L- 12
AIR POLLUTION METEOROLOGY

Air Pollution and Control (Elective-I)

Contents of unit-IV

The meteorology and air pollution

L-12 →Introduction, Different meteorological factors and their effect, laps rate and stability of the atmosphere, stability classes Problems on temperature gradient and stability.

L-13 →Inversion phenomenon, Precipitation and its relation to scavenging pollutant in the air, wind pattern, direction, velocity and fluctuations, Problems, Maximum Mixing Depth, problems. .

L-14 → MMD problems continued, plume behaviour.

L-15 →Models of diffusions and dispersion, GDM- assumptions, model equation, limitations, problems.

L -16→GDM problems continued, Line source

L-17 →Effective stack height, Problems.

L -18→ Min of safe stack height, problems.

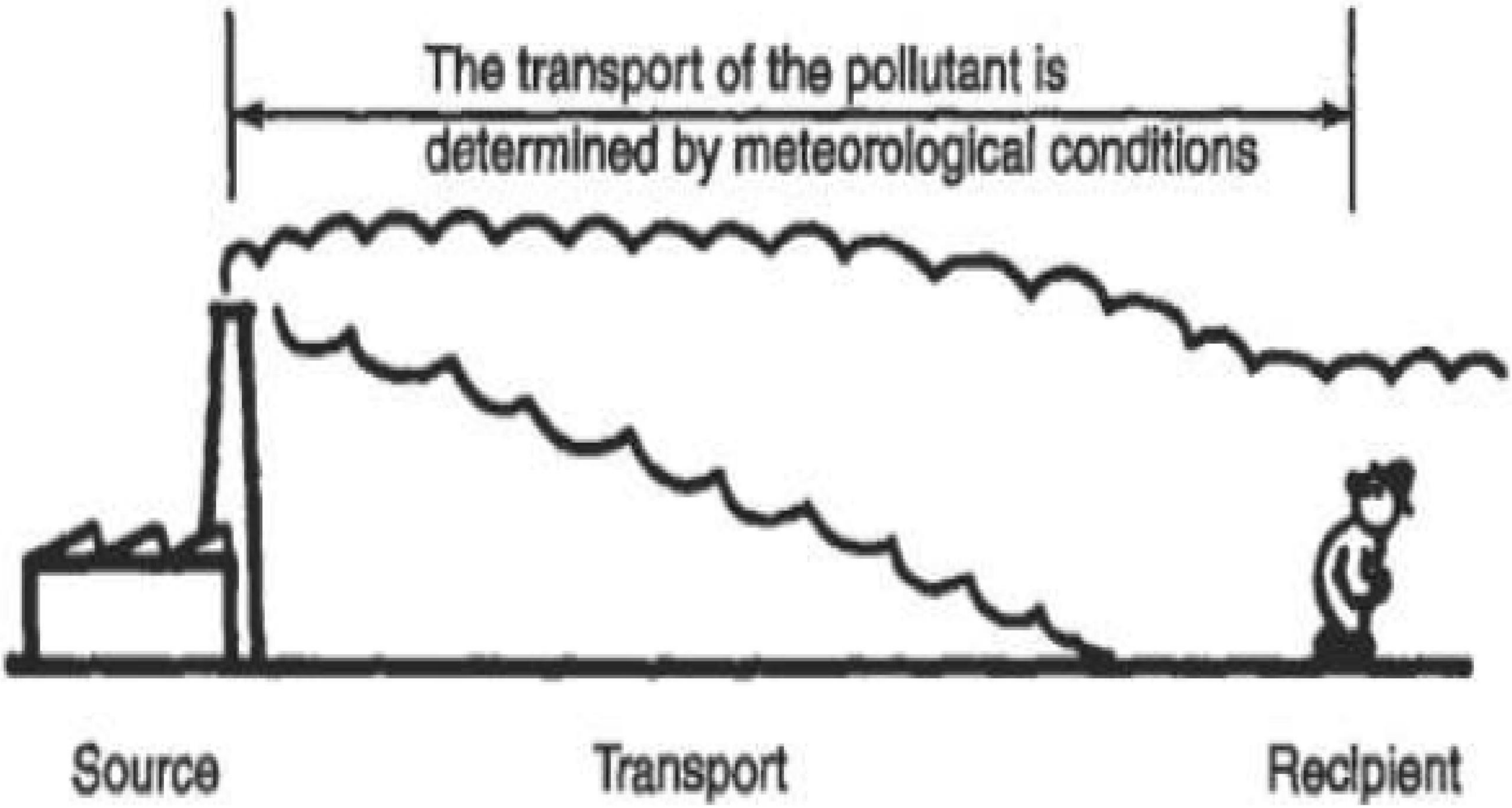
What is Meteorology?

- **Meteorology is the science of the atmosphere.** The atmosphere is the media into which all air pollutants are emitted.
- Atmospheric processes such as the **movement of air (wind) and the exchange of heat** (convection and radiation for example) dictate the fate of pollutants as they go through the stages of transport, dispersion, transformation and removal. **Air pollution meteorology is the study of how these atmospheric processes affect the fate of air pollutants.**

- Knowledge of air pollution meteorology is used to manage and control the release of pollutants into the ambient air.
- Managing the release of air pollutants helps ensure that ambient pollutant concentrations comply with national ambient air quality standards.
- Knowledge of air pollution meteorology is essential in order to understand the fate and transport of air pollutants.

An air pollution problem involves three parts:

- The pollution source
- The movement or dispersion of the pollutant
- The recipient



