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LIGHTNING: METEOROLOGY'S NEW TOOL

Nicole Kufa* and Richard Snow

Embry-Riddle Aeronautical University, Daytona Beach, Florida

1. INTRODUCTION

Lightning strikes the earth about 100 times every second, and it is deadlier than any other natural phenomenon, so why don't we know more about it (Robinson, 1993)? One reason may be because it is hard to gather data in an environment with violent updrafts and downdrafts, and about 125 million gallons of water being released as rain. One can imagine what the instruments on a weather balloon experience after reading William H. Rankin's, a U.S. pilot, amazing experience ejecting at 47,000 feet and negative 70 degrees Fahrenheit from his aircraft after it was tossed around when he was caught in the middle of a thunderstorm in July 1959,

> I became a molecule trapped in the thermal pattern of the heat engine, buffeted in all directions…I zoomed straight up, straight down, feeling all the weird sensations of G forces – positive, negative, and zero… All this time it had been raining so torrentially that I thought I would drown in mid-air (Robinson, 1993, p. 118).

The middle of a thunderstorm may very well be the most violent place on the planet, and born from it all, is the mysterious phenomenon we call lightning (fig. 1).

Recently, scientists who study lightning have graduated from looking at the basics of lightning characteristics such as its current, flash rate, or multiplicity. They have taken a step further, applying what they know about lightning, especially lightning with positive polarity, to predict the environment a storm is in and also to predict the formation of tornadoes in severe storms. In the present paper, the role positive lightning plays as meteorology's new prediction tool is examined. The following studies demonstrate that the development of lightning patterns in a storm may signal the formation of a tornado or reveal the environment a storm was developed in or into which it is moving.

2. LIGHTNING FORMATION

First, it is important to discuss how lightning is formed. Uman (1971) describes the process. Lightning transfers electrical charge from the atmosphere to the ground, so in order for it to occur, a region of the atmosphere has to accumulate a large enough charge to electrically break down the insulation of the air between it and the ground. In a thunderstorm, this tends to happen many times. Within a thunderstorm, updrafts and downdrafts move particles around the cloud, and they eventually collide. The collisions create light, positively-charged particles that are blown upwards, and heavier, negatively-charged particles that fall to the lower region of the thundercloud. It is also thought that there is a small region of positive charge that sits at the very bottom of the cloud. Interestingly, the base of the negative region is roughly at the freezing level of the atmosphere. The lower the altitude of the freezing level, the more cloud-to-ground lightning, rather than intracloud lightning, the cloud will produce. Therefore, a lightning pattern with a high ratio of cloud-to-ground lightning compared to intracloud lightning would happen in latitudes closer to the poles. In warmer areas, such as the equator, the ratio would be lower (Uman, 1971).

Figure 1. Nighttime lightning strike

A typical lightning discharge originates from the negative region of the cloud. It starts with a "downward moving traveling spark" called the stepped leader (Uman, 1971, p. 73). It zigzags from the cloud to the ground in steps of about 50 yards long until it meets positive charge near the ground, such as the top of a tree or the tip of a lightning rod. When the negative stepped leader meets positive charge near the ground, the channel lights up as lightning. The lightning seen is called the return stroke, and it actually moves from the ground up. However, the return stroke travels around 20,000 to 60,000 miles per second, taking about 100 millionths of a second to get from ground to cloud, so the human eye sees the whole path light up at the same time. All the negative charge has been transferred from the stepped leader to the ground by the end of the lightning strike (Uman, 1971). However, most lightning strikes flash three or four times. Each additional flash starts with a dart leader, a leader that travels down without moving in steps. When the dart leader contacts

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* *Corresponding author address:* Nicole Kufa, Embry-Riddle Aeronautical Univ., Applied Aviation Sciences, Daytona Beach, FL, 32114; email: kufa0bb@erau.edu

the positive charge near the ground, the channel lights up and creates the next flash of lightning. Each dart leader starts higher in the negative region than the leader before it, depleting the built up negative charge in the cloud (Uman, 1969).

