National Meteorological Library and Archive

Fact sheet No. 2 – Thunderstorms

Introduction

A thunderstorm can be described as one or more sudden electrical discharges, manifested by a flash of light (lightning) and a sharp or rumbling sound (thunder). Thunderstorms are associated with convective clouds and are most often, but not necessarily, accompanied by precipitation at the ground.

Cumulonimbus clouds

(Latin: *cumulus* – heap; *nimbus* – rainy cloud)

Heavy and dense cloud, of considerable vertical extent, in the form of a mountain or huge towers. At least part of its upper portion is usually smooth, or fibrous or striated, and nearly always flattened; this part often spreads out in the shape of an anvil or vast plume. Under the base of this cloud, which is often very dark, there are frequently low ragged clouds either merged with it or not, and precipitation sometimes in the form of virga.

Figure 1. A mature cumulonimbus cloud.

Cumulonimbus clouds normally develop from large cumulus but they can also do so from stratocumulus or altocumulus. When they cover a large expanse of sky the under surface can present the appearance of nimbostratus. The character of the precipitation may be of assistance in identifying the cloud. Cumulonimbus gives showers, very often quite heavy for comparatively short periods of time. If hail, thunder or lightning are observed then, by convention, the cloud is cumulonimbus. The evolution of the cloud can also aid identification. The change from large cumulus with domed tops and a hard outline (produced by water drops) to a top with a softer fibrous outline (produced by ice crystals) marks the change from cumulus to cumulonimbus.

A Cumulonimbus cloud can be described as a 'cloud factory'; it may produce extensive thick patches of cirrus, altocumulus, altostratus, cumulus or stratocumulus. The spreading of the highest part usually leads to the formation of an anvil; if the wind increases with height, the upper portion of the cloud is carried downwind in the shape of a half anvil or vast plume.

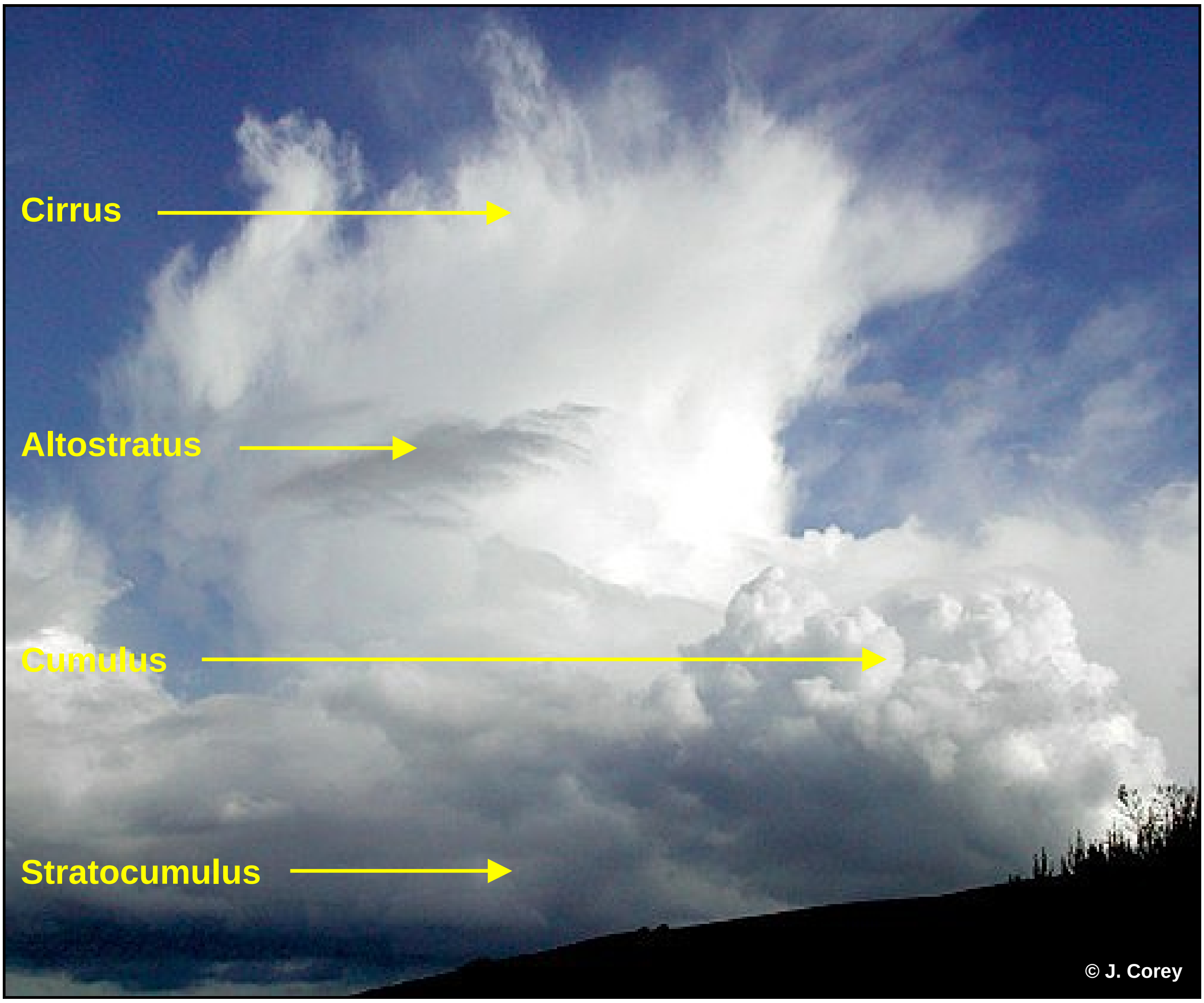


Figure 2. A cumulonimbus 'cloud factory'.

Not all cumulonimbus clouds bring thunderstorms; some just bring heavy showers or hail. On average, an individual cumulonimbus cloud takes only one hour to take shape, grow and dissipate. It produces less than 30 minutes of thunder and lightning. If a thunderstorm lasts longer than this, it is probably because there is more than one cumulonimbus present.

Case Study: 24 May 1989

Satellite imagery is very useful in locating cumulonimbus cloud development. On the 24 May 1989, very large cumulonimbus cells developed over southern England and the Midlands. The satellite image below shows these cumulonimbus cells clearly. The resulting cumulonimbus produced severe thunderstorm across parts of Hampshire, Surrey and Berkshire as well as the Midlands and northern England. There were reports of heavy rain and flooding across many areas with some places having well over two inches of rainfall – Aldershot, Cargate Reservoir reporting over 64 mm (2.5 inches) during the day.

