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Lightning Climatology for Low-level Flying Routes in the United States

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13. Abstract: This technical note documents lightning climatologies developed by AFCCC for regions of the central and western CONUS. This climatology was developed from a database of cloud-to-ground lightning strikes that occurred from March through October during 1986-91. Analysis of the lightning climatology showed that patterns of lightning strikes compared favorably with known preferred locations and times of thunderstorm development. It also showed that stratification of the lightning climatologies by 700-mb wind directions is useful in revealing locations of lightning-strike patterns and their movement.

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PREFACE

This technical note documents results of AFCCC Project 911020, completed by AFCCC's Simulation and Techniques Branch (AFCCC/SYT). The project analysts were Mr. William R. Schaub, Jr. and Capt Christopher A. Donahue.

The original customer was the Strategic Air Command, Directorate of Weather, at Offutt AFB, Neb. Following Air Force major command restructuring, the new customer became the Air Combat Command, Directorate of Weather, at Langley AFB, Va. The customer requested lightning climatologies stratified by 700-mb wind direction for low-level flying routes in the continental United States (CONUS) to enhance their weather support to low-level operations. It was agreed that AFCCC would concentrate its efforts on regions of the CONUS where low-level routes were dense.

Lightning climatologies were developed for five regions of the central and western CONUS. A database of cloud-to-ground lightning strikes that occurred from March through October during 1986-91 was used for two of the regions; the period from March through October during 1988-91 was used for the other regions. Upper-air data on 700-mb wind direction and speed for the same periods was used to stratify the lightning-strike observations by nine 700-mb wind direction categories including calm. Each region was divided into grid boxes such that the overall grid spacing was about 10 nautical miles. Lightning-strike observations for each grid box were summarized to obtain the average hourly strikes for each 700-mb wind category by month. Summarized data for each grid point was used to produce interactive personal computer graphics programs of the lightning climatologies.

The personal computer graphics programs enable the user to display the wind stratified lightning climatologies in graphs, tables, and isopleth analyses. One graph shows the average hourly lightning strikes by 700-mb wind direction category for any combination of grid boxes, months, and hours. Another graph shows the diurnal variation in the average hourly lightning strikes for any combination of grid boxes, months, and 700-mb wind direction categories. A third graph, based on upper-air data for a station representative of each region, shows the annual average number of occurrences and percent occurrence frequencies of 700-mb wind direction categories for 0000Z and 1200Z for any combination of months. A table option shows average hourly lightning strikes for each and all 700-mb wind direction categories and months, for any combination of grid boxes and hours. Isopleth analyses of the average hourly lightning strikes over the entire area are also available for any combination of months, hours, and 700-mb wind direction categories. Another feature allows the user to plot routes and display their lightning climatologies, or include them for reference in isopleth analyses.

Analysis of the lightning climatologies showed that the patterns of lightning strikes compared favorably with known thunderstorm patterns. It was also shown that stratification of the lightning climatologies by 700-mb wind directions is useful in revealing locations of lightning-strike patterns and their movement. AFCCC recommends use of the lightning climatologies as tools for planning and forecasting purposes.

The author is grateful to Maj Lauraleen O'Connor and Dr. Carol L. Weaver for their review and comments. He also appreciates the fine work by Capt Christopher A. Donahue who summarized and quality controlled the input data. Special thanks are extended to MSgt Robert G. Pena, and A1C Tobin A. Smith, and Kenneth G. Weston who produced the lightning graphics programs.

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Chapter 1

INTRODUCTION

1.1 Background. The Air Combat Command, Directorate of Weather (ACC/DOW) is responsible for weather forecast and planning support to military flying missions over large areas of the United States. As an example, accurate thunderstorm forecasts are essential to flight safety during low-level route flying missions. To enhance thunderstorm and lightning support to those missions, the ACC/DOW requested a computer based cloud-to-ground (CG) lightning-strike climatology, stratified by 700-mb wind direction categories, for five regions of the central and western United States as shown in Figure 1. The regions were selected for their density of low-level routes. AFCCC used a 6-year (1986-91) database of lightning-strike observations and upper-air observations for March through October to develop lightning climatologies for two of the regions; a 4-year (1988-91) database was used for the other regions. Interactive microcomputer graphics programs were produced to display the climatologies in graphs, tables, and isopleth analyses.

1.2 Related Studies. There have been many studies to determine the average number of thunderstorm days to identify preferred regions for thunderstorm development. An early work by the World Meteorological Organization (WMO), titled *World Distribution of Thunderstorm Days* (1956), provided worldwide isopleth analyses of the mean number of thunderstorm days. Even then it was noted that a better representation of thunderstorm activity would have been possible if lightning-flash observations had been available. Later, Changery (1981) produced a comprehensive climatology of mean monthly and annual thunderstorms for the United States. MacGorman et al. (1984) used an empirical equation that relates CG lightning-strike density to thunderstorm duration, and the thunderstorm duration data from Changery (1981), to obtain a CG lightning-strike climatology for the United States. Recent applications of lightning-strike data have shown close agreement between lightning-strike patterns and thunderstorm patterns. Changnon (1993) used CG lightning-strike data gathered within 11 nm of 63 stations across the United States during 1986-89 to develop a lightning climatology. Schaub (1993a) used 5 years of CG lightning-strike data to develop a lightning climatology with a 40 to 50 nm resolution over the United States. Cornell (1993) used the same data to demonstrate the utility of lightning strikes for verifying thunderstorms. Schaub (1993b, 1993c) used 4 to 6 years of CG lightning data to develop lightning climatologies with 10 nm resolution for two regions in the southwestern United States. Schaub and Bjornson (1994) used 5 years of CG lightning-strike data to develop a lightning climatology, stratified by either 700-mb wind direction or K-index, with a 10 nm resolution for a large area centered on Eglin Air Force Base in the Florida panhandle. Donahue and Schaub (1994) used 6 years of CG lightning-strike data to develop a similar climatology for Maxwell AFB, Ala. In both works, the lightning climatologies showed that 700-mb wind direction was closely related to lightning-strike locations, and movement, while the K-index appeared useful in differentiating between widespread and isolated lightning.

1.3 Analysis Procedure. Chapter 2 describes how CG lightning-strike and atmospheric sounding data for 1986-91 was used to develop lightning-strike climatologies stratified by 700-mb wind direction categories for two of the regions in Figure 1. For the other regions, data from the period 1988-91 was used. Each region was divided into a grid system where the grid point spacing provided an overall horizontal resolution of about 10 nm for the summarized lightning-strike data. Details of the grid system are given in Chapter 3, along with the methods used to stratify the lightning data by 700-mb wind direction categories. In Chapter 4, the options available in the microcomputer graphics program produced to display the lightning climatologies are discussed, and illustrative examples are used to compare the lightning climatologies to known thunderstorm patterns.

1.4 Findings. The lightning climatologies appeared consistent with expected diurnal and monthly variations in thunderstorm activity. The diurnal variations of lightning strikes agreed closely with known diurnal variations in thunderstorm frequencies. Likewise, monthly variations in average hourly lightning strikes coincided with changes in mean monthly thunderstorms in Changery (1981). Also, monthly patterns in isopleth analyses of the average hourly lightning-strike fields closely resembled the patterns in mean thunderstorms shown by Changery (1981). As illustrated in Chapter 4, the lightning climatologies verified known preferred spatial orientations of thunderstorms at certain times based on the 700-mb wind direction.

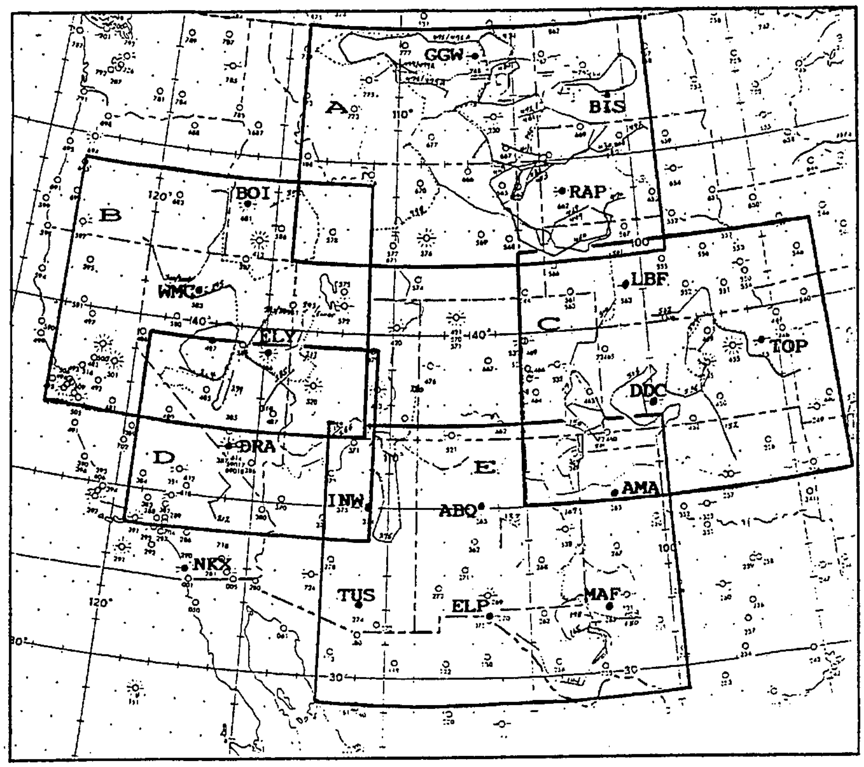

Figure 1. The area of interest. Analysis regions are in bold lines. Numbered low-level flying routes that existed in 1991 are also shown as thin and dotted lines within the analysis regions. Boundaries of the regions are: A - 42°00'N to 49°00'N and 99°00'W to 114°12'W; B - 37°00'N to 44°20'N and 110° 00'W to 123°06'W; C - 35°00'N to 42°20'N and 93°00'W to 105°06'W; D - 34°04'N to 39°34'N and 110°32'W to 119°32'W; and E - 29° 21'N to 37°21'N and 99°46'W to 112°26'W. Labeled stations by region are: A - Glasgow, Mont. (GGW), Bismarck, N.D. (BIS), Rapid City, S.D. (RAP); B - Boise, Idaho (BOI), Winnemucca, Nev. (WMC), Ely, Nev. (ELY); C - North Platte, Neb. (LBF), Dodge City, Kan. (DDC), Topeka, Kan. (TOP); D - Desert Rock, Nev. (DRA), San Diego, Calif. (NKX); E - Winslow, Ariz. (INW), Albuquerque, N.M. (ABQ), Amarillo, Texas (AMA), Tuscon, Ariz. (TUS), El Paso, Texas (ELP), and Midland, Texas (MAF).

Chapter 2

DATA AND LIMITATIONS

2.1 Lightning Data. The lightning data used was proprietary CG lightning-strike observations purchased from GeoMet Data Services (GDS), Inc., of Tucson, Ariz. The individual lightning-strike records were stored in AFCCC's relational database (DB2) for easy access. Over 17 million strikes occurred during the periods of record in the five analysis regions. The strikes were recorded by direction finders manufactured by Lightning Location and Protection (LLP), Inc., of Tuscon, Ariz. As described by Maier et al. (1983), the LLP equipment that makes up the National Lightning Detection Network (NLDN) uses triangulation to locate the strikes. Thus, every observation of a CG lightning strike provided by GDS was made by at least two direction finders. Figure 2 shows the NLDN direction finders that GDS operated in and near the analysis regions during 1986-91.

