Forecasting Lightning Using a Perfect Prog Technique Applied to Multiple Operational Models

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ABSTRACT: Using a multi-year period of observed cloud-to-ground (CG) lightning flashes over Alaska and the contiguous U.S. (CONUS), a climatology of lightning has been developed and is used along with NARR analyses to create prediction equations for lightning. The method uses a perfect prog(nosis) technique and logistic regression to build equations for predicting lightning within 10-km grids in Alaska and 40-km grids for the CONUS. These equations can be applied to a number of NCEP model forecasts including the GFS, NAM, RAP and SREF in real time. One of the primary applications of the lightning guidance is for predicting lightning-started wildfires. Since lightning often strikes in remote areas with rugged terrain, the fires that result from those ignitions often consume the most acreage with catastrophic results. Prediction of lightning, days in advance, allows for better planning and positioning of fire-fighting resources to attack fires while they are still small and more easily controlled.

Probabilistic lightning forecasts for 1, 3, and 10 or more CG flashes are made for Alaska (10 x 10 km grid box) while probabilistic forecasts for 1, 10, and 100 or more CG flashes are made for the CONUS (40 x 40 km grid box). The ability to produce forecasts from a variety of models offers several unique benefits. Hourly forecasts for the short term (0 to 18 hours) can be produced using the RAP model. At the other end of the spectrum, 3-hour forecasts can be produced using the GFS model out to 7.5 days. In addition, the same equations can be applied to an ensemble (e.g., SREF) to produce a range, or envelope, of probabilities for each 3 hour time period.

INTRODUCTION

The Perfect Prog (Prognosis) Forecast (PPF) system to predict probabilistic Cloud-to-Ground (CG) lightning (Bothwell 2002a) was first implemented at the Storm Prediction Center (SPC) in 2003. It combined a Principal Component Analysis with Logistic regression to produce a set of forecast equations that could run using any model input data. Originally, it was designed to aid in predicting dry thunderstorms (lightning with little rainfall) that spark major wildfires in the western United States.

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When given adequate lead time prior to a major thunderstorm event, fire-fighting resources can be pre-positioned to quickly contain the starts before they become large, uncontrollable fires that have the potential to devastate large areas.

The PPF system was also designed to provide guidance for the prediction of thunderstorms with high lightning CG flash rates which, in addition to an enhanced threat from lightning, often can be related to severe weather and/or heavy rainfall. Attempts at predicting the number of flashes (Reap 1986), especially the high CG flash events, have had little success. To better predict large flash events, using a "pseudo-log" scale, forecasts are produced for 1 or more CG flashes, 3 or more, 10 or more, 30 or more and 100 or more CG flashes. Events with 100 or more CG flashes per grid "cell" per 3 hours are infrequent in most sections of the country, but with this method, probabilities can be produced for high flash-rate events.

The objectives as originally detailed in Bothwell (2002a) were to 1) develop a statistical scheme to predict thunderstorms (dry or wet storms) as well as thunderstorms with high CG flash rates 2) fill in the (short-term) gap between purely extrapolative systems and model based systems and 3) run on any forecast model.

BACKGROUND

Starting in 2003, the PPFs used input data from the North American Mesoscale (NAM) model out to 84 (3.5 days) hours and the Rapid Update Cycle (RUC) model on a 40x40 km grid (Fig. 1). In 2008, the forecasts were expanded to Alaska using input data from the Global Forecast System (GFS) model out to 180 hours (7.5 days) (Bothwell and Bucky 2009). Forecasts are produced from each model cycle. In addition, the three-hour forecasts are combined (simply by using the maximum probability of any of the three-hour time periods) to produce forecasts for other time intervals, such as 24 hours. In 2006, these forecasts were made available to the fire community on an experimental web page, and beginning in 2008, the Alaska forecasts (originally on a 45-km grid) were also made available on an experimental web page. In 2009, the Alaska grid was changed to a 10x10 km grid (Fig. 2). The forecast probabilities of lightning for Alaska are usually lower than probabilities for the lower 48 states, owing to a lower frequency of occurrence of lightning in Alaska (and usually for only about a 6 to 8 week period). Also, as the grid changed from 45 to 10 km, the probability of lightning in each of the smaller grid cells was reduced. Therefore, it is useful to compare the probability forecasts of lightning to the lightning climatologies (see examples in Figs. 3 and 4) to place them into context. Higher flash rates are rarer and probabilities are correspondingly lower for these types of event.

Beginning in 2011, using a new development set of approximately two years of analyses from the RUC model; equations were developed and applied to the NAM, GFS, RUC (now the Rapid Refresh (RAP)) and the Short Range Ensemble Forecast (SREF) input data to produce experimental lightning forecasts. Using the PP method, no changes are needed when models undergo an upgrade or a complete change (such as Eta to NAM or RUC to RAP). Also, the prediction scheme was streamlined, allowing all forecasts to run in real time and for model-to-model comparison. Two sets of equations were developed: one set was for the warm season, April through September, and the other for the cool season, October through March. Simple comparisons of the lightning forecasts for 1 or more CG flashes from these different models show that they generally produce similar results, with differences owing to the characteristics and data assimilation of each model.

As a part of a project to predict dry thunderstorms as well as all thunderstorms (funded by the Joint Fire Sciences Program (JFSP)), a more robust set of equations was developed (see Richardson 2013) using a 12-year lightning and precipitation climatology from 2000 to 2011 along with the corresponding 32-km North American Regional Reanalysis (NARR) data (Mesinger et al. 2006) at three-hour intervals (i.e., 00, 03, 06…18, and 21UTC).

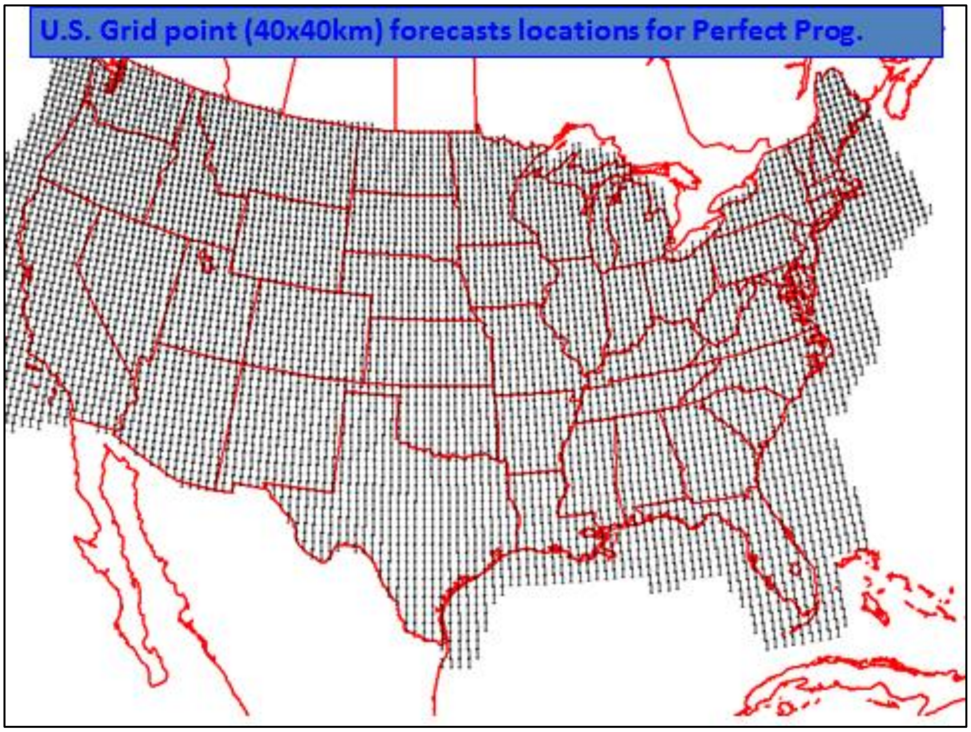

Figure 1. U.S. grid (40 x 40 km).

