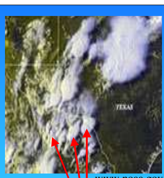
THE MOST COMMON TYPE OF THUNDERSTORM

- Warm, humid air rises to form cloud.
- Rain falls and thunder heard.
- Very little or no windshear.
- Falling rain and downdraughts cause the storm to decay.
- Short-lived: 30 to 90 minutes.



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THUNDERSTORMS

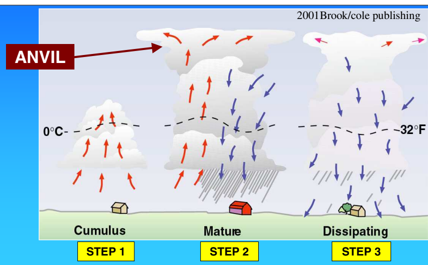
When unsaturated air rises, it cools at 9.8ºC per km of ascent. If it cools enough, then water vapour will condense onto particles suspended in the air (called cloud condensation nuclei) to form cloud droplets that we can see. Air must rise to form cloud.

The mechanism forcing air to rise may be surface heating, causing bubbles of warm air to rise, or the meeting of two dissimilar air masses. Ascent can also result from air being forced up and over hills or mountains. Upper-level divergence is important as it encourages low-level air to converge (causing air to rise).

Thunder is caused by the sudden heating (and therefore expansion) of air due to lightning, so it is not possible to have thunder without lightning having occurred first.

Most commonly, thunderstorms last between 30 and 90 minutes.

HOW THE MOST COMMON TYPE OF THUNDERSTORM DEVELOPS



STEP 1. Warm air rises to form cumulus clouds. The rising air cools, and when the relative humidity of this air reaches 100% water droplets form on condensation nuclei and cloud forms. If the air remains warmer than the surrounding air then it will remain unstable and continue to rise.

STEP 2. When water droplets form, latent heat is released, making available more energy to grow the cloud. If enough energy is available, the cloud can reach (and sometimes even enter) the stratosphere. However, the stratosphere is a stably-stratified region of the atmosphere. Because of this, vertical development of the cloud is suppressed and the cloud top spreads horizontally, shown as an anvil top.

Raindrops can collide with one another and coalesce to form larger drops. If they become large enough, then they become too heavy to be held aloft by the updraughts in the cloud. As they fall, they collect further smaller raindrops and grow larger still.

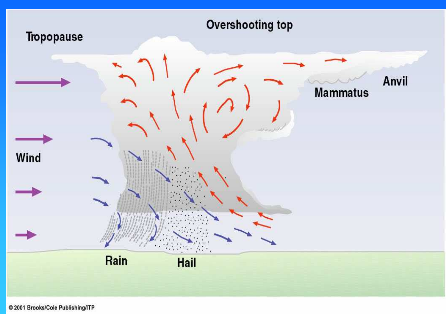
In addition, cooler air is entrained (drawn in) into the cloud and as this air is more dense than the warm air within the cloud it too begins to fall.The combined effects of the falling rain and entrained air cuts off the rising warm air, thus causing the cloud to dissipate.

STEP 3. With the energy supply having been effectively cut off by the rain and cooler air, the cloud dissipates. Cooler, drier surrounding air causes any warm parcels of remaining air to evaporate and the life cycle of the thunderstorm to be completed.

SEVERE THUNDERSTORMS

- Same sequence of development as the most common type of thunderstorm except that … … wind shear is present … … separating the rising air and falling rain.
- The thundercloud becomes self-supporting.
- It can last for hours.
- And it can produce severe weather hazards.

