ANOMALOUS CLOUD-TO-GROUND FLASH DENSITIES OVER SOUTHERN NEVADA

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ABSTRACT

Seven warm seasons (June through September, 1993-1999) of cloud-to-ground (CG) lightning flashes have been analyzed for southern Nevada. Part of this analysis focused on extreme or unusual lightning events. Results show that desert thunderstorms can generate large flash densities. Local flash densities of 4 to 11 fl/km^2 can be produced. Cloud-to-ground flash rates of 100 to 300 fl/hr accompanied these intense storms. The flash densities are larger than anticipated for a desert region and help emphasize the lightning hazard in one of the fastest growing metropolitan areas in the United States. Such large flash densities are quite hazardous to people, to aviation, to communications systems, and to power distribution networks.

INTRODUCTION

Most of the population of Nevada is located in the Las Vegas (LAS) metropolitan area where more than one million residents live. Tourism adds another dimension to the hazards posed by thunderstorms to people and property.

In early 1993 the Nevada Test Site (NTS) lightning detection system, described in detail by Scott (1988), 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 1999 have been 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.

Thunderstorm activity and the accompanying CG lightning is primarily a summertime phenomenon in southern Nevada (Randerson, 1997 and Skrbac, 1999). 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 1999.

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 and precipitation tends to be sparse. 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 (Skrbac, 1999).

Summer is thunderstorm season for the desert southwest, which includes southern Nevada. Annually, Las Vegas and Desert Rock average 13 to 14 thunderstorm days (Skrbac, 1999 and Randerson, 1997), respectively; however, nearly 80% of these storms occur during the warm season (Randerson, 1997). Approximately 55% of the thunderstorm days 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 dramatically increase the convective instability of the atmosphere over Arizona. This phenomenon can be associated with significant thunderstorm development and heavy precipitation in Arizona, Nevada, and Utah. Some of these storms can be severe.

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 (all figures are on the last page) shows that the topography of southern Nevada is complex and consists of mostly north-south oriented mountain ranges separated by small basins and dry lake beds (playas). Elevations range from approximately 200 m above mean sea level (MSL) in the Colorado River valley to nearly 3650 m MSL for Mt. Charleston in the Spring Mountain Range, west of Las Vegas (LAS). The Sheep Range, to the north of LAS, contains two peaks with elevations between 2900 m and 3000 m.

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.

ANALYSIS

Preliminary assessments of the spatial and temporal distribution of warm season cloud-to-ground lightning in southern Nevada has been prepared by Randerson (1999) and Randerson and Sanders (1999) and a 7-yr climatology is being presented at this conference (Sanders and Randerson, 2000). These reports describe the dramatic inter-annual variability of warm season cloud-to-ground lightning in southern Nevada. This variability is typical of desert climatic zones.

Climatological summaries are composed of many events. Some of these are extreme events that can produce large/anomalous flash densities. This report focuses on anomalies and extreme events because they are the ones that can have the greatest impact on people and property. For this analysis, an extreme cloud-to-ground lightning event is one in which a thunderstorm produces a flash density $\geq$ 4.0 fl/km^2. For easy reference, and a logical linkage to the diurnal heating cycle, local daylight time is used in this report.

ANOMALIES

Spring Mountains: Analysis of the entire 7-yr warm season data base revealed three unusual areas of large flash density. The most active of these is located on the northwest end of the Spring Mountain range but not over the highest terrain. A small area containing a flash density of 31 fl/km^2/7 warm seasons (4.4 fl/km^2/ws) was identified over terrain ranging from 1250 to 1400 m above mean sea level. Review of the data base indicates that this anomaly was probably an artifact of the short data base and was dominated by very active lightning events in 1997 and 1999. However, preliminary data from 2000 indicate that it may have occurred this past summer; an inactive warm season.

Blue Diamond: Another fascinating anomaly was found just northeast of the small community of Blue Diamond, NV, located southwest of downtown Las Vegas. For the seven warm seasons, a small area of 29 fl/km^2 (4.1 fl/km^2/ws) was discovered approximately 2 km east-northeast of Blue Diamond. This active lightning area is shown in Fig. 2. This flash density is comparable to that measured in the eastern United States when adjusted for 70% detection efficiency (multiply by 1.4) as done by Orville (1994). This calculation yields a flash density of 5.8 fl/km^2. We believe this anomaly to be real because it has occurred in the same general area each year; except for 1996, the least active lightning season in the data record. For this site, seasonal flash densities ranged from 1.0 fl/km^2 in 1996 to 14.0 fl/km^2 in 1998. The diurnal distribution of flash activity is erratic with the peak activity tending to occur between 1000 PDT and 1500 PDT with activity continuing well after sunset. This erratic pattern is probably due to the short data record for such a small area. No positive flashes were detected within this anomaly. A physical explanation for this active flash area is not clear; however, it does occur in an area where the terrain rises abruptly nearly 200m (see Fig. 2).

