DEPARTMENT OF ATMOSPHERIC AND OCEANIC SCIENCE

The Effect ENSO Has on Lightning Using NLDN and OTD/LIS Lightning Detection Networks

Scholarly Paper in partial fulfillment of the requirements for an MS degree in the Department of Atmospheric and Oceanic Science, University of Maryland

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Abstract

Understanding the characteristics and features of lightning is critical to meteorologists, climate scientists, and atmospheric chemists. When lightning occurs, nitric oxide gas (NO) gets released into the atmosphere and mixes with sunlight and other gases to produce ozone. Ozone is a potent greenhouse gas and can be very hazardous when found in the lower troposphere. Approximately 10% of the ozone present in the Earth's atmosphere is found in the troposphere. Ozone found in the stratosphere, however, is beneficial, as it blocks harmful ultraviolet radiation from reaching the Earth's surface. It is important to study when and where lightning will strike and to determine if climate change, namely global warming, will have any effect on the occurrence of lightning.

Lightning detection networks, both ground-based and satellite-based, are useful means of studying lightning. The National Lightning Detection Network (NLDN), a ground-based lightning detection network, has shown to be a powerful tool in studying lightning, especially after its major upgrade in the mid-1990's. The Optical Transient Detector (OTD) and Lightning Imaging Sensor (LIS) networks, both satellite-based, are also frequently used networks for studying lightning.

The El Niño-Southern Oscillation (ENSO) is a climate pattern that occurs in the tropical Pacific and affects sea surface temperature and surface pressure. El Niño is characterized as the 'warm' phase of ENSO, while La Niña is known as the 'cool' phase. Studies show that ENSO does in fact influence lightning activity along the Gulf Coast of the United States. Recent studies indicate that El Niño events typically generate greater flash rates along the Gulf Coast, while neutral or La Niña phases tend to have little or no effect on flash rates.

Historical records of lightning flash rates and lightning climatology are fairly new; therefore, it is crucial for scientists to study lightning activity and to gain a better understanding of how it affects other meteorological and chemical fields.

Introduction

I. Lightning

Lightning is a common meteorological phenomenon that occurs in most regions around the globe. It is caused by an atmospheric discharge of electricity and is most commonly found in thunderstorms (Columbia Encyclopedia, 2008). The electrical charge occurs due to an imbalance between positive and negative charges between the cloud and ground (cloud-to-ground), between two locations in the same cloud (intracloud), or between two different clouds (intercloud) (Columbia Encyclopedia, 2008). The majority of lightning strikes occur within the cloud (Ahrens, 2003). Approximately 20% of lightning strikes occur between the cloud and ground, affecting both land and people at the surface (Ahrens, 2003)

Thunderstorms are generated when convective processes take place at the surface. During convection, a warm pocket of air, known as a thermal, rises, expands, and cools as it is transported aloft. As the thermal rises, it mixes with the cooler air surrounding it and eventually cools to the point where it becomes saturated, if there is enough water vapor present. At its saturation point, the moisture will condense, form a cloud, and produce precipitation if there are enough cloud condensation nuclei (CCN) and ice nuclei present. The depth of the cloud is dependent on the stability of the atmosphere. Thunderstorms are most often found in cumulonimbus and cumulus congestus clouds, which develop when the atmosphere is conditionally unstable, i.e. the environmental lapse rate is less than the dry adiabatic lapse rate, but greater than the moist adiabatic lapse rate (Ahrens, 2003). Cumulonimbus and cumulus congestus clouds are characterized as very deep, unstable clouds, and can have a depth of 4 kilometers or greater (Ahrens, 2003). Inside these clouds, water particles exist in the lower layers, where the air is warmer, while ice particles are found in the colder regions near the top of the cloud (Ahrens, 2003). During a thunderstorm, ice crystals and hailstones are present (UCAR, 2000). Ice crystals have a positive charge, while hailstones have a negative charge (UCAR, 2000). During a thunderstorm, intense vertical mixing takes place; updrafts are responsible for transporting ice crystals upward in the cloud, while downdrafts displace hailstones lower in the cloud (UCAR, 2000). As this process occurs, positive charge is distributed in the upper portion of the cloud, while negative charge is found near the base of the cloud (UCAR, 2000). As the thunderstorm develops, the negative charge near the base of the cloud tries to interact with positive charge located on the Earth's surface and creates a stepped leader (UCAR, 2000). When the stepped leader and the positive charge meet, an electric current carries a positive charge up into the cloud and produces a return stroke, which is responsible for making lightning visible to humans (UCAR, 2000).

It is well-known that convection, and therefore lightning, are more frequent over land than water, due to differences in their thermodynamic properties (Williams and Stanfill, 2002). Convective available potential energy (CAPE) is a good measure of instability in the atmosphere and can determine the likelihood of convection occurring (Williams and Stanfill, 2002). It has been shown that the value of CAPE is two times greater over land than over ocean water (Williams and Stanfill, 2002). Williams and Stanfill (2002) also explain that convection is greater over land due to the amount of cloud condensation nuclei (CCN) and ice nuclei present in the atmosphere. Deep convection requires a high value of CAPE, as well as an abundant supply of CCN and ice nuclei, which are greater over land; therefore, convective processes are more intense and more frequent over land surfaces (Williams and Stanfill, 2002).

II. Lightning Detection Networks

Lightning is a difficult quantity to measure, as it can be unpredictable and challenging to locate. Rockets and other spacecraft are methods to investigate lightning behavior in an up-close manner (NASA / Goddard Space Flight Center, 2010). Sounding rockets are able to detect intracloud flashes with better accuracy than cloud-to-ground flashes (NASA / Goddard Space Flight Center, 2010). High-altitude aircraft, such as the U-2 and ER-2, have been able to fly above large thunderstorms at an altitude of about 20 kilometers, to analyze electrical characteristics of lightning found within the thunderstorm (NASA / Goddard Space Flight Center, 2010).

Ground-based and satellite-based lightning detection networks are frequently used to study lightning behavior (NASA / Goddard Space Flight Center, 2010). Scientists commonly use both national and regional lightning detection networks, which utilize magnetic direction finders, time-of-arrival (TOA) techniques, and VHF interferometry (NASA / Goddard Space Flight Center, 2010). Three frequently used lightning detection networks include the National Lightning Detection Network (NLDN), a ground-based network, and the Optical Transient Detector (OTD) and Lightning Imaging Sensor (LIS) detection networks, which are both satellite-based networks.

III. El Niño-Southern Oscillation

El Niño-Southern Oscillation (ENSO) is a climatological phenomenon that occurs in the tropical Pacific every 3-7 years. During non-El Niño conditions, there are typically easterly trade winds along the equator due to the Walker Circulation. However, during an El Niño event, atmospheric pressure rises over the western Pacific and decreases over the eastern Pacific, which causes the trade winds to weaken and/or reverse direction. The reversal of the trade winds in the eastern Pacific causes warmer than average ocean waters along the eastern Pacific, which in turn produces wetter than average conditions along the western coast of North America and drier than average conditions in places such as Indonesia and India. El Niño typically lasts between 9-12 months and under extreme El Niño conditions, it can be hazardous to marine life and the fishing industry (Ahrens, 2003). Near the end of an El Niño period, atmospheric pressure over the eastern Pacific reverses and begins to rise, while atmospheric pressure in the western Pacific starts to fall. This swing in reversal of surface pressure at both ends of the Pacific is known as the Southern Oscillation. Studies show that the reversal in surface pressure and warming of ocean waters occur almost simultaneously, so scientists have combined the names of these phenomena and now call it the El Niño-Southern Oscillation (Ahrens, 2003).

Motivation

Lightning flash rates are important phenomena to study and are closely connected to meteorology, climate change, and atmospheric chemistry. Since lightning is found in convective thunderstorms, it is important to study the dynamics and relationships between lightning flash rates and convective meteorology and how climate change may affect the production of lightning. Determining whether or not El Niño and/or La Niña may affect lightning production has sparked the interest of many scientists and researchers (LaJoie and Laing, 2008).

Ocean-atmosphere climate phenomenon, such as the El Niño-Southern Oscillation, significantly affects the jet stream and meteorological patterns across the southwestern part of the United States, Gulf Coast region, and the southeastern part of the United States. During an El Niño event, the Gulf Coast region of the United States experiences warmer and wetter than average conditions, which often means more convection, resulting in an increase in thunderstorms and lightning flashes. It is important to study the relationship between ENSO and lightning, to determine whether or not there is a change in the frequency and/or intensity of lightning flash rates in the regions affected by ENSO.

