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Examining the Lightning Polarity of Lightning Caused Wildfires

Nicholas J. Nauslar
Desert Research Institute
Division of Atmospheric Sciences, CEFA
Reno, NV
nauslar@dri.edu

I. INTRODUCTION

Lightning is the main natural ignition source for U.S. wildfires and accounts for 15% of wildfires and 60% of acres burned (NIFC 2013). The percentage of lightning ignitions increases above 50% across the western United States especially in the Intermountain West and more sparsely populated areas. There is some debate and several theories pertaining to what are the main factors for lightning-ignited wildfires. Viegas et al. (1992) and Meisner et al. (1993) cite fuel moisture as the main contributor while Dissing and Verbyla (2003) argues fuel type. Flannigan and Wotton (1991), Latham and Schlieter (1989), Latham and Williams (2001) and Fuquay et al. (1979) theorize a long continuing current (LCC) is the most important factor. This is due to the extended length of time the lightning strike is in contact with the fuels. Flannigan and Wotton (1991) also indicate that the multiplicity of strikes is an important, if not the most important predictor for lightning-ignited wildfires as other studies have shown it weakly related to a LCC (Shindo and Uman 1989). Hely et al. (2001) discusses the importance of the existing weather conditions, which is supported by Wierzchowski et al. (2002), who also indicates fuel conditions are as important as the weather conditions. Ordonez et al. (2012) uses a generalized linear model with fuel type, fuel conditions, and weather conditions as input to predict lightning-ignited wildfires.

The purpose of this study is to examine the polarity of all lightning strikes that occur within 1-2-km of lightning-ignited wildfires. Latham and Williams (2001) theorized that positive strikes are more likely to ignite wildfires due to the larger magnitude or increased temperature associated with positive lightning strikes. Hall and Brown (2006) showed there was no difference between the number of positive lightning strikes and the highest multiplicity occurring within a 2-km or a 4-km radius. Additionally, Larjavaara et al. (2005) examined lightning-ignited wildfires in Finland and its results contradicted North American studies that showed positive flashes and high multiplicity of negative flashes are needed for ignition. Pineda et al. (2012) confirms what Larjavaara et al. (2005) and Hall and Brown (2006) found by showing polarity, multiplicity, and peak current of lightning associated with lightning-ignited wildfires are similar to the broader lightning climatology. Pineda et al. (2012) also discusses holdovers, which are fires that smolder for multiple days before the intensity increases and the fire spreads.

Six dry thunderstorm cases from 2006-2009 that ignited many wildfires are examined in this study related to previous work (Nauslar 2010; Nauslar et al. 2013). These cases were chosen to minimize holdovers since most of these fires were reported during the event. Nauslar (2010) and Nauslar et al. (2013) have detailed descriptions of the meteorology and distribution of strikes for each of the cases to help guide the data retrieval and analysis. All CG lightning strikes within 1-km and 2-km of each fire during the time period for each case was gathered and analyzed for the purpose of specifically examining the polarity. The analysis was undertaken to determine if positive lightning strikes are more efficient or more frequently associated with lightning-ignited wildfires. Additionally, the frequency of positive and negative strikes being associated with lightning-ignited wildfires was compared to the climatological proportion of all lightning strikes positive and negative strikes

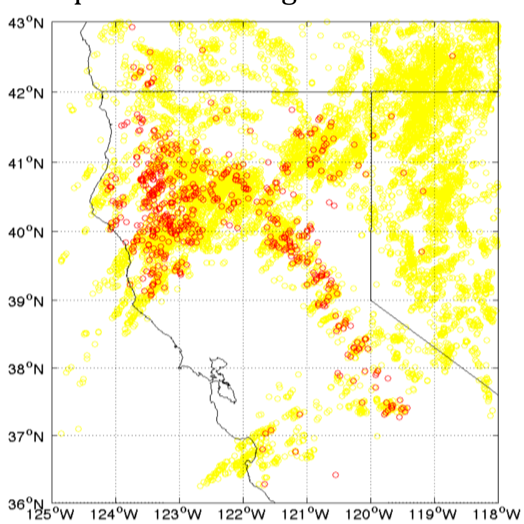

Figure 1. Lightning-ignited wildfires (red circles) overlaid with CG lightning strikes (yellow circles) for 20-22 June 2008. One example of the six cases examined.