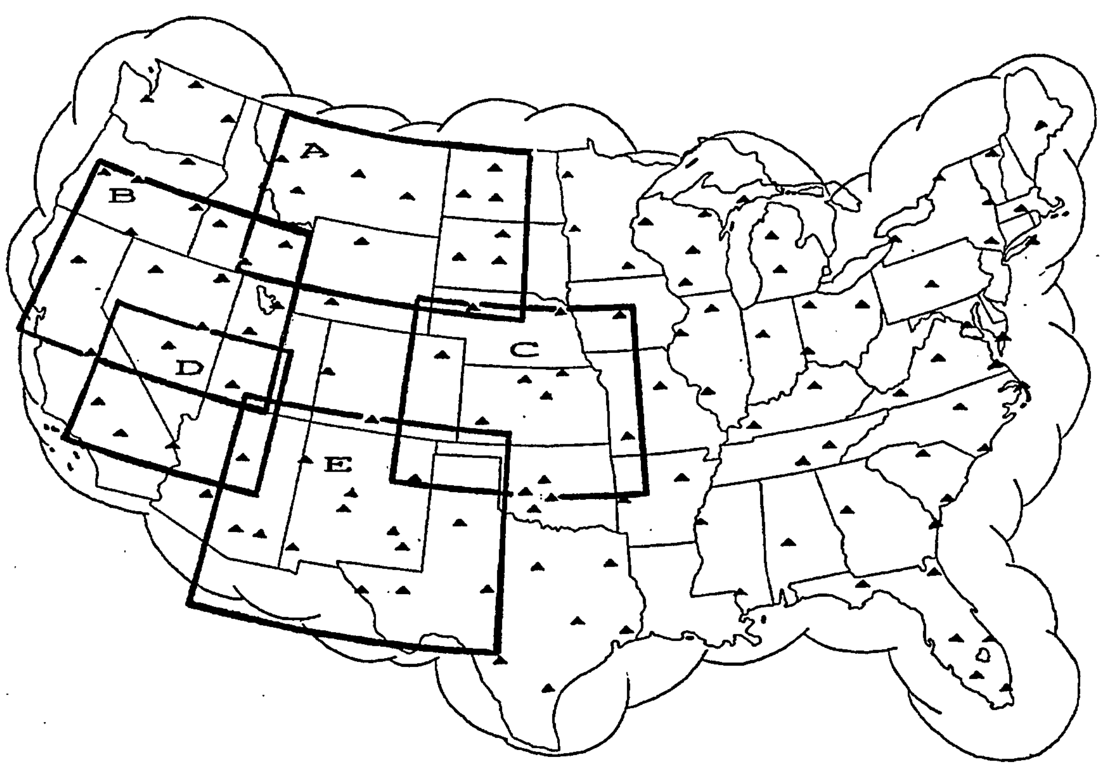

Figure 2. Lightning direction finder locations. Triangles represent approximate locations of NLDN direction finders that operated across the United States during 1986-91. The analysis regions are shown in bold lines as in Figure 1. Scalloping shows the nominal range of 215 nautical miles. Source: GDS (personal communication).

2.2 Lightning Data Limitations. Most evaluations of CG lightning-strike data quality include discussions of detection efficiency and strike location accuracy. The period of record is also important for a representative database.

2.2.1 Detection Efficiency. The detection efficiency is the ratio of the number of CG strikes detected to the number that actually occurred. It is primarily a function of the range or the distance of a strike from the direction finders. MacGorman et al. (1984), reported detection efficiencies of 70 to 85 percent for strikes within 54 nm of direction finder networks in Oklahoma and Florida. Over the NLDN, a detection efficiency of 70 percent is estimated for strikes within a 215-nautical mile range of direction finders (Orville et al., 1990). Beyond that nominal range, strikes are still detected, but at less efficiency. For the present work, Figure 2 shows that during 1986-91 all of the analysis regions were well within the nominal range for a 70-percent lightning detection efficiency.

2.2.2 Location Accuracy. Like detection efficiency, the strike location accuracy depends on the range of the strike; but it also depends on the number of direction finders that record the strike, the distance between direction finders, and where the strike occurs in relation to the direction finders (Maier et al., 1983). According to GDS, the lightning strike locations are generally accurate to within 1 to 2 nautical miles.

2.2.3 Period of Record. As previously stated, the period of record for the CG lightning-strike data was 6 years for two of the analysis regions, and 4 years for the others (see Table 1). In a recent study that compared CG lightning strikes to thunder events, Changnon (1993) showed that due to the high interannual variability in lightning strikes, a short period of record may not be representative of longer-term conditions. For that reason, the average hourly lightning-strike values presented in this work are considered marginally representative as compared to values that could be obtained from a longer period of record. Orville (1991) suggested that at least 10 years of lightning-strike data may be necessary to produce a truly representative climatology.

2.3 Upper-Air Data. Atmospheric soundings from AFCCC's DATSAV Upper-Air database, described in USAFETAC/TN—77-2, *USAFETAC DATSAV Data Base Handbook* (1977), were used to obtain 700-mb wind data. Three upper-air sites were selected for each analysis region, except Region E which had six, as shown in Table 1.

2.4 Upper-Air Data Limitations. Upper-air observations were available only twice daily at 0000Z and 1200Z. No attempt was made to interpolate upper-air variables from those times to other hours of the day. As described in Chapter 3, it was assumed that the upper-air data for 0000Z was valid for lightning strikes that occurred from 1800Z to 0559Z. Similarly, upper-air data for 1200Z was assumed valid for strikes that occurred from 0600Z to 1759Z. Obviously, those assumptions ignore upper-air changes between soundings, but the changes are usually considered small. The data used in this work was decoded and validated for data elements, but no further quality control was done.

Table 1. Graphics program names, upper-air sites, and periods of record for lightning-strike and upper-air data for each low-level region shown in Figure 1.

Region	Program Name	Upper-Air Sites	Period of Record
A	Montana	Rapid City, SD (RAP) Glasgow, MT (GGW) Bismarck, ND (BIS)	Mar-Oct, 1988-91
B	Nevada	Winnemucca, NV (WMC) Ely, NV (ELY) Boise, ID (BOI)	Mar-Oct, 1986-91
C	Kansas	Dodge City, KS (DDC) Topeka, KS (TOP) North Platte, NE (LBF)	Mar-Oct, 1988-91
D	Nellis	Desert Rock, NV (DRA) Ely, NV (ELY) San Diego, CA (NKX)	Mar-Oct, 1986-91
E	Holloman	North of 33°N: Albuquerque, NM (ABQ) Winslow, AZ (INW) Amarillo, TX (AMA) South of 33°N: El Paso, TX (ELP) Tuscon, AZ (TUS) Midland, TX (MAF)	Mar-Oct, 1988-91

Chapter 3

METHODOLOGY

3.1 Lightning Data Preparation. The following numbers of CG lightning-strike observations were extracted from AFCCC's relational database for the analysis regions and periods of record shown in Table 1: A - 1,814,436; B - 2,218,983; C - 5,354,784; D - 1,771,486; and E - 6,082,312. Each lightning observation contained the year, month, day, hour, minute, and latitude and longitude in decimal degrees. The datasets of lightning observations were sorted by year, month, day, and hour for merger with the upper-air data. After sorting, each hour included lightning strikes that occurred on that hour and during the 59 minutes after that hour. For example, lightning strikes for 1800Z included all that occurred from 1800Z to 1859Z.

3.2 Upper-air Data Preparation. Within each analysis region, data for the three upper-air sites shown in Table 1 were considered representative of the entire region, except for Region E where the first three sites were used for the part north of 33°N, and the last three for the other part. Using three upper-air sites minimized the number of times with missing 700-mb wind data. Data for the first upper-air site had priority. If data was missing for any day and time, data for the second site was used. Similarly, if data for the second site was missing, data for the third site was used. The 700-mb wind direction and speed in knots for 0000Z and 1200Z were extracted to build an upper-air dataset for each analysis region. The upper-air datasets were sorted by year, month, day, and hour for merger with the lightning datasets.

3.3 Wind Stratified Lightning Dataset. To stratify by 700-mb wind direction categories, the datasets of lightning and upper-air observations for each region were merged based on the following conditions:

- Lightning observations between 0600Z to 1759Z were matched with the 1200Z upper-air observations.
- Lightning observations between 1800Z the previous day to 0559Z were matched with the 0000Z upper-air observations.

After merging the datasets, every lightning observation for each analysis region contained a 700-mb wind direction and speed, including missing values. Those lightning observations that contained missing wind direction and speed were deleted, since a wind direction category could not he assigned. The effect on the original number of lightning-strike observations for each region was minimal, because less than five percent of the observations were deleted.

3.3.1 Wind Direction Categories. The 700-mb wind direction and speed in each lightning-strike observation was used to assign one of nine wind direction categories to each observation. The first category, C (calm), was assigned to an observation if the wind speed was less than 5 knots regardless of wind direction. The other eight categories: N (north); NE (northeast); E (east); SE (southeast); S (south); SW (southwest); W (west); and NW (northwest) were assigned if the speed was equal to or greater than 5 knots, and the direction was within the following ranges:

- N - direction between 340° and 360° or direction between 000° and 020°
- NE - direction equal to or greater than 021° but less than 070°
- E - direction equal to or greater than 070° but less than 115°
- SE - direction equal to or greater than 115° but less than 160°
- S - direction equal to or greater than 160° but less than 205°
- SW - direction equal to or greater than 205° but less than 250°
- W - direction equal to or greater than 250° but less than 295°
- NW - direction equal to or greater than 295° but less than 340°

3.4 Wind Frequency Distribution Dataset. The upper-air data for the primary upper-air site in each region (El Paso for all of Region E) was used separately to produce frequency distributions by month and hour for the nine 700-mb wind direction categories. Every 0000Z and 1200Z upper-air observation with reported 700-mb wind direction and speed was used to determine the category. Next, the total for all years and the annual average were calculated for each category by month and hour. Then the total for all years was calculated for all nine categories by month and hour. The percent occurrence frequency (POF) for each category by month and hour was calculated as follows:

POF = all-years total each category/all-years total all categories (1)

A dataset was built for each region that contained the annual average number of occurrences and POF for each wind category by month for either 0000Z or 1200Z. Each dataset was used to display 700-mb wind direction frequency distribution charts in the applicable lightning graphics program described in Chapter 4.

3.5 The Grid System. To prepare the wind stratified lightning dataset for each region for summarization at a horizontal resolution of approximately 10 nm, each analysis region in Figure 1 was divided into a grid system with the grid point spacing and numbers of individual grid boxes as shown in Table 2. A partial sketch of the grid system for Region E (Holloman) is shown in Figure 3 for reference. To simplify analysis, the grid boxes were assumed to be square. Actually, the distances between degrees of latitude on the earth vary little from pole to equator, while the distances between degrees of longitude increase from pole to equator. Therefore, the real areas enclosed by grid boxes in each region are not square and increase from north to south. As a result, a bias exists for slightly higher counts of strikes in grid boxes at lower latitudes within each region. However, for purposes of this analysis the bias is considered minor.

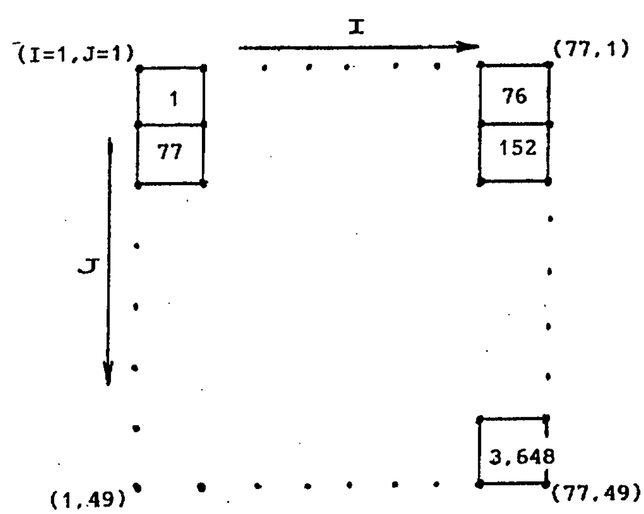

Figure 3. Sketch of the grid system for Region E (Holloman).

3.6 Gridding the Data. To obtain values for the total strikes in individual grid boxes within each analysis region, a grid box number was calculated and assigned to each lightning observation by first converting the latitude and longitude of the strike from degrees to minutes. From procedures given in Hoke et al. (1985), the following equations were used to calculate the grid-point Cartesian coordinates (x,y) for each lightning observation:

$$x = \{(LON1 - LONMIN)/MIN\} + 1 \qquad (2)$$

$$y = \{(LATl - LATMIN)/MIN\} + 1 \qquad (3)$$

where:

LATMIN = latitude of lightning strike in minutes

LONMIN = longitude of lightning strike in minutes

LATl = latitude in minutes at upper-left corner of grid system

LONl = longitude in minutes at upper-left corner of grid system

Next, grid-point indexes (I,J) were defined as follows:

$$I = INT(x) \qquad (4)$$

$$J = INT(y) \qquad (5)$$

where: The operator INT acts to keep only the whole part of the numbers for x and y. Lastly, the grid box number (BOXNUM) for each lightning observation was calculated from the following:

$$BOXNUM = I + \{SIDEBOX(J-l)\} \qquad (6)$$

where: SIDEBOX is the number of grid boxes in the east-west direction. As an example, using Region E (Holloman) and referring to Table 2, the upper-left corner of Region E is located at 37°21'N/112°26'W. From equations 2 through 5, the values of I and J for that point are both one. From equation 6, where SIDEBOX equals 76 for Region E, the grid box number for a lightning strike at that point is one. As shown in Figure 3, the index I varies from 1 on the left side of the grid system to 77 on the right side. The index J varies from 1 at the top to 49 at the bottom. The grid box numbers increase from 1 in the upper-left corner to 76 in the upper-right corner, and so on to box number 3,648 in the lower-right corner. Once the above gridding procedure was complete for each analysis region, every lightning-strike observation had a grid box number for identification.

