P1.8

USING THE PERFECT PROGNOSIS TECHNIQUE FOR PREDICTING CLOUD-TO-GROUND LIGHTNING IN MAINLAND ALASKA

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1. INTRODUCTION

Lightning initiated fires in mainland Alaska are responsible for millions of acres burned each decade. Though the direct impact to humans by the fires is limited by the sparse population of the state, large fires in this heavily forested region have the capability to devastate the ecosystem and scenery of a state in which the hunting and tourism industries are major sectors in the state's economy. In addition, localized thunderstorms present a significant risk to the aviation industry of Alaska. Furthermore, large smoke plumes caused by these fires have the potential to produce large areas of air pollution as the smoke disperses across Alaska, Canada, and eventually the continental United States. Routine and accurate thunderstorm forecast guidance with sufficient lead time can help reduce the risk of fires (caused by lightning) growing to become large uncontrolled fires.

Since the initial development of a perfect prognosis (PP) lightning prediction system in 2002 (Bothwell 2002), the Storm Prediction Center (SPC) has expanded the system (Bothwell 2008) to cover Alaska in 2008. These forecasts will be used in conjunction with ongoing predictive research into dry thunderstorms conducted at the USDA Forest Service, Pacific Wildland Fire Sciences Lab in Seattle. The PP equations for Alaska were developed from the North American Regional Reanalysis (NARR) (Mesinger and DiMego 2005) using data from 2000 to 2007. In an initial pilot project for the summer of 2008, 3 hour forecasts out to 180 hours on a 45 km grid were made using interpolated Global Forecast System (GFS) model input data. Forecasts were made for 1, 3, 10, 30 and 100 Cloud-to-Ground (CG) flash events per three hour period, and verification of one or more and 10 or more events are presented herein.

Potential users will be operational weather forecasters in Alaska as well as the Alaska Fire Service (AFS). The AFS is part of the Alaska Interagency Coordination Center (AICC), and is charged with providing wildland fire suppression services for all Department of the Interior and Native Corporation Lands in Alaska, which comprise a large portion of the state. When given adequate lead time prior to a major thunderstorm event, the AFS can be on alert for potential fire starts in the forecasted lightning areas and can be ready with pre-positioned firefighters and equipment to quickly contain fires while they are small, before they become large, uncontrollable fires that have the potential to devastate large areas. The overall goal is to decrease the number and acreage of large, catastrophic fires started by lightning, which will reduce the impact on the environment, improve the tourism and hunting sectors of Alaska's economy, and reduce firefighting expenditures.

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2. BACKGROUND

Other methods of objective prediction of CG lightning in Alaska (Reap, 1991; Shafer and Gilbert 2008) have utilized the Model Output Statistics (MOS; Glahn and Lowry, 1972) as opposed to the PP approach in this work. Reap used the Nested Grid Model (NGM) output for six hour forecasts going out to a maximum of 30 hours while Shafer and Gilbert utilized the GFS model output to produce three hour forecasts out to 84 hours and six hour forecasts from 90 to 156 hours. Reap's forecasts were able to achieve a 70% Probability of Detection (POD) at the 10% or greater forecast threshold, but only a 10% POD at the 18% forecast threshold. This was due to the MOS equation's inability to produce many probability forecasts above 15%, which was a consequence of the relative rarity of lightning activity in Alaska according to Reap. Shafer and Gilbert's verification focused on Brier Skill Scores (BSS) which indicated a 10-12% percent improvement over climatology out to 60 hours, 5% improvement out to 102 hours, and positive improvement over climatology beyond 102 hours.

3. DATA AND METHODOLOGY

To develop the equations, the NARR data were acquired from 2000 to 2007. Thermodynamic, moisture, and momentum fields from all levels of the atmosphere were combined with a CG lightning climatology (Buckey and Bothwell 2009) created on a 45km grid using lightning data from the Bureau of Land Management (BLM) network of lightning sensors. The lightning detection network consists of eleven lightning direction sensors located throughout Alaska and from six sensors located in the Yukon Territory operated by the Canadian Lightning Detection Network (Fig. 1). A correlation matrix was produced from the combined data set using an S-PLUS statistical software package. From there, principal component analysis identified the best twelve predictors and these were incorporated in the regression model.

The regression model was then tested over the summer of 2008 from 10 June to 31 August. As little lightning was observed in 2008 after 25 July, results presented below will be from the 10 June to 25 July. For this work, the selection of the input numerical weather prediction model to use for testing the equation was severely restricted by data availability constraints. Several operational models do not provide forecasts for the entire mainland Alaska domain. Of the models that do forecast for Alaska, the GFS model was chosen for several reasons. Firstly, the model output is available in three-hour intervals for 180 forecast hours, providing the potential for relatively long-range forecasts that are important for planning purposes. Secondly, as the anchor of the National Centers for Environmental Prediction models, it is readily familiar to operational meteorologists in Alaska. Lastly, PP lightning forecasts are prepared at the SPC using the GFS 1° x 1° model grids as input (remapped to 45 x 45 km grid), reducing the lag between cycle time and forecast availability.