Rachel: North of the NTS, the two mountain ranges bordering Emigrant Valley gradually converge in the north end of the valley. The larger of the two ranges, the Belted Range, extends from the north-central part of the NTS north-northeastward, forming the western boundary of the valley. The smaller range, the Groom Range; located south of Rachel, NV, borders the east side of the valley and is oriented north-northwest to south-southeast. Both ranges contain mountain peaks above 2500 m above mean sea level (MSL) and converge to form a 1700-m pass approximately 25 km southwest of Rachel. The pass is approximately 400 m above the dry lake bed or playa located 30 km to the south-southeast. Moreover, there is a 2250-m mountain located just east of the pass. The crescent shape of the north end of this valley, the predominance of southerly afternoon boundary-layer flow, and the intense summertime heating of the ground, create an ideal environment for the production of vertical motion, thunderstorms, and lightning when moisture is present. As the thunderstorms develop, they tend to move northeastward; reaching their peak electrical phase just northeast of the pass. The resulting cloud-to-ground lightning anomaly is shown in Fig. 3.

For the seven warm seasons, a total of 34 fl/km^2 (4.9 fl/km^2/ws) have been detected. Notice, this site is more active than the Blue Diamond anomaly. For this site, the seasonal flash densities ranged from 1 fl/km^2 in 1997 to 10 fl/km^2 in 1995. Diurnally, flash activity begins early (1000 PDT), increases rapidly to 1200 PDT, remains elevated until 1700 PDT, and ceases after 2000 PDT; emphasizing the connectivity to the diurnal heat cycle.

INTENSE THUNDERSTORMS

Intense thunderstorms occur over southern Nevada almost every summer. These storms are frequently accompanied by brilliant cloud-to-ground lightning, strong surface winds, blowing dust, heavy rain, and occasionally large hail. In this analysis, an intense thunderstorm is defined as one that produced flash densities $\geq$ 4 fl/km^2 within a consecutive 4-hr period. Some of these storms are described next. Cloud-to-ground flashes were not corrected for detection efficiency.

1993

During 1993, the most active thunderstorm period was the first week of August. Significant thunderstorms developed to the north and east of the NTS between 1200 and 1600 PDT on August 3. Two areas of vigorous cloud-to-ground lightning were identified. One area, located to the north of the NTS, developed over the 2600-m peaks of the Belted Range and drifted eastward over Emigrant Valley. A maximum flash density of 7 fl/km^2 occurred with this thunderstorm. The peak flash rate, 80 fl/hr, occurred between 1310 and 1404 PDT.

The other active thunderstorm system developed near Beatty, NV, after 2200 PDT on August 4. These storms developed rapidly and moved eastward across the NTS between 2300 PDT on the 4th and 0200 PDT on the 5th. Peak flash densities of 3 to 5 fl/km^2 occurred along a southwest-northeast line through Mercury The peak flash rate, 349 fl/hr, occurred between 0000 and 0059 PDT and within a 20 km circle enclosing this active flash area. The largest flash densities were detected 4-5 km southwest of Mercury (4 fl/km^2) and 18-20 km northeast of Mercury (5 fl/km^2). The storm located southwest of Mercury was very close to the Desert Rock Meteorological Observatory (DRA) where the observer on duty reported "FREQ LTGICCCCG ALQDS" with TRW-. Only 0.76 mm of precipitation was measured at DRA during this thunderstorm.

1994

On July 19, between 1906 and 2026 PDT an intense thunderstorm developed over the high terrain southwest of Rachel, NV. This storm produced a flash density of 5 fl/km^2 and a flash rate of 21 fl in 20 min. The storm developed rapidly, drifted northeastward and dissipated quickly.

Very active nocturnal thunderstorms developed rapidly over southern Nevada on August 19. Intense cloud-to-ground lightning was concentrated between 0000 PDT and 0600 PDT. The peak hourly flash rate for all the thunderstorm cells was 326 fl/hr between 0200 and 0259 PDT. Flash densities of 4 to 6 fl/km^2 occurred along the south side of Interstate Highway 15, between Las Vegas and Mesquite, NV. The peak flash density, 6 fl/km^2, was detected just west of Mesquite, near the small community of Riverside. A flash rate of 5 fl/km^2 was measured between Moapa and Overton, NV.