Earth's surface has a negative charge, while the ionosphere has a positive charge. During fair weather, Earth has a potential difference of 200,000 to 500,000 volts from the ionosphere (Christian & McCook, n.d.). In fact, if it were not for the continuous lightning strikes that hit Earth each second, the planet would lose all of its negative charge in just a few hours. In Martin Uman's words, "thunderstorms act as batteries to keep the earth charged negatively and the atmosphere charged positively" (1971, p. 152). Scientists do not fully understand why lightning sometimes strikes Earth and why other times it will strike the inside of a cloud (fig. 2).

The current theory is that lightning strikes toward Earth when the "electric field gradient in the lower regions of the cloud is stronger in the downward direction" (Christian & McCook, n.d., p. 2).

Figure 2. Intracloud Lightning

3. FORMATION THEORIES

Recent research reported by Mark Schrope has yielded a new theory about the way lightning is formed. According to Schrope (2004), J. Dwyer of the University of Florida Research Group has been studying x-ray emissions from lightning, but from his research thinks these emissions are linked with the formation of lightning. No one is sure what causes the x-ray emissions, but Dwyer believes that it is a process called "runaway breakdown." In the runaway breakdown process, still unproven since it was first suggested in 1961, subatomic particles, such as the electrons found in lightning, take on a quality that reduces the drag on them as they move faster. The faster they travel, the less drag they experience in a situation analogous to a runaway train going down a steep grade. When the high-energy electrons collide with air molecules, they could create more electrons from the collisions.

The latest theory about lightning formation says that when the cloud builds up enough of a negative charge to break the insulating ability of the air, lightning will discharge. However, electric field measurements do not measure up to the theoretical electric field needed to produce lightning in this manner. Dwyer believes that negative charge built up by the runaway breakdown process could involve an electric field 10 times smaller, which is a value closer to the actual electric field measured by scientists in association with lightning (Schrope, 2004).

A study of Florida thunderstorms by American and Japanese researchers revealed that rising pockets, or "bubbles" of lightning are associated with a rising positively charged layer in thunderstorms (Ushio, Heckman, Christian, & Kawasaki, 2002, p. 1). The rising concentrations of lightning were typically 3 to 6 kilometers in diameter and about 1 to 3 kilometers in height. These concentrations started at the freezing level in the cloud, and 58% of the pockets rose at the rate of 11 to 17 meters per second. Often in summer storms, a new bubble of lightning replaced an older one that was already rising. The rising bubbles of lightning were due to a rising layer of positive charge in the Florida thunderstorms, and the researchers concluded that the lightning pockets were made of negative leaders, which "tend to propagate through positive charge" (Ushio et al., 2002).

Recently, there have been studies performed to isolate some factors that change the characteristics of lightning, such as flash rate, current, and multiplicity. For example, four scientists from two universities in Tel Aviv, Israel, analyzed lightning data from winter storms that traveled over the Mediterranean Ocean and into the northern and central parts of Israel (Altaratz, Levin, Yair, & Ziv, 2003). When the storms were on land, there was a maximum of ground strikes over Mount Carmel. The researchers concluded it was because of topographical forcing. Also, lightning in their study was detected in a higher frequency over the sea in the mid-winter months, but the frequency in the summer storms was the same over land or sea. The researchers concluded the heat and humidity fluxes from the warmer sea destabilized the colder air above, fueling cloud convection, and in turn, creating more lightning with topography and strong cloud convection affecting the location of lightning strikes (Altaratz, Levin, Yair, & Ziv, 2003).

4. POLLUTION AND LIGHTNING

Another study from Texas A&M University, found that smoke aerosols from Central American biomass burning advected into the central plains of America and significantly changed the characteristics of lightning in storms formed in the polluted air. Murray, Orville, and Huffines (n.d.) report that there was twice the normal amount of positive lightning compared to other years, and the median peak currents of flashes changed as well. In negative lightning, the median peak current decreased while in positive lightning, the median peak current was reported to be 20 kilo amperes higher than normal in some states. Furthermore, the average strokes per flash also were analyzed. In some states, negative lightning went from an average of 2.8 strokes per flash to between 1.0 and 1.4 strokes per flash, while positive lightning had no change in the number of strokes per flash. It appears that the factor of pollution in the thunderstorms affect the characteristics of lightning. However, it is still unknown exactly how the unusually high concentration of aerosols spawn changes in the current, percentage of positive lightning, and strokes per flash.