Before being disseminated, the forecasts are subjected to additional quality controls at each grid point with the goal of setting the lightning probability to zero in areas where the atmosphere is forecast to be highly unlikely to be able to support a thunderstorm. The QC controls used are: 1) the Lifting Condensation Level (LCL) temperature must greater than -10°C, 2) the Most Unstable Convective Available Potential Energy (MUCAPE) must be greater than zero, and 3) the Equilibrium Level (EL) pressure must less than 600 millibars. If any of these conditions are not met, the thunderstorm probability for that grid box is set to 0%. The process of quality controlling the final forecast output resulted in large areas of very low probability forecasts (areas of approximately < 2% chance of one or more flashes) being set to 0%, which will be discussed in the next section. After being QC step is completed, the forecasts were disseminated via the Internet and were available to the AICC and weather forecasters in Alaska six hours after the model cycle time.

4. RESULTS

An overall summary of the verification statistics can be seen in Fig. 2. The most obvious observation is that at lower forecast probabilities, less than 30% the PP model has an under-forecast bias, in that the relative frequency of lightning occurring is greater than the average forecast percentage. At higher forecast probabilities, the opposite occurs; there is an over-forecast bias with the lightning relative frequency is less than the forecast values. The neutral point is located at the 40% forecast bin, where near perfect reliability occurs. Another important feature is that there is very little resolution in the relative frequency of lightning occurrence between the 40% bin and the 50% bin. In other words, the relative frequency of lightning is nearly constant when forecasts are between 35% and 54% inclusive.

Forecasts for ten or greater flashes (Fig. 2) show similar results as the one flash forecasts, except the transition from under-forecasting to over-forecasting occurs at the 30% forecast bin. The ten flash or greater threshold also does not suffer as great of an under-forecasting bias at low probabilities. This can be attributed to the QC not being as aggressive because a 2% forecast chance of ten flashes or greater requires a more favorable forecast environment than a 2% chance for one flash or greater. Given the more favorable environment, the chance of passing the QC checks is much improved.

In regards to the distribution of forecasts, the vast majority of non-zero forecasts for both one or greater and ten or greater flashes were in the lowest three bins, representing forecast probabilities between 1% and 14%. While higher forecast probabilities are not uncommon, they are not produced nearly as frequently because environments considered extremely favorable for thunderstorm development, i.e. high MUCAPE environments, are relatively rare in Alaska when compared to contiguous US environments. Despite the tendencies for over or under-forecasting, the observed relative frequencies of lightning always increase as the forecast probability increases with the sole exception noted above, a much desired quality by forecasters in a probabilistic forecast system.

An “early season” case from 12 UTC 13 June 2008 (Fig 3) illustrates how the PP forecasts can provide important information as far out as eight days for Alaska. The forecasts are able to capture the shifting of the thunderstorm activity from day to day, as well as predict the reduction of activity after the

17 June. The minimum in convection around 19-20 June has been shown in a lightning climatology (Buckey and Bothwell 2009) to be part of a minimum in activity before convection once again increases by late June into early July.

As mentioned in the introduction, the stated goal of the PP system is to alert users of times in which lightning initiated fires are a possibility in combination with dry fuels. In 2008, nine large fires were identified as lightning ignited by the AFS. The days the fires ignited were 29 June, 6, 7, 8, and 9 July. The 29 June (00-03 UTC 30 June) example is a single model run. The 6-9 July examples are all from the 00 UTC 6 July GFS run. Figures 4a and 4b are the climatologies of one and ten flash forecasts respectively for 9 July to 13 July. These are included so that a comparison of the climatology to the forecasts can be made. Figures 5a, 5b, and 6a to 6h depict the forecasts for both one and ten CG flash forecasts with the verifying lightning overlaid in text. An attempt to mark fire start locations caused by lightning on the plots was made; however, the exact time of most fire starts are unknown. Fires are often spotted by aerial surveys at least a day after ignition, leading to some approximation in the valid forecast time to use. Times were estimated by overlaying lightning activity with the fire start locations, taking into account the fire report date and time. The approximate positions are shown on the figures.

The figures demonstrate that the lightning events that caused fires, for the most part, were forecast extremely well. Many of the lightning events that produced fires had forecast probability values greater than 50% for one flash or more, which account for only 2% of all non-zero forecasts. Additionally, most of the fire events had 20% or higher probability for ten flashes or greater, which account for 7% of all non-zero forecasts. The 9 July event was well forecast by the PP model three days in advance of the event (Figs 6g and 6h) with forecast values of above 50% for one or more strikes and almost 30% for ten or more strikes in the vicinity of the fire start three days in advance of the event. However, the prediction system is not perfect, as seen in the 8 July case (Figs. 6c and 6d) which had many ‘missed’ lightning boxes (when lightning occurred in a 0% box) in the 48-51 hour forecast from the 00 UTC 6 July. The forecast wasn’t completely without value, as the model was able to determine that conditions favorable for lightning were going to present in central Alaska 48 hours in advance. A later forecast from 12 UTC 7 July, (Figs. 7a and 7b) was able to predict the lightning activity much better. This indicates that the later GFS run was more able to predict favorable lightning conditions compared to the earlier 00 UTC 6 July run.

5. CONCLUSIONS

It has been demonstrated that reliable PP forecasts out to at least 84 hours with value out to seven days can be made for summer CG lightning activity in Alaska for both one flash or greater and ten flashes or greater. Overall, at lower forecast probabilities, lightning activity was under-forecasted, but above 40% for one flash, 30% for ten flashes, lightning activity was over-forecasted. The PP forecasts not only are able to predict major lightning events, some more than four days in advance, but non-event days were also accurately forecast. The PP forecasts were also useful in forecasting not only the day-to-day geographic variation in lightning but also many of the lightning strikes that ignited fires. This will aid the AICC and the AFS in quickly anticipating fire starts, and thus enabling them to better prevent fires from becoming large and destructive.