3.7 Lightning Data Summarization. The dataset of lightning stratified by 700-mb wind direction categories for each analysis region was summarized to obtain the average number of strikes for each grid box by month, hour, and wind direction category. As a result, every grid box in each analysis region had a wind stratified lightning-strike climatology for use in the graphics program discussed in the next chapter.

Table 2. Grid spacing in minutes of latitude or longitude, total number of grid boxes, and coordinates in degrees and minutes of the upper-left corner for each analysis region.

Region	Grid Spacing	Grid Boxes	Coordinates
A	12	2660	49°00'N/114°12'W
B	11	2640	44°20'N/123°06'W
C	11	2640	42°20'N/105°06'W
D	10	1782	39°34'N/119°32'W
E	10	3648	37°21'N/112°26'W

Chapter 4

LIGHTNING CLIMATOLOGY AND RESULTS

4.1 The Lightning Graphics Program. A microcomputer graphics program was written for each analysis region to interactively display the lightning climatologies. The minimum requirements to run the program are: IBM or IBM-compatible machine with an 80286 processor or higher; 640 KB of memory; MS-DOS version 3.2 or later; EGA, VGA, or compatible display; Epson-compatible dot matrix or HP Laser Jet printer for hard copies, and 8 MB to 15 MB of hard-drive space.

4.1.1 Program Particulars. Before describing the graphics displays, a few particulars about the program follow:

- For consistency, average hourly CG lightning-strike values are displayed throughout the program. If several months and (or) hours are selected for a display, the average hourly values collected by the program for the display are divided by the number of months and hours, so that the displayed values are always hourly averages.

- The program uses the average hourly lightning-strike value for a grid box at a grid point defined by the upper-left corner of the grid box.

- If several grid boxes are selected for a graph or table, the value displayed is the sum of the average hourly values for the grid boxes. Thus, area averages are displayed.

- In contrast to graph and table displays, isopleth analyses display contours of the average hourly lightning strikes based on each grid point (grid box) value.

- All hours are shown in Zulu (Greenwich Mean Time). To obtain Central Standard Time (CST) subtract 6 hours from Zulu; for Mountain Standard Time (MST), subtract 7 hours from Zulu; and for Pacific Standard Time (PST) subtract 8 hours from Zulu.

4.1.2 Graphics Displays. The lightning graphics program uses the wind stratified lightning-strike climatology and 700-mb wind direction climatology for each analysis region to present several displays. The displays include bar graphs, tables, and isopleth analyses as listed below:

- Bar Graphs of the diurnal variations of the average hourly lightning strikes by hour (0000Z-2300Z). One, several, or all grid boxes; months; and 700-mb wind direction categories may be selected.

- Bar graphs of the variations of average hourly lightning strikes by 700-mb wind direction categories (Calm, N, NE, E, SE, S, SW, W, and NW). One, several, or all grid boxes; months (Mar-Oct); and hours (0000Z-2300Z) may be selected.

- Bar graphs of the annual average number and percent occurrence frequencies of 700-mb wind direction categories for an entire region for 0000Z and 1200Z. One, several, or all months may be selected. These graphs are based on the following data for each region:

  Rapid City, S.D. data for Region A (Montana)

  Winnemucca, Nev. data for Region B (Nevada)

  Dodge City, Kan. data for Region C (Kansas)

  Desert Rock, Nev. data for Region D (Nellis)

  El Paso, Texas data for region E (Holloman)

- Tables of the average hourly lightning strikes for each 700-mb wind direction category and all categories, for each month, and for all months. One, several, or all grid boxes and hours may be selected.

- Isopleth analyses of the average hourly lightning strikes over the entire area. One, several, or all months, hours, and 700-mb wind direction categories may be selected.

- Another feature allows the user to plot routes and display their climatologies, or include routes for reference in isopleth analyses.

4.2 Examples of Diurnal Lightning-Strike Variations. To illustrate diurnal variations in lightning strikes, an area around Holloman AFB, N.M., in Region E was selected. The month of August was chosen since it has the highest thunderstorm frequency as shown in the *Surface Observation Climatic Summaries (SOCS)* for Holloman AFB (1992). An area centered on Holloman AFB, consisting of six grid boxes on each side and about 3,600 square nautical miles, was used to obtain the graph shown in Figure 4 for all 700-mb wind direction categories. Figure 4 shows that most lightning strikes occur between 1700Z (1000 MST) and 0800Z (0100 MST). The highest average value (about 650) at 2000Z (1300 MST) agrees closely with the SOCS for Holloman AFB (1992) which shows that the highest frequency of thunderstorms reported on hourly observations at Holloman AFB occurs from 1500 MST to 1700 MST.

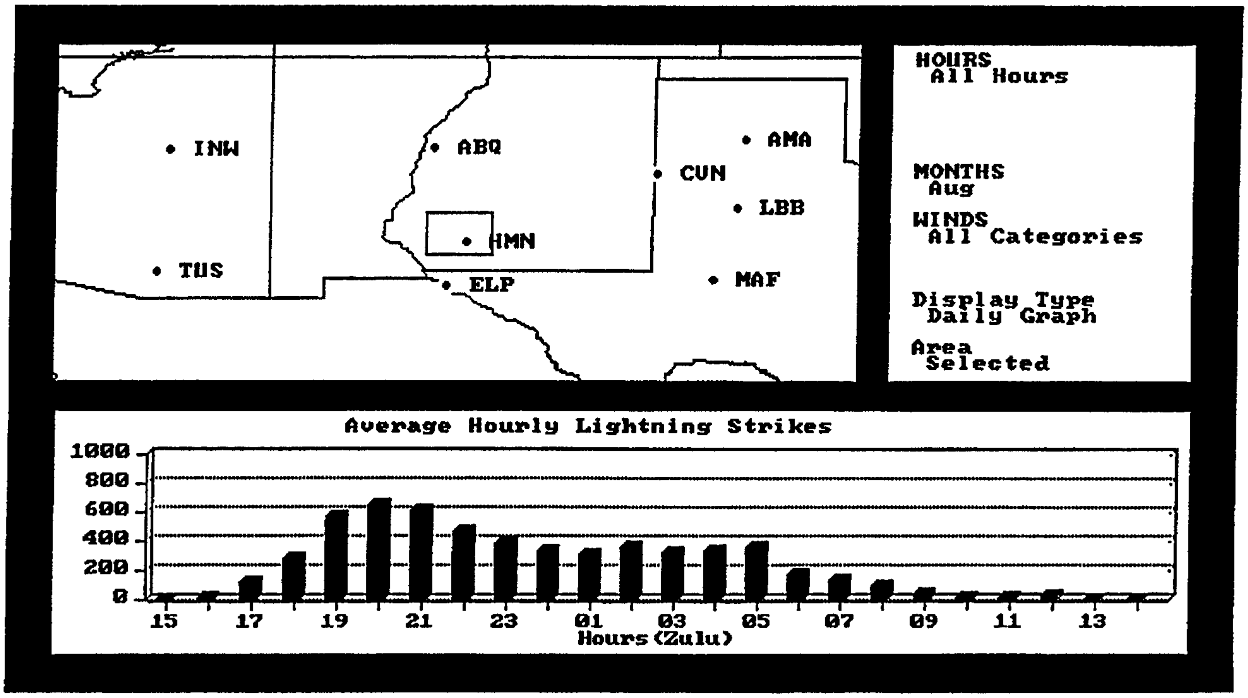

Figure 4. Diurnal variations in lightning strikes around Holloman AFB, N.M. during August. Graph starts at 0800MST (1500Z) and shows average hourly lightning strikes for all 700-mb wind directions within an area of about 3,600 square nautical miles centered on Holloman AFB (HMN).

4.3 Monthly Lightning-Strike Variations. An example of monthly lightning-strike variations was taken from Region D (Nellis). It is well known that most thunderstorms occur over the southwestern United States during the summer months of July, August, and September. The SOCS for Nellis AFB, Nev. (1992) shows that for all hours and all months, the frequency of thunderstorms based on hourly observations increases to a maximum in August with the highest frequencies in July through September. A similar trend occurs in the monthly variations of average hourly lightning strikes. To illustrate this, an area centered on Nellis AFB (LSV), Nev., consisting of six grid boxes on each side and about 3,600 square nautical miles (Figure 5), was used to obtain Table 3. As seen in Table 3, the months of July through September have the highest average hourly lightning strikes based on all 700-mb wind direction categories, with the maximum in August. The table also shows a predominance of strikes when the 700-mb winds are from the south and southwest, especially during the summer.

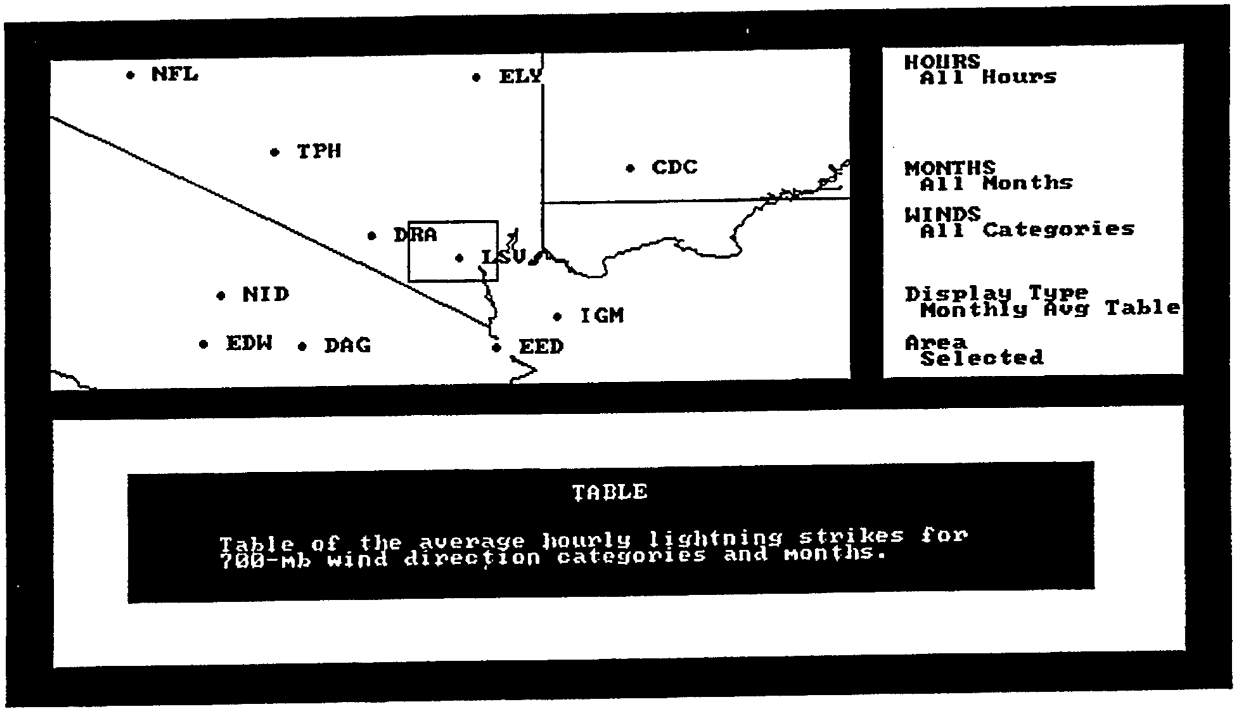

Figure 5. Microcomputer screen view from the Nellis lightning graphics program. Nellis AFB (LSV) is shown centered within an area of about 3,600 square nautical miles. The area was selected for a table display of average hourly lightning strikes for all 700-mb wind direction categories and months.

Table 3. Monthly variations in average hourly lightning strikes by 700-mb wind directions for all hours around Nellis AFB, Nev. The area of analysis is shown in Figure 5.

