4.2 DEVELOPMENT OF AN OPERATIONAL STATISTICAL SCHEME TO PREDICT THE LOCATION AND INTENSITY OF LIGHTNING

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1. INTRODUCTION

Often the first, and sometimes only, lightning strike of a thunderstorm can result in personal injury or death. Additionally, intense lightning storms (i.e., those producing extremely large numbers of Cloud-to-Ground (CG) lightning flashes) pose a threat to aviation, electric utilities, and forested areas, as well as many other public and private concerns. Predicting storms with high numbers of flashes or peaks in flash rates are also important because these storms often produce severe weather in the form of hail, damaging wind, tornadoes and flash floods. Although Total Lightning (Cloud Lightning (CL) as well as CG lightning) detection systems are becoming more widespread, only CG lightning is addressed in this paper.

Over the past year, three hourly probability forecasts on a 40 X 40 km grid for one or more CG lightning flashes from a statistical lightning prediction scheme (Bothwell 2002) have been made available to the meteorologists at the Storm Prediction Center (SPC). This scheme employs a set of lightning climatology predictors as well as meteorological predictors in a "perfect prog (*prog*nosis)" approach. Preliminary verification scores have shown this to be a reliable method for predicting one (or more) flashes. This approach has now been expanded to include high numbers of CG flashes (herein defined as 100 or more).

López and Holle (1986) reported CG lightning flash density approximately follows a logarithmic distribution. At the SPC, CG lightning flashes are gridded to match the same 40 X 40 km grid as the probability forecasts. The gridded lightning contours (which are set at 1, 3, 10, 30, 100, 300, 1000, and 3000 CG flashes per given time interval) follow this general logarithmic distribution. This allows intense lightning areas to be quickly and easily identified.

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2. INTENSE LIGHTNING

Previous attempts by researchers to predict the actual number of lightning flashes have generally shown little skill. At the same time, there is a growing realization that intense lightning storms impact both lives and property. Such was the case with thunderstorms that moved through the Tampa/St. Petersburg, Florida, area on 15 July 2000 and produced over 4500 CG flashes per hour (Demetriades 2000).

While Reap (1986) attempted to predict several categories of lightning density, including more significant convection (i.e., 2, 20, …,100 CG flashes per grid box), he found that the overall predictability of high lightning densities was very low. Rather than predict actual numbers of flashes—which has generally been unsuccessful, especially for predicting the largest numbers of flashes—this work predicts the probability of exceeding a given number of flashes. Since there is no precise definition of severe lightning flash rates, this predictive scheme allows any threshold of CG flashes to be predicted. In this case, 100 or more CG flashes were chosen to delineate areas of intense convection. Using the perfect prog approach, the methodology is in place to calculate probabilities for areas of intense or severe lightning (if and when severe lightning may be defined in the future). This technique appears to provide valuable probabilistic information.

3. RELATIONSHIP TO SEVERE WEATHER

While severe weather (i.e., hail, damaging wind, tornado, and/or heavy rain) can and does occur with little or no CG lightning, areas of intense CG lightning flashes are often associated with strong to severe storms. In addition, changes in flash rates and positive CG flashes themselves may be linked to the tornado production in thunderstorms (MacGorman and Rust 1998). Kempf and Krider (2003), as well as others in the past, have found a strong connection between daily rain volumes and corresponding counts of CG lightning. They go on to state that reports of CG lightning can possibly be useful for estimating the locations and amounts of convective rainfall in large, mesoscale convective systems and for forecasting and analyzing the associated flood events. Thus the ability to predict thunderstorms with high numbers of CG flashes can, in part, provide valuable information about the potential for various types of hazardous thunderstorms.

