Chapter 9
Atmospheric Stability

9.1 Air Stability

Atmospheric stability is a measure of atmospheric status which determines whether or not air will rise, sink, or be neutral. In general stability refers to air tendency to rise or to resist vertical motion (Salby 1996; Houghton 2002; Hewitt and Jackson 2003; Lutgens and Tarbuck 2009; Hantel 2013). As the air parcel rises, it will expand and cool adiabatically to its dew point (i.e. the level of condensation) at which clouds are formed. There are four mechanisms that trigger air rising (Markowski and Richardson 2010):

1. Orographic lifting, which occurs when air cannot move through a mountain, and it is forcing to flow over a mountain barrier.
2. Frontal lifting happens when a warmer, less dense air is forced to rise over cooler, denser air along the front line.
3. Convergence is an atmospheric condition that exists when there is a horizontal net inflow of air into the region, resulting in an upward flow. When air converges along the Earth's surface, it is forced to be raised, because it can go down.
4. Updraft, local convective rising, as the result of unstable atmosphere and vertical transport of heat and moisture through the convection (Fig. 9.1).

When air encounters an obstacle, it is forced to lift upwards across the slope. On the upwind side of obstacle, air cools adiabatically, while at the downwind side, it heats adiabatically. Hence, a more increasing humidity occurs at the upwind side than that of the downwind side. Another possible way of lifting the air is the convergence of the flow of air at Earth's surface, which forms a low pressure and increased vertical velocity, and the air begins to rise. In this case, divergence of the wind occurs in the upper layer. Occurrence of vertical (ascendant) flow of air is noted in the boundary areas, which exist in the frontal surfaces warm and cold fronts, outflow boundary surfaces (thunderstorms), and dry lines. Individual air particle may be obtained by taking convection or lifting by heating the surface (diabatic). Particles

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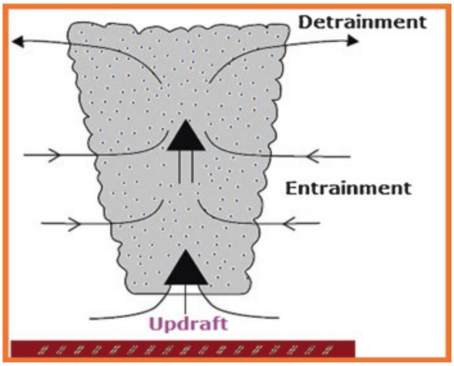


Fig. 9.1 Air rising caused by convection

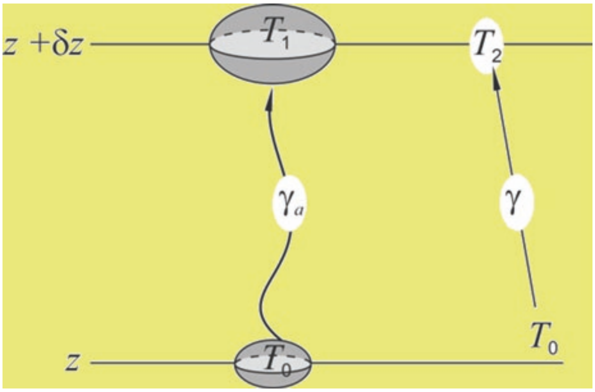


Fig. 9.2 Adiabatic and environmental vertical temperature gradient

with hot air can be collected from the surface and mixed with ambient air. The convection mechanism is responsible for development of clouds with vertical development (cumulus clouds), as precursors of thunderstorm clouds, known as cumulonimbus. The stability of the layer of the atmosphere can be estimated by comparing the vertical stratification of the atmosphere (Lutgens and Tarbuck 2009). It is obtained by upper air sounding measurements and analysis of dry and wet adiabatic rates (Fig. 9.2).

