P2.9 DEVELOPING GFS-BASED MOS THUNDERSTORM GUIDANCE FOR ALASKA

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1. INTRODUCTION

Cloud-to-ground (CG) lightning is one of the leading causes of weather related fatalities in the United States (U.S.). In heavily forested areas such as Alaska, CG lightning also is a major contributor to the initiation of forest fires. Graphical, probabilistic guidance for thunderstorms over Alaska would allow the fire weather community and other users to better assess the CG lightning threat, and thereby aid in the protection of life and property.

For many years, National Weather Service (NWS) forecasters have used Model Output Statistics (MOS; Glahn and Lowry 1972) guidance produced by the Meteorological Development Laboratory (MDL) as an aid in generating text forecast products issued to the user community. However, forecasters now are required to produce forecasts on a high-resolution grid in support of the National Digital Forecast Database (NDFD; Glahn and Ruth 2003). Recently, updated thunderstorm probability guidance based on output from the Global Forecast System (GFS) was implemented for the contiguous U.S. (CONUS) to satisfy NDFD grid requirements. This new gridded thunderstorm guidance system has now been expanded to cover the state of Alaska.

This paper describes the development of the new MOS thunderstorm guidance over Alaska. GFS forecast data and lightning observations are used to develop equations for the probability of a thunderstorm at 3-h, 6-h, 12-h, and 24-h intervals on a 48-km grid, for each GFS model cycle. Objective verification scores are shown for an independent data sample (the 2006 warm season). Finally, a forecast example is presented for an event that was responsible for igniting two Alaska wildfires in July of 2006.

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2. EQUATION DEVELOPMENT

2.1 *Lightning Data Description*

An archive of CG lightning observations from the Bureau of Land Management (BLM) network of magnetic direction-finding sensors was used to define thunderstorm events for the MOS system. Complete descriptions of the BLM network, its methods of detection, detection efficiency and location accuracy are given in Reap (1991) and Dissing and Verbyla (2003).

The BLM lightning data presented several challenges to the MOS thunderstorm development. First, BLM sensor coverage is sparse, with only 9 sensors located over the Alaska interior between the Brooks Range to the north and the Alaska Range to the south (Reap 1991). This results in very limited flash detection over the far northern and southern portions of the state, as well as over water areas. Additionally, BLM lightning data were not available east of 135°W. Data for this region is part of the North American Lightning Detection Network owned by Canada, and could not be acquired without substantial cost to MDL. Thus, no lightning data were available for Southeast Alaska and the Juneau area. These limitations are addressed later in this section.

2.2 *Predictand Definition*

As in previous MOS thunderstorm developments (e.g., Hughes 2002, 2004), a thunderstorm is defined as the occurrence of one or more CG lightning strikes within a grid box during a defined period. Each lightning observation was assigned to a grid cell on a 48-km Polar Stereographic grid (with dimensions 97x69). The rectangular 48-km grid is shown in Fig. 1. CG flash counts for each grid box were tabulated for eight 3-h periods (e.g., 0000-0259 UTC, 0300-0559 UTC, …, 2100-2359 UTC). Binary indicators then were assigned to each grid box and 3-h period: a “1” if one or more flashes occurred, or a “0” if no activity occurred. Similar binary indicators were assigned to each

6-h, 12-h, and 24-h period ending at 0000, 0600, 1200, and 1800 UTC. The binary lightning indicators served as the predictands in the MOS system.

2.3 *Seasons and Projections*

The Alaska thunderstorm season is relatively short, with nearly 90% of the lightning strikes occurring during June and July (Reap 1991). Due to limited data availability, and the rareness of thunderstorms during the cool season, equations were developed only for the warm season—the period May 1 through September 30. Separate 3-, 6-, 12- and 24-h forecast equations were developed for each projection, for all four GFS model cycles. Three-hourly equations were developed out to 84 hours in advance for each cycle, while 6-, 12-, and 24-hourly equations were developed out to 192 hours for the 0000 and 1200 UTC cycles, and out to 84 hours for the 0600 and 1800 UTC cycles.

