Predicting Lightning Risk Nationwide

FINAL REPORT TO THE JOINT FIRE SCIENCE PROGRAM
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Abstract

Background

This project follows from the results of a previous JFSP-funded project (01-61-6-08), in which we developed an algorithm to identify convective days on which there is a high probability for dry thunderstorms. Using upper-level sounding data from Spokane, WA, we were able to distinguish between wet and dry convective days using the dewpoint depression at 850 hPa, and the temperature difference between 850 hPa and 500 hPa (Rorig and Ferguson 1999). We demonstrated the applicability of this algorithm in the Pacific Northwest and northern Rocky Mountains by successfully identifying days (in hindcast) when lightning-caused fires ignited during the 2000 fire season (Rorig and Ferguson 2002). This probability algorithm was then modified to be applied to model-generated data, using the model's vertical sigma levels. We generated daily predictions of the probability of dry thunderstorms using MM5 model output for the Pacific Northwest (Rorig et al. 2007). The goal of the current project is to expand the geographic extent of the dry thunderstorm probabilities, and to include a prediction of the risk of lightning outbreaks, whether they occur with or without precipitation.

Description

There were four major objectives for this project:

Create dry thunderstorm risk predictions for additional geographic regions, including Alaska and parts of Canada.

The methodology for developing risk predictions for dry thunderstorms requires a compilation of statistics from observed variables at upper-air (radiosonde) stations (Rorig et al 2007). Specifically, the dewpoint depression is vertically interpolated to a model sigma level of 0.90 (which corresponds to approximately 1000 meters AGL), and temperature is vertically interpolated to the 0.90 and 0.48 (approximately 5000 meters AGL) sigma levels. The dewpoint depression at sigma=0.90 and the temperature difference between the 0.90 and 0.48 sigma levels are then interpolated from the upper-air stations to the grid cells in the model domain.

The geographic scope of the dry thunderstorm risk algorithm was extended from the Pacific Northwest (WA, OR, ID, MT) to the western US, including ND, SD, NE, KS, OK, TX, and all states westward. Table 1 lists the means of the two variables for wet and dry days, and the probability that the means are different (using the Student's T-test), for all upper-air stations in those states. Those means were then interpolate to the gridded domain of the 12-km North

American Mesoscale Model (NAM), which is run 4 times daily out to 84 hours. Figures 1 and 2 show the interpolated dewpoint depression at the sigma=0.90 level for dry and wet days, respectively. We use the 00Z initialization and 24-hr and 48-hr forecasts to generate the risk predictions, because the algorithm was developed using 00Z sounding data (late afternoon, local time). Figure 3 shows an example of a 24-hour prediction of the probably dry thunderstorms when convective activity is expected.

The same set of statistics was compiled for the Alaska and adjacent Canadian upper-air stations as were compiled for the western US (Table 2). Most of the lightning activity occurs in the central and southwest part of the state where maximum daily temperatures routinely top 70 degrees F during the summer. The central part of the state is the overwhelming preferred area for lightning during the early and middle of the season, but starting in July, lightning activity begins to shift southwestward (Buckey and Bothwell 2009). This agrees with Reap (1991) who found most lightning in Alaska occurs in the interior between the Alaska Range and the Brooks Range, during the months of June and July. Because most of the upper-air stations did not have enough "thunderstorm days" (defined as at least one lightning strike within 10 km of the station) to compile meaningful statistics, we've included only the stations with sufficient data to compute the means. The first thing to note is that there is no significant difference between the mean values of the variables on wet and dry days at any of the upper-air stations, with the exception of the sigma = 0.90 dewpoint depression at Fairbanks. This suggests the high-based, dry thunderstorms seen in the western US are not typical in the Alaskan interior. Both Sullivan (1963) and Reap (1991) found that low-level moisture and wind convergence, associated with low-pressure troughs, are necessary for the formation of thunderstorms. We therefore compute the probability of lightning strikes in Alaska, without making a distinction between wet and dry days.

Merge these predictions with algorithms from NOAA's Storm Prediction Center that predict the risk of high numbers of cloud-to-ground flashes.

