

HAZARDOUS WEATHER PHENOMENA

Thunderstorms

Bureau of Meteorology › Weather Services › Aviation



A thunderstorm is a cumulonimbus (CB) cloud in which electrical discharge can be seen as lightning and heard as thunder. A thunderstorm is potentially the most violent and destructive meteorological phenomenon confronting general aviation pilots.



Thunderstorm Development

A thunderstorm is essentially a cloud that produces lightning. The lightning is a gigantic spark created when an enormous imbalance of positive and negative charge occurs. It greatly heats the surrounding air to many thousands of degrees, causing the air to expand violently, resulting in the crashing noise known as thunder.

For a thunderstorm to form, moist air must be able to rapidly rise through the atmosphere. Three main ingredients are necessary for this to occur:

1. An unstable atmosphere (evidenced by a strong vertical lapse rate, i.e. temperature falls rapidly with height) which, when associated with high surface temperatures, provides a favourable environment for the strong vertical atmospheric motions that produce thunderstorms.
2. A lifting mechanism (to initiate the vertical motion) such as low level convergence of airstreams, a frontal system, orographic uplift or local differences in heating.
3. Sufficient moisture (water vapour) in the low levels of the atmosphere. As air rises it cools, causing the invisible water vapour to condense into visible water droplets that form the cloud. The condensation process releases latent heat into the atmosphere, making the rising air more buoyant, fuelling further cloud growth.

Types of Thunderstorms

The type and severity of any thunderstorm will depend largely on the instability (buoyancy) of the rising air within the thunderstorm and the structure of the wind within the atmosphere. Wind generally tends to increase in speed and change direction with increasing altitude. This change in wind direction and/or speed with height is known as vertical wind shear.

The most severe thunderstorms occur in an environment with strong instability and strong wind shear.



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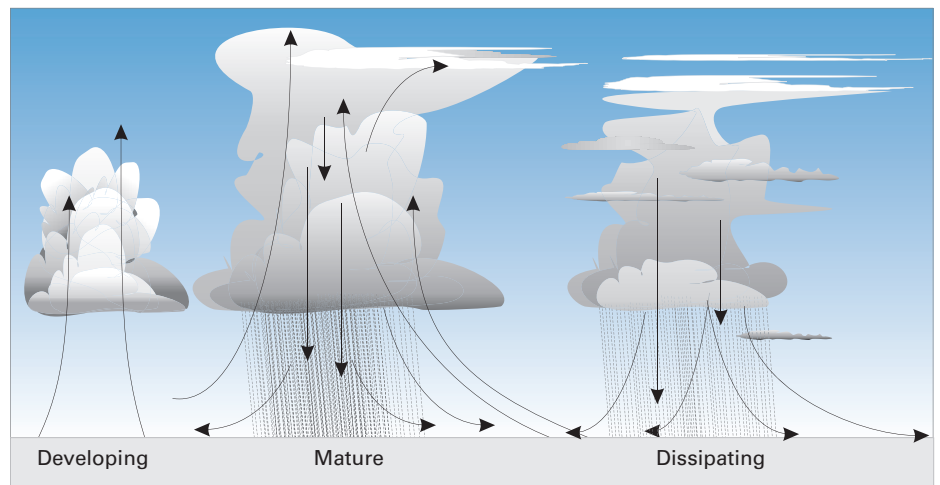
The dynamical building block of a thunderstorm is the convective cell, which is a compact region of strong vertical motion. Research has shown that convective cells, as observed visibly and on radar, often evolve in identifiable patterns. The most commonly observed storm types are classified as the **ordinary cell**, the **multicell** and the **supercell**.

The Ordinary Cell Thunderstorm

This is the most basic and common thunderstorm type, forming in an environment of weak vertical wind shear. It is a relatively weak weather system which initially consists of a single updraft which rises rapidly through the troposphere producing large amounts of water droplets and ice particles. When the water and ice become too heavy for the updraft to support, they begin to fall, creating a downdraft that quickly replaces the updraft. As the downdraft mixes with drier air in the lower troposphere, strong evaporative cooling may occur, accelerating the downdraft (because of negative buoyancy) which spreads out horizontally on reaching the surface.

