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SHORT RANGE AND STORM SCALE ENSEMBLE FORECAST GUIDANCE AND ITS POTENTIAL APPLICATIONS IN AIR TRAFFIC DECISION SUPPORT

David R. Bright*, Jonathan P. Racy, Steven J. Weiss, Russell S. Schneider, and Jason J. Levit
NOAA/NWS/NCEP Storm Prediction Center
Norman, Oklahoma

John J. Huhn and Michelle A. Duquette
MITRE Corporation
Center for Advanced Aviation System Development (CAASD)
McLean, Virginia

Jack S. Kain and Michael C. Coniglio
NOAA/OAR/National Severe Storms Laboratory
Norman, Oklahoma

Ming Xue and Fanyou Kong
CAPS/University of Oklahoma
Norman, Oklahoma

1. Introduction

The mission of the National Weather Service (NWS) Storm Prediction Center (SPC) is to provide forecasts and guidance to the American weather enterprise concerning high-impact, hazardous mesoscale weather across the conterminous United States. This includes, but is not limited to, the following high-impact phenomena: thunderstorms, severe thunderstorms (i.e., thunderstorms producing large hail, damaging wind, and/or tornadoes), excessive convective rainfall, critical fire weather conditions, and short-term forecasts of intense (and often convective) snow, freezing rain, and blizzards.

As a source of guidance to help meet its national mission, the SPC has incorporated ensemble prediction systems into all of its forecast program areas (e.g., Bright et al. 2007). And since almost 90% of all SPC products are for forecast periods three days or less, the National Centers for Environmental Prediction (NCEP) Short Range Ensemble Forecast (SREF; Du et al. 2006) system is particularly well suited to meet the operational demands of the SPC. Specialized post-processing of the SREF is performed to extract information relevant to the SPC mission, including innovative applications toward the convective forecast problem (Bright et al. 2008) and the development of calibrated probabilistic thunderstorm and severe thunderstorm guidance (Bright and Grams 2009; Bright and Wandishin 2006; Bright et al. 2005). Here, calibration infers additional statistical post-processing to provide reliable, unbiased, and skillful probabilistic guidance for the phenomena of interest.

The impact of convection on the aviation industry has been well documented in the technical literature (e.g., Huberdeau and Gentry 2004) as well as in the popular media (e.g., The New York Times, 23 May 2007: "F.A.A. Warns of Increasing Flight Delays"). In general, the SPC does not produce convective forecasts exclusively for aviation decision support. Instead, operational SPC convective products are designed to serve a wide variety of users. These products include both categorical and probabilistic information for broad based decision support, particularly among the NWS Weather Forecast Office (WFO), emergency management, and broadcast media communities. Since 2007, the SPC has been collaborating with the MITRE Corporation's Center for Advanced Aviation System Development (CAASD) to (a) review currently available SPC operational products and how they might be utilized at the FAA's Air Traffic Control System Command Center (ATCSCC) for strategic decision support of traffic flow management (TFM) beyond the 6-hour time frame of the NCEP's Aviation Weather Center (AWC) Collaborative Convective Forecast Product (CCFP; see http://aviationweather.gov/products/ccfp/info for information on the CCFP), and (b) develop and evaluate operational mesoscale and experimental storm-scale ensemble guidance specifically for aviation related strategic planning and decision support beyond 6 hours. This type of research begins to address current challenges within the TFM and weather communities on translating weather forecast information into operational impact on the National Airspace System (NAS). The former is the topic of a companion paper by Huhn et al. (2009), while this paper focuses on ensemble guidance that may be used in TFM strategic planning and decision support. A related project also involves collaborating with the AWC to develop hourly SREF guidance concerning convective initiation and trends for the high-density air traffic routes such as the northeast United States (hereafter Northeast Corridor or NEC for short) as guidance for the CCFP.

**Corresponding author address*: David R. Bright, Storm Prediction Center, 120 David L Boren Blvd, Norman, OK 73072; e-mail: david.bright@noaa.gov

This paper will briefly outline convective ensemble guidance that may be useful in aviation decision support and strategic planning. Section 2 describes mesoscale SREF guidance that has already been developed and is currently available to NCEP forecasters through NWS operational display software and external customers via the World Wide Web (http://www.spc.noaa.gov/exper/sref). Ongoing mesoscale ensemble projects under development for the 2009 convective season (i.e., approximately April through September) are presented in section 3. Section 4 then shows examples of output from an experimental Storm Scale Ensemble Forecast (SSEF) system, which is a high-resolution ensemble system that explicitly predicts convection and thunderstorm updrafts and downdrafts. The activities are summarized in section 5. References and figures are in sections 6 and 7, respectively.

2. Operational Short Range Ensemble Forecast (SREF) Guidance

The SPC SREF is constructed by post-processing all 21 members of the NCEP SREF plus the 3-hour time lagged, operational WRF-NAM (for a total of 22 members) every 6 hours (03, 09, 15, and 21 UTC). Output is available at 3h intervals through 87 hours. The SPC SREF post-processing focuses on diagnostics relevant to the prediction of SPC mission-critical high-impact, mesoscale weather. To illustrate the application of this output for aviation related convective forecasting, the SREF guidance from the 15 UTC run on 10 June 2008 is used. All SREF charts presented in this section are available in real-time on the SPC website at http://www.spc.noaa.gov/exper/sref/.

Figure 1 shows the 9 hour SREF forecast of mean 500 hPa geopotential height, temperature, wind vectors, and isotachs valid at 00 UTC 11 June 2008. A trough is predicted to be exiting the Great Lakes region with a 64 kt mid level jet over eastern Lake Ontario. At the surface, a cold front is expected to extend from low pressure over Quebec through eastern New York, Washington, D.C., to western South Carolina (Fig. 2). Instability should be moderate with the SREF mean most unstable CAPE (MUCAPE; CAPE is an abbreviation for Convective Available Potential Energy) approaching 2000 J/kg around Washington, D.C., and greater than 1000 J/kg across much of the NEC (Fig. 3). The SREF mean 3 hour precipitation forecast indicates a swath of precipitation will be over much of the NEC extending along and behind the frontal boundary to southern Appalachia (Fig. 4). Essentially all of the precipitation produced by the SREF members is convective (separation between the explicit grid resolved and convective implicit precipitation is not shown). The SREF mean fields are consistent and indicate the development of a convective area of precipitation that will impact the NEC late in the day. As to further specifics concerning potential impacts of the convection on aviation, the SREF mean convective cloud tops exceed 45,000 feet AGL in a band along and just ahead of the surface frontal boundary, indicative of thunderstorms that could potentially block aviation routes across the Southeast, Mid Atlantic, and Northeast (Fig. 5). In a probabilistic sense, over 90% of the SREF members predict the convective cloud tops will exceed 37,000 feet AGL (Fig. 6; 37,000 feet AGL was chosen because it is the maximum forecast height used in the CCFP). Note that Fig. 6 is actually a conditional probability, because it is based on the vertical profile of temperature and moisture at each grid point and therefore represents the potential top of a convective cloud should one develop.

The SPC also provides calibrated, post-processed guidance in various program areas. Calibration infers the application of a statistical technique to remove systematic biases such that probabilistic forecasts are now reliable and skillful. Bright et al. (2005) and Bright and Grams (2009) provide information on the SPC SREF thunderstorm calibration technique with detailed verification results that show the forecasts to be both reliable and skillful. The 9 hour SREF calibrated thunderstorm forecast for the three hour period ending at 00 UTC 11 June 2008 shows a 40 percent chance of thunderstorms (as indicated by at least one cloud-to-ground lightning strike within 10 miles of a point) from western New England to northern Washington, D.C., with a 30 to 40 percent extending southwestward to the Gulf Coast (Fig. 7). The actual cloud-to-ground lightning strikes that occurred in the 3-hour window ending at 00 UTC 11 June 2008 are consistent with the SREF thunderstorm guidance, with dense coverage from West Virginia/Virginia northward to the international border (Fig. 8). The calibrated probability of a severe thunderstorm (Bright and Wandishin 2006; probabilities represent the chance of at least one severe thunderstorm within 25 miles of a point, where a severe thunderstorm is defined as surface winds $\geq$ 50 kts, hail $\geq$ 0.75", and/or the occurrence of $\geq$ 1 tornado) is 3 to 9% from Washington, D.C. northward into Canada, with decreasing but non-zero values extending southwestward from Washington, D.C. along and near the surface frontal boundary to the Gulf coast (Fig. 9). Actual severe weather reports for the 3 hour period ending at 00 UTC 11 June 2008 show numerous hail and wind reports (no tornadoes), particularly over western Maine, eastern New York, and eastern Pennsylvania to Washington, D.C., with scattered reports south of Washington, D.C. to western South Carolina (Fig. 10).

As previously shown, the conditional probability of convective cloud tops exceeding 37,000 feet is more than 90 percent along and ahead of the surface cold front including a large swath through aviation routes along the East Coast (Fig. 6). The product of the conditional convective cloud top probability and the calibrated thunderstorm probability forecast should provide an approximation to the total probability of thunderstorm tops exceeding 37,000 feet AGL. This approach shows a 30 to 40 percent chance of thunderstorms with tops in excess of 37,000 feet AGL (within 10 miles of a point; Fig. 11) along the entire frontal boundary from western New England to western South Carolina. The result is approximate because the SREF probabilistic forecast of convective cloud tops has not been calibrated and therefore retains the systematic biases of the raw model output. Nevertheless, because the SREF probabilistic thunderstorm guidance is calibrated, a short verification period for the summer of 2008 indicates the thunderstorm top result is largely reliable (Fig. 12).

