A Lightning Primer

Introduction

Lightning, the thunderbolt from mythology, has long been feared as an atmospheric flash of supernatural origins: the great weapon of the gods. The Greeks both marveled and feared lightning as it was hurled by Zeus. For the Vikings, lightning was produced by Thor as his hammer struck an anvil while riding his chariot across the clouds. In the East, early statues of Buddha show him carrying a thunderbolt with arrows at each end. Native American tribes in North America believed that lightning was due to the flashing feathers of a mystical bird whose flapping wings produced the sound of thunder.

Thunderbird on top of a Totem Pole (Photo credit: Dr. Haggis)

Today, scientific rather than mystical techniques are used to explain lightning with experimental procedures replacing intuitive concepts. Yet, we remain in awe of lightning which still shines with its mystery, and rightly so. Typically, more than 2,000 thunderstorms are active throughout the world at a given moment, producing on the order of 100 flashes per second. Each year, lightning is responsible for about 24,000 deaths per year, 240,000 injuries per year, and millions of dollars in property damage per year.

While these are more than sufficient reasons for NASA to pursue lightning research, lightning has a direct effect on day-to-day operations as well. The avoidance of lightning strikes to a spacecraft during launch relies heavily on the ability of meteorologists to accurately forecast and interpret lightning hazards to NASA vehicles under varying weather situations. Severe hazards for NASA due to lightning have been well documented. One major incident occurred during the 1969 launch of the Apollo 12 mission when lightning briefly knocked out vital spacecraft electronics. Fortunately, the astronauts regained control.

Lightning striking near a spacecraft (Photo credit: NASA)

The unmanned Atlas Centaur 67 carrying a Naval communication satellite was determined to have been struck by a triggered cloud-to-ground lightning flash on March 26, 1987. The lightning current apparently altered memory in the digital flight control computer. This glitch resulted in the generation of a hard-over yaw command, which caused an excessive angle of attack, large dynamic loads, and ultimately the breakup of the vehicle.

On a smaller scale, two sounding rockets being prepared for launch from NASA's Wallops Island, Virginia in 1987 were prematurely launched as a direct result of lightning.

It is now well recognized that lightning strikes near aircraft most often originate from the craft itself. The flash is believed to begin with the inception of a leader, propagating in both directions away from the craft. These are called "triggered" lightning flashes.

Although a systematic compilation of information of lightning casualties exists, it is still difficult to obtain accurate statistics on lightning injuries and fatalities. Many case histories show heart damage. **I**nflated lungs and brain damage have also been observed from lightning fatalities. Loss of consciousness, amnesia, paralysis and burns are reported by many who have survived.

Deaths and injuries to livestock and other animals, thousands of forest and brush fires, and millions of dollars in damage to buildings, communications systems, power lines, and electrical systems are also the result of lightning.

Cloud-to-ground lightning. (Photo credit: Dag Peak)

Finally, the threat of lightning causes many work stoppages and lost production increasing the time and cost required to prepare NASA spacecraft for flight.

History

Benjamin Franklin performed the first systematic, scientific study of lightning during the second half of the 18th century. Prior to that time, electrical science had developed to the point where positive and negative charges could be separated. Electrical machines could, by rubbing together two different materials, store the charges in primitive capacitors called Leyden Jars from which sparks could be generated and observed.

Painting of Benjamin Franklin. (Photo credit: Philadelphia Museum of Arts)

While others had previously noted the similarity between laboratory sparks and lightning, Franklin was the first to design an experiment which conclusively proved the electrical nature of lightning. In his experiment, he theorized that clouds are electrically charged, from which it follows that lightning must also be electrical. The experiment involved Franklin standing on an electrical stand, holding an iron rod with one hand to obtain an electrical discharge between the other hand and the ground. If the clouds were electrically charged then sparks would jump between the iron rod and a grounded wire, in this case, held by an insulating wax candle.

This experiment was successfully performed by Thomas Francois D'Alibard of France in May 1752 when sparks were observed to jump from the iron rod during a thunderstorm. G. W. Richmann, a Swedish physicist working in Russia during July 1753, proved that thunderclouds contain electrical charge and was killed when lightning struck him.

Before Franklin accomplished his original experiment, he thought of a better way to prove his hypothesis through the use of a kite. The kite took the place of the iron rod, since it could reach a greater elevation and could be flown anywhere. In 1752, during a thunderstorm in Pennsylvania the most famous kite in history flew with sparks jumping from a key tied to the bottom of damp kite string to an insulating silk ribbon tied to the knuckles of Franklin's hand. Franklin's grounded body provided a conducting path for the electrical currents responding to the strong electric field buildup in the storm clouds.

In addition to showing that thunderstorms contain electricity, by measuring the sign of the charge delivered through the kite apparatus, Franklin was able to infer that while the clouds were overhead, the lower part of the thunderstorm was generally negatively charged.

Little significant progress was made in understanding the properties of lightning until the late 19th century when photography and spectroscopic tools became available for lightning research.

Lightning current measurements were made in Germany by Friedrich Pockels (1897-1900) who analyzed the magnetic field induced by lightning currents to estimate the current values.
Time-resolved photography was used by many experimenters during the late 19th century to identify individual lightning strokes that make up a lightning discharge to the ground.

Lightning research in modern times dates from the work of Charles Thomson Rees Wilson who was the first to use electric field measurements to estimate the structure of thunderstorm charges involved in lightning discharges. Wilson, who won the Nobel Prize for the invention of the Cloud Chamber, made major contributions to our present understanding of lightning.

Research continued at a steady pace until the late 1960's when lightning research became particularly active. This increased interest was motivated both by the danger of lightning to aerospace vehicles and solid state electronics used in computers and other devices, as well as by the improved measurement and observational capabilities by advancing technology.

