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An Analysis in Cloud-To-Ground Lightning Over Land versus Water

Elizabeth A. Boll

ANALYSIS IN CLOUD-TO-GROUND LIGHTNING FLASHES OVER LAND –VS- WATER

THESIS

Elizabeth A. Boll, Lieutenant, USAF

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DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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Elizabeth A. Boll, B.S.

First Lieutenant, USAF

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Elizabeth A. Boll
First Lieutenant, USAF

Approved:

Gary R. Huffines	2 March 2000
Gary R. Huffines (Chairman)	Date
Cecilia A. Miner	3 March 2000
Cecilia A. Miner (Member)	Date
Michael P. Susalla	2 March 2000
Michael P. Susalla (Member)	Date

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Elizabeth A. Boll

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Abstract

Understanding lightning characteristics over land and water is vital to achieving optimal safety and success in Air Force missions. Lightning safety rules are often based on experience rather than a scientific understanding of lightning. Examining lightning characteristics over water and land will assist in a better understanding of lightning and provide answers that can protect human lives and property.

Water and land have different compositions and surface conductivity values. A lightning stroke is detected through a change in the electro-magnetic field at the surface. The change in surface conductivity values from land to water can affect the detection of a lightning stroke and its associated parameters. The change in composition from water to land can also affect the dynamics of a storm and the lightning discharge process.

Data from the Salt Lake City, Mobile Bay, New Orleans, Kennedy Space Center, and Lake Okeechobee were used to determine if there are differences in lightning characteristics or behavior over land versus water. The National Lightning Detection Network (NLDN), Global Atmospherics, Inc., Tucson, Arizona recorded the lightning parameters.

Differences were seen in eleven of the twelve characteristics compared over water and land. Results varied from area to area and over time, there was not a consistent response due to the change in underlying surface type. Not all differences could be directly attributed to the change in underlying surface type. In conclusion, the change in underlying surface type did not produce consistent change in lightning characteristics or behavior. Water did influence lightning characteristics and behavior in specific cases of median peak current differences and diurnal pattern.

Analysis in Cloud-to-Ground Lightning Flashes over Land-vs-water

1. Introduction

1.1 Problem Statement

Does lightning behave differently over land versus water? Does the change in surface composition and conductivity cause a difference in the number of cloud-to-ground lightning flashes, the number of positive cloud-to-ground lightning flashes, or the maximum intensity?

Lightning hinders Air Force operations and can damage or destroy Air Force assets. Lightning also disrupts and destroys civilian property and lives. Answering the question of whether lightning behaves differently over land versus water will be one step toward achieving optimal safety and mission success. Lightning safety rules are often based on experience rather than a scientific understanding of lightning. Examining lightning characteristics over water and land will assist in a better understanding of lightning and provide answers that can protect human lives and property. Do we need different safety rules and over water or can one set of safety regulations apply that will protect all assets in all locations? Can we tell pilots whether it would be safer to fly over water or land in a storm?

" Any research on lightning is likely to yield information of practical value," [Pierce, 1974]. This quote from the 54th annual meeting of the American Meteorological Society (AMS) holds true today. Lightning research attempts to minimize or eradicate destructive occurrences by providing knowledge that improves the ability to avoid the threat of lightning or improve lightning protection equipment. To answer the question of

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This paper follows the style of the Journal of Geophysical Research whether or not lighting is different over land or water is one more piece of knowledge that will help explain the behavior and characteristics of lightning, as well as improve lightning safety regulations.

1.2 Background

A Cloud-to-Ground (CG) flash is a composite event. First, a series of coronal discharges (stepped leaders) extend from an electrified cloud toward the ground [Uman, 1987]. As the stepped leader nears the ground it induces an upward discharge from the earth. This connection of the stepped leader with the ground produces a return stroke that is characterized by an intense luminosity that propagates upward from the earth to the cloud.

CG flashes can have multiplicity, or more than one combination of leaders and return strokes. In the case of a second stroke in a flash, the leader is a dart leader and travels down the ionized path of the first stroke without branching [Uman, 1987]. The dart leader may connect with the ground at the same place as the stepped leader or it may induce another upward discharge from a nearby location.

Other characteristics of CG flashes include their polarity (positive or negative), which is determined by the net-charge the flash lowers to the ground [Uman, 1987]. In addition to polarity, a flash's peak current can be determined through analysis of the radiation field the strokes produce.

The National Lightning Detection Network (NLDN) [Cummins et al., 1998] detects CG flashes in the United States. The NLDN is a combination of Magnetic Direction Finders (MDFs) and Time of Arrival (TOA) sensors. The NLDN records the location, time, polarity, peak amplitude, and multiplicity of CG flashes.

These lightning characteristics have been collected nationwide since 1989 allowing large-scale study of lightning behavior [Cummins et al., 1995]. Using this data to examine the difference in lightning characteristics over land and water will help Air Force commanders manipulate Air Force assets in order to maximize mission success and minimize damage. The decision to operate in the vicinity of lightning is currently determined by past experience and mission demand rather than by a true understanding of lightning. A better understanding of lightning characteristics will provide the knowledge to rewrite operational procedures in the vicinity of lightning and give the Air Force a performance and safety advantage.

1.3 Scope

NLDN data from 1995 to 1998 are used to investigate lightning behavior over land and water. NLDN data confines the characteristics studied to the number of flashes, location, polarity, peak amplitude, and multiplicity of cloud-to-ground flashes. Summertime flash data will be isolated and analyzed over three coastal and two inland areas for observable differences in the parameters recorded by the NLDN.

Comprehensive analysis in each area will also be broken down into yearly, monthly, daily, and hourly analysis of lightning characteristics. Synoptic scale features may be offered as explanations to any observed phenomenon but no other data source such as radar, satellite, or surface charts will be inspected in the initial data isolation.

The five areas looked at in this report include, Mobile Bay, Kennedy Space Center (KSC), the Salt Lake City (SLC) area, the New Orleans area, and Lake Okeechobee. Mobile Bay, New Orleans, KSC, and the SLC areas all contain a body of saltwater that is used to separate the lightning flashes between those that hit land and those that hit water; no small sources of water, such as rivers, are considered. These four areas all contain bodies of saltwater but there are differences between the four areas, such as surrounding topography, that prevent all the data from being lumped together. Lake Okeechobee is the one body of freshwater in this study. The comparisons are made between land and water flashes in the same geographical location rather than comparing a large collection of flash data taken over different bodies of water.

The data used to examine the difference between lightning over land and water consists of flashes that occurred on summertime storm days. Summertime storm days for this research have been defined as days with lightning activity during the months of May, June, July, August, and September. From this data, days with storms within the geographical areas of interest were isolated for diurnal and monthly analysis. These days were chosen through a visual and numerical review of all summertime days with flash activity. A general rule of thumb was to keep days with more than 1000 flashes some exceptions were made to capture storms that lasted longer than the predefined 24 hr day. This decision was based on the Salt Lake City (SLC) area data and applied to the other four areas to compile a consistent data set.

The overall approach involves isolating flash parameters from the NLDN data and analyzing them for any contrast between land and water. The NLDN is covered in more detail in Chapter Two along with the literature review, which covers some lightning characteristics previously studied. The data will be inspected for characteristic and behavioral differences between flashes that strike land and those that strike water. The parameters are examined for overall differences, yearly variation, diurnal variation, and monthly variation. An explanation of how the NLDN parameters were inspected with relation to their underlying surface and the theoretical reasons why the underlying surface could influence lightning characteristics are in Chapter Three. Four types of analysis are applied to the five areas and the results are summarized in Chapter Four. Once the flash characteristics are compared over land versus water the conclusions are discussed in Chapter Five along with recommendations for future work

1.4 Summary of Key Results

Differences were seen in eleven of the twelve characteristics compared over water and land. The results varied from area to area and over time, there was not a consistent response due to the change in underlying surface. Not all differences can directly be attributed to the change in surface type. In conclusion, the change in underlying surface does not produce consistent change in lightning characteristics or behavior. Water does influence lightning behavior in some individual cases as is discussed in Chapter Five. Overall, it cannot be said whether Air Force missions would be safer over land or water

2. Background and Literature Review

2.1 Lightning Process

The characteristics of cloud-to-ground (CG) flashes were mentioned in Chapter One. This section will provide some background on the entire lightning process, the detection of CG flashes, and the sensor network used in the United States to record CG flash data.

2.1.1 Charging Process

A CG flash begins as a series of coronal discharges from an electrified cloud. Within a storm cloud, there are regions of positive and negative charge that produce electric fields sufficient to cause a coronal discharge. These regions are produced by the separation of charge within the thunderstorm. There are two major theories to explain the separation of charge - precipitation theories and convection theories [Uman, 1987]. In the precipitation theory, falling particles in the cloud interact with particles in the updraft and through collision become oppositely charged. This creates a positive bipolar cloud. In convection theory charge near the surface of the earth is swept into the cloud [Uman, 1987]. These theories help explain a bipolar cloud (Fig 1). Observations have been made of more complex charge regions in clouds [Stolzenburg et al., 1998]. A coronal discharge will occur from any charge region that builds up a strong enough surrounding electric field to exceed a breakdown threshold.

2.1.2 Discharge Process

Once the threshold value is exceeded and a coronal discharge occurs it forms a leader out into the air. Additional charge can flow from the cloud down this leader creating a large potential at the end of the leader and another coronal discharge. This series of coronal discharges form the stepped leader (Fig 1). In CG flashes the stepped leader moves towards the ground and causes an upward discharge from the surface, this is called the attachment process. Once the connection has been made, the charge moves rapidly down the main channel and forms a wave that moves up from the ground toward the cloud, this is called the return stroke. The return stroke is characterized by intense luminosity and travels at one-third the speed of light [Uman, 1987]. The peak current of the stroke comes from the return stroke detection.

The flash can end here or additional discharges can follow the same path as the first stroke and initiate a subsequent return stroke. When a flash has a second combination of leaders and return strokes, the leaders are called dart leaders. A flash can have many subsequent strokes after the first stepped leader connects with the surface. The number of strokes in a flash is called its multiplicity.

CG flashes are also classified by their polarity, positive or negative. Polarity is determined by the net charge that is lowered to the ground by the flash. The polarity of a flash as reported by the NLDN is determined by the first stroke in the flash. Figure 1 shows examples of the four types of CG flashes.

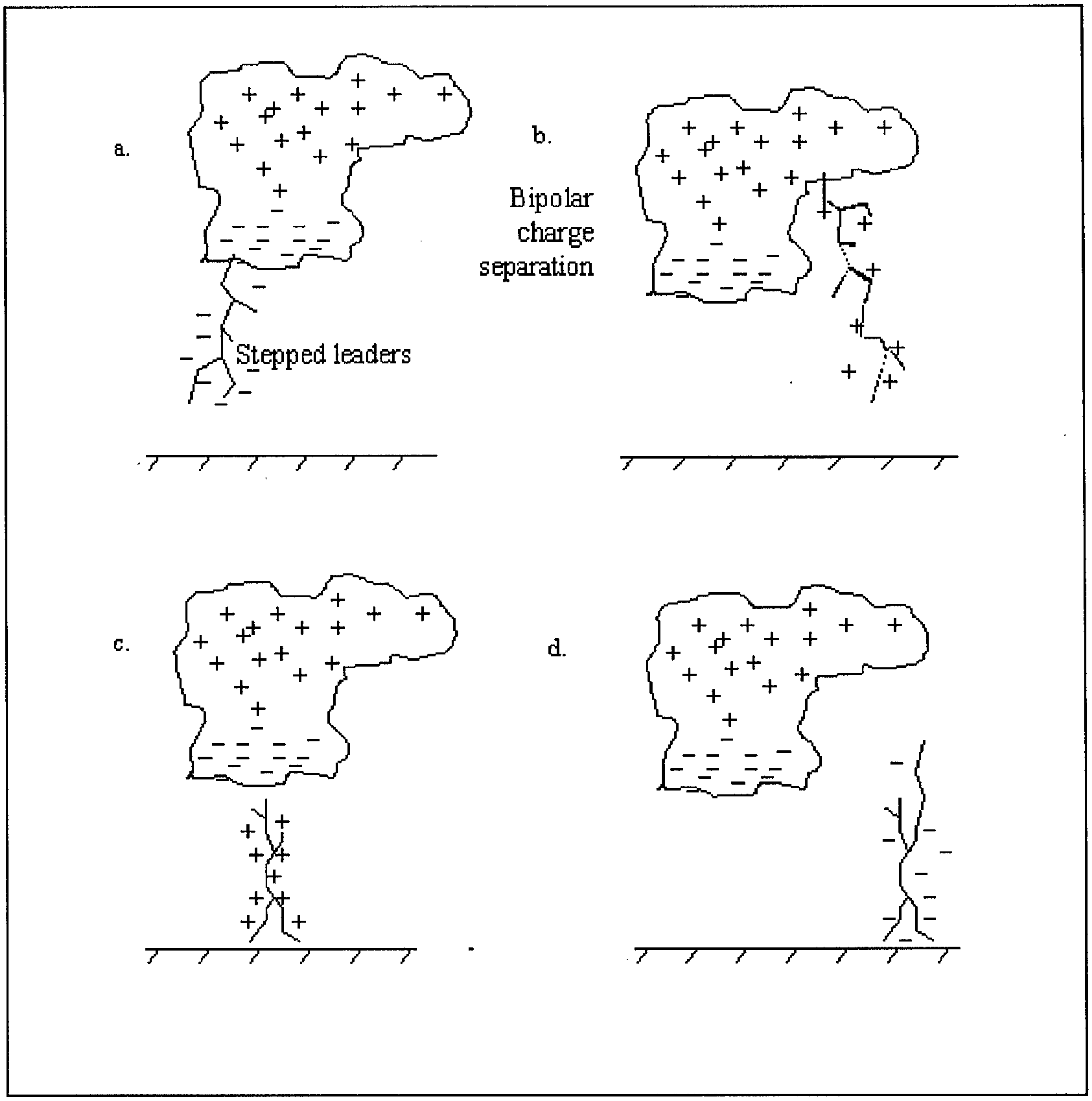

Figure 1. Cloud-to-Ground Lighting Flashes. The top left picture (a) demonstrates a negative CG flash, this type of negative CG flash accounts for ~90 % of all CG flashes. In (b) a positive Cg flash is depicted, this type of CG flash accounts for ~10 % of all CG flashes. Also possible are positive ground-to-cloud flashes (c) and negative ground-to-cloud flashes (d). Indicated by (a) and (b) are the stepped leaders that occur in each flash and the charge separation that occurs in each lightning producing storm cloud. [after Uman, 1987]

2.2 Lightning Detection and Return Stroke Waveform

A lightning stroke is detected through the electro-magnetic signal produced when net charge is transferred to the ground (Fig 2). This section will explain how the magnetic direction finders (MDFs) and time-of-arrival sensors (TOAs) used by the NLDN detect the electro-magnetic waveforms to determine flash characteristics and how the change in surface conductivity from land to water affects this detection process.

During a CG lightning flash, net charge is lowered to the ground; this produces a change in the environmental electric field at the surface [Krider et al., 1976]. Depending on the signal's rise time and the amount of time the signal remains above the background electric field, the flash is classified as a CG flash or an intracloud flash. Later in this section it will be shown that a change in surface conductivity affects the rise time of the signal and may cause the NLDN to mislabel some intracloud flashes as CG flashes.

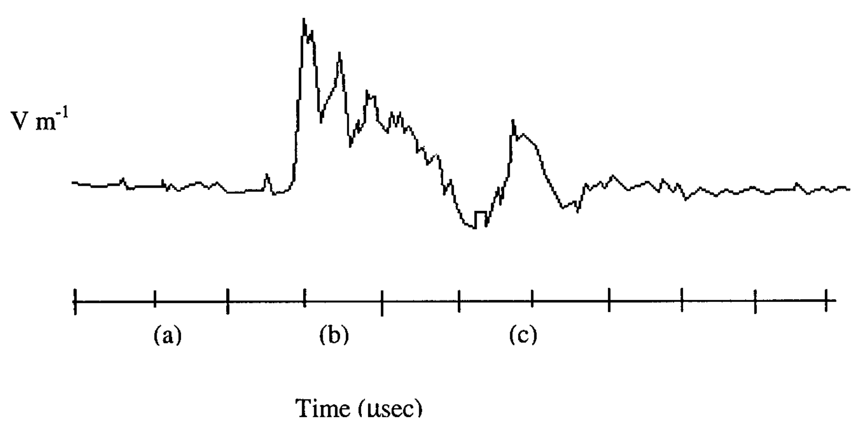

Figure 2. Electric field waveform of return stroke. Above point (a) the small rises indicate the stepped leaders, above point (b) the large rise indicates the return stroke and above (c) is the subsequent stroke signal. Magnetic waveforms are similar. [after Krider et al., 1980]

There are two ways for the NLDN to detect the return strokes in CG flashes from which the NLDN can determine location and peak current of the flash. The first method measures the electric and magnetic radiation field generated by the return stroke (MDFs) [Krider et al., 1976]. The second method measures the change in the electric field at several locations (TOAs) [Lyons et al., 1989].

When measuring the magnetic and electric fields there are several terms to consider but it has been shown that the radiation term is the most important after distances of a few tens of kilometers [Uman et al., 1975]. From the electro-magnetic field relationships it has been determined that radiation attenuates as 1/r over a perfectly conducting earth. This is important in the peak current determination and the shape of the wave detected in the magnetic field (Fig 2).

The radiation term dominates the waveform, rise time, and length of time the signal remains above the background signal [Cooray, 1989]. As the lightning discharge signal propagates over land or water, the radiation field is attenuated differently. Weidman and Krider [1978] discuss some of the differences in attenuation over water and land. They assume that attenuation will be less over water due to the lower conductivity of seawater. Important conclusions from their work are that strokes over seawater have faster rise times and larger high-frequency structures. This can affect the classification of a flash as either CG or intracloud.

So far we have seen that the change in surface conductivity does modify the detection of strokes over seawater and indicates that the physical differences between land and water can be seen in lightning measurements. The change of surface conductivity and composition can also affect the determination of the peak current.

To determine the current of a flash Lin et al. [1980] suggested using the transmission line model (TLM) to estimate the peak current. The TLM assumes the stroke is a vertical line with constant return stroke velocity and that the waveform travels over a perfectly conducting earth. Lin et al. [1980] and Uman et al. [1982] suggest that the peak current can be found through the relationship between the breakdown current and the vertical electric field intensity $E_z(t)$ or the horizontal magnetic flux density B(t) using:

$$I_{pk}(t) = -\frac{2\pi\varepsilon_0 c^2 R}{v} E_{pk}\left(t + \frac{R}{c}\right)$$

where $I_{pk}(t)$ is the peak current at time t, ν is the return stroke velocity, and $E_{pk}\left(t + \frac{R}{c}\right)$ is the peak in the electric field associated with the peak current (Fig 2b) at time t, c is the speed of light, ε_o is the permittivity of free space, and R is the distance to the charge. There are assumptions made in this equation for peak current that may result in inaccurate values. The assumption of ν being constant may not be accurate. Also, the $E_{pk}\left(t + \frac{R}{c}\right)$ term assumes the waveform traveled over a perfectly conducting earth, which is not accurate. The signal may traverse several different surface conductivities on the way to the sensor; therefore, differences in land and water should also be noticed in the peak current calculation through the alteration of the electric field intensity or the horizontal magnetic flux density.

The change in surface conductivity from land to water can have immediate effects on the peak current because there is less attenuation to the signal over water and the rise-times are faster which allows for weaker CG flashes and some intra-cloud flashes to be included that would not be picked up over land.

Farther away from the shore the signals should be attenuated less over water as they travel back to the sensors, and therefore the median current should increase over water. Some other changes from land to water could affect the waveform determination and peak current calculation such as a change in air pressure or humidity. These in turn, could affect the return stroke velocity, which is assumed constant in the TLM approach to determining the peak current.

2.3 NLDN

2.3.1 History of the NLDN

The National Lightning and Detection Network (NLDN) began in 1987 when regional networks from the western United States and Midwest merged with the State University of New York at Albany Lightning Detection Network. At that time, the detection network consisted of gated, wideband magnetic direction finders (MDFs) [Cummins et al., 1998]. The MDF's were manufactured by Lightning Location and Protection, Inc. and were designed to sample return stroke waveforms to determine which strokes were primary CG strokes or secondary CG strokes in a flash. Multiple sensors are used to pinpoint the location of the flash. These MDFs are also colocated with flat-plate electric antennas, which determine the polarity of the stroke [Krider et al., 1980].

The detectors sense a change in the magnetic field and infer the stroke's radial direction. The strength of the flash is also correlated to the amount of flux measured in the magnetic field; a stronger detected waveform correlates to a stronger stroke. These intensities are range normalized to 100 km to eliminate bias created by strokes that are very near one sensor. This normalization allows the strength of all the strokes detected by the NLDN to be compared without having to consider each stroke's distance to the sensors. For example, strokes that are detected 50 m or 175 m have a signal strength that are normalized to have a equivalent signal strength of a stroke that was sensed at 100 m. The range normalization equation is discussed in Chapter Three.

Also in the late 80's, Atmospheric Research Systems, Inc (ARSI) manufactured a network of time-of-arrival (TOA) sensors. The TOA sensors translate the time they sense an electro-magnetic pulse into a range from which the stroke could be located. The intersection of four TOA sensor outputs gives an accurate location of the stroke. This method assumes that the electromagnetic pulse travels at the speed of light and is not affected by surface or air conductivity [Cummins et al., 1998].

2.3.2 NLDN Upgrade

In 1994 the NLDN underwent a technological upgrade to provide better detection, reliability, and real-time distribution. The upgrade involved combining the MDFs with the TOA sensors into a new sensor called the Improved Accuracy from Combined Technology (IMPACT) sensor. The current NLDN, operated by Global Atmospherics, Inc., is a merger of the two companies that make MDFs and TOA sensors and consists of 59 Lightning Position and Tracking System (LPATS) sensors and 47 IMPACT sensors. Both types of systems have been modified to have comparable sensitivities and detection rates [Cummins et al., 1998].

Modifications to the IMPACT sensors included increasing their gain, reducing the trigger threshold, and changing the waveform acceptance criteria to detect more distant flashes [Cummins et al., 1998]. The LPATS sensors, a TOA type sensor, originally could be triggered by nearby intra-cloud lightning; this was corrected by reducing the gain. The waveform criteria from the IMPACT sensors were added into the LPATS sensors to improve detection accuracy and make a more homogenous system.