3. Short Range Ensemble Forecast (SREF) Guidance Under Development for 2009

The SPC is in the process of testing and evaluating SREF-based convective guidance specifically for aviation decision support and strategic planning. Current and ongoing research efforts are focusing on increasing the temporal resolution of SREF guidance across the NAS for the upcoming convective season (March through October, 2009), with specialized calibrated impact guidance being explored that is inclusive of thunderstorms, thunderstorm cloud tops, and historical air traffic flow. As mentioned in the introduction, the production of hourly SREF-based guidance is being done in conjunction with the AWC to help support CCFP activities, and in collaboration with MITRE CAASD to explore guidance that may be useful in TFM strategic planning beyond the six hour time frame of the present CCFP.

The SPC has a long history of convective forecasting and is widely recognized for its expertise in thunderstorm and severe thunderstorm forecasting, but its knowledge of TFM issues over the U.S. is relatively limited. To address this shortcoming and increase awareness of the relationship between convection and TFM, an hourly composite of commercial and general aviation air traffic was constructed so SPC meteorologists could better visualize and understand "normal" aviation traffic conditions. MITRE CAASD furnished the data for the compositing by providing a snapshot of aircraft positions at the top of each hour of the case study date. The aircraft position data were gridded to construct the composites and to provide position information for exploration into potential SREF calibration. The composite of all air traffic at or above 25,000 AGL at 00 UTC on the NOAA/NWS grid 215 (Lambert Conformal with 20 km grid length; see http://www.nco.ncep.noaa.gov/pmb/docs/on388/tableb.html for further grid information) clearly shows the main aviation corridors across the nation, as well as the congestion that exists from the Chicago area to New York (Fig. 13). The exact same plot on the SREF output grid (NOAA/NWS grid 212; Lambert Conformal with 40 km grid length) tells the same story albeit a bit more blurred (Fig. 14). It is this latter 40 km grid that is currently used to produce calibrated SREF guidance.

Figures 13 and 14 have been normalized by the number of days in the sample, and therefore represent the percentage of time at least one aircraft $\geq$ 25,000 feet AGL is contained within the grid box at 00 UTC. One of the most congested areas is, for example, northeast West Virginia where over 85 percent of the time an aircraft was located inside the 40 km grid box (Fig. 14). A one-point correlation map that statistically correlates all gridded 00 UTC aircraft position data to the 09 UTC SREF 15 hour calibrated thunderstorm forecasts (from 2005 through 2008 valid at 00 UTC) over northeast West Virginia is shown in Fig. 15. The chart indicates that the SREF 15 hour prediction of thunderstorms over northeast West Virginia is weakly, negatively correlated to air traffic from just west of New York City to just west of Washington, D.C. (Pearson ordinary correlation coefficient between -0.3 and -0.4), and weakly-to-moderately, positively correlated over the Atlantic and southern Canadian routes (correlation 0.3 to 0.5). Although no significance testing has yet been performed, it appears from this simple exercise that the SREF thunderstorm guidance alone may be useful for TFM guidance purposes; the planned inclusion of additional predictors (e.g., thunderstorm tops, contiguous areas, etc.) will likely enhance the relationship.

Another first-step approach at convective weather impact guidance for aviation is to assume the composited location of aircraft above 25,000 feet AGL (i.e., the snapshot probability of at least one aircraft $\geq$ 25,000 feet, Fig. 14) and the calibrated probability of a thunderstorm (Fig. 7) are independent. The product of the two should therefore represent a first-order proxy for the gridded probability of en route aircraft encountering thunderstorms (Fig. 16). Using this approach and returning to our case study, Fig. 16 indicates that at 00 UTC 11 June 2008 the most likely area for en route TFM issues due to thunderstorms is eastern Pennsylvania where the probabilities exceed 30 percent, and over southwest Virginia/eastern Tennessee and southeastern Georgia. In fact, the SREF guidance may be useful for extended strategic planning, as the 18 hour forecast from the 03 UTC 10 June 2008 SREF (i.e., guidance available the previous evening and valid at 21 UTC 10 June 2008) shows the potential for substantial en route TFM issues due to thunderstorms through the heart of the NEC (Fig. 17). The 6-hour CCFP valid at this time but issued nearly 12 hours later at 15 UTC highlights much the same area (Fig. 18); the SREF guidance may have provided earlier indicators and increased confidence of a high-impact event. Similarly, for flights below 10,000 feet AGL (historical composite plot not shown), the juxtaposition of aircraft and thunderstorm potential is maximum from the Washington, D.C., area to the New York City area (probabilities around 30%), and across major airports in Texas and the Southeast (e.g., Orlando, Atlanta, Dallas-Fort Worth, Houston; Fig. 19).

4. Experimental Storm Scale Ensemble Forecast (SSEF) Guidance and the NOAA Hazardous Weather Testbed

The NOAA Hazardous Weather Testbed (HWT) Spring Experiment is highly collaborative activity organized annually by the Storm Prediction Center (SPC) and National Severe Storms Laboratory (NSSL). Its objective is to bring together numerical model developers, research scientists, operational forecasters, and university faculty and students to accelerate the transfer of cutting edge research and advances in forecasting technology to NWS and SPC operations. See Kain et al. (2003a; 2003b) for more information about the Spring Experiment. Since 2007, the Spring Experiment has largely focused on the development and evaluation of a 10-member WRF Storm Scale Ensemble Forecast (SSEF) system with grid spacing of 4 km. The ensemble contains a diversity of initial condition and model physics perturbations. For potential operational forecasting applications, the SSEF is designed to provide explicit probabilistic guidance on high impact convective weather events by quantifying aspects of uncertainty and offering insights about a possible range of solutions. See Xue et al. (2007, 2008) and Kong et al. (2007, 2008) for more SSEF information and initial SSEF verification results, and the 2008 HWT Spring Experiment Operations Plan for details on the real-time experiment activities (http://hwt.nssl.noaa.gov/Spring_2008/opsplan/Spring_Experiment_2008_ops_plan_v6_6May.pdf).

The prediction of convective-scale hazardous weather is very important from both meteorological and public service/societal impact perspectives. Accurate prediction of such weather continues to be a major challenge. At 4 km grid spacing, clouds and storm systems are explicitly resolved (albeit somewhat coarse and ideally even higher-resolution is preferred). As a result, more detailed storm-scale information, both in deterministic and probabilistic formats, can be extracted from the high-resolution SSEF. Particularly important is the explicit storm morphology that can include updraft strength, downdraft strength, mesocyclones, cloud top and base height, gaps in linear segments, individual storm cell tracks, in-cloud hydrometeor type, QPF, turbulence, etc. Parameters such as these from the SSEF can be viewed as a collection of deterministic forecasts encompassing a range of possible outcomes or as a statistical ensemble yielding probabilistic forecasts that elucidate uncertainty associated with localized but extremely significant high-impact events. The application of various statistical techniques can further refine the likelihood of an event through probabilistic calibration, spatial and/or temporal band-pass filtering, and other techniques designed to isolate information specific to the hazard of interest. The explicit prediction of storm-scale parameters in a high-resolution ensemble has shown the potential for immediate societal benefit. This is accomplished through decision support designed specifically for localized yet high-impact weather affecting many components of public safety and commerce, including aviation. The potential benefits directly relevant to aviation from the SSEF include but are not limited to: visibility/ceiling, low cloud coverage, cloud base and tops, gaps in convective clouds, low level wind shear, downbursts, icing probability (super-cooled water content), fog and low cloud probability, clear air turbulence, thunderstorms, and severe thunderstorms. Unfortunately, the high computational cost to run the SSEF in real-time operations is probably still five to ten years away. [But the acquisition of computing resources through a Center for Analysis and Prediction of Storms at the University of Oklahoma (CAPS/OU) grant, has resulted in experimental SSEF output to be available for 30 to 35 days in each of the springs of 2007, 2008, and 2009.] The following examples illustrate three straightforward aviation relevant applications of the 2008 experimental SSEF.

The calculation of *updraft helicity* (UH; UH is the vertical component of the scalar product of the velocity and vorticity vectors integrated vertically at each grid point between two and five kilometers AGL) for each member of the SSEF is used to predict explicitly the probability of supercell thunderstorms (i.e., supercells are a class of thunderstorms with deep, persistently rotating updrafts that are commonly associated with severe convective weather and most tornadoes). Experience in the HWT Spring Experiment suggests that at the 4 km grid length, SSEF values of UH $\geq$ 50 m^2s^{-2} correspond reasonably well to real-world supercell thunderstorms. The 26 hour SSEF UH forecast from the 00 UTC 21 April 2008 SSEF (valid at 02 UTC 22 April) indicates a 40 to 50 percent probability of a supercell within 25 miles of a point over central Oklahoma (Fig. 20). Elsewhere, one member (i.e., 10 percent probability) of the SSEF predicted a supercell over north central Oklahoma and over central Kansas; otherwise, the remainder of the domain (which covers the eastern 3/4 CONUS) had no supercells predicted. The verifying radar analysis at 0142 UTC 22 April 2008 does indeed show an isolated supercell over central Oklahoma (Fig 21; the reflectivity shows a splitting thunderstorm cell just south of Norman, Oklahoma). This storm went on to produce large hail in excess of two inches. The SSEF provided almost remarkable guidance concerning the potential of isolated supercells with approximately one day of lead time.