Likewise, Robert C. Cowen (2003) reports that a recent study by Richard Orville and his students at Texas A&M University reveal that pollution can actually spawn lightning. Lake Charles and Baton Rouge were two areas with higher lightning activity than their surrounding areas. They also are the sites of numerous oil refineries. The researchers concluded that it was not just a coincidence, and that pollution somehow enhances a cloud's ability to accumulate electrical charges and build up that critical cloud-to-ground voltage. Scientists already know that condensation nuclei such as pollution make cloud droplets that are smaller than normal. When these smaller droplets get caught in an updraft, they are easily blown to the freezing upper levels of the cloud where they become supercooled or turn into ice. It is this mix of supercooled water and ice that electrically charge the particles. When particles accumulate enough charge, lightning is produced. In Orville's study, pollution was a factor that increased the occurrence of lightning. Unlike the study by Murray et al., Orville only analyzed the number of strikes in the Baton Rouge and Lake Charles area. It could be that other characteristics besides the rate of lightning were different. Also, shrinking cloud droplet sizes because of pollution based condensation nuclei, as suspected in Orville's study, could have also caused the lightning characteristics to change in the study by Murray et al. (fig. 3).

Figure 3. Lightning over water

5. WINTER STORM LIGHTNING

Research by Hunter, Underwood, Holle, and Mote (2001) found that cloud-to-ground lightning patterns could predict the amount and kind of precipitation in winter storms. In winter storms formed by arctic fronts, which are cold fronts initiated by air moving south from the Canadian region of North America, cloud-to-ground lightning was found in or near subfreezing surface air and in areas of frozen precipitation. Also, in winter storms that had mesocyclone activity, cloud-to-ground lightning was found more often in the warmer sector of the mesocyclone and away from the surface freezing line. In this study, lightning patterns were analyzed to help predict the location and intensity of frozen precipitation with Hunter et al. (2001) concluding that when a storm is in the arctic front phase and lightning is observed near the surface freezing line, it may indicate that there is substantial frozen precipitation downwind where air temperatures are already below freezing.

6. CHARGES

While most lightning delivers negative charge to the ground, scientists have observed that about 5% of lightning strikes deliver a positive charge. That is, the stepped leader is positively charged and it contacts negative charge near the ground to create lightning. It is not yet fully understood why this happens. One idea proposed by Uman (1971) explains that positive lightning probably occurs when the positive upper region of a cloud is blown to the side by strong winds coming close to a mountain or the surface of Earth. This hypothesis is supported by more recent data showing positive lightning can be the dominant type during the dissipating stage of a thunderstorm (Rakov, n.d.). In this stage of a thunderstorm, the anvil shaped top is created by strong upper level winds blowing the top section off to the side (Veimeister, 1961). Furthermore, a study by Fuquay (n.d.) also found positive lightning occurred in the last 30 minutes, the dissipating stage, of thunderstorms in the Rocky Mountains. A positive downward moving leader that followed a path horizontally out of the cloud and then to the ground initiated the positive lightning in the study. These lightning strikes are commonly called a bolt from the blue because they can travel more than 25 miles from the thundercloud in which they originated (NOAA, n.d.). Scientists are not sure what processes yield positive lightning, especially because it undermines what lightning is supposed to do—keep the earth negatively charged.

According to Rakov (n.d), positive lightning is different from negative lightning in several ways. One way is that positive lightning usually has only 1 stroke per flash, while 80 percent of negative lightning has 2 or more strokes per flash. Positive lightning with more than 1 stroke is very rare. Also, positive lightning delivers more coulombs of charge to the ground than negative lightning. The median peak current in positive lightning is higher in winter than in summer. Current and charge data is hard to study for positive lightning because of its rarity, and because scientists are still not sure how positive lightning forms.

The Severe Thunderstorm Electrification and Precipitation Study (STEPS 2000) put forth a more recent theory about how positive lightning may occur. According to Blakeslee (2000) researchers documented many positive lightning strikes and measured the charge structures of thunderstorms for 8 weeks in 2000. The preliminary data indicate that the charge structure in thunderstorms is often inverted with the negative charge on the top and the positive charge below. These data were confirmed by weather balloons from the National Severe Storms Laboratory. In fact, the researchers found positive lightning and charge structure reversals even in smaller storms, although it was earlier believed that the phenomenon only happened in large supercell storms. The researchers suspect there may be a link between reversal of charge structure in a storm and positive lightning. However, they still do not understand exactly how a storm could reverse its electrical charges (Blakeslee, 2000).