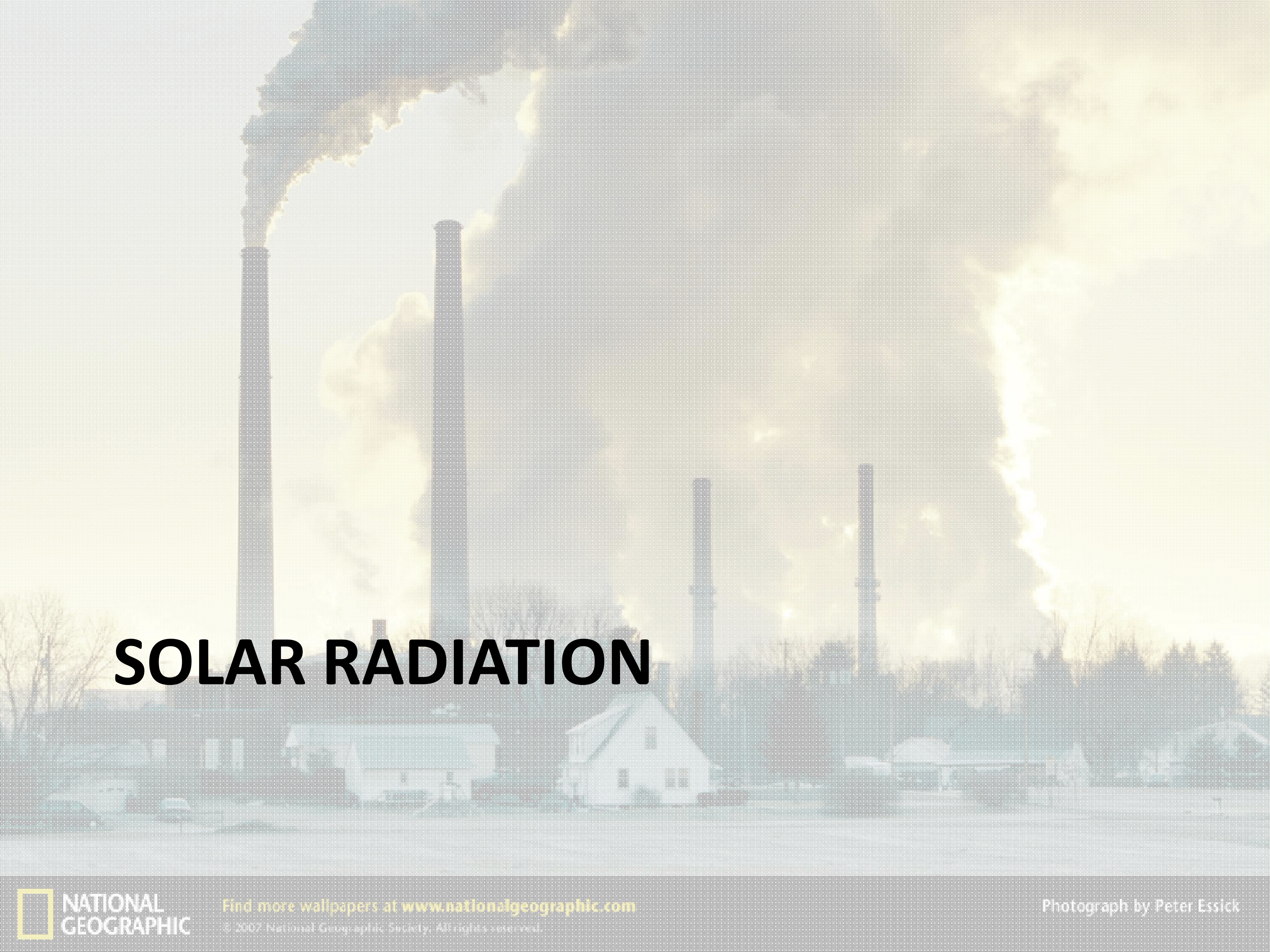
Importance of meteorology

- Understanding air pollution meteorology and its influence in pollutant dispersion is essential in air quality planning activities.
- Engineers use this knowledge to help locate air pollution monitoring stations and to develop implementation plans to bring ambient air quality into compliance with standards.
- Meteorology is used in predicting the ambient impact of a new source of air pollution and to determine the effect on air quality from modifications to existing sources.

- When meteorological conditions develop that are not conducive to pollutant dispersion, governmental air pollution agencies must act fast to ensure that air pollutants don’t build up to unacceptable levels in the air we breathe.
- When pollutant levels become excessively high, an air pollution episode results and emissions into the atmosphere must be curtailed.
- Example is Donora episode

- The towns people were accustomed to receiving some emissions from the local steel mill, zinc smelter, and sulphuric acid plant.
- But, they were not prepared for the dangerously high concentrations of pollutants that built up and became trapped over the town.
- The meteorological conditions in Donora during this five-day period (high pressure system and strong temperature inversion) produced light winds and dense fog.
- The air was not able to move horizontally or vertically and just lingered over the town.

SOLAR RADIATION



Solar Radiation

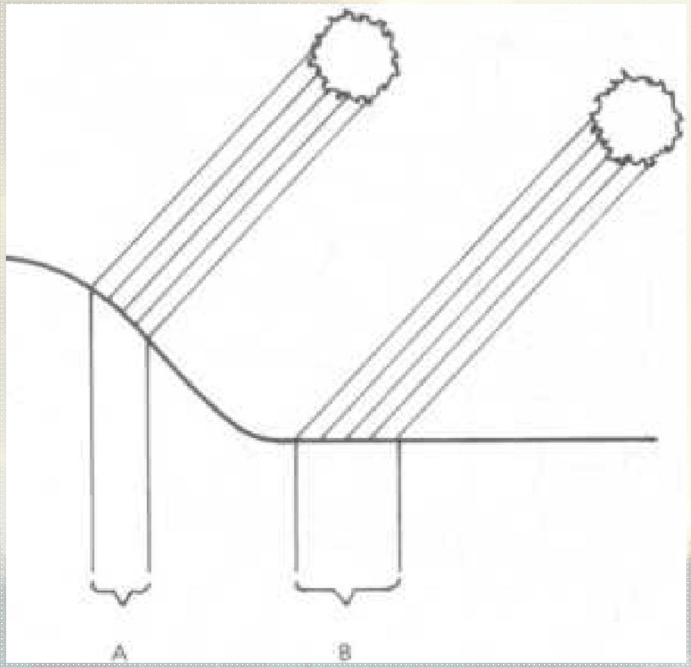
- At upper boundary of atmosphere, vertical solar radiation = 8.16 $J/cm^2 min$ (solar constant)
- Maximum intensity at λ = 0.4 to 0.8 µm = visible portion of electromagnetic spectrum
- ~ 42% of energy
  - Absorbed by higher atmosphere
  - Reflected by clouds
  - Back-scattered by atmosphere
  - Reflected by earth's surface
  - Absorbed by water vapor & clouds
- 47% adsorbed by land and water

Insolation

- Quantity of solar radiation reaching a unit area of the earth's surface
  - Angle of incidence
  - Thickness of the atmosphere
  - Characteristics of surface
- Albedo: fraction of incident radiation that is reflected by a surface

Solar Incidence Angle

- angle between sun's rays and an imaginary line perpendicular to the surface (0º)
- maximum solar gain is achieved when incidence angle is 0º
- Tangent in morning and approximately perpendicular
- angle depends on surface



Information and image source: http://www.visualsunchart.com/VisualSunChart/SolarAccessConcepts/

BASICS OF AIR MOVEMENT

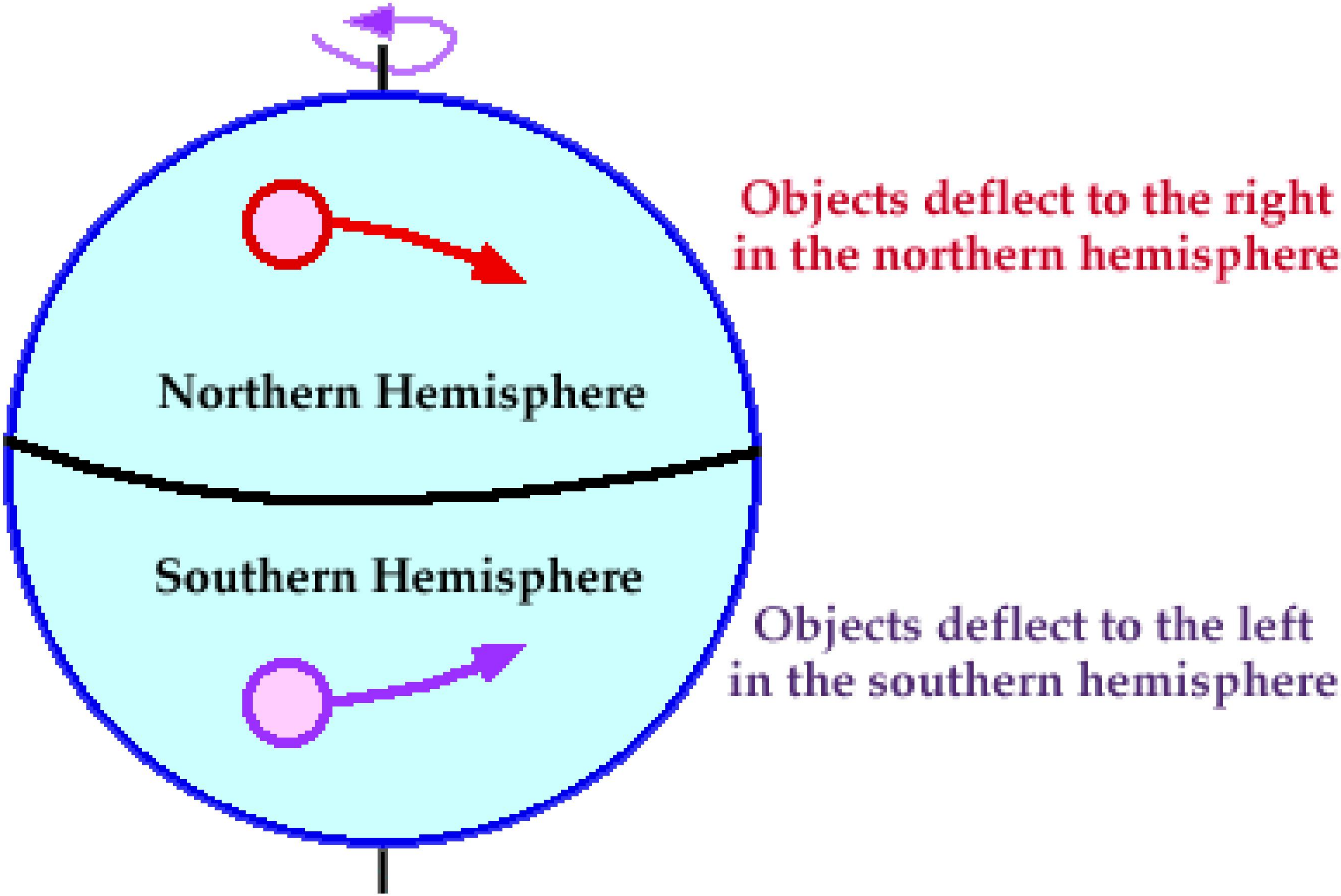
- Air pressure differences cause the movement of air
- Air moving parallel to the ground is called **wind**
- Air moving up or down is called a **current**