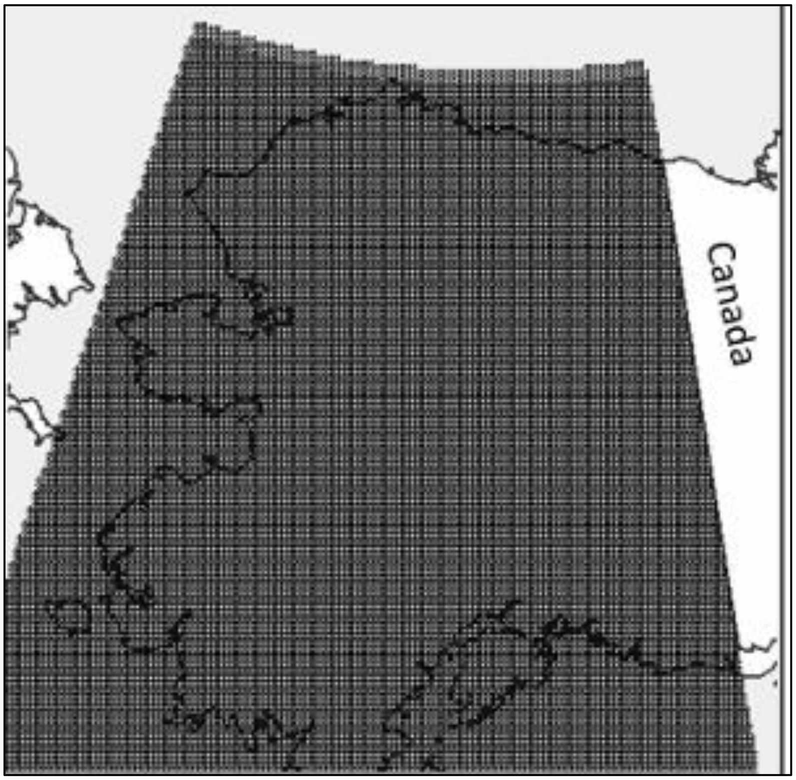

Figure 2. Alaska grid (10 x 10 km).

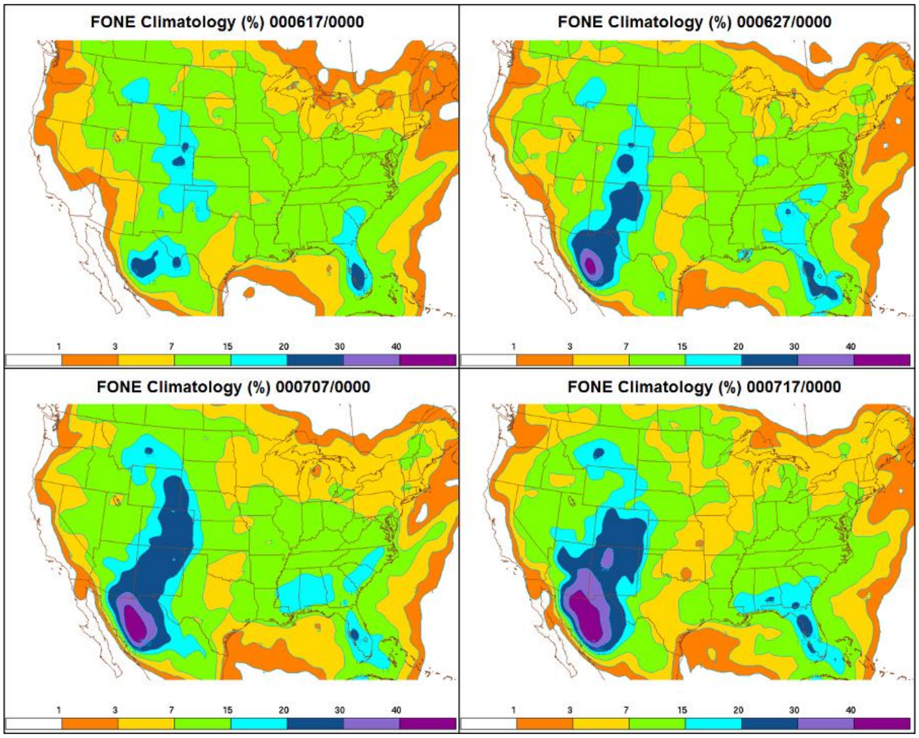

Figure 3. Sample climatology (%) plots for one or more CG flashes over the CONUS at 00-03 UTC for 5-day periods centered on the day shown.

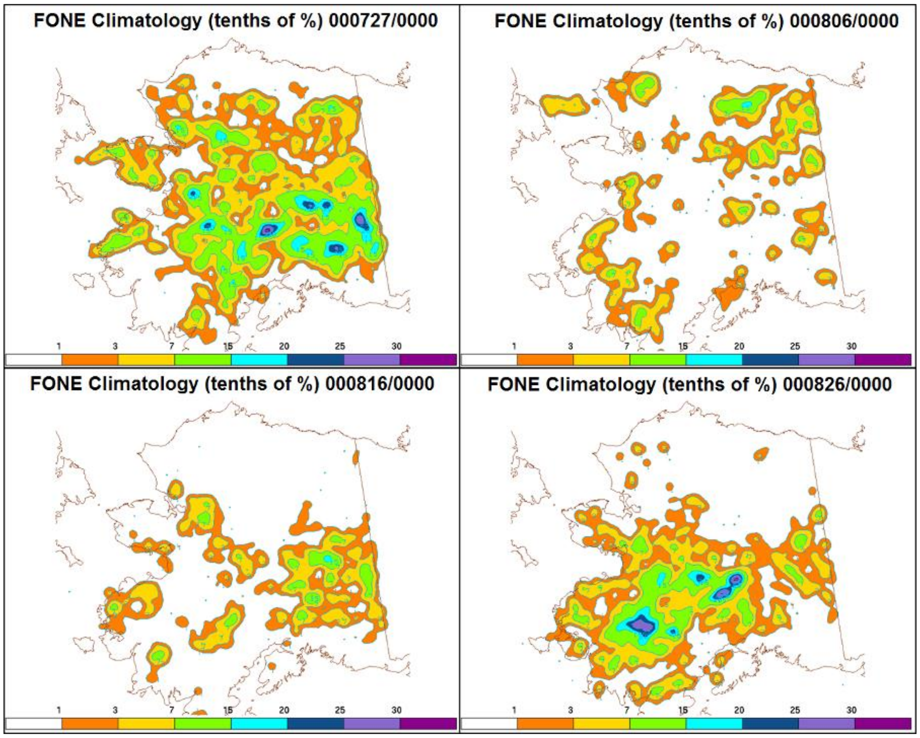

Figure 4. Sample climatology (tenths of %) plots for one or more CG flashes over Alaska at 00-03 UTC for 5-day periods centered on the day shown.

