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EVOLUTION OF THE EXPERIMENTAL/AUTOMATED PERFECT PROG LIGHTNING FORECASTS AT THE STORM PREDICTION CENTER

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1. INTRODUCTION

The Perfect Prog (Prognosis) Forecast (PPF) system used for probabilistic Cloud-to-Ground (CG) lightning (Bothwell 2002a) prediction was first implemented at the Storm Prediction Center (SPC) in 2003 on a 40 km grid over the lower 48 states. Results of the forecasts using hourly analysis to produce a 3 hour forecast as well as RUC and NAM input data to produce forecasts to 12 and 84 hours, respectively, have been reported in Bothwell (2005, 2006, 2008, and 2009). In 2008 the PPF system expanded to 3 hourly forecasts through 7.5 days covering Alaska using GFS (1x1 degree) input data interpolated to a 45 km grid (Bothwell and Buckey 2009). The system has continued to evolve in 2009 as the grid size decreased from 45 km to 10 km for Alaska.

Originally, the PPF system was designed to aid in predicting dry thunderstorms (lightning with little rainfall) that spark major wildfires in the western United States. It was also designed to aid in the prediction of thunderstorms with higher lightning flash rates which, in addition to an enhanced threat from lightning, often can be associated with severe weather and/or heavy rainfall. Since 2003, the original equations have been producing forecasts for 1 or more, 10 or more and 100 or more CG flashes, across the lower 48 states.

The equations were produced using a two year developmental sample (2001 and 2002) and were designed to produce three hour forecasts at 40 km resolution. The equations can be changed to run on different forecast time periods and resolutions. The PPF system is designed to produce forecasts using any NWP model data as input. It currently runs on four different data sets at the SPC. The input NWP model data includes the GFS, NAM and RUC as well as the SPC hourly three-dimensional gridded analysis (Bothwell et al. 2002). This results in a multi-model forecast system that provides 3 hour forecasts for periods from zero to 180 hours.

To support fire weather forecast experiments, since 2006 the perfect prog forecasts have been provided to the Western Region (WR) National Weather Service (NWS) and the forecasters from the various Federal wildland fire agencies in the western United States. A set of automated perfect prog lightning forecasts are produced during the summer time climatological peak in the lightning started wildfires over the West. This experimental system provides guidance for the prediction of dry thunderstorms and is available on an SPC internet web page.

In 2007, this experimental guidance was expanded to the NWS Weather Forecast Office (WFO) in Raleigh, NC, as part of their effort to forecast high flash density CG lightning events for the early morning Hazardous Weather Outlook. The guidance was similar to that for the western United States; however, the emphasis was on lightning events of 100 more CG flashes per 40 km grid box per 3 hours.

In 2008 and 2009, at the request of the NWS and forestry offices in the Western United States, forecasts for 10 or more CG flashes per grid box were transmitted as gridded data sets to NWS and forestry offices in the Western United States for their use in forecasting more significant dry thunderstorm events. These lightning forecasts were evaluated along with fuel dryness and lightning initiated starts. Positive results have been reported over the past two summers.

Examples of the forecasts and observed lighting as well as verification results using the different input gridded data (hourly, RUC, NAM, and GFS) have been presented previously (Bothwell 2002b, 2005, 2006, 2008, and 2009).

2. PREDICTION METHODOLOGY

The objectives as detailed in Bothwell (2002b) were to 1) develop a statistical scheme to predict thunderstorms as well as thunderstorms with high CG flash rates 2) fill in the (short-term) gap between extrapolative systems and model based systems 3) run on any forecast model or gridded data set and 4) gain a better physical understanding of the differences in environmental conditions for low and high CG flash storms.

A lightning climatology using data from 1995 to 2002 was developed both as a component of the statistical lightning predictor set and to provide insight into how lightning varied spatially and temporarily across the U.S.

As described in Bothwell (2002a), a principal component analysis grouped over 200 candidate predictors from RUC analyses every three hours into a predictor set of approximately 10 new predictors, with each new predictor related to a distinct physical process. Finally, logistic regression was used to statistically develop the perfect prog equations. The equations were developed for 18 different regions and each 3 hour time periods for summer, fall, winter and spring. Figure 1 shows the grid points that were used in the forecasts and verification.

For Alaska, the procedure was basically the same as in Bothwell (2002a) except the number of candidate predictors submitted to the principal component analysis was expanded to include more of the model data at each isobaric level (every 25 mb) and 8 years of training data (2000 to 2007) available using 3 hourly data from the North American Regional Reanalysis (NARR). Figure 2 shows the grid points used for 2008 (45 km grid length) for Alaska. Three hourly forecasts were produced using GFS 1X1 degree input data that were first interpolated to a 45 km grid in 2008.

3. SIGNIFICANT LIGHTNING

The question of what amount of lightning becomes “significant” depends on many things. First to consider is if the event will be impacting people and/or property, and if so, how long it will occur. This relates to the location in question including population density, as well as the geographic size of the area. Other things to consider are the availability of dry fuels, time of day and time of year. One CG flash can kill a person, and it can also start a major wildfire. However, the more lightning flashes, generally the more likely that a wildfire could result (depending on fuels and resources to fight the fires). Large numbers of CG flashes and/or long duration events also impact airline traffic flow and cause major power outages. In addition, severe weather events including heavy rainfall are often associated with large CG flash events.

