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METEOROLOGICAL CASE STUDIES OF LIGHTNING STRIKE VICTIMS IN COLORADO

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1. Introduction

Since 2000, the National Weather Service (NWS) in Pueblo, CO has been analyzing the meteorology associated with lightning strike incidents in Colorado. The motivation for this research is twofold; first, we wish to accurately document the location of where people were located relative to the rain area when they were affected by a Cloud to Ground (CG) lightning flash, and second, to observe how close previous CG lightning flashes were to the victim.

In this paper, CG flash plots (distance vs time) of each case are shown, along with radar data overlaid with CG data. By examining these variables, we can observe the lightning frequency/trends immediately prior to the casualty and we can observe the precipitation characteristics of the storm at the casualty location.

2. Background

A total of 20 cases have been examined to date, some in considerable detail (NOAA 2012, Hodanish 2008, Hodanish 2006). The first case occurred in 2000 (Hodanish 2004), while the most recent case occurred late in the summer of 2011. It should be noted that not every lightning flash which caused a casualty (fatality or injury) in Colorado during the last 12 years has been examined. The author of this paper is an operational meteorologist, and examines lightning casualty cases as time permits.

To determine which CG flash caused the casualty, two pieces of information are required. The first piece of information is acquiring the exact time when the lightning flash hit the victim, while the second piece of information is documenting the specific location where the victim was struck. Typically, the location of the victim is well documented. Emergency responders will use GPS to mark the location of where the victim was found after being struck (this assumes the victim was not moved until the emergency medical authorities arrived). On the other hand, determining the exact time that a lightning flash incident occurred can be difficult, especially if it is only one victim and no other people were in the vicinity when the flash occurred. This is typically the case of lone hikers in the Colorado high country. Those who were casualties of a lightning flash in more densely populated areas, or if a group of people were affected, then the time of the incident is likely to be more accurately documented.

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A complicating factor in this study was found to occur when multiple CG flashes occurred around the time and location of the lightning incident. In this scenario, it was difficult to ascertain which flash actually caused the casualty. In this paper, cases where the exact CG flash could not be determined, then the flash which occurred closest to the victim or closest to the time prior to the 9-11 call (if a 9-11 call was made) was assumed to be the flash which caused the casualty.

In Hodanish (2006) and Hodanish (2008), the following definitions were used to define the frequency of CG lightning activity prior to a flash that caused a lightning casualty:

Frequent CG activity: CG activity during the 5 minute time period up to the time of the casualty that occurs on average at the rate of greater than or equal to 1 flash per minute within a 6 mile (9.7 km) radius of the casualty location.

Infrequent CG activity: CG activity during the 5 minute time period up to the time of the casualty that occurs on average at a rate of less than 1 flash per minute within a 6 mile (9.7 km) radius of the casualty location.

A subset of infrequent CG activity are events in which the first flash from the cell produced a casualty. This event type is defined as:

First flash of the convective cell: No CG lighting within a 6 miles (9.7 km) radius in a 30 minute time period up to the time of the casualty.

In this paper, these same definitions will be used. In the above definitions, the distance of 6 miles (9.7 km) was chosen because this is the distance in which people should be in safe shelter when lighting is occurring (30-30 lightning rule, AMS 2002). The flash rate values of < 1 flash per minute and >= 1 flash per minute were arbitrarily chosen.

3. Data Analysis

3.1 Lightning vs Time Plots

For 18 of the 20 cases in this study, it could be determined, within reasonable certainty, which flash caused the casualty. In order to examine the CG lightning frequency prior to the victims being struck, "time vs distance" CG lightning plots were created. Two plots for each case are shown (Figure 1). In each of these plots, the "0.00" on the abscissa indicates the time when the victim was struck. The first plot shows the CG activity within 10 miles and 30 minutes prior to the victim being struck, while the second plot shows the CG activity within 6 miles and 10 minutes of the casualty location. The "10 mile/30 minute" plots show a "wide view" of the spatial and temporal aspects of the CG lightning activity while the "6 mile/10 minute" plots show data within the immediate area of the casualty location. Additionally, a portion of the "6 mile/10 minute" plots are highlighted in red shading to emphasize the lightning activity which was occurring immediately prior (5 minutes) to the victim being struck. Throughout this study we will emphasize the lightning activity which was occurring within this red shaded area.

For two of the cases in this study, it could not be determined which flash caused the casualty. This is because the victims were not found until well after the lighting activity moved out of the area. For one of the cases (Mineral County, Figure 2), the victim was not found until several days after the casualty occurred (the location of the body was marked by GPS). A review of the lightning data between the time he was last seen and the time he was found indicated only one short lived thunderstorm occurred at the victims' location, and this storm occurred on the 28th of July 2008. The storm lasted for about 35 minutes and produced 19 CG flashes. A review of the CG activity in this case indicated 5 flashes occurred within 0.5 miles of the victims' location. Any of these flashes could have caused the fatality.

For the second case (Evans, Colorado), the victim was not found until about 12 hours after he was struck. The victim was found in an open field in Evans and was last seen around 0245 UTC (845 pm MDT). A thunderstorm occurred shortly after this time, and a plot of the lighting data within 10 miles of the victims' location indicated one of two flashes likely caused this fatality. The first flash occurred around 0309 UTC and the second around 0312 UTC (Figure 3).

In order to observe nearby CG strike activity shortly before the victims were struck, flash rates for the 18 cases were calculated within 6 miles and 5 minutes prior to the casualty event. This was done to observe what the flash rates were prior to the incident, to determine whether the storms were producing significant amounts of lightning activity or little (or none) prior to the casualty occurring. In this study, we consider a storm is producing ***frequent*** CG activity if the flash rate is >=1.0 flashes per minute, and ***infrequent*** CG activity if the flash rate is < 1.0 flashes per minute.

Table 1 shows the date and general location for each of the 20 events in this study. This table also shows the time of the flash which caused the casualty, the latitude and longitude of the victims' location and the number of flashes/flash rate which occurred within 6 miles and 5 minutes prior to the flash which caused the casualty. Of the 18 cases that the author was confident which flash caused the casualty, six (33%) had frequent CG activity (>=1 flash/min), while the other 12 cases (66%) had infrequent CG activity (<1.0 flashes/min). Of the 12 cases which had infrequent CG activity, three were "first flash of the convective cell" events. As mentioned previously, in two of the cases shown in Table 1, it could not be determined which flash caused the casualty.

3.2 Composite Radar/Lightning Plots

Figure 4 a-r shows composite radar and lightning data for 18 of 20 cases (for two cases, case 1 (Pikes Peak – 000725) and case 17 (Mineral – 080724), radar data was not available). In each figure, the flash which likely caused the casualty is indicated by a white arrow or is circled. Radar reflectivity data, displayed in 1 km resolution, was either from NWS Doppler radar KPUX (Pueblo, CO) or KFTG (Denver, CO).

It should be mentioned that the areal coverage shown in Figures 4 a-r varies, and

that the radar colors (dBz values) differ from plot to plot (please see color scale at upper left for corresponding dBz values in each figure). Additionally, the city locations on the plots are indicated by a "+" symbol. These "+" symbols should not be confused with positive CG flashes which are shown on some of the plots. The author apologizes for these inconveniences.

Except for one case (Evans – 090606), the lightning data shown in Figure 4 a-r shows CG data which occurred during a 1 minute time period. As an example, if the flash which caused the casualty occurred at 2345:09 UTC, then any flashes that occurred between 2345:00 and 2345:59 UTC are shown in the figure.

An examination of the radar data show that the reflectivity at the time of the flash were typically in the 35-45 dBz range, indicating (from a radar perspective) that light to moderate rain was falling at the time. Only two cases, the Rocky Ford case (Figure 4i) and CSU-Ft Collins case (Figure 4o) had radar indicated "heavy rain" (>50 dBz), occurring at the time of the flash which caused the casualty.

It should be noted that quite a few of the cases shown in this paper occurred in mountainous terrain, and the radar reflectivity may have been compromised due to beam blockage. With that said, however, media reports of several of the cases indicated that "rain was not falling at the time of the flash", even though radar showed reflectivity at the time of flash occurrence. This is likely due to the dry climate of Colorado. It is not uncommon for radar to detect "echoes" associated with the storm, but the precipitation does not reach the ground. In these situations, what the radar is detecting is virga.