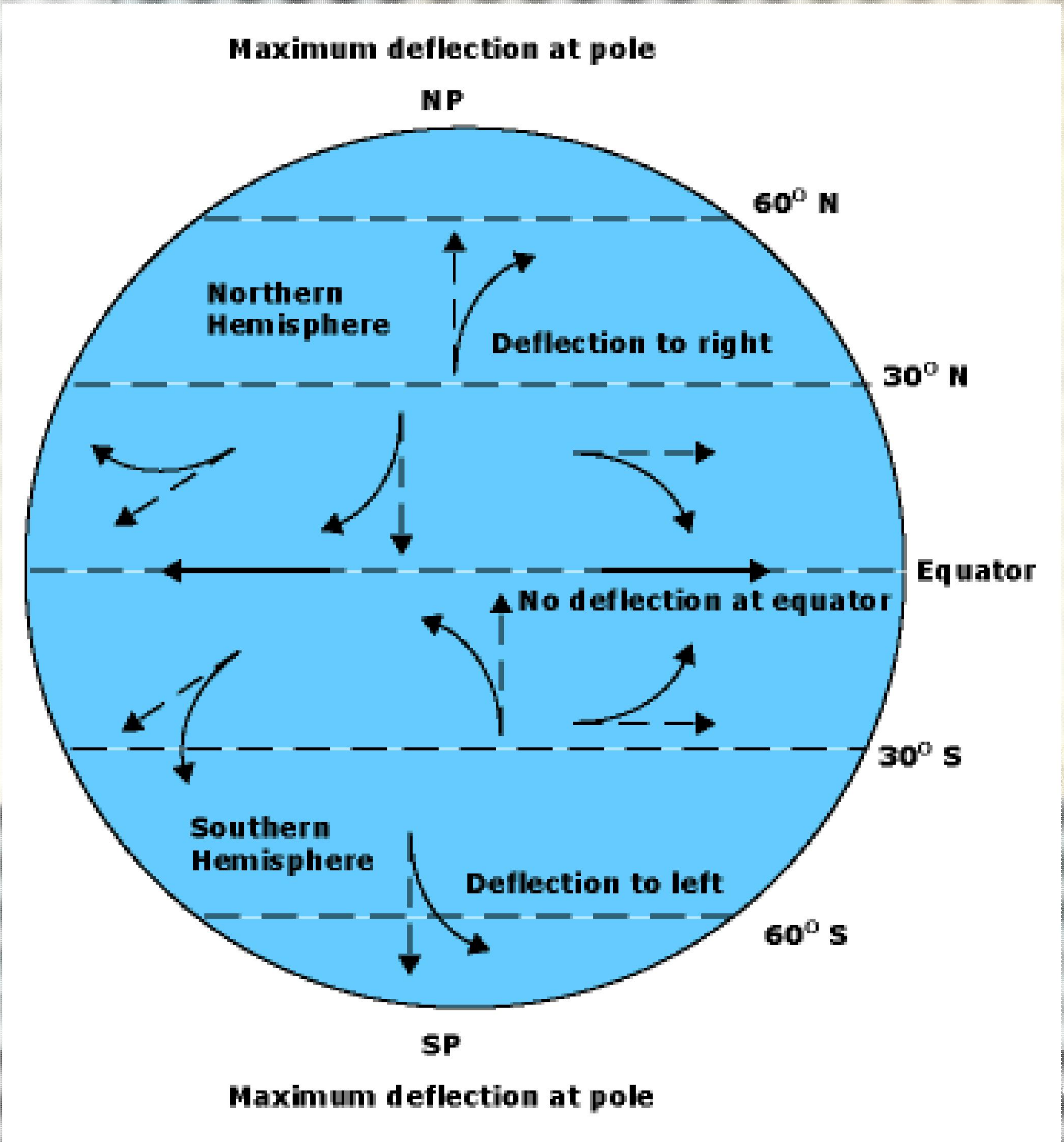
- Air generally moves from the poles to the equator, this is because air flows from high pressure to low pressure
  - High pressure forms when cold air sinks (at the poles)
  - Low pressure forms when warm air rises (at the equator)
- But the air doesn’t flow in a straight line

Coriolis Effect

- Causes air to move in a curved path
- It is caused by the Earth spinning on its axis
- The Earth spins fastest at the equator, and slowest near the poles
- As air moves from the equator to the pole, it will travel east faster than the land beneath it causing the air to follow a curved path

