# The Evolution of Multi-Scale Ensemble Guidance
## in the Prediction of Convective and Severe Convective Storms
## at the Storm Prediction Center

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## 1. Introduction

As the National Weather Service (NWS) begins an evolution toward proactive decision support of high-impact events, it is likely that ensemble forecast guidance will play an increasingly larger role in the operational forecast process (NRC 2006). Several years ago, the Storm Prediction Center (SPC) recognized the immediate and long-term benefit of ensemble guidance, and began delving into ensemble applications and numerical forecastability in earnest around 2002. Since that time, the SPC has devoted considerable resources from the Science Support Branch (SSB) and the NOAA Hazardous Weather Testbed (HWT) toward the specialized development and refinement of NCEP ensemble prediction systems. This development focuses on high-impact weather and includes thunderstorms, hail, wind, tornadoes, excessive convective rainfall, localized extreme winter weather, and dangerous fire weather conditions.

The operational forecast products issued by the SPC embrace the concepts of uncertainty and decision support. Nearly all operational products include an accompanying representation of uncertainty, generally in the form of a probabilistic forecast to supplement the categorical (or deterministic) information. This brief note does not describe the operational products issued by the SPC, but simply provides a brief overview of the multi-scale ensemble guidance available or under development at the SPC.

## 2. Multi-scale Ensemble Guidance

### 2.1 Medium-range Ensemble Guidance

The NCEP Global Ensemble Forecast System (GEFS) is primarily used as guidance in the

producing the SPC's medium-range forecast products (i.e., forecasts ranging from about 3 to 8 days). Due to the relatively coarse resolution of the GEFS system (currently T126L28, or ~100 km equivalent grid length with 28 vertical layers) and the lack of model or physics diversity within the system, the GEFS is mainly used to assess large-scale forecastability of the evolution of synoptic and planetary waves. As an example, consider the large-scale pattern predicted by the GEFS for the devastating southern California wildfires of mid October, 2007. Figure 1 shows the 96 hour GEFS ensemble mean of 500 hPa geopotential height and absolute vorticity valid at 00 UTC 22 October 2007. The 500 hPa spaghetti diagram (single contour interval of 5760 m) is shown in Fig. 2. The GEFS was clearly supportive of a high-amplitude pattern with strong upper ridging in the West and a trough over the central U.S. The spaghetti indicates uncertainty in the longitudinal location of the trough axis, with one cluster of solutions indicating a trough axis over Kansas/Oklahoma, and a second cluster (containing more members) closer to the Arizona/New Mexico border. In either case, the ensemble mean predicted by the GEFS is unusual, with the ridge over the eastern Pacific more than 2 standard deviations above normal, and the central U.S. trough over 1.5 standard deviations below normal (Fig. 3).

### 2.2 Short-range Ensemble Guidance

The NCEP Short Range Ensemble Forecast (SREF) is best suited for assessing confidence and evaluating the range of possible scenarios for high-impact events associated with the uncertainty of the mesoscale environment. The time range of application is generally from a few hours to about three days. In this time range, synoptic scale predictability is typically high, such that forecast uncertainty is almost always associated with

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differences in the mesoscale environment or sensible weather parameters. One of the most widely applied methods of interrogating the SREF at the SPC is through the use of joint probabilities. Consider the joint probability of environmental conditions believed favorable for significant tornadoes (e.g., see Thompson et al. 2003) shown in Fig. 4. (Actually, as a substitute for the joint probability, this example uses the product of the individual probabilities. The validity of this assumption depends on the independence of the predictors. In using the product, it is assumed all predictors are independent or nearly independent.) This chart depicts a 36 hour SREF forecast (valid 21 UTC 7 April 2006) produced by taking the product of the following five probabilities: (1) mixed layer CAPE $\geq$ 1000 J/kg; (2) mixed layer LCL $\leq$ 1 km; (3) 0-1km AGL storm-relative helicity $\geq$ 100 $m^2/s^2$; (4) 0-6 km AGL bulk shear $\geq$ 40 kts; and (5) 3-hr convective precipitation $\geq$ 0.01". A substantial area of higher combined probabilities is shown over the Mid-South, providing high-confidence from the SREF that an environment favorable for strong and violent tornadoes was likely. Indeed, the forecaster used information from the SREF (and other prognostic models and parameters as well) for decision support and issued the first ever "High Risk" SPC outlook for the Day 2 period (Fig. 5). Indeed a large outbreak of severe weather and tornadoes did occur (Fig. 6) over much of the Mid-South. The environmental information from the SREF is also useful for calibrated ensemble guidance. Much of this guidance is available on the SPC website (http://www.spc.noaa.gov/exper/sref) under the menu heading, "Post-Processed Guidance." Additional experimental guidance is also under development, such as the probability of tornadoes (Fig. 7). This figure shows the 27 hour SREF (valid 00 UTC 12 June 2008) probability of at least one tornado within 25 miles of a point. Tornado warnings valid at this time are overlaid in white.

