The Spatial Relationship Between Lightning and CAPE

By
Stephanie Bradshaw

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Carthage College
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Abstract

Thunderstorm formation depends on environmental stability and the existence of electrification mechanisms. Because electrification mechanisms such as the ice-graupel collision process, described with the Relative Diffusional Growth Rate Theory, depends on convection for charge separation, and convection relates to Convective Available Potential Energy (CAPE), the relationship between CAPE and lightning is determined. A Spearman Rank Correlation revealed a small positive correlation between lightning and CAPE, and corresponding p-values indicate this correlation is significant. The evaluation of the relationship between CAPE and lightning lends meaningful insight into thunderstorm formation and electrification, providing an understanding that can enhance severe weather forecasting products.
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1 Introduction

1.1 Problem Statement

Thunderstorms have been found to develop differently depending on their environment. Because of this, it comes as no surprise that the phenomena associated with thunderstorms are also affected by varying environmental conditions. Since non-inductive electrification mechanisms rely on convection and gravity to separate charged particles, the amount of convection in a thunderstorm influences the amount of lightning in a storm. When the conditions favor the development of significant convective regions in a thunderstorm, the storm is more likely to support electrification mechanisms and produce copious amounts of lightning. On the other hand, conditions without significant convection tend to produce less lightning because the electrification mechanism is not supported as well as the conditions favoring high convection. In this study, I hypothesize that a positive correlation exists between convective available potential energy (CAPE) and lightning because electrification processes within thunderstorms depend on convection for charge separation and CAPE indicates the potential for the environment to become unstable, leading to convection.

1.2 Thunderstorm Formation

In order to more completely motivate a spatial comparison between CAPE and lightning it is first necessary to consider thunderstorm formation. Thunderstorms form out of unstable environments created as a result of an unequal distribution of heating, which drives atmospheric motions. Radiation from the sun strikes the Earth at varied angles of incidence, which causes some regions on Earth to receive more energy than others. Averaged over a year, the poles experience a net energy deficit (cooling) because they have more outgoing longwave radiation than absorbed solar radiation. On the other hand, the tropics experience an energy surplus (radiative) because the amount of solar radiation exceeds the amount of
outgoing longwave radiation. Consequently, the tropics tend to be warmer than the poles and are constantly being heated by radiation. Warm air is less dense than cold air at a given pressure according to the ideal gas law, so gradients in heating create density (and by extension, pressure) gradients (Lutgens and Tarbuck 2010; Moran 2012). Pressure (force per area) gradients drive atmospheric motions as air flows from high pressure toward low pressure.

Less dense, rising warm air leads to unstable environments favorable to thunderstorms. As long as the air is warmer than its surroundings, it will continue to be unstable, to rise, and to build clouds. Once the clouds grow large enough, they enter into the thunderstorm growth stages. The first stage of thunderstorm growth is called the cumulus stage and is characterized by vertically growing clouds and updrafts, which form as a result of upward flowing air that is warmer than its surroundings. Eventually, precipitation forms and is released from the cloud, marking the second stage of thunderstorm formation called the mature stage (Lutgens and Tarbuck 2010; Moran 2012). In order for precipitation to form, cloud droplets must grow to be roughly one million times their volume, and they do so by the Bergeron process or the collision-coalescence process (Lutgens and Tarbuck 2010). Precipitation is released from the downdraft region of a thunderstorm, so the development of a downdraft alongside of an updraft is characteristic of the mature stage of a thunderstorm. The last stage of thunderstorm development is called the dissipating stage. Here the storm begins to become stable again. The updrafts formed from relatively warm air are no longer present, and only downdrafts remain (Lutgens and Tarbuck 2010; Moran 2012).