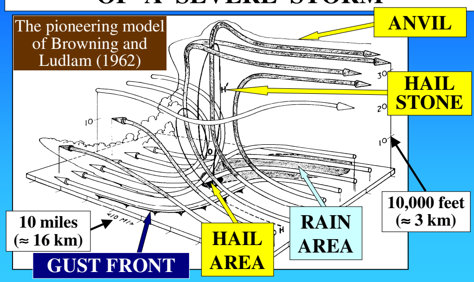
When there is marked wind shear, organized self-supporting cumulonimbus systems can develop. In such circumstances, cumulonimbus activity can continue for several hours.



The important difference between the development of ordinary and severe thunderstorms is wind shear.

If the wind speed increases with height, rising air can become separated from the falling rain and cooler air. Therefore, dissipation of the storm does not occur. The storm instead develops.

THREE-DIMENSIONAL STRUCTURE OF A SEVERE STORM



The storm which struck the Wokingham area of Berkshire on 9 July 1959 produced hailstones more than 2.5 cm in diameter. This storm was studied in detail by Professor Frank Ludlam of Imperial College and his team of co-workers, who produced a striking three-dimensional model of the airflow within the storm and explained how large multi-layered hailstones may form in such weather systems. The diagram on the slide is taken from a paper entitled *Airflow in convective storms* by K.A.Browning and F.H.Ludlam published in the April 1962 issue of the *Quarterly Journal of the Royal Meteorological Society* (Volume 88, pp.117-135).

In the above diagram, streamlines of air in which condensation occurred are shaded. The surface areas affected by rain and hail are shown by, respectively, grey and black shading. Heights are shown in thousands of feet. Precipitation formed in air which entered the storm near position H (bottom right). As shown, the precipitation was carried across relative to the storm to around 13-15,000 feet, whereupon it fell and re-entered the strong updraught near position O. Some precipitation particles reached altitudes of 30,000 feet or more and grew into large hailstones before falling again, forward of the strong updraught, near position H'. The storm moved from left to right, with rain on its left flank and a squally 'gust front' (shown as a cold front) on its right flank. Behind the storm, chilled air reached the ground.

SEVERE THUNDERSTORMS

TYPES OF WEATHER HAZARD

- Flash floods
- Lightning
- Downbursts
- Hail
- Tornadoes

Severe cumulonimbus storms produce heavy precipitation. If a storm becomes stationary or almost stationary over an area, a large amount of rain may fall in a short time. A large amount of water may therefore drain away over a limited area, rushing down valleys and causing flash flooding.

Severe storms may also be accompanied by lightning, downbursts, damaging hail or even tornadoes.

FLASH FLOODS

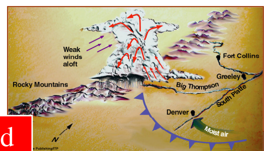
- Rainfall concentrated in a small area.
- Clouds can hold enormous amounts of water.
- If too much rain falls too quickly for the land to absorb …
  … flash flooding can occur.
- Risk of severe property damage …
  … and loss of life.

A single thundercloud can produce 500 million litres of rain! The cloud can form, produce rain and dissipate in 30 to 90 minutes, so any rain that falls is likely to do so over a concentrated area. This is just from one cloud!

Remember that it is usual for there to be a number of thunderclouds generated when the atmospheric conditions are favourable, rather than just one cloud. The amount of rain falling over an area can overload the drainage system in cities as well as rivers (e.g. in London in August 2004, when a large amount of untreated and partly-treated sewage was released into the River Thames in order to prevent sewers overflowing during heavy rainfall.)

EXAMPLE:

- Big Thompson Canyon, near Denver, USA.
- 31 July 1976
- Storm stalled over mountains.
- 20 cm of rain fell in one hour.
- Water rushed down a canyon that was popular for picnics and hiking.



145 people died

2001Brooks/Cole publishing

One of the surprising aspects of the Big Thompson incident was that it did not rain in the canyon at all. The cloud formed over a mountain range some miles away.

A flash flood of this nature can result in a wall of water rushing down a valley or canyon without any warning.

