

CHAPTER TWO

SOME CONCEPTS IN CLIMATOLOGY

2.1 The Adiabatic Process

An important principle to remember is that, in the troposphere, the first layer of the atmosphere, temperature decreases with altitude. This means that warm rising air becomes cooler and heavier. It would therefore imply that polluted air released from industrial stacks obeys this “law” if it is warmer than surrounding air.



Figure 2.1: Warm air rising from SAPREF stacks, October 2002

Source: GroundWork

During the adiabatic process, a gas, such as air, is heated or cooled, without heat being added to or taken away from the gas, but rather by expansion and compression. In the atmosphere, adiabatic and non-adiabatic processes are taking place continuously. The air near the ground is receiving heat from or releasing heat to the ground through long and short wave radiation as illustrated in Figure 2.2 below. These are non-adiabatic processes.

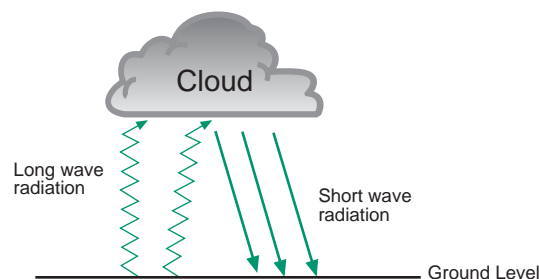


Figure 2.2: Heat transfer through radiation

However, in the free atmosphere somewhat removed from Earth’s surface, the short-period processes are adiabatic. When a parcel of air is lifted in the free atmosphere, it cools. The drop in temperature is a result of the decrease in atmospheric pressure at higher altitudes.

To equalize this pressure, the parcel must expand (increase in volume). In expanding, it is doing work. In doing work, it uses heat. This results in a lowering of temperature as well as a decrease in the pressure and density. When a parcel of air descends in the free atmosphere, pressure increases. To equalize the pressure, the parcel must contract (volume decreases). In doing this, work is done on the parcel. This work energy, which is being added to the parcel, shows up as an increase in temperature. The pressure and density increase in this case also.

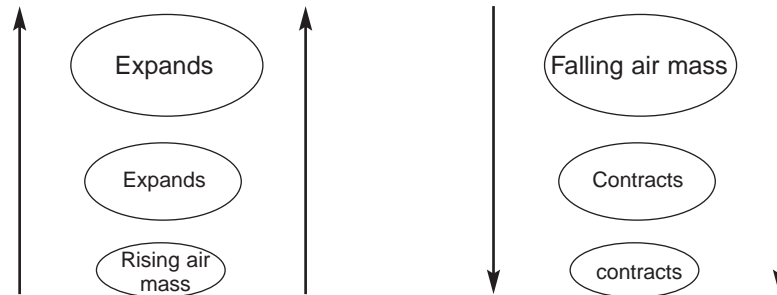


Figure 2.3: The behaviour of rising and falling air masses

If the total amount of heat in a parcel of air is held constant (no heat is added or released), then when the parcel expands, its temperature drops. When the parcel compresses, its temperature rises. In the atmosphere, if the parcel of air was forced to descend, it would warm up again without taking heat from the outside. This process, whereby a rising or falling air parcel experiences a change in temperature without gain or loss of heat from outside the air parcel, is called adiabatic. Adiabatic processes are very important in the atmosphere, and adiabatic cooling of rising air is the dominant cause of cloud formation. In discussing the adiabatic process, several terms are used that you need to understand.

2.2 Lapse Rate

Lapse rate is the rate of decrease of temperature with altitude. Thus, the lapse rate of the temperature is synonymous with the vertical temperature gradient. The temperature lapse rate is usually positive, which means that the temperature decreases with altitude.

2.2.1 Environmental Lapse Rate (ELR):

The change in temperature of still air i.e: atmospheric air, follows the Environmental Lapse Rate, which varies considerably, but averages about $6.5^{\circ}\text{C}/1000\text{ m}$. This is also known as the Normal Lapse Rate. In still air, if you went up in a hot air balloon carrying a thermometer and taking the air temperature every 1000 metres, the temperature would drop 6.5°C for every 1000 metres on average. The rate of temperature change as you rise in still air is not as great as the rate of change of rising air. That is, the air parcel does not cool off as fast.