4. METHODOLOGY

The lightning climatologies as well as the predictors and probability forecasts are all computed on a 40 x 40 km grid (shown in Figure 1). At this resolution, each grid box is approximately equal in size to an average county in the central or eastern United States. The lightning climatologies are calculated for each five-day period (pentad) of the year. They are developed using quality control data after the last major upgrade to the National Lightning Detection Network (NLDN) in 1994 and include the eight years from 1995 through 2002. In addition to providing information to the predictive equations, the climatologies are available graphically so meteorologists at the SPC can better understand at what locations and times lightning is more likely to occur. As shown in Figures 2 through 6, these climatologies (discussed in the next section) contain a wealth of information.

The predictors were derived from RUC analyses every three hours from 2001 and 2002. Since lightning is detected over the land and ocean areas immediately adjacent to the contiguous United States, separate predictive equations were developed for every three hours in each of 18 regions shown in Fig. 1. Each of the three hourly equations is valid for a three-month period (e.g., June, July, and August).

Initially, the scheme was used to produce 3-hour forecasts for one or more lightning flashes per 40 x 40 km grid box, in both the short term (0 to 3 hours) using hourly three-dimensional analyses, as well as longer term from model forecasts (out to 60 hours). These predictions were originally designed to provide guidance out to two days for the SPC fire weather forecast products (Bothwell 2000) that highlight the chance for dry thunderstorms (those with a tenth of an inch or less of rain) that start wildfires. The lightning guidance products can also be useful for the short term forecasting of thunderstorm activity.

The perfect prog forecasts are run using input fields from both the RUC and ETA forecast models, in addition to the hourly three-dimensional analysis produced at the SPC. In an evaluation of both warm and cool season sets of forecasts, the perfect prog guidance for one or more lightning flashes using the RUC forecast model exhibited good reliability through the 12 to 15 hour forecast period. Forecasts from different models and even different runs of the same model (such as the RUC forecasts produced every three hours) can be compared on the SPC National AWIPS (N-AWIPS) computer displays. Important differences as well as consistency (between models and model runs) are easily highlighted in this manner.

Currently the forecasts are being implemented operationally for areas of 100 or more flashes per three hours, although probabilities for even higher flash rates can be developed. Section 6 will discuss the accuracy of this method and explore the implications it has for forecasting a range of significant weather events.

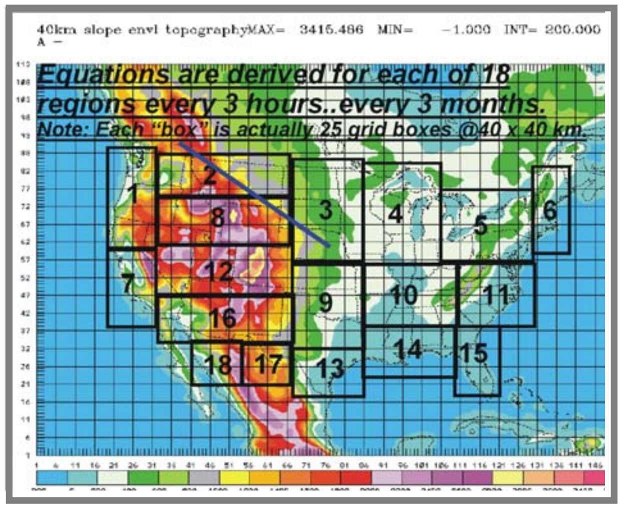

Figure 1. Location of each of the 18 regions that use separate equations. Each of the large grid squares shown above contains 25 of the 40 km grid boxes.