RESULTS

Comparison of forecasts using old and new equations

PPF lightning forecasts for fire weather meteorologists as well as the fire community described above have been reported on previously (see Bothwell 2002b, 2005, 2006, 2008a, 2008b and 2009). Using these "legacy" equations with the NAM model as input, the results of these lightning probability forecasts for all forecast times and all forecast cycles for the months of June, July and August of 2013 are shown on the two reliability diagrams on the left in Fig. 5. The newest PPF lightning forecasts developed by Richardson (2013) with GFS model as input are shown for comparison on the two reliability diagrams on the right in Fig. 5. The new forecasts exhibit an improvement in reliability even though longer-range forecasts are included in the comparison (out to 180 hours for the GFS compared to 84 hours for the NAM). For forecasts of one or more CG flashes, both approaches reveal under-forecasting in the lower percentages and over-forecasting at the higher percentages. As the histograms show, fewer forecasts actually produce the higher percentages.

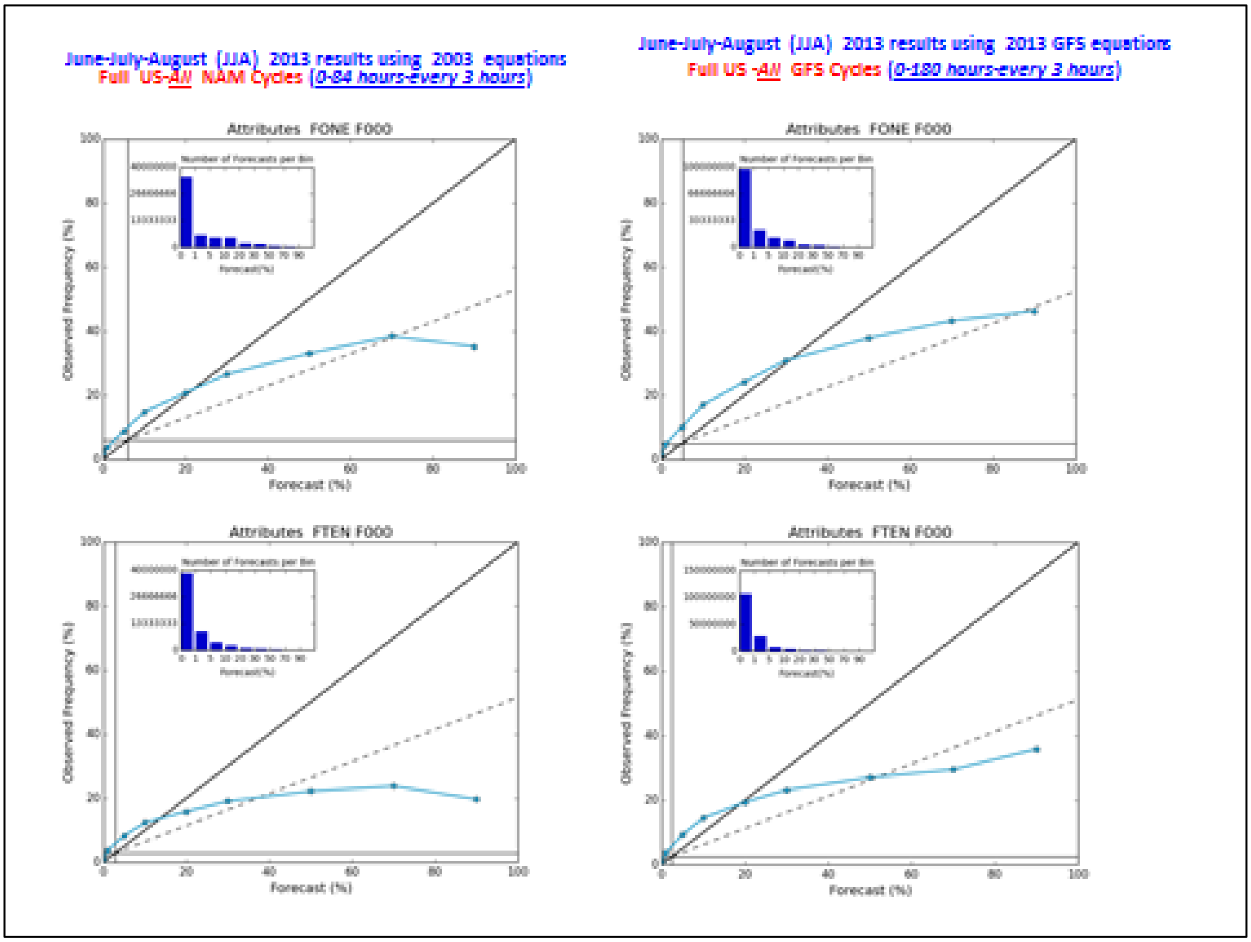

Figure 5. Reliability diagrams and histogram (insets) for June, July, and August (JJA) lightning probability forecasts over the CONUS for 2013. Upper left is for one or more CG flashes and the lower left is for ten or more CG flashes using the "legacy" equations. The upper right is for one or more CG flashes and the lower right is for ten or more CG flashes using the 2013 equations developed with 12-year sample. Perfect reliability is the black diagonal line, and the no-skill line is the dashed line.

Forecasts for July 19, 2013

On the evening of July 19, 2013, more than 740 cloud-to-ground lightning strikes hit Las Vegas over three hours. Figures 6 through 13 show the 24-hour lightning probability forecasts (maximum probability at each grid point from any of the individual 3-hour forecasts). In the figures, if lightning occurred, a "1" is plotted to represent the occurrence of lightning at the grid location (to reduce the cluttering on the map). Only Fig. 10 showing the forecast for 100 or more CG flashes has the hundreds digit plotted on the map. Forecasts using the "legacy" equations with NAM input data; the 2011 equations with the NAM, GFS, RAP and SREF as input; and the 2013 equations with GFS as input are shown in the follow figures. Figures 9 and 10 are using equations developed with 12 years of data and therefore more lightning and significant lightning events compared to Fig. 8 where the development data was only 2 years. Figure 10 captures the majority of the area with flashes in excess of 100 flashes.

Most of the forecasts in the following figures show that Las Vegas was on either the western edge of the lightning probabilities or in the gradient area with increasing probabilities to the east.

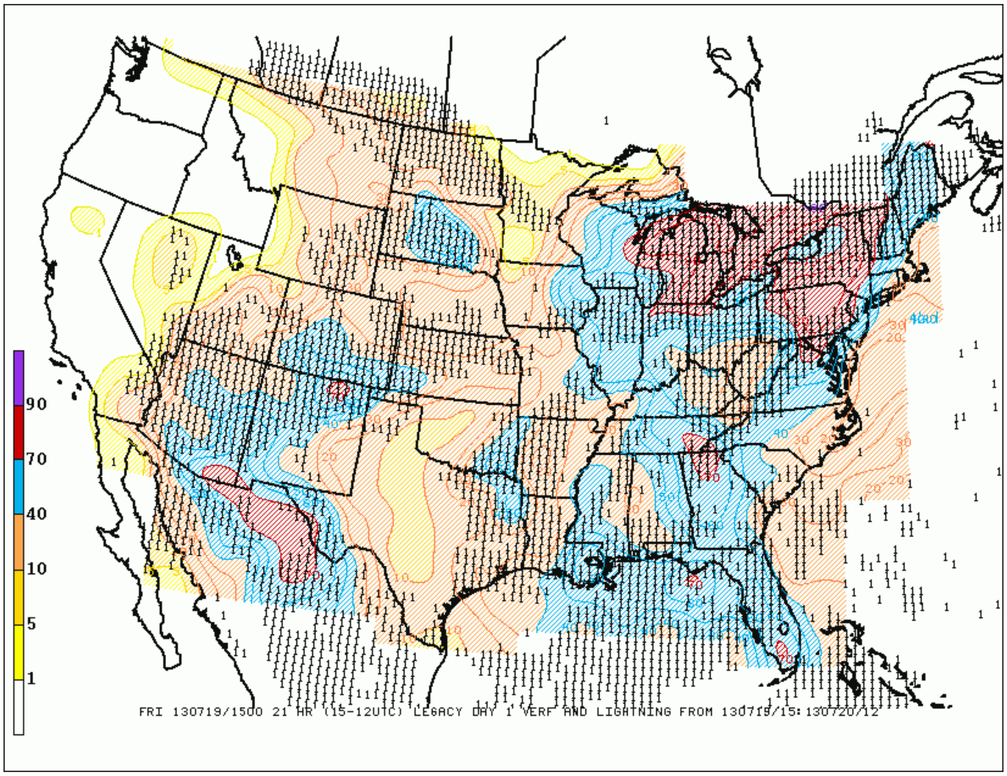

Figure 6. Forecast for one or more CG flashes from 15 UTC 7/19/13 to 12 UTC 7/20/13 using the "legacy" code (probability shaded). If lightning occurred within a grid box, a "1" is plotted. This version of the NAM forecasts did not include the initial analysis time.