## 2.3 Rapid-refresh Ensemble Guidance

The Rapid Update Cycle (RUC) is a high-frequency (hourly) short-range (12 hours) deterministic model forecast to support aviation and other mesoscale weather forecast users such as the SPC (Benjamin et al. 2004). The SPC receives hourly RUC forecasts through 12-hours (i.e., F012) on the 3-hourly synoptic times (i.e., extended RUC forecasts), and hourly forecasts through 9-hours (i.e., F009) otherwise. A natural extension of the RUC deterministic system is toward a Rapid Refresh Ensemble Forecast (RREF), designed to provide a rapid update for probabilistic forecasting and decision support of high-impact mesoscale phenomena. The SPC has developed a local beta version of a RREF

system based entirely on time-lagged RUC forecasts. In its current configuration, the system runs automatically each hour using the current forecast and as many previous forecasts as available. Thus, every one-hour forecast contains 10 ensemble members, beginning with the 1-hour forecast of the most recent RUC, and ending with the 10, 11, or 12-hour forecast an extended RUC run. Advancing forward in time the number of ensemble members decreases until only two ensemble members remain at forecast hour 9 (F009). To address the declining and aging membership that occurs naturally with time, the system is weighted in both time and space such the total number of grid points used each forecast hour remains approximately constant. Due to the preliminary stage of development, specifics are retained for a future paper. An example of the output for a 1-hour calibrated probability of thunderstorms is shown in Fig. 8.

## 2.4 Storm-scale Ensemble Guidance

High-resolution numerical models (i.e., horizontal grid lengths < ~5 km) begin to resolve explicitly moist convective processes. They therefore have the ability to predict, at least to first-order, the convective mode associated with thunderstorms. Convective mode implies the accurate simulation of discrete convective cells, linear or bowing convective line segments, and discrete or embedded multicellular or supercellular structures. And because convective mode is generally well correlated to the type of severe weather (i.e., tornadoes, wind, hail, and/or heavy rain) (Gallus et al. 2008), these models may be capable of providing definitive guidance on the type of severe convective weather to expect. However, the uncertainty associated with initial conditions and numerical models that plague deterministic weather prediction on the synoptic and mesoscale, is equally valid for storm-scale phenomena. Of course the temporal and spatial scale of storm-scale predictability is inherently less than for the larger scales, but the utility of ensemble guidance should be just as useful when applied to storm-scale prediction. This is the subject of recent activities at the Experimental Forecast Program (EFP) within the NOAA Hazardous Weather Testbed (HWT). In collaboration with the The University of Oklahoma/CAPS, the SPC and NSSL have been evaluating the utility of a real-time Storm Scale Ensemble Forecast (SSEF) during EFP activities in 2007 and 2008, and will again in 2009. Fig. 9 shows a 26 hour SSEF prediction of the probability of the updraft helicity exceeding 50 $m^2/s^2$ (within 25 miles of a point). Subjective experience indicates that values over 50 $m^2/s^2$ are associated with supercell convection. Over central Oklahoma an area is shown

with more than 40 percent of the members indicating the potential of at least one supercell thunderstorm valid at 02 UTC 22 April 2008. Indeed, the radar valid at 0142 UTC shows an isolated splitting supercell close to the area where the SSEF indicated the potential of a supercell thunderstorm (Fig. 10). Similarly, other tools have been developed and tested, such as the probability of linear modes (Fig. 11a-c). This series depicts the 24-hour, 26-hour, and 28-hour forecasted probability of a squall line of more than 200 miles in length, valid at 00, 02, and 04 UTC 18 April 2008, respectively. The verifying radar and the impact to aircraft operations around DFW is provided at 01 UTC 18 April 2008 (Fig. 12).