Examples showing the importance of lightning climatology have been shown in Bothwell (2005, 2006, 2008, and 2009) and Buckey and Bothwell (2009). The SPC lightning climatologies have provided insight into what “significant” lightning might be. Figure 3 shows examples of what the probability of 1, 10, 100 or more, and the average number of CG flashes, look like from 21 to 00 UTC for a typical 5 day period (pentad) in the summer. In Fig. 3, 21 to 00 UTC is around the climatological maximum across the U.S. Figures 4a and 4b show examples for Alaska at approximately the same resolution (40km-U.S. vs.45km-Alaska) for 00 to 03 UTC, or the approximate climatological maximum for lightning in Alaska. The probability for either 1 or more or 10 or more flashes is much lower for Alaska than for the lower 48 states. Even 10 or more CG flashes can be considered a “rare event”.

As shown in Fig. 3, single flash (or, in general, low number of CG flash) events are much more likely to occur than large numbers of CG flashes, and they are much more likely in certain locations than others. The original lightning data for the lower 48 states originally included 1995 to 2002 but is now being expanded to 1995 through 2009. Lightning data from 2000 to 2007 were used for Alaska.

For the purposes of fire weather forecasting of thunderstorms that ignite wildfires, it was generally found from experience that forecasts of 100 or more CG flashes (for most of the lower 48 states as well as Alaska) were more rare and much more likely to be associated with wetting rains, thus normally not presenting a major wildfire threat. Areas such as Florida can be the exception. In 2007, Florida was in an extreme drought and two major lightning events started two major wildfires in the dry swamps. Examples of forecasts and verification results for the forecasts of 1, 10 and 100 or more flashes will be shown in the next section.

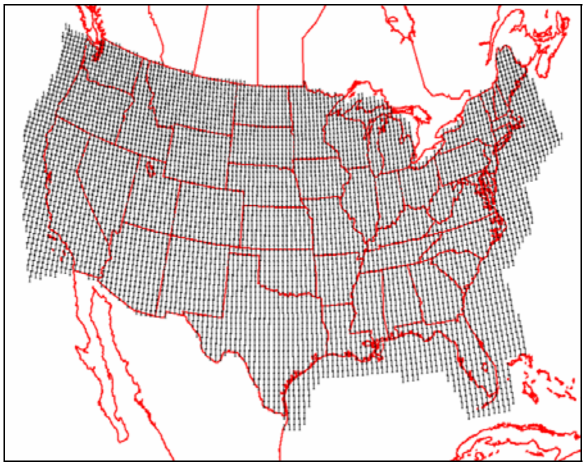

Figure 1. 40 km grid point locations. These points are also the same points used for the verification.

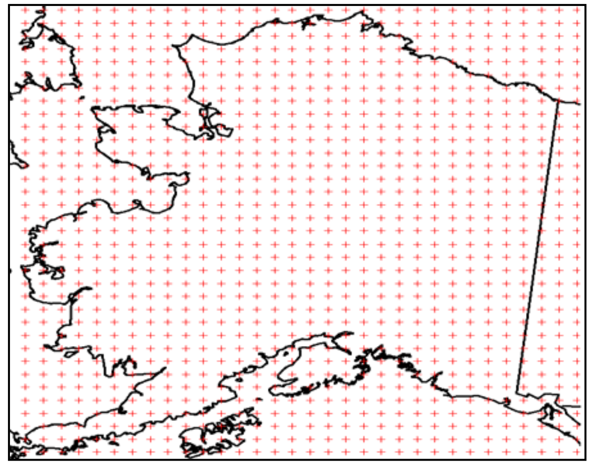

Figure 2. 45 km grid point locations. These points are also the same points used for the verification.