Characteristics of a Storm

LIGHTNING

Lightning storm off of the coast of Greece (Photo credit: Manolis Thravalos)

As the ice particles within a cloud (called hydrometeors) grow and interact, they collide, fracture, and break apart. It is thought that the smaller particles tend to acquire positive charge, while the larger particles acquire more negative charge. These particles tend to separate under the influences of updrafts and gravity until the upper portion of the cloud acquires a net positive charge and the lower portion of the cloud becomes negatively charged. This separation of charge produces enormous electrical potential both within the cloud and between the cloud and ground. This can amount to millions of volts, and eventually the electrical resistance in the air breaks down and a flash begins. Lightning, then, is an electrical discharge between positive and negative regions of a thunderstorm.

A lightning flash is composed of a series of strokes with an average of about four. The duration of each lightning stroke varies, but typically averages about 30 microseconds. (The average peak power per stroke is about 10^{12} watts.)

Lightning strike in slow motion (Source: NOAA)

THUNDER

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Sound is generated along the length of the lightning channel as the atmosphere is heated by the electrical discharge to the order of 20,000°C (3 times the temperature of the surface of the sun). This compresses the surrounding clear air producing a shock wave, which then decays to an acoustic wave as it propagates away from the lightning channel.

Although the flash and resulting thunder occur at essentially the same time, light travels at 186,000 miles per second, almost a million times the speed of sound. Sound travels at the relatively snail pace of 0.5 miles per second. Thus the flash, if not obscured by clouds, is seen before the thunder is heard. By counting the seconds between the flash and the thunder and dividing by 5, an estimate of the distance to the strike (in miles) can be made.

CLOUDS AND RAIN

When moisture-laden warm air is heated, it begins to rise. As these currents or bubbles of warm moist air rise higher in the atmosphere, both the surrounding air pressure and temperature decrease. The air bubbles expand, causing cooling of the moisture eventually condensing to form clouds. As the cloud cools further, more moisture condenses, and the water droplets making up the cloud grow and merge until some become so large and heavy that the air currents within the cloud can no longer support them. These water droplets begin to fall as rain.

Small rain storm near a village (Photo credit: Bidgee)

HAIL

Air currents in cumulonimbus clouds can be very violent. Even when lightning is not produced, pellets of ice may grow by the accumulation of liquid droplets. When the updrafts are very strong, the growing ice pellets can be suspended for long periods, allowing them to grow larger. Eventually some may become too large for a given updraft and begin to fall as hail. Diameters are typically 5 to 10 mm, although a 200.6 mm hailstone has been recorded.

Image of largest recorded hailstone that fell in Vivian, South Dakota (Photo credit: National Weather Service)

Types of Lightning Discharges

THE MOST COMMON TYPES OF LIGHTNING

Cloud-to-ground lightning is the most damaging and dangerous form of lightning. Although not the most common type, it is the one which is best understood. Most flashes originate near the lower-negative charge center and deliver negative charge to Earth; however, an appreciable minority of flashes carry positive charge to Earth. These positive flashes often occur during the dissipating stage of a thunderstorm's life. Positive flashes are also more common as a percentage of total ground strikes during the winter months.

Cloud-to-ground lightning strikes in a town (Photo credit: Aline Zaninella de Oliveria Cardoso)

Intra-cloud lightning is the most common type of discharge occurring between oppositely charged centers within the same cloud. Usually the process takes place within the cloud and looks from the outside of the cloud like a diffuse brightening which flickers; however, the flash may exit the boundary of the cloud and a bright channel, similar to a cloud-to-ground flash, can be visible for many miles.

Image of intra-cloud lightning (Photo credit: Matt Buck)

The ratio of cloud-to-ground and intra-cloud lightning can vary significantly from storm to storm. Storms with the greatest vertical development may produce intra-cloud lightning almost exclusively. Some suggest that the variations are latitude-dependent, with a greater percentage of cloud-to-ground strikes occurring at higher latitudes. Others suggest that cloud-top height is a more important variable than latitude.

Details of why a discharge stays within a cloud or comes to ground are not understood. Perhaps a flash propagates toward the Earth when the electric field gradient in the lower regions of the cloud is stronger in the downward direction.

Depending upon cloud height above ground and changes in electric field strength between cloud and Earth, the discharge stays within the cloud or makes direct contact with the Earth. If the field strength is highest in the lower regions of the cloud a downward flash may occur from cloud to Earth.

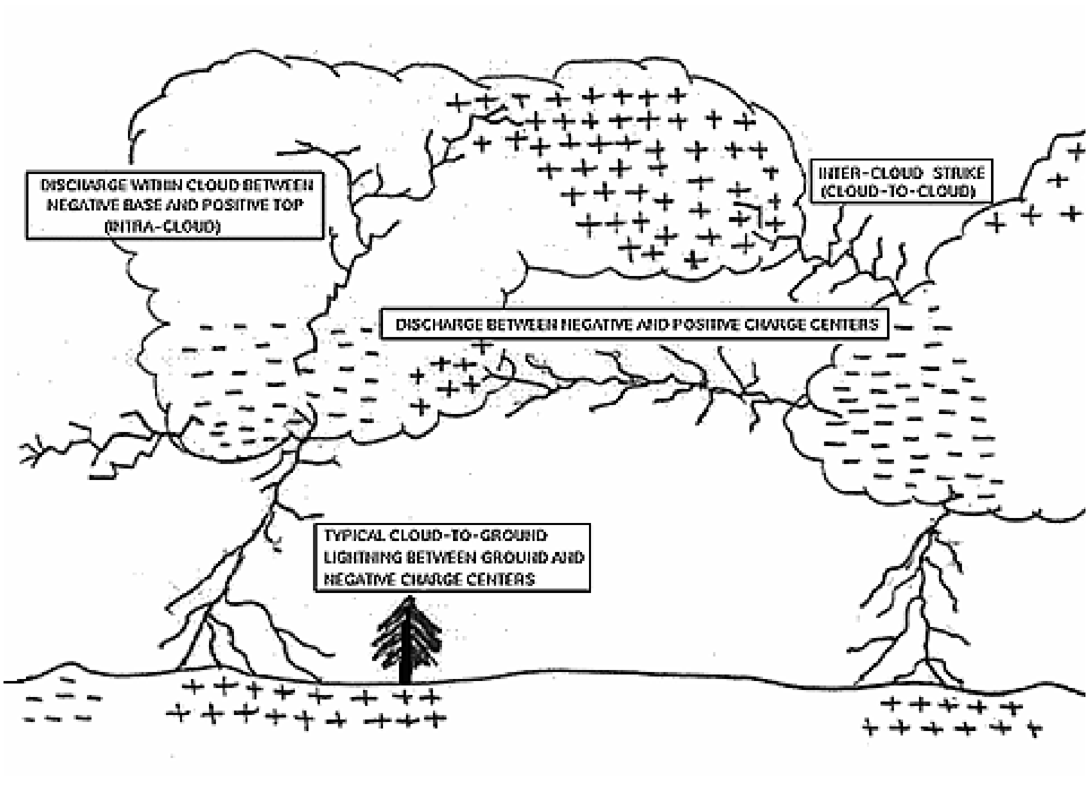
Inter-cloud lightning, as the name implies, occurs between charge centers in two different clouds with the discharge bridging a gap of clear air between them.