Table of Average Hourly Lightning Strikes

700-mb Wind Direction

For 0-23 Hours Zulu

	CALM	N	NE	E	SE	S	SW	W	NW	ALL
MAR	0	0	0	0	0	0	1	0	0	1
APR	0	0	3	0	2	3	1	1	0	10
MAY	0	0	0	3	1	2	4	4	2	16
JUN	0	0	0	1	6	6	7	1	0	21
JUL	4	1	0	11	2	32	12	3	32	97
AUG	0	4	0	18	7	62	55	4	2	152
SEP	3	1	5	4	7	12	20	4	3	59
OCT	0	0	0	0	1	3	0	1	0	5
NOV	0	0	0	0	5	1	0	0	0	6
DEC	0	0	0	0	0	0	0	0	0	0
ALL	7	6	8	37	31	121	100	18	39	367

4.4 Wind Stratified Lightning Climatology Example. The month of August was chosen to illustrate the wind stratified lightning-strike climatology from Region B (Nevada). Locations in that region also experience a maximum of lightning strikes in August. An area centered on Mountain Home AFB (MUO), Idaho, consisting of six grid boxes on each side and about 3,600 square nautical miles (see Figure 6), was used to obtain Figure 7. As shown in Figure 7, for the hours of highest average strikes from 2000Z (1300MST) to 2300Z (1600MST), the 700-mb winds were mostly from the southwest when the highest value of average hourly lightning strikes occurred.

4.5 Wind Direction Frequencies. As an example of the frequency distribution graphs of 700-mb wind directions, Region A (Montana) was used as shown in Figure 8 for July. The graphs shown in Figure 9, based on data from Rapid City, S.D., show that the most frequent 700-mb wind directions in Region A during July are from the southwest to northwest.

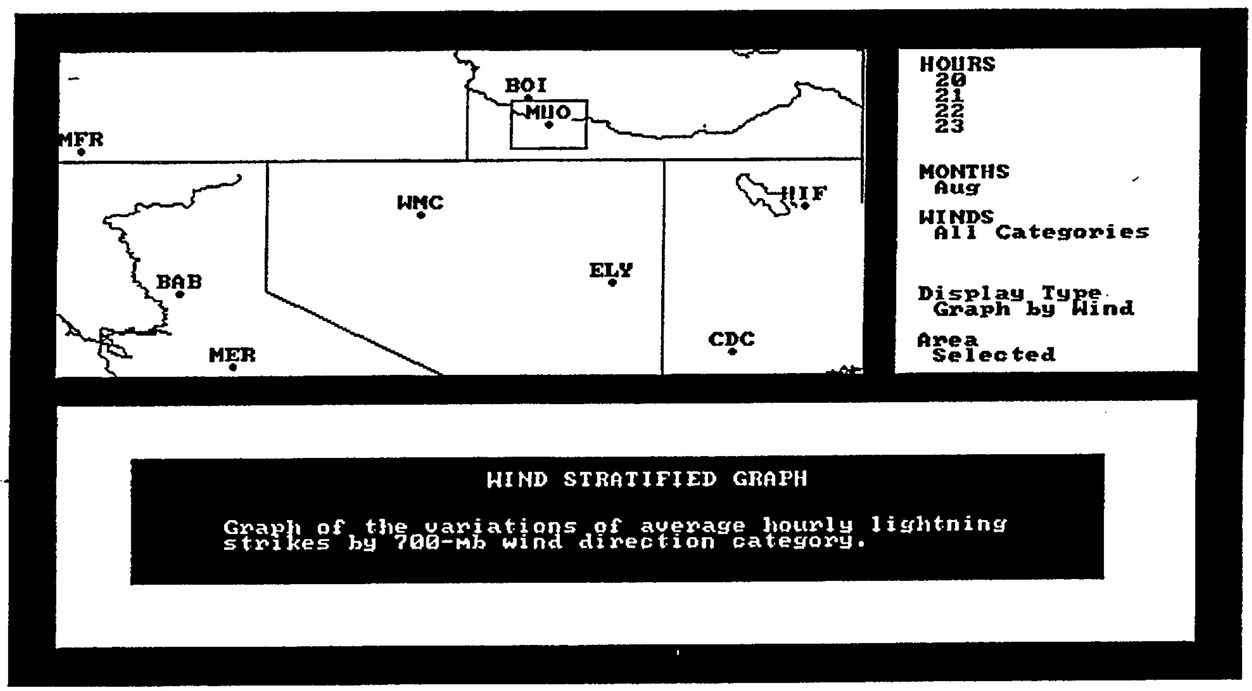

Figure 6. Microcomputer screen view from the Nevada lightning graphics program. Mountain Home AFB (MUO) is shown near the top, centered within a 3,600 square-nautical-mile area. The area was selected to display average hourly lightning strikes by 700-mb wind direction for the hours from 2000Z (1300MST) to 2300Z (1600MST) during August.

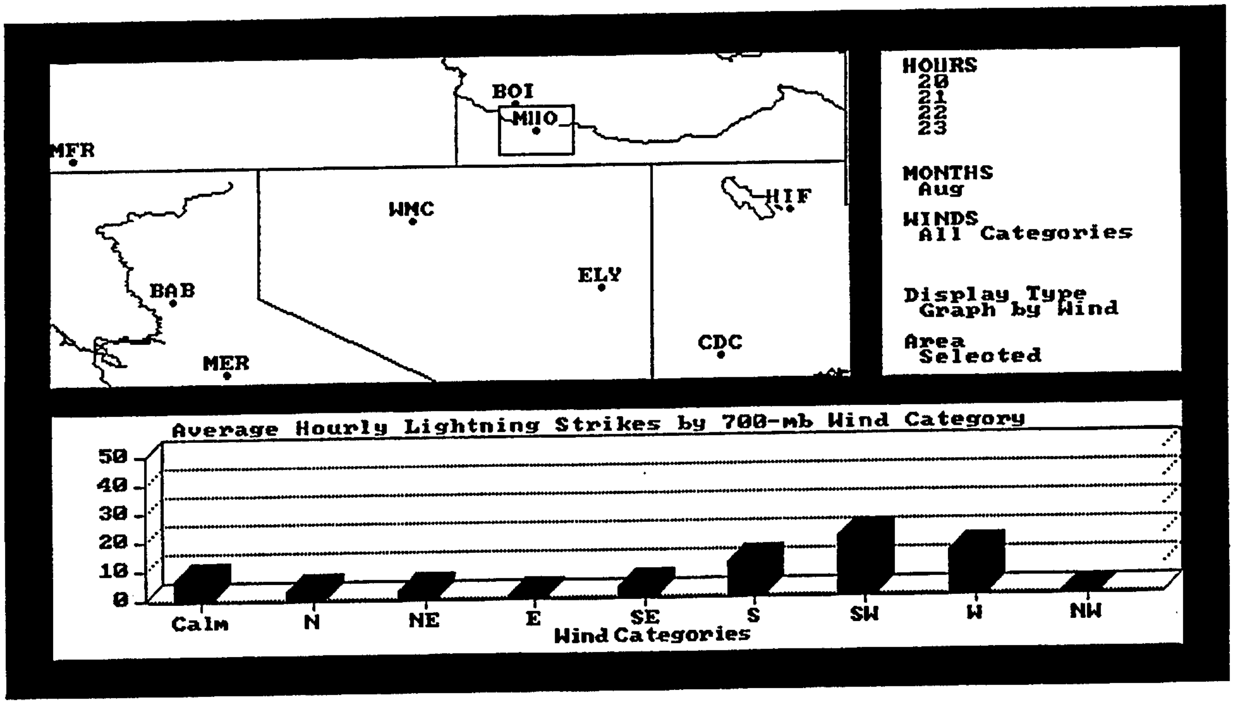

Figure 7. Graph of variations in average hourly lightning strikes by 700-mb wind directions from 2000Z (1300MST) to 2300Z (1600MST) during August around Mountain Home AFB, Idaho. The area of analysis is as described in Figure 6.

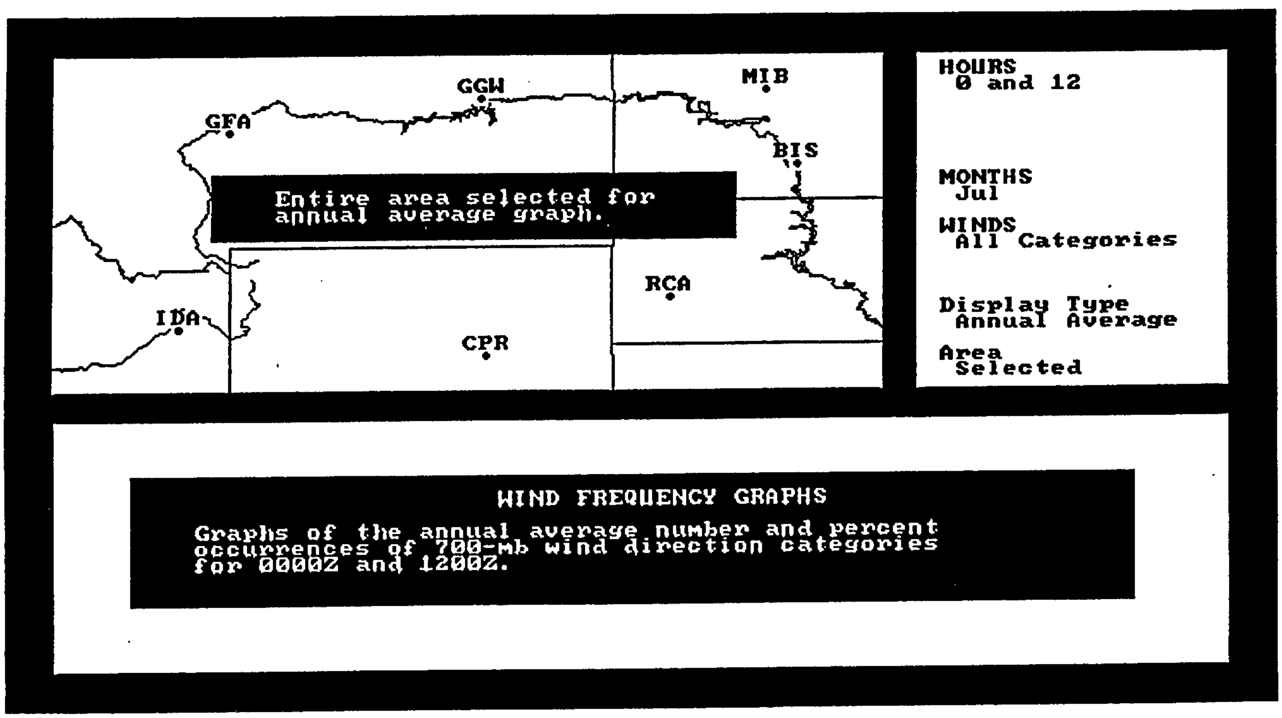

Figure 8. Microcomputer screen view from the Montana lightning graphics program. The entire region is automatically selected to display the annual average number and percent occurrence frequencies of 700-mb wind directions for 0000Z and 1200Z in July.

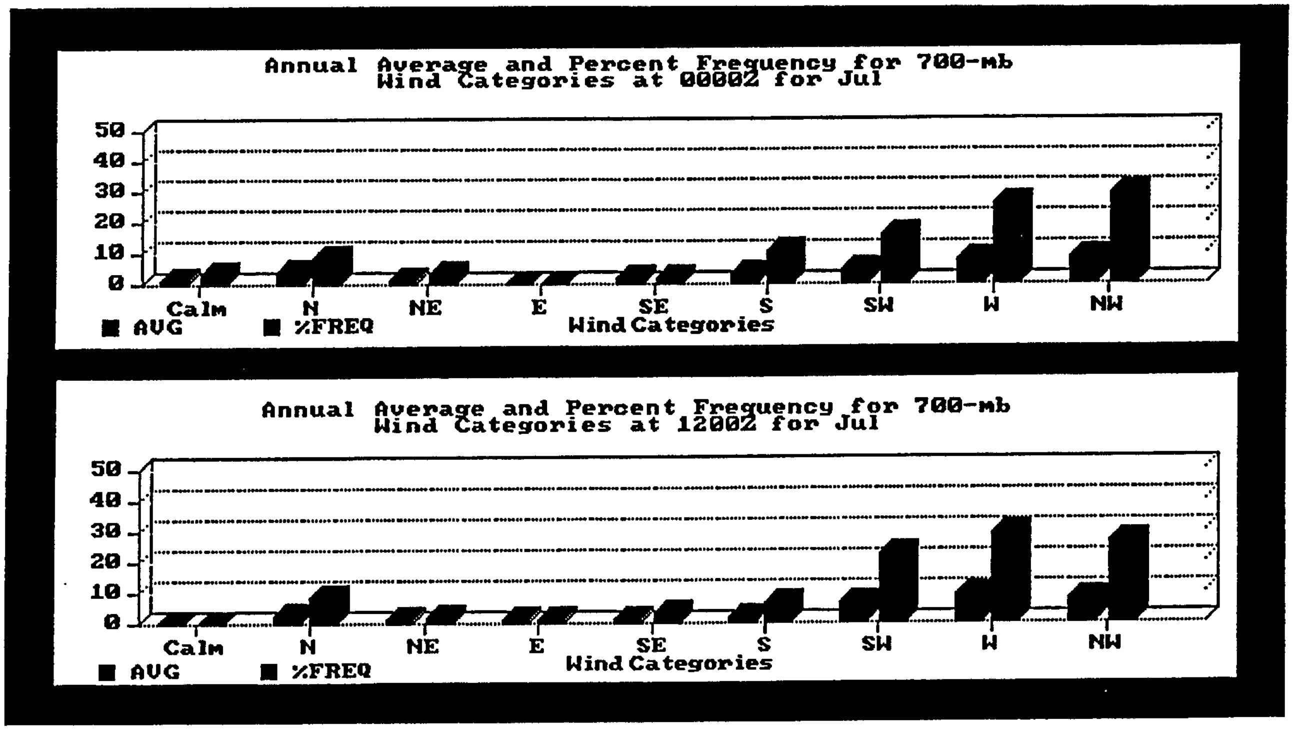

Figure 9. Graphs of the annual average and percent frequency for 700-mb wind categories at 0000Z and 1200Z in July over Region A (Montana). At each 700-mb wind direction category, the left-hand bar is the annual average count and the right-hand bar is the percent occurrence frequency.

