NOAA Technical Memorandum NWS WR-204

PRELIMINARY ANALYSIS OF CLOUD-TO-GROUND LIGHTNING IN THE VICINITY OF THE NEVADA TEST SITE

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Las Vegas, Nevada
November 1988

U.S. DEPARTMENT OF COMMERCE / National Oceanic and Atmospheric Administration / National Weather Service

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This publication has been reviewed
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PRELIMINARY ANALYSIS OF CLOUD-TO-GROUND LIGHTNING IN THE VICINITY OF THE NEVADA TEST SITE

ABSTRACT

Cloud-to-ground lightning (CG) constitutes a severe hazard to both personnel and sensitive equipment. The Weather Service Nuclear Support Office (WSNSO) operates an Automatic Lightning Detection Network to ensure maximum protection on the Nevada Test Site (NTS). This study describes the lightning network in some detail. The accuracy and detection efficiency of the system is also investigated.

Lightning data were collected and analyzed for the period July 1986 through August 1987. Of particular interest in this data set was the temporal variation of both positive and negative CG flashes. In addition, factors that may influence the character and distribution of lightning flashes were studied.

PRELIMINARY ANALYSIS OF CLOUD-TO-GROUND LIGHTNING IN THE VICINITY OF THE NEVADA TEST SITE

I. INTRODUCTION

Recent development of equipment that can accurately locate and detect certain properties of lightning on a real-time basis has been beneficial to the operational meteorologist as well as to the researcher. National Weather Service (NWS) Western Region meteorologists are especially familiar with the Automatic Lightning Detection System (ALDS) operated by the Bureau of Land Management (BLM) (Krider, et. al., 1980). The NWS Western Region has been involved with collecting and disseminating this real-time lightning data from the BLM since 1982. The data are processed at the NWS Forecast Office in Boise, ID, where various products are created for dissemination via the AFOS communications loop (Rasch and Mathewson, 1984).

However, real-time lightning products are only available via AFOS, at a minimum, every 30 minutes. This interval is unsatisfactory to provide timely support of operations at the Nevada Test Site (NTS). To ensure the maximum protection of personnel and equipment, the Weather Service Nuclear Support Office (WSNSO), under the auspices of the Department of Energy (DOE), activated an ALDS at the NTS in July 1986.

This system represents an opportunity in the West to assess the viability of the NTS/ALDS configuration. Utilizing lightning data gathered during the period July 1986 through August 1987, this study attempts to investigate factors that might influence the character and distribution of cloud-to-ground (CG) flashes. The accuracy of flash placement possible with the NTS system (explained in the next section), in conjunction with other resources available, makes the NTS an ideal location to undertake this investigation.

II. LIGHTNING DETECTION NETWORK ACCURACY AND EFFICIENCY

The NTS network consists of four Direction Finders (DFs) manufactured by Lightning Location and Protection, Inc. (LLP), (Krider, et. al., 1980). Figure 1 shows that currently one DF is located in each of the corners of the NTS. The rectangular shape of the NTS leads to east-west baselines of approximately 40 km, and north-south baselines of almost 75 km. As seen in Figure 2, lightning information from the DFs is multiplexed from the NTS to the Position Analyzer (PA) at the Nevada Operations Office in Las Vegas.

The PA processes the raw DF data and automatically computes the locations of the lightning flashes by triangulation, utilizing input from at least two of the DFs (LLP/PA Manual, 1984). Since bearing angles from the DFs have an estimated angular accuracy of +1 degree (Krider, et. al., 1980), the trigonometric calculations lead to a decrease in the confidence of flash placement as the distance to the flash increases. This uncertainty is expressed in the probability or error ellipse (Figure 3). If one assumes that a flash occurs at the center of an ellipse, the probability ellipse is defined as a region within which a flash has a 50 percent or greater probability of being placed by the calculations of the PA.