5. LIGHTNING CLIMATOLOGY

Figures 2 through 5 are examples of the three-hour frequency of occurrence (or probability) of CG lightning during the warm season for the pentad centered on 22 July and highlight many important features. It should be noted that probabilities decrease with distance from the outer boundary of the lower 48 states due mainly to decreasing detection efficiency. Figure 2 shows the period from 09 to 12 UTC when thunderstorms would normally be at a minimum, while Fig. 3 is for the time period 12 hours later (21 to 00 UTC) when thunderstorm activity across the United States nears its diurnal maximum. In Fig. 2, convection is nearly absent over the peninsula of Florida (less than 5 percent), yet maximized over the nearby Gulf and Atlantic areas as the land breeze over Florida dominates. Elsewhere, lightning probabilities are near a minimum over the United States, except for an area of 10 to 15 percent over Kansas and parts of the upper Midwest. When compared to the peaks in afternoon activity, it is apparent that the more preferred time for activity in the Midwest is actually during the overnight hours. Twelve hours later, from 21 to 00 UTC, Florida and much of the Southeast experiences a maximum in activity as the sea breeze regime normally is in place during this time period (Fig. 3). Also, the Southwest Monsoon activity reaches a peak this time of year and during the late afternoon, as shown in Fig. 3. High probabilities extend northward from just south of the Arizona and New Mexico border to the Northern Rockies. The area in southwest Montana and northwest Wyoming corresponds well to areas where wildfire starts due to lightning are also high.

Figures 4 and 5 are for the same time periods as Figs. 2 and 3, but are for the probability of 100 or more flashes. Rather than displaying probabilities in five percent bins, probabilities are in single percent bins. In addition to valuable information about the preferred locations of high flash storms, these figures also show how these probabilities change from morning to afternoon.

Instead of probabilities of over 70 percent for one or more flashes, the largest climatological probability for 100 or more flashes is of the order of a few percent at night and only up to 10 percent during the day. Thus, if a forecast probability for 100 or more CG flashes in the late afternoon

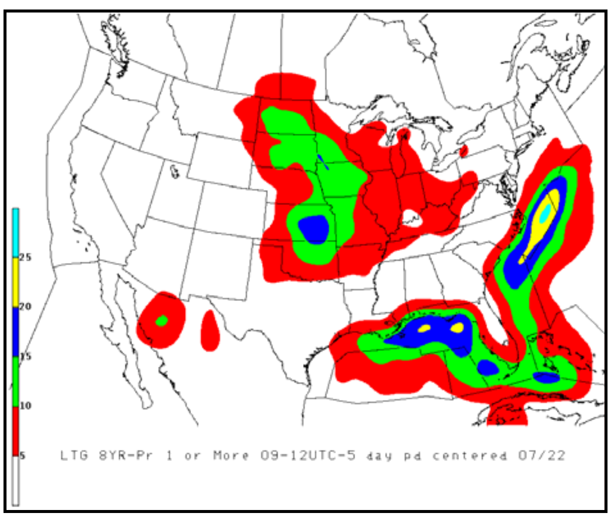

Figure 2. Three hour probabilities of one or more CG flashes—09 to 12 UTC 22 July.

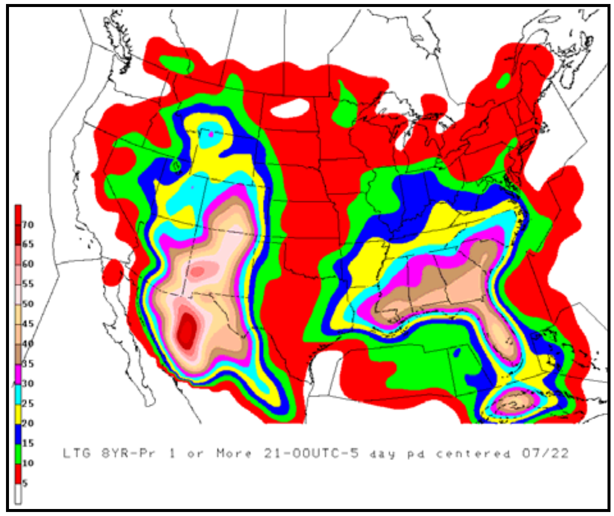

Figure 3. Same as Fig. 2, but 12 hours later, 21 to 00 UTC centered on 22 July.

