2.6 PROBABILISTIC LIGHTNING FORECAST GUIDANCE FOR AVIATION

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1. INTRODUCTION

Thunderstorms account for a significant percentage of air traffic delays. To provide tactical support for air traffic management, more graphical and probabilistic weather forecast guidance is needed at higher resolution and for shorter time periods than the guidance currently available. Using statistical techniques, the Meteorological Development Laboratory (MDL) has produced automated probabilistic thunderstorm guidance for many years. Traditional MDL Model Output Statistics (MOS; Glahn and Lowry 1972) products support aviation weather operations by providing site-specific forecast guidance for wind, ceiling height, sky cover, visibility, obstruction to vision, and thunderstorms for over 1500 locations, most of which are airports. The equations to predict the probability of thunderstorms are developed for the contiguous United States (CONUS) by using observed lightning data and output from numerical weather prediction models. More details describing the equation development are provided later in this paper.

To meet the needs of the aviation community, the work described here concentrates on the development of thunderstorm guidance at shorter temporal and smaller spatial resolutions than previously available MOS thunderstorm guidance. A new set of probability forecast equations has been created by using model output from the Global Forecast System (GFS; Iredell and Caplan 1997). Equations have been developed which will produce probabilistic forecast guidance on a 20-km grid over the CONUS. The forecasts will cover 3-h periods out to 36 hours in advance, and will be generated four times daily. Similar statistical techniques are also used in the Localized Aviation MOS Program (LAMP) (Glahn and Ghirardelli 2004), which is designed to provide improved forecast guidance more frequently for even shorter time periods. Inputs such as METAR observations, lightning strike data, and radar reflectivity are used to update the MOS guidance and improve the forecasts for aviation support. In this paper, more details regarding the development of the MOS thunderstorm products will be provided, and an example of the 20-km guidance for a thunderstorm outbreak is presented.

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2. EXISTING THUNDERSTORM GUIDANCE

MOS forecast equations are developed by applying linear multiple regression techniques to relate the occurrence of thunderstorms to forecast variables from numerical models. Thunderstorm and severe thunderstorm probability forecast guidance is currently available from four cycles of the GFS, out to 84 hours in advance on a 48-km grid covering the CONUS for 6-, 12-, and 24-h periods (Hughes 2001). Thunderstorm guidance is also available from the MDL extended-range system based on 0000 UTC GFS model output for 12- and 24-h periods out to 192 hours in advance. In addition to the GFS systems, thunderstorm and severe thunderstorm probability forecasts are generated from the 0000 and 1200 UTC cycles of the Eta model (Black 1994) on a 40-km CONUS grid for 6-, 12-, and 24-h periods out to 60 hours in advance (Hughes 2002).

The thunderstorm/severe weather guidance is available in the GFS and Eta MOS alphanumeric messages (Dallavalle et al. 2004) at specific sites. A nearest-neighbor approach matches the MOS stations to the nearest thunderstorm grid point. In addition, graphical thunderstorm products are available on the MDL web site. The gridded thunderstorm forecasts are analyzed to a National Weather Service (NWS) standard 40-km grid for display. For more information on these and other MOS products, visit
http://www.nws.noaa.gov/mdl/synop/products.shtml

3. DEVELOPMENT OF 20-KM GFS-BASED THUNDERSTORM GUIDANCE

3.1 *Definition of the Thunderstorm Predictand*

A thunderstorm is defined as the occurrence of one or more cloud-to-ground lightning strikes during the defined period. Observations of cloud-to-ground lightning data from the National Lightning Detection Network (NLDN; Cummins et al. 1994) are used to define thunderstorm events for the MOS system. Nine years of NLDN data, from January 1995 through December 2003, were available for the creation of the predictand data. Each lightning strike observation was assigned to a cell on a 20-km Lambert Conformal grid of 301x225 cells (Fig. 1). The original 20-km grid was then trimmed to an area within 25 km of the CONUS where the coverage of the strike data was reliable. Areas defined as marine zones by the NWS were also included. All strikes for a given hour within a grid box were added up and assigned to the center of that grid box. Hours with no reports of lightning were considered non-thunderstorm events. It was assumed that there were no missing cases of thunderstorms. The hourly thunderstorm reports were then summed for eight 3-h periods, 0000-0300, 0300-0600, 0600-0900 …2100-0000 UTC.