6. FUTURE WORK

For the summer of 2009 and beyond, the QC controls will be reexamined and possibly modified to allow for more low-range forecasts in order to reduce the under-forecasting bias that exists at those percentages. Additionally, future forecasts will be made on a 10 km grid for mainland Alaska, increasing the resolution by nearly twentyfold. Lastly, plans are being made to expand the input model grids to include ensembles, in particular the Short Range Ensemble Forecasts (SREF) out to eighty-four hours.

7. REFERENCES

Buckey, D. R. and Bothwell, P.D, 2009: A Climatology and the Intra-Seasonal Variation of Summertime Cloud-to-Ground Lightning in Mainland Alaska. Fourth Conference on Meteorological Applications of Lightning Data, Phoenix, AZ, Amer. Meteor. Soc., 7 pp.

Glahn, H.R. and Lowry, D.A 1972: The Use of Model Output Statistics (MOS) in Objective Weather Forecasting. *J. Appl. Meteor.,* **11**, 1203-1211.

Mesinger and DiMego G., 2005: North American Regional Reanalysis. *Bull. Amer. Meteor. Soc.,* **87**, 343-360.

Reap, R. M., 1991: Climatological Characteristics and Objective Prediction of Thunderstorms over Alaska. *Wea. Forecasting.,* **6**, 309-319.

Shafer, P.E., and Gilbert, K, 2008: Developing GFS-Bases MOS Thunderstorm Guidance for Alaska. Third Conference on Meteorological Applications of Lightning Data, New Orleans, LA, Amer. Meteor. Soc., 10 pp.

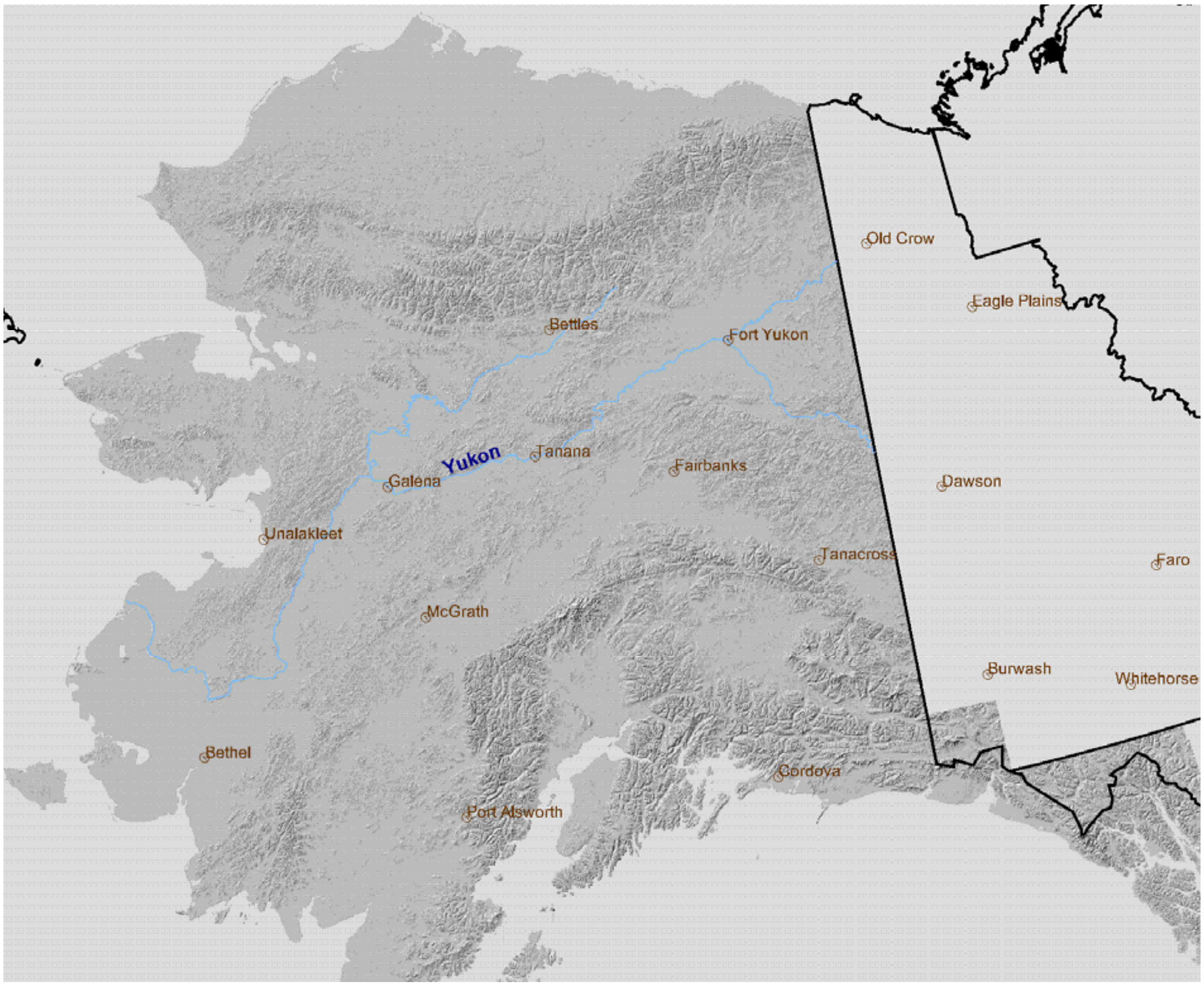


Figure 1- Map of Lightning Direction Finders in Alaska and Yukon Territory.

