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Descriptive and Conditional Climatology for Specific Launch Commit Criteria for Cape Canaveral, Florida

Edward C. Goetz

DESCRIPTIVE AND CONDITIONAL CLIMATOLOGY FOR SPECIFIC LAUNCH COMMIT CRITERIA FOR CAPE CANAVERAL, FLORIDA

THESIS

Edward C. Goetz, Captain, USAF

AFIT/GM/ENP/00M-07

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Edward C. Goetz, B. S.

Captain, USAF

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Edward C. Goetz, B. S.
Captain, USAF

Approved:

Gary R. Huffines (Chairman)	2 March 2000 date
Cecilia A. Miner (Member)	2 March 2000 date
Craig C. Largent (Member)	2 March 00 date
Daniel E. Reynolds (Member)	2 March 00 date

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Edward C. Goetz

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Abstract

In 1987, an unmanned Atlas-Centaur-67 launched from the Cape triggered a lightning discharge that disabled the on-board guidance system and Range Control destroyed the platform. This incident spurred the review and revision of the natural and triggered lightning launch commit criteria (LCC). The LCC are a set of eleven complex rules that are constantly evaluated by the Launch Weather Team (LWT) of 45th Weather Squadron (45WS). Unfortunately, the 45WS LWT does not have either a descriptive or conditional climatology for many of the LCC.

This thesis addresses the lightning and the cumulus LCC. A descriptive climatology for both the lightning and the cumulus LCC is presented for the 1989 to 1998 period. Additionally, the climate of the Cape is divided into four seasons, and a conditional climatology is introduced for the cumulus LCC. The conditional climatology procedure uses a season-specific discriminant function to classify the radiosonde observations into either the violation or no violation group for the four seasons. Because of the limited number of cumulus violation cases, the statistical significance of the four seasonal discriminant functions could not be verified. Therefore, further refinement of the seasonal discriminant functions is needed to make them a more useful forecasting tool.

DESCRIPTIVE AND CONDITIONAL CLIMATOLOGY FOR SPECIFIC LAUNCH COMMIT CRITERIA FOR CAPE CANAVERAL, FLORIDA

1. Introduction

1.1 Background

The danger associated with rocket triggered lightning came to the forefront in 1969 when Apollo 12 triggered two lightning flash discharges, one cloud-to-ground (CG) and one intracloud, as the spacecraft traveled through a weak non-lightning producing cold front (Uman and Krider 1989). The vehicle was not seriously damaged but it demonstrated the vulnerability of such launches to triggered lightning. Prior to Apollo 12, the only LCC was for lightning within 10 NM of station (Roeder et al. 1998).

The next significant event contributing to the evolution of the LCC was in 1987 as an unmanned Atlas-Centaur-67 (AC-67) platform was launched in conditions similar to those during the 1969 Apollo 12 launch, but the results were more catastrophic (Uman and Krider, 1989). The vehicle's launch triggered a lightning discharge to ground, disabling the onboard computer's guidance system thus causing the vehicle to yaw unexpectedly, and the vehicle was destroyed by Range Control. This incident spurred the review and a major revision of the lightning LCC (Roeder et al., 1998). Since AC-67, the use of the modern natural and triggered lightning LCC has resulted in no triggered lightning strikes to launched rockets.

Florida has the distinction of being labeled the "lightning capital" of the United States and this title is well deserved (Hodanish at el. 1996). Byers and Braham (1949) first recognized that mesoscale meteorological influences present in Florida frequently provided all the ingredients favorable for thunderstorm production. Son... these influences include copious low-level moisture, thermal instability, and lift. Cape Canaveral Air Station and NASA's Kennedy Space Center (KSC) are located in this area of frequent thunderstorms, thus the threat of triggered and natural lightning is ever-present and significantly impacts any space launch.

Currently the 45th Weather Squadron (45WS) provides weather support to both the Cape and KSC, but has no statistically based forecasting references for predicting the occurrence of any LCC violation. Additionally, mission planning has no descriptive climatology of any LCC violations to determine the best time to establish a future launch date. Thus LCC violations have delayed 35% and cancelled 4.7% of the planned launches (Roeder et al. 1998). The cost of a cancellation can range from $150,000 to over $1,000,000 depending on the launch vehicle. The above delay and cancellation rates are for the LCC prior to the new 1998 LCC.

As these launch catastrophes. delays, and cancellations illustrate, the threat to space vehicles by triggered or natural lightning warrants attention. This is not surprising since Central Florida has the highest incidence of lighting in the United States (Hodanish et al. 1996); therefore, lightning has a large impact on space launch activities from KSC and the Cape, so any research addressing the prediction of a violation for any LCC is justifiable.

The natural and triggered lightning LCC comprise a set of eleven very concise rules used to avoid the lightning threat to launches from the Eastern Range and Kennedy Space Center (Roeder et al. 1998). These rules are complex, multifaceted, and very atypical within operational meteorology. As such, the 45WS Launch Weather Team

(LWT) must have unequivocal and convincing evidence that not a single LCC is violated for the launch to occur. Without this concise evidence before the launch, the launch will be delayed or cancelled, depending on the time remaining in the launch window. The LWT can consist of up to eight people to evaluate the LCC during a launch. This many people may be required to evaluate the complex LCC under rapidly changing, threatening weather and to analyze the numerous and diverse weather sensors used by the 45WS.

1.2 Problem Statement

Given a particular target launch date, will the LCC be violated? For example, what is the probability the lightning LCC rule will be violated on January 22nd? Given the current weather parameters for January 22nd, what is the probability the cumulus LCC rule will be violated? Though the two questions are similar, the means to answering the respective questions is very different. At present, the 45WS forecasters have no statistically based answer for these questions. This research focuses on providing a descriptive LCC climatology table and a statistically based conditional climatology table to assist in predicting a violation of specific LCC. The LCC examined in this research consist of the lightning and the cumulus cloud LCC.

1.3 Implications

Since nearly one in every three launches is delayed and one in twenty is cancelled, these failures to launch are costly both monetarily and in human resources (Roeder et al. 1998). A possible reduction of both the launch delay and cancellation percentage rates experienced at the Eastern Range and KSC would be most welcomed. This thesis will hopefully give the mission planners a scientifically based method for planning launches using the descriptive LCC violations table and a conditional climatology table for use on launch day by the 45WS forecasters.

2. Literature Review

2.1 Canaveral's Thunderstorm Periods and Predictors

Cape Canaveral is located near the center of Florida on the eastern side of the peninsula and is home to America's space shuttle missions. Figure 1 shows the geographic location of Cape Canaveral on the Florida peninsula. The very mission of

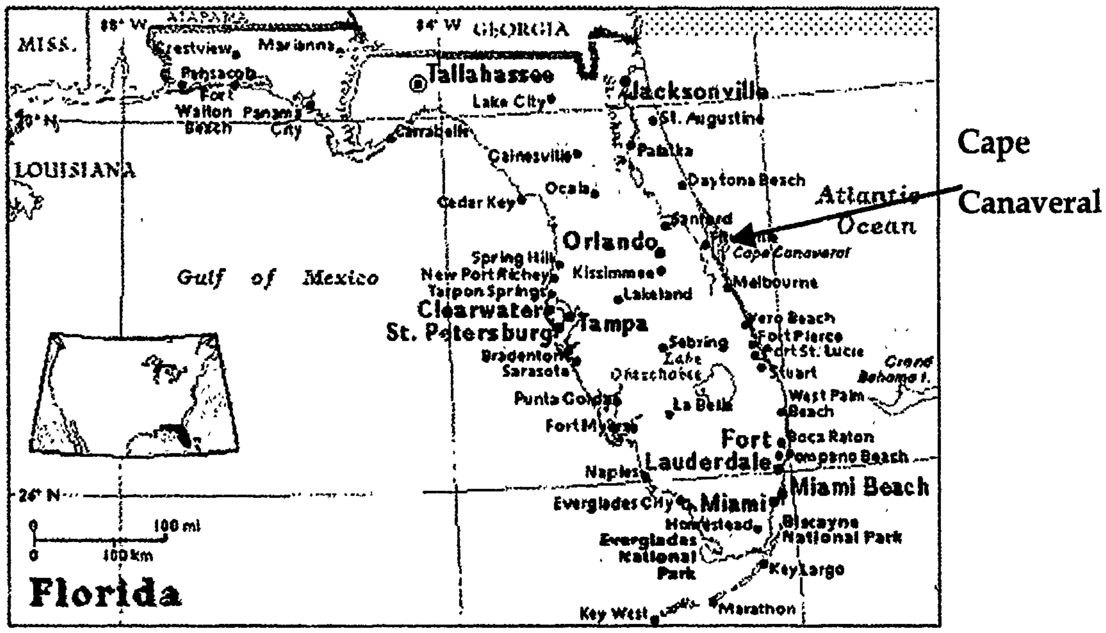


Figure 1. Map of Florida (National Geographic Society, 1995).

Canaveral makes it vulnerable to many weather phenomena, especially thunderstorms. Unfortunately, Central Florida has the highest incidence of lighting in the United States (Hodanish et al. 1996). This is due primarily to the subtropical ridge (Bermuda High) axis position and the resultant low-level wind direction. Climatologically the ridge axis is frequently located over the north-central part of the peninsula. In the warm season (June through August), the ridge axis is forced south as the land heats up, thus producing a low-level flow from the southwest over the central peninsula. This allows the low-level flow to collide with the sea breezes along the east-central part of Florida.

Florida generally has a near-tropical climate, especially at lower latitudes, and in the summer. In 1948, Byers and Rodebush identified the three key ingredients necessary for the formation of frequent thunderstorms: low-level moisture, thermal instability, and lift. The low-level moisture is a product of Florida having water on three of its sides and the abundance of land-locked water (Hodanish et al. 1996). Thermal instability is derived from the contrast between the land and any adjacent water source. Lift is produced in part by the differential heating, but mostly the resultant low-level wind field generates lift. This horizontal low-level convergence is caused as the afternoon sea breezes enter from both sides of the peninsula, thus creating mesoscale boundaries at these sea breeze interfaces. Additionally, this low-level convergence transports some of the resident moisture aloft, which helps the vertical growth of convective cells to thunderstorm status (Byers and Rodebush 1948). Their idea that the summer's low-level horizontal convergence was responsible for the unusually high frequency led to further studies on sea breeze interaction.

Neumann (1968), using the fact that Florida's thunderstorm activity is cyclical in nature, investigated the Cape's thunderstorm season. Neumann studied thirteen years (1951, 1952, and 1957 - 1967) of surface data from Cape Kennedy and found 1,223 separate thunderstorms on 912 calendar days. Thunderstorm periods were defined and based on a 15-day moving average of the days with thunderstorms for the entire period. The 15-day period was chosen by trial and error as a 5-day moving average "introduced an apparent second harmonic to the annual cycle with a quasi-periodicity of 9 to 12 days" and a 30-day moving average excessively smoothed the data. The 15-day moving average did not introduce a second harmonic nor did this period duration contribute to excessive smoothing of the variations in the data. The equation used by Neumann (1970) to obtain this 15-day moving average is given by the equation,

$$Freq_n = (1/15) * \sum_{n-7}^{n+7} T_k$$

where $Freq_n$ gives the 15-day moving average for the specific day number, n is the day number, and T_k is the frequency of at least one thunderstorm for that day number.

Figure 2 depicts the results of the application of the above equation (Neumann 1970). Noticeable are the dual maxima during the seasonal thunderstorm cycle (May through September). During this period, on average thunderstorms can be expected on

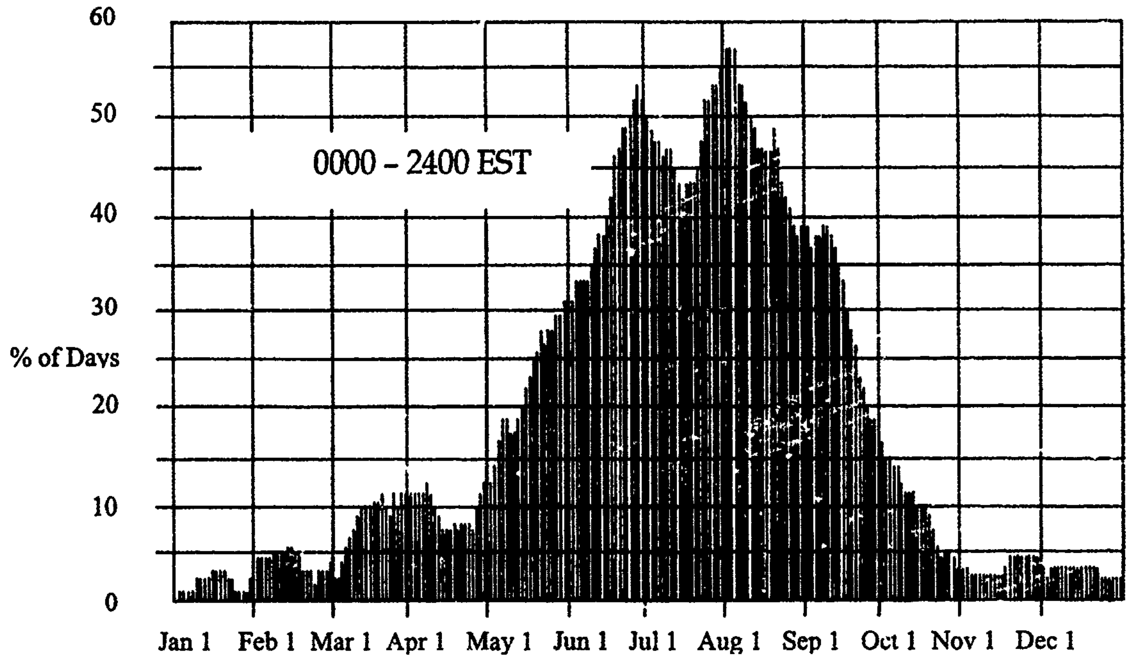


Figure 2. 15-Day Average of Thunderstorm Frequency (adapted from Neumann 1970).

over 25% of the days between mid-May and late September, thus defining what is called the main convective thunderstorm season. The first maximum occurs around June 30th and the second on August 3rd. Additionally, the most storms occurred in the months of

July and August. Furthermore, not a single thunderstorm ever occurred during the period from late December to mid-January.

Further study of Figure 2, depicting the Cape's thunderstorm climatology, led Neumann (1968) to the define the following eight periods, also summarized in Table 1:

Period 1 – (November through early March). The occurrence of a monthly storm is associated primarily with synoptic scale boundaries (fronts) causing instability and/or convergence.

Period 2 – (Early March through early April). An increase in thunderstorm activity is mainly a result of pre-frontal squall lines.

Period 3 – (Mid April). Minor decrease in storm activity is due to cessation of synoptic scale events and the lack of sufficient daytime heating.

Period 4 – (Late April through June). Increasing solar insolation coupled with the inherent instability provides a steady increase in thunderstorm activity.

Period 5 – (First half of July). The mid-level ridge, with its associated stability, is frequently over Florida during this period and probably results in the decrease of storm development.

Period 6 – (Latter part of July through early August). This period is depicted as the second maximum in Figure 2 and associated with the retreat of the mid-level ridge axis to the south. But the low-level ridge line drifts northward and provides greater instability by way of warmer temperatures.

Period 7 – (Early August through first third of September). Decreasing solar insolation leads to a gradual decrease in thunderstorm activity, but nocturnal and early morning storms' occurrence reaches a maximum during this period as synoptic systems impact the area.

Period 8 – (Latter part of September through October). Rapid decline in storm activity as solar insolation decreases and conditions are more stable.

Table 1. Eight Cape Canaveral thunderstorm periods defined by Neumann (1968).

Period	Month
1	November through early March
2	Early March through early April
3	Mid April
4	Late April through June
5	First half of July
6	Latter part of July through early August
7	Early August through first third of September
8	Later part of September through October

Though these periods listed in Table 1 are specific for Cape Kennedy's thunderstorm activity, the question of what factor(s) is most influential in the occurrence of a thunderstorm at the Cape was not addressed. In 1970, Neumann addressed this very issue for the purpose of forecasting the probability of thunderstorms at or near the Cape during the thunderstorm season (May through September). The key factors, listed in order of significance for storm probability determination, are the 914-m (3000-ft) wind direction and speed, and date of the year (Neumann 1970).

During May through September, Neumann (1970) postulated a westerly wind component would advect landmass thunderstorms across the Cape, but an easterly wind would advect storms away from the area. Additionally, light and variable winds would allow storms to occur in the Cape's immediate vicinity. Using the same thirteen-year observation period as before, the 1200 UTC, 914-m resultant wind was calculated using a 25-day moving average to smooth out sample irregularities. The seasonal, resultant wind displayed a fairly regular pattern with winds from the southwest occurring in both the summer and winter and southeasterly winds in September only giving way to northeasterly winds in October and November. Typically on days with only afternoon storms the winds were from the southwest, whereas early morning storms developed when winds were from the east.

Though the low-level direction is the single best predictor, there are nonetheless occasions when storms do not develop over the Cape even when the winds are most favorable (Neumann 1970). On these occasions, measurements aloft indicated mid-level dryness, which is seemingly the result of synoptic scale divergence. This occurs most frequently in July, when the thunderstorm activity temporarily decreases, as the 500-mb ridge resides directly over the Cape as identified for period 5 (Table 1). The ridge induces synoptic scale mid-tropospheric subsidence, which effectively thwarts storm development. Though the 914-m wind direction is the single best predictor of storm development, it is not the only one as an investigation and the correlation of the 1200 UTC 914-m wind direction and speed demonstrated.

Climatology of the 914-m wind direction and speed is southerly at 1.9 m s^{-1} for the May through September period (Neumann 1970). The wind speed alone explained only a small amount of the statistical variance in the occurrence of storms. For example, as depicted in Figure 3, a wind speed of 10 m s^{-1} would give a probability of 34% for the occurrence of an afternoon thunderstorm. Also, 8 m s^{-1} appears to be the best speed for the development of airmass storms since the peak at 18 m s^{-1} is primarily associated with synoptic scale systems that provide additional vertical lift. Speed alone proves to be a poor predictor of afternoon thunderstorm occurrences, but examining just the direction shows more promise.

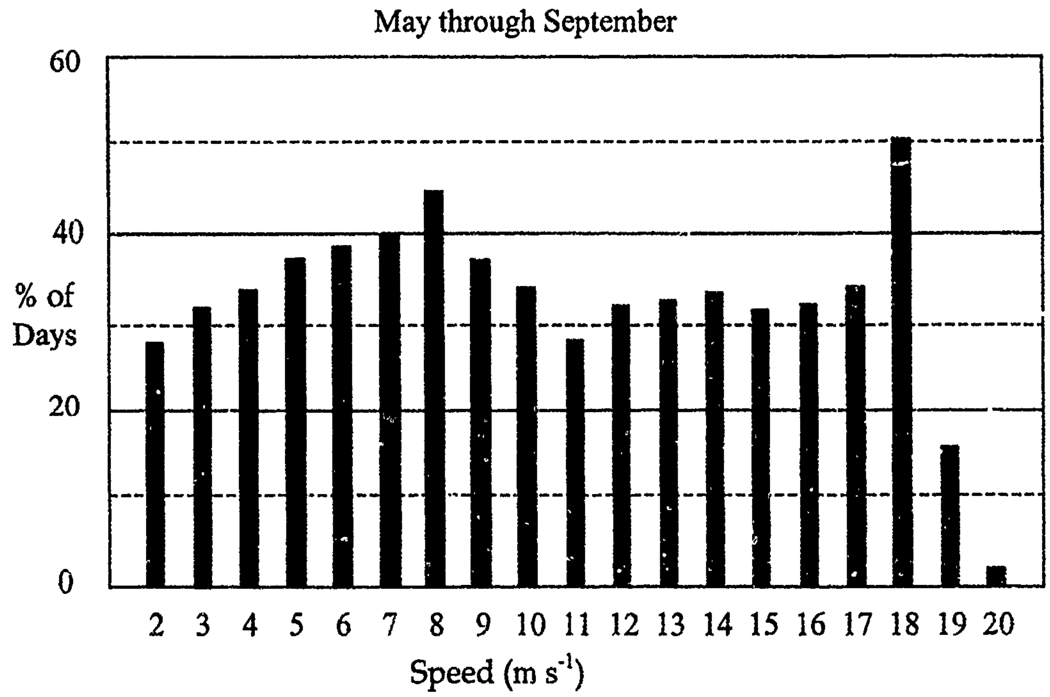


Figure 3. Afternoon Thunderstorm Probability using only the 1200 UTC 914-m wind speed (adapted from Neumann 1970).

Figure 4 was produced using of the wind direction in 10-degree increments as a predictor (Neumann 1970). Immediately obvious is the greater than 50% probability associated with winds from 200 - 280 degrees. These probabilities far exceed those depicted for the speed only, lending validity to the statement that wind direction is the most significant predictor for afternoon thunderstorm development on the Cape.