Due to the earth's rotation

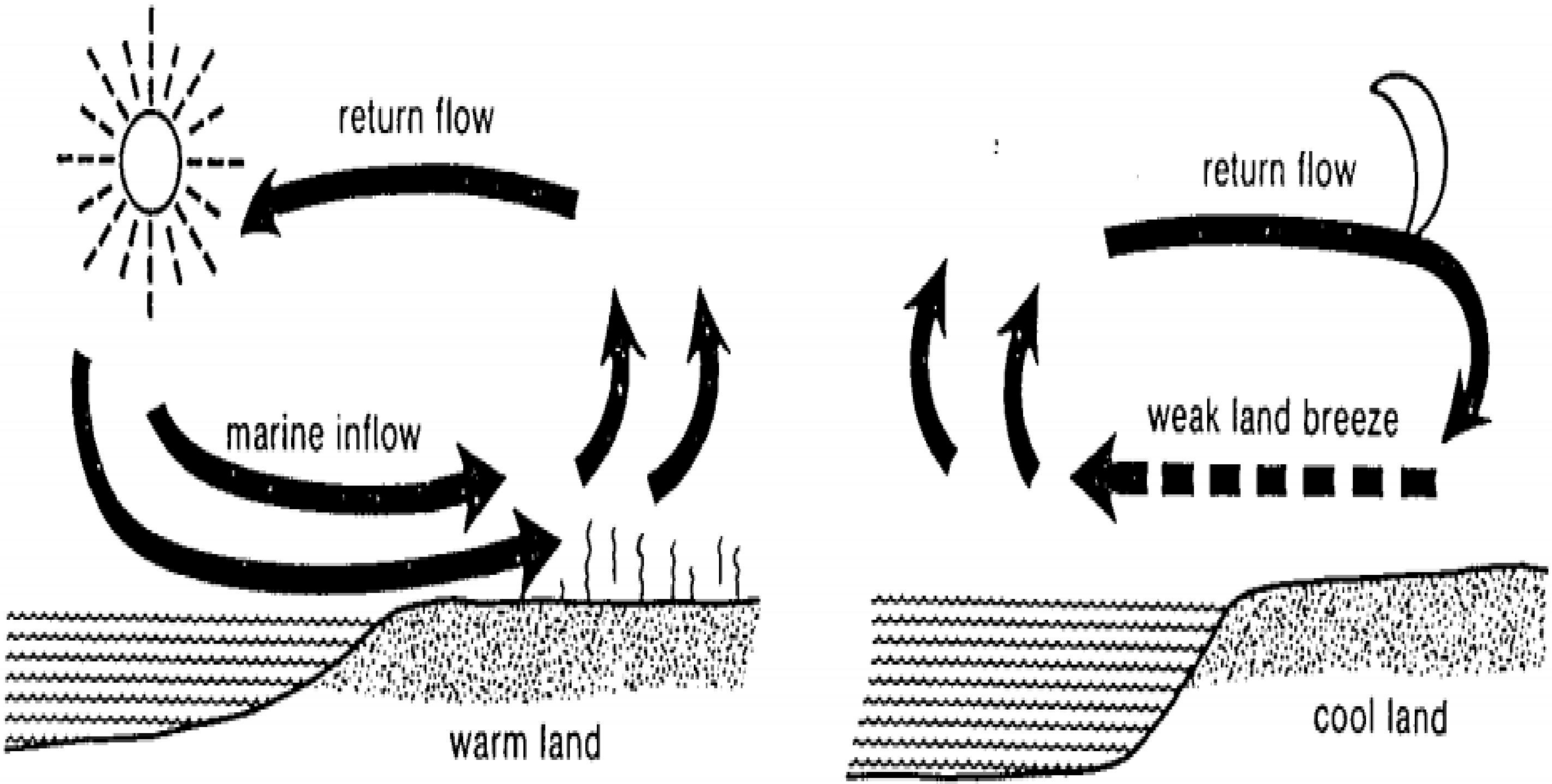



Maximum deflection at pole
NP
60° N
Northern Hemisphere
Deflection to right
30° N
Equator
No deflection at equator
30° S
Southern Hemisphere
Deflection to left
60° S
SP
Maximum deflection at pole

LAND AND SEA BREEZE

- Because land surfaces heat and cool quicker than the sea or other water bodies, temperature gradients develop that can result in the generation of localised wind flows.
- **A sea breeze develops during the day as the air over the land warms more quickly than the air over the sea.**
- **It rises, bringing in an onshore breeze, with a return flow aloft.**

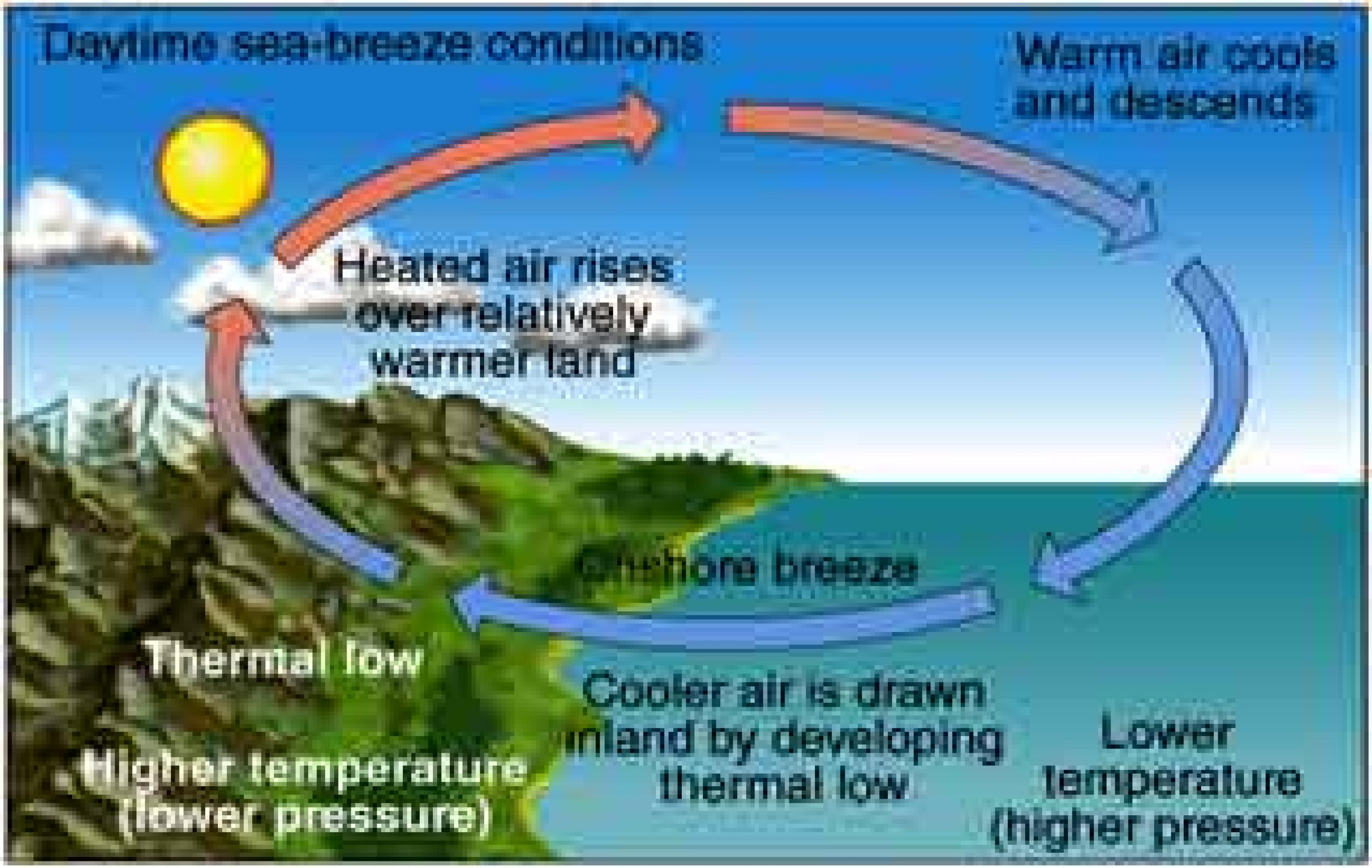
- **At night the opposite occurs and a land breeze develops, flowing towards the sea under an area of subsidence.**
- Sea breezes are generally strongest during the day in summer and land breezes strongest during winter nights.
- **They can both have significant effect s on air quality over urban areas, as they are recirculating air currents that can return pollutant s (instead of remove them) to an area fro m which the y were released earlier in the day .**