1.3 Lightning Formation

Thunderstorms are well known for their capabilities of producing an electrical environment suitable for lightning development. The objective of lightning is to equalize the charge differences between the distinctly charged regions of a thunderstorm (Lutgens and Tarbuck
Once the electrical potential between the charged regions is high enough, a lightning discharge will occur. When the discharge begins, branches of charge, called stepped leaders, stream from the cloud. As the leader approaches the ground, the electric field near the surface of the Earth becomes large and another channel streams from the ground toward the cloud (Geophysics Study Committee et al. 1986; Lutgens and Tarbuck 2010; Moran 2012). These channels meet, and current flows through the channel forming a lightning stroke. Forty to eighty milliseconds after the initial lightning stroke, a leader, called a dart leader, forms along the previous channel (Geophysics Study Committee et al. 1986). Dart leaders initialize another lightning stroke called a return stroke. Each lightning flash, as seen with the human eye, can contain multiple return strokes following the same channel. Typically two to four return strokes accompany a lightning discharge (Geophysics Study Committee et al. 1986; Moran 2012).

The process described above provides details for the formation processes for a lightning discharge between a cloud and the ground, but there are different types of lightning. Cloud-to-ground (CG) lightning can be either positive or negative, and lightning can occur between charged regions inside of the clouds. Negative CG lightning forms when the stepped leader is negatively charged and connects to a positively charged channel from the ground. On the other hand, positive CG lightning is formed when a positive leader connects to a negative channel from the ground. Lightning occurring inside of the clouds is called intra-cloud lightning (IC) (Geophysics Study Committee et al. 1986; Lutgens and Tarbuck 2010). Most of all lightning is IC lightning (Lutgens and Tarbuck 2010). However, CG lightning has been studied more vigorously than IC lightning because CG lightning tends to cause the most destruction to humans. Positive CG, negative CG, and IC lightning are the three main types of lightning, but there are more, less commonly encountered classifications of lightning such as gigantic jets, which occur when lightning travels vertically, through the top of a thunderstorm (Moran 2012).
1.4 Lightning Detection Methods

1.4.1 Ground-based Data

To study lightning, ground based sensors detect electromagnetic waves associated with lightning, which is especially useful to detect and locate lightning. These electromagnetic waves can be studied in the very high frequency (VHF) range of the electromagnetic spectrum (3-300 MHz) or in the low frequency (LF) and very low frequency (VLF) ranges (3- 300 kHz). Studying VHF and VLF/LF portions of the electromagnetic waves provide useful insight into different aspects of lightning. Analyzing the VHF portion of the electromagnetic waves has allowed for the imaging on whole lightning channels in three dimensions, while analyzing the LF or VLF portion of the electromagnetic waves has allowed the location of the lightning to be pinpointed. There are specific techniques used to study the frequencies associated with lightning generated electromagnetic waves including electric and magnetic field amplitude techniques, magnetic field direction finding, and time arrival techniques (Rakov and Uman 2006). The electric and magnetic field amplitude techniques work with mathematical formulas representing the electric or magnetic field amplitude and the distance from the sensor to the location of the lightning process which is an unknown. Collecting enough measurements allows for the unknown location to be solved for. The magnetic field direction finding method utilizes vertical and orthogonal loop antennas, and the time of arrival method investigates the arrival time of the electromagnetic field signal to the sensor.

Various ground-based lightning detection networks use the techniques mentioned above to detect and locate lightning on Earth. Furthermore, multiple sensors or stations are generally set-up and used to detect lightning using triangulation methods. The triangulation methods associated with multiple sensors are capable of detecting the location of the lightning process, while single sensors are limited to detecting the occurrence of lightning, but not the location of the individual lightning flashes. This is why the multiple sensor technique is generally used for ground-based networks. There are various lightning detection networks
throughout the world that use this multi-sensor technique along with combinations of the electric and magnetic field amplitude techniques, the magnetic field direction finding techniques, and the time arrival techniques. The U.S. National Lightning Detection Network (NLDN) is one such network. The NLDN combines the magnetic field direction finding method and the time of arrival methods (Rakov and Uman 2006). Another ground based network dedicated to detecting and locating lightning is the World Wide Lightning Location Network (WWLLN). According to a study by Hutchins et al. (2012), the WWLLN had sixty VLF stations as of April 2012. The more stations a network has, the better detection accuracy obtained (Hutchins et al. 2012).