Though the wind direction and speed appear to predict thunderstorms with a reasonable degree of accuracy this is somewhat misleading if the time of the year is not considered (Neumann 1970). As displayed in Figure 2, the probability increases almost linearly from early May (11%) to a maximum (49%) by the end of June. Early July shows a slight decline (39%), but another maximum (51%) is reached by early August. Then the gradual, roughly linear, decline to 16% by the end of September. For instance, when considering the season as a whole, a wind from 220 degrees at 5 m s^{-1} with a 66%

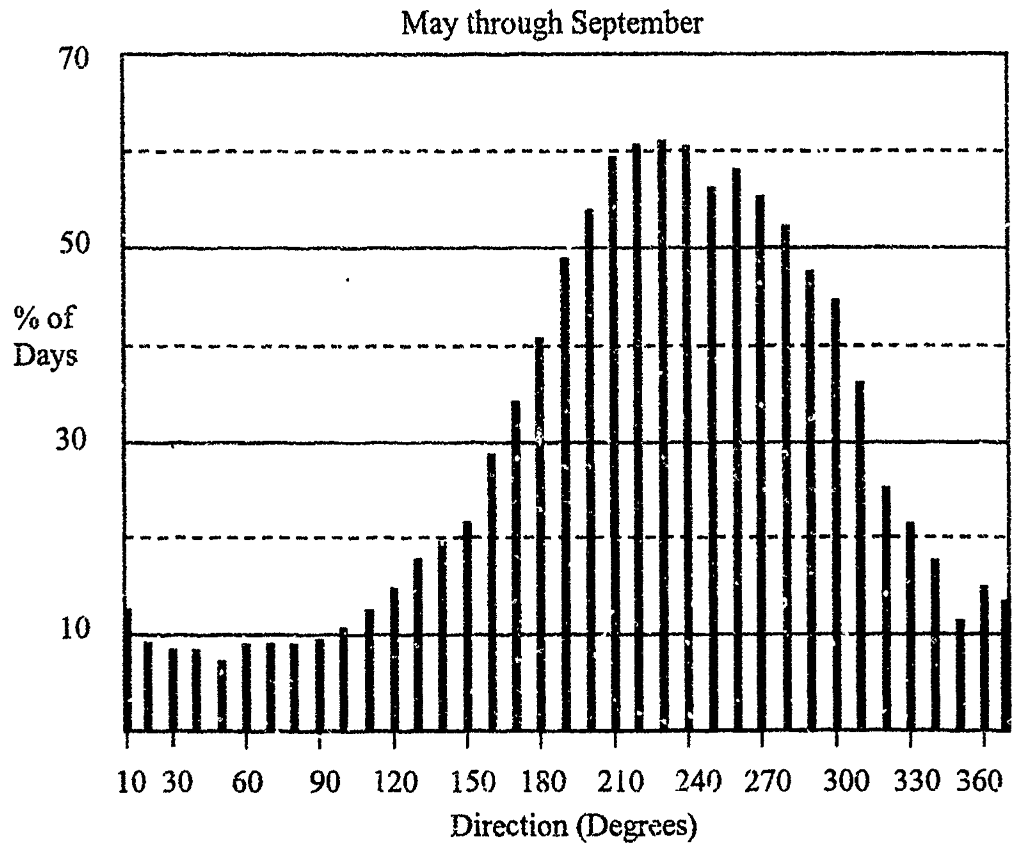


Figure 4. Afternoon Thunderstorm Probability using only the 1200 UTC 914-m wind direction (adapted from Neumann 1970).

probability of producing afternoon storms did not achieve this same probability at specific times within the period. If the wind was evaluated on 1 May the corresponding probability was 27%, whereas the same wind produced a nearly 90% probability on 1 August. Therefore, any afternoon thunderstorm forecast addressing only the wind's speed and direction would not provide the greatest probability associated with the development of storms on the Cape.

Though Neumann (1968) developed his thunderstorm periods specifically for the Cape based on reported storm observations, Hodanish et al. (1996) investigated the monthly lightning climatology for the entire state using ten years of National Lightning Detection Network (NLDN) data. This ten-year record contained over 25 million flashes in just Florida alone. The NLDN uses two different lightning detection sensors, the magnetic direction finders (MDFs) and time-of-arrival (TOA) sensors.

In 1985, the state of Florida was instrumented with MDFs (Hodanish et al. 1996). Over the years, TOA sensors have been added to the MDFs. These two sensors differ in how they detect the flash. The MDFs use the magnetic field component of the electromagnetic (EM) wave generated by a flash (Uman 1987: 356-358). The TOA sensors use the electric field component associated with the EM wave. This combination of sensors detects both intracloud and CG flashes (Hodanish et al. 1996).

The NLDN is highly accurate, but it does not detect nor record every cloud-to-ground flash (Cummins et al. 1998). The detection efficiency has improved over the years with the addition of the TOA sensors (Hodanish et al. 1996). For computing the respective flash density, a detection efficiency of 70% was used for the lightning climatology study. Hodanish et al. (1996) categorized the lightning climatology of Florida into four seasons as listed in Table 2, as opposed to Neumann's (1968) eight periods listed in Table 1.

Table 2. Seasons as defined by Hodanish et al. (1996).

Season	Months
Cool	November through February
Spring	March through May
Warm	June through August
Autumn	September and October

The cool season is characterized by minimal flash densities of usually less than 0.1 km^{-2} for the entire state (Hodanish et al. 1996). These lower densities are the result of the decreased solar insolation and the greater atmospheric stability over the region. Any lightning is attributed to the passage of infrequent mid-latitude cyclones. The cool season gives way to the spring transitional season.

The spring transitional season displays a marked increase in lightning occurrence as the cold stable air weakens and mid-latitude cyclones become more frequent and are more electrically active (Hodanish et al., 1996). For example, central Florida's record hailstorms and the "storm of the century" both occurred in March, when flash densities are influenced by synoptic systems, and accompanied by copious lightning activity. Mid-latitude cyclones are favored during this period as both solar insolation and low-level moisture increase, and the air aloft remains cool and dry. As the season moves into May, the flash density is more a result of mesoscale interactions than of synoptic scale disturbances, as the polar jet moves north and the land/sea breeze interface zones strengthen. Sea breeze movement is controlled by the low-level synoptic pattern, as storms develop along this interface the low-level winds will either assist or impede the inland progress of the storms. For example, an easterly, synoptic, low-level flow would assist any storms that develop as a result of the east coast sea breeze, and these storms would propagate inland. Conversely, inland movement of storms that developed along the west coast sea breeze would be hindered by the easterly synoptic low-level flow. However, if the synoptic flow were weak the east and west sea breezes would coilide at some halfway point and the storms would develop in the center of the peninsula. In general, the movement of storms forming along the sea breeze interface is influenced by both the strength and the direction of the low-level synoptic wind field. The spring season's flash densities are uniform for much of the state with an increase during May. The Cape follows the same pattern. The season ends with a statewide increase in flash density, and this increase is even greater in the following warm season.

The warm season is the most electrically active period as the state experiences a significant increase in cloud-to-ground flashes, especially over the peninsula (Hodanish et al. 1996). Also, the flash densities are at their annual maxima during the warm season as most of the state has a flash density of 1 flash km^{-2}, but over the central peninsula this density is 3 flashes km^{-2}. The Florida climate is more tropical, and storms occur on an almost daily basis as a result of the position of the subtropical ridge axis (Bermuda High), which influences the low-level wind pattern. During July, which is the most active period of the year, two large areas of peak flash density occur over the state's center. Additionally, the areal coverage of the west coast maximum is much larger than the east coast maximum, which borders the Cape to the west, as the prevailing low-level wind is southeasterly during this month. August has the same bimodal pattern as July, but the respective east and west areas have shrunk, and areas of greater than 3 flashes km^{-2} have separated. This areal decrease and separation is probably a result of the weakening low-level flow as the respective sea breezes no longer collide along the backbone of the peninsula. This general decrease in flash densities continues into September, which marks the beginning of the autumn transitional season.

The autumn transitional season sees the flash densities decrease sharply statewide as the thermal contrast between land and sea diminishes and the associated sea breezes weaken (Hodanish et al., 1996). The high bimodal flash densities (> 3 flashes km^{-2}) that once occupied Central Florida during the warm season are now gone as the synoptic flow gains a northerly component when the Bermuda High migrates over the Atlantic. October brings another decrease in flash density, usually less than 0.33 flashes km^{-2}, as the occurrence of lightning becomes more dependent on the passage of synoptic disturbances across the peninsula.

Did the NLDN data used by Hodanish et al. (1996) to create the four season lightning climatology show significant variations in comparison to the eight thunderstorm periods as proposed by Neumann (1968)? No significant differences were noted since Hodanish et al. included the entire state; thus the seasons were more general and broader. But similarities do include the increase in thunderstorm activity for the Cape from June to August as noted by Neumann (periods 4 – 6 in Table 1), which corresponds well to the characteristics of the warm season set forth by Hodanish et al. (1996). Also, the cool season is comparable to Neumann's period 1 (Table 1) and the associated lack of thunderstorm activity. Though Neumann (1968) used surface observations for the Cape and Hodanish et al. (1996) examined NLDN data for the entire state to identify thunderstorms, the classification periods or seasons for the storms and their causes were very similar.

2.2 Electric Field Mills and the NLDN

The 45WS uses many instruments to monitor the atmosphere and evaluate the LCC rules (Harms et al. 1997). One instrument is the launch pad lightning warning system (LPLWS) or commonly called the electric field mill. This system is comprised of 31 field mills distributed in and around the launch and operations areas of the Cape and KSC, as shown in Figure 5.

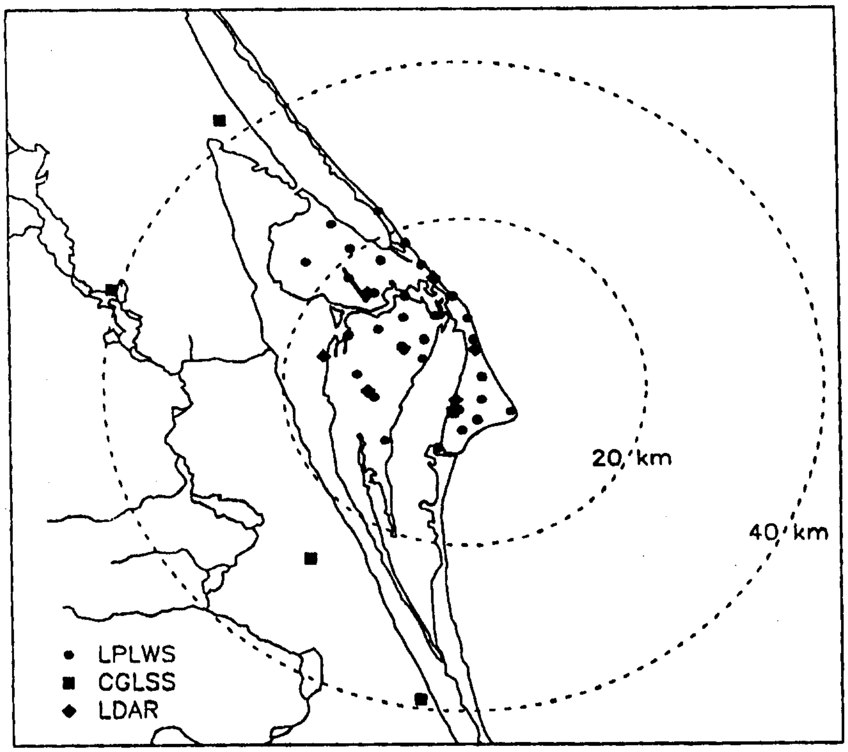


Figure 5. Location of LDAR and LPLWS sensors (Harm et al. 1997).

The NASA Marshall Space Flight Center developed the LPLWS field mill instruments and base station computer (Harms et al. 1997). The USAF 45th Space Wing developed the LPLWS host computer and real-time display and also integrated and tested the overall system. The LPLWS operates 24 hours per day, 7 days per week (Harms et al., 1997). Field mills measure the atmosphere's electric potential and record this value in volts per meter (V m^{-1}). The atmosphere's "fair weather" electric field, devoid of any clouds or weather, is caused by a net negative charge overhead for non-mountainous terrain and is approximately –100 V m^{-1} (MacGorman and Rust 1998: 29). Unlike field mills, which measure the electric potential of the atmosphere, the NLDN measures the lightning's electrical discharge.

The NLDN was established in 1987 as regional networks were merged to provide only CG lightning information over a national domain (Cummins et al. 1998). Sensors in the network now consist of magnetic direction finders (MDFs) and time-of-arrival (TOA) sensors. The network consists of 106 sensors nationwide and provides both real-time and historical lightning data to private industries, the National Weather Service, and other government agencies. Because of continued upgrades and improvement since 1991, the location accuracy has been improved by a factor of 4 to 8. Furthermore, flashes with a peak current above 5 kA have an expected detection efficiency from 80% to 90%. But what information is recorded by the NLDN sensors?

Once a flash occurs and is detected by the sensors, this information is transmitted to the Network Control Center (NCC), operated by Global Atmospherics, Inc in Tucson, Arizona (Cummins et al. 1998). The NCC processes the data to provide the time (in UTC), the location (latitude and longitude to the ten thousandths), and peak current (a measure of the polarity and current associated with only the first flash in the stroke) of each detected discharge. This newly processed data is quickly disseminated to real time users as turnaround is typically within 30-40 seconds of the lightning discharge.

2.3 Lightning Launch Commit Criteria

The Launch Commit Criteria (LCC) is a set of eleven rules used by NASA to avoid the threat of lightning during launches from the USAF's Cape Canaveral and NASA's KSC (Roeder et al. 1998). These rules have evolved over time from the crude rules used to avoid natural lightning to the modern rules that now address the threat of both natural and triggered lightning. The main focus of the current LCC is for preventing triggered lightning. General descriptions of the individual LCC rules that will be examined in this study are as follows:

1) Lightning LCC: Do not launch for an established time interval if a lightning flash occurs in a thunderstorm and that storm is within a set distance of the vehicle's flight path. Also, do not launch for a predetermined time interval if a flash occurs within a set distance of the flight path. An exception is if the lightning producing cloud is far enough away from the flight path, a minimum of one field mill is within an established distance of each flash, and the electric field measurements for specific mills is less than a required crucial value for a set time period.

2) Cumulus Clouds LCC: Do not launch if any cumulus cloud top is within a designated distance of the flight path and is colder than an established threshold for various levels. An exception is if the cloud is free of precipitation, the cloud top's horizontal distance to a field mill is less than a predetermined length, and the electric field measurements for specific mills is less than a required crucial value for a set time period. This rule excludes altocumulus, cirrocumulus and stratocumulus clouds.

3. Methodology

3.1 Objectives

The primary goal of this thesis is to provide a descriptive climatology for both the lightning and cumulus LCC violations and a conditional climatology (probability) for the cumulus LCC. The descriptive climatology is an unconditional probability to assist in the long range planning of launches. Unconditional probability is the ratio of the number of times the event occurs to the total number of opportunities for occurrence of the event (Kachigan 1991: 57-58). For example, if rolling a single fair die, the probability of the three-dot side landing face up is 1/6, since the six sides of the cube would have an equal chance of landing face up. Conversely, a conditional climatology, which will use the correctly classified percentage, is a conditional probability that will provide the KSC with a statistically derived tool to aid in the short term forecasting of a possible cumulus LCC violation. Conditional probability is the probability of one outcome, given that another outcome has occurred (Kachigan 1991: 70). For instance, given that the Federal Reserve did not raise the prime interest rate what is the probability that the stock market will go up? The classification percentage is simply the likelihood of an individual or object belonging to a specific group as determined by that individual or object's discriminant score and will be discussed in Section 3.3.2.

3.2 Data

The data available consisted of NLDN data, rawinsonde/radiosonde observations (RAOBs), and surface observations. Since only approximately a year of field mill data was available from the source, this data was not included in this study. A brief description of the aforementioned data, the original data format, and how the data was modified and organized follows.

3.2.1 NLDN Data

The NLDN data examined includes all months for the period 1989 through 1998 and is for cloud-to-ground flashes only. This data provides the following information about each lightning flash: year, month, day, hour (in UTC), minute, second, latitude, longitude, peak current (positive or negative polarity), and multiplicity (number of return strokes). The data was filtered using the program lightning_NLDN which is contained in Appendix A. This program is an Interactive Data Language® (IDL®) program and searches the NLDN data for any single flash within 12 nautical miles of the KSC's launch point and only these flashes were retained. Though a violation of the lightning LCC requires a distance of less than or equal to 10 nautical miles, the 12 nautical miles distance was used because it provides a larger data set for launch planning and allows for errors in flash position (Cummins et al. 1998). The unconditional monthly and annual probabilities were then determined, thus providing the descriptive climatology.

3.2.2 Rawinsonde/Radiosonde Observations (RAOBs)

The RAOB data acquired from the Air Force Combat Climatology Center (AFCCC) were for the ten-year period of 1989 through 1998; however, the RAOBs for 1989 to 1991 were woefully incomplete. Since the ROABs were needed for the statistical analysis of the cumulus LCC violations, this incomplete RAOB data set limited the cases of the cumulus violations reviewed to the period of 1992 through 1998.

The RAOB provides the following information: pressure level, pressure level height, temperature, dew point temperature, wind direction, and wind speed. Though the

RAOB data gives a snapshot of the atmosphere, the reported RAOB most often has some missing wind or temperature values. Since these values are needed for statistical analysis, it is necessary to account for as much of the missing data as possible. Therefore even if the data is missing from a specific level, the values measured at other levels provide insight into the missing values. Assuming temperature, moisture, wind direction and speed are continuous across small distances, and to make the model simple to implement, linear interpolation was used to account for any missing temperature or wind values. The following linear interpolation example refers to the values in Table 3, which represents a portion of a RAOB with missing values.

Table 3. Sample of a RAOB with missing values.

Pressure (mb)	Height (m)	Temperature (°C)	Dew Point (°C)	Wind Direction (Degrees)	Wind Speed (kts)
1000	80	23.1	19.0	90	29
975	304	Missing	Missing	Missing	Missing
950	527	20.2	20.0	100	39
750	2617	15.0	13.2	110	39
700	3189	14.0	14.0	110	39

Using linear interpolation to determine the missing temperature at 975 millibars (mb) involves the following process. First, determine the range of the pressure between the two levels with all values (1000 mb and 950 mb), which is 1000 mb – 950 mb = 50 mb. Next, determine the range between the one pressure level with all values (1000 mb or 950 mb) and the one missing values (975 mb). Using the 1000 mb level gives 1000 mb – 975 mb = 25 mb. Thus the ratio between the 1000 mb and the 975 mb level to the 1000 mb level and the 950 mb level is 25 mb / 50 mb = 0.5. Next, calculate the range between the temperatures at the two levels with all values, which is 23.1 °C - 20.2 °C =

) °C. Let x equal the missing temperature value in degrees Celsius at the 975 mb level, this gives the ratio of x / 2.9. Setting the two ratios equal as shown below,

$$\frac{25}{50} = \frac{x}{2.9},$$

and solving for x gives x = 1.45 °C. The value for x is rounded off to the higher tenths, so x = 1.5 °C. This value of x is subtracted from the 1000 mb temperature. Finally, the 975 mb temperature is given the value of 21.6 °C. Similar interpolation for the remaining values gives the values listed in Table 4.

Table 4. Sample of RAOB with linear interpolation applied.

Pressure (mb)	Height (m)	Temperature (°C)	Dew Point (°C)	Wind Direction	Wind Speed (kts)
1000	146	23.1	19.0	90	29
975	304	21.6	19.5	95	34
950	597	20.2	20.0	100	39

Linear interpolation was employed when studying the RAOBs associated with all the 176 cumulus LCC violations used for statistical analysis. This interpolation afforded a more complete data set. Additionally, since the cloud codes to be examined are classified as low clouds, only the 1000 mb level, 925 mb level, 850 mb level, and the 700 mb level were evaluated. These levels are mandatory and appear on every RAOB.

To insure the validity of the linear interpolation method, data denial verification was used on 45 random cases of the 176 cases under consideration to check the percentage of error associated with the temperature, dew point temperature, and wind direction at various pressure levels. For data denial verification, the known values were assumed missing and linear interpolation was applied and this calculated value was compared to the known value. For the 45 cases examined, the cumulative error percentage – the summed percentage the calculated values deviated from the known values – for each parameter is listed in Table 5. The error percentage was calculated by dividing the interpolated value by the known value. Any divided value greater than 1 had 1 subtracted from it and any value less than 1 was itself subtracted from 1. For example, if the calculated was 1.032, then this would give 1.032 – 1.000 = 0.032. This result was rounded off to the nearest hundredths and made a percentage, so the error percentage for this example would be 3%.

Table 5. RAOB parameter and the associated Error Percentage.

Parameter	Error Percentage
Temperature	< 2 %
Dew Point	< 4 %
Wind Direction	< 2 %

The values for the dew point depression and wind direction for the four pressure levels were weighted using a logarithmic variation of the trapezoidal rule (Hornbeck 1975: 146). Since pressure levels are nonlinear, which means when comparing two equal pressure ranges but for different levels the distance between the respective levels will not be the same. For example, from Table 3 the pressure ranges from 1000 mb to 950 mb and the 750 mb to 700 mb both equal 50 mb. However, the distance between the 1000 mb and 950 mb levels equals 447 meters, whereas the distance between the 750 mb and 700 mb levels equals 572 meters. Therefore, a logarithmic approach was used on the pressure because it makes the values more linear and more compatible with the dew point depression and wind direction. This approach was done in Mathcad® and this template is given in Appendix B.

