Fig. 8-1. Lightning at sunset with rain fall streaks over Cheyenne, WY, 21 July 2020. Jan Curtis.

Fig. 8-2. Lightning illuminating its thunderstorm during the 'blue hour' of twilight more than 30 min after sunset over Cheyenne, WY, 13 Jun 2021. Jan Curtis.

Wonders of the Atmosphere
Chapter 8: Lightning

Started 16 Oct 2024

8.1 Thunderbolts

Fig. 8-3. Lightning strike less than 300 m away, 10 Aug 2022 Jan Curtis.

In distant thunderstorms, lightning (Fig. 8-1, Fig. 8-2) often puts on a silent light show for the viewing pleasure of spectators. Careful though, for a little later, with no warning, a blinding flash of lightning (Fig. 8-3) zaps down to the ground perilously close, turning night into day for an instant. A fraction of a second later, the concussion of thunder's sonic boom rattles, terrorizing and deafening people and animals on the ground who barely escaped death.

Thunder may well be the atmosphere's most terrifying natural phenomenon and it is certainly is the most startling because of its sudden, deafening sonic boom, enough to make anyone jump out of their skin. Thunder can deafen and stun, but the lightning that causes it is the real culprit, killing by electrocution. Little wonder that almost every ancient religion had its god of lightning and thunder, often the chief god, who threw thunderbolts. That includes Yahweh and Allah.

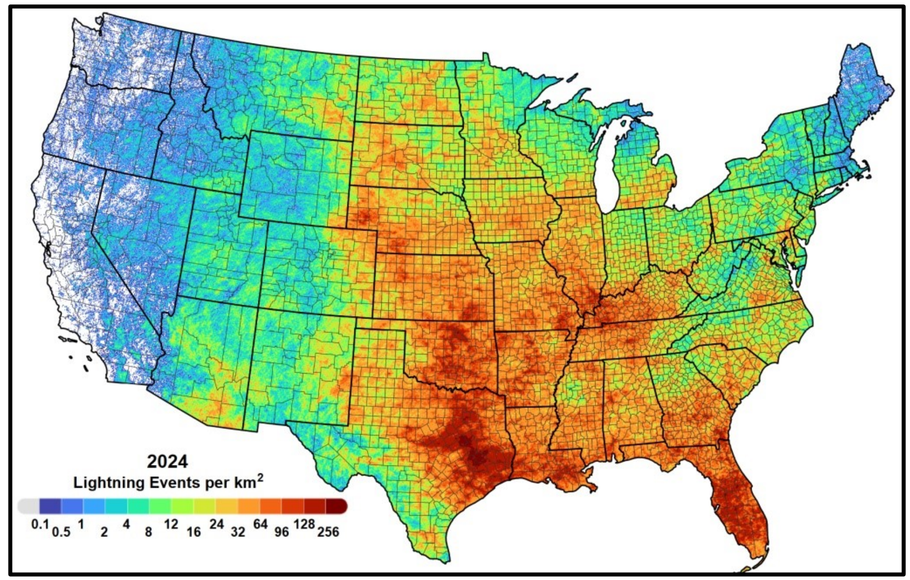

Fig. 8-4. Lightning strikes per km^2 in the United States 2024. Vaisala

Throwing lightning bolts must keep the gods quite busy for, in righteous anger as lessons to the wayward, they throw some 1.4 billion bolts a year (Fig. 7-2 and Fig. 8-4) or 45 per second. At least once, however, Zeus was sad he had to throw a bolt.

When Phaethon, son of a mortal woman, discovered that his father was Apollo, the Greek God of the Sun, he extorted a gift from his father to drive the Chariot of the Sun across the sky for just one day. Almost immediately on the steep climb after dawn, Phaethon lost control of the horses that drew the chariot, which went awry across the sky creating the Sahara Desert among other disasters. Zeus had to throw his bolt, killing the poor lad, who fell to Earth as a shooting star.

On 24 Dec 1971, 17-year old Juliane Koepcke fell to Earth but survived after a lightning bolt struck Lansa Flight 508 on its way to Pucallpa, Peru in the Amazon Rainforest. Lightning hits planes so often they are designed with an outer metal shell to direct it away harmlessly. But on 24 Dec 1971 the plane's shell failed. The plane broke apart 3 km above the rainforest and ejected the passengers in midair.

Juliane survived the fall by a freakish combination of events. She was strapped to her seat, which acted like a parachute that was likely slowed further by the thunderstorm updraft. Finally, the impact was buffered by shredding through the rainforest canopy. Fourteen other passengers survived the fall, but only Juliane, trained in survival techniques, made it out alive despite multiple injuries.

Lightning claims between 2000 and 24,000 lives annually around the world[1]. (Estimates vary widely.) The situation has become much better in the United States. Up until the early 1950's lightning used to claim between 200 and 400 American lives, but since then Americans have become much more lightning savvy, and the death toll has fallen to only about 15[2]. This means that in the United States, less than 1 in a million lightning flashes results in a death. More than 10 times as many are struck by lightning but survive, though often with debilitating physical and psychological injuries.

The impossibility of predicting precisely when and where a bolt will strike increases its danger by surprise. This was illustrated by a video taken during a soccer match in 2024 in Peru[3]. The unsuspecting players were walking calmly across the field during a break in the match and simply fell over as the lightning ran invisibly along the ground (though it sometimes leaves scars as in Fig. 8-5)and through them. One player never got up.