1.4.2 Satellites

Ground-based sensors are useful for studying lightning processes, but they are not the only option. Some satellites have single station optical sensors, which detect light scattered by clouds (Rakov and Uman 2006). The accuracy of these satellites are limited and they can not detect if the lightning is CG or IC. Despite these limitations, satellites have proven to be useful in various studies such as the Bailey et al. (2007) study on diurnal lightning distributions using the Optical Transient Detector (OTD) and the Lightning Imaging Sensor (LIS) (Bailey et al. 2007). Other satellites used for lightning detection include two in the Defense Meteorological Satellite Program (DMSP), the Sounding Satellite ISS-b, and the Blackbeard receiver on the Alexis Satellite. The DMSP satellites primarily detected lightning around dusk, dawn, and midnight. The Sounding Satellite ISS-b sensed high frequency radiation, and the Blackbeard receiver detected radio frequency emissions in the very high frequency realm of the electromagnetic spectrum (Rakov and Uman 2006). Using satellites for detection and location of lightning has capabilities of being very useful in lightning research for the future, but require some further advancement to reduce their limitations.
1.5 Electrification

As mentioned earlier, lightning formation requires charge separation, which forms as a result of electrification mechanisms. Investigating thunderstorms by deploying balloons into thunderstorms, has allowed for the study of these separated charge regions by measuring electric fields (Stolzenburg and Marshall 2008). Electric field data indicates these charge regions typically form normal polarity tripole structures, which are composed of lower positive, middle negative, and upper positive charge regions. Inverted polarity structures are also possible with a charge structure opposite the normal polarity thunderstorm (lower negative, middle positive, and upper negative charge regions), but the conditions in which inverted polarity storms form are not well understood (Rust et al. 2005). Both normal and inverted polarity structures are further complicated by screening charges and by variability of meteorological conditions within thunderstorms. Screening charges typically form around the borders of the thunderstorm as a natural consequence of the conductivity of the atmosphere.

Although thunderstorms typically exhibit tripole structures, they can be more complicated depending on the convective activity in a storm. As mentioned earlier, inside of a thunderstorm, updraft and non-updraft (or downdraft) regions can exist. Updraft regions experience vertical velocities exceeding one meter per second. Non-updraft regions experience downward vertical motion or heavy precipitation. The updraft and non-updraft regions inside of a thunderstorm tend to produce varied charge structures. Figure 1 shows the difference between the charge regions in an updraft versus a non-updraft region as adapted from Stolzenburg and Marshall (2008). The updraft regions tend to have a normal tripole structure, while the non-updraft regions tend to form a more complicated structure with extra charge regions.

The dominant theory to account for the separation of charge in thunderstorms is called the Relative Diffusional Growth Rate Theory, which proposes a non-inductive charging method where charge is transferred as a result of collisions between ice and graupel (a soft
hail formed when super-cooled water rimes a snowflake) particles (Saunders 2008; Moran 2012). During an ice-graupel collision, the particle growing fastest by vapor diffusion loses mass and the negative charge associated with it (Dash, Mason, and Wettlaufer 2001). The mass lost and gained is associated with negative charge because of the way ions diffuse in the particle. Therefore, a neutrally charged particle that loses mass during a collision will become positively charged because there are less negative charges than positive charges. After charging, the particles move by gravity and convection to form regions of charge within a thunderstorm, which is necessary for lightning formation. Since graupel is larger than an ice particle, it is more likely to fall down with gravity, while the ice particle is more likely to move upwards with convection in a thunderstorm (Saunders 2008). Figure 2 shows a collision between a graupel and an ice particle and the resulting charge. Figure 3 shows how the Relative Diffusional Growth Rate Theory could work within a normal polarity tripole structure thunderstorm.
Figure 2: A depiction of the Relative Diffusional Growth Rate Theory as a graupel particle (large particle) collides with an ice particle (small particle). The particles have an inner positive charge region (red) and outer negative charge region (blue). The amount of color in and the size of each particle are not drawn to scale. The top row represents the graupel particle as growing faster than the ice particle. The bottom row represents the ice particle growing faster than the graupel particle. The up and down arrows indicate the direction of particle motion with gravity and convection.