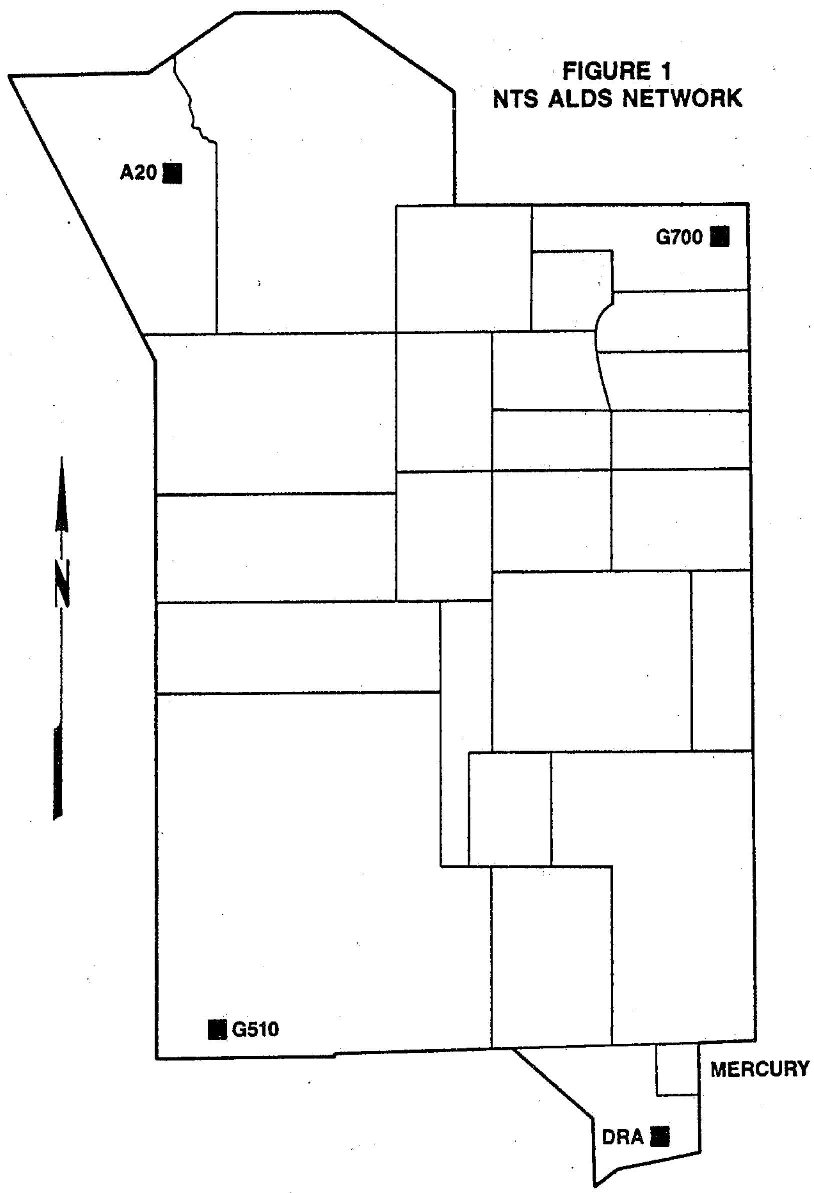
From the PA, the processed lightning data are routed to various display devices in the DOE family of operations (see Figure 2). Additionally, flash information such as flash polarity, number of return strokes, and all raw DF information, is transmitted to an archive device. The archival capability allows WSNSO meteorologists access to detailed flash data for system analysis and research applications.

For the NTS/ALDS, with an average baseline of about 56 km between DFs, the confidence in the flash location outside of about 170 km is quite low. This fact is graphically portrayed in contour plot of lines of equal accuracy of the flash location, derived from the probability ellipse chart. Careful study of Figure 4 indicates especially low confidence in flash location to the southeast and northwest, outside of 170 km, no doubt attributable to the short east-west baseline (40 km).

With the mission of the WSNSO in mind (support of DOE operations on the NTS), the sensor gain was lowered to be more compatible with the baseline length of the NTS network. Lowering the gain reduced the nominal range (nominal range is defined loosely as the range at which the detection efficiency starts to fall off) of the DF from approximately 370 km to 90 km. This eliminated most of the flashes that occurred beyond the point where the PA can process lightning flashes accurately.

Presently, only a cursory ground-truth analysis has been conducted on the NTS/ALDS. A preliminary estimate of flash locations inside the designed nominal range indicates the multi-site detection efficiency of the NTS/ALDS (approximately 80 percent) is in line with data from previous studies (Mach, 1984, MacGorman et. al., 1984). Locations of CG flashes were pinpointed on several occasions on and near the NTS by WSNSO and Los Alamos National Laboratory (LANL) personnel during the summer of 1986. Comparison of the limited ground-truth data with the NTS/ALDS locations indicates a very close agreement (1 km or less from their true position).