Earlier researchers found charge structures to be more complex than previously thought when they studied mesoscale convective systems. A mesoscale convective system is an organized cluster of thunderstorms in which the whole system lives longer than an individual embedded thunderstorm, and is larger than a supercell thunderstorm. The charge structure was made of multiple layers of opposite charge. For example, Hunter et al. (1991) report measuring 11 distinct charge layers with 10 out of the 11 concentrated in a 5 km deep area that coincided with an inflow region of the mesoscale convective system. Another study by Stolzenburg et al. (n.d.) found that within updrafts, the basic charge structure had 4 layers of alternating charge with positive being on the bottom and negative on the top. Also, outside of updrafts, there was a basic charge structure of 6 layers with alternating charges having a positive layer starting at the bottom followed by a negative region on top and so on. The layers outside of updrafts were found to be shallower and had larger charge densities than the layers found within updrafts. The two studies suggest that charges in a cloud do not always follow the conventional model in which negative charge is on the bottom and positive charge is on top.

Another idea about positive lightning reported by Blood (2005) in the *Bulletin of the American Meteorological Society* came from the International H_2O Project in which Larry Carey and Kurt M. Buffalo studied the link between positive lightning and severe weather, such as hail and tornadoes. The researchers found that storms with predominantly positive lightning have stronger updrafts that create a deep column of liquid water in the storm. This is the kind of mix of supercooled water and ice crystals that electrify a storm, and the researchers believe it is the updrafts that change the charge structure towards producing positive lightning. In the H_2O project, strong updrafts in the severe storms they studied ingested moist air that changed the storm enough to create positive lightning (Blood, 2005).

Lang and Rutledge (2002) published a study with a similar idea of how positive lightning is produced. They observed 11 thunderstorms and noticed that the ones that produced positive lightning also had significantly large volumes of updrafts reported to be greater than 10 meters per second and greater than 20 meters per second. These same storms also produced more rain and hail than other storms. The conclusion is that the positive lightning may result from an elevated region of positive charge, combined with enhanced net positive charge regions from the large updrafts (Lang and Rutledge, 2002). Both the International H_2O Project and this study suggest updrafts are a key ingredient to make positive lightning (fig. 4).

Figure 4. Cloud-to ground lightning

Another study, the Stratospheric-Tropospheric Experiment: Radiation, Aerosols and Ozone (STERAO), concentrated on lightning and its relationship to updrafts, and was reported by Dooling (1999) in the *NASA Science News*. In the article, James Dye, a researcher at the National Center for Atmospheric Research, explains how lightning often is found in weaker updrafts from 10 to 40 meters per second (22-90 mph). The faster the updraft, the more frequent the lightning. However, lightning avoided the very strong updrafts and instead, became more frequent at the edges of the updraft. Dye also explains that no one knows why this happens. However, it could be that ice and liquid water collide more frequently at the edges of the updraft rather than inside it, separating charges to cause lightning. In the 1999 study by Dye, it was found that lightning is directly related to updrafts of various intensities (Dooling 1999).

7. LOCAL CONDITIONS

Moreover, the local environment of a storm can influence its charge structure, as found in the following studies. In the first, thunderstorms were studied that formed in varying gradients of equivalent potential temperature (a measure of moisture and temperature content in the air). According to Smith, et al. (2000), storms that formed just upstream of a maximum of equivalent potential temperature in regions of strong equivalent potential temperature gradients produced predominantly positive lightning. However, storms that formed downstream of an equivalent potential temperature maximum and in a weak equivalent potential temperature gradient produced mostly negative lightning. When the positive lightning storms crossed the equivalent potential temperature maximum, their updrafts intensified and their polarity switched to negative. Half of these storms produced tornadoes, while only 10% of the negative lightning storms did. Smith et al. (2000) concluded that when the updrafts intensified, they ingested a lot of liquid water into the storms. However, as the storms crossed the equivalent potential temperature maximum, their updrafts may have weakened and possibly could no longer contain all that liquid water, resulting in very heavy precipitation. In turn, the massive precipitation may have initiated a redistribution of the charge structure in the storms. It also could have initiated downdraft-induced tornadogenesis (fig. 5). In this study, changes in the local environment played an important role in the severity of a storm and changing its charge distribution (Smith, LaDue, and MacGorman, 2000).