The life cycle of an ordinary thunderstorm cell may be divided into three stages determined by the magnitude and direction of the predominating vertical motions. These stages are:

- the developing (or cumulus) stage, which is characterised by an updraft throughout the cell.
- the mature (or cumulonimbus) stage, which is characterised by both updraft and downdraft, at least in the lower half of the cell. This is the stage of maximum lightning activity.
- the dissipating stage which is characterised by downdrafts throughout the cell.



The ordinary cell is normally 5–10 km in horizontal extent and usually short-lived (15–30 minutes) in its mature stage as the downdraft eventually completely replaces the updraft, depriving the storm of its source of warm, moist air. It has been observed that the ordinary thunderstorm cell can sometimes produce severe weather (high winds, hail, weak tornadoes) for a short time if the updraft or downdraft is strong enough.

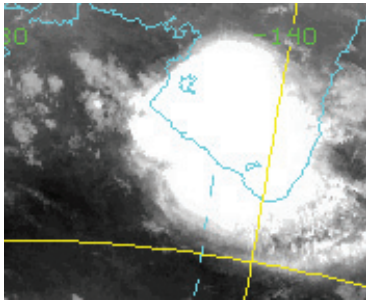
The Multicell Thunderstorm

Most thunderstorms are multicellular, i.e. a cluster of short-lived ordinary cells moving as a single unit with each cell in a different stage of the thunderstorm life cycle. The cold outflows from each combine to form a large gust front which provides a lifting mechanism for new updraft development, which can then lead to new cells forming. The degree of organisation of this thunderstorm type gives it a relatively long life and a greater chance of producing severe weather over a broad area. They tend to form in environments with moderate vertical windshear. They are more potent than single cell thunderstorms but considerably less so than supercells.

In terms of organisation, two types of multicellular thunderstorms are the squall line and the meso-scale convective complex.



Squall line thunderstorms.



Meso-scale convective complex over the Gulf of Carpentaria.



Supercell thunderstorm.



Roll cloud.



Shelf cloud.



Wall cloud.

A **squall line** is a multicell thunderstorm where the cells are arranged in a long line. The adjacent cells are so close together that they form a continuous line of thunderstorms accompanied by a continuous, and often strong, surface gust front at the line's leading edge, hence the name squall line. They develop along a linear lifting mechanism such as a cold front or a pre-frontal trough and also within the inter-tropical convergence zone.

Squall lines can be particularly dangerous to aircraft in flight since they can present a wall of severe weather which is too wide, high and long to negotiate. Cloud bases can change rapidly and are often very low. Flying beneath the cloud is an extremely hazardous procedure due to the high probability of encountering strong downdrafts, hail, rain, poor visibility, severe turbulence and low cloud.

A **meso-scale convective complex** is a nearly circular cluster of many interacting thunderstorm cells at various stages of development, covering an area that can exceed 500 kilometres in diameter. They have the potential to produce severe weather in the form of moderate-sized hail, weak tornadoes and heavy rainfall.

The Supercell Thunderstorm

As a general rule, the greater the altitude of the top of the thunderstorm, the more likely it is that the system will produce severe weather. The supercell, characterised by a single rotating updraft reaching great vertical extent, is relatively rare but is the most destructive and long-lasting of all thunderstorms. It is a well-organised cell that forms in an environment of strong vertical wind shear, strong instability and large moisture supply. The essential factor in its development is the presence of the strong vertical wind shear which favours a long-lasting vigorous updraft by organising the wind flows such that the precipitation falls alongside, not into, the updraft; and a strong inflow of moist boundary-layer air feeding into the storm is maintained. A supercell thunderstorms can thus persist for several hours (up to seven hours has been observed) in its mature stage.