Figure 3: A representation of the Relative Diffusional Growth Rate Theory in a normal polarity thunderstorm. The color scheme and particle orientation follow Figure 2.
1.6 Convective Available Potential Energy

The formation of lightning is dependent on charge separation by the ice-graupel electrification mechanisms, which suggests a relationship between lightning and convection because the charge separation after an ice-graupel collision depends on convection and gravity. Convective available potential energy (CAPE) is related to convection because CAPE is a measure of the instability in the environment. In unstable environments, a parcel of air, which is relatively warmer than the surrounding air, rises because it is less dense than the surrounding air. CAPE is a measure of the energy an air parcel has as it rises a certain distance through the atmosphere. More specifically, CAPE is determined mathematically using the integral given below where $F$ is the upward buoyancy force per unit volume on the rising air parcel, $\rho'$ is the density of the air parcel, $LFC$ is the level of free convection, $EL$ is the equilibrium level above which the parcel is no longer warmer than its environment, and $z$ represents a vertical distance (Wallace and Hobbs 2006). Convection feeds on the potential energy (represented by CAPE) inherent in the temperature and moisture stratification as a parcel of air moves vertically in the atmosphere.

$$CAPE = \int_{LFC}^{EL} \left( \frac{F}{\rho'} \right) dz$$  

Furthermore, CAPE is described as the area between $EL$ and $LFC$ on a skew-T ln p plot, hence the use of the integral in the equation. Based on this equation, CAPE represents the energy of a warm parcel of air as it moves through the atmosphere to the point where it is no longer unstable. CAPE is measured here in Joules per kilogram. Generally it is thought that CAPE values between 1000 and 2500 J/kg are adequate to support moderate convection, values between 2500-4000 J/kg are adequate to support strong convection, and values greater than 4000 J/kg indicate a potential for extreme convection (Wallace and Hobbs 2006). Because CAPE is thought to relate to convection, due to it being a measure
of the potential for instability in the environment, and because thunderstorm electrification mechanisms depend on convection for charge separation, there is a potential relationship between CAPE and lightning globally.

### 1.7 Geographic Relationships Between CAPE and Lightning

The geographic variations of lightning are expected to support the relationship between lightning and CAPE. Lightning strokes in oceanic storms are found to be stronger than those over the land and intense negative lightning discharges have been observed more often over the ocean than over the land (Hutchins 2013). However, thunderstorms located over land tend to produce more lightning in general than storms located over the ocean (Altaratz et al. 2003). According to a study near Papua New Guinea as mentioned in Rakov and Uman (2006), lightning flash counts were nine times higher over the land than over the ocean (Rakov and Uman 2006). Another such study mentioned was done using the OTD and LIS satellite lightning detection systems, which found the same trend. Ocean storms tend to produce less lightning than continental storms. There have been some exceptions to this trend such as the Altaratz et al. (2003) study on Mediterranean storms. In this case, the larger frequencies of ground flashes were found to be over the sea rather than the land, but this could be due to the Mediterranean modifying a colder air mass originating from Europe, which would cause an increased moisture content leading to a decrease in stability (Altaratz et al. 2003).

There are some suggestions for why oceanic storms generally produce less lightning than continental storms. Hutchins et al. (2013) suggested lightning frequency data could be offset because oceanic storms do not occur as often. Another explanation, which is perhaps more commonly used, is the difference in lightning frequency between the ocean and land masses could be because of the way thunderstorms electrify. As mentioned earlier, the ice-graupel electrification mechanism involves the separation of charges by convection and
gravity after collisions occur. Because of this dependence on convection, oceanic storms are thought to form with updrafts that are weaker than the threshold needed to allow for the occurrence of ice-graupel electrification processes (Rakov and Uman 2006). Lower vertical velocities associated with weaker updrafts leads to slower cloud evolution and inefficient charge separation (Altaratz 2003). Without the conditions necessary for electrification, a lightning discharge can not occur. Furthermore, the difference in lightning frequency over the land and over the ocean can be related to CAPE. During the afternoon, heating of the land surface greatly enhances CAPE, which gives rise to more vigorous convection, and more lightning over the land (Wallace and Hobbs 2006).