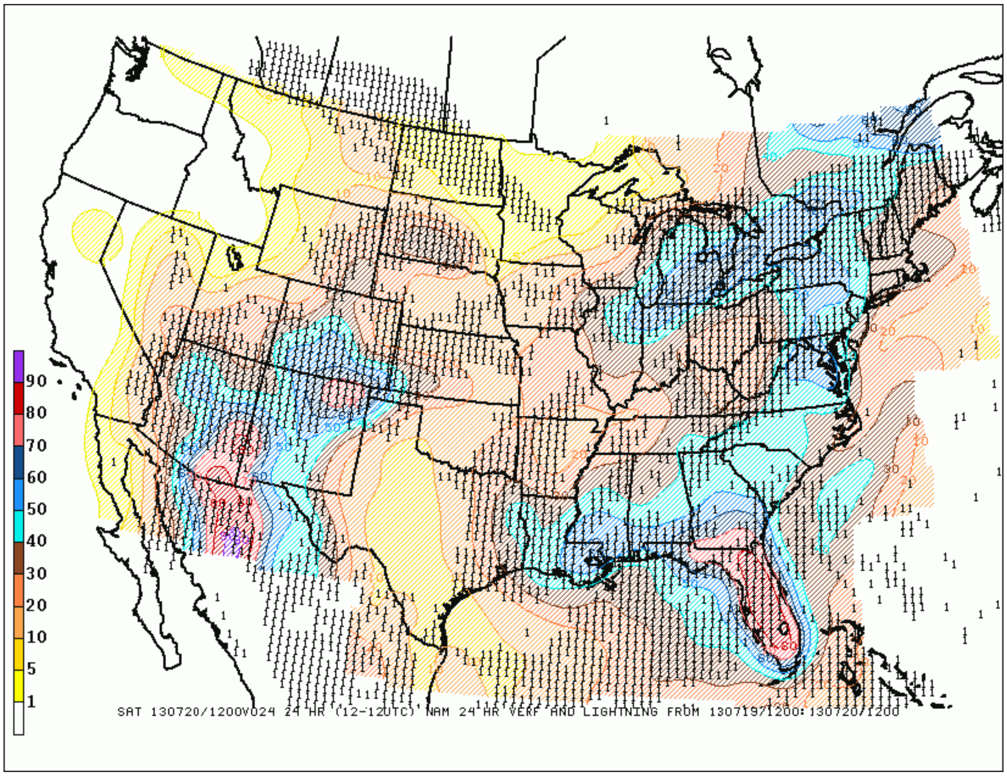

Figure 7. **Same as Fig. 6, except from equations developed in 2011 using 2 years of RUC analyses.**

