J3.4 Automated Gridded Forecast Guidance for Thunderstorms and Severe Local Storms Based on the Eta Model

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1. INTRODUCTION

The Meteorological Development Laboratory (MDL) has long been active in developing forecast guidance techniques for hazardous weather, including lightning, severe local storms, and heavy precipitation. Our most recent research involves development of a complete suite of thunderstorm and severe local storm guidance based on output from the Eta model (Black 1994). In conjunction with development of Eta-based thunderstorm products, efforts are also underway to produce automated thunderstorm forecasts for 3-h intervals from both the Global Forecast System (GFS) and the Eta model.

For the very short-range projections out to 3 hours in advance, MDL developed and implemented automated analysis and forecast techniques based primarily on remote sensor observations, especially lightning data. These experimental advective statistical convective forecasts are valid for the 0-3 h time frame (Kitzmiller 2002). Until now, however, there has been a lack of automated short-range guidance valid for the 3-6 h time period, which is a critical time period for the aviation community. We have recently begun employing statistical techniques based on the Eta model to derive thunderstorm and severe local storm probability guidance extending from 3 to 60 hours in advance. The basic approach for creating these forecast products is described in this paper and our initial verification results are presented. Examples of the performance of the Eta-based objective thunderstorm forecasts during a severe weather outbreak are also shown. With the completion of this Eta-based development, there will be a full set of objective thunderstorm guidance from different numerical models available to forecasters starting from the first 3-h period after a model's initial time, all the way to day seven.

2. AVN- AND MRF-BASED MOS THUNDERSTORM GUIDANCE

MDL is responsible for producing the Model Output Statistics (MOS; Glahn and Lowry 1972) guidance. In 2000, MDL implemented a statistical weather forecast system based on output from what was then the Aviation (AVN) and medium-range (MRF) runs of the GFS. As part of this system, equations to predict the probability of thunderstorms and severe thunderstorms were derived for the contiguous U.S. (CONUS) by using cloud-to-ground lightning and severe local storm reports, described in Section 4.

Thunderstorm and severe thunderstorm forecasts are produced for 6-, 12-, and 24-h periods for all four cycles of the AVN run of the GFS, out to 84 hours in advance (Hughes 2001). The 6- and 12-h guidance out to 72 hours in advance is available in AVN MOS alphanumeric messages (Dallavalle and Erickson 2000). The 24-h guidance out to 84 hours, as well as the 6- and 12-h guidance out to 72 hours in advance, are also available in binary form as BUFR (Binary Universal Form for the Representation of meteorological data) messages. In addition, MRF MOS thunderstorm forecasts have been generated since May 2001. These forecasts are produced for 12- and 24-h periods out to 192 hours in advance from 0000 UTC and are available in the MRF MOS alphanumeric messages (Erickson and Dallavalle 2000). The 12- and 24-h thunderstorm forecasts are also available in BUFR messages. No severe thunderstorm guidance is available in the MRF MOS.

3. OBSERVED RELATIVE FREQUENCIES

Five years of cloud-to-ground lightning and severe local storm reports (October 1994 - September 1999) were used to develop monthly lightning and severe thunderstorm climatologies for the CONUS for 3-, 6-, 12-, and 24-h periods. Each lightning strike and report of a tornado, large hail, or damaging wind event contained information about the latitude, longitude, and time of the event, which was used to place the observation on a grid of 113x89 blocks, each approximately 48 km on a side, covering the CONUS and adjacent areas. Over 128 million cloud-to-ground lightning strikes, and 100,000 storm reports were processed to generate monthly relative frequencies for each period at every grid point used in the development. Because the severe thunderstorm reports were relatively rare, the severe thunderstorm relative frequencies tended to be discontinuous in space. Figure 1 shows the monthly cloud-to-ground lightning relative frequency valid for August, covering the 1200 - 1200 UTC time period. Nine-point spatial smoothing was applied to this relative frequency for legibility.