An effective range study conducted with the modified IMPACT sensors found that their detection range had increased, and the sensor baseline had increased to between 275 km and 325 km. Therefore, the total number of sensors in the NLDN was reduced from 130 to 106 in 1995. Data, from these 106 sensors, was used to resolve a new location algorithm for the upgraded system. The new algorithm overcomes many of the problems inherent in each of the sensors. Furthermore, the algorithm allows for a variety of IMPACT and TOA sensor combinations without loss in accuracy. Figure 3 shows the placement and combination of the 106 sensors in the NLDN. There are similar distance and sensor combinations around the five areas of interest with some exceptions, there are areas south of KSC and east of the Salt Lake that have shorter distances to the required number of sensors. The NLDN requires that at least one IMPACT sensor detects the stroke along with a combination of up to two more IMPACT sensors or up to three TOAs. Also there is an area west of the Mobile Bay, in addition to all of southern Louisiana, where greater distances need to be covered to reach the required number of impact sensors.

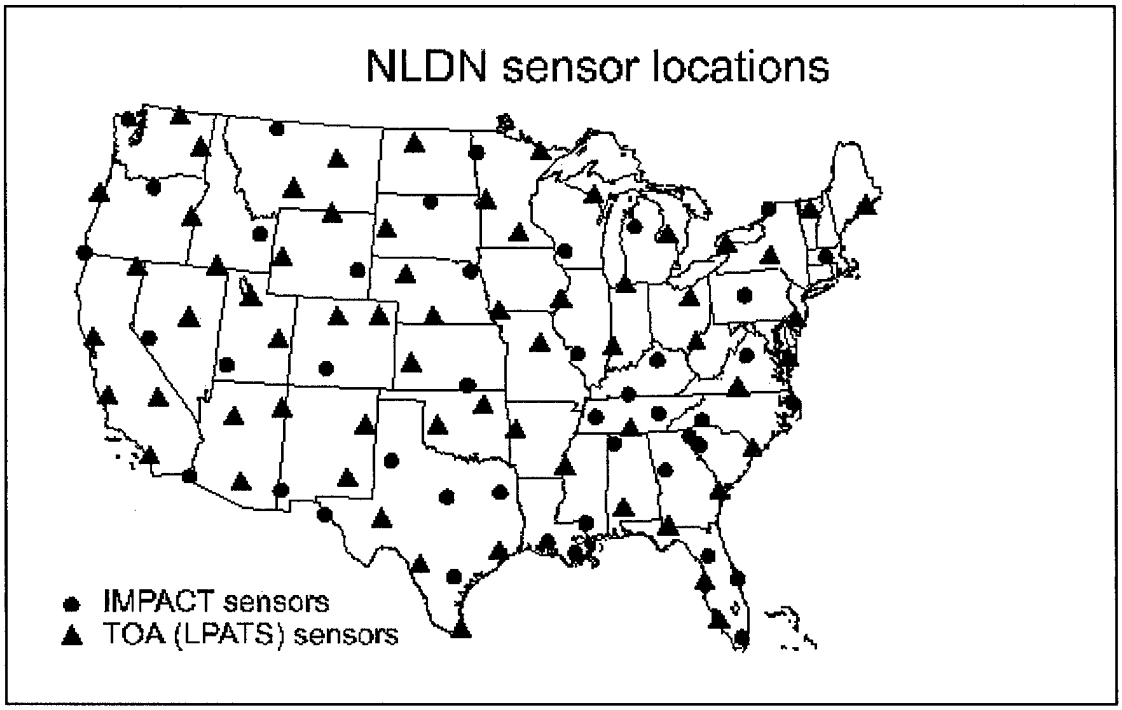

Figure 3. NLDN sensor locations. [after Cummins et al., 1998]

The upgrade also includes a new method for counting multiplicity. Now, strokes are grouped into a flash according to how many strokes fall within a 10 km range of the first return stroke and have less than 500 ms between successive strokes. Polarity is not accounted for when grouping strokes into a flash; distance and time are the only variables considered. The multiplicity is limited to 15 strokes per flash in the new location grouping method [Cummins et al., 1998].

2.3.3. NLDN Accuracy

Real-time data processing is subject to errors that are corrected as the data is reprocessed for storage and research purposes. One error can occur in the reprocessed data set when the system is saturated. Saturation happens when there are more than 35,000-50,000 flashes per hour over the entire US [Mach et al., 1986; Passi and Lopez, 1989]. When this occurs the reprocessed data can have up to 5% more strokes than the real-time data, and occasionally this difference can be as high as 20%.

Location accuracy of the new IMPACT system is predicted to have a median value of 500 m. Reviews in Florida and New York conducted after the upgrade support that the location accuracy is in fact within 500 m to 800 m [Cummins et al., 1998]. Flash detection, for flashes stronger than 5 kA, has improved from 65-80% in the early 90's to 80-90% after the upgrade [Cummins et al., 1998]. The improved system's subsequent stroke detection efficiency saw little improvement and is still around 50%.

Studies by Pinto et al. [1996], have shown that subsequent strokes are not always weaker than the first return stroke. However, it is from the viewpoint that the first return stroke is strongest that the NLDN currently is designed. Therefore, the NLDN only reports the range normalized signal strength (RNSS) of the first return stroke. The RNSS will be covered in more depth in Chapter Three.

Peak current is estimated from the RNSS and is therefore also normalized to 100 km. The improved NLDN does detect small signals (less than 5 kA) that were too small to distinguish in the past. Therefore Idone et al. [1993] computed a new equation for converting RNSS to peak current:

$$Ipeak = 0.185 * RNSS$$

where *Ipeak* is the peak current of a flash. RNSS is defined above

The modifications to the IMPACT and LPATS sensors allow for the detection of small positive charges. Positive flashes less than 10 kA are treated as intracloud flashes. A rule of thumb to follow to get an accurate flash count is that a flash should only be considered a positive flash if it exceeds 10 kA [Cummins et al., 1998]. .

The NLDN has improved location and detection accuracy since the upgrade in 1994. Therefore, if results from this study are compared to results using data prior to 1995, the changes in the NLDN should be considered. For each flash NLDN records year, month, day, hour, minute, second, latitude, longitude, Range Normalized Signal Strength (which is converted to peak current and polarity), and multiplicity. It should be remembered that there are changes to peak current calculations, multiplicity detection, and an increase in small positive current returns since the upgrade.

2.4 Climatological Summary of Lightning in the United States

Most of this climatological background will demonstrate lightning trends over land in the mid-latitudes; however, there are some important offshore trends noted in this summary. The somewhat limited knowledge of oceanic lightning from the Tropical Ocean and Global Atmosphere Coupled Ocean and Atmosphere Experiment (TOGA COARE) is summarized in Section 2.3.

It is important to understand the general pattern of lightning in the United States before looking for differences between lightning over land and water. Walter Lyons (FMA Research, Inc., Fort Collins, Colorado) and Richard Orville (Texas A&M University) have both published comprehensive cloud-to-ground lightning studies in the Continental United States. Lyons et al. [1998] focus on summertime large peak current (I_{peak} >75 kA) flashes. Orville's studies summarize the annual characteristics (1989-1991) and density of flashes (1992-1995) throughout the United States. Both used the National Lightning Detection Network (NLDN) as their data source. Orville and Silvers' 1992-95 study [1997] and Lyons et al. [1998] study used data taken during years that encompassed the NLDN upgrade. Therefore the upgrade has to be considered when examining their results. Orville completed his first lightning study [1994] before the NLDN upgrade. The upgrade does require a change in data interpretation, but the summaries from all three studies are comparable. A quick review of three climatological summaries will show the existing trends and patterns of lightning in the United States.

Orville's 1989-1991 study of lightning characteristics used data from the NLDN when the system consisted of Magnetic Direction Finders. Conclusions from this study show an overall flash density maximum over Florida, with secondary density maxima over the Midwest and the Carolina coast. Orville [1994] also concluded that positive flashes accounted for 3.66 percent of all flashes with the density maximum of positive flashes over the Midwest. The high flash density over the Carolinas is thought to be due to a higher than average number of lightning sensors in the area [Huffines, 1999]. The number and placement of lightning sensors was reconfigured in 1994. After the reconfiguration, Orville and Silvers' 1992-95 results no longer show a flash density maximum in the Carolinas [Orville and Silver, 1997].

Overall, conclusions from Orville and Silvers' 1992-1995 study [1997] compare well with Orville's earlier work [1994]. Again, these results showed maxima of flash density over Florida and the Midwest, with a maximum in positive flash density in the Midwest. Orville and Silvers' 1992-1995 study looking at all positive flashes [1997] indicates an overall increase in the percentage of positive flashes during 1995. Part of this positive flash increase is attributed to the increased gain in the improved NLDN [Cummins et al., 1998]. Pinto et al. [1996] completed a study in Brazil using a time-of-arrival (TOA) system and suggests that most of these small amplitude positive cloud-to-ground flashes are indeed real, and not equipment error.

Lyons et al. [1998] studied a total of 14 summer months from 1991-1995. This study is in agreement with the large flash density areas over Florida and the Midwest observed by Orville [1994] and Orville and Silver [1997]. Lyon et al. [1998] supports the area of dense positive flashes in the Midwest (Fig 4)

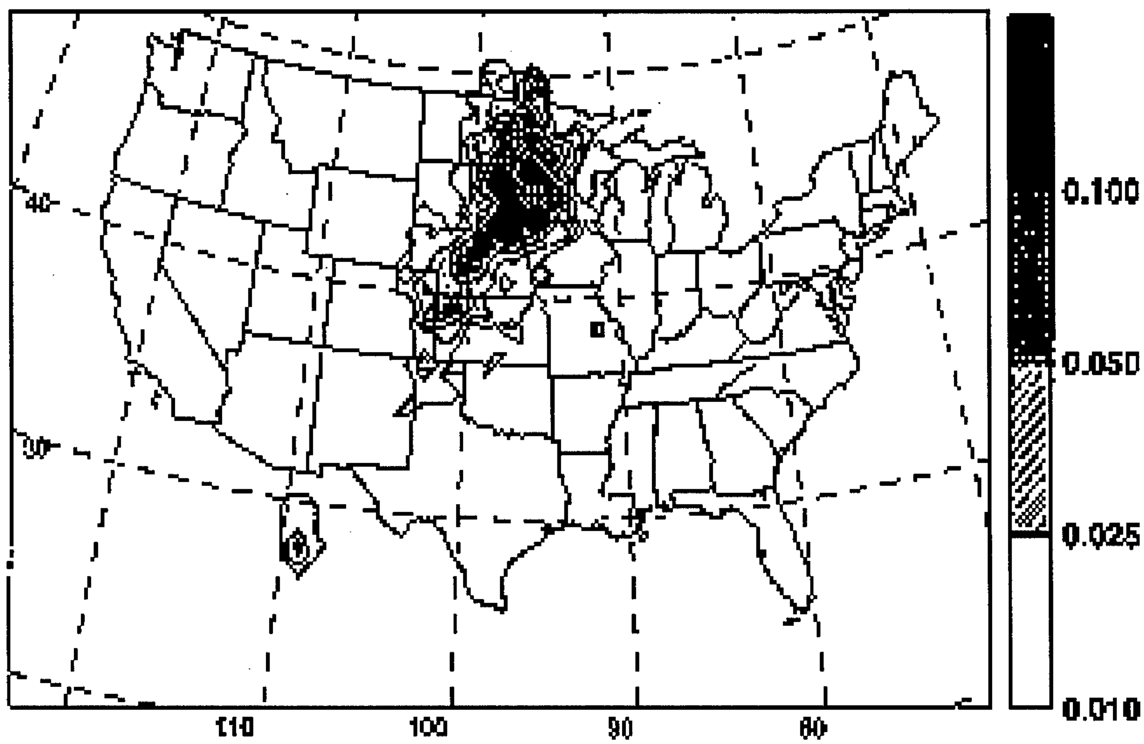

Figure 4. Positive large peak current (Amp>75 kA) Cloud-to-Ground flashes. Shading indicates flashes per km^2 [Lyons et al., 1998]

Lyons et al. [1998] contoured large peak current flashes, but there is good agreement between the placement of the large peak current flashes and percent of positive flashes depicted by Orville [1994]. From Figure 4, it can be seen that large amplitude positive flashes are unlikely around Mobile Bay or KSC. Figures 4 and 5 show that the Great Salt Lake does not fall into either density maxima and indicates that the Great Salt Lake receives fewer high amplitude flashes than Mobile Bay or KSC. Figures 4 and 5 also indicate a lack of polarity preference over the Lake. Lyon's study goes on to show trends in negative flashes, multiplicity, and trends in different strength flashes.

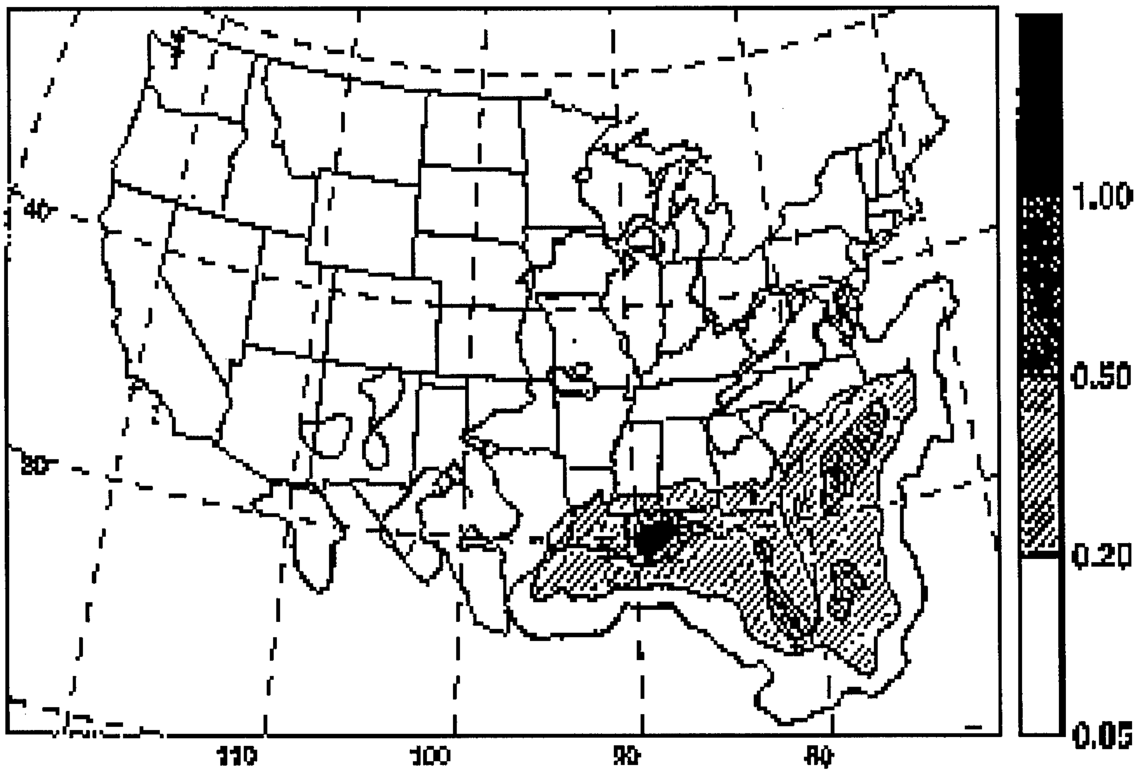

Figure 5. Negative large peak current (Amp > 75 kA) Cloud-to-Ground flashes. The shading indicates flashes per km^2 [Lyons et al., 1998]

Figure 5 illustrates areas of high negative flash density offshore along the southeastern United States and along the gulf coastline. Notice the localized maximum east of New Orleans into the Mobile Bay; the source of this has not been determined [Lyons et al., 1998]. Due to the placement of the NLDN sensors, the detection efficiency falls off rapidly after the first 200 km off shore so the contours cannot be trusted after 200 km. Lyons et al. [1998] also depict trends in multiplicity with maxima in Florida and the

Midwest. The area of maximum multiplicity for both negative and positive flashes is the Midwest, with a secondary negative maximum located over Florida [Lyons et al., 1998].

The summary of data over the United States from the early 90s shows trends in lightning distributions. Now that there is a foundation for lightning characteristics over land in the mid-latitudes the conclusions from TOGA COARE will be discussed to show some observed trends in lightning characteristics over tropical ocean water.

2.5 Findings from TOGA COARE

Data from the Tropical Ocean and Global Atmosphere Coupled Ocean and Atmosphere Experiment (TOGA COARE) [Lucas and Orville, 1998; Peterson et al., 1996; Orville et al., 1997] imparts some valuable background information for land versus water lightning studies. One component of the experiment was to study oceanic lightning providing some insight into lightning characteristics over saltwater. For a detailed explanation of the instrumentation used in TOGA COARE, see Peterson et al. [1996].

Lucas and Orville [1998] examined data acquired from magnetic direction finders, requiring flashes to be detected by the MDF at Kavieng in Papua New Guinea, to study oceanic lightning. In the 1998 study all flashes to the north of the island and MDF were considered ocean flashes. The study on oceanic lightning was limited to flash totals, diurnal changes, and overall trends over a four-month period. It was established that flash counts over land were higher than over water and the diurnal flash maximum for both land and water occurred around midnight. This diurnal maximum is in contrast to the Continental United States where diurnal variations are stronger and the maximum flash count happens around 1600 L for relatively smooth terrain [Lucas and Orville, 1998]. The conclusions from this oceanic lightning study have limited application due to the limited scope of variables considered.

A more comprehensive lightning study was done during TOGA COARE [Orville et al., 1997] using three modified MDFs. This study did not differentiate between land and ocean flashes, but did mention some good points to consider in future work. First, the median positive peak current varied from 24 kA (Oct) to 62 kA (Jun). This variation is not fully explained by Orville et al. [1997], and prompts future research to examine these differences. Another interesting observation from the Orville et al. [1997] study was the proposed correlation between lower air conductivity and lower flash density. Not conclusively determined, it too prompts future research to investigate this correlation further.

Overall, the data from TOGA COARE was not as insightful as first expected, but it does provide data from an area geographically similar to Florida and lightning data from a pure saltwater area to contrast with lightning data over land.

2.6 Application of climatological summaries to the areas of interest

The main reason for a general summary of lightning over the Continental United States is to understand established lightning characteristics for the three areas of interest. It has been established that the majority of lightning flashes in the Continental United States occur in the summertime with daily flash maxima in the late afternoon for relatively flat terrain. Large amplitude lightning density maxima have been observed near Mobile Bay and offshore around Florida. During a 1983 summertime study [Reap, 1986] a local flash density maximum was discovered south of the Great Salt Lake.

Figures 4 and 5 show that Mobile Bay and KSC both fall into areas of high negative flash density. Both areas are located at similar latitudes, and have sea breezes as their main triggering mechanism for the development of lightning producing thunderstorms. The water temperature, the salinity, and conductivity of the waters surrounding each are not exactly the same. Recall that there is an unexplained negative flash anomaly near Mobile Bay; this is one of the few differences between Mobile Bay and KSC. The Great Salt Lake, in contrast, is at a higher latitude and altitude, and has different weather patterns with fewer lightning flashes. In addition, the salinity of the Great Salt Lake is 3-5 times higher than ocean saltwater. It is informative to compare the three sites, but the reasons for these differences have to be explained in future comparisons.

2.7 Previous Comparisons of Lightning Characteristics Over Land versus Water

Tyahla and Lopez [1994] completed a lightning study at Kennedy Space Center (KSC). This study set forth to prove that the initial charge on a cloud-to-ground lightning stroke would be transported away from the strike point faster with a surface of higher conductivity. Rapid dissipation of the charge at the surface could lead to faster charge transfer down the channel and consequently produce a larger current amplitude [Tyahla and Lopez, 1994]. They did not conclusively prove or disprove this theory.

Their experiment used triggered flashes from many different thunderstorms in the summer of 1985. The area of land flashes was roughly 75 km away from the area of water flashes (about 40 km offshore). There was much discussion about site errors, gain bias, and directional bias in the MDFs that will not be discussed here since it is not directly applicable to the lightning detection equipment used in this study. One effect of interest is the differential attenuation of the signals over surfaces with different conductivities [Tyahla and Lopez, 1994].

The amount of attenuation depends on the frequency being observed. Tyahla and Lopez [1994] were expecting a frequency around 100 kHz and ruled out attenuation as a problem, citing a study done in 1956 using similar frequencies. Johler et al. [1956] demonstrated that there was negligible attention to the frequency due to propagation over a surface with conductivity of $5x10^{-3}$ mho m^{-1} over a distance of 64 m. To account for attenuation over water with a conductivity value of 4 mho m^{-1} [Barrick, 1971], Ming and Cooray [1991] concluded that the radiation field from a lightning return stroke is attenuated less than two percent over a distance of 70 km across smooth or rough waters. For further explanation of this see Cooray [1987]. Although current NLDN sensors are not within 70 km of each other, individual flashes fall at a variety of distances away from one IMPACT or TOA site. Therefore, this information, although only validated at 70 km, is helpful and similar attenuation precautions should be addressed during future research.

The conclusions drawn from the Tyhala and Lopez [1994] study are unclear. They expended a great deal of energy to have homogenous data sets to compare, but kept four times more land flashes than water flashes in the final data set. They observed a greater percentage of strong flashes (greater than 75 kA) in the water data set. Instead of investigating a scientific reason for this observation they altered their statistical analysis until the difference no longer appeared. Tyhala and Lopez [1994] did not state their results with confidence. They spent equal time explaining statistical and instrumentation errors as cause for their observations as they did saying that it could have been a physical reason.

In light of the Lyons et al. [1998] research showing a large current density off shore near the Kennedy Space Center (KSC) combined with the fact that there is now improved instrumentation, it is possible to examine the different lightning characteristics over land versus water. It is now possible to look at several summers worth of data and more characteristics than just peak current amplitude. It is time to reexamine the subject of lightning characteristics over land versus water.

3. Methodology and Analysis

3.1 Theory

Seawater, freshwater, and land have different surface conductivity values. Lightning strokes produce a change in the surrounding electric and magnetic radiation fields. The measurement of this change determines if a CG stroke occurred, and determines the location and signal strength of the stroke. As mentioned in Section 2.2, the mathematical theory used to determine the waveform and peak current considers radiation as the dominant term and has established that radiation attenuates as 1/r where r is the distance from the sensor to the detected charge. The waveform is assumed to travel over a perfectly conducting earth. Therefore, the change in surface conductivity from land to water may cause errors in peak current calculations. Another assumption is made when the signal strength is used to calculate peak current; this assumption is that the return stroke velocity is constant. Other lightning properties may be affected by this change in surface conductivity as well, but this study is limited to the properties recorded by the NLDN.