FIGURE 1
NTS ALDS NETWORK



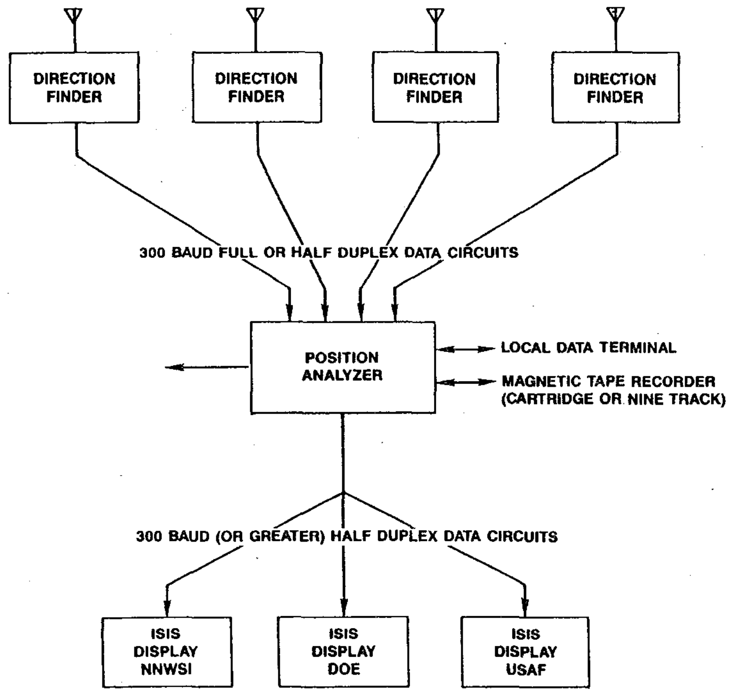


FIGURE 2
NETWORK CONFIGURATION FOR THE NTS LIGHTNING LOCATING SYSTEM

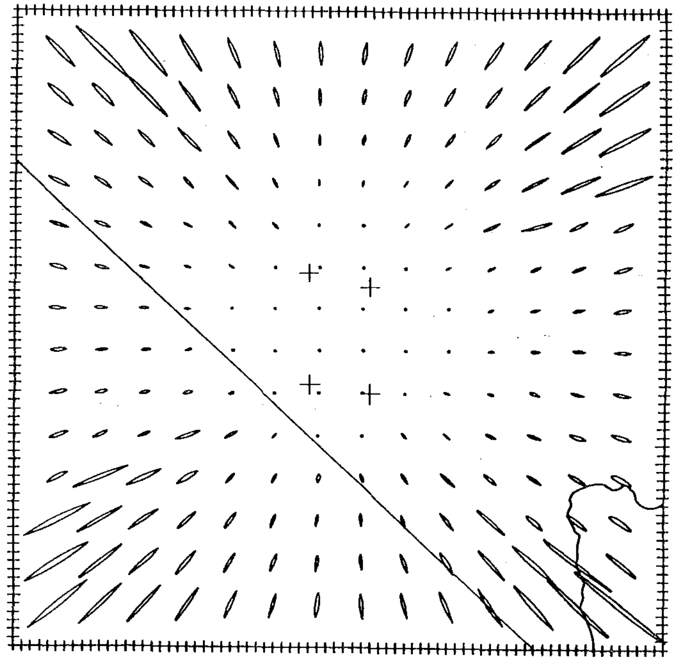


FIGURE 3
NTS/ALDS SYSTEM ACCURACY
(50% PROBABILITY ELLIPSES)

A more elaborate ground-truth program, the Lightning Identification and Verification Evaluation Study (LIVES) Project, was attempted during the summer of 1987. WSNSO personnel were deployed in and around the NTS at locations where closed-circuit television cameras were located. These individuals communicated with a command post via two-way radios to coordinate camera aiming and to keep an event log for cross-reference purposes. In addition, the lightning warning system maintained by LANL on the NTS was closely monitored.

The LANL system (described in Buset and Price, 1974) is a lightning warning system manufactured by Meteorology Research, Inc.. Coupled to the atmosphere by means of a radioactive probe, the instrument measures the slow varying electric field as well as the faster changing electrostatic component due to a lightning discharge. When a lightning discharge occurs, the distance to the discharge is computed and then transmitted to a strip recorder. Though different in principle, the LANL system is similar to the field mill in the parameters that one attempts to measure. Unfortunately, like the field mill, the LANL system is unable to discriminate among cloud-to-ground, cloud-to-cloud, and intra-cloud discharges.

However, by comparing data sets from the LANL system, the NTS/ALDS and ground observers, estimates can be made of the percentage of CG flashes versus total lightning discharges as well as other useful relationships. This may be accomplished through the correlation of ground reports with flash locations from the NTS/ALDS. These correlations, in turn, can also be compared with output from the LANL system.

The lack of thunderstorm activity on the NTS during the summer of 1987 resulted in a lightning flash data set too small to allow any definite conclusions to be drawn. However, some ground-truth validation utilizing a limited set of observations from LANL will hopefully be incorporated into a subsequent report.

III. LIGHTNING CLIMATOLOGICAL DATA

During the period July 23, 1986 through August 26, 1987, the NTS network detected a total of 45,092 CG flashes (Table 1). Of these, 1377 (or 3 percent) were positive cloud-to-ground flashes. Consequently, nearly 97 percent of the detected flashes were negative, very close to the percentage other investigators (Fuquay, 1982 and Mielke, 1986) have found in the western United States.

Using only sunset-sunrise as a discriminator, the percentage of positive flashes increased to 4.5 percent after sunset (Table 1). This figure is nearly twice the percentage of positive flashes received during the daylight hours. This is phenomenon, noted by other investigations (Orville, et. al., 1983 and Mielke, 1986), is developed further in a later section.