3.2.3 Surface Observations

AFCCC also provided the surface observations for KSC for the ten-year period of 1989 - 1998. This data set was very complete, but it is noteworthy that at the beginning of July 1996 the data required for each hourly observation changed. After 1 July 1996, every hourly observation was required to report the cloud group in the additive data portion. Prior to this time, the cloud group was reported only every three hours.

The cloud group provides the cloud code type needed to help determine the occurrence of all cumulus violations for the study period. In general, the cumulus LCC is violated whenever a cloud code 3 or 9 is present since these cloud codes indicate a cumulonimbus is present either with or without other low clouds. The Air Force Manual 15-111 Surface Weather Observations contains the exact definition of these cloud codes (Department of the Air Force 1998b: 36).

The surface observation provides the following information: date, time, wind direction and speed, visibility, weather, cloud cover, temperature, dew point temperature, and additive data. The IDL® program CumulusAIRWAYS, contained in Appendix C, was used to interrogate the yearly surface observations and identify any cumulus LCC violations for the ten-year period. These programs identified any hourly observation containing a low cloud code 3 or 9 with any type of precipitation and a broken or overcast low cloud layer below 4,000 feet. This criterion was used to identify any cumulus LCC violation, though for statistical analysis, only the violations occurring between 1992 - 1998 were used because of the limited RAOB data prior to 1992.

3.3 Statistical Approach

This section briefly discusses the reason for the stratification of the cumulus data into four seasons and explains the statistical method of discriminant analysis that was used to analyze the RAOB data.

3.3.1 Data Stratification

The cumulus violations were also stratified into four seasons using the same seasonal classification as Hodanish et al. (1996). This is reasonable since the conditions needed for a cumulus violation are similar to those conditions preceding a thunderstorm since both instances require the presence of a cumulonimbus cloud (cloud code 3 or 9). Finally, Section 4.1.2 provides additional reasoning on why this seasonal stratification was applied.

3.3.2 Discriminant Analysis

Discriminant analysis is a statistical technique that uses independent predictor variables in a weighted function to categorize the given data into two or more groups. Having assigned the individuals or objects to one of two or more groups, the objective is to identify or discriminate any differences between the average group score profiles (Dillon and Goldstein 1991: 360). Therefore, the respective groups are discriminated amongst using the observed scores based on the set of independent predictor variables. Additionally, discriminant analysis invokes a strategy for finding a means of classifying individuals or objects into groups with accuracy (Dillon and Goldstein 1991: 363). Dillon and Goldstein (1991) state that "discriminant analysis can be thought of in terms of a rather simple 'scoring system' that assigns each individual or object in the sample a score that is essentially a weighted average of the individual's or object's values on the

Similarly, the spring (March – May) season's cumulative plot of cumulus set of independent variables." These weighted averages give the discriminant function, which is a derived variable defined as a weighted sum of values on the individual predictor variables (Kachigan 1991: 219). Once this score is found it is compared to the critical "cutoff score" to determine to which group the individual or object belongs. The "cutoff score" is the dividing line between the classification of the two groups and is selected so that it minimizes misclassification (Kachigan 1991: 223).

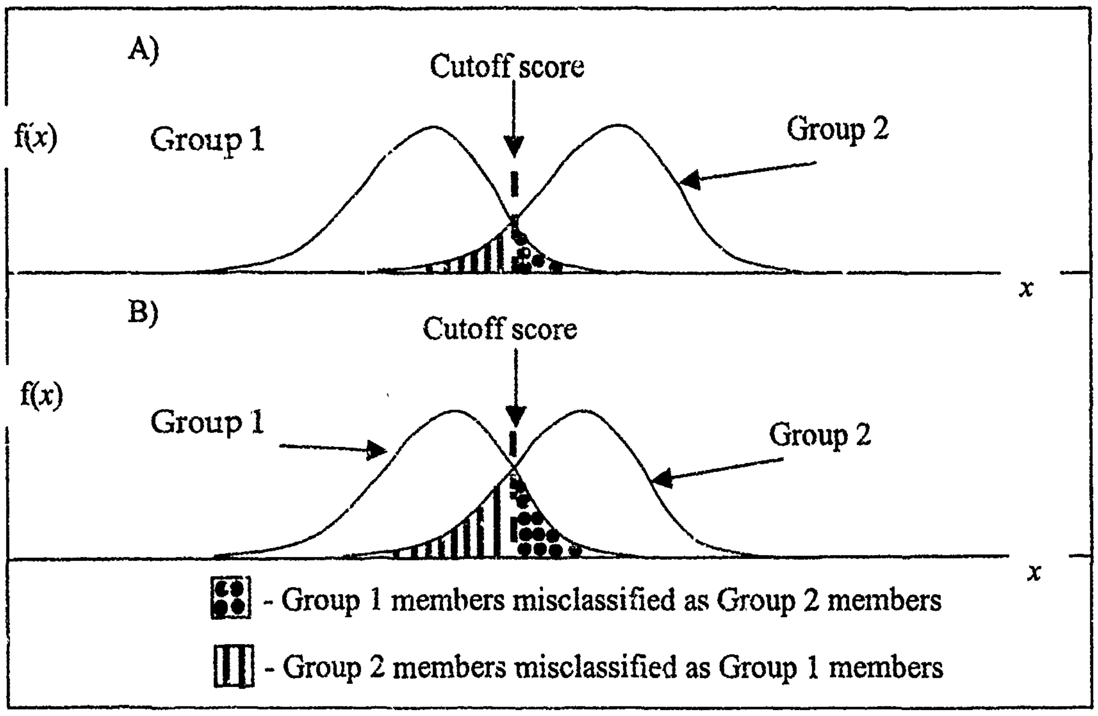


Figure 6. Discriminant Analysis Error Classification (adapted from Kachigan 1991). Depicts the simplest type of discriminant problem, where two groups of objects, group 1 and 2, are measured on a single predictor variable x.

Figure 6 shows the two types of classification errors associated with discriminant analysis. A large group difference between the two groups on the predictor variable(s), as in part A of Figure 6, gives fewer classification errors. Conversely, a small group difference between the two groups on the predictor variable(s) results in more classification errors as depicted in part B. Therefore, the above classification may not provide an error-free method for classifying the groups since the measured characteristic of the populations may overlap. Once all individuals or objects are classified they are entered in a confusion matrix as displayed in Table 6. The rows of the matrix relate to the actual group membership, whereas the columns give the predicted group membership (Dillon and Goldstein 1991: 371). Therefore, the "hits" (correct classifications) appear on the main diagonal (values 20 and 22) and the "misses" are listed in the off diagonal.

So how does the discriminant function work in conjunction with a confusion matrix? For example, if L is the discriminant function defined as:

$$L = 0.5X_1 + 2.3X_2,$$

where X_1 and X_2 are the respective independent predictor variables, then a confusion matrix of 50 classifications could give the results as depicted in Table 6. This confusion matrix (or contingency table) provides the correctly classified percentage for the "training sample". The correctly classified percentage is a conditional probability since the predictor variable values occur before the case is classified in the confusion matrix. The "training sample" is the set for which the group classification (dependent variable) is known for each of the respective independent predictor variables and from which the discriminant function and cutoff score are derived (Wilks 1995: 408). The training sample is randomly selected from the sample and is generally as few as 10 cases for each predictor variable used though no definite number was found in the literature review. For this study, the training sample contained RAOBs from days a violation occurred and days when no violation occurred. A discussion of the predictor variables used is in Section 3.3.3. The respective discriminant function is validated using a percentage of the sample that was not used to derive the discriminant function and is called the "validation sample". This validation process will also provide a new confusion matrix based on the validation sample, but uses the classification rule (cutoff score) determined by the training sample.

Table 6. **Confusion Matrix example** (adapted from Dillon and Goldstein 1991).

	Predicted Group	
Actual Group	**1**	**2**
1	20	5
2	3	22

A chi-squared (χ^2) test is applied to the training sample confusion matrix (contingency table) to assess its validity using the Statistix® software. The χ^2 value tests the confusion matrix or contingency table's observed discrepancies from that of a chance distribution for statistical significance (Kachigan 1991: 123). For a training sample confusion matrix to be statistically significant for this study, a significance level (labeled α) of 0.01 is used and the χ^2 value or the test statistic from the confusion matrix must be equal to or greater than 6.64. The validation sample will be statistically significant if the χ^2 value ≥ 2.71 and the respective p-value is ≤ 0.1. The significance level is simply the probability that the null hypothesis will be rejected when in fact the null is true (Devore 1995: 307). Assessing the validity of the training sample confusion matrix tests whether the null hypothesis should be rejected or not. For this study, the null says that the discriminant function is not better than random chance, and the alternate suggests the discriminant function is better than random chance. If $\chi^2 \geq 6.64$, then the discriminant function for that season is statistically significant at the chosen α level and the alternate is chosen. Additionally, the Statistix® χ^2 test will produce a p-value. The p-value is the smallest level of significance at which the discriminant function would not be better than just random chance, so a p-value $\geq$ 0.01 will mean the discriminant function is not statistically significant and the null is not rejected. The p-value is the probability; calculated assuming the null is true, of getting a χ^2 value of at least as extreme as the one actually obtained (Devore 1995: 336). For example, if $\chi^2 = 6.64$ with a corresponding p-value = 0.01 for a confusion matrix then there is a 1 in 100 chance of getting a χ^2 of 6.64 when assuming the null is true. Or put more succinctly, there is a 1% chance the null is true.

From Table 6, the percentage of cases classified correctly is calculated by (20 + 22) / 50 so 84% are correctly classified and 16% are misclassified. Therefore, if given the discriminant function one can discern the associated probability of correctly classifying that object using the individual or object's predictor variables based on the training sample. Also, the χ^2 equals 23.27 and the p-value is approximately 0.0 which means the associated discriminant function is found to be statistically significant.

For this study there are four distinct seasons; therefore each season will have a specific discriminant function and cutoff score. Application of the season specific discriminant function and "cutoff score" will determine into which group the ROAB (predictor variable) is to be categorized. The season specific correctly classified percentage can be examined to determine the probability of a classification being correct for the training sample. This correctly classified percentage is a conditional probability since it gives the probability of an occurrence given that the predictor variables have already occurred. But this conditional probability does not give an exact time when the predictor variables will fall into the respective category.

3.3.3 Predictor Variables

Because of the duplication of violations for a respective ROAB the actual number of cases in the training sample and the validation sample are listed in Table 7. Duplication of violations means that if a cumulus violation occurred at 0600 UTC and 0700 UTC for the same day, and the RAOBs occurred at 0200 UTC and 1200 UTC of that day, then only one of the two cases was used in deriving the discriminant function, which is discussed in Section 4.1.3.1. This is valid because the discarded case would be classified the same as the case used in deriving the function, since both cases would use the same predictor variable values. For both cases, the weighted averages of the dew point depression and wind direction would be derived from the same 0200 UTC and 1200 UTC RAOBs. Therefore no value is added to the accuracy of the discriminant function by including duplicate cases. Additionally, these discarded cases were not included in the function's validation sample, since they would duplicate a case in the training sample.

Table 7. Cases in the training sample and validation sample.

Season	training sample	validation sample	Total Cases
Cool	17	4	21
Spring	22	4	26
Warm	56	14	70
Autumn	22	4	26

The predictor variables selected for this study were the dew point depression and the wind direction at the respective pressure levels. These pressure levels include the

1000 mb, the 925 mb, the 850 mb, and the 700 mb levels. The wind direction was selected as a predictor variable based on the findings of Neumann (1968) and the probability between the wind direction and the occurrence of a thunderstorm. This probability was shown previously in Figure 4.

Dew point depression (dd) was selected because the formation of a cloud is dependent on the amount of moisture in the air parcel. The dew point depression is the algebraic difference between the ambient temperature and the dew point for the specific level, both of which are provided on the RAOB in degrees Celsius. The dew point is the theoretical temperature to which the air parcel would have to be cooled for the parcel to become completely saturated. Since the dew point is a measure of when the air parcel is saturated, the dew point depression is a measure of how much moisture is in the air parcel. For instance, if the RAOB shows the 1000 mb level has a temperature of 15.5 °C and a dew point of –1.1 °C then the dew point depression is calculated as 15.5 °C – (–1.1 °C), which gives a dd = 16.6 °C. In comparison, if the 850 mb level's dd is 3.0 °C, then the 850 mb parcel is moister than the 1000 mb parcel. The 850 mb parcel is more saturated since this parcel is closer to the dew point, which is the temperature when the parcel will be completely saturated. Therefore, in comparing two parcels, the one with the smaller dew point depression contains more moisture. Table 8 displays the dew point depression rule of thumb for cloud amounts as established by Technical Note 98/002 from the Air Force Weather Agency (AFWA) (Department of the Air Force 1998a: 2-9).

Table 8. Determining Cloud Amounts from Dew Point Depressions defined by AFWA (1998).

Dew Point Depression (°C)	Cloud Amount
0 to 2	Overcast
2 to 3	Broken variable Scattered
3 to 4	Scattered
4 to 5	Scattered variable Few
> 5	Clear

4. Analysis and Results

4.1 Analysis and Results

This section applies the methodology described in the previous chapter in analyzing the NLDN data, the surface observations, and the RAOB data. Also, the results from this analysis will be shown.

4.1.1 NLDN Analysis and Results

As described in section 3.2.1, the NLDN data was examined to find any cloud-to-ground flash within 12 nautical miles of the Cape's launch pad coordinates using the IDL® program in Appendix A. There were over 92,000 flashes meeting the criteria for the 1989 - 1998 period. The total flashes associated with each year are listed in Table 9.

Table 9. Yearly flashes within 12 nautical miles of KSC.

Year	Flash Count	Year	Flash Count
1989	5,361	1994	9,136
1990	9,285	1995	7,569
1991	6,095	1996	13,858
1992	10,293	1997	13,807
1993	8,035	1998	8,801

The data counts in Table 9 were filtered further so only a single count was given for each hour of the day that a flash occurred within 12 nautical miles, regardless of the total number of flashes occurring within the respective hour. This single count is called the flash hour. For example, if January 1st had a flash at exactly 1200 UTC and another flash occurred five seconds later, then 1200 UTC would count as a single flash hour.

Table 10. Annual flash hours for KSC.

Year	Flash Hours	Year	Flash Hours
1989	207	1994	333
1990	242	1995	285
1991	291	1996	280
1992	302	1997	304
1993	241	1998	250

The flash hours are listed in Table 10 and totaled 2,735 for the ten-year period. These respective yearly hours provided the basis for the monthly descriptive lightning climatology and these unconditional probability tables are in Appendix D. Table 11 displays a portion of the August results from Appendix D. These were calculated by dividing the cumulative monthly occurrences for that hour by total number of possible occurrences. For example, for the 10-year period a single cumulative flash occurrence on January 1st at 1100 UTC would be calculated as 1/10 and equal 10%, but in Table 11 and Appendix D this is displayed as a single digit to keep the table more legible. A value of 6 for August 15th at 2000 UTC means that for that day and hour there were 6 flashes in the 10 year period meeting the distance criteria; thus there is a 60% unconditional probability of a flash within 12 nautical miles of the launch pad for this date and time.

Table 11. Portion of August lightning climatology from Appendix D. Values are one-tenth of the associated cumulative daily probability of a lightning flash being within 12 nautical miles of KSC for a specific hour.

	Time (UTC)							
Day	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
15	0	1	2	2	6	4	3	1
16	1	0	1	1	2	3	2	0
17	1	3	1	1	2	3	1	1
18	2	0	2	4	2	2	1	0

Table 12. **Portion of Annual lightning climatology from Appendix E.** Values are the associated cumulative monthly probability of a lightning flash being within 12 nautical miles of KSC for a specific hour.

	Time (UTC)							
Month	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Jun	12	14	15	19	18	16	12	8
Jul	5	11	18	23	20	19	16	14
Aug	11	13	21	22	20	17	16	11
Sep	7	7	12	12	13	11	8	9

Additionally, Appendix E contains a table depicting the cumulative hourly unconditional probability of a lightning LCC violation for every month and Table 12 displays a portion of Appendix E. Summing the flash occurrences for every day of the month for a specific hour, then dividing these totals by the number of days in the month and multiplying these totals by 100 calculated these probabilities. Using Table 12 or Appendix E, a value of 20 for August at 2000 UTC means this hour of August has a 20% cumulative unconditional probability of having a flash within 12 nautical miles of the launch pad.

Table 13. Annual thunderstorm hours for KSC.

Year	Thunderstorm Hours	Year	Thunderstorm Hours
1989	234	1994	312
1990	168	1995	212
1991	250	1996	198
1992	251	1997	196
1993	190	1998	168

In comparison to Table 10, which used NLDN data, Table 13 lists the thunderstorm hours for each year using the surface observations. This count was calculated by first considering only those hourly observations 10 minutes before and after the hour that reported a thunderstorm. Additionally, this data was filtered further so only a single hourly observation within the 20-minute range was counted and called the thunderstorm hour. This procedure leads to the unequal values for the respective years listed in Table 10 and 13. For example, if a surface observation reported a thunderstorm at 1215 UTC and the storm ended by 1235 UTC, no thunderstorm hour would be counted. If the storm were within 12 nautical miles of KSC the flash hour count (Table 10) would have a hit for the 1200 UTC hour. This would lead to an under representation for the thunderstorm hour when compared to the flash hour for this hour. Similarly, if a storm starts at 1200 UTC and ends at 1250 UTC the flash hour would only have a count for the 1200 UTC; however, the thunderstorm hours would have a hit for both the 1200 UTC and the 1300 UTC. This would provide an under representation in the flash hours when compared to the thunderstorm hours for this period. Table 13 is presented only for a comparison with the data in Table 10.

4.1.2 Surface Observation Analysis and Results

As discussed in Section 3.2.3 all cumulus violations were identified using IDL® programs, such as presented in Appendix C. Additionally, as put forth in Section 3.3.1 the cumulus violations were stratified into four seasons as developed by Hodanish et al. (1996), but why was this four season stratification applied for this study?

This stratification was chosen after examining the histograms for the respective seasons. The graphs in Appendix F show the histograms for the cumulus violations for each of the four seasons and the cumulative cumulus violations for the 1992 – 1998 period. The period prior to 1992 was not included in the plots because no RAOBs were available for the statistical analysis in Section 4.1.3. Figure 7 displays the three

Figure 7A. Histogram for 1 Jul 96 to Dec 98 (every hour examined) (24 cases)

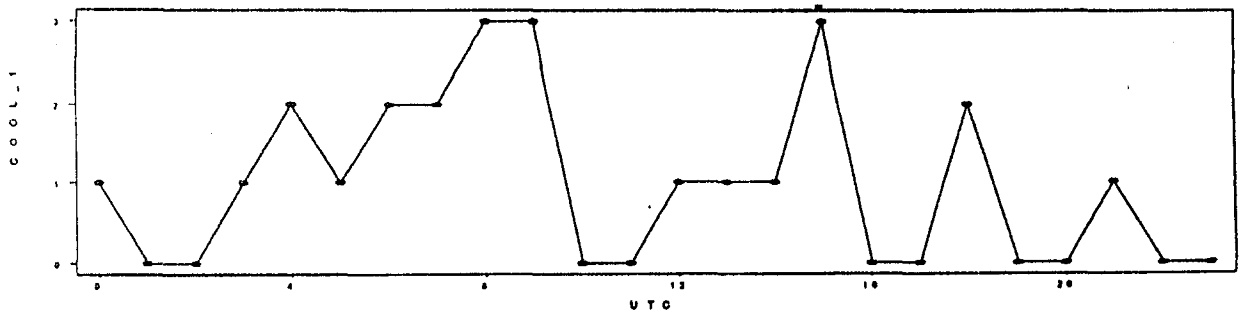


Figure 7B. Histogram for 1 Jan 92 to 1 Jul 96 (every 3 hours examined) (7 cases)

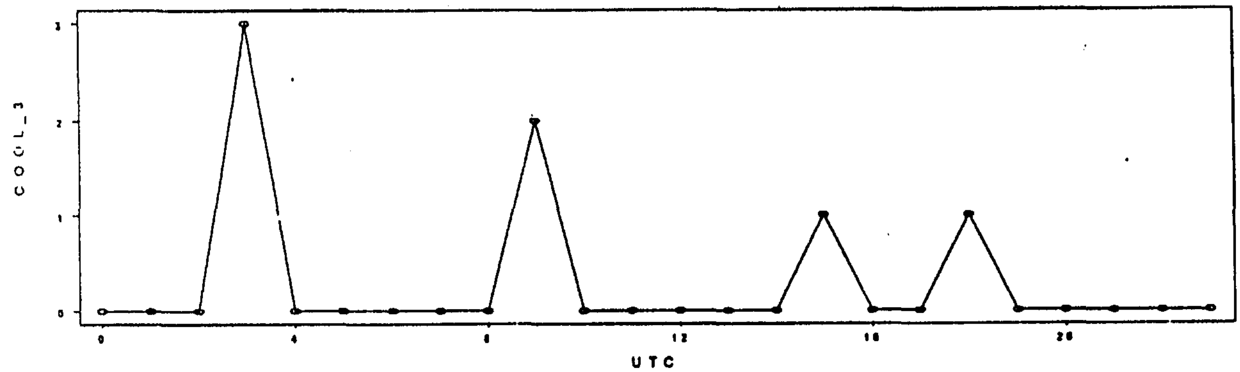


Figure 7C. Cumulative Histogram of above plots (31 cases)

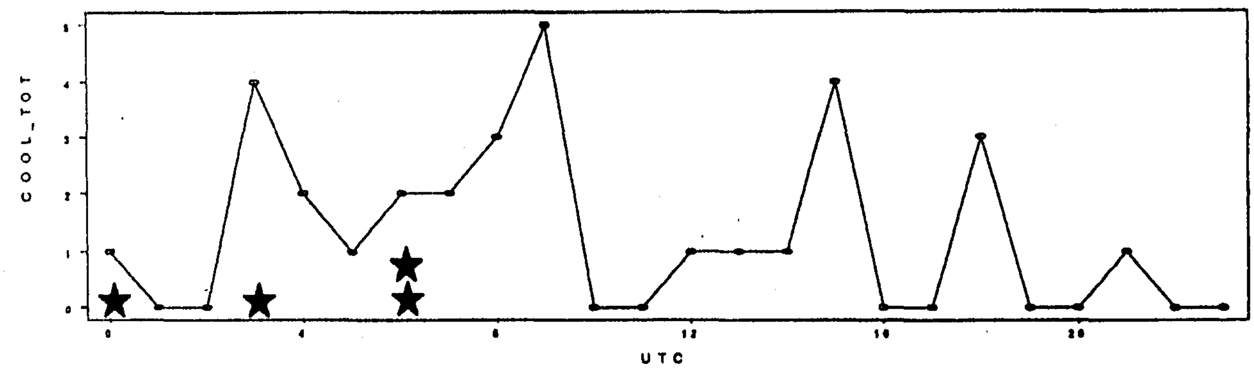


Figure 7. Cool Season Histograms (Nov – Feb). Vertical axis represents the number of cumulus violations for the defined period. Horizontal axis represents the time of occurrence for the violation. Stars mark the times used for discriminant analysis.

histograms for the cool season. The top plot, Fig. 7A, displays all hourly violations for the period after 1 July 1996, since before this time the surface observations did not include the needed cloud group on an hourly basis. The middle plot, Fig. 7B, displays the cases prior to 1 July 1996, when the cloud group was only available every three hours. Finally, the bottom plot (Fig. 7C) is the seasonal cumulative plot. The star above the abscissa of each seasonal cumulative plot denotes the randomly selected cases used for the validation of the respective seasonal discriminant. The final page in Appendix F is for all seasons and uses the same plotting format of the seasonal violations as discussed previously, but does not display the cases used for validation.