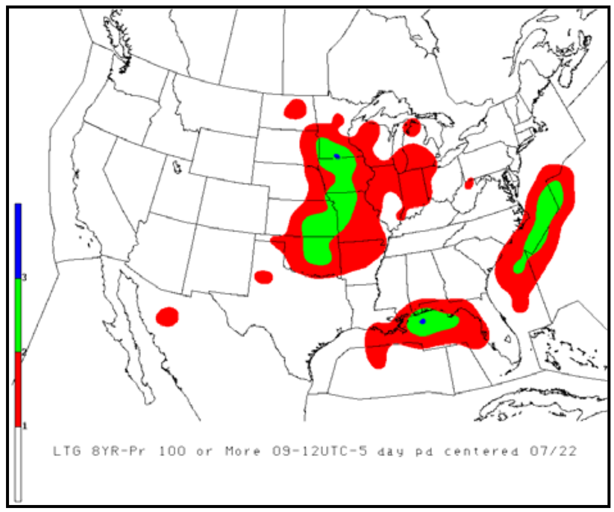

Figure 4. Same as Fig. 2 but at one percent intervals for probability of 100 or more CG flashes from 09 to 12 UTC 22 July.

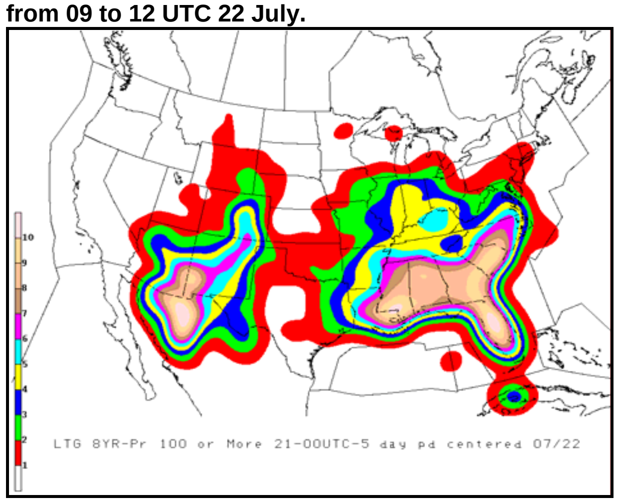

Figure 5. Same as Fig. 4, but for 21 to 00 UTC.

were well in excess of ten percent, that is higher than would be expected from climatology, and would be considered important.

6. CASE STUDY

During the late afternoon and early evening of 10 November 2004, strong thunderstorms developed over central and eastern Oklahoma. They eventually moved eastward into western Arkansas before diminishing about 12 hours later. Significant lightning (greater than 100 flashes per three hours) was observed through the late afternoon and evening. In addition, several weak tornadoes with minor damage (along with a few wind and hail reports) were reported from the storms in the late afternoon and early evening.

Figure 6 shows that during the late afternoon in early November, the climatological probability for 100 or more CG flashes is less than two percent over all areas of the United States, and less than one percent in Oklahoma. Thus, predicted probabilities of one or two percent in Oklahoma can be considered to be significant indications of unusually intense thunderstorms in early November. Probabilities of one or two percent (or higher) can be very important. Further, it will be shown that the forecasted probabilities exhibit good continuity in space and over time.

As an example of the forecast ability using input from the RUC model, Fig. 7 is a 12 to 15 hour forecast for high lightning density (100 or more CG flashes) from the RUC 12 UTC model run. Forecasts from the complete RUC model run

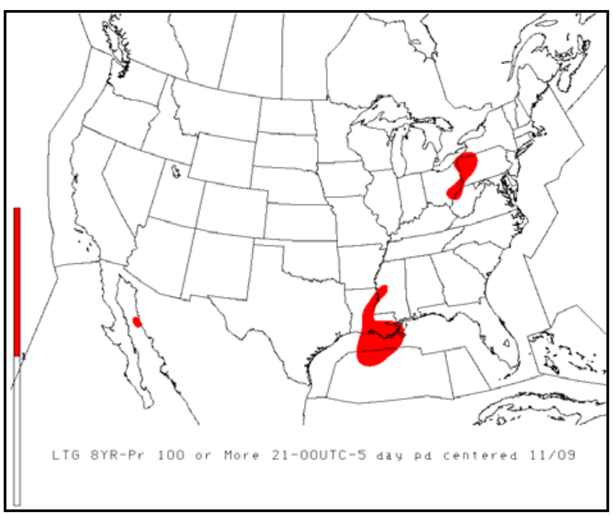

Figure 6. Probability of 100 or more CG flashes during the late afternoon (21 to 00 UTC) for the 5-day period (pentad) centered on 9 November. Note that the highest probability is less than 2 percent.