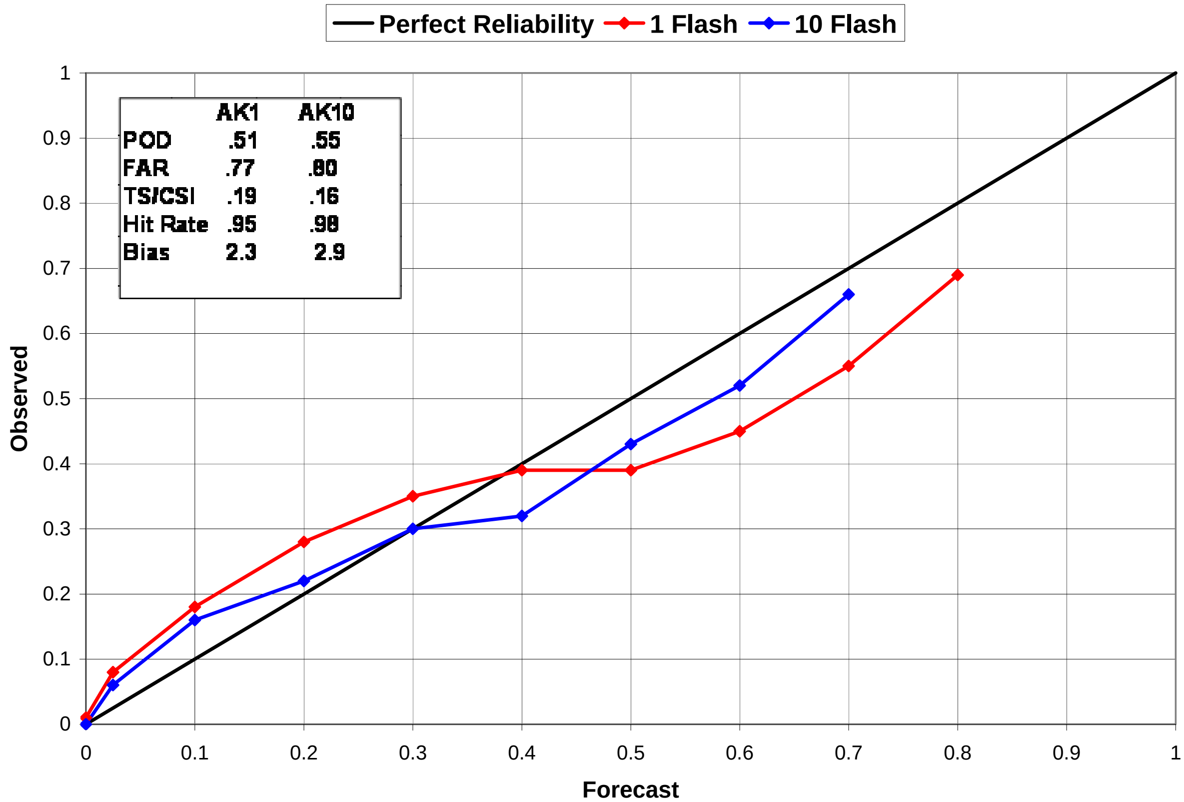


Figure 2- Reliability diagram with 2x2 matrix statistics for one flash and greater and ten flashes or Greater Forecasts Valid: June 10th-July 25th 0-84 hour forecasts for 00Z-03Z only. Small numbers of forecasts above 80% (49 total forecast points) for one flash and above 70% (31 total forecast points) for ten flashes prevented analysis of these bins. Insert box shows Probability of Detection (POD), False Alarm (FAR), Threat Score/Critical Success Index (TS/CSI), Hit rate and Bias for 1 or more flashes (AK1) and 10 or more CG flashes (AK10) for 10% probability threshold.

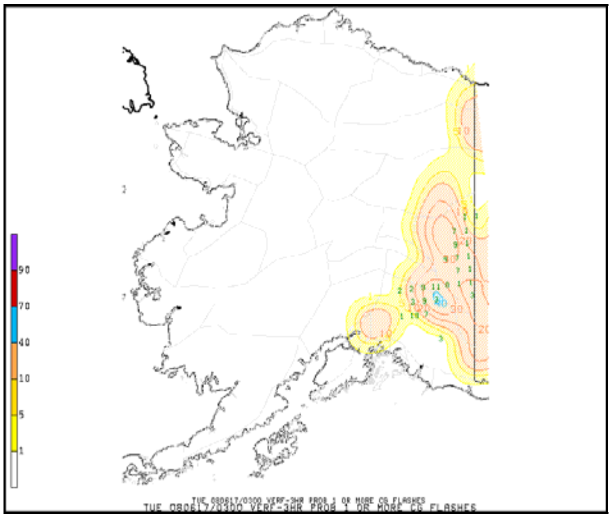


Figure 3a - 12 to 15 hour perfect prognosis forecast for 1 more CG flashes and lightning verification from the 12 UTC 13 June 2008 GFS model input. Color fills are the forecast probability, while the plotted numbers are the observed lightning in that time frame.