3.2 *Lightning Relative Frequencies*

Relative frequencies of lightning, generated from cloud-to-ground lightning observations, are made available to the statistical forecast system as potential predictors. The relative frequencies are also valuable as a tool for comparing the accuracy of the forecast guidance to forecasts based on climate. Nine years of cloud-to-ground lightning reports (January 1995–December 2003) were included to develop monthly lightning climatologies for the CONUS for 3-h time periods Figure 2 is a sample of the 3-h relative frequencies for July, valid for the period from 2100–0000 UTC. At a resolution of 20 km over this 3-h time period in July, lightning is not expected more than 10% of the time for most of the CONUS. However, there are areas over Florida and the Southwest where the relative frequencies approach 50%.

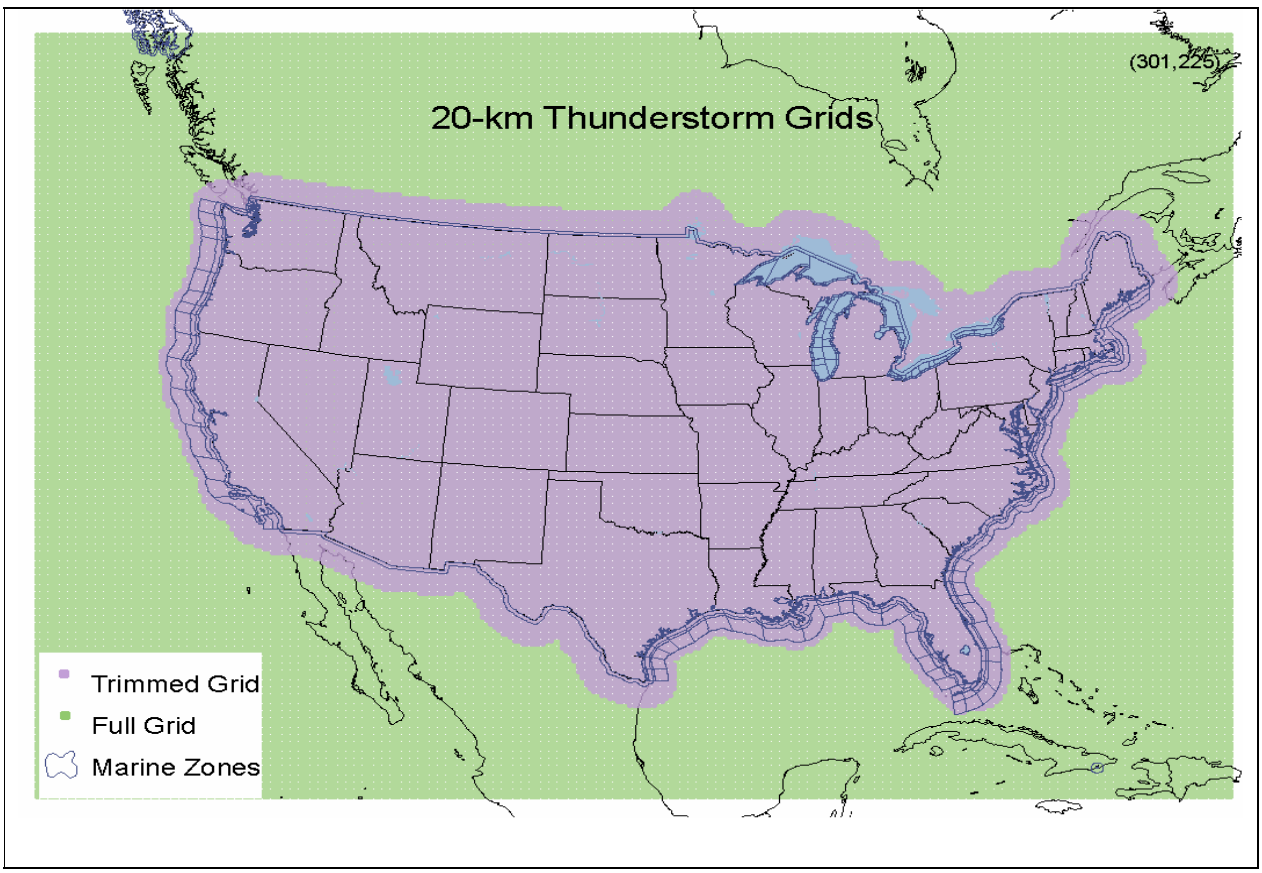

Figure 1. Grids used for the 20-km GFS MOS thunderstorm development. The trimmed area around the CONUS shows the portion of the grid used in the development.