An earlier event that drew international attention to what can happen if you stand out in the open or under a tree during a thunderstorm took place on 28 June 1975 when the golfing great Lee Trevino and two others were struck by lightning that ran along the wetted ground on the 13th hole. Each survived but was seriously injured. Trevino needed two spinal surgeries and a few years before he was able to play competitive golf again. Alerted by this incident, American deaths from lightning strikes dropped below 100 for good that year.

Fig. 8-5. A hole in one. Radial damage pattern from a lightning bolt that struck the flag. Posted by @RickShielsPGA, 14 Jul 2020.

Exposed sites such as open fields, golf courses, beaches, and especially water bodies such as lakes, increase one's vulnerability. Standing under a solitary tree, hoping for protection from a thunderstorm, is now widely known as a dangerous thing to do. A recent video, posted 04 Jul 2023 of 31 cattle killed while huddling under a tree during a storm in Cullman County, AB illustrates that danger.

https://www.youtube.com/watch?v=_dy65dpH_IY

In preparing photographs and videos, Jan has been within 30 m of a lightning strike a half dozen times despite beating strategic retreats. Once he was deafened for ten minutes by a nearby bolt that shattered the small tree he had been standing near moments earlier. At a different time and place, several of his relatives were struck but survived a nearby bolt that traveled along the wet ground.

Fig. 8-6. Panorama of thunderstorm with lightning, 20 May 2021 100 km east of Cheyenne, WY. Jan Curtis.

Fig. 8-7. Last gasp lightning striking ground from a dying thunderstorm over Tucson, AZ, 16 Aug 2018. Jan Curtis.

Now, with lightning detectors as simple as AM radios and extreme vigilance few Americans mess around with lightning. In Sapphire, NC, one of countless places around the United States, as thunderstorms near, sirens, tripped by lightning detectors, go off requiring people to get out of Fairfield Lake, away from the beach, and out of local pools. Discretion is the better part of valor.

Lightning statistics have become quite accurate over the past 25 years as sensor technology has improved and spread. The National Lightning Detection Network[4] recorded an annual average in the United States of 23 million flashes, 55 million strokes (the visible bright, flickering light we see) and 36.8 million ground strike points. During the peak lightning month (June), about 3.7 million strikes occur. Florida, the nation's thunderstorm capital, has the highest concentration of strikes at 116/km^2. The West Coast, chilled by the cold California current that suppresses convective activity, has the lowest strike rate of < 1/km^2 (Fig. 8-4).

Fig. 8-8. Chaiten eruption cloud 03 May 2008 and its lightning bolts including a rare green bolt. ©Carlos Gutierrez UPI/Landov.

Thunderstorms produce the vast majority of lightning strikes (e. g., Fig. 8-1, Fig. 8-2, Fig. 8-6, and Fig. 8-7). Ash-laden *pino* (pine tree shaped) clouds from volcanic eruptions produce abundant lightning strikes but major eruptions occur much less often than thunderstorms. The eruption cloud of Chaiten (Satan), Chile on 03 May 2008 (Fig. 8-8) produced myriad lighting strikes, at least one of which was bright green, by discharging O atoms much as in the aurora. Sandstorms and major earthquakes also can produce lightning.

Lightning has been both a curse and a blessing. In the Western United States lightning is the cause of more than 50% of the wildfires[5] because it often strikes dry ground with desiccated vegetation as tinder. But it is in the lightning burned areas of the African Savannah that chimpanzees now and early humans once foraged as well. Perhaps lighting even was the spark that taught humans to save and perhaps even create fire by striking rocks together and later, learning to strike flint and iron pyrite together to create a spark that would ignite dry tinder.

8.2 Lightning and Thunder Characteristics

Lightning is a giant electrical spark. Even those who know the numbers remain impressed. The core temperature of a lightning bolt may exceed 30,000°C, making it brighter and bluer than the Sun. The typical flash packs a wallop of 300 million volts and 30,000 amps, and extreme bolts may exceed 1 billion volts and 200,000 amps. Compare this to typical American household electricity of 110 volts and circuit breakers of 25 or 50 amps. Each bolt releases between about 50 and 1500 kilowatt hours of energy, depending on the type of lightning[6]. That is enough to power the typical American home between about 2 and 50 days, if only we could capture that energy.

The typical length of a lightning bolt is of order 10 km but some can be much, much longer. The longest documented single bolt stretched 766 km from Texas across Louisiana to Mississippi. And the bolts can emanate from the thunderstorm anvil, far from all the weather on the ground and literally strike as a bolt from the blue.

Anyone who has seen lightning knows it travels fast. When a bolt is forging its path its typical speed is 300,000 km per *hour*. Once the lightning channel is established the bolts travel much, much faster, at up to one third the speed of light, or about 100,000 km per *second*. Since sound travels much slower – 1 km in just under 3 s, hearing thunder 3 s after seeing a lightning flash means the nearest part of the lightning bolt was 1 km away.

The near instantaneous enormous heating of the air along the channel of the bolt – to temperatures approaching 30,000°C – produces the explosive, supersonic expansion shock wave that is thunder. The thunder's sound is intimately connected with the pressure wave of the expanding air, which can certainly produce temporary deafness and even damage the ear drum.

Thunder can vary from a deafening and shocking clap that can scare the wits out of anyone to a prolonged rumble. It may start with a preliminary hiss, then a bang and can echo or reverberate for what seems to be an eternity but rarely lasts 30 seconds. Of course multiple closely spaced and timed bolts can prolong the noise considerably.

