

Verification of the WFAS Lightning Efficiency Map

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Abstract—A Lightning Ignition Efficiency map was added to the suite of daily maps offered by the Wildland Fire Assessment System (WFAS) in 1999. This map computes a lightning probability of ignition (POI) based on the estimated fuel type, fuel depth, and 100-hour fuel moisture interpolated from the Remote Automated Weather Station (RAWS) network. An attempt to verify the efficiency map was made using cloud-to-ground (CG) lightning discharge data acquired at the Missoula Fire Lab (through the Vaisala Corporation network), lightning fire location data from within USDA Forest Service (FS) Region 1 boundaries, and daily 100-hour fuel moisture values retrieved from historical National Fire Danger Rating System (NFDRS) archives for the 2003 fire season. Daily POI maps were recomputed for 153 days (May through September). Daily CG lightning density grids for the same timeframe were computed from lightning discharge data and were multiplied by the POI grid to yield a daily 1-km predicted number-of-fires or fire “possibility” grid. A daily lightning-caused fire density grid was produced using various agency fire occurrence databases from May through September. While preliminary spatial neighborhood analysis showed some predictive capability, the predicted number of lightning caused fires exceeded the actual reported fires. This overestimation could be due to the lack of differentiation between an ignition and reported fire and errors in fire occurrence databases. Being able to predict whether lightning resulted from a “wet” or “dry” storm could improve predictive ability. More refined and spatially accurate fuel maps have become available and are planned to be incorporated into future models.

Introduction

Lightning is the primary cause of wildland fire ignitions in the Western United States. Networks to detect cloud-to-ground (CG) lightning strikes have covered this region in various forms since the 1970s. Presently, the network covering the continental United States, operated by Vaisala Corporation, advertises an 80 to 90 percent detection efficiency and a 500 m spatial accuracy. To date, we are not aware of any attempts to correlate individual CG discharges to actual lightning fires. This is due to a variety of reasons including the questionable quality of fire start data and the tendency of lightning ignitions to become “holdover” fires.

In 1999, a Lightning Ignition Efficiency map (USDA Forest Service 2002) was added to the Wildland Fire Assessment System (WFAS). This map computes a lightning probability of ignition (POI) based on the estimated fuel type, fuel depth, and 100-hour fuel moisture interpolated from the Remote Automated Weather Station (RAWS) network. The efficiency values are on a per-CG discharge basis, and the map is based on a 1-km² pixel. The values on the map are generated by an algorithm based on a laboratory research

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study (Latham and Schlieter 1989). Verification of the algorithm was delayed by lack of a suitable data set covering a range of input variables and a large number of fires. We generated such a data set for the year 2003 spanning the months of May through September for an area covering approximately Region 1 of the USDA Forest Service.

This study is a “first cut” at analyzing the data. We wanted to become familiar with use of GIS-based data storage, presentation, and analysis techniques. In particular, we wanted to explore presentation of point data, such as lightning and fires, as gridded density data on the landscape, and examine the results both visually and statistically.

Data

Lightning flash and stroke data came from Vaisala Corporation (Cummings and others 1998). Each flash in the data set has a date, time, latitude, and longitude. Values needed for calculating environmental variables came from the National Fire Danger Rating System (NFDRS) through operational RAWS stations. The base fuel map used to decipher fuel type and depth for the POI calculation came from Schmidt and others (2002). During May through September 2003, a total of 709,879 flashes were recorded and used in this study. One day’s data are shown in figure 1, comprising 21,192 flashes. Flashes are shown here regardless of the polarity of the flash, because the WFAS algorithm was generated to be polarity-free.

Fire locations were obtained from the USDA Forest Service, Montana Department of Natural Resources and Conservation (DNRC), Idaho Department of Lands (IDL), Bureau of Indian Affairs (BIA), Bureau of Land Management (BLM), National Park Service (NPS), and Fish and Wildlife Service (FWS). In all, the recorded latitude and longitude of 1,948 fires attributed to lightning along with the discovery dates were entered into the set. The results for 1 day’s data are shown in figure 2.