4 Discussion and Findings

Based on data shown in section 3.1, people who were struck by lightning in Colorado were typically affected by storms that were producing infrequent CG activity. Flash rates, as measured within 6 miles and 5 minutes of the flash which caused the casualty, were typically less than 1 flash per minute. Of the 18 cases in which it was determined which flash caused the casualty, 66% percent (12/18) had 5 minute flash rates less than 1 flash per minute, while 33% (6/18) had flash rates greater than or equal to 1 flash per minute.

In 3 of the cases which fell under the "infrequent CG activity" category (< 1 flash per minute), no lighting was observed within 6 miles and 30 minutes of the flash which caused the casualty.

As discussed in section 2, there were two cases in which it could not be determined which flash caused the casualty. Likewise, flash rates prior to these casualty events could not be calculated.

We now examine the spatial and temporal aspects between the flash that caused the casualty and the flash immediately prior to this flash. For brevity, the flash which caused the casualty is defined as "$Flash_{(F)}$", while the flash immediately prior is defined as "$Flash_{(F-1)}$". We only examine those flashes in which "$Flash_{(F-1)}$" occurred within

5 minutes and 6 miles of *Flash*$_{(F)}$ [Note: this temporal/spatial region is the "red shaded area" of the plots shown in Figure 1). Of the 18 cases, 13 had "*Flash*$_{(F-1)}$" occur within 5 minutes/6 miles of *Flash*$_{(F)}$ Of these 13 cases, the average distance between "*Flash*$_{(F-1)}$" and "Flash$_{(F)}$" was 3.28 miles, while the average time was 121 seconds. For the other 5 cases (Pikes Peak, Littleton, Rocky Ford, Jeffco, and Browns Canyon), "*Flash*$_{(F-1)}$" occurred either beyond 5 minutes/6 miles of "Flash$_{(F)}$", or "*Flash*$_{(F-1)}$" never occurred at all.

Radar analysis indicated that in nearly all of the cases, the lightning flash which caused the casualty were associated with echoes greater than 20 dBz, with most of the flashes occurring with dBz values ranging between 35 and 45 dBz.

Overall, a majority of the people struck by lightning in Colorado are struck by storms that produce infrequent CG activity, that is, storms that produce less than 1 flash per minute. In addition, rainfall at the time of the event (according to radar analysis) was typically light to moderate (or possibly not occurring at all). Based on this information, *people are reminded that ANY cloud to ground lightning is dangerous, no matter how infrequent it is. In addition, just because it is not raining does not mean lightning cannot be a threat.*

In addition, 3 of the 20 cases (15%) in this study showed that *people can be struck by the first flash of the storm. People should be alert to developing thunderheads above, and seek shelter if the skies appear threatening.*

More information about these individual case studies can be found on the NOAA/NWS Pueblo Colorado Lightning Resource Page located at:

http://weather.gov/pub/ltg.php

Then click on "lightning casualty case studies".

5. Acknowledgments

The author thanks Dr. Paul Wolyn, SOO NWS PUB; Jennifer Stark, MIC NWS PUB and Donna Franklin (NWS HQTRS) for their support.

6 References

American Meteorological Society, 2002: Lightning safety awareness statement. AMS website: http://www.ametsoc.org/POLICY/lightningpolicy_2002.html

Hodanish, S. J., 2006: Meteorological case studies of lightning strike victims in Colorado. 86th Annual AMS conference, Atlanta GA, Amer. Meteor. Soc

Hodanish, S. J. 2008: Meteorological case studies of lightning strike victims in Colorado - An Update. 89th AMS conference, Phoenix, AZ. Amer. Meteor. Soc.

Hodanish, S.J., Holle, R., and D. Lindsey. 2004: A small updraft producing a fatal lightning flash. *Weather and Forecasting*, **19**, pp 627-632.

NOAA 2012: Colorado Lightning Casualties: Case Studies, HTML document: .http://www.crh.noaa.gov/pub/?n=/ltg/case_studies_index.php.

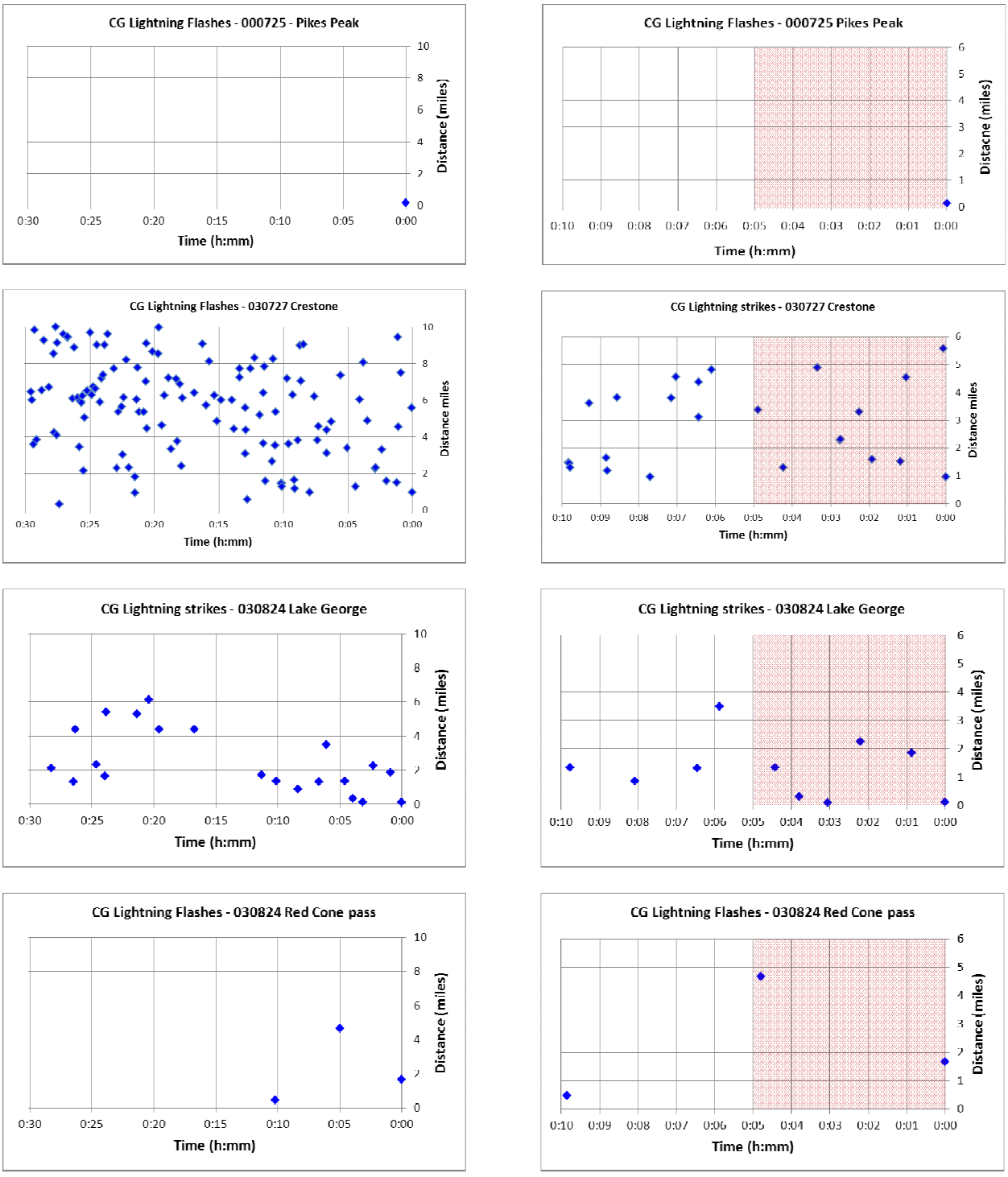
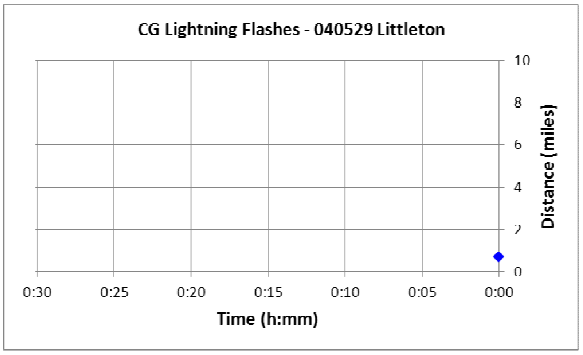
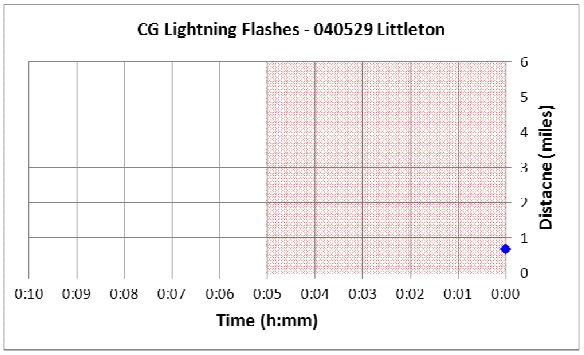
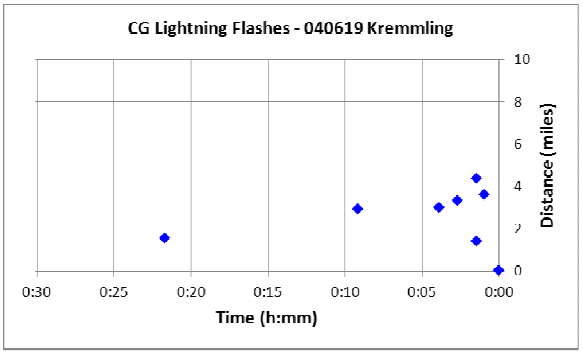
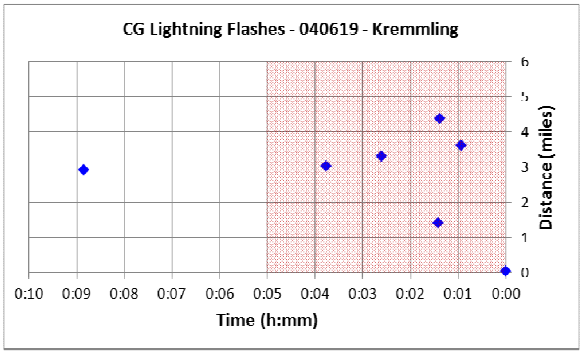