The peak decibel level of thunder depends on the power of the lightning bolt, its distance, and its orientation. Thunder from bolts that strike close by tend to be louder because sound weakens as it spreads with distance. The decibel level is higher and lasts a shorter time when the bolt is oriented at near right angles to the observer so that all the noise reaches at almost the same time. Jan's recording of such a booming thunderbolt with follow-up reverberations can be heard along with the lightning that produced it at,

https://www.flickr.com/photos/79387036@N07/51417257579

8.3 Discovering the Nature of Lightning

How do thunderstorms manage to produce lightning? Discovering the nature of lightning and how it forms took centuries, even after the Scientific Revolution, and is now at last mostly but still not fully answered.

Understanding lightning began with the realization that it might be a giant spark. The same electrical buildup and breakdown via sparks, but on a much smaller scale than lightning, occurs when you strike flint against pyrite or rub amber against fur as the Ancient Greeks did. (Little wonder that the words, electron and electricity were taken from ēlektron, the Greek word for amber.) More commonly, sparks occur when you remove sweaters or walk across a carpet in dry weather or rub a balloon against your hair. As the opposite charges build, extending your hand toward the doorknob or bringing the balloon close can create a spark (or cause your hair to stand on end). The spark can sting, but holding a metal key so that the electric charge goes through the key to the doorknob or balloon (which may pop) eliminates the pain, somewhat like a lightning rod.

Rubbing produces static electricity by a *triboelectric* effect (tribo = rubbing) that transfers negative charge from your hair to the balloon. Exactly how and why electric charge is transferred by rubbing or striking two objects, in particular when both objects are made of the same material, is still not fully understood.

Scientists and aficionados began to investigate electricity seriously in the 1600's. In 1746, Pieter van Musschenbroch invented a device to store electric charges he generated with a friction machine. Benjamin Franklin called the storage device a Leyden jar and built his own, for experiments and entertainment such as electrocuting a turkey. On his first attempt, Franklin almost killed himself by accidentally giving himself the shock designated for the turkey.

Franklin had more in mind than mere entertainment. The repulsion of the two strands of the Leyden jar led to his discovery that there are positive and negative electric charges, with like charges repelling and opposite charges attracting. And, of course, his famous 1752 kite experiment during a thunderstorm, which gave him small shocks, proved that lightning is a giant electrical spark.

The lightning rod was Franklin's great life-saving contribution. Though it might capture more strokes by sticking up above the main structure, it guides the current safely into the ground. It took several decades for Franklin's invention to be widely adopted. In that interval, many lives were needlessly lost. Perhaps the paradigm case was when in 1769 lightning struck the unprotected Church of St. Nazaire in Brescia (now Italy), which served as a repository for 100 tons of gunpowder. The resulting explosion destroyed ⅙th of the city and killed 3000 people. That event went a giant step toward replacing church bell ringers (many of whom were electrocuted) with lightning rods as a more effective form of protection from lightning.

8.4 How Thunderstorms Generate Charge

Thunderstorms are in effect combined electric generators and capacitors, both building and storing electric charges until the air can take it no longer, and a sudden discharge occurs.

The electrification process begins with a background electric field. Cosmic rays (mainly protons) that bombard Earth from Space give the ionosphere a positive + charge while the Earth has a negative – charge. The atmosphere's potential or voltage gradient averages 100 V/m and though positive charges constantly leak down from the ionosphere to the ground, the air is normally an insulator that easily withstands the average voltage gradient. But thunderstorms raise the voltage gradient by orders of magnitude, causing the air to break down as an insulator and become a conductor.

How does a thunderstorm act as a friction machine and capacitor? The rubbing that in a thunderstorm is the collision of hydrometeors. The great hint that ice is involved is that thunderstorms only produce lightning when the cloud top temperature is below about -20°C. Ice particles also tend to separate after colliding, which is necessary for separating electric charges as well. In the sub-freezing region, the hydrometeors consist of a mix of supercooled droplets, ice crystals, graupel (ice particles that have accreted a community of droplets), and hail.

The primary charging occurs when graupel and crystals collide. Warning: The sign of the charging depends on condensed water and ice content, collision rates, and temperature. When these values are

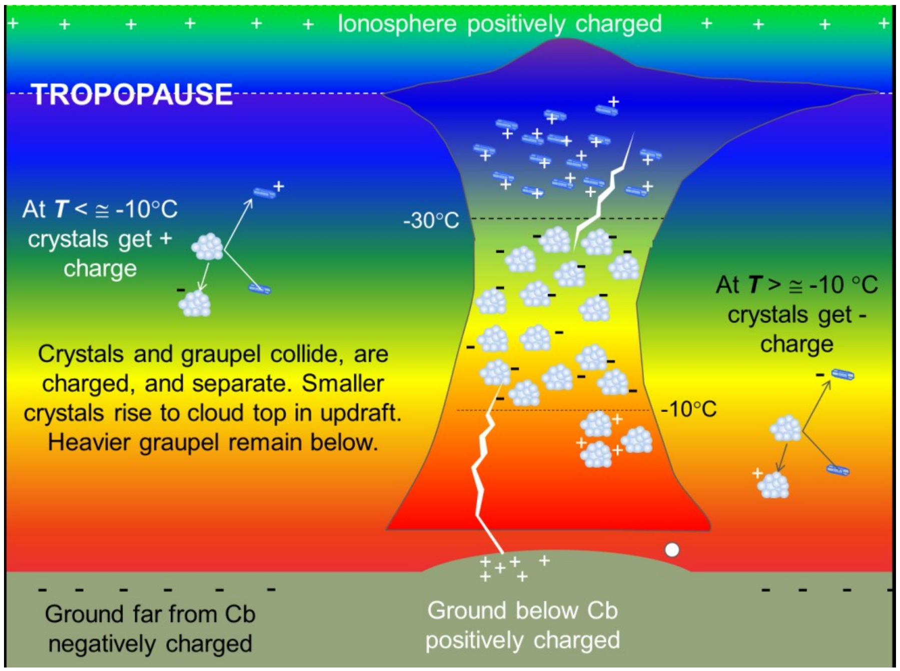

Fig. 8-9. Lightning (cloud to cloud and cloud to ground) and the generation of electrical charges in a thunderstorm. SDG.