However, the hour of maximum CG lightning activity was very close to the time of maximum cumulonimbus (CB) activity as reported in observations taken at the Yucca Weather Station (1962-1975) summarized by Quiring (1976) in his study on the NTS. Figure 5 is a plot of the number of CG flashes as function of time as measured by the ALDS. Figure 6 represents the number of CB occurrences versus time on the NTS. Both curves peak at approximately 2300Z (1700 PDT), certainly not unexpected given the relationship between lightning and CB activity.

Table 1

Statistics of Cloud-to-Ground Lightning from the NTS for July 23, 1986 through August 26, 1987

Total cloud-to-ground flashes -	45092
Total positive cloud-to-ground flashes -	1377
Percent positive cloud-to-ground flashes -	3.1%
Cloud-to-ground flashes (daytime) -	33697
Positive cloud-to-ground flashes (daytime) -	861
Percent positive cloud-to-ground flashes -	2.6%
Cloud-to-ground flashes (nighttime) -	11395
Positive cloud-to-ground flashes (nighttime)-	516
Percent positive cloud-to-ground flashes -	4.5%

A. Lightning Flash Rate

Lightning flash rates were studied in some detail. The flash rate, as well as the number of CG flashes detected by the NTS/ALDS, pales in comparison to results from the National Severe Storm Laboratory network in Oklahoma and the National Aeronautics and Space Administration network in southern Florida. Goodman and MacGorman (1985) found that mesoscale convective complexes in Oklahoma often have flash rates in excess of 3000 hr^{-1}. The most active lightning day measured by the NTS/ALDS was August 8, 1987, when almost 2,200 flashes were detected.

Interesting to note, however, was the comparison of flash rates detected from individual airmass thunderstorms. CG flash rates measured by the NTS/ALDS for individual thunderstorms were 1 to 2 min^{-1}. This figure is in close agreement with flash rates in air mass thunderstorms measured by both Maier and Krider (1983), and Rust, et. al., (1981).

Although no severe thunderstorms were identified on the NTS during the 13-month period, two thunderstorms did produce surface wind gusts approaching severe criteria (50 kt). Flash rates of 7 min^{-1} (consistent with the flash rates of severe thunderstorms from the studies cited in the previous paragraph) were detected by the NTS/ALDS

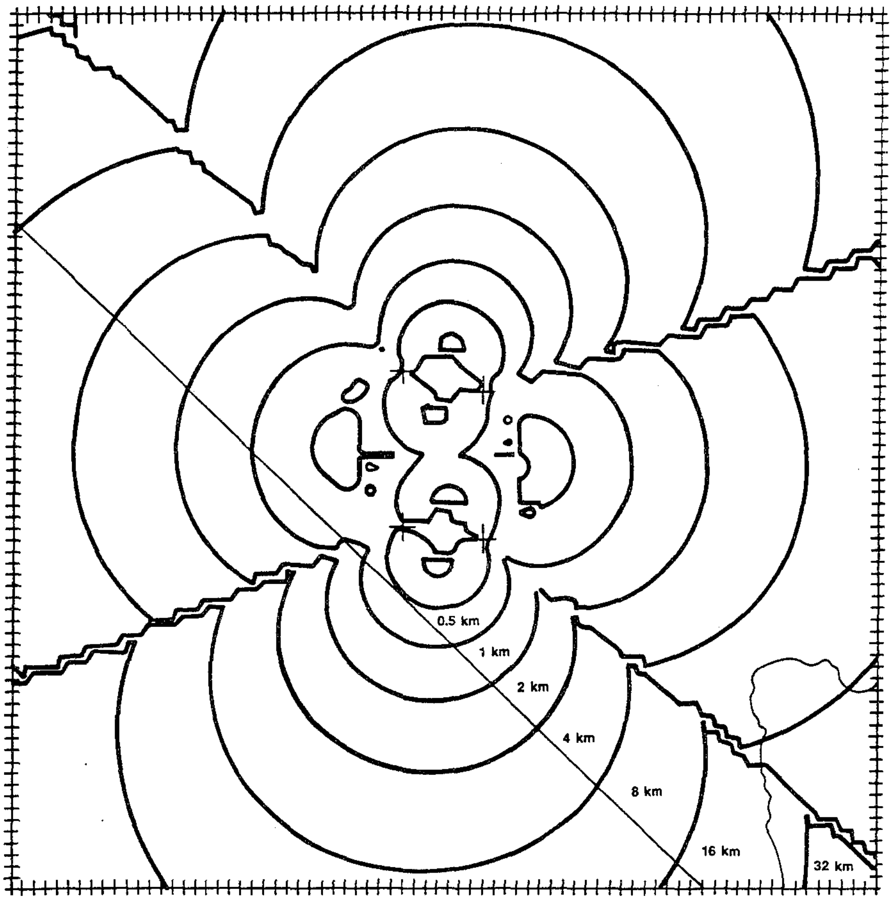


FIGURE 4
NTS/ALDS SYSTEM ACCURACY
(CONTOUR PLOT SHOWING LINES OF EQUAL ACCURACY.
VALUES ARE THE LENGTH OF THE SEMI-MAJOR
AXIS OF A 50% PROBABILITY ELLIPSE.)