4. DEVELOPMENT OF ETA-BASED THUNDERSTORM GUIDANCE

4.1 Data Collection

The National Lightning Detection Network (NLDN) cloud-to-ground lightning data were used to define the

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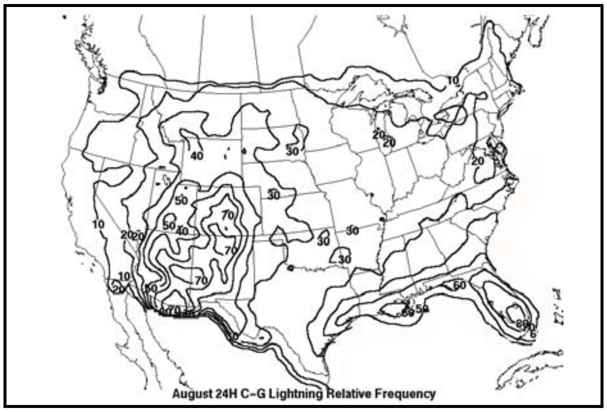

Figure 1. The monthly 24-h (ending at 1200 UTC) cloud-to-ground lightning relative frequency for August.

presence of a thunderstorm for 3-, 6-, 12-, and 24-h periods. An upgrade was made to the NLDN in 1994 (Cummins et al. 1998), so data before 1994 were not included in the development of the observed relative frequencies. Additional lightning data through September 2001 were available for the Eta thunderstorm guidance development.

The predictand data for severe thunderstorms consisted of individual reports of tornadoes, large hail, and thunderstorm wind gusts or damage, compiled and quality controlled by the Office of Climate, Water, and Weather Services (OCWWS) from local storm data reports. These storm reports were obtained by NWS Forecast Offices and were stored in the NWS severe weather data base. For consistency with the lightning data, only storm reports from 1994 and after were included in the MOS development. Because of the sparsity of storm data, efforts were made to remove missing or suspect grid areas where the storm data appeared to be unreliable. For the AVN MOS development, a Geographical Information System was used to study the relationship of the severe storm reports to the population density of the area covered by the grid. Data from areas with very low population density were not included in the developmental sample, which removed about 20% of the grid boxes (Fig. 2). This modification seemed to slightly improve the forecast equations. However, after seeking advice from the Storm Prediction Center (SPC), a different approach was used to eliminate unreliable grid points from the Eta MOS. Instead of removing grid points based on low population density, the data were analyzed for September 1994 through September 2001, and all grid boxes that never reported a severe weather event, yet experienced thunderstorms, were removed from the developmental sample. This also removed about 20% of the grid boxes (Fig. 3). There was a great deal of overlap between the AVN and the Eta MOS development points. The most notable differences occurred in portions of western Texas, Nebraska, and South Dakota, where it would seem that efforts have been successful to report severe weather events, even though the population density is relatively low in those areas. This analysis also revealed a suspicious lack of reports

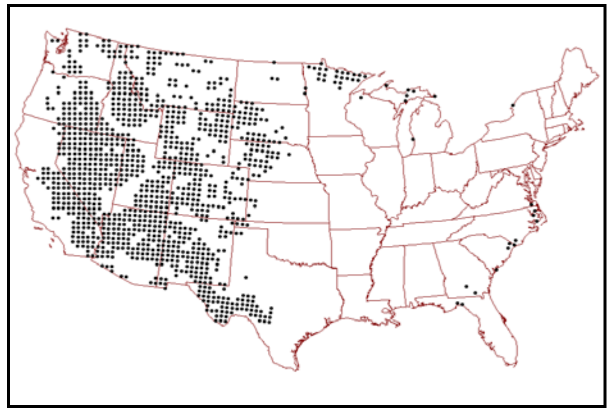

Figure 2. Grid points not used in the AVN MOS severe thunderstorm development.

in a few grid boxes with relatively high population densities, even though all of the surrounding grid boxes reported severe thunderstorm events. Although some of the grid boxes were removed for equation development, the final MOS equations are valid for the entire CONUS, so forecasts are generated for every severe thunderstorm grid box.

4.2 Predictand Definition

A thunderstorm was defined by one cloud-to-ground lightning strike during the defined period. All strikes for a given hour within a given box were added up and assigned to the grid box labeled by the center point. Hours with no reports of lightning were simply considered non-thunderstorm events. It was assumed there were no missing cases of thunderstorms. The hourly thunderstorm reports were then summed for the appropriate 3-, 6-, 12-, or 24-h period.