II. DATA AND METHODS

1. DATA

Cloud-to-ground (CG) lightning data from the National Lightning Detection Network™ (NLDN) and wildfire data from the quality controlled Fire Program Analysis (FPA) fire database were examined. The NLDN lightning data provides the month, day, year, hour, minute, second, latitude, longitude, polarity, magnitude, and multiplicity for each CG strike recorded with an approximate location accuracy of 0.5 km and detection rate around 90% (Cummins et al. 1998). Additionally, positive CG flashes < 10 kA were excluded due to the possible inclusion of misidentified cloud flashes (Orville et al. 2002). The FPA fire database provides a multitude of data for each fire, but the focus was on the month, day, year, latitude, longitude, and cause.

The analysis was confined to six dry thunderstorm case studies that ignited many fires during their short duration across different regions of the western United States (west of the Rocky Mountains)(Figure 1). The dates are: 1) 20-21 June 2008; 2) 16-17 July 2007; 3) 1 August 2009; 4) 21 August 2009; 5) 25-26 June 2006; and 6) 20 August 2006. Most of the fires ignited from the dry thunderstorms in these cases started the day of the lightning or the day after. This minimized the effect of holdovers. In total there were 1,910 fires and approximately 80,000 CG lightning strikes across the six cases.

2. METHODS

The analysis (primarily done in MATLAB) began with finding all CG lightning data within a 1- and 2-km radius (Figures 2-3; Appendices (A) 1-2). These radius values (1- and 2-km) were chosen to account for the location error of the CG lightning data (0.5 km) and for any possible error of the fire location (Cummins 1998). Hall and Brown (2006) used 2-km and 4 km respectively for their lightning climatology project for similar reasoning. No lightning strikes were included that occurred after the declared fire start or before the start of the event. All of the dry thunderstorm events' durations ranged from one to three days.

Once all of the CG lightning data was organized by fire for 1- and 2-km radii, data counts included: 1) number of fires with and without CG strikes; 2) number of negative and positive strikes within the specified radius per case; and 3) number of fires with positive strikes, negative strikes or both. Additionally, some basic statistics were calculated including: 1) median of polarity, number of strikes per fire, and multiplicity; 2) lightning efficiency (number of fires divided by number of strikes); and 3) ratios comparing positive and negative strike characteristics.

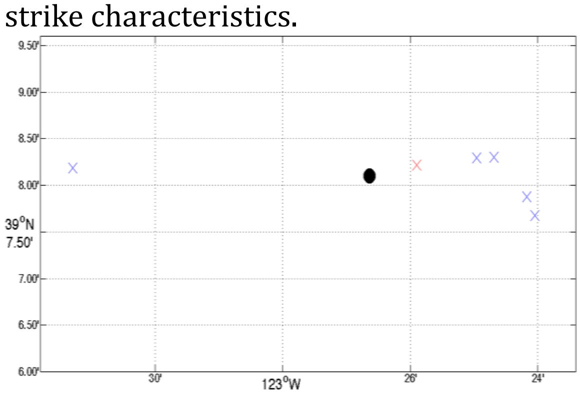

Figure 2. Example plot of 21 June 2008 fire (black circle, filled) with lightning strikes occurring within 1-km. Red X denotes a positive lightning strike and a blue X denotes a negative lighting strike.