2.4 *Lightning Relative Frequencies*

Seventeen warm seasons of BLM lightning observations (1990-2006) were used to develop monthly lightning relative frequencies for 3-, 6-, 12-, and 24-h periods for each 48-km grid box (Fig. 1). The frequencies are used to study the climatological characteristics of lightning in Alaska, and are made available as potential predictors in the MOS system. Due to the lack of BLM data east of 135°W (section 2.1), relative frequencies could not be computed for Southeast Alaska. Ten warm seasons of METAR observations (1997-2006) were examined for 15 sites in Southeast Alaska in an attempt to estimate the relative frequencies for this region; however, an insufficient number of thunderstorm events were observed to allow for reliable frequencies to be computed. Thus, the relative frequencies for gridpoints east of 135°W were set to zero, and these points were excluded from the developmental sample.

An example of a 12-h lightning relative frequency during the month of July, valid for the period 1800-0600 UTC, is shown in Fig. 2. Fig. 2 reveals a major axis of lightning activity over the Alaska interior, bounded by the Brooks Range to the north and the Alaska Range to the south. These patterns are similar to those found in previous studies of Alaska thunderstorms (e.g., Reap 1991; Dissing and Verbyla 2003). Frequency values are greatest over east-central Alaska and into the Yukon Territory, where values are > 20%. 24-h frequencies (not shown) approach 30% in these areas during July. The interior of Alaska is characterized by a continental climate, where intense solar heating is the main driving mechanism for thunderstorms during the warm season. The absence of significant lightning along the coastal areas may be partially due to decreased detection efficiency of the BLM network, but is mainly due to the influence of relatively cold ocean water, which stabilizes the lower atmosphere and prevents the formation of convection (Reap 1991).

2.5 *Developmental Technique and Predictors*

Six warm seasons of GFS model forecasts (2001-2006) and relative frequencies derived from seventeen warm seasons of BLM lightning observations (section 2.4), were available to develop the equations. Since very little lightning is observed prior to May 15 or after September 15, the developmental period was restricted to 15 May – 15 September (124 days per warm season). The 2006 warm season initially was withheld as an independent data sample for testing, while the 2001-2005 warm seasons were used to develop the test equations. However, all six warm seasons were used to develop the equations that will be implemented operationally.

The equations were developed using a generalized operator approach. Geographic Information Systems (GIS) software was used to select a subset of points from the rectangular (97x69) 48-km grid (Fig. 1) to use in equation development. The points enclosed by the blue polygon in Fig. 1 were selected for the developmental sample (703 points), which corresponds to the region where BLM network flash detection and the lightning relative frequencies are the most reliable. The developmental gridpoints (Fig. 1) were combined into one region to increase the sample size and the stability of the equations. Similar approaches have been used in previous studies of Alaska thunderstorms (e.g., Reap 1991), and in previous MOS thunderstorm developments over the CONUS (e.g., Hughes 2002, 2004).

Linear screening regression was used to relate the occurrence of thunderstorms to forecast predictors from the 0000, 0600, 1200, and 1800 UTC cycles of the GFS model. This method, known as Regression Estimation of Event Probabilities (REEP; Glahn 1985), linearly relates the binary lightning predictand to one or more continuous or binary predictors. This method is much less computationally demanding than logistic regression, and operational experience has shown that the predicted values can usually be treated as specifications of the probability for the event (Wilks 2006). The REEP method sometimes can result in probability values lying outside the interval (0,1); however, this problem is handled by truncating the probabilities to the (0,1) range before they are transmitted to users.

Potential GFS forecast predictors offered to the screening regression included heights and temperatures on pressure levels, temperature lapse rates, convective precipitation, wind and moisture divergence, temperature and vorticity advection, vertical velocity, various stability indices (e.g., lifted index, K-index, Total Totals index, etc.), as well as the sine and cosine day of the year. Many of these predictors were offered in both continuous and binary form. Cross products also were offered as potential predictors, including the product of the K-index and the lightning relative frequency.

2.6 *Most Important Predictors*

GFS convective precipitation amount and the cross product of K-index and lightning relative frequency (KF) often were among the first predictors selected in the equations. Convective precipitation is highest in areas where instability and moisture profiles support convective updrafts (and thus thunderstorm development). Larger values of KF indicate regions where increased mid-level moisture and instability are coincident with higher climatological thunderstorm frequencies. This interactive predictor has been found to be useful in previous MOS thunderstorm developments (e.g., Hughes 2002, 2004), and in studies of Florida thunderstorms (e.g., Reap 1994). As expected, stability parameters such as Total Totals and K-index were selected frequently. Relative vorticity and vertical velocity also were selected, indicating that synoptic-scale forcing is important to thunderstorm development.