Lightning is also important to the atmospheric chemistry field. When lightning is produced, nitric oxide (NO) is emitted into the troposphere (NASA / Goddard Space Flight Center, 2009). Once the NO is released, it reacts with sunlight and other gases in the atmosphere and produces ozone (NASA / Goddard Space Flight Center, 2009). Ozone is an important greenhouse gas; in the lower troposphere, it has a hazardous effect on human and plant life (NASA / Goddard Space Flight Center, 2009). In the stratosphere, however, it is beneficial to have abundant ozone present, because it blocks dangerous ultraviolet radiation from reaching the Earth's surface (NASA / Goddard Space Flight Center, 2009). It is also extremely important to study the effects global warming has on lightning (NASA / Goddard Space Flight Center, 2009). A recent press release by Dr. Kenneth Pickering and Dr. Lesley Ott, both research scientists at NASA / Goddard Space Flight Center, suggests that lightning may have a positive feedback with respect to global warming (NASA / Goddard Space Flight Center, 2009). This feedback loop was also proposed by other scientists in the past. Scientists speculate that warming surface temperatures, due to global warming, may produce more thunderstorms, which leads to an increase in lightning and NO emissions, which in turn creates more ozone, greater radiative forcing, and warms the surface even more (NASA / Goddard Space Flight Center, 2009).

Data

I. National Lightning Detection Network (NLDN)

The National Lightning Detection Network (NLDN) is a commonly used ground-based lightning detection network in the United States. The NLDN is operated by Vaisala Inc., located in Tucson, Arizona. This ground-based network consists of over 100 remote sensing stations located across the United States, which immediately capture the electromagnetic signal given off after lightning strikes the Earth's surface (Cummins et al., 1998). Each of these sensors is capable of detecting cloud-to-ground lightning strikes at a distance of more than 400 kilometers away (NASA / Goddard Space Flight Center, 2010). The domain of the recorded NLDN flash rates are 18.0ºN to 60.0ºN and 60.0ºW to -130.0ºW (NASA / Goddard Space Flight Center, 2010). Included in the approximately 100 sensors, are 11 Lightning Position and Tracking Systems (LPATS) scattered across the United States, extending hundreds of miles into the Pacific and Atlantic Oceans (NASA / Goddard Space Flight Center, 2010). LPATS is part of the time-of-arrival (TOA) system provided by the Atmospheric Research Systems, Inc. (ARSI) (NASA / Goddard Space Flight Center, 2010). The TOA system digitizes the waveform of a received lightning flash at each sensor and precisely times the peak with a resolution of up to 100 nanoseconds (NASA / Goddard Space Flight Center, 2010). Lightning Location and Protection, Inc. (LLP) created a lightning location method that combines TOA and magnetic direction finders (MDF), known as the improved accuracy from combined technology (IMPACT) method (Cummins et al., 1998). A map of the NLDN sensors, including IMPACT and LPATS sensors (NASA / Goddard Space Flight Center, 2010), is shown in Figure 1.

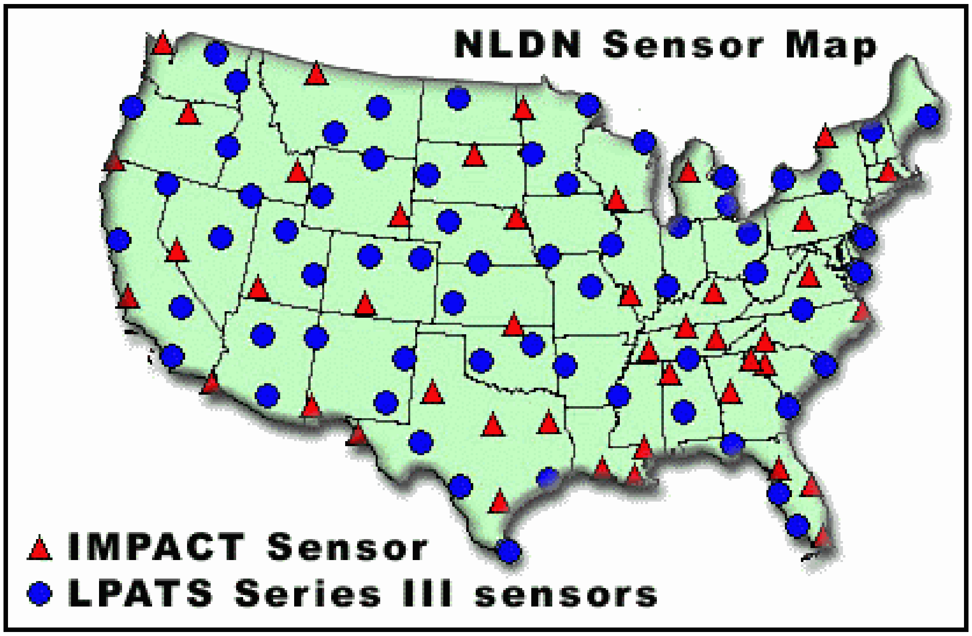


Figure 1 NLDN Sensor Map displaying its IMPACT and LPATS Sensors.

The NLDN's flash rate data and stroke data have been available since 1987 (NASA / Goddard Space Flight Center, 2010). Flash rate data comes from the NLDN and provides pertinent information about lightning characteristics, such as the time, location, amplitude, and polarity of each lightning flash. Previous studies show that there may be as many as 20 return strokes in a single flash. In addition to this, studies also suggest that approximately half of all flashes contain subsequent strokes that propagate to more than one location. The purpose of the NLDN's stroke data is to improve and expand on flash data by capturing characteristics of each known subsequent stroke. It is important to note that the NLDN measures cloud-to-ground flashes; most intracloud and intercloud flashes are not sampled (Orville and Huffines, 2001).

The NLDN first began in 1987 when data from networks in the western United States and Midwest were joined together with the University of Albany network, in hopes of providing lightning detection on a national scale (Cummins et al., 1998). Initially, the sensors consisted of gated, wideband magnetic direction finders (MDF's) and were designed to detect return stroke waveforms in cloud-to-ground lightning (Cummins et al., 1998). Due to a growing interest in the use of a national-scale lightning detection network, Vaisala, Inc. made significant improvements to the NLDN, resulting in more accurate and efficient in lightning detection (Cummins et al., 1998). According to Cummins et al. (1998), the four primary objectives of the NLDN upgrade include:

1. Improve the location accuracy of the network in order to meet the growing needs of the electric utilities
2. Provide an infrastructure that could process and deliver both stroke and flash information in real-time
3. Improve the detection efficiency for strokes and peak currents of 5 kA and greater
4. Improve the long-term reliability of the NLDN

With respect to detection efficiency, the NLDN upgrade was designed to increase overall detection efficiency to between 80% and 90% (Cummins et al., 1998). Prior to the upgrade, detection efficiency of the NLDN was between 65% and 80% from 1992 to 1994; however, the upgrade improved detection efficiency values to 85% for flashes with peak currents above 5 kA (Cummins et al., 1998). The NLDN went through another upgrade in 2002, which improved detection efficiency to 90% or greater (Biagi et al., 2007). Figure 2 shows the mean annual flash density of cloud-to-ground flashes over the continental United States and the adjacent ocean waters using the NLDN (Orville and Huffines, 2001). You can see that the greatest flash density occurs in Florida and along the Gulf Coast region. The Great Plains also have a moderate flash density, which is expected considering they have frequent thunderstorm outbreaks throughout the year, especially in the spring. The west coast of the United States and adjacent ocean waters have few flashes, due to a lack of deep convection in those regions.