1.8 Summary

Since electrification mechanisms, such as the ice-graupel mechanism described with the Relative Diffusional Growth Rate Theory, rely on convection to separate charged particles, the amount of convection in a thunderstorm influences the amount of lightning in a storm. CAPE, a measure of the potential energy of an air parcel and an indicator of environment stability, is related to convection because convection occurs as a result of instabilities. This suggests the existence of a relationship between CAPE and lightning. To characterize this relationship, correlations are computed and evaluated in this study.

1.9 Hypotheses

\( H_O \): The amount of convective available potential energy does not correlate positively to the frequency of lightning on earth.

\( H_A \): The amount of convective available potential energy correlates positively to the frequency of lightning on earth.
2 Data and Methods

Era-Interim Reanalysis data, the World Wide Lightning Location Network (WWLLN) lightning data, and Python are utilized in this study to investigate the relationship between lightning and CAPE globally. ERA-Interim reanalysis data is produced by the European Centre for Medium-Range Weather Forecasts (ECMWF) and is based on the 2006 release of IFS (Cy31r2) (Berrisford et al. 2011). This particular set of reanalysis data includes cumulative surface CAPE in three hour time steps for the years 1979 until present day. However, this study examines CAPE for July and August 2015 between 15:00 to 18:00 UTC, which is an active time period for thunderstorms in Africa. It also includes up to 80 km spatial resolution.

For each lightning stroke detected, the WWLLN lightning data includes the date, time, location with regards to latitude and longitude, residual fit error, number of WWLLN stations participating in the location fit, the RMS energy of the stroke, the energy uncertainty, and the subset of stations between 1000 and 8000 km from the stroke that were used in the energy estimate. In particular, this study examined the global lightning strokes spatially for the time period corresponding to the CAPE data (July and August 2015 between 15:00 and 18:00 UTC).

To study the relationship between lightning and CAPE, the CAPE and lightning per area are compared to one another using a Spearman correlation, which is taken over many points at different geographical locations. The Spearman correlation technique was chosen because it does not assume a normal distribution of data (Triola 2015). From this technique correlation coefficients and p-values are determined, indicating the strength of the correlation and the probability of the correlation to occur in a random environment. A comparison of the findings with visual maps, lends additional insight into correlation patterns.
3 Results

As indicated above, CAPE and lightning are compared to determine if a correlation exists between the two. Figure 4 contains CAPE maps for each day evaluated in this study. Between each individual map, variations in CAPE can be seen. In particular, one example of the variability of CAPE is a difference in CAPE in the Gulf of Mexico through the month of July. At the beginning of July (1st and 8th), there is a region of CAPE with values between 3200 and 4000 J/kg. Towards the end of July (22nd and 29th) these values have decreased to be between 2000 and 4000 J/kg. This indicates CAPE does vary on these weekly time scales on a month to month basis as used in this study.