Another SSEF algorithm being explored in the HWT is the detection of convective line segments or squall lines. The algorithm is designed to detect convective lines (straight or curved) that meet the following conditions: (a) a contiguous area of 1 km AGL reflectivity $\geq$ 35 dbZ, with (b) a total length along the line $\geq$ 200 miles (other lengths are also being evaluated but are not shown), and (c) a length to width aspect ratio $\geq$ 5. Because the grid spacing is so fine, as in the UH example in Fig. 20, the probabilistic guidance is expanded spatially to show the probability of a squall line within 25 miles of a point. Fig. 22 shows the 26 hour forecast from the 00 UTC 17 April 2008 SSEF (valid at 02 UTC 18 April). In this case, the forecast probability of a squall line meeting the conditions specified above exceeds 60 percent at 02 UTC, which is up from only 10 percent at 00 UTC (figure not shown). The impact of a squall line on aviation has the potential to cause large disruptions within the NAS. However, the potential usefulness of guidance for such a phenomenon is shown in Fig. 22. The squall line that existed at 01 UTC presented an almost impenetrable wall to air traffic just west of Dallas-Forth Worth terminal area (Fig. 23).

The final example of potential SSEF utility to aviation related convective hazards is based on the production of synthetic severe weather reports called proxy synthetic indicators (PSI). These PSI are used to infer a simulated severe weather report for each member of the SSEF. The PSI during the 2008 HWT experiment were defined as: UH $\geq$ 75 m^2/s^2, squall lines $\geq$ 100 miles with convective lowest model level winds $\geq$ 30 kts, or lowest model level winds $\geq$ 50 kts. If any of these conditions were met for any member, then the grid point was flagged as containing a PSI. (It should be mentioned that this approach is preliminary in nature, and additional development and statistical testing is being conducted to provide more robust PSI parameters.) A random resampling technique was then used to thin the observations (since all ten members of the ensemble contributed to the PSI count), and a Gaussian kernel density estimation (Brooks et al. 1998) was used to convert the resampled reports into a probabilistic forecast. Figure 24 shows all PSIs (prior to thinning) along with the final SSEF probabilistic forecast from the 00 UTC 30 May 2008 SSEF valid for the eight-hour period between 22 UTC 30 May and 06 UTC 31 May. The anecdotal potential of the approach is evident in Fig. 25, which again shows the final probabilistic SSEF forecast and all actual reports of severe weather that occurred during the eight hour forecast period. A similar PSI-type approach could be expanded to address specific aviation hazards.

5. Summary

Ensemble forecast guidance from the SPC post-processing of the SREF has been used as guidance for convective forecasting, and is currently being expanded for aviation related applications in order to begin to translate meteorological model data into operational impacts on the NAS. These applications can possibly be utilized as supplementary weather information for TFM beyond 6hrs due to a large number of transcontinental and international flights operating today. With further research, it is believed that these applications could increase the lead-time for air traffic managers to assess NAS capacity impacts due to convective weather and thus improving strategic decision making efficiency. Aviation enhancements to the SPC SREF for 2009 specifically include hourly calibrated SREF thunderstorm guidance and the development of additional calibrated impact guidance for the NAS. Based on early work at the NOAA HWT, the application of storm scale ensembles such as the SSEF, which explicitly predict convective storms, show enormous potential for mitigating societal impacts, especially for aviation and TFM strategic planning for the NAS. Through the use of case studies and future analysis, these applications have the potential to allow Traffic Flow Managers to take a systemic approach to strategically plan routing structures for the NAS well beyond the current 6 hour lead time, potentially minimizing the use of broad based traffic management initiatives on days with synoptic scale convective outbreaks forecast. However, the high computational cost means the real-time, operational production of such high-resolution ensemble systems remains five to tens years away.

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7. FIGURES

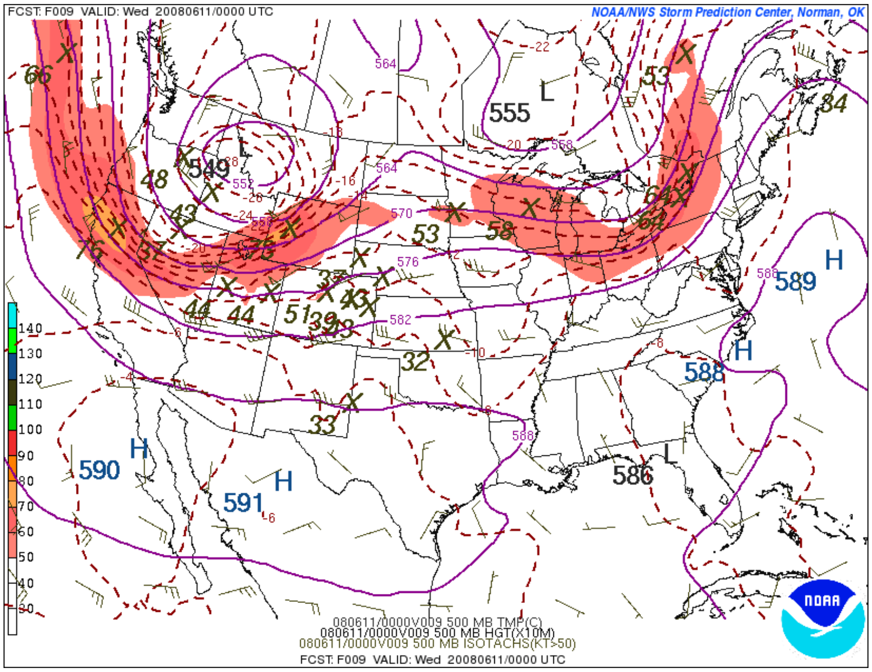

FIG. 1. The 9 hour SREF forecast of mean 500 hPa geopotential height (solid), temperature (dashed), wind vectors, and isotachs (shaded). The initial SREF time is 15 UTC 10 June 2008 and the forecast is valid at 00 UTC 11 June.

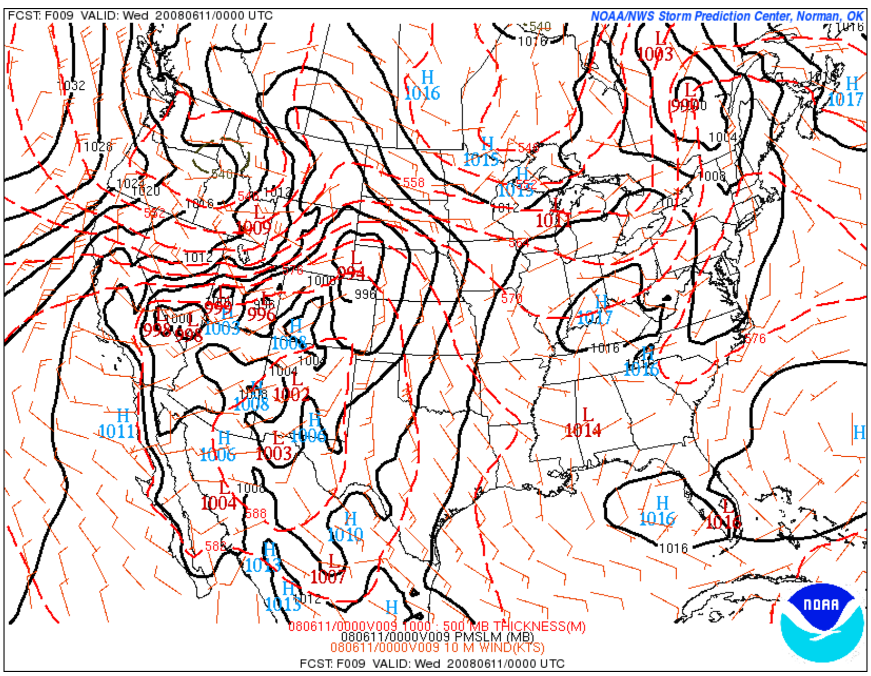

FIG. 2. SREF forecast as in Fig. 1, except showing the mean sea level pressure (solid), 1000-500 hPa thickness (dashed), and 10 meter winds.

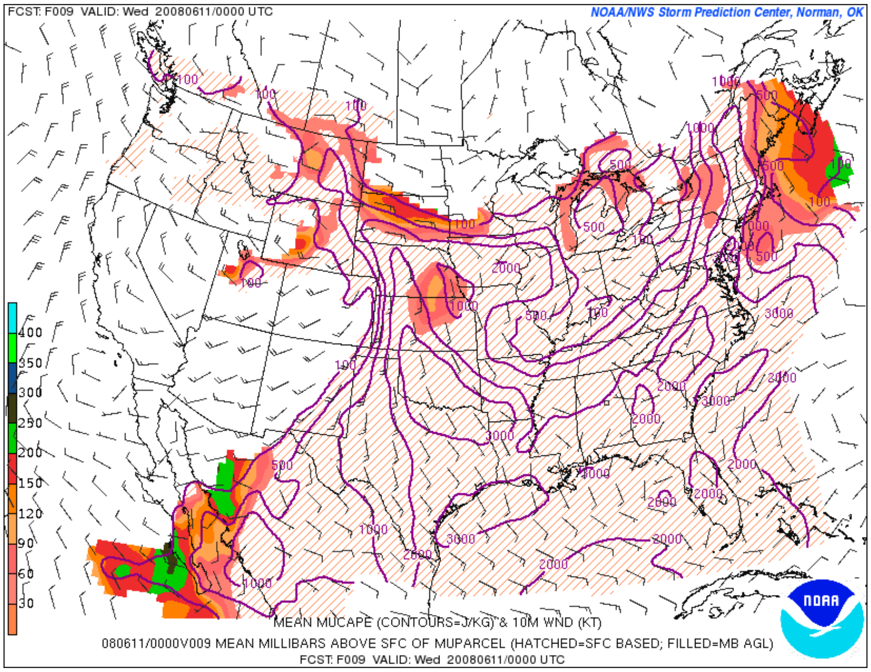

FIG. 3. SREF forecast as in Fig. 1, except showing the mean most unstable CAPE (MUCAPE; solid) and the mean most unstable lifted parcel level (MULPL; shaded and hatched). Hatched MULPL indicates the mean most unstable parcel is located within 30 hPa of the surface.