Upon examining the respective seasonal cumulative graphs (bottom plot), each histogram exhibits the basic characteristics of the seasons defined by Hodanish et al. (1996). For instance, the cool season's cumulative plot of cumulus violations displayed in Figure 8 shows a great deal of variability for the time of a cumulus violation. Furthermore, this period has the lowest number of cumulus violations (31 cases) even though this is the longest period (November – February). This variability is similar to the reduced flash density documented in Hodanish et al. (1996) and is related to the unpredictable and infrequent passing of mid-latitude cyclones, which are the main cause of thunderstorms for this season.

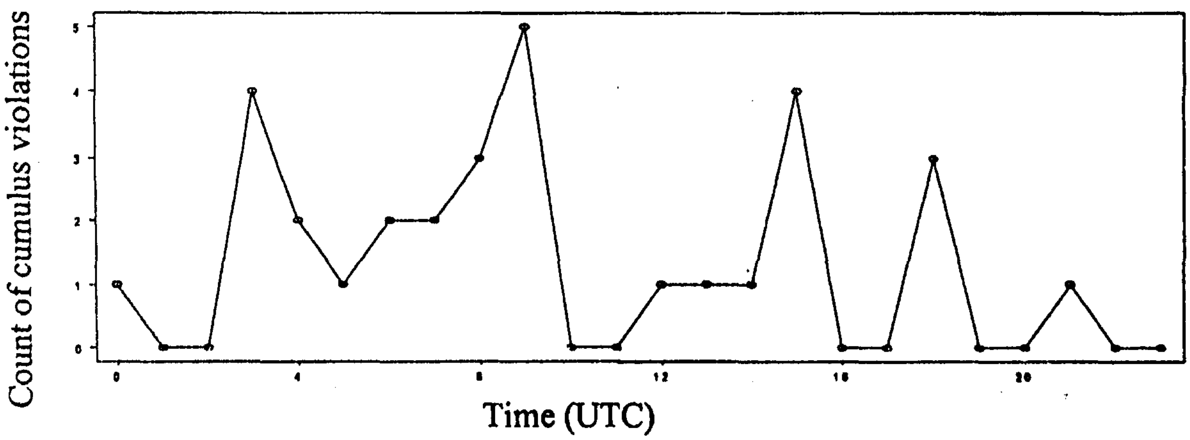


Figure 8. Cool Season Cumulative Histogram of Cumulus Violations.

Similarly, the spring (March – May) season's cumulative plot of cumulus violations, displayed in Figure 9, exhibits a little less variability for the time of a violation when compared to the cool season's cumulative plot (Fig. 8). This lesser degree of

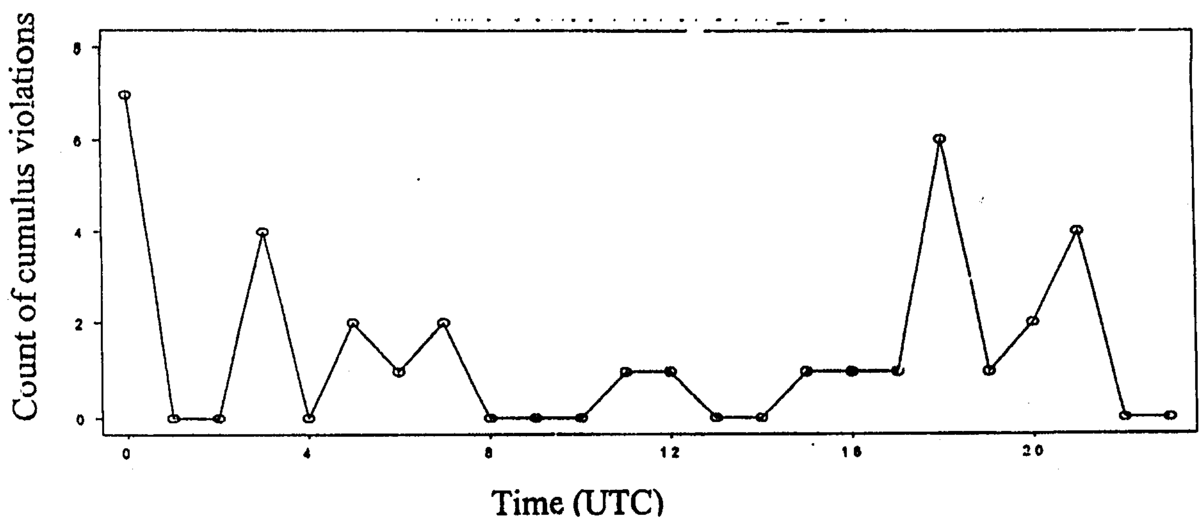


Figure 9. Spring Season Cumulative Histogram of Cumulus Violations.

variability is most likely the result of decreased frontal passages early in the period, and the formation of the sea breeze as solar insolation increases as the period progresses. These conditions translate into more cumulus violations later in the day because of the associated maximum daily heating and the resulting sea breeze, especially from 1500 UTC to 0000 UTC. Additionally, the number of cumulus violations increases to 34 cases and this coincides to the increase in lightning activity for this season as outlined by Hodanish et al. (1996).

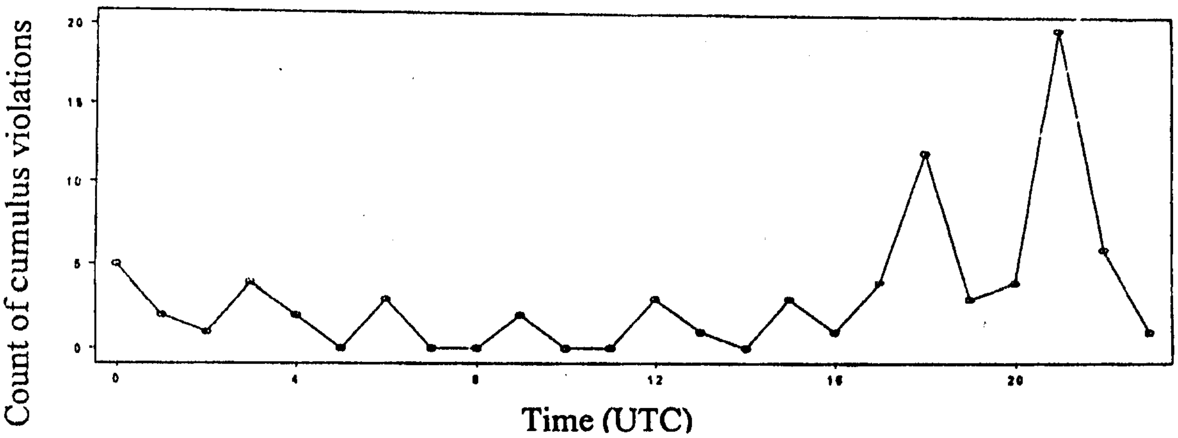


Figure 10. Warm Season Cumulative Histogram of Cumulus Violations.

Figure 10 displays the warm season's (June – August) cumulative histogram of cumulus violations, which is the most electrically active period in terms of flash density (Hodanish et al. 1996), and correspondingly this period also contains the most cumulus violations. A total of 77 cumulus violations were found for the 1992 – 1998 period as displayed in Section 4.1.3 in Table 15. This is primarily the result of the low-level wind pattern associated with the Bermuda High and the subsequent sea breeze interface, plus the abundant solar insolation and low-level moisture. The warm season's cumulative plot of cumulus violations shows the least variability for the time of a violation for all the seasons as the weak synoptic flow and the prevalent sea breeze combine to produce late afternoon air mass thunderstorms. This late afternoon time for storm occurrence compares favorably with the most frequent time for a cumulus violation, which is from 1800 UTC to 0000 UTC.

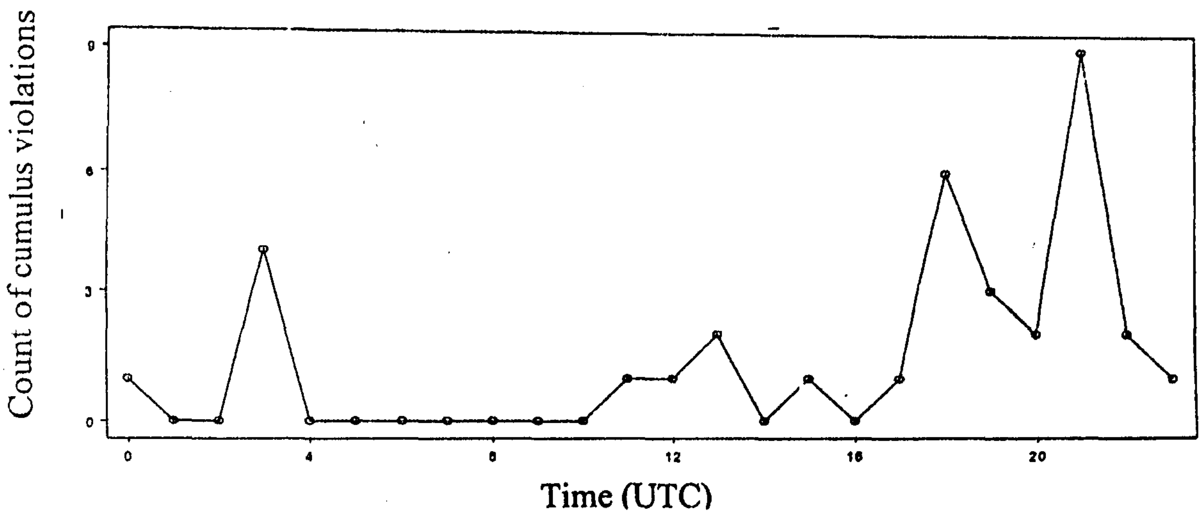


Figure 11. Autumn Season Cumulative Histogram of Cumulus Violations.

The autumn season's (September – October) cumulative plot of cumulus violations, shown in Figure 11, displays a degree of variability similar to the spring period (Figure 8). Just as the flash densities decrease (Hodanish et al. 1996), so do the cumulus violations to 36 cases from the warm season's 77 violations. This decrease is a consequence of the decrease in the development of the sea breeze and the intrusion of more stable air later in the period as the Bermuda High migrates westerly, plus the solar insolation decreases. Additionally, later in the period the cumulus violations become more dependent on the passage of synoptic disturbances. Because of the above justification for each season, the cumulus violations were stratified into seasons similar to the thunderstorm classification introduced by Hodanish et al. (1996).

Table 14 contains a portion of results listed in Appendix G. Appendix G is the hourly unconditional probability for a seasonal cumulus violation for the 1989 - 1998 period and these probabilities are season specific. For instance, the warm season's 0000 UTC gives a 7% probability relative to that season and was computed by dividing the number of 0000 UTC violations by the total number of warm season violations. Table 15 lists the annual seasonal cumulus violations. For the warm season, 7 violations occurred at 0000 UTC, and there were 102 seasonal violations, which gives 7 / 102, so there is approximately a 7% probability of a violation at 0000 UTC during the warm season as displayed in Table 14. Similar calculations were done for the other seasons.

Table 14. Portion of hourly probability for Seasonal cumulus violations as given in Appendix G.

	Time (UTC)					
Season	**00**	**01**	**02**	**03**	**04**	**05**
Cool	6	0	0	11	6	3
Spring	20	0	0	8	0	4
Warm	7	2	1	6	2	0
Autumn	3	0	0	13	0	0

4.1.3 RAOB Analysis and Results

After the surface observations were used to identify all cumulus violations for the 1989 - 1998 period, only the violations after 1992 were used since this period had corresponding RAOBs. The annual violations for each respective season for the 1989 - 1998 period are listed in Table 15 and totaled 229 violations. The RAOB cases used to derive the respective seasonal discriminant functions totaled 176 for the 1992 to 1998 period. Of these cases, 80 percent of the warm cases and 90 percent of all the other three seasons were selected randomly for the training sample. The training sample contained equal cases of RAOBs with and without a violation. The remaining 20 percent of the warm season cases and the 10 percent of cases for the other seasons were used for the validation sample of the seasonal discriminant functions. The validation sample was constructed by matching the number of RAOB cases with a cumulus violation not used in the training sample with an equal number of RAOB cases without a violation. If possible, the RAOBs associated with the violation cases were chosen so they were within at least twelve hours of the time of occurrence, but none were during the actual time of occurrence. The concept of the training and validation sample was defined in Section 3.3.2.

Table 15. Annual Seasonal Cumulus LCC violations.

Year	Cool	Spring	Warm	Autumn	Year total
1989	3	5	6	0	14
1990	2	2	11	4	19
1991	0	10	8	2	20
1992	2	4	11	3	20
1993	0	0	2	3	5
1994	3	3	7	5	18
1995	2	1	10	4	17
1996	2	8	15	10	35
1997	7	9	12	4	32
1998	15	9	20	5	49
Season Total	36	51	102	40	229

4.1.3.1 Deriving the Seasonal Discriminant Functions

Appendix H provides a well-documented Mathcad® template that goes step-by-step through deriving the cool season's discriminant function. Additionally, the template also contains the equations used, a reference for the equations, the determination of the discriminant function, and the validation of the discriminant function. Finally, determining the respective discriminant functions for the other seasons follows the process outlined in Appendix H.

Generally the process involved finding the instances when a cumulus violation occurred and when one did not; thus two groups were identified. For each of the cases selected, the weighted averages of the dew point depression and the wind were calculated from the RAOB using the trapezoidal rule for the four levels listed previously in Section 3.3.3. These two weighted averages, calculated using Appendix B, for each case of both groups were entered into a matrix. The respective sample mean and the sample variance for both the dew point depression and the wind were calculated for each group. Next, a sample variance-covariance matrix was calculated for each group. The sample variance-covariance matrix not only provides the variance of each predictor variable within the group but also the covariance, which measures how strongly the predictor variables are related to one another (Devore 1995: 213). A strong relationship, either positive or negative, results in a covariance value not close to 0. Devore (1995) states "the defect of the computed covariance value is that it depends critically on the units of measurement." The sample variance-covariance matrices are used to find the pooled sample variance-covariance matrix, which yields a pooled estimate of the dispersion of the data around their means (Wilks 1995: 409). The pooled sample variance-covariance matrix is used to compute "a direction $\mathbf{d}_1$ in the K-dimensional space of the data, such that the distance between the two mean vectors is maximized when the data are projected onto vector $\mathbf{d}_1$" (Wilks 1995: 410. Basically, this reduces the discrimination problem from one of reviewing relationships between data vectors to looking at a single scalar value. The elements in the vector $\mathbf{d}_1$, as displayed in Figure 12, are the associated weights for the predictor variables (precipitation and temperature) in the discriminant function. The

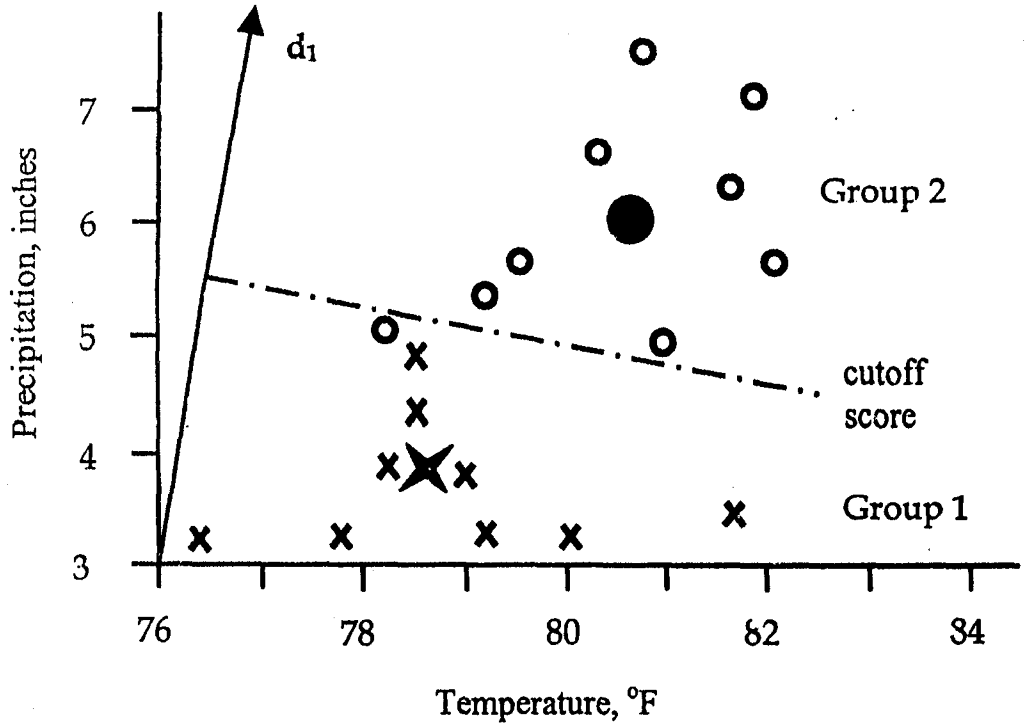


Figure 12. Geometry of linear discriminant analysis (adapted from Wilks 1995). Heavy symbols denote the two mean vectors.

vector $\mathbf{d_1}$ is also used to find a cutoff score that will determine which classification the predictor variables will be placed, either Group 1 or Group 2 as shown in Figure 12. Once the discriminant function and cutoff score are determined, a confusion matrix and the resulting correctly classified percentage are calculated for the training sample as discussed in Section 3.3.2. Finally, the validation of the discriminant function is performed using the validation sample data that was not used initially to calculate the discriminant function.

Table 16 lists the seasonal discriminant functions, the conditional probability and the cutoff score as determined for each seasonal training sample. The W and the DD listed in Table 16 with each discriminant function represent the weighted averages for the wind direction and the dew point depression, respectively, as derived using the template in Appendix B and are not assigned units. The conditional probability is nothing more than the correctly classified percentage as determined from the confusion matrix for each season's training sample. The understanding of the conditional probability is important because this percentage is based on the training sample and as such the reported error rates are optimistically low or biased, since the data used to construct the classification rule was also used to evaluate the rule (Dillon and Goldstein 1991: 371). The cutoff score, which is a unitless number, is used to determine to which group the value computed for the seasonal discriminant function would be classified. For all seasons, a discriminant function value less than or equal to the assigned cutoff score means the RAOB would be classified in the no violation group.

Table 16. Discriminant Functions, Conditional Probability and Cutoff Score.