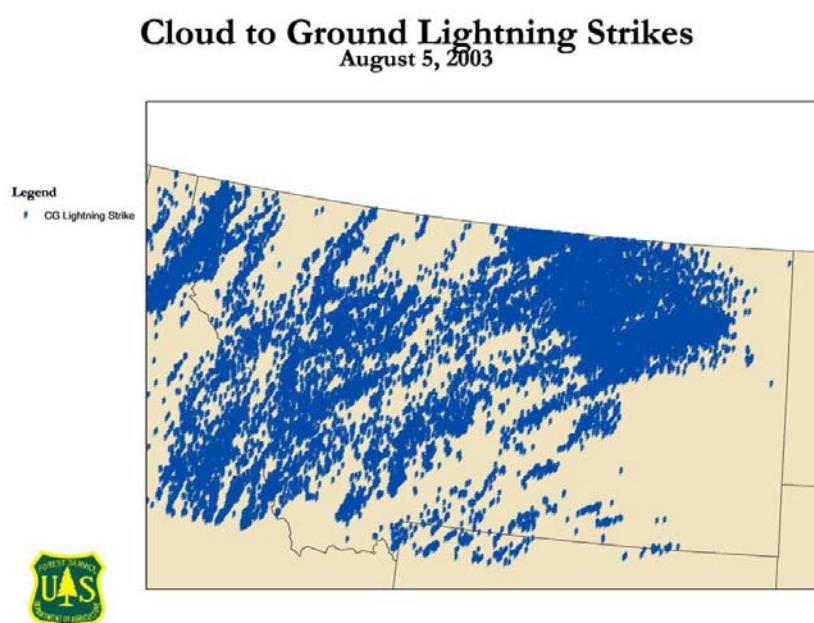


Figure 1—Cloud-to-ground lightning strikes (positive and negative), Northern Rockies, August 5, 2003.

Lightning Ignited Fire Locations August 5, 2003

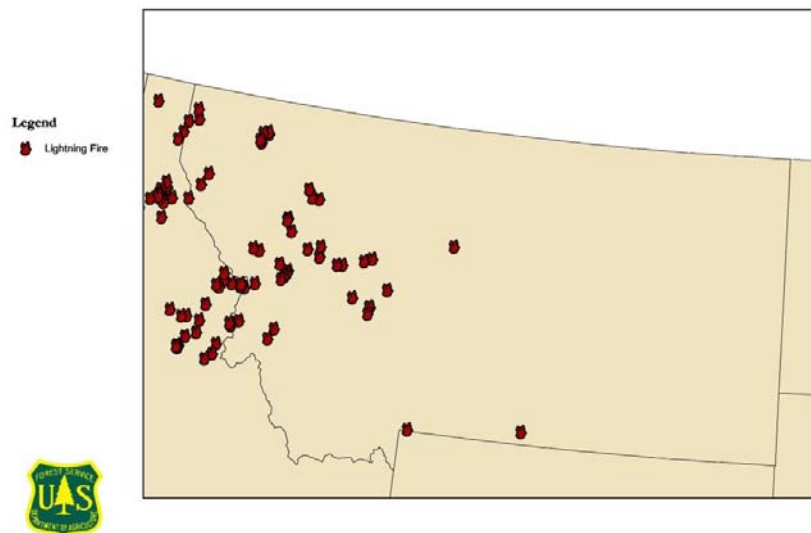


Figure 2—Lightning-caused fires, August 5, 2003.

For our analysis, we needed to calculate the WFAS daily lightning probability (efficiency). The algorithm requires a fuel type, depth, and the 100-hour NFDRS fuel moisture. Ignition probability in most fuels depends on fuel moisture. Short needled fuels depend more on duff depth (USDA Forest Service 2002). The ignition probabilities that depend on fuel moisture are not really in the 1-hour fuel moisture class but are closer to 25 to 50 hour. Because we are estimating the probability in the morning for the day, we chose the 100-hour class as the best representation. The 100-hour moistures were obtained from RAWs stations through the NFDRS data warehouse using FireFamily Plus (Bradshaw and McCormick 2000). The 100-hour fuel moisture values were converted to 1-km² grids using the weighted inverse distance-squared interpolation method (Burgan and others 1997). The moisture field for a sample day is shown in figure 3.

Observed 100-hour FM August 5, 2003

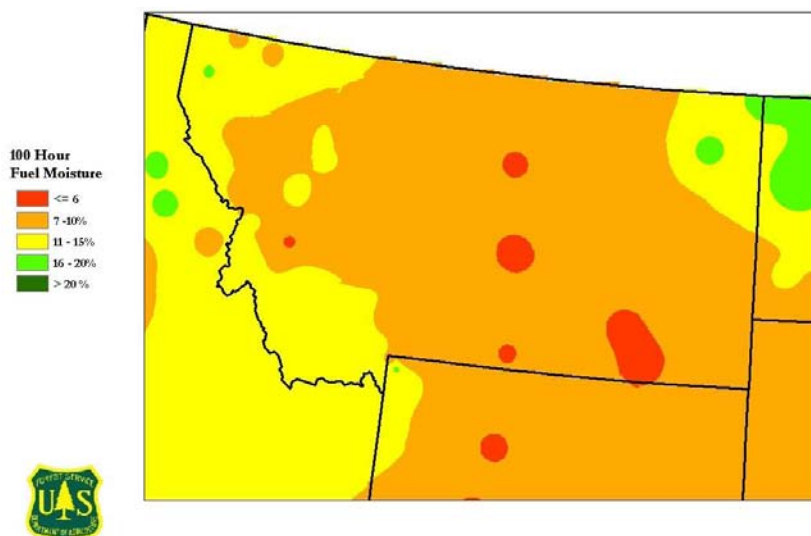


Figure 3—Interpolated 100-hour fuel moisture map, Northern Rockies, August 5, 2003.

The lightning probability algorithm has six fuel types: long-needled species such as ponderosa pine (*Pinus ponderosa*), short-needled species such as Douglas-Fir (*Pseudotsuga menziesii*), intermediate needle such as lodgepole pine (*Pinus contorta*), mixed high-altitude such as Englemann spruce (*Picea engelmannii*), grasses and hardwoods, and other nonconsidered such as water, farmland, cities, and barren land. The map of lightning fuel types, derived from Schmidt and others (2002), is static and applied here on a 1-km² pixel basis (fig. 4).