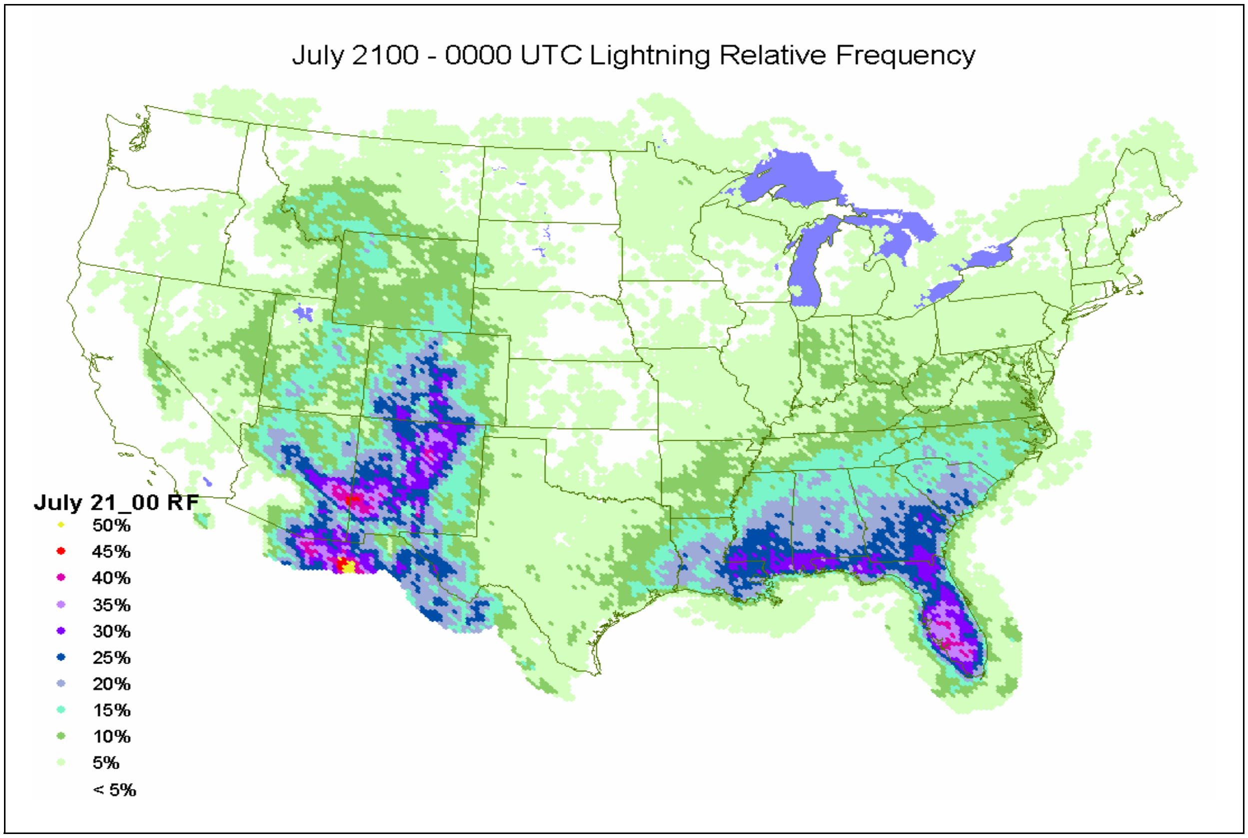

Figure 2. July cloud-to-ground lightning monthly relative frequencies for the period 2100 – 0000 UTC.

3.3 *Seasonal Stratification and Sample Size*

MOS thunderstorm equations were developed for spring (March 16–June 30), summer (July 1 - October 15), and cool (October 16 – March 15) seasons. A little more than 5 years of GFS model data, October 1998 through December 2003, and monthly relative frequecies derived from 9 years of lightning observations, were available to develop the equations. Separate forecast equations were developed for each projection, from 3-6, 6-9, 9-12,…, 33-36 hours in advance, for all four cycles, and every season.