4.6 Regional Lightning-Strike Patterns. Isopleth analyses of the average hourly lightning strikes in each region were examined to compare lightning-strike patterns to known thunderstorm patterns. Examples are presented to show how well the lightning-strike patterns compare to patterns in mean monthly thunderstorms. As a thunderstorm climatology reference, the work by Changery (1981) was used in which he produced a comprehensive climatology of mean monthly and annual thunderstorms for the United States. The climatology was based on 10 to 30 years of record for individual thunderstorm beginning and ending times at 450 primary stations that took observations 24 hours a day. An example is also given to show how the 700-mb wind direction influences lightning-strike locations and movements of lightning patterns.

4.6.1 Region A (Montana) Patterns. Analyses of the diurnal variations in average hourly lightning strikes over Region A in July, based on all 700-mb wind directions, showed two distinct trends in lightning activity. In the first case, an analysis was made over the mountainous parts of Region A, roughly west of a line from Great Falls, Mont. (GFA) to Casper, Wyo. (CPR). Lightning-strike activity reaches a maximum at 2000Z (1300MST or 1400CST) in that area. In contrast, for the remainder of Region A over the high plains, lightning-strike activity reaches a maximum at 0200Z (1900MST or 2000CST). The hours of 2000Z and 0200Z, along with the most frequent 700-mb wind directions for 0000Z (1700MST or 1800CST) from Figure 9, were used to obtain the isopleth analyses in Figures 10 and 11. It is evident that the lightning-strike patterns in the western part of the analysis region (Figure 10) shift to the central and eastern parts (Figure 11) later in the day. In general, Figure 12 shows that the region averages about 12 thunderstorms in July, with the highest variability in the mountains (where the isopleths are most packed).

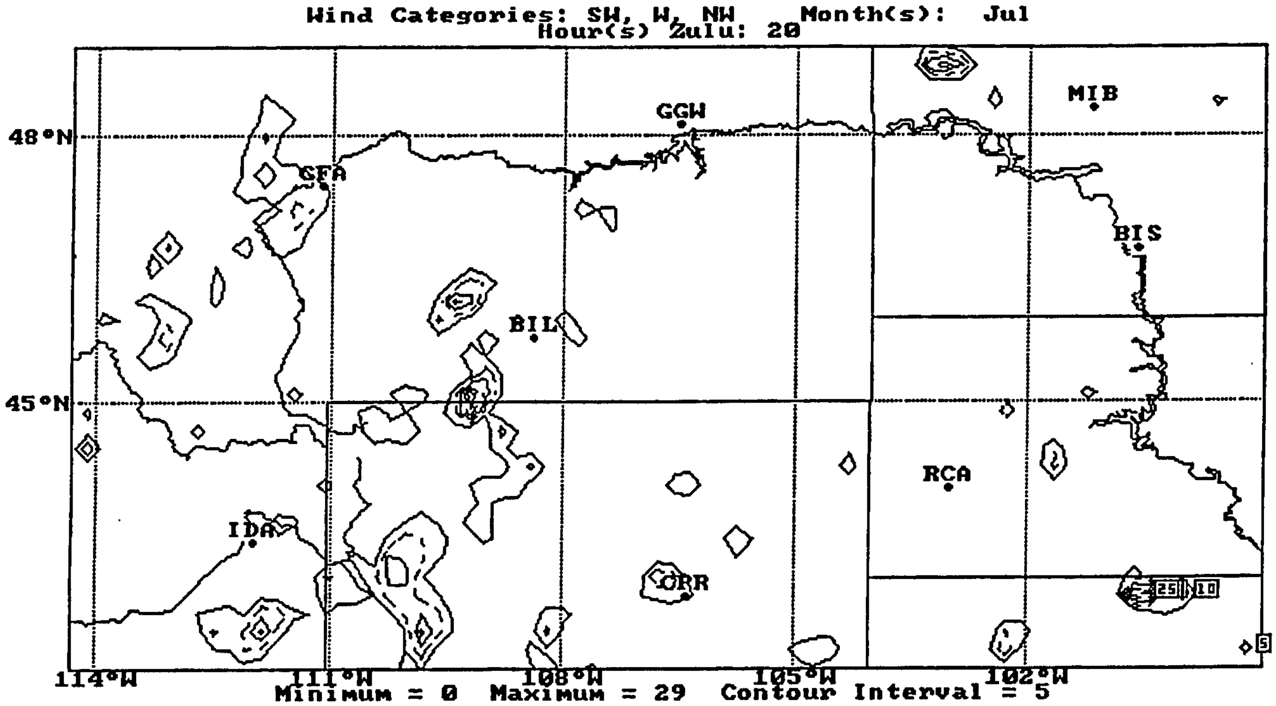

Figure 10. Isopleth analysis of the average hourly lightning strikes over Region A (Montana) during July for 2000Z (1300MST or 1400CST) with 700-mb winds from the southwest, west, and northwest.

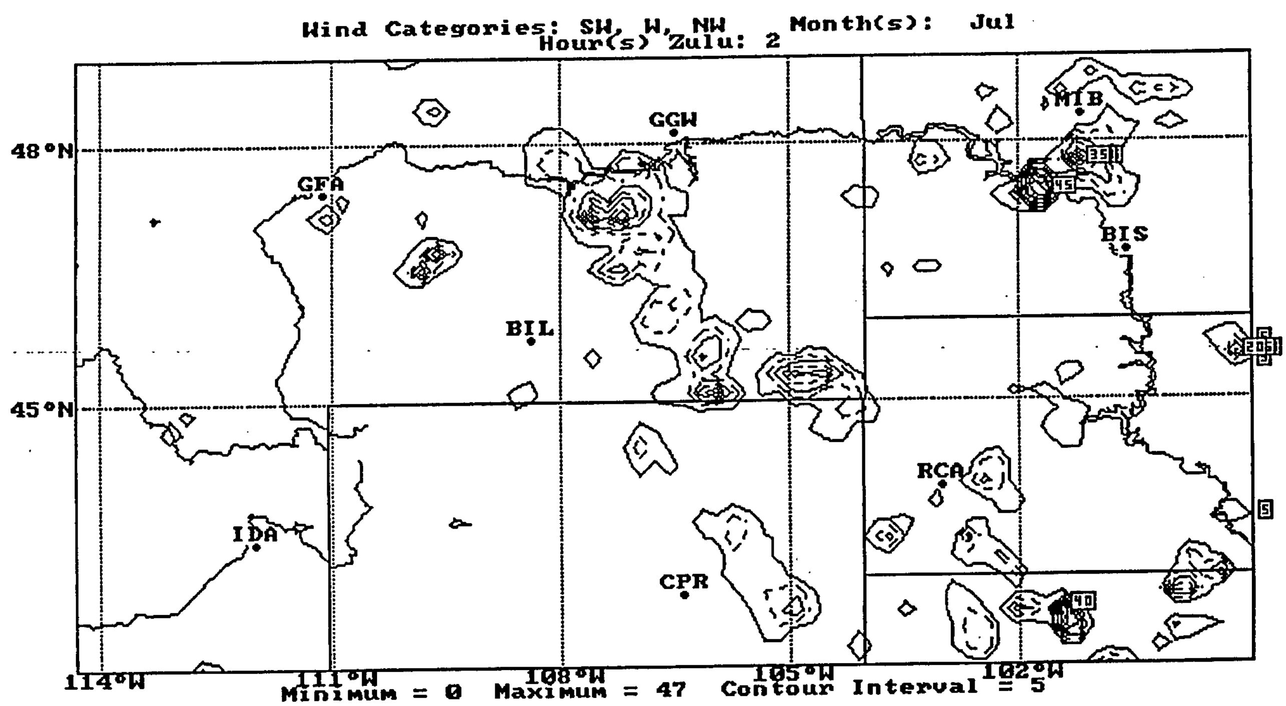

Figure 11. Isopleth analysis of the average hourly lightning strikes over Region A (Montana) during July for 0200Z (1900MST or 2000CST) with 700-mb winds from the southwest, west, and northwest.

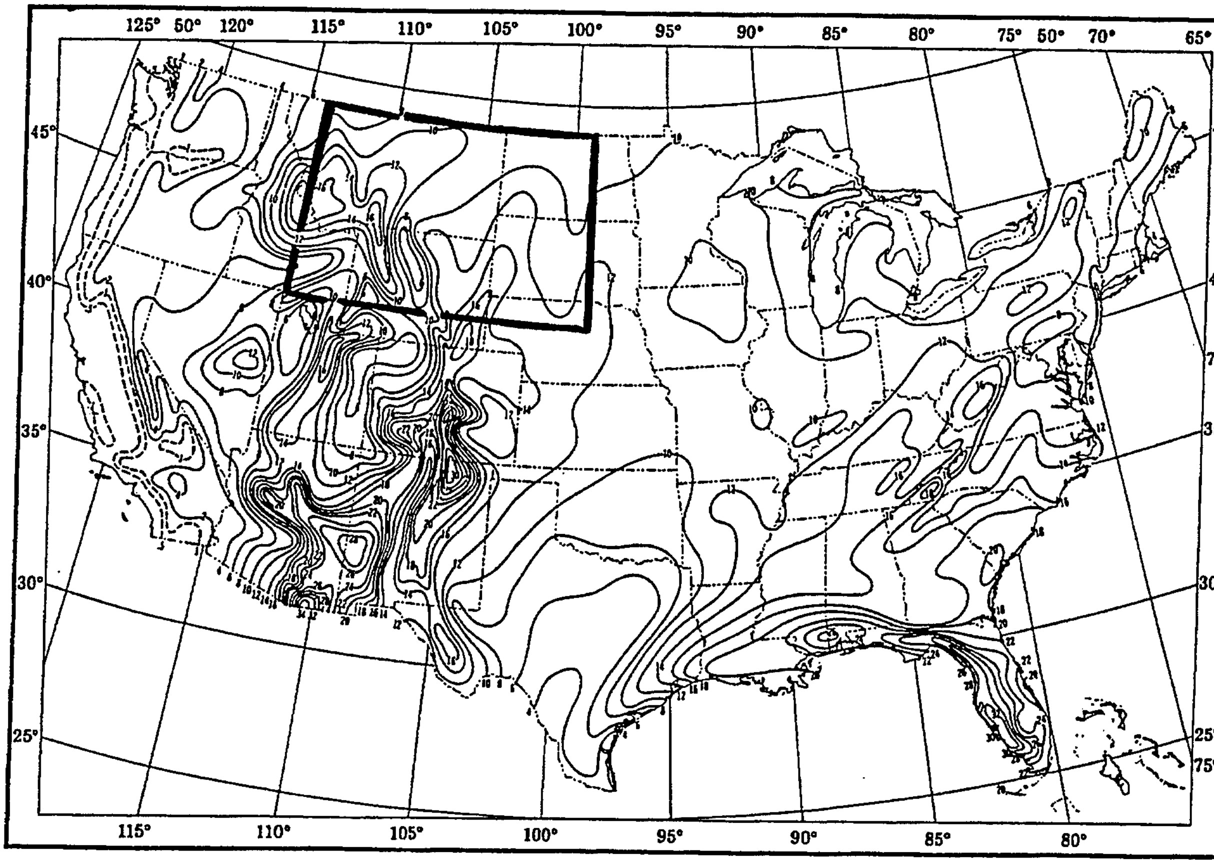

Figure 12. Analysis of the mean number of thunderstorms during July over the United States. Region A (Montana) is shown in bold lines. Adapted from Changery (1981).