Spatial patterns are revealed between the CAPE maps. Some of the highest CAPE values appear over the ocean (Persian Gulf region as on August 8th with a CAPE value of about 11000 J/kg). There are also values of high CAPE that appear over continents such as a region in India on July 29th with a CAPE value around 4800 J/kg, but these values of CAPE tend to be lower in magnitude than those over the ocean. Another example of this is on July 1, 2015. The regions of high CAPE on this day tend to be over the ocean or on the border of the continents as it is in the Gulf of Mexico, near India, in the Persian Gulf, and near the South China Sea. There are regions of CAPE on the continents on this day such as over Africa, but the oceanic CAPE values are greater (around 4800 J/kg or greater for oceanic compared to 2400 J/kg values or less in Africa). Spatial patterns are also present with regards to latitudinal zones. On all the maps in Figure 4 regions of CAPE greater than zero appear near the equator, the surrounding tropical regions, or in the midlatitudes (23.5S to 23.5N) with emphasis in the Northern Hemisphere.
Figure 4: Global CAPE where the colors given in the color bars to the right of the images represent CAPE in Joules per kilogram.
Figure 5 shows the lightning corresponding to the same time period as the CAPE maps. Comparing each of the lightning maps reveals similarities between the spatial location of lightning. With regards to latitudinal zones, lightning generally occurs between 23.5 degrees south and 23.5 degrees north. Though lightning does occur over the ocean, as indicated by lightning off of the coast of the United States in the Atlantic Ocean, it primarily occurs over land. Most of the lightning found on the maps in Figure 5 are located in or very close to Africa, North America, Europe, and Southeast Asia. This is consistent with observations made by Hutchins (2013), Altaratz et al. (2003), and Rakov and Uman (2006). However, this pattern does not always follow the regions of highest CAPE because some of the highest CAPE regions are found over the ocean as indicated in Figure 4.

Looking more closely at CAPE and lightning, there are some examples where high CAPE regions correspond to lightning and some examples where high CAPE does not correspond to lightning. The Persian Gulf region of high CAPE on August 8th, does not have any lightning on that same day. However, in Africa on July 8th, there is a region of relatively high CAPE, where lightning strikes are observed. Similarly, on July 22nd there is lightning in the same locations as the high CAPE region in Europe and near India. From these observations it is apparent that lightning does occur in regions of high CAPE, but there are regions of high CAPE without lightning.
Figure 5: Global lightning distribution where the green dots represent lightning.
Figure 6: A logarithmic comparison between lightning and CAPE with the line of best fit given in red.
To conceptualize the relationship between lightning and CAPE quantitatively, the lightning per area is compared to CAPE. To do this, the data points were compared on a logarithmic scale and a line of best fit was determined. The best fit line takes on the form of a power law because of the logarithmic scale. The formula for such an equation is given below in equation 2, where $A$ and $b$ are fitting parameters specific to each date evaluated.

$$CAPE = A \times \text{Lightning}^b$$  \hspace{1cm} (2)

Figure 6 shows the logarithmic comparison between lightning and CAPE as well as the line of best fit. As seen visually in the graphs, for all dates evaluated, the slopes of the lines were slightly positive. Also, the graphs indicate that high CAPE can correspond to low lightning, but most of the high lightning data points appear to occur in regions with high CAPE. For example, on August 8th, there are four data points towards the lower left hand corner of the graph, which indicates some lightning occurred with low CAPE. However, the vast majority of the points correspond to regions of higher CAPE. Furthermore, towards the right side of the graph, at values of high lightning, there are not any data points near the low CAPE values. This pattern occurs in all of the graphs given in Figure 6.

To quantify this relationship and determine the relationship’s significance, a Spearman rank correlation is used, and the results of this are given in Table 1. The Spearman Rank Correlation Coefficients ranged between 0.163 and 0.267, which indicates a small positive correlation. This correlation is significant as evident with the very small p-values. Therefore, CAPE correlates positively to lightning, and this correlation is significant.
Table 1: The spearman correlations and corresponding p-values between global CAPE and lightning for July and August 2015.

<table>
<thead>
<tr>
<th>Date</th>
<th>Correlation Coefficient</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 1, 2015</td>
<td>0.175</td>
<td>$3.61 \times 10^{-17}$</td>
</tr>
<tr>
<td>July 8, 2015</td>
<td>0.189</td>
<td>$6.48 \times 10^{-21}$</td>
</tr>
<tr>
<td>July 15, 2015</td>
<td>0.267</td>
<td>$5.18 \times 10^{-44}$</td>
</tr>
<tr>
<td>July 22, 2015</td>
<td>0.139</td>
<td>$8.87 \times 10^{-14}$</td>
</tr>
<tr>
<td>July 29, 2015</td>
<td>0.194</td>
<td>$2.57 \times 10^{-21}$</td>
</tr>
<tr>
<td>August 1, 2015</td>
<td>0.196</td>
<td>$1.65 \times 10^{-27}$</td>
</tr>
<tr>
<td>August 8, 2015</td>
<td>0.210</td>
<td>$8.33 \times 10^{-27}$</td>
</tr>
<tr>
<td>August 15, 2015</td>
<td>0.205</td>
<td>$2.60 \times 10^{-26}$</td>
</tr>
<tr>
<td>August 22, 2015</td>
<td>0.257</td>
<td>$1.93 \times 10^{-38}$</td>
</tr>
<tr>
<td>August 29, 2015</td>
<td>0.163</td>
<td>$1.10 \times 10^{-17}$</td>
</tr>
</tbody>
</table>