OTHER TYPES OF LIGHTNING

There are numerous names and descriptions of various types and forms of lightning. Some identify subcategories and others may arise from optical illusions, appearances, or myths. Some popular terms include: *ball lightning, heat lightning, bead lightning, sheet lightning, silent lightning, black lightning, ribbon lightning, colored lightning, tubular lightning, meandering lightning, cloud-to-air lightning, stratospheric lightning, red sprites, blue jets, and elves.*

DESCRIPTION OF LIGHTNING DISCHARGE PROCESSES

With the initial breakdown of the air in a region of strong electric fields, a streamer may begin to propagate downward toward the Earth. It moves in discrete steps of about 50 meters each and is called a stepped leader. As it grows, it creates an ionized path depositing charge along the channel, and as the stepped leader nears the Earth, a large potential difference is generated between the end of the leader and the Earth. Typically, a streamer is launched from the Earth and intercepts the descending stepped leader just before it reaches the ground. Once a connecting path is achieved, a return stroke flies up the already ionized path at close to the speed of light. This return stroke releases tremendous energy, bright light, and thunder. Occasionally, where a thunderstorm grows over a tall Earth grounded object, such as a radio antenna, an upward leader may propagate from the object toward the cloud. This "ground-to-cloud" flash generally transfers a net positive charge to Earth and is characterized by upward pointing branches.



The lower part of a thundercloud is usually negatively charged. The upward area is usually positively charged. Lightning from the negatively charged area of the cloud generally carries a negative charge to Earth and is called a negative flash. A discharge from a positively-charged area to Earth produces a positive flash.

The initial breakdown and propagation are similar for intra-cloud lightning, but the discharge generally occurs between regions of opposite charge. Without the benefit of air conducting Earth, intra-cloud lightning does not produce a return-stroke-like feature. Rather, it is characterized by slower propagating "recoil streamers" and "K" changes. Nevertheless, tremendous energy, bright light, and thunder are still produced by intra-cloud lightning.

Means of Studying Lightning

ROCKETS

For many investigations, lightning must be observed from as close a vantage point as possible. One technique is to probe inside hostile thunderstorms in order to study how thunderclouds electrify, but this does not ensure close-up encounters with lightning. Close-up measurements are difficult to obtain because of the unpredictability of where and when lightning will strike; hence, methods have been developed to create lightning discharges under somewhat controlled conditions.

Rocket-triggered lightning research has been an important tool for close-up investigations.

With this technique, small sounding rockets connected to long copper wires have replaced Franklin's kite. These rockets are launched into thunderstorms with electronic sensors located near the bottom-end of the wire instead of a key. When the rocket is struck by lightning, the wire is vaporized.

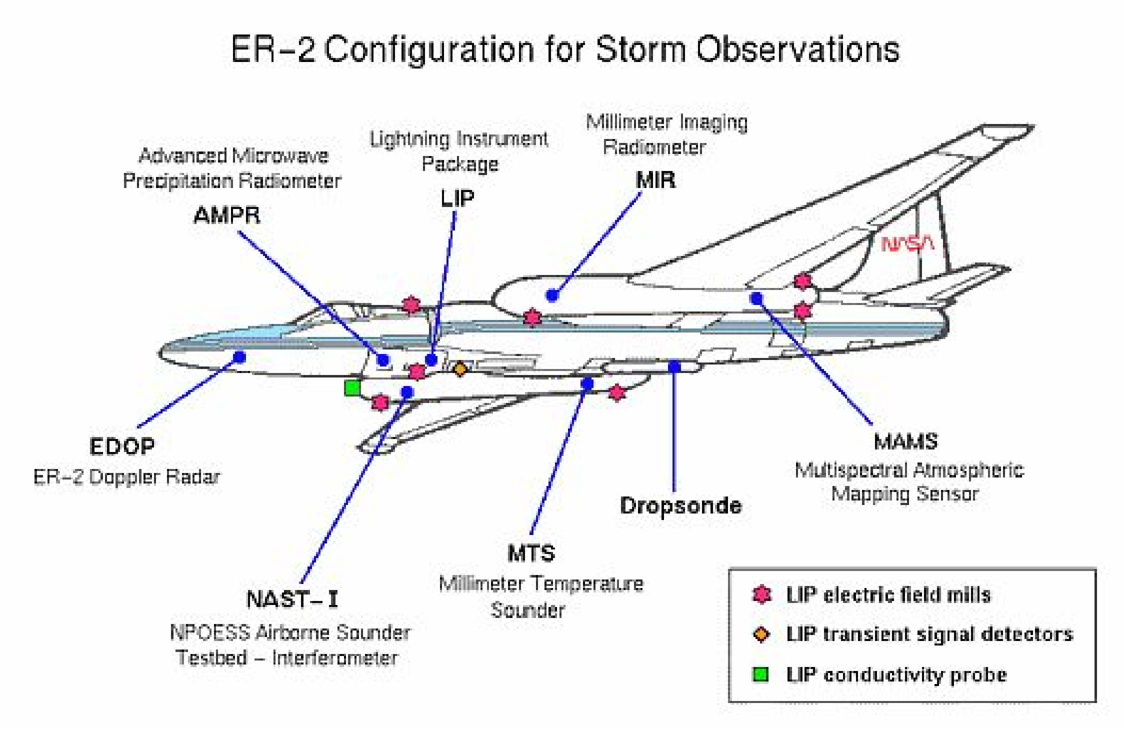
Data collected before and during the occurrence of lightning provide detailed information of the discharge's characteristics. Sounding rockets can also provide in-cloud measurements of thunderstorms in a challenging environment. While extensive ground-based optical and electrical measurements of lightning have been made, the emphasis has been on cloud-to-ground discharges with little study of intra-cloud lightning being undertaken. This is partly due to the fact that optical measurements of in-cloud lightning are severely affected by light scattering from water droplets within the cloud. For this reason, ground-based measurements alone have not been considered an appropriate means for determining the optical characteristics of lightning as viewed from above.