Between 1300 PDT and 1700 PDT, on August 19, strong thunderstorms developed north of the NTS, over essentially the same general area of the Belted Range that the storms of August 3, 1993, developed. These storms appear to have been driven by the interplay of intense diurnal heating and topography. The peak flash density was 8 fl/km^2 and the maximum flash rate was 156 fl for the 42-min period between 1452 and 1534 PDT. A total of 359 fl were detected within a 10 km circle centered near the storm. Only one positive flash was detected and it was associated with the area of peak flash density. Another thunderstorm developed 15 km northeast of this storm and southwest of Rachel, NV. The second storm generated a peak flash density of 6 fl/km^2.

1995

Although there were several active thunderstorm days in 1995, few produced large flash densities. June 29 was a very active thunderstorm day. Between 2000 and 2200 PDT an energetic line of thunderstorms developed from west of Las Vegas, north-northeastward over the Sheep Range. Along this 100-km line there were several areas of large flash density; the two largest being 5 fl/km^2. One of these was just north of Highway 95 and the other approximately 10 km north of Red Rock Canyon State Park. The peak hourly flash rate was 112 fl/hr between 2100 and 2159 PDT; however, this rate was for multiple storms.

On August 22, an interesting thunderstorm occurred north of the NTS and southwest of Rachel, NV; in the same general area as one of the storms in 1994. In this storm, the flash density was large and the flash rate small. This storm produced a flash density of 10 fl/km^2 between 1057 and 1443 PDT, and a peak flash rate of only 19 fl/hr between 1200 and 1259 PDT.

1996

The summer of 1996 was rather dry with fewer than normal thunderstorm days. Only one thunderstorm has been identified as noteworthy. It developed over and along the eastern slopes the Pahranagat Range, just west of Alamo, NV. This storm occurred on September 9-10, between 2200 PDT and 0100 PDT on the 10th. The maximum detected flash density was 6 fl/km^2. The peak flash rate of 100 fl/hr occurred between 2250 and 2350 PDT.

On July 14, another active thunderstorm formed over a 3000-m peak in the southern part of the Sheep Range, north of Las Vegas. The maximum flash density with this storm was 5 fl/km^2. Most of the cloud-to-ground lightning occurred between 1200 and 1400 PDT. The peak flash rate of 61 fl in 45 min occurred between 1237 and 1322.

1997

Every month experienced thunderstorm activity; however, mid-June to mid-July was inactive. Much cloud-to-ground lightning was produced by thunderstorms in early September. Thunderstorms covered much of southern Nevada throughout the day on the 3rd. These storms combined to generate two areas of 7 and 8 fl/km^2 over the northern end of the Spring Mountains. In addition, approximately 4% of the flashes on the 3rd deposited positive charge to the ground.

On September 5, an intense thunderstorm developed rapidly over the extreme northwest end of the Spring Mountains between 2000 and 2200 PDT. A peak flash density of 11 fl/km^2 was measured approximately 20 km south of Mercury, NV, near 36^0 29'N and 116^0 00'W. This flash density occurred between 2059 and 2110 PDT when a peak flash rate of 58 fl were detected within an 11 min period. A total of 125 fl occurred between 2045 and 2115 PDT. The flash density and flash rate associated with this thunderstorm are both the largest contained in the 7-yr, warm season, data base analyzed in this study.

1998

During the evening of July 19, a mesoscale convective system (MCS) developed over southwestern Utah and southeastern Nevada. Figure 4 is an infrared satellite image of the MCS as it reached peak intensity (as defined by the coldest cloud top temperatures) between 2230 and 2330 PDT. The MCS formed as two strong thunderstorms merged; one moving southward, across the mean flow, from near Caliente, NV, and the other moving southwestward from near St. George, UT. The storms merged near Moapa, NV. This intense storm system produced much cloud-to-ground lightning, heavy rain, strong surface winds, and blowing dust. The most intense cloud-to-ground lightning associated with this MCS occurred in the vicinity of Mormon Mountain, located northeast of Moapa, NV. Figure 5 displays the locations of the 1064 cloud-to-ground flashes detected between 2230 and 2330 PDT in the vicinity of the MCS shown in Fig. 4. Comparison of these two figures shows that the axis of the flashes was oriented northwest to southeast; along the axis of the coldest cloud-top temperatures.