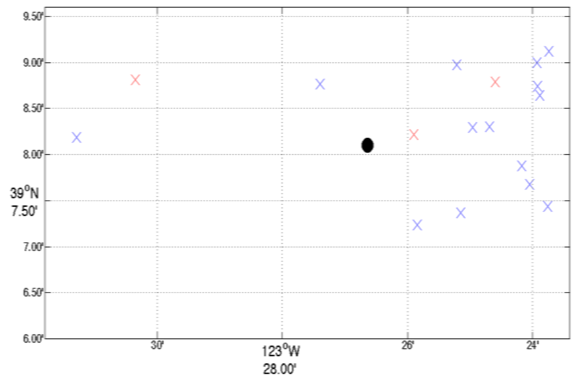

Figure 3. Same as Figure 2 except for 2-km

III. RESULTS
1. 1-km

All of the data and statistics for the 1-km data can be found in Table 1 and A3-A8. Median of multiplicity ranged from one to three for the cases and the median of polarity was less than -15 kA for each case with one exception (20 August 2006), and the overall median of polarity was -16.94 kA. The maximum number of lightning strikes associated with one fire was 38. The median of number of strikes per fire was 2.5 and more than 60% of all fires had less than five strikes for all cases. Lightning efficiency for the 1-km radius ranged from 18-56% for the six cases. Positive strikes accounted for 2-9% of all lightning strikes. No strikes occurred within 1-km 20-40% of the time over the six cases. Of all fires that had a lightning strike within 1-km, 98% had at least one negative lightning strike. Different ratios were calculated to examine and compare positive and negative lightning strikes within the 1-km radius. One ratio was comprised of fires that had at least one positive strike within 1-km compared to the total number of positive strikes that occurred within 1-km of any fire. This ratio was much higher (90%) than the same ratio using negative strikes (33%)

for the six cases. Fires with only positive strikes within 1-km ranged from two to eight per case with an overall median of four. The ratio of fires with at least one positive strike within 1-km and fires with at least one negative strike within 1-km was 12%.

2. 2-km

All of the results for the 2-km data can be found in Table 2 and A9-A14. Similar to the 1-km radius data, the median of multiplicity for the cases ranged from one to three, and the median of polarity was less than -15 kA for each case except for 20 August 2006. The median of polarity for all cases was -16.95 kA, which is nearly identical to the 1-km median. The maximum number of lightning strikes within 2-km of a fire was 84 with an overall median of 5.25. Each case at least doubled the number of strikes per fire when increasing the radius from 1 to 2-km. The lightning efficiency dropped to 6-23% due to the increase of strikes within the larger radial distance. Fewer fires had no strikes with the percentage dropping to 11-31%. Positive lightning strikes accounted for 2-10% of all lightning strikes. Of all fires that had a lightning strike within 2-km, 98% had at least one negative lightning strike. Fires with only positive strikes within the 2-km radius ranged from zero to eight with a median of five. The ratio of fires with at least one positive strike within 2-km and all positive strikes within 2-km of any fire was again higher (76%) than the same ratio using negative strikes (19%) for the six cases. The ratio of fires with at least one positive strike within 2-km and fires with at least one negative strike within 2-km was 19%, which was 7% higher than the 1-km ratio.

Table 1. Summary statistics of all six cases for the 1-km radial distance

1-km Radius	
Median of Strikes Per Fire	2.5
Median of Polarity	-16.94
Median of Fires with Positive Strikes to Total Fires with Strikes Ratio	0.15
Median of Fires with Negative Strikes to Total Fires with Strikes Ratio	0.98
Median Percentage of Fires with Strikes	0.79
Median of Fires with Only Positive Strikes	4.00
Median of Positive to Negative Strike Ratio	0.04
Median of Fires with Positive Strikes to Total Positive Strikes Ratio	0.90
Median of Fires with Negative Strikes to Total Negative Strikes Ratio	0.33
Median of Positive to Negative Strike Fire Ratio	0.12

