An Objective Method for Verifying Red Flag Warnings Issued for Lightning Activity

Richard Arkell and Ryan Knutsvig
National Weather Service Forecast Office, Elko, NV
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1. Introduction

The Red Flag Warning is, arguably, the single most important wildfire-related product that the National Weather Service (NWS) issues to the fire-fighting community. It can be defined as a warning for forecast or occurring conditions in which there is a critical combination of dry fuels and weather that are capable of supporting extreme fire behavior.

NWS Forecast Offices (WFO's) issue Red Flag Warnings based on a variety of criteria. Two of the most common are those issued for gusty winds and low relative humidity, and those issued for lightning activity. Most WFO's have red flag criteria for wind/RH events, while around half of all offices have criteria for lightning. Other criteria used by various WFO's include significant wind shifts, such as with frontal passage, a high Haines Index, a high Fire Danger Rating, and poor overnight RH recoveries. In all cases, fuels must be sufficiently dry.

With regard to lightning-based Red Flag Warnings, some WFO's issue warnings for lightning, whether wet or dry, and some issue warnings specifically for dry lightning only. Either way, one of the primary verification variables is the areal coverage, or spatial distribution, of the lightning strikes.

At the Elko (LKN) WFO, the criteria for lightning-based Red Flag Warnings is specifically for dry lightning, and it is for an areal coverage of 15% or greater for each fire weather zone. Dry lightning is defined in the LKN forecast area as lightning produced by thunderstorms that produce less than a tenth of an inch of precipitation. It should be noted that some forecast offices use different precipitation thresholds to define "dry", such as a quarter inch of precipitation.

This paper examines the verification of Red Flag Warnings based on lightning activity. Verifying these Red Flag Warnings is one of the biggest challenges facing fire weather forecasters in the NWS. The determination of areal coverage, specifically, has been, historically, somewhat subjective.

We will examine the historical process of determining areal coverage, both at LKN and around the country, and present a process to more objectively determine the areal coverage for any event. This process uses one existing Graphical Forecast Editor (GFE) procedure and three new GFE smart tools, which are collectively referred to as the

"Lightning Radius Method", in an attempt to objectify the process. The process was used operationally for the first time at LKN for the entire 2008 and 2009 fire seasons, and met with significant success, based on forecaster feedback.

2. Traditional Method for Determining Areal Coverage at LKN

At LKN, verification of dry lightning coverage for an event has traditionally been determined by printing out the hourly lightning strike maps from D2D, subjectively integrating the areal coverage over the course of the event, and then penciling out any areas where storms were deemed to be wet. This was complicated by the fact that, in some events, the thunderstorms transitioned from dry to wet.

This subjective estimation process can produce highly variable results, depending upon who is doing the estimation. For one thing, the lightning strike distribution across a zone is often highly irregular, with outlying storms that may or may not be included in the areal coverage. For another, an event can be a combination of discrete "episodes" or events, as for example when diurnal afternoon lightning is followed overnight by a short wave that triggers additional lightning activity.

This verification process needs to be conducted very close in time to the event itself. This is the case for two reasons. The first is that much of the lightning data in the Advanced Weather Interactive Processing System (AWIPS), and data needed for determining wet versus dry, are "perishable". That is, it is no longer available several hours later. The second reason is that it is easier to verify an event when it is still "fresh" in the minds of the staff.

3. Survey of Verification Methodologies at Forecast Offices Across the U.S.

A survey was conducted of dry lightning verification methodologies at 119 of the NWS's 122 WFO's. These methodologies are contained in the Annual Operating Plans (AOP's) of the ten Geographic Area Coordination Centers (GACC's) in the conterminous U.S., plus Alaska. Interestingly enough, although there is ample documentation on Red Flag Warning issuance criteria, there is very little information on verification methodologies, especially with regard to how areal coverage of lightning strikes is determined. This is in contrast to information on Red Flag Warning verification for warnings based on gusty winds and low relative humidity, for which there is significant detail.