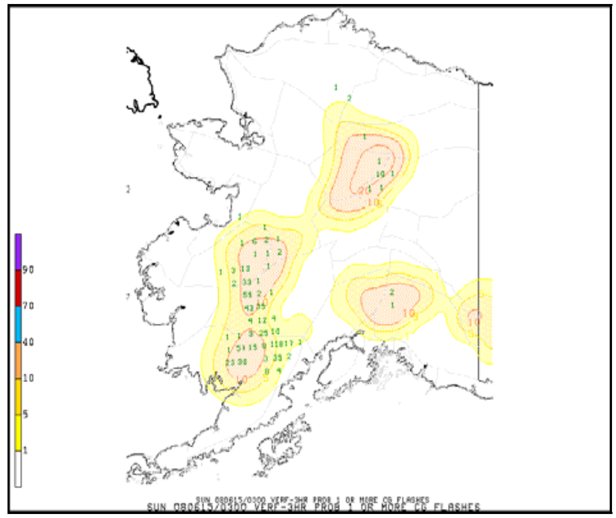


Figure 3b - Same as Figure 3a except for 36 to 39 hour forecast using same GFS model run (12 UTC 13 June 2008)

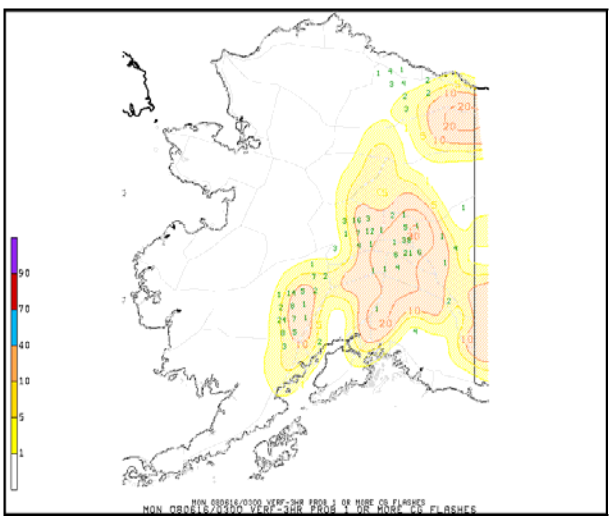


Figure 3c - Same as Figure 3a except for 60 to 63 hour forecast.

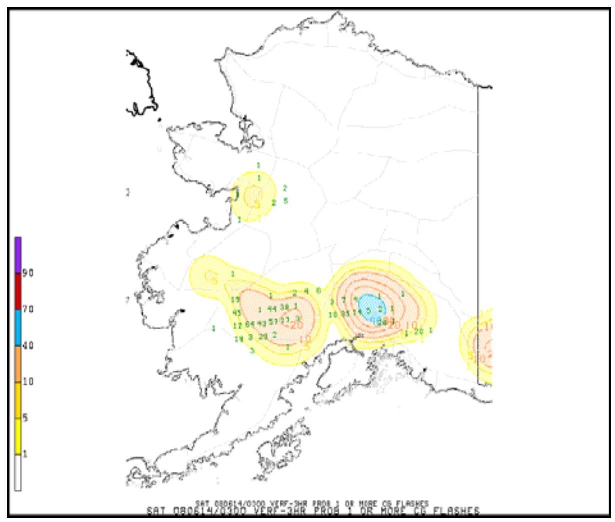


Figure 3d - Same as Figure 3a except for 84 to 87 hour forecast.

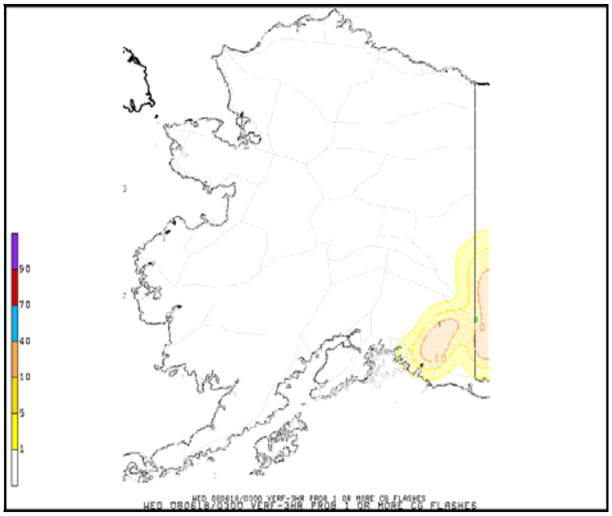


Figure 3e – Same as Figure 3a except for 108 to 111 hour forecast.

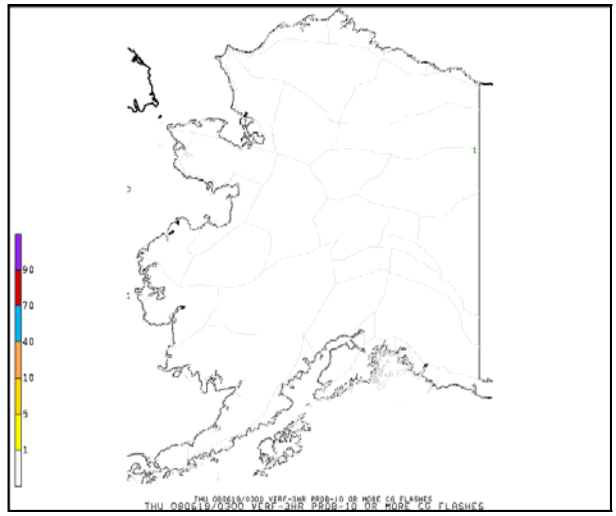


Figure 3f – Same as Figure 3a except for 132 to 135 hour forecast.