Briefly mentioned at the end of Section 2.2, the change in surface conductivity from land to water should show immediate affects in the detected radiation field. However, there are more differences between land and water than just conductivity that could affect lightning characteristics and behavior.

Other properties that differ between land and water are their surface temperatures and their physical consistency. Water is flat when compared to mountainous terrain and water has a different chemical composition than land. Air directly above water will have different properties than air directly above land, such as different relative humidity, conductivity, temperature, and composition. These differences may affect the physics of the lighting discharge process, the detection process, or the dynamics of the storm. Similar to the change in surface conductivity values, these factors may result is differences in lightning characteristics and behavior over water versus land.

3.2 Data Collection

Data for this project comes from the National Lightning Detection Network (NLDN). The history, upgrade, and accuracy of the NLDN were covered in Section 2.3 with a brief explanation of lightning detection in Section 2.2. This section highlights what parameters the NLDN records and some issues that need to be considered in analysis. As stated in Section 2.3.3, for each cloud-to-ground flash the NLDN records the year, month, day, hour, minute, second, latitude, longitude, Range Normalized Signal Strength (which is converted into peak current and polarity), and multiplicity.

Section 2.2 explains how surface conductivity may affect the determination of peak current. Using the NLDN equation for peak current, the same concerns in 2.2 can be applied to the NLDN data. The assumption that the signal travels over a perfectly conducting earth combined with the fact that land and water have different surface conductivity values can lead to inaccurate signal strength measurements and peak current calculations. To find peak current (I_{peak}) NLDN uses the following equation,

$$Ipeak = 0.185 * RNSS$$

where RNSS is range normalized signal strength. To determine RNSS the NLDN uses the following equation,

$$RNSS = C * SS * (r / I)^{p} \exp((r\text{-}I)/A)$$

where C is a constant, SS is raw signal strength, r is the range in kilometers, l is the normalization range which is set to 100 km, p is the attenuation exponent (p = 1.13), and A is the e-folding length for attenuation which is set to 10^5 km [Cummins et al., 1998]. These equations are based on the transmission line model [Uman, 1975; Lin et al., 1980] and are affected by a change in underlying surface conductivity as discussed in Section 2.2. It should also be noted that p was found empirically in Florida by Orville [1991] assuming A was infinite, so there may be some error with p when used in other locations.

The placement of the sensors throughout the NLDN should be considered when analyzing results. Ideally, the NLDN should provide equal coverage over the entire United States; however, the requirement that a flash must be picked up by at least one IMPACT sensor and the sparse placement of IMPACT sensors in the western United States, may influence the observations of lightning behavior. IMPACT sensors are up to 500 km apart in northern Utah; this spread combined with the terrain blocking affect of the mountains could deteriorate the effectiveness of the NLDN [Huffines, 1999].

Huffines [1999] also contoured the distances between required sensors in the United States and found that the distances vary within each area of interest. These distances indicate how far a stroke's signal has to travel before it is detected by the NLDN. Huffines' work [1999] indicates two pockets of smaller 200 km range requirements near Salt Lake City. Conversely, the rest of the state has 300-400 km range requirements for lightning to be detected by the correct NLDN configuration. Near Mobile Bay and southern Louisiana there are isolated pockets of larger range requirements (400 km range) surrounded by 300 km range requirements throughout the rest of the area. These variations need to be considered when examining the contour data but do not affect the three other analyses completed in this study.

The NLDN appears to be undercalculating the multiplicity since the 1994 upgrade. The global average multiplicity calculated by Thomson [1980] was 3.5 strokes per flash. The observed multiplicity averages for 1996 and 1997 ranged from 1.9 to 2.1 [Cummins et al., 1998]. Cummins et al. [1998] feel this lowered average is consistent with the increased accuracy of detection. Calculations of the multiplicity in this research have shown averages of 1.1 to 2.7 strokes per flash for all areas. Previous studies of multiplicity have recorded up to 14 strokes per flash [Uman, 1987]. Another indicator that multiplicity may not be calculated correctly in the present NLDN is that fact that the median current values decreased after the upgrade. This could indicate that the subsequent strokes of a flash are being mislabeled as a new flash, and therefore these subsequent strokes with lower peak currents are being averaged into the median current values.

3.3 Data Processing

As previously stated, the goal of this research is to determine if there is a difference in lightning flash behavior and characteristics over land versus water. Due to the lack of control data and observations it is not possible to prove statistical correlation between water and specific lightning parameter changes. For example, it is not the goal of this research to say that if a storm spends 15 minutes over saltwater it will result in a 10 kA decrease in median negative current. The goal is to determine if a difference exists in behavior or parameter values of lightning over water versus land through comparison of similar parameters over small areas on chosen storm days. Choosing specific days allowed for the analysis of lightning characteristics on a scale of hours, days, months, and years using various processing methods. This processing allowed for discussion of diurnal, monthly, yearly, and overall differences between lighting over land or water. The following discussion presents processing techniques using the Salt Lake City data set. The same processing was performed on the other four areas with the processing information presented in the appendices. Important analysis and results from all areas will be discussed in Chapters 4 and 5.

To look for differences in lightning characteristics between land and water requires that the lightning characteristics can be seen in relation to geography. There are two ways to demonstrate the differences in characteristics between land and water. The first way is to contour characteristics over the five areas and visually analyze the results for variations in the patterns of different characteristics such as median positive current or flash density. The second way to associate lighting flashes with the underlying surface is to use the latitude and longitude of each flash to determine if the flash hit water or land. This method of tagging each individual flash allows for numerical analysis of the results, and allows for analysis on a smaller time and spatial scale than contouring does.

Before the lightning could be separated between land or water flashes, the raw data had to be read back from the NLDN and the flashes for the times and areas of interest had to be found. The programs to structure the NLDN data and find flashes over a certain time and area were supplied by Major Gary Huffines as used in his dissertation work [Huffines, 1999].

3.3.1 Contour Method

Contoured data provides a quick picture of flash density, median positive current and median negative current patterns. Four-year averages of these characteristics were examined to determine if there was a distinct difference between their values over land and water. The contours were created by breaking down the areas into 0.05 ° longitude by 0.05 ° latitude boxes and finding the median current or flash density in each box. Flash density is determined by dividing flash count by resolution in kilometers so the overall flash density is flashes per kilometer $^{-2}$. Median values are used due to the shape of the peak current distribution, the distribution is right skewed (Fig 6). An average value would be affected by the values in the right tail, whereas a median current value represents the values that occur most often. Median current is determined by finding a histogram of the peak currents in each box and choosing the median value. This method showed some trends between land and water but did not distinctly show the same trends in all areas (Fig 7). The placement of sensors may also contribute to the results seen in the contours.

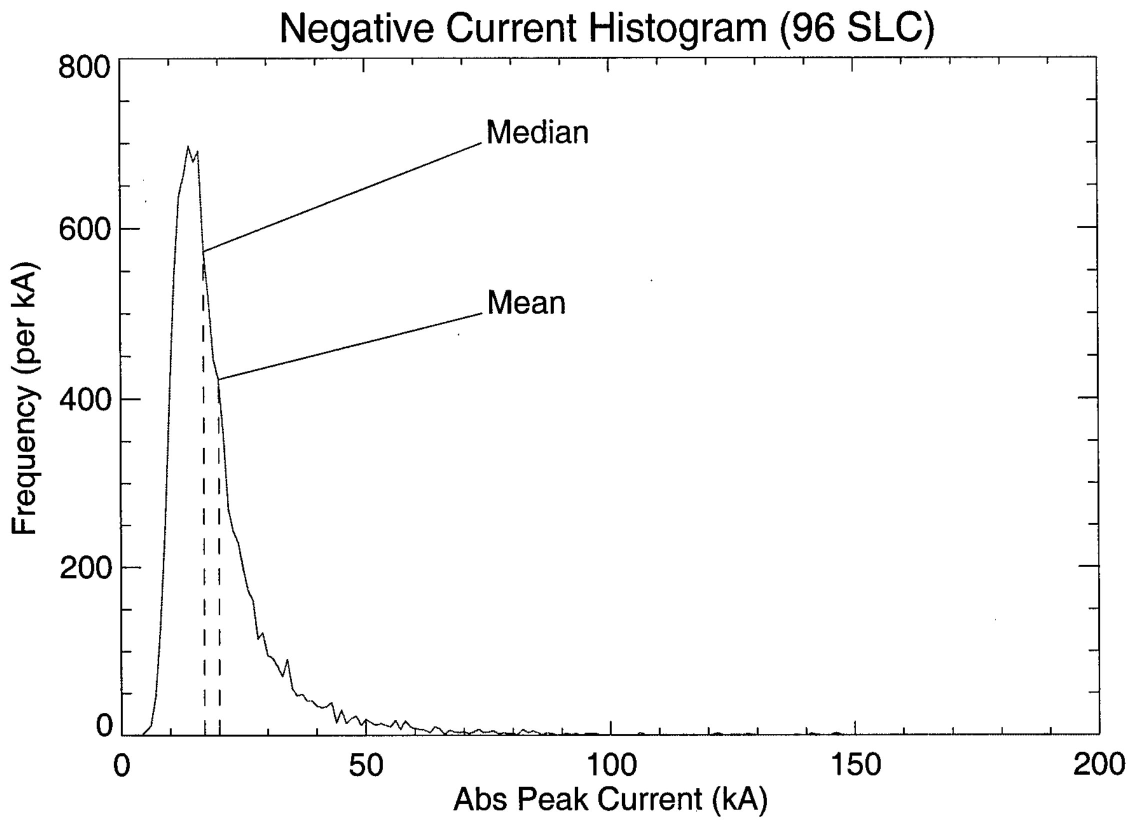

Figure 6. Median and mean. This figure shows the distribution of the negative peak currents for May-September 1996. The right skew is a typical distribution for peak current; therefore the median value is used to best represent the peak current values.

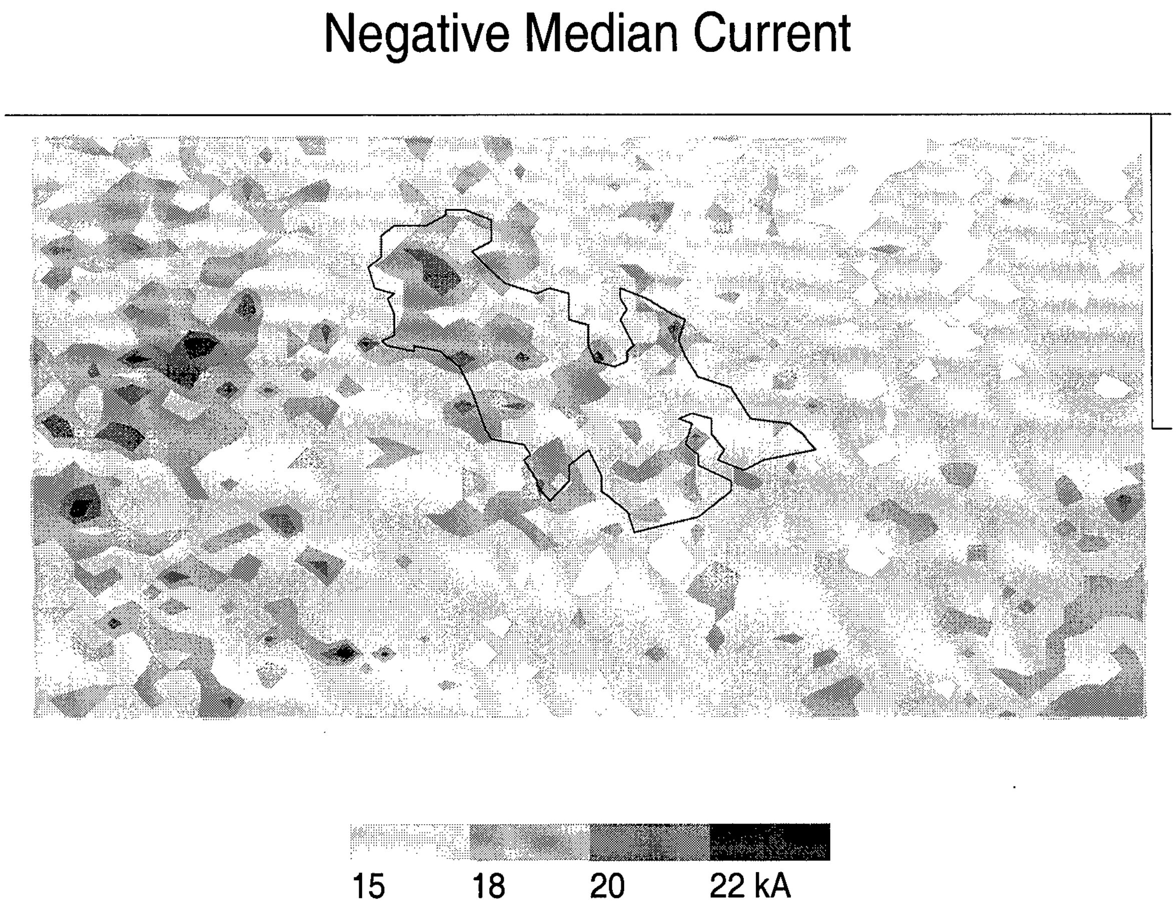

Figure 7. Negative median current. This figure shows the absolute value of negative median current over the SLC area. The data used to create this figure are all days May-September (1995-1998). The body of water in the center of the picture is the Great Salt Lake.

3.3.2 Determination of Storm Days

The first step toward separating lightning flashes between land and water was to find the storm days in each area. Storm days were found by counting the number of flashes per day over the areas of interest from May through September (95-98). Examination of the number of flashes per day, both numerically and graphically, over the Salt Lake City area indicated that days with more than 1000 flashes were days with storms localized over the areas of interest. Days with less than 1000 flashes were generally days with storms on the fringes of the area. In addition to looking at flashes per day to determine storm days, the flashes per hour were graphed to determine when the diurnal maxima occurred. For example the hourly histogram in Salt Lake City indicated that the daily max occurs from 3 p.m. local through 12 p.m. local. Therefore, the storm days are defined as days with more than 1000 flashes between 6 UTC- 6 UTC, which is midnight to midnight local time. When storms lasted longer than the 24 hr period, the following day was added into the data set. The 1000 flashes per day criterion became a general rule of thumb to pick storm days in the other areas but the hours changed to capture the full storm day. Lake Ockeechobee and the KSC area data were run from 7 UTC-7 UTC, which is 3 a.m. to 3 a.m. in local time. The New Orleans and Mobile Bay area data were examined from 0 UTC- 0 UTC, which is 7 p.m. to 7 p.m. in local time. Although the results from the five areas cannot be combined, it is important to keep the same minimum criteria in all areas. Having storm days of the same magnitude in each area is important for determining if the observed results are due to the change in underlying surface or due to a change in the number of flashes.

3.3.3 Separating Lighting Flashes using Latitude and Longitude

The method of separating flashes into those that hit water and those that hit land allows for numerical analysis in the determination of differences between lightning characteristics over land and water. To separate the flashes into land or water strikes, the boundaries of the bodies of water were handgridded from the surrounding area at a 0.25° resolution. These coordinates that frame the water were built into a matrix of two latitudes (marking the top and bottom of the lake) by each 0.25° change in longitude. The size of the surrounding area can be changed without affecting the water boundary matrix.

Once these matrices were built, the latitude and longitude of each lighting flash in the area were run though this matrix to check if it fell inside the water boundary or outside, over land. The programs to separate flashes and the coordinates used for the water boundaries are in Appendix A.

Since the water was gridded out, the separation of water and land flashes is not perfect but the number of flashes miscatagorized is very small compared to the total number of flashes over each surface (Fig 8). Data is interpolated between each pair of matrix points to increase accuracy when comparing the lightning flashes latitude and longitude to the matrix. Even with the interpolation, the accuracy of separation is determined by the resolution of the map and the pairs of latitudes each flash is compared with. For example there can be more than one set of latitude points for each longitude point. This will improve the accuracy of separation.

Once each flash in the area has been determined as striking land or water, the properties associated with that flash could also be categorized as land or water. The isolated storm days were then used with the time of flash as the data set to split the flash parameters between land and water. The following figure demonstrates the size of the SLC area and the accuracy of separating the flashes and their associated data. In Table 1, the parameters recorded for the storm days isolated in the SLC area are listed.

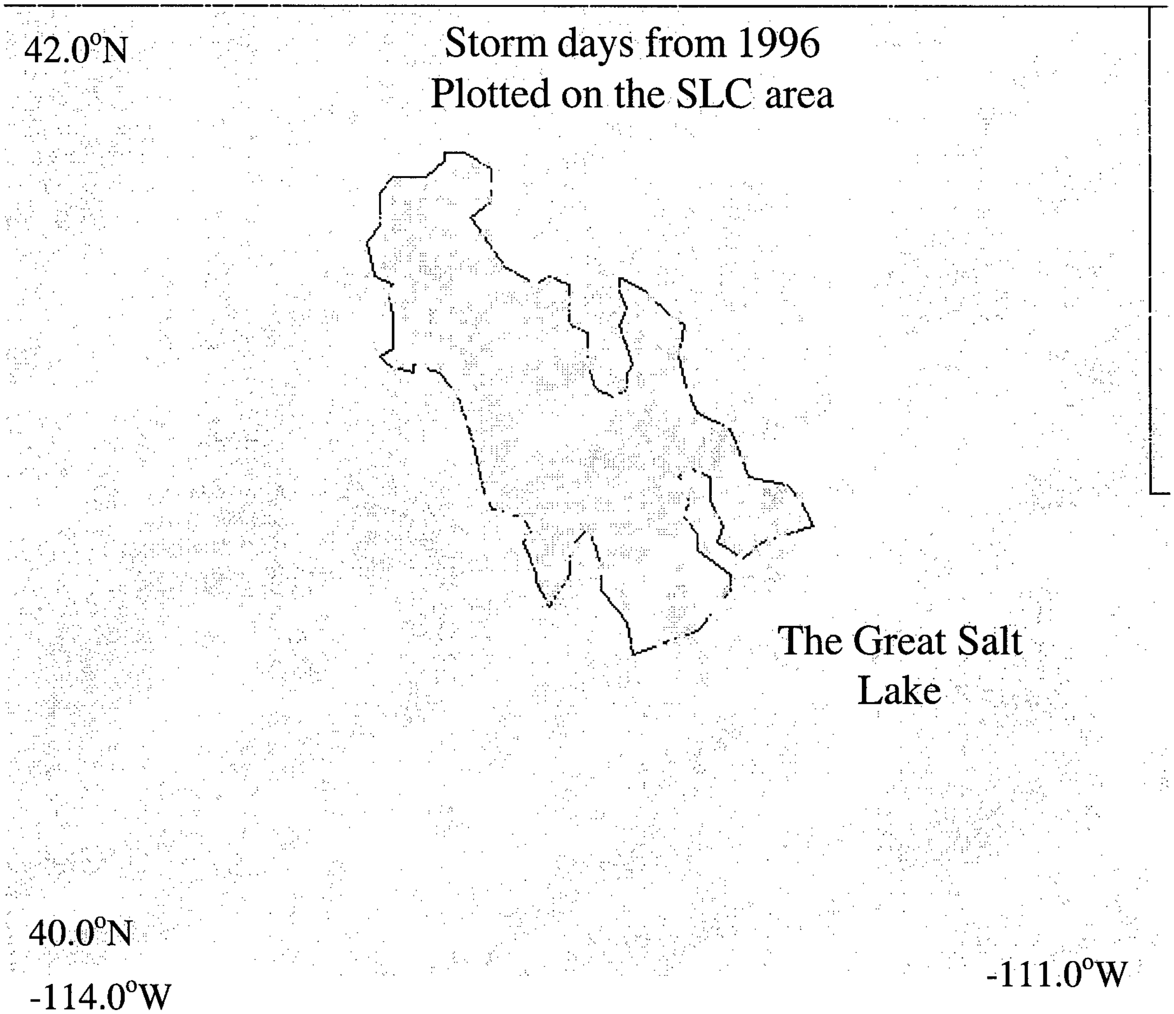

Figure 8. 1996 Storm days over SLC. This figure depicts the area used to separate flashes between land and water in the SLC area. The flashes that were determined as striking water are (*) and the flashes that were determined as striking land(.) show the accuracy of separation using the matrix method. Of the 54 days isolated for the SLC data, 9 days were recorded in 1996 and are depicted here.

Table 1. Storm day parameters. This table shows the parameters recorded for each storm day. The parameters recorded in columns labeled 'negative flash count' through 'positive multiplicity' were also recorded for land flashes.