Season	**Discriminant Function**	**Conditional Probability**	**Cutoff score**
Cool (Nov–Feb)	– 0.0128*W – 0.3812*DD	76.5%	– 4.529
Spring (Mar–May)	0.0014*W – 0.2422*DD	72.7%	– 0.962
Warm (Jun–Aug)	0.0053*W - 0.4558*DD	67.9%	– 0.860
Autumn (Sep–Oct)	0.0041*W – 0.5142*DD	70.5%	– 1.471

The following example illustrates the way Table 16 is to be applied. If for a spring season RAOB, W = 217 and DD = 5.70, using the spring's discriminant function gives

$$0.0014 * 217 - 0.2422 * 5.70 = -1.077.$$

Comparing this value against the spring season's cutoff score of – 0.962 means this RAOB would be classified in the no violation group In contrast, if the spring season RAOB had W = 240 and DD = 1.62 the resulting discriminant function value would equal – 0.056 which is greater than the respective cutoff score. Therefore, this spring season RAOB would be classified in the violation group.

Table 17. Cool Season's training sample Confusion Matrix. Group classification was determined using the respective derived discriminant function a cutoff score.

	Predicted Group	
Actual Group	**1**	**2**
1	15	2
2	6	11

The cool season's training sample confusion matrix is listed in Table 17. Using the chi-squared (χ^2) test, as outlined in section 3.3.2, on the data in Table 17 gives χ^2 = 10.09 and a p-value = 0.0015 (Table 18). Table 18 contains all the seasonal χ^2 and p-values for the respective confusion matrices of the training sample data as determined by Statistix®. As is apparent from Table 18, all the respective discriminant functions were found to be statistically significant for the training sample confusion matrix. However, as mentioned previously, the high χ^2 and the low p-values are based on the training sample's confusion matrix, which produces a biased or optimistically low reported error rate. Also, the p-value (Section 3.3.2) should not be interpreted as an indicator of how inaccurately each seasonal discriminant function will correctly classify a new RAOB.

Table 18. Seasonal χ^2 and p-values. Values shown are derived from each seasonal Confusion matrix.

Season	χ^2	p-value
Cool	10.09	0.0015
Spring	9.17	0.0025
Warm	14.36	0.0002
Autumn	8.19	0.0042

4.1.3.2 Validation of the Derived Seasonal Discriminant Functions

Table 19. Cases in each Seasonal validation sample.

Season	Number of Cases
Cool	8
Spring	8
Warm	28
Autumn	8

Testing the statistical significance of the validation of each discriminant function was limited because of the small number of cases in each seasonal validation sample, as is listed in Table 19. Because of the relatively small sample sizes for each validation sample, the χ^2 test was applied to only the warm season.

Table 20. Correctly Classified Percentage for seasonal validation samples.

Season	Correctly Classified
Cool	100%
Spring	75%
Warm	61%
Autumn	75%

Table 20 displays the correctly classified percentage for each seasonal validation sample for the number of cases listed in Table 19. Immediately noticeable is the 100% classification accuracy of the validation sample for the cool season discriminant function. This is encouraging, but because of the small sample size this value should be considered with some caution. However, it is noteworthy that this period also has the highest classification accuracy as displayed in Table 16. Additionally, this discriminant function had the second highest χ^2 and the second lowest p-value, as displayed in Table 18. The higher, correctly classified percentage values, in both Table 16 and 20, are probably the result of the seasonal atmospheric conditions that allow for a more representative discriminant function. For example, a cool season cumulus violation is typically dependent on the passage of cold fronts. Therefore, prior to a front there should be an appreciable increase in moisture (dew-point depression decreases) and a definitive wind shift. Both of these features would be incorporated in deriving the seasonal discriminant function by the pooled variance-covariance matrix. Therefore, if enough cases were in the cool validation sample this discriminant function might be found to be statistically significant. But since the cool season cases are so few, no definitive conclusions can be made from the results of the χ^2 test. Wilks (1995) states that "classes with small numbers of expected counts should be avoided and sometimes a minimum of five 'expected' events per class is imposed." Likewise, the spring and autumn discriminant functions show pron[illegible]t without a larger validation sample to test for statistical significance little can be concluded as discussed above for the cool season function.

Table 21. Warm Season's validation sample Confusion Matrix.

	Predicted Group	
Actual Group	**1**	**2**
1	9	5
2	6	8

In comparison to the cool season, the warm season's atmosphere is much more thoroughly mixed or homogeneous, when a violation does or does not occur. During this time of the year, the atmosphere over Florida is nearly tropical with almost no frontal passages, thus the differences in dew point depression and wind direction are usually subtle. Because of these subtle differences it is much harder to discriminate between instances when a violation occurs and when a violation does not occur. Therefore, one would expect this season's discriminant function to be the least accurate, which is exactly the case as indicated by the percentages in Tables 16 and 20. Additionally, the χ^2 value is 1.29 and the p-value is 0.26 after applying a chi-square test to the data in Table 21. This low χ^2 value and the subsequent high p-value mean the warm season's discriminant function did not perform as well on the validation sample as it did on the training sample, but this bias of the discriminant function was discussed previously in Section 4.1.3.1. When the guides for testing significance are applied, as noted in Section 3.3.2, this discriminant function proves to be statistically insignificant. But these values could be the by-product of a small validation sample size used. Additionally, the portion of the warm season's atmosphere that was interrogated (1000 mb, 925 mb, 850 mb, and 700 mb) is more homogeneous during warm season when compared to the other three seasons. Because of this, the upper pressure level (700 mb) may need to be higher in the atmosphere to detect any discernable difference in the dew-point depression or wind direction. Another approach may be to include more or all levels in the 1000 mb to 700 mb range from the RAOB. During the warm season, the differences in the dew-point depression and wind direction are very subtle for the days with a cumulus violation and days with out a violation. Therefore, the inclusion of more measurement points may allow the detection any small changes in either the dew-point depression or wind direction. This would be reflected in more representative derived discriminant function and a higher correctly classified percentage.

Though all of the discriminant functions displayed in Table 16 have promise the small validation sample size limits the application of most statistical test for significance. These tests, namely the χ^2 test, would have assessed the validity of whether the seasonal discriminant functions were statistically significant and if they outperformed random guessing with a degree of certainty as discussed in Section 3.3.2.

5. Conclusions and Recommendations

5.1 Conclusions

This study sought to provide a descriptive climatology for both the lightning and cumulus LCC violations and a conditional probability for the cumulus LCC. The respective descriptive climatology was found but the conditional probability for the cumulus violations proved to be more elusive.

Both a lightning and cumulus descriptive climatology were found and will aid in the long-term mission planning of launches from the Cape. Prior to this study, the Cape did not have this descriptive climatology. The lightning climatology isolated over 92,000 flashes, as discussed in Section 4.1.1. This descriptive lightning climatology is listed in Appendices D and E. The procedure used for calculating the descriptive lightning climatology was straightforward. Coupled with the known accuracy of the NLDN data, as discussed in Section 2.2, this climatology should be considered very reliable and useful.

Using the 229 cumulus violations identified, the descriptive climatology for a cumulus violation is in Appendix G and gives the season relative hourly probability for a violation. The criteria for defining a cumulus violation were defined in Section 3.2.3 and the probability calculations were explained in Section 4.1.2. The stratification of the cumulus violations into four seasons, as introduced by Hodanish et al. (1996) was a good decision. The number of seasonal cumulus violations identified matched the general findings of the Hodanish et al. (1996) study. For instance, their study concluded that the warm season (June – August) was the most active and the cool season (November – February) was the least active climatologically for lightning. Similar results were found for the cumulus stratification as the cumulus warm season had the highest incidence of violations (77 cases) and the cumulus cool season had the lowest number of violations (31 cases), as discussed in Section 4.1.2. However, the initial assumptions used to define a cumulus violation may have led to an under representation of cases. For example, a cumulus violation needed a broken or overcast low cloud layer less than or equal to 4,000 feet. However, the AFWA TN-98/002 (Department of the Air Force 1998a) classifies low clouds from near the surface to 6,500 feet above ground level. The 4,000 feet height assumption is for a typical atmosphere and this height was suggested by the sponsor. Unfortunately, this height may not be representative of the tropical conditions that Florida experiences during the warm season.

The conditional climatology to aid the operational forecaster in forecasting the occurrence of cumulus violations was not as straightforward as the descriptive climatology approach. The data were stratified into four seasons as discussed previously for the descriptive climatology. This stratification afforded the derivation of season specific discriminant functions that should provide a higher percent of correctly classified cases if compared to a single function for the entire year. In building the most representative seasonal specific discriminant function, 80-90% of the identified cumulus violation cases were used in deriving the discriminant functions. This presented an unforeseen problem because the number of cases used in the training sample (Section 3.3.2) did not allow a large enough validation sample (Section 3.3.2) to be classified when verifying the discriminant functions as discussed in Section 4.1.3.2. The limited validation sample size, except for the warm season, did not allow the confusion matrix to be statistically interrogated for significance. Therefore, even though each season has a discriminant function and classification rule they have no statistical merit and no conclusions can be made about these functions performance in forecasting. Additionally, the seemingly poor performance in validating the warm season's function, where the χ^2 value equaled 1.29, may be an indicator that the predictor variables are not the only ones. But since Neumann's 1970 study clearly shows that the wind direction is a prime predictor of thunderstorm activity, at least for the May – September period, then this predictor variable should be included in deriving the discriminant functions. Also, since saturation or near saturation is required for cloud formation the dew point depression is a logical predictor. As such, the conditional climatology for the cumulus cloud LCC does not have any statistical merit.

5.2 Recommendations for Future Research

The launch commit criteria (LCC) are comprised of eleven rules. This began with a request from the sponsor for a descriptive climatology of the LCC. In the future, it would be more beneficial to have a list of which LCC are the most frequently violated based on either launch postponement or cancellation or both. The LCC violated the most could then be addressed first, thus providing more value to the sponsor.

Future research could concentrate on refining the discriminant functions listed for the cumulus violations with the inclusion of other predictor variables. For instance, as shown in Figure 3, Neumann (1970) found the probability of thunderstorm activity using the date of the year (Fig. 2) and the 914-meter (3,000 foot) wind speed (Fig. 3). Therefore, the wind direction at the various levels, available from the RAOB, may improve the discriminant functions. The time of the year may also improve the functions. Additionally, the inclusion of more levels between the 1000 mb to 700 mb range, for all relevant predictor variables, might detect subtle differences and this may produce more representative and accurate discriminant functions.

The lack of total cases for validation could possibly be re-evaluated since the RAOBs between 1989 and 1991 exist. This was discovered two weeks prior to the thesis due date and therefore was not addressed. Furthermore, the cloud height needed for a cumulus violation as addressed previously could be varied from season to season. Additionally, the discriminant functions from Table 13 could be evaluated by the 45WS to determine if they are of any value.

Finally, the field mill data was not included in this study because less than one year of the data were made available, but much more of this data is available from the Cape. Any future study of the LCC may need to incorporate this other data source as it may provide another valuable predictor variable.

Appendix A

IDL® Program to find flashes within 12 nautical miles of launch pad.

```
pro lightning_NLDN                                  ;Last Modified  8 Nov 99
                                                    Written by Edward C. Goetz
;**********************************************
;        This is a program to view NLDN data by date over a specific geographic region
; and plots these flashes.  Then filters out any ; flashes that are outside the specified
; threshold (> 12NM from launch ; pad).  Also, a histogram is constructed and plotted
; using the julian ; hour (the year specific julian day*24 plus the hour the flash
; occurred on that day) for that flash.   Those julian hours are then used to create the
descriptive climo.
;**********************************************
        close,/all

;******* Set format for output  ***********
;  f_form= {year mon day hour(Z) min sec lat long pk_current; multiplicity}

form="(I4,1X,I2,1X,I2,1X,I2,1X,I2,1X,I2,1X,f9.4,1X,f9.4,1X,f9.4,1X,I2)"

;******** Define the years and months to be searched  ********

        years = ['89','90','91','92','93','94','95','96','97','98']

        months = ['jan','feb','mar','apr','may','jun','jul','aug','sep','oct','nov','dec']

        nyears = n_elements(years)
        nmonths = n_elements(months)

;** Erases the data in the associated files that are called later **

        for j=0,nyears-1 do begin
        file_name = "/home/kramer1/users/egoetz/thesis/Lightning/Lgtng_NLDN_results
                  /19" + strcompress(years(j),/remove_all) + $         "flashes.txt"

                  openw,2,file_name
                  close,2
        endfor

;******** Lat / long for a launch area  *********

        launch_lat=28.526427
        launch_lon=-80.574509
        earth_rad=(6371/1.852)          ; gives earth's radius in NM
```

```
;identifies where the file is located
inpath = '/home/fujita12/flash/lgh19'

filelist = strarr(nyears*nmonths)

;** Assign each monthly file to a position in an array **************

for y = 0, nyears - 1 do        $

 for m = 0, nmonths - 1 do    $
  filelist[y*nmonths + m]=inpath + years[y] + '/' + months[m] + years[y] + '.lgh'

;********************************************* **
;       Calc the Julian date for the start and stop of period
;*********************************************

d1=julday(1,1,1989)
d2=julday(12,31,1998)

ndays= d2-d1 +1                ;total days to be evaluated
counts=lonarr(ndays)

;** Generate numbers 1 to 100 and makes all nums two digits **********

num=strcompress(sindgen(100),/remove_all)

num[0:9]= '0' + num[0:9]

for day=0, ndays-1 do begin
        caldat,d1+day,m,d,y
        caldat,d1+day+1,m_2,d_2,y_2
                dates=[num[m] + '/' + num[d] + '/' + num[y mod 100] + ' ' + $
                 '00:00:00',num[m_2] + '/' + num[d_2] + '/' + $
                num[y_2 mod 100] + ' ' $ + '00:00:00']

findtime,dates,startind,startpos,lastind,lastpos,filelist,11L

currentind = startind
currentpos = startpos

done = ((currentind GE lastind) AND (currentpos GE lastpos))

        region=[27.5, 29.2, -81.5, -79.3]       ;sets the region coords
```

```
        map_set,0,-100,0,limit=region([0,2,1,3]),/usa, /con_color   ;sets the map
        nflashes=0

;*** gets all flashes inside the defined region *****

    while not(done) do begin
    f=getchunk(filelist,startind,stoppos,lastind,lastpos,region,$
            currentind,currentpos,11L,50000)

        if (n_elements(f) GT 1) then begin
            nflashes = nflashes + n_elements(f)/11
            f = exp_lgh(f) :extracts flash data

;*********************************************
; Plots flashes w/in the region and plots the 12NM circle (approx)
;*********************************************
        plots,f.lon,f.lat,psym=1, color = 14
        deg = findgen(361)*!dtor
        r = 22.2/6370.0
        x = launch_lon+((cos(deg)*r)/!dtor)
        y = launch_lat+((sin(deg)*r)/!dtor)
        plots, x(0), y(0)
        for i = 1, 360 do plots, x(i), y(i), /color,/continue

;** Find flashes that are within 12NM of launch pad ***********
            r = earth_rad * cos(launch_lat * !dtor)
            x = r * ((launch_lon - f.lon) * !dtor)
            y = earth_rad * ((launch_lat - f.lat) * !dtor)
            d = (y^2.0 + x^2.0)^0.5

;***        Keep those flashes w/in 12 NM of pad **********************

            keep = where(d LE 12.0, count)
            if (count GT 0) then begin
                f = f(keep)     ;reassigns flashes  w/in 12NM

                nflashes = n_elements(keep)

;*** Saves the flashes w/in 12NM to the specific yearly file **

            year=strcompress(f[0].year,/remove_all)

            file_name ="/home/kramer1/users/egoetz/thesis/ Lightning/ $
            Lgtng_NLDN_results/" + year + "flashes.txt"
```

```
                        openw,2,file_name,/append
                        printf,2,f,format=form
                        close,2
                endif

        endif else begin
                print,'   No Flashes are w/in Region '
                print
        endelse

        done = ((currentind GE lastind) AND (currentpos GE lastpos))

    endwhile

    endfor          ;ends the ndays loop

;*********************************************
;       Read from file of flashes w/in 12NM to determine file length.
;*********************************************

    s = " "
    hist=lonarr(366L*24L + 1)

    for j=0,nyears-1 do begin       ;steps through all years

        total=0L
        n = 0L

        close,/all

        file_name ="/home/kramer1/users/egoetz/thesis/Lightning/ $
        Lgtng_NLDN_results/19" + strcompress(years(j),/remove_all) + $
        "flashes.txt"

        openr,3,file_name

        while not (EOF(3)) do begin
                readf,3,s
                n = n + 1
        endwhile

        total = n
        close,3

        info=fltarr(10,total)
```

```
          openr,3,file_name

          readf,3,info

;*******************************************
;       Compare the flashes to filter out any times so that if the day and hour are the
; same that only one flash is kept. This single flash violates the criteria for that hour.
; Then need to calculate the julian date + HOUR of occurence to use in plotting the
; HISTOGRAM.
;*******************************************

          jul_day_hr=lonarr(total)

          for i=0L,total-1 do begin

;***** Computes the julian day_hour for each individual year *****

     jul_day_hr(i)=(julday(info(1,i),info(2,i),info(0,i))*24 + $
          fix(info(3,i))) - julday(1,1,info(0,i)) * 24

          endfor          ;ends total loop

     ;**********************************
     ;       Compiles the HISTOGRAM for the period.
     ;**********************************

          ;computes the Total_hist

          hist= histogram(jul_day_hr,min=0,max=366*24,input=hist)

          ;computes each ANNUAL histogram

          hist= histogram(jul_day_hr,min=0,max=366*24)

          plot,hist          ; used to plot each ANNUAL historgram


     file_name="/home/kramer1/users/cgoetz/thesis/Lightning/Lgtng_NLDN_results/$
          19" + strcompress(years(j),/remove_all) + "annual_hist.gif"


     file_name_1 ="/home/kramer1/users/cgoetz/thesis/Lightning/$
     Lgtng_NLDN_results/19" + strcompress(years(j),/remove_all)$
     + "annual_hist.txt"
```

```
;****** Saves each ANNUAL hist .gif file to the specified file ***

            write_gif,file_name,tvrd()

;*****************************************************
;       This finds the julian_day_hr that the frequency was 1 or greater
; by using a where statement. These postions are then saved to a .txt
; file. This saves each ANNUAL jul_day_hr
;*****************************************************

            keep = where((hist GT 0),count)

            if (count GT 0) then begin

                    close,/all
                    openw,3,file_name_1
                    printf,3,keep

            endif

            close,/all

        endfor          ;ends the index for nyears
;*****************************************************
;       Saves the total_hist.gif file

        file_name = "/home/kramer1/users/egoetz/thesis/Lightning/ $
                Lgtng_NLDN_results/total_hist.gif"

        plot,hist       ; Used when plottting the total_hist for nyears
        write_gif,file_name,tvrd()

        keep = where((hist GT 0),count)

            if (count GT 0) then begin

                    close,/all
                    openw,3,file_name
                    printf,3,keep

            endif
        close,/all
        plot,hist
end
```

Appendix B

Mathcad® template that incorporates the trapezoidal rule to find the weighted average of the dew point depression and the wind direction.

Calculate the weight of the 1000mb level

$$level1000 := \frac{\log\left(\frac{1000}{925}\right)}{2}$$

$level1000 = 0.017$

Calculate the weight of the 925mb level

$$level925 := \log\left(925 + \frac{75}{2}\right) - \log\left(925 - \frac{125}{2}\right)$$

$level925 = 0.048$

Calculate the weight of the 850mb level

$$level850 := \log\left(925 - \frac{125}{2}\right) - \log\left(700 + \frac{150}{2}\right)$$

$level850 = 0.046$

Calculate the weight of the 700mb level

$$level700 := \frac{\log\left(\frac{850}{700}\right)}{2}$$

$level700 = 0.042$

$$levels := \begin{bmatrix} level700 \\ level850 \\ level925 \\ level1000 \end{bmatrix} \qquad levels = \begin{bmatrix} 0.042 \\ 0.046 \\ 0.048 \\ 0.017 \end{bmatrix}$$

$$interval := \log\left(\frac{1000}{700}\right)$$

Used to return the dew point depression and the wind direction int the proper units.

