8.4 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.

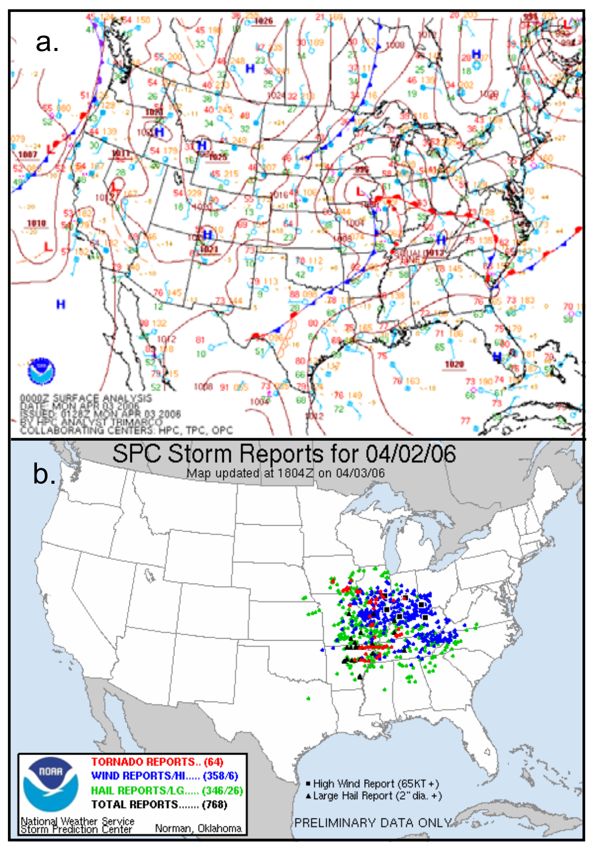

Figure 1. a) HPC surface analysis valid 0000 UTC 3 April 2006 and b) SPC Storm Reports for 2 April 2006

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.

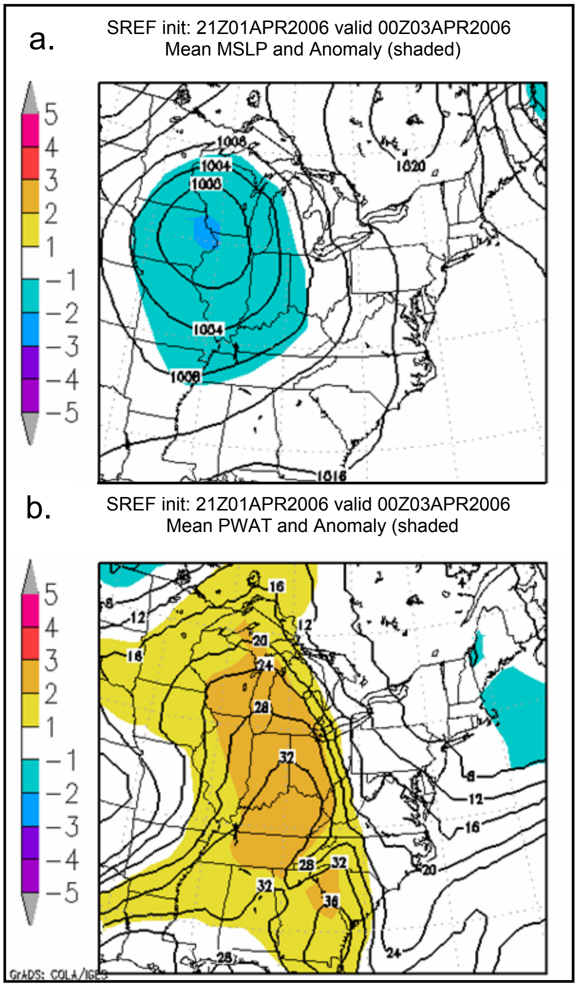

Figure 2. SREF forecasts initialized at 2100 UTC 1 April 2006 showing the 21-member ensemble mean of a) sea-level Pressure (hPa) and standardized climate anomaly (shaded, SD) and b) precipitable water (mm) and anomaly (shaded). MSLP and PWAT contours every 4 hPa and 4 mm respectively.