## 3. Summary

The SPC has been building a suite of multi-scale ensemble guidance since 2002. Large scale guidance is primarily based on the NCEP GEFS and is used to determine the forecastability of the synoptic pattern, primarily in the medium range (days 3 to 8). A considerable amount of effort has been invested in the mesoscale environment using the NCEP SREF system. Much of this work is available online at http://www.spc.noaa.gov/exper/sref/, and ongoing development continues in the area of calibrated guidance for high impact phenomena such as tornadoes. New ensemble systems under development and/or evaluation at the SPC and the Hazardous Weather Testbed include the RREF based on time-lagged hourly RUC forecasts, and the SSEF system for ensemble guidance on convective mode and intensity. The RREF is envisioned as a continuously updating probabilistic guidance system for thunderstorms and other high-impact phenomena. The SSEF is designed to provide probabilistic guidance of convective mode. With multiple plausible scenarios of convective mode derived from the SSEF, the explicit prediction of high-impact phenomena such as supercells, squall lines, lightning, excessive rainfall, etc. that impact aviation and public safety are directly mined.

## 4. References

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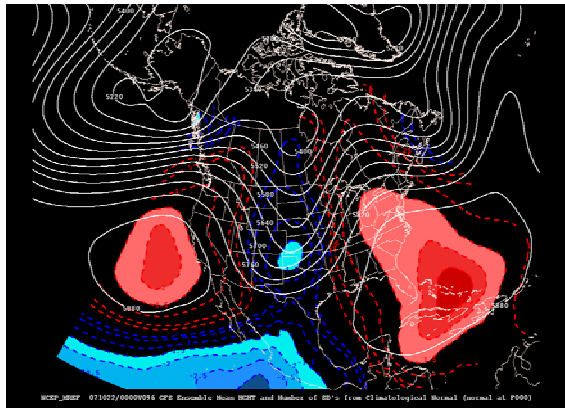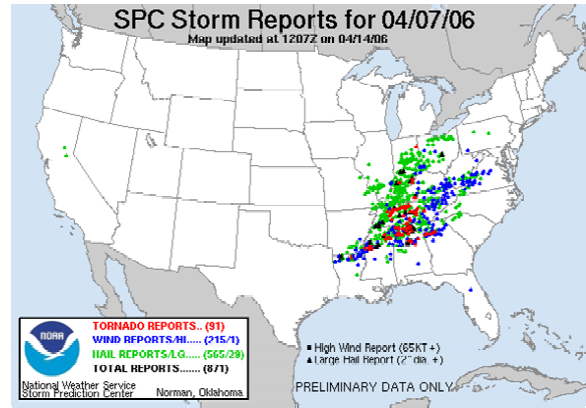
## 5. Figures
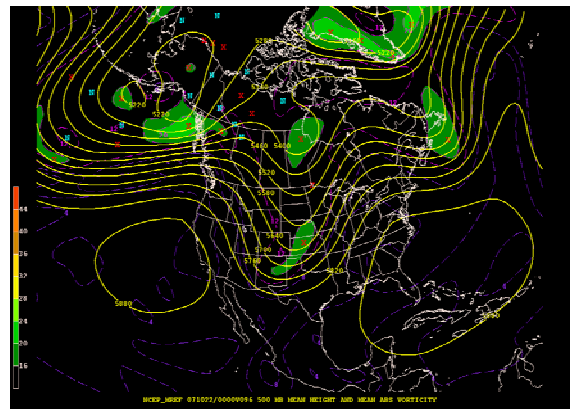


