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FIVE-YEAR, WARM SEASON, CLOUD-TO-GROUND LIGHTNING ASSESSMENT FOR SOUTHERN NEVADA

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ABSTRACT

This analysis was undertaken to provide new information on CG lightning in southern Nevada and to create a preliminary climatology of CG lightning in this mountainous desert environment. Information presented here has documented the spatial and temporal distributions and flash densities of CG lightning in southern Nevada. These, and future, data will increase our knowledge of desert thunderstorm and lightning activity; thereby contributing useful information that should aid in reducing vulnerabilities to CG lightning, to improving the quality and timeliness of weather forecasts, and to reducing costs due to thunderstorm and CG lightning damage.

Five warm seasons (June through September, 1993-1997) of cloud-to-ground (CG) lightning flashes are analyzed for southern Nevada. The results show a large inter-annual variation in CG lightning for the analysis area with 1996 containing the fewest number of flashes (11,693) and 1994 being the most active (36,441 flashes). A total of 129,528 flashes were detected within the 107,520 km^2 analysis area for an average flash density of 0.24 fl/km^2/warm season. For the five warm seasons, 2.2% of the flashes deposited positive charge to the ground. The largest flash densities tended to occur over terrain above 1500 m above mean sea level (MSL). Small flash densities were confined to dry lake beds and to lower elevations. The average maximum seasonal flash density was 7.3 fl/km^2 over the Spring Mountain Range. The maximum single season flash density was 17.4 fl/km^2 over the Spring Mountain Range in 1997. The peak, individual, thunderstorm flash density was 11.8 fl/km^2 over the Belted Mountain Range located north of the NTS on August 19, 1994. However, during preparation of this manuscript, a peak thunderstorm flash density of 23.2 fl/km^2 was measured on July 19, 1998, in a small mountainous area located approximately 100 km northeast of Las Vegas. These large flash densities are similar to those measured in the eastern United States and in Florida. In general, average warm season flash densities of 2 to 3 fl/km^2 covered approximately 16,000 km^2 of southern Nevada, or 14% of the entire State. Similar flash densities, corrected for detection efficiency (multiply fl/km^2 in this report by 1.4), have been measured over the Great Plains (Orville and Silver, 1997). Such large flash densities are quite hazardous to people who live in the mountains and for those who use them for recreation during the summer months. Furthermore, CG lightning can disrupt power grids and communications networks vital to people and to their safety.

Diurnally, the maximum hourly flash rate occurs between 1600 and 1659 PDT with minimum activity between 0700 and 0759 PDT. Over the mountains, the peak flash rate occurs between 1300 and 1359 PDT and can remain elevated until 0200 PDT. Positive flashes occur during all hours with peak activity between 1700 and 1759 PDT. Positive flashes appeared to be related to storm dissipation.

FIVE-YEAR, WARM-SEASON, CLOUD-TO-GROUND LIGHTNING ASSESSMENT FOR SOUTHERN NEVADA

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I. Introduction

Cloud-to-ground (CG) lightning flash data have been collected and archived for that area of southern Nevada surrounding the Nevada Test Site (NTS) since 1986. The original network of four magnetic direction finders was laid out in 1986. This lightning detection technology has been documented by Krider et al. 1980 and the NTS network has been described in detail by Scott (1988). The NTS network was designed to provide high detection capability on and within 170 km of the NTS and has been used to guard the safety of personnel working on and around the NTS. In early 1993 the system was upgraded and expanded to give better coverage not only of the NTS but also of the area surrounding the NTS and including the metropolitan area of Las Vegas, the largest city and most densely populated region in Nevada. During this upgrade, new software was implemented that did not permit access to prior data. Consequently, in this study, only the CG lightning data from 1993 through 1997 were analyzed. The area of analysis was enclosed within a circle with a radius of 185 km, centered on Control Point-1(CP-1) on the NTS. Figure 1 illustrates most of the 107,520 km^2 geographical area covered by this investigation. However, since little CG lightning was detected beyond 100 km west of CP-1 and 150 km south of CP-1, the western 45 percent and southern 10 percent of the figure were eliminated to conserve space and to enhance figure size.

Thunderstorm activity and the accompanying CG lightning is primarily a summertime phenomenon in the vicinity of the NTS (Quiring 1977 and 1983) and over southern Nevada (Randerson, 1997). Consequently, in this study the focus was on warm-season lightning where the warm season is defined as June through September. Cloud-to-ground lightning data were summarized and analyzed for these four summer months for the five-year period 1993 through 1997. The annual warm season CG flash summaries are tabulated in Table.1. The data listed in this table illustrate the large interannual variability in CG lightning (thunderstorm) activity in a desert environment. A total of 129,528 cloud-to-ground lightning flashes flashes were detected for the period of record and for the analysis area. Of these flashes, 126,636 lowered negative charge to the ground (negative flashes) and 2,892, or 2.2%, lowered positive charge to the ground (positive flashes). This average is similar to that reported by Fuquay (1982) for three summers in the northern Rocky Mountains and by Orville and Silver (1997) for southern Nevada. Based on the total number of flashes detected during five warm seasons within the study area, the mean annual (warm season) CG flash density for the analysis area is 0.24 flashes/sq km (fl/km^2). This number is smaller than the annual average of 2.0 fl/km^2, for the contiguous United States, that can be derived from the data presented by Orville (1994), and is slightly smaller than the annual flash densities portrayed over southern Nevada in the figures presented by Orville and Silver (1997) for 1992 through 1995. No attempt was made to account for

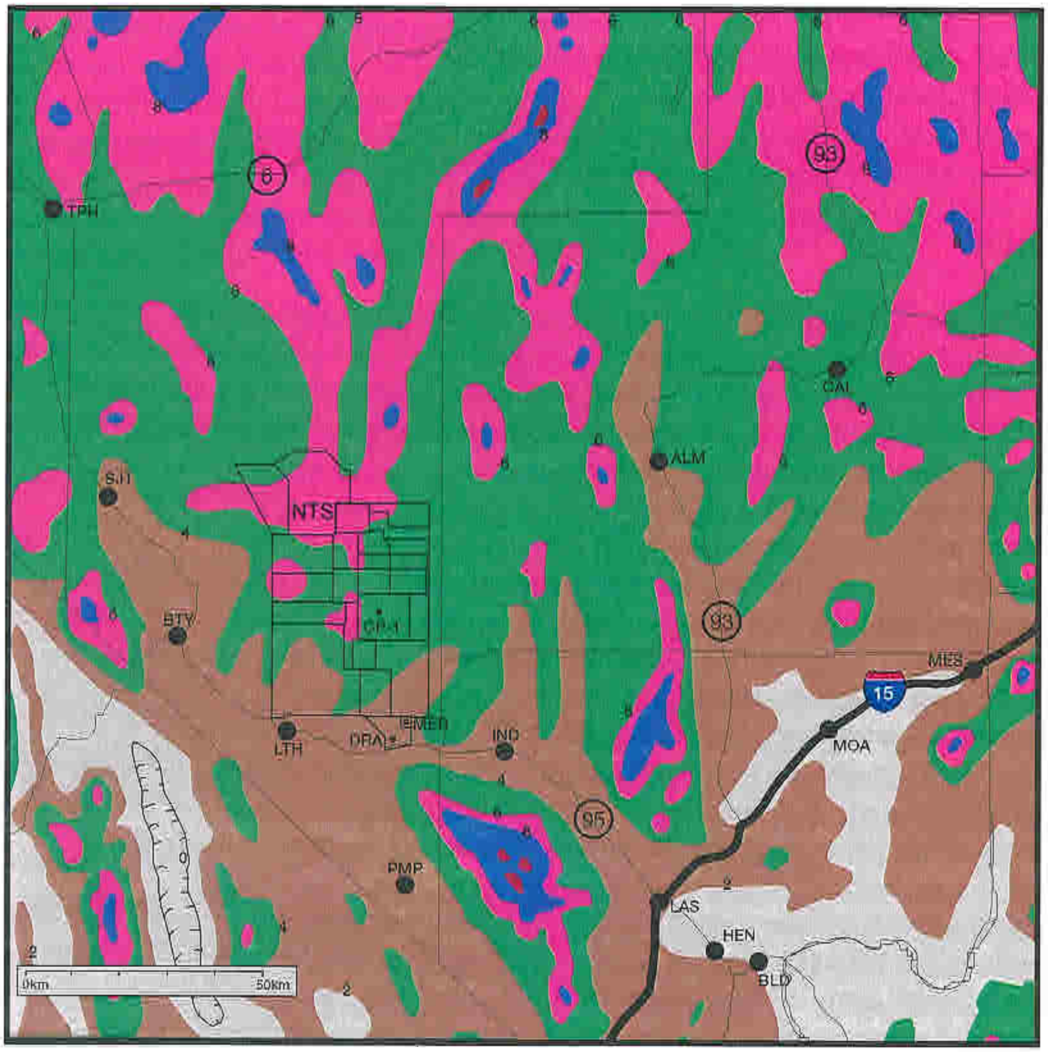

Figure 1. Smoothed contours of topography. Contours are for 2000 ft (610 m) intervals above mean sea level (MSL). White areas represent terrain below 2000 ft (610 m) MSL, brown is 2000 - 3999 ft (610 - 1219 m), green is 4000 - 5999 ft (1220 - 1829 m), purple is 6000 - 7999 ft (1830 - 2439 m), blue is 8000 - 9999 ft (2440 - 3049 m), and red is above 10000 ft (3050 m).

undetected CG flashes; only flashes actually detected are counted in the summaries described in this report.

Table 1. Warm season (June through September) cloud-to-ground lightning flash totals for 1993 through 1997.

Year	Total Flashes	Positive Flashes	Percent Positive
1993	19,183	345	1.8
1994	36,367	596	1.6
1995	27,354	579	2.1
1996	11,686	274	2.3
1997	34,938	1,098	3.1
Total	129,528	2,892	2.2

A characteristic of desert thunderstorms is that many produce little precipitation. For example, in Las Vegas, Nevada (LAS), 85% of all warm-season precipitation events have set-hour rainfall depths of 0.10 in (2.5 mm) or less (Randerson, 1997). Although desert thunderstorms exhibit this tendency toward little or no precipitation production, they all generate lightning. Consequently, lightning may be a representative measure of desert thunderstorm activity. Another important attribute of desert thunderstorms is that some can be very intense, producing strong outflow winds, dense blowing dust, frequent CG lightning, locally heavy precipitation, and flash flooding. Desert thunderstorms pose a serious threat to life and property. More study of these storms is needed. Accordingly, this analysis was undertaken to describe the CG lightning distribution over the complex terrain setting of southern Nevada, to continue to expand the scientific understanding of desert thunderstorms, and to contribute to improved forecast procedures for these dangerous storms.

II. Climatology and Topography

Southern Nevada lies on the southwestern edge of the Great Basin and on the northeastern edge of the Mojave Desert. Consequently the climate is arid with limited precipitation. Two fundamental physical factors drive precipitation events in southern Nevada: those resulting from cool-season, mid-tropospheric cyclones and those resulting from summertime convection. Thunderstorms and cloud-to-ground lightning over southern Nevada are infrequent from October through May. Summer is the thunderstorm season for the desert southwest which includes southern Nevada. Annually, Las Vegas and Desert Rock average 9-10 thunderstorm days , respectively, from June through September.

Thunderstorms and severe thunderstorms generally occur during July and August when moist tropical air can flow northward over the lower Colorado River valley and into Arizona, southern Nevada, and Utah. This seasonal event is referred to as the southwestern monsoon by many researchers and weather forecasters (Bryson and Lowery, 1955, Hales, 1972, Brenner, 1974, Carleton, 1985, Balling and Brazel, 1987, Douglas, et al., 1993, and others). Furthermore, McCollum et al. (1995) have shown that low-level moisture from the Gulf of California can increase the convective instability of the atmosphere over Arizona dramatically. On occasion, this phenomenon is associated with significant thunderstorm development and heavy precipitation in Arizona, Nevada, and Utah. A recent summary and analysis of extreme precipitation events for southern Nevada has been presented by Randerson (1997).

Topography, of course, can play a critical role in modulating thunderstorm activity and in augmenting precipitation near mountain ranges. On the mesoscale, mountain ranges can create thermally driven convergence zones that enhance thunderstorm development (Hill, 1993, Maddox et al. 1995, and Runk, 1996). Figure 1 shows that the topography of southern Nevada is complex and consists of north-south oriented mountain ranges separated by small basins and dry lake beds. Elevations range from approximately 500 m above mean sea level (MSL) in the Colorado River valley to nearly 3650 m MSL for Mt. Charleston in the Spring Mountain Range located west of LAS. The Sheep Range, to the north of LAS, contains two peaks with elevations between 2900 m and 3000 m.

Over the NTS, terrain above 2000 m MSL extends from Shoshone Mountain (2200 m MSL) northward, forming the Belted Range and Kawich Range that extend northward from the NTS. The Quinn Canyon Range, located in the north cental part of Fig. 1 contains several peaks ranging from 3000 m to 3500 m MSL. In the northeastern quarter for Fig. 1, the Delmar Mountains are located between Alamo (ALM) and Caliente (CAL), Nevada.

The southeastern quadrant of Fig. 1 contains the Colorado and Virgin River valleys with terrain generally below 1700 m MSL. The Virgin Mountains, located just south of Mesquite (MES), Nevada, separate these two river basins. Most of the population of Nevada is located in the Las Vegas (LAS) metropolitan area where more than one million residents live, not including tourists. In general, the topography in the northern half of Fig. 1 lies above 1500 m MSL with a few mountain peaks reaching to near 3500 m MSL while in the southern half of the figure the terrain lies below 1500 m except for the Spring Mountains and the Sheep Range. Death Valley is located in California to the southwest of the NTS and a large flat basin, the Amargosa Desert, lies to the south and west of the NTS.

III. Analysis

Spatial: Individual CG lightning flashes were located and placed in 2.34 km by 2.34 km (or 5 km^2) bins or boxes and overlaid on the analysis area. Approximately 21,504 bins covered this area. CG flash densities were calculated by summing the number of flashes detected inside each of these boxes. The resulting seasonal totals were plotted at the center of each 5 km^2 box to produce annual warm season summaries of total flash counts. The plotted data were then analyzed by contouring the data field. Contour intervals were selected to represent flash densities of 1.0, 2.0, 4.0, 8.0, and 12.0 fl/km^2. To acquire the mean for the five warm seasons, the flash densities for each summer were totaled and then contoured using the same procedure as for the annual contours, except the contours are divisible by 25 (5 yr times 5 km^2) to yield fl/km^2/warm season.

Temporal: Warm season summaries of the hourly variation in CG lightning are presented as bar graphs with time (UTC and PDT) on the ordinate and flash count on the abscissa. These summaries are for the hour beginning at the identified time and ending 60 min later. For example, the plot for 1800 UTC (1100 PDT) is for flashes that occurred between 1800:00:00 and 1859:59:59 UTC. Both negative and positive flashes are summarized. Positive flash totals are plotted as a clear area located on top of the solid bars which represent the total hourly negative flash count. Also, PDT is used in discussing lightning events since it is the local time used during the summer months.

Within the 5-yr data record there were series of days containing periods of very active CG lightning. These periods tend to last from 48 to 96 hours and have been classified as active CG lightning episodes (ALEs). Watson et al. (1994) reported a similar phenomena of "bursts" in an analysis of CG lightning over Arizona. The criteria for an ALE are: 1) a period of CG lightning that produced at least 2000 fl/24 hr within the analysis area, 2) preceded or immediately followed by at least one 24-hr period with at least 1000 fl, and 3) CG lightning persisting for 48 hr or more. To identify these unusual events, the data base was scanned in 24-hr time blocks for all five years and the episodes extracted for analysis relative to available precipitation data and meteorological observations. Each warm season, except 1996, had at least one ALE event and 1994 had four. One of the three 1997 ALEs was very active (September 2-5).

IV. Seasonal Summaries

June-September 1993

The summer of 1993 was not an active thunderstorm season over southern Nevada. On average, Las Vegas (LAS) experiences 9 thunderstorm days from June through September and Desert Rock (DRA), on the NTS, 10 days (Randerson, 1997). During the summer of 1993, only five thunderstorms days occurred in LAS and only four occurred at DRA. As a result, a total of only 18,838 negative and 345 positive CG flashes were detected within the analysis area.

