The Bureau of Meteorology

Aviation services

Atmospheric stability and the aerological diagram

Reference material

Understanding the stability of the atmosphere is important when determining a range of weather conditions, including cloud types, turbulence, thunderstorm development and fire behaviour. The aerological diagram is a useful tool for interpreting atmospheric stability.

Simplifying the atmosphere

Parcel theory is a simplified way to approximate the behaviour of air in the atmosphere, particularly in relation to convection and stability. It assumes that a small parcel of air rises or sinks depending on how its temperature and moisture properties interact with the surrounding atmosphere's stability profile.

Atmospheric stability

Atmospheric stability describes the atmosphere's resistance to vertical motion, and determines whether air will rise (unstable), sink (stable) or remain in a neutral state (neutral).

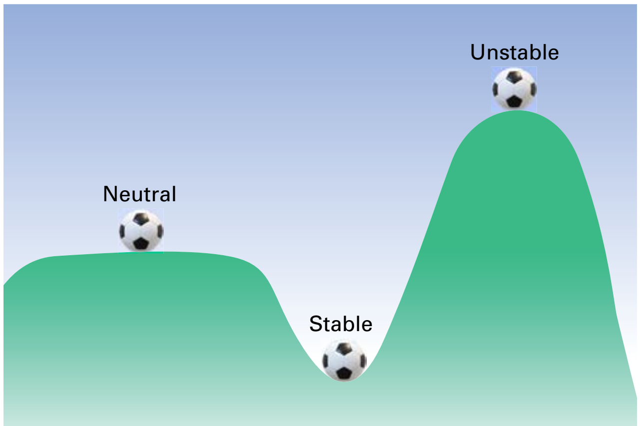
Vertical motion of air is an important driver of weather. Sometimes rising air is made visible by the development of clouds or by the rising dust in dust devils. Violent vertical motion can be seen in tornadoes. At other times, rising air may occur in the absence of any visual clue. Subsiding (sinking) air is normally relatively gentle and usually associated with clear conditions.

A **stable atmosphere** will suppress or resist vertical motion. If a lifted parcel of air is cooler, and therefore denser than the surrounding atmosphere, the parcel will tend to sink once the lifting mechanism ceases. Such an environment is defined as being stable.

An **unstable atmosphere** will enhance or encourage the vertical movement of air. If a lifted parcel of air is warmer and less dense than the surrounding atmosphere, the lifted parcel will continue to rise once the lifting mechanism ceases. In this case the environment is defined as being unstable.

A **neutral atmosphere** will neither suppress nor enhance vertical motion. If a lifted parcel of air is the same temperature as the surrounding air, the conditions are said to be neutral.

In some situations, the atmosphere is stable for unsaturated parcels of air but unstable if saturated. This is called **conditional instability**.



To envisage atmospheric stability, imagine a ball on a flat surface. If you were to roll the ball slightly it would change position and remain there (**neutral**). If the ball was in a dip, pushing it part-way out of the dip would result in it returning to the bottom of the dip (**stable**). If the ball was at the top of a hill, pushing it over the hill would result in it rolling down the hill, away from its initial position (**unstable**).

Adiabatic processes

An **adiabatic process** is where a parcel of air cools or warms due to a change in pressure and volume (expansion or compression), with no heat exchange between the parcel and the surrounding air.

Adiabatic cooling occurs when an air parcel expands and becomes less dense as it moves to lower pressure (higher altitude)

Adiabatic warming occurs when an air parcel compresses and becomes denser as it moves to higher pressure (lower altitude).

In reality, some mixing with the air outside the parcel normally occurs, and heat may also be lost or gained through radiation, however adiabatic processes are still useful in explaining how the atmosphere behaves.