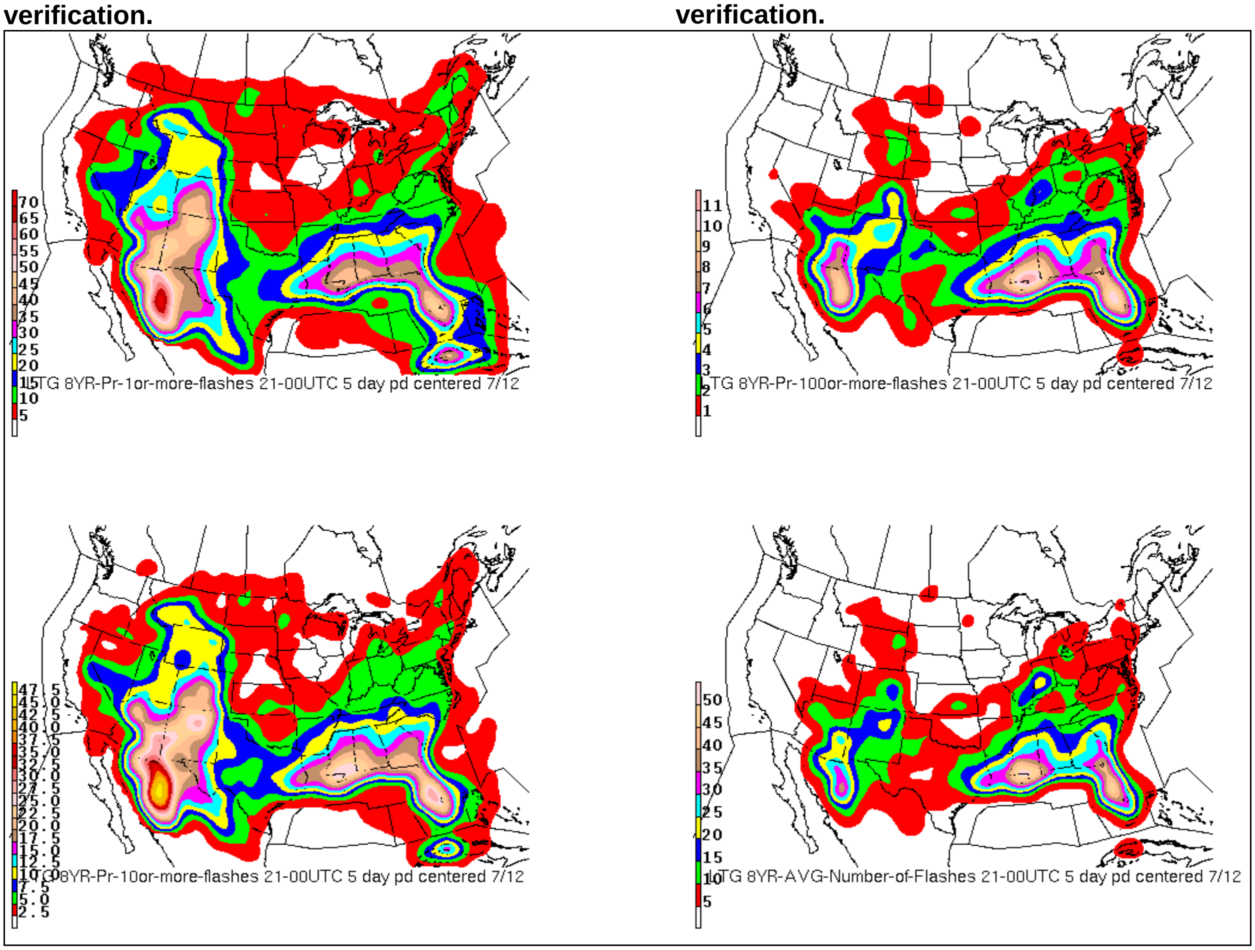

Figure 3. Lightning climatology (40 km grid length) for 5 day period centered on July 12 for 21 to 00 UTC (approximately the time of maximum convective activity). Upper left-probability of 1 or more CG flashes, lower right-probability of 10 or more CG flashes, upper right-probability of 100 or more CG flashes and lower right-average number of CG flashes (note color fill intervals change for each figure).

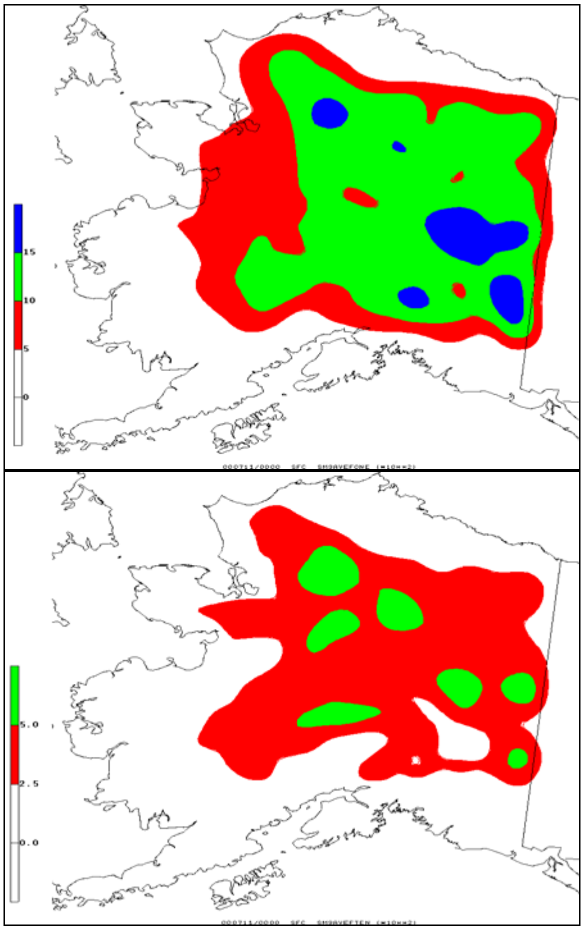

Figure 4 (above). Lightning climatology for Alaska for 5 day period centered on July 11 for 00 to 03 UTC (approximate peak in convective activity). Top (4a) is for probability of 1 or more CG flashes per 45 km grid box (every 5%) and bottom (4b) is for 10 or more flashes (every 2.5%).

Figure 5 shows three examples of the probability of 1 or more CG flashes across the entire 5 day time period (pentad) centered on July 12. As Fig. 5 shows, the probability of 1 or more CG flashes depends of the size of the grid box. Figure 5a is for a 40 km grid while 5b is for a 20 km grid and 5c is for a 12 km grid. For the gridded climatology, the resolution of the grid partially determines the probability. Higher probabilities occur for larger grid boxes, and decrease dramatically as the size of the grid box decreases (from 40 to 20 to 12 km in this example)