The spatial distribution of CG lightning for the warm season of 1993 is shown in Figure 2. Clearly, the important role of topography on CG lightning enhancement can be seen by comparing the flash density analysis in Fig. 2 with the smoothed terrain shown in Fig 1. The maximum seasonal flash density occurred in the Belted Range to the north of the NTS where 53 flashes per 5 km^2 were detected, yielding a maximum seasonal flash density of 10.6 fl/km^2. Another band of large flash density extends eastward from near MER, over the Sheep Range, and then northeastward toward Caliente, Nevada (CAL). Also, large flash densities (4 fl/km^2) occurred in the northwestern part of Yucca Flat and over the Shoshone Mountains on the NTS. Figure 2 shows that seasonal flash densities less than 1.0 fl/km^2 occurred over much of the area to the west of the NTS. In general,

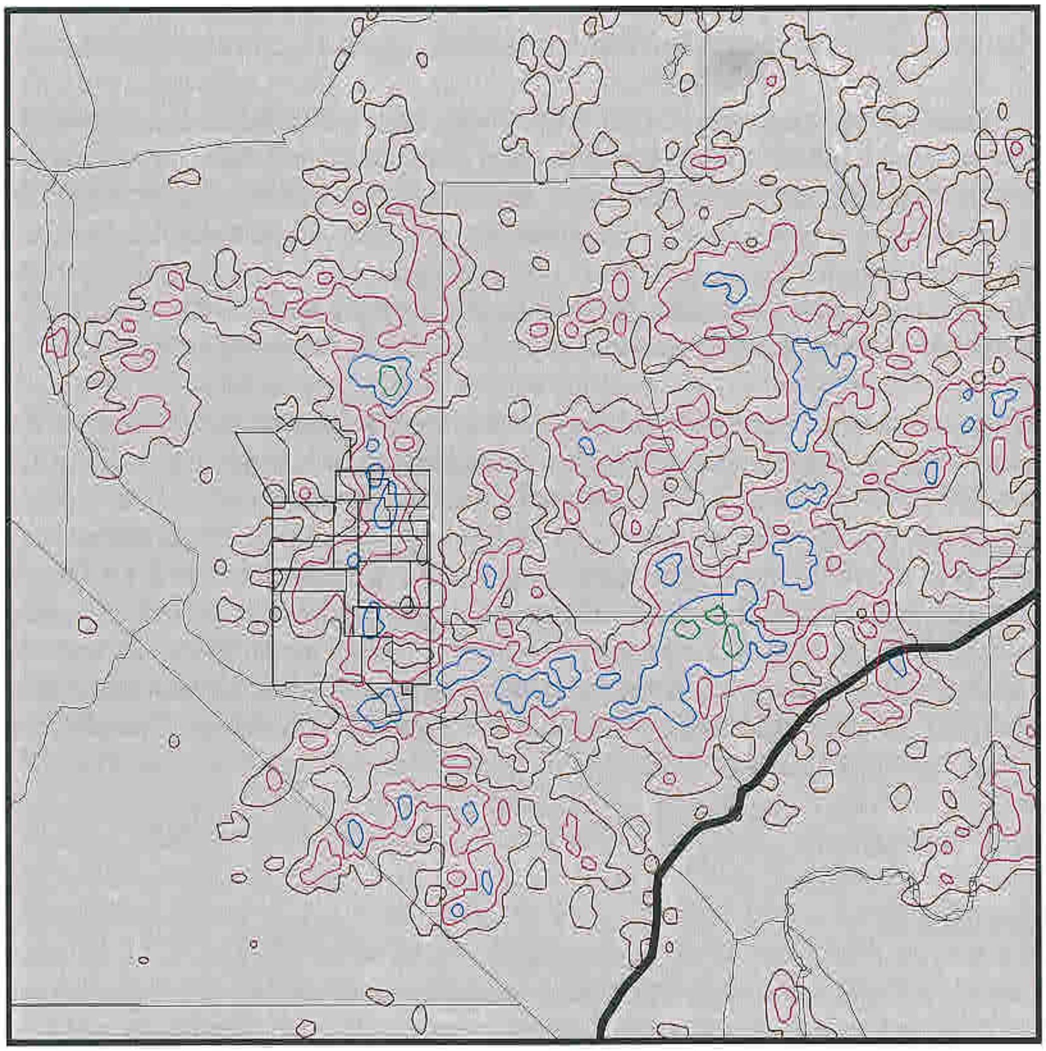

Figure 2. CG lightning flash density field for June through September 1993. Contour values are: 1.0 fl/km^2 is in black, 2.0 is in red, 4.0 in gold, 8.0 in blue, and 12.0 or more is in green. Total flash count is 19,183 flashes

warm season flash densities on the NTS were less than 2.0 fl/km^2; especially in the dry lake beds where flash densities were less than 1.0 fl/km^2.

During the 1993 warm season, flash densities in populated areas ranged from near 1.0 to 3.0 fl/km^2. A seasonal flash density of 2.6 fl/km^2 was measured over Mercury, on the NTS. Curiously, the seasonal flash densities in the small mountain villages (KYL and LEE) located in the Spring Mountains ranged from only 1.0 to 1.5 fl/km^2. Flash densities over the Las Vegas valley were near 1.0 fl/km^2. Over the Lake Mead Recreational area seasonal flash densities ranged from less than 1.0 fl/km^2 to near 2.0 fl/km^2; however, this area is near the limit of detectability and, therefore, will not be included in this report.

The diurnal variation of flash rate for the 1993 warm season is shown in Fig. 3. This figure clearly exhibits the well-known late-afternoon (1600-1659 PDT) peak in lightning activity. However, two curiosities appear in Fig 3. First, is the increase in CG lightning after 2200 PDT with a maximum at local midnight. This nocturnal activity may be related to the maintenance of strong convective instability long after sunset over the desert in summer. Second, is the apparent increase in CG flashes with positive polarity between 1500 and 2200 PDT. This phenomena could be related to the increase in positive CG flashes reported by Fuquay (1982) during storm dissipation or to microphysical charge separation processes that can occur in thunderstorms (MacGorman and Burgess, 1994).

Positive flashes were randomly distributed throughout the area of analysis. Table 1 shows that 1.8% of the 1993 CG flashes were positive. Of the positive flashes, 11 occurred within the boundaries of the NTS and none occurred within 35 km of the center of downtown LAS. Most of the population of southern Nevada is contained within the metropolitan Las Vegas area.

The most active thunderstorm period was during the first week of August and this activity resulted in the only ALE event for 1993. Significant thunderstorms developed to the north and east of the NTS between 1000 PDT and 2330 PDT on August 3. Two areas of vigorous cloud-to-ground lightning can be easily identified in Fig. 4. The area to the north of the NTS developed over the 2600-m peaks in the Belted Range and drifted eastward over Emigrant Valley. A maximum flash density of nearly 40 fl/5 km^2 or 8.0 fl/km^2 occurred with this thunderstorm. The other area developed over the Sheep Range (north of LAS) and moved eastward. This activity is noteworthy because of the 2.0 fl/km^2 contour encloses an area of approximately 500 km^2 and contains a small area within which the flash density was 7.4 fl/km^2. On this day the temporal flash rate had a distinctive diurnal pattern with lightning activity beginning at 1000 PDT and ending by 2300 PDT. However, the flash rate increased rapidly (tripled) between 1200 PDT and 1300 PDT. Flash rates remained at 500 to 550 fl/hr between 1400 PDT and 1800 PDT, decreasing rapidly after 1800 PDT. Few flashes with positive polarity occurred before 1400 PDT. The majority of the positive flashes occurred after 1600 PDT with the peak positive flash rate occurring between 1800 and 2100 PDT, during storm dissipation.

Very active thunderstorms developed after sunset over the NTS on August 4. These thunderstorms developed rapidly after 2100 PDT. The flash density analysis associated with these thunderstorms

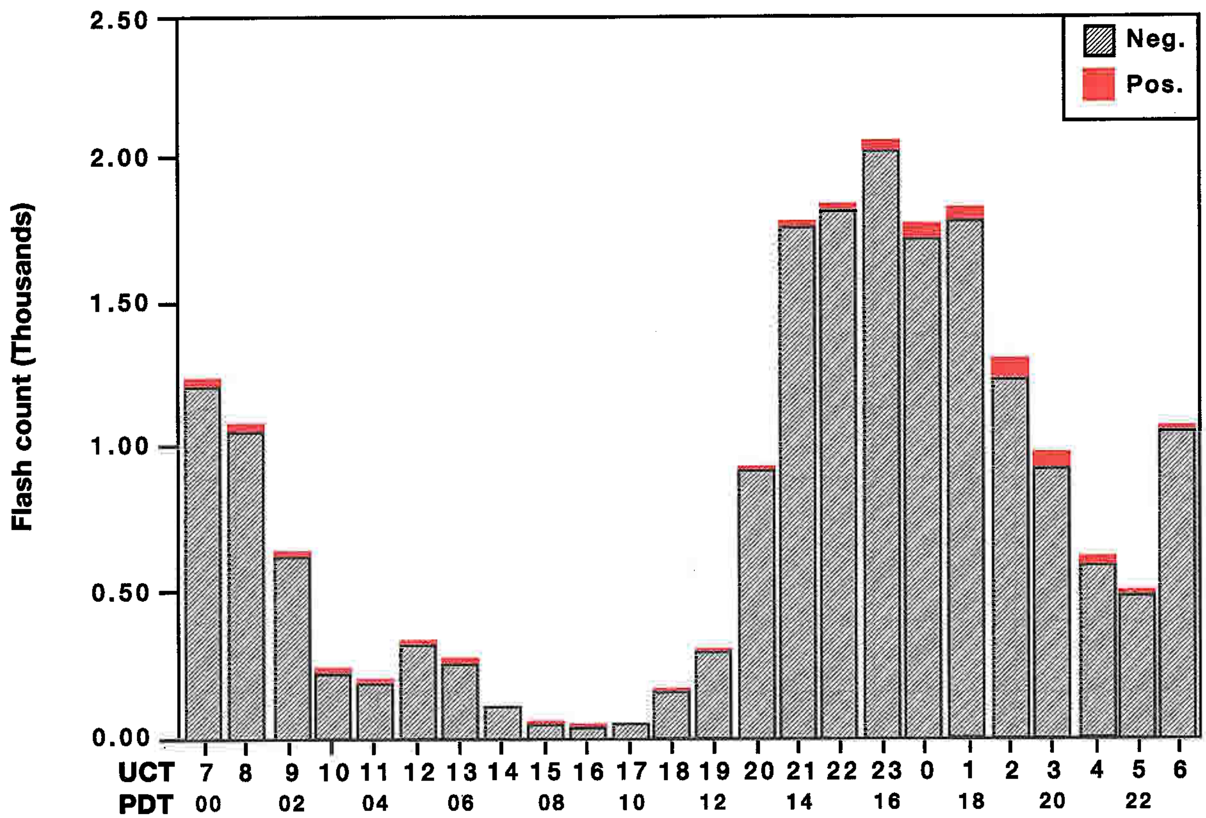

Figure 3. Diurnal distribution of CG lightning flashes for June through September 1993. Hourly flash rates are for the hour beginning at, say, 11:00:00 Universal Coordinated Time (UCT) and ending at 11:59:59 UCT, or 04:00:00 Pacific Daylight Time (PDT) to 04:59:59 PDT. The hourly negative flash count is represented by the black hatched bars and the positive flash count is plotted in red.

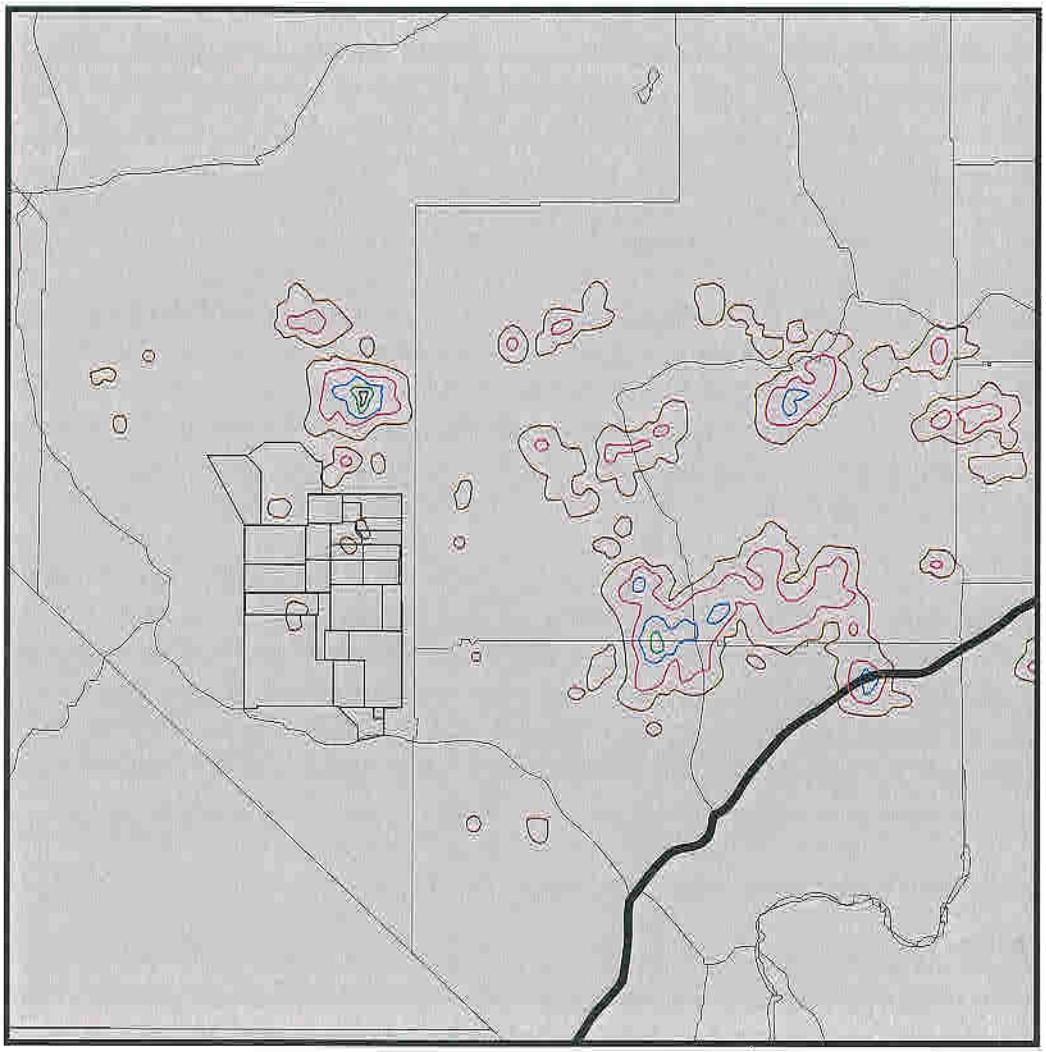

Figure 4. Flash density analysis for 1026 PDT, August 3, 1993, through 2331 PDT, August 3, 1993. Contour values are: 1.0 fl/km^2 is in gold, 2.0 is in red, 4.0 in blue, 6.0 in green, and 8.0 in black. Total flash count is 3756 flashes.

is presented in Fig. 5. The axis of maximum flash density extends roughly east-west across the extreme southeastern part of the NTS. A flash rate of 6.6 fl/km^2 occurred to the southwest of MER and another of 6.0 fl/km^2 to the northeast of MER. A noteworthy lightning producer appears to have developed over the southern end of the Shoshone Mountains and moved eastward, across the northern half of Frenchman Flat. A peak flash density of 4.2 fl/km^2 accompanied this thunderstorm.

June-September 1994

Table 1 shows that the summer of 1994 was the most active lightning season of the five-year period analyzed in this study. A total of 36,367 flashes were detected, of which, 596 were positive flashes. The spatial summary of these flashes is portrayed in Fig. 6. The primary difference between Figs. 2 and 6 is that much more CG lightning occurred in the eastern half of Fig. 6 and especially over the high terrain in the northeastern quadrant of the figure. This activity contributed significantly to the large 1994 seasonal total. Although there were nearly twice as many flashes in 1994 as in 1993, there were some similarities in the CG lightning patterns for two seasons. First, the flash densities decease westward from the western boundary of the NTS into the Armagosa Desert. Flash densities in this area were less than 1.0 fl/km^2. Second, the small area of maximum seasonal CG flash activity located to the north of the NTS in Fig. 2 is also seen in Fig. 6, but with a greater seasonal flash density; 71 fl/5 km^2 (14.2 fl/km^2). Third, the area of large flash density located to the east of the Sheep Range is present, but with 1994 being more active than 1993. A peak warm season flash density of 40-60 fl/5 km^2 or 8.0-12.0 fl/km^2 was detected along the eastern slopes of the Sheep Range. A characteristic of the spatial distribution of CG lightning, that is resolved better in Fig.6 than Fig. 2, is the small CG lightning flash densities in the valleys, basins, and dry lake beds of this desert region. Reference to the topography shown in Fig. 1 helps to visualized this phenomena. Apart from the above is the fact that the maximum annual flash density measured was 73 fl/5 km^2 or 14.6 fl/km^2 just southwest of Modena, Utah, near the Utah-Nevada border.

The largest seasonal flash densities in populated areas occurred in the mountain villages located in the Spring Mountains (KYL and LEE), were approximately 2.0-4.0 fl/km^2, respectively. Comparable flash densities were also measured in the vicinity of CAL, ALM, and MOA. In Las Vegas and the other communities in the analysis area, flash densities were generally less than 2.0 fl/km^2. On the NTS, seasonal flash densities ranged from 5.0 fl/km^2 near CP-1, to 3.6 fl/km^2 in the vicinity of Shoshone Mountain, to near 2.0 fl/km^2 at Mercury, to 1.0 fl/km^2 or less near Yucca Mountain. The large seasonal flash density (5.0 fl/km^2) near CP-1 occurred between 1400 PDT and 1800 PDT on August 13, 1994. During this intense thunderstorm the peak flash rate of 333 fl/hr occurred between 1500 and 1600 PDT with most of the positive flashes between 1700 and 1800 PDT, during storm dissipation.