The Perfect Prog (Prognosis) Forecast (PPF) system to predict probabilistic Cloud-to-Ground (CG) lightning (Bothwell 2002) was first implemented at the Storm Prediction Center (SPC) in 2003. The perfect prog (PP) system is designed to produce forecasts using any Numerical Weather Prediction (NWP) model data as input. The PP forecast system provides useful guidance on lightning and significant lightning from zero to 84 hours for the lower 48 states at a horizontal resolution of 12 km using the NAM model, and out to 180 hours for Alaska at a resolution of 10 km using the GFS model.

The performance for both the 12 km NAM and 10 km GFS forecasts are similar, so we will just present the Alaska verifications here. Figure 4 shows a comparison of the predicted probability of at least 1 and 10 lightning strikes with observed lightning strikes for 9 July 2008. An overall summary of the verification statistics can be seen in Fig. 5. 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 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. 6) 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.

Test an improved dry lightning algorithm based on physical processes rather than statistical techniques.

We considered a variety of more physical models to use for the lightning probabilities, involving multiple atmospheric properties contained in or derivable from forecast model data. It became apparent, however, that each of these either reduced to a statistical model, similar to those already in use, or would require running a point-specific detailed physical model that would take so long to run, it would be operationally useless, in that the model could not be run in real time (for example, it would take 24 hours to produce a 12-hour forecast). We therefore conclude that it is not feasible at this time to use an algorithm based on physical, rather than statistical processes.

Apply the newly developed algorithms to the latest operational weather forecast model as experimental products.

We are currently generating daily predictions of the probability of lightning strikes, and of lightning strikes without wetting rainfall in the western US, using the operational 12-km NAM models for the continental US. The 10-km GFS model predictions for Alaska are found at http://www.spc.noaa.gov/exper/fcstfirewxltg/loopmainak.html.

Key Findings:

- The dry lightning probabilities were computed on the part of NAM 12-km domain covering the western US, and daily predictions are made available via the Internet

- The perfect prog forecasts of the probability of 1- and 10- strikes were generated for the NAM 12-km domain, and combined with the dry lightning probabilities over the western US to generate a prediction of the probability of the occurrence of dry lightning
- The perfect prog forecasts of the probability of 1- and 10- strikes were generated for the GFS 10-km domain over Alaska, and compared well with observed lightning strikes
- There is no significant difference in the predictive variables for dry vs. wet thunderstorms at Alaska upper air stations.
- It was not feasible to use a physics-based model to predict the occurrence of dry lightning because would require running a point-specific detailed physical model that would be so computational intensive that it would not produce output in real-time.

Management Implications

Predicting the probability of fire ignitions is a complicated exercise as many variables interact when sustained ignition occurs. Both current and future weather conditions are important, as well as fuel type, fuel loadings, and fuel moisture. Whether or not ignitions grow into large fires depends on the location of the fire, whether there are resources available to extinguish them in a timely manner, and whether wetting rains occur after the initial ignition. The scope of this project was confined to better understanding and predicting the likelihood of lightning outbreaks, and whether or not those outbreaks will occur without wetting rains.

The tools developed here will be helpful to both fire weather forecasters and to the land management community. Although these are considered experimental products, users will have access to predictions showing where the probability is high for lightning strike outbreaks in the eastern US and Alaska, and in the western US, where dry thunderstorms are a common occurrence, where the probability is high for those lightning strike outbreaks to occur without concurrent wetting rainfall. Because these tools are web-based, they are accessible to all users. The forecasts are currently available out to 84 hours, at horizontal resolutions of 10 – 12 km. As new NWS forecast models become available (higher resolutions, longer forecast periods), these algorithms can be applied to new models to produce enhanced prediction of lightning risk.

Future Work Needed

While predictions of the risk of large outbreaks of dry thunderstorms are necessary for assessing the risk of wildfire ignitions, they are not sufficient. Fuel type and fuel condition (key components of the NFDRS) are also important in predicting fire ignitions. Current predictions include the number of strikes anticipated and predicted fuel moisture conditions, but a constant fuel type is assumed and the variability of fuel types on the landscape is thus not considered. By incorporating spatially distributed fuels data, we will be able to capture the variability of the fuels in the fire risk prediction. We have obtained funding to fill in these gaps by:

1. Incorporating fuels information into our predictions of dry lightning outbreaks to produce new forecast products that predict the risk of sustained fire ignitions from dry thunderstorm outbreaks.
2. Create an underlying component that provides information on fire weather predictions and uncertainty important to fire ignition risk.