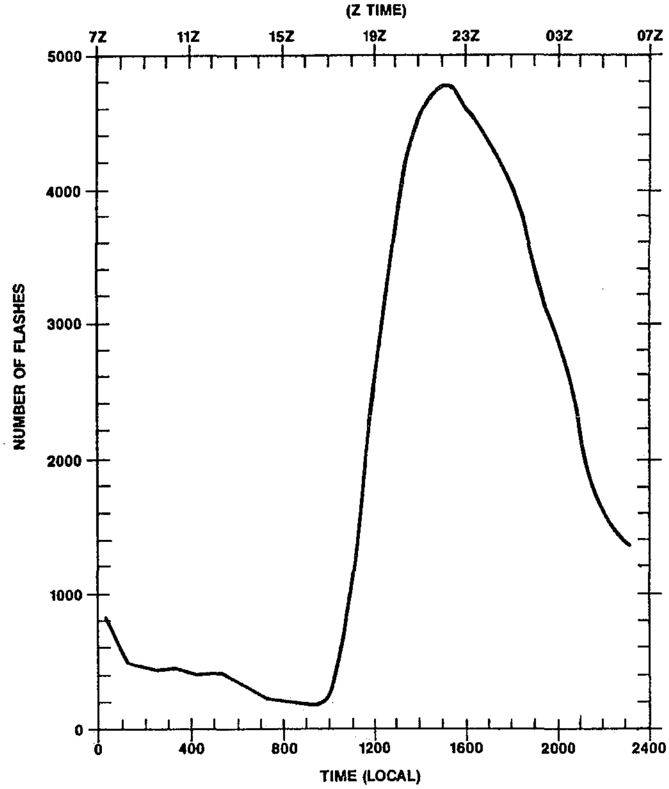


FIGURE 5
NUMBER OF CG FLASHES MEASURED BY
THE NTS ALDS AS A FUNCTION OF TIME

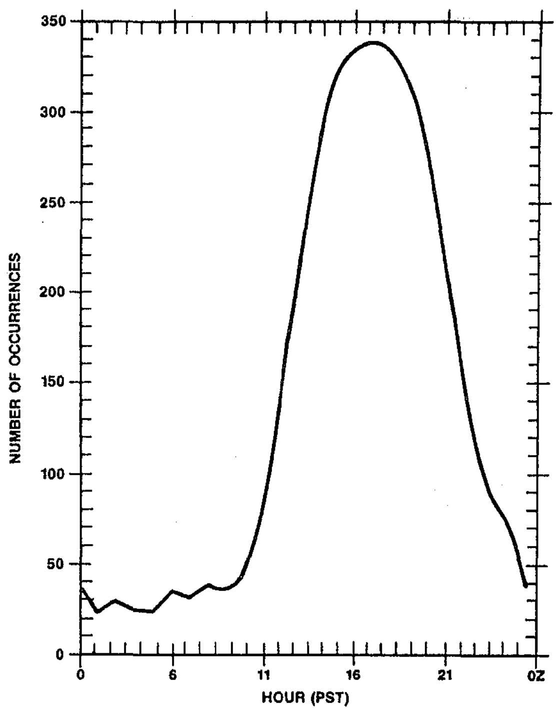


FIGURE 6
CB ACTIVITY ON THE NTS FOR MAY-SEPTEMBER
AFTER QUIRING (1976)

with both of these storms. However, several other thunderstorms also produced flash rates of 6-7 min^{-1}, but were not observed to produce severe weather.

As Mielke (1986) stated, flash flooding is an important problem for the NWS Western Region. He reported evidence of a relationship between negative CG clusters and flash flood events. Four events were documented this past summer where the NTS/ALDS indicated clustering of CG flashes, and "heavy" rainfall could be documented through the NTS rainfall network (heavy rain being defined as in excess of .75 inch in 1 to 2 hours). At least one heavy rainfall event occurred, though, where the flash data did not indicate clustering. The implication is that clustering of strikes may indicate flash flood potential, but lack of clustering does not necessarily mean heavy rains are not possible.

B. Lightning Flash Data Versus Terrain

Lightning flash density studies by Buset and Price (1974) conducted over the NTS indicate that thunderstorms tend to develop over high terrain. A climatology of radar echoes in part of the southwestern United States (Randerson, 1976) also pointed to this preference (Figure 7). However, a summary plot of lightning flashes in the vicinity of the NTS for the period June 15 through August 26, 1987, overlaid with a terrain map (Figure 8), indicates that this preference for high terrain may not extend as strongly to CG flashes as one might intuitively believe.