$interval = 0.155$

Dew-point depression (dd) in tenths of degree °C

$$X := \begin{bmatrix} 2.2 \\ 5.7 \\ 4.3 \\ 5.0 \end{bmatrix}$$

2.2 is the dd at 700 mb level

5.7 is the dd at 700 mb level

4.3 is the dd at 700 mb level

5.0 is the dd at 1000 mb level

$$DdX := \frac{(X \cdot levels)}{interval}$$

This gets the value back into units of Celsius

$DdX = 4.18$

Where (X * levels) =

2.2 * 0.042 + 5.7 * 0.046 + 4.3 * 0.048 + 5.0 * 0.017 = 0.646

0.646 / 0.155 = 4.18

Wind in whole degrees

$$WX := \begin{bmatrix} 135 \\ 195 \\ 270 \\ 230 \end{bmatrix}$$

Winds at 700 mb level

Winds at 850 mb level

Winds at 925 mb level

Winds at 1000 mb level

$$WB := \frac{WX \cdot levels}{interval}$$

This gets the value back into units of degree

$WB = 203$

Where (WX * levels) =

135 * 0.042 + 195 * 0.046 + 270 * 0.048 + 230 * 0.017 = 31.51

31.51 / 0.155 ≈ 203

Appendix C

; IDL99 Program to find the time of a Cumulus LCC violation.

```
pro CumulusAIRWAYS                                      Last modified 13 Oct 99
                                                        Written by Edward C. Goetz
; ***************************************************************************
;       This prgm reads in the data from the selected AIRWAYS formatted surface
; observation file and saves the data into a 11 X n array.  Each element in that row has a
; specific (i,j) position.
;****************************************************************************
        close,/all

        fn=dialog_pickfile(filter="~/sfcobs/")      ;allows selection of a specific file
        if (fn eq "") then return                   ;if no file is selected the program is exited

; ***** determine the total number(total rows) of sfc ob files that will be read *******
        print
        print,fn
        print

        openr,2,fn
        n=0
        s=""            ; defines a string variable

        while not (EOF(2)) do begin  ; returns the number of rows in the file
                readf,2,s
                n=n+1
        endwhile
        total=n-1
        close,2
;************ read file header into an array ***************
        openr,2,fn
        file_name=""
        readf,2,s
        readf,2,file_name,format="(a2)"
        file_name= "sfc" + file_name + "mod.txt"
        close,2
        openr,2,fn
        readf,2,s                       ;reads in the Header in the file, so it will be skipped

;************ reads in each row as a single string variable n *************
        lines=strarr(total)
        readf,2,lines
        close,2
```

```
        data=strarr(10,total)
;*****************************************************************************
;       separates out each element (column) in each row to a specific array value by using
; the '&' symbol as the identifier(this identifier is what is used in each sfc ob file)
;*****************************************************************************
        for i=0,total-1 do data(*,i)=str_sep(lines(i),"&")

;*****************************************************
;       Keeps only the obs occurring 10 min prior and 10 min after the hour
;*****************************************************

        keep=where((fix(strmid(data[1,*],2,2)) GE 50) OR (fix(strmid(data[1,*],2,2)) LE
                10),count)
        counter_obs=n_elements(keep)
        if (count GT 0) then begin
                data=data(*,keep)
        endif else begin
                print,'No data found that meets time criteria'
                return
        endelse

;*****************************************************
;       NOTE:  AIRWAYS only carries the necessary cloud group every 3 hours, only
; those sfc obs (00Z, 03Z,..etc) need to be reviewed for the following matching criteria.
;*****************************************************
        time=['0000', '0300', '0600', '0900', '1200', '1500', '1800', '2100']
        n_time=n_elements(time)
        keep=where(strpos(data[1,*],time(0)) GE 0)

        for i=1,n_time-1 do begin
                keep=[keep,where(strpos(data[1,*],time(i)) GE 0)]
        endfor

        counter_obs=n_elements(keep)
        count=n_elements(keep)

        keep=keep(sort(keep))

        if (count GT 0) then begin
                data=data(*,keep)
        endif else begin
                print,'No data found that meets time criteria'
        endelse
```

```
;***********************************************************************
;       This searches the file for the criteria specified in the conditions remark.  These
; results are reassigned to the data array for further review.  May cause more than one ob
; identified for a specific time since a "TSRA" would cause the conditions to be
; identified twice, but repeated obs are eliminated.
;***********************************************************************
        if (count GT 0) then begin
                conditions=['TS','RA','GS','SN','DZ','SG','SH','IC','PL','GR']
                n_condition=n_elements(conditions)
                counter=n_elements(data)/10
                keep1=bytarr(counter)*0B

                for i=0,n_condition-1 do begin
                        count=0
                        temp=where((strpos(data(4,*),conditions(i)) GE 0),count)
                        if (count GT 0) then keep1(temp)=1B
                endfor

                keep=where(keep1 GT 0, count)
                if (count GT 0) then begin
                        data=data(*,keep)
                endif else begin
                        data=0
                        print,'No data meets precip criteria '
                endelse
        endif

;*****************************************
;       Checks data for any BKN or OVC layer and keeps that data.  Uses counter to
; determine if data is in the matrix
;*****************************************
        conditions1=['BKN', 'OVC']
        n_conditions1=n_elements(conditions1)
        counter=n_elements(data)/10

        if (counter GT 0) then begin
                keep2=bytarr(counter)*0B
                for i=0,n_conditions1-1 do begin
                        count3=0
                        temp=where((strpos(data(5,*),conditions1(i)) GE 0), count3)
                        if (count3 GT 0) then keep2(temp)=1B
                endfor
                keep=where(keep2 GT 0, count4)
                if (count4 GT 0) then data=data(*,keep)
        endif else print,'No data matches precip criteria'
```

```
;***************************************************
;       Checks the height of the BKN layer to see if it is less than or equal to 4000 feet.
;***************************************************

        a=size(data)
        BelowBKN_OVC=bytarr(a[2])*0B
        if (counter GT 0) then begin
                keepBKN=where((strpos(data(5,*),'BKN') GE 0),countBKN)
        ; determines which ob has a BKN layer and the string position of that layer
                if (countBKN GT 0)then begin            ;finds the height of the BKN layer
                        hgtBKN=strarr(countBKN)
                        for i=0,countBKN-1 do begin
                                hgtBKN(i)=strmid(data[5,keepBKN(i)],strpos(data[5,keep
                                        BKN(i)],'BKN')+3,3)
                        endfor

                        keepBKN2=where(fix(hgtBKN) LE 40,countBKN2)

                        if (countBKN GT 0) then begin
                                BelowBKN_OVC[keepBKN[keepBKN2]] = 1B
                        endif else begin
                                print,'No data matches the BKN layer criteria'
                        endelse
                endif else begin
                        print,'No data matches the BKN layer criteria'
                endelse
        endif

;***************************************************
;       Checks the height of the OVC layer to see if it is less than or equal to 4000 feet.
;***************************************************
        if (counter GT 0) then begin
                keepOVC=where((strpos(data(5,*),'OVC') GE 0),countOVC)
                                ; determines which ob has a OVC layer
                                ; and the string position of that layer
                if (countOVC GT 0)then begin            ;finds the height of the OVC layer
                        hgtOVC=strarr(countOVC)

                        for i=0,countOVC-1 do begin
                                hgtOVC(i)=strmid(data[5,keepOVC(i)],strpos(data[5,keep
                                        OVC(i)],'OVC')+3,3)
                        endfor

                        keepOVC2=where(fix(hgtOVC) LE 40,countOVC2)
                                if (countOVC2 GT 0) then begin
                                        BelowBKN_OVC[keepOVC[keepOVC2]] = 1B
```

```
                    endif else begin
                            print,'No data matches the OVC layer criteria'
                    endelse

            endif else begin
                    print,'No data matches the OVC layer criteria'
            endelse
        endif

;**** Keeps only the obs that have met all of the previous criteria ******

        keep=where(BelowBKN_OVC EQ 1,count_keep)
        if (count_keep GT 0) then data=data(*,keep)

;*************************************************
;       Searches each REMARKS column (10,*) for each row of the surface ob to
; determine if low cloud type 3 or 9 is present. Then stores this index position in the
; Cumulus array that a violation occurs. So for a cumulus index = 0, means the first ob
; meet the criteria for CUMULUS. CUMULUS indices [2 5 55 87...] used to print out the
; date this criteria was met. NOTE: IDL starts at 0, so an array of size 10 is {0,1,...,8,9}
;*************************************************
        counter=n_elements(data)/10
        if (counter GT 0) then begin
                cumulus=where((strpos(data(9,*),'13') GE 0) OR
                        (strpos(data(9,*),'19') GE 0), count)
        endif else begin
                print,'No data matches all criteria'
                return
        endelse
        if (count GT 0) then data=data(*,cumulus)

;******* Writes the data to the selected file ********************************
        cases=n_elements(data)/10
        file_name="/home/kramer1/users/egoetz/thesis/Cumulus/Sfc_violates/" +
                file_name
        openw,2,file_name

        for i=0,cases-1 do begin
                printf,2,data(*,i)
        endfor
        close,2
end
```

Appendix D

Monthly descriptive climatology of a lightning flash within 12 nautical miles of the Cape.

Table D-1: January Lightning Descriptive Climatology

Values are one-tenth of the associated cumulative daily probability of a lightning flash being within 12 nautical miles of the Cape for a specific hour.

Time (UTC)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
23	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
19	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	1	0
18	1	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0
17	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0

Table D-2: February Lightning Descriptive Climatology

Values are one-tenth of the associated cumulative daily probability of a lightning flash being within 12 nautical miles of the Cape for a specific hour.

	Time (UTC)																							
Day	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
6	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	[illegible]
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	1	2	1	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
22	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	2	1	0	1
23	0	0	0	0	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Tab[illegible] March Lightning Descriptive Climatology

Values are one-tenth of the associated cumulative daily probability of a lightning flash being within 12 nautical miles of the Cape for a specific hour

	Time (UTC)																							
Day	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
1	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2
2	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0
3	1	0	0	0	0	0	0	0	1	1	0	1	1	0	0	0	1	1	0	0	0	0	0	0
4	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
7	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	1	1	2	2	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
19	1	1	1	2	1	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	1	1	1
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
21	1	0	0	0	0	0	0	0	0	1	1	1	0	0	1	2	1	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
26	0	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2	1
29	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
30	1	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0
31	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0	1	1	2

Table D-4: April Lightning Descriptive Climatology

Values are one-tenth of the associated cumulative daily probability of a lightning flash being within 12 nautical miles of the Cape for a specific hour.

	Time (UTC)																							
Day	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
1	2	0	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	1	1	0	0	1	0	1	0	1	1	1	1	0	0	0	1
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	1
16	1	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
20	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	1	1	1	0	1
22	1	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
23	0	0	[illegible]	0	0	0	0	0	0	0	0	0	0	1	0	1	2	2	3	3	1	2	1	1
24	1	0	0	0	0	0	0	0	0	0	0	[illegible]	[illegible]	0	0	0	0	0	1	0	1	1	1	0
25	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0
27	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	1	0

Table D-5: May Lightning Descriptive Climatology

Values are one-tenth of the associated cumulative daily probability of a lightning flash being within 12 nautical miles of the Cape for a specific hour.

	Time (UTC)																							
Day	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
2	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	2	1	1	1
4	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	1
5	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
6	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0
12	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	1	0	0	1	1	1
13	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
14	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0
15	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
16	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
17	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0
20	1	1	0	0	0	1	1	1	1	1	1	1	1	0	0	0	1	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2
22	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2	1	1
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	1	1	0	0	0	0	0
26	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	1	2
27	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
28	2	2	0	1	0	1	0	0	0	0	0	0	0	0	1	3	2	2	1	2	2	3	2	0
29	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1
30	1	2	1	0	0	0	0	0	0	0	0	0	[illegible]	0	0	0	0	0	0	0	0	1	0	1
31	3	2	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	2	2	0

Table D-6: June Lightning Descriptive Climatology

Values are one-tenth of the associated cumulative daily probability of a lightning flash being within 12 nautical miles of the Cape for a specific hour.

	Time (UTC)																							
Day	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2	1	0	1	0
2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	2	3	4	2	2	2	0	0
3	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1
4	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	2	1	1
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	1	1	1	1	0
6	1	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	2	2	1	2	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	2	1	1	1
8	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	1	2	2	3	3	3	2	0	1
9	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	1	1	1	1
10	1	0	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2	0	0	0
11	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	1	2	4	3	3	3	2
12	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	1	3	3	2	2	1
13	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	2	2	2	1	1
14	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	1	1	1	1	2	1	2	0	2
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	1	2	1	0
16	1	0	0	0	0	0	0	0	0	1	1	1	1	0	1	2	2	0	0	0	0	0	0	0
17	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	3	4	2	2	2	0	1	1
18	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	0
19	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	2	3	4	2	1
20	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2	1	1	1	2
21	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	3	1	1	2	3	4	1	0
22	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	2	1	2	3	2	3
23	2	1	0	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	2	1	1	3	2
24	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	1	2	2	2	2	1	1
25	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	3	3	3	4	3	2	0
26	0	0	1	2	2	1	1	1	0	0	1	1	0	1	0	1	5	4	3	2	3	2	2	0
27	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	2	3	2	1	1	0	0
28	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	3	3	1	3	1	2	0
29	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	2	2	1	2	1	2	1	0
30	0	1	0	1	1	0	0	0	0	0	0	0	0	1	1	0	1	2	2	2	1	1	2	3

Table D-7: July Lightning Descriptive Climatology

Values are one-tenth of the associated cumulative daily probability of a lightning flash being within 12 nautical miles of the Cape for a specific hour.

Time (UTC)

Day	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	2	1	0	0	1	1	0	0	0	0	0	0	0	0	0	1	1	1	2	3	3	3	4	3
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	3	1	1	1	3	1	1
3	0	0	0	0	0	0	0	1	1	0	0	0	1	1	1	0	0	1	3	2	1	2	2	0
4	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	0	2	2	2
5	1	2	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	3	3	3	3	1	1	1
6	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	3	3	3	3
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	1	1	2	2	2	1
8	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	3	3	1	2	3	1	2
9	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	4	2	2	0
10	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	3	4	3	2	1	2
11	2	2	1	1	1	2	1	0	0	0	0	0	0	0	0	0	1	1	4	5	4	1	1	0
12	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	2	2	2	1	1	2	2	2
13	1	1	1	2	1	1	1	1	1	0	0	0	1	0	0	0	2	3	1	4	1	2	2	1
14	1	0	0	0	0	0	0	0	0	2	1	0	1	1	0	0	0	1	3	2	2	0	2	1
15	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2	1	2	2	2
16	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	1	1	1	1
17	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	2	2	1	2	1	1	1
18	0	0	0	0	0	1	2	2	0	0	2	2	0	0	0	0	0	1	1	1	2	2	3	3
19	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	2	2	3	3	1	2
20	2	0	0	0	0	0	0	0	0	1	0	0	0	1	1	1	3	3	2	1	0	0	2	1
21	1	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0	1	3	2	0	0
22	0	0	0	0	0	0	1	1	1	1	0	1	0	0	0	0	2	0	1	2	2	3	1	1
23	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	1	1	1	2	2	1	2
24	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	4	3	2	2
25	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2	2	3	2	1
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	2	4	3	2	2	1
27	0	0	0	0	0	1	0	1	1	0	1	0	0	0	0	0	0	0	0	1	1	2	1	2
28	1	2	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	2	1	3	2	1
29	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	3	2	2	2	3
30	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	2	2	3	2	0	0	0
31	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	3	2	0	0	1

Table D-8: August Lightning Descriptive Climatology

Values are one-tenth of the associated cumulative daily probability of a lightning flash being within 12 nautical miles of the Cape for a specific hour.

Time (UTC)

Day	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	3	1	0	0	0
2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	2	2	2	2
3	1	0	0	0	0	0	2	1	0	1	0	0	0	0	0	0	1	2	4	5	4	4	3	0
4	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	1	3	3	3	3	2	1	1
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	6	4	2	1	1	2
6	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	2	2	2	2	1
7	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	1	2	0	1	1	0	1	1
8	1	0	1	1	1	0	1	1	0	1	1	0	0	0	0	0	1	3	2	2	5	3	3	3
9	2	2	2	2	0	0	0	0	0	0	0	0	0	0	1	1	0	2	3	3	4	2	2	0
10	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	1	1	1	2	2	3	4	5	3
11	2	3	2	1	0	0	0	0	0	0	0	1	0	0	0	0	1	2	2	2	3	1	2	0
12	0	0	1	2	1	1	1	1	1	0	0	0	0	0	0	1	0	0	1	1	1	2	2	2
13	1	2	1	3	1	1	0	0	0	0	0	0	0	0	1	1	1	1	4	3	3	2	1	3
14	2	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	4	3	4	5	4	5	3	2
15	1	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	2	2	6	4	3	1
16	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1	1	2	3	2	0
17	0	1	0	0	0	1	1	1	0	1	0	0	1	1	0	1	1	3	1	1	2	3	1	1
18	2	1	1	1	0	0	0	0	1	1	1	1	1	1	1	2	2	0	2	4	2	2	1	0
19	1	1	0	0	1	1	1	1	1	1	0	1	0	0	0	2	1	1	2	3	2	1	0	1
20	1	0	1	1	2	1	0	0	1	0	0	0	1	1	0	0	1	0	2	3	2	3	3	1
21	1	1	1	2	0	0	0	0	0	0	1	0	0	1	1	1	0	2	2	2	0	1	2	2
22	2	3	4	3	3	2	2	2	2	0	0	0	0	0	0	0	1	1	2	2	2	1	2	3
23	2	2	1	1	0	0	0	0	0	1	2	0	0	1	2	1	3	0	0	1	1	1	3	3
24	1	1	1	2	0	0	0	0	0	0	2	1	0	0	0	0	0	0	1	2	2	2	1	0
25	0	2	1	0	0	1	1	0	0	1	0	0	1	1	1	2	3	3	1	1	1	0	1	0
26	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	3	1	1	1	0
27	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	2	2	1	0	0	0	0
28	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	1	2	1	1	0	0	0	0	0
29	0	1	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	1	0	0	0	1	1	1	1	2	0	1	2	1	1	1	1
31	0	0	1	0	0	1	1	1	1	1	1	1	0	1	0	0	0	2	2	1	0	1	1	0

Table D-9: September Lightning Descriptive Climatology

Values are one-tenth of the associated cumulative daily probability of a lightning flash being within 12 nautical miles of the Cape for a specific hour.

	Time (UTC)																							
Day	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
1	0	0	0	0	0	1	1	2	1	0	0	0	0	0	0	1	2	1	2	2	1	0	0	1
2	2	1	0	0	0	1	1	1	0	0	0	0	1	1	1	1	2	1	3	2	1	0	0	1
3	2	1	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	1	4	3	2	0	0	1
4	1	0	0	1	0	0	2	1	1	0	1	0	0	0	1	2	2	1	0	1	0	0	0	0
5	0	1	0	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	1	1	0	0	1	0
6	2	2	2	0	0	0	0	0	1	0	0	0	0	0	1	0	2	0	1	1	2	1	0	1
7	1	2	2	1	0	0	1	1	0	0	0	0	0	0	0	0	1	1	1	2	3	2	1	1
8	1	1	0	1	1	1	1	0	1	1	1	1	1	2	1	2	1	2	3	2	2	3	3	1
9	0	0	0	0	0	1	2	2	1	1	1	1	0	1	0	0	0	2	2	2	2	2	0	0
10	0	0	1	1	0	0	0	1	0	0	0	1	0	1	2	2	1	1	2	2	1	1	2	2
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2	3	3	0	1
12	0	1	0	1	1	0	0	0	0	0	1	0	1	1	0	0	2	0	0	1	0	0	0	1
13	0	0	2	1	0	0	0	0	0	0	0	0	1	2	1	1	1	1	1	0	1	1	1	0
14	0	2	1	1	1	0	0	0	1	1	1	0	1	0	1	1	1	0	0	0	0	0	0	0
15	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1	1	1
16	1	2	0	0	0	0	0	2	1	1	0	0	0	0	0	0	0	0	0	1	2	2	1	1
17	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	3	3	2	3	1	2
18	2	0	1	1	0	1	1	0	0	0	0	0	1	0	1	0	0	0	1	2	2	2	1	1
19	0	0	0	0	0	1	1	1	1	1	1	0	1	0	0	1	3	1	1	3	1	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	1	1	1	1	0	1	1	0	1	0	0	0	0	0	0	0	0	1	2	2	1	2
22	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	1
23	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1
24	2	0	1	1	1	0	0	0	0	1	1	0	1	1	0	1	1	0	0	0	2	2	2	1
25	1	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	0	1	1	1	4	2	3	1
26	0	1	1	2	2	1	0	1	2	2	1	1	1	1	1	2	1	2	2	1	2	2	2	1
27	1	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	3	2	2	2	2	1
28	2	3	1	2	0	1	0	0	0	1	1	1	0	1	0	0	1	2	1	0	1	0	1	1
29	1	1	1	0	2	1	1	1	1	0	0	0	0	0	0	1	0	0	1	1	1	2	1	2
30	0	1	2	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table D-10: October Lightning Descriptive Climatology

Values are one-tenth of the associated cumulative daily probability of a lightning flash being within 12 nautical miles of the Cape for a specific hour.

Day	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
														Time (UTC)										
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	2	1	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	1	1	1	1	1	0
4	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	1	2	0	1	0	1	0	0
6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	1
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
8	2	1	1	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	1	1	1	1	2
9	2	2	2	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	2	2	1	0
10	1	0	0	0	1	0	0	0	1	0	2	1	1	1	1	1	1	0	1	1	1	0	0	0
11	1	0	0	0	0	0	0	1	0	0	2	0	0	1	1	0	0	0	0	1	1	1	1	0
12	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	1	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
14	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	2	0	0	1	0	0	1	1	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1
19	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	1	1	0	0	0	0	0	0	1	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	2

Table D-11: November Lightning Descriptive Climatology

Values are one-tenth of the associated cumulative daily probability of a lightning flash being within 12 nautical miles of the Cape for a specific hour.