The most common areal coverage threshold for lightning-based Red Flag Warnings is 25%. A smaller percentage of offices use the same 15% coverage threshold that LKN uses. For some of these offices, like LKN, the coverage is specifically for dry thunderstorms, while for others it is for wet or dry storms. A few offices also include an Energy Release Component (ERC) in the determination of wet versus dry.

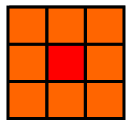
Other criteria used by offices get away from specific coverage criteria and instead take into account seasonal and climatological criteria. An example of this is: "Increased thunderstorm activity, wet or dry, during an extremely dry period". And then, there are criteria that combine coverage and climatological criteria, as "First significant lightning event, wet or dry, with at least15% coverage, after an extended hot and dry period." Other offices, especially in the eastern U.S., specify the occurrence of any dry lightning as being sufficient for a Red Flag Warning since it is climatologically rare. And many offices do not have red flag criteria based on lightning activity.

In virtually all AOP's, the discussion of verifying lightning-based Red Flag Warnings is either absent or very limited, especially with regard to the determination of areal coverage. A good example of a much generalized discussion is the following: "All Fire Weather Watches and Red Flag Warnings must be verified during the shift that follows the event (or non-event). Each should be documented in the database… A space for comments is provided on the Watch/Warning Log sheet. Attach to the Log sheet any observations or other information that can be used in the verification process."

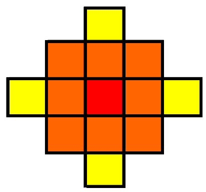
4. Detailed Description of the Lightning Radius Method

LKN has made an attempt to objectify the areal coverage component of lightning-based red flag verification. Objectifying this process is problematic because lightning strike distribution is quite variable from event to event. Assigning a percent coverage can be a very subjective process. For example, in a given fire weather zone, one event might produce 100 strikes over a small area, while another event might produce the same 100 strikes spread out across the entire zone. Usually, the event with the greater spatial dispersion of strikes will be a greater challenge for initial attack by fire fighters.

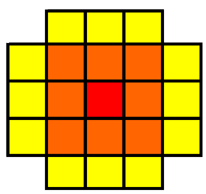
For operational consistency, LKN has operated on the principle that, for most situations, an objective verification approach is best. The challenge is to quantify the affect of the spatial distribution of the strikes. Simply counting the grid boxes with lightning strikes, however, wouldn't be of any value because there are over 24,000 2.5 km grid points in the Elko forecast area. It would take, on average, over 500 lightning strikes in each forecast zone to reach the 15 percent verification threshold. Therefore, an "area of influence" approach was adapted, where each lightning strike would define an area of several grid boxes concentric around the grid box with the strike. This would create an "area of influence" for each strike which approximates a circle. Three areas were chosen, with 9, 13, and 21 grid boxes. These areas have "effective radii" of 4.2 km, 5.1 km, and 6.5 km, respectively, which will be referred to from here on as 4 km, 5 km, and 6 km. The resulting areas of influence comprise 56, 81, and 131 square km, respectively (see Figure 1).



Total grid boxes	9
Area of one box (km^2)	6.3
Area of 9 boxes (km^2)	56
Area of 9 boxes (mi^2)	21.7
Effective radius (km)	4.2
Effective radius (mi)	2.6



Total grid boxes	13
Area of one box (km^2)	6.3
Area of 9 boxes (km^2)	81
Area of 9 boxes (mi^2)	31.4
Effective radius (km)	5.1
Effective radius (mi)	3.2



Total grid boxes	21
Area of one box (km^2)	6.3
Area of 9 boxes (km^2)	131
Area of 9 boxes (mi^2)	50.7
Effective radius (km)	6.5
Effective radius (mi)	4.0

Figure 1. Grid Schemes for Lightning Radius Method

The procedure created consists of running one GFE procedure and three GFE smart tools. The method, called the Lightning Radius Method, which is used to compute the statistics for 4 km, 5 km, and 6 km areas of influence, consists of running the procedure “RunLtg” created by Science & Operations Officer (SOO), Tim Barker of WFO Boise, which creates hourly and 12-hourly lightning strike grids, and three smart tools created by Ryan Knutsvig (SOO, WFO LKN): “LightningSum”, “LightningRadius”, and “LightningStats”. Detailed documentation on all of these software packages can be found on the NWS Meteorological Development Lab (MDL) Smart Tools Repository website (Barker, 2006 and Knutsvig, 2008). Detailed instructions for using the Lightning Radius Method can be found in Appendix A below.