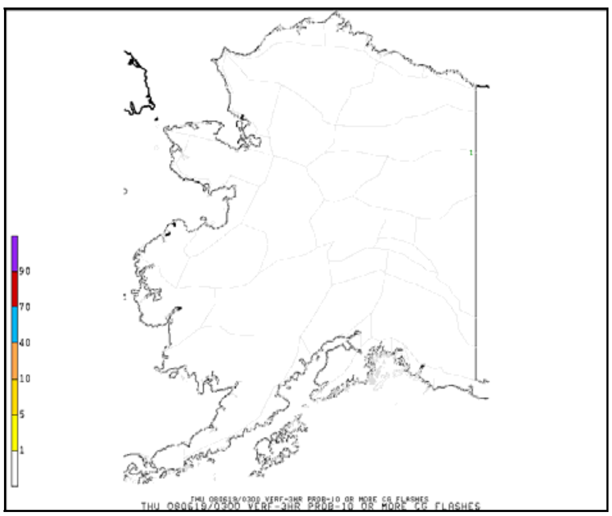


Figure 3g - Same as Figure 3a except for 156 to 159 hour forecast.

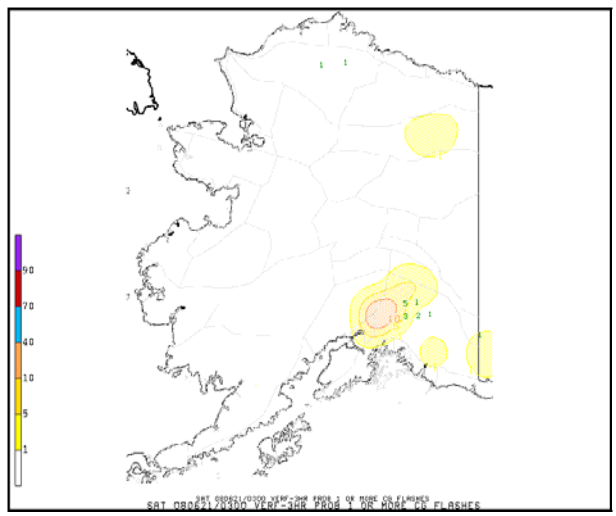
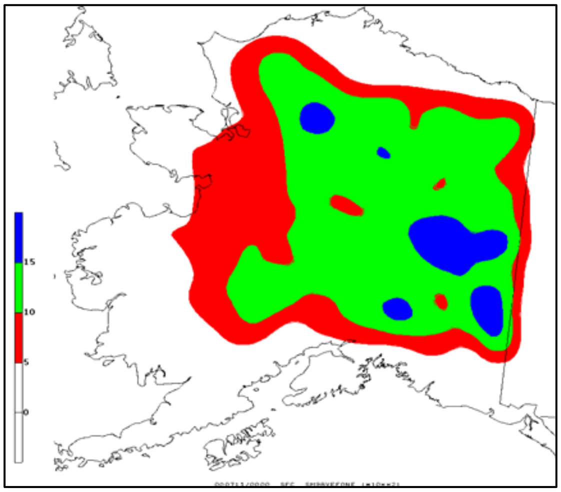


Figure 3h - Same as Figure 3a except for 180 to 183 hour forecast.



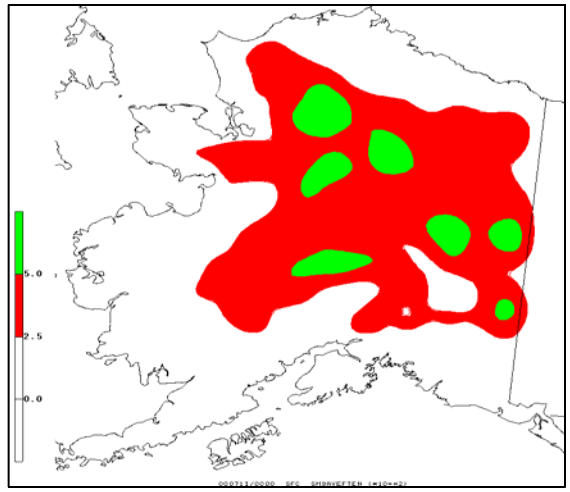
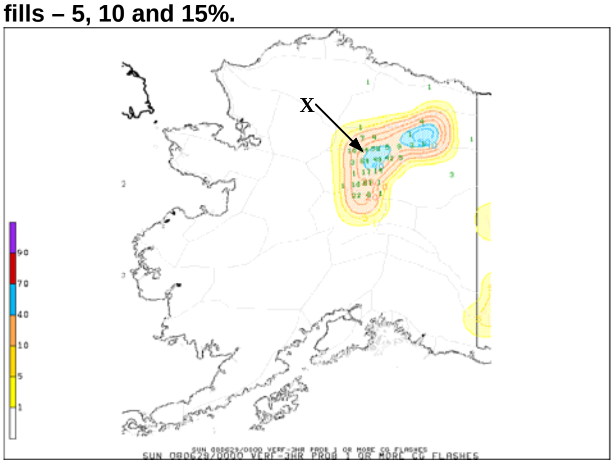


Figure 4a - Climatology of a grid box receiving one flash or greater from 9-13 July at the diurnal maximum of lightning activity (00 to 03 UTC). Color fills – 5, 10 and 15%.

Figure 4b - Same as Figure 4a except for 10 or more flashes. Note color scale differences – color fills 2.5 and 5%.