Time (UTC)

Day	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
14	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	1	0	0	0	0	0	1	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
22	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	1	0	1	1	1	0	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0
24	1	1	1	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	[illegible]	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table D-12: December Lightning Descriptive Climatology

Values are one-tenth of the associated cumulative daily probability of a lightning flash being within 12 nautical miles of the Cape for a specific hour.

Time (UTC) \ Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0

Appendix E

Cumulative hourly probability of a lightning flash within 12 nautical miles of the Cape for every month. Values are the associated cumulative monthly probability of a lightning flash being within 12 nautical miles of Cape for a specific hour.

Time (UTC)

Mon	00	01	02	03	04	05	06	07	08	09	10	11
Jan	1	1	0	1	0	0	0	0	1	0	0	1
Feb	1	1	0	1	1	0	1	1	1	1	1	1
Mar	2	3	3	2	1	2	1	2	2	1	1	1
Apr	3	2	1	2	1	1	0	1	1	0	0	0
May	5	5	3	1	1	1	1	1	1	1	0	0
Jun	6	5	2	3	3	1	0	1	0	1	2	1
Jul	6	4	2	2	2	2	2	2	2	2	1	2
Aug	7	8	7	7	4	3	4	3	3	3	3	2
Sep	7	8	6	6	3	4	4	5	5	3	4	3
Oct	4	2	1	1	1	0	1	1	1	0	1	1
Nov	1	1	1	0	1	1	1	1	1	0	0	1
Dec	0	[illegible]	0	0	0	0	0	0	0	0	0	0

	12	13	14	15	16	17	18	19	20	21	22	23
Jan	1	0	1	0	1	1	2	2	1	0	0	0
Feb	0	0	1	0	0	0	0	1	1	1	0	1
Mar	0	0	1	1	2	1	2	2	2	3	3	3
Apr	0	0	1	1	2	3	4	3	3	3	3	2
May	0	0	1	1	2	2	4	4	5	6	5	5
Jun	1	1	2	5	12	14	15	19	18	16	12	8
Jul	1	2	2	3	5	11	18	23	20	19	16	14
Aug	2	3	3	6	11	13	21	22	20	17	16	11
Sep	3	4	4	5	7	7	12	12	13	11	8	9
Oct	1	1	2	2	1	2	3	4	5	4	4	3
Nov	0	0	0	0	1	1	1	0	1	0	0	0
Dec	1	1	1	1	0	1	1	1	0	0	0	0

Appendix F

Seasonal Histograms and Annual Histogram for Cumulus Violations.

Figure F-1: Cool Season (Nov – Feb)

Vertical axis represents the number of cumulus violations for the defined period. Horizontal axis represents the time of occurrence for the violation. Stars mark the times used for discriminant analysis.

Figure F-1A. Histogram for 1 Jul 96 to Dec 98 (every hour examined) (24 cases)

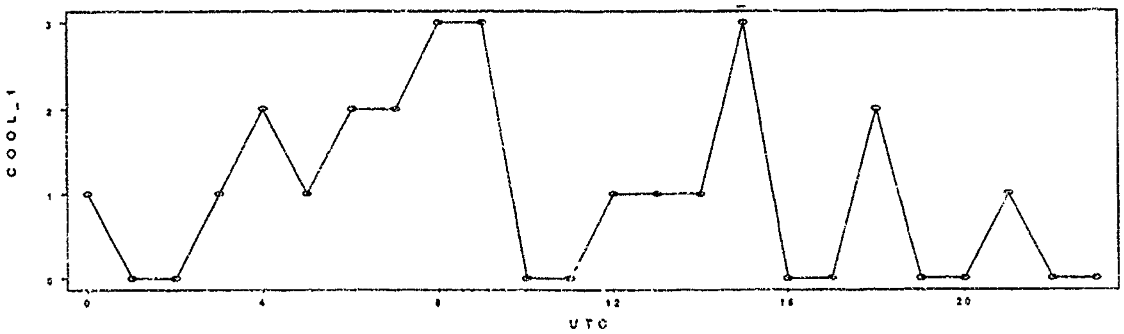


Figure F-1B. Histogram for 1 Jan 92 to 1 Jul 96 (every 3 hours examined) (7 cases)

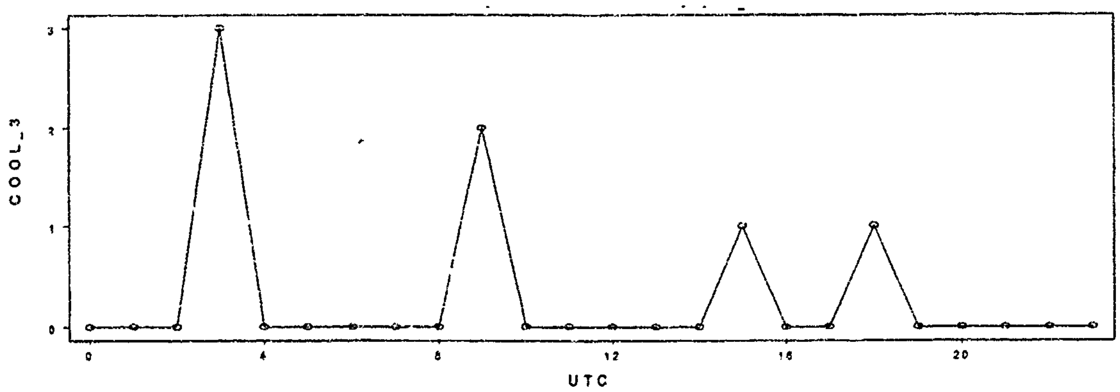


Figure F-1C. Cumulative Histogram of above plots (31 cases)

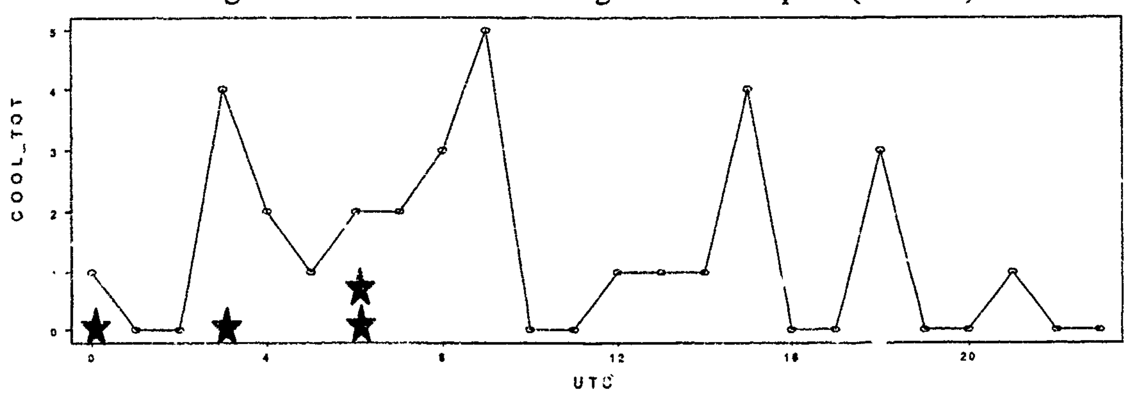


Figure F-2: Spring Season (Mar – May)

Vertical axis represents the number of cumulus violations for the defined period. Horizontal axis represents the time of occurrence for the violation. Stars mark the times used for discriminant analysis.

Figure F-2A. Histogram for 1 Jul 96 to Dec 98 (every hour examined) (26 cases)

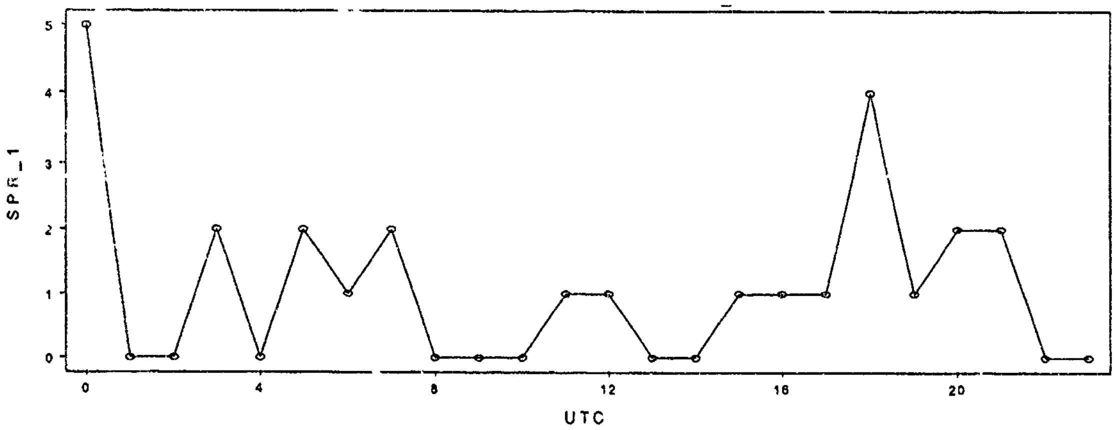


Figure F-2B. Histogram for 1 Jan 92 to 1 Jul 96 (every 3 hours examined) (8 cases)

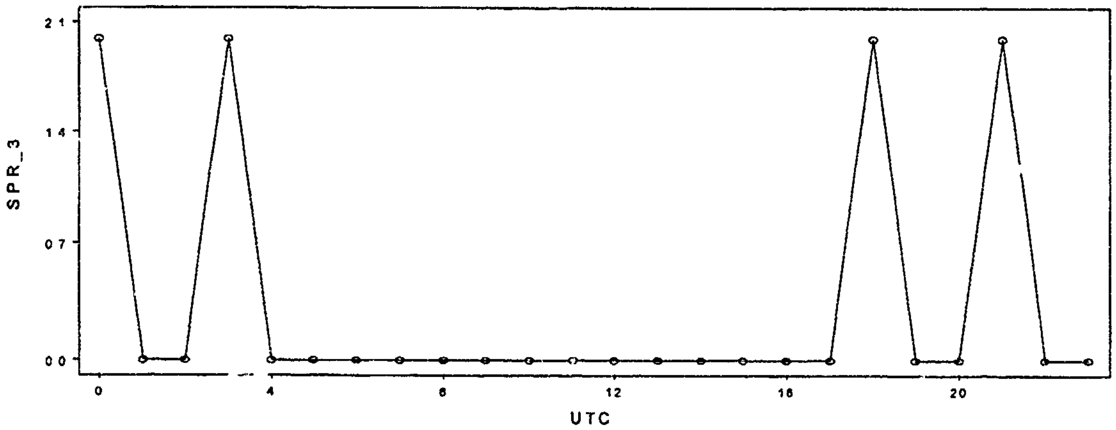


Figure F-2C. Cumulative Histogram of above plots (34 cases)

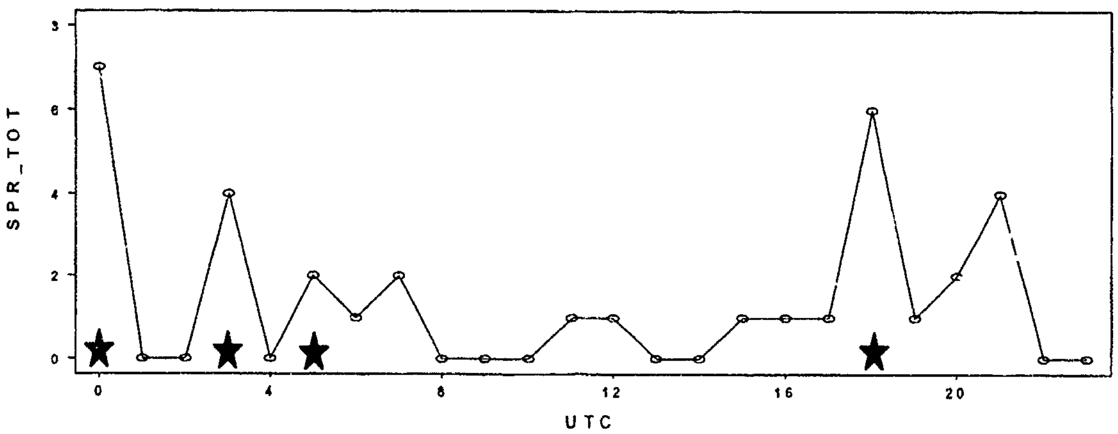


Figure F-3: Warm Season (Jun – Aug)

Vertical axis represents the number of cumulus violations for the defined period. Horizontal axis represents the time of occurrence for the violation. Stars mark the times used for discriminant analysis.

Figure F-3A. Histogram for 1 Jul 96 to Dec 98 (every hour examined) (47 cases)

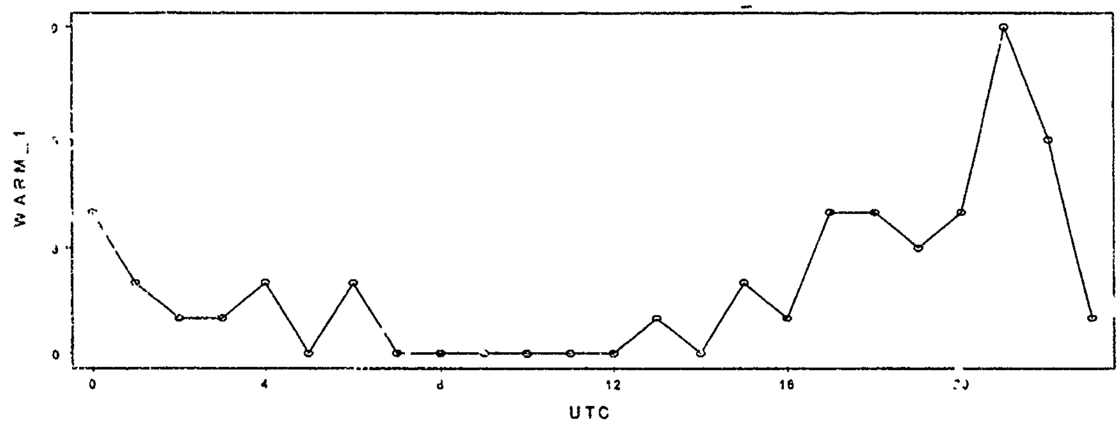


Figure F-3B. Histogram for 1 Jan 92 to 1 Jul 96 (every 3 hours examined) (30 cases)

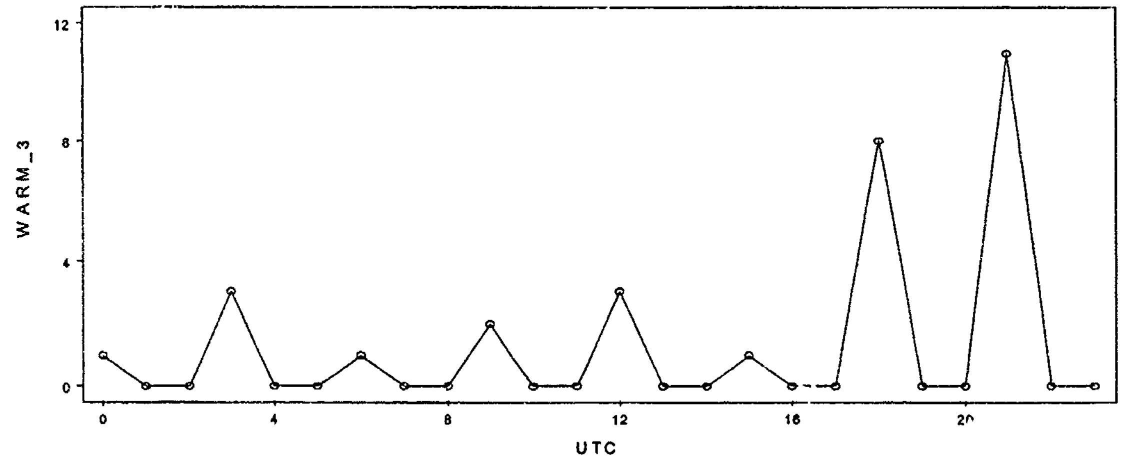


Figure F-3C. Cumulative Histogram of above plots (77 cases)

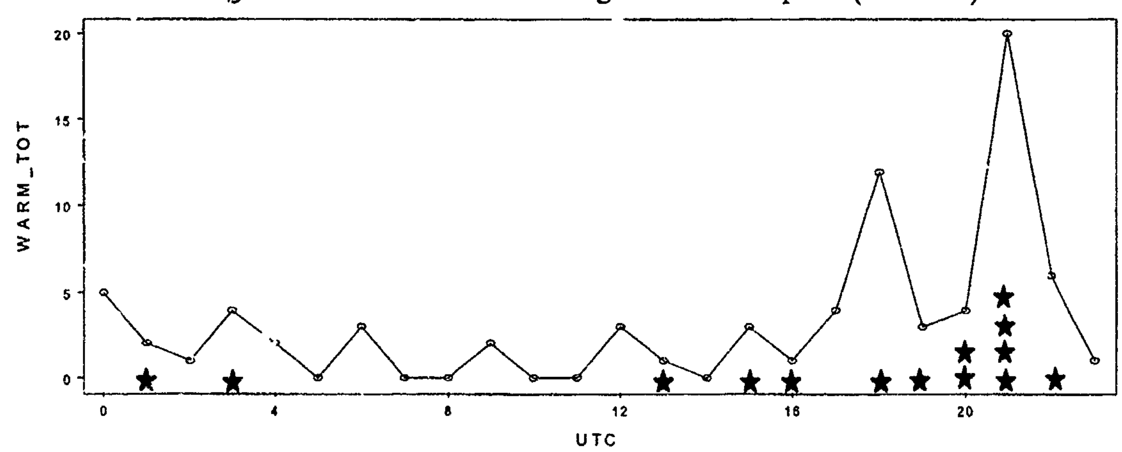


Figure F-4: Autumn Season (Sep – Oct)

Vertical axis represents the number of cumulus violations for the defined period. Horizontal axis represents the time of occurrence for the violation. Stars mark the times used for discriminant analysis.

Figure F-4A. Histogram for 1 Jul 96 to Dec 98 (every hour examined) (19 cases)

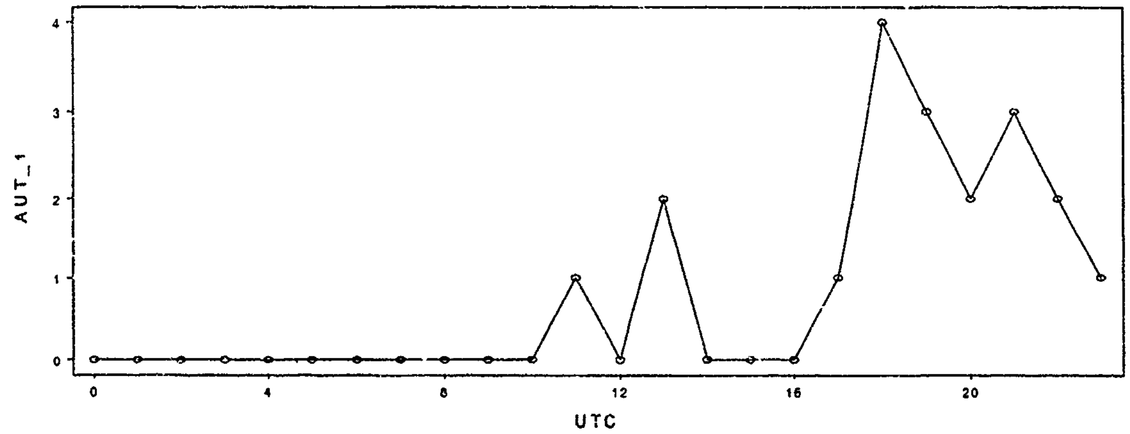


Figure F-4B. Histogram for 1 Jan 92 to 1 Jul 96 (every 3 hours examined) (15 cases)

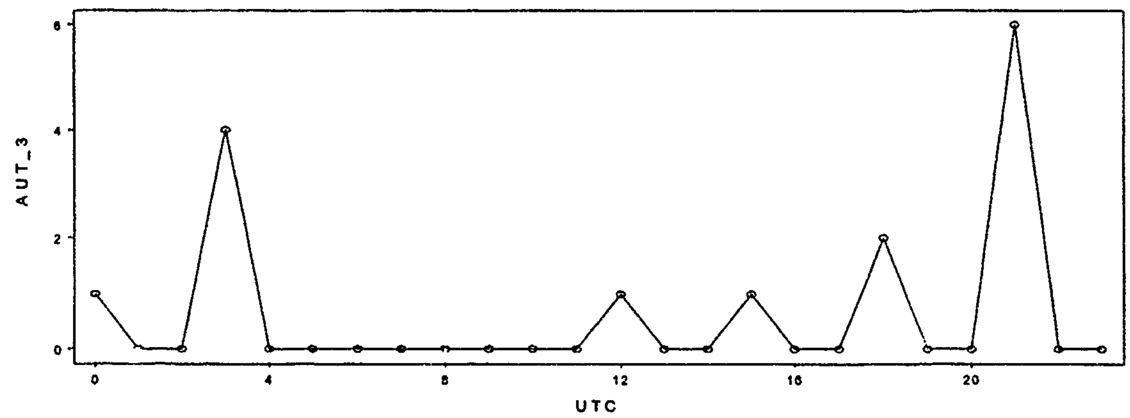


Figure F-4C. Cumulative Histogram of above plots (34 cases)

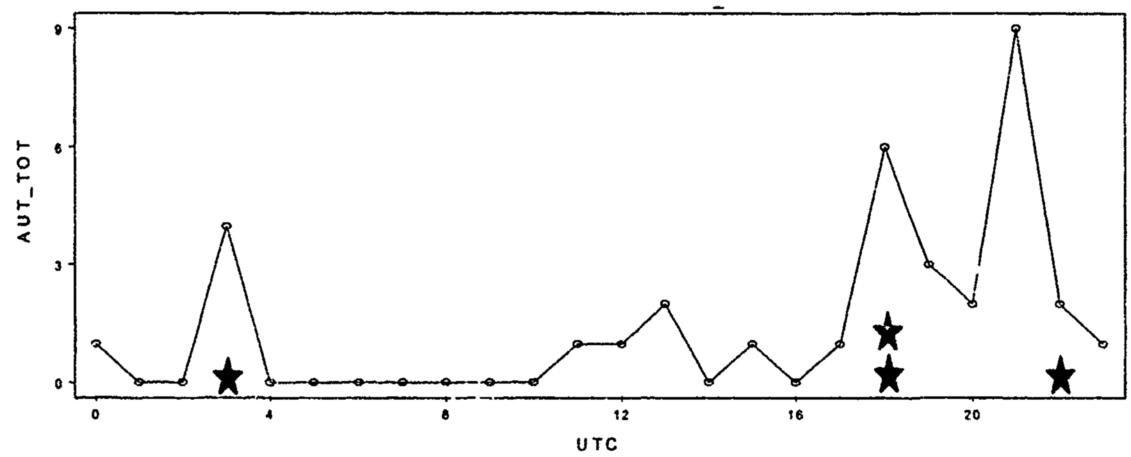


Figure F-5: All Seasons (Jan – Dec)

Vertical axis represents the number of cumulus violations for the defined period.
Horizontal axis represents the time of occurrence for the violation.