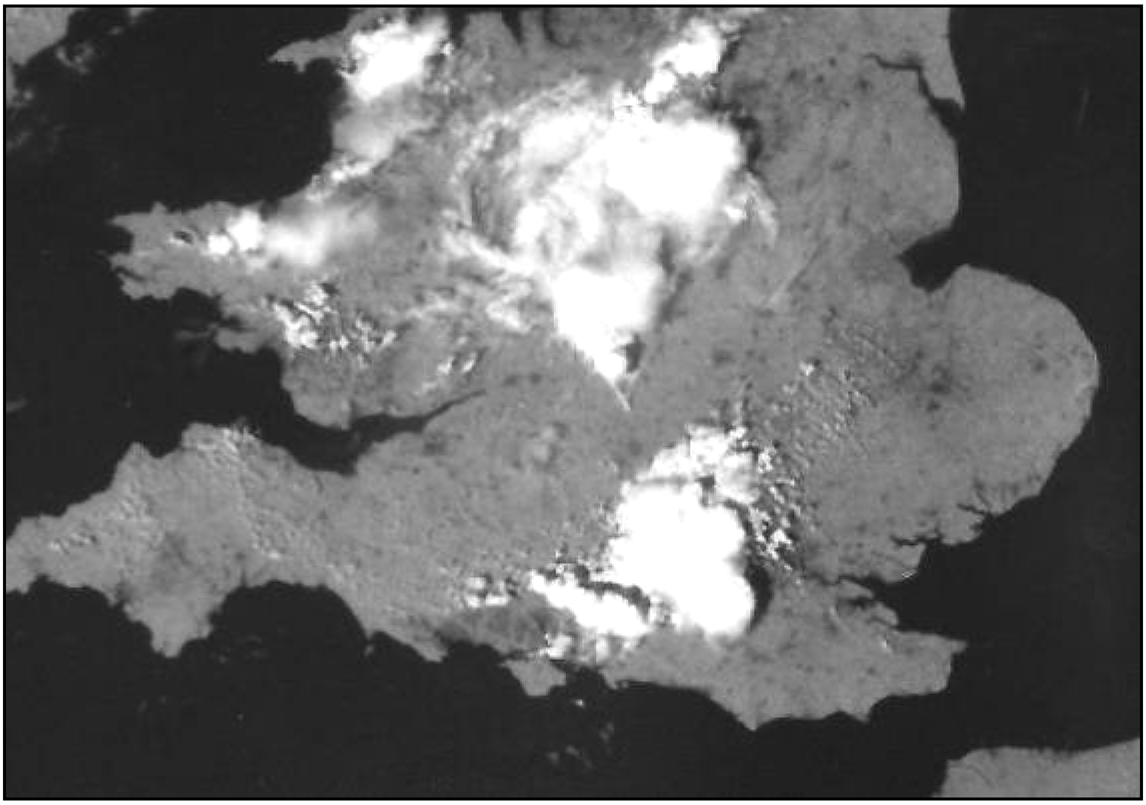


Figure 3. Visible satellite imagery for 1244z on 24 May 1989.

Station	Rainfall (mm)	Start time	Duration (hr:mm)	Return period (yrs)
South Farnborough	51	1210	1:09	275
South Farnborough	56	1210	1:30	195
Bracknell	35	1150	0:36	120
Bracknell	45	1150	4:40	33

Table 1. Return periods for observed rainfall amounts for South Farnborough and Bracknell.

Station	Rainfall (mm)	Station	Rainfall (mm)
Aldershot, Cargate Reservoir	64.2	Merrist Wood	53.5
Mickleham	62.2	Frimley Pumping Station	51.6
South Farnborough	60.2	Wisley	52.6
Pirbright Institute	56.5	Bracknell, Beaufort Park	45.6

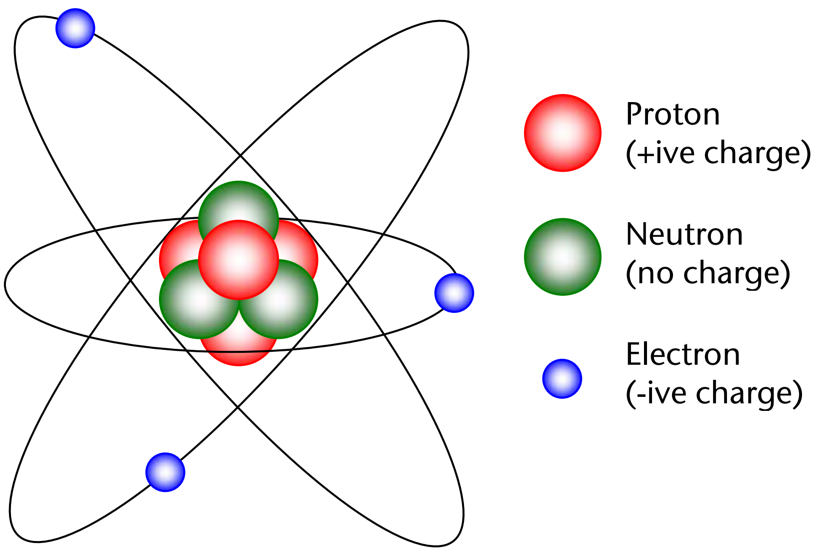
Table 2. 24-hour (0900-0900) rainfall totals for 24 May 1989.

Electrical charges with a cumulonimbus cloud

Lightning is a large electrical spark caused by electrons moving from one place to another.

Figure 4. Lightning seen over Budapest, Hungary.

Electrons are fundamental sub-atomic particles that carry a negative electric charge. They are so small they cannot be seen, but when lightning flashes they are moving so fast that the air around them glows. The actual streak of lightning is the path the electrons follow when they move.



An atom consists of three basic parts, a Proton (which has a positive charge), a Neutron (which has no charge) and an Electron (which has a negative charge). Electrons cling to the positively charged centre of the atom because they have a negative electrical charge. During a thunderstorm, some of the atoms in the cloud lose their electrons and the others gain extra ones.

Figure 5. Basic structure of an atom.

Water droplets form inside a storm cloud. They are propelled towards the top of the cloud by strong internal winds (updraughts), where they turn to ice. Some of the pieces of ice grow large into hail, but others remain very small. As the pieces of hail get larger, they fall back through the cloud, bumping into smaller ice particles that are still being forced upwards. When the ice particles collide, some electrons are transferred to the hail. The electrons give the hail a negative charge, while the ice particles that have lost electrons gain a positive charge.