The diurnal distribution of 1994 CG lightning activity is graphed in Fig. 7. The figure does show the standard peak in CG lightning at 1600 PDT and the steady decline in CG lightning in the early evening. Nevertheless, by comparing Figs. 3 and 7 it is easy to see that a late night secondary maximum is present in both figures, with the one in Fig. 7 occurring two hours later than the one in Fig. 3. The physical reason for this phenomena is unknown; however, it may be related to the

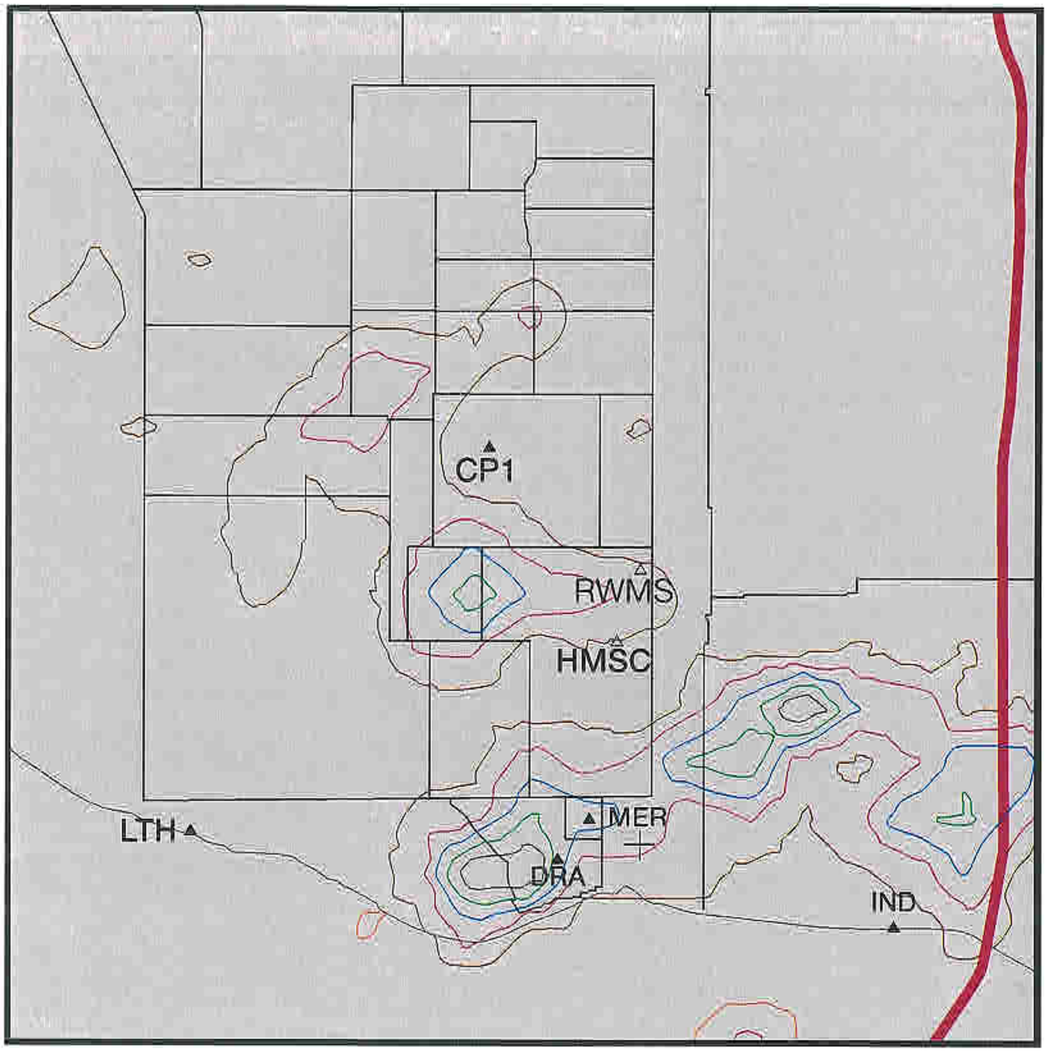

Figure 5. NTS flash density analysis for 2102 PDT, August 4, 1993, through 0204 PDT, August 5, 1993. Contour values are: 1.0 fl/km^2 is in gold, 2.0 is in red, 3.0 in blue, 4.0 in green, and 5.0 in black. Total flash count is 1067 flashes. Maximum flash density is 33 flashes within the 5.0 fl/km^2 located west of DRA and 30 flashes within the 5.0 fl/km^2 contour located northeast of Mercury (MER). The heavy red line on the right-hand side of the figure is the eastern boundary of the NTS lightning alert zone. HMSC is the Hazardous Materials Spill Center, RWMS is the Radioactive Waste Management Site, and UCC is the Yucca Flat Weather Station.

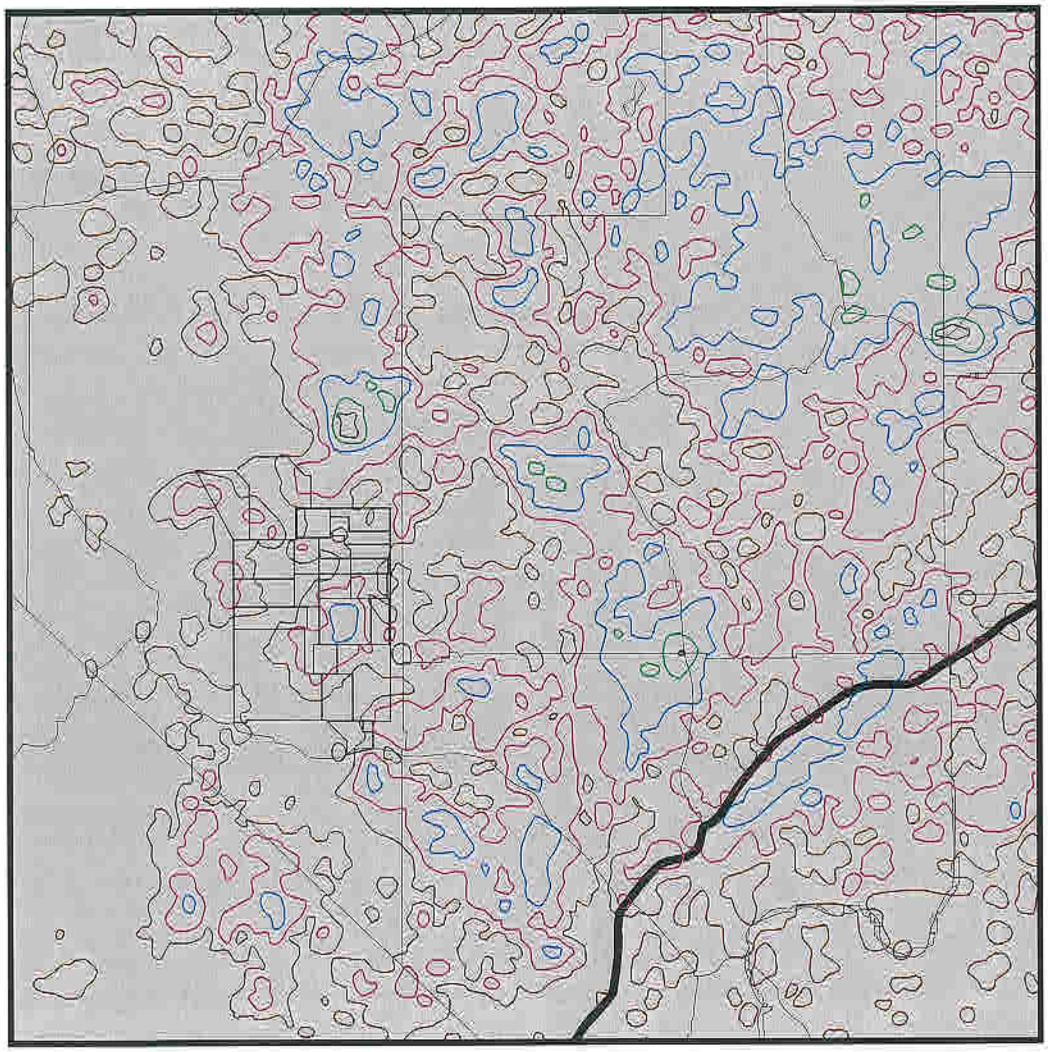

Figure 6. CG flash density field for June through September 1994. Contour values are: 1.0 fl/km^2 is in gold, 2.0 is in red, 4.0 in blue, 8.0 in green, and 12.0 or more is in black. Total flash count is 36,367 flashes. Maximum flash density is 73 fl/5 km^2 within the 12.0 contour near the Utah-Nevada border and 71 fl/5 km^2 within the 12.0 contour located north of the NTS.

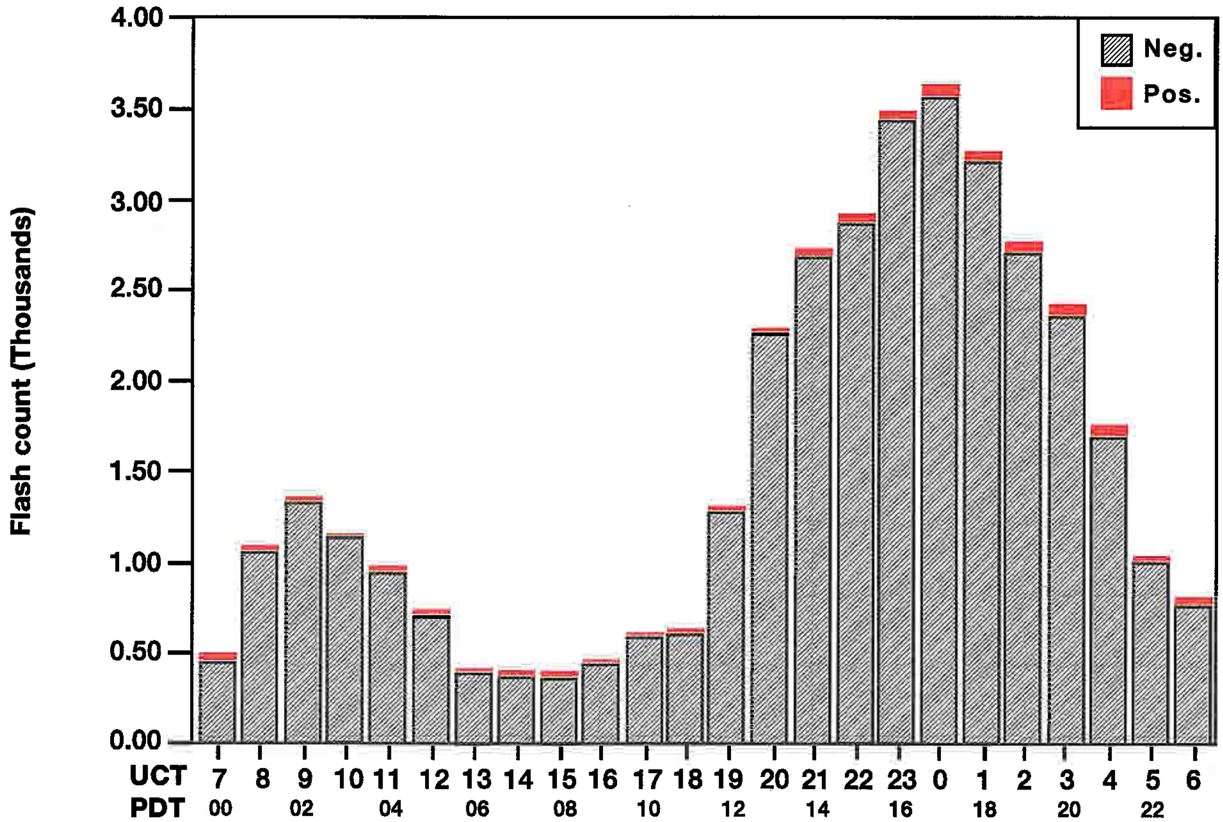

Figure 7. Diurnal distribution of CG lightning flashes for June through September 1994. See Fig.3 for additional information.

maintenance of strong convective instability lasting until long after sunset over the desert in summer (Randerson, 1997).

Table 1 indicates that in 1994, 1.6% of the CG flashes were positive, slightly less than 1993, even though there was more CG lightning in 1994 than in 1993. Of the positive flashes, 23 occurred within the boundaries of the NTS and 15 were detected within 35 km of the center of downtown LAS. Most of the positive flashes were detected east of a north-south line overlaid on the western, north-south boundary of the NTS. Figure 7 shows that even though positive flashes occurred during all hours, many of them where in the 1500-2200 PDT period, as in 1993, and appear to be associated with dissipating thunderstorms.

An analysis of individual 1994 CG lightning patterns revealed four ALEs. These episodes occurred on July 18-20, July 29-30, August 10-14, and August 17-21. Of these, the area of largest flash densities accompanied thunderstorms that developed over the Belted Range, to the north of the NTS, between 1200 and 1900 PDT on August 19. The CG pattern attributed to this storm is shown in Fig. 8. By comparing the flash density contours in Fig. 8 with the topographic chart in Fig. 1 it can be seen that the CG lightning was concentrated near the 2600-m peaks in this mountain range. A peak flash density of 59 fl/ 5 km^2 (11.8 fl/km^2) was measured. The maximum hourly CG lightning flash rate of 438 fl/hr, including five positive flashes, occurred between 1600 and 1700 PDT. The storm dissipated rapidly after 1800 PDT as it moved slowly eastward.

Prior to the activity described above, two very active thunderstorm systems developed to the northwest and to the northeast of Las Vegas between 0000 and 0700 PDT on August 19. Figure 9 shows that the areas with the large flash densities were detected along, and to the south Interstate 15 between MOA and MES and to the south of DRA. Peak flash densities of 6.4 fl/km^2 were measured near MES, 5.8 fl/km^2 near MOA, and 5.6 fl/km^2 south of DRA. The hourly flash rate associated with these thunderstorms is plotted in Fig.10. The CG lightning south of DRA developed just prior to 0000 PDT, moved slowly eastward, and dissipated rapidly after 0300 PDT. A total of only 2.0 mm of precipitation was measured at DRA, located along the northern edge of the area of maximum flash density. The thunderstorms near MOA developed rapidly after 0200 PDT and produced a peak flash rate of 867 fl/hr, including three positive flashes, between 0300 and 0400 PDT. These storms moved eastward and began to dissipate after 0400 PDT. During dissipation there were six positive flashes (0.8% of the total) generated between 0400 and 0500 PDT and eleven positive flashes (2% of the total) generated between 0500 and 0600 PDT. The large flash rate between 0200 and 0259 PDT (1122 flashes/hr) represents flashes from both thunderstorm systems.

In September there were two ALEs that produced considerable CG lightning with positive polarity. Between 1700 PDT, September 19 and 0500 PDT, September 21 there were 3114 flashes detected, of which 110 or 3.5% were positive. Then between 1400 PDT, September 28, and 0400, September 30, thunderstorm activity produced 823 flashes of which 97, or 11.8%, were positive. Figure 11 shows that most of these flashes were concentrated between 1600 and 0600 PDT.

During the 1994 warm season, a Mesoscale Convective System (MCS) began developing west of

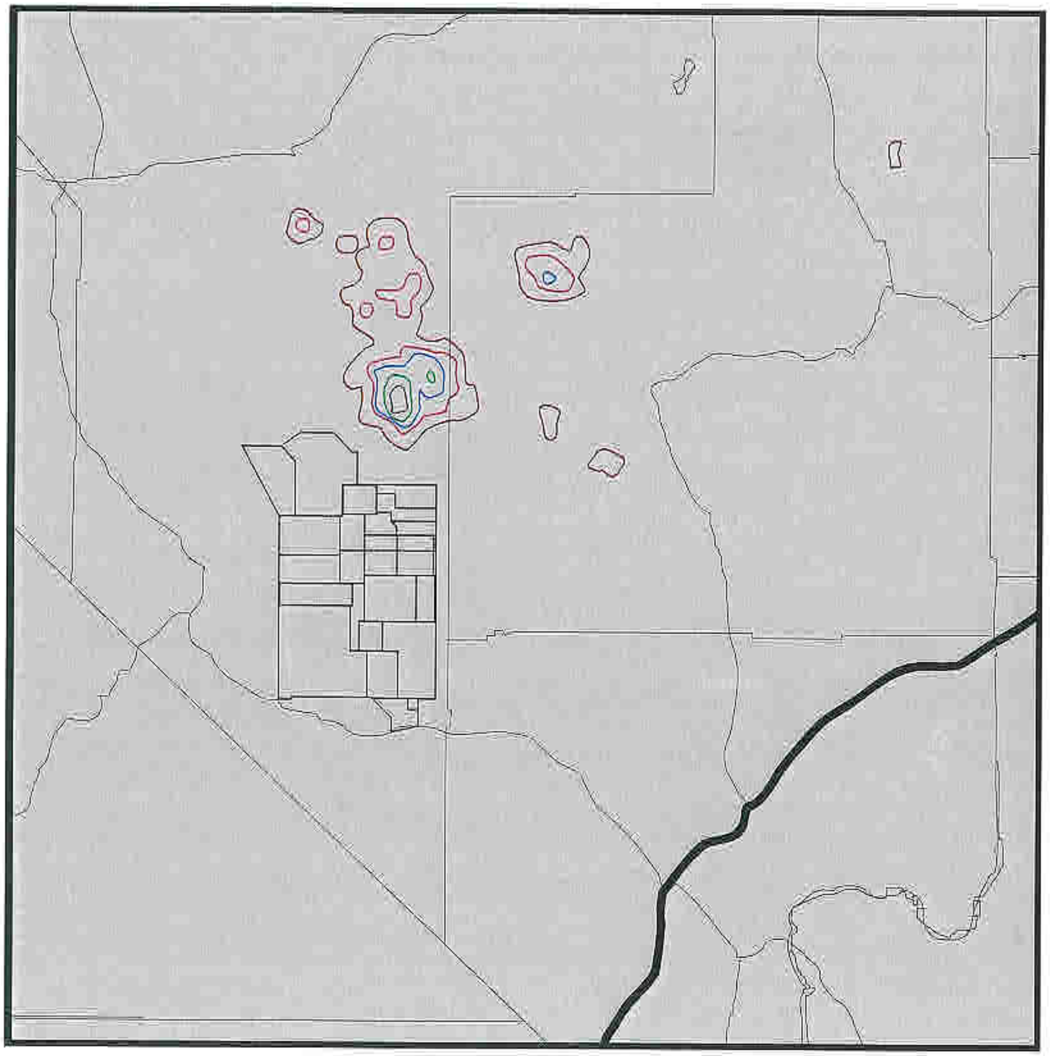

Figure 8. Flash density analysis for 1310 PDT, August 19, 1994, through 1800 PDT, August 19, 1994. Contour values are 1.0 fl/km^2 is in gold, 2.0 is in red, 4.0 in blue, 8.0 in green, and 10.0 in black. Total flash count is 19,183 flashes. Maximum flash density within the black contour is 59 fl/5 km^2. Total flash count is 1399 flashes.