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

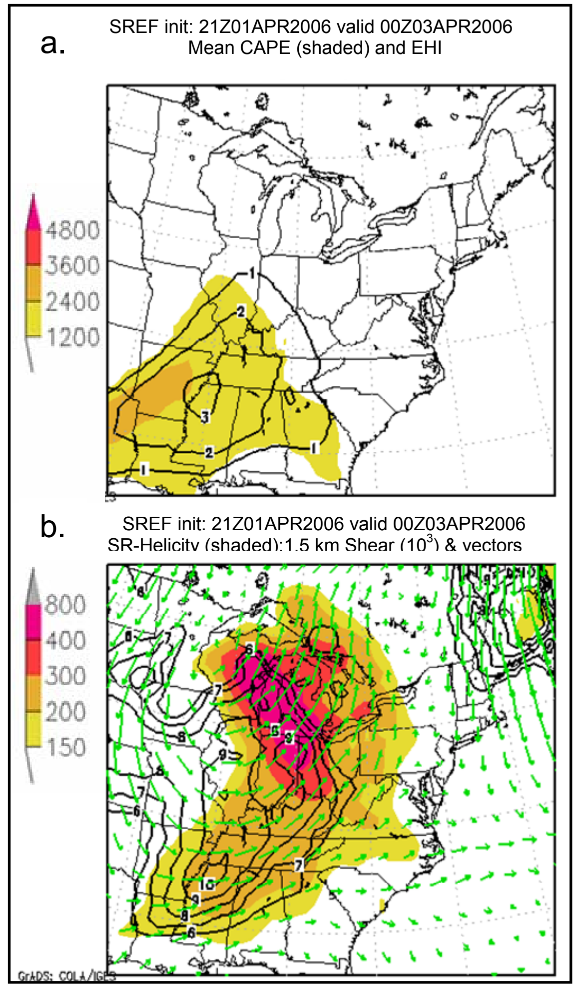

Figure 3. As in Figure 2 except showing a) mean CAPE (shaded, Jkg^{-1}) and EHI and b) mean SR-Helicity (shaded, m^2s^2), 1.5km Shear magnitude (s^{-1} x 10^3), and 1.5 km Shear vectors.

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^2s^2 from Indiana to Wisconsin, generally along and north of a strong warm front (Fig 3b). SRH of 200-300 m^2s^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.

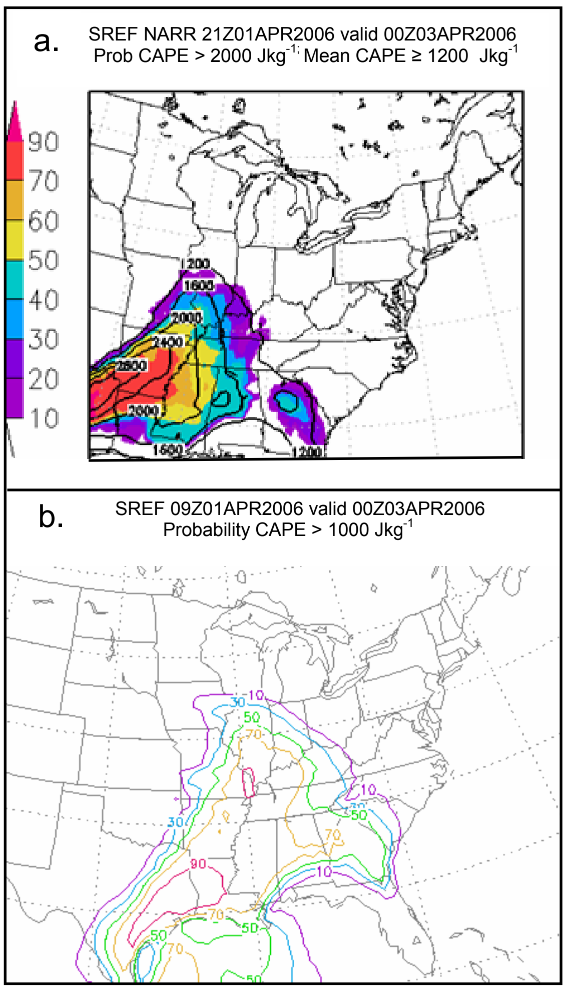

Figure 4. SREF forecasts initialized at (a) 2100 UTC and (b) 0900 UTC 1 April 2006 valid 0000 UTC 3 April 2006 showing the SREF of a) Probability of CAPE > 2000 Jkg^{-1} (shaded) and mean CAPE ≥ 1200 Jkg^{-1} and b) Probability of CAPE > 1000 Jkg^{-1}.

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^2s^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.