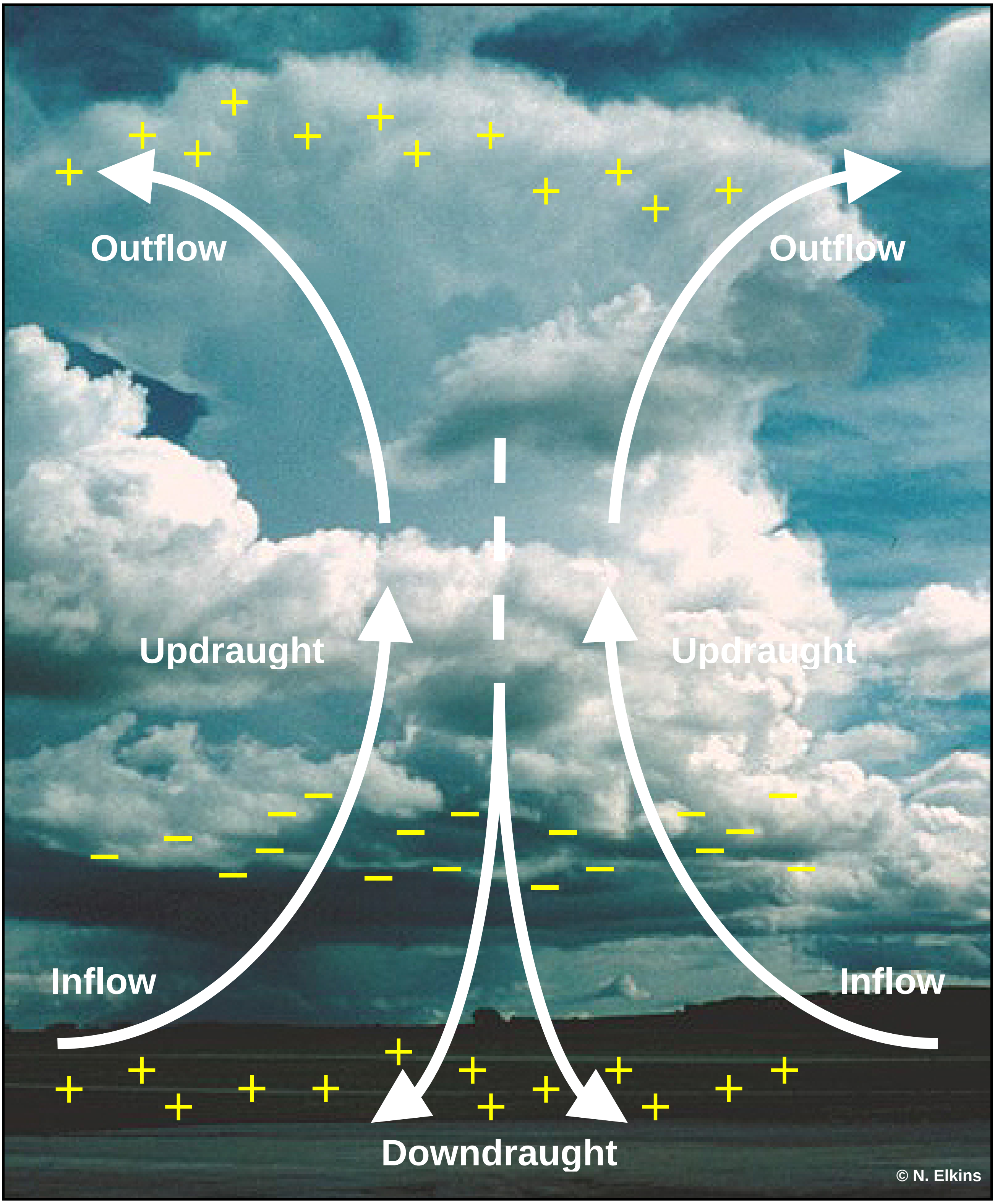
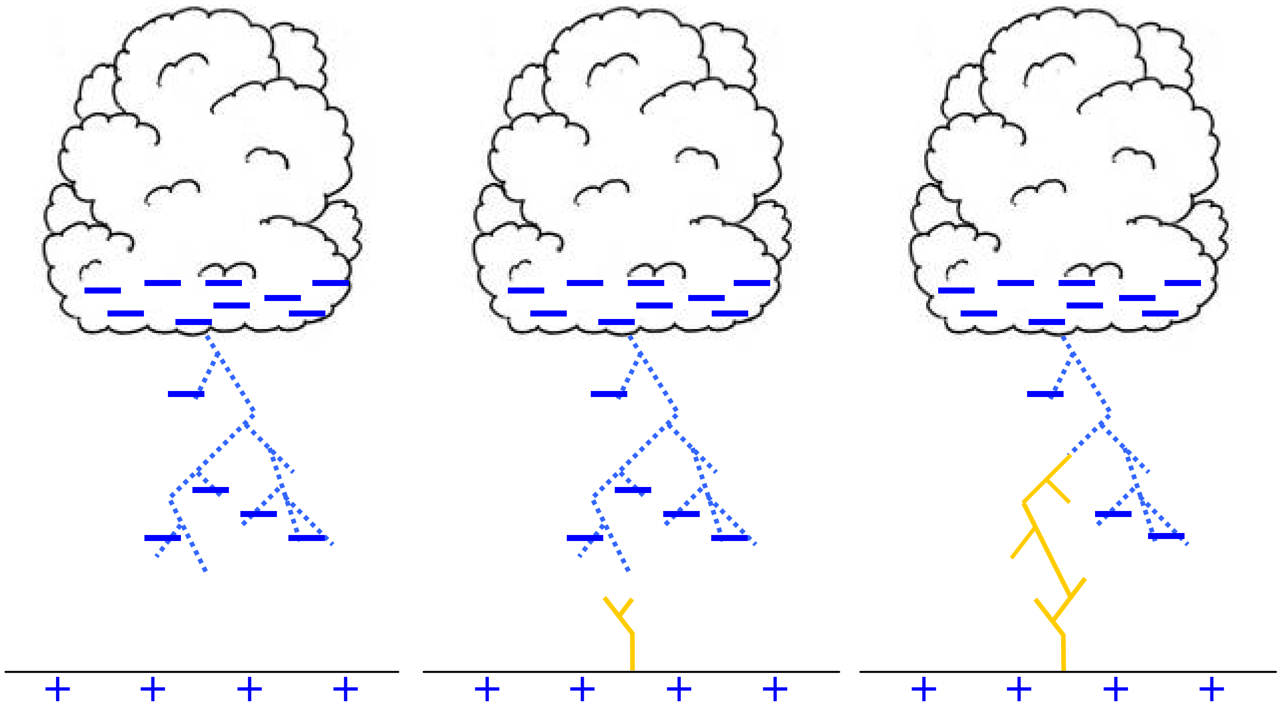


Figure 6. Updraughts and downdraughts in a cumulonimbus cloud.

The winds continue to carry the ice particles upwards, giving the top of the cloud a positive charge. Some of the hail has now grown so heavy that the winds can no longer propel them upwards and so collect in the lower part of the cloud, giving it a negative charge. As well as being attracted to the positive atoms in the top of the cloud, the atoms are attracted to positive atoms in other clouds and on the ground. If the attraction is strong enough, the electrons will move towards the positive atoms. The path they make in doing so is the flash of lightning.