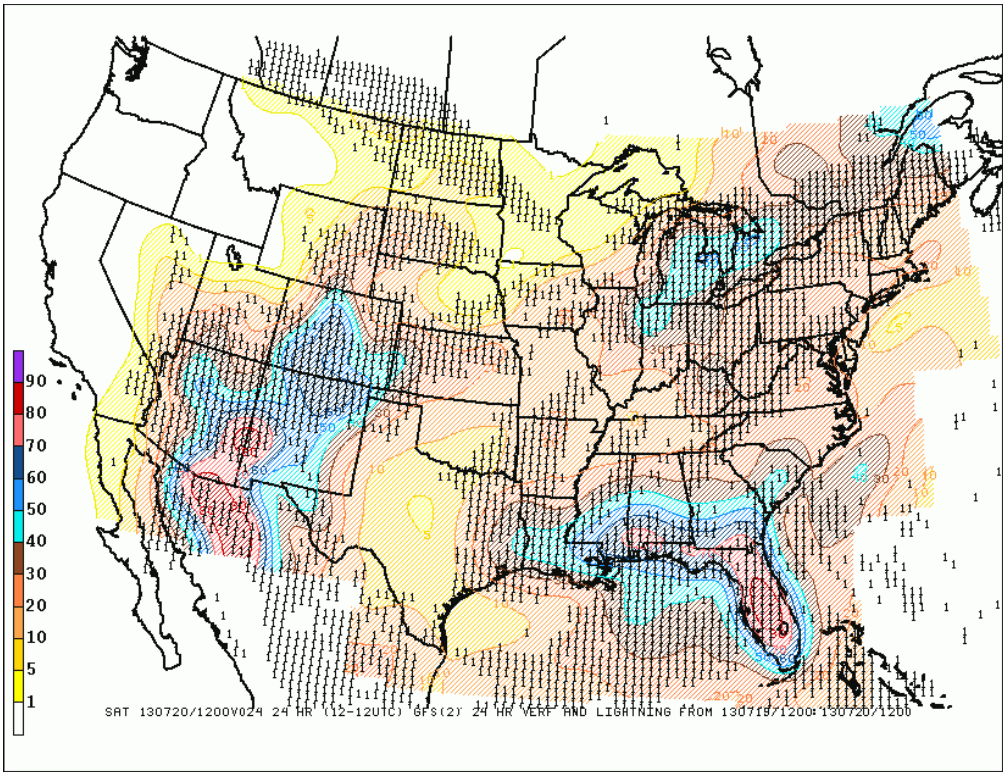

Figure 8. **Same as Fig. 7, except using GFS input data.**

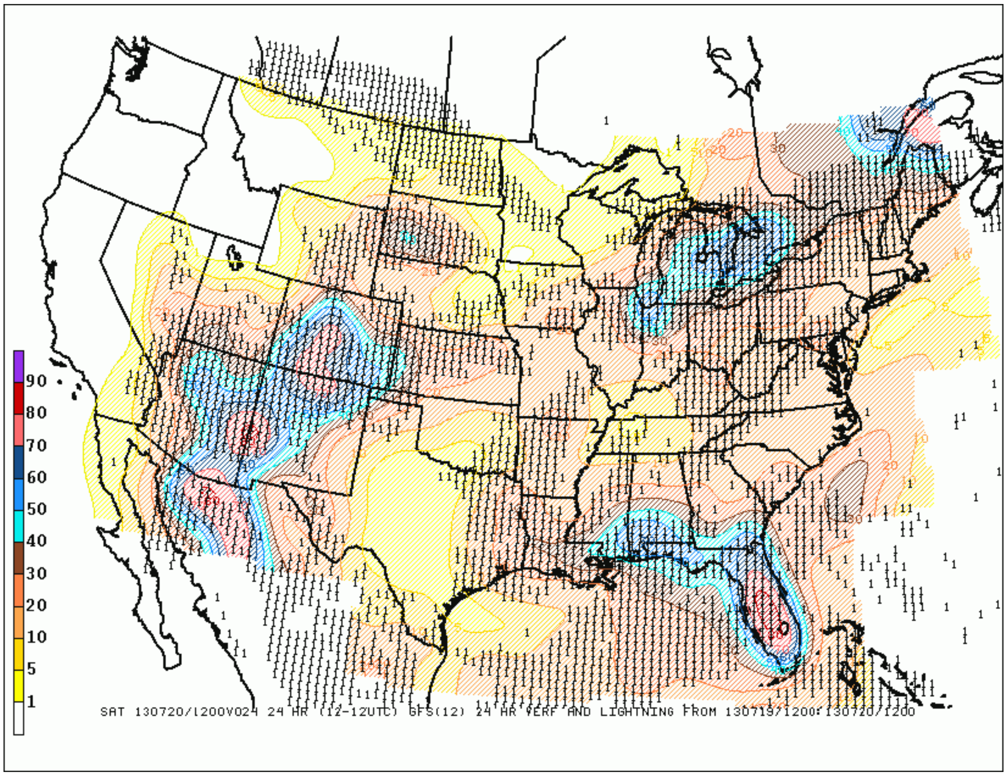

Figure 9. **Same as Fig. 8, using the newest PPF equations (12-year developmental dataset).**

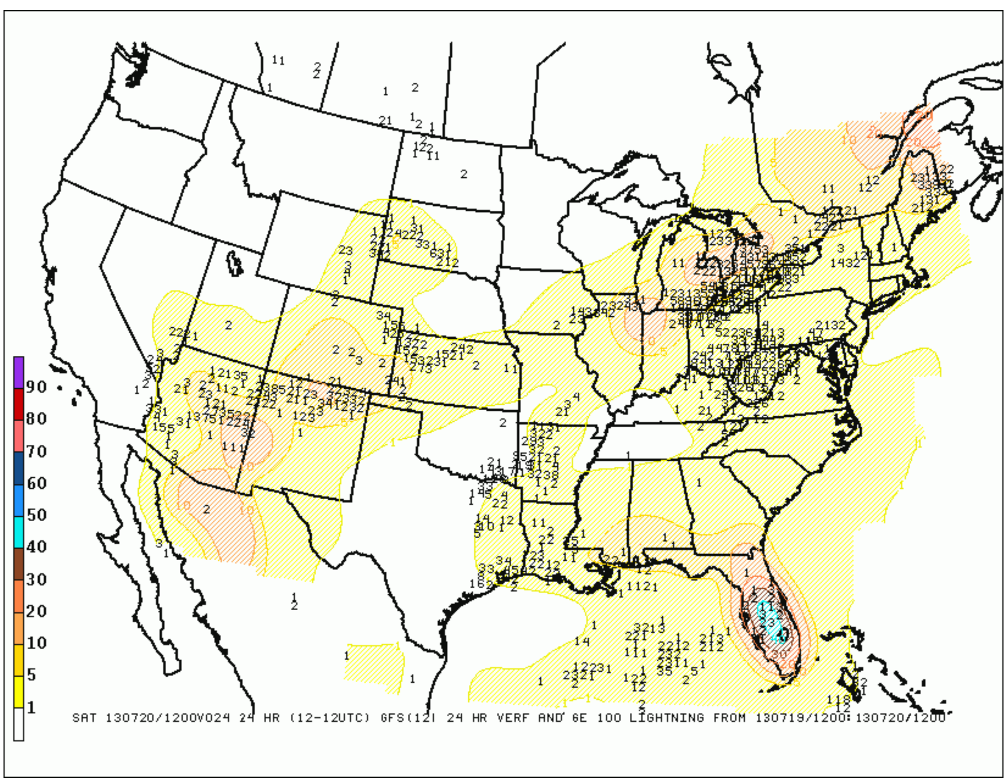

Figure 10. **Same as Fig, 9, except for forecasts for 100 or more CG along with the 100s digit plotted.**

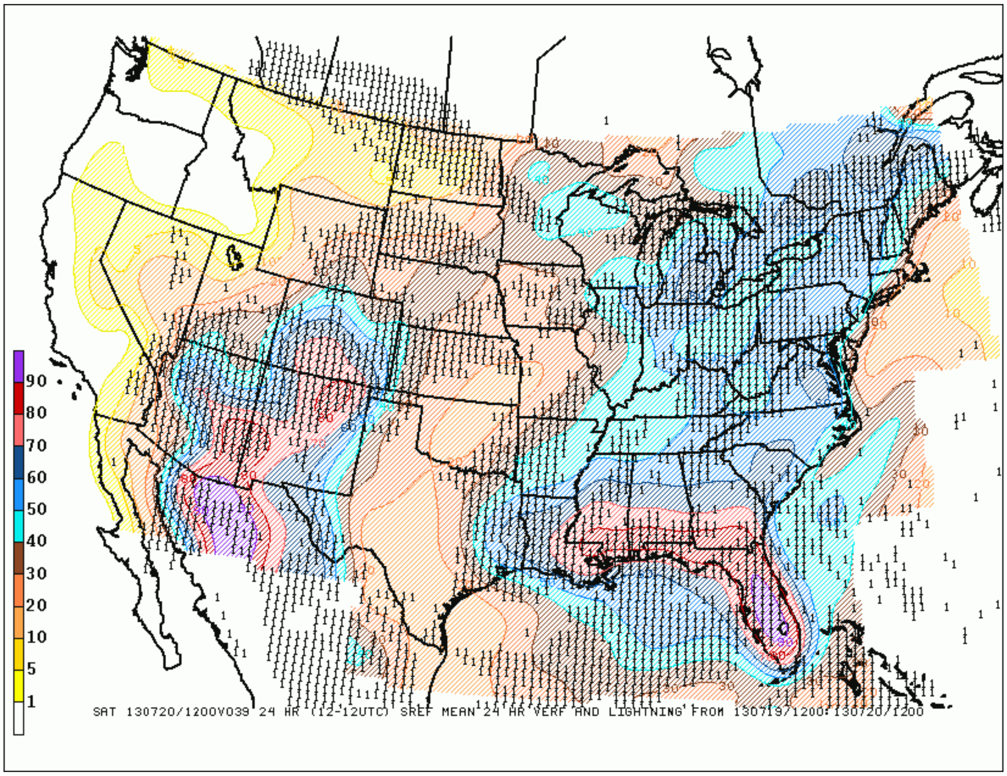

Figure 11. Same as Fig. 8, except plotting the SREF mean probability.