9.2 Static Atmospheric Stability

Static atmospheric stability (hereinafter referred to as atmospheric stability) is determined by comparing the vertical temperature gradient of the part of the air (or air) that is assumed to rise (or descend) dry adiabatically or moist adiabatically and the vertical temperature gradient of the surrounding air (Ćurić 2000; Ćurić and Janc 2016). Depending on the value of the temperature gradient, the atmosphere can be stable, neutral, and unstable. The value of the lapse rate is strongly dependent on the amount of water vapour in the air. Dry air cools at about 1 °C/100 m (the "dry adiabatic lapse rate"), while moist air usually cools at less than 0.6 °C/100 m ("moist adiabatic lapse rate"). The word adiabatic means that no outside heat is involved in the warming or cooling of the air parcels. To define the stability of the atmosphere, according to the vertical temperature gradient, there are three possible conditions:

Absolutely stable. The atmosphere is absolutely stable when the air at the surface is either cooler than the air aloft (an inversion) or the temperature difference between the warmer surface air and the air aloft is not very great (i.e. the environmental lapse rate is less than the moist adiabatic rate and it is positioned over the wet and dry adiabat).

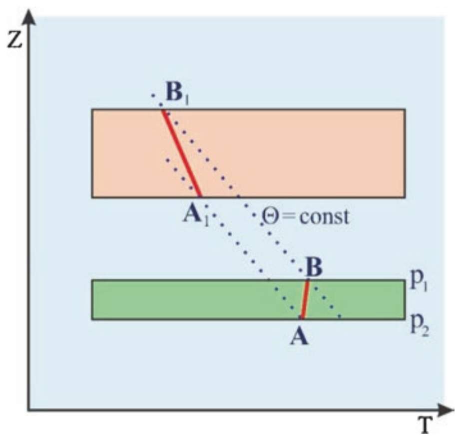
Absolutely unstable. The atmosphere is unstable when the surface air is much warmer than the air aloft (i.e., the environmental lapse rate is greater than the dry adiabatic rate, and it lies under the wet and dry adiabat).

Conditionally unstable. The atmosphere is conditionally unstable when unsaturated air can be lifted to a point where condensation occurs, and the rising air becomes warmer than the air around it. This takes place when the environmental lapse rate lies between the moist adiabatic rate and the dry adiabatic rate.

9.3 Stability Due to Air Movement

It is of great importance to know how vertical displacements of air layers affect the change in static stability. This mechanism of vertical displacement of air layers is most often due to the divergence of the ground level (divergence) in the high-pressure system (anticyclone) or due to the near surface layer air flow (convergence) in a cyclone. Observe a layer of air in the form of a square which, when lifted, remains unsaturated (Fig. 9.3). If the cross-sectional area of the air is assumed to

Fig. 9.3 The variation of air stability due to the displacement of the air layer



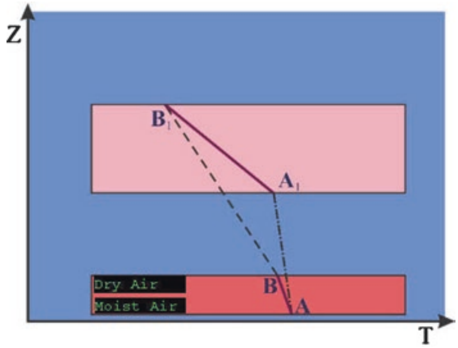


Fig. 9.4 Illustration of the mechanism of convective instability in the air layer. Line AA1 represents wet adiabat and line BB1 dry adiabat

remain unchanged, the air layer will occasionally lift to become thicker as it climbs into an area of lower pressure and less density, where the same mass of air is distributed in a larger volume. It's a layer where the air is statically stable (temperature inversion). It is evident by observing the change of temperature between points A and B on the lower and upper boundaries of the air layer, which do not change their relative position when lifting the layer. As the air layer rises, the temperatures of points A and B change dry adiabatically (lines of constant potential temperature θ) at altitude; there will be an increase in the instability in the layer, when the temperature between the points A1 and B1 declines. One can also observe the opposite case, when, e.g. in the anticyclone the air goes down. In this case, the static stability of the air increases, forming a subsidence inversion (sinking air) in that layer (Fig. 9.4). This often happens in the area of subtropical high pressure centres where significant air pollution can occur in large urban areas because inversion prevents the ventilation of air above such areas.