A ***stepped leader*** (**—**) comes down from the cloud | An ***upward* streamer** (**+**) shoots up from the ground | The stepped leader and upward streamer meet...

Figure 7. Stepped leader and upward streamers.

As negative charges collect at the base of the cloud, they repel the electrons near the ground's surface. This leaves the ground and the objects on it with a positive charge. As the attraction between the cloud and the ground grows stronger, electrons shoot down from the cloud. The electrons move in a path that spreads in different directions - like a river delta. Each step is approximately 50 metres long and the branching path is called a **stepped leader**. Further electrons follow, making new branches. The average speed at which the stepped leader cuts through the air is about 270,000 miles per hour.

As the stepped leader approaches the ground, positive electrical sparks rise from tall objects such as trees and buildings. These sparks are known as **upward streamers**. When the stepped leader meets the upward streamer, the lightning channel is completed. When the lightning channel is complete, the electrons in the channel rush towards the ground. This is the return stroke which lights up the channel. The first electrons to reach the ground light up the bottom of the channel. The upper part of the channel glows as the electrons move rapidly down it. Therefore, the light from the flash starts at the ground and moves upwards. The branches of the stepped leader are also lit up, but not as brightly as the main channel as there are fewer electrons present. The lightning flash ends when there are no electrons left in the channel.

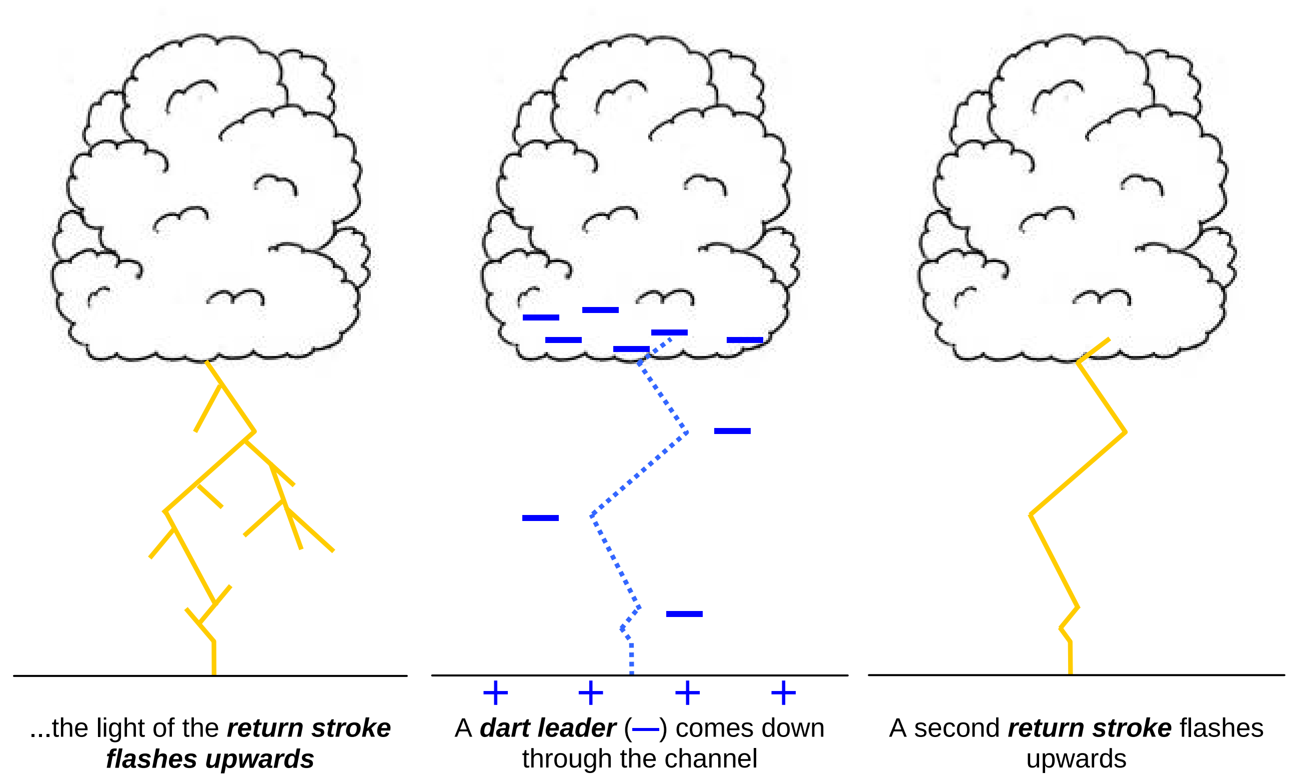


Figure 8. Return stroke and dart leaders.

If lightning flickers, it is probably because there has been more than one **return stroke**. When the lightning channel is empty it is possible for electrons from another part of the cloud to enter it. The movement of the electrons into the channel is called a **dart leader**. It causes another return stroke to occur. The repeated return strokes and dart leaders make the lightning appear to flicker because of the great speed at which they occur.

Types of lightning

There are several types of lightning, these are:

- Ball lightning
- Rocket lightning
- Pearl-necklace lightning
- Ribbon lightning
- Forked lightning
- Sheet lightning
- Streak lightning

Ball lightning

A rare form of lightning in which a persistent and moving luminous white or coloured sphere is seen.

Rocket lightning

A very rare and unexplained form of lightning in which the speed of propagation of the lightning stroke is slow enough to be perceptible to the eye.

Pearl-necklace lightning

A rare form of lightning, also termed ‘chain lightning’ or ‘beaded lightning’, in which variations of brightness along the discharge path give rise to a momentary appearance similar to pearls on a string.

Ribbon lightning

Ordinary cloud-to-ground lightning that appears to be spread horizontally into a ribbon of parallel luminous streaks when a very strong wind is blowing at right angles to the observer's line of sight.

Forked lightning

Lightning in which many luminous branches from the main discharge channel are visible.

Figure 9. Forked lightning.

Sheet lightning

The popular name applied to a ‘cloud discharge’ form of lightning in which the emitted light appears diffuse and there is an apparent absence of a main channel because of the obscuring effect of the cloud.

Figure 10. Sheet lightning.

Streak lightning

Lightning discharge which has a distinct main channel, often tortuous and branching, the discharge may be from cloud to ground or from cloud to air.

Figure 11. Streak lightning.

Thunder

The word 'thunder' is derived from 'Thor', the Norse god of thunder. He was supposed to be a red-bearded man of tremendous strength; his greatest attribute being the ability to forge thunderbolts. The word Thursday is also derived from his name.