Figure F-5A. Histogram for 1 Jul 96 to Dec 98 (every hour examined) (116 cases)

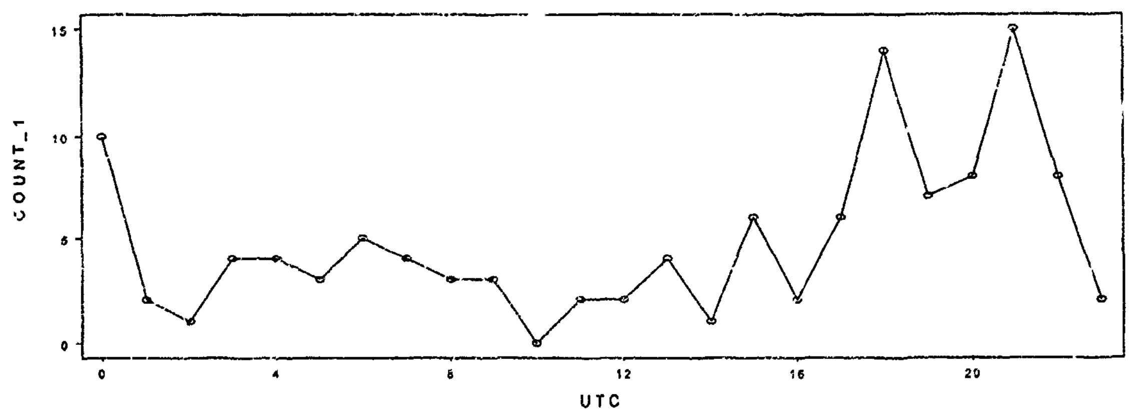


Figure F-5B. Histogram for 1 Jan 92 to 1 Jul 96 (every 3 hours examined) (60 cases)

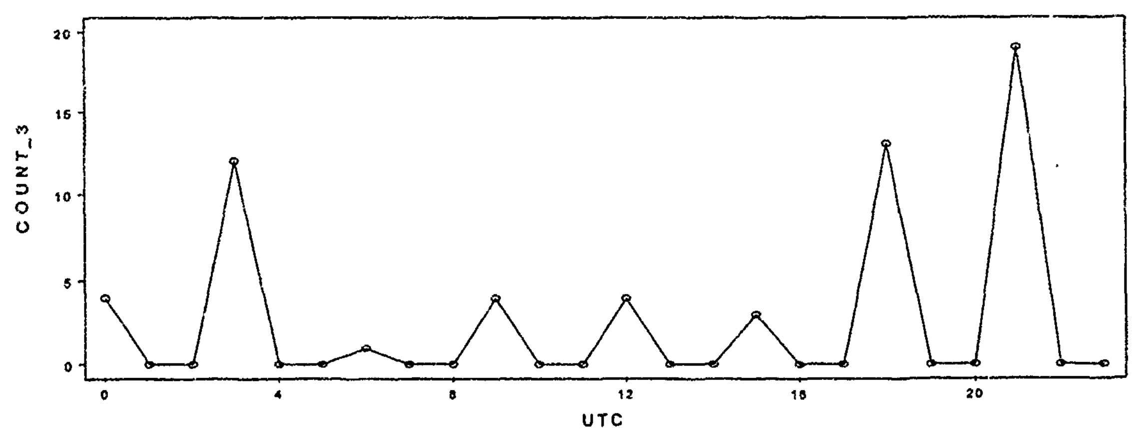
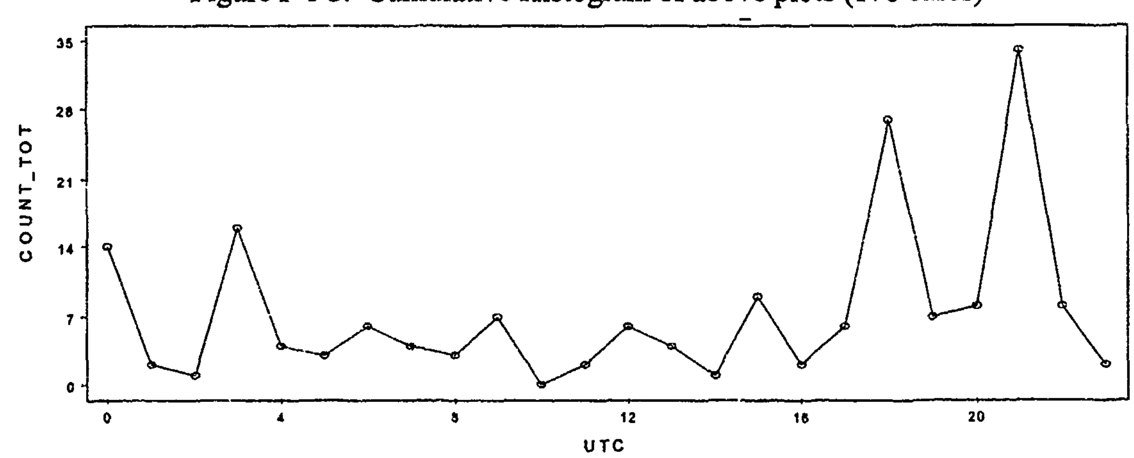


Figure F-5C. Cumulative Histogram of above plots (176 cases)



Appendix G

Hourly probability for a Seasonal Cumulus LCC violation. Values are the associated seasonal probabilities for the occurrence of a cumulus violation for a specific time.

	Time (UTC)							
Season	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**
Cool	6	0	0	11	6	3	8	6
Spring	20	0	0	8	0	4	4	4
Warm	7	2	1	6	2	0	3	0
Autumn	3	0	0	13	0	0	0	0
	08	**09**	**10**	**11**	**12**	**13**	**14**	**15**
Cool	8	17	0	0	6	3	3	14
Spring	0	8	0	2	4	0	0	4
Warm	0	3	0	0	4	1	0	5
Autumn	0	3	0	3	3	5	0	5
	16	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Cool	0	0	8	0	0	3	0	0
Spring	2	2	20	2	4	14	0	0
Warm	1	4	21	3	4	27	6	1
Autumn	0	3	18	8	5	28	5	3

Appendix H

Mathcad® template used for deriving the cool season discriminant function.

This template is used to verify the results produced by S-Plus 2000 and to compute the validation of the derived Fisher discriminant function. Additionally, this template provides the equations used, the reference for the equations and the step-by-step process used to determine the discriminant function, L.

For discriminant analysis to be used there are two key assumptions. First, the number of independent variables (dd and winds) must have a multivariate normal distribution. Secondly, the variance-covariance matrix of the independent variables in the two groups must be the same. This means that variance of the given predictor variable is the same in the respective populations from which the groups of measurements have been drawn and the correlation (covariance) between any two predictor variables is the same in the respective populations from which the measurements are sampled (Kachigan, pg. 219).

X is a matrix/vector of 34 cases used to determine the discriminant function for the cool season. The first column is the weighted average dew-point depression (dd) and the second column is the weighted average for the winds, Appendix B shows how these averages were computed. The first 17 rows are for those cases when a Cumulus LCC violation occurred and the last 17 are cases when a violation did not occur.

Abar, Bbar and S_{plus} values are from S-Plus 2000. Abar is the means for the wind (top value) and the dd for the cases when cumulus violation did occur and the Bbar is the respective means for when a violation did not occur. S_{plus} is the pooled sample variance-covariance matrix for the entire X matrix. The pooled sample variance-covariance matrix is used because the covariance structure is assumed to be equal (Wilks, pg. 409).

$$X := \begin{bmatrix} 3.6 & 282 \\ 2.71 & 219 \\ 1.53 & 103 \\ 0.8 & 127 \\ 2.47 & 224 \\ 3.33 & 181 \\ 4.44 & 198 \\ 7.26 & 196 \\ 4.72 & 199 \\ 3.81 & 232 \\ 2.88 & 225 \\ 3.47 & 191 \\ 6.51 & 129 \\ 2.89 & 166 \\ 2.45 & 181 \\ 3.22 & 152 \\ 2.93 & 115 \\ 6.19 & 250 \\ 1.81 & 254 \\ 6.39 & 179 \\ 3.34 & 193 \\ 6.08 & 74 \\ 11.3 & 348 \\ 2.44 & 340 \\ 10.85 & 267 \\ 6.15 & 181 \\ 6.67 & 332 \\ 2.69 & 268 \\ 5.28 & 189 \\ 2.82 & 225 \\ 10.12 & 330 \\ 3.74 & 298 \\ 3.88 & 256 \\ 14.89 & 37 \end{bmatrix}$$

$$\text{Abar} := \begin{bmatrix} 183.5294 \\ 3.471765 \end{bmatrix} \qquad \text{Bbar} := \begin{bmatrix} 236.5294 \\ 6.155294 \end{bmatrix} \qquad S_{plus} := \begin{bmatrix} 5013.765 & -29.66355 \\ -29.66355 & 8.03686 \end{bmatrix}$$

ORIGIN≡1 Ensures that all indices start at 1.

Define sample size for each group (= 17)

$$n_1 := \frac{\text{rows}(X)}{2} \qquad n_2 := n_1 \qquad n := \text{rows}(X)$$

Determine the associated sample variance-covariance matrices needed to find the pooled sample variance-covariance matrix $\mathbf{S_p}$

Step #1: Find the respective sample means for the dew point depression (dd) and the winds for both groups. Sample mean equation is from Devore, pg. 20.

Cumulus violation, A **No cumulus violation, B**

Dew-point depression

$$Abar_{dd} := \frac{\sum_{i=1}^{n_1} \left(X^{<1>}\right)_i}{n_1} \qquad Bbar_{dd} := \frac{\sum_{i=n_2+1}^{n} \left(X^{<1>}\right)_i}{n_2}$$

$$Abar_{dd} = 3.471765 \qquad Bbar_{dd} = 6.155294$$

Winds

$$Abar_{w} := \frac{\sum_{i=1}^{n_1} \left(X^{<2>}\right)_i}{n_1} \qquad Bbar_{w} := \frac{\sum_{i=n_2+1}^{n} \left(X^{<2>}\right)_i}{n_2}$$

$$Abar_{w} = 183.5294 \qquad Bbar_{w} = 236.5294$$

$$A_{tot} := \begin{bmatrix} Abar_w \\ Abar_{dd} \end{bmatrix} \qquad B_{tot} := \begin{bmatrix} Bbar_w \\ Bbar_{dd} \end{bmatrix}$$

$$A_{tot} = \begin{bmatrix} 183.529412 \\ 3.471765 \end{bmatrix} \qquad B_{tot} = \begin{bmatrix} 236.529412 \\ 6.155294 \end{bmatrix}$$

These values match the group means determined by S-Plus for the dew-point depression and winds as given above for **Abar** and **Bbar**.

Step #2: Find the respective sample variances for the dew point depression (dd) and the winds for both groups. Sample variance equation is from Devore, pg. 29.

Define individual matrices to compute the variance-covariance matrix, by assigning matrix **A** the first 17 rows of matrix **X** and **B** matrix the last 17 rows of matrix **X** using the Mathcad function *submatrix*.

$$A := \text{submatrix}(X, 1, n_1, 1, 2) \qquad B := \text{submatrix}(X, n_1 + 1, n_1 + n_2, 1, 2)$$

Assigns the columns of the matrices **A** and **B** to the respective vectors below.

$$Add := \left(A^{<1>}\right) \quad Aw := \left(A^{<2>}\right) \qquad Bdd := B^{<1>} \quad Bw := B^{<2>}$$

<u>Sample variance of dew-point dression</u>

$$Addvar := \frac{\sum_{i=1}^{n_1} \left(Add_i - Abar_{dd}\right)^2}{n_1 - 1} \qquad Bddvar := \frac{\left[\sum_{i=1}^{n_2} \left(Bdd_i - Bbar_{dd}\right)^2\right]}{n_2 - 1}$$

$$Addvar = 2.551 \qquad Bddvar = 13.523$$

<u>Sample variance of winds</u>

$$Awvar := \frac{\sum_{i=1}^{n_1} \left(Aw_i - Abar_w\right)^2}{n_1 - 1} \qquad Bwvar := \frac{\sum_{i=1}^{n_2} \left(Bw_i - Bbar_w\right)^2}{n_2 - 1}$$

$$Awvar = 2.249 \cdot 10^3 \qquad Bwvar = 7.778 \cdot 10^3$$

Step #3: Find the respective sample covariances for both groups. Sample covariance equation (discrete case) is from Devore, pg. 213. The respective sample variance-covariance matrices are $\mathbf{S_A}$ and $\mathbf{S_B}$.

Cumulus violation, A

$$COVARA := \frac{\sum_{i=1}^{n_1} \left(Add_i - Abar_{dd}\right)\cdot\left(Aw_i - Abar_w\right)}{n_1 - 1} \qquad COVARA = 13.588$$

$$S_A := \begin{bmatrix} Awvar & COVARA \\ COVARA & Addvar \end{bmatrix} \qquad S_A = \begin{bmatrix} 2249.14 & 13.588 \\ 13.588 & 2.551 \end{bmatrix}$$

No cumulus violation, B

$$COVARB := \frac{\sum_{i=1}^{n_2} \left(Bdd_i - Bbar_{dd}\right)\cdot\left(Bw_i - Bbar_w\right)}{n_2 - 1} \qquad COVARB = -72.915$$

$$S_B := \begin{bmatrix} Bwvar & COVARB \\ COVARB & Bddvar \end{bmatrix} \qquad S_B = \begin{bmatrix} 7778.39 & -72.915 \\ -72.915 & 13.523 \end{bmatrix}$$

Step #4: Find the pooled sample variance-covariance matrix from the respective sample variance-covariances matrices, $\mathbf{S_A}$ and $\mathbf{S_B}$. Pooled sample variance-covariance equation is equation 9.57 from Wilks, pg. 409.

$$S_P := \frac{\left(n_1 - 1\right)\cdot S_A + \left(n_2 - 1\right)\cdot S_B}{\left(n_1 + n_2 - 2\right)} \qquad S_P = \begin{bmatrix} 5013.76471 & -29.66355 \\ -29.66355 & 8.03686 \end{bmatrix}$$

This matches the S-Plus variance-covariance matrix below.

$$S_{plus} = \begin{bmatrix} 5013.765 & -29.66355 \\ -29.66355 & 8.03686 \end{bmatrix}$$

Step #5: Find the direction ($\mathbf{d_1}$) that maximizes the distance between the two samples mean vectors, $\mathbf{A_{tot}}$ and $\mathbf{B_{tot}}$. This transforms the matrix **X** into a scalar value known as *Fisher's discriminant linear function,* L (Wilks, pg. 410).

Find $\mathbf{d_1}$ using the equation 9.58a from Wilks, pg. 410.

$$d_1 := S_p^{-1} \cdot (A_{tot} - B_{tot})$$

$$d_1 = \begin{bmatrix} -0.013 \\ -0.381 \end{bmatrix}$$

These are the weights of the discriminant funciton, the top value is associated wtih the wind and the other is for the dd.

Step #6: Find the cut off scoreusing the equation 9.59 from Wilks, pg. 410. This value is used to determine into which group the predictor variables will be classified.

$$cutoff := d_1^T \cdot \left[\frac{(A_{tot} + B_{tot})}{2} \right]$$

$$cutoff = (-4.529)$$

Step #7: Find the discriminant function scores for the Cool cases based on the "training sample" of 34 total cases, 17 with a cumulus viol and 17 without a violation.

Assigns the columns of **X** to the respective vectors below.

$$winds := X^{<2>} \qquad dd := X^{<1>} \qquad i := 1 .. rows(X)$$

$$L_i := -0.013 \cdot winds_i - 0.381 \cdot dd_i$$

Discriminant Function for Cool Season

Step #8: Using the discriminant function and the cut off score for the Cool cases as defined above to classify all the predictor variables (dd and winds) for all 34 cases of the "training sample" using the sample rule defined below. Construct a confusion matrix to determine the correctly classified percentage.

Rule for classification:

if $L \leq -4.529$ then group B
$L > -4.529$ then group A

Using this classification rule then of the first 17 values, which are from the predictor variables in group A (violation occurred) then the values at position 1 and 8 are the only two misclassified as group B. Likewise, of the last 17 values which are associated with no violation and group B. then the values at positions 19, 21, 22, 28, 29 and 30 are the 6 values misclassified as belonging to group A. This classification results in the confusion matrix defined below adn gives a correctly classified percentage of 76.5% for the "training sample."

L =

	1
1	-5.038
2	-3.88
3	-1.922
4	-1.956
5	-3.853
6	-3.622
7	-4.266
8	-5.314
9	-4.385
10	-4.468
11	-4.022
12	-3.805
13	-4.157
14	-3.259
15	-3.286
16	-3.203
17	-2.611
18	-5.608
19	-3.992
20	-4.762
21	-3.782
22	-3.278
23	-8.829
24	-5.35
25	-7.605
26	-4.696
27	-6.857
28	-4.509
29	-4.469
30	-3.999
31	-8.146
32	-5.299
33	-4.806
34	-6.154

Confusion Matrix

$$\begin{bmatrix} \text{I} & A & B \\ A & 15 & 2 \\ B & 6 & 11 \end{bmatrix}$$

This matches the S-plus Confusion Matrix

$$\text{Corr\_Classified} := \frac{(15+11)}{\text{rows}(X)}$$

Sum of main diagonal divided by total cases.

$$\text{Corr\_Classified} = 0.765$$

Step #9: Use the discriminant function and the cut off score for the Cool cases as defined above to validate the discriminant function using the cases not included in the "training sample" set.

Validation Cases for the discriminant function, L

$$X_{val} := \begin{bmatrix} 2.41 & 205 \\ 1.3 & 193 \\ 2.45 & 181 \\ 3.22 & 152 \\ 6.4 & 223 \\ 10.08 & 218 \\ 1.45 & 339 \\ 9.48 & 122 \end{bmatrix}$$

The first four are when a Cumulus violation occurred and the last four are when it did not.

Assigns the columns of $\mathbf{X_{val}}$ to the respective vectors below.

$$winds_{val} := X_{val}^{\langle 2\rangle} \qquad dd_{val} := X_{val}^{\langle 1\rangle} \qquad j := 1 .. rows(X_{val})$$

$$L_{val_j} := -0.013 \cdot winds_{val_j} + -0.381 \cdot dd_{val_j}$$ **Discriminant Function for Cool Season**

Classification rule:
if $L \le -4.529$ then grp B
$L > -4.529$ then grp A

$L_{val_j} =$

-3.583
-3.004
-3.286
-3.203
-5.337
-6.674
-4.959
-5.198

Using the classification rule above gives the first four values as group A and are correctly classified. Similarly, the last four values are correctly classified as group B. The resulting confusion matrix and the correctly classified percentage of 100% for the validation cases are given below.

Confusion Matrix

$$\begin{bmatrix} \text{ı} & A & B \\ A & 4 & 0 \\ B & 0 & 4 \end{bmatrix}$$

$$Corr\_Classified := \frac{(4+4)}{rows(X_{val})} \qquad Corr\_Classified = 1$$

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