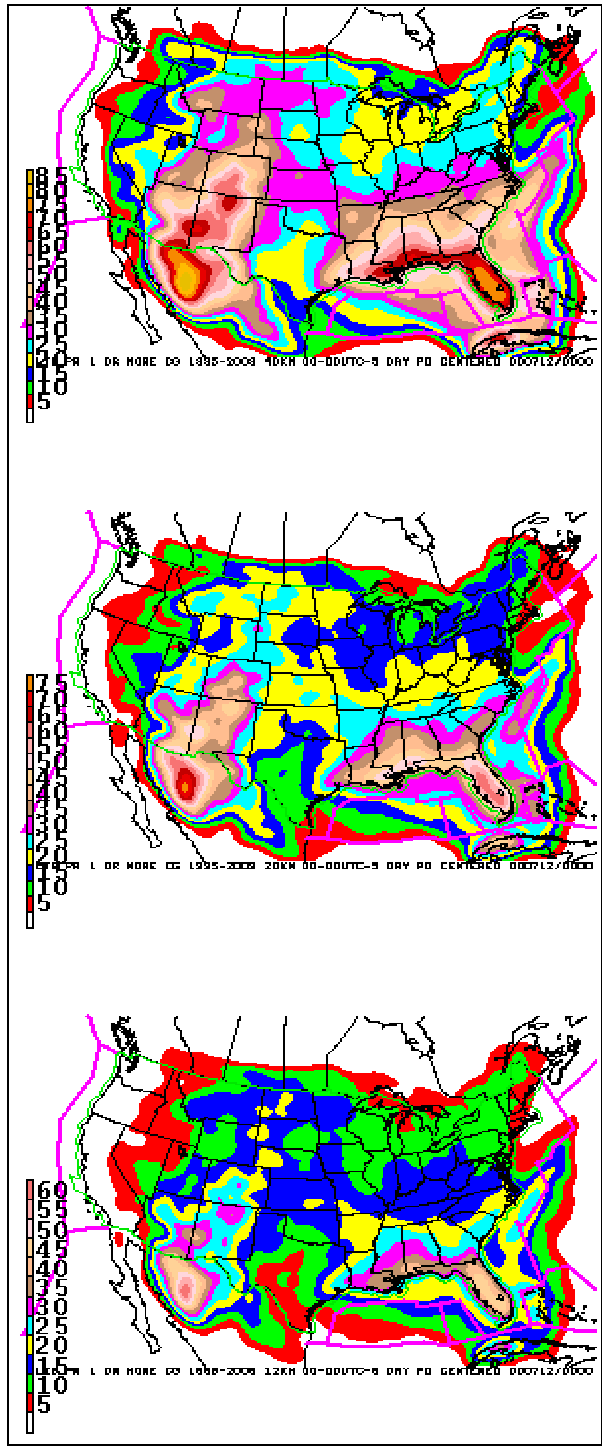

Figure 5 (above). Climatological probability of 1 or more CG flashes during the 5 day period centered on July 12 on 40 km grid (5a-top), 20 km grid (5b-center) and 12 km grid (5c-bottom). Based on lightning data from 1995 through 2009.

4. LIGHTNING FORECASTS-VERIFICATION

Since 2006, experimental, automated forecasts for several classes of lightning events have been produced for National Weather Service (NWS) Western Region Forecast Offices and the USDA Forest Service. These include forecasts for 1 or more flashes and 100 or more CG flashes. Beginning in 2008, forecasts for 10 or more flashes were made available in gridded form for the western U.S. WFO's and fire agencies. This experimental program was established to assess the potential for improving dry thunderstorm forecasts (catching the big outbreaks) by merging forecasts of significant lightning, 10 or more CG flashes, with fuel dryness values. The Day 1 forecast period covered 18 to 06 UTC while the Days 2, 3, and 4 periods covered 06 to 06 UTC. In this evaluation of the forecasts, the 12 or 24 hour probability was simply taken to be the maximum of any of the individual 3 hour forecasts for 10 or more CG flashes.

The reliability diagram for forecasts of 10 or more CG flashes for Days 1, 2, 3 and 4 (June-August 2008) is shown in Fig. 6 for the western U.S. (west of 102^{o} longitude). Each of the days exhibits some under forecasting for probability values of 10 to 40 percent and then over forecasting from 60 to 90 percent. There were too few forecasts above 95 percent to be plotted.