A typical WFAS ignition probability product is shown as figure 5. The probability of ignition for the Northern Rockies on August 5, 2003, is shown in figure 6.

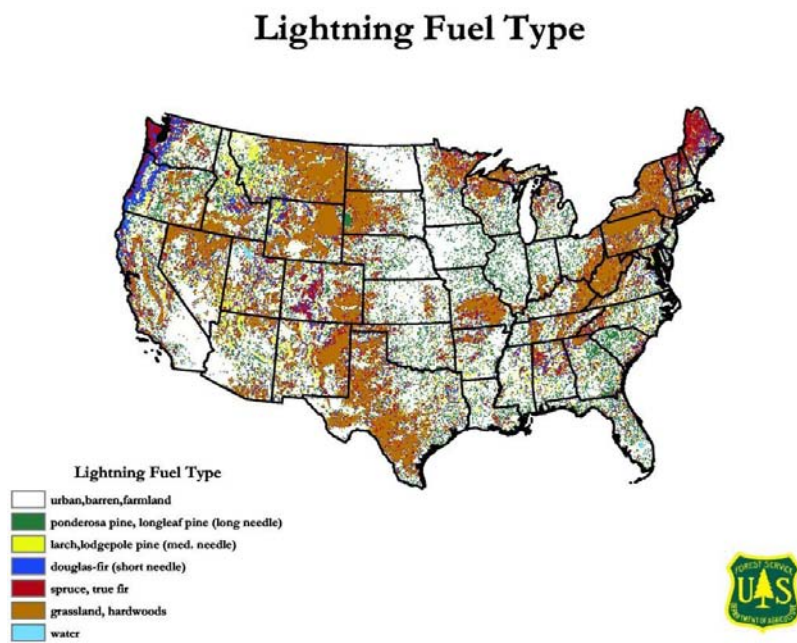


Figure 4 – Lightning fuel types.

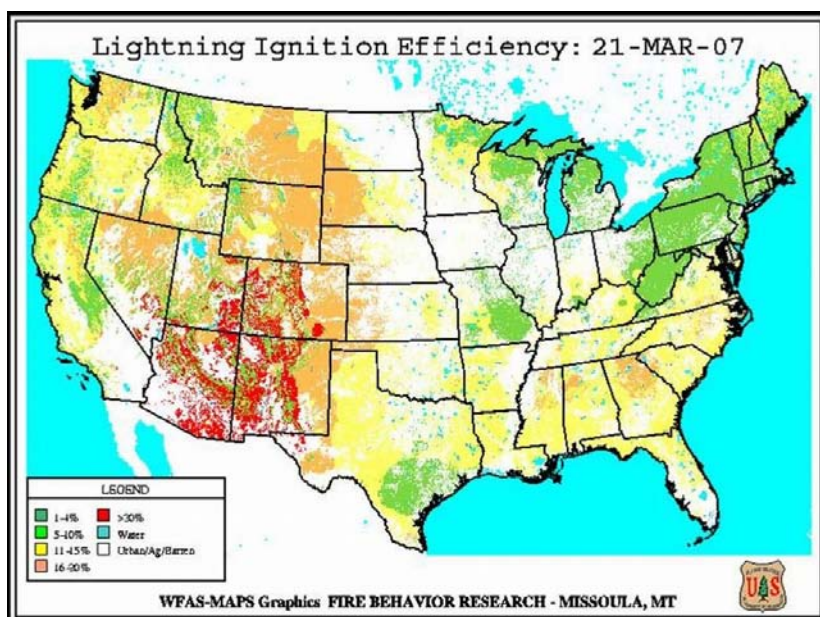


Figure 5 – WFAS lightning probability of ignition, March 21, 2007.

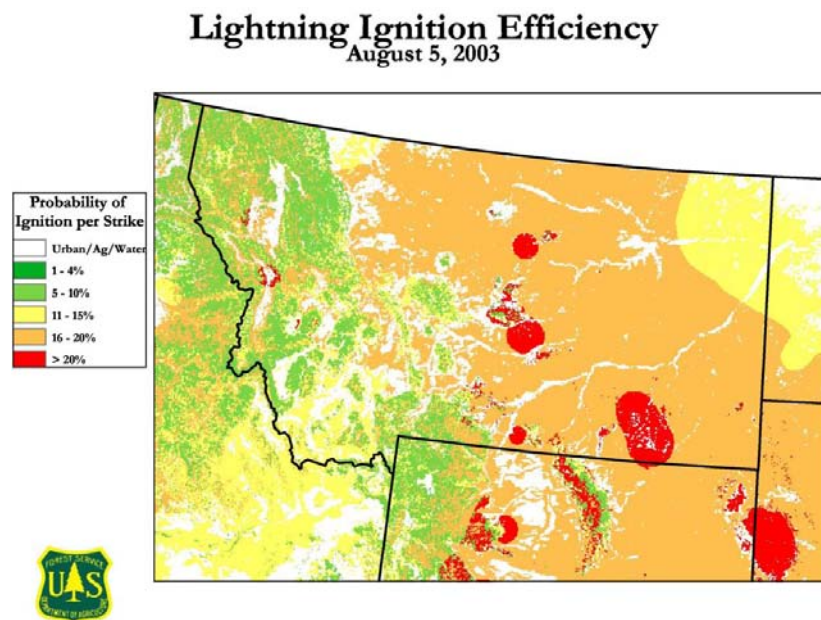


Figure 6—Probability of ignition, Northern Rockies, August 5, 2003.