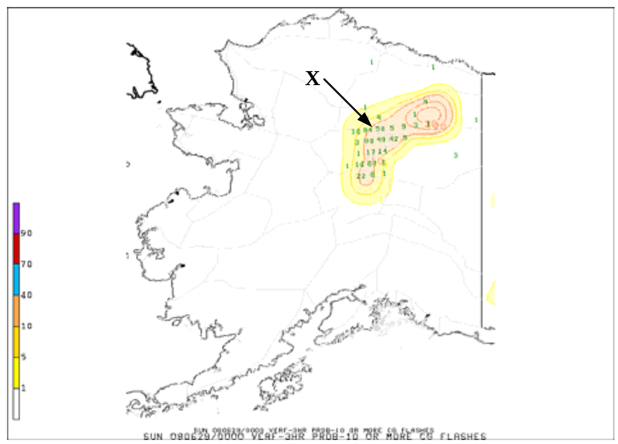
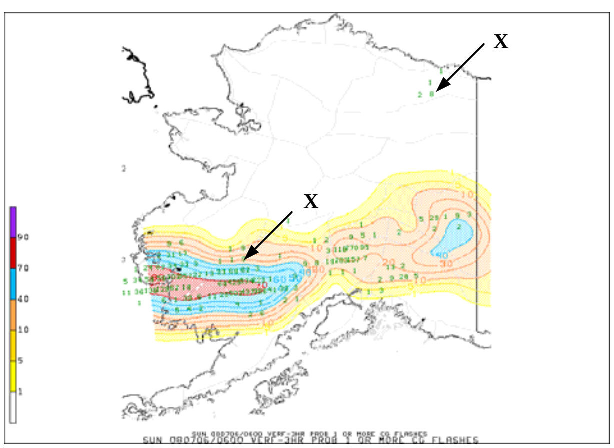


Figure 5a - 00 UTC 28 June 2008 GFS input, 21-24 hour forecast for 1 or more flashes. Estimated fire start is marked with an X and arrow.

Figure 5b - Same as 5a except for forecasts for 10 or more flashes.



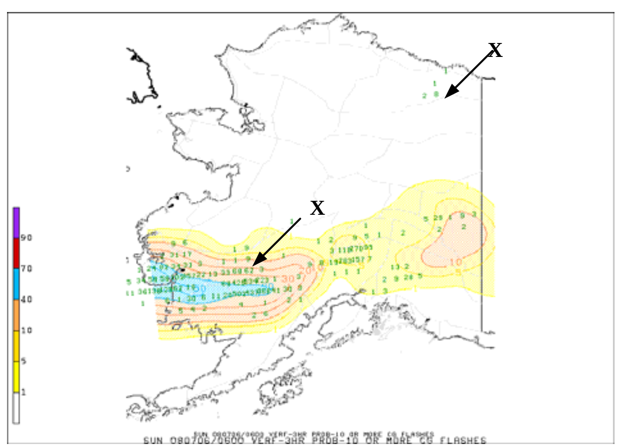


Figure 6a – 00 UTC 06 July 2008 GFS input, 3-6 hour forecast for 1 or more flashes. Estimated fire starts are marked with an X and arrow.

Figure 6b - Same as 6a except for forecasts for 10 or more flashes.

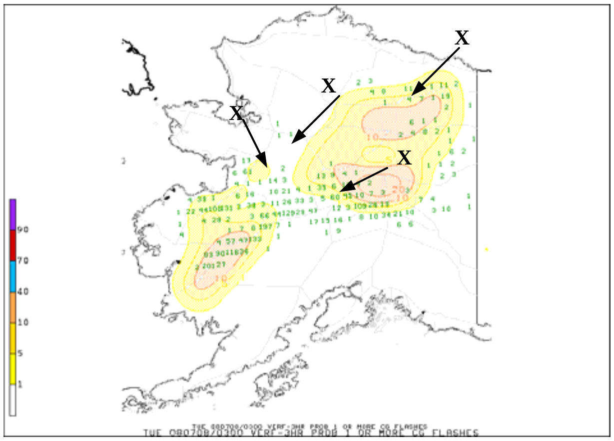


Figure 6c - Same as Figure 6a except for 48-51 hour forecast using same GFS model run (00 UTC 6 July 28).

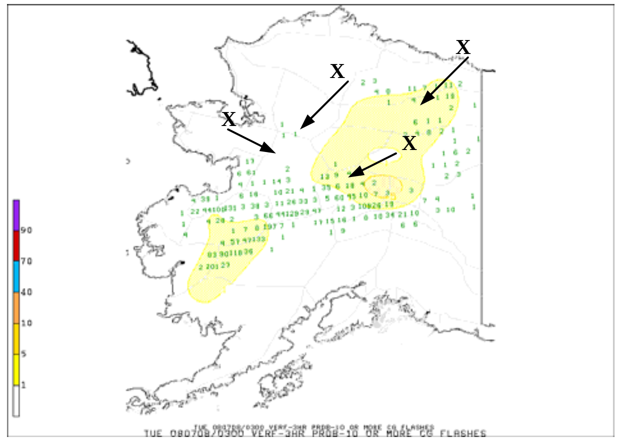


Figure 6d - Same as 6c except for 48-51 hour forecast.

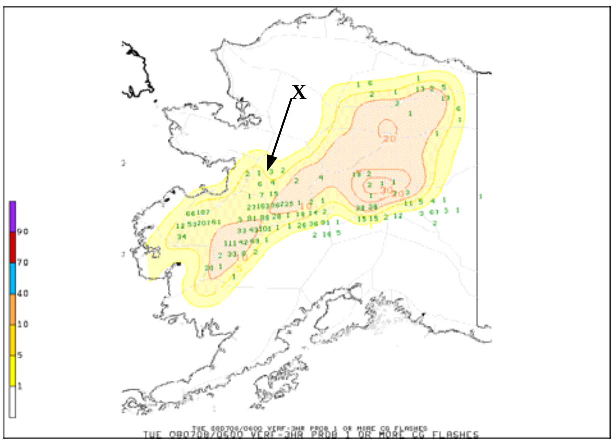


Figure 6e - Same as Figure 6a except for 51-54 hour forecast.