1: low, collisions give ice crystals + charge and graupel – charge. This charging dominates most thunderstorms for -30°C < ***T*** < -10°C.

2: high, collisions give ice crystals – charge and graupel, + charge. This charging dominates most thunderstorms for -10°C < ***T*** < 0°C.

The resulting situation and electrification charging processes are illustrated in Fig. 8-9. Inside the thunderstorm, crystals with + charge dominate the upper part of the cloud, usually where ***T*** < -30°C. Graupel with – charge dominate in the middle heights of the cloud between about -30°C < ***T*** < -10°C. A smaller region of graupel with + charge dominates nearer the cloud bottom for -10°C < ***T*** < 0°C.

The segregation of + from – electric charge into separate regions in a thunderstorm occurs because ice crystals and graupel segregate. Most ice crystals are smaller and lighter and have a slower terminal velocity than most graupel, so the crystals get swept up high in the cloud by the updraft while the graupel remain below.

This explains why cumulonimbus is the by far the main cloud genus to produce lightning. If there is no strong updraft extending high in the troposphere, there is no charge separation and no lightning. That is why cumulus humilis, stratocumulus, altocumulus, cirrocumulus, cirrus, stratus, altostratus, and cirrostratus, all with their gentle updrafts or circulations and little or no accretion do not produce lightning. Lightning and thunder do occur in the stratiform shields of organized thunderstorm clusters, or Mesoscale Convective Systems (MCS) and intense winter storms and but only in or associated with embedded thunderstorms. In blizzards it is called thunder snow.

Lightning bolts represent the attempt to neutralize + and – charge concentrations in the separate regions of the cloud that have grown excessive and at the same time reduce excessive electric field gradients. Since the two major repositories of charge are the + charged crystals high in the cloud and the – charged graupel lower in the cloud, more than ⅔ of all lightning flashes occur within the cloud or between two nearby thunderstorm clouds. Less than about ⅓ of all lightning bolts occur between the cloud and the ground.

8.5 The Life of a Lightning Bolt

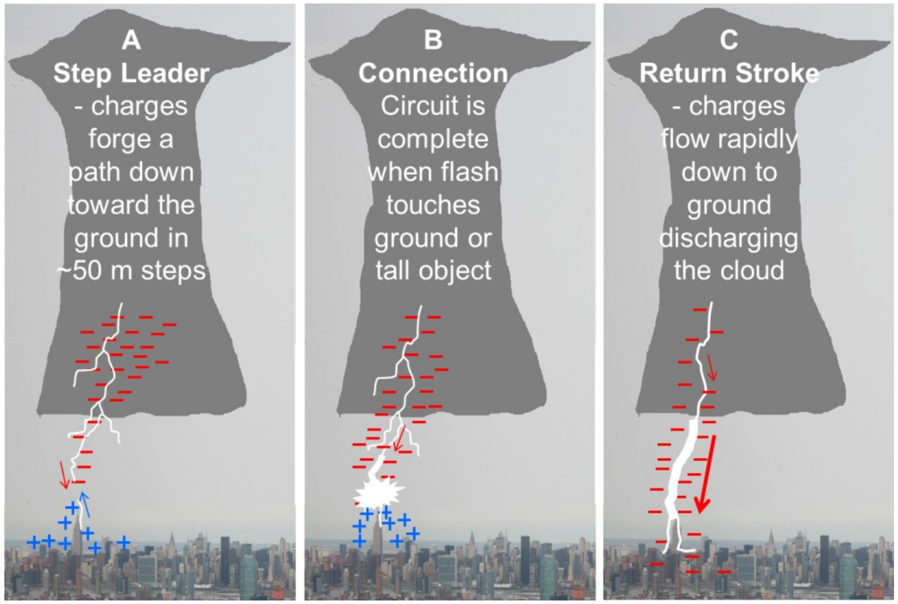

Fig. 8-10. Stages in cloud to ground lightning stroke. A: Step leader, B: Connection, C: 'Return' stroke. SDG.

Fig. 8-11. Step leader. A stack of 100 frames over 0.25 s on 31 Jul 2022. Jan Curtis. In any single frame the leads look like short, isolated meteor trails.

Lightning bolts evolve in a series of stages, illustrated in Fig. 8-10 for the case of cloud-to-ground lightning. As the predominantly – charge region lower in the thunderstorm forms, it repels the normally small – charge on the ground enough so that the ground beneath thunderstorms becomes + charged. The + charges on the ground, attracted to the – charges in the cloud, concentrate on any high point such as a mountain, a hill, a tall building or church steeple, a tree, or even a flag on the green of a golf course.

Fig. 8-12. The change between the step leader (top) and the bright return flash for cloud-to-ground lightning, 26 Aug 2023. Jan Curtis.

As the charges in the cloud continue building, the electric field gradient eventually surpasses the insulating capacity of the air and a conducting channel of – charges begins moving away, either toward the + charge region above (which will produce cloud to cloud lightning) or down to the ground. This is called the step leader because it occurs in steps of roughly 50 m, with branching paths (most failing) as the insulating property of the air is overcome.