4.6.2 Region B (Nevada) Patterns. In Nevada, a concentrated area of thunderstorms occurs in the east-central part of the state near Ely, especially during July and August. A graph of the diurnal variations in average hourly lightning strikes over east-central Nevada in July, based on all 700-mb wind directions, showed that lightning activity is highest from 1900Z (1100PST) to 2100Z (1300PST). Using those times to obtain a wind stratified graph for the same area, it was shown that most lightning strikes occurred when the 700-mb winds were from the southeast. The hours from 1900Z to 2100Z, and 700-mb winds from the southeast, in July were used to obtain the isopleth analysis in Figure 13. The lightning-strike pattern shows an area of maximum strikes near Ely, in excellent agreement with the pattern of mean thunderstorms shown in Figure 14.

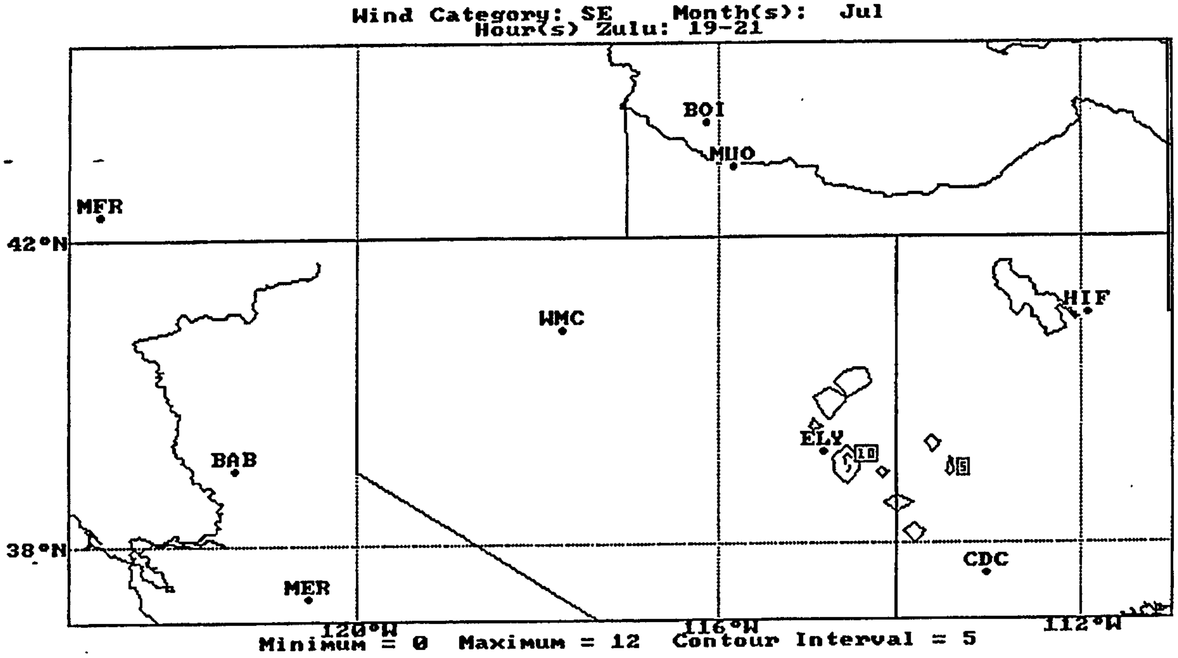

Figure 13. Isopleth analysis of the average hourly lightning strikes over Region B (Nevada) during July for 1900Z (1100PST) to 2100Z (1300PST) with 700-mb winds from the southeast.

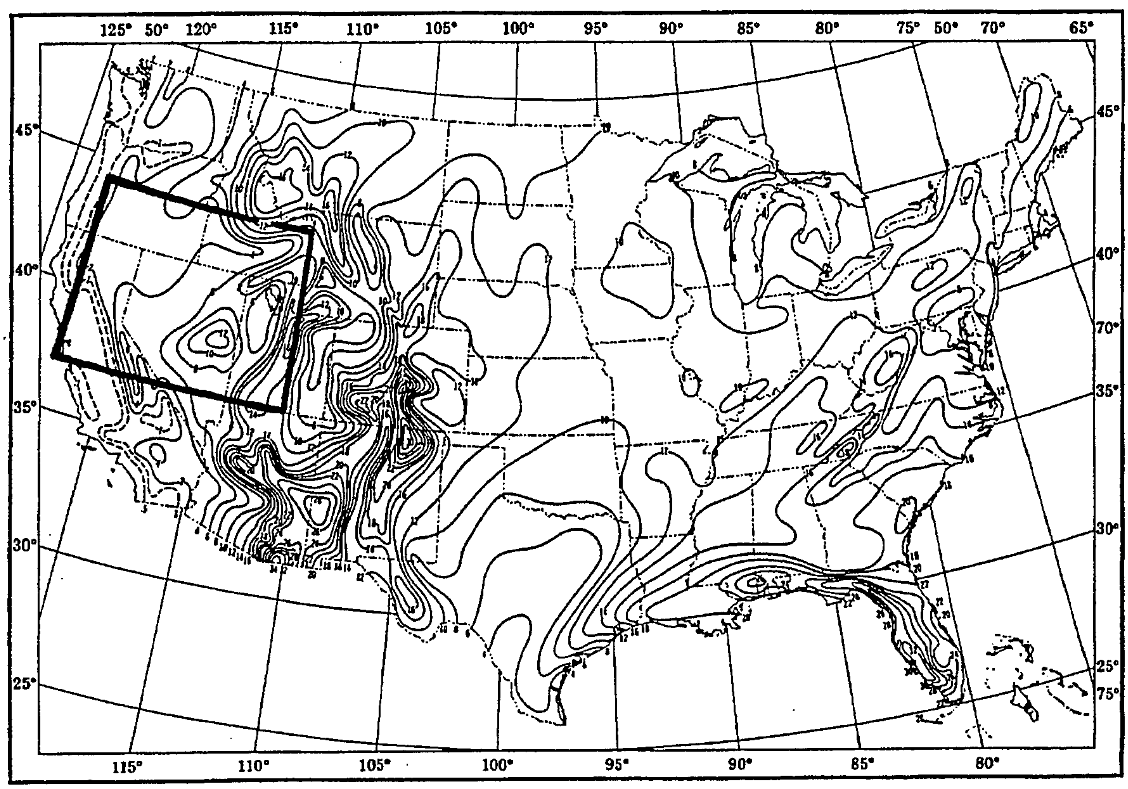

Figure 14. Analysis of the mean number of thunderstorms during July over the United States. Region B (Nevada) is shown in bold lines. Adapted from Changery (1981).

4.6.3 Region C (Kansas) Patterns. As an example for Region C, the month of June was used to compare lightning-strike patterns with an area of maximum thunderstorm activity in eastern Kansas and western Missouri. A graph of the diurnal variations in average hourly lightning strikes over that particular area, based on all 700-mb wind directions, showed that lightning activity is highest from 0100Z (1900CST) to 0500Z (2300CST). Those hours in June for all 700-mb wind directions were used to obtain the isopleth analysis in Figure 15. The area of lightning strikes between Topeka, Kan. (TOP) and Whiteman AFB, Mo. (SZL) agrees very well with the thunderstorm pattern shown in Figure 16.

4.6.4 Region D (Nellis) Patterns. Region D was analyzed for July to determine the hours and 700-mb wind directions associated with the most lightning activity. The analysis showed that 2200Z (1400PST) has the most lightning strikes with 700-mb winds from the southwest. The month of July at 2200Z with southwest winds at 700 mb was used to obtain the isopleth analysis in Figure 17. As seen in the lower-right part of Figure 17, an area of thunderstorms exists over west-central Arizona, east-southeast of Kingman (IGM). The same pattern exists in the mean thunderstorm analysis shown in Figure 18.

4.6.5 Region E (Holloman) Patterns. In a study by Gudencge et al. (1954), it was noted that summertime thunderstorms usually developed over the mountains to the west of Holloman AFB when lower tropospheric winds were from the southwest. An example is shown in Figure 19 for September at 0000Z (1700 MST) with 700-mb winds from the southwest. An area of lightning strikes is over the northwestern part of Holloman AFB (HMN). The lightning presumably originated with thunderstorm development over the mountains to the southwest through west, although no strikes were evident in the 2300Z (1600 MST) isopleth analysis. Later at 0100Z (1800 MST), as shown in Figure 20, an area of lightning strikes appears to the north of Holloman AFB. Apparently it is the same area of strikes as seen in Figure 11, but shifted northeastward by the southwest 700-mb winds. In another example, this time with the focus on lightning patterns over northeastern and southwestern New Mexico in July, analysis showed that lightning activity peaks around 2000Z (1300MST) when the 700-mb winds are from the south or southwest. The lightning-strike patterns are shown in Figure 21. Comparison with the mean monthly thunderstorm pattern for July over New Mexico in Figure 22 again shows excellent agreement.

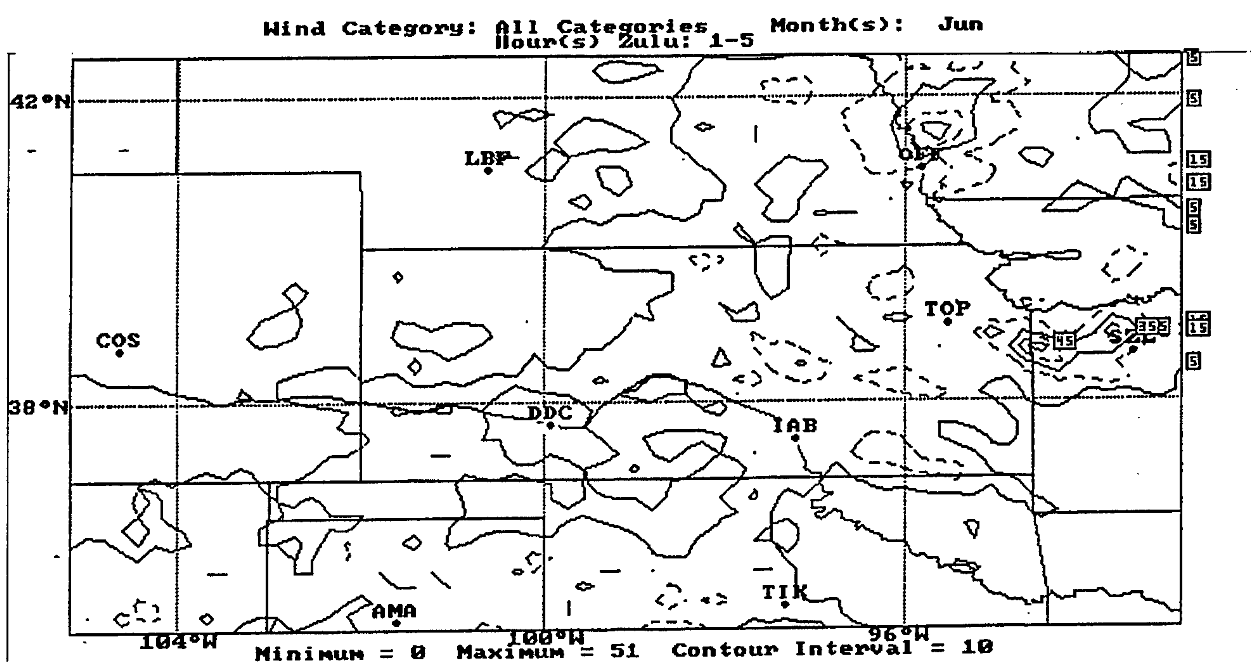

Figure 15. Isopleth analysis of the average hourly lightning strikes over Region C (Kansas) during June for 0100Z (1900CST) to 0500Z (2300CST) and all 700-mb wind directions.