3. VERIFICATION

To assess the skill of the GFS thunderstorm guidance, the Brier score and the percent improvement of the Brier score (the Brier Skill Score) compared to an equation containing only climatology (i.e., the lightning relative frequencies and the sine of the day number) was computed for each forecast projection. As stated in section 2.5, test equations were developed by withholding the 2006 warm season from the sample. Forecasts generated from the test equations on the 2006 warm season then provided an independent dataset for verification.

Brier Skill Scores for the GFS MOS 3-h thunderstorm guidance are shown in Fig. 3 for the period 15 May – 15 September 2006, generated from the 0000 UTC model runs. The guidance for all projections is skillful, although significant diurnal variation is evident. The greatest skill scores are achieved during the most active periods (2100-0300 UTC), with minimal skill during periods with little lightning (1200-1800 UTC). Scores for the 6-h and 12-h thunderstorm guidance (not shown) have similar diurnal variations. Brier Skill Scores for the 24-h thunderstorm guidance is shown in Fig. 4. Scores range from a 10-12% improvement over climate at days 1 and 2, and then decrease toward minimal skill by day 7. In general, the 6-, 12- and 24-h guidance for both the 0000 and 1200 UTC cycles was found to have skill out to around 156 hours. Forecasts for projections beyond 156 hours will be left blank in the operational MOS text messages. Additional information on the operational products is given in Section 5.

4. FORECAST EXAMPLE

On July 6-7, 2006, a low pressure system and associated frontal boundary produced widespread thunderstorms across much of southern Alaska. This event produced nearly 18000 CG lightning strikes in a 24-h period, and was responsible for igniting two wildfires that burned 6700 acres near the Kuskokwim Delta in SW Alaska (BLM 2006).

The surface analysis valid at 0600 UTC on the 7th (Fig. 5) shows an area of low pressure centered over SW Alaska with a surface trough trailing from the low southwestward through the Aleutians. A stationary front extended from the low eastward to just south of Fairbanks and into the Yukon Territory. The airmass south of the front is relatively warm and moist, with dewpoints in the upper 50s south of the front and in the 40s north of the front.

A 24-h GFS MOS thunderstorm probability forecast and corresponding lightning strike verification are shown in Figs. 6a and 6b, respectively, for the period ending at 1800 UTC on 7 July. It is evident that a majority of the lightning strikes (Fig. 6b) occurred south of the stationary front in the warm unstable airmass, with most of the activity concentrated near convergence zones generated by the low pressure center and surface trough. The 24-h GFS MOS forecast generated from the 1200 UTC run on 6 July (Fig. 6a) captured the activity very well, with probabilities approaching 70% over SW Alaska. The 3-, 6-, and 12-h forecasts for this same period (not shown) also captured the observed trends in lightning activity very well during the event. Users of this gridded guidance would have been alerted hours (or perhaps days) in advance that a widespread thunderstorm event was likely to occur over SW Alaska.

5. PRODUCTS

The GFS MOS thunderstorm guidance described in this paper will become available to users beginning in May 2008, in alphanumeric text format for 130 sites in Alaska, as well as on high resolution grids to support the NDFD. A nearest-neighbor approach is used to generate the alphanumeric station guidance by matching the MOS stations to the nearest thunderstorm gridpoint (Fig. 1). The short range GFS MOS station guidance (MAV) will contain the 6- and 12-h thunderstorm probabilities out to 84 hours, while the extended range message (MEX) will contain 12- and 24-h probabilities out to 156 hours. In addition to the alphanumeric text products, the 3-, 6-, and 12-h probabilities will be available in graphical form at 3-km resolution as part of the National Digital Guidance Database (NDGD). For more information on these and other products, visit www.nws.noaa.gov/mdl/synop/products.shtml.

6. SUMMARY AND CONCLUSIONS

MDL has developed new GFS-based MOS thunderstorm guidance for Alaska in support of the NDFD, and will be implemented on May 1, 2008. This new guidance will be a valuable tool for decision makers. The gridded probability forecasts will allow the fire weather community to better assess the threat for lightning-initiated fires days in advance. Aviation users and planners of outdoor activities also will benefit from the new guidance described in this paper.