HIGH ALTITUDE PLANES

In order to determine the requirements for making optical measurements from space, U-2 and ER-2 high altitude airplanes have been used to study the electrical and optical characteristics of lightning activity in thunderstorms. Flying at an altitude of 20 kilometers and at speeds of 200 meters per second, they are capable of flying over very large thunderstorms.

ER-2 high altitude airplane (Photo credit: NASA)

Much has been learned from these aircraft observations. For example, they have confirmed Charles Thomson Rees Wilson's theory that strong electric fields over the tops of thunderstorms cause conduction currents to flow to the tops of clouds. The penetrative convective cells, which rise above the anvil, are the most active electric regions in the storm and cause the most intense electrical stresses.



ER-2 configuration for storm observations (Photo credit: NASA)

The ER-2 has a larger payload capability than its predecessor, the U-2. Both have provided direct observations of severe thunderstorms and other clouds using multi-sensor payloads including lasers, infrared, visible and microwave scanners, spectrometers, and electric field antennas.

In addition, photography of lightning from above clouds has been accomplished using an open shutter technique. In this method, the camera is pointed toward the thundercloud with the shutter open. In the dark sky, no light falls onto the film until lightning strikes.

SPACE SHUTTLE

To complement the optical measurements from aircraft, video lightning images have been taken during a number of space shuttle flights while conducting the Mesoscale Lightning Observation Experiment (MLE). These observations have revealed many interesting lightning events.

For example, on April 28, 1990, a video image from space showed a single stratospheric luminous discharge appearing to move upward into clear night air. This was recorded on the space shuttle STS-32 mission using the payload bay TV camera.

The direction of this event has not been firmly established; however, the stratospheric discharge is of interest because it may provide evidence for a theory postulated by Charles Thomson Rees Wilson in 1925. This theory predicted that electric fields can cause ionization at great heights and could therefore give rise to discharges between clouds and the upper atmosphere.

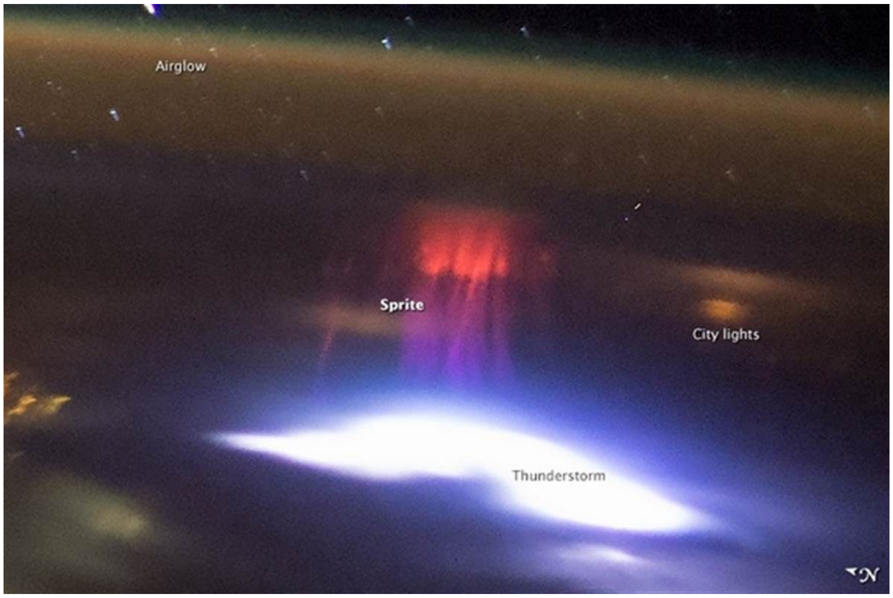


Image of a sprite over a thunderstorm and city lights (Photo credit: NASA)

Stratospheric lightning could potentially deposit significant energy into the stratosphere, causing important chemical perturbations. In addition, these lightning events may generate strong electric fields and electromagnetic pulses which might interact with the Earth's ionosphere and magnetosphere. Finally, strong fields at high altitudes may generate runaway electrons that could then produce high energy x-rays and even gamma rays. Thus, it is possible that lightning may generate electromagnetic radiation, ranging from extremely low frequency to gamma radiation.