Thunder is the sharp or rumbling sound that accompanies lightning. It is caused by the intense heating and expansion of the air along the path of the lightning. The rumble of thunder is caused by the noise passing through layers of the atmosphere at different temperatures. Thunder lasts longer than lightning because of the time it takes for the sound to travel from different parts of the flash.

How far away is a thunderstorm?

This can roughly be estimated by measuring the interval between the lightning flash and the start of the thunder. If you count the time in seconds and then divide by three, you will have the approximate distance in kilometres. Thunder is rarely heard at a distance of more than 20 km.

Are thunderstorms dangerous?

Most people are frightened by the crackles and rumbles of thunder rather than the flash of lightning. However, thunder cannot hurt anybody, and the risk of being struck by lightning is far less than that of being killed in a car crash. Ninety per cent of lightning discharges go from cloud to cloud or between parts of the same cloud, never actually reaching the Earth. Most of the discharges that do strike the ground cause little or no damage or harm. Lightning takes the shortest and quickest route to the ground, usually via a high object standing alone.

How common are thunderstorms?

Thunderstorms occur throughout the world, even in the polar regions, with the greatest frequency in tropical rainforest areas, where they may occur nearly daily. The most thundery part of the earth is the island of Java where the annual frequency of thunderstorms is about 220 days per year. In temperate regions, they are most frequent in spring and summer, although they can occur in cold fronts at any time of year. Thunderstorms are rare in polar regions due to the cold climate and stable air masses that are generally in place, but they do occur from time to time, mainly in the summer months. In recent years, thunderstorms have taken on the role of a curiosity. Every spring, storm chasers head to the Great Plains of the United States and the Canadian Prairies to explore the visual and scientific aspects of storms and tornadoes.

In the United Kingdom thunder is a variable element, the highest and lowest annual totals of thunderstorm days at many individual stations ranges from less than 5 in a quiet year to 20 or more in an active one. One consequence of this is that published maps showing the average frequency of days of thunder differ considerably in detail according to the period of records used. They agree, however, in showing that the average annual frequency is less than 5 days in western coastal districts and over most of central and northern Scotland, and 15 to 20 days over the east Midlands and parts of southeast England. There is relatively little seasonal variation on the western seaboard but elsewhere summer is the most thundery season.

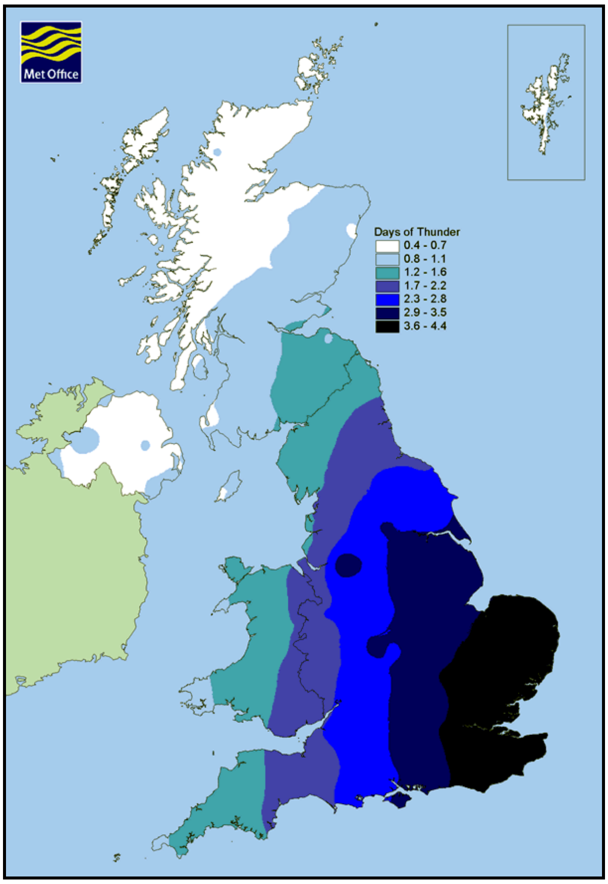


Figure 12. Average number of days of thunder during spring (1971 to 2000).

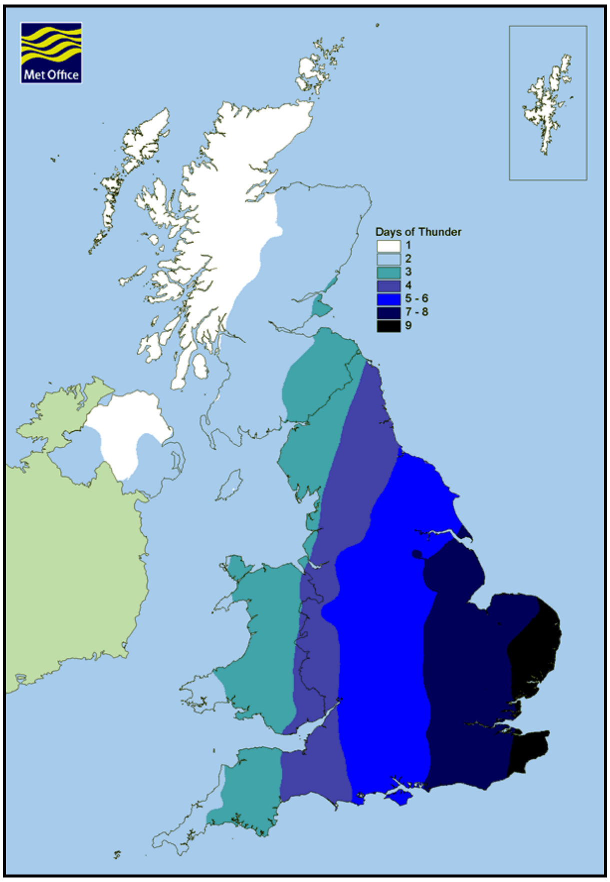


Figure 13. Average number of days of thunder during summer (1971 to 2000).

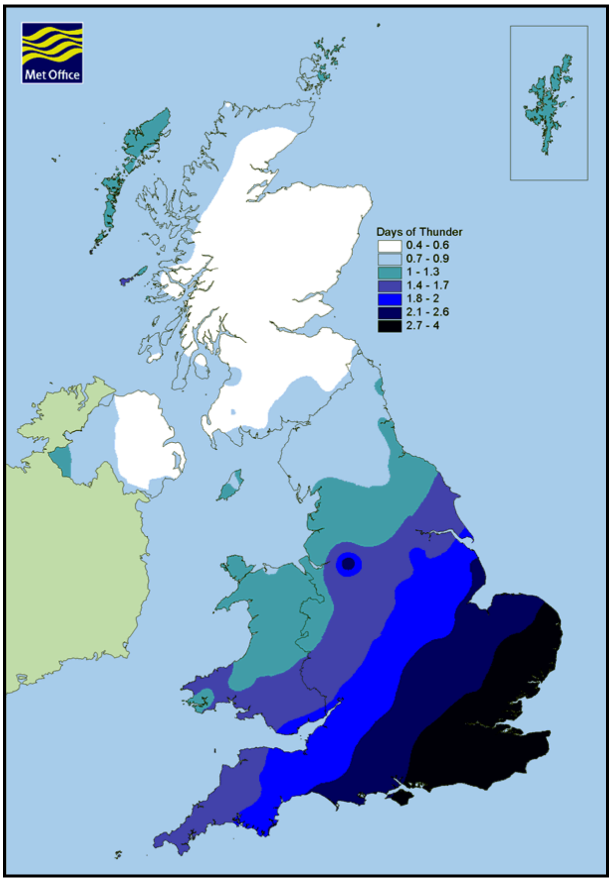


Figure 14. Average number of days of thunder during autumn (1971 to 2000).