Day	Month	Year	Total Flash Count	Total Flash Count over Land	Total Flash Count over Water	Negative Flash Count over Water	Maximum Peak Neagtive Current	Positive Flash Count over Water	Maximum Peak Positive Current	Negative Multiplicity	Positive Multiplicity
4	5	95	311	268	43	43	-38.52	0	0	1.372	0
5	5	95	932	755	177	162	-129.09	15	47.21	1.488	1.067
21	5	95	1046	739	307	305	-62.07	2	11.38	1.905	1
22	5	95	2721	2620	101	95	-55.94	6	25.25	1.558	1.5
31	5	95	83	82	1	0	0	1	14.02	0	1
1	6	95	1312	1261	51	50	-41.55	1	41.35	1.96	1
22	8	95	822	699	123	121	-79.03	1	16.78	2.033	1
23	8	95	1375	1335	40	40	-36.78	0	0	1.525	0
3	9	95	292	291	1	1	-16.19	0	0	1	0
4	9	95	6215	5704	511	496	-111.7	13	71.6	1.732	1.077
27	5	96	1213	1209	4	3	-31.69	1	73.74	1	1
8	6	96	866	848	18	18	-43.7	0	0	2.222	0
4	7	96	2427	2143	284	271	-58.31	12	77.2	1.804	1.083
16	7	96	3915	3444	471	403	-62.29	62	97.94	1.886	1.177
28	7	96	1508	1505	3	3	-45.38	0	0	1	0
29	7	96	365	365	0	0	0	0	0	0	0
1	8	96	2503	2229	274	271	-78.51	2	13.45	1.863	1
11	9	96	4	4	0	0	0	0	0	0	0
12	9	96	3328	3205	123	117	-66.25	6	40.27	2.103	1.167
9	6	97	911	900	11	7	-70.39	4	56.91	1.286	1
10	6	97	1415	1338	77	64	-49.28	13	66.36	1.406	1.308
11	6	97	1154	784	370	366	-67.91	1	10.62	2.03	1
12	6	97	3825	3549	276	259	-123.15	17	69.25	2.456	1.059
13	6	97	2549	2441	108	88	-46.53	20	63.46	1.659	1.1
14	6	97	725	724	1	1	-22.5	0	0	1	0
10	8	97	1828	1609	219	160	-56.52	58	60.81	1.756	1.034
11	8	97	1649	1258	391	381	-99.23	7	83.05	1.958	1.286
12	8	97	2840	2629	211	200	-143.73	10	41.35	2.87	1.1
17	8	97	2320	1823	497	481	-54.09	11	21.52	2.008	1
2	9	97	851	794	57	56	-45.55	1	15.34	2.696	1
5	9	97	1638	1345	293	288	-89	3	27.68	2.08	1
6	9	97	1385	1354	31	29	-47.42	2	50.26	1.931	1
7	9	97	2258	2110	148	140	-109.78	6	96.81	2.643	1
10	9	97	3899	3195	704	693	-91.24	5	17.58	2.54	1
11	9	97	5422	5292	130	130	-52.37	0	0	1.623	0
9	5	98	1466	1175	291	274	-193.18	17	244.61	2.142	1.235
10	5	98	1065	991	74	63	-109.59	11	114.92	1.54	1
12	6	98	728	695	33	26	-95.52	7	157.53	1.731	1.286
13	6	98	736	604	132	125	-108.28	7	63.75	1.864	1.286
10	7	98	1509	1435	74	71	-60.37	3	61.98	1.535	1
23	7	98	2042	1909	133	124	-72.15	9	51.99	1.573	1
24	7	98	1142	1049	93	91	-161.82	2	11.28	1.747	1.5
7	8	98	989	977	12	12	-22	0	0	1.083	0
8	8	98	3342	3013	329	320	-62.62	9	165.87	1.569	1
9	8	98	3256	2619	637	630	-73.24	7	21.55	1.902	1
10	8	98	2495	2242	253	249	-66.58	4	33.67	2.032	1
20	8	98	1758	1659	99	95	-135.94	4	31.45	1.958	1

These recorded items (Table 1) were further manipulated for the analysis. Averages were taken of the maximum peak negative and positive currents over different time frames. In this first separation of the water and land flash parameters the maximum daily peak positive and negative current were determined to examine the large amplitude flash characteristics in each area. The contours, along with the hourly analysis described in the next section, examine the median positive and negative current characteristics. The different time frames used to analyze all the parameters in Table 1 include all storm days in each area together; also, the storm days were broken down by year and by month. In addition average negative and positive multiplicities were found over water and land, and total positive and negative flash counts were found over land and water. These flash counts were used to find the percent of positive flashes respectively over water and land. The flash counts were also used to find the number of weak positive flashes (<10 kA). The percent of positive flashes was found to show the breakdown of the polarity in each area. Since positive flashes below 10 kA are not included in positive current analysis, the number of small amplitude flashes were found for each surface to see if one surface's results could be affected by a higher number of lost flashes. As mentioned above, the comparison of multiplicity may not be a worthwhile analysis.

In Table 2 an example of these average values is demonstrated using all 54 storm days from SLC. The same averages were found for the storm days isolated in the other four areas. Figures in Appendix B show the size of the other four areas and indicate how many storm days were isolated in each area. These storm days were analyzed in the same manner as depicted in Table 2.

Table 2. Storm day results. This table list the average values of the characteristics mentioned above for all 54 storm days examined in SLC. The same average characteristics were found for storm days from 1995, 1996, 1997, 1998, May (95-98), June (95-98), July (95-98), August (95-98), and September (95-98).

Total Count	Total Land Count	Total Water Count	
97444.00	87941.00	9503.00	
Avg Total/day	Avg Land Count/day	Avg Water Count/day	
1873.92	1691.17	182.75	
Avg Neg Max_I (land)	Avg Neg Max_I (water)	Avg Pos Max_I (land)	Avg Pos Max_I (water)
-136.78	-68.19	117.86	45.84
Avg Neg Mult (land)	Avg Neg Mult (water)	Avg Pos Mult (land)	Avg Pos Mult (water)
1.91	1.72	0.88	0.88
Percent Water Flashes	Percent Positive (land)	Percent Positive (water)	
9.12	5.15	7.44	
Flashes < 10 kA (water)	Flashes <10 kA (land)		
38.0	244.0		

3.3.4 Hourly Median Peak Current

The hourly positive and negative median peak current values were calculated for each storm day. These hourly current values, along with the hourly flash count, demonstrate the diurnal pattern, and are used in the comparison of active flash hours and corresponding peak current values over the four-year period. The median percent of positive flashes was also calculated per hour for all of the storm days (Fig 10). This adds to a better understanding of the diurnal pattern. The hourly values can be combined into daily averages and both can be compared to the contouring work and past research to detect if the water in each area affects the diurnal cycle.

In addition to using those comparisons to detect a change in the diurnal pattern, the hourly positive and negative median peak currents were recorded over water and over land (Fig 9). This hourly breakdown of median current was only done for days with more than 100 flashes over water. Of the 54 storm days isolated in the SLC area, 30 days had more 100 flashes over water. The number of days with more than 100 flashes over water for the other areas is listed in Appendix B. This allowed for direct comparison of the diurnal patterns over water and land in order to detect differences between land and water on an hourly time scale. Diurnal patterns change with latitude and topography, so it is important to look for changes between land and water uniquely in each area.

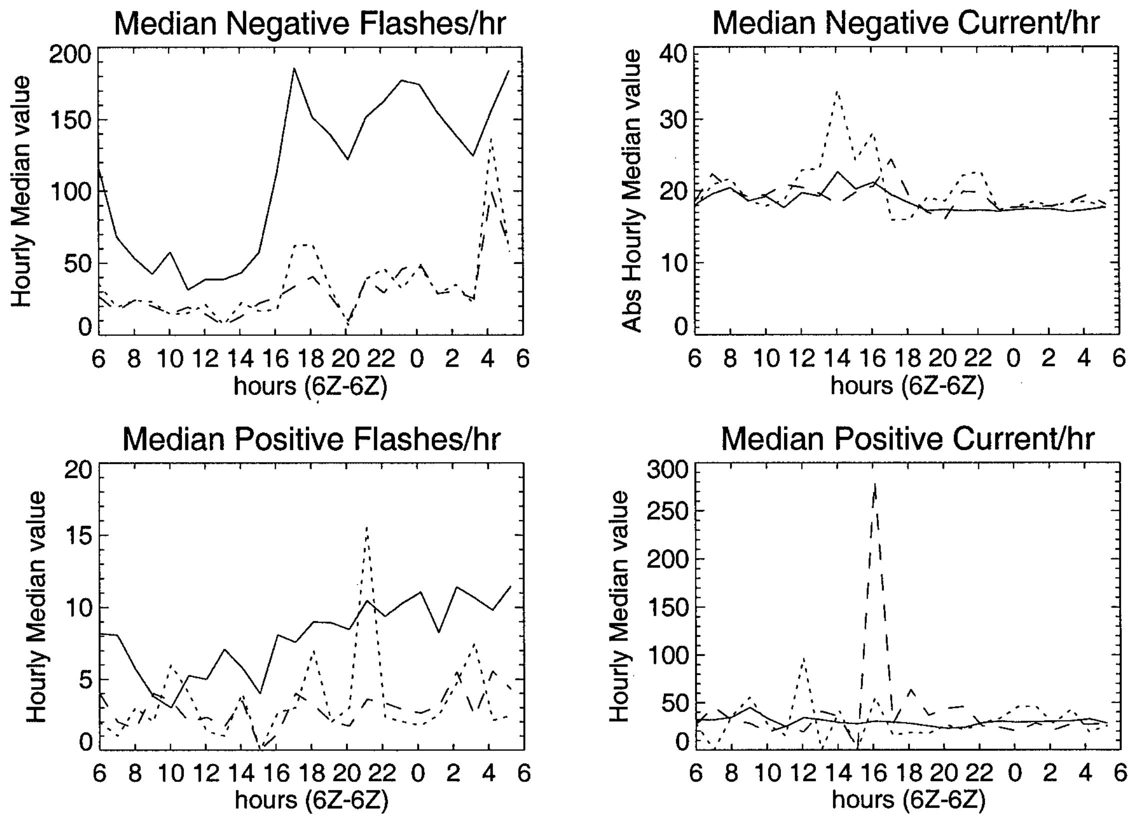

Figure 9. Median hourly analysis. This figure shows the hourly analysis for all 54 storm days in the SLC data set. The overall (solid line) hourly patterns superimposed over the water flashes (...) hourly pattern and the land flashes (---) hourly pattern.

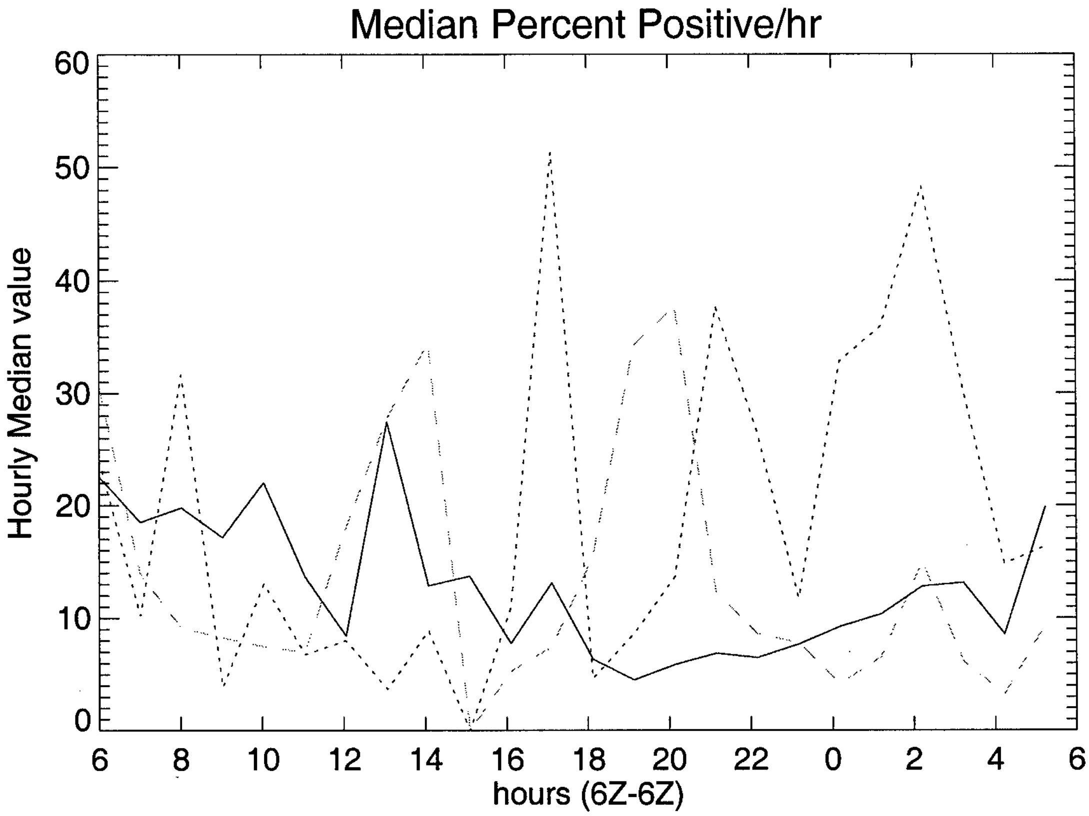

Figure 10. Hourly percent of positive flashes. This figure shows the median hourly values of the percent of positive flashes for all 54 storm days in the SLC data set. The overall pattern (solid line) is superimposed on the percent of positive flashes over water (…) and the percent of positive flashes over land (---).

3.3.5 Comparison of Peak Current Distribution

To detect a change in peak current distribution between land and water the peak currents were plotted to compare distribution of positive water and land flashes and negative water and land flashes. These histograms were examined for each year for the five areas. The amount of water and land in each area also needs to be considered in this method. Areas such as the Great Salt Lake Area will always have higher land flash counts. To account for this the graphs can be normalized to examine whether the distributions truly are the same. Figure 11 is an example of a peak current histogram, which demonstrates the distributions of land and water flashes' peak current. These histograms were normalized to determine if the distributions have different modes (Fig 12).

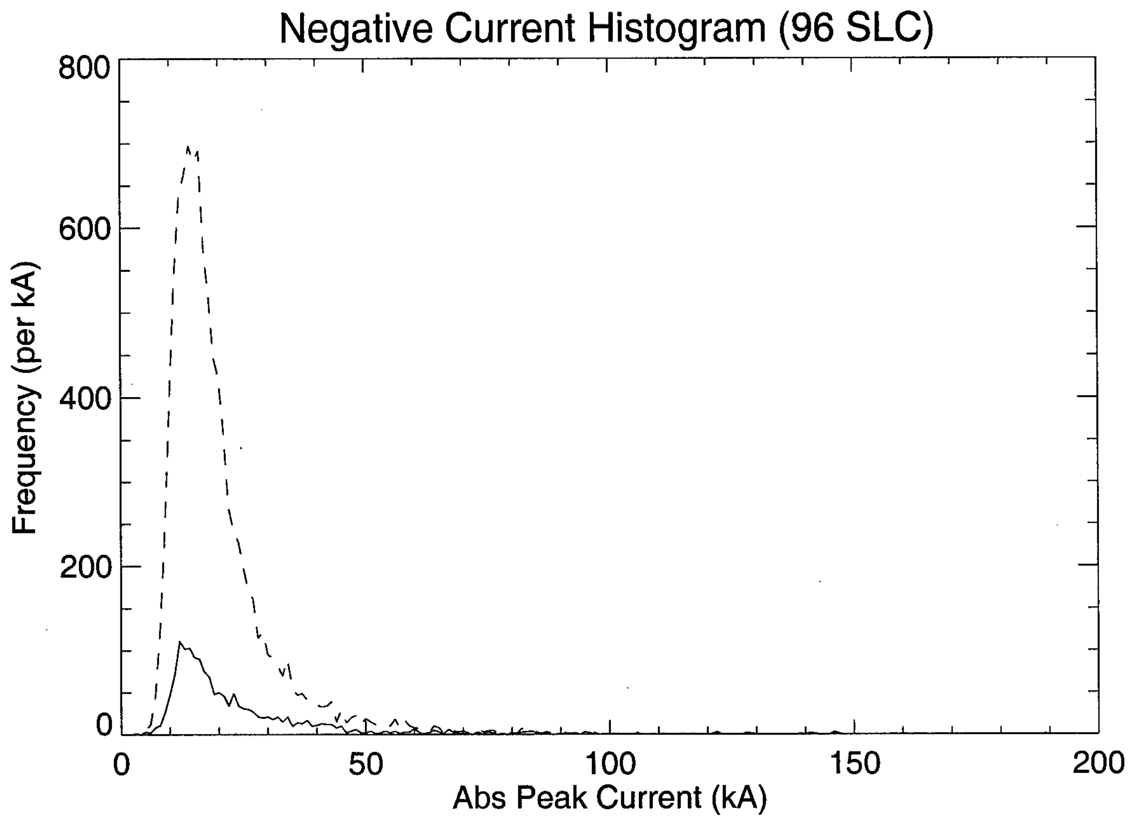

Figure 11. Peak current distribution. Histogram of the water (solid) and land (---) flashes negative peak current distribution for the Salt Lake City flash for 1996 (May-September). This figure gives the size and shape of the negative peak current distribution over land and water. These distributions indicate if the two distributions differ. The negative current distribution showed a skewed distribution over land and water.

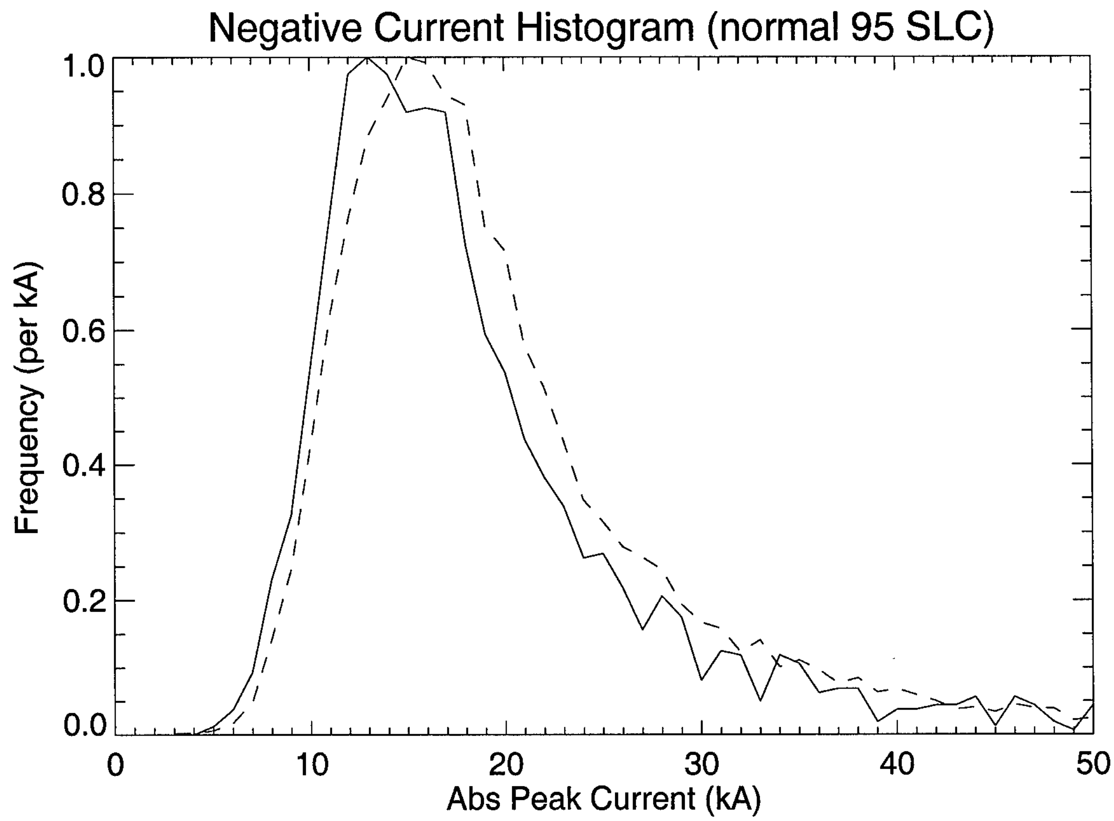

Figure 12. Normalized distribution. This is an example of the normalized distribution using data from May though September (1995) over the SLC area. The solid line is the negative peak current distribution of flashes over water and the (--) dashed line is the negative peak current distribution over land. The normalization allows the modes to be compared even when the quantity of peak currents in each distribution is different.

4. Results

4.1 Characteristics

The methodology section discussed the several ways the four years worth of data was examined to discover if differences exist in lightning characteristics or behavior over water and land. This section will summarize the characteristics examined and which characteristics displayed different values over land and water. The characteristics that did show differences are discussed further in this chapter.

Table 3. Observed differences. This table is a list of characteristics examined over land and water and indicates which characteristics showed differences between the two surfaces. The *italicized* items are not independent characteristics; they were examined to help explain differences seen in the other items listed.

Characteristics		Differences (Y/N)
Flash Density		Y
Median Flash Count	Positive and Negative	Y
Percent of Positive Flashes		Y
	Average Percent of Positive Flashes	Y
	Median Percent of Positive Flashes	Y
Percent of Flashes < 10 kA		Y
Multiplicity	Positive and Negative	N
Peak Current Distribution	Positive and Negative	Y
Median Peak Current	Positive and Negative	Y
Maximum Peak Current	Positive and Negative	Y

4.2 Flash Density

Flash density was examined through the contour data. The general trend was that flash density was higher over land than over water (Fig 15). The SLC flash density data did not show a clear difference between land and water; there were areas of higher flash density at the south end of the lake and around the southeast side of the lake (Fig 13). The Mobile Bay has the same flash density as the surrounding land, however the flash density values are lower in the Mobile Bay data then the other southern areas. Lake Okeechobee has an area of high flash density in the lake, which is one of the few exceptions in the southern locations to the trend of higher flash densities over land (Fig 14).

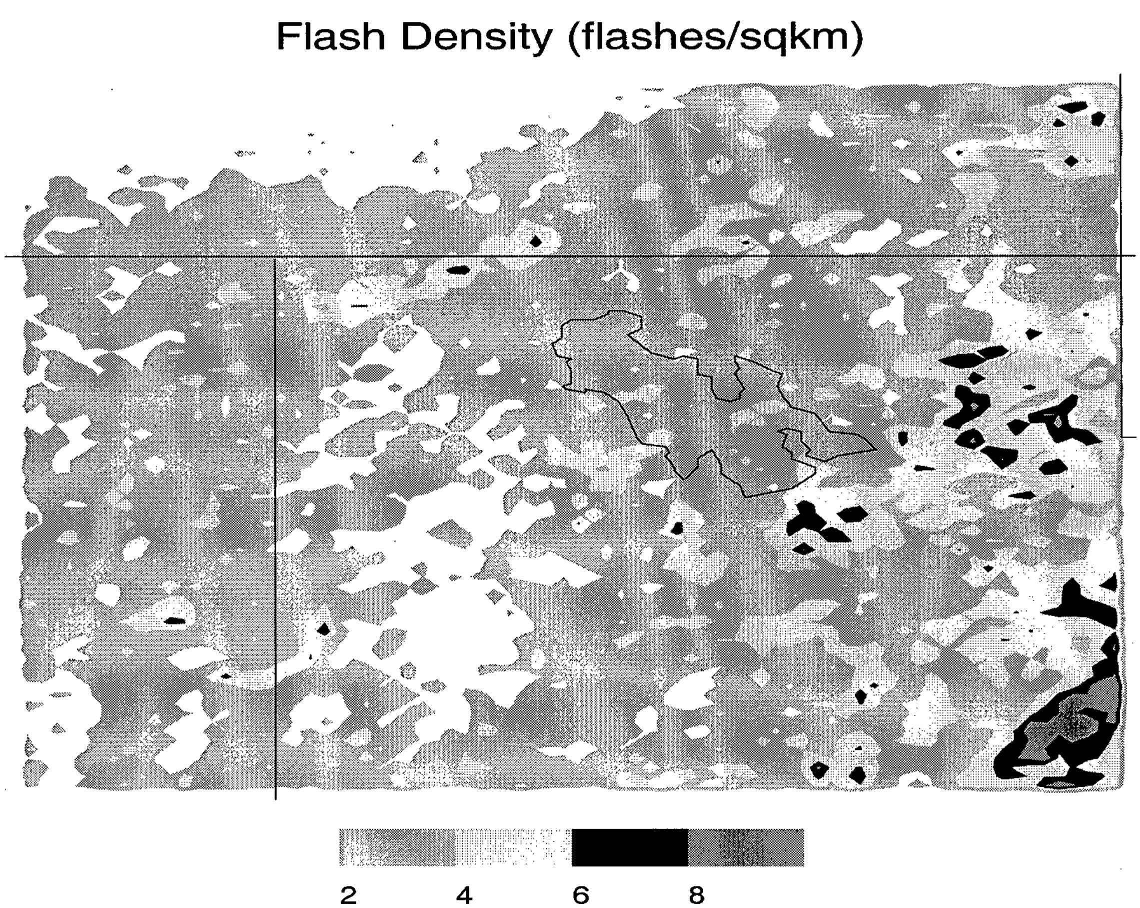

Figure 13. SLC flash density. This is a contour of the flash density in flashes per km^2.