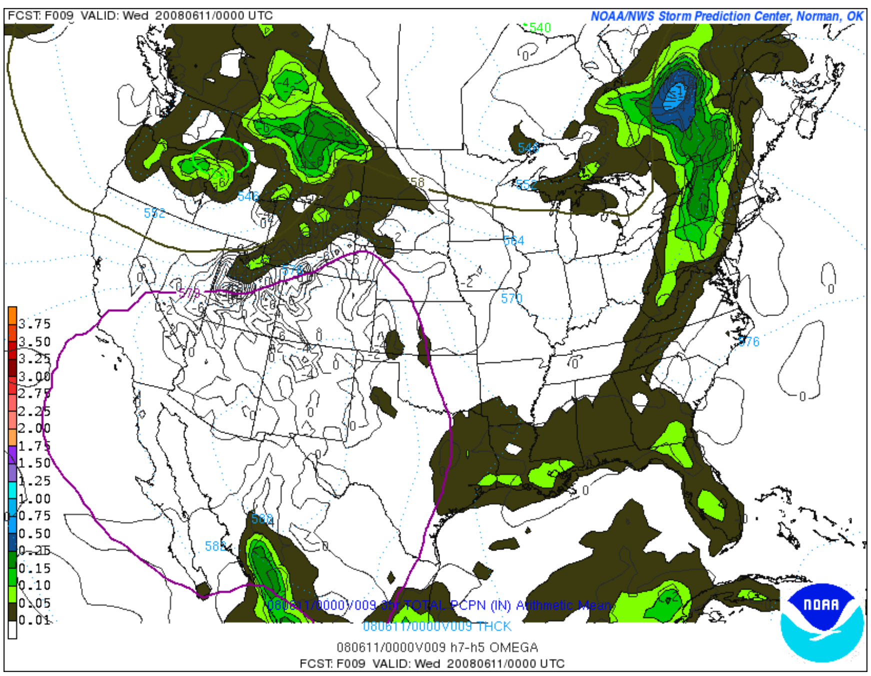

FIG. 4. SREF forecast as in Fig. 1, except showing the mean 3 hour accumulated precipitation (shaded), the mean thickness (thick solid and dotted lines), and the mean upward vertical motion (thin solid).

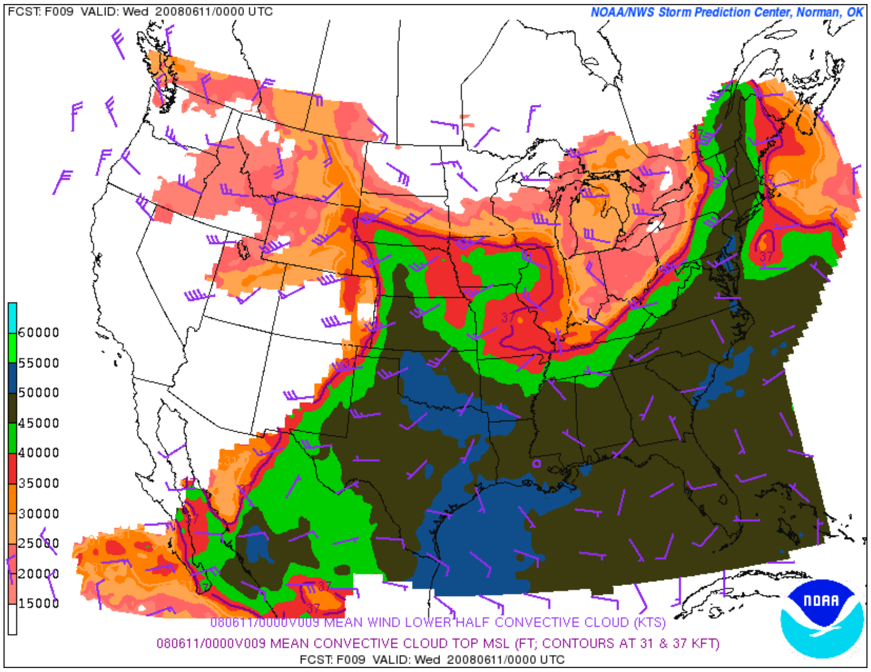

FIG. 5. SREF forecast as in Fig. 1, except for the mean convective cloud top (shaded in feet AGL with contours at 31,000 and 37,000 feet AGL) and the mean wind in the lower half of the convective cloud, based on the vertical profile of temperature and moisture at the grid point (assuming that a convective cloud were to develop).

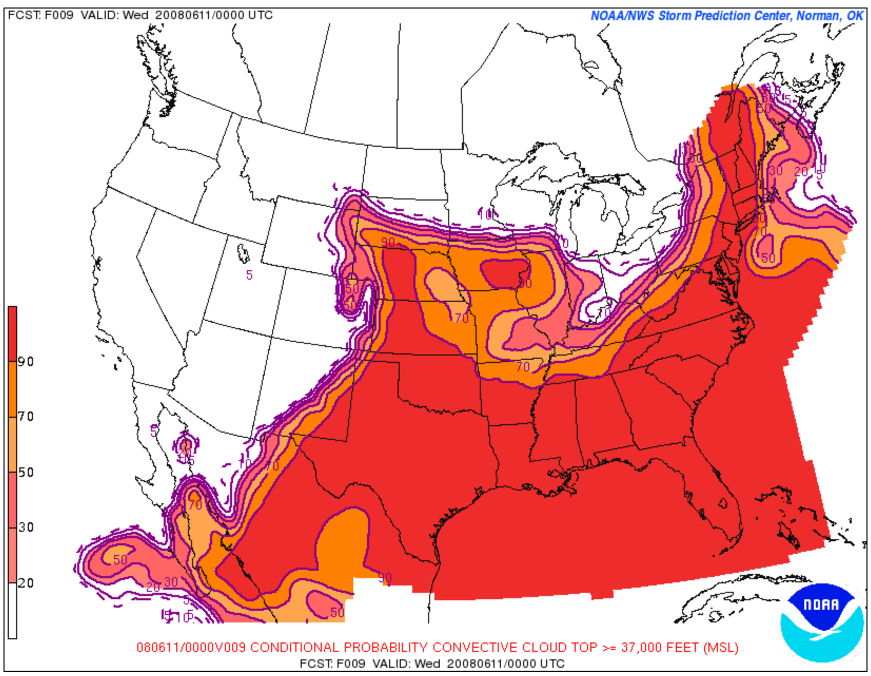

FIG. 6. SREF forecast as in Fig. 1, except for the uncalibrated probability of (conditional) convective cloud tops ≥ 37,000 feet AGL (lines and shaded). The ensemble mean (conditional) convective cloud top at 37,000 feet AGL is also shown (dashed). The forecast is based on the vertical profile of the environment at the grid point, and is therefore conditional on the occurrence of a convective cloud.

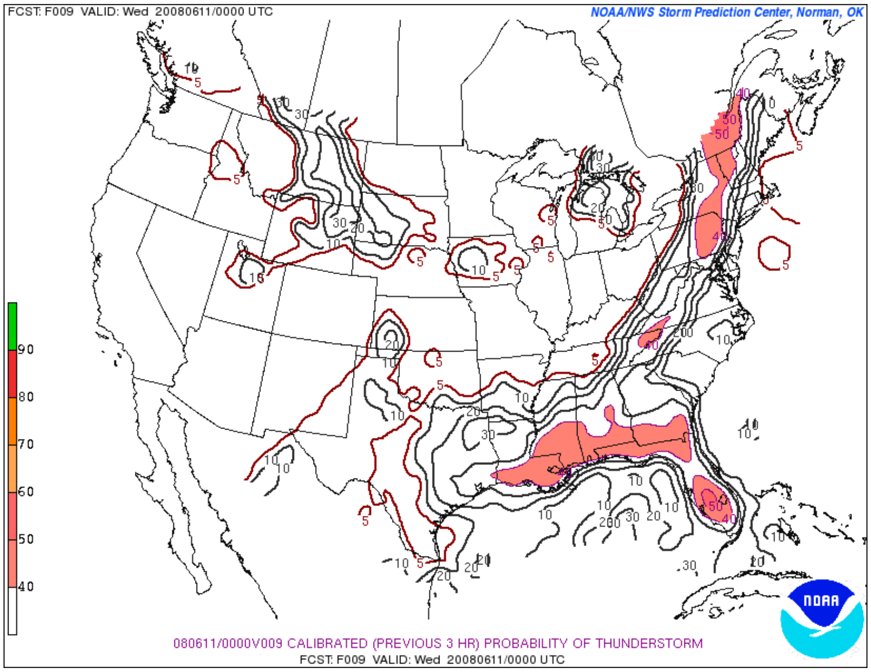

FIG. 7. SREF forecast as in Fig. 1, except for the calibrated probability of a thunderstorm (within 10 miles of a point) for the 3 hour period ending at 00 UTC 11 June 2008.