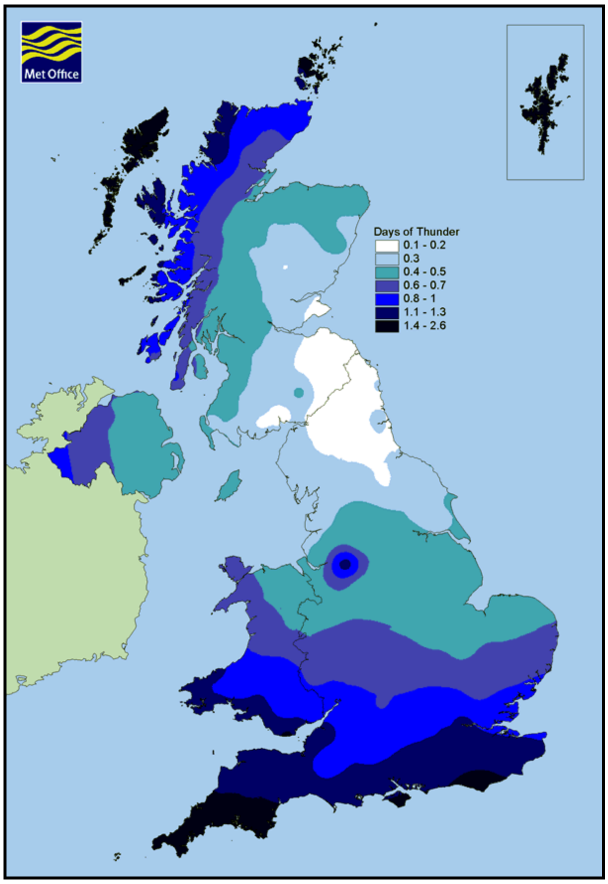


Figure 15. Average number of days of thunder during winter (1971 to 2000).

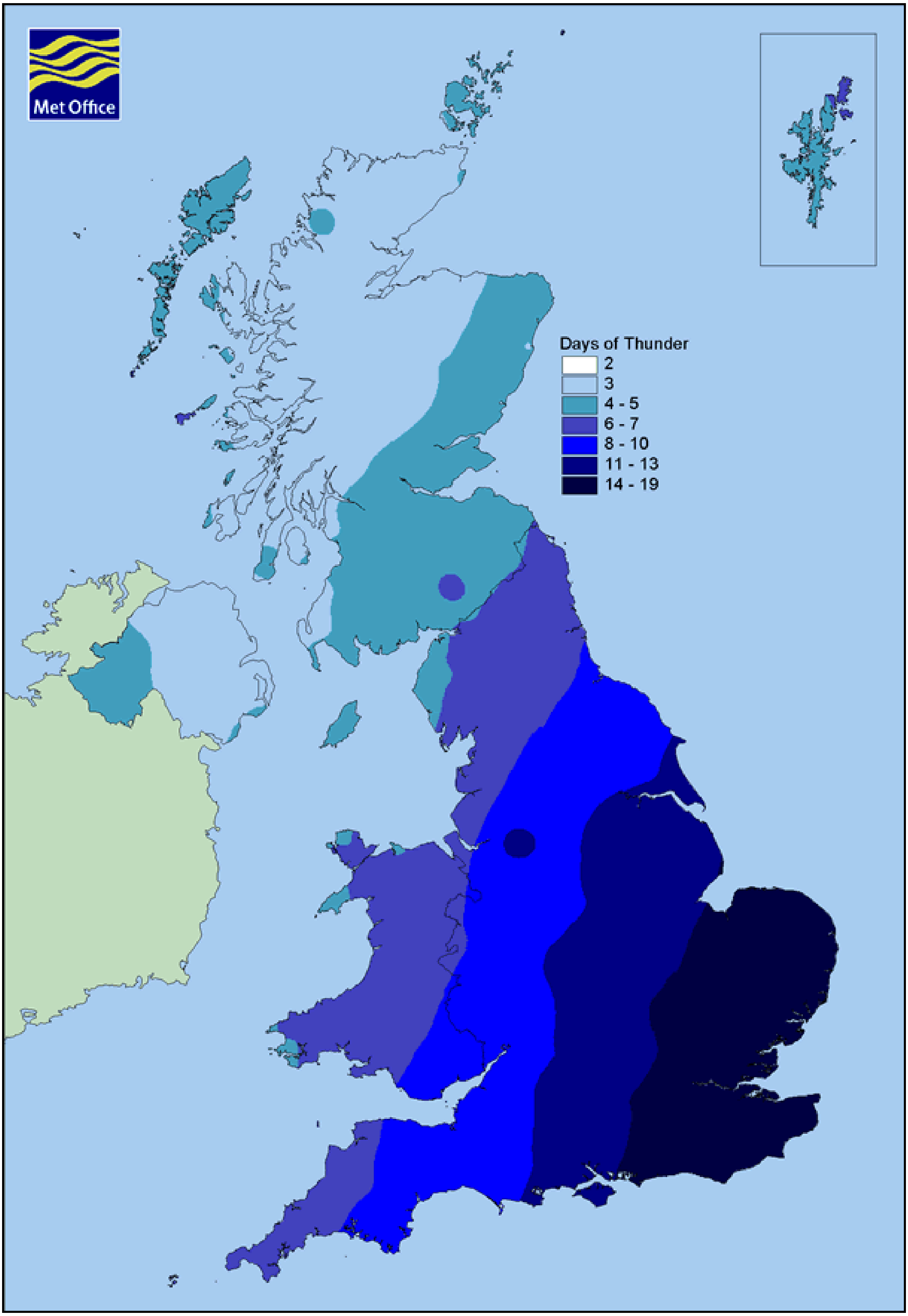


Figure 16. Average number of days of thunder during the whole year (1971 to 2000).