The severe thunderstorm reports were also assigned to grid boxes and summed over the appropriate period. The severe thunderstorm predictand was made conditional on a thunderstorm. Thus, only thunderstorm events were considered. If a thunderstorm occurred and no severe thunderstorm reports were received, then the event was non-severe. If a thunderstorm occurred and severe thunderstorms were

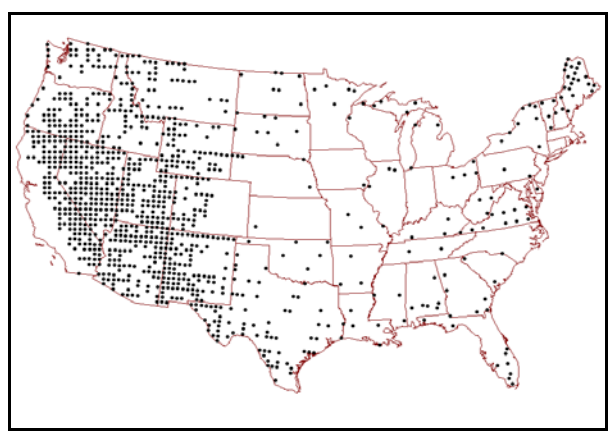

Figure 3. Same as Fig. 2, except for Eta MOS.

reported, then the event was severe. If no thunderstorm occurred, the severe thunderstorm predictand for that period was omitted.

4.3 Predictors

MOS forecast equations were developed by applying linear multiple regression techniques to relate the occurrence of thunderstorms or severe thunderstorms (the predictand) to forecast variables (the predictors) from the Eta model. A regionalized approach was used for the equation development. Data for all grid boxes were combined into one region to increase the sample size and the stability of the equations. Separate forecast equations were developed for each projection, forecast period, and season.

Eta model output was available every 6 hours from 6 to 48 hours in advance from both the 0000 and 1200 UTC cycles. Potential predictors offered to the regression program included Eta model output fields interpolated to the center of the grid boxes, variables derived from model output fields, and observed relative frequencies for each grid box. Predictors most often selected for the Eta MOS thunderstorm equations were vertical velocities at 700 and 500 hPa, model forecasts of convective precipitation amount offered in binary form, stability indices, and the product of the K-index and the observed relative frequency. Important predictors in the severe thunderstorm equations included the 500 hPa wind speed, surface CAPE, the SWEAT index, 700 to 500 hPa differences of equivalent potential temperature, and observed relative frequencies.

4.4 Projections and Products

Equations to predict the probability of a thunderstorm and the conditional probability of a severe thunderstorm for 6-h, 12-h, and 24-h periods were developed from the 0000 and 1200 UTC cycles of the Eta model. Eta MOS equations were developed for spring (March 16 - June 30), summer (July 1 - October 15), and cool (October 16 - March 15) seasons. Five seasons of model and observational data, March 1997 through October 2001, were available to develop the summer and spring equations. Four seasons, October 1997 through March 2001, were available for the cool season equations.

Forecasts are generated for 6-h periods valid 6-12, 12-18,..., 48-54, and 54-60 hours in advance. Equations for the 12-h periods are valid 6-18, 12-24,..., 42-54, and 48-60 hours in advance. Equations for the 24-h periods are valid for periods of 12-36, 24-48, and 36-60 hours in advance. The 6- and 12-h forecasts will be available in Eta MOS text messages (Dallavalle and Erickson 2002). All of the 6-, 12- and 24-h forecasts will be available in the Eta MOS BUFR messages.

Equations are also being developed to predict the probability of a thunderstorm for 3-h periods from the Eta and AVN models. More information regarding the 3-h equation development will be presented at the conference.

4.5 Preliminary Results

The skill of the Eta-based thunderstorm and severe thunderstorm forecasts was assessed by comparing them with the AVN MOS thunderstorm forecasts. Figure 4 shows the percent improvement in the Brier score of the Eta 6-h thunderstorm forecasts over the AVN 6-h thunderstorm forecasts from 12 to 60 hours in advance for the summer of 2001 (July through September). The Eta forecasts are more skillful for most of the projections through 42 hours, but at 48 hours and beyond the AVN forecasts have more skill. This result was expected since the Eta MOS forecast equations did not have Eta model predictors available after the 48-h projection. Overall differences between the two systems were small.

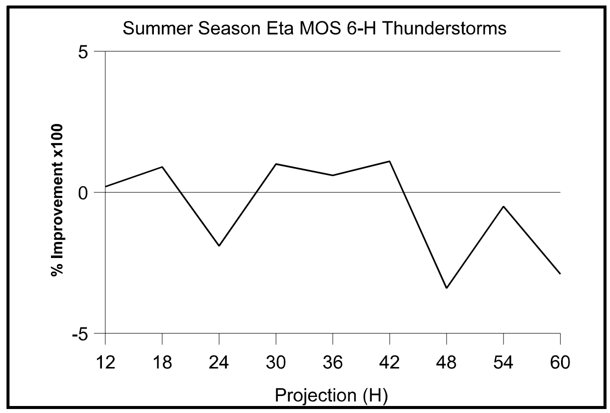

Figure 4. Percent improvement in terms of the Brier score for the Eta MOS versus the AVN MOS thunderstorm forecasts.