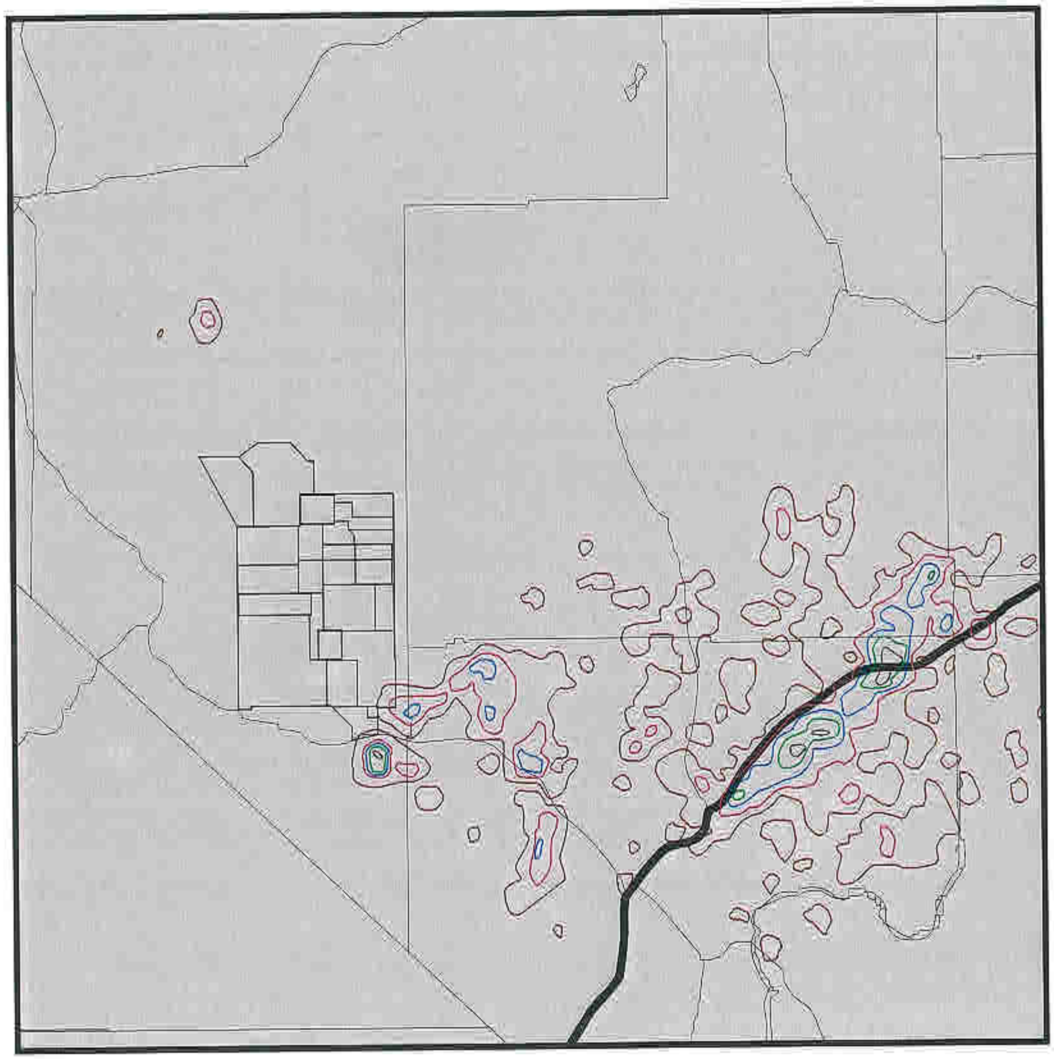

Figure 9. Flash density analysis for 0100 PDT, August 19, 1994, through 1230 PDT, August 19, 1994. Contour values are: 1.0 fl/km^2 is in gold, 2.0 is in red, 3.0 in blue, 4.0 in green, and 5.0 in black. Total flash count is 4540 flashes. Maximum flash density is 32 fl/5 km^2 within the black contour near the Nevada-Arizona border and 28 fl/5 km^2 south of the NTS.

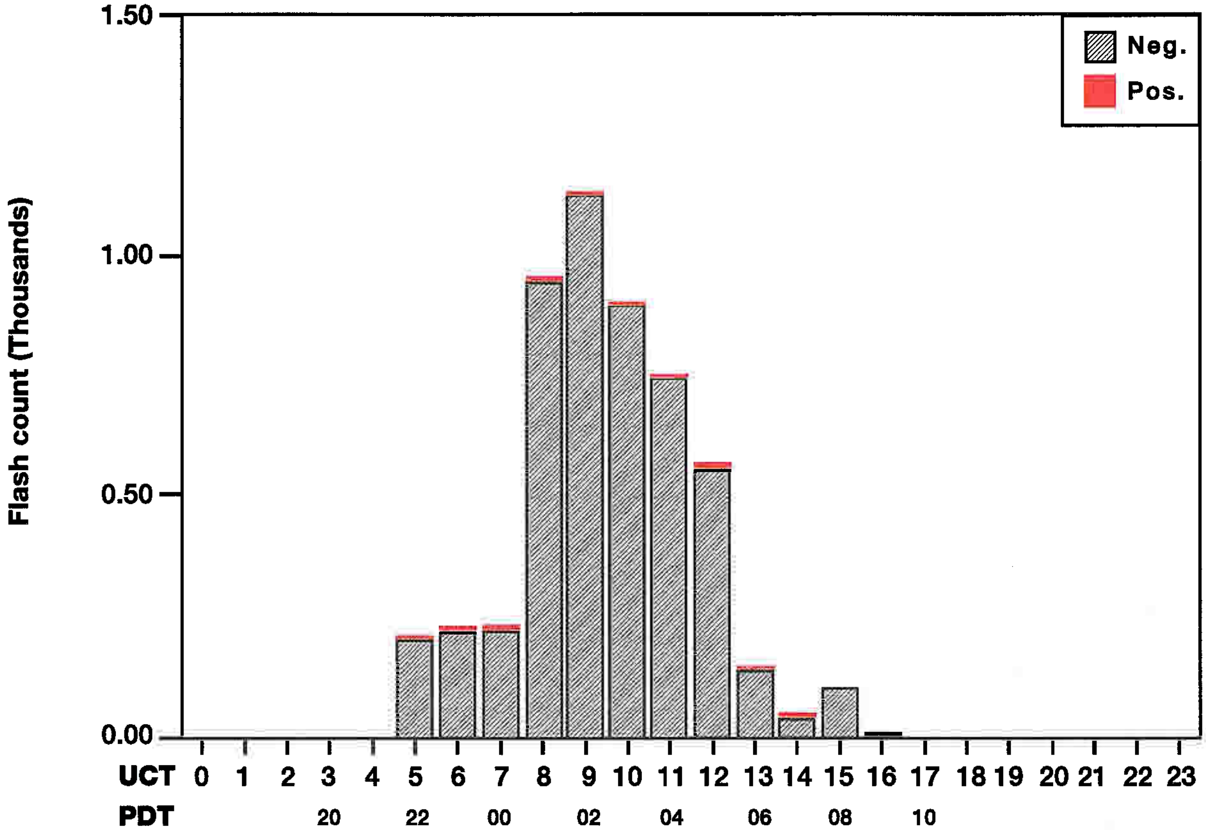

Figure 10. Hourly CG flash rates for the thunderstorms of August 19, 1994. For additional information, see Fig. 3.

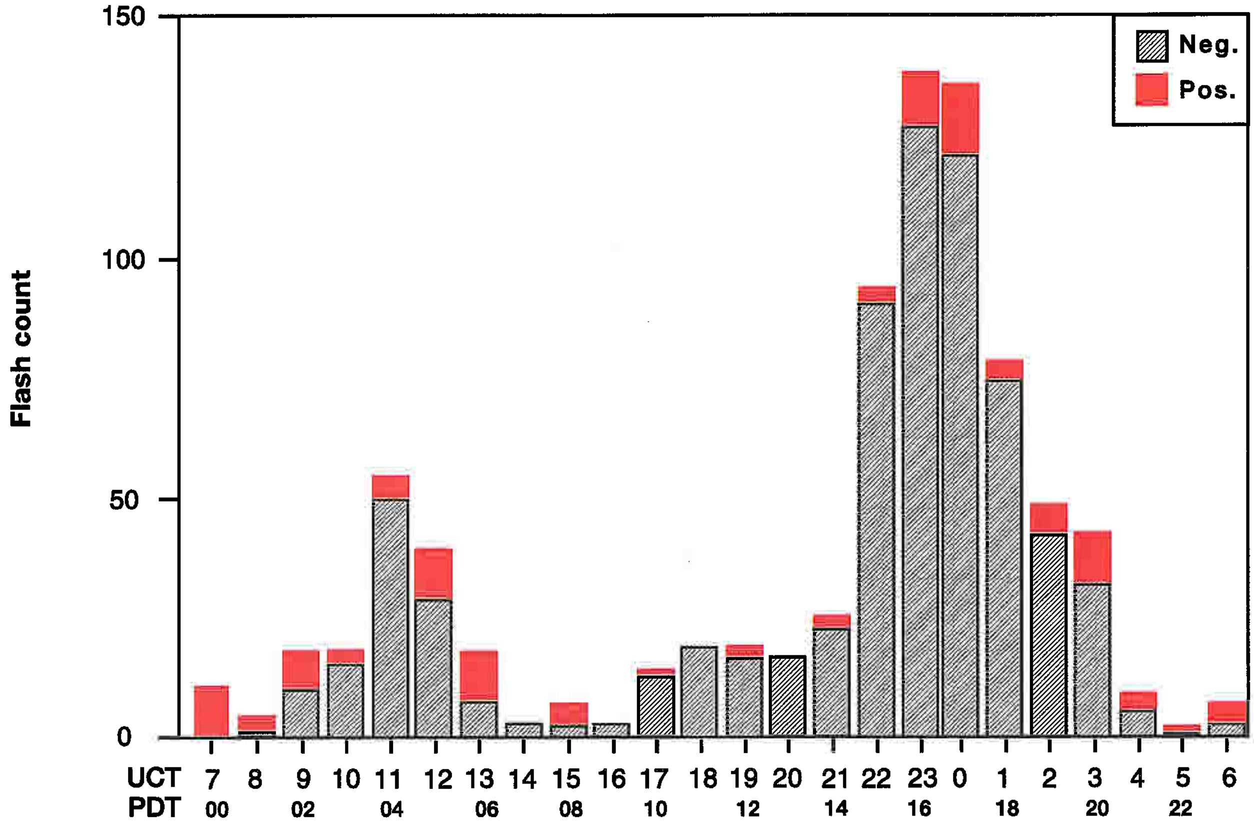

Figure 11. Hourly CG flash rates for the thunderstorms of September 28 through September 30, 1994. The total flash count is 823 flashes, of which 97, or 11.8 percent are positive. For additional information, see Fig. 3.

Milford, Utah, during the early afternoon of July 18. This storm moved southwestward into southern Nevada, developing considerable CG lightning along its track. A peak flash rate of 590 fl/hr was measured between 1700 and 1800 PDT. CG lightning appears to have been concentrated on the right flank of this storm as it moved southwestward across southern Nevada. No positive flashes were detected before 1700 PDT. Positive flashes were confined to 1800 to 2200 PDT during which the total hourly flash rate decreased from 409 fl/hr to 39 fl/hr as the storm slowly dissipated. Additional information on this storm has been provided by Randerson (1997).

June - September 1995

The 1995 GC lightning season produced a total of 27,354 flashes of which 26,775 were of negative polarity and 579 were positive. Figure 12 represents the 1995 flash density analysis for southern Nevada. This figure shows that during the1995 warm season most of the CG lightning was confined to the northern part of the figure. Furthermore, flash density deceased westward from the western boundary of the NTS. As in 1993 and 1994, the greatest seasonal flash density was in the Belted Range, located to the north of the NTS, where flash densities of 8.0 to 12.0 fl/km^2 were detected. It is important to note that these areas of large flash density are not in exactly the same location as in 1993 and 1994.

Over most of the NTS and in Las Vegas, flash densities were generally less than 1.0 fl/km^2. In the small farming communities of ALO and CAL the flash density was 2.0 fl/km^2. In Las Vegas the flash density ranged from 1.0 -2.0 fl/km^2 on the west side of the city to generally less than 1.0 fl/km^2 to the east.

The diurnal variation in the 1995 seasonal flash rate (Fig 13) is slightly different from those of 1993 and 1994. The secondary maximum that was so apparent in the previous two years between 2300 and 0300 PDT (Figs. 3 and 7), was not present in 1995 (Fig. 13). However, there was a minor elevation of the flash rate at 2100 PDT which is probably an artifact of the 1995 warm season CG lightning. As in 1993 and 1994, CG flashes with positive polarity tended to be concentrated into late afternoon and early evening (1400 to 2000 PDT). Few positive flashes were measured between local midnight and 1000 PDT.

An analysis of individual 1995 CG lightning patterns revealed three ALE events. These ALEs occurred on June 28-July 2, August 20-25, and September 2-7. Of these, the CG lightning activity during August 20-25 produced the greatest flash count with a total of 7478 flashes. The contour analysis for this episode is reproduced in Fig. 14. The area of largest flash density (8.8 fl/km^2) was located approximately 20 km southeast of Adaven, Nevada (ADV). Analysis of this lightning pattern and of other thunderstorms in the area indicates that most the CG lightning associated with this maximum was produced between 1100 PDT and 1400 PDT on August 23. There appear to have been three separate thunderstorms; however, the most active CG lightning period was between 1200 and 1259 PDT. Thunderstorm movement was toward the northeast at about 15 km/hr and only one positive flash was detected. Based on this information, it appears that the primary thunderstorm developed over or near the 2700-m peak located approximately 20 km south of ADV. The other

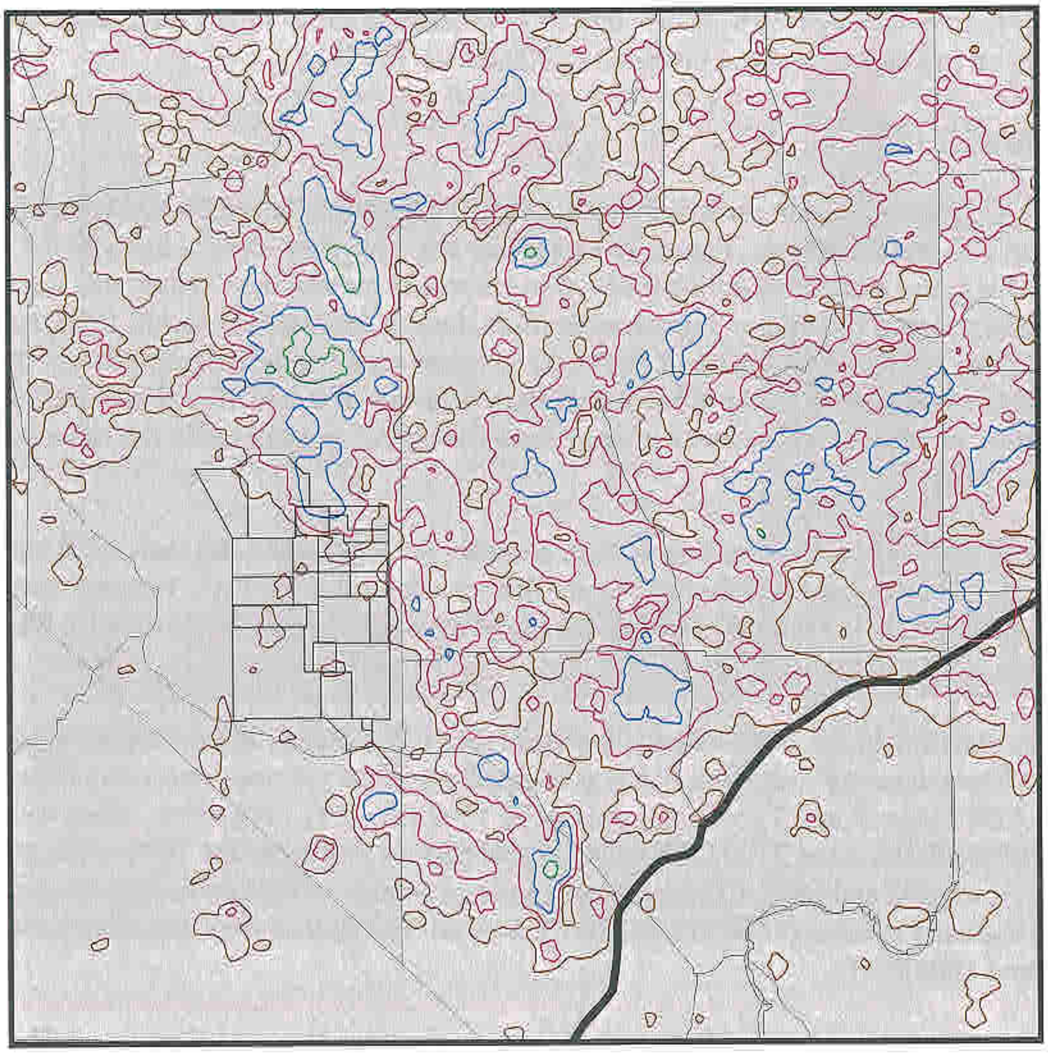

Figure 12. CG flash density field for June through September 1995. Contour values are: 1.0 fl/km^2 is in gold, 2.0 is in red, 4.0 in blue, 8.0 in green, and 12.0 in black. Total flash count is 27,354 flashes. Maximum flash density is 60 fl/5 km^2 within the black contour located north of the NTS.

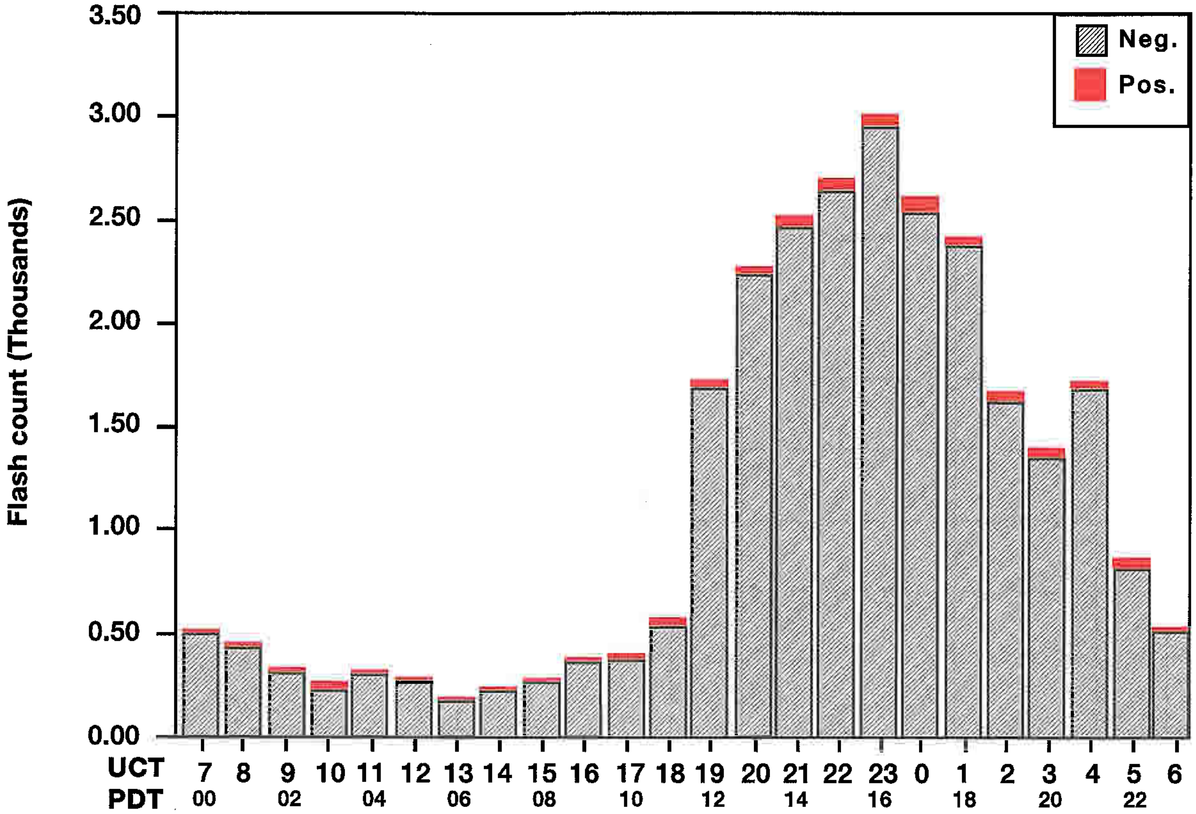

Figure 13. Diurnal distribution of CG lightning flashes for June through September 1995. See Fig.3 for additional information.