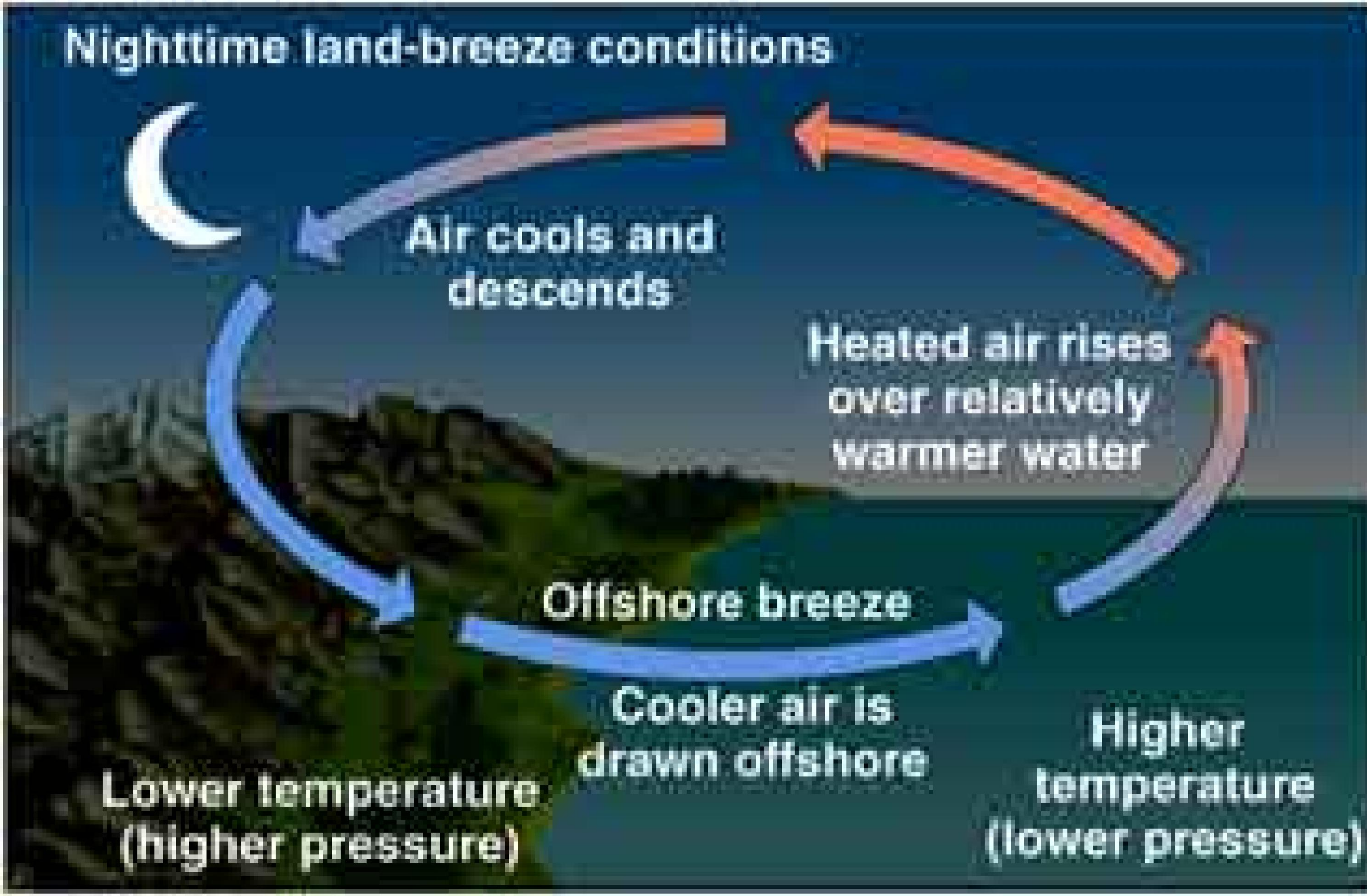
(a) Sea breeze

(b) Land breeze

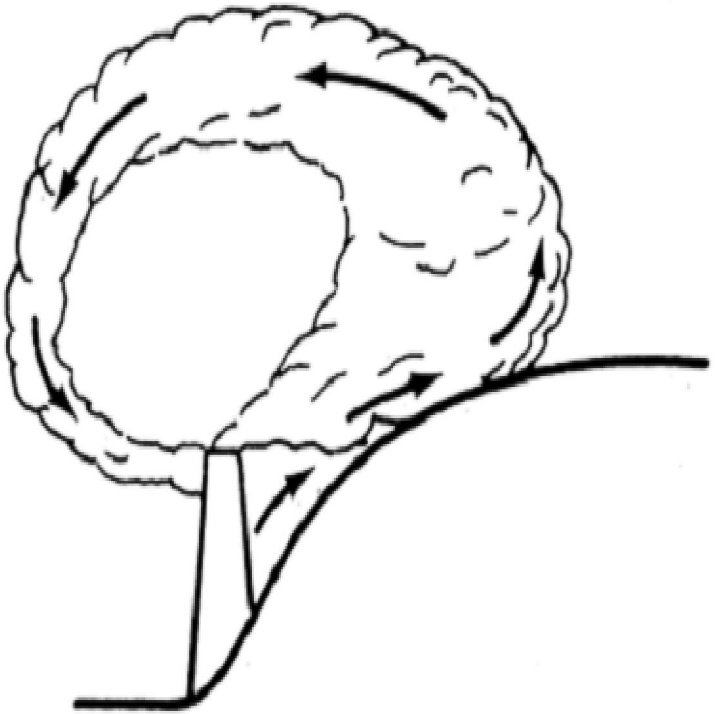
Sea breeze – at day time



Land breeze- at night



Valley breeze



VALLEY BREEZE (daytime)

MOUNTAIN BREEZE (nighttime)

- Mountain and valley winds are generated due to similar heating and cooling mechanisms to sea–land breezes.
- During the day the air above a slope is heated and becomes warmer than neighboring air at the same height above sea level, but further above the ground. It rises due to convection, and up slope mountain winds occur.

- At night the mountain slopes cool more quickly than the surrounding air, and the cool air drains down the slope, generating valley winds.
- This heating and cooling often results in closed circulation patterns, which can trap and/or recirculate air pollution in the mountain –valley system .

Factors Likely to increase the Levels of Air Pollution

Certain conditions help make air pollution worse. Basically these are factors which prevent air circulation, and concentrate air effluent into areas. Examples of these include;

- calm conditions
- low level emission sources
- temperature inversions
- high buildings and narrow streets

Factors responsible for scavenging of Air pollutants

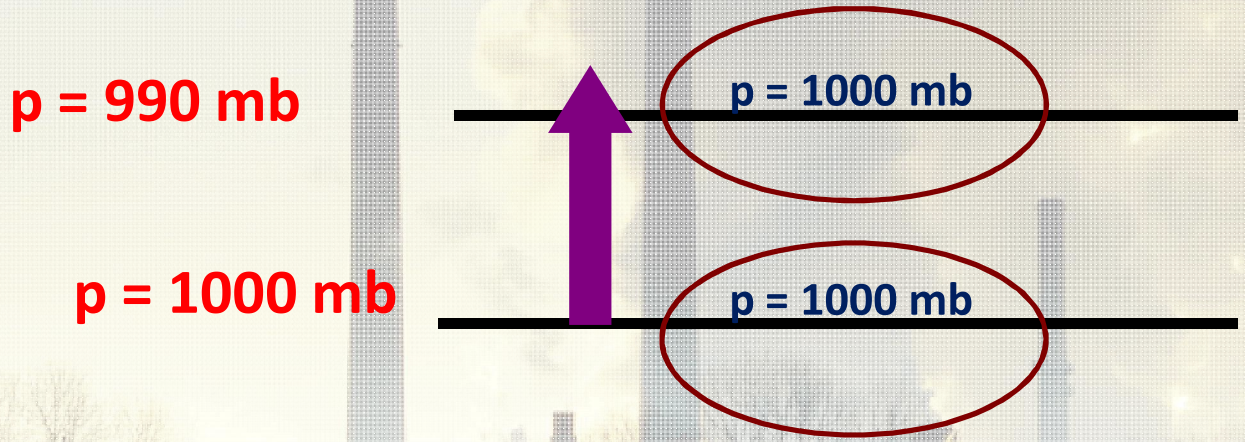
By contrast other conditions are known to lower air pollution levels in general. These are those conditions that encourage circulation or remove pollutants from the atmosphere. Examples include;

- windy or turbulent conditions
- high levels of vegetation
- high level emission sources such as smoke stacks
- rain

What is adiabatic cooling?