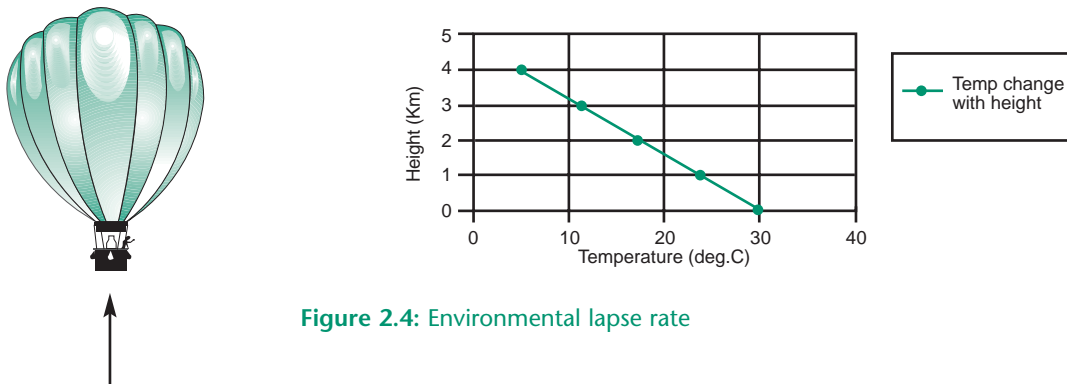


Figure 2.4: Environmental lapse rate

2.2.2 Dry Adiabatic Lapse Rate (DALR)

If a parcel of air is lifted, its pressure is decreased because pressure decreases with height, and its temperature falls due to the expansion. If the air is dry and the process is adiabatic, the rate of temperature fall is 1°C per 100 metres of lift (10°C per Km). This is known as the Dry Adiabatic Lapse Rate. Stated otherwise, Dry Adiabatic Lapse Rate is the rate of temperature change of rising air with changing altitude when no condensation is taking place. If the air subsides, it warms up at the dry adiabatic lapse rate.

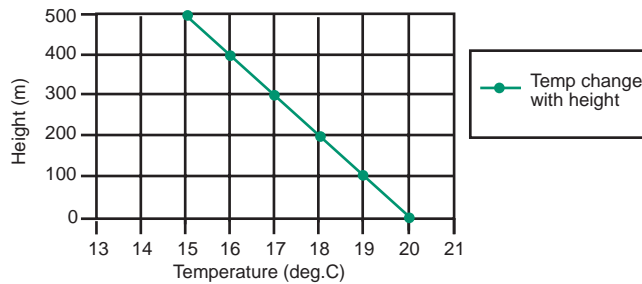


Figure 2.5: Dry adiabatic lapse rate

2.2.3 Wet (Saturated) Adiabatic Lapse Rate (SALR)

When an air mass is lifted, it cools at the Dry Adiabatic Lapse Rate of 1°C per 100 metres as long as it remains unsaturated (relative humidity below 100 percent). If the original moisture is being carried along with the mass as it ascends and it cools to its saturation temperature, the relative humidity reaches 100%. The dew point is reached and condensation takes place.

The dew point is the temperature at which the air becomes saturated and condensation takes place. As water condenses, heat is released, called latent heat. The air then absorbs it, and the adiabatic cooling rate decreases. However the released latent heat gives an added impetus to the rising air. The lifting condensation level occurs when condensation takes place releasing latent heat, which gives additional push to the rising air mass. The process during the saturated expansion of the air is called the Saturation Adiabatic, or the Wet Adiabatic Lapse Rate.

The **lifting condensation level** is the altitude at which condensation begins. When this happens, two opposing trends go on at the same time within this parcel of air. It is rising and cooling, but it is also condensing and being warmed. The result is that it cools at a lower rate than the dry adiabatic lapse rate. You can look up at the windward sides of mountains and see where the lifting condensation level is, because that is where you will see the bases of clouds that have formed.

The saturated lapse rate varies with the original temperature of the air parcel, but $0.5^{\circ}\text{C}/100$ metres is a commonly used value.

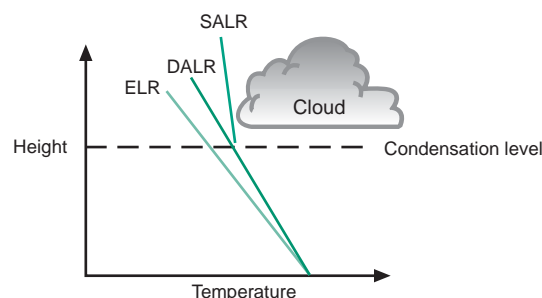


Figure 2.6: Saturated adiabatic lapse rate (SALR)

2.3 Inversion

Inversions describe the atmospheric conditions when the temperature increases with altitude, rather than decreases as is the usual situation in the troposphere. Inversions result from the selective absorption of Earth's radiation by the water vapour in the air, and also from the sinking of air, which results in its compression and heating.