In its effort to forge a conducting channel (essentially a wire of ionized air), the step leader zigzags downward with many failed leads of short, rapidly fading meteor-like trails in a 'forked' pattern, (Fig. 8-11) hence it is sometimes called *forked lightning*. As the step leader nears the ground, it is attracted to a streamer, a channel of positive charge reaching up, usually from a tall object, such as a tree, house, telephone pole, or the Empire State Building.

Step leaders reach the ground in a millisecond, so quickly that the human eye cannot distinguish them from the main strokes that follow though ultrafast photography can, as in the stack of 100 closely spaced frames over 0.25 s on 31 Jul 2022 (Fig. 8-11) which make the leaders appear continuous. These frames are part of the video

https://www.flickr.com/photos/79387036@N07/52256821316/

The video animates 15 minutes of intense lightning activity, slowing for each event. In particular, it shows the step leader's erratic advance and explosive change after leader and streamer connect. The final bolt of the video almost knocked Jan to the ground.

When the oppositely charged leader and streamer connect, often as a blinding flash, the powerful electrical current of the main stroke, begins flowing. The main stroke sends negative charges (electrons) hurtling *down* to the ground at up to ⅓ the speed of light (100,000 km/s) making it ill-advised to stand under a tall object during a thunderstorm! The two photos in Fig. 8-12 capture the change that occurred from the step leader to the main stroke.

The main stroke is called the return stroke because it appears in ultrahigh speed cameras to move upward even as the negative charges move downward. The apparent upward motion is analogous to the upstream propagation of a wave of depression in the water level of a reservoir after a dam has burst and the water cascades downstream.

A single return stroke seldom discharges the cloud completely. Up to 30 return strokes may occur within a half second after the initial discharge to complete the job until the charges rebuild.

Fig. 8-13 Five cloud-to-ground (CG) strikes in 2.5 min within 5 miles from an approaching storm on 30 Sep 2023. Jan Curtis.

8.6 Inventory of Lightning Types[7]

Lightning bolts connect regions of opposite charge. Believe it or not, there are several different types of bolts. The most common are intracloud bolts followed by cloud-to-ground bolts that transport – charges downward (–CG). Less common are cloud-to-ground bolts that transport + charge downward (+CG), ground-to-cloud bolts, cloud-to-cloud bolts (CC) and cloud to air (CA) bolts.

Negative Cloud to Ground (–CG) **Lightning** starts from the main region of – charged graupel. It is distinguished by its downward diverging branches that accompany the main strokes, as in Fig. 8-3, Fig. 8-7, Fig. 8-12, and Fig. 8-13. This type of lightning tends to occur later in the lifespan of a thunderstorm, specifically after it has developed strong downdrafts, which increase the electric field gradient near the ground by transporting negative charges downward. Just think of getting a shock from a spark when you bring your hand closer to a doorknob after walking across a rug on a dry day.

Fig. 8-14. A single +CG strike 300 m away with branches not reaching the ground, 26 Aug 2021. Jan Curtis.

Positive Cloud to Ground (+CG) **Lightning** gives the ground a positive charge by transporting the more mobile negative charges upward. +CG starts with a downward-moving positively charged stepped leader from the region of positive charge near cloud base or high in the cloud, particularly from the anvil. It is usually associated with organized, severe thunderstorms including supercells, the trailing stratiform precipitation regions of squall lines, and mesoscale convective systems. Sprites (see §8.7) are usually associated with this type of lightning.

Fig. 8-15. A bolt from high in the cloud out into clear air. ©MarianMalaquin

Fig. 8-16. GC lightning is identified by the divergence of strikes up from the ground, 3 Aug 2012 S of Santa Fe, NM. Jan Curtis.

+CG lightning bolts represent less than 5% of all cloud to ground strikes but are on average 10 times more energetic than –CG lightning. The features that distinguish +CG bolts include,

Fig. 8-17. Stacks of frames showing CA lightning (top) and Anvil crawlers, (bottom) with a few distant CG bolts. 29 May 2020 Cheyenne, WY. Stacking prevents blurring and reduces overexposure but can weaves together discontinuous bolts. Jan Curtis.

1: branches tending not to reach the ground,
2: often a single strike,
3: great brightness and,
4: loud thunder with a series of deep, low-frequency sonic booms.

Sometimes, long, bright +CG bolts extend from high in the cloud or the base of the anvil miles out into clear air (Fig. 8-15), striking by complete surprise, hence the saying, “out of the blue”.

Ground to Cloud (GC) Lightning (Fig. 8-16) is distinguished by upward diverging branches, though some upward-moving lightning is branchless below the cloud base. It often emanates from elevated points on the ground where it is often seen extending up from the tops of skyscrapers. Negative charge may move up or down.

Cloud-to-Air (CA) Lightning is a discharge that jumps from a cloud into clear air and terminates abruptly, sometimes as a branch of the main channel of cloud to ground lightning (Fig. 8-17).

Fig. 8-18. Intracloud lightning stays within the confines of the cloud, 13 Jun 2021. Jan Curtis.

Intracloud (IC) Lightning is the most common type of discharge (⅔ to ¾ of all strikes) and refers to lightning embedded within a single storm cloud, which jumps between opposite charge regions in the same cloud (Fig. 8-18 and Fig. 8-19). Early in the thunderstorm’s life IC is by far the dominant form of lightning. However, once strong downdrafts form, which transport negative charges closer to the ground CG lightning increases and IC lightning subsides.

Sheet Lightning is a term used to describe clouds illuminated by lightning discharges where the actual lightning channels are either inside the cloud or below the horizon (i.e. not visible to the observer). Although sheet lightning is often associated with IC lightning, it includes any lightning bolts blocked from direct view by clouds, terrain, or the Earth’s curvature (Fig 8-19).