Table 2. Summary statistics of all six cases for the 2-km radial distance

2-km Radius	
Median of Strikes Per Fire	5.25
Median of Polarity	-16.95
Median of Fires with Positive Strikes to Total Fires with Strikes Ratio	0.17
Median of Fires with Negative Strikes to Total Fires with Strikes Ratio	0.98
Median Percentage of Fires with Strikes	0.78
Median of Fires with Only Positive Strikes	5.00
Median of Positive to Negative Strike Ratio	0.03
Median of Fires with Positive Strikes to Total Positive Strikes Ratio	0.76
Median of Fires with Negative Strikes to Total Negative Strikes Ratio	0.19
Median of Positive to Negative Strike Fire Ratio	0.19

IV. DISCUSSION

1. FIRES AND POSITIVE CG LIGHTNING STRIKES

Positive polarity CG lightning flashes do have statistics and data to support they are more associated or better equipped to ignite wildfires. The ratio of fires with at least one positive strike within the specified radial distance and all positive strikes within a specified radial distance of a fire is higher (90% for

1-km and 76% for 2-km) compared to the same ratio for negative strikes (33% for 1-km and 19% for 2-km)(Tables 1-2). Positive strikes generally comprise 2-10% of all lightning strikes (Fuquay 1982; Reap and MacGorman 1989; Cummins et al. 1998) and for these cases positive strikes account for 2-10% of all lightning strikes within the specified radial distance. The ratio of fires with at least one positive strike within the specified radial distance and fires with at least one negative strike within the specified radial distance has a range of 9-49% with a median of 15% (Tables 1-2; A3-A14). Fires with at least one positive strike within the specified radial distance also account for a median of 16% of all fires with at least one lightning strike within the specified radial distance (Tables 1-2). These ratios support that positive strikes are exceeding their 2-10% proportion of all lightning strikes.

2. FIRES AND NO POLARITY DIFFERENCE

Eight fires or less in every case with an overall median of 4.5 have only positive strikes within their radial distance (Tables 1-2). Examining fires with only positive strikes within a specified radial distance, a median of 2.50 fires was calculated for the 1-km radial distance and a median of 5.25 fires was calculated for the 2-km radial distance. For all six cases no more than eight fires occurred with only positive lightning strikes within the specified radial distances (A3-A14). More than half of all the fires with a lightning strike, including medians of 83% and 85% for 1- and 2-km respectively, had no positive strikes within their radial distance (Tables 1-2; A3-A14). Negative lightning strikes were associated with at least 83% of all fires with a lightning strike within the radial distance with a median of 98% for 1-km and 2-km (Tables 1-2; A3-A14). Considering negative lightning strikes comprise 90-98% of all lightning strikes for these cases, one could argue that negative lightning strikes performed at or even slightly better than its own proportion of all lightning strikes. Finally, there was no discernable relationship between more positive lightning strikes and better overall lightning efficiency.

V. CONCLUSIONS

The analysis covered the examination of CG lightning strikes from six dry thunderstorm cases that produced approximately 80,000 lightning strikes and 1,910 wildfires. Positive strikes accounted for 2-10% of all lightning strikes, which coincides with previous studies (Fuquay 1982; Reap and MacGorman 1989; Cummins et al. 1998). Positive strikes exceeded this 2-10% proportion in terms of igniting fires by being associated with a median of 15% for all fires with a lightning strike within 1-km and a median of 17% for all fires with a lightning strike within 2-km examined in the study (Tables 1-2). Positive strikes also had a higher ratio of strikes to fires than that of negative strikes. However, there are major caveats. 98% of fires with a lightning strike within the radial distance had a negative lightning strike associated with it (Tables 1-2). Additionally, there was no discernible relationship between more positive lightning strikes and better overall lightning efficiency.