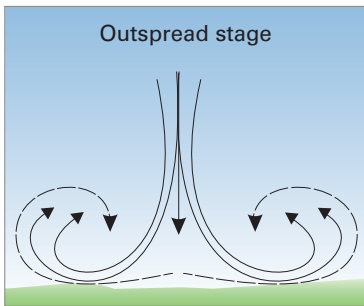
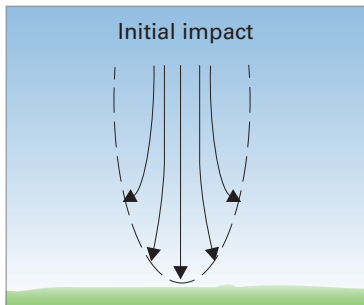
The rotating updraft is thought to be dependent upon the presence of wind speed shear in the mid levels which can cause a rolling about the horizontal axis of this mid-level air which, if lifted into the vertical by convection, can result in the updraft rotating. Any low-level shear that may exist will contribute to the rotation if it is lifted into the updraft through the storm's inflow. This rotating updraft can lead to the formation of tornadoes.

The dividing line between the cold downdraft and the warm updraft at the surface is called a gust front. In some cases the gust front can be identified at a distance from the supercell by the presence of a detached (horizontal, tube-shaped) **roll cloud** that is situated directly behind the gust front. These clouds are seldom accompanied by severe weather. However, damaging winds may occur under a **shelf cloud** (also known as arcus cloud) which can form on the edge of the gust front. It is an elongated wedge-shaped cloud attached to the leading edge of the supercell where the cold downdraft forces warm moist air upwards. A rotating **wall cloud** may form in the rain-free updraft area towards the rear of the thunderstorm. It occurs in the area of strongest updraft which entrains moist cool air from the nearby downdraft, allowing condensation at altitudes lower than that of the ambient cloud base. Most tornadoes form within wall clouds.

Aviation-related Hazards Associated with Thunderstorms

All thunderstorms have the potential to be hazardous to aviation no matter what their size or intensity. These hazards include:

- severe wind shear and turbulence
- severe icing
- hail
- downbursts
- lightning
- tornadoes
- heavy rain
- poor visibility
- low cloud
- rapid air pressure changes



Schematic of downburst.

Downbursts

The outflow from a storm's downdraft will occasionally produce winds of destructive force. When precipitation falls into drier air inside or below a thunderstorm, it immediately begins evaporating. This evaporation cools the surrounding air, increasing its density, causing it to accelerate downwards. A downburst is a concentrated downdraft, typically lasting five to fifteen minutes, and is of unusually high speed such that it can cause damage on, or near, the ground. The term **microburst** is used to describe a downburst which causes damage over an area with horizontal dimensions of less than four kilometres.

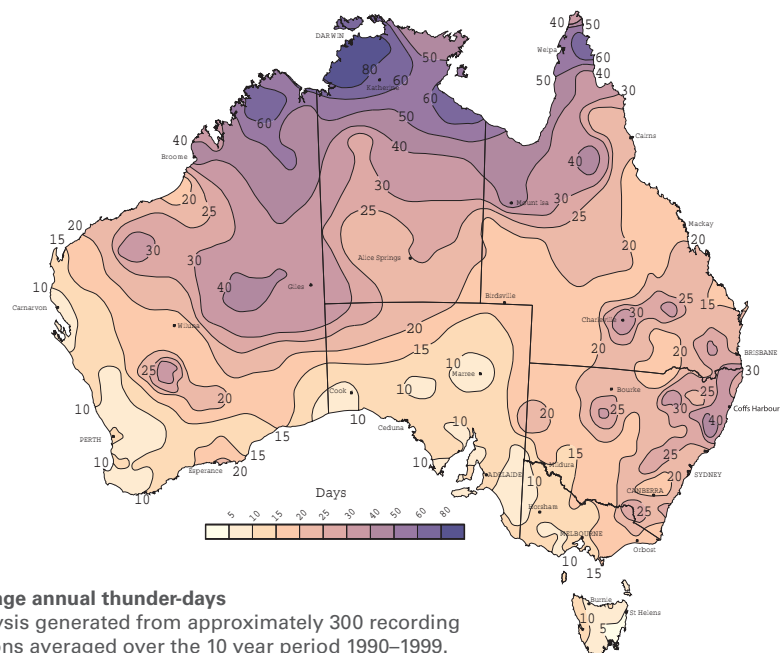
Downburst winds originate from the cloud base and diverge when they make contact with the ground. The rapid change in wind speed and direction associated with downbursts poses a threat to aircraft during take-off and landing phases, during which an aircraft will first encounter a strong headwind, then a downdraft which is the vertically descending section of the downburst, and finally a region of strong tailwind. If a pilot was to over-compensate for the lift experienced in the headwind, a dangerous drop in altitude may occur when the lift disappears in the downdraft and tailwind regions.