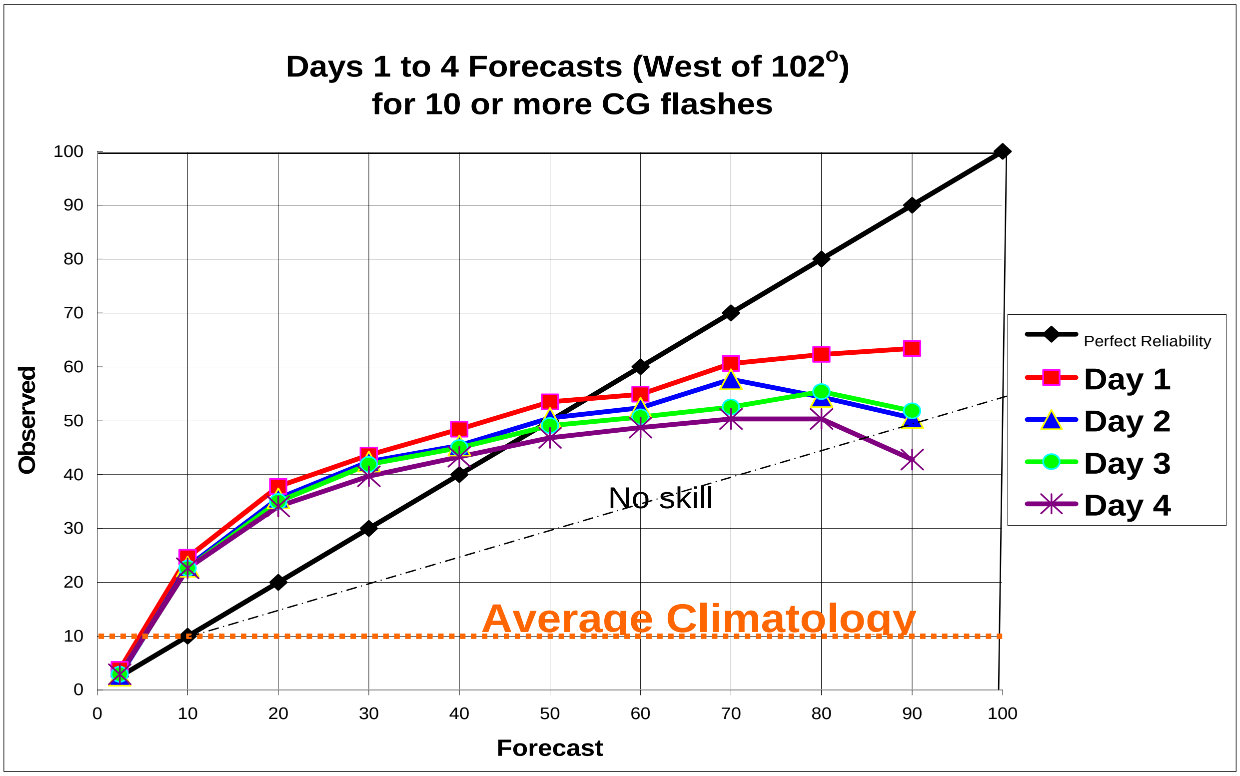

Figure 6. Reliability diagram for forecasts of 10 or more CG flashes for Day 1 (18 to 06 UTC) and Days 2, 3 and 4 (each 06 to 06 UTC using 12 UTC NAM input data). An average climatology across the western U.S. for 10 or more CG flashes is shown as the dashed orange line and the "no-skill" line is the gray dashed-dotted line.

Although thunderstorms with 10 or more CG flashes per 3 hour periods are much less common in Alaska compared to the western U.S. (or elsewhere in the U.S), the newest perfect prog forecast equations in 2008 for Alaska produced more reliable results as shown in Fig. 7. The maximum activity in the U.S. from all 21 to 00 UTC forecasts is compared with the maximum in activity for Alaska (00 to 03 UTC) forecasts through 84 hours.

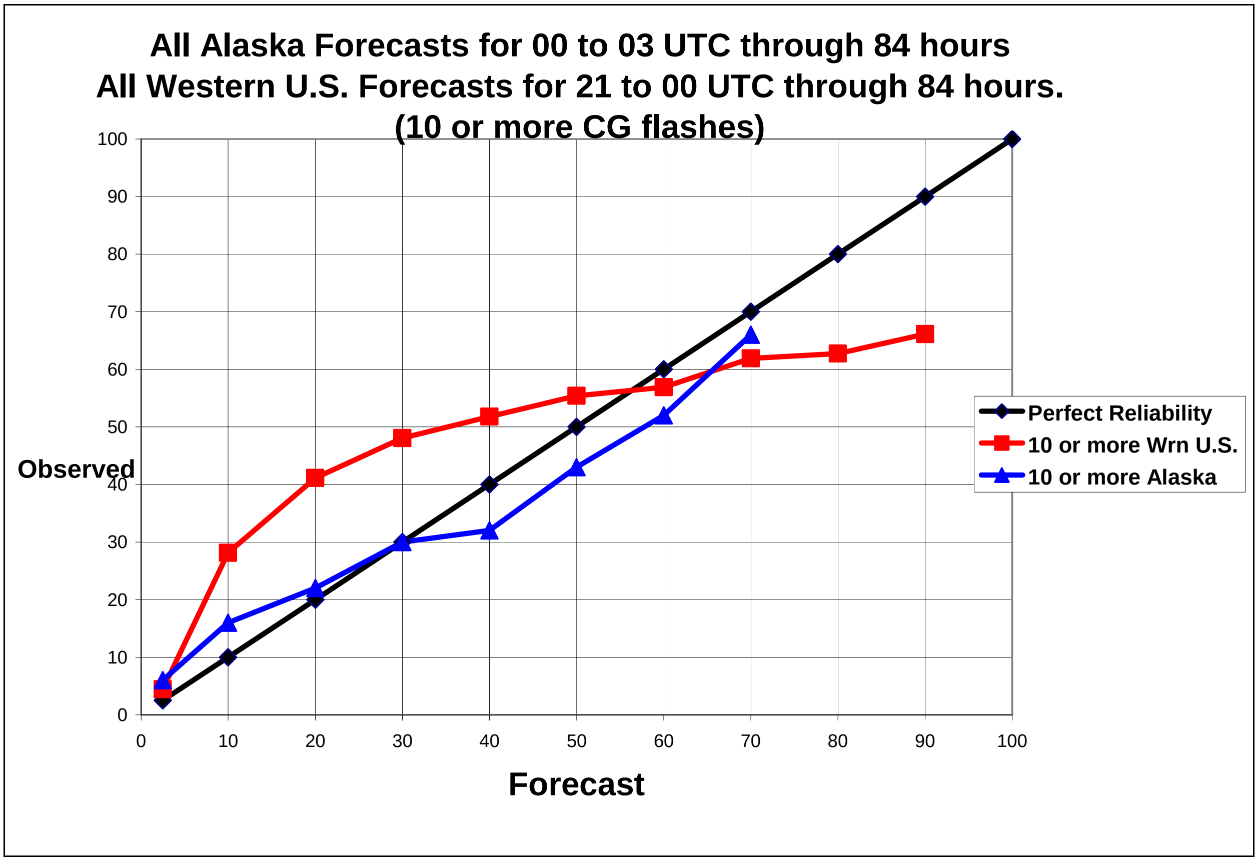

Figure 7. Comparison of all forecasts at peak in afternoon activity (21-00 UTC) through 84 hr - forecasts for 10 or more CG flashes (west of 102 longitude)-red squares; 10 or more CG flashes for Alaska-blue triangles except for climatological max for 00 to 03 UTC.