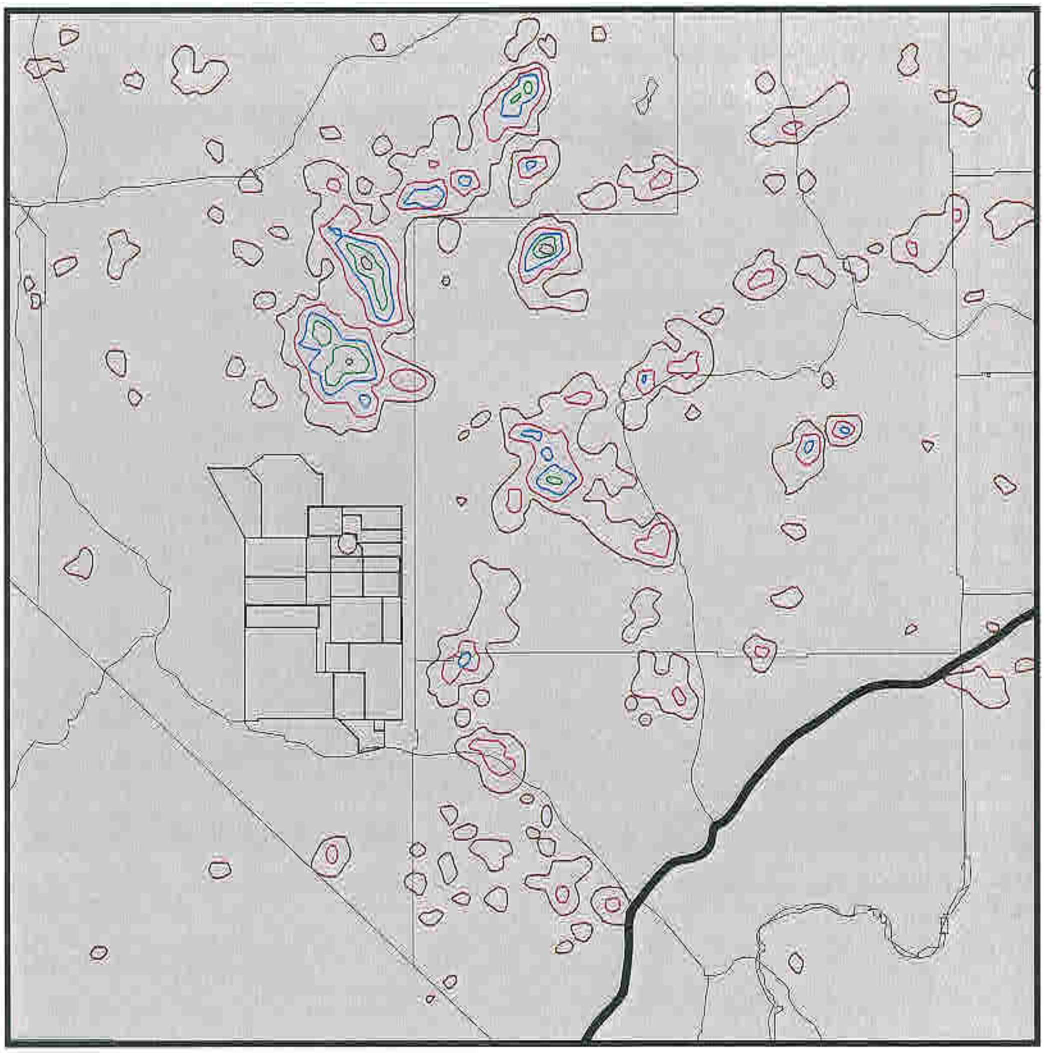

Figure 14. Flash density analysis for 1315 PDT, August 20, 1995, through 1943 PDT, August 25, 1995. Contour values are: 1.0 fl/km^2 is in gold, 2.0 is in red, 3.0 in blue, 4.0 in green, and 6.0 in black. Total flash count is 7478 flashes. Maximum flash density is 44 fl/5 km^2 within the black contour located approximately 80 km northeast of the NTS.

areas having noteworthy CG lightning flash densities (of 4.0 to 6.0 fl/km^2) were located north of the NTS over the Belted and Kawich Ranges and the Quinn Canyon Range, north of ADV.

Another ALE with large flash densities occurred between June 28 and July 2. This episode produced 9284 CG flashes, of which 6525 occurred on the 29th and 30th. The flash contour analysis for this episode is shown in Fig. 15. The peak flash density measured was 36 fl/5 km^2 (7.2 fl/km^2) located over the Kawich Range to the north of the NTS. Two other active areas can be seen to the northwest of LAS (6.0 fl/km^2 contour) and near the northern border of the NTS (6.0 fl/km^2 contour). A 4.0 fl/km^2 contour appears over the Sheep Range. During this activity, 192 positive flashes (2%) were randomly distributed throughout the contour pattern in Fig 15; however, there did appear to be a slight concentration of positive flashes with the thunderstorms over the Kawich Range and near the northern border of the NTS.

June - September 1996

Of the five warm seasons used in this study, 1996 contained the least number of CG flashes, 11,686, of which 274 were positive. Figure 16 shows that the seasonal flash activity was focused in the middle and southern part of the analysis area. The peak seasonal flash density measured was 62 fl/5 km^2 (12.4 fl/km^2) over the 2500-m terrain on the northern end of the Spring Mountain Range. The axis of the 4.0 fl/km^2 contour is oriented along the ridge crest of this mountain range. Peak seasonal flash densities of 4.0 to 8.0 fl/km^2 can also be seen in Fig. 16 over the Sheep Range.

The largest 1996 warm season flash densities in populated areas occurred in the mountain villages located in the Spring Mountains (LEE and KYL), 3.0 to 5.0 fl/km^2, respectively. On the NTS flash densities of 2.0 to 4.0 fl/km^2 were detected over the higher terrain in the central and northern parts of the NTS. In the Las Vegas valley seasonal flash densities were less than 1.0 fl/km^2.

The diurnal distribution of 1996 warm season CG lightning, shown in Fig. 17, is somewhat different from the previous years. The principle distinction is that the maximum flash rate occurs at 1300 PDT instead of at 1600 PDT. However, as in 1993 and 1994, there was an evening increase in CG lightning at 2100 PDT, several hours earlier than in 1993 and 1994. As in 1993, 1994, and 1995, CG flashes with positive polarity tended to be concentrated into late afternoon and early evening (1400 to 2200 PDT). Minimum positive flash activity occurred between 0100 and 1000 PDT.

There were only three active CG lightning periods in 1996, none of which satisfied the ALE criteria. The most active lightning event occurred during a 7.5-hr period commencing after 1700 PDT on September 9. The flash contour analysis for this episode is shown in Fig.18. The maximum storm flash density was 58 fl/5 km^2 (11.6 fl/km^2) which was also the maximum single storm flash density measured for the 1996 warm season. The thunderstorm developed in the vicinity of Mt. Irish (2664 m), located north-northwest of ALM, and moved southward along the high terrain west of ALM. The peak flash rate was 198 fl/hr between 1800 and 1859 PDT. Only one positive flash was measured near this storm.

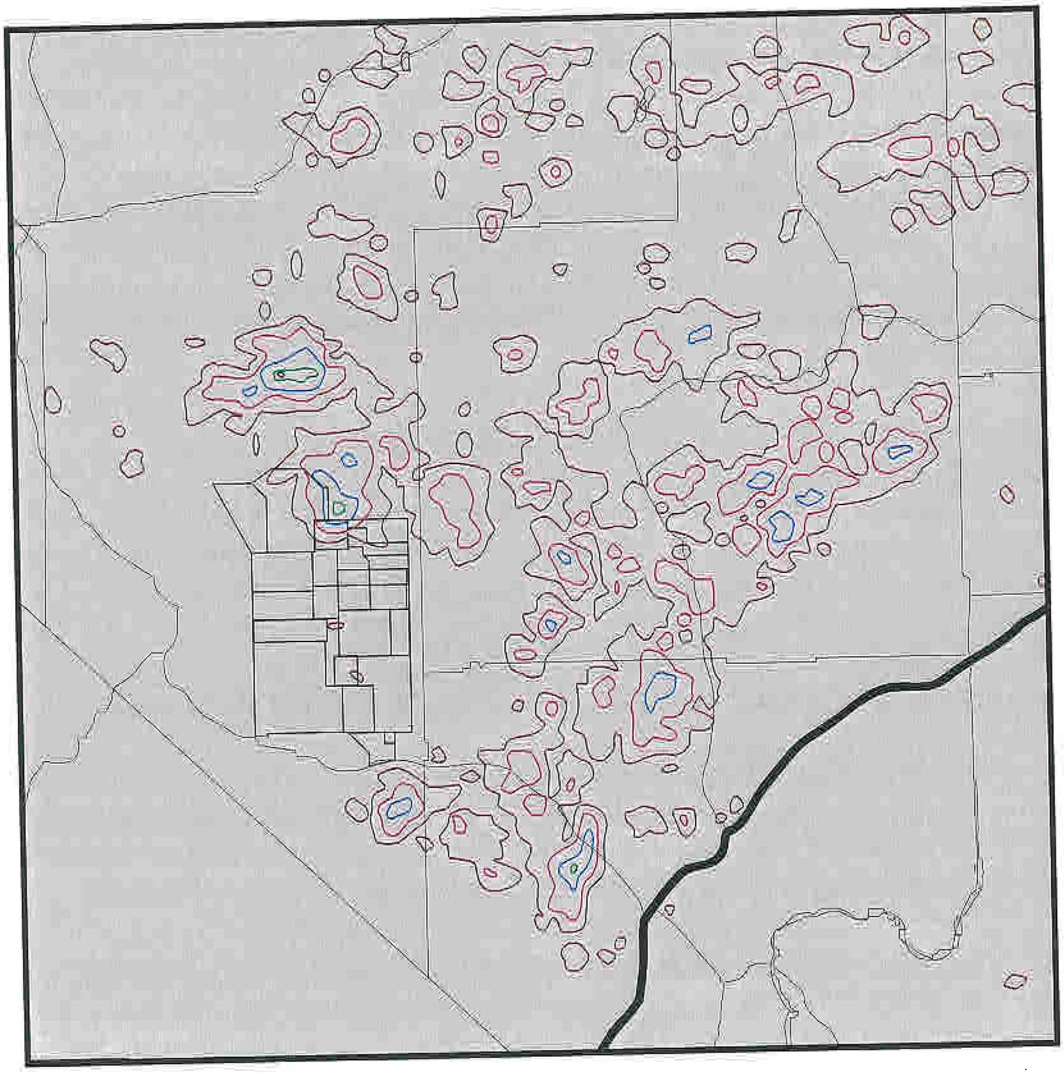

Figure 15. Flash density analysis for 1701 PDT, June 28, 1995, through 1631 PDT, July 2, 1995. Contour values are: 1.0 fl/km^2 is in gold, 2.0 is in red, 4.0 in blue, 6.0 in green, and 7.0 in black. Total flash count is 9284 flashes. Maximum flash density is 36 fl/5 km^2 located approximately 50 north of the NTS and over the Kawich Range.

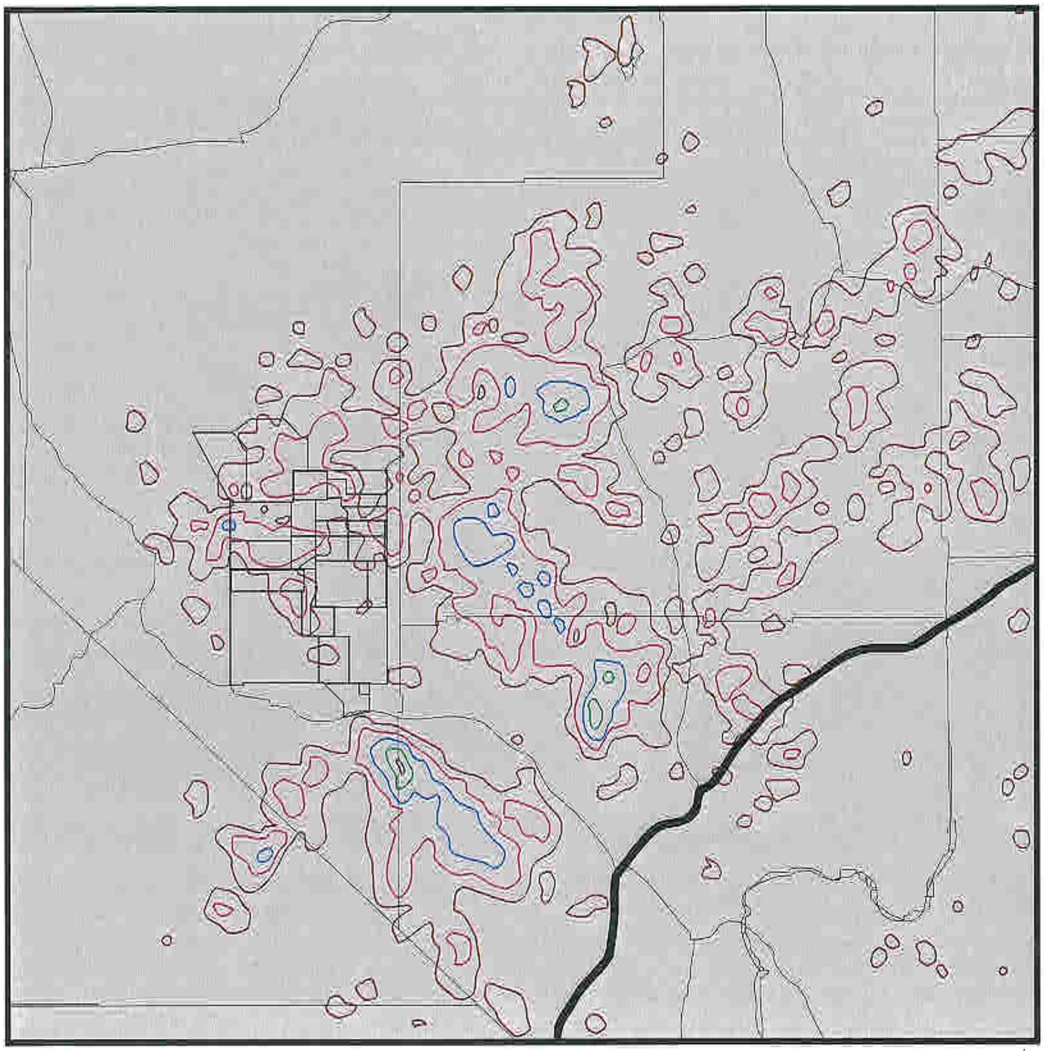

Figure 16. CG flash density analysis for June through September 1996. Contour values are: 1.0 fl/km^2 is in gold, 2.0 is in red, 4.0 in blue, 8.0 in green, and 12.0 in black. Total flash count is 11,686 flashes. Maximum seasonal flash density is 62fl/5 km^2 located over the Spring Mountain Range situated south of the NTS.

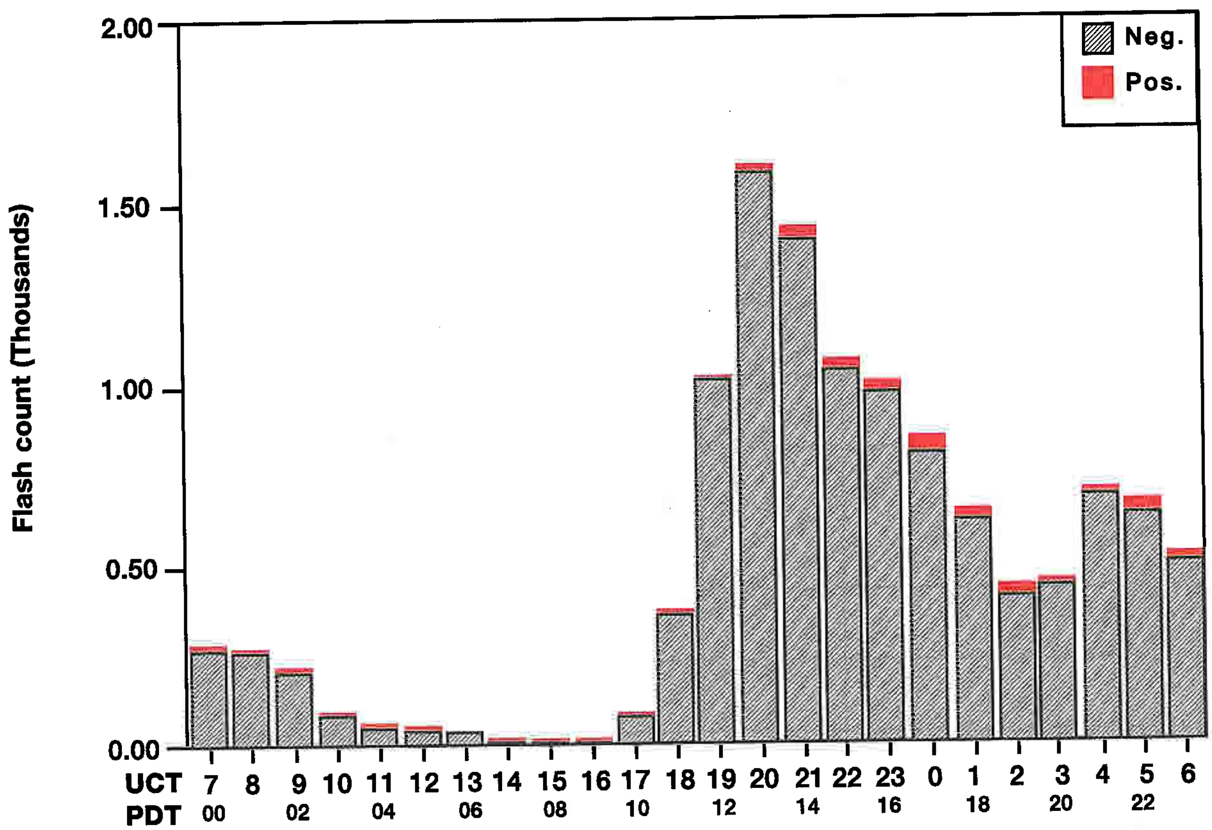

Figure 17. Diurnal distribution of CG lightning flashes for June through September 1996. See Fig.3 for additional information.