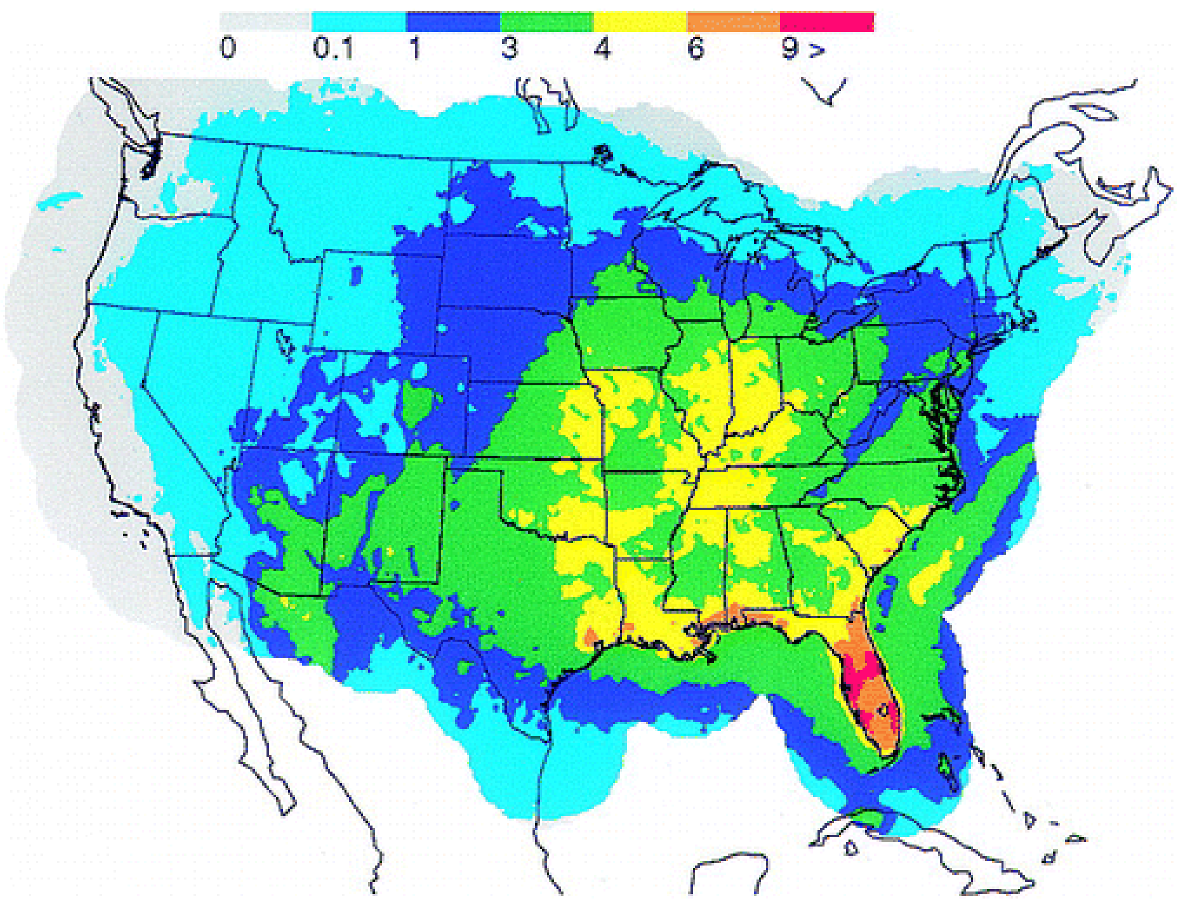


Figure 2 Mean annual flash density (Flashes per km² per year) containing over 216 million flashes for 1989-1998.

Four field campaigns were conducted in 2003 and 2004 in southern Arizona, northern Texas, and southern Oklahoma to assess the performance of the NLDN in its detection of cloud-to-ground lightning after its upgrade a few years before (Biagi et al., 2007). Biagi et al. (2007) made video recordings of lightning flashes using GPS time, where the flash and stroke detection efficiencies were determined by comparing the NLDN reports of cloud-to-ground flashes and strokes with those recorded on video.

In this study, the NLDN stroke detection efficiency is defined to be the percentage of all video strokes that were time correlated with a NLDN stroke report that was in a direction and at a range consistent with the video record (Biagi et al., 2007). The NLDN flash detection efficiency is the percentage of video flashes that had at least one stroke at a time and direction that were coincident with an NLDN stroke report during that flash (Biagi et al., 2007). After gathering the time, location, and direction of viewing of each recording session, the authors searched the NLDN dataset for reports of small, single-stroke flashes that were supposed to be found within the range of the camera field (Biagi et al., 2007). The video recordings were then analyzed to determine whether any channels to ground or other types of luminous activity appeared at the same time or in the same direction (Biagi et al., 2007).

The results from this study show that the combined 2-year average flash detection efficiency in Arizona was 93% and the measured stroke detection efficiency was 76% (Biagi et al., 2007). In Texas and Oklahoma, the combined 2-year average flash detection efficiency was 92%, while the measured stroke detection efficiency was 86% (Biagi et al., 2007). These results indicate the NLDN upgrade has improved both the flash and stroke detection efficiency of cloud-to-ground lightning and that the improvements in detection efficiency can be attributed to better detection of low-amplitude strokes (Biagi et al., 2007).

II. Optical Transient Detector (OTD)

The Optical Transient Detector (OTD) is a satellite-based lighting detection network that provides global coverage and is a combination of both electronic and optical elements (Boccippio et al., 2000). The OTD was originally developed as a project at NASA's Marshall Space Flight Center in Huntsville, Alabama and was first launched in April 1995. The OTD is a polar-orbiting satellite, meaning that the instrument does not stay above the same location for more than a few minutes per day. The OTD is capable of detecting momentary changes in an optical scene, indicating a lightning strike. The OTD is also more sophisticated than earlier instruments, because it provides much greater detection efficiency and spatial resolution. The OTD was developed with hopes to improve our understanding of atmospheric and precipitation processes. The OTD operates using a solid-state optical sensor and includes features such as a lens system, a detector array, and circuitry to convert the electronic output of the system's detector array into useful data.

At the peak of its orbit, the OTD flew at an altitude of 710 kilometers and had an inclination angle of 70 degrees. OTD data are gathered and then transmitted to a ground station in West Virginia on a daily basis. Like the NLDN, the OTD detects lightning flashes 24 hours a day, including both daytime and nighttime, and has a detection efficiency of approximately 40% to 65% (Boccippio et al., 2000). Data had been collected from the OTD since it first launched in April 1995 to April 2000, when the satellite was released from orbit (Boccippio et al., 2000).

III. Lightning Imaging Sensor (LIS)

Rainfall, especially tropical rainfall, is particularly difficult to measure, due to its high spatial and temporal variability (Boccippio et al., 2002). Since the majority of the tropical region is ocean, measuring rainfall in this area is limited, due to a lack of in-situ measurements (Boccippio et al., 2002). A new measuring system, called the Tropical Rainfall Measuring Mission (TRMM), was launched in 1997 and was designed for measuring tropical rainfall variability (Boccippio et al., 2002). The TRMM satellite follows a circular orbit and flies at an altitude of 350 kilometers, with an inclination of 35 degrees to the equator (Boccippio et al., 2002).

The Lightning Imaging Sensor (LIS) aboard the TRMM satellite was intended to investigate the occurrence of lightning on a global scale and the relationship between lightning, precipitation, and meteorological and physical parameters (Boccippio et al., 2002). The LIS detects lightning flashes in and near the tropics, namely from approximately 35ºS to 35ºN (NASA / Goddard Space Flight Center, 2010). The LIS consists of a staring imager that is designed to locate and identify lightning with a storm-scale resolution of 5-10 kilometers over a large region of the Earth's surface (Boccippio et al., 2002). When a lightning strike occurs, the instrument records the time the lightning strike occurred, measures the radiant energy, and estimates the location (Boccippio et al., 2002). The LIS instrument plays a crucial role in lightning detection studies by providing a global and thunderstorm climatology that is beneficial in studying global-scale processes and mesoscale phenomena (Boccippio et al., 2002).

Lightning is especially important during the summer season (June, July, August) in the Northern Hemisphere. Lighting is most frequent over land, due to a lack of convection and instability over ocean water, but is also found in the Intertropical Convergence Zone (ITCZ). Convective processes are dominant in the tropics during the summer and it is important to know how well the OTD/LIS model captures lightning strikes. According to the NOAA's Climate Prediction Center (CPC), a neutral ENSO event occurred during the summer of 2003, while a moderate El Niño event occurred during the summer of 2004 (NOAA / Climate Prediction Center, 2010). It is important to see how lightning flash rates differ between a neutral ENSO event (2003) and an El Niño event (2004). Figures 3, 4, and 5 show how lightning flash rates differ between the neutral event and El Niño event using the 'Data' for all three summer months. The 'Data' consists of climatological OTD flash rates poleward of 35º and approximately 98-day monthly average flash rates from LIS centered about the month of interest. Figures 6, 7, and 8 show how lightning flash rates differ between the neutral event and El Niño event using the 'Model' for all three summer months. The 'Model' refers to the monthly average flash rate for the month of interest, as parameterized using a meteorological field from the MERRA reanalysis (Global Modeling and Assimilating Office, 2008).

In the MERRA reanalysis, flash rates were parameterized using the MERRA variables 'large-scale and anvil evaporation of precipitating condensate' and 'convective evaporation of precipitating condensate.' These variables were combined to form the ‘total evaporation of precipitating condensate’ (reevap term) and is defined as the total amount of precipitation that evaporates from a large-scale anvil and convective cloud (Global Modeling and Assimilating Office, 2008).