The Lightning Radius Method computes the number of lightning strikes and percentage coverage for any GFE edit area for 4 km, 5 km, or 6 km areas of influence, with fire weather zones being the most common edit areas chosen. The statistics can be run for any length event, ranging from 1 to 12 hours or more. Examples of the resulting graphics and statistics are shown in Figures 2 through 5.

A key aspect of the Lightning Radius Method is that overlapping areas of influence from adjacent lightning strikes only count once. Therefore, 100 lightning strikes all in close proximity, with significant overlapping areas of influence, will result in a lower percent coverage than a 100 strikes spread over a large area where there are no overlapping areas of influence. This approach is essential to the concept of approximating the impact of lightning strike distribution, and resulting fire starts, on fire fighting logistics. Fire starts close together will usually be easier to attack than those that are spread out over a large area.

A good example of this distribution effect can be illustrated with a particular event. On July12, 2008, Zone 457 (Northern Nye County and Lander and Eureka Counties south of U.S. 50) had 454 strikes. The areal coverage using a 5 km area of influence was 33 percent. A few weeks later, on July 27, another event produced 661 strikes in the same zone, but the areal coverage was only 22 percent. The second event had 207 more strikes and yet had a third less coverage area. This reflects the much more densely packed distribution in the second case. From a fire fighting point of view, initial attack for the second event might be easier than for the first, despite having 207 more strikes, due to the closer proximity of strikes and potential fire starts.

Figures 2, 3, and 4 below show the Radius Grid graphics for an event for areal coverage's of 4 km, 5 km, and 6 km radii, respectively. Figure 5 shows the GUI with lightning strike and coverage statistics for a given radius. See Appendix A for more details.

For the 2008 and 2009 fire weather seasons, the Lightning Radius Method was used on an experimental basis at Elko to verify all lightning-based warnings. It remains to be seen which radius will turn out to be best, although preliminary indications are that the 5 km radius works best in most situations for the Elko forecast area. It may turn out that the other radii could be useful at other forecast offices and for special conditions. For example, if fuels are abnormally dry and ignition efficiencies high, the 6 km radius may be more useful for verification. Likewise, if fuels are damp due to recent rains, a 4 km radius may work better.

The Lightning Radius Method is also run on a cron every day at 12 UTC to compute the areas of influence for each of LKN's five (seven starting in 2009) fire weather zones at all three radii for the previous 24 hours. These data are archived and emailed to the fire weather team as a summary of the previous day's lightning. In addition to verifying Red Flag Warnings, the Lightning Radius Method will allow the Elko office to develop a lightning climatology for strikes and percent coverage at 4, 5, and 6 km, for individual fire weather zones and the forecast area as a whole.