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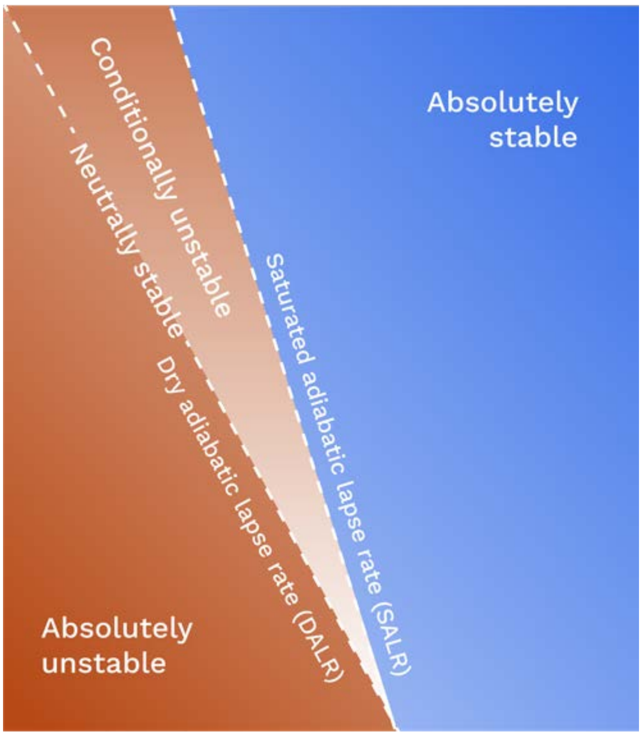
Lapse rate

The rate of change of temperature with height for a displaced parcel of air is termed the **adiabatic lapse rate**.

The **dry adiabatic lapse rate (DALR)** is the rate at which the temperature of a dry (unsaturated) air parcel changes as it ascends or descends through the atmosphere. It is approximately 3°C per 1,000 feet.

The **saturated adiabatic lapse rate (SALR)** is the rate at which the temperature of a moist (saturated) air parcel changes as it ascends or descends through the atmosphere. The SALR is often taken as 1.5°C per 1,000 feet, although the actual figure varies according to the amount of water vapour present and the temperature of the air parcel. (An air parcel at a higher temperature can contain more water vapour than when at a lower temperature.)

The SALR is less than the DALR because as a parcel of saturated air ascends and cools, water vapour condenses into water droplets, releasing latent heat into the parcel, which slows the cooling (and helps to maintain the air parcel's buoyancy). Conversely, if a saturated parcel descends and warms, water droplets will evaporate causing heat (latent heat of evaporation) to be absorbed from the parcel, thus reducing the rate of warming (generally termed evaporative cooling).



Determining stability

Warm air is less dense than cool air meaning it is more buoyant, so air rises if it is warmer than its surroundings.

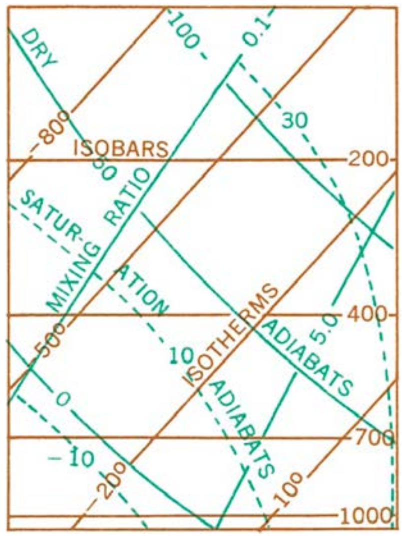
If the temperature profile is known, the rate of change of temperature with height (the environmental lapse rate) and thus the stability of the atmosphere, at that point in time, can be determined. Temperature profiles are plotted on aerological diagrams to determine the stability of the atmosphere or layers thereof.

Aerological diagram

Data for aerological diagrams are generally obtained from the balloon flights which carry a radiosonde through the atmosphere. Additional data can be obtained from atmospheric profilers, satellite imagery and aircraft meteorological data relay (AMDAR) data. Model F160 aerological diagram forecasts are available and are derived from numerical weather prediction data.