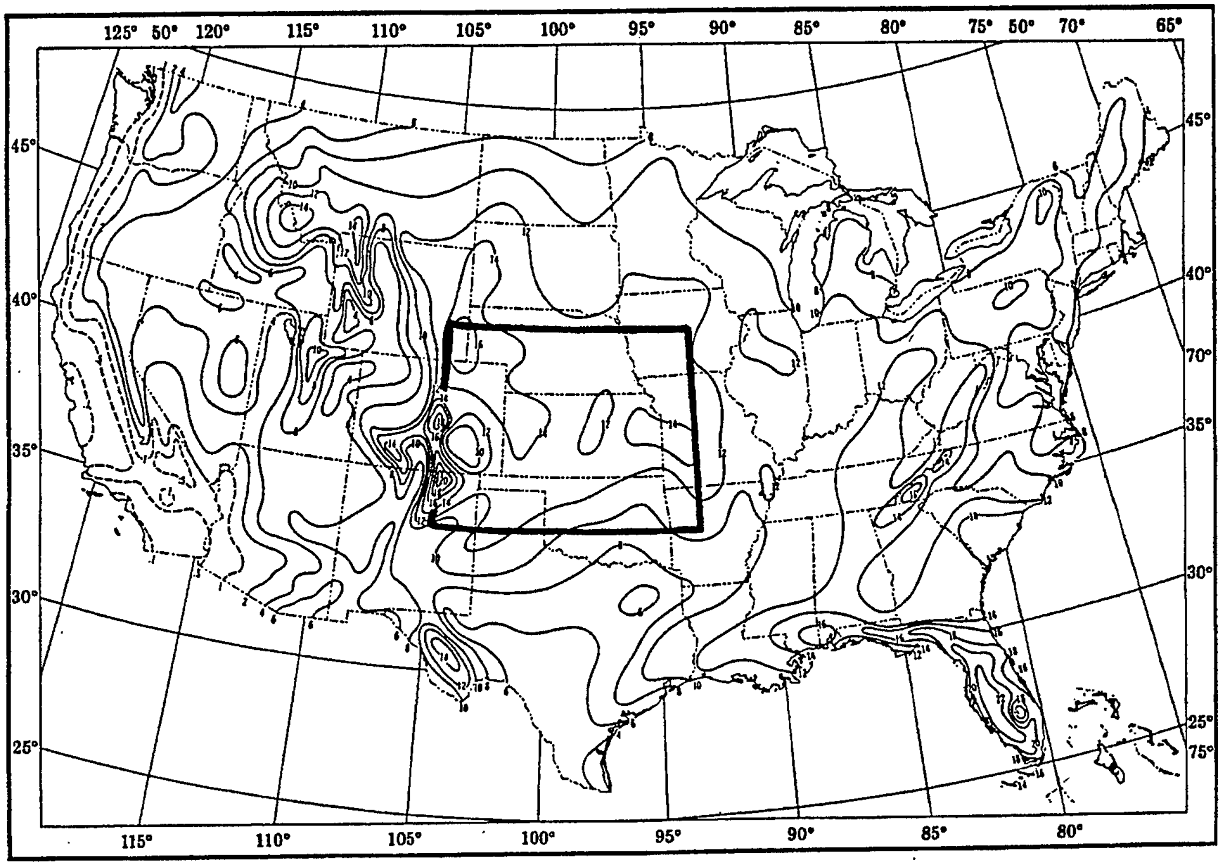

Figure 16. Analysis of the mean number of thunderstorms during June over the United States. Region C (Kansas) is shown in bold lines. Adapted from Changery (1981).

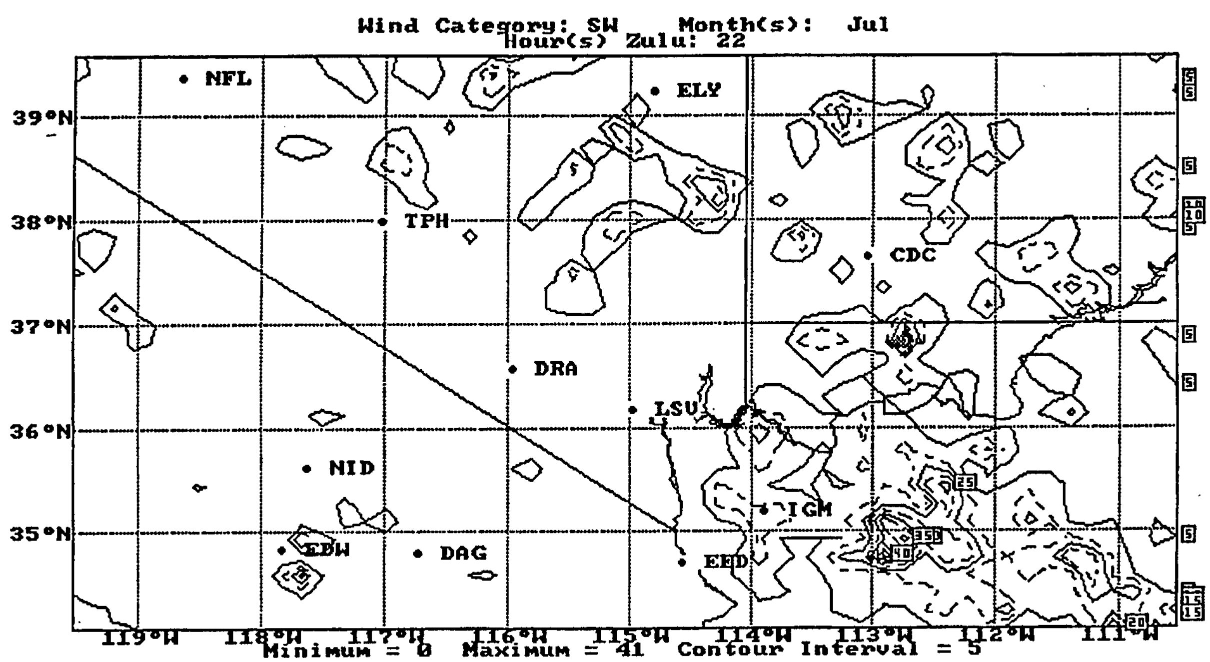

Figure 17. Isopleth analysis of the average hourly lightning strikes over Region D (Nellis) during July for 2200Z (1400PST) with 700-mb winds from the southwest.

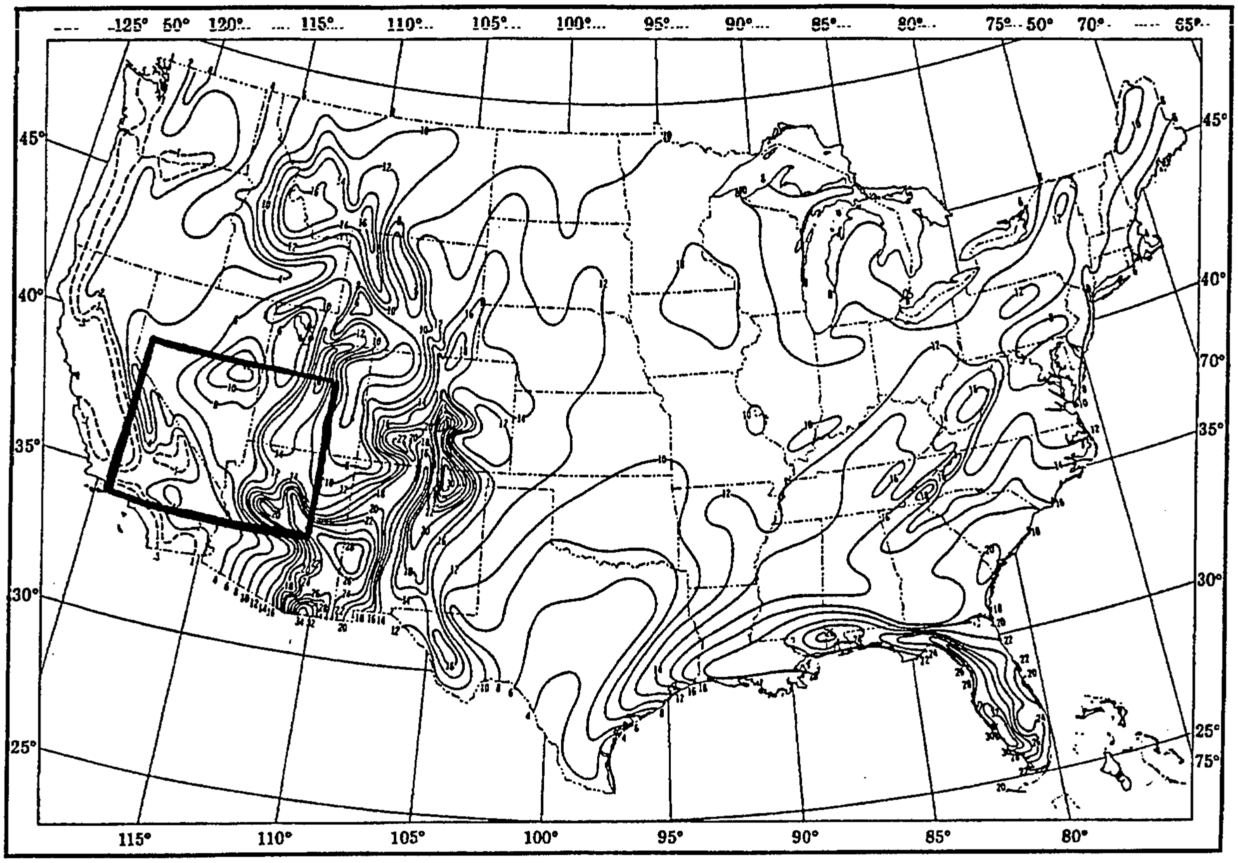

Figure 18. Analysis of the mean number of thunderstorms during July over the United States. Region D (Nellis) is shown in bold lines. Adapted from Changery (1981).

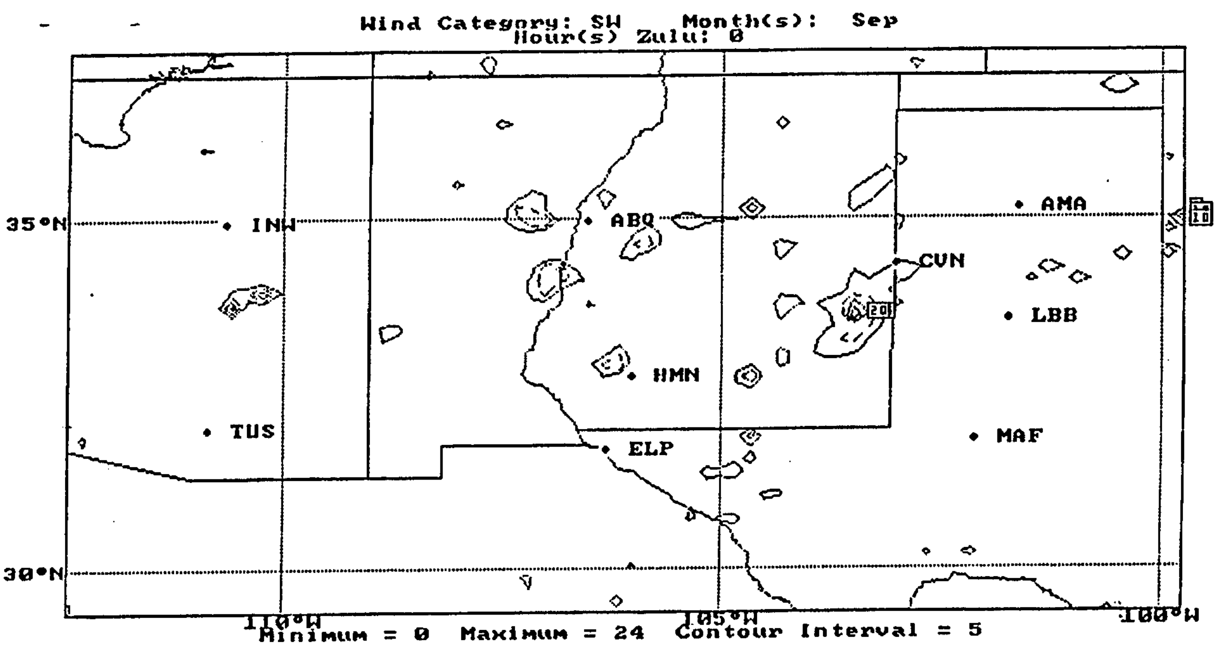

Figure 19. Isopleth analysis of the average hourly lightning strikes over region E (Holloman) during September for 0000Z (1700MST) with 700-mb winds from the southwest.