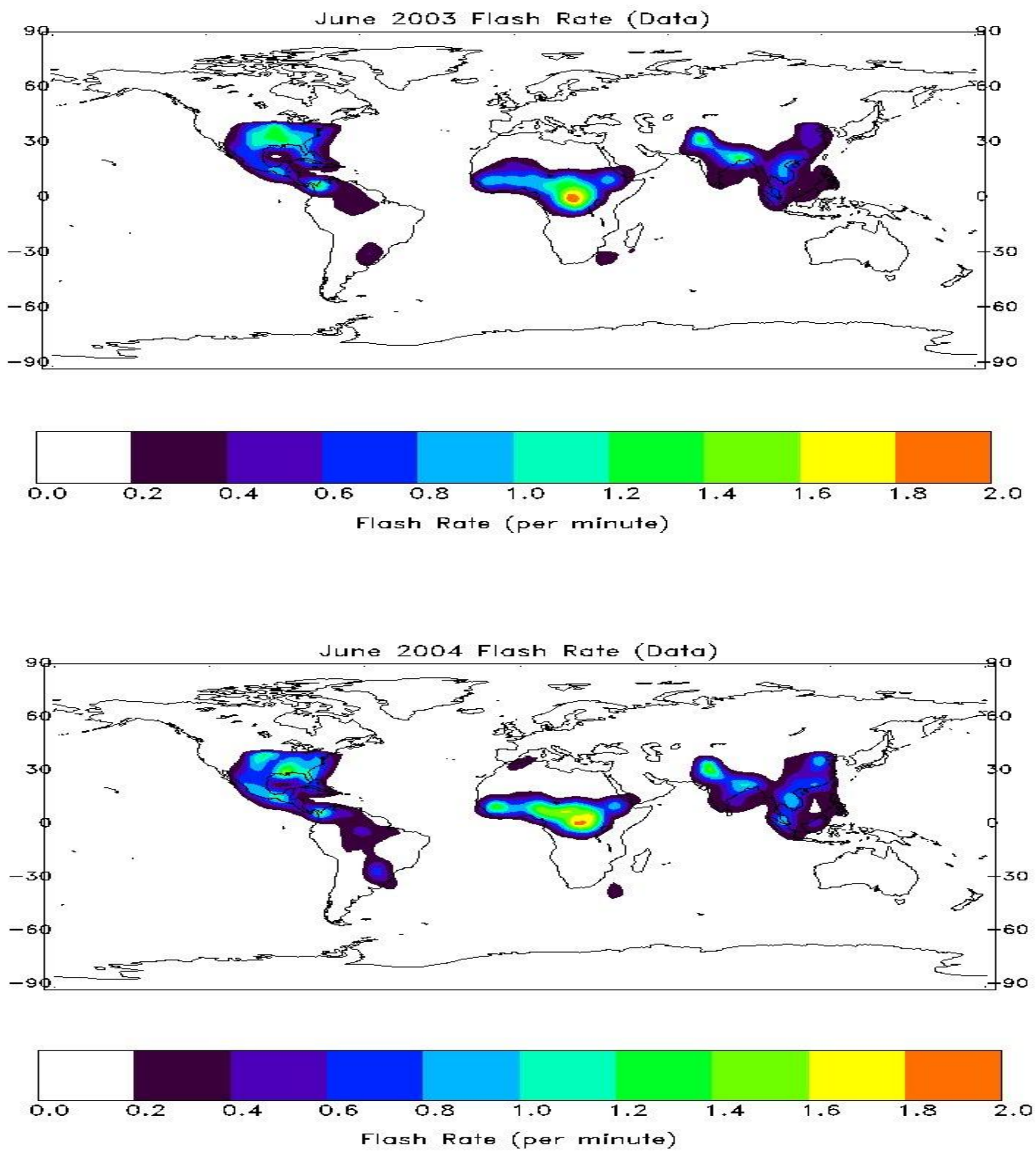


Figure 3 Top panel shows climatological OTD flash rates poleward of 35º and approximately 98-day average flash rates from LIS centered about June 2003 (Neutral month). Bottom panel shows climatological OTD flash rates poleward of 35º and approximately 98-day average flash rates from LIS centered about June 2004 (El Niño month).

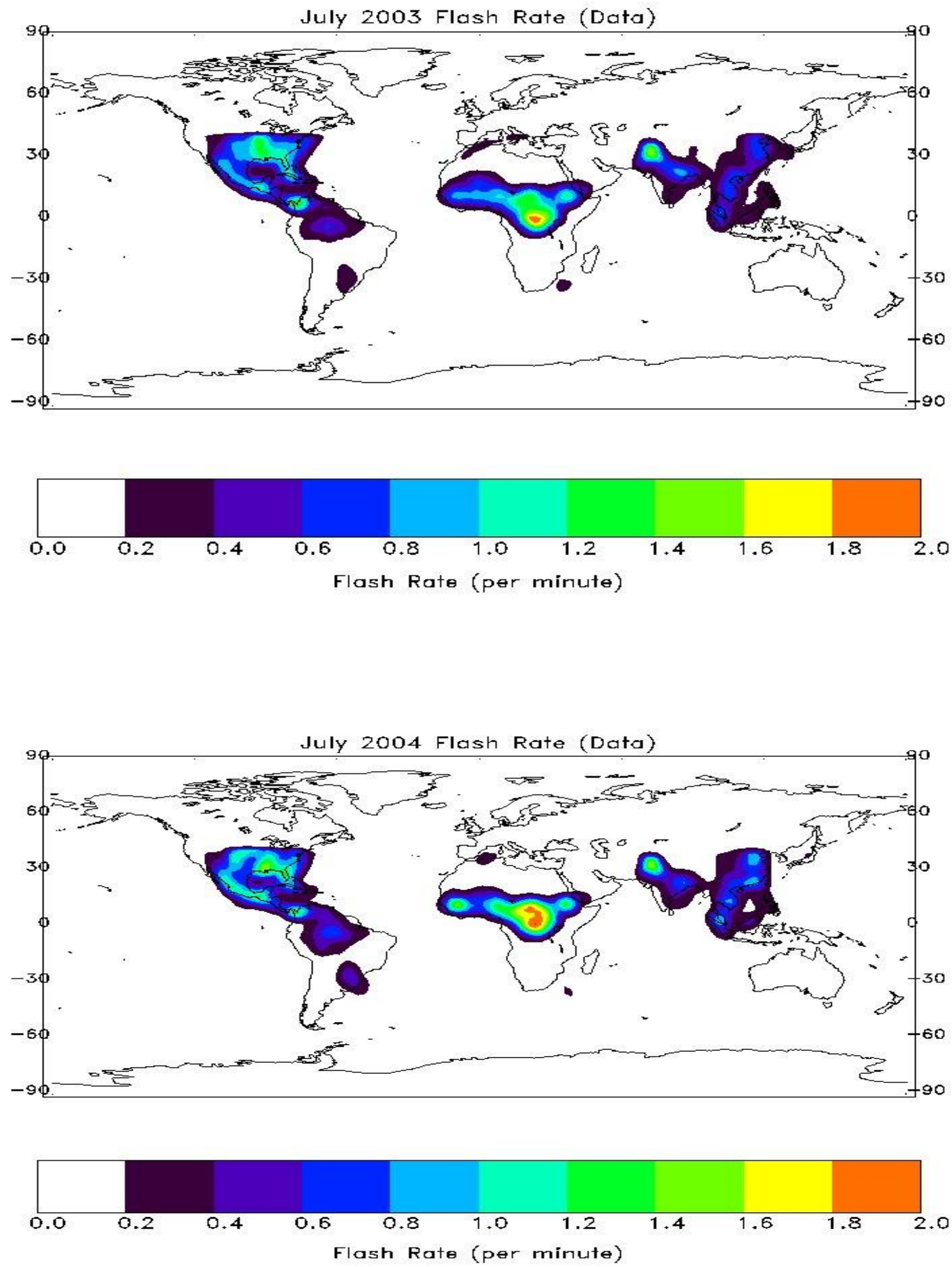


Figure 4 Top panel shows climatological OTD flash rates poleward of 35º and approximately 98-day average flash rates from LIS centered about July 2003 (Neutral month). Bottom panel shows climatological OTD flash rates poleward of 35º and approximately 98-day average flash rates from LIS centered about July 2004 (El Niño month).