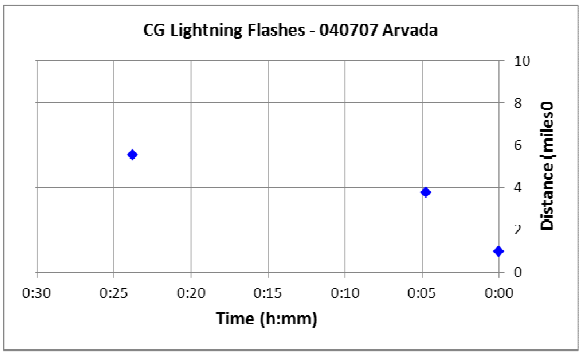
Figure 1. Time vs distance plots of CG activity for 18 of the 20 cases. In each of the cases, the author was confident, within reason, of which flash caused the casualty. The plots on the left show the CG lightning activity within 10 miles and 30 minutes leading up to the casualty, while the plots on the right show the CG activity within 6 miles and 10 minutes leading up to the time of the casualty. The light red shading in the 6 mile/10 minute plots emphasizes the 5 minutes prior to the casualty occurring. "0:00" represents the time of the casualty. Table 1 (below) lists all of the cases.

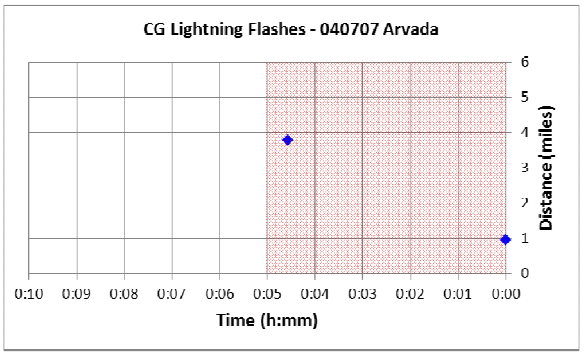


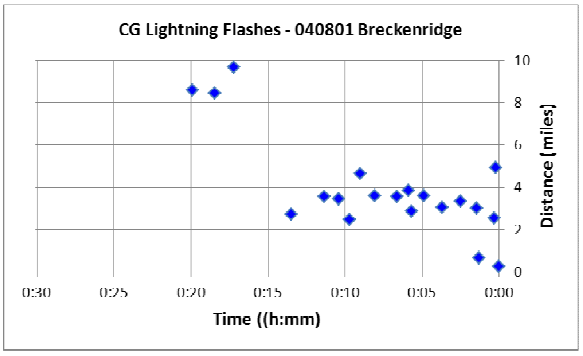


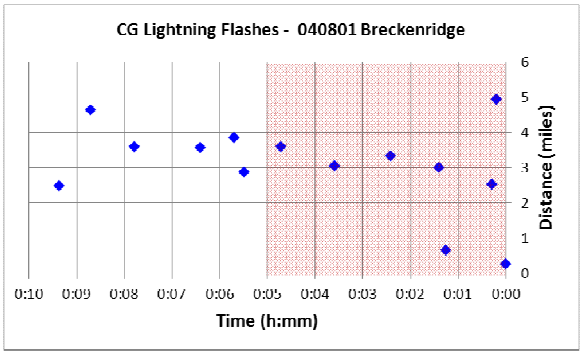












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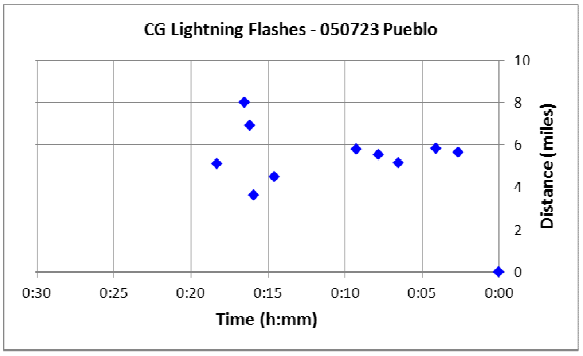