Researchers from the Geophysical Institute at the University of Alaska have confirmed shuttle observations by capturing images on videotape of what appear to be brief flashes of light emanating from thunderstorms into the stratosphere. These stratospheric optical flashes, also known as sprites, were photographed from NASA's DC-8 Airborne Laboratory while flying at an altitude of about 12 kilometers during a night-time mission to videotape lightning over Iowa and Kansas during June and July of 1993. Recent studies have shown that a sprite typically occurs over a Mesoscale Convective System and is usually triggered when positive cloud to ground lightning discharges, which are associated with early very low frequency perturbations. Sprites are brief, persisting from a few milliseconds to about 200 milliseconds. The flashes are narrow, initiate at about 65 kilometers altitude, and extend to altitudes of 85 kilometers.

LIGHTNING DETECTION NETWORKS (GROUND-BASED MEASUREMENT)

National and regional lightning networks that use magnetic direction finders, time of arrival techniques, or very high frequency interferometry provide important lightning and storm information. For a number of years, the Federal Government assisted in the financing of a national lightning data service combining independently operated systems into one network. Used primarily for operational evaluation by NOAA, it evolved into a product with substantial value for both private industry and by other Federal agencies. Today, recognition of the importance of lightning detection with economically-viable and commercially-sponsored systems is apparent.

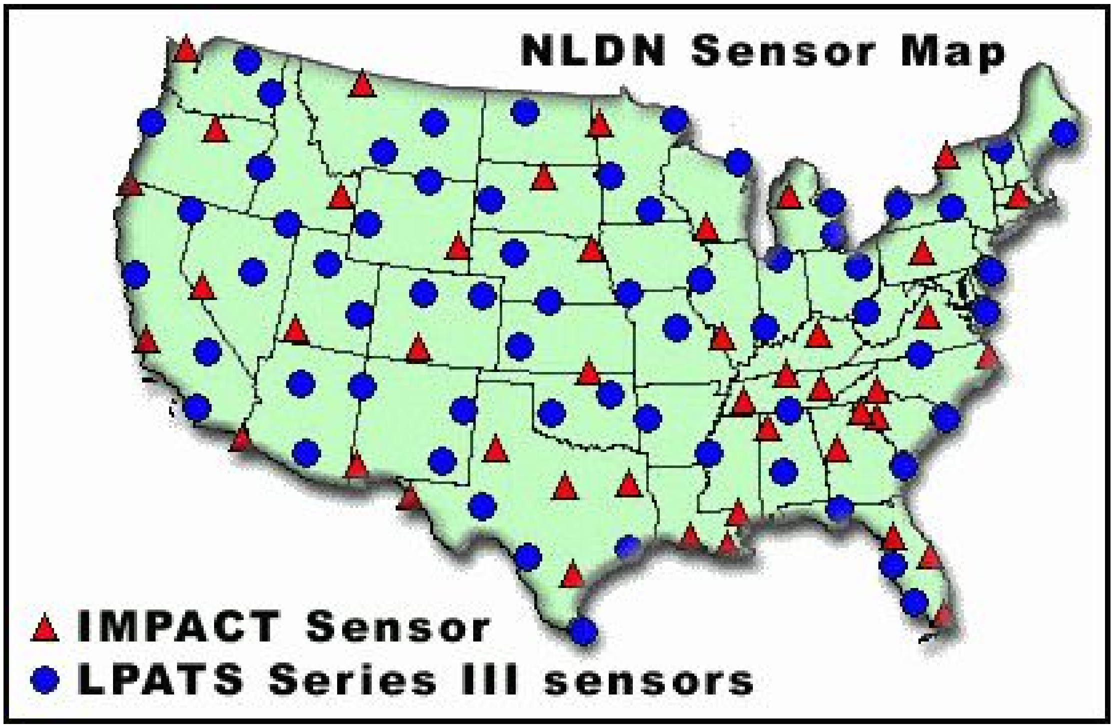
The National Lightning Detection Network (NLDN) operated by Global Atmospherics, Inc. (GAI) in Tucson, Arizona is a network of at least 130 magnetic direction finders that cover the entire United States. Each direction finder determines a direction toward a detected electromagnetic lightning discharge. The location of the lightning discharge is determined by triangulation. Each of these sensors is capable of detecting cloud-to-ground lightning flashes at a distance of around 400 kilometers away. Processed information is transmitted to the Network Control Center (NCC) in the form of a grid map showing lightning across the U.S.

A National Lightning Detection Network (NLDN) (Photo credit: NASA)

The Atmospheric Research Systems, Inc. (ARSI) time-of-arrival (TOA) system provides 11 Lightning Position And Tracking Systems (LPATS) covering the United States and extends hundreds of miles into both oceans and beyond the borders of Canada and Mexico. ARSI ground strokes lightning data includes information on latitude and longitude, date and time, polarity, and amplitude.

GDS purchased the ARSI system and is in the process of combining the direction finding and time of arrival techniques into a single comprehensive network.