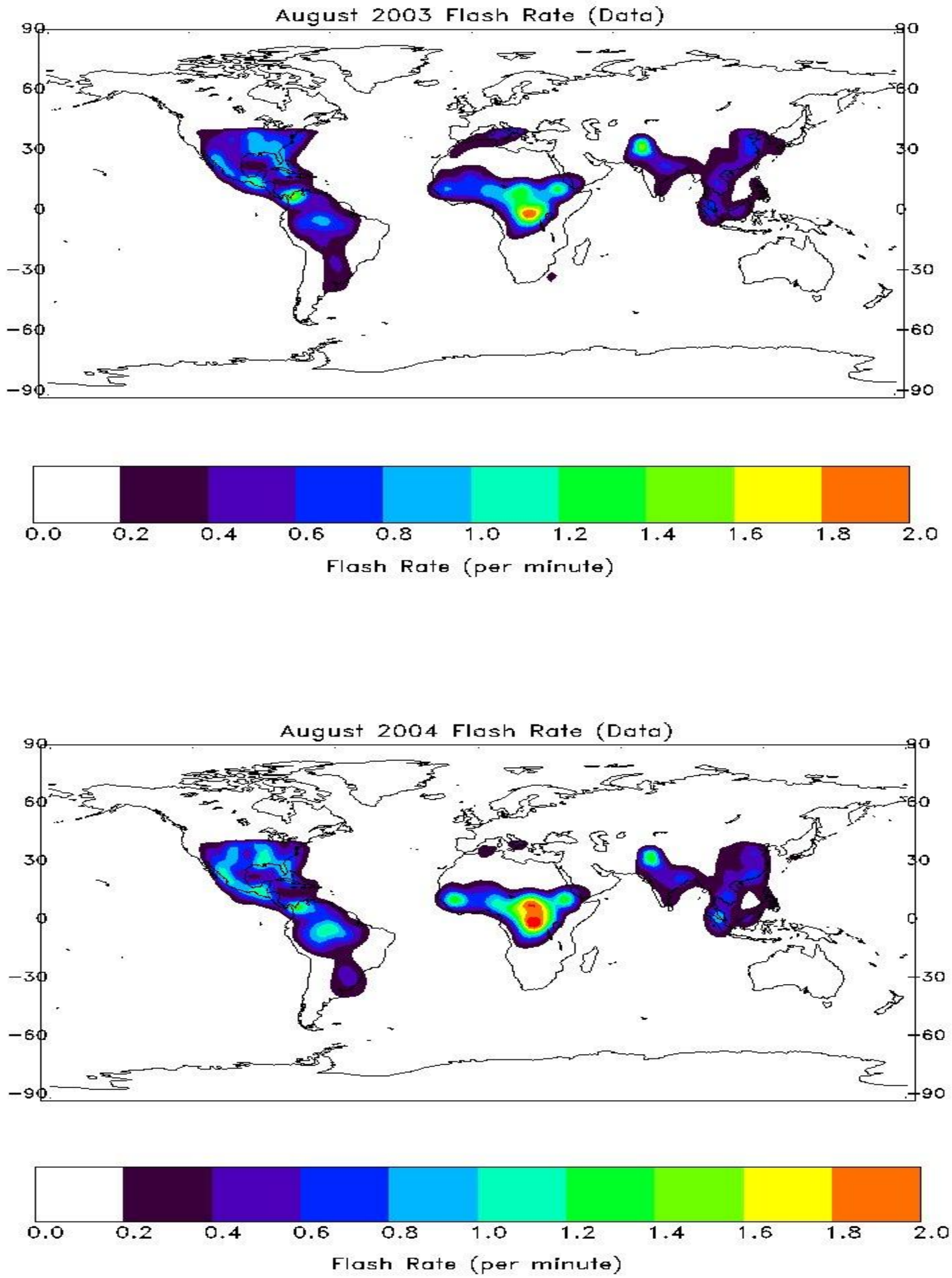


Figure 5 Top panel shows climatological OTD flash rates poleward of 35º and approximately 98-day average flash rates from LIS centered about August 2003 (Neutral month). Bottom panel shows climatological OTD flash rates poleward of 35º and approximately 98-day average flash rates from LIS centered about August 2004 (El Niño month).

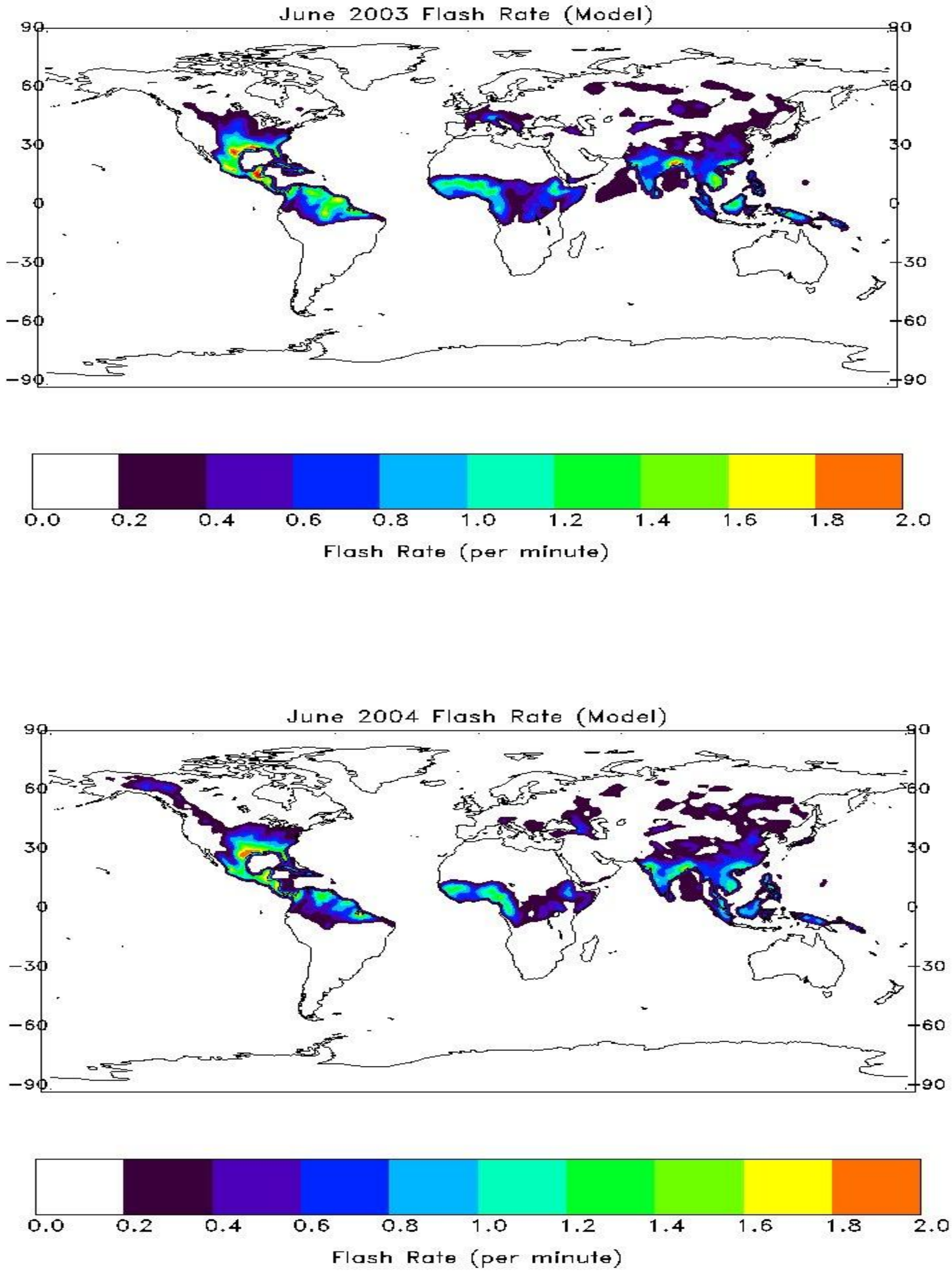
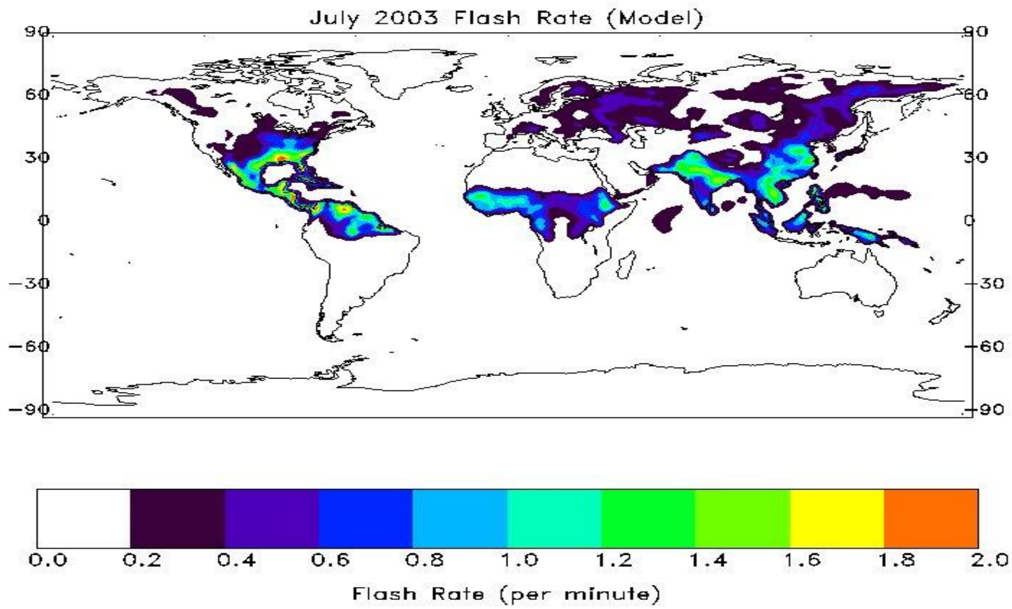


Figure 6 Top plot shows monthly average flash rates as parameterized using the 'reevap term' from the MERRA reanalysis for June 2003 (Neutral month). Bottom plot shows monthly average flash rates as parameterized using the 'reevap term' from the MERRA reanalysis for June 2004 (El Niño month).