For Alaska in 2009, the grid spacing of the forecasts was decreased to 10 km from 45 km (still using the 1x1 degree GFS input data). For comparison purposes, the 00 UTC (overnight run) was still run at 45 km and the 06, 12, and 18 UTC runs were at 10 km. Figure 8 shows how both forecasts generally capture the area of CG lightning well; however, the probabilities for the 10 km grid are lower as the climatology for much smaller grid boxes (not shown for Alaska) is also greatly reduced. Figure 9 is for the same time periods, but for forecasts or 10 or more CG flashes rather than 1 or more flashes as in Fig. 8. Again, probabilities are lower for the higher resolution grid and users of this type of data should be aware of changes when the grid size changes.

Finally, in Fig. 10, a much longer lead time forecast valid for 1 or more and 10 or more flashes at 72 to 75 hours is shown. These forecasts capture the event well approximately 3 days in advance.

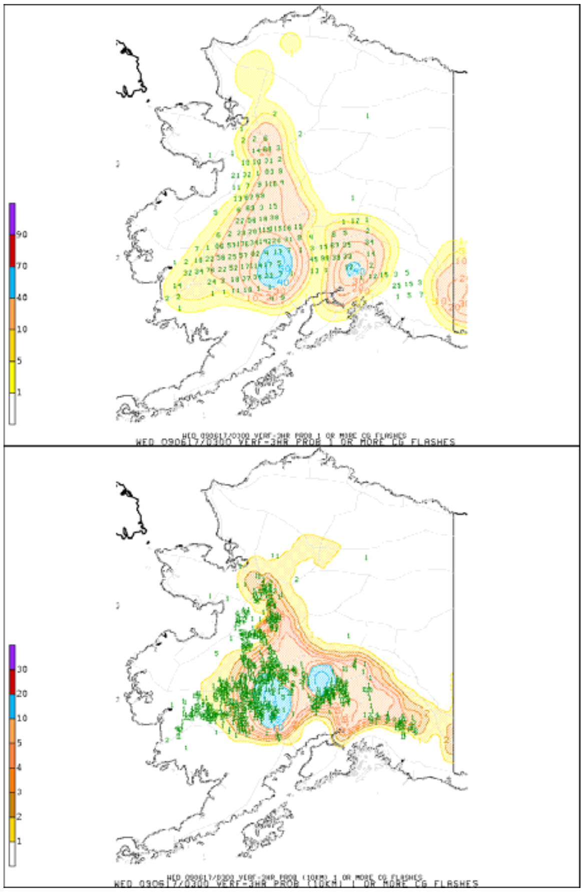

Figure 8. 24 to 27 hour forecast for 1 or more CG flashes on a 45 km grid (top) and 12 to 15 hour forecast on a 10 km grid (both valid from 00 to 03 UTC 17 June 2009)

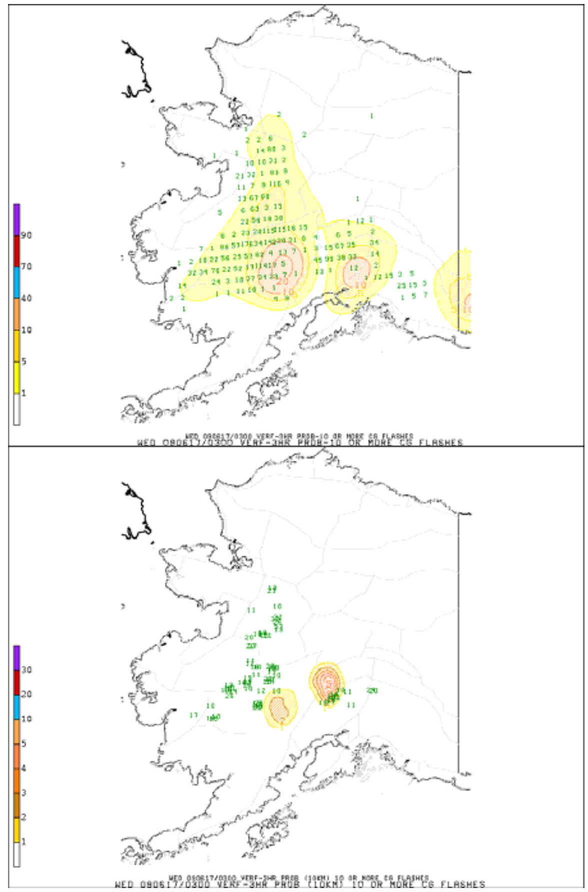

Figure 9. Same as for Figure 8, but for forecasts of 10 or more CG flashes.