**Figure 1.** The 96-hour GEFS forecast of ensemble mean geopotential height and vorticity valid at 00 UTC 22 October 2007.
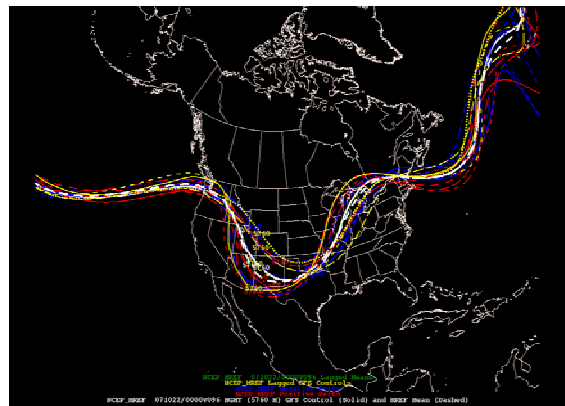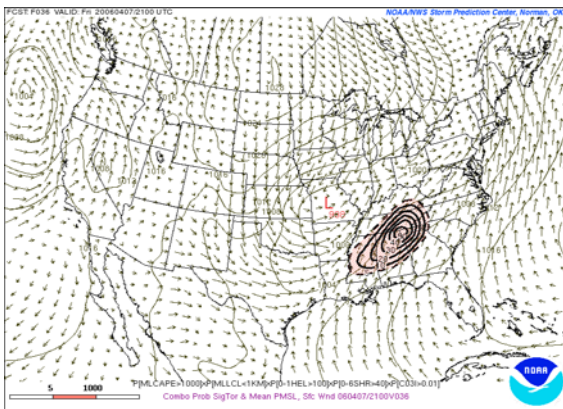


**Figure 2.** Date and time as in Fig. 1, except the single contour value (or spaghetti) of 5760 meters.

**Figure 3.** Date and time as in Fig. 1, except the ensemble mean height overlaid on the departure from normal (in units of standard deviation).



**Figure 6.** The storm reports as received by the SPC for the period 12 UTC 7 April to 12 UTC 8 April 2006.



**Figure 4.** The product of five SREF probabilities indicative of environments favorable for significant tornadoes as described in the text (shaded). The SREF forecast hour is F036 valid at 21 UTC 07 April 2006. Mean PMSL and 2 meter wind vectors also plotted.
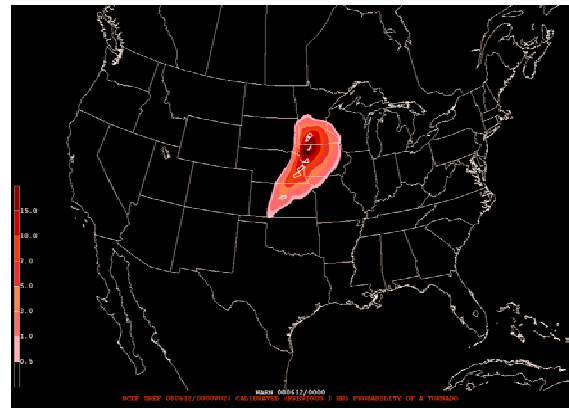


**Figure 7.** The 27 hour SREF calibrated probability of ≥ 1 tornado for the period 21 UTC 11 June to 00 UTC 12 June 2008. Tornado warnings valid at 00 UTC shown as white polygons.
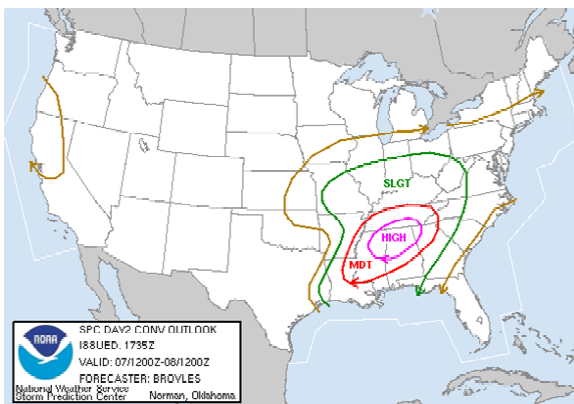


**Figure 5.** The SPC Day 2 Severe Weather Outlook issued at 1735 UTC 06 April 2006 for the period 12 UTC 7 April to 12 UTC 8 April 2006.