There are several aerological diagram types. The Bureau of Meteorology uses the Skew T – Log P (F160) aerological diagram. The Skew T – Log P name reflects the fact that:

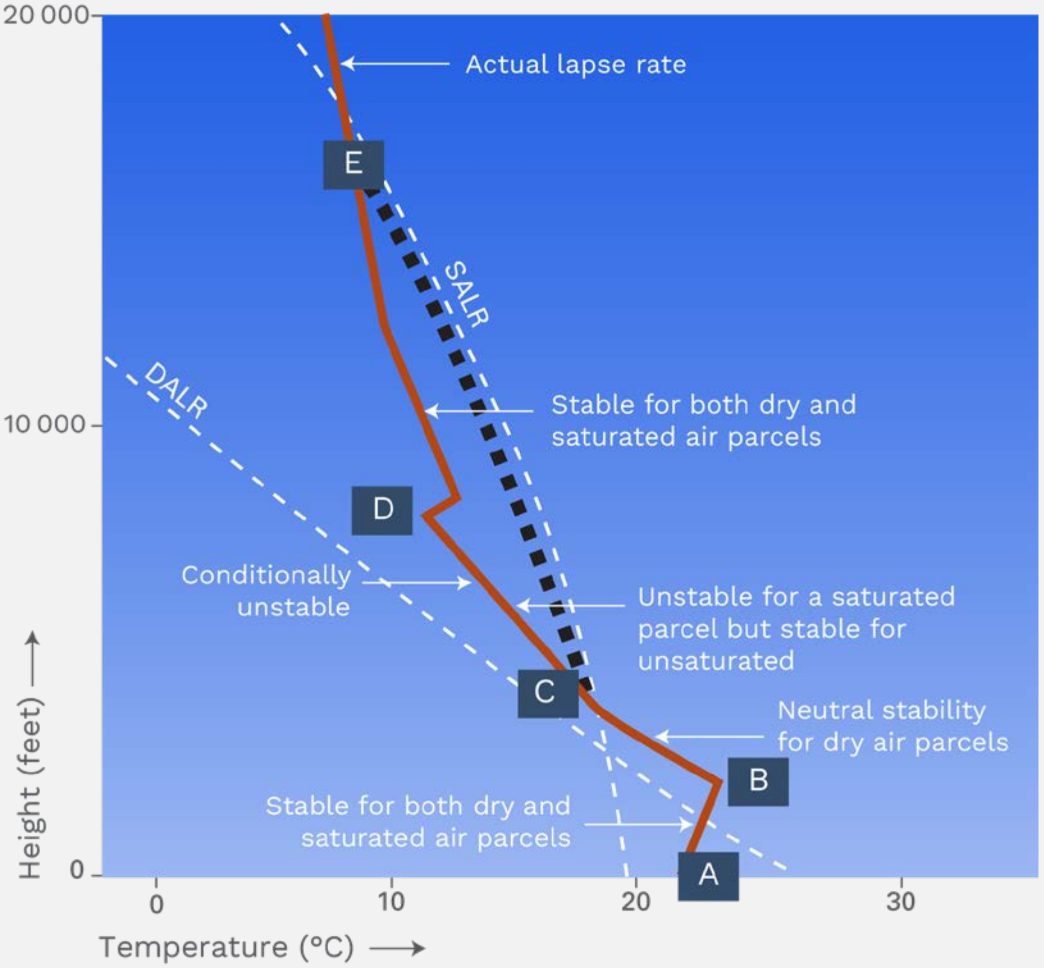
- temperature is plotted on the horizontal axis with isotherms (lines of equal temperature) skewed from the lower left to the upper right of the chart
- pressure is plotted on the vertical axis with isobars (lines of equal pressure) spaced using a logarithmic scale.



The aerological diagram also includes saturation mixing ratios (lines of constant mass of water vapour divided by mass of dry air in a saturated air parcel), dry adiabats and saturation adiabats. Superimposed on these is a plot of the actual variation in air temperature and dew point with height. Wind direction and speed are plotted on the right-hand side of the diagram. Additionally, indices calculated from the data are displayed at the top-right of the image.

The aerological diagram allows meteorologists to obtain a snapshot of the atmosphere above a specific location, from the surface to around the 100 hPa level. They can then determine the atmosphere's stability by comparing the actual temperature profile with the DALR and SALR.