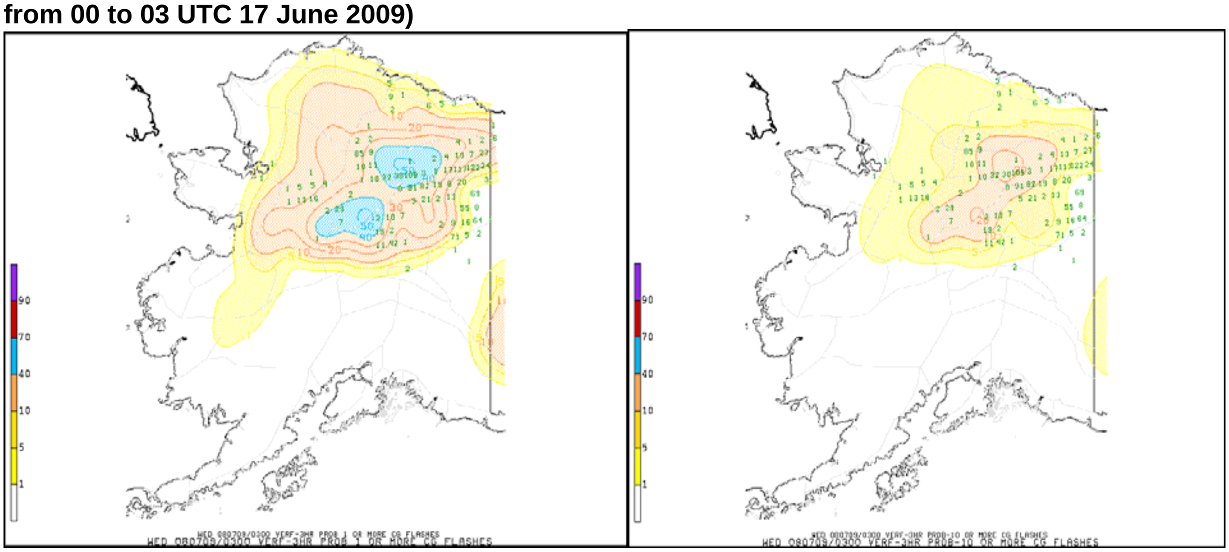

Figure 10. 72 to 75 hour forecasts from GFS model input valid from 00 to 03 UTC 9 July 2008. Left graphic is forecast for 1 or more CG flashes (contours) and lightning (plotted numbers). Right graphic is forecast for 10 or more CG flashes and lightning.

Finally, even though it is rare, during the extreme drought of early 2007 for much of the southeast, the PPF system was able to correctly forecast events over Florida with well over 100 CG flashes that ultimately were responsible for lightning started wildfires over the dry swamp areas along the Georgia/Florida border, as well as over south Florida. Figures 11 and 12 are forecasts for 100 or more CG flashes for the Day 1 (12 to 12 UTC) period and the plots of lightning where grid boxes reported 100 or more CG flashes.

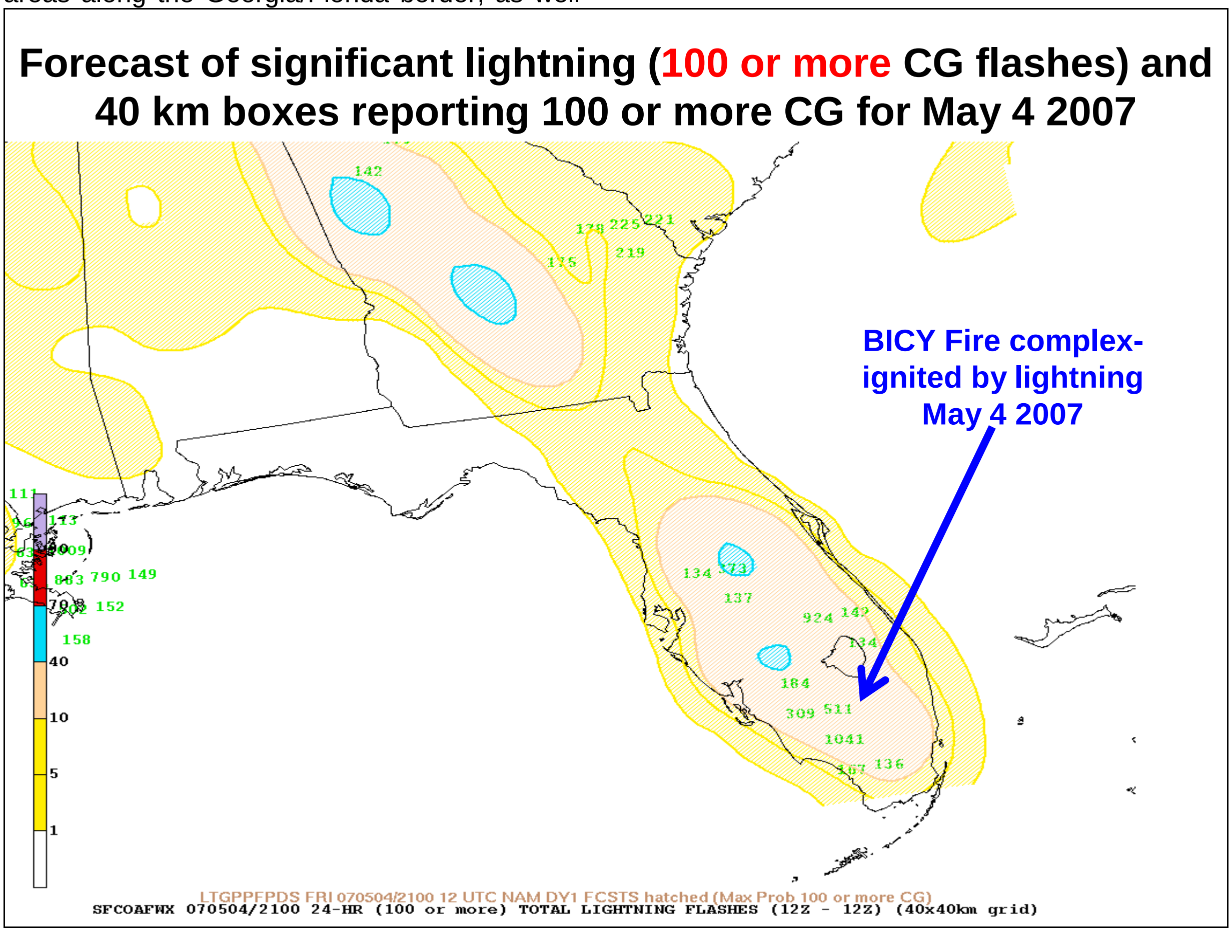

Figure 11. 4 May 2007- 24 hour forecast of 100 or more CG flashes and lightning plots for 40 km grid boxes with 100 or more CG flashes.