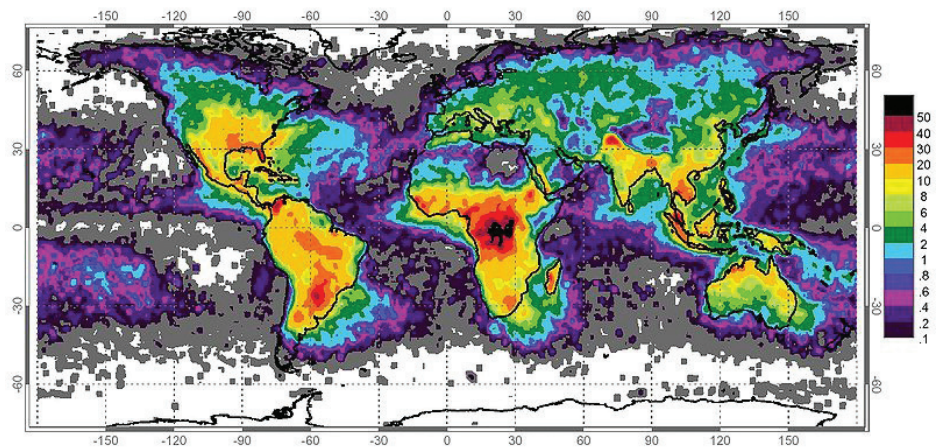
A microburst can be characterised as wet or dry. A wet microburst, which can occur with a range of thunderstorm types, is accompanied by significant precipitation at the surface. It develops in environments characterised by weak vertical wind shear and deep moisture capped by a dry layer.

In a dry microburst, precipitation at the surface is either very light or does not occur at all, although virga (precipitation falling from a cloud but evaporating before reaching the ground) may be present. They develop in environments with weak vertical wind shear, dry low levels and moist mid levels. The dry microburst is initiated by evaporative cooling. If the air underneath a cloud is relatively dry then rain and ice crystals falling from the cloud will quickly evaporate and chill the air. The cooled air will be heavier than the surrounding environmental air and will therefore accelerate downward. Dry microbursts can develop in the absence of lightning and thunder. High-based cumulus and altocumulus have been observed to produce damaging dry microbursts.

Location & Seasonal Variations

Thunderstorms are most frequent over the northern half of the country, and generally decrease southward, with lowest frequencies in southeast Tasmania. A secondary maximum is apparent in southeast Queensland and over central and eastern New South Wales, extending into the northeastern Victorian highlands. Thunderstorm frequency does not, in general, appear to vary in any consistent way with rainfall.





Global lightning frequency, data from space-based optical sensors. Image, NASA.

Tropics

Meteorological conditions over the northern half of Australia are very favourable for thunderstorms in the warmer months of October through to March. During this time, low pressure lies across northern and central Australia (giving rise to the low level convergence and vertical motion that favour thunderstorm development), and high moisture levels exist particularly in coastal areas. The peak frequency for thunderstorms is in the vicinity of Darwin with over eighty thunder-days per year. Thunderstorm frequency is far less for the remainder of the year due to the dry and stable conditions associated with the subtropical high-pressure belt which normally lies over the continent during the period April to September.

Thunderstorm frequency decreases in the southern parts of the tropics and the adjacent desert areas of central Australia. This is because the air, though often very hot, is generally drier. The exception is over inland Western Australia where a wide area experiences over thirty thunder-days per year. However, many of these are so-called 'dry' thunderstorms, with little or no rain, because of the lack of moisture in the low levels of the atmosphere which acts to evaporate any falling precipitation. Again, thunderstorms are heavily concentrated in the summer half-year.