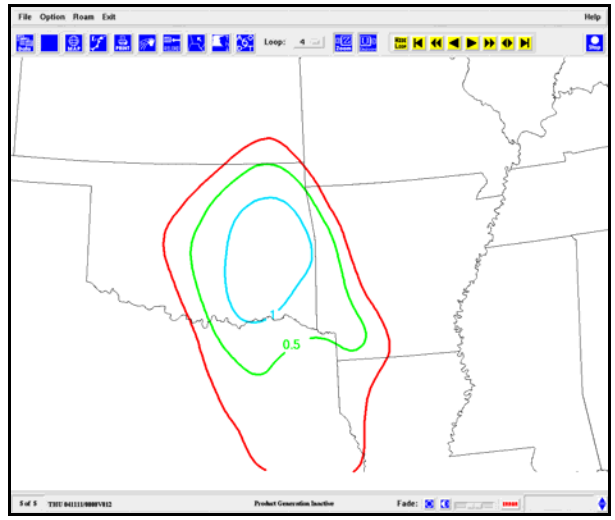

Figure 7. N-AWIPS display of the 12 to 15 hour forecast of 100 or more flashes from 12 UTC 10 November 2004 RUC (Valid 00 to 03 UTC 11 November 2004). Contours are 0.25, 0.5, and 1 percent.

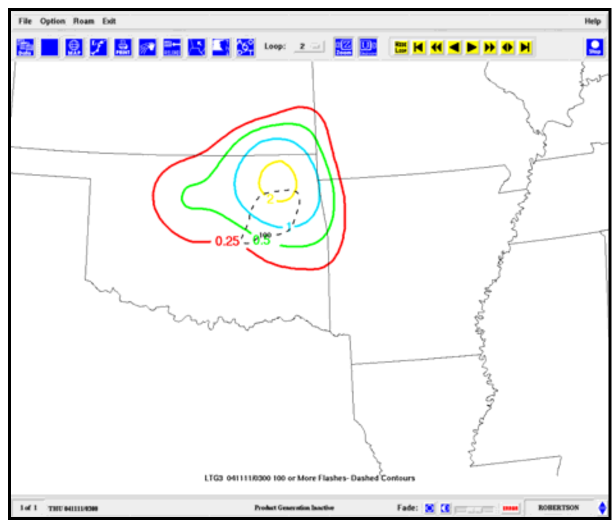

Figure 8. Zero to 3-hour forecast of 100 or more flashes (valid 00 to 03 UTC 11 November 2004). Location of 100 or more CG flashes—black dashed line. Probability contours for 100 or more CG flashes are 0.25, 0.5, 1 and 2 percent.

had indicated the greatest likelihood for the significant lightning would occur around this time. Highest probabilities from this forecast (valid 00 to 03 UTC) were between one and two percent. This corresponds to the time most of the severe weather was occurring (around 00 UTC).

Figure 8 shows the 0 to 3-hour forecast for 100 or more CG flashes from the SPC hourly analysis and the area of 100 or more flashes for the same time period. As would be expected, the 0 to 3-hour forecast was better able to pinpoint the exact area compared to the 12 to 15 hour forecast. The severe reports were between 2230 UTC and 04 UTC from central to east central Oklahoma.

