of Wind
W Component of Wind

Mean |r| above random

Lead time (minutes)
Results

Strong Supercell – Low Level Wind Speed – 3000 meters

Rear Flank Downdraft
Forward Flank Gust Front
Rear Flank Gust Front
Precipitation Core
Mesocyclone
Storm Environment

- Potential Temperature
- Pressure
- Water Vapor Mixing Ratio
- U Component of Wind
- V Component of Wind
- W Component of Wind
Results

Strong Supercell –Lowest Level Pressure Perturbation –3000 m

- Rear Flank Downdraft
- Forward Flank Gust Front
- Rear Flank Gust Front
- Precipitation Core
- Mesocyclone
- Storm Environment

- Potential Temperature
- Pressure
- Water Vapor Mixing Ratio

- U Component of Wind
- V Component of Wind
- W Component of Wind
Results

Strong Supercell – Lowest Level Vertical Vorticity – 500 meters

- Rear Flank Downdraft
- Forward Flank Gust Front
- Rear Flank Gust Front
- Precipitation Core
- Mesocyclone
- Storm Environment

- Potential Temperature
- Pressure
- Water Vapor Mixing Ratio
- U Component of Wind
- V Component of Wind
- W Component of Wind
Results

Strong Supercell – Lowest Level Vertical Vorticity – 2500 meters

Rear Flank Downdraft
Forward Flank Gust Front
Rear Flank Gust Front
Precipitation Core
Mesocyclone
Storm Environment

Potential Temperature
Pressure
Water Vapor Mixing Ratio
U Component of Wind
V Component of Wind
W Component of Wind
Summary

- Demonstrated a method of quantifying possible preferred locations for targeted observation of supercells
- Three locations tended to show highest sensitivity at 40-60 min lead times
Future Work

- Comparison of results to weaker supercell cases
- Observing System Simulation Experiments (OSSEs)
Questions?

Adam Houston: ahouston2@unl.edu
George Limpert: george.limpert@unl.edu