There is a low frequency of thunderstorms (less than 25 days per year) along parts of the Queensland coast, especially in the very wet section between Cooktown and south of Innisfail. This is the wettest part of Australia, yet thunder-days are less frequent than in most remaining areas of the tropics. This is due to the combination of the orographic influences driving rainfall (the steering flow being unfavourable for thunderstorms tracking over the eastern coastline), and the stability of the southeast trade winds for much of the year.

Mid-latitudes

The secondary thunderstorm maximum over New South Wales occurs mainly during the summer months. The frequency of thunderstorms is largely due to the influx of moisture from the Coral and Tasman Seas combined with low level convergence into low pressure troughs. Orography also plays a part, with local maxima over the Great Dividing Range, and favourable steering flow tracking thunderstorms toward the coast. Instability over this area is often accentuated by strong wind-shears and/or upper atmospheric cold pools which have originated from higher latitudes.

Thunderstorms are less frequent in Victoria, Tasmania, and the southern parts of Western and Southern Australia, with less than 10 days per year in some areas. This is partly because of the relatively lower incidence at these latitudes of the warm and humid air masses favourable for thunderstorm development. It is also because during the potentially favourable warmer months, the subtropical high pressure belt lies over or near this area, giving rise to stable conditions unconducive to thunderstorm development. There is a local maximum of activity over the high country of northeastern Victoria and the Snowy Mountains, which appears to be mainly an orographic effect. Thunderstorms are again most frequent in the warmer months, but some occur in association with active cold frontal systems in winter and spring.

In contrast with most other parts of Australia, Perth experiences a winter maximum in thunderstorm frequency. This reflects the prevalence at this time of active frontal systems, which produce a winter rainfall maximum along the southwest coast, whereas the summer months are generally hot and dry. A similar feature is apparent in western Tasmania, also experiencing a weak maximum in winter activity. By contrast, Hobart, shielded by topography from the frontal systems of the winter westerlies, experiences a summer maximum. In fact thunderstorms in Hobart are rare in the cooler months, with an average of less than one thunder-day for the entire April-September period.

Detection & Monitoring

The primary tool for detecting and monitoring thunderstorms is the weather-watch radar, which may be accessed through the Bureau of Meteorology website www.bom.gov.au/weather/radar. The site includes valuable information on how to interpret radar images. Some aircraft are also equipped with radar for detecting and avoiding thunderstorms.

Satellite pictures also provide useful information, particularly in areas not covered by radar, by giving the pilot a broad understanding of where thunderstorms are developing and the horizontal extent of those cells, noting that high level cloud will often mask the true placement of the cell(s) below.

A pilot in command of an aircraft must advise Air Traffic Services (ATS) promptly of any hazardous weather encountered or observed either visually or by radar. Whenever practicable, those observations should include as much detail as possible, including location and severity of the hazard. Hazardous weather includes, in particular, thunderstorms, severe turbulence, hail, icing, line squalls, and volcanic ash cloud (AIP Gen 3.5 Section 6.2). Moreover, a pilot in command should make a special AIREP when requested or as soon as practicable after encountering any SIGMET phenomenon, or any other meteorological condition which is likely to affect the safety or markedly affect the efficiency of other aircraft (AIP Gen 3.5 Section 11.1).

Forecasts & Warnings

Thunderstorm forecasts are included in Area Forecasts, Trend Forecasts (TTF) and Aerodrome Forecasts (TAF). Cumulonimbus clouds are forecast in Significant Weather (SIGWX) charts. Warnings issued for thunderstorms include Airport Warnings for some locations, AIRMETs and SIGMETs.

An AIRMET will be issued for the occurrence or expected occurrence of isolated or occasional thunderstorms affecting the layer below FL185 if the thunderstorms have not previously been mentioned in a current Area Forecast.

SIGMET for thunderstorms are issued when they are:

- obscured (OBSC) by haze or smoke,
- embedded (EMBD) within other cloud layers,
- frequent (FRQ), i.e. with little or no separation between clouds and covering more than 75% of the area affected, or
- squall line (SQL) thunderstorms along a line of about 100 nautical miles or more in length, with little or no separation between clouds.