Another study published two years later also took a look at how the local environment around a storm can change its lightning pattern. Gilmore and Wicker (2002) studied 20 supercell storms and observed lightning polarities in respect to forming next to or moving through a mesoscale outflow boundary, defined as cold mid-level air that is brought down to the surface in the downdraft of a thunderstorm creating a mini-cold front in front of the thunderstorm. They found that storms that remained on the warm side of the mesoscale outflow boundary and storms that formed directly on the boundary tended to produce weaker low-level rotation and had the largest negative [lightning] flash rates (Gilmore and Wicker, 2002).

When 11 storms crossed the outflow boundary, five of them had increased positive lightning rates within an hour. The scientists concluded the large positive lightning rates were associated with descending [radar] reflectivity cores, which are a large core of descending air and moisture that were larger in area and magnitude than the other storms in the study. Gilmore and Wicker (2002) hypothesized several theories of how and when the charge structure changes in a storm:

- If a supercell has predominantly negative lightning and an updraft intensifies, changes in hail fields result in the negatively charged region of the storm to be elevated, reducing negative lightning rates.

- When there are large increases in liquid water content and updraft temperature during updraft intensification, descending graupel and hail grow at faster rates. This situation favors a strong positively charged region to be lower in the cloud, and increases positive lightning rates.

- When updrafts decrease, and hail and graupel grow more slowly, the lower positively charged region weakens, and favors a lower region of negative charge. This creates a predominance of negative lightning.

- When graupel or hail is relatively immature, it suggests low terminal fall speeds (slowing down the rate of growth of hail/graupel). This situation favors the conventional charge structure in which negative lightning happens most often.

Figure 5. Tornado near Union City, Oklahoma (NOAA)

Gilmore and Wicker’s study certainly proposes that electrification happens from the interaction between liquid and solid water in the cloud. They also suggest that lightning polarity is a result of the location of regions of negative and positive charge in the cloud.

Blood (2005) reports that Carey and Buffalo studied storms that crossed over a ridge of equivalent potential temperature similar to the study by Smith et al. (2000). In the report, Carey explains studies have found that storms switch polarity as they move from the drier side of the ridge into the moist region of the ridge. Updrafts take up the moist air, and the warmth reduces the effectiveness of warm precipitative processes, such as collision and coalescence, which in turn increase the amount of cloud water available at supercooled temperatures for cloud electrification. The scientists conclude that warmer clouds display more negative charged lightning, but colder clouds with more instability, showed predominantly positive charged lightning. They believe that a better understanding of positive lightning can give forecasters a tool in predicting the severity of a storm. These findings support the original observation that positive lightning is found often in severe storms. The study also supports the idea that the structure of a storm can change when the environment it is in changes (Blood, 2005).

8. TORNADO PREDICTION

As lightning polarity patterns and their relationship with severe weather are observed by research scientists, the importance of the patterns becomes more evident. If researchers could look deeper into how lightning behaves just before hail falls or a tornado forms, they could save property and lives. Studying lightning patterns preceding the formation of a tornado was one of STEPS 2000's goals. Like the STERAO project, the STEPS 2000 study reported by Henson (2000) in the *University Corporation for Atmospheric Research Quarterly* also was intrigued by lightning free zones in the area of a storm with an intense updraft. Their lightning detection equipment found a doughnut-like ring of lightning with no lightning activity inside of it. Out of two storms with lightning-free holes that were tracked, one of them produced a tornado inside the hole. Many researchers believe that lightning-free zones inside a storm can predict where a tornado might form because they pinpoint the location of the strongest updrafts.