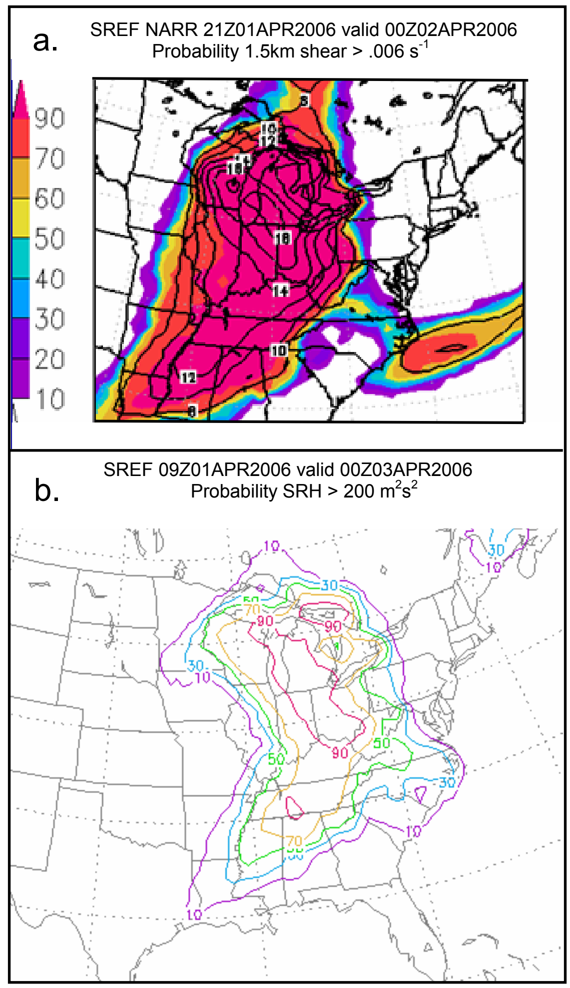

Figure 5. As in Figure 4 except showing a) Probability of 1.5 km mean shear > .006 s^{-1} (shaded) and mean shear magnitude > .006 s^{-1} and b) Probability of SRH > 200 m^2s^2.

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

(STP) 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

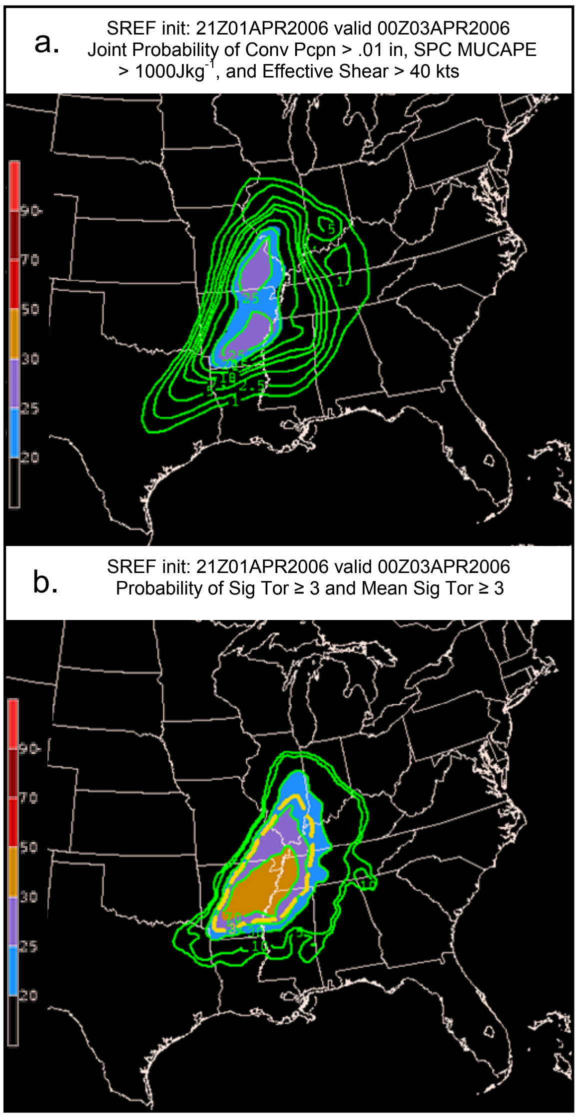

Figure 6. SREF forecasts initialized at 2100 UTC 1 April 2006 showing a) Joint Probability of 3 hr. Convective Precipitation > .01 in, SPC MUCAPE > 1000Jkg^{-1}, and Effective Shear > 40 kts and b) probability of Significant Tornado Parameter ≥ 3 (shaded) and Mean Significant Tornado Parameter ≥ 3 (yellow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

the lower and central Mississippi Valley. It is interesting to note the tornado maximum across the lower Mississippi Valley (Fig. 1) corresponds well with the Joint Probabilities and STP depicted by the SREF in Figure 6.

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.