This will allow for a complete prediction of the likelihood of ignition and sustained burning from lightning outbreaks, and a better quantification of the uncertainty in the predictions.

Deliverables

Cross-walk Table

Deliverable	Description	Delivery Dates
Web page	Improved predictions of lightning risk, including descriptions of development and verification	Complete and continuing
General Tech Report	Documentation for standardized procedure to incorporate the predictions in other model domains -	Forthcoming (in progress)
Conference proceedings	Presentations and extended abstracts	Complete and continuing
Journal articles	Peer-reviewed articles on updated dry lightning algorithm and the new lightning outbreak risk algorithm	Forthcoming (in progress)
Software	Appropriate computer software available for download	Complete

Conference Proceedings:

Bothwell, P.D., 2009: Development, operational use, and evaluation of the perfect prog national lightning prediction system at the Storm Prediction Center. Fourth Conference on Meteorological Applications of Lightning Data, Phoenix, AZ, Amer. Meteor. Soc., 11 pp.

Bothwell, P.D and Buckey, D. R., 2009: Using the perfect prognosis technique for predicting cloud-to-ground lightning in mainland Alaska. Fourth Conference on Meteorological Applications of Lightning Data, Phoenix, AZ, Amer. Meteor. Soc., 10 pp.

Buckey, D. R. and Bothwell, P.D, 2009: 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

Bothwell, P.D., 2010: Evolution of the experimental/automated perfect prog lightning forecasts at the Storm Prediction Center. Third International Lightning Detection Conference, April 21-22, Orlando, FL, Vaisala, Inc.,Tucson,10pp.

Web Sites:

http://www.airfire.org/tools/daily-fire-weather

http://www.spc.noaa.gov/exper/fcstfirewxltg/loopmainak.html

Peer-reviewed Publication

Rorig, M.L. and Bothwell, P.D, 2010: An improved algorithm for predicting the risk of dry thunderstorms in the western United States. In preparation.

Presentations

Rorig, M. and Bothwell, P. October 2009. Update on model-generated predictions of Dry Thunderstorm Risk. Eighth Symposium on Fire and Forest Meteorology, Kalispell, Montana, October 13 – 15.

Rorig, M. December 2009. Predicting Lightning Risk. 4th International Fire Ecology & Management Congress, Savannah, Georgia, November 30 – December 4.

Bothwell, P.D., 2009: Development, operational use, and evaluation of the perfect prog national lightning prediction system at the Storm Prediction Center. Fourth Conference on Meteorological Applications of Lightning Data, Phoenix, AZ, Amer. Meteor. Soc., 11 pp.

Bothwell, P.D and Buckey, D. R., 2009: Using the perfect prognosis technique for predicting cloud-to-ground lightning in mainland Alaska. Fourth Conference on Meteorological Applications of Lightning Data, Phoenix, AZ, Amer. Meteor. Soc., 10 pp.

Buckey, D. R. and Bothwell, P.D, 2009: 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

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Bothwell, P.D., 2002: Prediction of Cloud-to-Ground Lightning in the Western United States, Ph.D., University of Oklahoma, 178pp.

Buckey, D.R. and P.D. Bothwell, 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.

Reap, R.M. 1991. Climatological characteristics and objective prediction of thunderstorms over Alaska. Weather and Forecasting 6:309-319.

Rorig, M.L. and S.A. Ferguson, 1999. Characteristics of lightning and wildland fire ignition in the Pacific Northwest. Journal of Applied Meteorology 38:1565-1575.

Rorig, M.L. and S. A. Ferguson, 2002. The 2000 Fire Season: Lightning-caused fires. Journal of Applied Meteorology 41,786-791.

Rorig, M.L., S. J. McKay, S. A. Ferguson, and P. Werth, 2007. Model-generated predictions of dry lightning risk. Journal of Applied Meteorology and Climatology 46:605-614.

Sullivan, W.G. 1963. Low-level convergence and thunderstorms in Alaska. Monthly Weather Review 91:89-92.

Table 1. Statistics for upper air stations, western US.