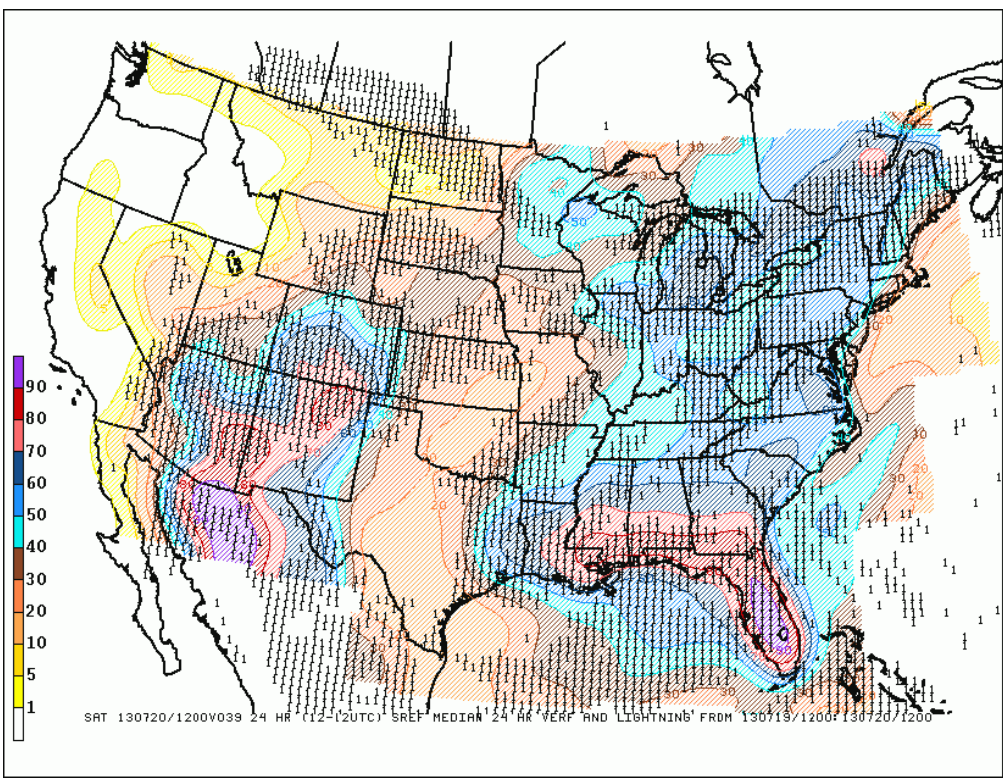

Figure 12. Same as Fig. 8, except for plotting SREF median probability.

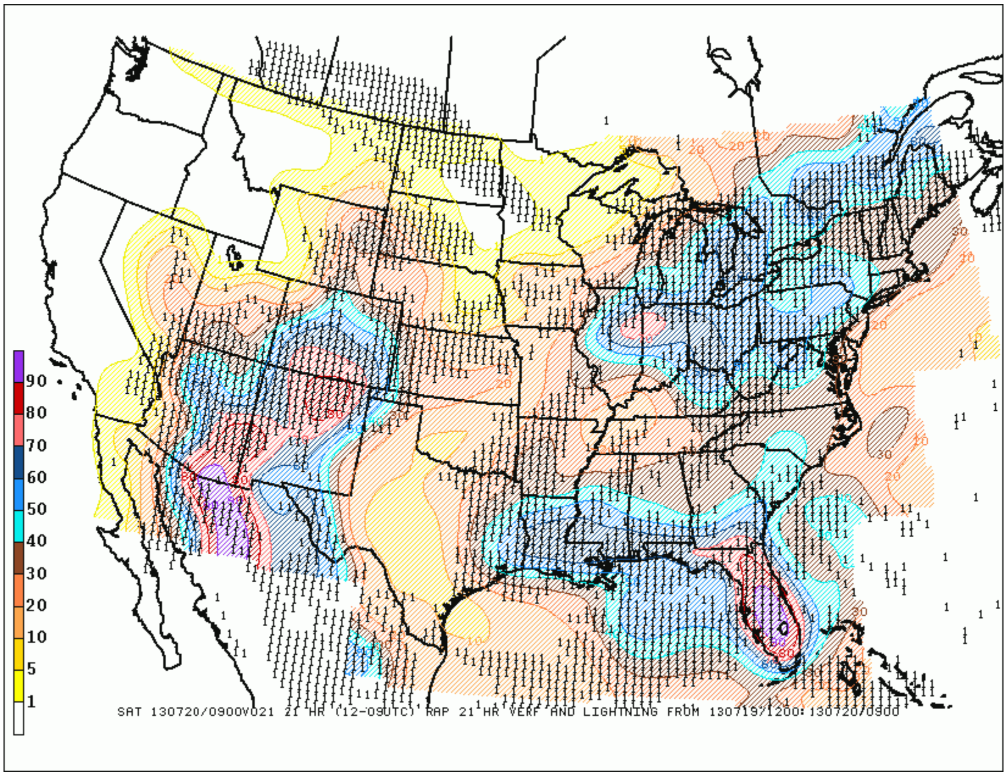

Figure 13. **Same as Fig. 8, except for RAP 18-hour forecast ending at 09 UTC.**

Forecasts for September 5-6, 2013

One of the largest lightning events ever recorded in Washington and Oregon occurred from early on the 5th to early on the 6th of September, 2013 where over 35,000 CG strikes were recorded in a 24-hour period. Figures 14 through 18 show the 24-hour lightning probability forecasts (maximum probability at each grid point from any of the individual 3-hour forecasts). As before, in these figures, if lightning occurred, a "1" is plotted to represent the occurrence of lightning at the grid location. Only Figs. 17 and 18 showing the forecast for 10 (100) or more CG flashes has the tens (hundreds) digit plotted on the map. Forecasts made using the 2011 equations with the NAM and GFS as input are in Figs. 14 and 15. The 2013 equations with GFS as input showing probabilities for 1, 10 and 100 or more CG flashes are shown in Figs.16-18. The GFS forecasts using the 2013equations have higher probabilities across Washington and Oregon and even though the probabilities for 10 or more and 100 or more CG flashes are lower (than for 1 or more), they generally capture the areas with the most number of flashes (10 or more and 100 or more, Figs. 17 and 18).

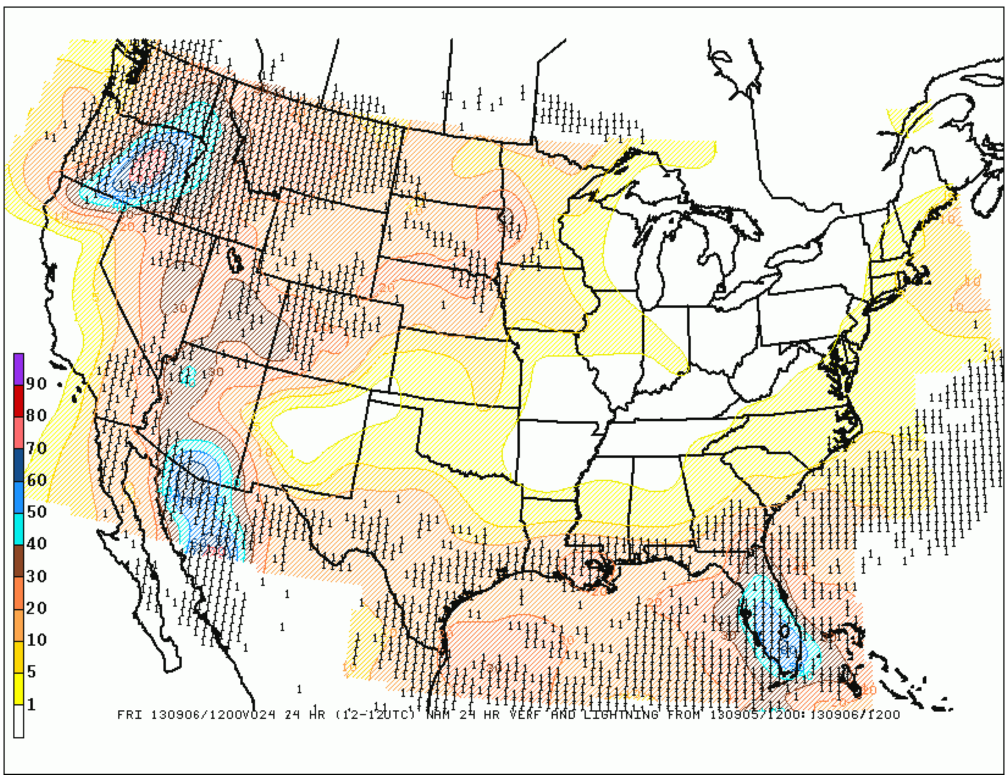

Figure 14. NAM probability forecast (shaded) for 1 or more CG flashes and lightning from 12 UTC 9/5/13 to 12 UTC 9/6/13 using the 2011 equations.