Why does air cool when it rises?

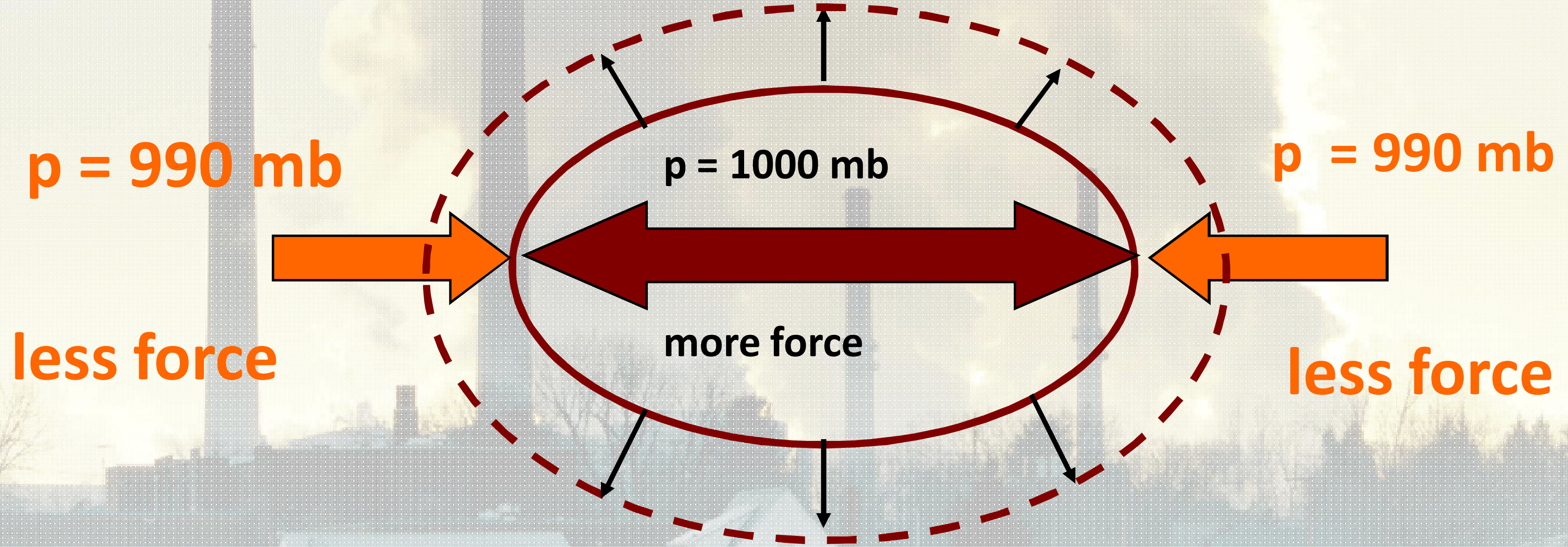
When air rises is encounters lower pressure



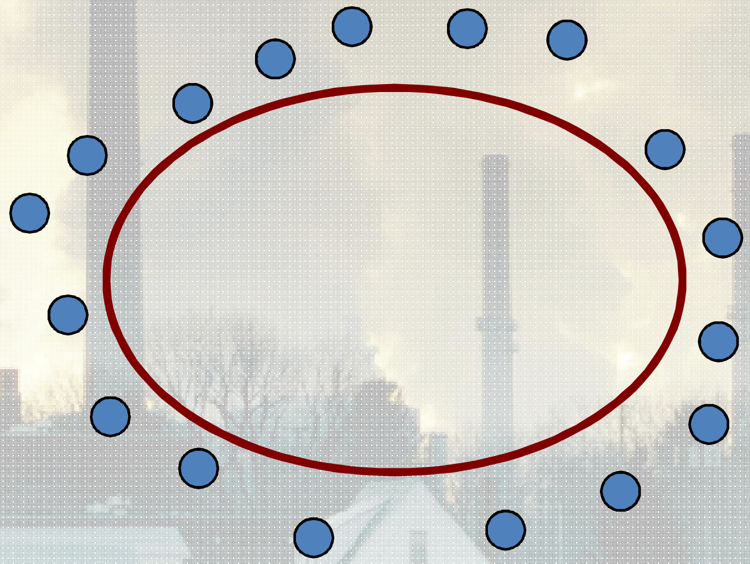
Momentarily, as the air parcel rises it has a higher pressure than the surrounding molecules.

This mean that there is more force exerted by the molecules inside the parcel than is being exerted by the molecules outside the parcel and the parcel expands.

This means there is more force exerted from inside the parcel than there is from the outside and the parcel expands.



In order for the parcel to expand it has to push away (displace) the surrounding molecules. Thus, the molecules inside the parcel must some of their internal energy in order to do this work.



Since the temperature is a function of the internal energy, when the internal energy decreases, then the **temperature decreases**.

Thus, the **rising parcel expands and cools.**

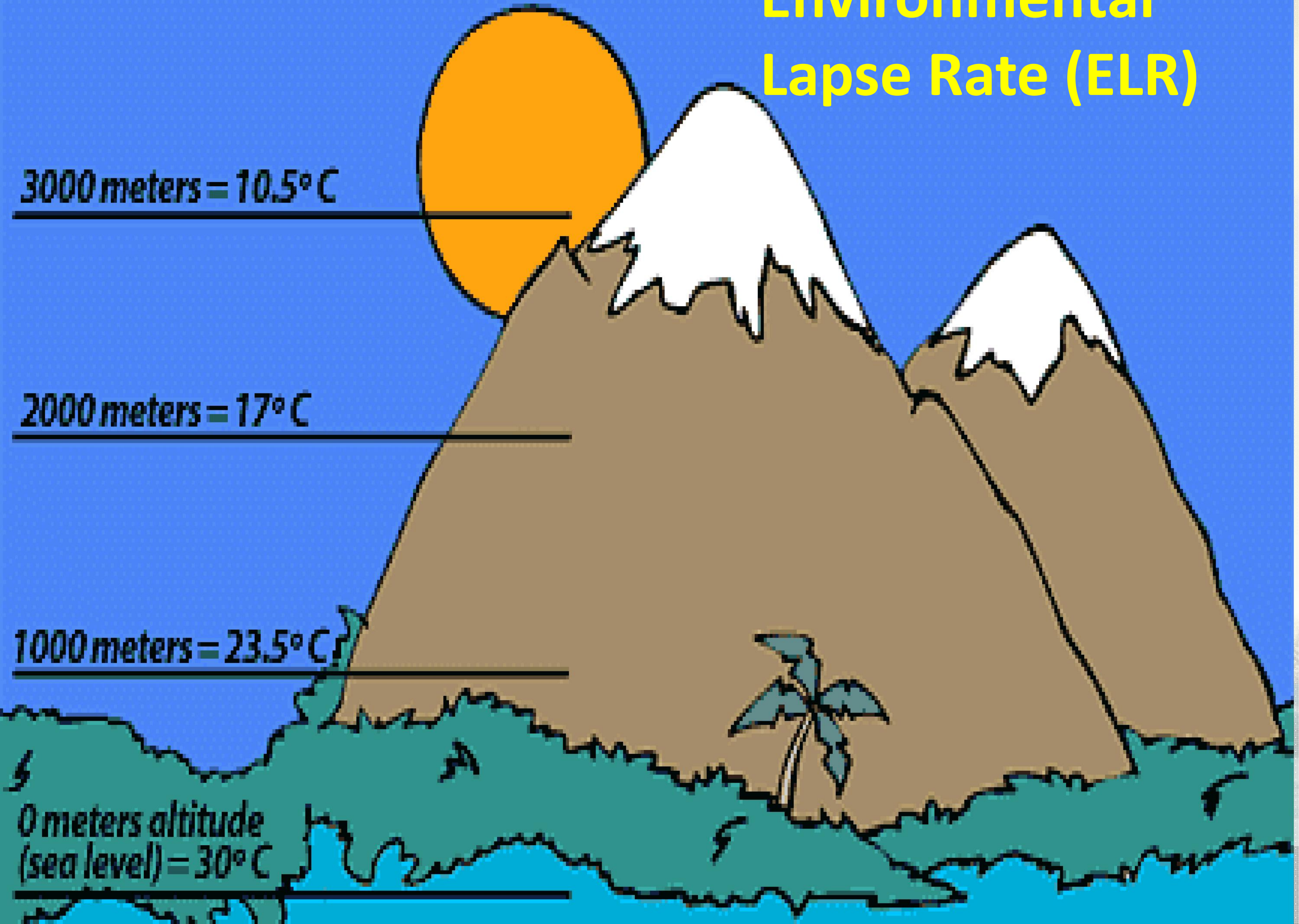
This process is called **adiabatic cooling.**