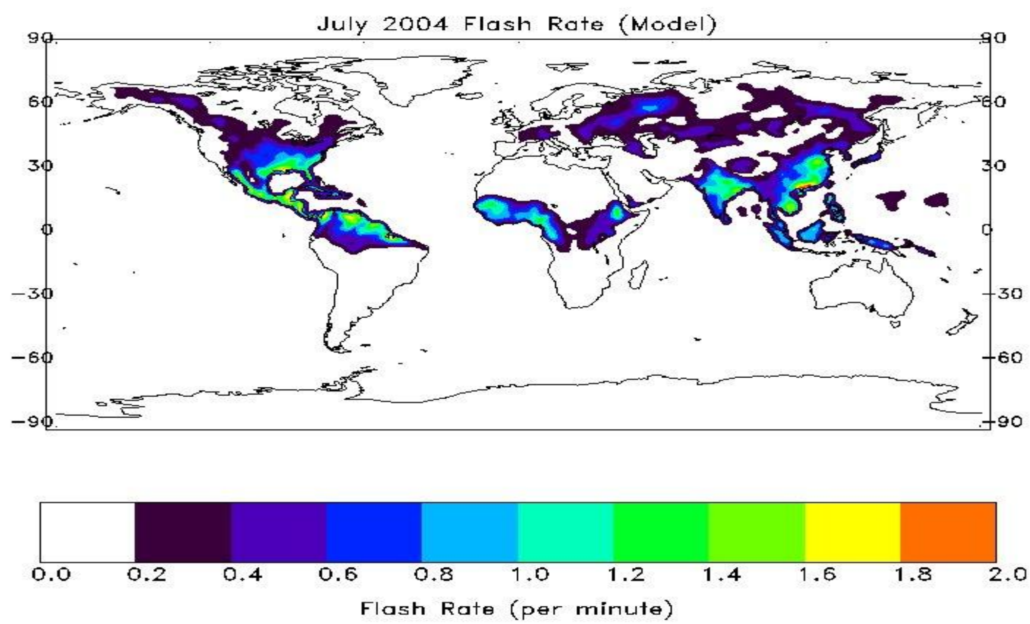
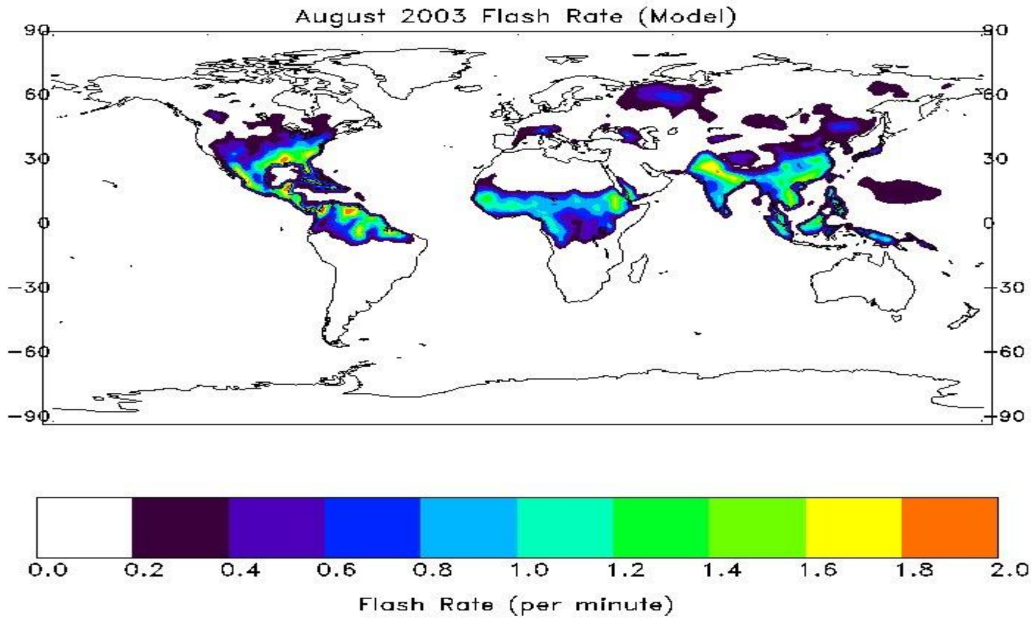


Figure 7 Top plot shows monthly average flash rates as parameterized using the 'reevap term' from the MERRA reanalysis for July 2003 (Neutral month). Bottom plot shows monthly average flash rates as parameterized using the 'reevap term' from the MERRA reanalysis for July 2004 (El Niño month).



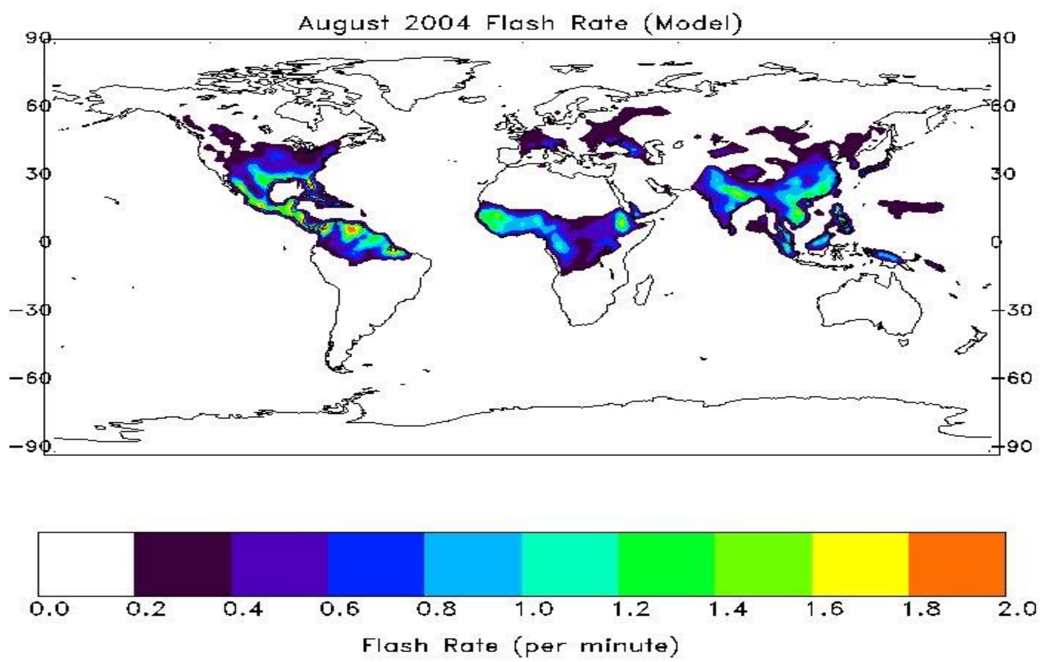


Figure 8 Top plot shows monthly average flash rates as parameterized using the 'reevap term' from the MERRA reanalysis for August 2003 (Neutral month). Bottom plot shows monthly average flash rates as parameterized using the 'reevap term' from the MERRA reanalysis for August 2004 (El Niño month).

The model flash rate was parameterized as: Flash Rate = K * (reevap term), where the variable K is chosen so that the global sum of [K * (reevap term)] equals the global flash rate from OTD/LIS version 1.2 climatology.

The results comparing the ‘Data’ for the neutral event (2003) and El Niño event (2004) differed slightly between the summer months of 2003 and 2004. June 2004 shows slightly greater flash rates in the southeastern United States, especially near the Alabama / Mississippi coast, compared with 2003. This is expected, since studies show that El Niño results in greater than average flash rates over the southeastern United States and Gulf Coast region. The ‘Data’ plots for June 2003 and June 2004 are fairly similar in most other regions around the world. The ‘Data’ comparison for July 2003 and July 2004 show similar results to those seen in June 2003 and 2004, with respect to the southeastern United States. July 2004, however, shows slightly greater flash rate values over Congo than June 2003. Lastly, the ‘Data’ results for August 2003 and August 2004 do not show much variation, except for a fairly high flash rate maximum over Congo in August 2004.