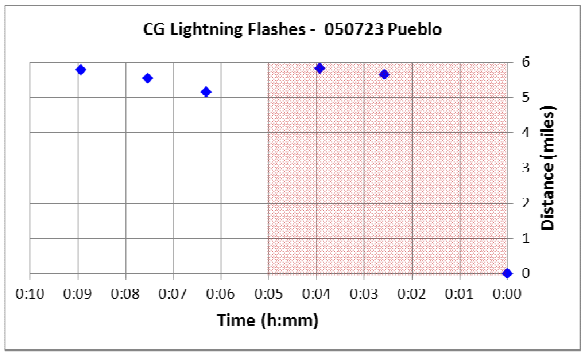

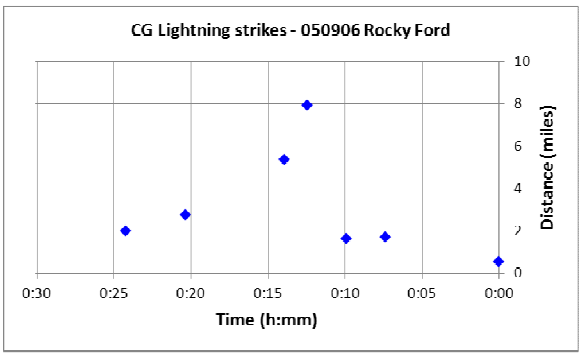

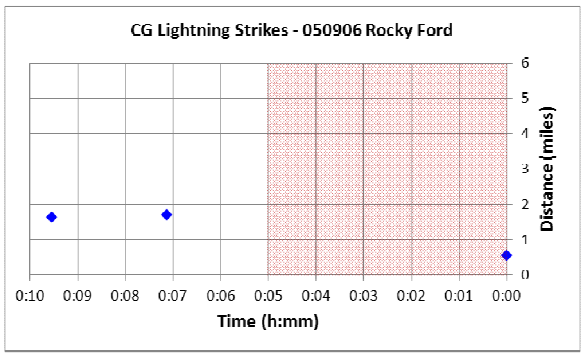

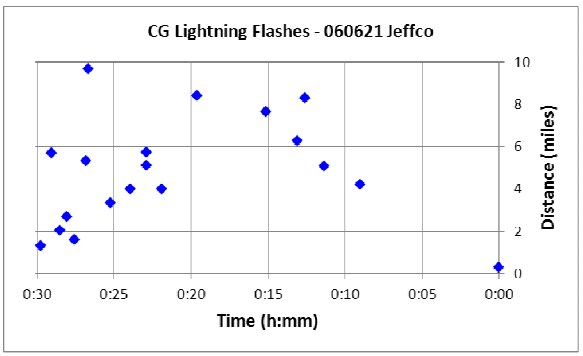

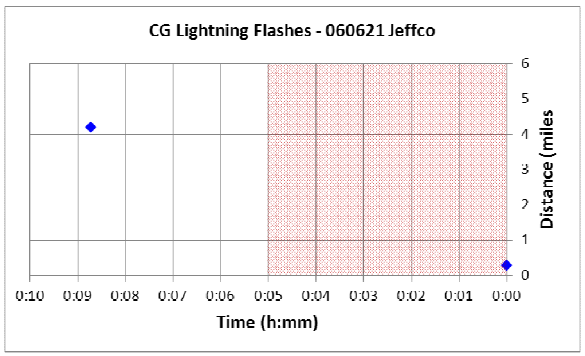

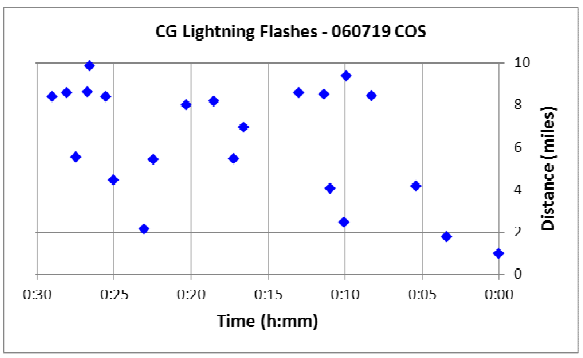

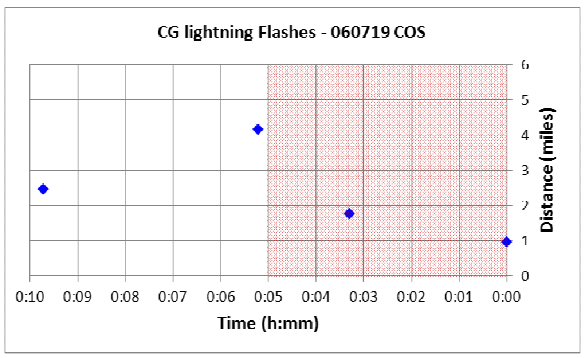

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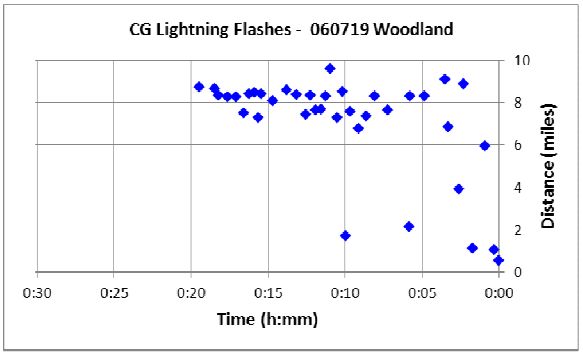

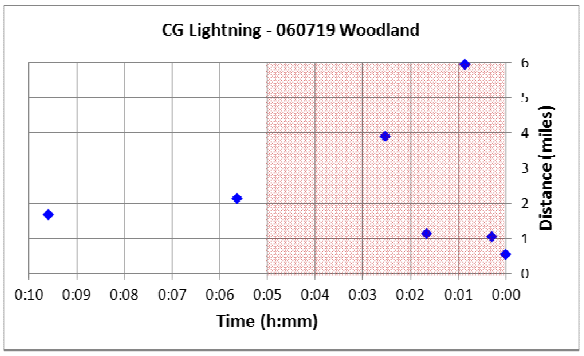

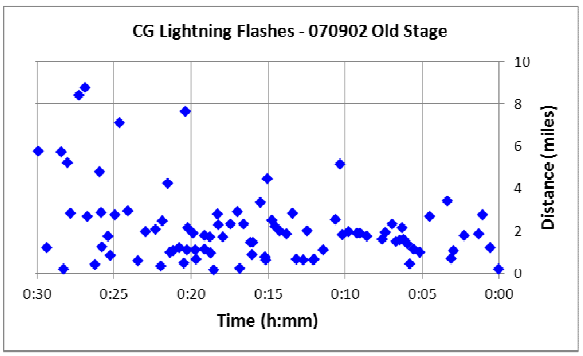

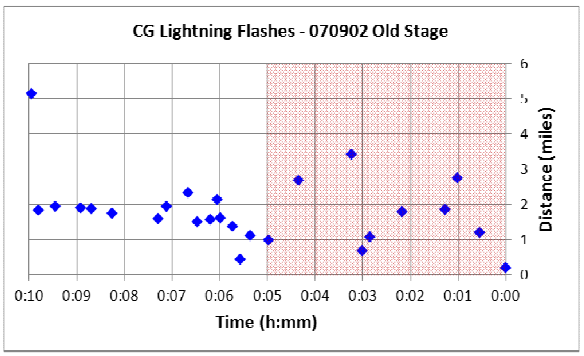

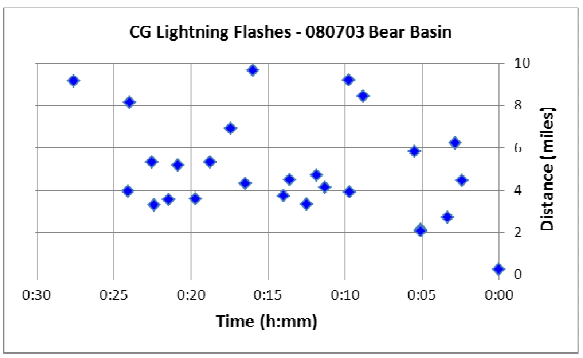

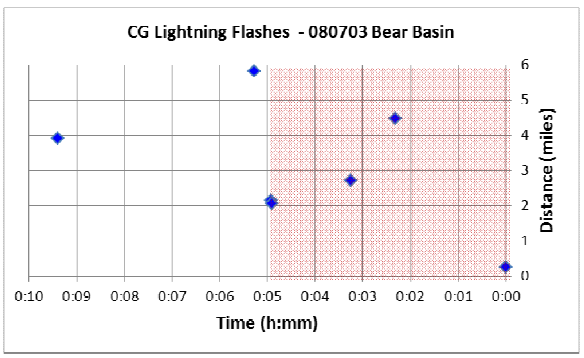

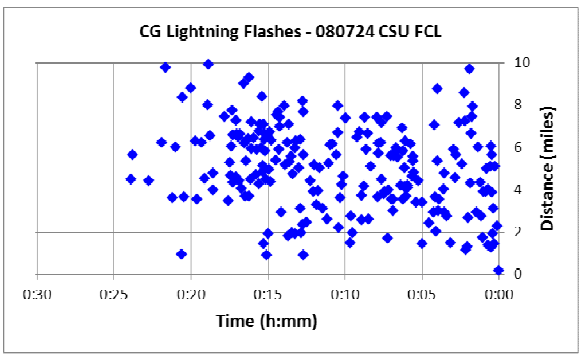

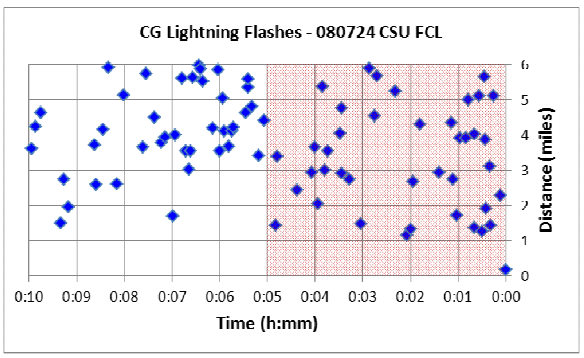

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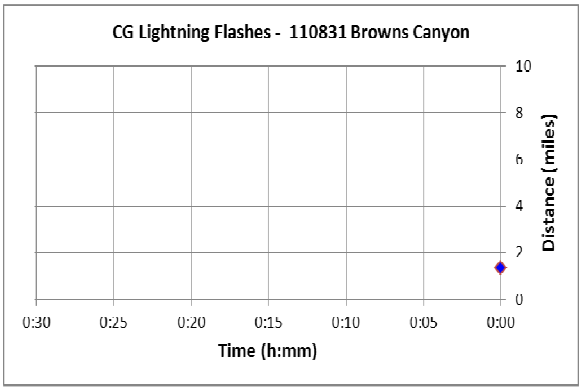