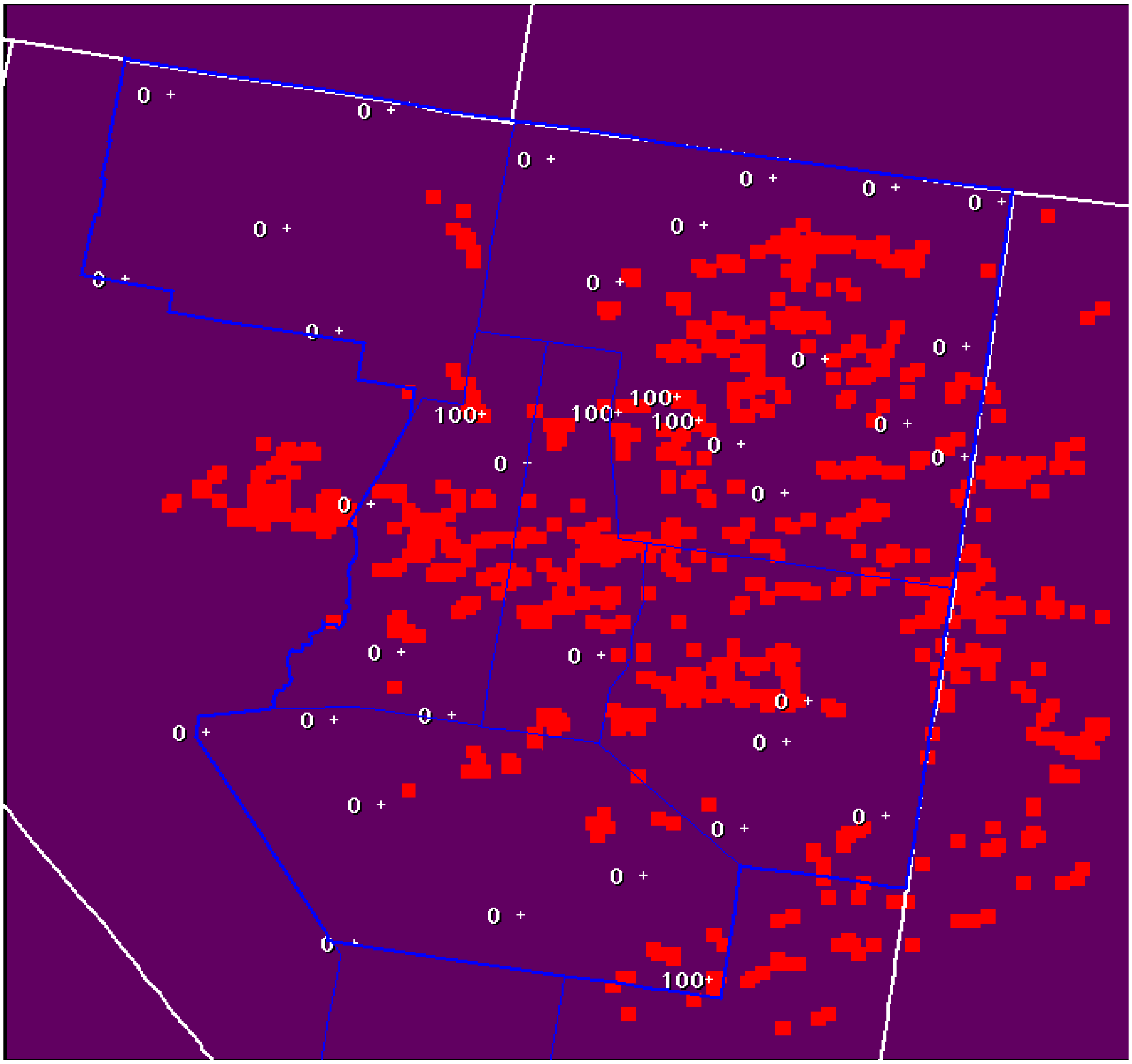


Figure 2. Example of Radius Grid for 4.2 km. Blue lines delineate counties in the WFO Elko County Warning Area. (See Appendix A for details.)