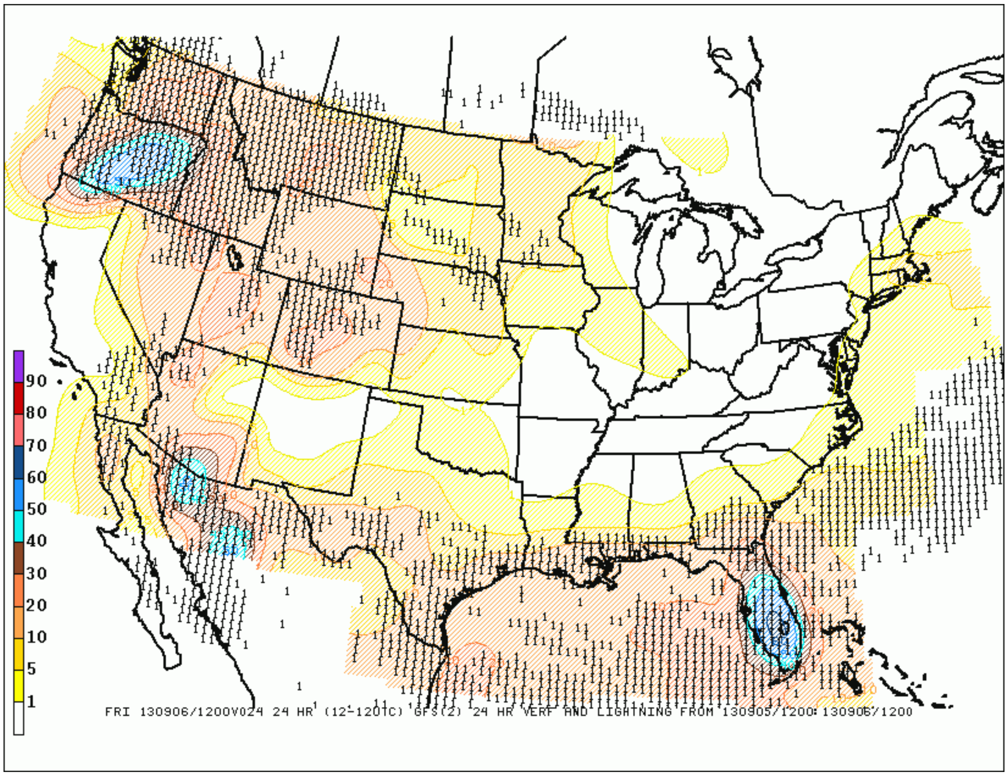

Figure 15. **Same as Fig. 14. except for GFS input data.**

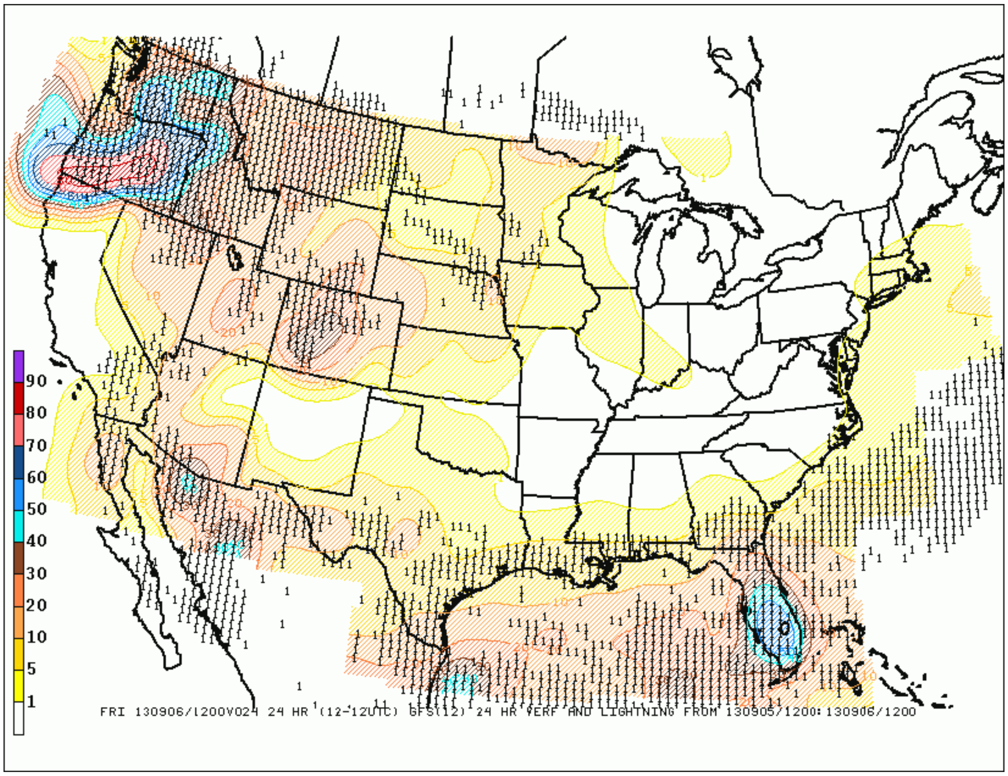

Figure 16. **Same as Fig. 15, except for using the new 2013 equations with the GFS.**

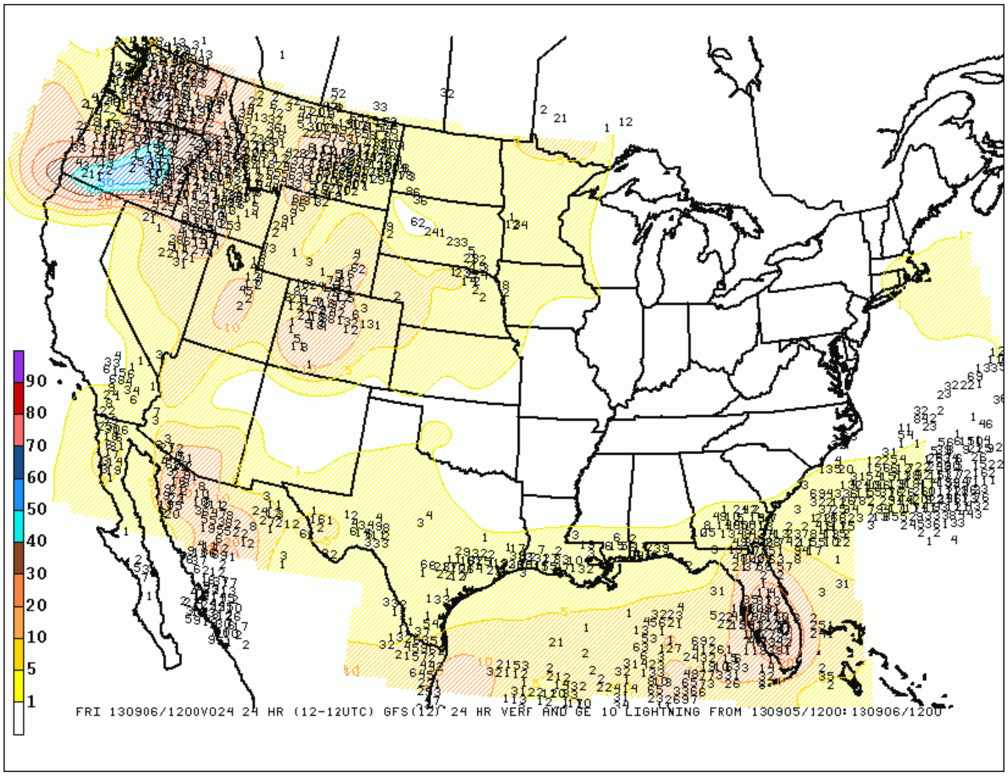

Figure 17. Same as Fig. 16, except for 10 or more CG flashes with tens digits plotted.