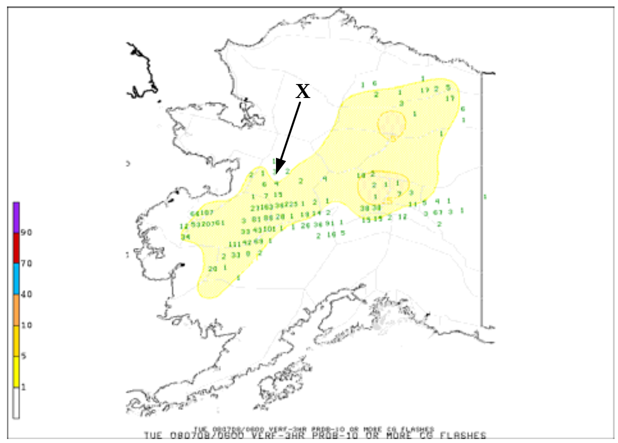


Figure 6f - Same as 6e except for forecasts for 10 or more flashes.

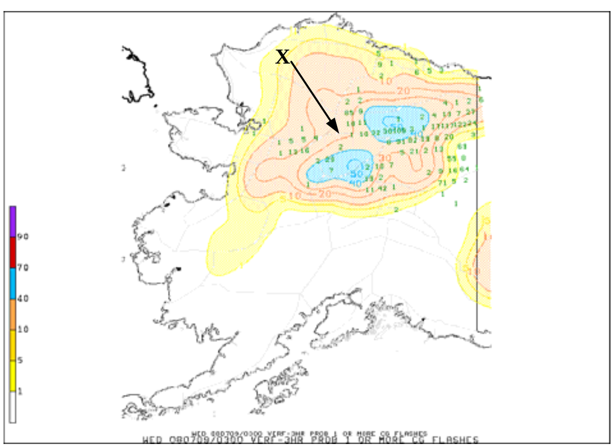


Figure 6g - Same as Figure 6a except for 72-75 hour forecast.

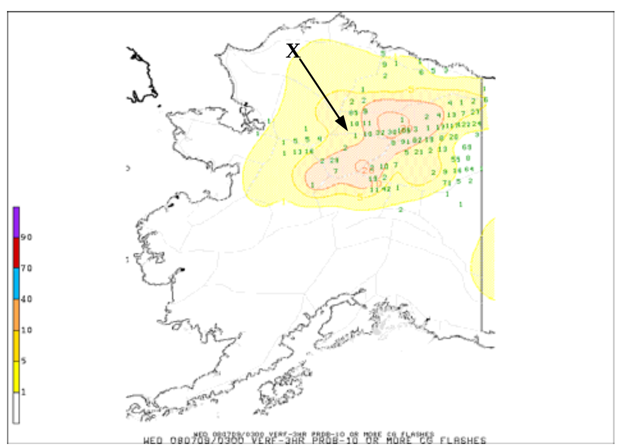


Figure 6h - Same as 6g except for forecasts for 10 or more flashes.

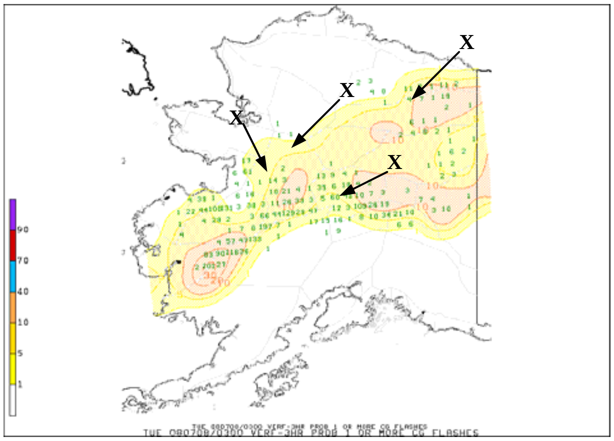


Figure 7a - 12 UTC 07 July GFS input 12-15 hour forecast for 1 or more flashes. Forecast valid for the same time as Figure 6c.

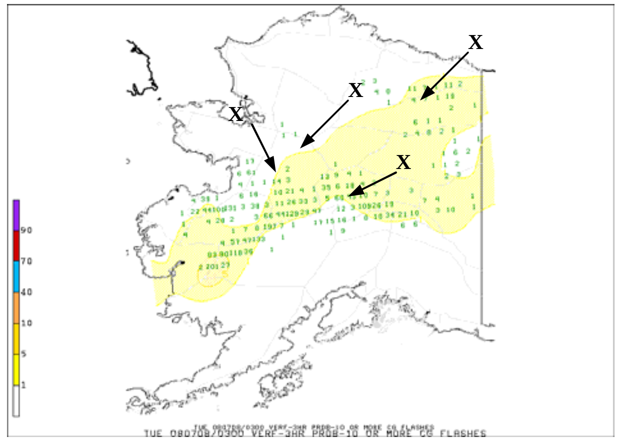


Figure 7b - Same as figure 7a forecast for 10 or more flashes.