A related term, *heat lightning*, is any lightning or lightning-induced illumination too far away for thunder to be heard. Heat lightning got its name because it is often seen on hot summer nights with distant thunderstorms.

Fig. 8-19. Sheet lightning with an isolated distinct bolt at right, east of Cheyenne, WY16 Jul 2018. Jan Curtis.

Fig. 8-20. Anvil crawlers move horizontally along the base of the anvil while CG strikes are usually vertical, Vail AZ 16 Aug 2018. Jan Curtis.

Fig. 8-21. Anvil crawler 03 Jul 2019 25 minutes after sunset. Jan Curtis.

Cloud-to-Cloud (CC or Intercloud) Lightning travels between two or more clouds. It is a less common form but certainly the form of the record longest lightning bolt. *Spider lightning* refers to long, horizontally moving flashes often seen on the underside of the stratiform region of squall lines and MCS's (Fig. 8-17, Fig. 8-20, and Fig. 8-21). Such lightning bolts are often referred to as *anvil crawlers*, which are animated in the video referenced above in §8.5 connection with Fig. 8-11 on 31 Jul 2022.

Fig. 8-22. Ribbon lightning with three adjacent ionized paths displaced by high winds displaced on 27 Jul 2014 (left) and three distinct ionized paths on 20 May 2020 (right). Jan Curtis.

Ribbon Lightning occurs in thunderstorms with high cross winds and many return strokes. As the wind blows each successive is displaced sideways giving the appearance of parallel ribbons. The bolt in the left panel of Fig. 8-22 on 27 Jul 2014, which struck ground a mere 300 m away, consisted of three strokes that graded continuously from dark to bright magenta to white from left to right. The bolt in the right panel occurred on 20 May 2020, and consisted of three distinct but closely spaced parallel strokes. Faster cross winds and longer intervals between strokes help ribbons separate. (Camera movement during the capture of a series of return strokes can also produce a similar effect.)

Fig. 8-23. The last instant when a lightning discharge dissipates. Jan Curtis.

Bead Lightning is the name given to the decaying stage of a lightning channel, which cools after a return stroke, and its luminosity breaks up into segments (Fig. 8-23). It describes the dying gasp of a normal lightning discharge.

Staccato lightning is a short-duration CG lightning stroke that often appears as a single very bright flash with considerable branching. It occurs in strong thunderstorms and is a fearsome sight to witness. (Fig 8-24).

Ball Lightning[9] is one of the best-known natural phenomena that few have seen. Jan's great uncle, as a teen, witnessed ball lightning during an intense lightning storm. Seeking shelter under a rural underpass with a small stream that was fenced off, a glowing orb about 6 inches in diameter appeared to move on top of the fence after a CG strike nearby. It hissed and years later discovered the odor he smelled was that of ozone. After perhaps 15 seconds, it exploded with a loud report.

Fig. 8-24. Stack of staccato lightning bolts during an intense thunderstorm, 5 Sep 2019. Jan Curtis.

We will pass on this elusive phenomenon until there are certifiable photos or videos, as there now are for…

8.7 Transient Luminous Events: Sprites, Etc.

One glance at the red sprite in Fig. 8-25 might make you ask, "What in the world is this and why haven't I seen anything like this before?" Indeed, red sprites are relatively rare and can only be seen under specific and optimal conditions. An Jin (Angel An) joined a scientific

Fig. 8-25. Red sprites grading to blue at bottom above a mesoscale convective complex over India and Nepal 19 May 2022, seen from near Lake Pu Moyongcuo at altitude 5000 m. ©An Jiu (Angel An).

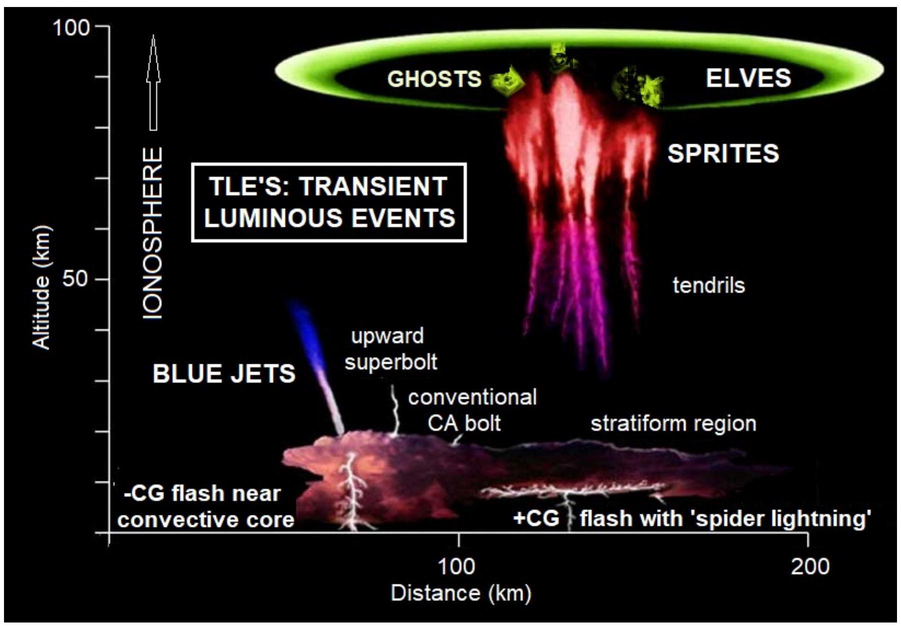

Fig. 8-26. TLE's and the Thunderstorms they are associated with. NOAA Adapted from Carlos Miralles (Aerovironment) and Tom Nelson (FMA).

expedition to Lake Pu Moyongcuo 5000 m above sea level on the Tibetan Plateau hoping to encounter and photograph sprites. Her hopes were more than realized when a large mesoscale convective system formed over northern India on the night of 18-19 May 2022, producing the natural fireworks she captured in Fig. 8-25.