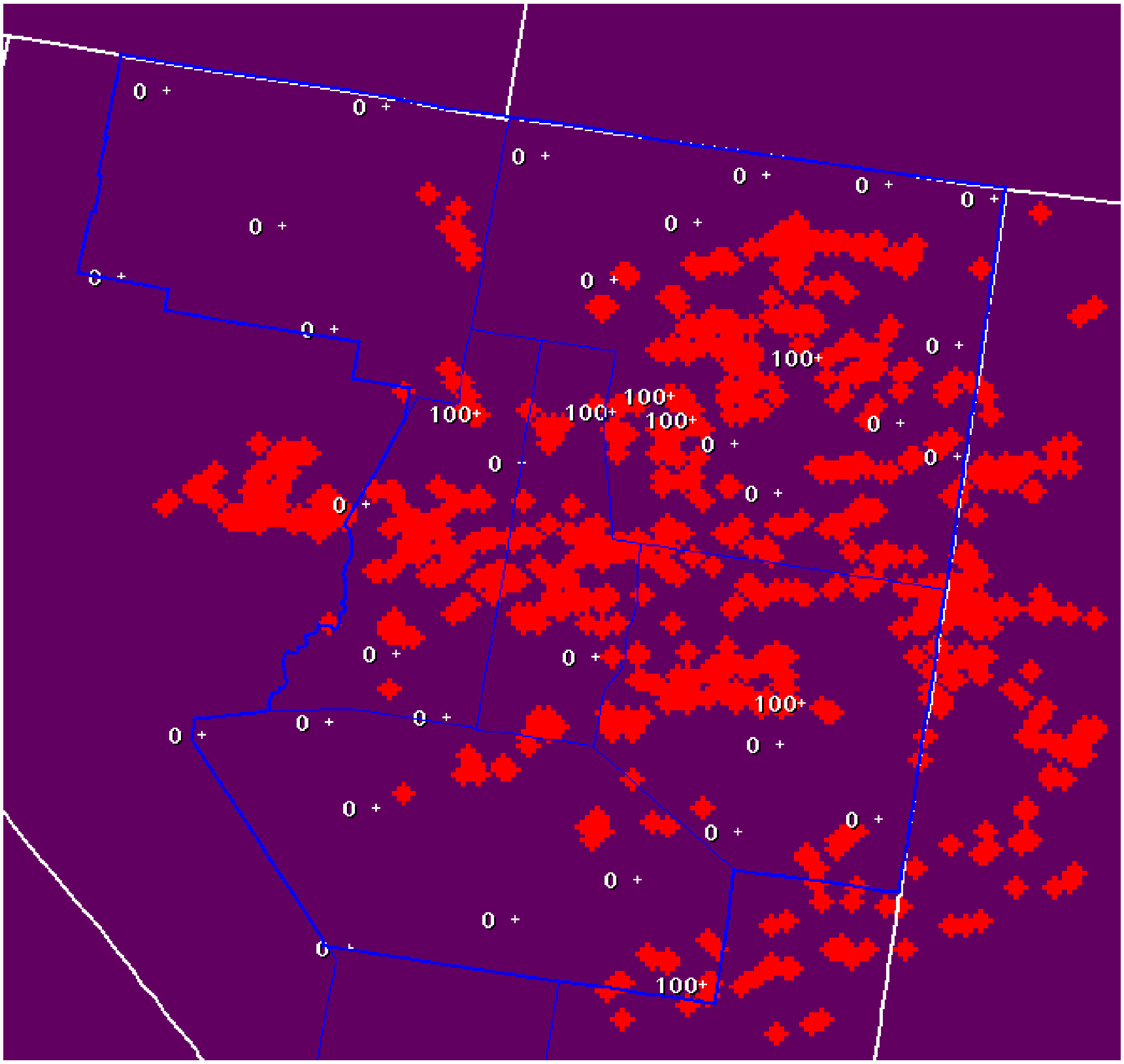


Figure 3. Example of Radius Grid for 5.1 km. Blue lines delineate counties in the WFO Elko County Warning Area. (See Appendix A for details.)