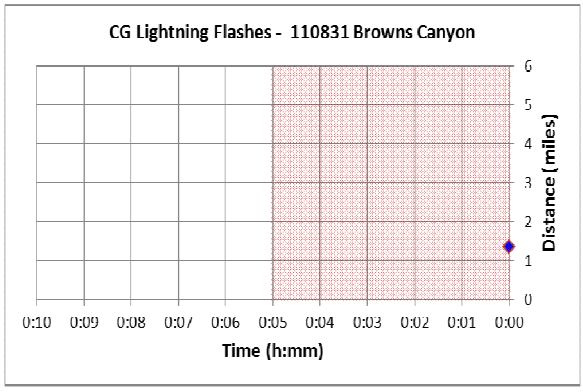

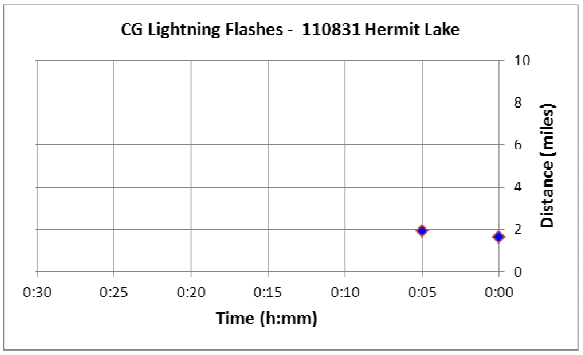

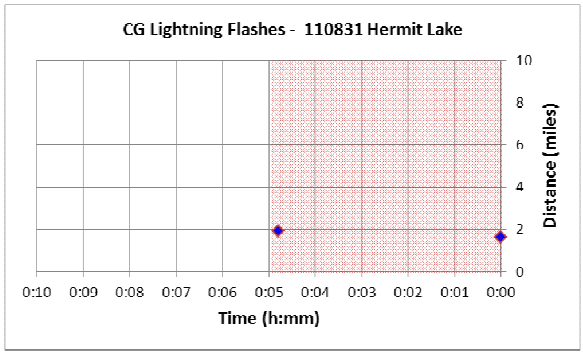

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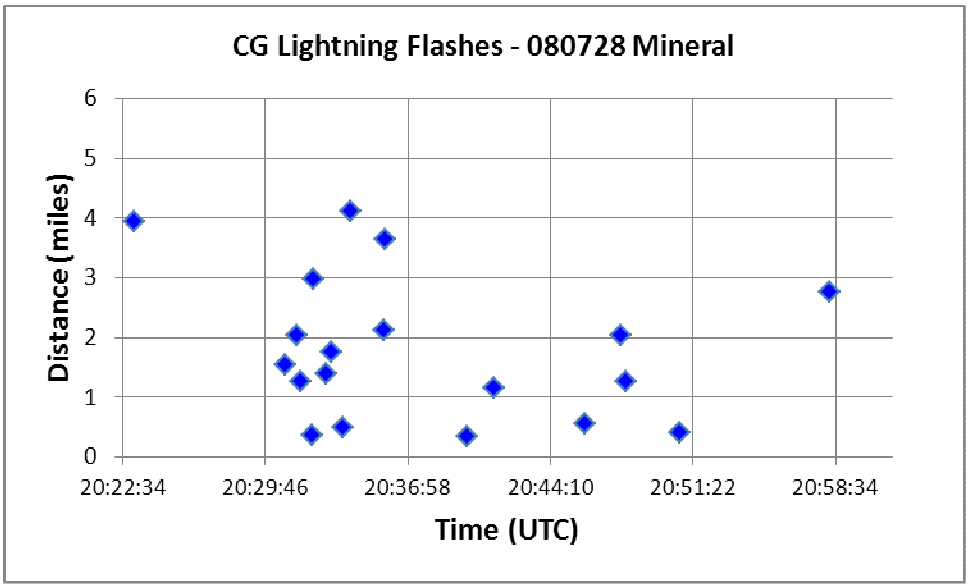

Figure 2 (above). The plot above shows the lightning activity associated with the fatality that occurred in Mineral County on top of the Continental Divide. All of the lighting with this event is shown (19 flashes). Five of these flashes occurred within 1 mile of where the victim was found, and either of them could have caused the casualty.

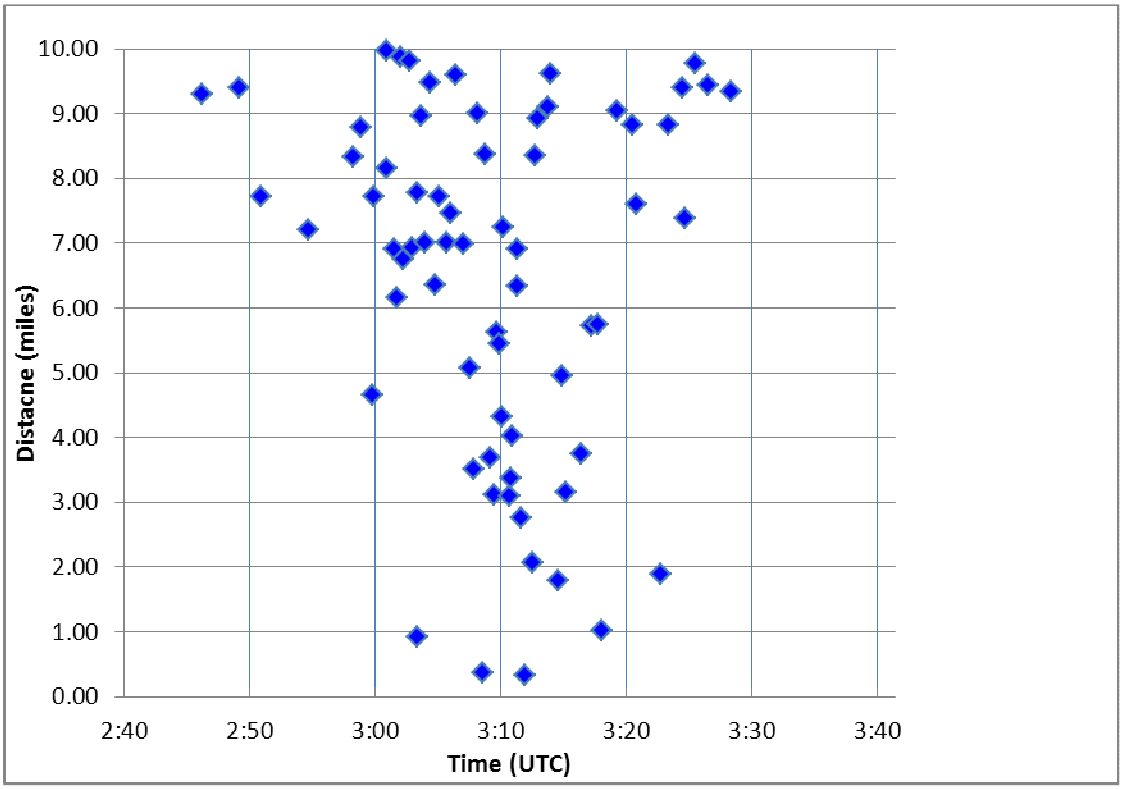

Figure 3 (above). The plot above shows the lightning activity associated with the fatality that occurred in Evans, Colorado. All of the CG lighting flashes which occurred within 10 miles of the fatality location are shown. Two of these flashes, one occurring at 0309:07 UTC and the other at 0312:28 UTC, occurred within less than 0.5 miles of the victims' location. Either one of these flashes could have caused the casualty.

Table 1. Case #, date, general location, time of the flash which likely caused the casualty, latitude/longitude of strike victims' location and CG flash rates 5 minutes prior to the flash which caused the casualty.