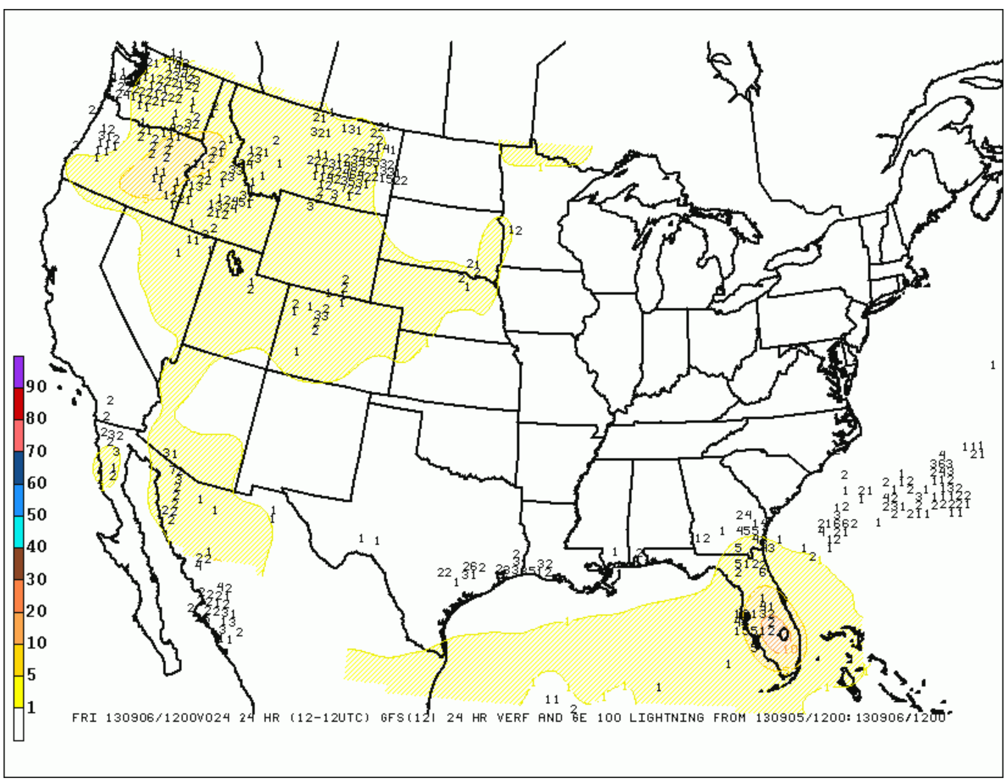

Figure 18. Same as Fig. 16, except for 100 or more CG with 100s digits plotted.

Example of Alaska Forecast 12 UTC July 30 to 12 UTC July 31, 2013

New equations have also been developed for Alaska using the 12-year (2000 to 2011) development dataset (Richardson 2013). Given the lower frequency of lightning in Alaska and the smaller grid boxes (10-km compared to 40-km over the CONUS), the probabilities for one or more CG flashes in Alaska are much lower than for the lower 48 states. As the climatologies show in Fig. 4 (plotted in tenths of percent), a maximum probability for 1 or more CG flashes may reach only 2 to 3 percent. Figure 19 is an example of the forecast for July 30-31, 2013 along with the observed lightning.

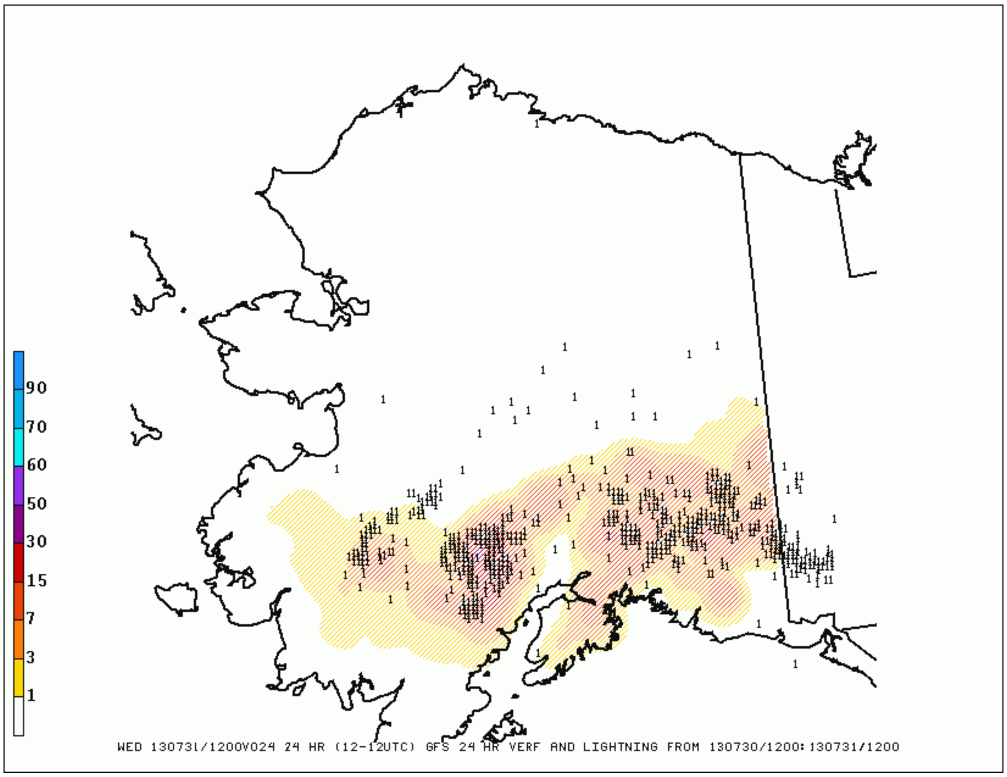

Figure 19. Example of 24-hour lightning probability forecast for Alaska for 1 or more CG strikes from 12 UTC 7/30/13 to 12 UTC 7/31/13 and observed lightning courtesy Alaska BLM network.

CONCLUSIONS

The Perfect Prog Forecasting method used for lightning prediction at the SPC has evolved over the past decade. The procedures have been streamlined to produce timely forecasts from all of the main operational models (NAM, GFS, RAP, and SREF). Because the equations use input grids from each of these models, the resultant probability forecasts from model to model can be compared. Also, these forecasts cover both the short-term and long-term forecast periods. Every hour, the RAP produces updated 3-hourly forecasts out to 18 hours. Every 6 hours, the NAM and SREF produce 3-hourly forecasts out to 84 and 87 hours, respectively. Finally using GFS input, the 3-hourly lightning forecasts extend out to 180 hours (7.5 days).

Each model will produce slightly different probabilities as shown in the examples here, and confidence can be increased when the models are in agreement. Also, longer-lead forecasts are continually updated with each new model cycle until the RAP model updates the forecast on an hourly basis. Ultimately, these forecasts can provide an "envelope" or range of expected probabilities of lightning occurrence to the forecaster.

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