9.4 Convective Instability

In the mornings in summer, it often happens that the lower part of the ground layer of air (Fig. 9.4. lower position) is saturated with water vapour and in the upper part is unsaturated. Such a layer is stable, because it can also cause ground-level night inversion of temperature. Under the influence of intense heating, such a layer rises (Fig. 9.4, upper position). As it rises, the air layer becomes absolutely unstable. This occurs because the air temperature of the lower air layers changes moist adiabatically, by line AA1, which is slower than the temperature rate of the upper air layers. Air temperature of the upper-unsaturated air layers changes dry adiabatically, along line BB1. In such cases, the rising air layer is said to be convectively unstable. The mechanism described is responsible for the appearance of the most developed convective clouds, cumulonimbus, in the tropics and temperate latitudes. This mechanism of instability apparently occurs in the lower layers of the troposphere.

9.5 Low-Level Inversions

Inversions play an important role in determining cloud forms, precipitation, and visibility. An inversion acts as a cap on the upward movement of air from the layers below. As a result, convection produced by the heating of air from below is limited to levels below the inversion. A weather situation typical for occurrence of low-level temperature inversion is shown in Fig. 9.5.

During winter period at the Northern Hemisphere (or summer period at Southern Hemisphere), the solar radiation is weaker, so less heating comes to the Earth's surface. In addition, if there is a snow cover, the ground becomes colder due to the process of radiation cooling, and rapid heat and near surface temperature decrease. The persistent high-pressure system with stable atmospheric conditions, mainly calm or weak horizontal winds, suppresses air mixing near the surface, and clear skies increase the rate of cooling at the Earth's surface. The absence of vertical and horizontal mixing near the Earth's surface favours the development of a low-level temperature inversion, where the positive vertical temperature gradient exists in each atmospheric layer. In such stable atmospheric stratification, the portion of the column atmosphere acts as an energy barrier that does not allow vertical transport and mixing of ground air with the environment. The specific topography of the terrain (the landscape) especially in urban areas and valleys plays also significant role in the formation and intensity of temperature inversion. During the day, surface inversions normally weaken or disappear when the Sun warms the ground. Inversions play an important role in determining cloud forms, precipitation, and visibility. An inversion acts as a cap on the upward movement of air from the layers below. As a result, convection produced by the heating of air from below is limited to levels

Fig. 9.5 Specific weather situation during temperature inversion

below the inversion. A weather situation typical for occurrence of low-level temperature inversion is shown in Fig. 8.5. The formation of low-level inversions and their persistence for a longer period accelerates the pollution accumulation and contributes to formation of extreme pollution episodes with a poor air quality (Spiridonov 2010). There are four types of inversions: radiation, turbulence, subsidence, and frontal.

Radiation (night-time) or ground inversion develops when air is cooled by contact with a colder surface until it becomes cooler than the overlying atmosphere; this occurs most often on clear nights, when the Earth's surface cools off rapidly by radiation (see Fig. 8.4). If the temperature of surface air drops below its dew point, fog may result. Topography largely affects the magnitude of ground inversions. If the land is rolling or hilly, the cold air formed on the higher land surfaces tends to drain into the hollows, producing a larger and thicker inversion above low ground and little or none above higher elevations.

A turbulence inversion often forms in lower layer of the planetary boundary layer (PBL) at the near surface layer, when calm air overlies turbulent air. Within the turbulent layer, vertical mixing carries heat downwards and cools the upper part of the layer. The unmixed air above is not cooled and eventually is warmer than the air below; an inversion then exists.

A frontal inversion occurs when a cold air mass undercuts a warm air mass and lifts it aloft; the front between the two air masses then has warm air above and cold air below. This kind of inversion has considerable slope, whereas other inversions are nearly horizontal. In addition, humidity may be high, and clouds may be present immediately above it.

A subsidence inversion develops when a widespread layer of air is sinking. The layer is compressed and heated by the resulting increase in atmospheric pressure, and as a result the lapse rate of temperature is reduced. If the air mass sinks low enough, the air at higher altitudes becomes warmer than at lower altitudes, producing a temperature inversion. Slow descent air in areas with a high pressure is an important factor in the modification of air mass. This slow descent air is responsible for the development of inversions formed in the free atmosphere – a layer lying high above the Earth's surface. These inversions of subsidence form slow descent air that is heated by adiabatic compression. Air subsidence almost never goes down below the Earth's surface. Near the Earth's surface, there is always some weak turbulent mixing. This poorly downs the air intercepts by turbulent mixing.

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