As an air parcel rises, it encounters lower pressure. As a result, it expands and its temperature drops. If it is known how much the temperature changes, meteorologists can predict if the parcel will be warmer or cooler than its environment and thus the stability of the parcel can be determined.



Interpreting a simplified aerological diagram

In general, when the lapse rate of the air mass is:

- less steep than the DALR, then the atmosphere is absolutely unstable
- the same as the DALR, then the atmosphere is neutrally stable
- between the DALR and the SALR, then the atmosphere is conditionally unstable
- greater than the SALR, then the atmosphere is absolutely stable.

The red line, in the above simplified aerological diagram, depicts the temperature profile (and thus the environmental lapse rate). The DALR and SALR are depicted by the white dashed lines. Stable, unstable, neutral and conditionally unstable layers in the air can be determined by comparing the actual lapse rates of the air mass with the DALR and the SALR

A to B – stable layer
Any air parcel (dry or saturated) forced to rise between A and B, and cooled at either the DALR or SALR, will remain cooler than the environmental temperature and would sink once forcing ceases. The layer is therefore stable, as is the inversion layer above D.

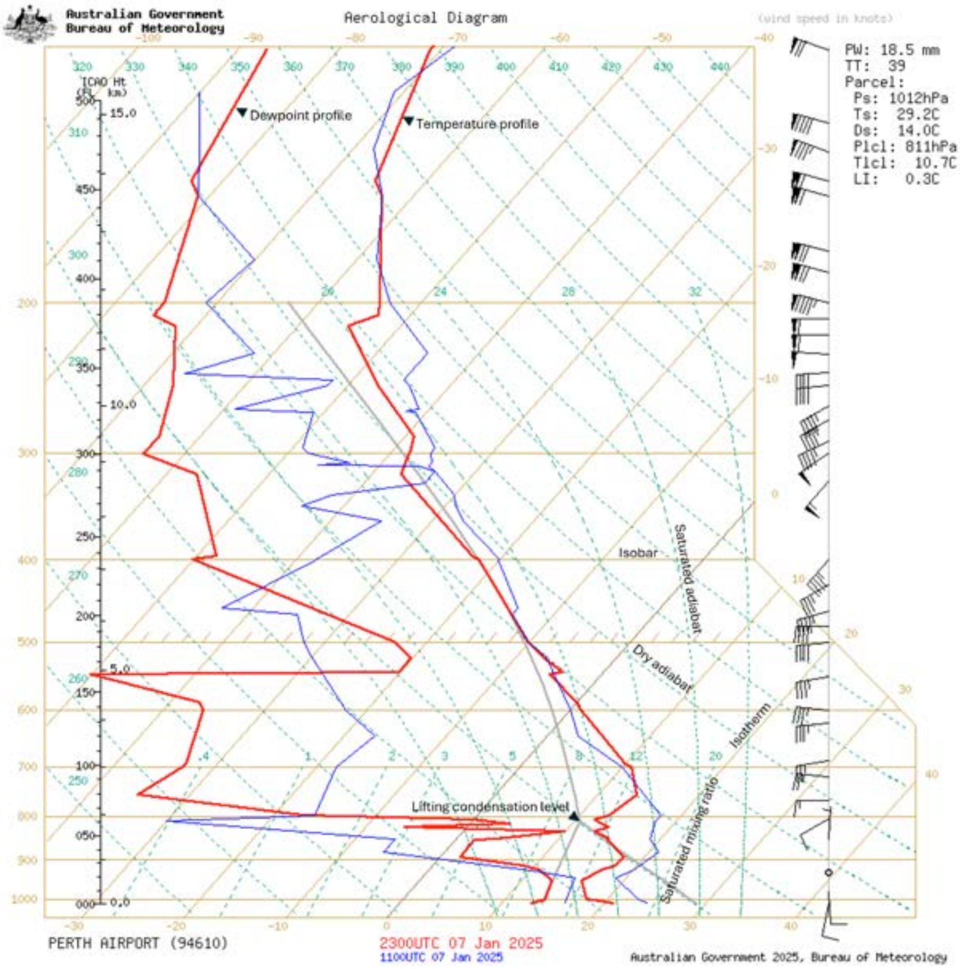
B to C – neutral layer
A dry parcel forced to rise through the neutrally stable layer between B and C will continue to rise only if forcing continues, because the parcel would be neither warmer nor cooler than the environment.