Case #	Date yymmdd	General Location	Time of Casualty (UTC) hhmm:ss	Latitude /Longitude of victims' location	#flashes/5min, (fl/min)
1	000725	Pikes Peak	1856:54	38.8417, -105.0425	0/5 min, (0.0 fl/min)
2	030727	Crestone	2236:13	37.9900, -105.6250	10/5 min, (2.0 fl/min)
3	030824	Lake George	2246:24	38.9650, -105.3355	5/5 min, (1.0 fl/min)
4	030824	Redcone Pass	2126:20	39.5317, -105.8217	1/5 min, (0.2 fl/min)
5	040529	Littleton	1842:40	39.6000, -105.1200	0/5 min, (0.0 fl/min)
6	040619	Kremmling	2045:49	40.0665, -106.3936	5/5 min, (1.0 fl/min)
7	040707	Arvada	0012:37	39.8333, -105.1300	1/5 min, (0.2 fl/min)
8	040801	Breckenridge	2038:06	39.4730, -105.9550	7/5 min, (1.4 fl/min)
9	050723	Pueblo	2359:59	38.2886, -104.5778	2/5 min, (0.4 fl/min)
10	050906	Rocky Ford	0007:00	37.9970, -103.7287	0/5 min, (0.0 fl/min)
11	060621	Jeffco	2311:20	39.8763, -105.0639	0/5 min, (0.0 fl/min)
12	060719	Colo Sprgs (COS)	2352:15	38.9055, -104.7720	1/5 min, (0.2 fl/min)
13	060719	Woodland	2329:01	38.9928, -105.0575	4/5 min, (0.8 fl/min)
14	070902	Oldstage	0052:29	38.7415, -104.9116	9/5 min, (1.8 fl/min)
15	080703	Bear Basin	2242:11	38.1716, -105.2940	4/5 min, (0.8 fl/min)
16	080724	CSU, Ft Collins	0118:15	40.5739, -105.0816	40/5 min, (8.0 f/lmin)
17	080724	Mineral (contdvd)	Unknown	37.9508, -107.0315	could not be determined
18	090606	Evans	Unknown	40.3788, -104.7366	could not be determined
19	100612	Brown Canyon	2212:38	38.6800, -106.0920	0/5 min, (0.0 fl/min
20	110831	Hermit Lake	2151:58	38.0900, -105.6320	1/5 min, (0.2 fl/min

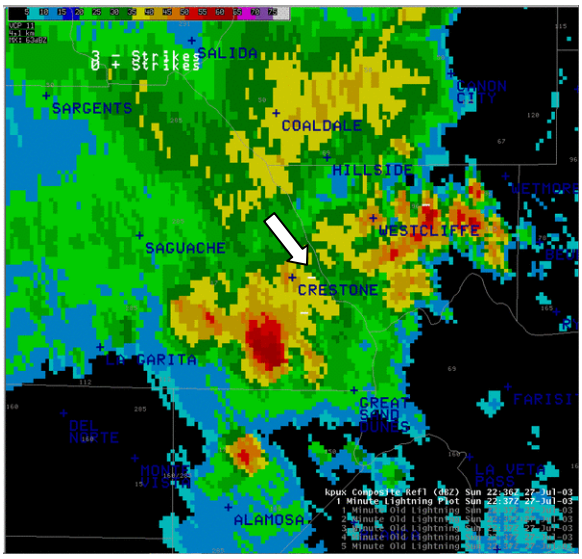

Figure 4-a (above). Crestone 030727 case: Composite radar reflectivity from KPUX and lightning activity associated with the Crestone case. Light rain was likely occurring at the time of this event. The flash (small white "-") which caused the casualty likely occurred at 2236:13 UTC (white arrow points toward flash).

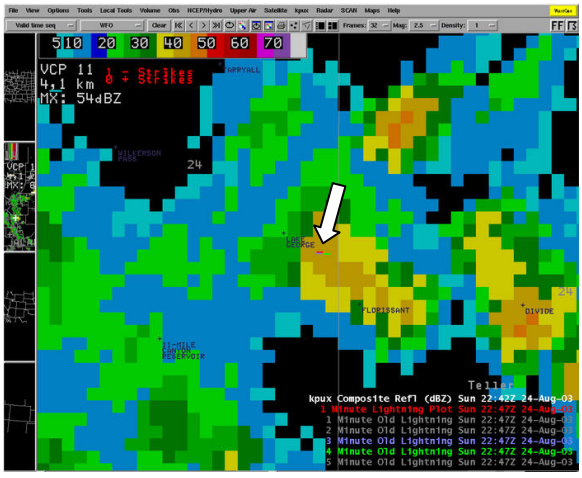

Figure 4-b (above). Lake George 030824 case: Composite radar reflectivity from KPUX and lightning activity associated with the Lake George case. Moderate rain was likely occurring at the time of this event. The flash (small red "-") which caused the casualty likely occurred at 2246:24 UTC (white arrow points toward flash).

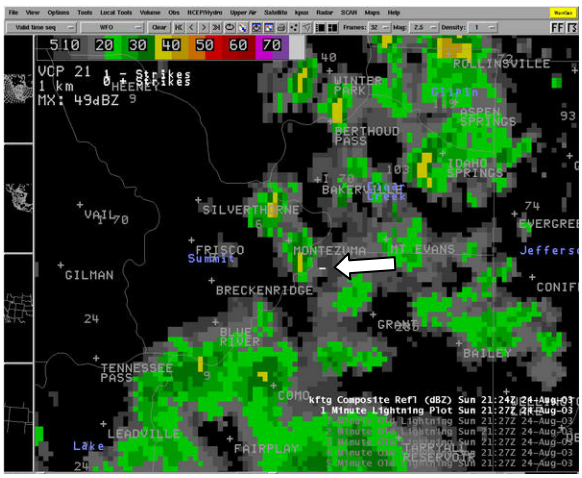

Figure 4-c (above). Red Cone Pass (030824) case: Composite radar reflectivity from KFTG and lightning activity associated with the Red Cone case. Very Light or no rain was likely occurring at the time of this event. The flash (small white "-") which caused the casualty likely occurred at 2126:20 UTC (white arrow points toward flash).

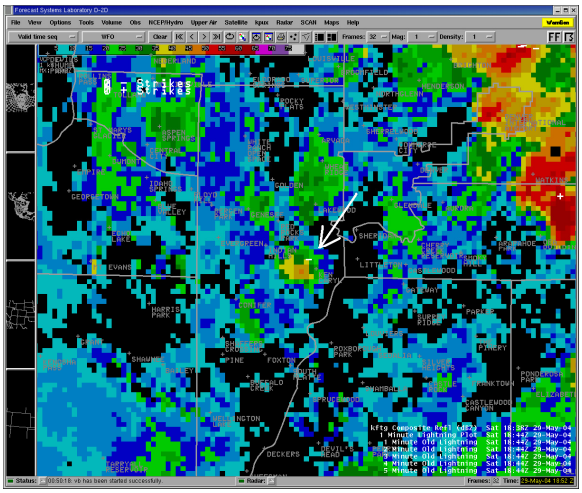

Figure 4-d (above). Littleton (040529) case: Composite radar reflectivity from KFTG and lighting activity associated with the Littleton case. Light to moderate small rain showers were likely occurring at the time of this event. The flash which caused the casualty likely occurred at 1842:40 UTC (white arrow points toward flash).

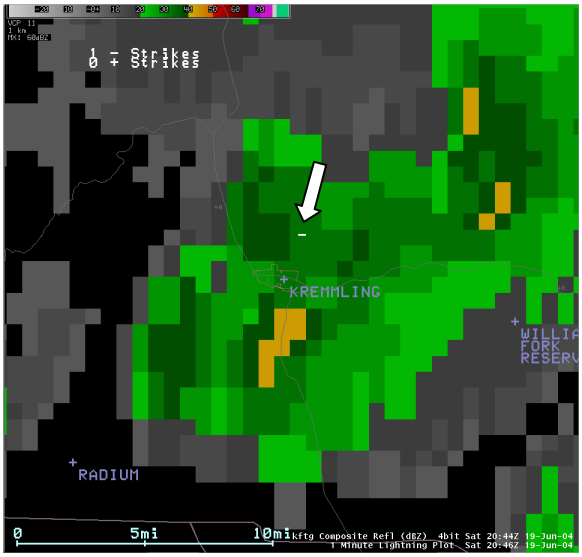

Figure 4-e (above). Kremmling (040619) case: Composite radar reflectivity from KFTG and lightning activity for the Kremmling case. Light rain was likely occurring at the time of this event. The flash which caused the casualty likely occurred at 2045:49 UTC (white arrow points towards flash).

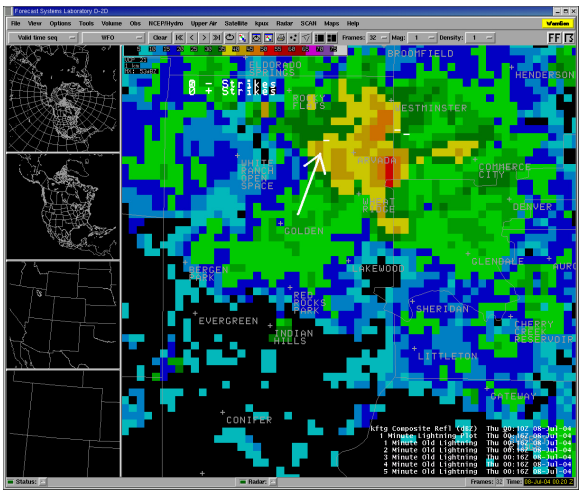

Figure 4-f (above). Arvada (040707) case: Composite radar reflectivity from KFTG and lightning activity for the Arvada case. Light to moderate rain was likely occurring at the time of this event. The flash which caused the casualty likely occurred at 0012:37 UTC (white arrow points towards flash).