Flash densities of 7 to 9 fl/km^2 were detected between 2000 and 2300 PDT. A peak hourly flash rate of 540 fl/hr occurred between 2200 and 2259 PDT; however, these flashes were associated with the MCS; not with a single thunderstorm. This storm system moved southwestward, sweeping across the Lake Mead National Recreational Area and into the Las Vegas metropolitan area just before midnight. There was extensive damage to docks and boats at Lake Mead. In Las Vegas, a lightning strike caused a hotel roof to ignite, there were power outages across the city, minor street flooding , and considerable debris and roof damage reported. One person died of an apparent heart attack while being rescued from flood waters.

An MCS moved across southern Nevada in July 1994; however, this storm system did not develop the flash densities or flash rates of the 1998 MCS. Additional information on the 1994 MCS has been provided by Randerson (1997).

Two very active thunderstorms developed between 1500 and 1800 PDT on August 13. Both formed and dissipated rapidly. One storm formed along the ridge crest and eastern slopes of the Sheep Range. This storm generated a maximum flash density of 7 fl/km^2 and deposited 64 fl to the ground in 26 min, between 1640 PDT and 1706 PDT. The other thunderstorm developed over the NTS, approximately 5 km north of Mercury. This storm produced a flash density of 6 fl/km^2. Between 1500 and 1543 PDT, 66 cloud-to-ground flashes were detected.

1999

Between 1756 and 1819 PDT, on July 10, a noteworthy thunderstorm developed over the northwestern edge of the Spring Mountain Range, approximately 20 km south of Mercury, NV. This storm produced a flash density of 8 fl/km^2 over terrain 1500 to 1700 m above sea level. Within the 23-min active life of the storm, 69 cloud-to-ground flashes were detected. No positive flashes were measured.

On September 17, very active thunderstorms formed along a north-south line through the center of the NTS. These storms developed and dissipated quickly. One storm occurred over the middle of the NTS and produced a flash density of 5 fl/km^2 between 1243 and 1348 PDT. A total of 37 fl were produced in 55 min. At approximately the same time, another storm developed roughly 20 km northwest of Mercury. This storm also produced 5 fl/km^2 and 28 fl in 40 min. Approximately 1 hr prior to the NTS storms, a thunderstorm developed rapidly over the extreme north end of the Spring Mountains, producing 6 fl/km^2 and 31 fl in 27 min.

On July 8, between 1000 and 1300 PDT, heavy thunderstorms developed over the Las Vegas valley. Although these storms produced record daily precipitation totals and extensive flooding, they did not produce flash densities greater than 3 fl/km^2.

SUMMARY

The large cloud-to-ground lightning flash rates and densities described in this study were associated with active thunderstorms discovered, to date, in the data base. The following conclusions are drawn from this analysis:

1. Maximum storm flash densities were 4 to 11 fl/km^2; uncorrected for detection efficiency.

2. Flash rates for the more active storms ranged from near 100 fl/hr to just over 300 fl/hr; when normalized for a one-hour period.

3. A flash anomaly was found in the vicinity of Blue Diamond, NV, where there is an area of unusually frequent cloud-to-ground lightning during the warm season.

4. There may be two other anomalies. One may be north of the NTS, and southwest of Rachel, NV, just north of Emigrant Valley. The other is possibly over the northern end of the Spring Mountain Range. However, the data base is short; consequently, more study and additional data are needed to confirm this speculation.

5. There were few positive flashes with the

storms described in this paper; the only notable exception being the thunderstorms on September 3, 1997.

Additional analysis of the data based is needed. Flash densities and rates need to be related to meteorological data, satellite imagery, radar data, and precipitation amounts/rates to improve our understanding of the conditions under which high flash rates and flash densities occur in the desert southwest.

ACKNOWLEDGMENTS

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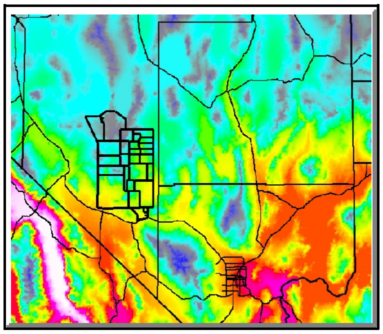

Figure 1. Topography of southern Nevada.