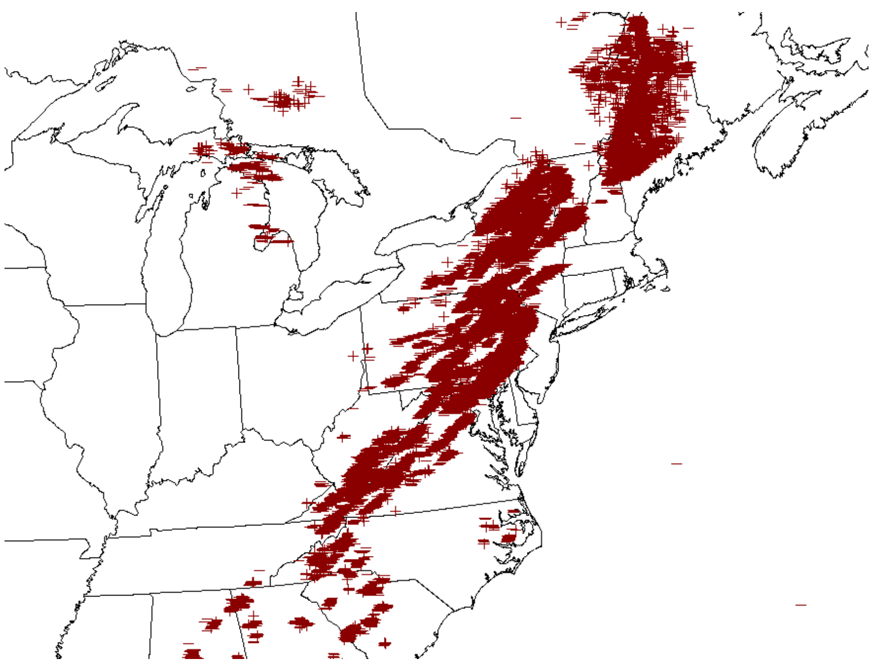

FIG. 8. Cloud-to-ground lightning strikes for the 3-hour period ending at 00 UTC 11 June 2008.

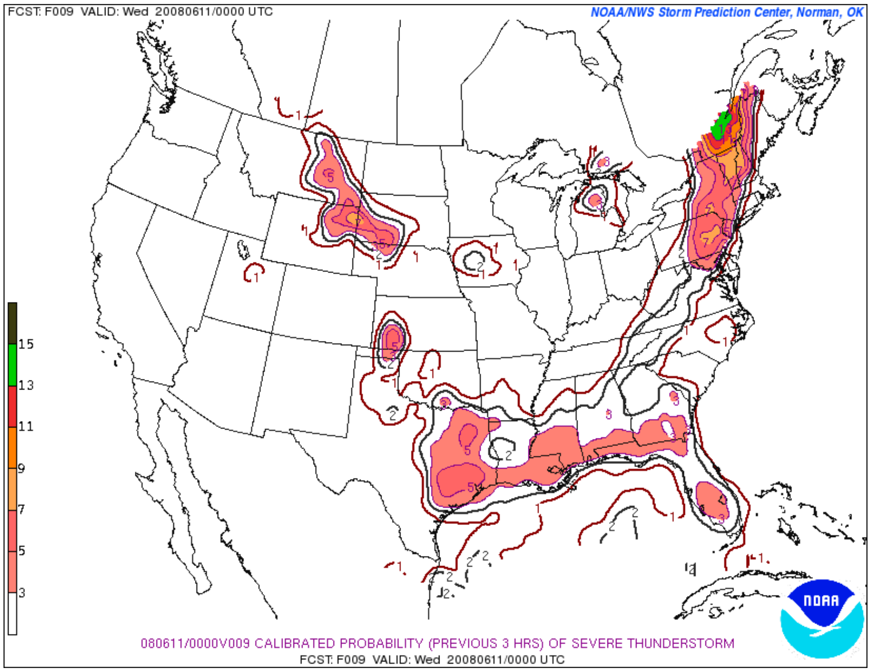

FIG. 9. SREF forecast as in Fig. 1, except for the calibrated probability of a severe thunderstorm (within 25 miles of a point) for the 3 hour period ending at 00 UTC 11 June 2008.

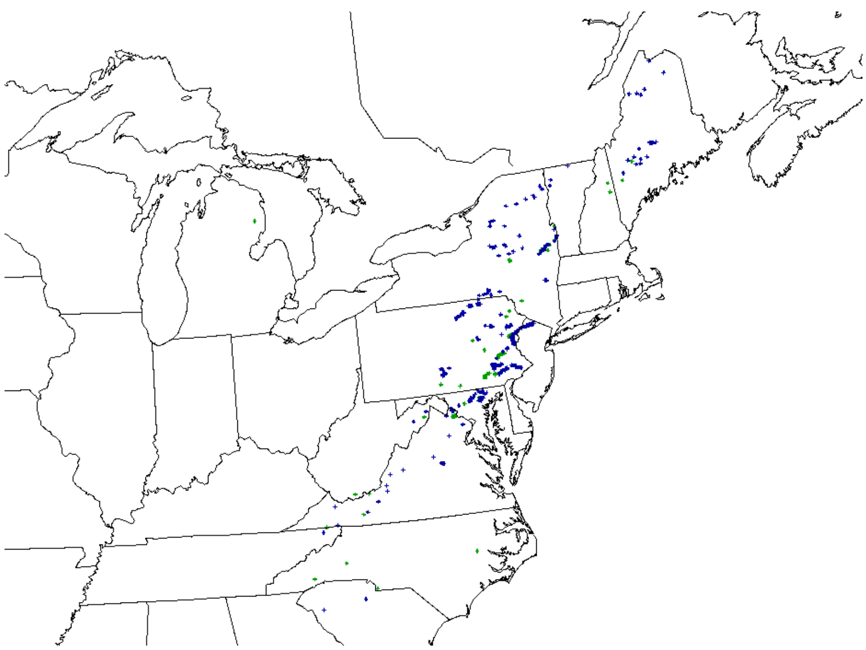

FIG. 10. Actual severe weather reports for the 3-hour period ending at 00 UTC 11 June 2008 (Wind - Blue; Hail - Green; No tornadoes reported).

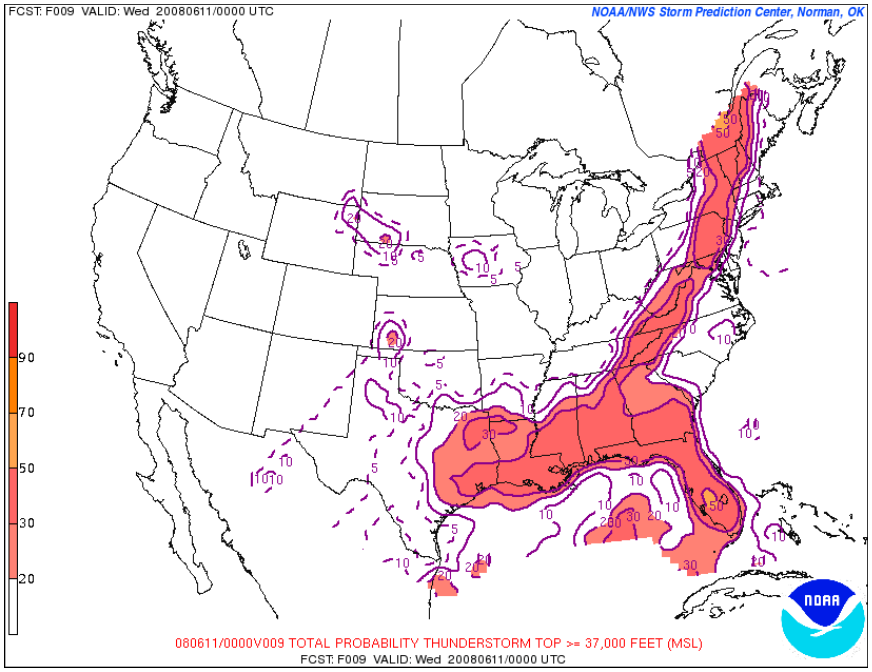

FIG. 11. SREF forecast as in Fig. 1, except showing an approximation of the total probability of thunderstorm cloud tops (within 10 miles of a point) ≥ 37,000 feet AGL. This chart was created by taking the SREF conditional cloud top probability (Fig. 6) and the calibrated thunderstorm probability (Fig. 7).