7. ACKNOWLEDGMENTS

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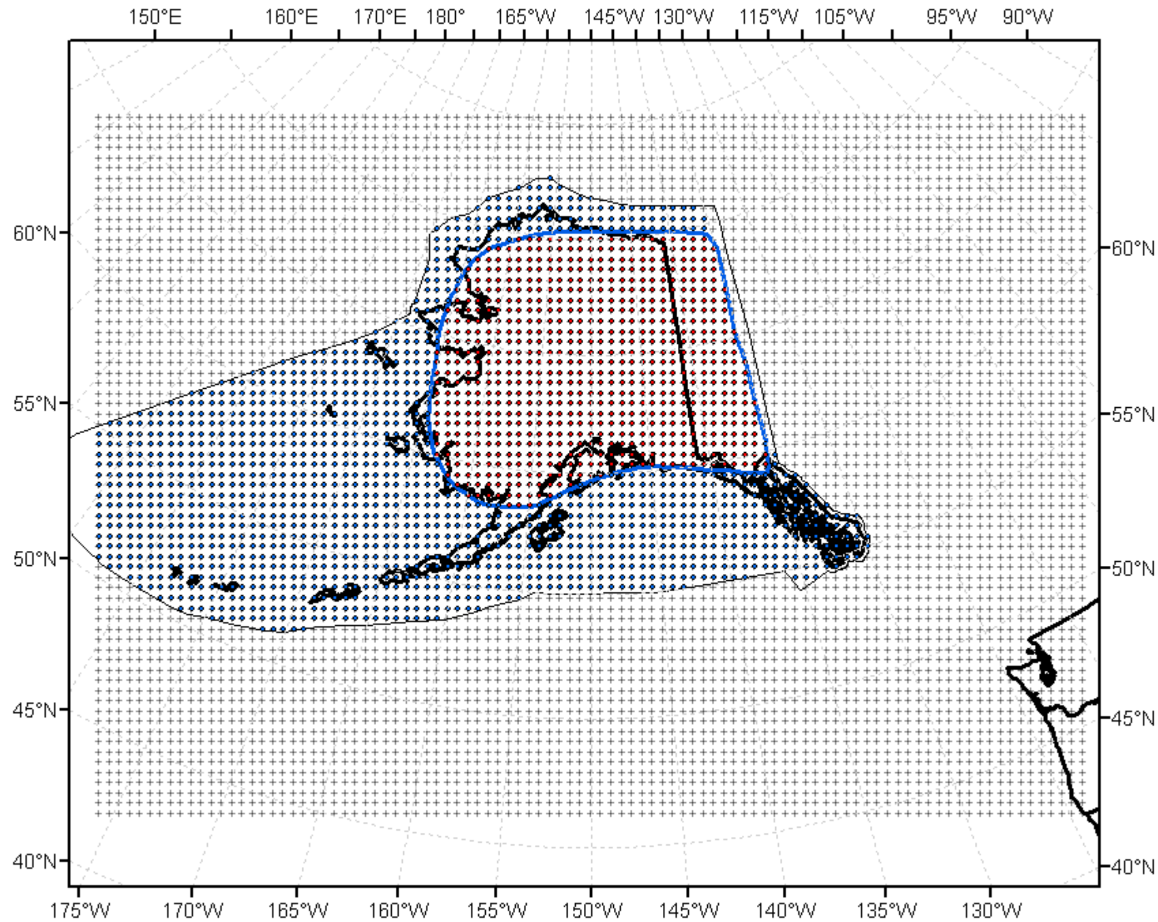

Figure 1. Polar Stereographic grid used for the 48-km GFS MOS thunderstorm development. The gridpoints used in equation development are enclosed by the blue polygon. The operational forecast gridpoints are enclosed within the larger polygon.