Upper Air Station		Dewpoint Depression (sigma=0.90)	Temperature Difference (sigma=0.90 – sigma=0.48)	Sample Size	t-test (DD/Tdiff)
Albuquerque, NM	Mean Dry	16.92	31.67	486	0.00/0.00
	Mean Wet	11.59	29.10	221	
Amarillo, TX	Mean Dry	12.46	31.18	317	0.00/0.00
	Mean Wet	8.10	28.42	358	
Bismarck, ND	Mean Dry	10.61	29.46	193	0.00/0.00
	Mean Wet	6.89	27.15	262	
Boise, ID	Mean Dry	16.98	34.64	100	0.00/0.00
	Mean Wet	9.667	30.98	61	
Denver, CO	Mean Dry	14.84	32.47	422	0.00/0.00
	Mean Wet	9.93	30.72	202	
El Paso, TX	Mean Dry	15.98	32.49	368	0.00/0.00
	Mean Wet	12.86	30.734	183	
Spokane, WA	Mean Dry	12.65	30.73	79	0.00/0.0001
	Mean Wet	7.23	28.84	70	
Glasgow, MT	Mean Dry	13.71	32.11	163	0.00/0.0005
	Mean Wet	9.82	30.51	143	
Grand Junction, CO	Mean Dry	17.59	33.23	377	0.00/0.00
	Mean Wet	11.89	29.93	146	
Great Falls, MT	Mean Dry	14.93	32.76	160	0.00/0.0001
	Mean Wet	9.85	30.92	125	
Lander, WY	Mean Dry	15.75	33.45	218	0.00/0.00
	Mean Wet	9.08	29.84	89	
Medford, OR	Mean Dry	14.97	33.73	42	0.0008/0.057
	Mean Wet	10.15	32.24	34	
Rapid City, SD	Mean Dry	12.87	32.15	282	0.00/0.00
	Mean Wet	8.57	29.94	232	
Salt Lake City, UT	Mean Dry	16.03	33.68	300	0.00/0.00
	Mean Wet	9.93	30.93	147	
Salem, OR	Mean Dry	7.04	28.71	22	0.001/0.20
	Mean Wet	3.46	27.68	28	
Tucson, AZ	Mean Dry	15.92	33.89	402	0.00/0.00
	Mean Wet	12.70	31.95	222	
Quillayute, WA	Mean Dry	5.07	26.93	6	0.0007/0.40
	Mean Wet	1.62	27.59	41	
Kelowna, BC	Mean Dry	16.48	33.28	25	0.14/0.08
	Mean Wet	14.28	31.61	20	

Table 2. Statistics for upper-air stations, Alaska.

Upper Air Station		Dewpoint Depression (sigma=0.90)	Temperature Difference (sigma=0.90 – sigma=0.48)	Sample Size	t-test (DD/Tdiff)
Bethel, AK	Mean Dry	5.53	26.2	6	0.28/0.24
	Mean Wet	6.74	27.24	11	
McGrath, AK	Mean Dry	8.07	28.42	21	0.20/0.08
	Mean Wet	7.18	28.58	14	
Fairbanks, AK	Mean Dry	9.67	30.29	35	0.05/0.16
	Mean Wet	7.01	27.45	15	
Anchorage, AK	Mean Dry	5.91	28.52	9	0.15/0.22
	Mean Wet	8.53	27.37	3	
King Salmon, AK	Mean Dry	6.77	28.67	3	
	Mean Wet	5.60	27.85	2	

Figure 1. Interpolated dewpoint depression for dry thunderstorm days.