Tornadoes usually form where a cold downdraft at the rear of a storm meets a warm horizontal inflow from an updraft near the bottom of the storm (Robinson, 1993). This downdraft has winds around it that spin clockwise, and is usually next to a counterclockwise spinning mesocyclone, which is a large spinning region of a supercell storm. The downdraft merges into the outside of the updraft forming a hook-shaped region of rain (Rasmussen, n.d.). When the hook shape is caught on radar, it also can help meteorologists predict the formation of a tornado (Robinson, 1993). VORTEX, the Verification of the Origins of Rotation in Tornadoes Experiment, as reported by Erik Rasmussen (n.d.), found new clues about tornado formation. For example, when a storm crosses over an outflow boundary, the temperature contrast from either side of the boundary supplies the air with horizontal rotation. If an updraft sweeps over this horizontal rotation, it will pull the rotating air upwards (Rasmussen, n.d.). Often, more than one tornado vortex is formed. The other vortices are usually smaller than the main one (Robinson, 1993). As these studies suggest, lightning research can help predict where in a storm tornadoes will most likely form.

Gatlin & Goodman (2004) analyzed lightning rates in two tornadic supercells in the southeastern U.S. In particular, they noted that a relative maximum of lightning rates occurred at least 15 to 20 minutes prior to tornado formation within the storm. Some of the maxima of lightning rates were due to strengthening updrafts measured on radar. In the first supercell storm they studied, the increase in the lightning rate correlated with the increase of shear in the bottom part of the storm. Shear is a term that describes wind that varies in direction and/or speed over a short distance. Wind shear in combination with an updraft or downdraft can provide the ingredients for rotation, and possibly a tornado, in a storm. As seen from the Gatlin and Goodman study, increasing lightning flash rates gave warning of possible tornadogenesis.

Polarity reversal of lightning around the time of tornado touchdown has also been studied. In a lightning study by Biggar (n.d.), it was reported that there was a polarity reversal from positive to negative preceding the formation of a tornado in a supercell storm. Fifteen minutes before the tornado touched down, lightning activity dropped significantly. Ten minutes before the tornado touched down, the polarity of the lightning reversed (Biggar, n.d.). These findings are similar to other studies of tornado-producing storms. For example, Knapp (1994) also found that many storms that started out with predominantly positive lightning switched polarity about ten minutes before a tornado formed. A study by MacGorman and Burgess (1994) found the most damaging of tornadoes in a storm formed after positive lightning began to decrease, leaving negative flashes dominant. Furthermore, the findings by Seimon (1993) were identical when he studied the F5 tornado that touched down in Plainfield, Illinois in 1990. With so many instances of polarity change occurring around the time of tornado touchdown, it seems very possible that lightning can predict tornado formation (fig. 6).

Figure 6. Tornado at Dimmit, Texas (NOAA)

Tropical cyclone tornadoes formed from tropical storm Beryl in 1994 and their associations with cloud-to-ground lightning were studied by researchers in the southeastern United States. Contrary to lightning patterns found in supercell thunderstorms in the Midwest, lightning patterns in tropical storms spawning tropical cyclones are different. For example, cloud-to-ground lightning rates decreased in the 30 minutes before tornado touchdown, and some of the cells' cloud-to-ground lightning stopped forming immediately as a tornado touched down. Also, no shift in lightning polarity occurred around the time of tornado development. Overall, lightning flash rates were higher in cells that formed tropical cyclone tornadoes. However, positive lightning was more common in tropical storm Beryl's non-tornadic cells, and median peak currents were also higher (McCaul, Buechler, Goodman, and Cammarata, 2003).

9. OTHER LIGHTNING

Furthermore, lightning is not limited to thunderstorms. It can be seen in other places such as in a volcanic ash plume. It is also found in sand storms and snowstorms and even can be initiated by nuclear bomb explosions. Lightning also can strike airplanes when there are no active thunderstorms around. Half of aircraft lightning strikes occur in precipitation in the form of ice or rain when the pilots had seen no lightning previously. In fact, Uman (1971) goes on to explain that a commercial airliner can expect to be hit by lightning once every 5,000 to 10,000 flight-hours. Rockets also can be struck by lightning. One example was the launch of the Apollo 12 in 1969, which was struck twice during lift off. Additionally, researchers use small rockets to artificially initiate lightning (fig. 7). In the rocket-and-wire technique, the lightning process is reversed. Instead of the cloud sending a stepped leader to the ground, a rocket attached to a very long, thin wire is sent to the cloud. Sparks from the rocket trigger a strike, and the lightning then travels down the wire to the ground, destroying the wire from its high temperature (Schrope, 2004). Furthermore, when a nuclear test bomb was detonated in 1952 in the Pacific, lightning was photographed propagating from several buildings around the test site around the bomb's plume. Like the rocket-and-wire lightning, it was also generated in reverse from leaders coming off the buildings (Uman, 1971). In short, lightning happens any time a built up charge needs to be discharged.