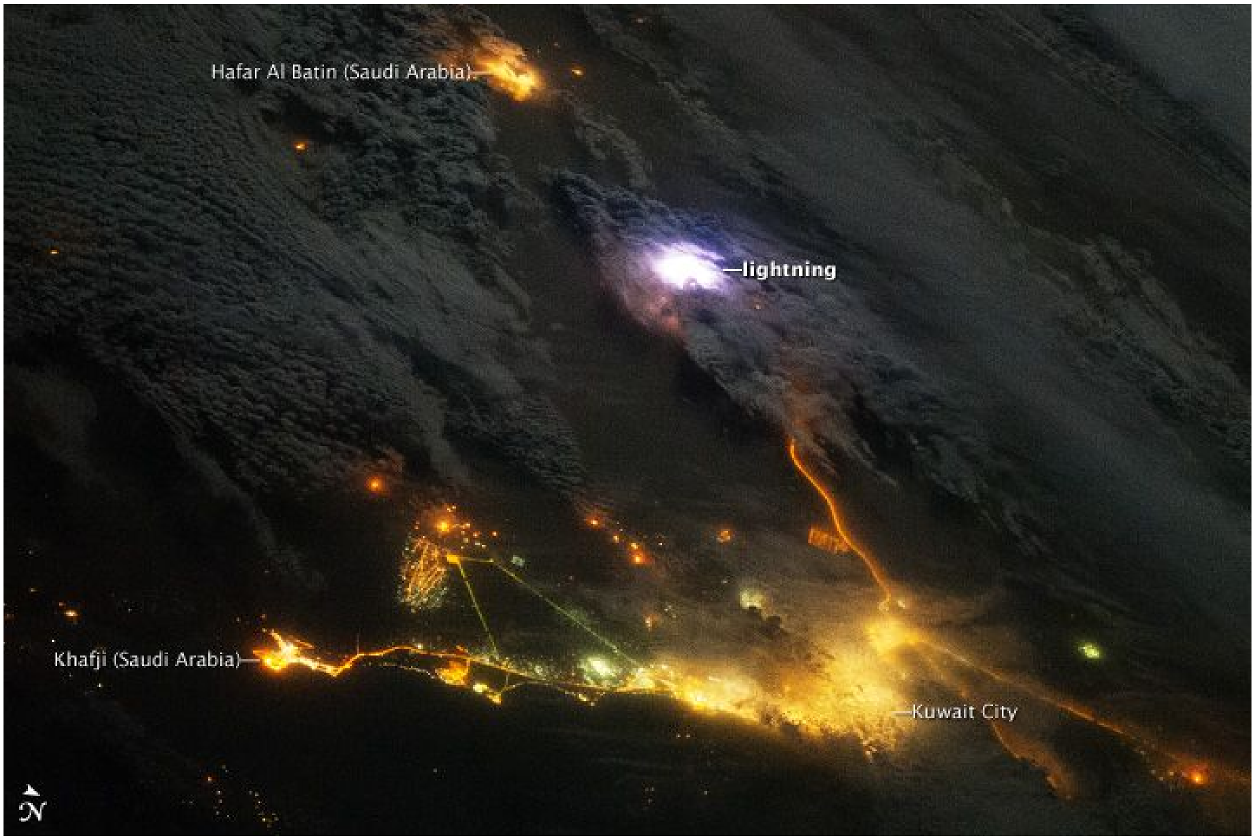
The TOA system operates by digitizing the waveform of a received lightning signal at each sensor and accurately timing the peak with a resolution of up to 100 nanoseconds. The difference of arrival time at four or more receivers is then used to calculate the location. The geographical positions of the various sensors making up the network are shown in the U.S. map below.



Internationally, two very different types of lightning detection and location networks have been developed. The SAFIR two-dimensional VHF interferometer system developed by the French aerospace research organization ONERA and commercialized by Dimensions of France, is used to provide detailed information on all types of lightning activity within a relatively small area. The VLF Arrival-Time Difference (ATD) system designed and operated by the United Kingdom Meteorological Office detects and locates lightning at very long range, but with less detection efficiency. In addition, other networks cover portions of Europe, Asia, Australia, China, and Canada.

SATELLITES

Global lightning signatures from the Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS) have been analyzed from the filmstrip imagery, which is archived at the National Snow and Ice Data Center in Boulder, Colorado. These signatures show up as horizontal streaks on the film images. The location of each of these streaks has been digitized in order to develop a preliminary database of global lightning activity.



Lightning storm over Saudi Arabia (Photo credit: NASA)

While the database continues to be enlarged, the available data are spotty, making a comprehensive history of global lightning behavior impossible to produce; however, direct digital OLS and LIS/OTD data are available, which greatly improves and expands the global lightning database.

Lightning annual, interannual, and seasonal variations could then be compared with other global datasets (e.g. precipitation or global and regional synoptic patterns) both to improve understanding of the role of lightning on a global basis.

The Optical Transient Detector (OTD)

The Optical Transient Detector (OTD) was a highly compact combination of optical and electronic elements. It was developed as an in-house project at NASA's Marshall Space Flight Center in Huntsville, Alabama. The name refers to its capability to detect the momentary changes in an optical scene which indicates the occurrence of lightning. The OTD instrument was a major advance over previous technology in that it gathered lightning data under daytime conditions, as well as at night. In addition, it provided much higher detection efficiency and spatial resolution than previously attained by earlier lightning sensors.

At the heart of the system was a solid-state optical sensor similar in some ways to a TV camera; however, in overall design and many specific features, OTD had to be uniquely designed for the job of observing and measuring lightning from space. Like a TV camera, the OTD had a lens system, a detector array (serving a function somewhat analogous to the retina in the human eye), and circuitry to convert the electronic output of the system's detector array into useful data.

Further Information on OTD: OTD Homepage

Lightning Imaging Sensor (LIS)

The Lightning Imaging Sensor (LIS) was designed to study the distribution and variability of total lightning on a global basis. It consists of a staring imager, which is optimized to locate and detect lightning.

LIS is a calibrated lightning sensor that uses a wide FOV optics lens with a narrow-band filter in conjunction with a high speed charge-coupled device detection array. A Real-Time Event Processor (RTEP) was used to determine when a lightning flash occurs, even in the presence of bright sunlit clouds.

Weak lightning signals that occurred during the day are hard to detect because of background illumination. The RTEP removed the background signal, thus enabling the system to detect weak lightning and achieve a 90% detection efficiency. LIS operates on two satellite platforms, the Tropical Rainfall Measuring Mission satellite (TRMM) and the International Space Station (ISS).

Lightning Imaging Sensor (LIS) in front of the solar panels on the International Space Station (ISS) (Photo credit: NASA)

Tropical Rainfall Measuring Mission (TRMM) was launched in November 1997, and was a space based system for measuring tropical rainfall and its variations. Its orbit was circular, at an inclination of 35 degrees to the equator, and at an altitude of 350 km. The low altitude of TRMM provided high resolution images, thus, more accurate rainfall measurements were obtained over very small areas of the globe. LIS contributed significantly to several TRMM mission objectives by providing a global lightning and thunderstorm climatology; however, the TRMM satellite stopped collecting data on April 8, 2015 and crashed in the Indian Ocean on June 15, 2015.