During the next three hour period (03 to 06 UTC 11 November 2004), Fig. 9 shows the forecast area of high lightning density expands with most of the intense lightning (now over 300

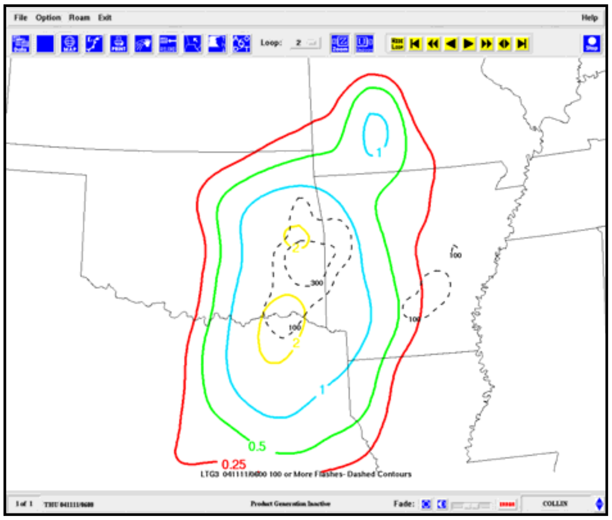

Figure 9. Zero to 3-hour forecast for the probability of 100 or more flashes (valid 03 to 06 UTC for 11 November 2004). Black dashed contours are 100 and 300 or more flashes. Probability contours of 100 or more are 0.25, 0.5, 1 and 2 percent.

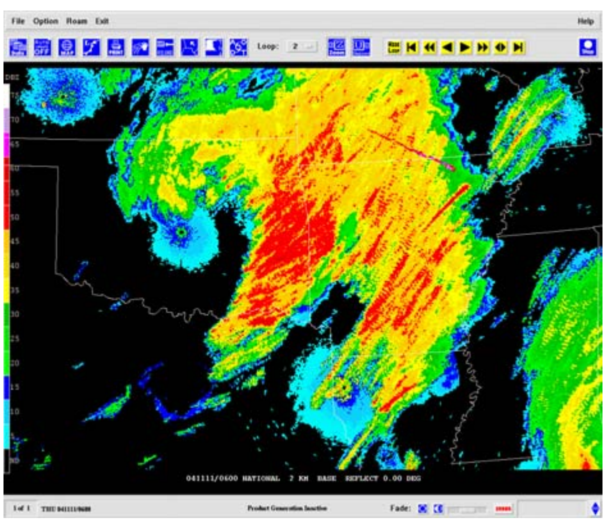

Figure 10. Radar imagery showing highest accumulated reflectivity during the three-hour period from 03 to 06 UTC for 11 November 2004.

CG flashes) near the center of maximum probability (over two percent). Although no large scale flooding rains were produced by these storms, the image (Fig. 10) showing maximum radar reflectivity accumulated for the three-hour period illustrates how a concentrated area of high reflectivity is also well within the forecast area of high lightning density.

The final three hour period shown here is from 06 to 09 UTC 11 November 2004 (Fig. 11). The forecasting scheme has the highest probability during the event at around this time.

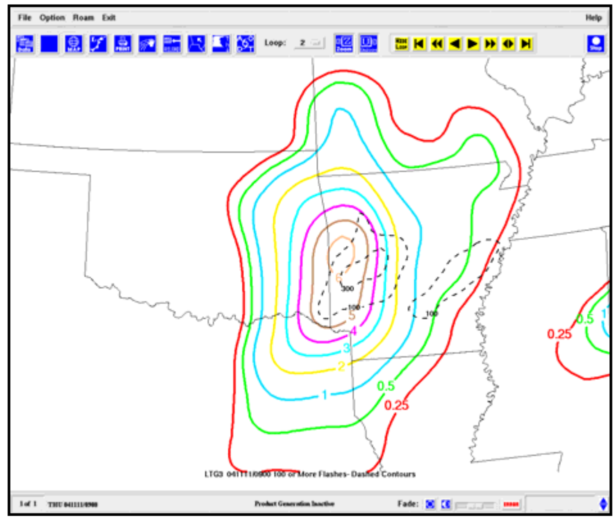

Figure 11. Same as Fig. 9 except for 06 to 09 UTC 11 November 2004. Maximum probability has increased to over 6 percent on the Oklahoma/ Arkansas border.