Analysis

Because we are exploring GIS techniques for the data analysis, we need to convert the point values for the lightning flashes and fire locations into densities; that is, the lightning flash and fire locations need to be converted into flashes or fires per square kilometer per day. In this way, we can apply the ignition probability on a daily basis to the daily flash density and compare to the daily fire density. In order to account for spatial error and to smooth the coarse edges, the density grids were refined using the ArcInfo spatial low pass filter “focalmedian” function. The focalmedian is a local neighborhood function and, in this instance, returned the median of the nine pixel values in the surrounding 3 X 3 matrix. Flash density for August 5 is shown in figure 7 and fire density in figure 8.

The lightning flash density can be directly combined with the probability of ignition data by a simple pixel-by-pixel multiplication. The results are presented here as an ignition “possibility” map (an invented name for this paper only) (fig. 9). For example, if a given pixel has a 20 percent probability of ignition, five flashes would be needed within that pixel to generate a fire possibility of one. Note that at this stage the fires are treated as a continuous variable. To improve interpretation the continuous data are grouped into eight classes in figure 9. Obviously there cannot be 0.06 fires, but a possible ignition/fire density map does convey information of possible use to wildland fire organizations.

Figures 10 and 11 show actual fires superimposed on the fire possibility map for August 5, 2003. The fire locations are shown as point data. We formulated the fires as a density, or fires per square kilometer per day, for the preliminary statistical examination described later. For now though, we wanted to have a visual representation of how accurate the prediction could be. Figure 11, a “blowup” of the outlined section of figure 10, shows an example of how well we succeeded.

Lightning Flash Density August 5, 2003

Legend

- 0 strikes / km²
- 1 strike / km²
- 2 strikes / km²
- 3 strikes / km²
- 4 strikes / km²
- 5 strikes / km²

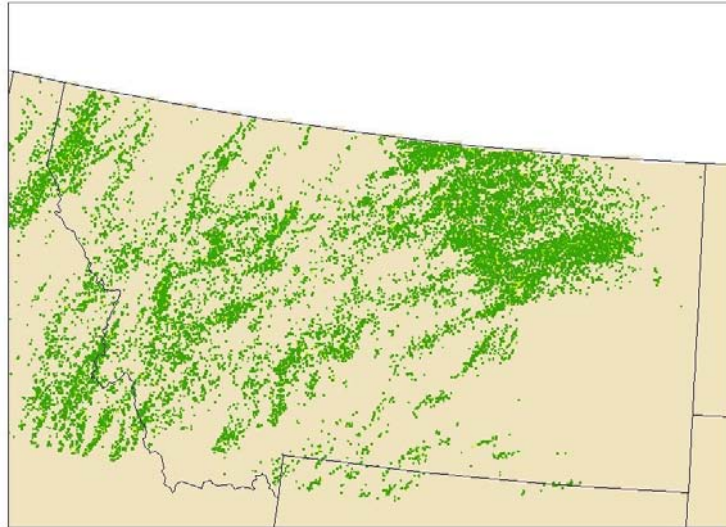


Figure 7—Lightning flash density, Northern Rockies, August 5, 2003.

Lightning Fire Density August 5, 2003

Legend

- 0 fires / km²
- 1 fires / km²
- 2 fires / km²

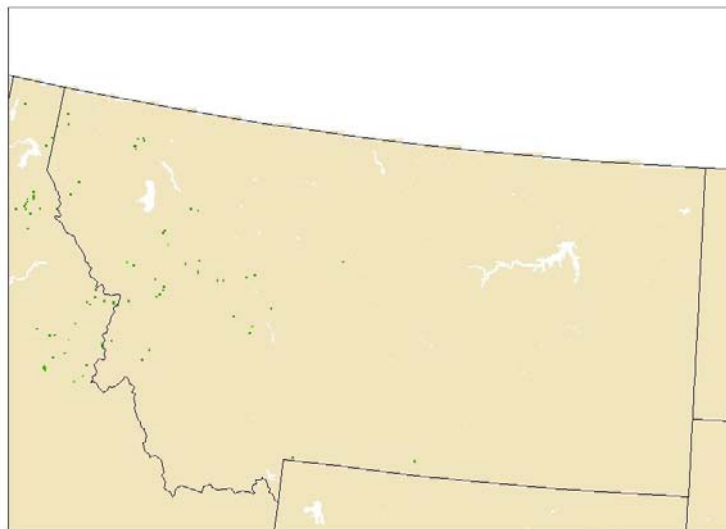


Figure 8—Lightning fire density, Northern Rockies, August 5, 2003.