FLASH FLOODS IN THE UK

- Lynmouth 1952
- Frontal rain and thunderstorms
- 34 deaths

- Boscastle 2004
- Frontal rain and thunderstorms
- 0 deaths

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On 15 August 1952, the village of Lynmouth in North Devon was devastated by a torrent of water which poured off Exmoor; 34 people died. On 29 May 1920, in and around the Lincolnshire town of Louth, 22 people died when water from a storm over the Lincolnshire Wolds caused the River Lud, normally a small stream, to rise 5 metres above its normal level. In Dorset and Somerset, there have been similar occurrences; and in all cases, severe storms caused the havoc. When such storms occur in the British Isles, the wind in the upper troposphere is typically from the south-west, with the wind in the lower troposphere from a north-easterly point (and pressure low to the south and south-west). If this flow is lifted orographically, the storm may become stationary and deposit several inches of rain in a short time. Thus, it is places below slopes that face northwards or north-eastwards that are most at risk.

In the case of the flash flood which occurred in Devon in August 1952 at Lynton and Lynmouth, a storm stalled over the moor and 9 inches (22 cm) of rain fell in 24 hours, causing 90 million tonnes of water to rush down the narrow East and West Lyn valleys, carrying boulders and trees with it. The flood destroyed 29 bridges and 100 buildings in its path and also caused the deaths of 34 people. A combination of frontal rain, topography and embedded thunderstorms produced the rain.

A similar set of circumstances brought about a flash flood that caused devastation at Boscastle, Cornwall, on 16 August 2004, when 6 cm (2ins) of rain fell in two hours, causing a three-metre high wall of water to rush through the village. The ground was already waterlogged and the rivers Valency and Jordan, which meet just above the village, were inundated.

LIGHTNING

- Electrification of clouds.
- Separation of electrical charges.
- Still not clear how lightning occurs.
- On average, approx 44,000 thunderstorms and 100×10^6 lightning discharges in Earth's atmosphere every day.
- About 2,000 storms in progress around the world at any given time.

There is still ongoing research into the exact cause of electrification within clouds.

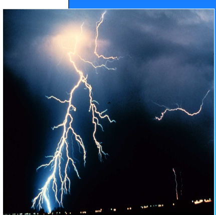
Large electrical gradients are generated within cumulonimbus clouds, but how electrification actually occurs within clouds is still the subject of research. Charge separation inside the clouds is such that upper parts of thunderstorms become positively charged while lower parts contain pockets of positive charge but are negatively charged overall. The charge on the earth's surface is positive underneath thunderstorms, negative elsewhere.

A lightning discharge occurs once an electric field has become intense enough for air's resistance to be overcome.

Approximately 44,000 thunderstorms and almost one hundred million lightning discharges occur in Earth's atmosphere every day. About 2,000 of these storms are in progress at any given moment.

LIGHTNING

- Lightning causes thunder, wildfires and electrical surges.
- 1-3×10^9 volts per flash.
- Types of lightning include cloud to cloud, cloud to earth and strange sprites, elves and blue jets.
- Thunderstorms most frequent in low latitudes.
- The most thundery place on Earth is Java, where the frequency is >200 days per year.



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The heat generated by a lightning flash causes the air around it to expand rapidly. This causes a compression wave which we hear as thunder. Therefore, we cannot have thunder without there being lightning present. Light travels at 300 million metres per second, so an observer sees a flash of lightning at virtually the instant the electrical discharge occurs. The sound of thunder travels much more slowly (at between 330 and 340m/s), taking about three seconds to travel a kilometre (five seconds to travel a mile).

Thunder is harmless, but the squally weather and the lightning responsible for the thunder create dangers and difficulties. For example, electrical discharges create static, which interferes with radio communications, and gas tanks struck by lightning may explode. Wildfires may be started and surges may occur in electric circuitry. It is estimated that lightning causes 10,000 wildfires a year in the USA alone.