3.4 *Developmental Technique and Predictors*

The 20-km GFS-based MOS thunderstorm equations were developed by applying linear multiple regression techniques to relate the occurrence of thunderstorms to forecast predictors from the 0000, 0600, 1200, or 1800 UTC cycles of the GFS model. Equations were developed with a regional approach. Data for all of the grid boxes on the trimmed grid, essentially 27,373 stations, were combined into one region to increase the sample size and the stability of the equations. Earlier attempts to develop the thunderstorm equations with multiple regions provided little or no improvement for most regions.

Potential predictors offered to the regression program included GFS variables and the observed relative frequencies for each grid box. Predictors most often selected for the 20-km GFS MOS thunderstorm equations were convective precipitation amounts, vertical velocities, the product of a vertical velocity and a relative humidity, the product of the K-index and the observed relative frequency, and various stability indices offered in grid binary form.

4. SKILL OF THE GUIDANCE

The Brier score (Brier 1950) and the percent improvement of the MOS guidance compared to a forecast based on the lightning relative frequencies were used to judge the skill of the guidance. The climatic relative frequencies used for the percent improvement score were generated from forecast equations derived by using a multiple linear regression technique, where the only predictor offered was the lightning relative frequency valid for the matching 3-h period.

Test equations were developed by leaving out the 2003 spring season. Guidance generated from the test equations on the 2003 spring season then provided an independent season for verification. Figure 3 shows the percent improvement over climate in terms of the Brier score, for the 1200 UTC guidance. The guidance for all projections is skillful, showing improvement over climate.

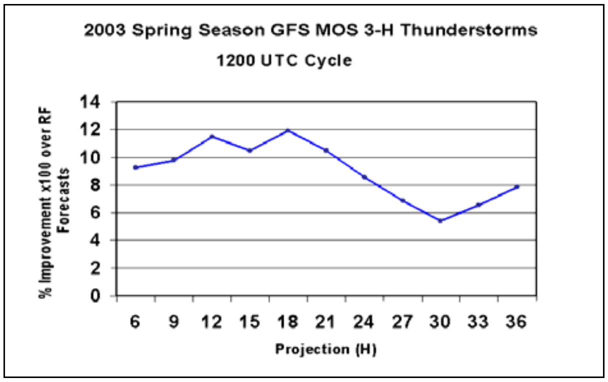

Figure 3. Percent improvement in the Brier score of the 3-h thunderstorm guidance over forecasts based on climate. Guidance was generated from the 1200 UTC model run for the spring of 2003.

5. FORECAST EXAMPLE

The thunderstorm event presented in this paper occurred in the early days of a massive severe weather outbreak during the spring of 2003. A sample of a forecast from the 1200 UTC cycle is shown (Fig. 4) for the 3-6 h forecast projection valid 1500–1800 UTC on May 4, 2003. Corresponding lightning observations on a matching grid covering the 1500-1800 UTC period are also shown. The forecast areas which match the occurrence of cloud-to-ground lightning probabilities are in the range of 15–30%. Notice even at this 3-6 h forecast projection, the probabilities do not get above 30% for this event. Earlier work (Hughes and Trimarco 2004) demonstrated that as we increase the resolution of the MOS probability guidance in time and space, the magnitude of the probabilities decreases, as the likelihood of an event at an exact time and point in space approaches zero. Users may need to adjust their expectations for the magnitude of the probabilities associated with an event at these smaller resolutions. For the aviation community, it may be desirable to produce a categorical thunderstorm product derived from the probabilistic fields

6. LAMP THUNDERSTORM GUIDANCE

Development is also underway to produce new LAMP thunderstorm products for 20-km grid boxes over the CONUS (Charba and Liang 2005). The thunderstorm events for these products are also defined by the occurrence of one or more cloud-to-ground lightning strikes. The thunderstorm probabilities are based on the LAMP technique whereby MOS thunderstorm probabilities are updated on an hourly basis by incorporating observations of lightning strike and radar reflectivity measurements, along with other surface-based observations, topography, and lightning climatology. The LAMP thunderstorm probabilities and categorical forecasts will be available for 2-h periods, including 0-2, 2-4, 4-6,…, and 22-24 hours in advance.