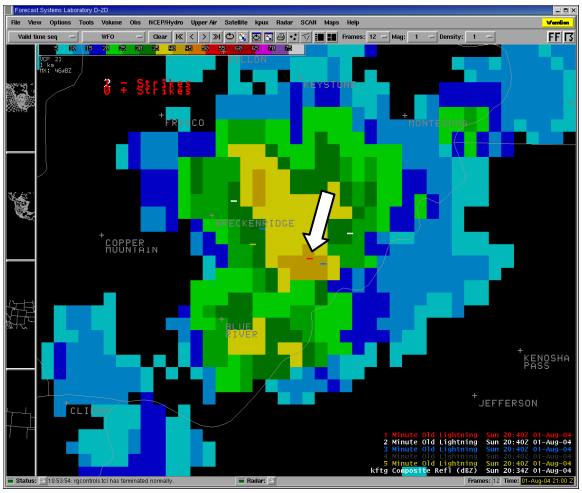

Figure 4-g (above). Breckenridge (040801) case: Composite radar reflectivity from KFTG and lightning activity for the Breckenridge case. Moderate rain was likely occurring at the time of this event. The flash which caused the casualty likely occurred at 2038:06 UTC (white arrow points towards flash).

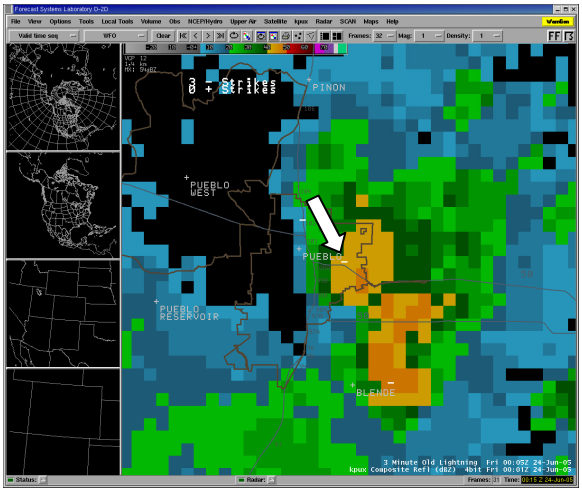

Figure 4-h (above). Pueblo (050723) case: Composite radar reflectivity from KPUX and lightning activity for the Pueblo case. According to media reports, no rain was falling at the time of the event, although radar would indicate light to moderate rain was occurring. The flash which caused the casualty likely occurred at 2359:59 UTC (white arrow points towards flash).

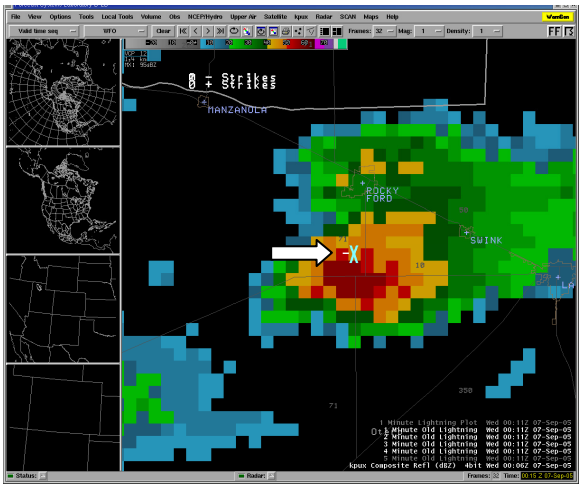

Figure 4-i (above). Rocky Ford (050906) case: Composite radar reflectivity from KPUX and lightning activity for the Rocky Ford case. Moderate to heavy rain was likely occurring at the time of this event. The flash which caused the casualty likely occurred at 0007:00. The white arrow points towards the flash. The blue "x" marks the location of the victim.

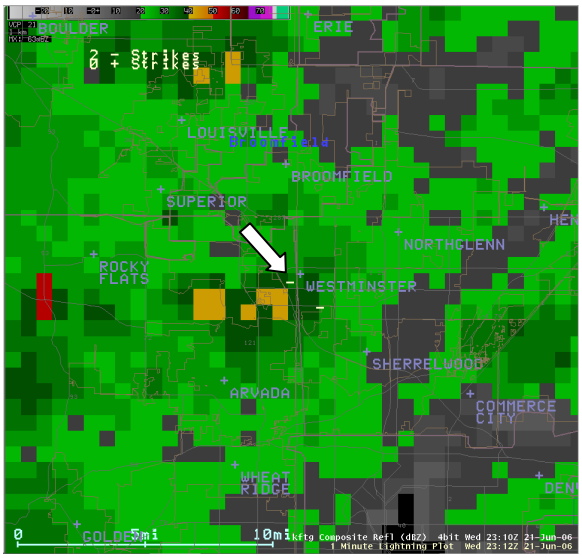

Figure 4-j (above). Jeffco (060621) case: Composite reflectivity from KFTG and lightning activity for the Jeffco case. Light rain was likely occurring at the time of this event. The flash which caused the casualty occurred at 2311:20 UTC (white arrow points towards flash).

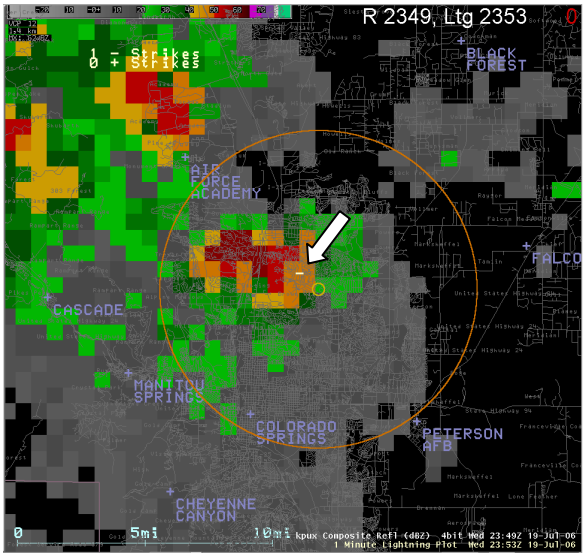

Figure 4-k (above). Colo Sprgs (060119) case: Composite reflectivity data from KPUB and lightning activity for the Colorado Springs case. The flash which caused the casualty likely occurred at 2352:15. Moderate rain was likely occurring with the flash (white arrow points towards flash). The orange ring in this case shows data within 6 miles of the flash.

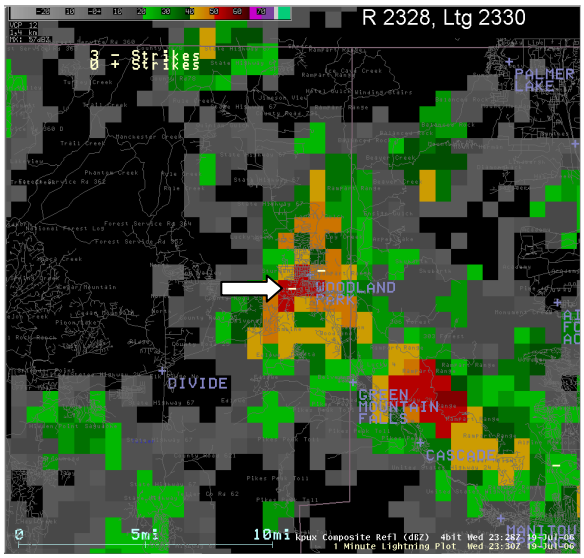

Figure 4-l (above). Woodland Park (061719) case. Composite reflectivity data from KPUB and lightning activity for the Woodland Park case. The flash which caused the casualty likely occurred at 2329:01. Moderate to brief heavy rain was likely occurring with the flash (white arrow points towards flash).