TRMM had a low Earth orbit with an inclination of 35 degrees which results in LIS observing lightning activity in the tropical regions of the globe. The wide angle lens, combined with the altitude of the TRMM platform, permits LIS to view a 600 km×600 km area of the Earth with a spatial resolution between 3 km and 6 km (3 km at nadir, 6 km at limb). Since the LIS travels around the Earth with a velocity greater than 7 km/s, the instrument can monitor individual storms and storm systems for lightning activity for almost 90 seconds as it passed overhead.

International Space Station (ISS) is a habitable satellite in a low orbit around the Earth. The ISS is used as a platform for scientific research in various scientific fields, such as astronomy, life sciences, physical sciences, and meteorology. LIS will be placed on the ISS in February 2017. This LIS will be able to collect data around the globe at higher latitudes than before. The ISS orbit is maintained by boost manoeuvres to keep the station altitude between 330 km and 435 km. The changing altitude results in a LIS spatial resolution of 4 km to 8 km, completing about 15.54 orbits per day, and viewing about 550 km of the Earth’s surface. The high inclination of the space station gives LIS the ability to "look" farther towards Earth's poles than the TRMM LIS viewing latitudes up to 54 degrees. The ISS travels around the Earth 7.667 km/s, the LIS instrument can monitor individual storms and storm systems for lightning activity.

Further LIS Information: LIS Homepage and ISS Utilization: LIS

Also see these documents:

- Blakeslee, R. J., H. J. Christian, M. F. Stewart, D. M. Mach, M. Bateman, T. D. Walker, D. Buechler, W. J. Koshak, S. O’Brien, T. Wilson, E. C. Colley, T. Abbott, J. Carter, S. Pavelitz, and C. Coker, **Lightning Imaging Sensor (LIS) for the International Space Station (ISS): Mission Description and Goals**, *XV International Conference on Atmospheric Electricity*, Norman, Oklahoma, June 2014.
- Blakeslee, R. and W. Koshak, 2016: **LIS on ISS: Expanded Global Coverage and Enhanced Applications**, The Earth Observer, 28, 4-14.
- Christian, H.J., R.J. Blakeslee, and S.J. Goodman, **The Detection of Lightning from Geostationary Orbit**, *Journal of Geophysical Research*, Vol. 94, 13,329-13,337, 1989.
- Christian, H.J., R.J. Blakeslee, and S.J. Goodman, **Lightning Imaging Sensor (LIS) for the Earth Observing System**, NASA Technical Memorandum 4350, MSFC, Huntsville, AL, February, 1992.

GEOSTATIONARY LIGHTNING MAPPER (GLM)

The Geostationary Lightning Mapper (GLM) a sensor onboard the Geostationary Operational Environmental Satellite - R series (GOES-R), which launched in November 2016. It is capable of continuously mapping lightning discharges during both the day and night with a spatial resolution of 10 km in geostationary orbit.

In a geostationary orbit, the GLM is capable of detecting and locating both cloud-to-ground and intra-cloud discharges with high spatial resolution and detection efficiency identify intensifying thunderstorms and tropical cyclones, which will aid in forecasting severe weather events.

Scientists will be able to study the electrosphere over dimensions ranging from the Earth's radius all the way down to individual thunderstorms. GLM is capable of detecting all types of lightning phenomena and will provide near uniform spatial coverage. Disseminating this information in near real time, these measurements could be related on a continuous basis to other observables, such as radar returns, cloud images, and other meteorological variables to enhance the accuracy of weather nowcasting.

The data will be used to determine flash rates and storm motion and evolution. This is then correlated with information obtained from other sensor systems, such as observations of precipitating electrons, VLF-ELF noise, and ULF waves in the ionosphere. GLM provides information that can only be obtained with a space based instrument. Because the data are distributed in real time, weather forecasters find it an invaluable tool for storm nowcasting, as well as for the issuing of severe storm and tornado warnings, detecting heavy rainfall and flash flooding, improving aviation flight rough planning, and studying long-term climate variability.

The GLM in geostationary orbit can be used for 1) Severe storm detection and warning (lightning, flash floods, tornadoes, hailstorms, and downbursts), convective rainfall estimation, storm tracking, aviation hazards (terminal and enroute use), hazard warnings: power companies, fuel depots, golf courses, etc, algorithms for forest fire likelihood forecasting (uses location, frequency, and duration of flashes). Can be used as an indicator of cyclone development and evolution. Improvement of long-term forecasting by quantifying lightning activity for the time of day, season, location, and storm type. Improvement in the understanding of the physics of the Global Electric Circuit. Increased understanding of lightning interactions with the magnetosphere and the ionosphere. NOx generation studies. Studies of whistler and other wave propagation phenomena. Magnetospheric-ionospheric research. 2) Solar-tropospheric studies.

Most importantly, it will help to better understand the Earth's atmosphere. As a response to fundamental forcing, lightning contains far more information than just the electrical aspects of the atmosphere. It tells where strong convection is occurring, when large quantities of water are forming in the mixed phase regions of storms, and suggests how latent heat is being released during the storm's life cycle. Since the microscales on which particles interact to generate electricity are coupled through storm scale processes to synoptic scale systems, lightning activity should provide information on the development of the atmosphere over many scale sizes.