This analysis shows both positive and negative lightning strikes can ignite fires with relative similar frequency. The ratio of fires with at least one positive strike within the radial distance and all positive strikes within the radial distance was 90% for a 1-km radius and 76% for a 2-km radius (Tables 1-2). This ratio coupled with positive strikes being associated with a median of 20% of all fires with at least one strike within the radial distance among other results suggest positive strikes may be more efficient in igniting fires. However, medians of 83% and 85% for 1- and 2-km respectively were calculated for fires with a strike within the radial distance did not have a positive strike (Tables 1-2). The better efficiency noted with positive strikes could be due to the aforementioned previous theories such as the LCC or large magnitude in kA. Storm structure could also contribute since positive lightning strikes can originate higher in the storm and tend to impact further outside of the rain core (Saunders 1993; Rutledge et al. 1990; Lang et al. 2004). Some research has also shown that low-precipitation thunderstorms have higher ratios of positive strikes (Curran and Rust 1992).

Using only dry thunderstorm cases helped ameliorate the holdover problem, but it could have introduced bias to the similar nature of the thunderstorms and the possible different storm structure associated with dry thunderstorms. More limitations of the study include the difference in fuels and fuel conditions and topography. Some of the strikes may not have hit fuels, but rocky outcrops, which can affect the lightning efficiency. The location measurement of lightning and wildfires also plays a limiting role. Future work could entail examining all the strikes and the strikes within a certain radial distance for comparison. Additionally, ranking the lightning strikes according to distance from the wildfire could also be beneficial.

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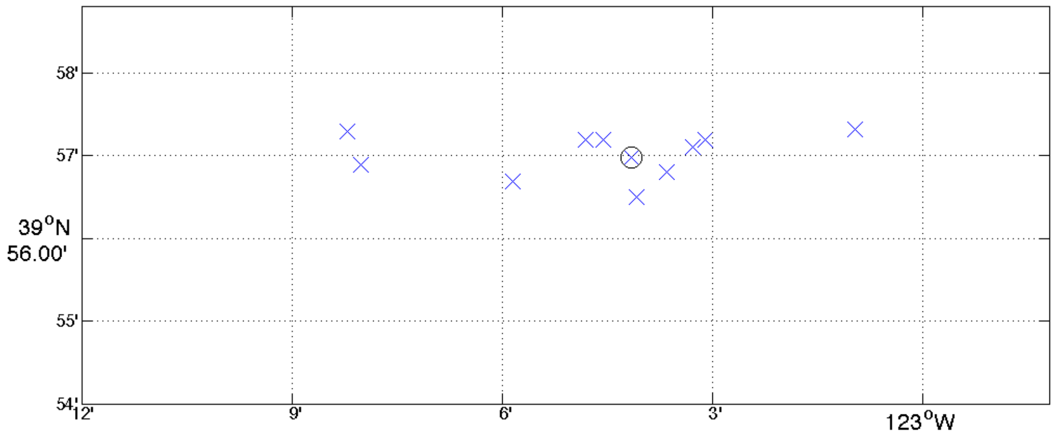
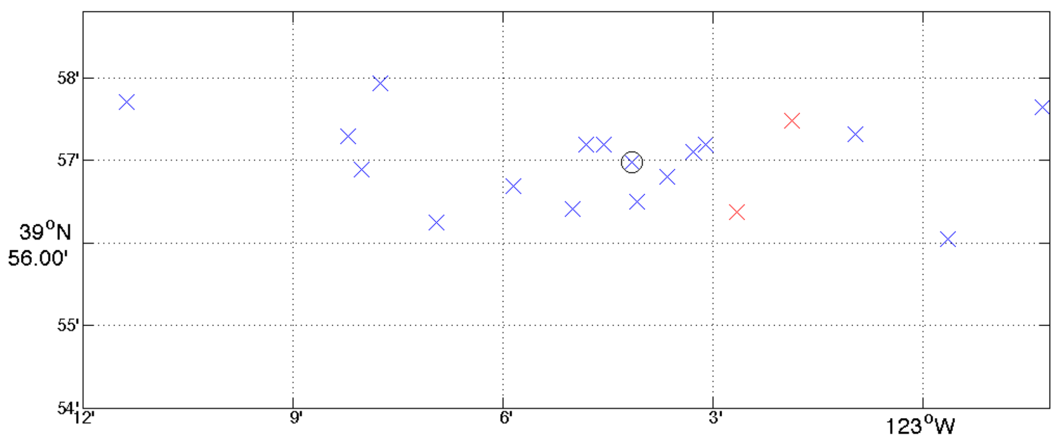
APPENDIX

A1. Same as Figure 2 except for all lightning strikes within 1-km of a different 21 June 2008 fire. Notice one negative strike is at the same location of the fire.