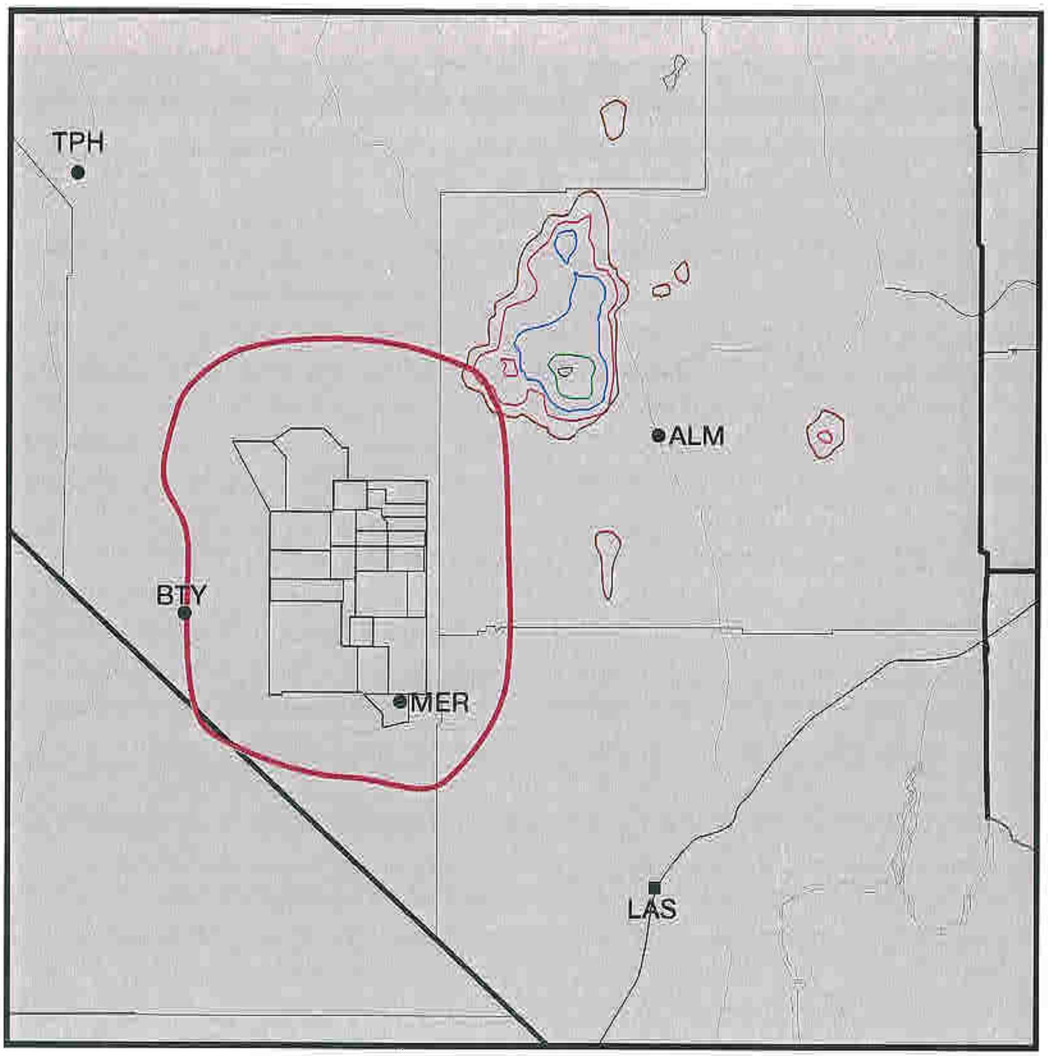

Figure 18. Flash density analysis for 1700 PDT, September 9, 1996, through 0030 PDT, September 10, 1996. Contour values are: 1.0 fl/km^2 is in gold, 2.0 is in red, 4.0 in blue, 8.0 in green, and 11.0 in black. Total flash count is 783 flashes. Maximum flash density is 58 fl/5 km^2 located within the black contour. The heavy red line encircling the NTS is the NTS lightning alert zone.

June - September 1997

The second most active CG lightning season was 1997 when a total of 34,938 flashes were detected within the analysis area. Moreover, Table 1 illustrates that the 1997 warm season contained many more positive flashes (1098) than in any of the previous four seasons.

Figure 19 describes the 1997 warm season flash density for the analysis area. The area of maximum flash density was located just south of MER, over the northern edge of the Spring Mountains. A peak seasonal flash density of 87 fl/5 km^2 or 17.4 fl/km^2 was measured within the 12.0 fl/km^2 contour analyzed over this area. This flash density was the largest found in the data base used in this study and is very close to the area of maximum flash density for 1996 (Fig. 16). In Fig. 19, there are large areas in which the flash density was 4.0 fl/km^2 or more. The largest of these is over the Spring Mountain Range. As in 1993 and 1994, CG flashes with positive polarity tended to be concentrated into late afternoon and early evening (1400 to 2000 PDT).

The largest seasonal flash densities in populated areas occurred in the mountain villages located in the Spring Mountains (LEE and KYL), 4.0 to 5.0 fl/km^2, respectively. Seasonal flash densities in the vicinity of CAL, ALM, and MOA were in the 1.0 to 2.0 fl/km^2 range. In the Las Vegas valley flash densities ranged from 1.0 to 2.0 fl/km^2. On the NTS, seasonal flash densities ranged from approximately 1.0 fl/km^2 near Yucca Mountain, to near 2.0 fl/km^2 in the dry lake beds and valleys to 3.0 fl/km^2 at MER, to 4.0 fl/km^2 over the higher terrain.

There were three ALEs in 1997. The most dramatic of these was the one that occurred between September 1 and 9. During this episode the most active thunderstorm period was from 0500 PDT September 2 to 0200 PDT September 4, when a total of 11,393 flashes were detected. Of these flashes, 544 or 4.8% were positive. Figure 20 portrays the flash density for this ALE. The area of maximum flash density was detected over the Spring Mountains, just south of MER, and is represented by the 8.0 fl/km^2 contour. Within this area the maximum flash density was 47 fl/5 km^2 or 9.4 fl/km^2. Another area of large flash density was detected over the Pintwater Mountain Range located north of IND. Peak flash densities of 4.0 fl/km^2 occurred over this Range. The thunderstorms that generated this ALE developed in very moist tropical air that had moved into the desert southwest in early September. The storms moved northeastward. During this active lightning period, many of the positive flashes occurred between 1700 PDT and 2300 PDT with the peak positive flash rate (77 fl/hr) at 2100 PDT.

Even though the 1997 warm season contained much thunderstorm activity, the peak, single storm flash densities were relatively small. During several active thunderstorm days the peak flash density was only 4.0 to 5.0 fl/km^2.

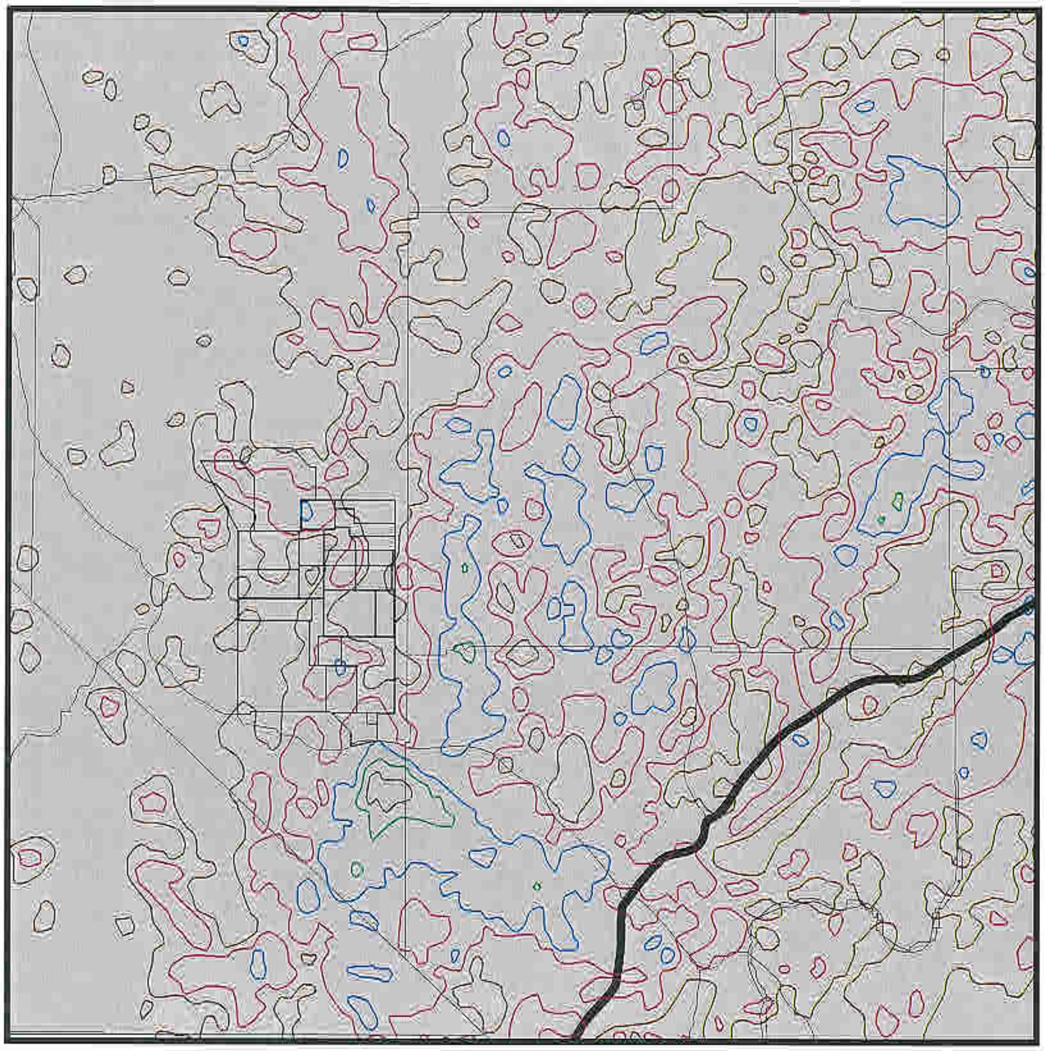

Figure 19. CG flash density analysis for June through September 1997. Contour values are: 1.0 fl/km^2 is in gold, 2.0 is in red, 4.0 in blue, 8.0 in green, and 12.0 in black. Total flash count is 34,938 flashes. Maximum seasonal flash density is 87 fl/5 km^2 is situated over the Spring Mountain Range located southeast of MER (see Fig 1).

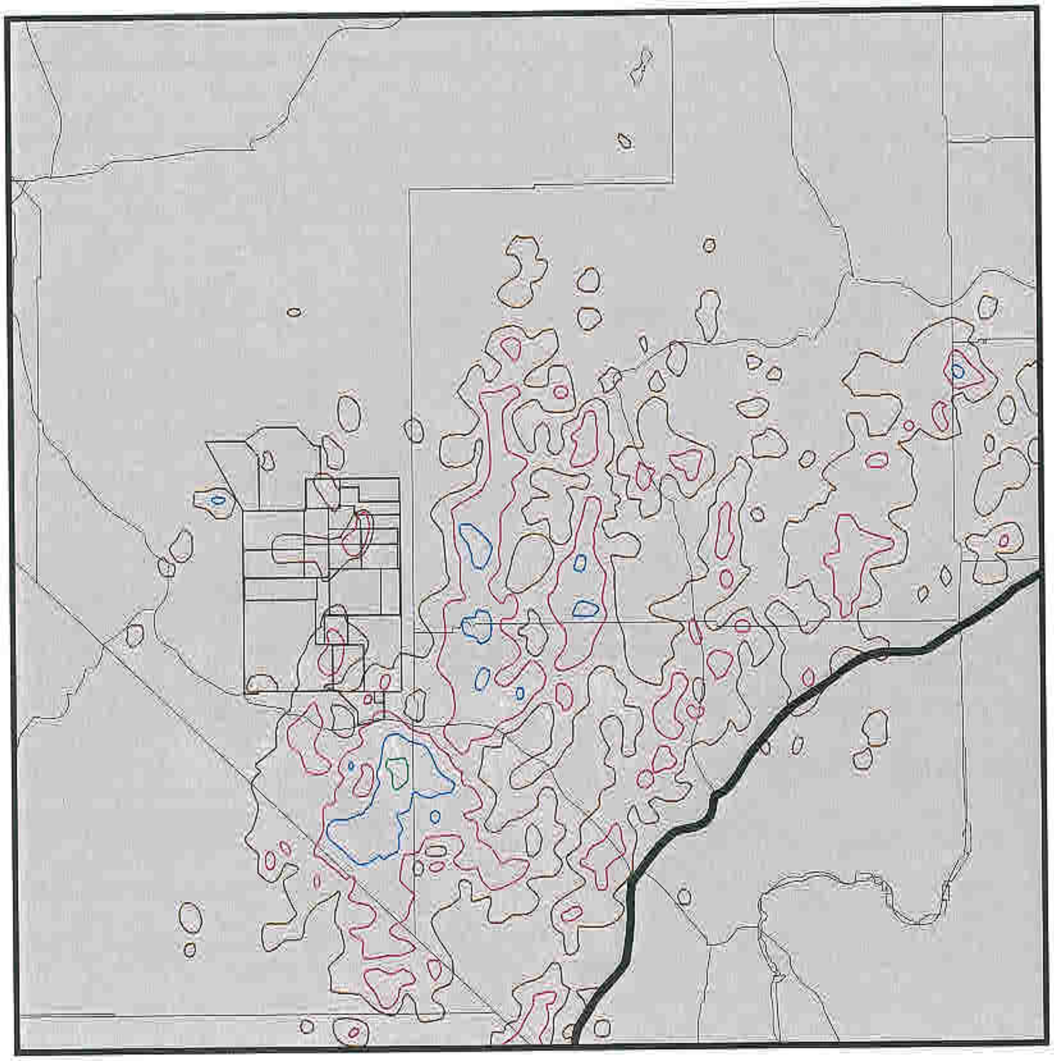

Figure 20. Flash density analysis for 0500 PDT, September 2, 1997, through 0201 PDT, September 4, 1997. Contour values are: 1.0 fl/km^2 is in gold, 2.0 is in red, 4.0 in blue, and 8.0 in green. Total flash count is 11,393 flashes. Maximum flash density is 47 fl/5 km^2 within the 8.0 fl/km^2 contour over the Spring Mountains located south of MER (see Fig. 1).

V. Five-Year Summary (1993-1997)

Southern Nevada Analysis

For the 5-year warm-season data record, the CG flash data were summarized according to 5 km^2 areas. This summary is shown in Fig. 21. Contours in this figure were configured to yield annual flash densities in units/km^2. For example, if the five-year total flash count in a 5 km^2 area is 75 flashes, then the contour passing through the center of this box would have an average seasonal value of 3.0 fl/km^2 (or 75fl/5 km^2/5 seasons = 3.0 fl/km^2/season). Contour values in Fig. 21 range from 1.0 to 6.0 fl/km^2.

Figure 21 shows that the average seasonal flash densities are greatest over high terrain (above 2100 m). Flash densities of 4.0 to nearly 7.0 fl/km^2 were measured in the vicinity of the large mountain ranges (Fig. 1). The maximum average seasonal flash density, 7.3 fl/km^2, occurred over the northern end of the Spring Mountain Range with 6.3 fl/km^2 over the Belted Range located north of the NTS. Flash densities of 4.0 to 6.0 fl/km^2 were generated by the Sheep Range and extend northeastward across lower terrain. Average seasonal flash densities of 2.0 fl/km^2 or more occurred over terrain above 5000 ft MSL (1524 m). Flash densities of 3.0 fl/km^2 or more are comparable to those reported by Orville and Silver (1997) east of the Continental Divide. Small seasonal flash densities (less than 1.0 fl/km^2) were measured over lower terrain (below 1500 m), over valleys, and west of a north-south line passing through the western north-south boundary of the NTS.

Comparing Figs. 2, 6, 12, 16, and 19, and especially Figs. 6 and 16, it becomes obvious that there is great variability in CG lightning activity from one warm season to the next. This observation is consistent with one of the primary characteristics of desert thunderstorms - great interannual variability. **Therefore, a 5-yr data base probably does not include enough realizations to form a robust or representative climatological data base for CG lightning over southern Nevada. As a result, the summaries in Figs. 21 and 22 may be more meteorological than climatological. However, some clear climatological patterns are resolved in these two figures. These climatological signals identify the modulating influence of terrain, the affect of surface heating, moisture availability, and the marked decrease in flash density to the west of the NTS.**

Flash Rates

Figure 22 graphically describes the diurnal flash rate for the 5-yr warm season period of record and area of analysis. The late afternoon peak at1600 to 1659 PDT is clearly evident as is the minimum near sunrise. The figure contains 126,636 negative flashes and 2892 positive flashes. Positive flashes have occurred at all hours; however, more positive flashes occur between 1600 PDT and 2300 PDT than at other times.