Lapse Rate

- Important characteristic of atmosphere is ability to resist vertical motion: stability
- Affects ability to disperse pollutants
- When small volume of air is displaced upward
  - **Encounters lower pressure**
  - **Expands to lower temperature**
  - **Assume no heat transfers to surrounding atmosphere**
  - **Called adiabatic expansion**

- The actual temperature profile of the ambient air shows the **environmental lapse rate.** Sometimes called **the prevailing** or **atmospheric lapse rate,** it is the result of complex interactions of meteorological factors, and is usually considered to be a decrease in temperature with height.

Environmental Lapse Rate (ELR)



Adiabatic Expansion

To determine the change in temperature with respect to elevation due to adiabatic expansion

- Atmosphere considered a stationary column of air in a gravitational field
- Gas is a dry ideal gas
- Ignoring friction and inertial effects

  (dT/dz)adiabatic perfect gas = - (g M/ C_p)

  - T = temperature
  - z = vertical distance
  - g = acceleration due to gravity
  - M = molecular weight of air
  - Cp = heat capacity of the gas at constant pressure

Adiabatic Expansion

(dT/dz) adiabatic perfect gas = - 0.0098°C/m = -0.98^{0} C/100 m (Can be approximated as -1^{0}C/100 m)

or

(dT/dz) adiabatic perfect gas = -5.4°F/ft

Change in Temp. with change in height

- Important is ability to resist vertical motion: stability
- Comparison of Γ to actual environment lapse rate indicates stability of atmosphere
- Degree of stability is a measure of the ability of the atmosphere to disperse pollutants

Lapse rate

- Lapse rate is the negative of temperature gradient
- Dry adiabatic lapse rate =

Metric:

Γ = - 1°C/100m or

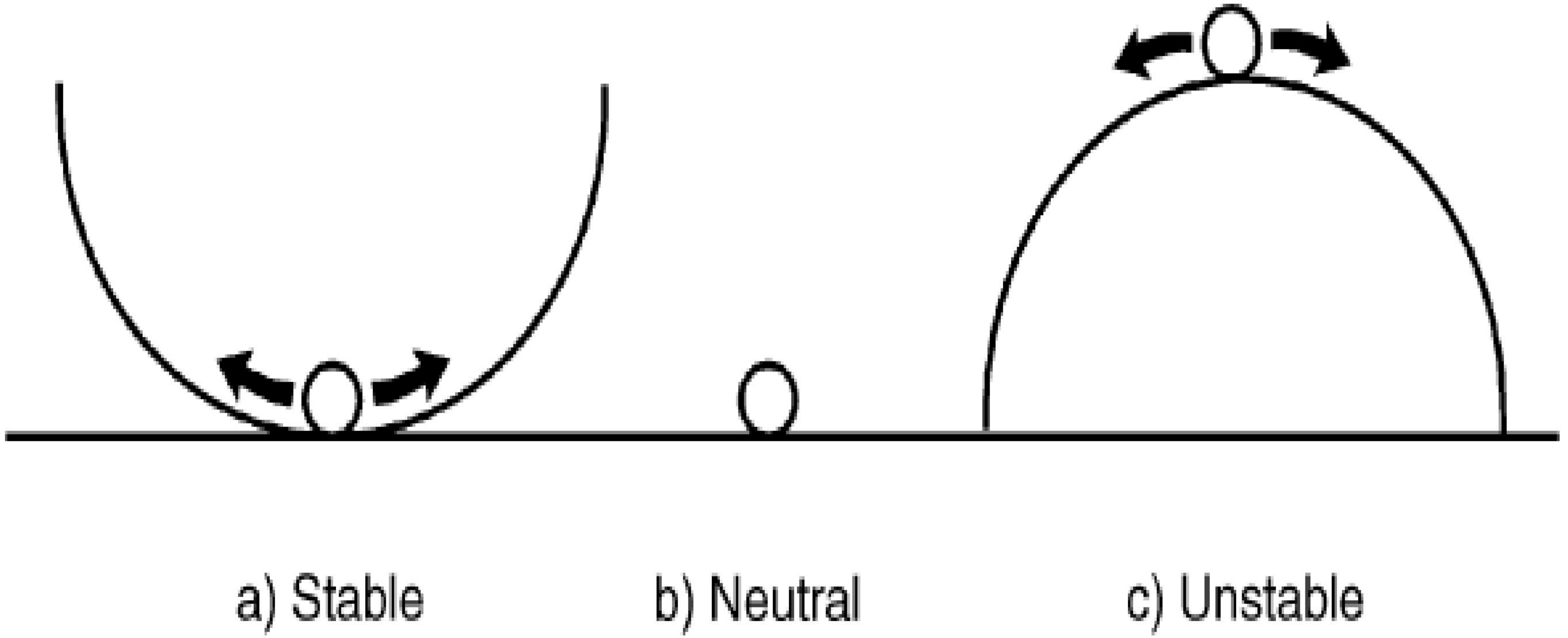
SI:

Γ = - 5.4°F/1000ft

Atmospheric Stability

- Affects dispersion of pollutants
- Temperature/elevation relationship principal determinant of atmospheric stability
- Stable
  - **Little vertical mixing**
  - **Pollutants emitted near surface tend to stay there**
  - **Environmental lapse rate is same as the dry adiabatic lapse rate**
- 4 common scenarios (Cases/Types)