A2. Same as A13 except for all lightning strikes within 2-km of the same fire. Notice one negative strike is at the same location of the fire.



1-km

A3. Results for 16-17 July 2007 for 1-km radius

16-17 JULY 2007	
Number of fires	231
Fires with no strikes	57
Fires with Positive Strikes	16
Total Positive Strikes	16
Total Negative Strikes	961
Lightning Efficiency	0.18
Median of Strikes per fire	4.00
Median of Polarity	-15.83
Median of Multiplicity	2.00
Fires with Negative Strikes	172
Fires with Strikes	174
Fires with Only Positive Strikes	2
Positive to Negative Strike Fire Ratio	0.09
Percentage of Fires with Strikes	0.80
Fires with Positive Strikes to Total Positive Strikes Ratio	1.00
Fires with Positive Strikes to Total Fires with Strikes Ratio	0.09
Positive to Negative Strike Ratio	0.02
Fires with Negative Strikes to Total Negative Strikes Ratio	0.18
Fires with Negative Strikes to Total Fires with Strikes Ratio	0.99

A4. Results for 20-21 June 2008 for 1-km radius

20-21 JUNE 2008	
Number of fires	601
Fires with no strikes	1600
Fires with Positive Strikes	105
Total Positive Strikes	134
Total Negative Strikes	1314
Lightning Efficiency	0.30
Median of Strikes per fire	3.00
Median of Polarity	-20.30
Median of Multiplicity	2.50
Fires with Negative Strikes	433
Fires with Strikes	441
Fires with Only Positive Strikes	8
Positive to Negative Strike Fire Ratio	0.24
Percentage of Fires with Strikes	0.79
Fires with Positive Strikes to Total Positive Strikes Ratio	0.78
Fires with Positive Strikes to Total Fires with Strikes Ratio	0.24
Positive to Negative Strike Ratio	0.09
Fires with Negative Strikes to Total Negative Strikes Ratio	0.34
Fires with Negative Strikes to Total Fires with Strikes Ratio	0.98

A5. Results for 25-26 June 2006 for 1-km radius

25-26 JUNE 2006	
Number of fires	340
Fires with no strikes	232
Fires with Positive Strikes	9
Total Positive Strikes	11
Total Negative Strikes	336
Lightning Efficiency	0.31
Median of Strikes per fire	2.00
Median of Polarity	-16.93
Median of Multiplicity	1.00
Fires with Negative Strikes	105
Fires with Strikes	108
Fires with Only Positive Strikes	3
Positive to Negative Strike Fire Ratio	0.09
Percentage of Fires with Strikes	0.59
Fires with Positive Strikes to Total Positive Strikes Ratio	0.82
Fires with Positive Strikes to Total Fires with Strikes Ratio	0.08
Positive to Negative Strike Ratio	0.03
Fires with Negative Strikes to Total Negative Strikes Ratio	0.32
Fires with Negative Strikes to Total Fires with Strikes Ratio	0.97

A6. Results for 1 August 2009 for 1-km radius

1 AUGUST 2009	
Number of fires	606
Fires with no strikes	210
Fires with Positive Strikes	37
Total Positive Strikes	41
Total Negative Strikes	2130
Lightning Efficiency	0.18
Median of Strikes per fire	4.00
Median of Polarity	-16.95
Median of Multiplicity	2.00
Fires with Negative Strikes	391
Fires with Strikes	396
Fires with Only Positive Strikes	5
Positive to Negative Strike Fire Ratio	0.09
Percentage of Fires with Strikes	0.74
Fires with Positive Strikes to Total Positive Strikes Ratio	0.90
Fires with Positive Strikes to Total Fires with Strikes Ratio	0.09
Positive to Negative Strike Ratio	0.02
Fires with Negative Strikes to Total Negative Strikes Ratio	0.19
Fires with Negative Strikes to Total Fires with Strikes Ratio	0.99