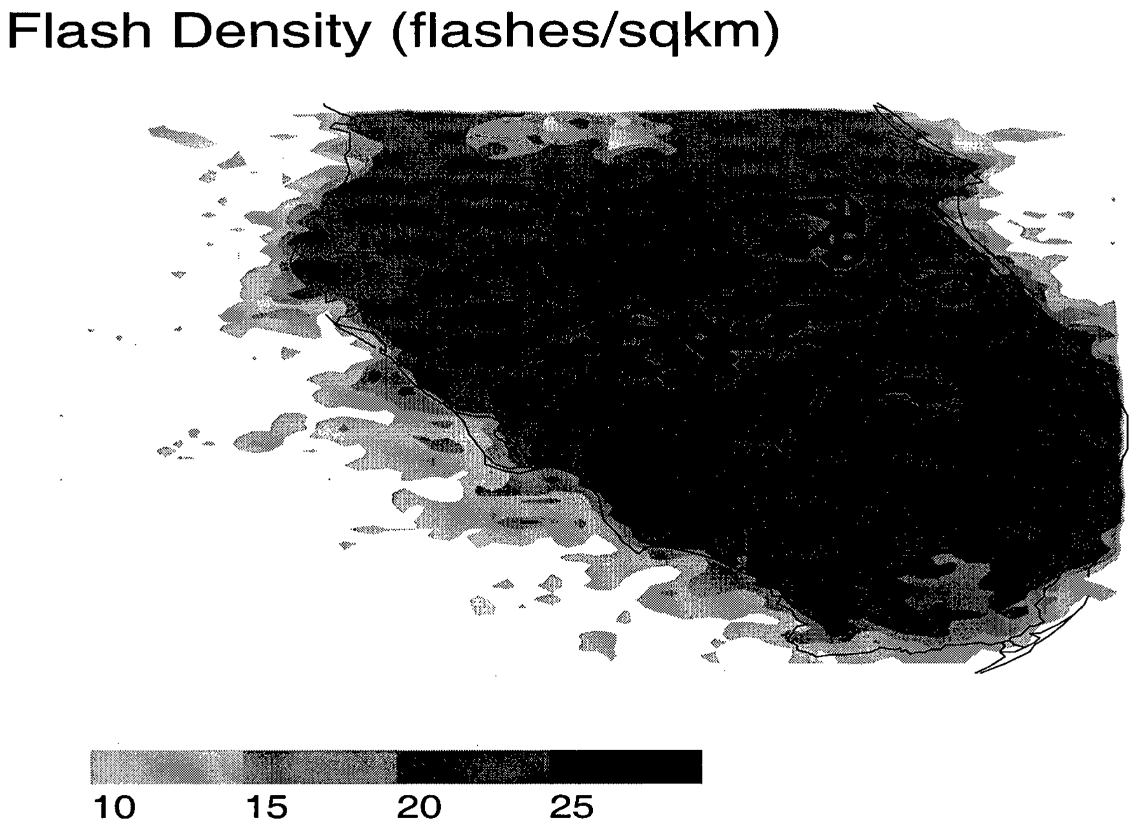

Figure 14. Flash density over Florida. The area of high flash density over Lake Okeechobee is one of the exceptions to the flash density being lower over water.

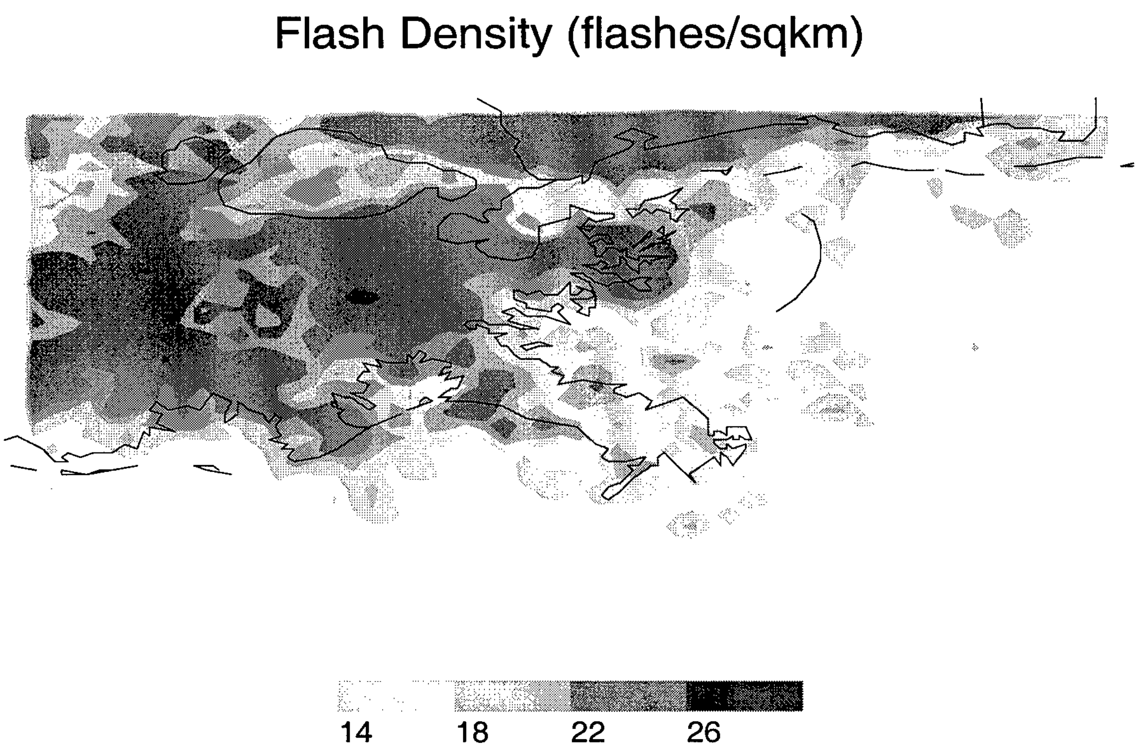

Figure 15. Flash density over the New Orleans area.

4.2.1 Flash Count

Flash count was examined in the hourly analysis of median values in conjunction with the hourly median peak current values. The median hourly flash count of negative and positive flashes over water and land were compared for differences. The following table summarizes the differences seen in the median hourly flash count.

Table 4. Negative flash count. This table indicates when there were differences in the negative flash count. 'Match' means the flash count over water and land agreed in time and value. *Water*, Land, or Neither indicates which surface had the overall higher flash count. 'No Match' means that even though on surface had a higher average value the flash count did not match on the hourly level.

Median Hourly Negative Flash Count	SLC	Mobile Bay	New Orleans	Lake Okeechobee	Lake Okeechobee (100 W. F.)	KSC
Overall	Match	Land (No Match)	*Water* (No Match)		Land	Neither (No Match)
May (95-98)	Match	*Water*	*Water* (No Match)		Land	*Water* (No Match)
June (95-98)	Match	*Water* (No Match)	*Water*		Land	*Water* (No Match)
July (95-98)	Match	Land (No Match)	Neither (No Match)		Land	Land (No Match)
August (95-98)	Match	Land (No Match)	Neither (No Match)		Land (No Match)	Land
September (95-98)	Match	Land (No Match)	*Water* (No Match)		Land	*Water*

The hourly values rarely matched in time. A daily average could be taken from the combination of the hourly median values, the daily averages showed less variation than the hourly values of median flash count. Tables 4 and 5 indicate which surface had the higher average flash counts and whether the hourly median values showed agreement or if the hourly median values did not match.

Table 5. Positive flash count. This table indicates when there were differences in the positive flash count. 'Match' means the flash count over water and land agreed in time and value. *Water*, Land, or Neither indicates which surface had the overall higher flash count. No match means that even though on surface had a higher average value the flash count did not match on the hourly level.

Median Hourly Flash Positive Count	SLC	Mobile Bay	New Orleans	Lake Okeechobee	Lake Okeechobee (100 W. F.)	KSC
Overall	*Water* (No Match)	*Water* (No Match)	*Water* (No Match)		Land	Neither (No Match)
May (95-98)	*Water* (No Match)	*Water* (No Match)	*Water* (No Match)		Land	Land (No Match)
June (95-98)	Neither (No Match)	Neither (No Match)	*Water*		Land (No Match)	Neither (No Match)
July (95-98)	*Water*	*Water* (No Match)	Neither (No Match)		Land	Land
August (95-98)	Land (No Match)	Land (No Match)	Neither		Land	Neither (No Match)
September (95-98)	Land (No Match)	Neither (No Match)	*Water*		Land	*Water* (No Match)

The hourly flash count was examined with hourly median current values (4.5.2). There were no distinct patterns in the hourly flash counts over water or land or any clear association between the two patterns. The amount of water flashes in each set did not seem to affect the connection between than land and water flash count pattern. For example, the water negative flash pattern matches the land negative flash pattern in the

SLC data even though no other data set with similar amount of water flashes shows a match.

4.3 Percent of Positive Flashes

The percent of positive flashes was examined in the yearly analysis, monthly analysis, and overall analysis of storm days and the hourly median analysis. A daily average was taken from the combination of the hourly median values. Table 6 indicates which surface had the higher average percent of positive flashes and whether the hourly median values of the percent of positive flashes over land and water matched in time.

Table 6. Median percent positive. This table indicates when there were differences in the percent of positive flashes over each surface. 'Match' means the percent of positive flashes over water and land agreed in time and value. *Water*, Land, or Neither indicates which surface had the overall higher percent of positive flashes. 'No match' means that even though one surface had a higher average value, the percent of positive flashes did not match on the hourly level.

Median Hourly Percent of Positive Flashes	SLC	Mobile Bay	New Orleans	Lake Okeechobee	Lake Okeechobee (100 W. F.)	KSC
Overall	*Water* (No Match)	Land (No Match)	Neither (No Match)		Neither (No Match)	Land (No Match)
May (95-98)	*Water* (No Match)	Land (No Match)	Water (No Match)		Neither (No Match)	Land (No Match)
June (95-98)	*Water* (No Match)	Land (No Match)	Neither (No Match)		Neither (No Match)	*Water*
July (95-98)	*Water*	Land	Land (No Match)		Land (No Match)	*Water* (No Match)
August (95-98)	Neither (No Match)	Land (No Match)	Land (No Match)		*Water*	Land
September (95-98)	Land (No Match)	Neither	*Water*		Neither (No Match)	Land (No Match)

The daily averages showed less variation in the percent of positive flashes over water versus land than the hourly median values of the percent of positive flashes over water versus land. There was rarely agreement between the percent of positive flashes over water and land on the hourly time scale. Some hours showed better agreement than others; for example, the percent of positive flashes over water and land showed better agreement around 22 UTC in the SLC data set. The daily average values of the percent of positive flashes ranged form 10 percent to 20 percent with outliers from 2 percent to 35 percent. Generally a difference was recorded if there was more than a 4 percent difference in overall values. The hourly values were determined not to match if there was not fairly good agreement in the hourly pattern between the two sets of percent of positive values. In addition to the daily and hourly variations, the median percent of positive flashes showed variation from month to month as well. Of interest are the changes that occur in August. Several characteristics change trends in August; for example water flashes have the higher percent of positive flashes in the SLC data until August and August is the only month that the Lake Okeechobee data has a surface with higher percent of positive flashes.

The percent of positive flashes were also compared between flashes over water and land using average values from the yearly analysis, monthly analysis, and the overall analysis of the storm days. The majority of the recorded values of average percent of positive flashes ranged from 4 percent to 8 percent with outliers to 2 percent and 20 percent. Any differences greater than 1 percent were recorded.

The fact that the SLC and Lake Okeechobee data sets show the most consistent result of water flashes having the highest percent of positive flashes seems to indicate that there may be an inverse relationship between the percent of water flashes and the percent of positive flashes over water. The SLC and Lake Okeechobee data set both have the lowest percent of water flashes and show the most consistent result of water having the highest percent of positive flashes. As seen in the median percent of positive flashes, there are several changes in trend or no differences in the month of August.

Table 7. Average percent of positive flashes. This table indicates when there were differences in the percent of positive flashes over each surface. *Water*, Land, or Neither indicates which surface had the overall higher percent of positive flashes. The (%) indicates the margin of difference between the percent of positive flashes over land versus water

Average Percent of Positive Flashes	SLC	Mobile Bay	New Orleans	Lake Okeechobee	Lake Okeechobee (100 W. F.)	KSC
Overall	*Water* (2 %)	Neither	Neither	*Water* (2 %)	Neither	Neither
1995	*Water* (7 %)	Neither	Neither	Neither	Land (1 %)	*Water* (1 %)
1996	*Water* (2 %)	*Water* (1 %)	Neither	*Water* (2 %)	Neither	Neither
1997	*Water* (1.5 %)	Neither	Neither	*Water* (1 %)	Neither	Neither
1998	Neither	Neither	*Water* (1 %)	*Water* (3 %)	Neither	Neither
May (95-98)	*Water* (11%)	Land (3 %)	*Water* (2 %)	*Water* (2 %)	Neither	Neither
June (95-98)	*Water* (4 %)	Neither	*Water* (2 %)	*Water* (2 %)	Neither	*Water* (1 %)
July (95-98)	*Water* (1 %)	*Water* (1 %)	Neither	*Water* (1 %)	Neither	Neither
August (95-98)	Land (1 %)	Neither	Neither	Neither	Neither	Neither
September (95-98)	Neither	*Water* (1 %)	*Water* (1 %)	*Water* (6 %)	Neither	Neither

4.3.1 Percent of Flashes < 10 kA

The percent of flashes less than 10 kA was found to determine if one surface had more small amplitude positive flashes than the other. The percents were found to help explain any detected differences in the other characteristics examined, such as the percent of positive flashes or median current. If there were more flashes < 10 kA over water versus land it could affect the percent of positive flashes or the median current calculations.

Table 8. Percent of flashes < 10 kA. This table indicates when there were differences in the percent of flashes < 10 kA over each surface. *Water*, Land, or Neither indicates which surface had the overall higher percent o flashes < 10 kA. The (%) indicates the margin of difference between the percent of flashes < 10 kA over land versus water.

Percent of flashes < 10 kA	SLC	Mobile Bay	New Orleans	Lake Okeechobee	Lake Okeechobee (100 W. F.)	KSC
Overall	Neither	*Water* (2 %)	Land (3 %)	*Water* (3 %)	*Water* (3 %)	Land (2 %)
1995	Neither	Neither	Neither	*Water* (3 %)	*Water* (1 %)	Land (2 %)
1996	Neither	Neither	Land (3 %)	*Water* (4 %)	*Water* (2 %)	Land (2 %)
1997	Neither	*Water* (2 %)	Land (2 %)	*Water* (2 %)	*Water* (2 %)	Land (2 %)
1998	Neither	*Water* (2 %)	Land (3 %)	*Water* (4 %)	*Water* (2 %)	Land (2 %)
May (95-98)	Neither	*Water* (1 %)	Land (2 %)	*Water* (3 %)	*Water* (3 %)	Land (4 %)
June (95-98)	Neither	Neither	Land (4 %)	*Water* (4 %)	*Water* (3 %)	Neither
July (95-98)	Neither	Neither	Land (4 %)	*Water* (2 %)	Neither	Land (5 %)
August (95-98)	Neither	*Water* (1 %)	Land (2 %)	*Water* (5 %)	*Water* (2 %)	Land (3 %)
September (95-98)	Neither	*Water* (1 %)	*Water* (3 %)	*Water* (2 %)	*Water* (1 %)	Land (3 %)

The percent of flashes < 10 kA was always less than 1percent in the SLC data. The percent of flashes < 10 kA ranged form 2 percent to 12 percent in the other areas. A smaller margin of difference usually correlated to smaller percent values, so all differences greater than 1 percent were recorded. The percent of flashes < 10 kA may be used to explain some results in specific areas but did explain any overall trends.

4.4 Multiplicity

Multiplicity of positive and negative flashes was examined in the yearly analysis, monthly analysis, and overall analysis of the storm days. No appreciable differences were observed between the multiplicity data over land versus water. The multiplicity values for negative flashes ranged from 2.3 percent to 2.9 percent in all areas except SLC were they ranged from 1.3 percent to 1.9 percent. The multiplicity values for positive flashes ranged from 0.95 percent to 1.13 percent and were a little lower over SLC and the complete Lake Okeechobee data set.

4.5 Peak Current

4.5.1 Peak Current Distribution

The peak current distributions of negative and positive flashes were compared over land and water. The negative peak currents usually had a right skewed distribution (Fig 6). The positive peak currents had more chaotic patterns; there was a right skew tendency but the shape was often more uniform than skewed. The chaotic patterns of the positive peak current distributions often made it impossible to determine if the distributions over water and land were different. After the distributions were normalized it could be determined which surface had the higher distribution mode for positive and negative peak currents. The variation in results from year to year cannot be explained by any large scale weather phenomenon and indicate that there is no consistent difference between distribution of peak current over water and land.

Table 9. Peak current distribution for positive flashes. This table indicates which surface had the higher mode in peak current distribution for positive flashes. 'Mixed results' indicates that although Land, *Water*, or Neither surface had the highest mode that the distributions did not have defined shapes. 'Match' indicates that the two modes were located in the same position.

Peak Current Distribution for Positive Flashes	SLC	Mobile Bay	New Orleans	Lake Okeechobee	Lake Okeechobee (100 W. F.)	KSC
1995	Neither (Mixed Results)	*Water*	*Water*	*Water*		Land
1996	Land (Mixed Results)	*Water*	*Water*	Land		Match
1997	*Water* (Mixed Results)	*Water* (Mixed results)	Match	Land		Match
1998	*Water* (Mixed Results)	*Water* (Mixed Results)	Match	Land		Match

Table 10. Peak current distribution for negative flashes. This table indicates which surface had the highest mode in the peak current distribution for negative flashes. 'Match' indicates that the two modes were located in the same position.

Peak Current Distribution for Negative Flashes	SLC	Mobile Bay	New Orleans	Lake Okeechobee	Lake Okeechobee (100 W. F.)	KSC
1995	Land	Match	Land	Land		Match
1996	Land	Land	*Water*	Land		*Water*
1997	Land	Match	Match	Land		Match
1998	Match	Match	Match	Land		Land

4.5.2 Median Peak Current

Median peak currents were examined in the median hourly analysis and the contour analysis. The southern areas contour analysis of median peak current showed an inverse relationship to flash density. The overall trend in the southern contour data was increasing median peak currents offshore and higher flash densities onshore. The positive median peak currents (Fig 16) showed a strong inverse relationship to flash density (Fig 15). The negative median peak currents increased offshore (Fig 17) but there were a few small areas of moderate flash density (Fig 14) with overlapping high median negative peak current values. The SLC contour data had a different relationship; the contours of higher median positive peak current matched with the areas of higher flash density at the south and southeast end of the lake. The higher median negative peak current values appeared at the north end of the Salt Lake (Fig 7) where flash density was low (Fig 13).

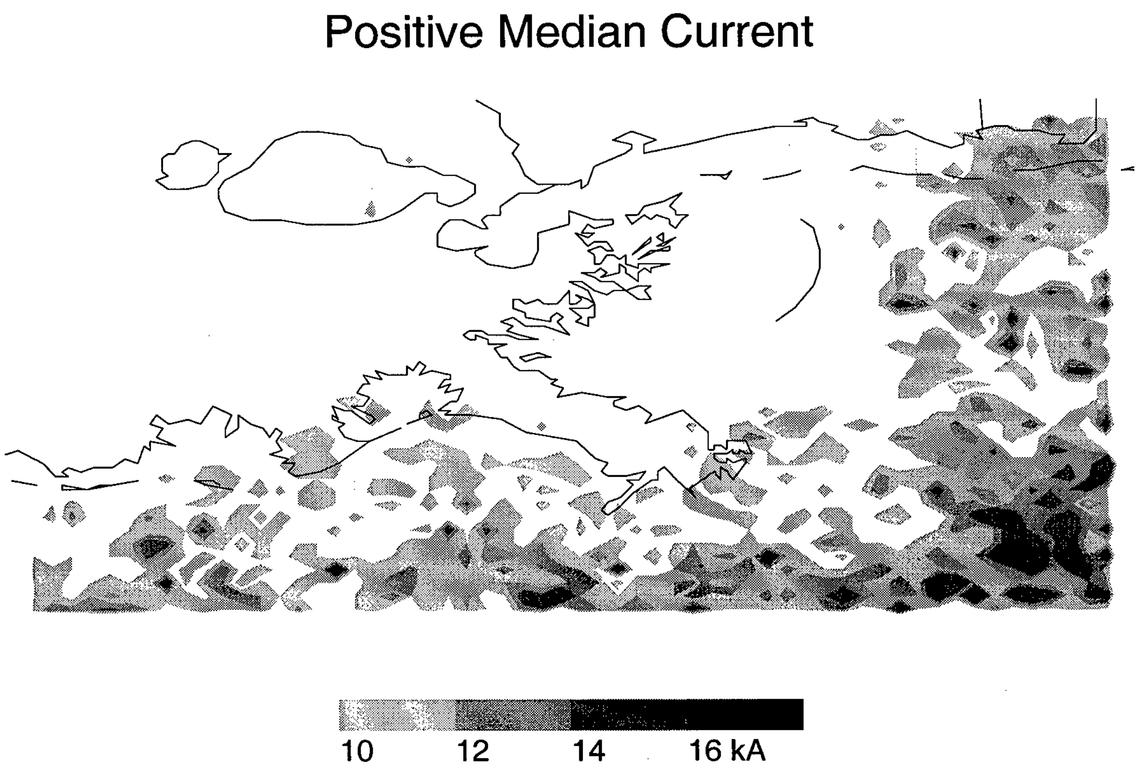

Figure 16. Positive median peak current around New Orleans.