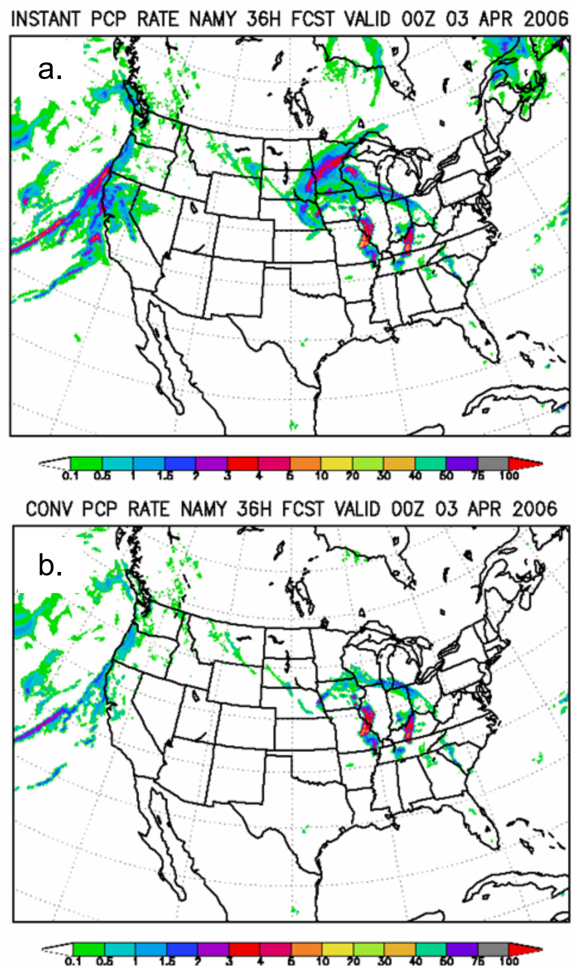

Figure 7. NAM-WRF 36 hr forecast of a) Instant PrecipitationRate and b) Convective precipitation rate, valid 0403/0000 UTC.

Figure 7 shows the NAM-WRF forecast of 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).

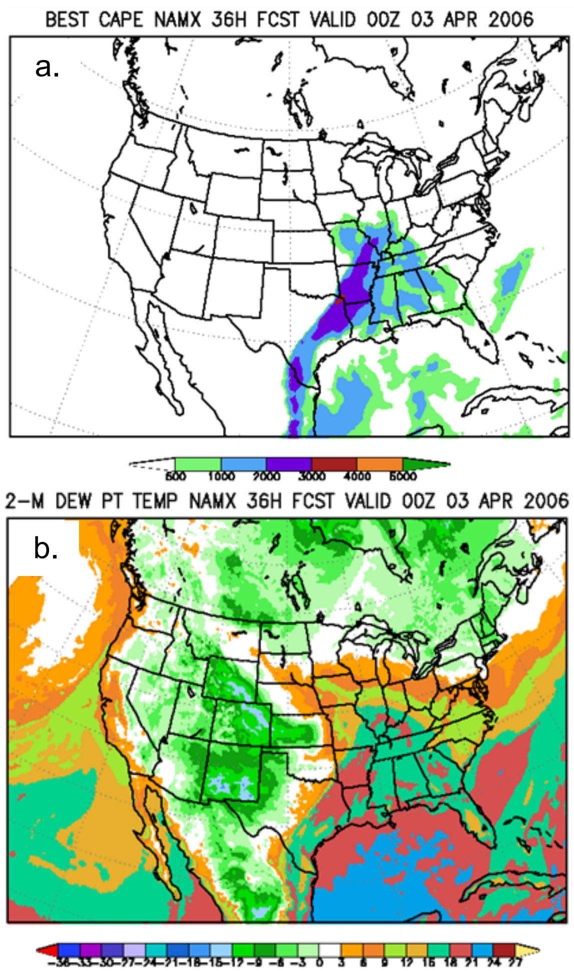

Figure 8. NAM-WRF 36 hr forecast of a) Best CAPE and b) 2 meter Dew Point temperatures, valid 0403/0000 UTC.

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^{o} 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.