A7. Results for 20 August 2006 for 1-km radius

20 AUGUST 2006	
Number of fires	102
Fires with no strikes	62
Fires with Positive Strikes	5
Total Positive Strikes	5
Total Negative Strikes	104
Lightning Efficiency	0.37
Median of Strikes per fire	2.00
Median of Polarity	-20.35
Median of Multiplicity	1.00
Fires with Negative Strikes	35
Fires with Strikes	40
Fires with Only Positive Strikes	5
Positive to Negative Strike Fire Ratio	0.14
Percentage of Fires with Strikes	0.62
Fires with Positive Strikes to Total Positive Strikes Ratio	1.00
Fires with Positive Strikes to Total Fires with Strikes Ratio	0.13
Positive to Negative Strike Ratio	0.05
Fires with Negative Strikes to Total Negative Strikes Ratio	0.38
Fires with Negative Strikes to Total Fires with Strikes Ratio	0.88

A8. Results for 21 August 2009 for 1-km radius

21 AUGUST 2009	
Number of fires	30
Fires with no strikes	12
Fires with Positive Strikes	3
Total Positive Strikes	3
Total Negative Strikes	29
Lightning Efficiency	0.56
Median of Strikes per fire	1.00
Median of Polarity	-11.70
Median of Multiplicity	2.00
Fires with Negative Strikes	15
Fires with Strikes	18
Fires with Only Positive Strikes	3
Positive to Negative Strike Fire Ratio	0.20
Percentage of Fires with Strikes	0.71
Fires with Positive Strikes to Total Positive Strikes Ratio	1.00
Fires with Positive Strikes to Total Fires with Strikes Ratio	0.17
Positive to Negative Strike Ratio	0.09
Fires with Negative Strikes to Total Negative Strikes Ratio	0.62
Fires with Negative Strikes to Total Fires with Strikes Ratio	0.83

2-km

A9. Results for 16-17 July 2007 for 2-km radius

16-17 July 2007	
Number of fires	231
Fires with no strikes	33
Fires with Positive Strikes	39
Total Positive Strikes	57
Total Negative Strikes	3062
Lightning Efficiency	0.06
Median of Strikes per fire	10.00
Median of Polarity	-15.70
Median of Multiplicity	2.00
Fires with Negative Strikes	198
Fires with Strikes	198
Fires with Only Positive Strikes	0
Positive to Negative Strike Fire Ratio	0.20
Percentage of Fires with Strikes	0.88
Fires with Positive Strikes to Total Positive Strikes Ratio	0.68
Fires with Positive Strikes to Total Fires with Strikes Ratio	0.20
Positive to Negative Strike Ratio	0.02
Fires with Negative Strikes to Total Negative Strikes Ratio	0.06
Fires with Negative Strikes to Total Fires with Strikes Ratio	1.00

A10. Results for 20-21 June 2008 for 2-km radius

20-21 JUNE 2008	
Number of fires	601
Fires with no strikes	75
Fires with Positive Strikes	257
Total Positive Strikes	442
Total Negative Strikes	4162
Lightning Efficiency	0.11
Median of Strikes per fire	6.50
Median of Polarity	-21.25
Median of Multiplicity	2.00
Fires with Negative Strikes	520
Fires with Strikes	526
Fires with Only Positive Strikes	6
Positive to Negative Strike Fire Ratio	0.49
Percentage of Fires with Strikes	0.89
Fires with Positive Strikes to Total Positive Strikes Ratio	0.58
Fires with Positive Strikes to Total Fires with Strikes Ratio	0.49
Positive to Negative Strike Ratio	0.10
Fires with Negative Strikes to Total Negative Strikes Ratio	0.13
Fires with Negative Strikes to Total Fires with Strikes Ratio	0.99