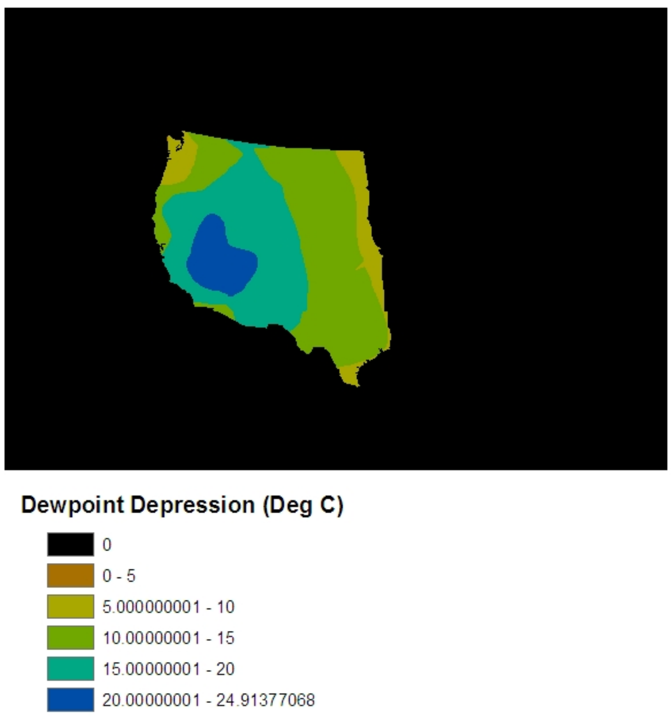

Figure 2. Interpolated dewpoint depression for wet thunderstorm days.

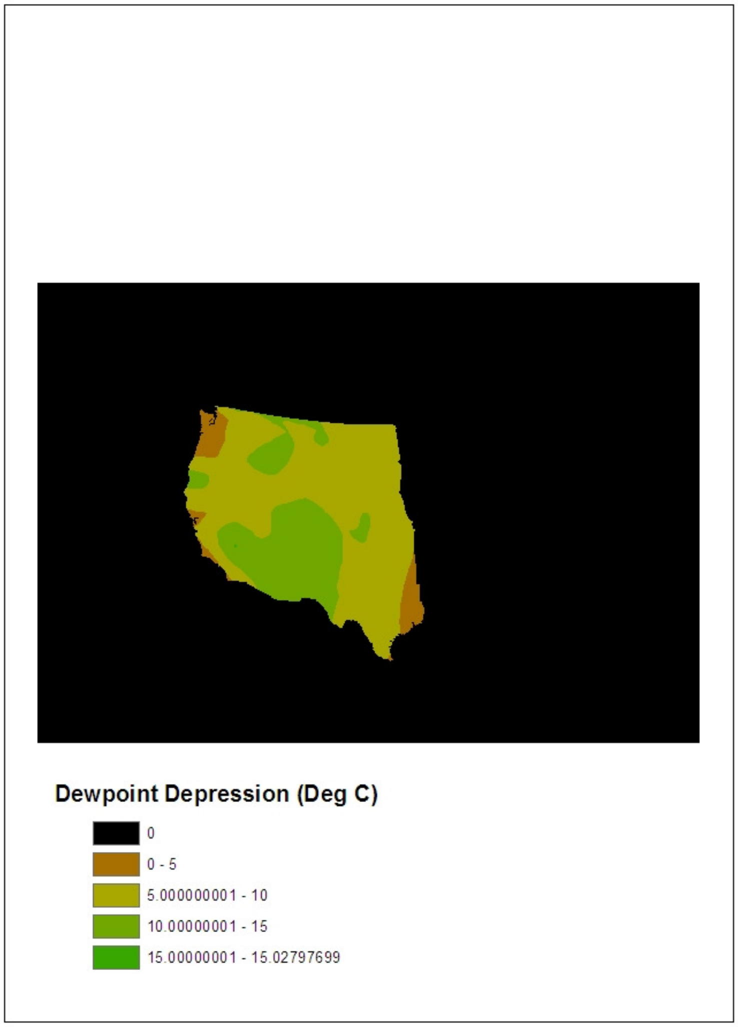

Figure 3 to go here.

Figure 4. Forecast for July 9, 2008 valid from 00 to 03 UTC using 00 UTC 06 July GFS input.
72-75 hour forecast for 1 or more (left) and 10 or more CG flashes (right) along with lightning from 00 to 03 UTC