C to D – conditionally unstable layer
A saturated parcel rising through the conditionally unstable layer from C to D, and cooling at the SALR, would be warmer than the environment and thus continue to rise unaided. On the other hand, an unsaturated parcel forced to rise would cool at the DALR and be cooler than the environment, and therefore sink once any forcing had been removed.

D to E – stable layer
Like the layer from A to B, all parcels, saturated or unsaturated rising between D and E would only continue to rise if they were forced upward, since the layer is stable. (The layer immediately above D is in inversion.)

C to E (black dashed line)
This depicts the cooling of a saturated air parcel displaced from point C and rising to E along the SALR. It would stop rising at E because its temperature at this point is the same as the environmental temperature and thus the air parcel loses its buoyancy.

Example aerological diagram



PW – precipitable water. The amount of rainfall generated if all the water vapour in the atmosphere was precipitated to the surface.

TT – total totals. A measure of atmospheric stability based on the temperature differences between 850 hPa and 500 hPa. A value of 44 or higher indicates sufficient instability for thunderstorms to develop.

Ps – surface pressure.

Ts – surface temperature.

Ds – surface dew point.

Plcl – pressure at the lifting condensation level. The lifting condensation level is the level at which the parcel becomes saturated when lifted dry-adiabatically.

Tlcl – temperature at the lifting condensation level.

LI – lifted index. A measure of atmospheric stability, generated by subtracting the temperature of the parcel when lifted to 500 hPa from the observed temperature at 500 hPa. Negative values indicate an unstable atmosphere.

The standard Bureau aerological diagram is shown, depicting the latest (2300 UTC) radiosonde data in red and the previous (1100 UTC) data in blue. A number of standard measures used to predict the weather are calculated from the data and shown at the top right of the diagram; elevation, based on a standard ICAO atmosphere, is depicted on the left of the diagram in both hectopascals (hPa) and feet.

Aerological diagrams are very useful for determining cloud layers, convective (e.g. thunderstorm) potential, and changes in air mass properties.

The Lifting Condensation Level (LCL), depicted in grey on the diagram, is the level at which cloud will form as it is the level an air parcel becomes saturated when raised (dry adiabatically). LCL is found by following the dry adiabat from the surface temperature and the saturated mixing ratio from the surface dew point; the level where these cross is the LCL. The calculated LCL on the diagram assumes a well-mixed lower atmosphere and uses the estimated maximum afternoon surface air temperature and the estimated surface dew point at that time. In the example above, the expected surface air temperature of 29.2˚C and dew point of 14.0˚C predicts an LCL of 811 hPa (around 6,600 ft). Forecasters use the LCL, as well as other measures not shown (for example the Convective Condensation Level (CCL), Level of Free Convection (LFC) and the Equilibrium Level (EL)), to estimate cloud and convective potential at the observation site, and nearby locations, adjusting surface conditions as required.

Wind direction and speed is plotted on the right using the current (2300 UTC) observations and standard wind barb symbols. The barbed or feathered end of the wind staff points to the direction from which the wind is blowing. Half lines represent 5 kt, full lines represent 10 kt, flags/triangles represent 50 kt, and calm (no wind) is represented by a small circle.