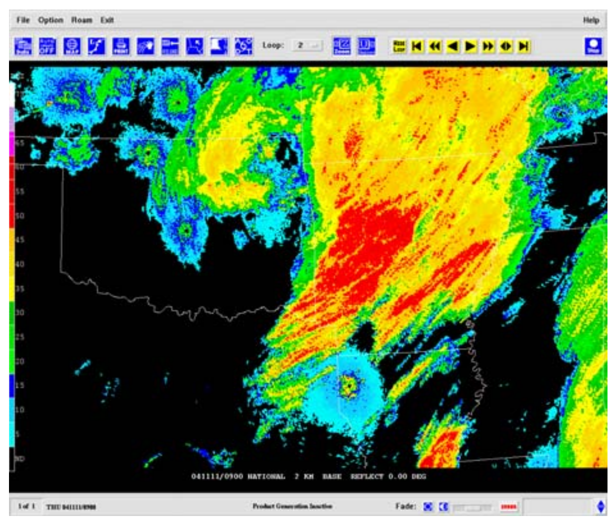

Figure 12. Same as Fig. 10, except for the time period 06 to 09 UTC 11 November 2004.

The probability of 100 or more flashes exceeds six percent on the Oklahoma/Arkansas border, nearly coincident with an excess of 300 flashes during the forecast time period and the large area of accumulated reflectivity shown in Fig. 12. After 09 UTC, both forecast probabilities and lightning (not shown) began to decrease.

7. SUMMARY

Preliminary work has shown the ability to predict areas of intense lightning hours in advance using a perfect prog approach incorporating lightning climatology and predictor fields from NWP models. Since severe weather in the form of hail, damaging wind, tornadoes, and flooding is often associated with the most intense areas of lightning, this connection offers additional information to meteorologists trying to predict when and where severe weather will occur. Additionally, although there is currently no clear definition of what constitutes a severe lightning storm, this method offers the chance to greatly increase our ability to predict intense areas of lightning. Different lightning thresholds can be used at any future time.

The forecast probabilities exhibit very good continuity both in space and time. Forecast probabilities usually improve as the event gets closer. If improvements are made to the model that is being used, those improvements would normally result in improved forecasts using the perfect prog scheme. The method already incorporates fields from both the RUC and Eta model, and is not tied to any specific model (such as MOS statistics are).

It is important when evaluating these predicted probabilities to compare them to the climatological probability of intense lightning. Although a forecast may appear to have a low probability of intense lightning, it may actually be many times greater than the climatological value of lightning for a given location and thus very significant.

8. REFERENCES

Bothwell, P.D., 2000: Forecasting dry thunderstorms as a part of fire weather outlooks at the Storm Prediction Center. *Preprints, Third Symposium on Fire and Forest Meteorology*, Long Beach, CA, Amer. Meteor. Soc., 76-79.

Bothwell, P.D., 2002: Prediction of Cloud-to-Ground Lightning in the Western United States, Ph.D., University of Oklahoma, 178pp.

Demetriades, Nicholas, 2000, Vaisala, Personal Communication.

Kempf, N.M., and E. Philip Krider. 2003: Cloud-to-Ground lightning and surface rainfall during the great flood of 1993. *Mon Wea. Rev*: **131**, pp. 1140–1149.

López, R.E., and R.L. Holle, 1986: Diurnal and spatial variability of lightning activity in northeastern Colorado and central Florida during the summer. *Mon. Wea. Rev*., **114**, 1288-1312.

MacGorman, D.R., and W.D. Rust, 1998: *The Electrical Nature of Storms.* Oxford University Press, 422 pages.

Reap, R.M. 1986: New 6-h thunderstorm probability forecasts for the West. NWS Technical Procedures Bulletin No. 362, NOAA, U.S. Department of Commerce, 8pp.