Lightning can be from cloud to ground, cloud to cloud (called sheet lightning) and even above or out of the tops of thunderclouds! The latter forms of lightning are called sprites and blue jets and are respectively red and blue in colour. Elves are patches of luminous light but unlike the other two do not shoot up out of the top of the cloud.

In dry air, which is a poor conductor of electricity, a field strength of about 3 million volts per metre causes small sparks when the atmospheric pressure is about 1000mb. Discharges occur in weaker fields when pressure is lower and air moist. Normally, strengths of between 0.4 and 0.7 million volts per metre are sufficient to cause lightning.

DOWNBURSTS

- Cool, dense air descends from cloud
- Microburst < 4 km
- Macroburst > 4 km
- Dry and wet types
- Severe hazard to aircraft (and boats)

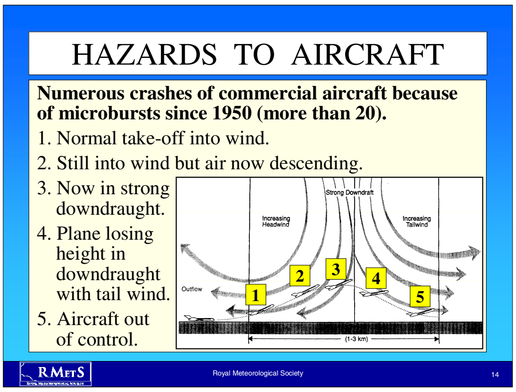
Air that is cooled within the cloud as a result of entrainment of cooler surrounding air or the rain process descends because of its increased density. This is normal and indeed occurs in all thunderclouds. It is called a downdraught. In severe storms, downdraughts may be as strong as 30-40m/s.

If a downdraught is localized and particularly strong, it can be dangerous for aircraft, as well as for small boats, which can be overturned. Downdraughts can be dangerous for fire-fighters, who can be caught out by a sudden change in wind direction.

When a downdraught reaches the ground, it spreads out in a roughly circular pattern. If its diameter is less than 4km the downdraught is classed as a microburst. If it is greater than 4kms it is classed as a macroburst.

All downbursts will result in a sudden change in wind direction, a fall in temperature and gusty wind. Where the outflowing cool air from the thunderstorm meets the warm air entering the storm, a gust front is found.

A downburst, be it micro or macro, can be either dry or wet. Dry downbursts normally occur from cumulonimbus clouds that have a high cloud base. In such circumstances, the falling rain evaporates before it reaches the ground and the fall streaks are known as virga. Wet downbursts form as part of the raining process and accompany rain (as can be seen in the picture on the slide).



An aeroplane that flies into a downburst first encounters an increasing head-wind (at 1 and 2), which adds to the speed of the air flowing over the aircraft's wings and thus increases lift. At 3, however, the strength of the downdraught begins to reduce the altitude of the aircraft; and at 4 and 5 the aircraft experiences both a tail-wind (which reduces air speed and lift) and a downward force from the downdraught. Over the years, there have been many air disasters caused this way, especially in North America.

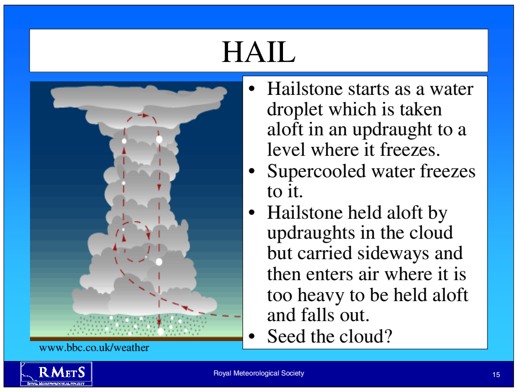
The first commercial airline crash attributed to a microburst was at Kano in Nigeria on 24 June 1956.

Microbursts are worse than macrobursts because of the small, localised areas they affect (4 km is approximately a runway length).