Figure 7. Triggering a lightning strike (NASA)

9.1 *Microbursts*

In addition to severe weather producing tornadoes or hail, a study by Altino, et al. (n.d.) analyzed lightning patterns before, during, and after a microburst event. Microbursts develop under a thunderstorm when a strong down draft creates a vertical, downward moving wind gust. The size of a microburst is less than 2.5 miles wide and the winds last from 2 to 5 minutes. Microbursts are dangerous to airplanes, especially if they get caught in one in a landing, or low power, configuration. The airplane does not have enough power to recover from the intense downward force acting on it, and crashes into the ground. The study found from a 5-minute scan of lightning that the cloud-to-ground lightning rate was 8.6 flashes per minute around the time of the microburst. In another 5-minute scan of lightning taken 9 minutes after the microburst started, the lightning rate had increased to 5.9 flashes per second. There was a significant increase in cloud-to-ground lightning after a microburst occurred with a total of 1769 lightning strikes recorded in the 5-minute scan (Altino, Knupp, and Goodman, n.d.).

9.2 *Additional Discharges*

Not long ago, a new type of electric discharge was discovered above thunderclouds. For many years, pilots have reported seeing flickering lights on top of storm clouds, but nobody believed them until researchers caught the strange lights on camera in 1989. Even astronauts from the space shuttle got a glimpse. They were named sprites. Finally, in 1994, a team from the University of Alaska at Fairbanks captured the first color images of sprites (Gibbs, n.d.). The sprites were red, and appeared when a strong positive lightning bolt struck Earth. However, some, although rare, sprites have appeared above large negative lightning strikes. Sprites can extend as high as 60 miles above the thundercloud. They are brightest around 30 to 45 miles high, with tendrils that hang down but never reach the cloud top. Amazingly, researchers estimate that sprites are about 30 feet wide, and occur mostly in large clusters spreading over 90 miles from above the original lightning bolt (Heidorn, 2004). The red color is caused by ionized nitrogen ("Capturing Sprites," 1996). Also, the lightning strikes that produce sprites give off a unique radio signal. From these signals, scientists have discovered that sprites, once thought to be rare, happen about once in every 200 lightning strikes (Heidorn, 2004).

In 1993, researchers from the University of Alaska found a new type of electrical discharge above a severe storm they flew over. This time, they saw blue light shooting up from the cloud tops. The researchers named them blue jets. Blue jets are cone shaped, and propagate out of the cloud top towards the ionosphere, a layer of the atmosphere ionized by solar radiation, 12 to 30 miles above Earth. Like sprites, blue jets are large—about 1 mile wide at their base and 5 miles wide at their top (Heidorn, 2004). However, blue jets are different from sprites because they do not form in association with a lightning strike. They seem to be associated with the charge separation in the cloud when there is strong hail activity ("Blue Jets and Starters," 2001).

In 1995, researchers from the University of Tohuku in Japan and Stanford University discovered another form of electrical discharge called elves. Elves are disk-like in shape and occur between 40 and 60 miles above Earth. Scientists believe they are caused when electromagnetic pulses in the form of radio waves pass through the ionosphere. Elves can be as large as 250 miles in diameter, and the lightning that triggers them has been seen as far as 50 miles away (Heidorn, 2004).

According to Lyons et al. (2203) scientists believe that sprites form when a lightning strike rapidly removes a large amount of charge from a layer of a cloud and creates an electric field. It is thought, as first theorized by Wilson in 1925, that the greater the charge lowered from the strike and the greater the length of the lightning bolt, the stronger the electrostatic field will be. The charge removal stresses the mesosphere to dielectric breakdown. Dielectric breakdown occurs when the insulating property of the mesosphere, the layer of the atmosphere that exists about 20 to 50 miles (30 to 80 km) above Earth's surface, fails from the strength of the electric field formed by the lightning bolt and becomes a conductor. As cited in Lyons et al. (2003), Stanley et al. found in 1999 that most sprites propagate from an altitude of about 75 kilometers, a height that falls within the mesosphere (fig. 8). Furthermore, blue jets are thought to form when a cosmic ray, a fast moving particle shot out of a cosmic explosion such as a supernova, hits an air molecule within an electrostatic field above a thundercloud. The collision "produces a shower of fast electrons; the upward pointing electrostatic field above the cloud can accelerate these electrons further, to energies at which they emit blue light" (Gibbs, n.d., p. 1).