A11. Results for 25-26 June 2006 for 2-km radius

25-26 JUNE 2006	
Number of fires	340
Fires with no strikes	184
Fires with Positive Strikes	17
Total Positive Strikes	22
Total Negative Strikes	943
Lightning Efficiency	0.16
Median of Strikes per fire	4.00
Median of Polarity	-16.60
Median of Multiplicity	1.00
Fires with Negative Strikes	152
Fires with Strikes	156
Fires with Only Positive Strikes	4
Positive to Negative Strike Fire Ratio	0.11
Percentage of Fires with Strikes	0.65
Fires with Positive Strikes to Total Positive Strikes Ratio	0.77
Fires with Positive Strikes to Total Fires with Strikes Ratio	0.11
Positive to Negative Strike Ratio	0.02
Fires with Negative Strikes to Total Negative Strikes Ratio	0.17
Fires with Negative Strikes to Total Fires with Strikes Ratio	0.97

A12. Results for 1 August 2009 for 2-km radius

1 AUGUST 2009	
Number of fires	606
Fires with no strikes	151
Fires with Positive Strikes	106
Total Positive Strikes	123
Total Negative Strikes	5787
Lightning Efficiency	0.08
Median of Strikes per fire	10.00
Median of Polarity	-17.30
Median of Multiplicity	2.00
Fires with Negative Strikes	447
Fires with Strikes	455
Fires with Only Positive Strikes	8
Positive to Negative Strike Fire Ratio	0.24
Percentage of Fires with Strikes	0.80
Fires with Positive Strikes to Total Positive Strikes Ratio	0.86
Fires with Positive Strikes to Total Fires with Strikes Ratio	0.23
Positive to Negative Strike Ratio	0.02
Fires with Negative Strikes to Total Negative Strikes Ratio	0.08
Fires with Negative Strikes to Total Fires with Strikes Ratio	0.98

A13. Results for 20 August 2006 for 2-km radius

20 AUGUST 2006	
Number of fires	102
Fires with no strikes	47
Fires with Positive Strikes	7
Total Positive Strikes	8
Total Negative Strikes	242
Lightning Efficiency	0.22
Median of Strikes per fire	4.00
Median of Polarity	-19.80
Median of Multiplicity	1.00
Fires with Negative Strikes	49
Fires with Strikes	55
Fires with Only Positive Strikes	6
Positive to Negative Strike Fire Ratio	0.14
Percentage of Fires with Strikes	0.68
Fires with Positive Strikes to Total Positive Strikes Ratio	0.88
Fires with Positive Strikes to Total Fires with Strikes Ratio	0.13
Positive to Negative Strike Ratio	0.03
Fires with Negative Strikes to Total Negative Strikes Ratio	0.23
Fires with Negative Strikes to Total Fires with Strikes Ratio	0.89

A14. Results for 21 August 2009 for 2-km radius

21 AUGUST 2009	
Number of fires	30
Fires with no strikes	10
Fires with Positive Strikes	3
Total Positive Strikes	4
Total Negative Strikes	82
Lightning Efficiency	0.23
Median of Strikes per fire	4.00
Median of Polarity	-14.48
Median of Multiplicity	3.00
Fires with Negative Strikes	17
Fires with Strikes	20
Fires with Only Positive Strikes	3
Positive to Negative Strike Fire Ratio	0.18
Percentage of Fires with Strikes	0.75
Fires with Positive Strikes to Total Positive Strikes Ratio	0.75
Fires with Positive Strikes to Total Fires with Strikes Ratio	0.15
Positive to Negative Strike Ratio	0.05
Fires with Negative Strikes to Total Negative Strikes Ratio	0.24
Fires with Negative Strikes to Total Fires with Strikes Ratio	0.85