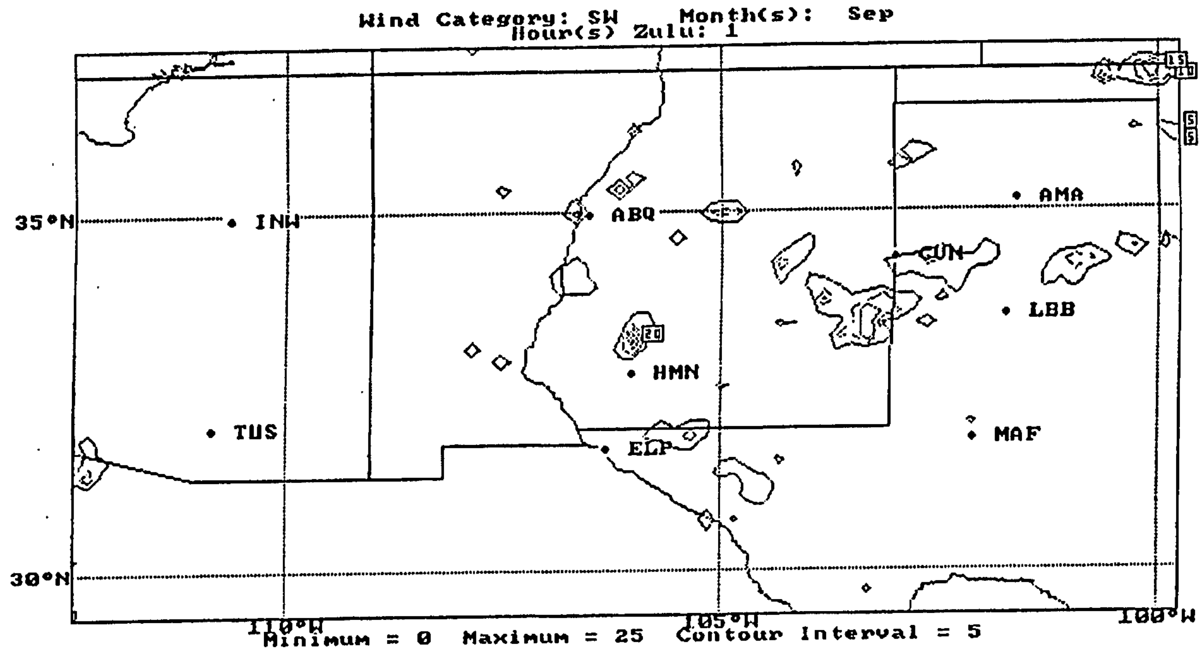

Figure 20. Isopleth analysis of the average hourly lightning strikes over region E (Holloman) during September for 0100Z (1800MST) with 700-mb winds from the southwest.

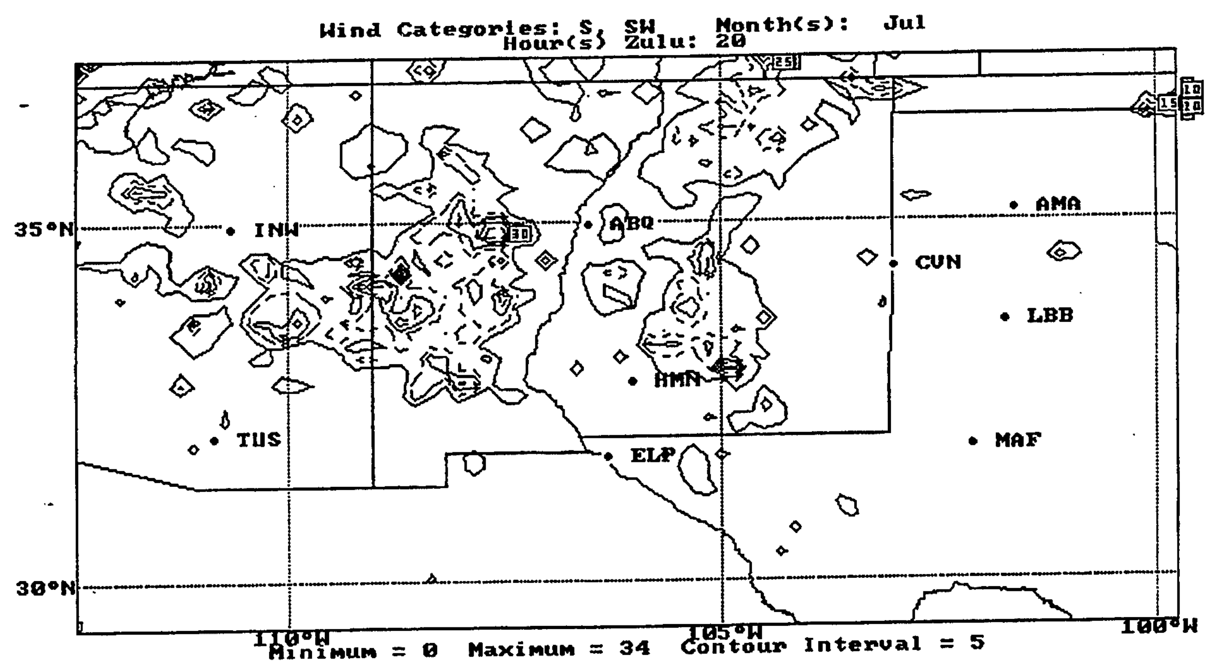

Figure 21. Isopleth analysis of the average hourly lightning strikes over Region E (Holloman) during July for 2000Z (1300MST) with 700-mb winds from the southwest.

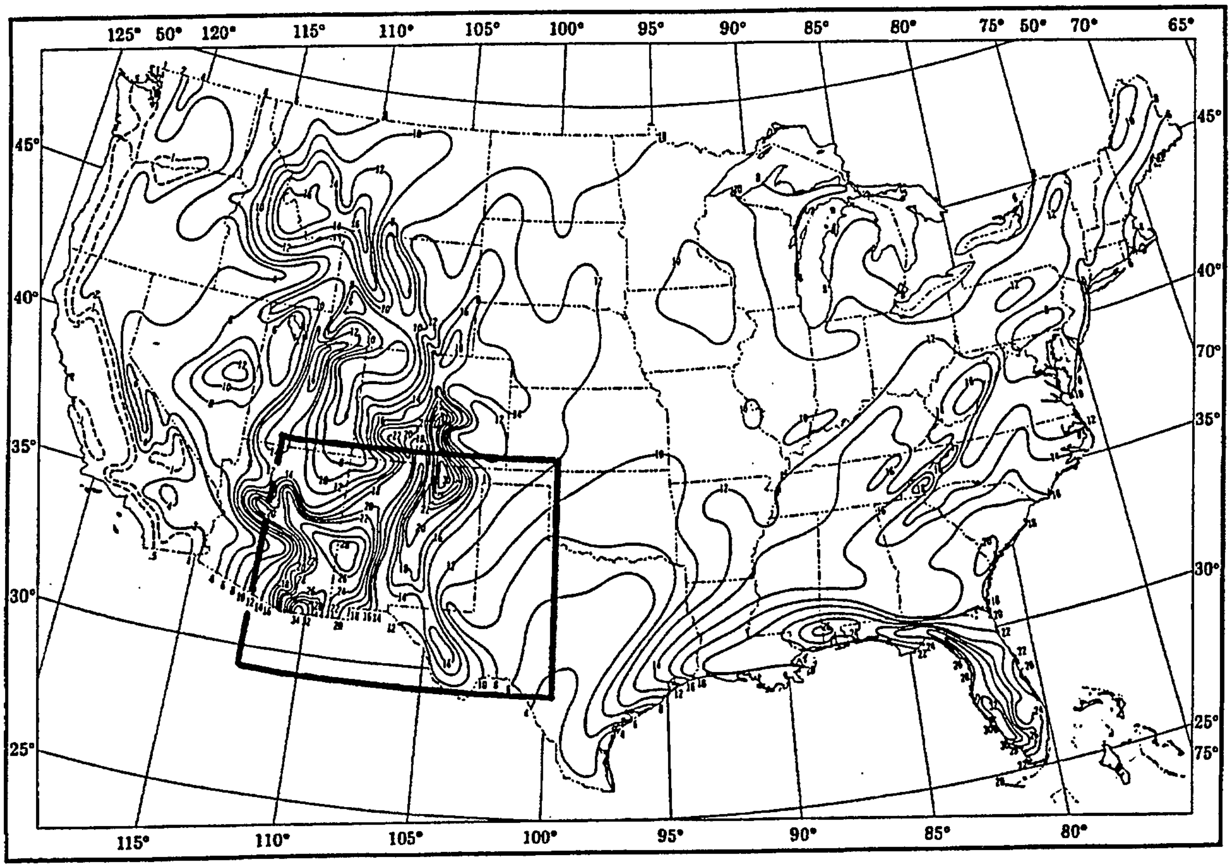

Figure 22. Analysis of the mean number of thunderstorms during July over the United States. Region E (Holloman) is shown in bold lines. Adapted from Changery (1981).

Chapter 5

SUMMARY

5.1 Discussion. The CG lightning-strike climatologies stratified by 700-mb wind directions were developed to help mission planners and weather forecasters more accurately predict thunderstorms near low-level flying routes in several regions of the United States. The lightning climatologies are also useful wherever guidance on lightning and thunderstorms is needed for resource protection, materials testing, and public safety. Despite some limitations in the lightning-strike and upper-air data used, it was shown by comparison to known temporal and spatial variations in thunderstorms that the lightning-strike climatologies adequately depict several of the variations. The wind stratification appeared effective at revealing lightning-strike locations and movement based on the 700-mb wind direction. Undoubtedly, the lightning-strike climatologies hold much more information about lightning-strike patterns than what was presented in this report.

5.2 Recommendation. AFCCC recommends use of the lightning climatologies as additional tools to predict thunderstorms. When used in combination with analyses of the meteorological situation, the lightning climatologies have potential to improve thunderstorm forecasts.

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GLOSSARY

ABQ	Location identifier for Albuquerque, N.M.
ACC/DOW	Air Combat Command/Directorate of Weather
AFB	Air Force Base
AFCCC	Air Force Combat Climatology Center (formerly USAFETAC)
AMA	Location identifier for Amarillo, Texas
BIS	Location identifier for Bismarck, N.D.
BOXNUM	Grid box number
C	Calm
CG	Cloud-to-ground (lightning)
CPR	Location identifier for Casper, Wyo.
CST	Central Standard Time
DATSAV	AFCCC's database of surface and upper-air data
DB2	AFCCC's relational database
DDC	Location identifier for Dodge City, Kan.
DRA	Location identifier for Desert Rock, Nev.
E	East
ELP	Location identifier for El Paso, Texas
ELY	Location identifier for Ely, Nev.
EGA	Enhanced Graphics Adapters
GDS	GeoMet Data Services, Inc.
GFA	Locatian identifier for Great Falls, Mont.
GGW	Location identifier for Glasgow, Mont.
HP	Hewlett Packard
I	Grid-point index
IBM	International Business Machines Corp.
IGM	Location identifier for Kingman, Ariz.
INT	Operator that acts to keep only the whole part of a number
INW	Location identifier far Winslow, Ariz.
J	Grid-point index
KB	Kilobyte
LATI	Latitude in minutes at upper-left corner of grid system
LATMIN	Latitude of lightning strike in minutes
LBF	Location identifier for North Platte, Neb.
LLP	Lightning Location and Protection, Inc.
LONI	Longitude in minutes at upper-left corner of grid system
LONMIN	Longitude of lightning strike in minutes
MAF	Location identifier for Midland, Texas
mb	Millibar(s)
MB	Megabyte
MIN	Grid spacing in minutes of latitude ar longitude
MS-DOS	Microsoft-Disk Operating System
MST	Mountain Standard Time
MUO	Location identifier for Mountain Home AFB, Idaho
N	North
NE	Northeast
NKX	Location identifier for San Diego, Calif.

NLDN	National Lightning Detection Network
NW	Northwest
POF	Percent occurrence frequency
PST	Pacific Standard Time
RAP	Location identifier for Rapid City, S.D.
S	South
SE	Southeast
SIDEBOX	Number of grid boxes in east-west direction
SOCS	Surface Observation Climatic Summaries
SW	Southwest
SZL	Location identifier for Whiteman AFB, Mo.
TOP	Location identifier for Topeka, Kan.
TUS	Location identifier for Tuscon, Ariz.
VGA	Variable graphics array
W	West
WMC	Location identifier for Winnemucca, Nev.
X	Grid-point Cartesian coordinate
Y	Grid-point Cartesian coordinate
Z	Zulu (Greenwich Mean Time)