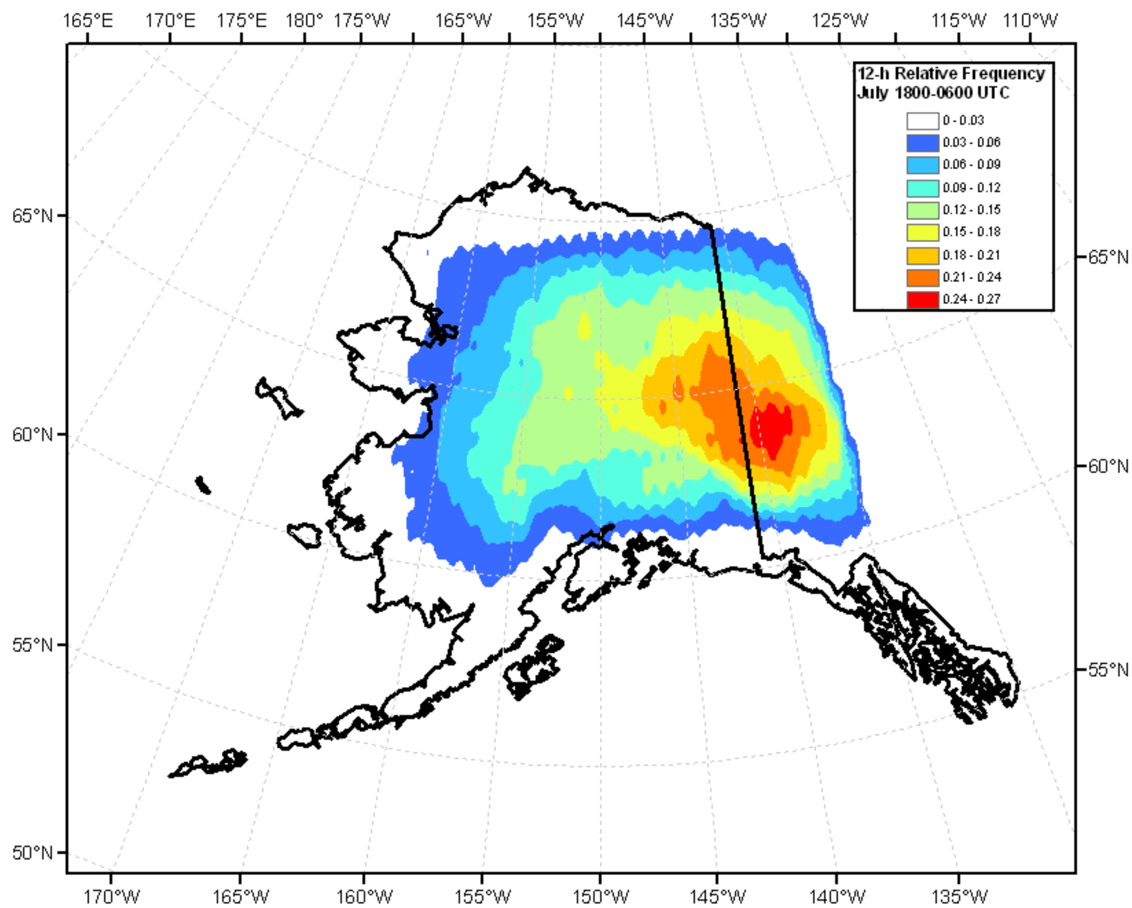

Figure 2. 12-h lightning relative frequency for July during 1800-0600 UTC.