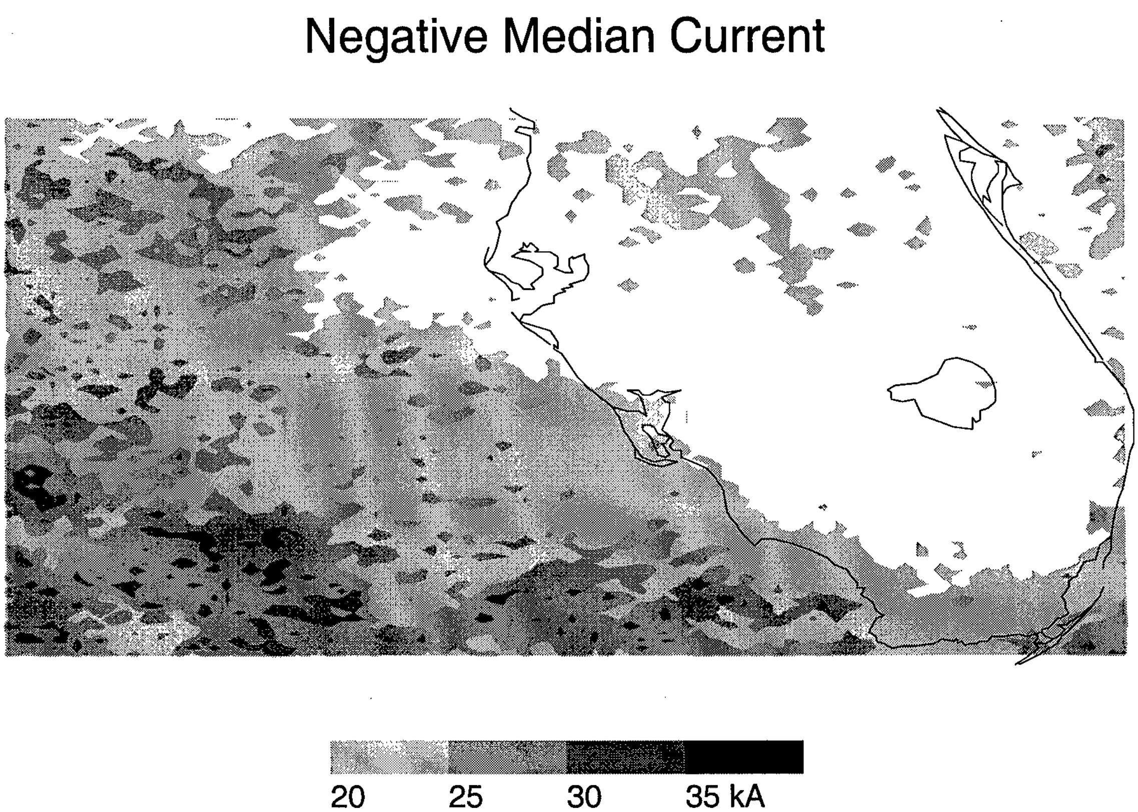

Figure 17. Negative median peak current around Florida.

The median peak current values examined in the hourly analysis did not show such a distinct difference in median peak current between land and water as the contour data demonstrated. The hourly median peak currents were examined along with the hourly median flash counts to see if an increase in median current simply correlated to an increase in flash count. The hourly flash counts also helped determine if observed hourly differences in median peak current over land and water had a consistent pattern that could be explained by storm tracks or diurnal forcing. Median peak current did not always increase or decrease with more or less flashes nor did a consistent relationship between the two factors appear. The hourly analysis did show when water influences the diurnal pattern but there was not a consistent diurnal pattern in the positive or negative peak current pattern. Some data did show a preference for having high median current values at certain hours. For example, there was often high median negative peak current values around 12 UTC in the SLC data and the Mobile Bay data showed a preference for high positive median peak current values around 10 UTC.

A daily average was taken of the hourly median values to determine which surface had an overall higher median peak current value. The hourly median values and daily averages were examined over the five summer months and showed variation from month to month. Tables 11 and 12 indicate which surface had the higher daily average values of median peak current and indicate whether or not the hourly median current patterns over land and water matched well. Since there was so much variation in the hourly values the overall 24 hr pattern was compared over water versus land instead of breaking down the results to each hour.

Table 11. Median peak negative current. This table indicates when there were differences in the median negative peak current. 'Match' means the median peak negative current over water and land agreed in time and value. *Water*, Land, or Neither indicates which surface had the overall higher values. 'No match' means that even though one surface had a higher average value, the median peak negative current did not match on the hourly level.

Median Hourly Negative Peak Current	SLC	Mobile Bay	New Orleans	Lake Okeechobee	Lake Okeechobee (100 W. F.)	KSC
Overall	*Water* (No Match)	Neither (No Match)	*Water*		Neither	*Water*
May (95-98)	Neither (No Match)	*Water* (No Match)	Neither		Land (No Match)	*Water*
June (95-98)	Neither (No Match)	*Water* (No Match)	*Water*		Land	*Water* (No Match)
July (95-98)	Neither (No Match)	*Water* (No Match)	*Water* (No Match)		Land	*Water* (No Match)
August (95-98)	Match	*Water* (No Match)	*Water*		Land	*Water*
September (95-98)	*Water*	Neither	*Water*		Land	Neither

The change from month to month is not completing explained by this chart. The hours of higher flash activity and higher median peak current values also shifted from month to month. For example, the hours of higher flash activity and higher median current in the Mobile Bay data shifted from 2 UTC in May to 12 UTC in September. The amount of flash activity and magnitude of median peak current values would also vary from month to month.

Table 12. Median peak positive current. This table indicates when there were differences in the median peak positive current. 'Match' means the median peak positive current over water and land agreed in time and value. *Water*, Land, or Neither indicates which surface had the overall higher values. 'No match' means that even though one surface had a higher average value, the median peak positive current did not match on the hourly level.

Median Hourly Positive Peak Current	SLC	Mobile Bay	New Orleans	Lake Okeechobee	Lake Okeechobee (100 W. F.)	KSC
Overall	Land (No Match)	Neither (No Match)	Neither (No Match)		Land (No Match)	*Water* (No Match)
May (95-98)	Neither (No Match)	Land (No Match)	Neither (No Match)		Land (No Match)	*Water* (No Match)
June (95-98)	*Water* (No Match)	Neither (No Match)	Neither (No Match)		Land	*Water* (No Match)
July (95-98)	*Water* (No Match)	*Water*	*Water*		Land	*Water* (No Match)
August (95-98)	Land (No Match)	*Water*	Neither (No Match)		Land (No Match)	*Water* (No Match)
September (95-98)	*Water* (No Match)	Neither	*Water*		Land	*Water* (No Match)

4.5.3 Maximum Peak Current

Maximum peak currents were found for positive and negative flashes in the yearly analysis, monthly analysis, and overall analysis of the storm days. Several of the differences in maximum peak current are large enough and consistent enough to be considered conclusive, but they may not be due to the change in underlying surface.

Maximum peak current also showed monthly variation like percent positive and there was often a change in trend or no differences in August.

Table 13. Maximum negative peak current. This table indicates when there were differences in the average maximum peak negative current. *Water*, Land, or Neither indicates which surface had the overall higher values. The (kA) indicates the margin of difference in absolute value between the average maximum peak negative current over land versus water

Avg. Max Negative Peak Current	SLC	Mobile Bay	New Orleans	Lake Okeechobee	Lake Okeechobee (100 W. F.)	KSC
Overall	Land (68 kA)	Neither	*Water* (33 kA)	Land (51 kA)	Land (34 kA)	*Water* (12 kA)
1995	Land (50 kA)	*Water* (17 kA)	*Water* (40 kA)	Land (50 kA)	Land (36 kA)	*Water* (23 kA)
1996	Land (72 kA)	*Water* (14 kA)	*Water* (29 kA)	Land (59 kA)	Land (41 kA)	*Water* (16 kA)
1997	Land (87 kA)	Neither	*Water* (23 kA)	Land (50 kA)	Land (25 kA)	Neither
1998	Land (63 kA)	Neither	*Water* (51 kA)	Land (48 kA)	Land (35 kA)	*Water* (15 kA)
May (95-98)	Land (66 kA)	*Water* (41 kA)	*Water* (15 kA)	Land (48 kA)	Land (26 kA)	*Water* (26 kA)
June (95-98)	Land (93 kA)	*Water* (13 kA)	Water (44 kA)	Land (40 kA)	Land (30 kA)	Neither
July (95-98)	Land (55 kA)	Neither	*Water* (39 kA)	Land (54 kA)	Land (42 kA)	Neither
August (95-98)	Land (59 kA)	Neither	Water (22 kA)	Land (52 kA)	Land (26 kA)	Neither
September (95-98)	Land (73 kA)	*Water* (38 kA)	*Water* (62 kA)	Land (66 kA)	Land (39 kA)	*Water* (45 kA)

The values of average maximum peak negative current ranged from -55.0 kA to –160.0 kA in the SLC data and from -101.0 kA to –211.0 kA in the other data sets. Margins of difference greater than 10 kA were recorded here. Statistics were not run on this data, but it will probably take a larger margin of differences to show significant difference in this characteristics. It is likely that several of the differences above can be shown to be statistically different however the difference in the maximum peak current values may not be solely due to the change in underlying surface.

Table 14. Maximum positive peak current. This table indicates when there were differences in the average maximum peak positive current. *Water*, Land, or Neither indicates which surface had the overall higher values. The (kA) indicates the margin of difference in absolute value between the average maximum peak positive current over land versus water

Avg. Max Negative Peak Positive Current	SLC	Mobile Bay	New Orleans	Lake Okeechobee	Lake Okeechobee (100 W. F.)	KSC
Overall	Land (72 kA)	Neither	Neither	Land (40 kA)	Land (35 kA)	Neither
1995	Land (73 kA)	*Water* (10 kA)	*Water* (13 kA)	Land (36 kA)	Land (26 kA)	Neither
1996	Land (64 kA)	Land (14 kA)	Neither	Land (50 kA)	Land (43 kA)	Neither
1997	Land (81 kA)	Neither	Neither	Land (36 kA)	Land (31 kA)	Neither
1998	Land (72 kA)	Land (23 kA)	*Water* (16 kA)	Land (39 kA)	Land (39 kA)	Neither
May (95-98)	Land (67 kA)	Neither	Neither	Land (34 kA)	Land (23 kA)	*Water* (18 kA)
June (95-98)	Land (94 kA)	Neither	*Water* (20 kA)	Land (39 kA)	Land (39 kA)	Neither
July (95-98)	Land (48 kA)	Land (18 kA)	Neither	Land (41 kA)	Land (42 kA)	Neither
August (95-98)	Land (80 kA)	Neither	Neither	Land (42 kA)	Land (34 kA)	Land (20 kA)
September (95-98)	Land (61 kA)	Land (13 kA)	Neither	Land (37 kA)	Land (22 kA)	*Water* (17 kA)

Similar to the maximum peak negative current, only margins of difference more than 10 kA were recorded. The KSC data supports the change of trends during August; all of the KSC data sets indicated that water flashes had higher maximum positive peak currents. They were not recorded due to the fact that the margin of difference was less than 10 kA, but August was the only month that land had the higher maximum positive peak current.

4.6 Accuracy

Due to the preliminary nature of this research it is important to focus on the reality of the results rather than on the application of statistical analysis. If statistical analysis is applied to these results in future work it should be noted that the assumption of normality with sample sizes greater than 30 may not be accurate. The purpose of this study is to find a difference in the parameters recorded by the NLDN between land and water. In an effort to find realistic differences, the parameters were sampled in a variety of ways in several areas. As mentioned in the previous chapters the data cannot be combined but the results can be compared to see if the observed differences between land and water are actually due to the change in the underlying surface. For example, the average maximum negative current is consistently higher over land in the SLC area. However, when compared to the other areas that have almost equal numbers of flashes over water and land, the maximum negative current over land is not always greater and the margin of difference is smaller. The same data has been run through the same analysis and produced the same results. Therefore the only change in the conclusions would occur if the parameters or data sets changed.

4.7 Significance

The data subsets were instrumental in determining the significance of the observed results. The observed results should be seen when other conditions, such as flash count, vary. Therefore, all results must be carefully examined to make sure any variation can be explained or if the variation in observed results indicates no preference between land and water in that parameter.

5. Conclusions

5.1 Characteristics

The results from the every characteristic analysis showed variation between areas. Several characteristics showed variation overtime within each area. For every trend that started to develop in the characteristics, exceptions were found. If a relationship started to develop between characteristics to explain the observed results, an exception were be found in another areas data or in a data subset. Therefore the change in underlying surface from water to land did not produce a consistent change in the lightning characteristics or behavior.

Despite the overall variation in the results some characteristics showed differences between land and water within one area. These differences will be summarized below along with a discussion of what may be causing the results. Some of the detected changes cannot be solely attributed to the change in underlying surface type. Some characteristics results appear to be directly affected by the underlying water surface. Some examples of results influenced by water will be discussed in Section 5.2.

5.1.1 Flash Density

The results had the overall trend of higher flash densities onshore. There were exceptions to this trend over the Great Salt Lake and Lake Okeechobee. The low flash densities in the Gulf of Mexico and Atlantic Ocean may be partly explained by the lack of NLDN sensors over water. The results over the Salt Lake may also be affected by the sensor placement in the NLDN. The south end of the lake is an area where lightning strokes need to travel shorter distances to the required sensors to be recorded; this may be part of the explanation for the higher flash density there. There also appeared to be an inverse relation between flash density and the median current in the four southern areas; the SLC data was an exception to this trend as well.

5.1.2 Percent of Positive Flashes

The SLC and Lake Okeechobee data started showing a relationship between small percents of water flashes in the data set and water flashes having the greater percent of positive flashes. SLC and Lake Okeechobee both had roughly 11 percent water flashes in their data and both SLC and Lake Okeechobee showed greater percent of positive flashes over water. There were exceptions to this trend in the New Orleans and KSC data. New Orleans and KSC had around 50 percent water flashes in their data and often had higher percent of positive flashes over water.

The greatest percent of positive flashes in the SLC data was in May (95-98), most of the flashes in May (95-98) are located at the north end of the lake. Flashes in the north area had to travel longer distances to be recorded by the NLDN. Positive flashes observed in this study had higher median peak current values than negative flashes; therefore more negative flashes than positive flashes would be attenuated across the longer distances to the required sensors.

5.1.3 Peak Current

The median currents examined in the contour data showed an overall trend to increase offshore in the southern areas. The Lake Okeechobee data did have one area of high negative median peak current over water. The SLC contour data revealed the higher positive peak currents were co-located with the higher flash densities around the south end of the lake and the higher median peak currents were at the north end of the lake.

The lack of NLDN sensors over water in the Gulf of Mexico and Atlantic Ocean may account for the increase in median current offshore. These differences may not appear again if more sensors were placed out in the water; although, the water depth increases at about the same place the higher median currents are observed. The change in water depth may influence the median current but cannot be certified until sensors are placed out in the water

The median currents examined in the hourly analysis did not indicate such clear differences between water and land. There was not a clear relationship between flash count and median current nor were there any consistent diurnal patterns. A few of the areas consistently had high median current values at certain hours often regardless of flash count.

The differences observed in the maximum peak current cannot be explained by the change in underlying surface type. The differences in the maximum peak current in the SLC data could indicate that storms do not reach maturity over the lake; this occurrence may not be do to the underlying surface but still indicates that the strength of the flashes is lower over the lake

The percent of water flashes seemed to affect the margin of difference between maximum peak current over water and land. As the percent of water flashes increased the margin of difference decreased, this indicates that if the body of water is large enough flashes will be encountered with maximum peak current values equal to land.

The results from the peak current distribution analysis did indicate that there were differences between peak current distributions over land versus water; however the differences varied and did not consistently show one surface type as having the same mode and distribution.

5.2 Results Influenced by Water

Water did affect specific recorded characteristics and behavior. This was seen in the positive contour around New Orleans, the monthly variations, the diurnal pattern in the Mobile Bay data, and the change in hourly median current when there was a match in the flash count pattern over water and land.

The positive median peak current is contoured around the New Orleans in Figure 16, the median positive peak currents increase offshore in general but there are no high median positive peak current contours right in the Mississippi delta area. This indicates that the flux off fresh water affects the median current differently than salt water.

When parameters were examined by month there was often a change in trend or no observable differences in the month of August (95-98). This indicates that the change in water temperature and salinity may affect the characteristics. No other factors change in a monthly fashion enough to affect the characteristics like the change water temperature. The water temperature increases from May to August. Land and water temperatures should be the most comparable in August, which may account for several characteristics showing no differences in August.

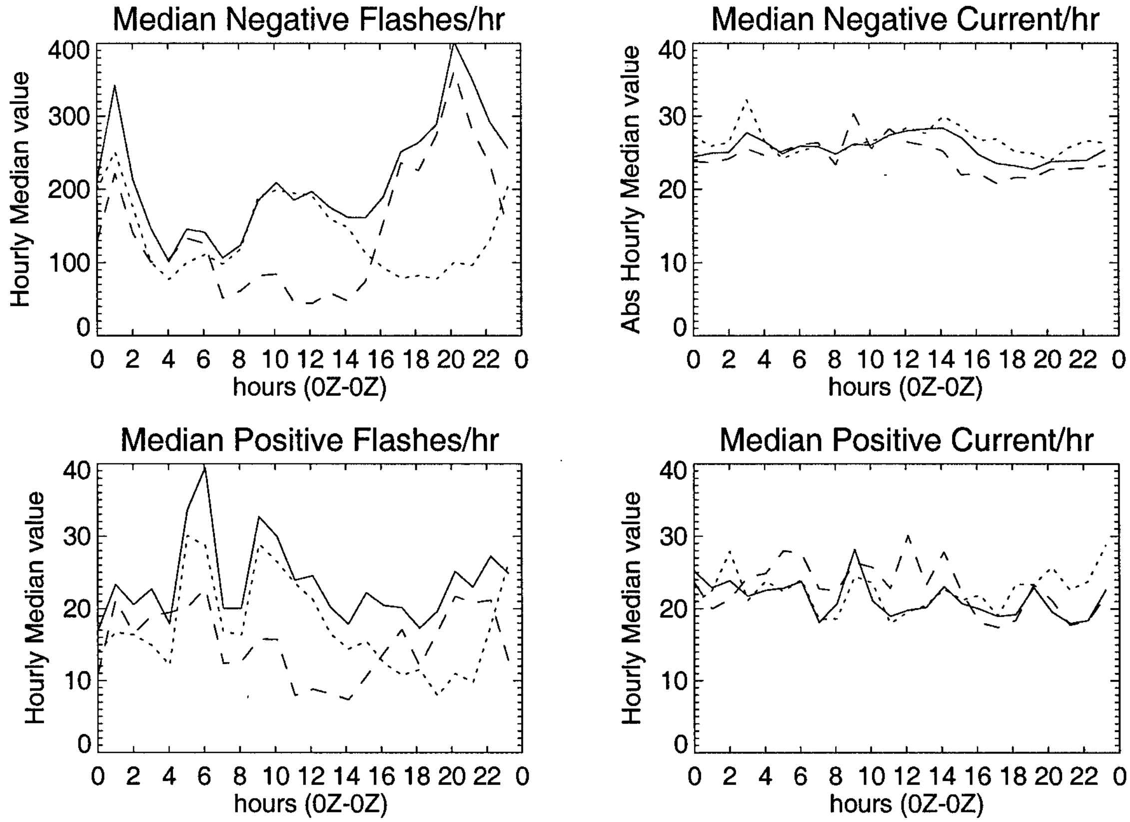

Figure 18. Median hourly analysis for Mobile Bay. This figure shows the hourly analysis for all storm days in the Mobile Bay data set. The overall (solid line) hourly patterns superimposed over the water flashes (...) hourly pattern and the land flashes (---) hourly pattern.

The diurnal pattern in the Mobile Data demonstrates water's influence on the flash count and median current. Water flashes dominate the values recorded around 10 UTC. This daily maximum shows how the water surface affects the diurnal pattern.

Figure 19 shows a match between negative flash count over water and over land but the median negative currents do not match. This indicates that the change in underlying surface type does affect the median current. All things in this data set appear to be the same except for the change in underlying surface.

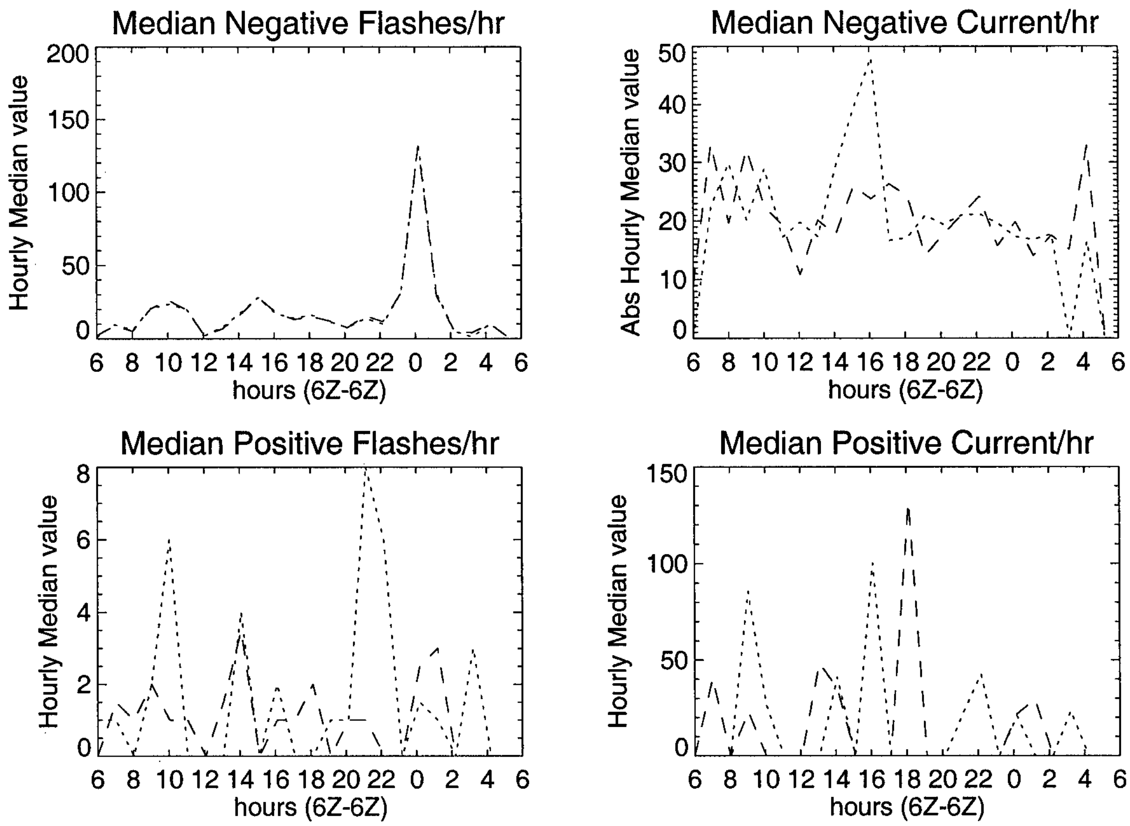

Figure 19. Median hourly analysis for SLC. This figure shows the hourly analysis for all storm days in the SLC data set May (95-98). The overall (solid line) hourly patterns superimposed over the water flashes (...) hourly pattern and the land flashes (---) hourly pattern.