5. SEPTEMBER 24, 2001 CASE STUDY

On September 24, 2001, a severe weather outbreak resulted in 19 tornadoes and 15 damaging wind reports across Maryland, Virginia, and Pennsylvania. Observations of the cloud-to-ground lightning strikes and the severe weather reports (large circles) are shown in Fig. 5 for the 6-h period ending 0000 UTC, September 25. The Eta MOS probability of thunderstorm forecast from 0000 UTC, September 24, valid for the 6-h period ending 0000 UTC, September 25, is shown in Fig. 6, with contours every 10%, starting at 10%. Figure 7 shows the forecasts of the conditional probability of severe thunderstorms, contoured every 5%, starting at 5%, for the same period.

6. FUTURE PLANS

During the summer of 2002, MDL will implement Eta MOS thunderstorm and severe thunderstorm guidance for 6-, 12- and 24-h periods out to 60 hours in advance. Efforts are underway to develop 3-h AVN- and Eta-based MOS equations for predicting thunderstorms and severe thunderstorms. Work is also in progress to update the MDL archive of the Eta model to include predictors every 3 hours out to 60+ hours in advance, and to increase the model resolution being archived from 90 km to 32 km. After the archive is updated, the thunderstorm and severe thunderstorm equations will also be updated to reflect the increase in resolution in both time and space. Within the next 2 years, probablistic thunderstorm forecasts will be available every 3 hours, from 3 to 84 hours in advance, based on output from two cycles of the Eta model, as well as four cycles of the AVN model.

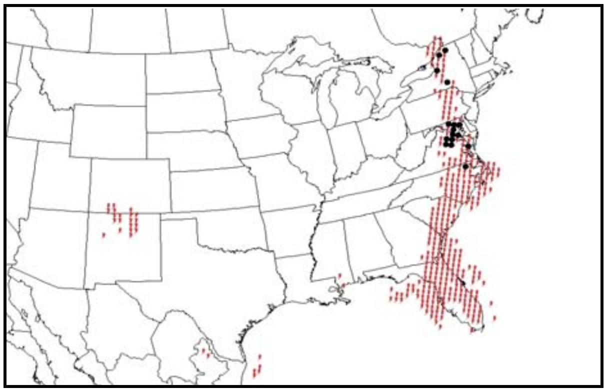

Figure 5. Six-hour cloud-to-ground lightning and severe weather observations ending September 25, 2001, at 0000 UTC.

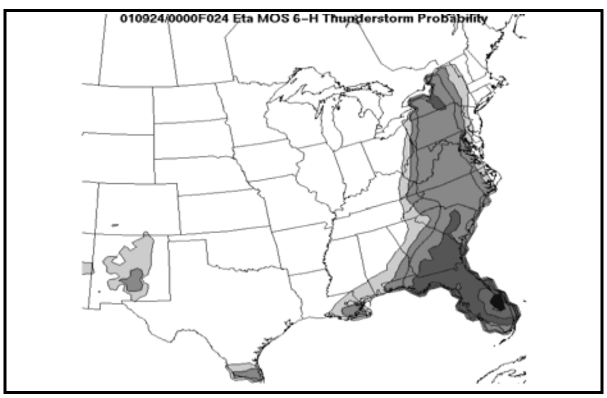

Figure 6. Eta MOS 18-24h probability of thunderstorm forecasts for the period ending at 0000 UTC on September 25, 2001.

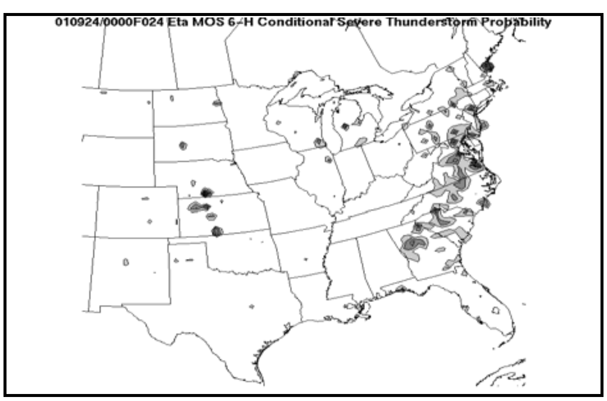

Figure 7. Same as Fig. 6, except for conditional severe thunderstorm forecasts.

Acknowledgments

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