Red sprites are just one of several different phenomena of Transient Luminous Events or TLE's that occur above thunderstorms Other TLE's include blue jets, halos, elves, and green ghosts (Fig. 8-26).

The first announcement of luminous meteorological phenomena extending high above thunderstorms was published with no fanfare as a single paragraph in the 16 January 1886 issue of ***Nature***.

> Leaving the port of Kingston, Jamaica, at dusk on November 23, 1885 the night was fine and starlit overhead but about 8 p. m. a heavy bank of cloud [thunderstorm] obscured the island and all around the upper edges of this cloud-bank brilliant flashes of light were incessantly bursting forth…while intermittently would shoot vertically upward continuous darts of light displaying prismatic colours…. Sometimes these darts of light were projected but a short distance above the cloud-bank but at others they ascended to a considerable altitude, resembling rockets more than lightning." T. Mackenzie.

A century passed with only occasional, haphazard notice of TLE's. For example, Jan noted,

> In 1976, while stationed in the navy in Norfolk, Virginia, I used to attend star parties south of Virginia Beach along the very dark Atlantic coastline. Occasionally, the group would notice a flash without seeing any signs of lightning (thinking it was a meteor explosion, distant heat lightning or naval ship artillery exercises). Twenty years later, while working at the Geophysical Institute in Fairbanks, AK, I learned that the flashes were, in fact, TLEs. It turns out that these elusive atmospheric phenomena occur off the mid-Atlantic coast in a kind of ground zero frequency max[11].

TLE's became a rage with lightning speed after R. C. Franz took the first serendipitous photograph on 06 July 1989 of a red sprite, only named later for its fleeting, fairy-like appearance using the ingenious acronym, Stratospheric Perturbations Resulting from Intense Thunderstorm Electrification (even though it mainly occurs in the Mesosphere). Since TLE's occur above thunderstorms and since they are too dim to see during the day, they are best seen on clear dark nights either from space or from the ground at least 100 km and up to about 500 km from the thunderstorms they are associated with.

Red Sprites are electrical discharges (but not lightning) that form in the lowest part of the ionosphere, extending through much of the mesosphere, from 50 to 90 km. They are typically 50 to 100 km across. Despite their size and potential drama, they only last up to about 300 milliseconds. They exhibit a variety of characteristic shapes resembling trees, columns, and angels, etc., illustrated in Fig. 8-27. Most sprites are faint, as in Fig. 8-28, and, as with the aurora, the light intensity is so low that most appear as white to the naked eye. Only the brightest appear red. All are best captured with high ISO camera setting used in low light photography.

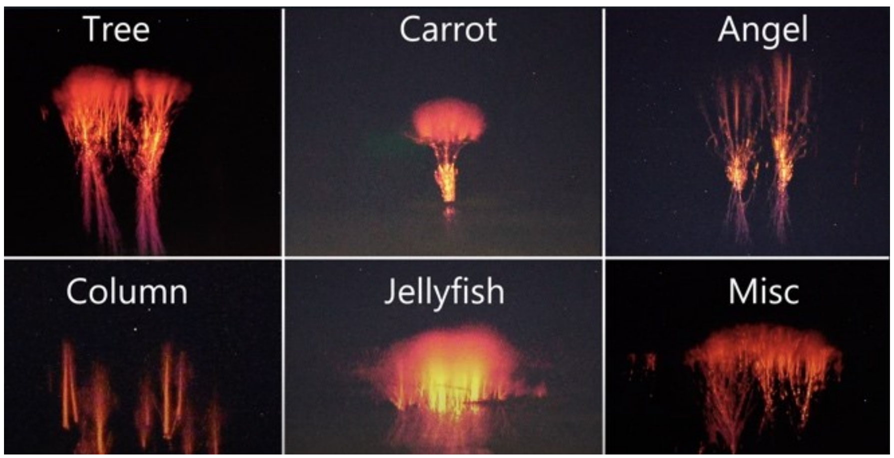

Fig. 8-27. Different shapes of sprites.

Red sprites are mainly associated with +CG bolts of great horizontal extent in severe, organized thunderstorms or Mesoscale Convective

Fig. 8-28. Selected stacked images taken over several minutes showing clusters of sprites well above a mesoscale convective system about 250 km east of Cheyenne, WY, 07 Aug 2017. Jan Curtis.

Systems, the latter which often persist through the night. The +CG bolt transfers negative charge upward to the thunderstorm top. This increases the voltage difference between the top of the thunderstorm and the positively charged ionosphere to the point it initiates the red sprite. However, the red sprite is not a lightning strike. Instead it is a cooler phenomenon akin to the aurora in which the electrons in N_2 are excited and raised to more energetic orbitals. The energy emitted as the excited electrons return to ground state corresponds to red light near the top of the mesosphere and blue light near its base. The color gradient occurs (as with the aurora) because the slower red transition dominates in thin air where it has adequate time to occur between collisions of molecules. In the denser air lower in the mesosphere where collisions occur so rapidly they disrupt the red transitions the weaker but more rapid blue transitions emerge.