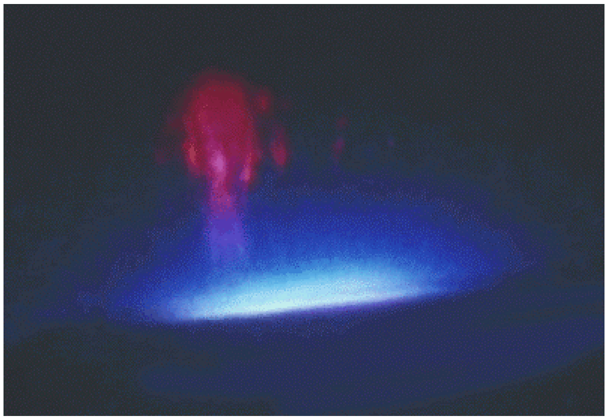

Figure 8. Red Sprite (NASA)

One group that studied sprites was the STEPS 2000 team. Earlier research on sprites found that sprites were always associated with positive lightning strikes occurring in the later stages of a mesoscale convective storm, and often when positive lightning had been striking for a few hours (Lyons, Nelson, Williams, Cummer, and Stanley, 2003). Also, other research suggests that the peak current of a positive cloud-to-ground strike is not a reliable predictor of whether a sprite will be produced. The currents of sprite-producing lightning are often 50% higher than the current of other positive lightning. However, currents in sprite-producing lightning have been found to be as little as 20 kA (Lyons, Nelson, Williams, Cummer, and Stanley, 2003). Sprites can only form from lightning with specific characteristics. For example, there has to be a large amount of charge transported from the cloud to the ground. While positive lightning fits this description, although there is no rule that says negative lightning does not. In fact, there have been sprites reported that were initiated by negative lightning in Mexico. However, positive lightning usually lowers more charge because it has a continuing current. Current flows for a longer period in a positive strike than in a negative strike.

The STEPS 2000 team believes that sprites in the high plains of America are formed when a large amount of charge is transferred from a cloud layer to the ground. More specifically, they found that the charge is drawn from the layer in the cloud close to the melting layer. The meting layer is a layer of cloud where at the top of the layer, frozen precipitation begins to melt as it falls, and at the bottom of the melting layer, the precipitation is fully melted, or in a liquid state. The melting layer is usually found right under the 0 degree Celsius isotherm. Moreover, the melting layer holds the cloud's dominant positive charge in it, possibly because the melting process creates it. However, scientists are not sure if it does. The research team found that positive charge in sprite-producing lightning was drawn from a height between 2 and 5 km., with the average height being 4.1 km. The melting layer in the storm was at 3.8 km. The positive lightning indeed drew charge from the positive layer of the cloud, just around the melting layer (Lyons, Nelson, Williams, Cummer, and Stanley, 2003).

The STEPS 2000 team also noted that as the storm matured, the centriod of lightning descended. It was not until the centroid of lightning became established in the lower part of the storm that positive lightning began to produce sprites. Furthermore, they found that one necessary ingredient for a sprite producing lightning strike is a large charge moment change. The value of charge moment change is found by multiplying the coulombs of charge in the lightning strike by the length of the bolt. All sprite-producing lightning strikes had a large charge moment change. However, they were not sure if other strikes with larges values of charge moment change failed to produce sprites. The Lyons et al. (2003) study reveals that strong lightning strikes that transfer a large amount of charge are essential for sprite formation.

10. SUMMARY

Over the past few years, lightning research has spawned more questions than answers. However, the research has also started a new chapter in our knowledge of lightning. From all the hard work, scientists have found a new tool they can use to help better understand the structure of a storm, and help predict the dangers of severe weather. The new tool is lightning, and with further research to refine our understanding of the role it plays in a storm, forecasters will one day include lightning data in their lists of what to look for as a storm develops.

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