Intensity of thunderstorms

The intensity of a thunderstorm is dependant on the number of lightning flashes per minute. There are three categories, these are:

- **Slight** - rate of 1 flash per minute
- **Moderate** - rate of 2 to 3 flashes per minute
- **Heavy** - rate of 4 or more flashes per minute

Lightning and thunderstorms – some facts and figures

- Number of thunderstorms occurring at any given moment: 2,000.
- Number of lightning strikes every second: 100.
- Number of lightning strikes a day: 8 million.
- A typical lightning bolt contains 1 billion volts and contains between 10,000 to 200,000 amperes of current.
- The average flash would light a 100 watt light bulb for 3 months.
- A typical flash of forked lightning lasts for about 0.2 seconds.
- The temperature of lightning's return stroke can reach 28,000°C.
- Lightning does strike twice, the Empire State Building in New York has been struck by lightning as much as 48 times in one day, but they have lightning conductors to carry the electricity harmlessly to the ground.

Lightning safety rules

Don't...

- Venture outside, unless absolutely necessary.
- Use plug-in electrical equipment like hair driers, electric toothbrushes, or electric razors during the storm.
- Use the telephone during the storm. Lightning may strike telephone lines outside.
- Take laundry off the clothesline.
- Work on telephone or power lines, pipelines, or structural steel fabrication.
- Use metal objects like golf clubs.
- Handle flammable materials in open containers.
- Stay on hilltops, in open spaces, near wire fences, metal clotheslines, exposed sheds, and any electrically conductive elevated objects.

Do...

- Stay indoors.
- Stay away from open doors and windows, radiators, metal pipes, and plug-in electrical appliances.
- Get out of the water and off small boats.
- Stay in your car if you are travelling. Cars offer excellent lightning protection.
- Seek shelter in buildings. If no buildings are available, your best protection is a cave, ditch, or under head-high clumps of trees in open forest glades.
- When there is no shelter, avoid the highest object in the area. If only isolated trees are nearby, your best protection is to crouch in the open, keeping twice as far away from isolated trees as the trees are high.
- When you feel the electrical charge - if your hair stands on end or your skin tingles - lightning may be about to strike you. Drop to the ground immediately.

Thunderstorm location

Why do we need to locate lightning flashes?

The accurate location of lightning is important to public safety. As well as the obvious dangers of the lightning strike itself, thunderstorms can result in intense precipitation, severe icing, wind shear, turbulence and gusting winds. These all offer areas of concern to aviation, the construction industry, public utilities and defence.

The Met Office's Arrival Time Difference (ATD) lightning location system provides lightning location data 24 hours a day, seven days a week. The information the system provides can be used to reduce the effects of thunderstorms and lightning on human activity.

Radio waves from lightning flashes

A lightning flash emits radio waves which spread out like the bands of circular ripples from a stone dropped into a pond. These radio waves travel at the speed of light. The radio waves from nearby flashes can be heard on a radio receiver as individual loud crackles, over a large range of radio frequencies. With a sensitive recorder, set at a particular frequency, there is continuous background crackling from the many distant lightning flashes that are occurring worldwide at any moment. The shape (or sound) of the burst of radio waves is unique to a particular flash on almost all occasions. Simply listening to the radio waves from a lightning flash gives no indication of where the flash occurred. However, observations of the time difference between the waves reaching two or more receivers can locate the flash with considerable accuracy.

The ATD system uses observations of the time of arrival of radio waves from flashes at a frequency of about 10 kHz. These waves travel long distances around the Earth with little loss of strength (apart from the unavoidable reduction with distance as the waves spread out) or change in shape of the wave pattern. In principle, lightning flashes can be detected from the other side of the world, but in practice the ATD system is used to locate flashes only within a range of about 8,000 to 10,000 km from the UK.

How are lightning flashes located?

A cork floating on a pond acts as a detector of passing ripples by bobbing up and down. Several corks can detect the same ripple pattern produced by a stone being dropped into the water. However, they will detect the ripples at different times because they are at different distances from the point of impact. The ATD system works on a similar theory.

The system consists of seven unmanned, automatic lightning sensors at different locations. There are two in the United Kingdom (at Camborne in Cornwall and Lerwick in the Shetland Isles) and five located overseas, at Keflavik (Iceland), Korppoo (Finland), Norderney (Germany), Gibraltar and Cyprus.

All the outstations are linked to the control station computer located at Met Office headquarters. This automatically controls the system and collates the lightning location data into various messages for onward transmission to customers. It is also possible to reconfigure the outstations from the control station in order to optimise their performance and rectify faults. This helps make the system resilient.

The sensors at all the outstations continuously detect the radio waves generated by flashes of lightning - these are called 'atmospherics', or 'sferics'. A designated station in the ATD network then acts as the 'selector' station. The sferics received at this station are individually selected and then any sferics observed around the same time at other outstations are requested by, and forwarded to, the control station. Because each sferic has a unique waveform shape - its own 'fingerprint', which will be similar at all the outstations that receive it - the control station is able to match up the sferic waveforms received at the outstations with the particular sferic it has selected (a process operationally unique to the ATD system known as waveform correlation).

The control station then designates one outstation as the reference station for this flash. This reference station is assigned an arrival time difference of zero. The time of arrival of this particular sferic at the other outstation that received it, in relation to the reference station, is calculated. Then, by calculating all the points where the arrival time difference between the reference station and the other station are the same, a line can be plotted representing all the theoretical places with the same arrival time difference between the two stations. Drawn on the Earth's surface, this line will represent a hyperbola.

If this same process is then repeated between the reference station and another station that received the same sferic, another hyperbola can be drawn, intersecting the first one. Repeating this process using all the stations that received the sferic waveform enables the control station computer to determine the flash location. If the sferic was received at four or more stations then an unambiguous source location can be defined. This will be the place where all the hyperbolae intersect.