Because of the large loss of life resulting from downbursts, many airports have, since the early 1990s, installed a specialist radar system known as Doppler radar. This type of radar can detect rain moving within the storm and as a result can identify a microburst "signature".

(NOTE TO LECTURER: THE DESCRIPTIONS OF AIRCRASHES WHICH FOLLOW ARE NOT PART OF THE FORMAL TALK AND CAN BE SKIPPED IF YOU ARE SHORT OF TIME.)

An example which shows the effects of a microburst occurred on 2 August 1985 when Delta 191 crashed at Dallas-Fort Worth, Texas, USA. This was



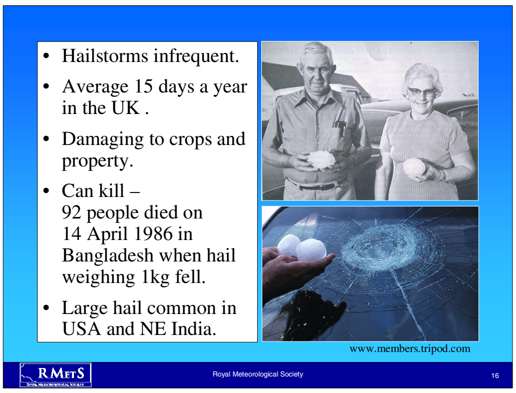
As we have seen in the previous diagrams, there are different things happening in different parts of the cloud. There are regions of updraughts and regions of downdraughts. Within these, the liquid content of the cloud varies. Also, there is supercooled water present as well as ice crystals.

Ice crystals are transported around the cloud by up- and down- draughts. Any supercooled water that collides with crystals will immediately freeze to them. If it freezes quickly, the layer of ice will be opaque, as air is trapped within it. If it freezes slowly, the layer will be clear. If a large enough hailstone is cut it open, it will be found to have rings like an onion.

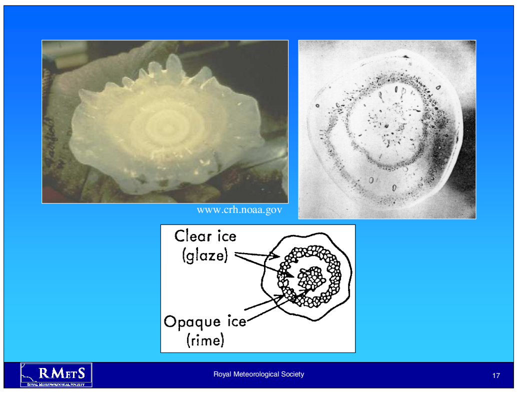
Ultimately, the hail will become too heavy for the updraughts and fall out of the cloud. The size of the hail depends greatly on the strength of the updraughts.

Note: the bands in the hail do not represent the number of times the hail has gone from the bottom to the top of the cloud (one or possibly two such trips are thought to be the maximum) but represent differing areas of supercooled water within the cloud.

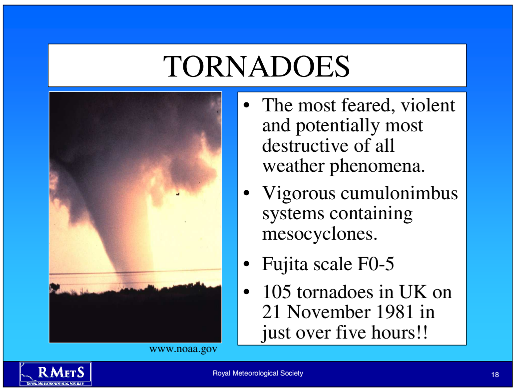
Experiments have been undertaken to seed a thundercloud with silver iodide. The aim is to introduce many thousands of particles that are similar in shape to ice nuclei. The aim is to encourage lots of smaller hailstones to form rather than a few large ones. It is unclear whether this approach is successful (as, for example, it is not known what would have happened if the experiment had not taken place) but there is anecdotal supporting evidence from Africa



In the UK, hail is not normally much larger than a centimetre or so in diameter. The largest recorded hailstones in the UK fell in Horsham, West Sussex, on 5 September 1958. Some were tennis-ball size and weighed 5 ounces (142 grams).



