USING ENSEMBLE PROBABILITY FORECASTS AND HIGH RESOLUTION MODELS TO IDENTIFY SEVERE WEATHER THREATS

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1. INTRODUCTION

Ensemble Prediction System (EPS) data from the National Centers of Environmental Prediction’s (NCEP) Short-Range Ensemble Forecast system (Du et al. 2004:SREF) are used to predict areas with a severe weather threat. This study illustrates the value of using SREF forecast products that depict probabilities of exceedance and joint probabilities of variables related to severe weather. Probabilities of exceedance for Convective Available Potential Energy (CAPE), Storm-Relative Helicity (SRH), height normalized (mean) shear, and the Energy Helicity Index (EHI) are examined. Joint probabilities of CAPE, effective shear, and 3 hr. convective precipitation are also considered.

SREF probability forecasts are examined for a vigorous severe weather event that occurred across much of the central Mississippi and lower Ohio Valleys on 2 April 2006. We will show that joint and exceedance probabilities from the SREF make it possible to clearly distinguish areas with the greatest severe weather potential.

A forecast strategy is proposed which utilizes 1) ensemble data for assessing the likelihood, mode, and forecast confidence of a severe weather event; 2) climatological anomalies for evaluating the historical context of an impending event; and 3) high resolution model data for determining the magnitude of moisture, the horizontal and vertical extent of moisture, important mesoscale structures, and relevant forcing mechanisms at short ranges.

2. METHODS

A recently developed North American Regional Reanalysis (NARR) climatology demonstrates the operational utility of climatological anomalies in forecasting severe weather events. Climatic anomalies were computed as described by Hart and Grumm (2001). For all fields the values were compared to the mean and divided by the standard deviation, producing standardized anomalies (SDs), indicating the departure of the field in standard deviations from normal.

Uncalibrated forecasts from the SREF were obtained in near real-time and archived for this case study. Relative frequencies (hereafter probabilities) were computed using each member’s forecast to exceed a parameter; for example CAPE > 1200 Jkg\(^{-1}\) vs. the total number of members in the EPS. No bias correction data were available. All data were displayed using GrADS (Doty et al).

3. CASE STUDY RESULTS

i. Introduction and SREF Data

A strong cold front brought severe weather to much of the central Mississippi and lower Ohio Valleys on 2 April 2006 (Fig. 1). There were 871 severe weather reports and 85 tornadoes. Around 29 people lost their lives in this deadly early-spring tornado outbreak.

Figure 1. a) HPC surface analysis valid 0000 UTC 3 April 2006 and b) SPC Storm Reports for 2 April 2006
This event had many features often associated with large severe weather events. A deep surface cyclone with a strong frontal system and a strong low-level jet moved across an area where the CAPE was unseasonably high. The low-level jet contributed to strong shear and high values of storm-relative helicity (SRH) in the SREF forecasts.

Figure 2a shows the mean-sea level (MSLP) and precipitable water (PWAT) forecasts from SREF forecasts initialized at 2100 UTC 1 April 2006 (format hereafter 0401/2100 UTC), valid at 0403/0000 UTC. The forecasts indicate a strong surface cyclone, with a central pressure greater than 2 SD below normal over the upper Mississippi Valley. In the warm sector, warm moist air is surging poleward, as evident by PWAT values greater than 32 mm (1.25 in).

Figure 2b shows the mean PWAT anomalies are forecast to be 2 to 3 SDs above normal in the warm sector (Fig. 2b). A comparison of Figures 2a and 2b suggests the close relationship and importance of moisture in the CAPE.

SREF forecasts initialized at 0401/2100 UTC illustrate ensemble means of CAPE, EHI, SRH, and 1.5 km height normalized (mean) shear at 0403/0000 UTC (Figs. 3 & 4). These data show CAPE between 1200-2500 Jkg\(^{-1}\) (Fig. 4a) and EHI values 1-3 from Illinois southward over most of the lower Mississippi Valley (Fig. 3a). Figure 3b shows ensemble means of SRH in the warm sector of 300-400+ m\(^2\)s\(^{-2}\) from Indiana to Wisconsin, generally along and north of a strong warm front (Fig 3b). SRH of 200-300 m\(^2\)s\(^{-2}\) extends southward into the lower Mississippi valley along and east of the cold front, where 1.5 km mean shear is .009-.010+ s\(^{-1}\) (approximately...
30 kts, Fig 3b). For this event, high instability, strong low-level shear, and strong forcing along the warm and cold fronts were in close proximity, indicating a high probability of severe weather and a higher than normal potential for tornadoes.

The 850 hPa winds in the warm sector were anomalously strong (not shown), and U-wind anomalies peaked around 3 SD’s above normal across the lower Mississippi Valley. 850 hPa V-wind anomalies around 2 SD’s above normal were indicated over Indiana and Michigan.

One of the strengths of an EPS is the ability to display probabilistic forecasts. Figures 4 and 5 show SREF forecasts initialized at 2100 UTC (4a) and 0900 UTC (4b) 1 April 2006, valid 0403/0000 UTC. These forecasts indicate a high probability of CAPE from 1200 Jkg$^{-1}$ to 2500 Jkg$^{-1}$ across the central and southern Mississippi Valley (Fig. 4) combined with high probabilities of low-level shear greater than .006 s$^{-1}$ and SRH greater than 200 m$^2$s$^{-2}$ (Fig. 5). The low-level shear is especially noteworthy along and near the frontal boundaries. These data show the close proximity of significant vertical wind shear and high CAPE over most of the central and southern Mississippi Valley.