Predicted Ignition/Fire Possibility August 5, 2003

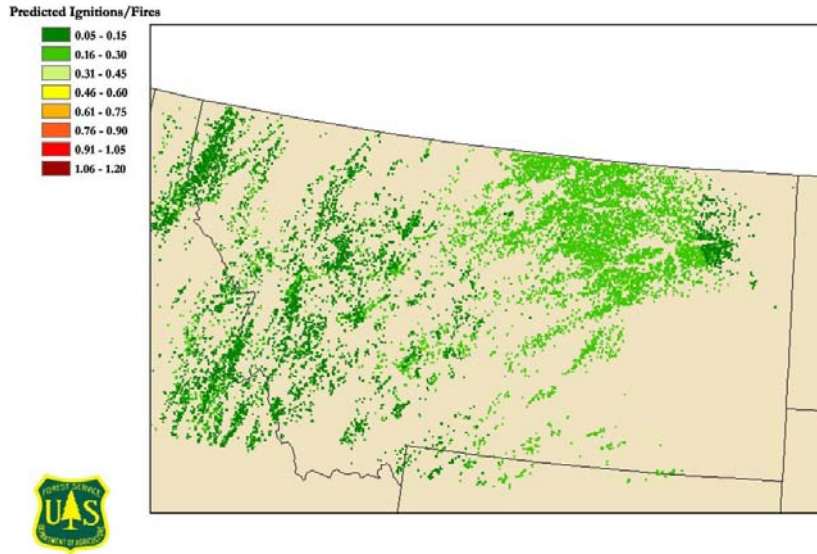


Figure 9—Predicted ignition possibility, Northern Rockies, August 5, 2003.

Predicted Ignition/Fire Possibility August 5, 2003

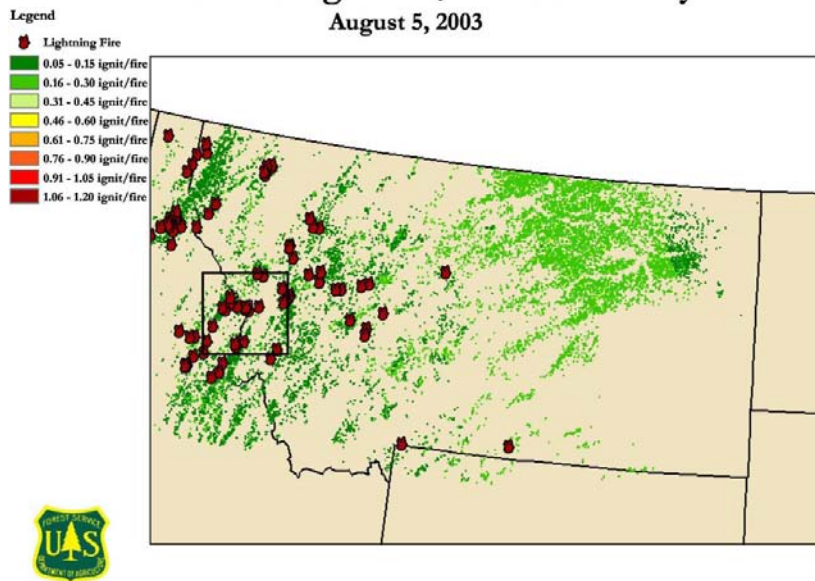


Figure 10—Predicted ignition possibility with lightning-caused fires, Northern Rockies August 5, 2003.

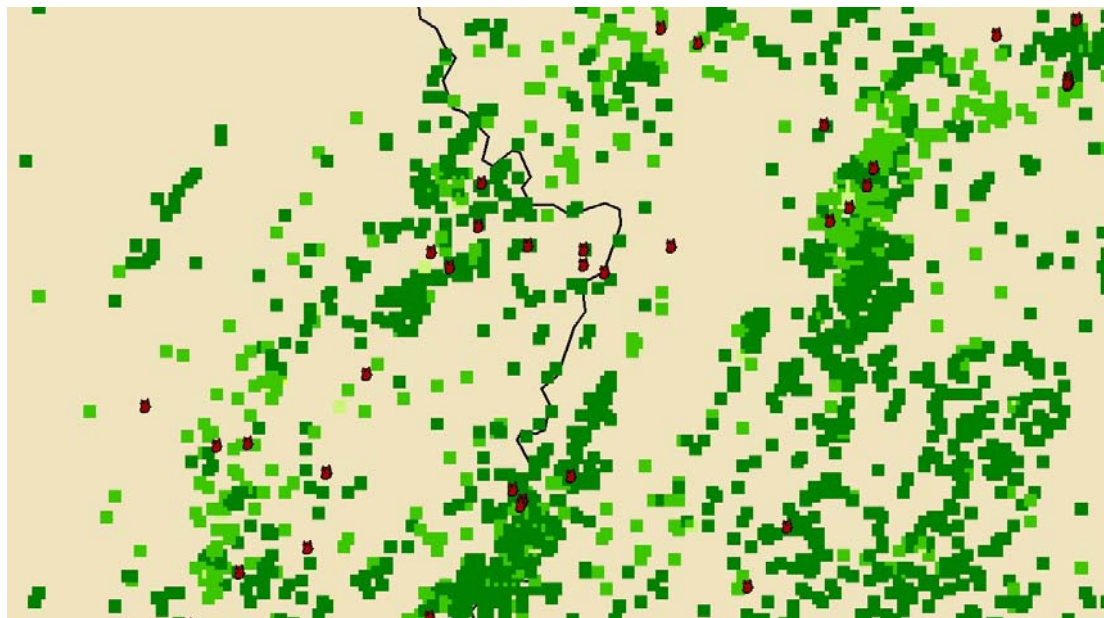


Figure 11—Closeup of outlined portion of figure 10.