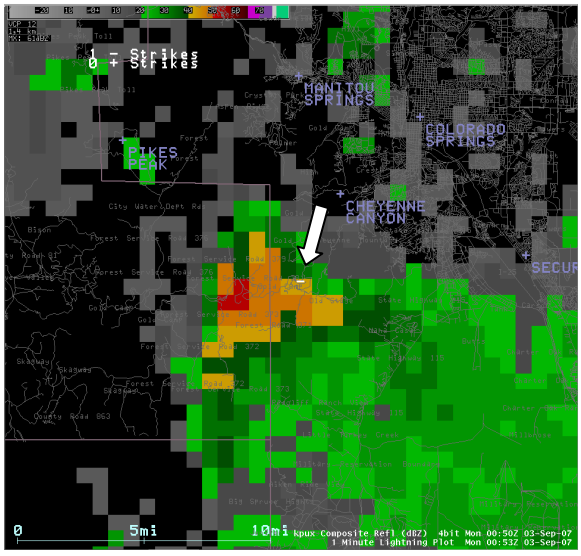

Figure 4-m (above). Old Stage (070902) case: Composite reflectivity data from KPUB and lightning activity for the Old Stage case. The flash which caused the casualty likely occurred at 0052:29. Light to moderate rain was likely occurring with the flash (white arrow points towards flash).

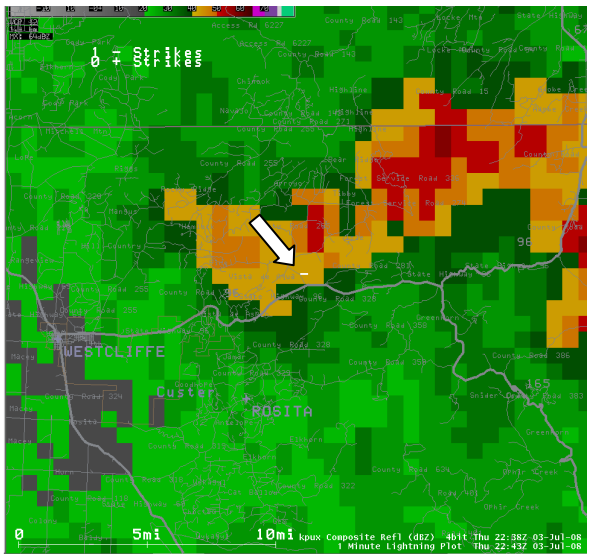

Figure 4-n (above). Bear Basin (080703) case: Composite reflectivity data from KPUB and lightning activity for the Bear Basin case. The flash which caused the casualty likely occurred at 2242:11. Light to moderate rain was likely occurring with the flash (white arrow points towards flash).

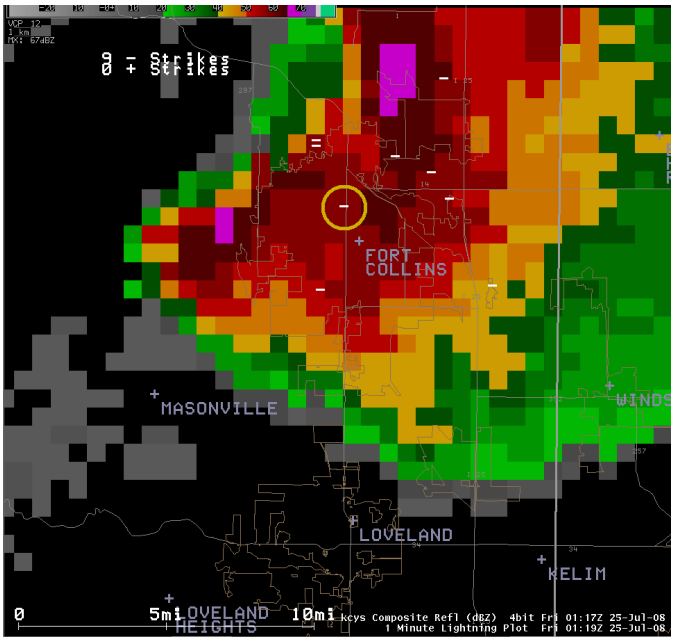

Figure 4-o (above). CSU, Ft Collins (080724) case: Composite reflectivity data from KFTG and lightning activity for the CSU, Ft Collins case. The flash which caused the casualty likely occurred at 0118:15 UTC. Heavy rain was occurring likely occurring at the time of the flash (flash is circled).

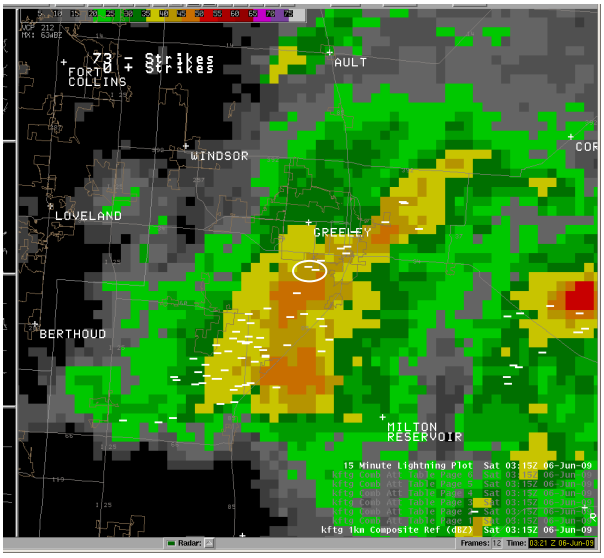

Figure 4-p (above). Evans (090606) case: Composite reflectivity data from KFTG along with lighting data for a 15 minute time period for the Evans case. It could not be determined which flash caused the casualty in this case, but the two flashes circled above were the most likely candidates. The two flashes occurred around 0310 UTC.

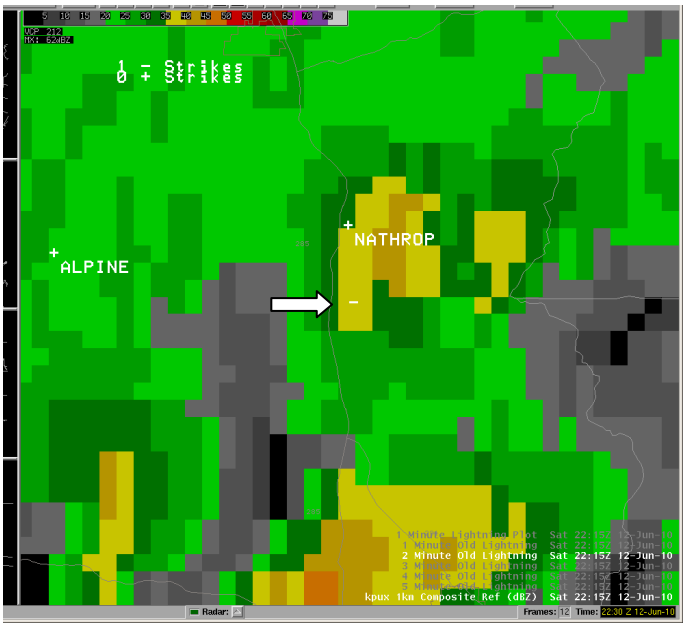

Figure 4-q (above). Browns Canyon (100612) case: Composite reflectivity data from KPUX and lightning activity for the Browns Canyon case. The flash which caused the casualty likely occurred at 2212:38 UTC. Light to moderate rain was likely occurring with the flash (white arrow points towards flash).

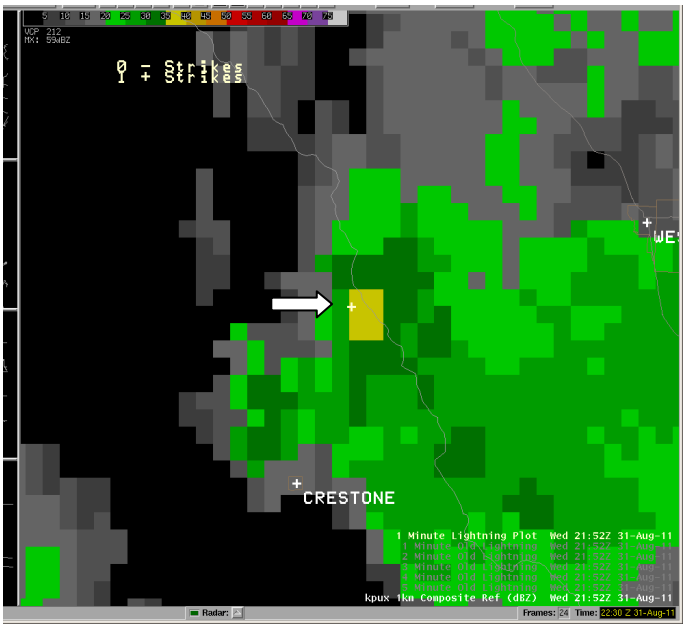

Figure 4-r (above). Hermit Lake (110831) case: Composite reflectivity data from KPUX and lightning activity for the Hermit Lake case. The flash which caused the casualty likely occurred at 2151:58UTC. Light to moderate rain was likely occurring with the flash (white arrow points towards flash).