The results from the ‘Model’ plots show greater variation over different regions around the world for all three summer months of 2003 and 2004. You can see that the ‘Model’ depicts higher flash rate values over the southeastern United States in June 2004. During the month of July, however, the ‘Model’ suggests higher flash rate values over the southeastern United States in 2003, which is not expected, since studies show that flash rates are greater during El Niño conditions. The ‘Model’ does suggest lower flash rate values over India in July 2004, which is expected, since El Niño conditions produce drier than average conditions over that region. Lastly, the ‘Model’ plot for August 2003 and 2004 are very similar to July 2003 and 2004, with higher flash rate values in August 2003 (neutral month) over the southeastern United States and lower flash rate values in August 2004 over India.

Method

I. Case Study Analyzing the Relationship Between Lightning and ENSO Over the Gulf Coast

Currently, there are very few published studies that analyze the relationship between lightning and ENSO over the Gulf Coast area. LaJoie and Laing (2008) found using the NLDN lightning climatology, that the Gulf Coast region has the greatest flash density in the United States, with a peak over central Florida. They examine lightning distribution on a 2.5 kilometer grid scale at monthly, seasonal, and annual scales to see how these lightning distributions change under ENSO conditions.

In this study, the area of interest is the southeast United States and its adjacent waters over the Gulf of Mexico. Cloud-to-ground lightning flash records from the NLDN are used as the dataset and occur over an 8-year period, namely from January 1995-December 2002. The phases of ENSO are categorized by the National Oceanic and Atmospheric Administration’s (NOAA’s) Climate Prediction Center (CPC) (LaJoie and Laing, 2008). To ensure the greatest results, the majority of this study was conducted after the major NLDN upgrade. After the flash density maps of the 8-year dataset are developed, they are compared to lightning climatologies. Next, lightning variability was then compared with previous phases of ENSO to determine if there is any correlation between the two.

The authors found approximately 60 million flashes detected over the Gulf Coast region in the 8-year period with a minimum of 6.76 million flashes in 2000 and a maximum of 8.12 million flashes in 1997 (LaJoie and Laing, 2008). They also note that the annual totals were low with respect to the mean for 1998-2001 and high with respect to the mean for 1995-1997 and 2002 (LaJoie and Laing, 2008). The majority of lightning flashes occur during the summer, with July having about 10 times the number of flashes than December (LaJoie and Laing, 2008).

Figure 9 shows the 8-year average of cloud-to-ground flash density over the Gulf Coast (LaJoie and Laing, 2008). The maximum flash density has a value of 10.06 per km^2 per year and occurs near Tampa, Florida (LaJoie and Laing, 2008). There is also a secondary maximum in southeast Florida, which corresponds to findings in previous studies, i.e. Reap (1994) and Lericos et al. (2002) (LaJoie and Laing, 2008). This secondary maximum arises due to the convergence of the east and west sea breeze fronts (LaJoie and Laing, 2008). There is also a smaller maxima along the northern Gulf of Mexico in Louisiana, from the Mobile area to New Orleans and Baton Rouge.

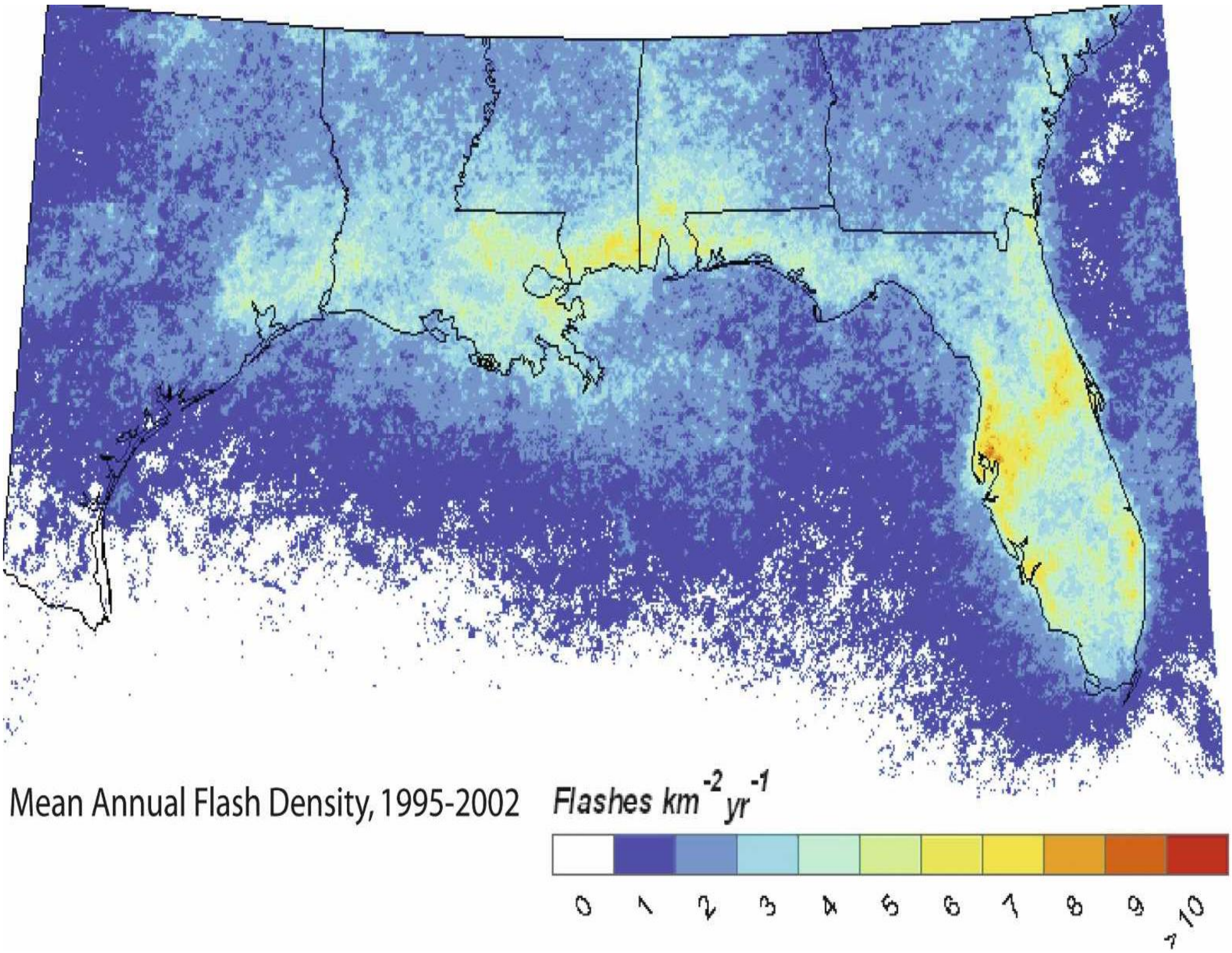


Figure 9 8-year mean annual flash density over the Gulf Coast region.

There is an observed value of 4-7 flashes per km² per year along the northwestern Gulf Coast region, in the Lake Charles area extending to the Houston area (LaJoie and Laing, 2008). Figure 9 also shows a decrease in flash density value as you go further away from land into the ocean, due to the fact that lightning is typically generated by convective processes and is far more common over land than water (LaJoie and Laing, 2008). Another reason is that detection efficiency significantly decreases the further you go away from land (Cummins et al., 1998).

An interesting result from this study is that enhanced flash densities are found along the coasts of the United States, mainly due to recurrent land and sea breeze circulations that can also be affected by coastline curvature and synoptic conditions (LaJoie and Laing, 2008). The intensity of lightning strikes decreases significantly as you move away from the coast toward the ocean, because the Gulf sea breeze circulation has less of an effect away from land and also convection is less intense over water than land.

LaJoie and Laing (2008) explain that the maximum flash density over the Gulf Coast occurs during the summer months. Specifically, July has the greatest number of lightning flashes, with a maximum number occurring over Florida. Figure 10 shows the average flash density for the Gulf Coast region for the 8-year period for June, July, and August, respectively. You can see from this figure that flash density values are significantly greater over the immediate Gulf Coast region and over much of Florida, with July and August having slightly greater values in these regions. The lowest average flash density over the 8-year period can be found in eastern Texas, near Houston and extending southward along the Gulf of Mexico coast. Overall, the majority of Florida experienced high average flash density values for all three summer months, but an interesting point is that southern Florida had a slight increase in average flash density in August. The main reason for the high flash density values in Florida is because of convergence from land and sea breezes, and not because of synoptic-scale effects.