In conclusion, the change in underlying surface did not produce consistent change in lightning characteristics or behavior. Water did affect the characteristics and behavior of lightning in specific cases. Overall it cannot be said whether Air Force operations would be safer over land or water while operating in the vicinity of lightning.

5.3 Recommendations for Further Research

There are two recommendations for further work on answering the question of whether or not lightning is different over land and water. One type of analysis was started during this research, but due to time, was not completed for all areas. It involved using the hourly median current values and visual plotting to track storms as they travel from land to water and back to land. This analysis was completed on the SLC area data and indicated a decrease in negative median current values as storms passed from water to land. The results for positive median current were not as clear but tended to decrease as the storms moved from water to land. This type of analysis showed monthly variations as well but it would be easier to tell if the storm moved into an area were sensor placement would affect the results. Also if the same results were observed in storms that moved toward and away from required sensors then it would help prove that those differences were due to the underlying surface.

Another way to examine the difference in lightning between land and water would be to get more data, optimally from a network that had lightning detection equipment far enough offshore to resolve the high median current observations offshore around Florida and the Gulf of Mexico.

One recommendation for research not directly related to the question addressed in this thesis is for lightning cessation. When looking at the hourly median currents it was observed that the highest hourly median currents occurred right before the storm ended. Therefore to correlate a median current value with the end of a storm could help forecast the cessation of lightning. A time scale smaller than an hour may be needed to actually forecast the end of lightning and average terminal median current values will probably change from area to area and show seasonal variation.

Appendix A: Programs and Coordinates

.The following programs were used to separate lighting flashes between land and water.

```
pro separate; program to read and manipulate

;writing a code that will read in latitude and longitude and then check
each flash in a time and area
;to see if flash is over water or land and save those flashes to a file
;*then I can take each file and run statistics on each set
; first I have to open the file that has the dates in and read it and
split it
; begin with closing device numbers just to make sure
; this program finds inside and outside flashes
;plots the inside total flashes, with a mark for the peak pos and neg
amplitude
; plots the outside total flashes with a mark for the peak positive
flash
; the output can be all stats, or individual ones
; if you go over a month you need to make months an array
;I have most of the plotting turned off
close,2
close,3

; define the file names I will be calling for the dates and for the lat.
and lon.
fn='~/slc/lakecord.txt'; see Figure 5.for coordinates


;*****************************first open lake coordinates file*****
openr,2,fn
s= ' '; make string
n=0; counter
while not (EOF(2)) do begin
      readf,2,s
      n=n+1
;print,s
endwhile
close,2
totaln=n; because no header so no n-1gheader in data
print, totaln
;print, s

;*******reopen file and give it format, which is not needed due to array
lakedata=fltarr(3,totaln-1)
      openr,2,fn
      format='(f8.3,3x,f6.3,3x,f6.3)'
      readf,2,lakedata,format=format
print,lakedata
minlat=lakedata[1,*]

maxlat=lakedata[2,*]
lon=lakedata[0,*]

close,2
```

```
print,minlat

;*****************get lightning data********************************

inpath='/home/fujita12/flash/lgh19'
years=['95','96','97','98']
months=['may','jun','jul','aug','sep','oct']
;files=inpath+years+ '/' + months + years + '.lgh'
nyears = n_elements(years)
nmonths = n_elements(months)
files = strarr(nyears*nmonths)
for y = 0, nyears -1 do $
  for m = 0, nmonths-1 do $
    files(y*nmonths+m) =
'/home/fujita12/flash/lgh19'+years(y)+'/'+months(m)+years(y)+'.lgh'
      dates1=['07/28/96 06:00:00', '07/29/96 06:00:00']

;findtime is a subroutine by Huffines[1999]

findtime,dates1,startind,startpos,lastind,lastpos,files,11L
      currentind=startind
      currentpos=startpos
      done=((currentind GE lastind) AND (currentpos GE lastpos))
region = [40.0,42.0,-114.0,-111.0]
      nflashes=0
; getchunk is a subroutine by Huffines[1999]
getchunk(files,startind,stoppos,lastind,lastpos,region,currentind,curren
tpos,11L,50000)
      print,n_elements(f)
      nflashes= n_elements(f)/11
      print,nflashes
f=exp_lgh(f)
help,f,/structure

;*****have flashes for whole area now need to start separating them,
first find the flashes that fall
;****into the longitudes by which the lake is gridded

      upperlat=41.8
      lowerlat=40.5
      westlon=-113.05
      eastlon=-111.925
      inside=bytarr(nflashes)*0

;****have a larger region run in Getchunk, now have smaller area that
matches coordinate matrix called within**************

      within = where((f.lat LE upperlat) and (f.lat GE lowerlat) and
(f.lon GE westlon)and (f.lon LE eastlon),count)
print, 'count within lon of lake',count

;**I modified as I went when there were no flashes in within or okay
some of the GT statements check do not work if there is an array of true
statements since I am not in a loop
; the next program runs a series of days
;**need to process with data inside and compare to index array of points
```

```
      dellon=0.025

      lonind=fix((f(within).lon - westlon)/dellon)
help,lonind
latzero=minlat[lonind]+((minlat[(lonind+1)< (totaln-1)]-
minlat(lonind))/dellon)*(f(within).lon-lon[lonind])
help,latzero
;print, latzero(20)

latone=maxlat(lonind)+((maxlat((lonind+1) < (totaln-1))-
maxlat(lonind))/dellon)*(f(within).lon-lon[lonind])
help,latone
;print,latone(20)
okay = where ((f(within).lat GE latzero)and(f(within).lat LE
latone),fcount)
help,okay
print,fcount
;if (okay GT 0 ) then inside(within(okay))= 1
inside(within(okay))= 1
outside=where(inside EQ 0, ocount)
inside=where(inside EQ 1,icount)


;** flashes inside boundary = f(inside)
;** flashes outside boundary = f(outside)

;****have to process inside and outside data statistics******

print,'total',nflashes,ocount,icount
      if (icount GT 0 ) then begin
                  print,'max', max(f(inside).peak)
            neglake=where(f(inside).peak LT 0.0,nlcount)

            if (nlcount GT 0) then begin
                   maxineg= min(f(inside(neglake)).peak)
            endif else begin
                  maxineg=0.0
            endelse
                  print,'neglake', nlcount,min(f(inside(neglake)).peak)

            poslake= where(f(inside).peak GT 10.0,plcount)
                  print,'poslake', plcount
            if (plcount GT 0) then begin
                  maxipos=max(f(inside(poslake)).peak)
            endif else begin
                  maxipos=0.0
            endelse
                  print,maxipos
print,'lool', f(inside(neglake)).peak
            locp= where(f(inside).peak EQ maxipos)
                  ;print, maxipos, f(inside(locp)).lon,
f(inside(locp)).lat



            locneg= where(f(inside).peak EQ maxineg)
```

```
                    ;print,
maxineg,f(inside(locneg)).lon,f(inside(locneg)).lat
      map_set,0,-100,0,limit=
region([0,2,1,3]),/usa,/noerase,/noborder,con_color=1
      ;map_continents, hires=1,/coasts, color=1
plots,f(inside).lon, f(inside).lat,color=14,psym=3
      ;plots,f(inside(locp)).lon,f(inside(locp)).lat,color=2,psym=2
      plots,f(inside(locneg)).lon,f(inside(locneg)).lat,color=9,psym=2

wait,10
            if(nlcount EQ 0) then nlmult=0
            if (nlcount EQ 1) then nlmult=( f(inside(neglake)).mult)
            if (nlcount GT 1) then nlmult= mean(
f(inside(neglake)).mult)
            ;nlmult= mean( f(inside(neglake)).mult)
            print, 'plcount', plcount
            if(plcount EQ 0) then plmult= 0
            if (plcount EQ 1) then plmult=( f(inside(poslake)).mult)
            if (plcount GT 1) then plmult= mean(
f(inside(poslake)).mult)
            print,nlmult,plmult
endif else begin
      nlcount=0
      maxineg=0.0
      plcount=0
      maxipos=0.0
      nlmult=0.0
      plmult=0.0
endelse

;**********all outside calculations*********

                  print,'maxoutside', max(f(outside).peak)
            negland= where(f(outside).peak LT 0.0,ntcount)
                  print,'negland',ntcount,min(f(outside(negland)).peak)
      maxoneg=min(f(outside(negland)).peak)
      posland= where(f(outside).peak GT 10.0, ptcount)
                  print, 'posland', ptcount
      if (ptcount GT 0) then begin
            maxopos= max(f(outside(posland)).peak)
            maxl= where(f(outside).peak EQ maxopos)
                  print, maxopos, f(outside(maxl)).lon,
f(outside(maxl)).lat
      endif else begin
      maxopos=0.0
      endelse
;**looking for pos and neg land multiplicity
      if(ntcount EQ 0) then ntmult=0
      if (ntcount EQ 1) then ntmult=( f(outside(negland)).mult)
      if (ntcount GT 1) then ntmult= mean( f(outside(negland)).mult)
      if(ptcount EQ 0) then ptmult= 0
      if (ptcount EQ 1) then ptmult=( f(outside(posland)).mult)
      if (ptcount GT 1) then ptmult= mean(f(outside(posland)).mult)
;ntmult= mean(f(outside(negland)).mult)
;map_set,0,-100,0,limit= region([0,2,1,3]),/usa,/noborder,con_color=1

;plot inside is above, f(inside).lon,f(inside).lat,color=14,psym=3
```

```
 plots, f(outside).lon,f(outside).lat,color=6,psym=3


 plots,f(outside(maxl)).lon, f(outside(maxl)).lat,color=2,psym=2

print,ntmult,ptmult
;print, day,months, years
da= 05
mon=05
yr=95
;***********need to write data I want to save to file in a format I
know*************
 openu, outfile, 'scrap.txt',/get_lun,/append
format="(I2,1x,I2,1x,I2,1x,I7,1x,I7,1x,I7,1x,I6,1x,f7.2,1x,I6,1x,f7.2,1x
,f6.3,1x,f6.3,I6,1x,f7.2,1x,I6,1x,f7.2,1x,f6.3,1x,f6.3)"
printf, outfile,
da,mon,yr,nflashes,ocount,icount,nlcount,maxineg,plcount,maxipos,nlmult,
plmult,ntcount,maxoneg,$
ptcount,maxopos,ntmult,plmult,format= format
close, outfile
free_lun, outfile
;**explain output, day, month yr, totalnumber of flashes in region,
number of flashes outside water, number
;flashes over water, number od\f negative flashes over water, max peak
current of  a negative flash over water
;, number of postive flashes over water, max peak positive current over
water, negativemultiplicty over
;water, positive multiplicity over water,, number of neg flashes over
land, maxnegative current over land,
; number of positive flashes over land, max positive peak current over
land, neg multiplicty over land,
;positive multiplicty over land, 18 items total
close,/all

end
```

```
pro newopic; program to separate flashes between land and water in the
New Orleans area

;************similar to separate program but this one shows how
;************to read in dates from a  file and loop through all storm
;********days, it is also missing the caculations used in separate
;*****New Orleans is the only are gridded by latitude.

close,2
close,3
fn='~/slc/newocord.txt'; see Table A.2.



;**********first open water coordinate  file***************
openr,2,fn
s= ' '; make string
n=0; counter
while not (EOF(2)) do begin
      readf,2,s
      n=n+1

endwhile
close,2
totaln=n; becasue no header so no n-1gheader in data
print, totaln

;********reopen file and give it format *******
gulfdata=fltarr(5,totaln)
      openr,2,fn
      format='(f6.3,3x,f6.2,3x,f6.2,3x,f6.2,3x,f6.2)'
      readf,2,gulfdata,format=format
;print,gulfdata
minlon1=gulfdata[1,*]

maxlon1= gulfdata[2,*]
lat = gulfdata[0,*]
minlon2=gulfdata[3,*]
maxlon2= gulfdata[4,*]
close,2


;******************get lightning data********************************

inpath='/home/fujita12/flash/lgh19'
years=['95','96','97','98']
months=['may','jun','jul','aug','sep','oct']

nyears = n_elements(years)
nmonths = n_elements(months)
files = strarr(nyears*nmonths)
for y = 0, nyears -1 do $
  for m = 0, nmonths-1 do $
    files(y*nmonths+m) =
'/home/fujita12/flash/lgh19'+years(y)+'/'+months(m)+years(y)+'.lgh'
print, files
      ;****dates1=['09/17/98 07:00:00', '09/18/98 07:00:00']
```

```
;****have files open know read in file of specific days**************
;fnd='~/mobile/newosplit.txt';open file with days in it
fnd='~/mobile/newosep.txt'; alternate form all days to subfiles
openr,3,fnd
see= ' '; make string
g=0; counter
while not (EOF(3)) do begin
      readf,3,see
      g=g+1
print,see
endwhile
close,3
totalg=g; because no header so no n-1gheader in data
print, 'totalg',totalg
print, see
;********reopen file and give it format **********
splitdata=fltarr(18,totalg)
      openr,3,fnd
format="(I2,1x,I2,1x,I2,1x,I7,1x,I7,1x,I7,1x,I6,1x,f7.2,1x,I6,1x,f7.2,1x
,f6.3,1x,f6.3,I6,1x,f7.2,1x,I6,1x,f7.2,1x,f6.3,1x,f6.3)"
      readf,3,splitdata,format=format
print,splitdata
days=splitdata[0,*]
print,'days', days
month=splitdata[1,*]
print, month

year=splitdata[2,*]
print, year
close,3

; ************assign time window*********
;****loop through all opened days, plot USA map first and again in end
for print reasons

num = strcompress(sindgen(100),/remove_all)
num[0:9] = '0'+num[0:9]

region = [28.6,30.5,-90.0,-88.5]
map_set,0,-100,0,limit= region([0,2,1,3]),/usa,/noborder,con_color=1


for l=0,totalg-1 do begin ; totalg-1 do begin

times = [num(month[l])+'/'+num(days[l])+'/'+num(year[l])+ ' 00:00:00',
num(month[l])+'/'+num(days[l]+1)+'/'+num(year[l])+ ' 00:00:00']
print, times
            ;print, times
      ;times=['05/22/95 06:00:00', '05/23/95 06:00:00']

findtime,times,startind,startpos,lastind,lastpos,files,11L
      currentind=startind
      currentpos=startpos
      done=((currentind GE lastind) AND (currentpos GE lastpos))
      nflashes=0
```

```
getchunk(files,startind,stoppos,lastind,lastpos,region,currentind,curren
tpos,11L,50000)
      print,n_elements(f)
      nflashes= n_elements(f)/11
      print,nflashes
f=exp_lgh(f)
help,f,/structure

;*****have flashes for whole area now need to start separating them,
;first find the flashes that fall into the longitude of the array of
;latitudes for the lake
      upperlat=30.35
      lowerlat=28.6
      westlon=-90.0
      eastlon=-88.50
      inside=bytarr(nflashes)*0
;****narrow region to within matrix and check flashes against that****

      within = where((f.lat LE upperlat) and (f.lat GE lowerlat) and
(f.lon GE westlon)and (f.lon LE eastlon),count)
print, 'count within bay',count

;**need to process with data inside and compare to index array of points
      dellat=0.025

      lonind=fix((abs(f(within).lat - upperlat)/dellat))
print,min(lat(lonind)), max(lat(lonind)), ' lat check'
help,lonind
print,'calc',minlon1[20],lat[20],minlon1[20],lat[21]
print,maxlon1[20],maxlon1[21]
print,minlon2[20],minlon2[21]
print,maxlon2[20],maxlon2[21]
lonzero=minlon1[lonind]+((minlon1[(lonind+1)< (totaln)]-
minlon1(lonind))/dellat)*(f(within).lat-lat[lonind])
help,lonzero
print, lonzero(20), f(within(20)).lat

lonone=maxlon1(lonind)+((maxlon1((lonind+1) < (totaln))-
maxlon1(lonind))/dellat)*(f(within).lat-lat[lonind])
help,lonone
print,lonone(20), f(within(20)).lat

lontwo=minlon2[lonind]+((minlon2[(lonind+1)< (totaln)]-
minlon2(lonind))/dellat)*(f(within).lat-lat[lonind])
lonthree=maxlon2[lonind]+((maxlon2[(lonind+1) < (totaln)]-
maxlon2(lonind))/dellat)*(f(within).lat-lat[lonind])
print,lontwo(20),f(within(20)).lat
print,lonthree(20), f(within(20)).lat
okay= where(((f(within).lon GE minlon1[lonind])AND (f(within).lon LE
maxlon1[lonind])),fcount)
okay2= where (((f(within).lon GE minlon2[lonind]) AND (f(within).lon LE
maxlon2[lonind])),f2count)
;okay = where ((f(within).lon GE lonzero)and(f(within).lon LE
lonone),fcount)
;okay2= where((f(within).lon GE lontwo) and (f(within).lon LE
lonthree),f2count)
help,okay
```

```
print,'fcount',fcount,'f2count',f2count

inside(within(okay))= 1
if (f2count GT 0) then begin
inside(within(okay2))= 1
endif
outside=where(inside EQ 0, ocount)
inside=where(inside EQ 1,icount)
print, 'icount',icount


plots, f(inside).lon, f(inside).lat, color=24, psym=2,symsize=.5

plots,f(outside).lon,f(outside).lat,color=25,psym=3
endfor
map_continents,/usa,color=255
close,/all
end
```

Table A.1. Great Salt Lake Coordinates. This matrix gives the latitudes per longitude used to grid the boundary of the Great Salt Lake out from the surrounding area.

Longitude	Bottom Latitude	Upper Latitude		Longitude	Bottom Latitude	Upper Latitude		Longitude	Bottom Latitude	Upper Latitude
-113.050	41.450	41.525		-112.625	40.800	41.450		-112.200	40.750	41.150
-113.025	41.450	41.600		-112.600	40.775	41.450		-112.175	40.750	41.150
-113.000	41.250	41.650		-112.575	40.805	41.425		-112.150	40.775	41.150
-112.975	41.250	41.650		-112.550	40.800	41.400		-112.125	40.875	41.125
-112.950	41.250	41.650		-112.525	40.900	41.350		-112.100	40.875	41.075
-112.925	41.250	41.650		-112.500	40.925	41.300		-112.075	40.875	41.050
-112.900	41.250	41.650		-112.475	40.850	41.200		-112.050	40.900	41.025
-112.875	41.250	41.675		-112.450	40.775	41.200		-112.025	40.900	41.025
-112.850	41.200	41.700		-112.425	40.750	41.225		-112.000	40.910	41.020
-112.825	41.150	41.700		-112.400	40.725	41.250		-111.975	40.925	41.025
-112.800	41.125	41.675		-112.375	40.675	41.400		-111.950	40.925	41.025
-112.775	41.025	41.675		-112.350	40.675	41.425		-111.925	40.925	40.975
-112.750	40.975	41.650		-112.325	40.675	41.400				
-112.725	40.950	41.475		-112.300	40.700	41.375				
-112.700	40.950	41.450		-112.275	40.700	41.375				
-112.675	40.950	41.450		-112.250	40.700	41.300				
-112.650	40.875	41.450		-112.225	40.725	41.175				

Table A.2. Mobile Bay Coordinates. This matrix gives the latitudes per longitude (in degrees) used to separate the Mobile Bay and Gulf of Mexico from the land.

Longitude	Latitude	Latitude		Longitude	Latitude	Latitude
-88.8	29.3	30.375		-87.875	29.3	30.4
-88.775	29.3	30.36		-87.85	29.3	30.35
-88.75	29.3	30.35		-87.825	29.3	30.35
-88.725	29.3	30.35		-87.8	29.3	30.35
-88.7	29.3	30.325		-87.775	29.3	30.25
-88.675	29.3	30.36		-87.75	29.3	30.25
-88.65	29.3	30.37		-87.725	29.3	30.25
-88.625	29.3	30.37		-87.7	29.3	30.25
-88.6	29.3	30.38		-87.675	29.3	30.25
-88.575	29.3	30.35		-87.65	29.3	30.25
-88.55	29.3	30.35		-87.625	29.3	30.26
-88.525	29.3	30.325		-87.6	29.3	30.27
-88.5	29.3	30.3		-87.575	29.3	30.275
-88.475	29.3	30.325		-87.55	29.3	30.3
-88.45	29.3	30.36		-87.525	29.3	30.35
-88.425	29.3	30.35		-87.5	29.3	30.35
-88.4	29.3	30.375		-87.475	29.3	30.35
-88.375	29.3	30.4		-87.45	29.3	30.4
-88.35	29.3	30.4		-87.425	29.3	30.42
-88.325	29.3	30.375		-87.4	29.3	30.3
-88.3	29.3	30.375		-87.375	29.3	30.3
-88.275	29.3	30.375		-87.35	29.3	30.32
-88.25	29.3	30.36		-87.325	29.3	30.34
-88.225	29.3	30.35		-87.3	29.3	30.35
-88.2	29.3	30.34		-87.275	29.3	30.34
-88.175	29.3	30.33		-87.25	29.3	30.38
-88.15	29.3	30.33		-87.225	29.3	30.4
-88.125	29.3	30.35		-87.2	29.3	30.4
-88.1	29.3	30.375		-87.175	29.3	30.44
-88.075	29.3	30.58		-87.15	29.3	30.5
-88.05	29.3	30.66		-87.125	29.3	30.52
-88.025	29.3	30.67		-87.1	29.3	30.45
-88	29.3	30.66		-87.075	29.3	30.45
-87.975	29.3	30.656		-87.05	29.3	30.47
-87.95	29.3	30.65		-87.025	29.3	30.5
-87.925	29.3	30.45		-87	29.3	30.47
-87.9	29.3	30.425				

Table A.3. New Orleans Coordinates. This matrix gives the longitudes per latitude (in degrees) used to separate the Gulf of Mexico from southern Louisiana.