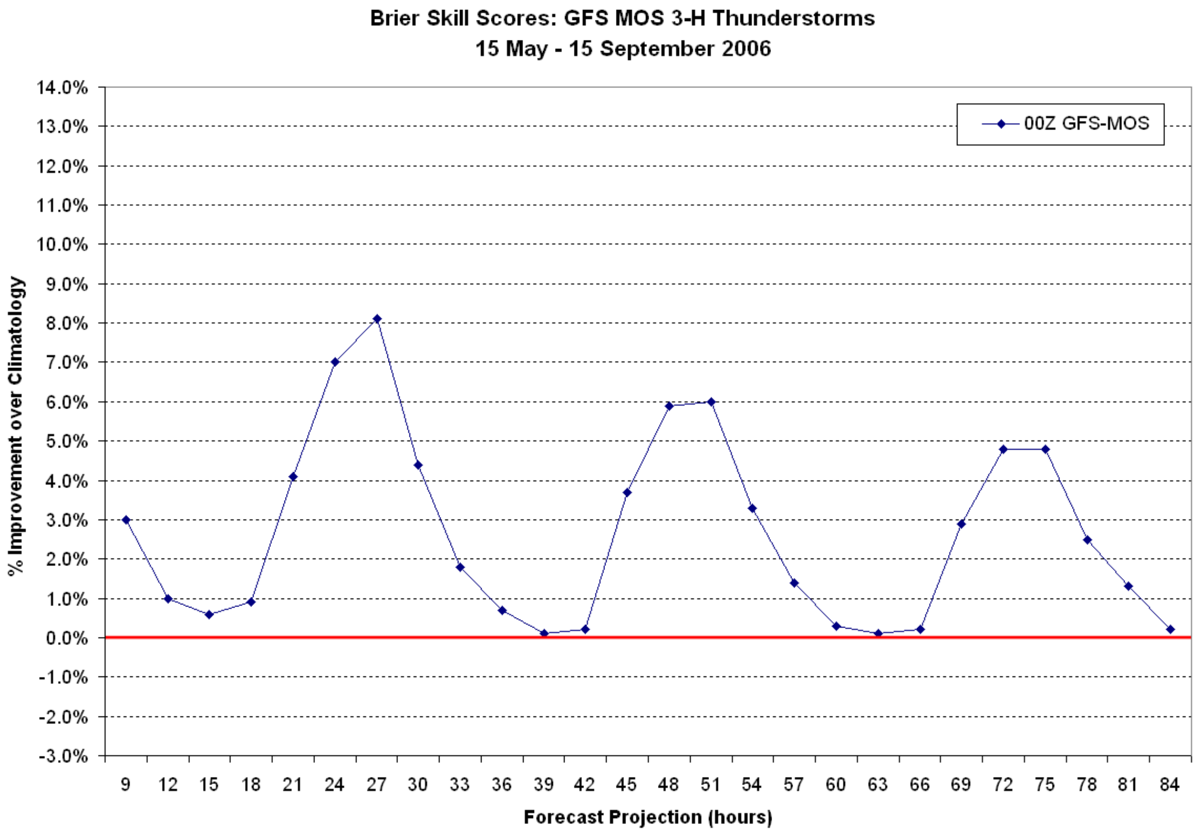

Figure 3. Brier Skill Scores for the GFS MOS 3-h thunderstorm guidance. Forecasts were generated out to 84 hours from the 0000 UTC model runs for 15 May – 15 September 2006. The zero skill line is indicated in red.