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EPS also allows the computation of Joint Probabilities, defined as the product of individual probabilities. Figure 9a illustrates SREF forecasts initialized at 2100 UTC 1 April 2006, showing the Joint Probability of 3 hr. Convective Precipitation greater than .01 in, SPC MUCAPE greater than 1000 Jkg$^{-1}$, and Effective Shear greater than 40 kts. Figure 9b shows the probability of the Significant Tornado Parameter
exceeding 3 and the ensemble Mean Significant Tornado Parameter greater than 3. MUCAPE is the most unstable parcel (unmixed) from the surface to 500 mb AGL. Effective shear is defined as the shear in the lower 50% of the convective cloud between the Lifted Parcel Layer (LPL) and Equilibrium Level (EL). The Significant Tornado Parameter is a multi-parameter index that includes effective bulk shear, effective SRH, 100 mb mean parcel CAPE, and 100 mb mean parcel LCL height. These data further illustrate an environment favoring severe storms with tornadoes across the lower and central Mississippi Valley.

**ii High Resolution model data**

While ensemble forecasts can help one to ascertain the likelihood, spatial potential, and mode of severe weather, high resolution model forecasts promote a better understanding of important mesoscale structures and their relevance to an impending event.

![Figure 6](image1.png)

**Figure 6.** SREF forecasts initialized at 2100 UTC 1 April 2006 showing a) Joint Probability of 3 hr, Convective Precipitation > .01 in, SPC MUCAPE > 1000 J/kg, and Effective Shear > 40 kts and b) Probability of Significant Tornado Parameter ≥ 3 (shaded) and Mean Significant Tornado Parameter ≥ 3 (yellow dash)

![Figure 7](image2.png)

**Figure 7.** NAM-WRF 36 hr forecast of a) Instantaneous (7a) and convective precipitation rates (7b), and clearly shows the convective potential along banded frontal structures as well as the grid scale precipitation northwest of the surface cyclone. Figure 8 shows the Best CAPE (8a) and surface dew points (8b), and indicates important moisture and instability details of the warm sector. The operational NAM-WRF, available in the Advanced Weather Information Processing System (AWIPS), highlighted...
important forcing mechanisms in a forecast of significant low-level frontogenesis and moisture flux convergence along the frontal features (not shown).

Using the equivalent reflectivity factor calculated from forecast mixing ratios of grid resolved hydrometeors, radar reflectivity products make it possible to display forecast fields from high-resolution numerical weather prediction (NWP) models. Model Reflectivity Products promote the visualization of detailed mesoscale and storm-scale structures capable of being forecast by finer resolution NWP models (Koch et al. 2005). Figure 9 compares real-time WSR-88D 0.5° Base Reflectivity and the lowest model level Simulated Radar Reflectivity product from the high resolution operational NAM-WRF, valid 0403/0000 UTC. Although it is not generally possible to make direct comparisons between actual and simulated radar, the simulated radar can reveal the nature of model-derived mesoscale forcing, especially associated with frontal systems. For example, Figure 9b indicates banded frontal and pre-frontal structures which correspond rather well with the actual radar (Fig. 9a), even though the real-time radar shows much greater Reflectivities in the convection. This information can be very useful to an analyst trying to understand how moisture, instability, and vertical wind shear are forecast to interact in a severe storm environment. Given the probabilistic information gained from the SREF, the additional high resolution NAM-WRF data allow us to infer multi banded structures in the forecast, with a high probability of a squall line with embedded and/or discrete supercells, and tornadoes.

Figure 8. NAM-WRF 36 hr forecast of a) Best CAPE and b) 2 meter Dew Point temperatures, valid 0403/0000 UTC.

Figure 9. a) Real-time WSR-88D 0.5° Base Reflectivity and b) lowest model level Simulated Radar Reflectivity (dBZ) from the operational NAM-WRF, valid 0000 UTC 3 April 2006.

Figure 10 contains the SPC Day 1 Convective Outlooks valid a) 0402/1630 UTC and b) 0403/0100 UTC. It is interesting to note the tornado maximum across the lower Mississippi Valley (Fig. 1) corresponds well with the Joint Probabilities.
and Significant Tornado Parameter depicted by the SREF in Figure 6.

4. CONCLUSIONS

SREF forecasts established a high likelihood of severe weather across much of the lower and central Mississippi Valley on 2 April 2006. Probability forecasts indicated an environment favoring severe storms with tornadoes, and the structure of the probabilities (tight gradients) indicated a high degree of agreement among the ensemble members. High resolution model data was used to determine the magnitude of moisture, the horizontal and vertical extent of moisture, important mesoscale structures, and relevant forcing mechanisms.

5. Acknowledgements

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6. REFERENCES


7. SREF AND WRF WEB SITES

1. 0000 and 1200 UTC WRF Forecast Graphics:
   http://www.emc.ncep.noaa.gov/mmb/mmbpill/nampl2_fullcy_c_2mbtop/index.html

2. 0600 and 1800 UTC WRF Forecast Graphics:
   http://www.emc.ncep.noaa.gov/mmb/mmbpill/opsnam_offtime/

3. SPC SREF: http://www.spc.nssl.noaa.gov/exper/sref/

4. EMC/NCEP SREF:
   http://www1.emc.ncep.noaa.gov/mmb/SREF/SREF.html

5. State College SREF and Anomaly Forecasts:
   http://eyewall.met.psu.edu/ensembles/java/ModelDisplay.html

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