Latitude	Longitude. 1	Longitude. 2	Longitude. 3	Longitude. 4
30.35	-89.34	-89.3	-89.15	-88.75
30.325	-89.34	-89.3	-89.22	-88.5
30.3	-89.35	-89.3	-89.25	-88.5
30.275	-89.4	-89.1	-89.1	-88.5
30.25	-89.44	-89.1	-89.09	-88.5
30.2	-89.45	-89.1	-89.08	-88.5
30.175	-89.5	-89.46	-89.44	-88.5
30.15	-89.57	-89.22	-89.2	-88.5
30.125	-89.66	-89.26	-89.22	-88.5
30.1	-89.68	-89.3	-89.23	-88.5
30.075	-89.68	-89.31	-89.21	-88.5
30.05	-89.71	-89.5	-89.2	-88.5
30.025	-89.72	-89.54	-89.39	-88.5
30	-89.85	-89.58	-89.44	-88.5
29.975	-89.85	-89.58	-89.45	-88.5
29.95	-89.74	-89.58	-89.39	-88.5
29.925	-89.75	-89.59	-89.37	-88.5
29.9	-89.74	-89.6	-89.32	-88.5
29.875	-89.66	-89.62	-89.24	-88.5
29.85	-89.43	-89.34	-89.31	-88.5
29.825	-89.4	-89.33	-89.31	-88.5
29.8	-89.36	-89.34	-89.29	-88.5
29.775	-89.44	-89.35	-89.28	-88.5
29.75	-89.43	-89.33	-89.27	-88.5
29.725	-89.64	-89.48	-89.43	-88.5
29.7	-89.61	-89.5	-89.43	-88.5
29.675	-89.53	-89.48	-89.45	-88.5
29.65	-89.52	-89.46	-89.45	-88.5
29.625	-89.65	-89.54	-89.5	-88.5
29.6	-89.73	-89.64	-89.58	-88.5
29.575	-89.66	-89.5	-89.5	-88.5
29.55	-89.68	-89.6	-89.59	-88.5
29.525	-89.65	-89.62	-89.59	-88.5
29.5	-89.64	-89.55	-89.55	-88.5
29.475	-89.94	-89.9	-89.55	-88.5
29.45	-90	-89.85	-89.54	-88.5
29.425	-90	-89.85	-89.51	-88.5
29.4	-90	-89.84	-89.45	-88.5
29.375	-90	-89.8	-89.35	-88.5
29.35	-90	-89.85	-89.33	-88.5
29.325	-90	-89.85	-89.2	-88.5
29.3	-90	-89.9	-89.16	-88.5
29.275	-90	-89.66	-89.15	-88.5
29.25	-90	-89.65	-89.14	-88.5
29.225	-90	-89.53	-89.03	-88.5
29.2	-90	-89.46	-89.02	-88.5
29.175	-90	-89.45	-89.02	-88.5
29.15	-90	-89.43	-89.03	-88.5
29.125	-90	-89.41	-89.04	-88.5
29.1	-90	-89.42	-89.05	-88.5
29.075	-90	-89.35	-89.05	-88.5
29.025	-90	-89.35	-89.33	-88.5
29	-90	-89.38	-89.35	-88.5
28.975	-90	-89.41	-89.36	-88.5
28.95	-90	-89.42	-89.38	-88.5
28.925	-90	-89.4	-89.4	-88.5
28.9	-90	-89.4	-89.4	-88.5
28.875	-90	-89.4	-89.4	-88.5
28.85	-90	-89.4	-89.4	-88.5
28.825	-90	-89.4	-89.4	-88.5
28.8	-90	-89.4	-89.4	-88.5
28.775	-90	-89.4	-89.4	-88.5
28.75	-90	-89.4	-89.4	-88.5
28.725	-90	-89.4	-89.4	-88.5
28.7	-90	-89.4	-89.4	-88.5
28.675	-90	-89.4	-89.4	-88.5
28.65	-90	-89.4	-89.4	-88.5
28.625	-90	-89.4	-89.4	-88.5
28.6	-90	-89.4	-89.4	-88.5

Table A.4. KSC Coordinates. This matrix gives the latitudes per longitude (in degrees) used to separate the Atlantic Ocean from the Florida coast.

Longitude	Latitude 1	Latitude 2	Latitude 3	Latitude 4
-80.85	28.9	28.95	28.96	29.1
-80.825	28.656	28.74	28.85	29.1
-80.8	28.55	28.76	28.8	29.1
-80.775	28.5	28.6	28.7	29.1
-80.75	28.4	28.6	28.7	29.1
-80.725	28.3	28.4	28.7	29.1
-80.7	28.3	28.4	28.7	29.1
-80.675	28.25	28.3	28.656	29.1
-80.65	28.2	28.26	28.65	29.1
-80.625	28.125	28.5	28.65	29.1
-80.6	28.06	28.6	28.65	29.1
-80.575	28.04	28.42	28.575	29.1
-80.55	27.09	28.44	28.5	29.1
-80.525	27.96	27.99	28.02	29.1
-80.5	27.94	27.95	28	29.1

Table A.5. Lake Okeechobee Coordinates. This matrix gives the latitude per longitude (in degrees) used to separate Lake Okeechobee

Longitude	Latitude	Latitude
-81.1	26.95	26.955
-81.075	26.9	27
-81.055	26.8	27
-81.025	26.88	27.1
-81	26.9	27.1
-80.975	26.86	27.2
-80.95	26.81	27.3
-80.925	26.76	27.05
-80.9	26.75	27.06
-80.875	26.74	27.07
-80.85	26.72	27.17
-80.825	26.7	27.19
-80.8	26.7	27.2
-80.775	26.69	27.18
-80.75	26.69	27.18
-80.725	26.74	27.15
-80.7	26.75	27.13
-80.675	26.82	27.1
-80.65	26.85	27.05
-80.625	26.87	27

Appendix B: Pictorial examples of each area.

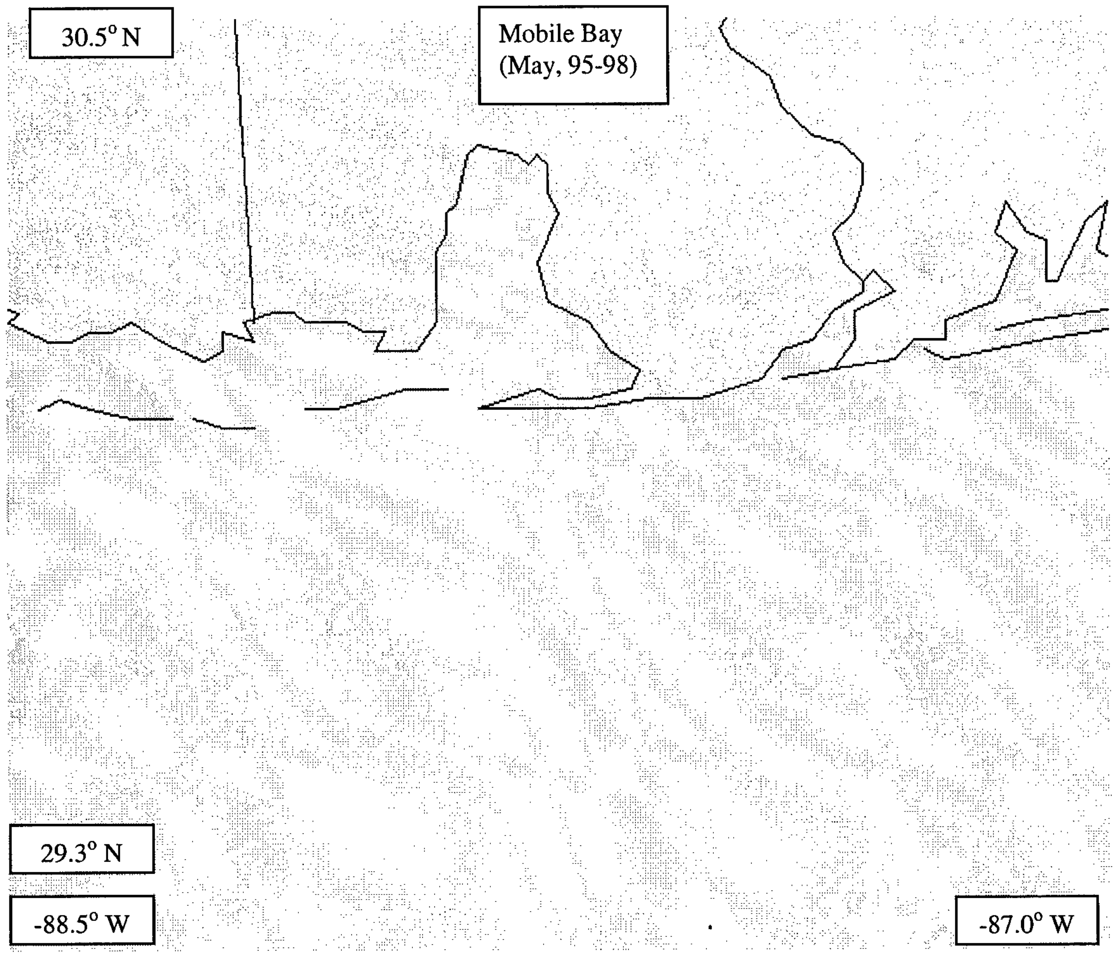

Figure B.1. Mobile Bay area. There was a total 113 storm days isolated in the Mobile Bay area. This picture depicts the storm days from May (95-98). The flashes determined to strike water are marked with (*) and flashes that strike land are marked (.). This picture shows the size of the Mobile Bay area as well as depicts the accuracy of the separation process. Of the 113 storm days, 102 days had more than 100 flashes over water. These 102 days were used for the hourly median analysis.

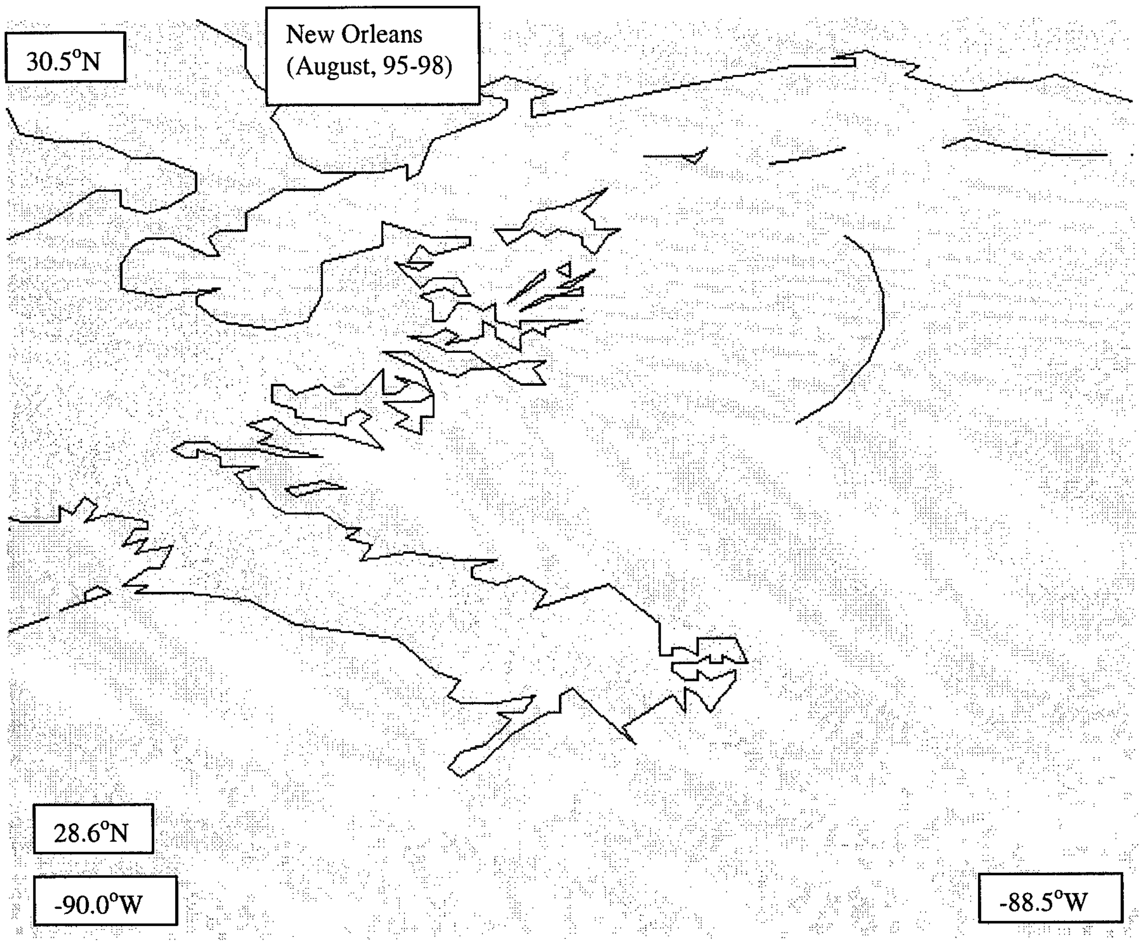

Figure B.2. New Orleans area. Of the 101 storm days isolated in the New Orleans area the storm days from August (95-98) are depicted in this picture. The flashes determined to strike water are marked with (*) and flashes that strike land are marked (.). This figure shows the size of the New Orleans area and depicts the accuracy of the separation process. There was 100 storm days with more than 100 flashes over water and they became the data set for the median hourly analysis.

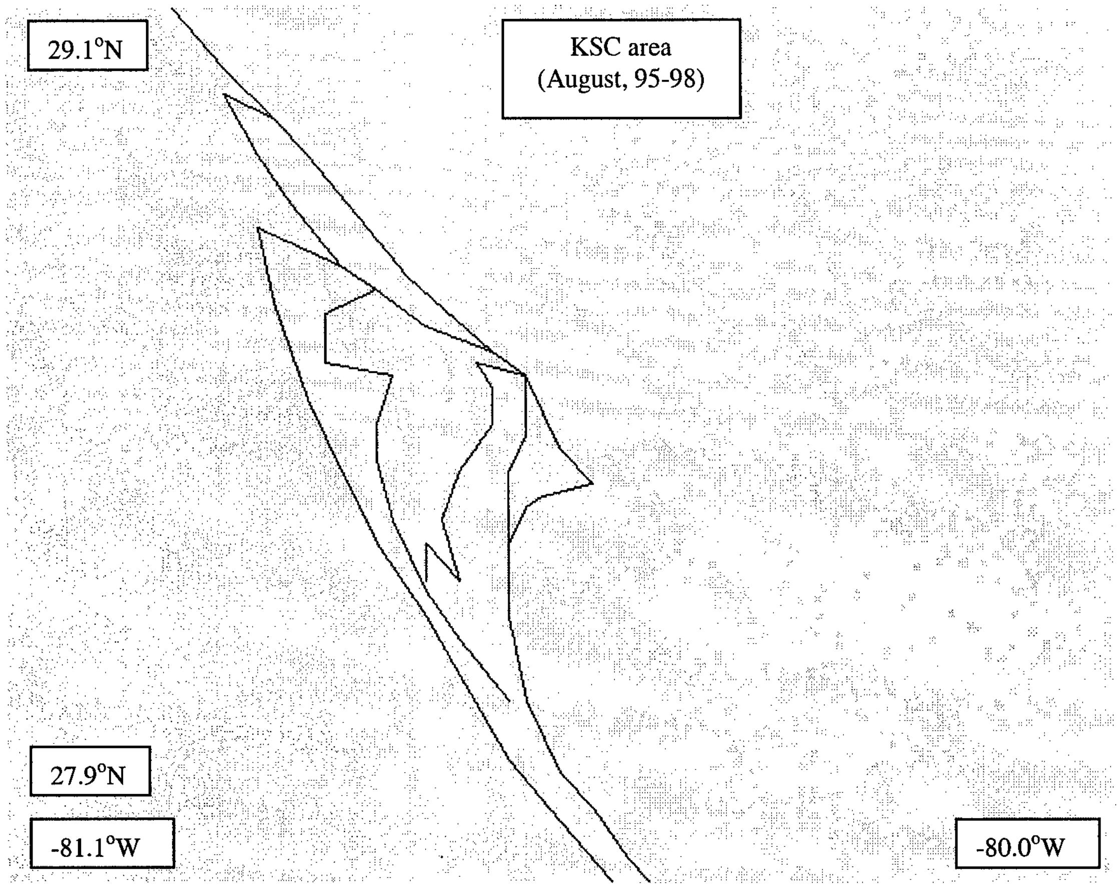

Figure B.3. KSC area. A total of 114 storm days were isolated in the KSC area, the days from August (95-98) are shown in this figure. The flashes determined to strike water are marked with (*) and flashes that strike land are marked (.). This figure shows the size of the area and the accuracy of the separation process. There was 102 storm days that had more than 100 flashes over water and were used in the hourly median analysis.

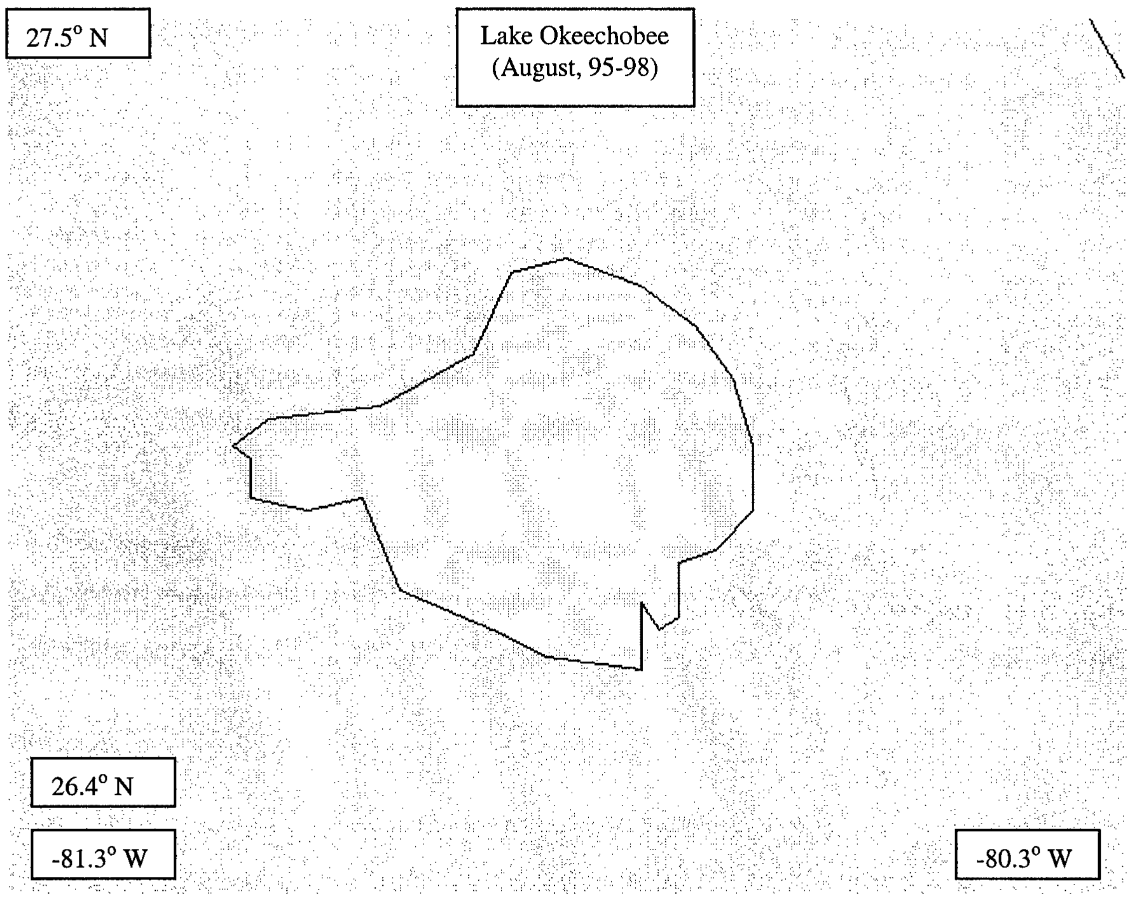

Figure B.4. Lake Okeechobee. There was a total of 210 storm days isolated in the Lake Okeechobee area. The flashes determined to strike water are marked with (*) and flashes that strike land are marked (.). Only 98 of 210 storm days had flashes with more than 100 flashes over water. This figure depicts the storm days with more than 100 flashes over water from August (95-98).

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Elizabeth A Boll, 1Lt, USAF

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Air Force Institute of Technology
Graduate School of Engineering and Management (AFIT/EN)
2950 P Street, Building 640
WPAFB OH 45433-7765

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75th OSS/OSW (AFMC)
Attn: Capt Mesenbrink
5970 Southgate Dr.
Hill AFB, UT 84056-5232 DSN:777-3519

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13. ABSTRACT *(Maximum 200 words)*
Understanding lightning characteristics over land and water is vital to achieving optimal safety and success in Air Force missions. Water and land have different compositions and surface conductivity values. A lightning stroke is detected through a change in the electromagnetic field at the surface. The change in surface conductivity from land to water can affect the detection of a stroke and its associated parameters. The change in composition from land to water can also affect the dynamics of the storm or lightning discharge process. Data from the Salt Lake City , Mobile Bay, New Orleans, Kennedy Space Center, and Lake Okeechobee were used to determine if there are differences in lightning characteristics or behavior over land versus water. The National Lightning Detection Network (NLDN), Global Atmospherics, Inc., Tucson, Arizona recorded the lightning parameters. Differences were seen in eleven of the characteristics compared over land and water. Results varied from area to area and over time, there was not a consistent response due to the change in underlying surface type. Not all differences could be directly attributed to the change in underlying surface type. In conclusion, the change in underlying surface type did not produce a consistent change in lightning characteristics or behavior. Water did influence lightning characteristics and behavior in specific cases of median peak current differences and diurnal pattern.

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