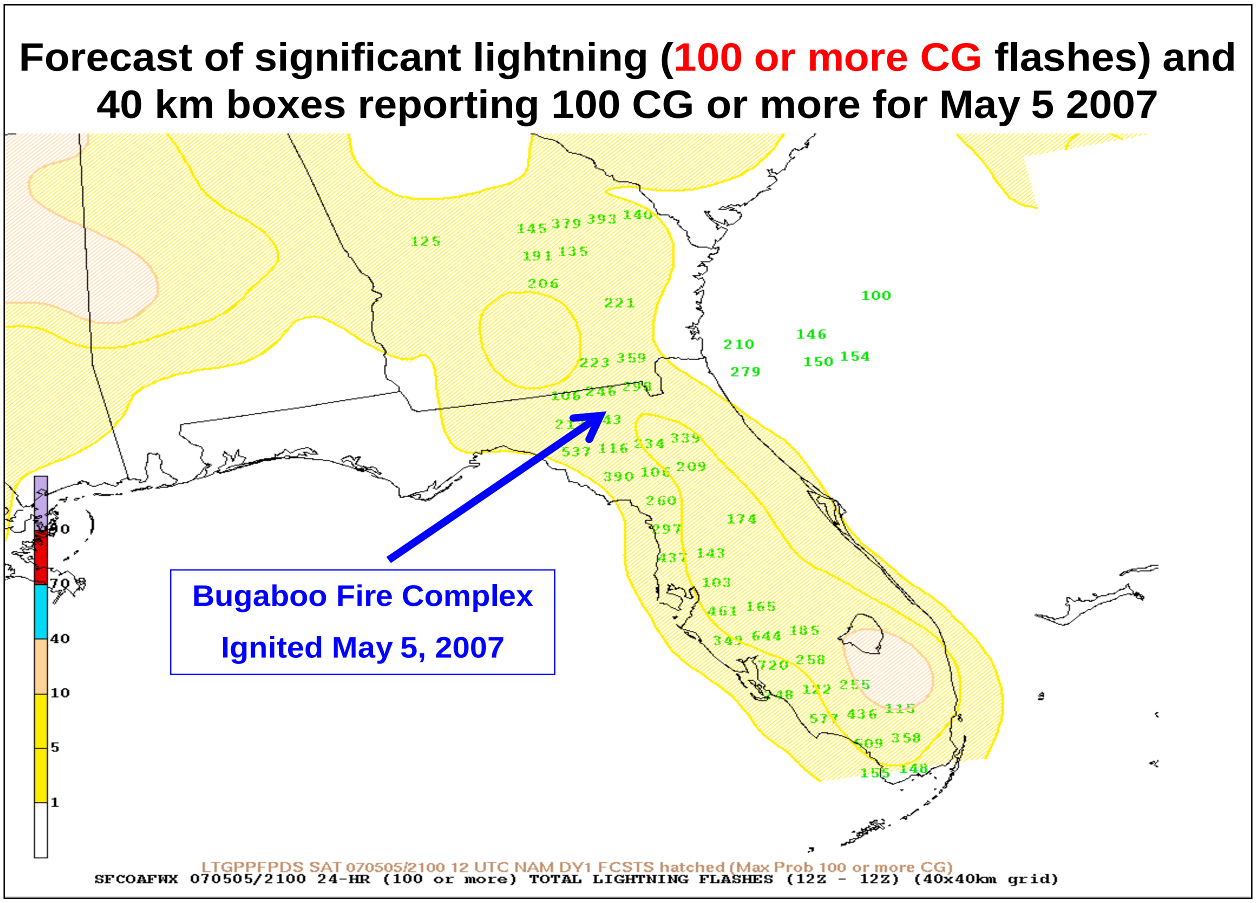

Figure 12. Same as for Fig. 12 but for next day, 5 May 2007.

5. CONCLUSIONS AND FUTURE WORK

Perfect Prog lightning forecasts produced at the SPC since 2003 have been made increasingly available to those involved in predicting lightning started wildfires and are providing useful forecasts for the prediction of the lightning events (1, 10 or 100 or more CG flashes) that can results in wildfires across both the lower 48 states and Alaska.

A revised and expanded predictor set using 1x1 degree GFS input data interpolated to a 45 km grid over Alaska in 2008 shows improved results over the first equations for the lower 48 states implemented in 2003. The forecasts for Alaska were further refined to an experimental 10 km grid for 2009. Similar improvements are planned for the summer of 2010 for the lower 48 states using 12 km NAM higher resolution equations.

Also, for the summer of 2010, new equations will produce perfect prog forecasts from each of the Short Range Ensemble Forecast (SREF) members. In this manner, an "envelope" of probabilities will be produced for each time period at 40 km resolution from 0 to 84 hours. It will also be possible to apply the perfect prog technique to GFS model input data in order to produce a 7.5 day (180 hr) forecast for the lower 48 states.

6. ACKNOWLEDGEMENTS

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