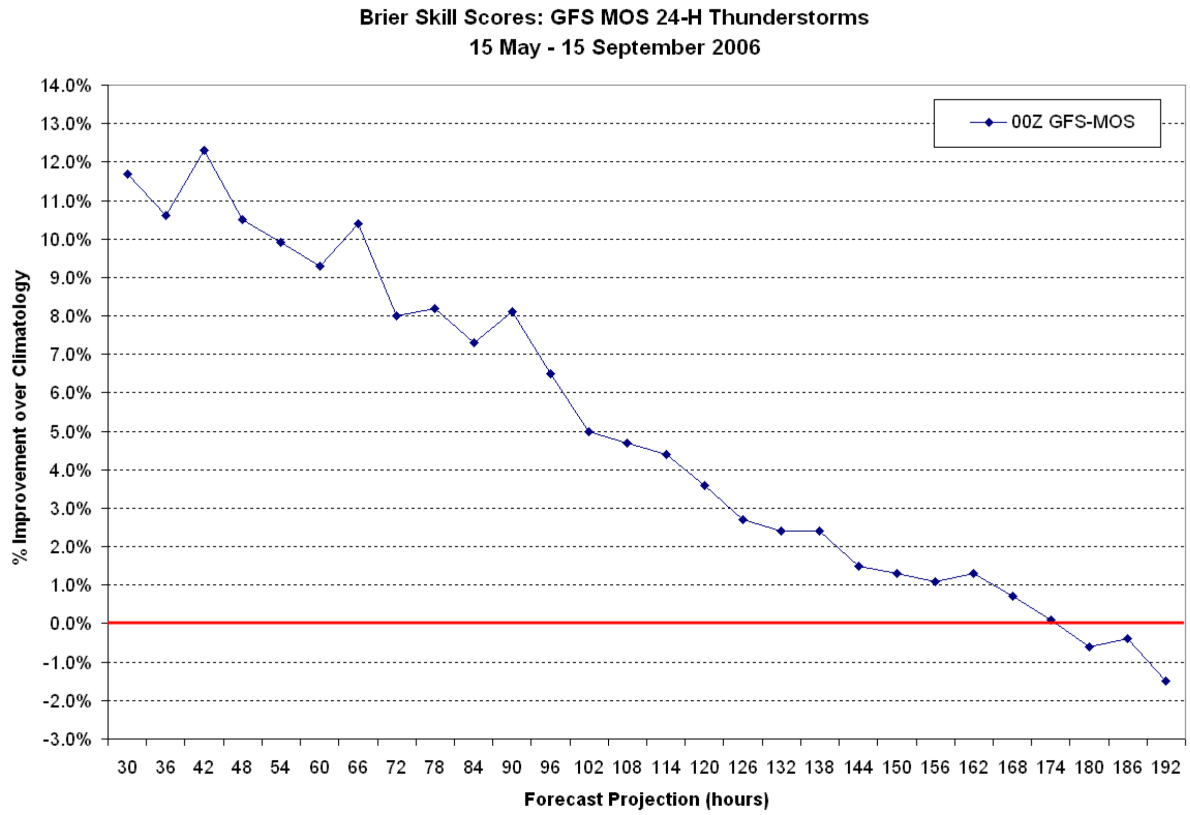

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Figure 4. Brier Skill Scores for the GFS MOS 24-h thunderstorm guidance. Forecasts were generated out to 192 hours from the 0000 UTC model runs for 15 May – 15 September 2006. The zero skill line is indicated in red.

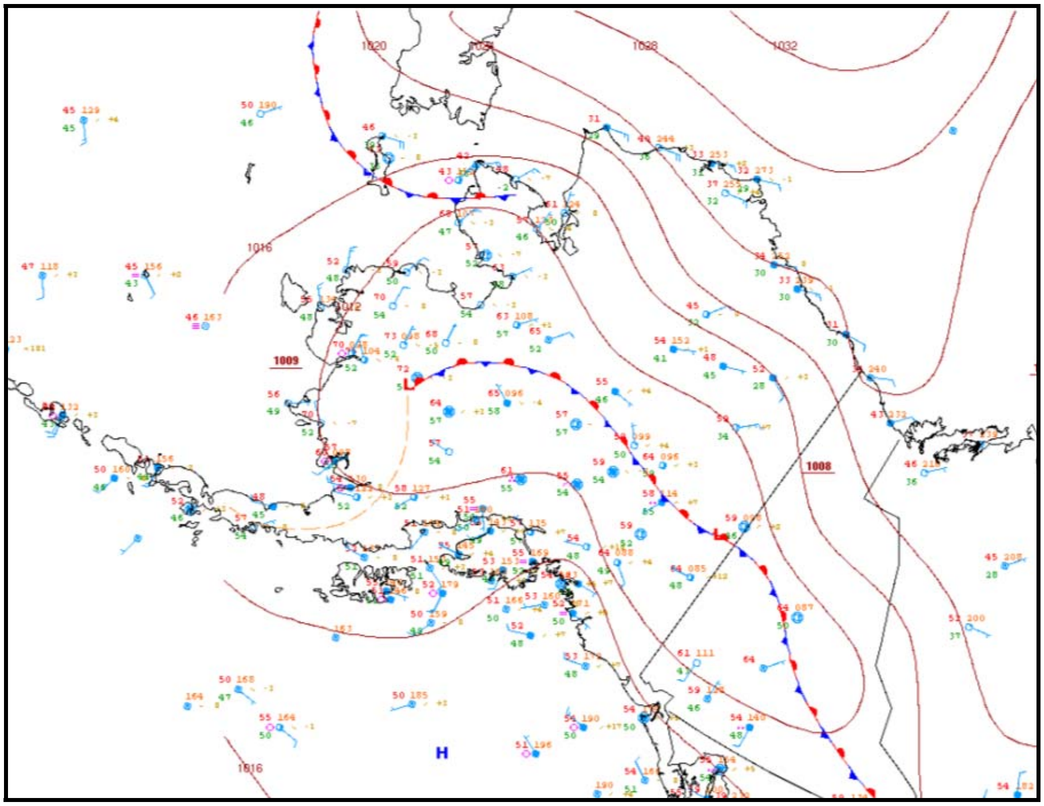
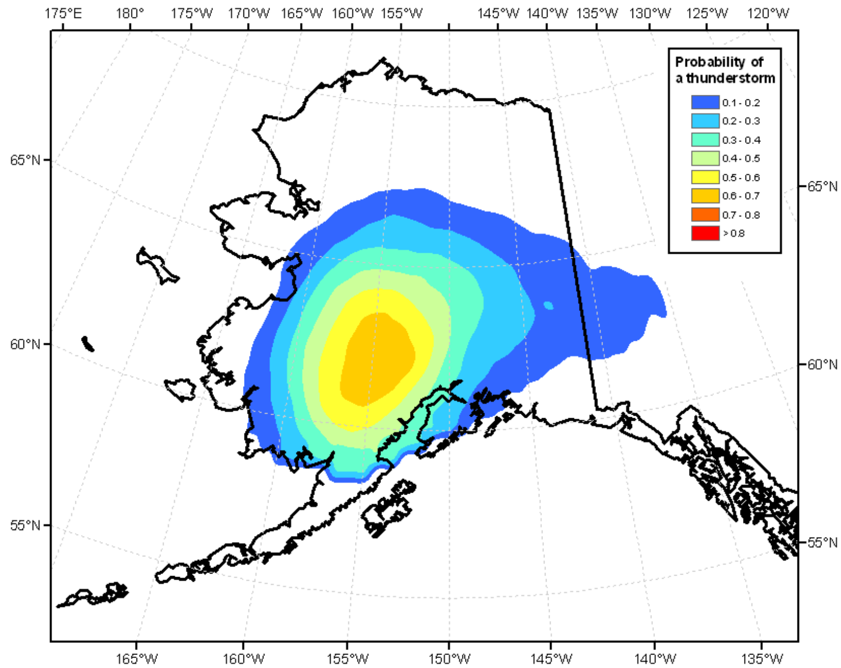