4 Discussion

As mentioned earlier, high CAPE values are thought to correlate with lightning. Wallace and Hobbs (2006) mentioned CAPE values between 1000 and 2500 Joules per kilogram are adequate to support moderate convection, values between 2500-4000 are adequate to support strong convection, and values greater than 4000 indicate a potential for extreme convection. All of the CAPE maps given in Figure 4 indicate the high CAPE values for each map are above these thresholds. Therefore, it is surprising to find values of high CAPE without lightning as indicated in the tables in Figure 6 and visually when comparing Figure 5 and Figure 4.

Furthermore, as mentioned earlier, generally, there are higher lightning frequencies over the ocean than over the land as indicated by Rakov and Uman (2006) and Hutchins (2013). However, the high CAPE values tend to be over the ocean rather than over the land. This indicates there is more instability and potential in an oceanic environment to produce convection than a continental environment, which is in conflict Hutchins et al. (2013), Altaratz et al. (2003), and Rakov and Uman (2006). These studies indicated there are more storms (at least lightning producing storms) over the land than over the ocean. With more
potential for instability as indicated by CAPE over the oceans, one might think there would be more storms over the ocean than over the land.

Altaratz (2003) suggested a reason for higher lightning counts over the land could be because there exists lower vertical velocities over the ocean than over the land, and these vertical velocities are essential for electrification, which is consistent with the Relative Diffusional Growth Rate Theory. Wallace and Hobbs (2006) support this by indicating land surface heating greatly enhances CAPE, leading to more vigorous convection over the land. If this is the case, then why are the high CAPE regions generally found over the ocean, and why are they not always associated with lightning? Perhaps the potential for instability measured in CAPE, does not directly relate to convection, or the electrification processes (ice-graupel collisions) are not entirely reliant on convection for separation of charges. Another explanation could be that the WWLLN is not as sensitive to IC lightning as it is to CG lightning. If IC lightning occurs more often than CG lightning over the oceans, then perhaps the lightning data set used in this study is missing some information. These possible explanations for this observation need to be investigated in future studies.

Other future studies include looking at time zones, geographical variability, and a seasonal dependence on the lightning and CAPE relationship. In this particular study, a time period from 15:00 to 18:00 UTC was used, which happens to be a time of high thunderstorm activity in Africa, but not necessarily in other parts of the world. In order to examine how this could change the results, a future study can split the world into its respected time zones and compare CAPE and lightning for the time periods that correspond to one another (i.e. in the afternoon over the entire globe). It would also be interesting to see how the relationship between CAPE and lightning would change over time, which could be analyzed using time series at various locations. Also, there could be geographical components influencing the results of this study (such as the ITCZ), so another idea for a future study would be to analyze potential geographic influences on CAPE and lightning.
5 Conclusion

CAPE and lightning have been compared to determine if a correlation exists between them. Although there were some instances where high CAPE occurred without high lightning counts, the correlations and p-values found when comparing lightning and CAPE indicated a small, but significant, positive correlation. For this reason, the null hypothesis, which stated CAPE and lightning do not correlate, can be rejected with reasonable confidence. There is a relationship between lightning and CAPE. However, this simple correlation is not the whole story of the data as indicated with high CAPE occurring without lightning. Further analysis needs to be done to explore why high CAPE does not always indicate high lightning counts. Exploring this topic further could provide an enhanced understanding of lightning and electrification processes inside thunderstorms.

References