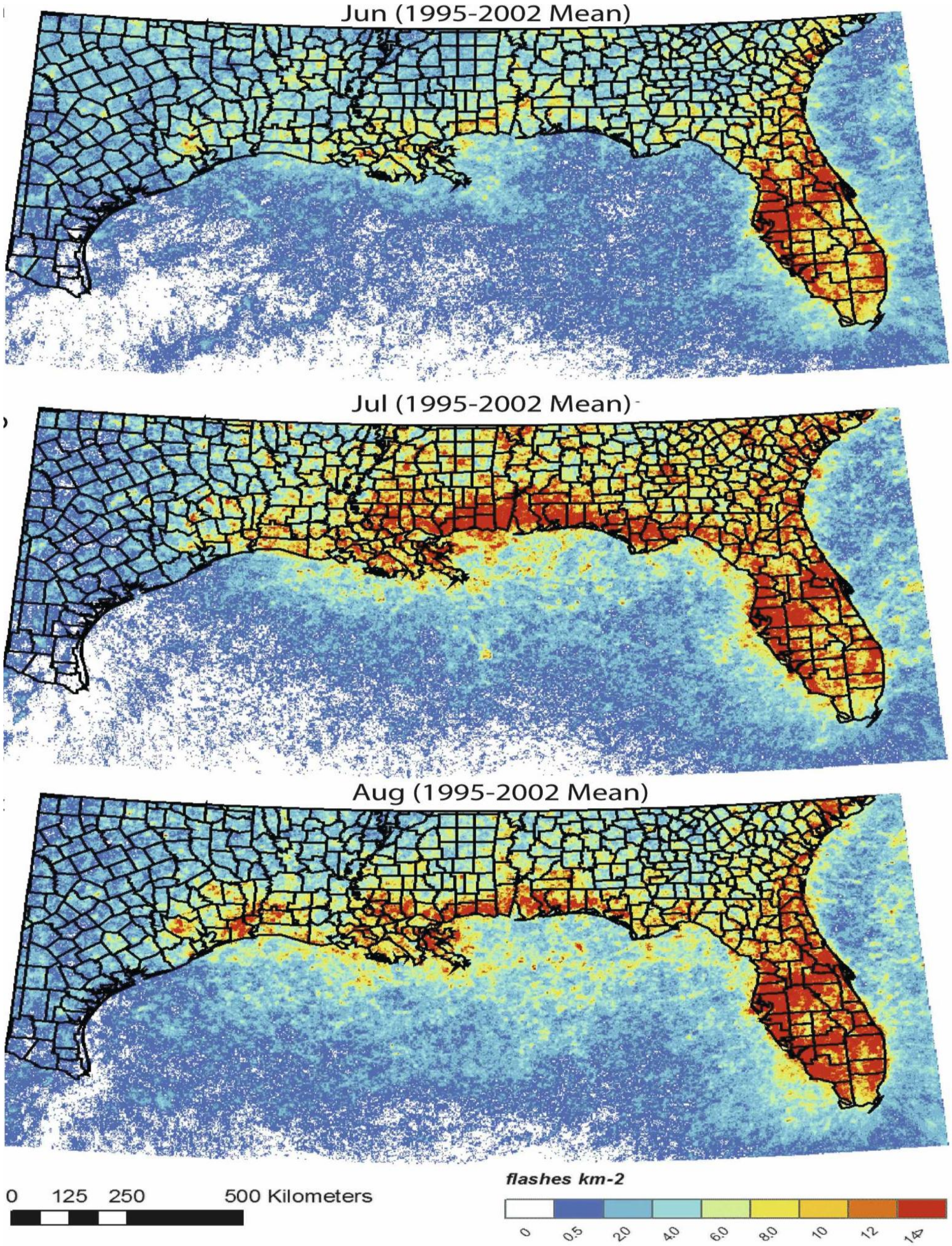


Figure 10 Average flash density (1995-2002) for June, July, and August.

The authors conclude that, even with a short study period, ENSO does in fact have an impact on lightning activity along the Gulf Coast (LaJoie and Laing, 2008). One of the strongest El Niño events on record occurred from 1997-1998, in which 1997 also happened to have the highest lightning anomaly. The lowest lightning anomaly occurred in 2000, which was also the year that had the lowest Oceanic Niño Index (ONI). Variations were also observed in spatial distributions and flash intensities in the seasonal and annual averages. In particular, the center of the Florida peninsula usually has moderate or high flash rates, but had a significantly lower average in 1997, due to an increase in northwesterly flow across the region. LaJoie and Laing (2008) also state that the summer months experience significantly less variability in lightning flash density, compared with the other seasons. Summertime thunderstorm activity occurs on a regular basis, due to the formation of airmass thunderstorms and thunderstorms generated by land and sea breeze circulations.

Results

Overall, the results from the ‘Data’ and ‘Model’ plots for the summer months of 2003 and 2004 are similar to what we expect during neutral and El Niño events. The majority of the summer months in 2004, for both the ‘Data’ and ‘Model’ plots, show higher flash rate values over the southeastern United States and lower flash rate values over India, which is expected during an El Niño event.

It is also evident that the El Niño-Southern Oscillation (ENSO) influences lightning activity along the Gulf Coast of the United States (LaJoie and Laing, 2008). In this study, lightning climatology maps were analyzed for the Gulf Coast region and then compared with flash density maps, which were constructed from 1995-2002. LaJoie and Laing (2008) analyzed the flash density maps to see if there was any correlation with active phases of ENSO. Results from this study show that the highest annual lightning flash rates occurred in 1997, at the same time the strongest El Niño event (1997-1998) was occurring. The lowest annual lighting flash rates occurred in 2000, which had mostly cool or neutral phases of ENSO occurring. Although the length of this period is relatively short (approximately 8 years), the lightning data and climatology used are fairly accurate and can be used to determine patterns or correlation between lightning flash rates and phases of ENSO. The results from this study are promising and the authors conclude that as more lightning data becomes available, further studies will be done to enhance these results.

Conclusion

Lightning is a meteorological phenomenon that is important to both meteorologists and atmospheric chemists. When lightning is emitted aloft, NO is produced and can interact with sunlight and other gases to create ozone in the troposphere (NASA / Goddard Space Flight Center, 2009). Ozone in the lower troposphere is known to have adverse effects on humans, as well as plant and animal life; however, stratospheric ozone is beneficial, as it blocks harmful ultraviolet radiation from reaching the Earth's surface (NASA / Goddard Space Flight Center, 2009). Because of these effects, it is extremely important for scientists to understand when and where lightning will strike and to determine how climate change will affect lightning, if at all.

Lightning detection networks, such as the NLDN, OTD, and LIS, are becoming a critical aspect when studying lightning and its characteristics. Although datasets from these networks have only been around since the mid-1990's or so, they are fairly accurate and provide a decent lightning climatology to use for research. Specifically, the performance of the NLDN has significantly improved since its major upgrade in the early 1990's. Flash and stroke detection efficiencies have drastically increased, creating a more accurate and reliable lightning detection network.

The result of the major upgrade to the NLDN proved to be successful in many ways, as indicated by a study performed by Biagi et al. (2007). Prior to the major upgrade, the flash detection efficiency of the NLDN was between 65% and 80% from 1992-1994 (Cummins et al., 1998). Currently, the flash detection efficiency on average is between 80% and 90% for first strokes with peak currents greater than or equal to 5 kA (Cummins et al., 1998). Biagi et al. (2007) conducted a study to evaluate the performance of the improved NLDN in detecting cloud-to-ground lightning across Arizona, Texas, and Oklahoma. They used video recordings of lightning flashes and GPS time, in which the flash and stroke detection efficiencies were determined by comparing the NLDN reports of cloud-to-ground flashes and strokes with those recorded on video (Biagi et al., 2007). Results from this study were impressive. Biagi et al. (2007) concluded that the flash detection efficiency for Arizona was 93%, while its stroke detection efficiency was 76%. In Texas and Oklahoma, the flash detection efficiency was 92%, while their stroke detection efficiency was 86% (Biagi et al., 2007). This study proved that the major upgrade of the NLDN has made great strides in improving the overall detection efficiency of lightning flashes (Biagi et al., 2007).

Recent studies have shown that phases of ENSO do influence lightning activity along the Gulf Coast region in the United States. It is important to understand how different ‘climate controls’ influence lightning distribution and to gain a better understanding of the factors that influence convection and possible lightning flashes (LaJoie and Laing, 2008). According to the study conducted by LaJoie and Laing (2008), the highest annual lightning flash rates were found during years when El Niño, the warm phase of ENSO, was occurring. It is also important to note that LaJoie and Laing (2008) found that lowest annual lightning flash rates occurred when a neutral or cool-phase of ENSO was present.

As you can see, it is important to understand lightning distribution and the factors which contribute to lightning development. Scientists are interested in learning more about lightning variability and how it is affected by various climate fluctuations. The current lightning detection networks used by scientists today now provide more accurate measurements and climatology datasets and will only continue to improve in the future.

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