Figure 5. Surface analysis produced by the Hydrometeorological Prediction Center (HPC), valid at 0600 UTC 7 July 2006.

a) **GFS MOS 24-H Probability of a Thunderstorm (1200 UTC run 6 July) Ending 1800 UTC 7 July 2006**



b) **24-H Observed Lightning Strikes Ending 1800 UTC 7 July 2006**

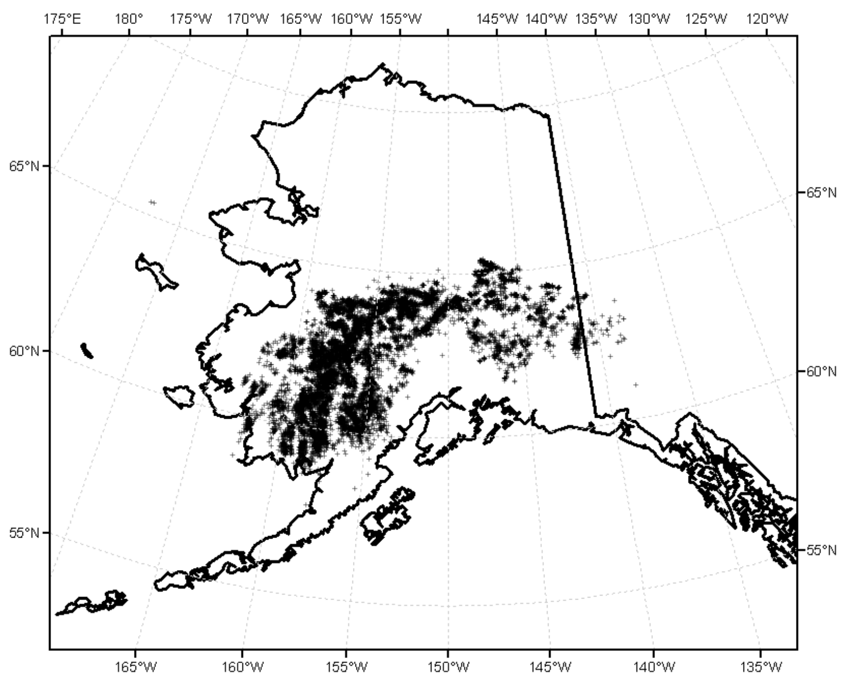


Figure 6. GFS MOS 24-h probability of a thunderstorm (a) and corresponding cloud-to-ground lightning strike verification (b) for the period ending at 1800 UTC 7 July 2006.