When air is subsiding (sinking), the compressed air heats adiabatically, causing the air parcel to become warmer than surface air below it. Rising currents of cool air lose their buoyancy and are thereby inhibited from rising further when they reach the warmer, less dense air in the upper layers of a temperature inversion.

Inversions are common during calm clear nights when the layer of air touching the ground cools more rapidly than the air above it because it is touching a cooler surface. As the night progresses, this process creates a cool layer of air closest to the surface and the temperature increases with height for up to several meters above this layer. These night-time inversions are known as nocturnal or radiation inversions. During a temperature inversion, air pollution released into the atmosphere's lowest layer is trapped there. (Figure 3.5)

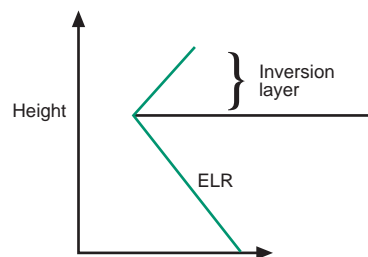


Figure 2.7: Inversion

2.4 Stability: $DALR > ELR$ or $TAP < TSA$

The atmosphere has a tendency to resist vertical motion. This is known as stability. The normal flow of air tends to be horizontal. If this flow is disturbed, a stable atmosphere resists any upward or downward displacement and tends to return quickly to normal horizontal flow.

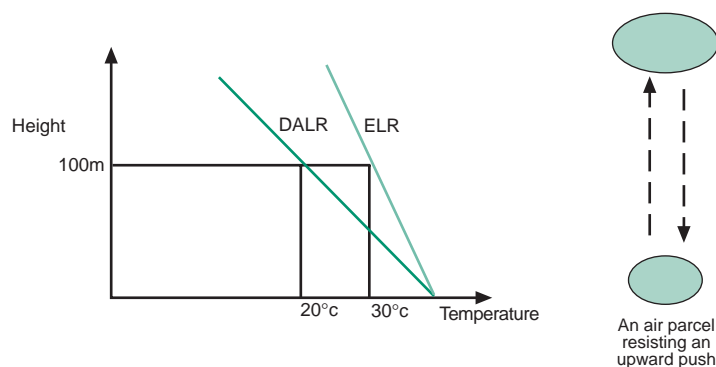


Figure 2.8: Stability

Note

TAP = Temperature of air parcel (DALR)

TSA = Temperature of surrounding air (ELR)

As figure 2.8 above illustrates, at 100m altitude, the temperature of the air parcel is 20°C, which is less than the temperature of the surrounding air, 30°C. To calculate the rate of change it is important to insert another altitude above 100m and observe the temperature difference along the temperature axis.

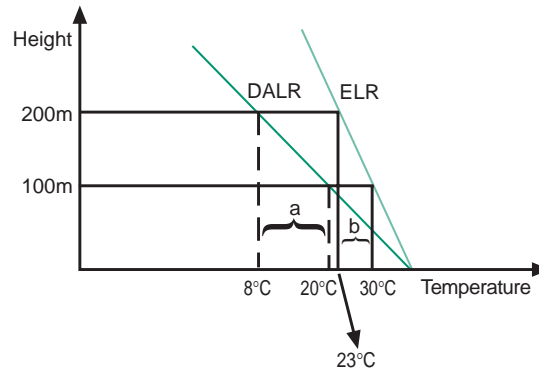


Figure 2.9: Determining rates of change

For the air parcel, at 100m the temperature is 20°C, at 200m its temperature drops to 8°C. This rate of change as indicated by (a) in the Figure above is 12°C. The temperature of the surrounding air at 100m is 30°C, at 200m it drops to 23°C with a 7°C rate of change (b). Hence DALR (12°C) is greater than ELR (7°C) hence $DALR > ELR$.

Atmospheric stability can be observed around industrial areas when the emissions from a stack are cooler than the surrounding air. The tendency will be for the emission to resist an upward movement and to move horizontally along the same level with the stack opening (Figure 3.1). Another example is around a mountain when a cool air mass is forced up the slope by a wind. At the top of the mountain, the air mass which is now cooler than air around the mountain will fail to move upward despite any further push especially in the absence of any mountain wedge. There will then be a downward movement on the reverse side of the mountain. The effects of Topography, stability and air pollution in South Durban will be discussed later in Chapter 4.

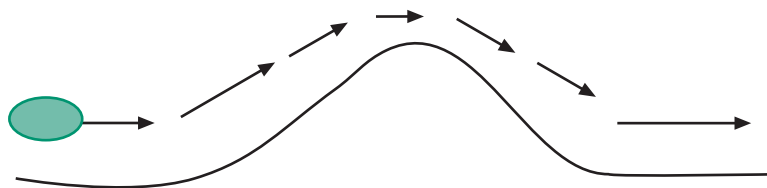


Figure 2.10: Stability

2.5 Instability: $DALR < ELR$

The atmosphere is unstable when a parcel starting at equilibrium is displaced slightly upward relative to its surrounding environment. It finds itself warmer than its environment (at its new altitude) and therefore continues to rise spontaneously away from its starting point.