In contrast, a recent study by Reap (1986) indicates a very high correlation between the location of lightning strikes and terrain. The discrepancy between the NTS study and the Reap study may lie in the scale within which each study was conducted. Without going into a detailed comparison, the NTS study utilized a terrain map at least an order of magnitude finer in detail. Additionally, though no definitive study has been done on the accuracy of the BLM/ALDS, the spacing average between the BLM/ALDS DFs (350 km) naturally leads to larger error ellipses than are produced with the NTS/ALDS over the region in which the NTS study was conducted. Thus, direct comparison of the results of the two studies is not possible.

Figure 8 (representing about one month's data) for example, demonstrates that although CG lightning flashes do strike higher ground, there are anomalies apparent. One such anomalous area is at the western edge of the NTS where a pronounced concentration of flashes was detected. Most of the flashes in that area occurred during one thunderstorm that remained nearly stationary away from the high terrain that prevails over a large part of the northwestern NTS. Another anomaly is located in the south-central part of the NTS. Though indeed the lack of correlation with the highest terrain may be a function of the limited data set, lightning flash maps from other months show this same tendency.

Based on the available data, positive CG flashes show the same tendency for striking away from the highest terrain. Figure 9 depicts the locations of the positive CG flashes around the NTS for the period July 23, 1986 through May 9, 1987. After having studied many thunderstorms with the NTS/ALDS, most of the positive CG flashes that do occur on the high terrain, generally flash either in the wake of or ahead of the thunderstorm. This conclusion was ascertained via a detailed, time-lapse analysis of many thunderstorms that produced positive CG flashes in the vicinity of the NTS. This observation has been confirmed by previous studies (Fuquay, 1982, and Rust, et. al., 1981).

IV. POSITIVE CLOUD-TO-GROUND FLASHES

Hardware improvements in the LLP/ALDS allow the detection of positive as well as negative CG flashes. As stated previously, negative CG flashes comprise the vast majority of CG lightning. However, recent studies indicate that positive flashes differ from their negative counterparts in at least two ways. The positive CG flash (which lowers positive charge to ground) apparently transfers many times the amount of charge to ground than the negative CG flash, and with a peak return stroke current many times the average negative flash (Brook, et. al., 1983). Continuing current following the return stroke of the positive CG flash has also been documented by several investigators (Fuquay 1982, Rust, et. al., 1985a).

The destructive potential of positive CG flashes has been recognized by the electrical power industry and the United States Forest Service, as well as the research community. Working conditions at the NTS often put personnel and electrically sensitive equipment in vulnerable positions with respect to lightning. Thus, the ability to physically relate the positive CG flash to certain parameter(s) is an important research topic.

A. Vertical Wind Shear

Recent studies by Rust, et. al. (1985b) and Brook, et. al. (1982), have both indicated a correlation between moderately strong 850-300 mb wind shear and the number of positive CG flashes. The intensity of the vertical wind shear through the electrically active portion of the thundercloud does seem to play an important factor in differentiating storms more prone to positive CG flashes.

Several thunderstorm systems were studied in detail utilizing information from the NTS/ALDS. Preliminary results indicate that the percentage of positive flashes increases under the influence of strong vertical wind shear. However, too little data are presently available over Nevada to draw any firm conclusions relating vertical wind shear to positive CG flashes.

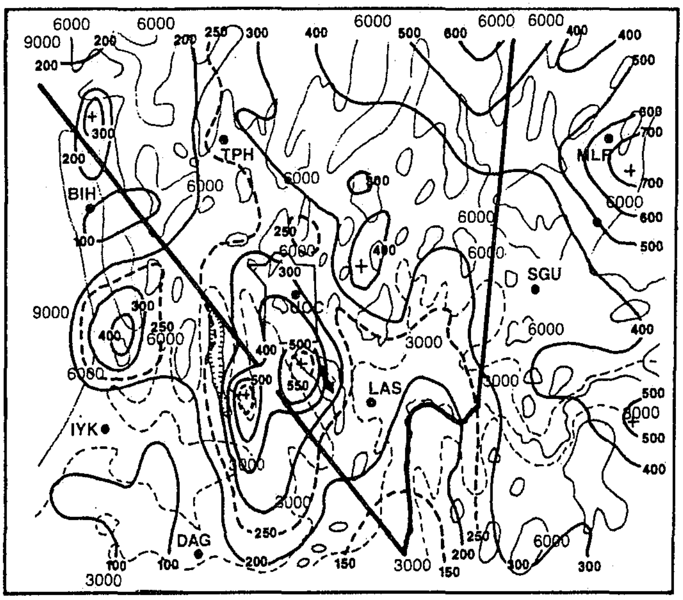


FIGURE 7
TOTAL NUMBER OF HOURS OF ECHO ACTIVITY FOR JUNE THROUGH SEPTEMBER 1971 AND 1972 (ADJUSTED FOR DETECTABILITY) AFTER RANDERSON (1976).