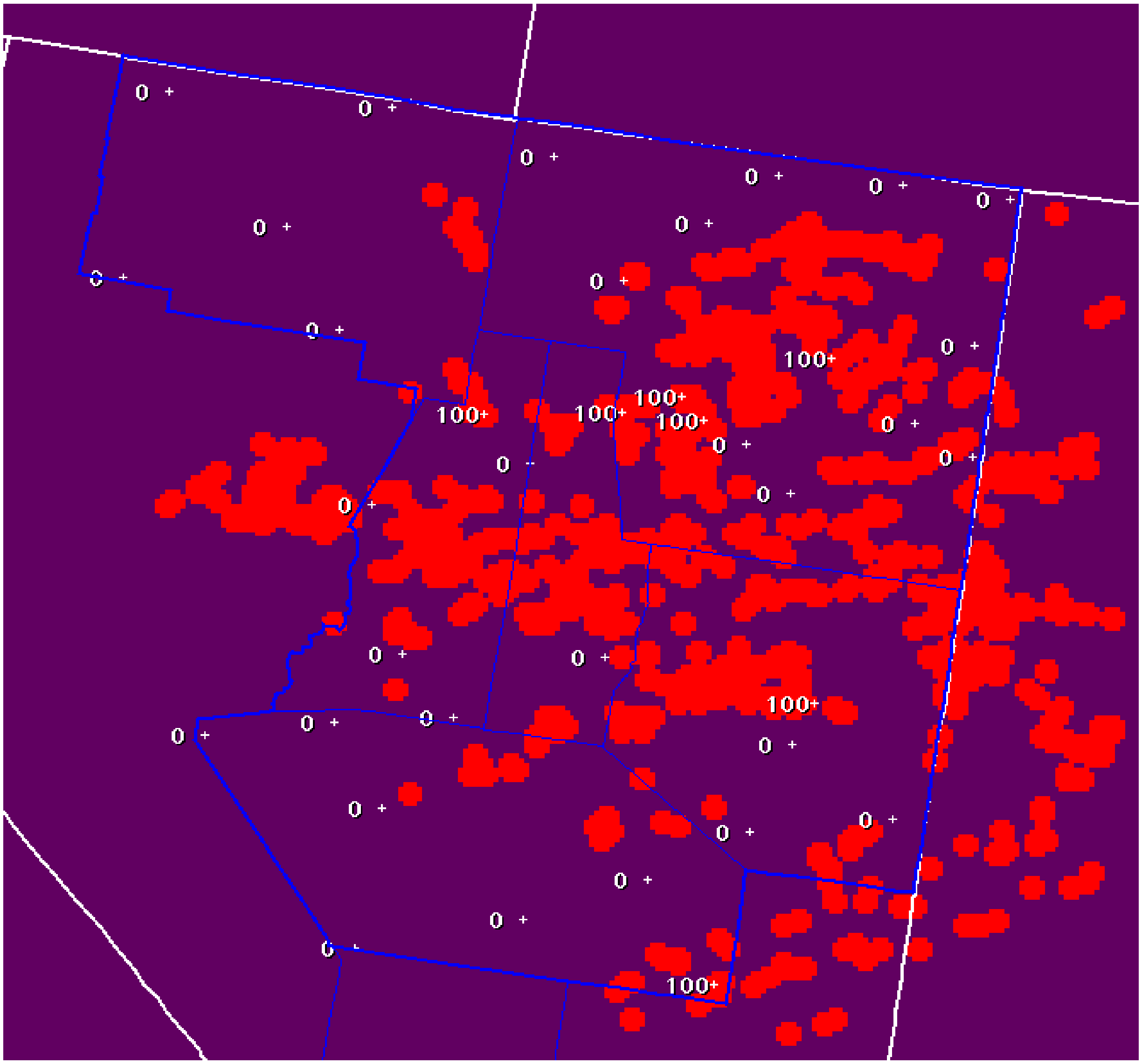


Figure 4. Example of Radius Grid for 6.5 km. Blue lines delineate counties in the WFO Elko County Warning Area. (See Appendix A for details.)