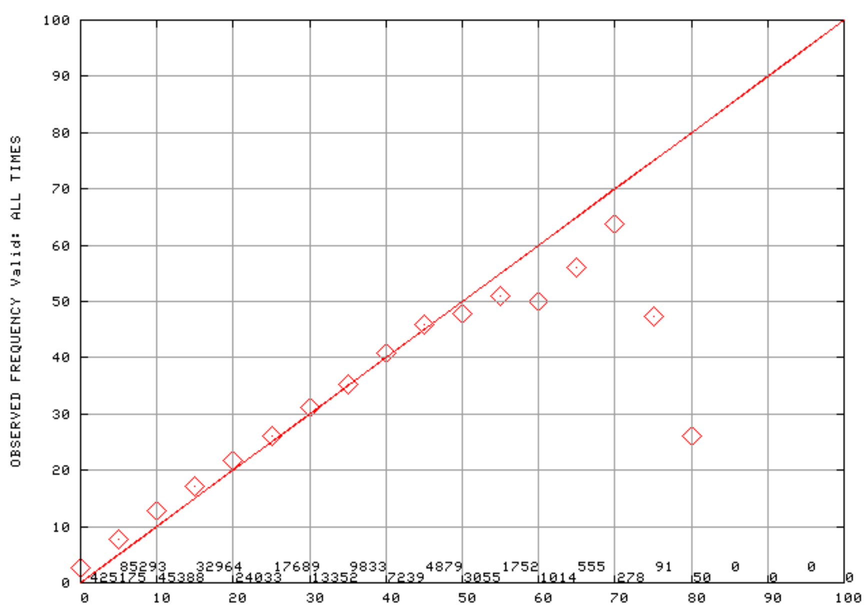

FIG. 12. Reliability diagram of the total convective cloud top forecasts shown in Fig. 11 for the summer of 2008. The solid diagonal line indicates perfect reliability where the forecast probability equals the observed frequency of occurrence. The decrease in reliability for predicted probability values greater than 60% to 70% is largely the result of small sample size. (These results are from the 03 UTC SREF predictions valid at 00 UTC the following day for the CONUS during June, July, and August 2008.)

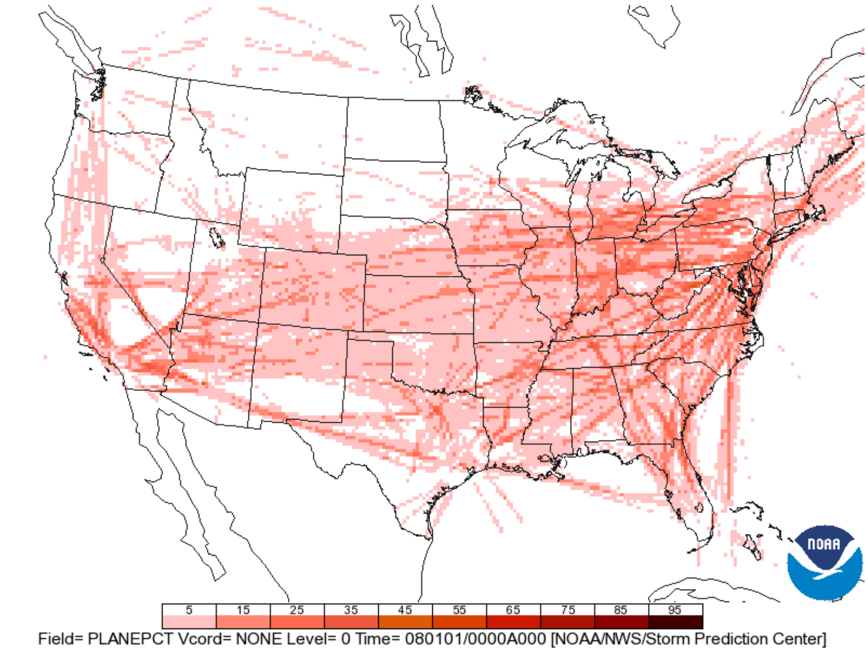

FIG. 13. A gridded composite of air traffic $\geq$ 25,000 feet AGL at 00 UTC . The grid shown is NWS grid 215, which is a Lambert Conformal with 20 km grid spacing.

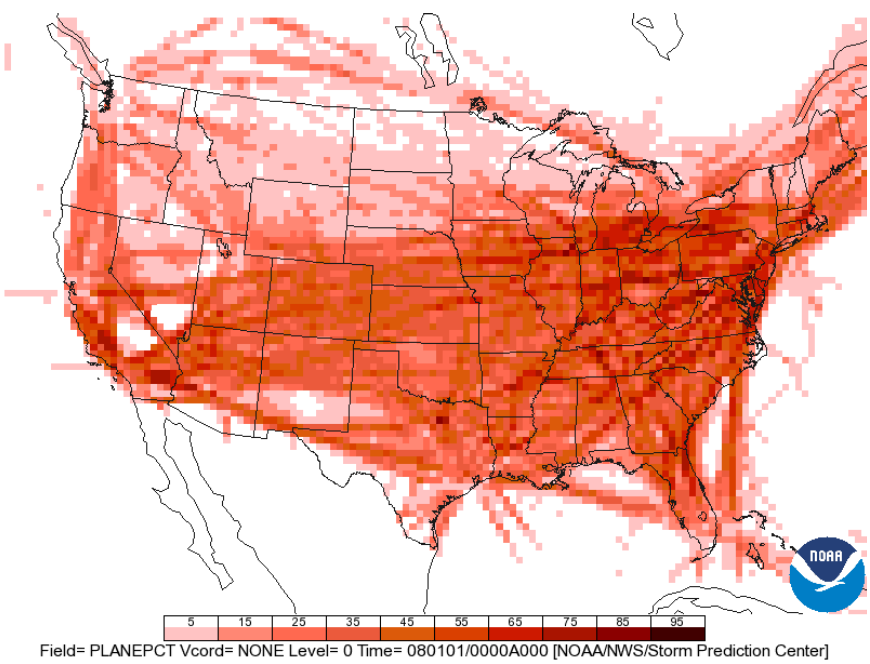

FIG. 14. As in Fig. 13 except on the SREF output grid, which is NWS grid 212 (Lambert Conformal with 40 km grid spacing). Although the 20 km grid (Fig. 13) resolves air routes much more clearly than the 40 km grid shown here, it is this 40 km grid that is currently used in all SPC SREF post-processing.

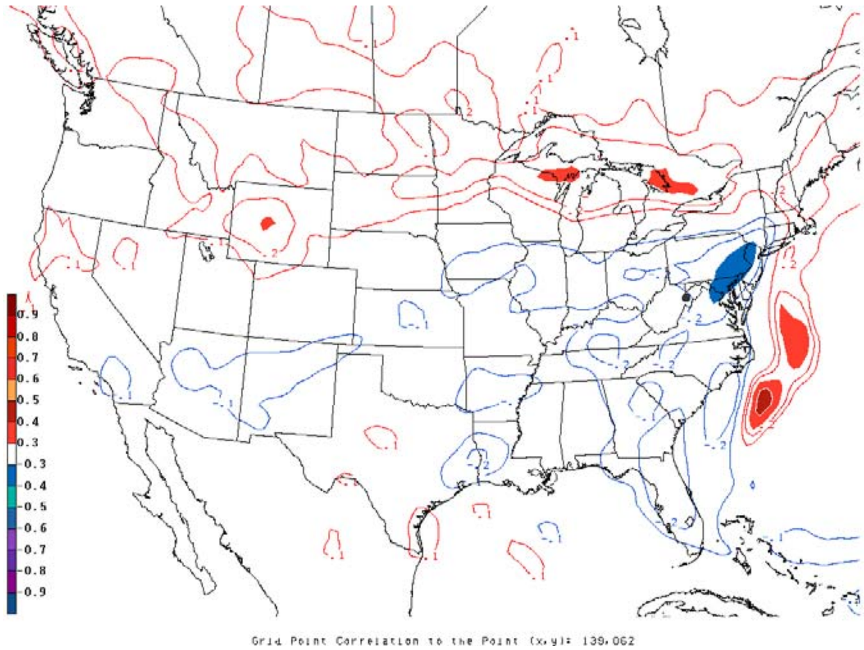

FIG. 15. A one-point Pearson ordinary correlation map for all gridded 00 UTC aircraft position data to the 09 UTC SREF 15-hour calibrated thunderstorm forecast (valid at 00 UTC) at the point shown over northeast West Virginia (large dot). As the SREF 15-hour calibrated thunderstorm forecast probabilities increase at the point in northeast West Virginia, negatively correlated areas (blues) show decreasing air traffic above 25,000 feet AGL in the 40 km grid box, and positively correlated areas show (reds) show increasing air traffic (above 25,000 feet AGL).