**Figure 8.** The 9 hour RREF calibrated probability of a thunderstorm valid 00 UTC to 01 UTC 19 Oct 2008. The CG lightning that occurred is indicated by the yellow symbol over northern Idaho.
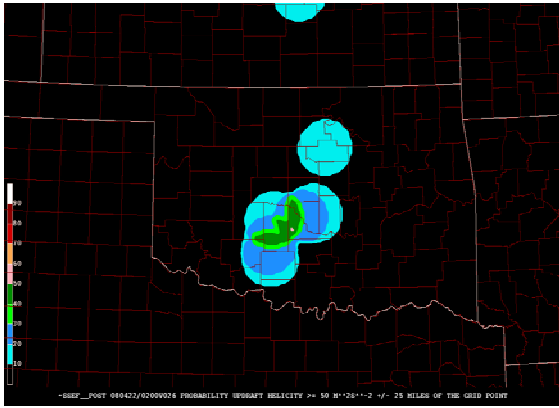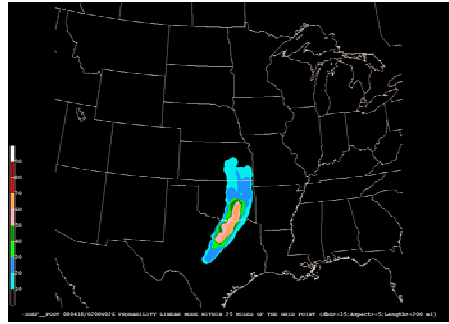
**Figure 9.** The 26 hour SSEF forecast of updraft helicity $\geq 50$ m$^2$/s$^2$ valid at 02 UTC 22 April 2008.
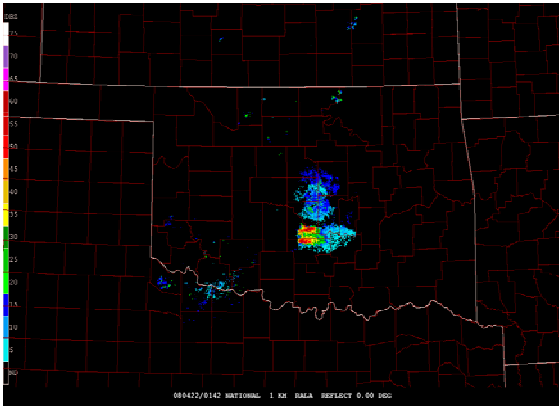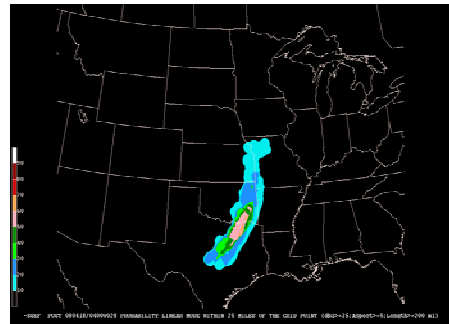


**Figure 10.** The 1 km AGL observed radar reflectivity valid at 0142 UTC 22 April 2008. An isolated splitting supercell is located over central Oklahoma.
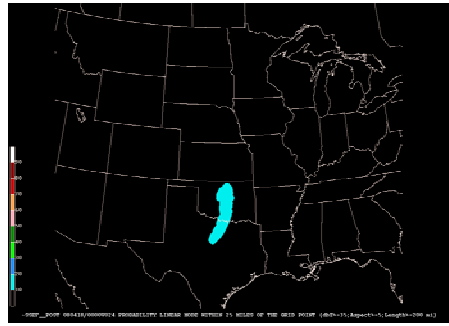


(a)

(b)

(c)

**Figure 11.** The (a) 24, (b) 26, and (c) 28 hour SSEF forecasted probability of a convective squall line valid at 00, 02, and 04 UTC 18 April 2008.



**Figure 12.** The observed composite reflectivity and aircraft movement over northern Texas near Dallas-Fort Worth International Airport at 01 UTC 18 April 2008.