On the whole, the visual picture is adequate. There are, of course, some fires ostensibly produced by lightning that are in places where there should not be any fires (fire possibility of zero). In general, however, the fires do seem to occur more often in the pale green patches rather than in the dark green ones; that is, fires are appearing in places where the expected density is higher as the legend in figure 8 shows. For comparison, figure 12 shows actual fires superimposed on the POI map for August 5, 2003.

For this preliminary examination we looked at the total data set in a more conventional manner. For the whole study period, the fires were “binned” by the probability of ignition categories they fell in for that day. Figure 13 presents a breakdown of the number of pixels of lightning ignition probability having fires in them. There are 168 fires in locations with a zero probability that they could be in unclassified places such as farmland or the like, or the fire locations are off slightly. Most fires fall in ignition probability classes up to about 0.25 and the remainder in classes greater than that.

Next, for each day in the study period, we multiplied the lightning strike density grid by the probability of ignition grid yielding a fire possibility grid. In other words, we only included pixels that had one or more lightning strikes in them. This analysis was done on a per day basis; that is, if a fire occurred, we looked to see what the corresponding fire possibility value was for the corresponding pixel on the same day. The results are shown in figures 14 and 15. Looking at the number of fires in the fire possibility classes in this more restricted way presents a different picture. According to figure 14, almost all of the fires occurred in 1 km² pixels having no flashes. Figure 15 shows that the remainders are distributed as one might expect because the flash density seldom exceeds more than one flash per pixel.

Lightning Ignition Efficiency August 5, 2003

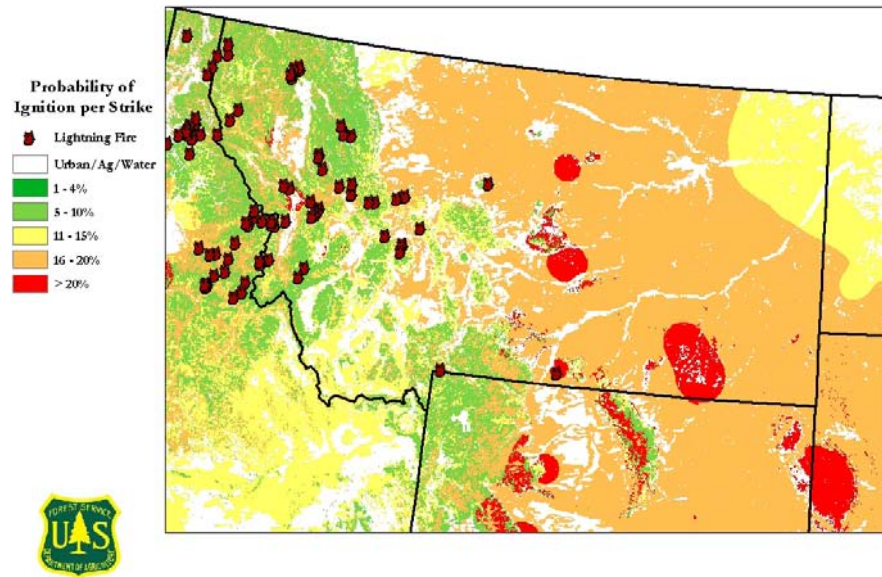


Figure 12—Lightning caused fires and probability of ignition, Northern Rockies, August 5, 2003.