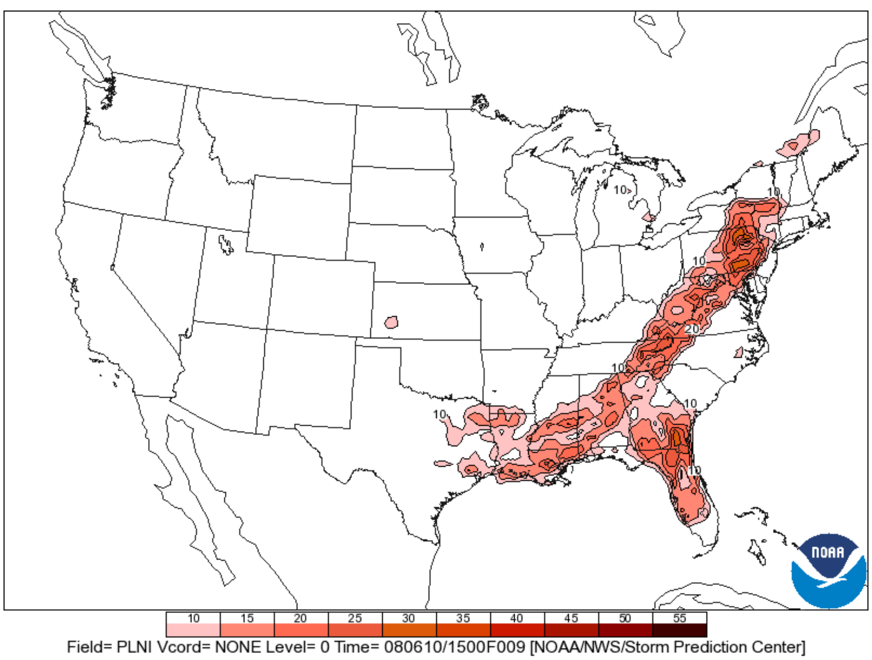

FIG. 16. SREF forecast as in Fig. 1, except the product of the calibrated thunderstorm guidance (Fig. 7) and the composited aircraft position data $\geq$ 25,000 feet AGL at 00 UTC.

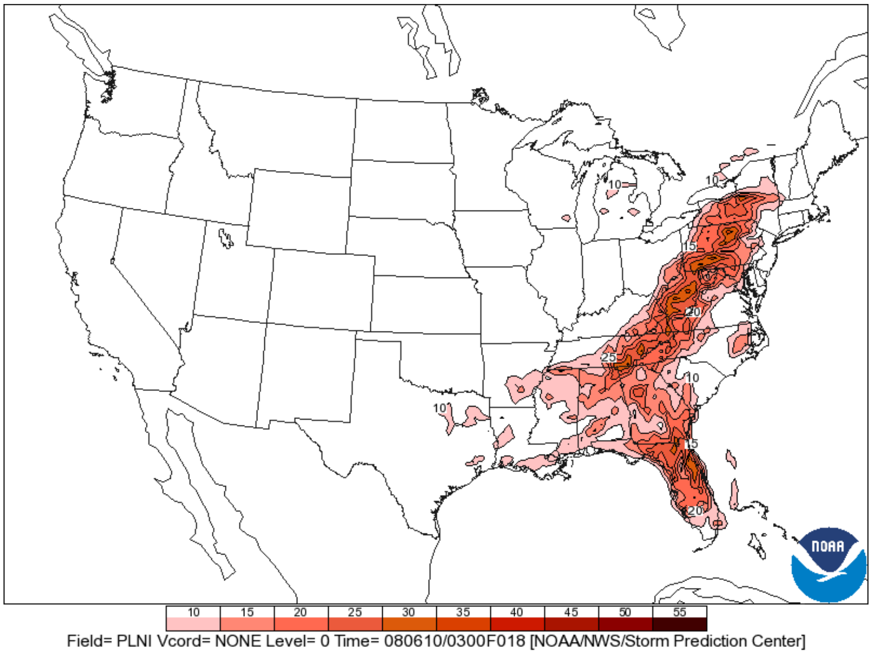

FIG. 17. SREF forecast similar to Fig. 16, except the product of the 18 hour forecast of calibrated thunderstorm guidance from the 03 UTC 10 June 2008 SREF and the composited aircraft position data ≥ 25,000 feet AGL at 21 UTC. Note the similarity of the 18 hour lead-time guidance to the 09 hour guidance (15 UTC SREF) in Fig. 16.

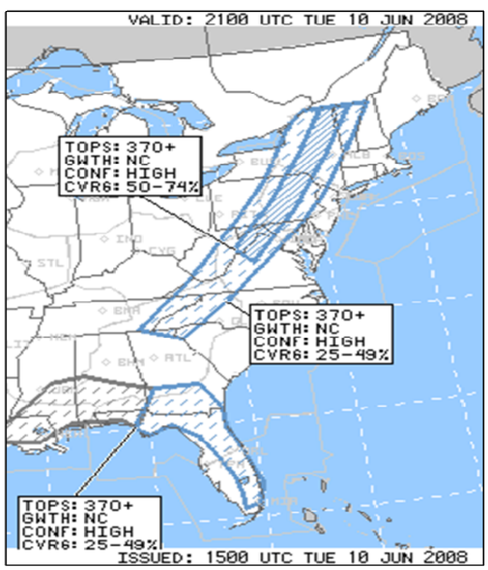

FIG. 18. The 6-hour lead-time CCFP forecast issued at 15 UTC 10 June 2008 and valid at 21 UTC 10 June 2008. The high confidence, medium coverage area from West Virginia/Virginia to northeast New York, and the high confidence, sparse coverage areas from southern Appalachia to the Canadian border and over eastern Florida, are consistent with the enroute impact guidance from the previous evening's 03 UTC SREF (Fig. 17) and the mid-morning 15 UTC SREF (Fig. 16 - valid at 00 UTC).

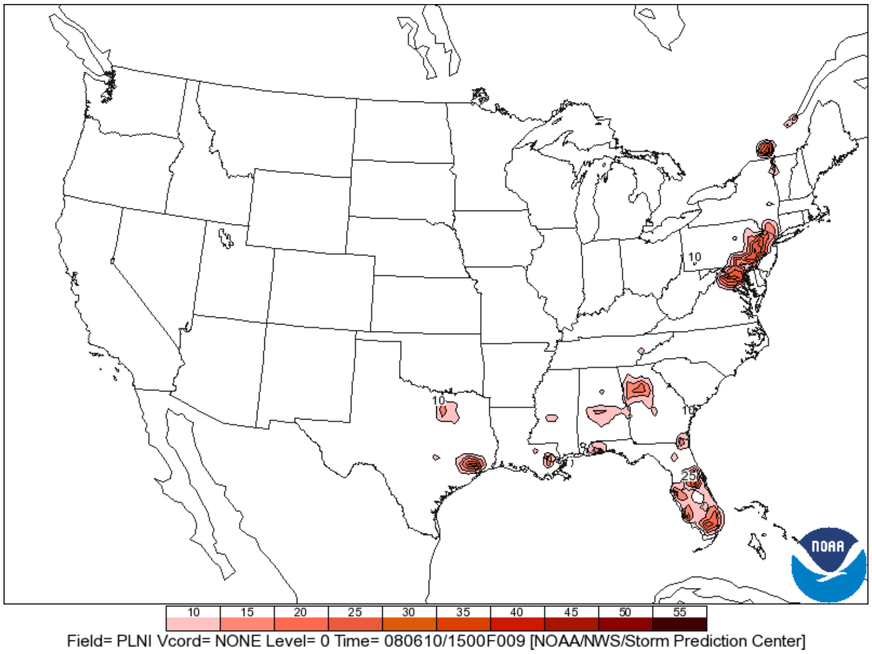

FIG. 19. As in Fig. 16 except using composited aircraft position data ≤ 10,000 feet AGL at 00 UTC.

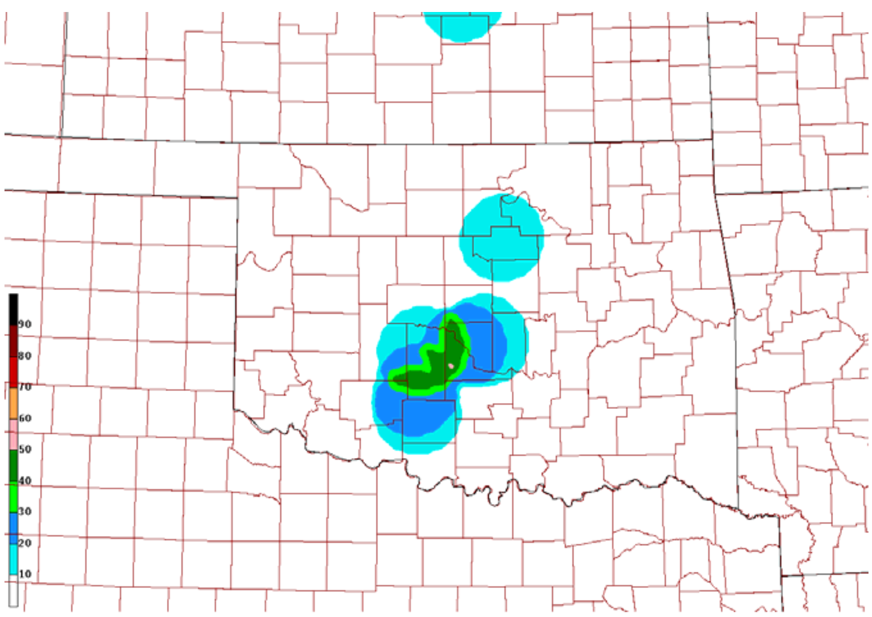

FIG. 20. The 26 hour SSEF forecast of the probability of updraft helicity (UH) ≥ 50 m^2/s^2 within 25 miles of a point. The initial SSEF time is 00 UTC 21 April 2008 and the forecast is valid at 02 UTC 22 April.