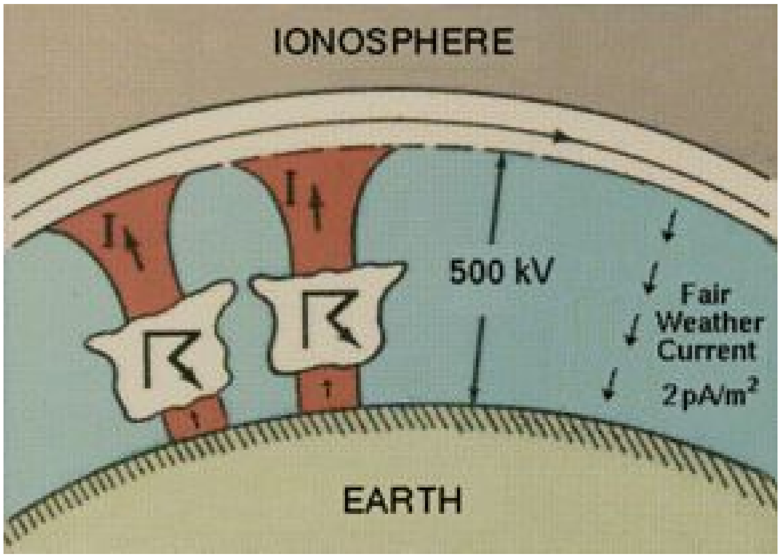
Further GLM Information: GOES-R GLM Factsheet

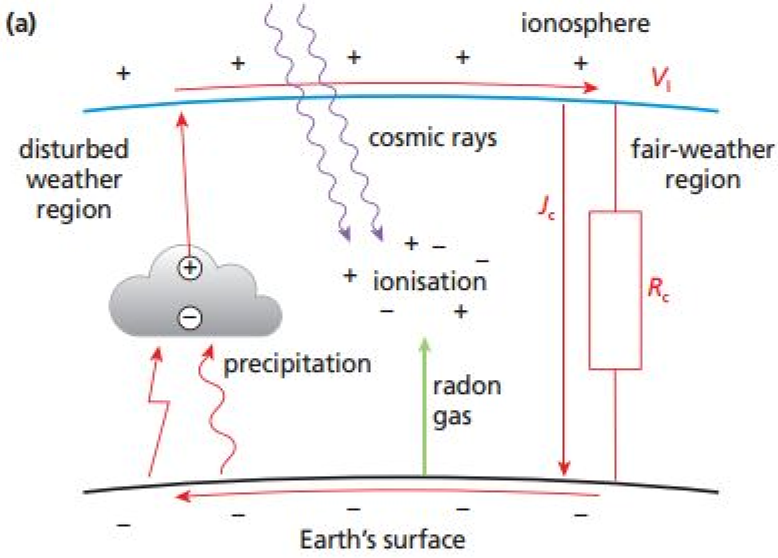
The Future of Lightning Detection in Space

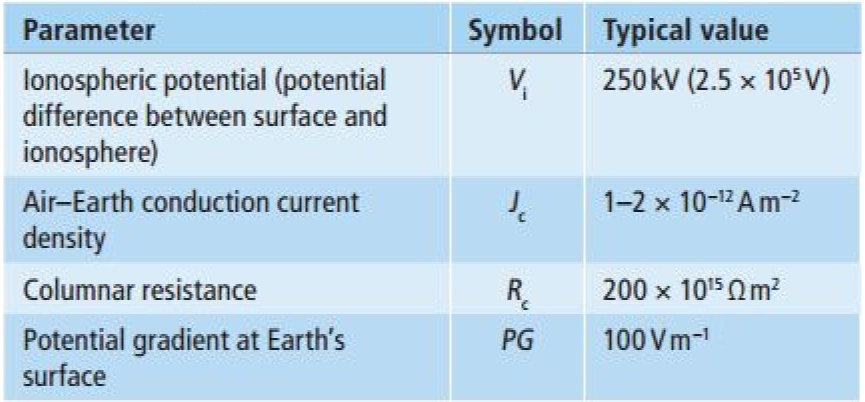
TBD

The Global Electric Circuit

During fair weather, a potential difference of 200,000 to 500,000 Volts exists between the Earth's surface and the ionosphere, with a fair weather current of about $2x10^{-12}$ amp/m^2. It is widely believed that this potential difference is due to the world-wide distribution of thunderstorms.







Parameter	Symbol	Typical value
Ionospheric potential (potential difference between surface and ionosphere)	V_i	250 kV (2.5×10^5 V)
Air–Earth conduction current density	J_c	1–2 $\times 10^{-12}$ A m^{-2}
Columnar resistance	R_c	200×10^{15} Ω m^2
Potential gradient at Earth's surface	PG	100 V m^{-1}

Present measurements indicate that an average of almost 1 ampere of current flows into the stratosphere during the active phase of a typical thunderstorm; therefore, to maintain the fair weather global electric current flowing to the surface, 1,000 to 2,000 thunderstorms must be active at any given time. While present theory suggests that thunderstorms are responsible for the ionospheric potential and atmospheric current for fair weather, the details are not fully understood.

Ground-based radio frequency measurements of global rates have significant uncertainties and limitations. A high resolution space based sensor is necessary in order to help eliminate some of the present uncertainties associated with measuring global lightning activity.

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Lightning Safety

The six most common dangerous activities associated with lightning strikes, in order, are:

1. Work or play in open fields
2. Boating, fishing, and swimming
3. Working on heavy farm or road equipment
4. Playing golf
5. Talking on the telephone
6. Repairing or using electrical appliances

If caught in the open during a strike and the hair on your head or neck begins to stand on end (this really happens) go inside the nearest building. If no shelter is available, crouch down immediately in the lowest possible spot and roll up in a ball with feet on the ground (DO NOT LIE DOWN).

Treatment if struck by lightning:

1. Check breathing and pulse
2. TREAT APPARENTLY DEAD FIRST
3. Perform mouth-to-mouth resuscitation
4. Apply cardiopulmonary resuscitation

Original: 1997
Updated: May 2017

Resources:

http://www.vaisala.com/Vaisala%20Documents/Scientific%20papers/Annual_rates_of_lightning_fatalities_by_country.pdf

https://www.google.com/url?q=https://arxiv.org/ftp/arxiv/papers/0906/0906.0429.pdf&sa=D&ust=1489763530139000&usg=AFQjCNHmz6C0ySb8jw478fQzhDJRX0ybvw