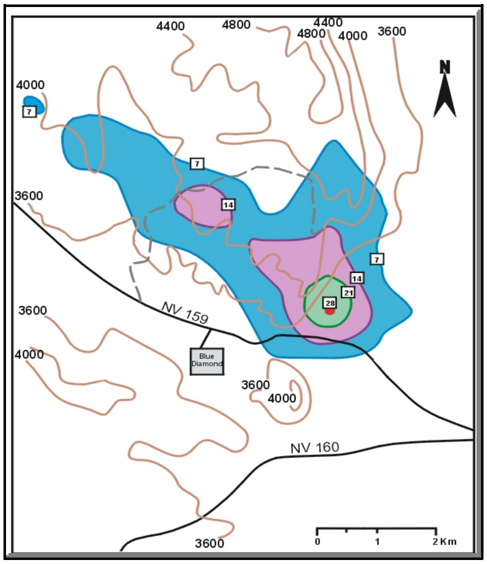

Figure. 2. Total number of cloud-to-ground flashes, June through September, 1993 through 1999, in fl/km^2. Contours are terrain elevation.

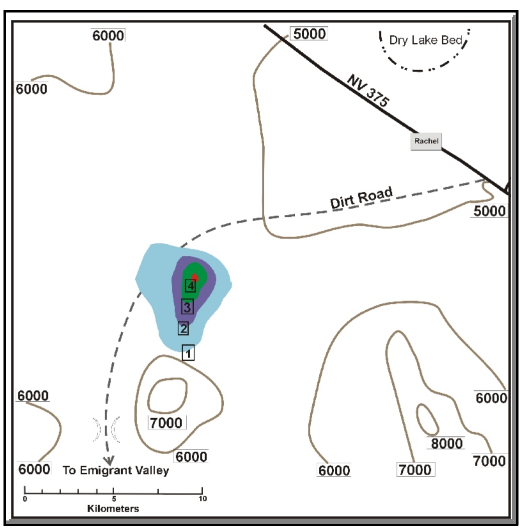

Figure 3. Total number of cloud-to-ground flashes, June through September, 1993 through 1999, in fl/km^2. Contours are terrain elevations.

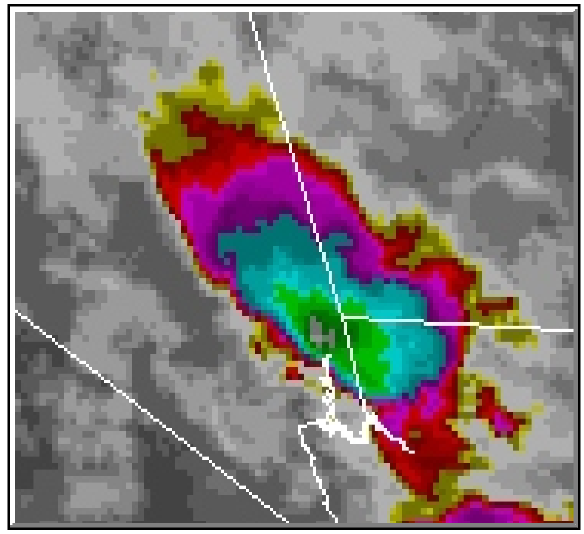

Figure 4. Infrared satellite image for 2300 PDT, July 19, 1998.

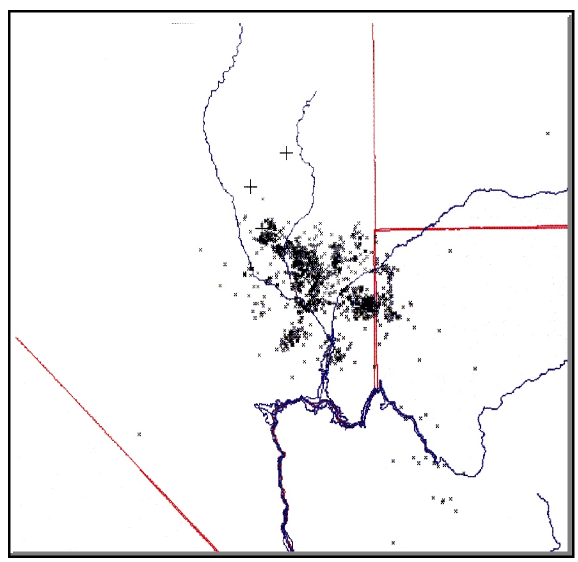

Figure 5. Cloud-to-ground lightning flash locations for 2230-2330 PDT, July 19, 1998.