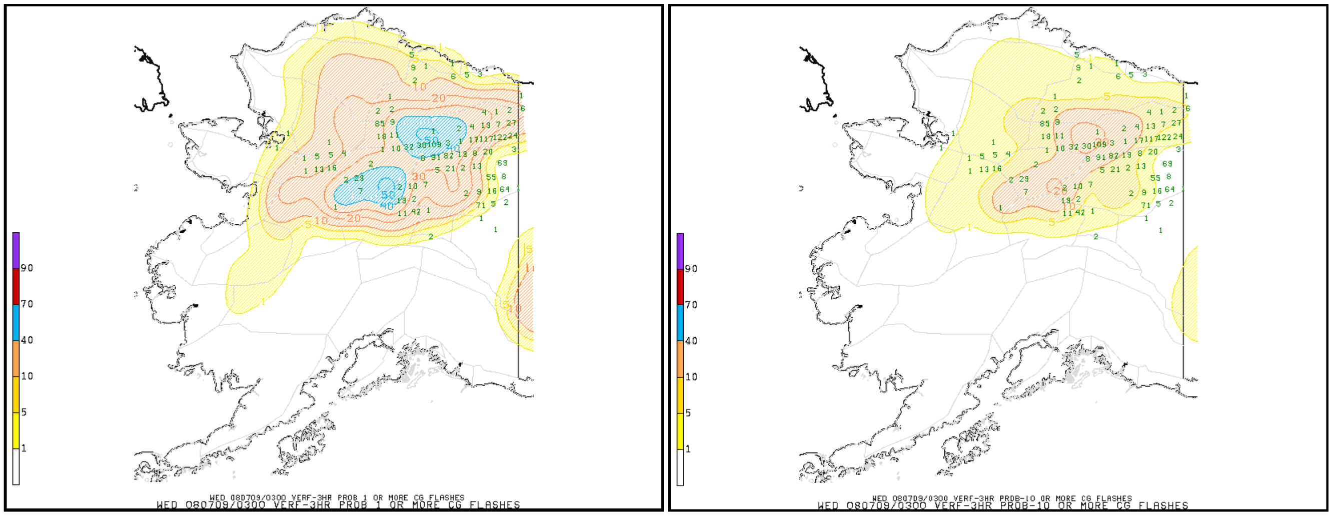

Figure 5. Reliability Diagram for One CG flash or Greater. Forecasts Valid: June 10th-July 25th, 0-84 hour forecasts for 00Z-03Z only. Diagram in the top left is the number of forecasts per bin. Small sample sizes prevented forecast above 80% from being analyzed.

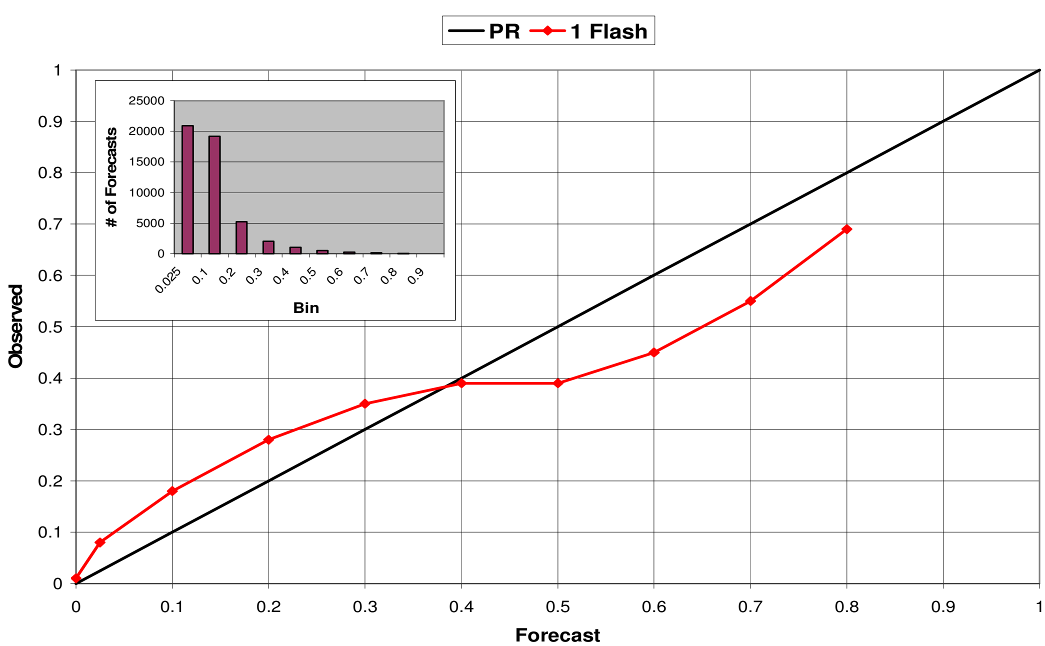

Figure 6. Same as Figure 4 except for ten flashes or greater forecasts. Small sample sizes prevented forecasts of greater than 70% from being analyzed.