Fig. 8-29. Blue jet emanating from an upward bolt above a thunderstorm over Big Bend National Park, TX 28 Jul 2022. ©Matthew Griffiths

Blue jets[12] shoot up from thunderstorm tops, often emanating from upward lightning bolts (Fig. 8-29). They extend up in narrow cones, fan out at top, typically reach 40-55 km and last a fraction of a second. Sometimes a blue jet extends so high it creates and is topped by a red sprite to form a **gigantic jet**, as above a thunderstorm near Shikengkong Mountain, China on 13 Aug 2016 (Fig. 8-30).

Astronauts are now attuned to the chance of seeing TLE's and have taken numerous photos of them. On 03 Jul 2025, astronaut Nicole Ayers captured a **gigantic jet** with nearby thunderstorm tops lit by lightning and the airglow above the distant horizon (Fig. 8-31).

Elves are rapidly expanding disk-shaped glowing regions up to 500 km in diameter. They last less than a thousandth of a second and occur above areas of active +CG lightning. They may result when an energetic electromagnetic pulse from a blue flash extends up into the ionosphere as a shock wave that lasts but an instant (Fig. 8-32).

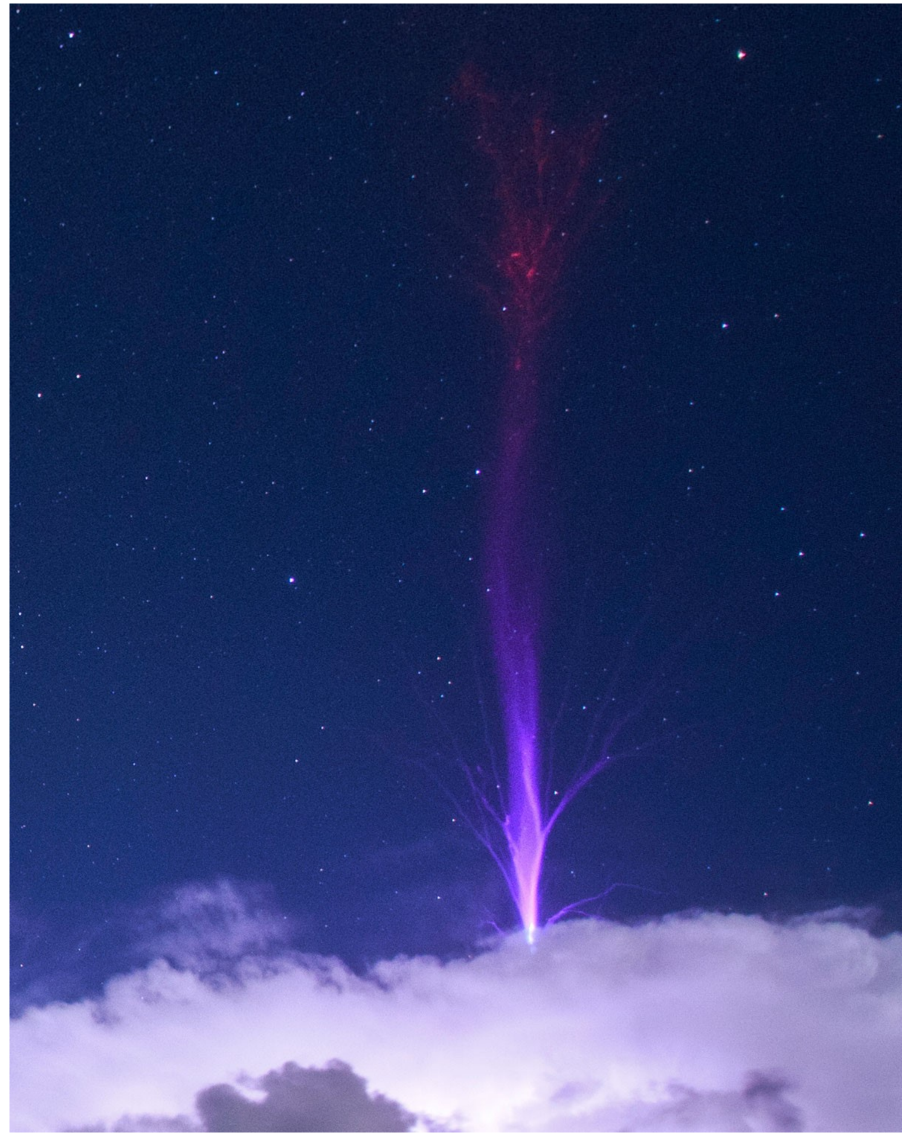

Fig. 8-30. Gigantic jet above a thunderstorm near Shikengkong Mountain, China 13 Aug 2016. ©Phebe Pan.

Fig. 8-31. Gigantic Jet above Mexico from the ISS, 03 Jul 2025. White regions are tops of lightning-lit thunderstorms . Faint green glow above horizon is the airglow. Nicole Ayers, astronaut.

Fig. 8-32. Blue jet with expanding elf ring 26 Feb 2019 central Pacific near Nauru, DTU Space, Daniel Schmelling/Mount Visual

Green ghosts have only been recently observed. They occur on rare occasion atop active red sprites and their color is due to excited O atoms returning to ground state, just as with the green aurora. We recommend the video by Pecos Hank,

https://www.youtube.com/watch?v=sIaYOdujmz4

TLE's have generated enormous excitement, perhaps in part because they are so rare and so transient. They are so brief that the photos must almost invariably be extracted as lucky single frames from videos and they show details the naked eye cannot fully capture but now cannot be denied or ignored as they were for so long.

Thus, not only do lightning bolts and TLE's light the skies, they light our lives.

Fig. 8-34. Lightning at sunset over Cheyenne, WY, 30 July 2016. Jan Curtis.