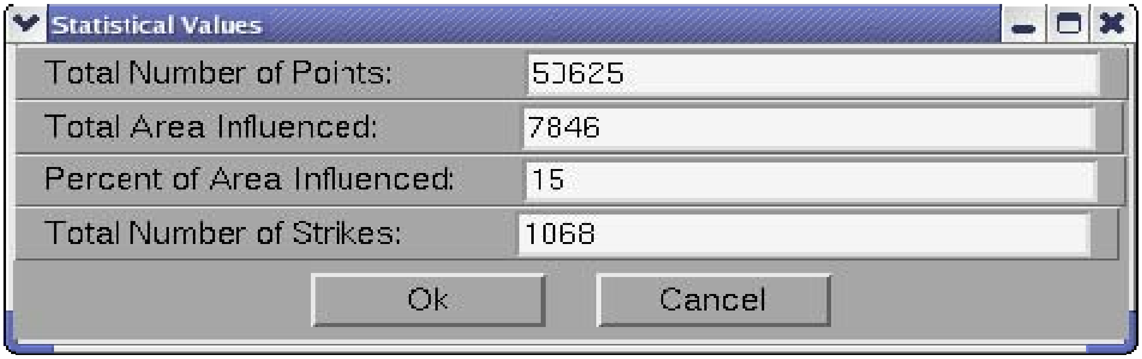
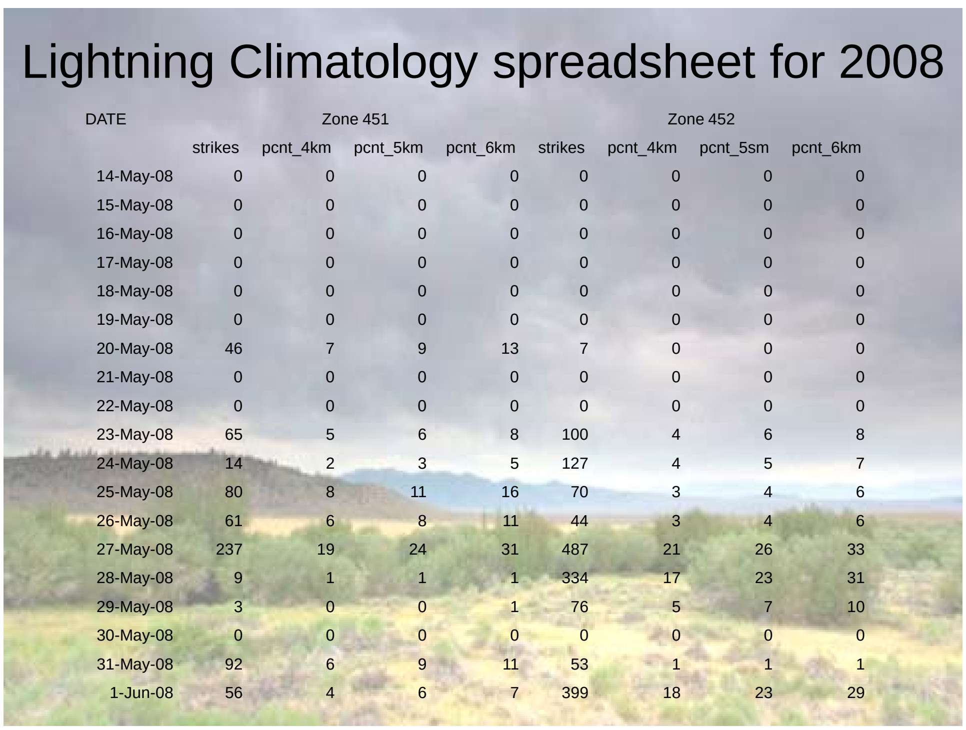


Figure 5. GUI Pop-up when "LightningStats" Is Run for a Particular Radius (see Appendix A for details)



