Adiabatic Processes, Stability and Instability

Few concepts are as fundamental to meteorology or as difficult to understand as adiabatic processes. As air rises (or falls) vertically it cools (or heats). This phenomena is due to the "gas laws" which relate temperature, pressure and volume of a parcel of air. These changes in temperature with changes in altitude are called adiabatic processes and they determine the state of the atmosphere, i.e., the degree of stability or instability of the atmosphere.

To determine how stable or unstable a given atmosphere is, one must compare the temperature of a parcel (of air) to the temperature of its surroundings (at the same height). If the temperature of the parcel is warmer than its surrounding environment, it is more buoyant than its surroundings and will rise higher. If the temperature of the parcel is cooler than its surroundings, it has negative buoyancy and will sink back toward the surface.

The term for the temperature of the surrounding air is the "Environmental Lapse Rate" (ELR). A typical value is 6.5° C. per kilometer. This means that the temperature falls 6.5° C. for every 1000 meters increase in altitude. The 6.5° C is an average value. It can not be used in actual calculations. The actual environmental lapse rate must be measured for a given time at a given place. This is done by sending up a weather balloon which measures the actual air temperature as it rises. This process is called 'taking a sounding'.

The "Dry Adiabatic Lapse Rate" (DLR) is 10° C. per kilometer. This is the rate at which a rising parcel will cool as long as condensation is not occurring. If condensation is occurring (because the temperature of the parcel has fallen below the dew point temperature), the parcel cools at the "Wet Adiabatic Lapse Rate" (WLR) of 5° C. per kilometer. The WLR is lower (less steep) than the DLR because latent heat is released into the parcel by the condensation of moisture. The parcel still cools as it rises, it just cools at a slower rate because of the added heat.

Taking some specific examples, if the ELR is 6.5° C. and the DLR is 10° C., the parcel will always be cooler than the surrounding environment, so it will sink. This is a stable atmosphere. However, a parcel cooling at the WLR of 5° C. will always be warmer than the surrounding environment at a given height, so it is buoyant and will continue to rise. This is an unstable atmosphere.

A situation can also develop where the ELR is between the DLR and the WLR. In this case, a parcel has negative buoyancy when cooled at the DLR but positive buoyancy when cooled at the WLR. This situation is called conditional stability (or conditional instability) because the state of the atmosphere depends on the condition of the parcel. Is it condensing or not? This is actually a relatively common state of the atmosphere. If a parcel rises (is pushed upward by a physical mechanism such as a cold front) to a height where condensation can begin, then it becomes unstable and starts to rise spontaneously as condensation continues.
Another situation that can develop is called an inversion or inversion layer. This is a layer of warmer air sandwiched between cooler air above and also below it. An upper level inversion is a typical feature in summer subtropical high pressure cells and is due to the descending and warming air within the high. A low level inversion can be caused by a cool land surface or a cool water surface (such as a cold ocean current) which cools off a thin layer of air close to the surface. The air above is actually warmer than the cool surface air. The warmth of the inversion layer (above the cool surface) dampens out vertical motions and contributes to a stable atmosphere.