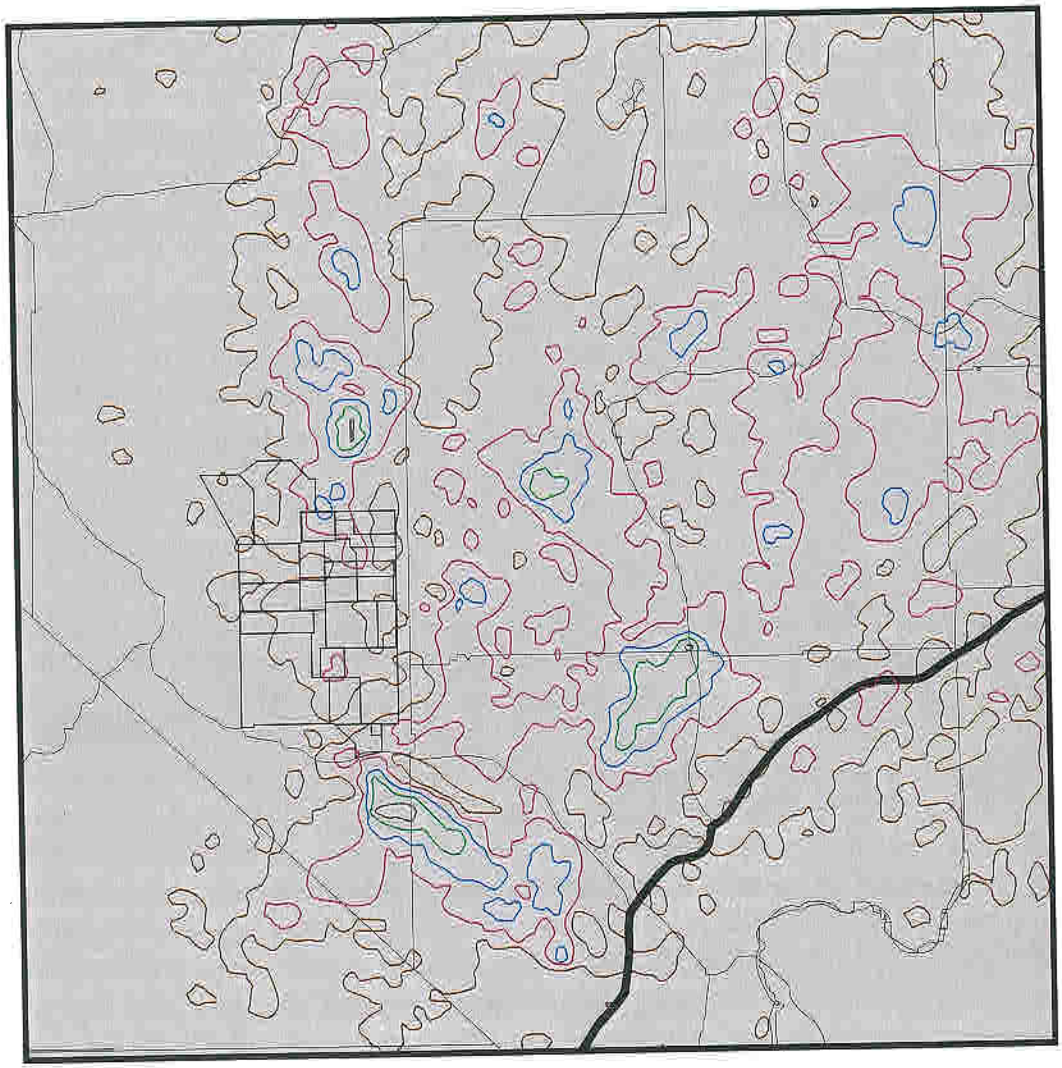

Figure 21. Southern Nevada warm season, total CG flash density analysis for June through September, 1993 through 1997. Contour values are: 1.0 fl/km^2 is in gold, 2.0 is in red, 3.0 in blue, 4.0 in green, and 6.0 fl/km^2 in black. Total flash count is 129,528 flashes of which 2.2% are positive flashes. The maximum total flash density is 183 fl/5 km^2 for a seasonal average of 7.3 fl/km^2 over the Spring Mountain Range located south of MER (see Fig 1).

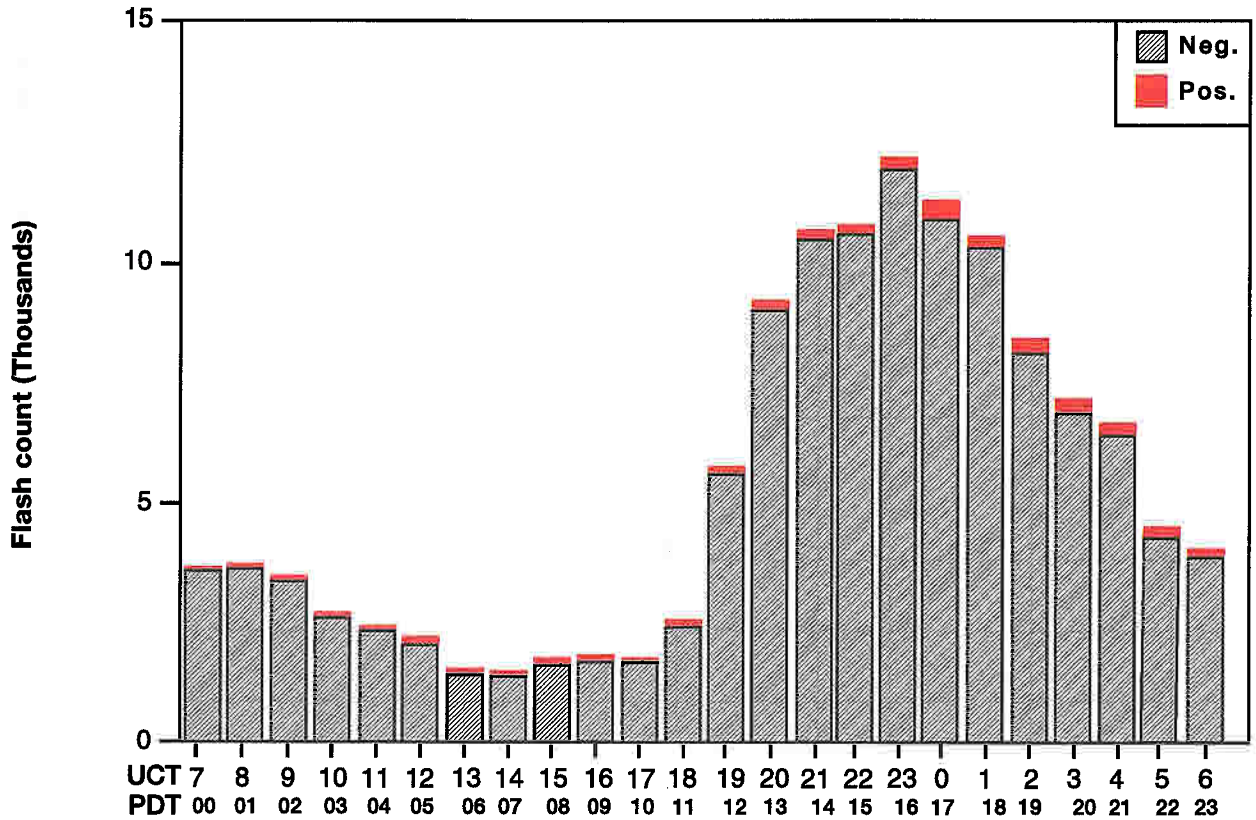

Figure 22. Diurnal distribution of CG lightning flashes for June through September, 1993 through 1997. See Fig.3 for additional information.

High-Terrain Analysis

Diurnal Variation - To capture the influence of terrain on the temporal variation of CG lightning, a sub-grid of Fig. 21 was created to include mostly the Spring and Sheep Mountain Ranges. This diurnal analysis is presented in Fig. 23. The data plotted in this figure is quite different from that in Fig. 22. Figure 23 indicates that convective activity reaches a peak at 1300-1359 PDT, three hours earlier than that for the larger area. Moreover, there is much more CG lightning activity late in the day and after sunset (2000 PDT) with peaks in activity at 2000 PDT and 0100 PDT. Most of the positive flashes occurred between 1100 and 2300 PDT with few between 2300 and 0700 PDT.

Spatial Variation - The sub-grid spatial analysis of the average seasonal flash density is presented in Fig. 24 and duplicates that shown in the corresponding area in Fig. 21, but with more detail. Key topographic features are identified in Fig. 25. A comparison of Figs. 24 and 25 shows that the axis of maximum seasonal flash density is oriented northwest-southeast, along or slightly east of the ridge crest of the Spring Mountain Range. The maximum average seasonal flash density of 182 fl/25 km^2 (7.3 fl/km^2) for the five-year period was measured inside the 175 fl/5km^2 contour located just south of the NTS and over the northern terminus of the Spring Mountains. One perplexing facet is that the maximum flash density is not closely tied to the highest peaks and terrain above 3000 m. The reason for this inconsistency is not obvious; however, it is probably related to the short data record and to domination of the data base by the large ALE event of September 1-5, 1997, when over 3800 CG lightning flashes occurred in the vicinity of the Spring Mountains, and especially in the area of this maximum flash density.

Another area of large flash density corresponds nicely with the Sheep Range located north of LAS. The peak seasonal flash density in this area is 5.0 fl/km^2. Notice that the flash density contours are oriented along the axis of highest terrain. Moreover, it appears that as thunderstorms develop over the highest terrain, they move northeastward, and achieve their maximum flash rates just northeast of the highest peaks.

Annual warm season flash densities for population centers located within Fig. 24 are listed in Table 2. To provide a flash density over more of the populated area; the tabulated values are per 5 km^2. Warm season flash densities for LAS range from 0.8 to 1.5 fl/5 km^2 for a seasonal average of 1.1 fl/5 km^2. As expected, larger flash densities occur at sites located at higher elevations (LEE and KYL) where small communities exist. Warm season flash densities at these two sites range from 1.0 to 5.2 fl/5 km^2. The large flash densities, in 1997, are dominated by the significant thunderstorm episode that occurred in early September 1997. Table 2 and Figure 24 indicate that the greatest threat to life and property is to residents of mountain communities, to hikers and mountain climbers who enter the Spring Mountains during thunderstorm season, and from fires that could be initiated by CG lighting in the forests and vegetated areas in and surrounding the mountains.

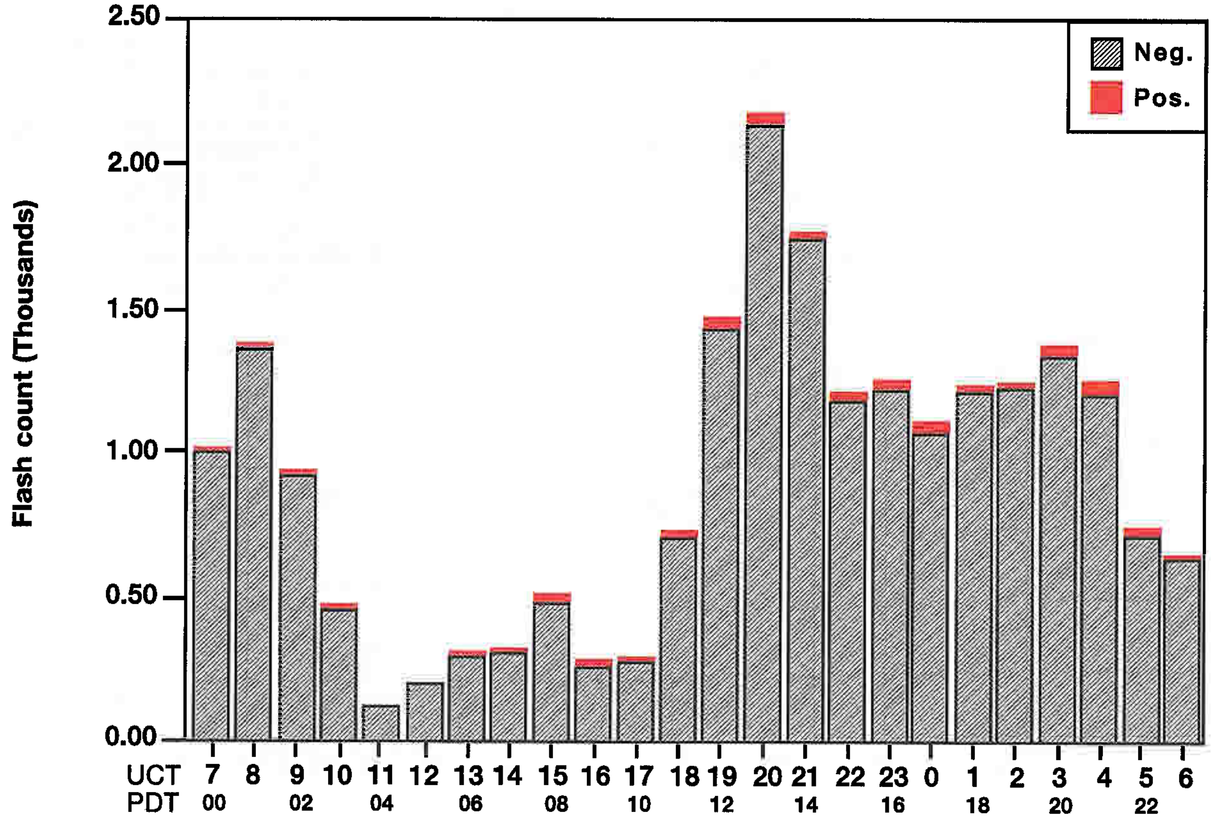

Figure 23. Diurnal distribution of CG lightning flashes for June through September, 1993 through 1997, for the mountainous sub-grid area defined in Fig. 24. See Fig. 3 for additional information.

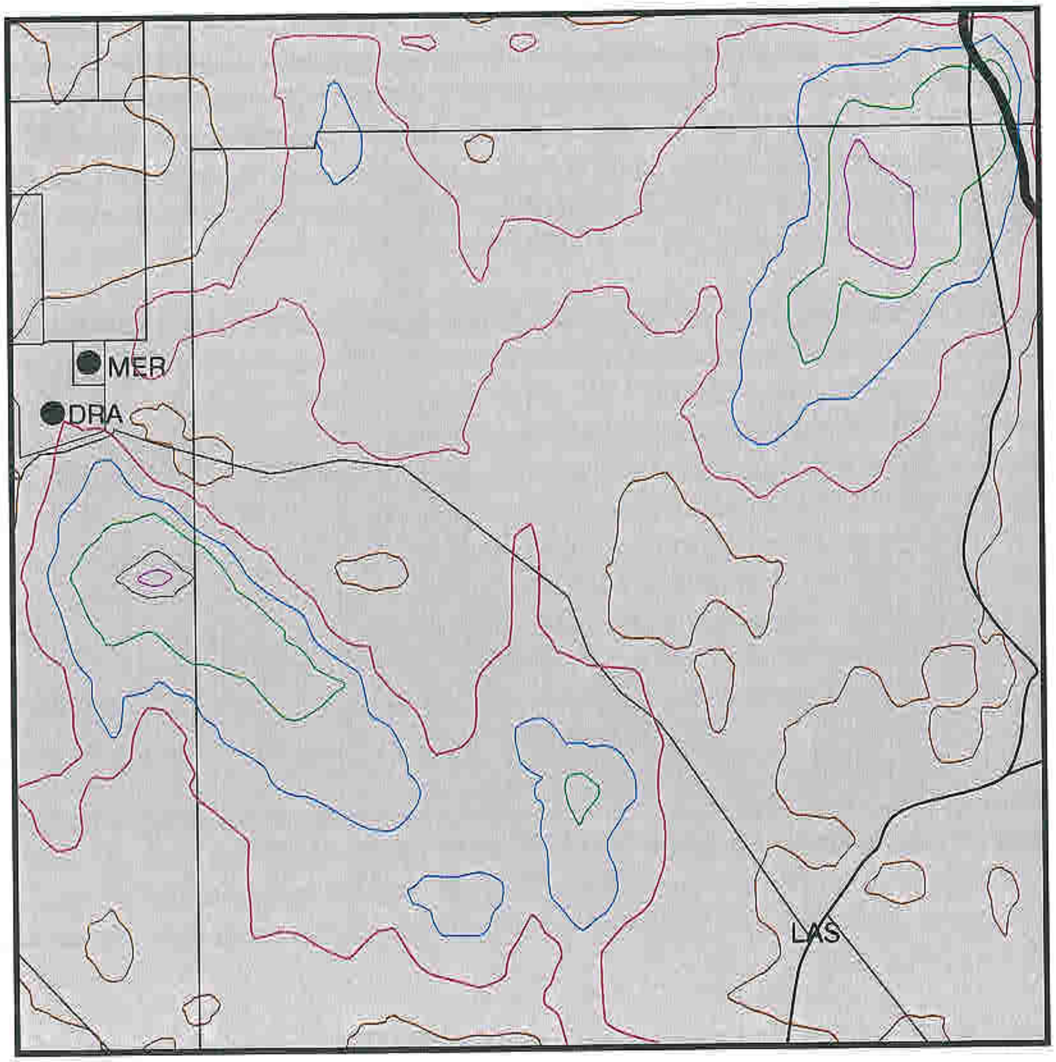

Figure 24. Average seasonal flash density in the vicinity of the Spring Mountain Range and the Sheep Range for June through September, 1993 through 1997. Contour values are: 1.0 fl/km^2 is in gold, 2.0 is in red, 3.0 in blue, 4.0 in green, and 6.0 in black, and 7.0 fl/km^2 in purple. Total flash count is 21,759 flashes. Key points of interest are identified in Fig. 25.