Note the concentric rings caused by supercooled water freezing to the hailstone.

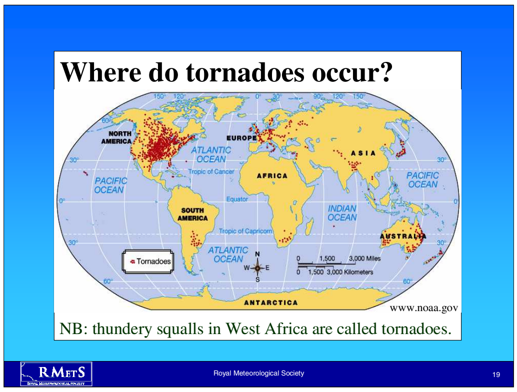


The strongest winds in the lower troposphere occur in the violent whirlwinds known as tornadoes (or twisters). Tornadoes are probably the most feared and violent of all weather phenomena. They are not very large – typically no more than a few hundred metres in diameter and only a few hundred metres in height – but wind speeds in them often reach 60 or 70m/s and sometimes 100m/s. Such is the concentrated power in tornadoes that destruction can be total in the swathes which they cut. Objects carried by the strong winds often become deadly projectiles. One tornado on 18 March 1925 travelled 219 miles through Missouri, Illinois and Indiana, USA, leaving 695 dead and 2,027 injured.

A funnel cloud which descends from below a cloud is classified as a tornado only when it touches the ground.

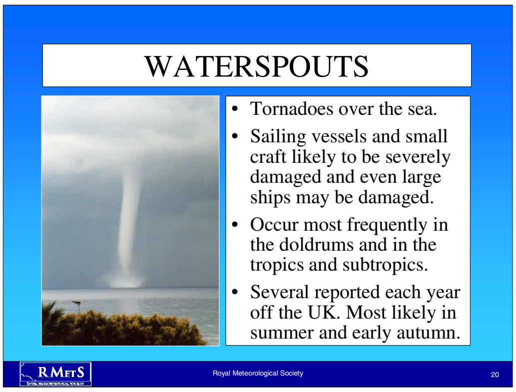
There are two tornado scales: the Fujita or F scale and the TORRO (UK and Europe scale). The former classifies the tornadoes from F0 to F5, depending on the amount of damage caused and estimated windspeed. This scale is used in America. The TORRO scale is from T0 to T10 and is based on the Beaufort wind scale.

Tornadoes can rotate clockwise or anti-clockwise. Anti-clockwise tornadoes are more common in the northern hemisphere and clockwise in the southern hemisphere as they gain their initial spin from the rotating thunderstorm and that can be large enough to be affected by the Coriolis force (the Earth's spin).



Tornadoes occur in specific areas of the world where thunderstorms are common. Although the area over the equator has many thunderstorms, there are no reported tornadoes. The reason for this is the lack of spin (Coriolis force). The main areas where tornadoes occur are North America, Europe, Australia, north-east India, Bangladesh and Japan.

Note the potential confusion that thundery squalls in West Africa are called tornadoes.



Tornadoes over the sea are called waterspouts. They are dangerous only when passing over vessels or offshore structures. Even the most seaworthy of ships may suffer damage if a waterspout passes directly over it. Sailing vessels and small craft are likely to be damaged severely if struck.

A waterspout travels with its parent cumulonimbus cloud at a speed of a few metres per second and generally exists for between ten and thirty minutes.

Waterspouts occur most frequently in the doldrums and in the tropics and subtropics, particularly over the South Atlantic Ocean, the Gulf of Mexico, the Mediterranean Sea and the Bay of Bengal. They are most likely to occur in late summer and early autumn.