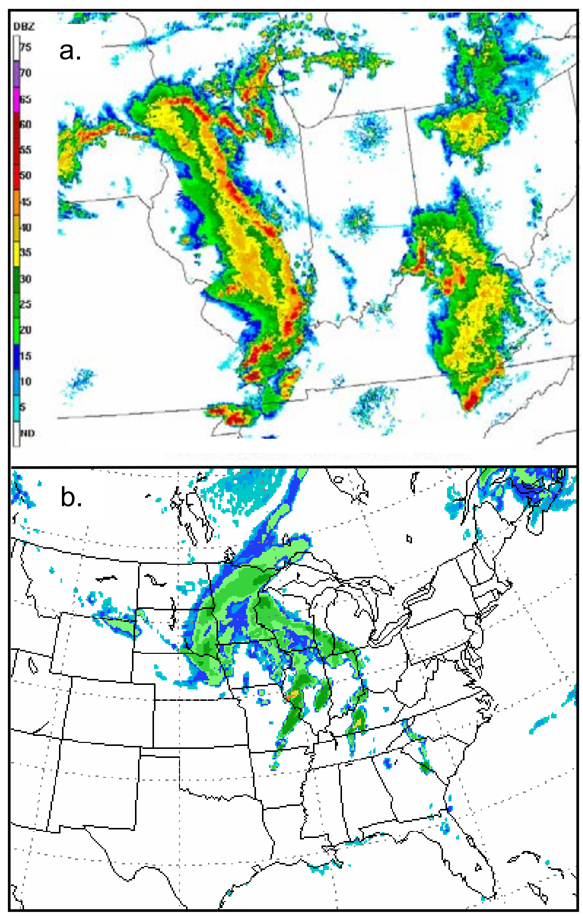

Figure 9. a) Real-time WSR-88D 0.5^{o} Base Reflectivity and b) lowest model level Simulated Radar Reflectivity (dBZ) from the operational NAM-WRF, valid 0000 UTC 3 April 2006.

Figure 10 contains the SPC Day 2 Convective and Probabilistic Outlooks, issued on 0401/1711 UTC and valid 0402-0403/1200 UTC. It is noteworthy that the severe weather potential for this event was forecasted 2 days before the onset of severe storms.

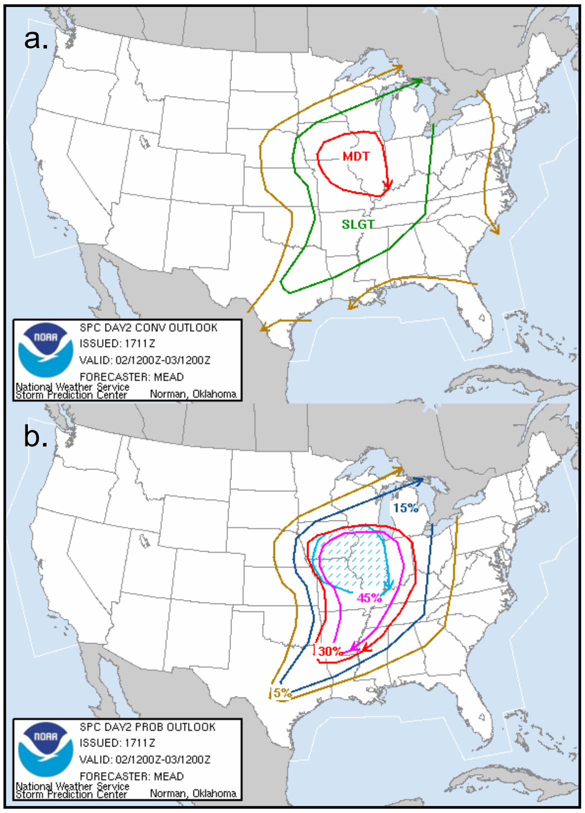

Figure 10. a) SPC Day 2 Convective Outlook, and b) the Day 2 Probabilistic Outlook, issued at 0401/1711 UTC and valid 0402/1200 UTC

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

Ron Holmes of the National Weather Service in State College for developing the prototype NARR means and standard deviations. Paul Knight of the Pennsylvania State University for resources to maintain and access the NARR datasets, David Bright (SPC) for producing the Joint Probabilities in Figure 9, and Jun Du (EMC/NCEP), for producing the CAPE probabilities in Figures 4 and 5, SPC/HPC for producing the HPC surface analysis and SPC Storm Reports in Figure 1, and EMC/NCEP for the NAM-WRF model graphics.

6. REFERENCES

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Koch S. E., B. Ferrier, M. Stoelinga, E. Szoke, S. J. Weiss, and J. S. Kain, 2005: The use of simulated radar reflectivity fields in the diagnosis of mesoscale phenomena from high resolution WRF model forecasts. *11th Conf. on Mesoscale Processes / 32nd Conf. on Radar Meteorology*, Albuquerque, NM, Amer. Meteor. Soc.

7. SREF AND WRF WEB SITES

1. 0000 and 1200 UTC WRF Forecast Graphics: http://www.emc.ncep.noaa.gov/mmb/mmbpll/nampll12_fullcyc_2mbtop/index.html

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

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

4. EMC/NCEP SREF: http://wwwt.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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