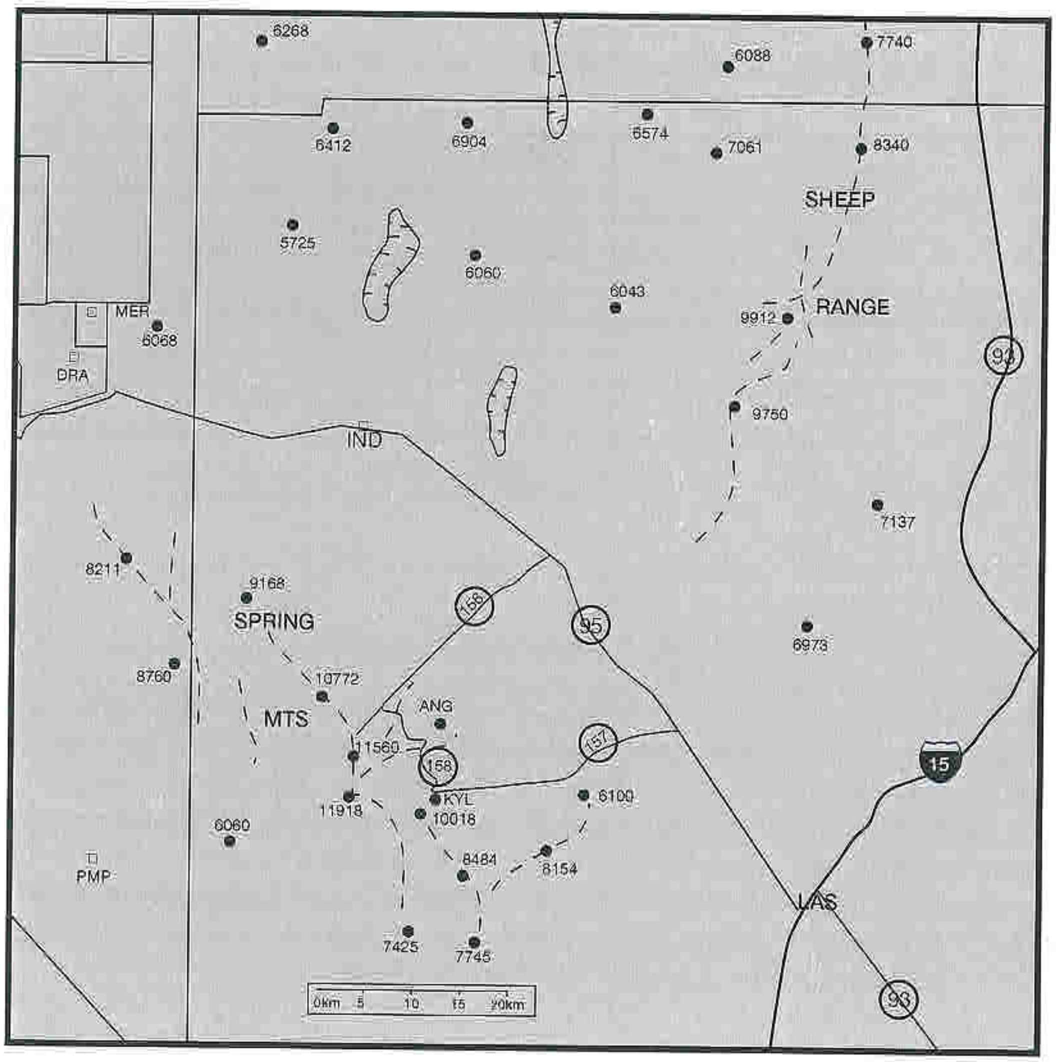

Figure 25. Reference map of key points of interest in Fig. 24. Elevations are in feet above mean sea level. Dashed lines represent ridge crests. See Fig. 1 for station identifiers. ANG is Angles Peak (8500 ft) and KYL is the Kyle Canyon village.

Table 2. Annual warm season flash densities (fl/5 km^2) for populated areas within Fig. 22.

LOCATION	1993	1994	1995	1996	1997	MEAN
			YEAR			
LAS	0.9	1.1	1.0	0.8	1.5	1.06
MER	2.6	1.9	1.0	0.8	3.0	1.86
PMP	0.8	0.9	0.8	0.9	3.8	1.44
KYL	1.0	2.2	2.0	3.5	4.6	2.46
LEE	1.3	3.4	2.4	5.0	5.2	3.46
IND	1.9	1.1	2.4	0.7	4.0	2.02

VI. NEVADA TEST SITE ANALYSIS

Protection of personnel and valuable equipment on the NTS from lightning is important from both a safety and economic perspective. Therefore, a detailed analysis of the warm season CG lightning flash density for the NTS was developed. Figure 26 represents this flash density pattern for the NTS. The maximum seasonal flash density (2.0 fl/km^2) is found over the extreme northern part of Yucca Flat. This active area is the result of thunderstorms that develop over the high terrain to the west and move northeastward over the valley. The maximum center over the southern part of the NTS is difficult to explain and is probably related to the short data base.

Another zone of elevated CG flashes extends southwest-northeast across MER and DRA, curving northward just east of the NTS. This activity appears to be aligned along a small mountain range called the Spotted Range. Small flash densities of 1.0 fl/km^2 , or less, appear over the dry lake beds of Yucca Flat, Frenchman Flat, and in the southwest corner of the NTS.

The diurnal pattern for the NTS, shown in Fig 27, contains the thermally driven peak at 1400-1459 PDT. There is also a secondary maximum at 1900-1959 PDT. The data also point to a enhancement in positive flashes between 1800-2300 PDT. This evening lightning activity is probably associated with thunderstorm development over the Spring Mountain Range that moves over the NTS. It may be driven by cold outflows and low-level mass convergence that releases convective energy over and near the NTS as the thunderstorms move away from the Spring Mountains.

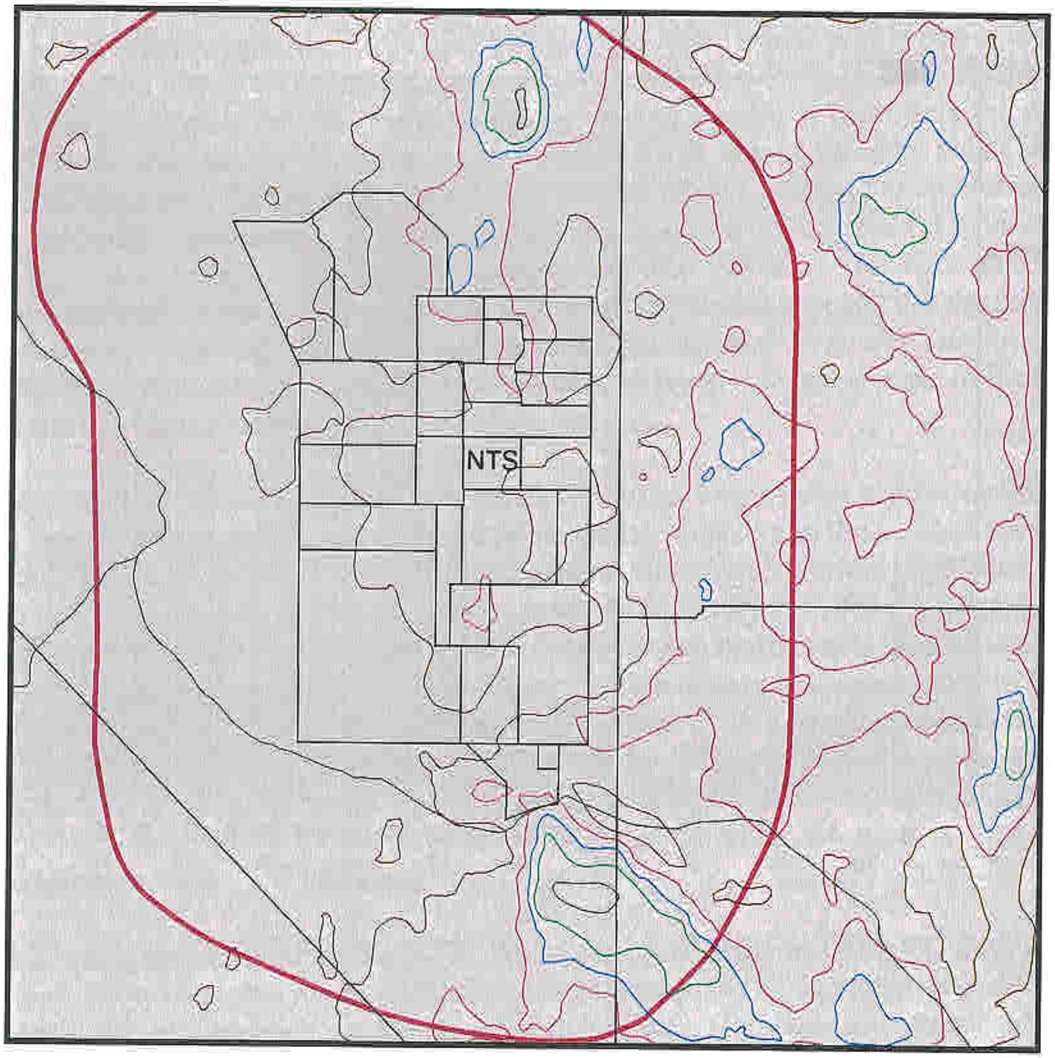

Figure 26. Average warm season flash density analysis for the Nevada Test Site, June through September, 1993 through 1997. Contour values are: 1.0 fl/km^2 is in gold, 2.0 is in red, 3.0 in blue, 4.0 in green, and 6.0 fl/km^2 in black. Total flash count is 33910 flashes of which 819 are positive flashes. The heavy red line encircling the NTS is the NTS lightning alert zone.

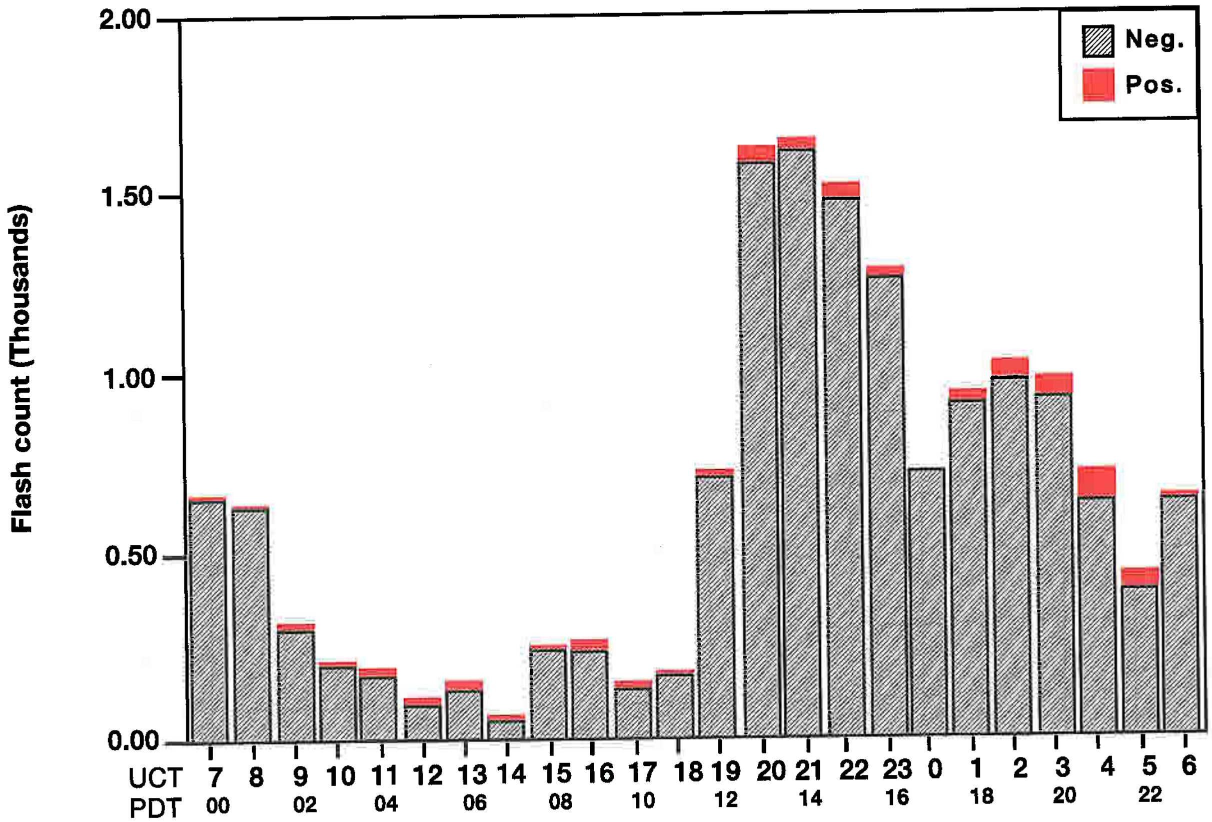

Figure 27. Diurnal distribution of warm season CG lightning flashes for the Nevada Test Site (NTS) for June through September, 1993 through 1997. See Fig. 3 for additional information.

VII. LAS VEGAS VALLEY ANALYSIS

The largest metropolitan area in southern Nevada is made up of Las Vegas, North Las Vegas, and Henderson and is referred to as the Las Vegas Valley. This metropolitan area is one of the fastest growing areas in the United States. During the 12-yr period from 1985 to 1997 the population doubled from approximately 600,000 residents to over one million and it is projected to reach 2.6 million by 2020 (McKinnon, 1998). This rapid growth is being accompanied by the concomitant problems associated with factors that relate to the quality of life; namely, air pollution, water resources, and traffic. In addition, as the population increases, the impact of local thunderstorms, flash flooding, wind damage, and lightning hazards will also increase. Tourism adds another noteworthy dimension to this problem. Annually, millions of families visit and use the recreational facilities of southern Nevada, including the Lake Mead Recreational Area and Toiyabe National Forest in the Spring Mountain Range. For these reasons, an initial estimate is made of the CG flash density for the Las Vegas Valley.

A high resolution flash density analysis was prepared for the Las Vegas valley and surrounding areas. A detailed analysis (for 1.0 km^2 areas) showed great spatial variability in the average annual warm season flash density for the five-year data base. In general, the analysis showed that within 10 km of downtown Las Vegas the average annual warm season flash density varied from 0.2 to 0.8 fl/km^2. Warm season flash densities per 5 km^2 are listed in Table 2. The analysis also showed that 15 to 20 km west of downtown Las Vegas (or Casino Center) the flash density increases rapidly to 1.0 to 2.0 $fl/\ km^2$. This increase is terrain driven. There also appears to be a northeast-southwest axis of enhanced flash density across Henderson, Nevada, located southwest of downtown Las Vegas. This activity appears to be driven by the McCullough Range of mountains located south of Las Vegas.

VIII. Precipitation Versus CG Lightning

There are 17 raingages located on the NTS. An attempt was made to relate CG flash density to precipitation. However, not all precipitation events generate CG lightning and many desert thunderstorms do not produce measurable precipitation. Consequently, there were heavy precipitation events (e.g. June 13-14, 1997) that produced precipitation totals of 25 mm or more on the NTS, and generated no CG lightning and there were significant CG lightning events that produced little precipitation. Consequently, this avenue of research was not pursued further. However, during this analysis the potential of relating flash rate and/or flash density to peak surface wind gusts from thunderstorm outflow appeared to have possibilities for future research.

IX. Conclusions

This analysis was undertaken to provide new information on CG lightning in southern Nevada and to create a preliminary climatology of CG lightning in this mountainous desert environment. Information presented here has documented the spatial and temporal distributions and flash densities of CG lightning in southern Nevada. These, and future, data will increase our knowledge of desert thunderstorm and lightning activity; thereby contributing useful information that should aid in reducing vulnerabilities to CG lightning, to improving the quality and timeliness of weather forecasts, and to reducing costs due to thunderstorm and CG lightning damage.

The following conclusions are drawn from this study:

1. There is a large inter-annual variation in warm season CG lightning over southern Nevada. For the five years summarized in this study the total measured flash counts ranged from 11,693 flashes in 1996 to 36, 441 flashes in 1994.

2. The annual average percentage of flashes depositing positive charge to the ground is 2.2%, slightly less than that reported by Orville (1994) for the contiguous United States for 1989-1991. However, in 1997, 3.1% of the warm season flashes were positive.

3. Maximum flash densities occurred over high terrain (above 1500 m); but not necessarily over the highest terrain. Minimum flash densities tend to occur over desert valleys and over terrain below 1500 m above mean sea level.

4. The maximum annual warm season flash density measured was 7.3 fl/km^2 over the northern end of Spring Mountain Range (Fig. 21). This activity did not occur over the highest terrain. In general, average warm season flash densities of 2 to 3 fl/km^2 covered approximately 16,000 km^2 of southern Nevada or 14% of the entire State. Similar flash densities, corrected for detection efficiency (multiply fl/km^2 in this report by 1.4), occur over the Great Plains (Orville and Silver, 1997). Correcting the 7.3 fl/km^2 for detection efficiency yields a flash density of 10.2 fl/km^2 which is comparable to the mean annual flash densities reported by Hodanish et al. (1997) in central Florida.

5. The maximum seasonal flash density was 17.4 fl/km^2 over the Spring Mountain Range in 1997 (Fig. 19).

6. The peak, individual storm, flash density measured in this study was 59 fl/5 km^2 (11.8 fl/km^2) over the Belted Mountain Range located north of the NTS (Fig. 8). However, during the preparation of this manuscript, a maximum daily flash density of 116 fl/5 km^2 (23.2 fl/km^2) was measured in the vicinity of the Mormon Mountains located northeast of MOA. This large flash density was associated with a MCS that moved southwestward across southern Nevada on July 19-20, 1998. This storm appears to have been a classic Type B thunderstorm (Randerson, 1997) or Maddox et al. (1980) Type IV pattern. As this MCS moved from near

St. George, UT, to LAS, it generated 7408 CG lightning flashes during the 14-hr period from 0000 UTC to 1400 UTC on July 20.

7. Diurnally, the maximum hourly flash rate occurred between 1600 and 1659 PDT (Fig. 22). Minimum CG flash activity occurred between 0700 and 0759 PDT. Hourly flash rates increase rapidly after 1100 PDT and decrease rapidly after 1800 PDT.

8. Warm season positive flashes occur during all hours; however, more occur between 1300 and 2200 PDT than during the other hours (Fig. 22). Peak positive flash activity is between 1700 and 1759 PDT. Few positive flashes occur between 0300 and 1100 PDT.

9. There appears to be a significant decrease in warm season flash density to the west of the NTS.

10. Over mountainous terrain located to the north and to the west of Las Vegas, the diurnal distribution of CG lightning is different from that for the entire analysis area. Peak flash rates occur between 1300 and 1359 PDT, three hours earlier than that for the entire area. In addition, CG lightning activity remains energetic until 0200 PDT (Fig. 23).

11. A 5-yr data base does not include enough realizations to form a robust or representative climatological data base for CG lightning over southern Nevada; however, some clear climatological patterns were resolved through this study.

12. CG lightning data indicate that desert thunderstorms that are not driven by macroscale or mesoscale dynamics tend to develop and dissipate rapidly.

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