There are 3 main kinds of air instability, absolute air instability, conditional air instability, and convective air instability.

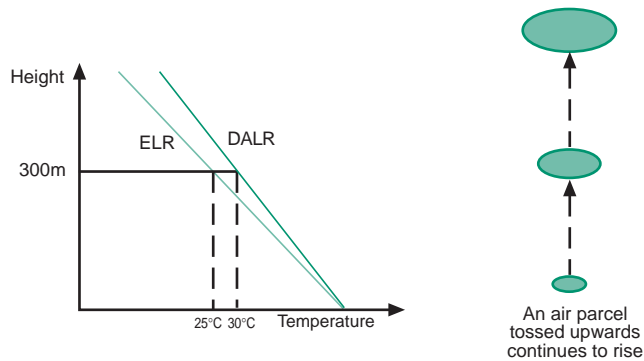


Figure 2.11: Instability

From Figure 2.11 above, the temperature of ELR at 300m altitude is 25°C and is less than the temperature of DALR 30°C at the same altitude. If we insert a new altitude above 300m or below to determine the lapse rates just like in Figure 2.9, we will realize that DALR is less than ELR (DALR < ELR). An example is a hot air balloon, which will continue to expand and rise once lifted from the ground.

From Figures 2.9 and Figure 2.11, we can conclude that there are two ways of determining atmospheric stability and instability, by comparing the temperatures of the air parcel and the surrounding air and by comparing the rates of temperature change in the two air masses.

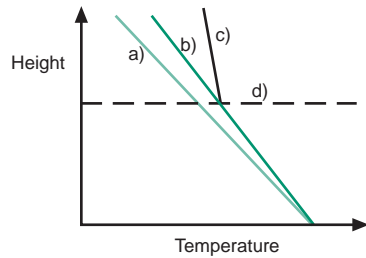
Hence, when:

- TAP < TSA = Stability
- TAP > TSA = Instability
- DALR > ELR = Stability
- DALR < ELR = Instability

Exercises

1. If a parcel of air is at 24°C at sea level, and it rises to 1000 meters at the DALR, what will be its temperature at that new height?
.....
2. What will its temperature be at 3000 meters?
3. If another air parcel at 4000 meters altitude has a temperature of -10°C, and it subsides to 3000 meters and then to 1000 meters, what would be its temperature at these two levels?
.....
4. Define DALR and illustrate it with an annotated diagram using situations mentioned in question 1 above.
5. The lifting condensation level is the altitude at which condensation begins. How would you discern the lifting condensation level on the windward sides of mountains?
.....
- 6 The figure below illustrates a particular type of instability as identified by the short line

above (d). Identify the various lapse rates from (a) to (c). What does the line (d) indicate?



- a)
- b)
- c)
- d)

7. Discuss the processes that lead to the occurrence of c).
8. Define air stability
9. What factors favour the occurrence of stability?
10. What enhances air stability?
11. When does an air parcel become unstable? What factors are responsible for air instability?
12. Define 2 types of instabilities of your choice and illustrate them with sketch diagrams.
13. If air is subsiding (say, it has gone over the crest of a mountain range, and is flowing down the leeward side of the mountains),
 - a) Will the temperature increase or decrease (assuming that all the moisture was removed from the air as it rose up the windward side)?
.....
 - b) Which lapse rate would you use to figure out the exact amount of change?
.....
14. State the lapse rates of the following:
 - a) Normal Environmental Lapse rate (E.L.R)
.....
 - b) Adiabatic Lapse Rate (A.L.R)
.....
 - c) Dry Adiabatic Lapse Rate (D.A.L.R)
.....
 - d) Saturated Adiabatic Lapse Rate (S.A.L.R)
.....
15. How would you determine the status of the atmosphere?
.....
16. If the E.L.R. is less than the S.A.L.R., then the air is
.....
17. If the E.L.R. is greater than the D.A.L.R., then the air is
.....
18. If the E.L.R. is between the S.A.L.R. and the D.A.L.R., then the air is
.....
19. Name four mechanisms that can induce the rising of an air mass.
 - a).....
 - b).....
 - c).....
 - d).....
20. State the atmospheric condition indicated by the statements below
 - a) $TSA > TAP$
 - b) $TAP > TSA$
21. What are the consequences of stability/instability of the atmosphere on the dispersal of pollutants?