Lightning Climatology spreadsheet for 2008

DATE	Zone 451				Zone 452			
	strikes	pcnt_4km	pcnt_5km	pcnt_6km	strikes	pcnt_4km	pcnt_5sm	pcnt_6km
14-May-08	0	0	0	0	0	0	0	0
15-May-08	0	0	0	0	0	0	0	0
16-May-08	0	0	0	0	0	0	0	0
17-May-08	0	0	0	0	0	0	0	0
18-May-08	0	0	0	0	0	0	0	0
19-May-08	0	0	0	0	0	0	0	0
20-May-08	46	7	9	13	7	0	0	0
21-May-08	0	0	0	0	0	0	0	0
22-May-08	0	0	0	0	0	0	0	0
23-May-08	65	5	6	8	100	4	6	8
24-May-08	14	2	3	5	127	4	5	7
25-May-08	80	8	11	16	70	3	4	6
26-May-08	61	6	8	11	44	3	4	6
27-May-08	237	19	24	31	487	21	26	33
28-May-08	9	1	1	1	334	17	23	31
29-May-08	3	0	0	1	76	5	7	10
30-May-08	0	0	0	0	0	0	0	0
31-May-08	92	6	9	11	53	1	1	1
1-Jun-08	56	4	6	7	399	18	23	29

Figure 6. Example of Lightning Climatology Spreadsheet Derived from Lightning Radius Method statistics

5. Summary and Conclusions

In the NWS fire weather forecast process, the primary emphasis in lightning-based red flags is typically on the areal coverage, or distribution, of strikes. The forecaster should, however, keep fuel conditions in mind, because the ultimate goal is to try to determine whether or not there will be a major wildfire outbreak.

At the base of the verification process, however, the primary concept still remains that of areal coverage. To this extent, having an objective tool to verify areal coverage is a significant improvement. The Lightning Radius Method is such a tool, and should be useable across all portions of the country, especially because of the adaptive aspect of being able to choose 4 km, 5 km, or 6 km radii to determine areal coverage.

Another strong aspect of the Lightning Radius Method is its ability to be used for research by creating data bases for lightning strikes counts and areal coverage at 4 km, 5 km, and 6 km. To that end, it might be beneficial if forecast offices had more access to lightning network data in the future. This could, in the long run, have a very positive influence on forecast skill.

Overall, the primary goal of this effort has been to provide some measure of objectivity to red flag warning forecast verification by taking into account lightning strike distribution and fuel moisture characteristics in the verification process. Lastly, the better the verification process, the better will be the feedback mechanism to improve forecast skill.

6. References

Barker, T., 2006: “Ltg” Version 1.0. The National Weather Service Smart Tool Repository. Developed Oct, 11th, 2006.
http://www.mdl.nws.noaa.gov/~applications/STR/generalappinfoout.php3?appnum=1085

Knutsvig, R., 2008: “Lightning Tools” Version 1.0. The National Weather Service Smart Tool Repository. Developed May, 8th, 2008.
http://www.mdl.nws.noaa.gov/~applications/STR/generalappinfoout.php3?appnum=1249

Appendix A – Steps for Lightning Radius Method in GFE

*********** while on work grid *************

1) Make a work grid that spans the time of the lightning event.

2) While still on the work grid, use the Populate Pull-down to **RunLtg**. This will create 1-hour and 12-hour grids of recent lightning strike data.

3) While still on the work grid, right click and choose **LightningSum**. This will give you a mostly green background. (If you want to see the lightning data more clearly, right click on upper color bar, pick “fit to data” and then “single grid.”)

4) While still on the work grid, right click and choose **LightningRadius.** A GUI will pop up. Pick 4.2 km, 5.1 km, or 6.5 km. This will create a radius grid that shows lightning strikes with appropriate areas of influence (see examples in Figures 2, 3, and 4 above).

************* while on radius grid ******************

5) Go to Radius Grid. Choose edit area (typically a fire wx zone). Right click and run **LightningStats.** A GUI will pop up with total number of lightning strikes and areal coverage in the chosen edit area (see example in Figure 5 above).

************* to runs stats for another zone ****************

5a) To do another zone, choose the edit area you want, and while still on Radius Grid, right click and run **LightningStats**. A GUI will again pop up with total number of lightning strikes and areal coverage for the appropriate edit area.

************* to do for a different radius *************

5b) To do for a different radius, go *back to the work grid* and run **LightningRadius** again. A GUI will pop up. Pick 4.2 km, 5.2 km, or 6.5 km. This will modify the radius grid. Then, *go to the Radius Grid*, adjust edit area as necessary, and run **LightningStats.**