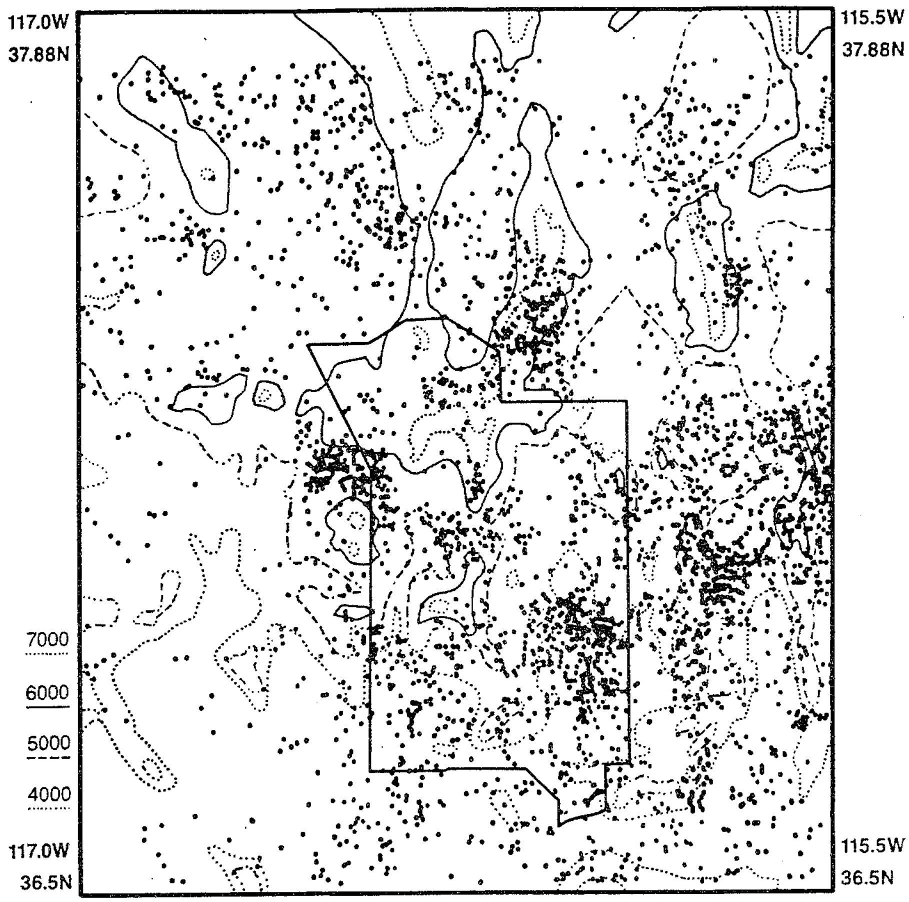


FIGURE 8
TOTAL CG FLASHES vs TERRAIN

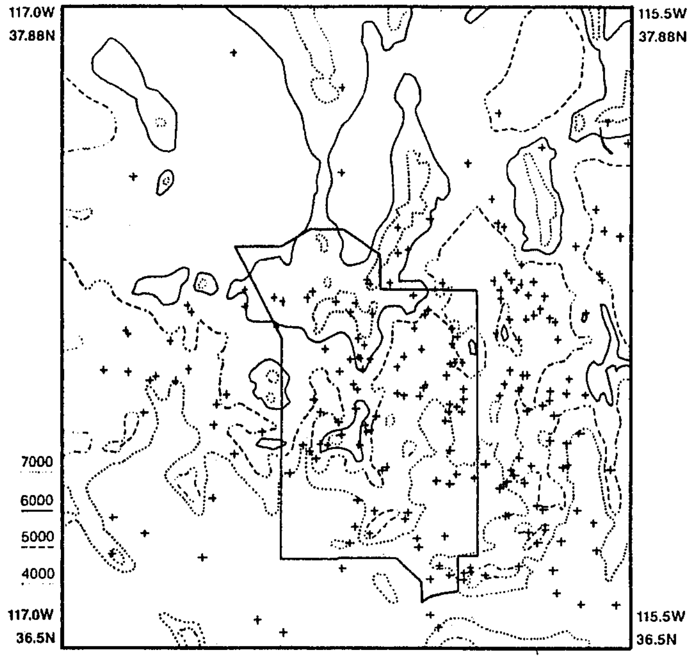


FIGURE 9
POSITIVE CG FLASHES vs TERRAIN

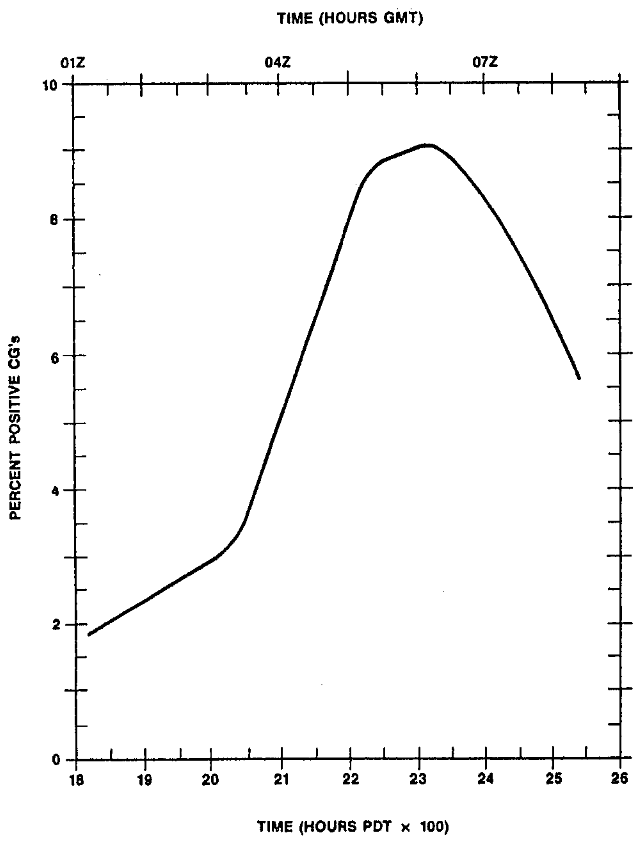


FIGURE 10
PERCENT POSITIVE CG FLASHES AS A FUNCTION OF TIME

B. Nocturnal Maximum

Positive CG flashes also exhibit a diurnal peak at approximately 0600Z, or roughly local midnight in the western United States (Figure 10). Data for the graph were derived by selecting all thunderstorm days from the NTS/ALDS data base where thunderstorm activity that began during the daylight hours continued after sunset by at least 2 hours. This data set was then broken into hourly intervals, and the percentage of positive CGs to total flashes was computed for each time interval. The graph, thus, represents a composite of lightning flashes that occurred on thunderstorm days that spanned local sunset.

The nocturnal maximum phenomenon can partly be attributed to the End-of-Storm-Oscillation (EOSO) (Moore and Vonnegut, 1977). EOSO is commonly observed in a dissipating thunderstorm when downdrafts predominate. As the cell collapses, downdrafts displace the negative charge in the lower cloud outward and expose the ground to the positive charge in the upper cloud. Normally, by local midnight, convection is diminishing (more storms are diminishing than are building); thus, the ratio of positive CG flashes can increase.

An additional source of positive CG flashes in diminishing thunderstorms is the cirrus anvil. Positive CG flashes are often observed emanating from the anvil during the mature and later stages of severe thunderstorms (Rust, et. al., 1981). The positive charge concentrated on ice crystals in the spreading anvil has an unobstructed path to the earth's surface, facilitating the production of positive CG flashes.

Some research indicates that the "nocturnal maximum" is not real, but a misidentified negative CG waveform signature (Orville, et. al., 1983). In theory, the misinterpretation is due to the reflection of a distant negative CG waveform off the stronger, nocturnal F-layer in the ionosphere that inverts the waveform. There is also the possibility that non-vertical channels of the intra-cloud or CG flash could cause waveform distortion, enough so that the DF could misidentify the received waveform. However, in the cases studied in detail utilizing the NTS/ALDS, the majority of the positive CG flashes were located inside or within 35 km of the NTS boundary which negates the reflection problem. This fact, combined with recent improvements in DF technology and increased signal strength thresholds for positive CG flashes, make both of these scenarios highly unlikely.