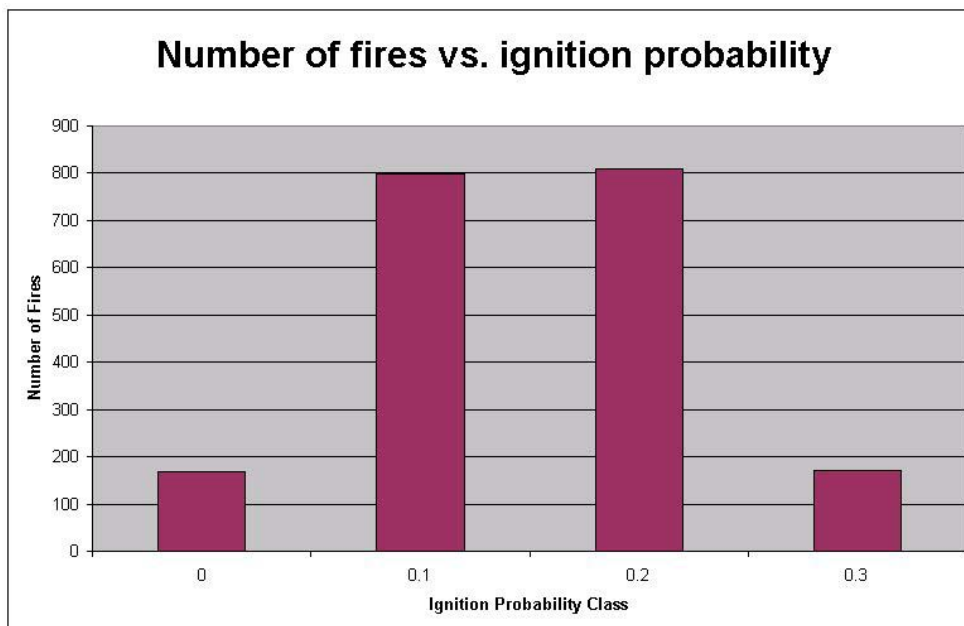


Figure 13—Number of fires in ignition probability categories.

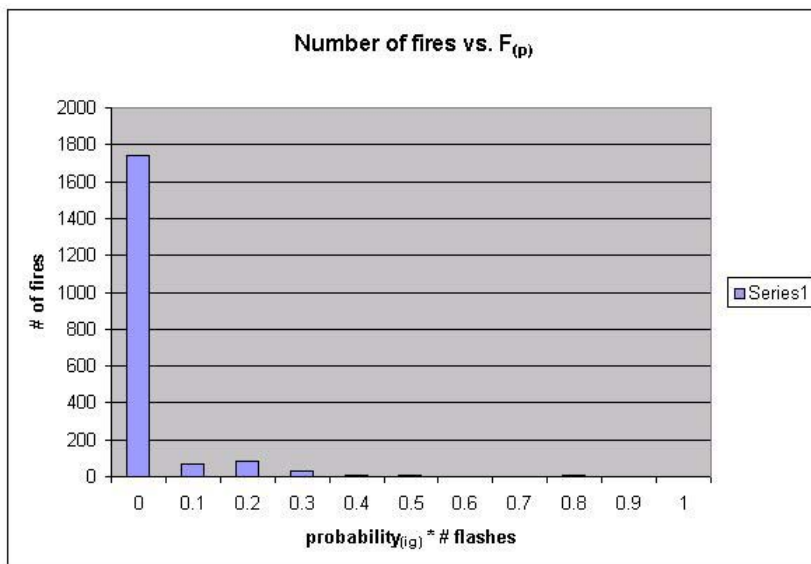


Figure 14—Total fires in fire possibility (F_p) categories.

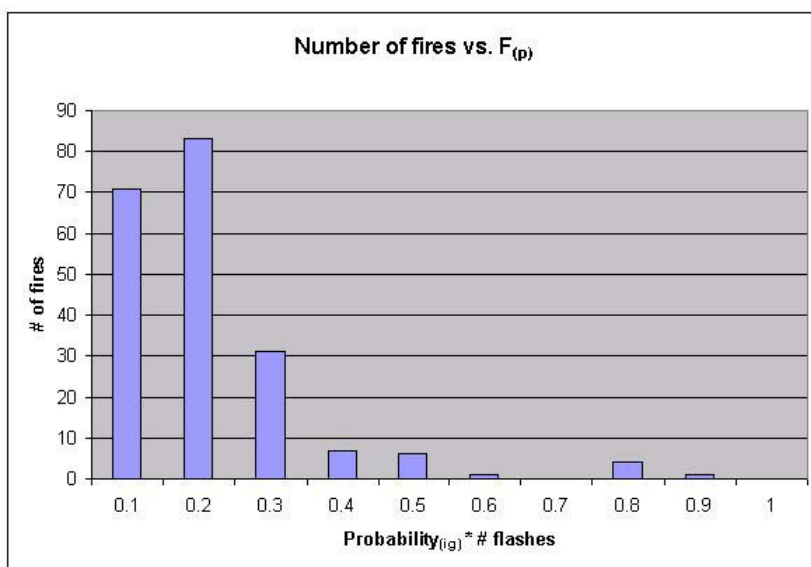


Figure 15—Total fires in fire possibility (F_p) categories—zero F_p excluded.

Discussion

We need to further consider the results from the data set. Presently, the POI map is calculated using a 1-km² grid size. Perhaps this grid size is too small given the errors inherent in the lightning and fire point data. In particular, the error in the lightning flash data is known to be on the order of 500 m in radius around the flash location and can be larger. Because the fire location data came from multiple agencies using different fire reporting protocol, the spatial and temporal error of the combined fire dataset is unknown. Across the study area, we assumed locations were determined with various techniques including Global Positioning System (GPS) receivers, maps, memory, best

guess, and so forth. We need to get an idea of the size of the potential fire location error by asking some questions of the agencies supplying the data. For example, DNRC warned that the fire location data from the multiagency jurisdictional area of eastern Montana was of poor quality. There appears to be a need for a multiagency standard protocol for determining fire ignition locations. Given the low cost and ready availability of GPS devices, we think they should be a standard tool provided to all initial attack crews.