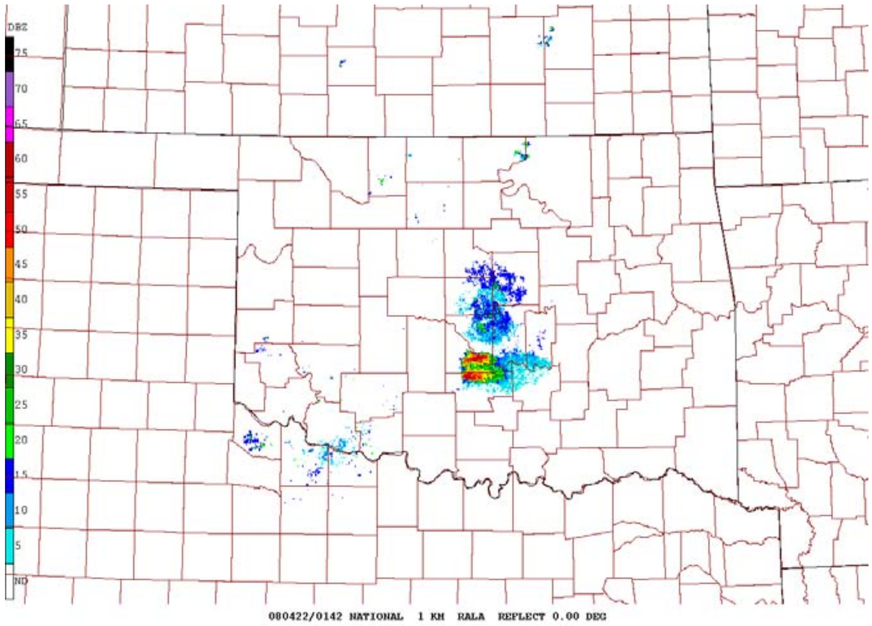

FIG. 21. Radar reflectivity at 0142 UTC 22 April 2008 showing a splitting supercell thunderstorm over central Oklahoma.

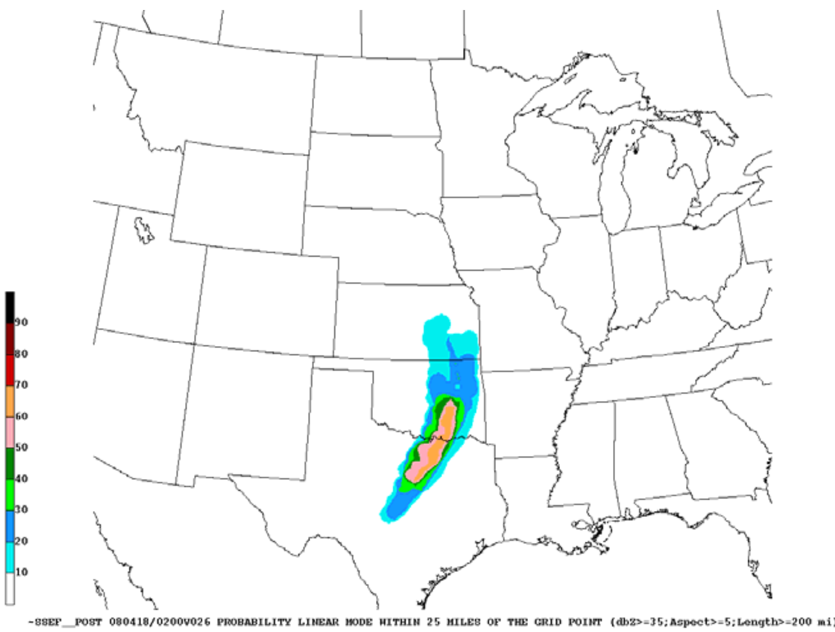

FIG. 22. The 26 hour SSEF forecast of the probability of a squall line (as defined in the text) within 25 miles of a point. The initial SSEF time is 00 UTC 17 April 2008 and the forecast is valid at 02 UTC 18 April.

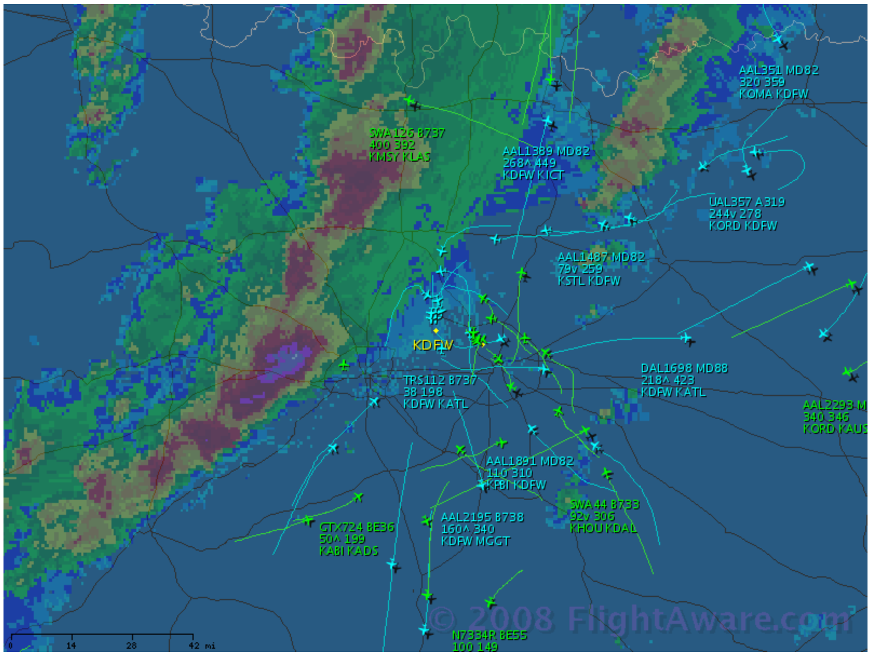

FIG. 23. Radar reflectivity and aircraft at approximately 01 UTC 18 April 2008.

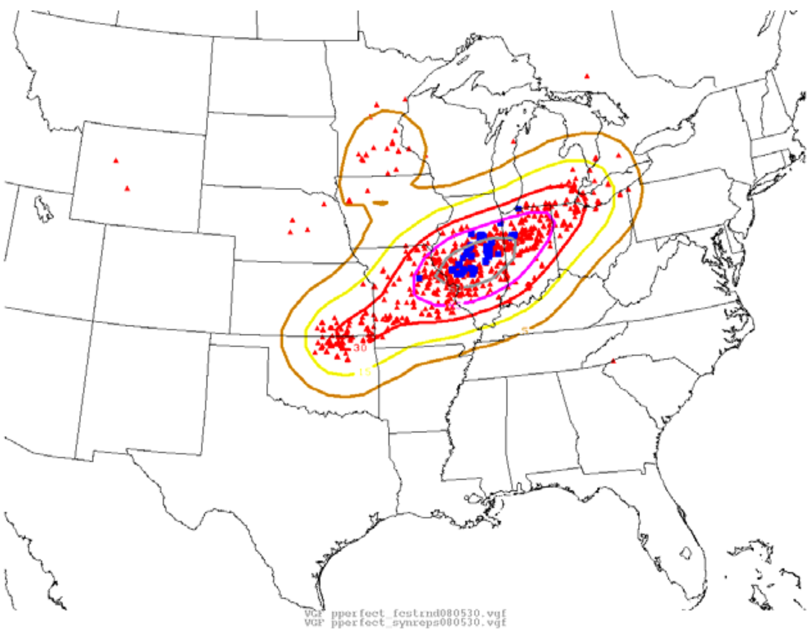

FIG. 24. **All** proxy severe indicators (PSI) from the ten member SSEF (prior to thinning through resampling) along with the final SSEF probabilistic forecast (solid contours; maximum probability 60 percent) from the 00 UTC 30 May 2008 SSEF valid for the eight-hour period between 22 UTC 30 May and 06 UTC 31 May. (Blue circles - Squall Line PSIs; Red triangles - UH PSIs; Blue squares - Lowest model level wind PSIs)

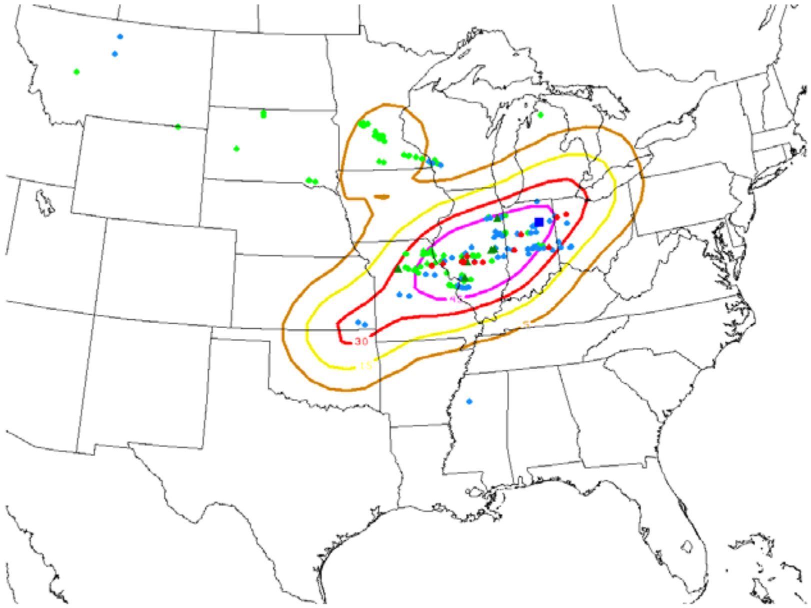

FIG. 25. Contours of the SSEF forecast as in Fig. 24, except with the preliminary NWS severe weather reports overlaid. (Blue - Winds; Green - Hail; Red - Tornadoes)