The MOS products are useful strategic planning tools, and forecasts provided by the LAMP guidance with shorter time periods and more frequent updates should provide tactical support. These LAMP thunderstorm products will be particularly useful in the critical 2-8 h time frame.

7. FUTURE WORK

The current GFS-based thunderstorm and severe thunderstorm guidance will be updated for 3-, 6-, 12-, and 24-h periods on a 40-km grid out to 84 h in advance from four cycles, with efforts aimed at improving the severe weather probability guidance. The extended-range thunderstorm guidance out to 192 h in advance will be updated, with the eventual addition of the 1200 UTC cycle package. In addition, GFS MOS thunderstorms will be developed for Alaska.

Eta-based MOS thunderstorm and severe thunderstorm guidance will be updated with model output archived at a higher resolution than MDL's original Eta model archive. Forecast guidance will be generated out to 84 hours in advance for 3-, 6-, 12-, and 24-h periods.

8. CONCLUSIONS

Probabilistic forecasts will become an increasingly valuable tool for decision makers. We believe the increase in temporal and spatial resolution of our thunderstorm guidance will assist the aviation industry in making critical decisions in the earliest

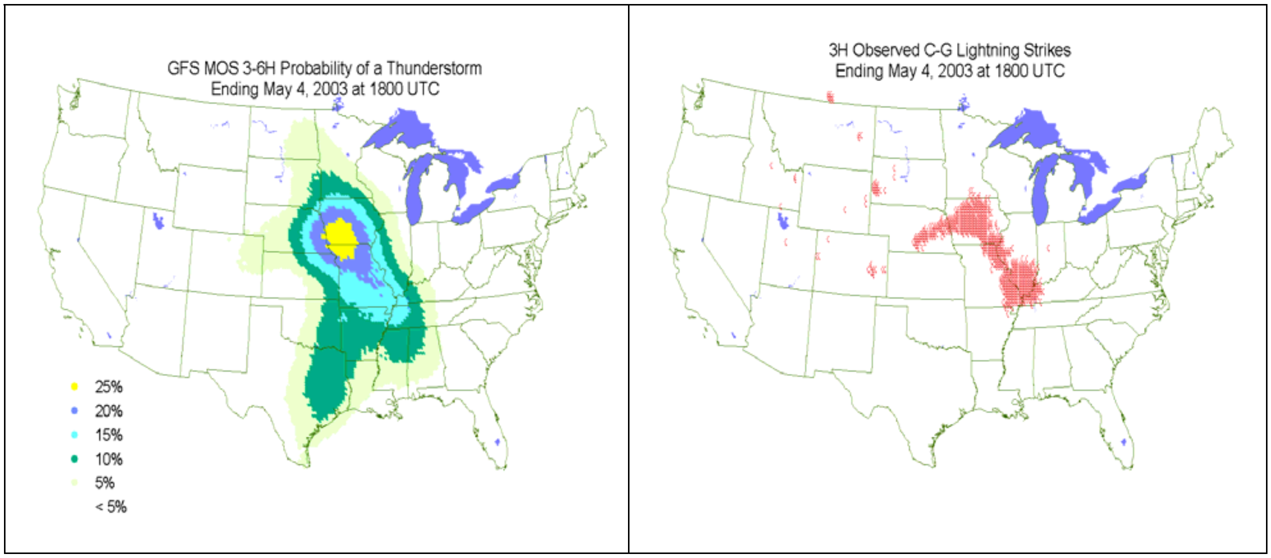

Figure 4. The left-side shows the MOS thunderstorm probability guidance valid for a 3-h period ending at 1800 UTC on May 4, 2003. Corresponding cloud-to-ground lightning strikes are shown on the right.

forecast periods. Work is also underway to develop categorical thunderstorm products from both the 20- and 40-km GFS thunderstorm guidance. Statistical techniques will be used to generate the thresholds for categorical forecasts, which will result in a higher probability of detection (POD) and lower false alarm ratio (FAR) than would result from selecting an arbitrary threshold in the probability values. Examples of the categorical forecasts will be presented at the conference. With feedback from the aviation weather community, the thunderstorm probability guidance can be tailored to meet the needs of the users.

9. ACKNOWLEDGMENTS

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