The number of reporting RAWS stations affects the accuracy of the POI calculation. Figures 3 and 6 show the relationship between the 100-hour fuel moisture value and the probability of ignition. The “bull’s eye” pattern observed for some areas in figure 3 is an artifact of the interpolation algorithm caused by low RAWS station densities. Figure 6 shows how the bull’s eye effect caused by the 100-hour moisture calculation manifests itself in the POI map. The number of operational RAWS stations typically waxes and wanes through the fire season. For example, we had 64 operational RAWS stations on May 1, the first day of the study period. On August 5, our example day, there were 81 operational RAWS stations and 78 on September 30. The station density is highest in the western part of Region 1 and lowest in the east.

The 1-day example shown in figures 10 and 11 highlights the model’s tendency to overpredict the potential number of ignitions/fires. Each colored pixel (brown represents zero probability) represents a probability of a predicted ignition or fire “possibility” greater than zero. The values of these pixels are derived from a simple multiplication of the probability of ignition and number of lightning strikes falling within that pixel.

There appears to be a need to distinguish between a potential ignition and an actual reportable fire. A certain percentage of lightning ignitions never become reportable fires. Ignitions can decay, grow and decay before being detected, or grow and become detected as fires (Latham 1979). “Holdover” fires are another subset that needs further study. The current POI map predicts potential ignitions. We attempted to verify the map using reported fires. Because no dataset of all lightning ignitions, including those that decay, exists, we were forced to use the reported fire database for verification.

We need to identify all of the potential factors that influence lightning ignition/fire growth. Variables accounted for in the POI/fire possibility calculation include fuel moisture (before the storm), fuel type, duff depth, and number of lightning strikes. Other factors that determine whether an ignition grows and becomes a reportable fire include fuel and duff moisture after the storm (“wet” versus “dry” lightning storm), available fuel for fire spread and for holdover prediction, temperature, relative humidity, and wind speed in the days following a lightning strike. The National Weather Service provides a Doppler radar estimate of accumulated rainfall (Storm Total Precipitation). This product can be used to estimate daily accumulated precipitation. Rorig and Ferguson (1999) developed a discriminant rule using the dewpoint depression at 85kPa and temperature difference between 85 and 50 kPa to classify convective days as either “wet” or “dry”. We plan to retrieve the appropriate upper air and daily estimated rainfall data for our study period and see if it proves to be a significant factor in predicting fires.

The NFDRS index Energy Release Component (ERC) is an indicator of potential heat release in the flaming zone at the head of a fire. The ERC can be considered an indicator of available fuel since it represents the contribution of all live and dead fuel to fire spread. It is also considered one of the best fire danger components for indicating the effects of intermediate to long-term drying (Hall and others 2003). Using the same techniques we employed to recreate the daily 100-hour fuel moisture values and POI index, we plan to

calculate the daily ERC values, combine with the POI model, and see if any correlation with fire prediction exists.

LANDFIRE (Rollins and Frame 2006) will soon have a more refined and spatially accurate fuel map available for the Western United States. We would like to use these data to update our lightning fuel type map used for fuel type and depth inputs in the POI calculation.

Our goal is to produce a fire probability model that provides managers with immediate information on where lightning caused fires are likely to occur. What has the best potential for success is a daily grid or contour map that incorporates lightning strike data, probability of ignition with other variables that prove significant such as the NFDRS index Energy Release Component (ERC), Doppler radar estimated precipitation, and upper air soundings.

What other questions can we attempt to answer with the 2003 data set?

- How are fires distributed by lightning probability fuel type? This can be easily accomplished by statistically comparing the fire database with the lightning fuel type map.
- How do we account for holdover fires? This will be tricky. There are large variances and random factors that drive some of the hidden processes that influence holdover fires. In the present verification effort, we only consider the lightning and probability of ignition values for the fire's reported ignition date. We could, for example, expand the scope of analysis of fire possibility out 7 days after the fire ignition date. Initial attempts to do this have proven problematic. By increasing the number of days in the analysis searching for a predicted fire, large numbers of predicted fire pixels with values of zero increase the statistical noise and resultant binary correlation values.
- What is the relative error between the lightning location and a possible resulting fire? Each lightning strike has an associated error ellipse. The fire locations do not. The relative error of each strike can be quantified using the error ellipse data. The lack of a cross-agency location reporting protocol along with other variables makes the errors in fire location point data hard to measure. We hope to use the error ellipse data to measure the lightning location error.
- Does the ignition probability actually predict fire probability? Given our preliminary verification analysis, the answer to this question is no. Increasing the pixel size is an obvious first step. We think that the incorporation of other predictors such as ERC (fire season drought or available fuel), radar rainfall estimates (Storm Total Precipitation), upper air sounding grids, or a spread variable into the fire probability model will significantly improve its predictive ability.
- Will stroke data rather than flash data improve the analysis? Each lightning strike is made up of multiple "strokes." This is referred to as the strikes' multiplicity. We have the stroke data for the study period and plan to substitute them for the strike data to see if they improve the analysis.

Acknowledgments

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