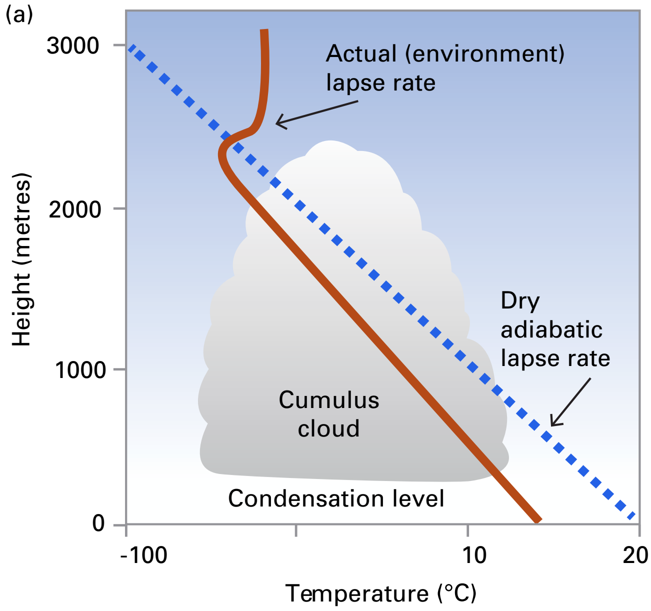
Cloud formation

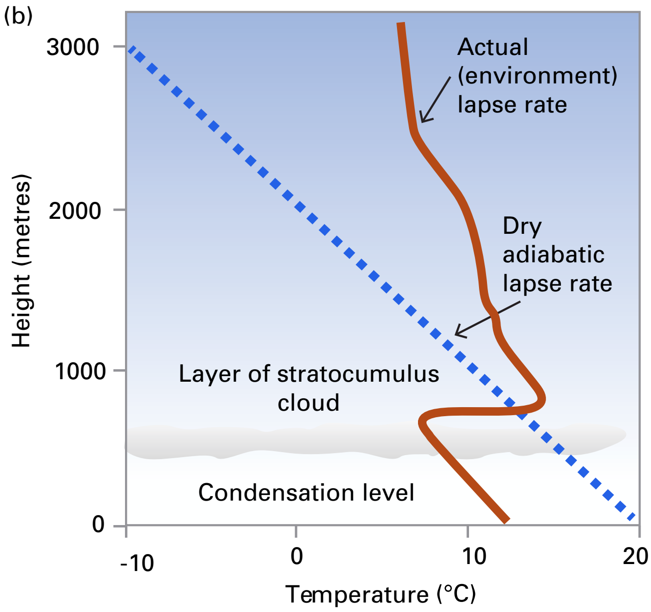
Convective clouds (e.g. cumulus) form when the air is sufficiently moist and unstable. Parcels of unsaturated air must be sufficiently buoyant to reach the condensation level and become saturated. Large convective clouds will form if the air is conditionally unstable over deep layers.

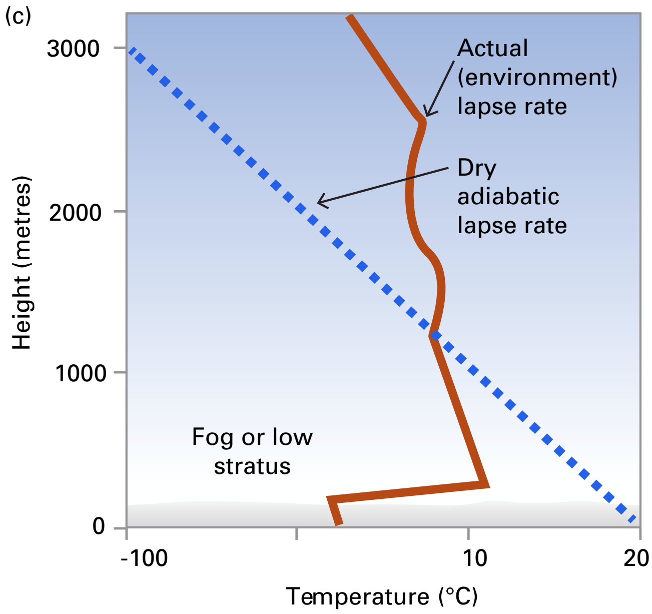
In the first diagram, labelled (a), the inversion layer is weak and relatively high; cumulus clouds, sometimes with showers, may develop in the conditionally unstable air. Cumulus tops may penetrate into the overlying inversion, but it will suppress their development.

In the second diagram, labelled (b), the inversion is stronger and much lower. Layers of stratocumulus or stratus, sometimes with drizzle, may form under the inversion (stable layer).

If the inversion is close to the ground, as shown in (c), low stratus or fog may form but the development of cumuliform cloud is not possible.







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