Indeed, at least two storm days studied over the past 18 months utilizing the NTS/ALDS showed peak convection and lightning activity after local sunset (23-24 July 1986, 25-26 August 1986). In these cases, the percentage of positive CG flashes was higher than "normal" while lightning activity was either increasing, or at least remaining at a peak level. Neither the anvils of dissipating thunderstorms nor the EOSO phenomenon would be adequate to explain the anomalously high positive CG percentages observed in the above situations.

There is little literature addressing this apparent nighttime maximum of positive CG flashes. Speculation would lead one to believe that, if this effect is indeed real, electric field changes that occur after sunset (both internal and external to the thundercloud) may somehow be responsible. Certainly more research needs to be done on this effect and on the cloud electrification processes that could cause a nighttime maximum of positive CG flashes.

V. SUMMARY

Preliminary analysis of the data set from the period July 23, 1986 through August 26, 1987 from the NTS/ALDS reveal the following:

1. For southern Nevada, approximately 97 percent of CG flashes lower negative charge to the ground. The remaining 3 percent lower positive charge to the ground.

2. In the majority of the cases, positive CG flashes were observed to strike away from the thunderstorm.

3. The CG flash rate maximizes at around 2300Z in the afternoon, coinciding approximately with the time of maximum cumulonimbus activity.

4. The ratio of positive to negative flashes, as well as the number of positive CG flashes, increases after sunset, maximizing at about 0600Z. The ratio of positive to negative flashes rises from about 2 percent during the afternoon to nearly 10 percent by midnight.

5. As noted by other authors, the vertical wind shear plays a role in the evolution of the positive CG flash. Positive CG flashes were observed to occur in areas of higher shear in three cases studied in detail. However, the data are too limited to draw firm conclusions.

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