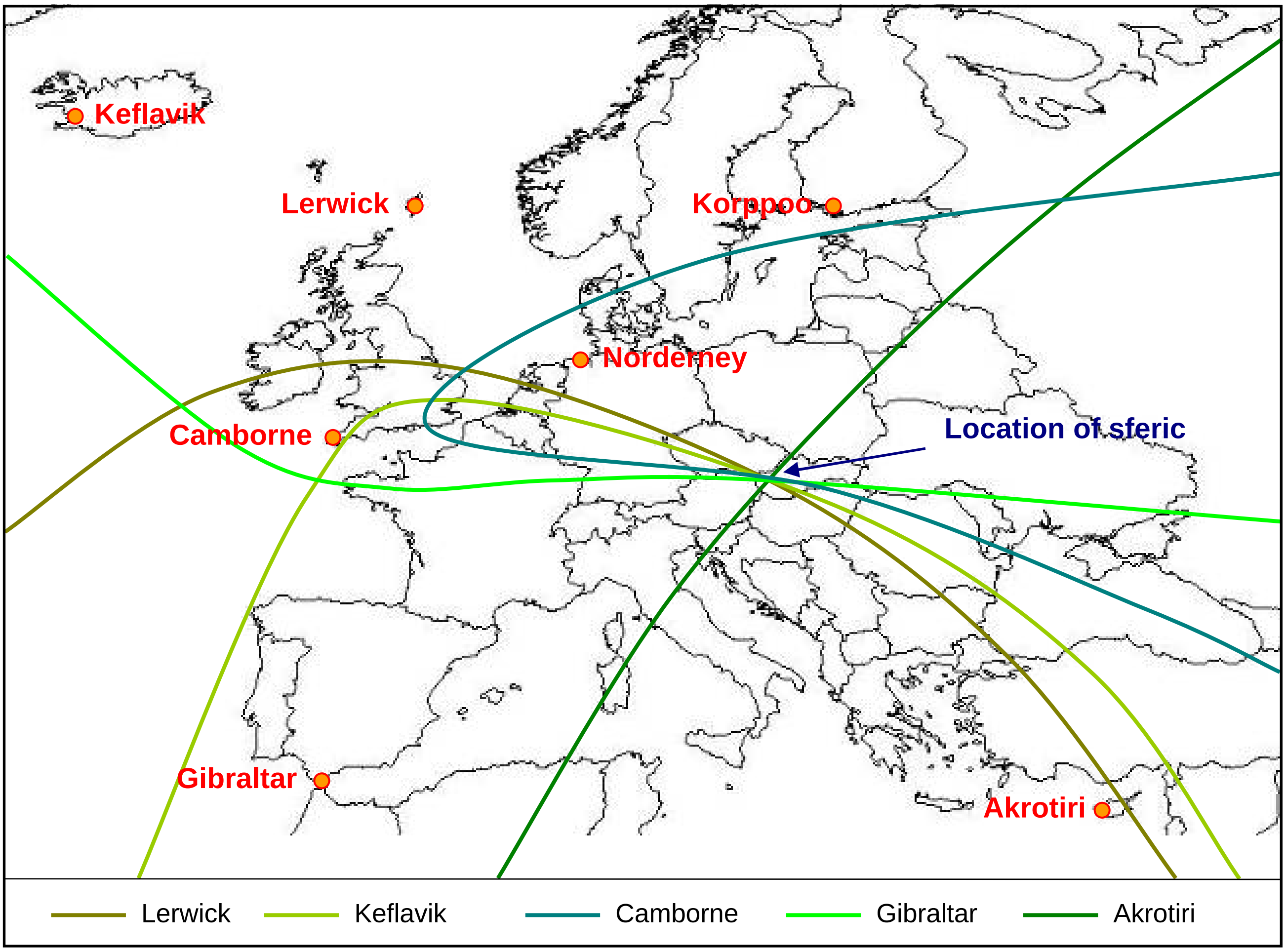


Figure 17. Calculated ATD hyperbolae. The point of intersection is where the sferic will be located.

The speed of the control station computer enables lightning locations to be determined in this way for anything up to thousands of flashes per hour.

Location confidence

A quality-control module in the control station carries out various checks on the calculated lightning flash locations ('fixes') before they are accepted. If the fix does not pass the various checks, it is rejected. In this way, whilst false fixes are not completely unknown, their rate is maintained at a very low level, ensuring confidence in the ATD system output as a whole.

Location accuracy

The ATD system measures location accuracy in points of degree latitude and longitude. Converting from this gives the approximate location accuracies as follows:

United Kingdom:	5.0 km
Europe:	20 km
3,000 km:	40 km
8,000 to 10,000 km:	100 km

If two lightning sensor receivers are about 300 km apart and a lightning flash occurs somewhere along the line joining the two receivers together then the arrival time difference of the sferic waveforms ranges from zero to only one millisecond (1/1,000th of a second). To obtain the required accuracy of a flash location, the time differences at two widely separated receivers must be measured to an accuracy of about one microsecond (1/1,000,000th of a second).

To achieve this each receiver has a rubidium oscillator - a form of accurate atomic clock - and the time of arrival of the sferic waveform is measured with that clock. Synchronisation of all the outstation 'clocks' is achieved by comparing them with GPS satellite time signals every ten minutes. Any drift in timing can then be identified and corrected. This ensures accurate lightning location data.

Other types of electrometeors

There are several other types of electrometeors, these are:

- St Elmo’s Fire
- Sprites
- Blue Jets
- Elves

St Elmo’s Fire

A more or less continuous, luminous electrical discharge of weak or moderate intensity in the atmosphere, emanating from elevated objects at the Earth’s surface (lightning conductors, wind vanes, masts of ships) or from aircraft in flight (wing-tips etc.).

It is also seen on projecting objects on mountains. This phenomenon may be observed when the electrical field near the surface of objects becomes strong. According to some observations, the character of St Elmo's fire varies with the polarity of the electricity being discharged. The negative 'fire' is concentrated so that a structureless glow envelops an elongated object such as a mast or an aerial; the positive 'fire' takes the form of streamers about 10 cm long. It may also appear as luminous globes, a number of which are sometimes seen along the aerial. The colour of St Elmo's fire can be violet or greenish.

The phenomenon is also termed 'corposant' (*corpo santo:* holy body) because of its once-supposed supernatural nature.

Sprites

Sprites are electrical discharges that occur high above the cumulonimbus cloud of an active thunderstorm. They appear as luminous reddish-orange, plasma-like flashes, last longer than normal lower stratospheric discharges (typically around 17 milliseconds), and cause the discharges of positive lightning between the cloud and the ground. Sprites usually occur in clusters of two or more simultaneous vertical discharges, typically extending from 65 to 75 km (40 to 47 miles) above the Earth, with or without less intense filaments reaching above and below. Sprites are preceded by a *sprite halo* that forms because of heating and ionization less than 1 millisecond before the sprite. Sprites were first photographed on July 6, 1989, by scientists from the University of Minnesota and named after the mischievous sprite (air spirit) Ariel in Shakespeare's *'The Tempest'*.

Blue Jets

Blue Jets differ from sprites in that they project from the top of the cumulonimbus above a thunderstorm, typically in a narrow cone, to the lowest levels of the ionosphere 40 to 50 km (25 to 30 miles) above the earth. They are also brighter than sprites and, as implied by their name, are blue in colour. They were first recorded on October 21, 1989, on a video taken from the space shuttle as it passed over Australia.

Elves

Elves often appear as a dim, flattened, expanding glow around 400 km (250 miles) in diameter that lasts for, typically, just one millisecond. They occur in the ionosphere 100 km (60 miles) above the ground over thunderstorms. Their colour was a puzzle for some time, but is now believed to be a red hue. Elves were first recorded on another shuttle mission, this time recorded off French Guiana on October 7, 1990.

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