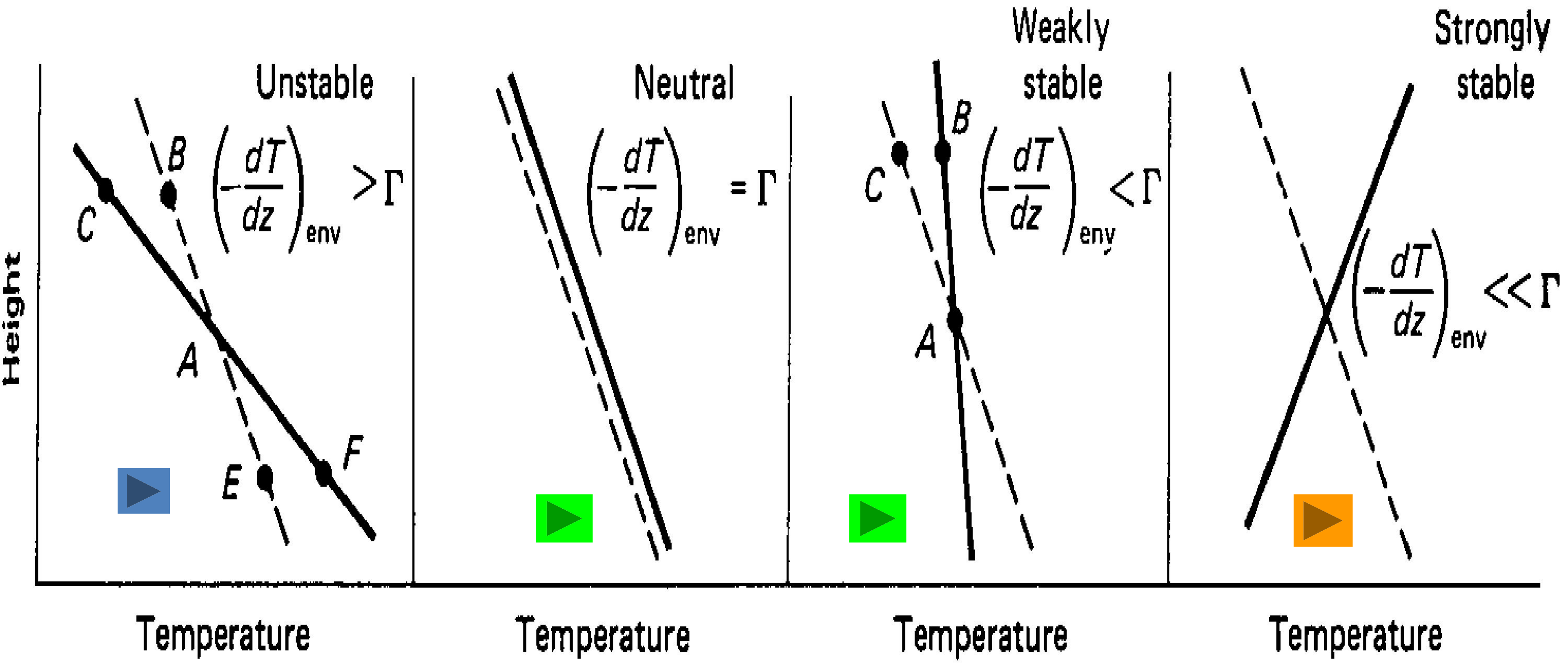
Atmospheric Stability



Stability Conditions

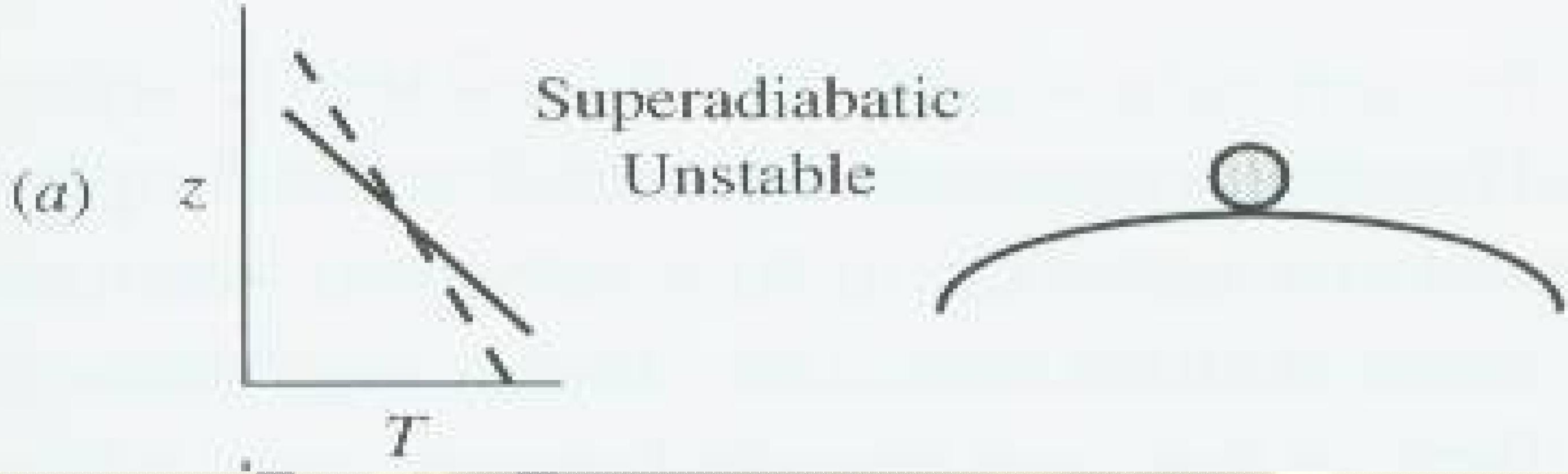
------ **Adiabatic lapse rate**

—— **Environmental lapse rate**



1. Super adiabatic Lapse Rates (Unstable)

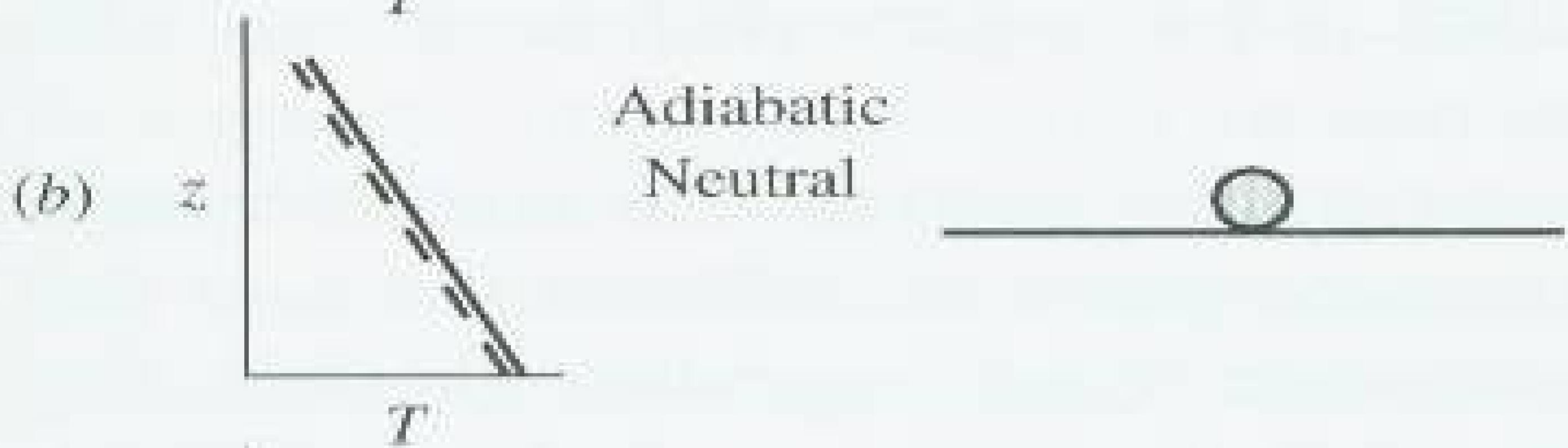
- Temperature decreases are greater than -10^{o} C/km
- Occur on sunny days
- Characterized by intense vertical mixing
- Excellent dispersion conditions



- **Superadiabatic --- Unstable**
  - **Environmental lapse rate > Γ**
  - **i.e. Actual temp. gradient (dT/dZ) is more negative**
  - **Small parcel of air displaced approximates adiabatic expansion**
  - **Heat transfer is slow compared to vertical movement**
  - **At a given point, $T_{parcel} > T_{surrounding\ air}$**
    - **less dense than surrounding air**
  - **Parcel continuously moves upward.**

2. Neutral Lapse Rates

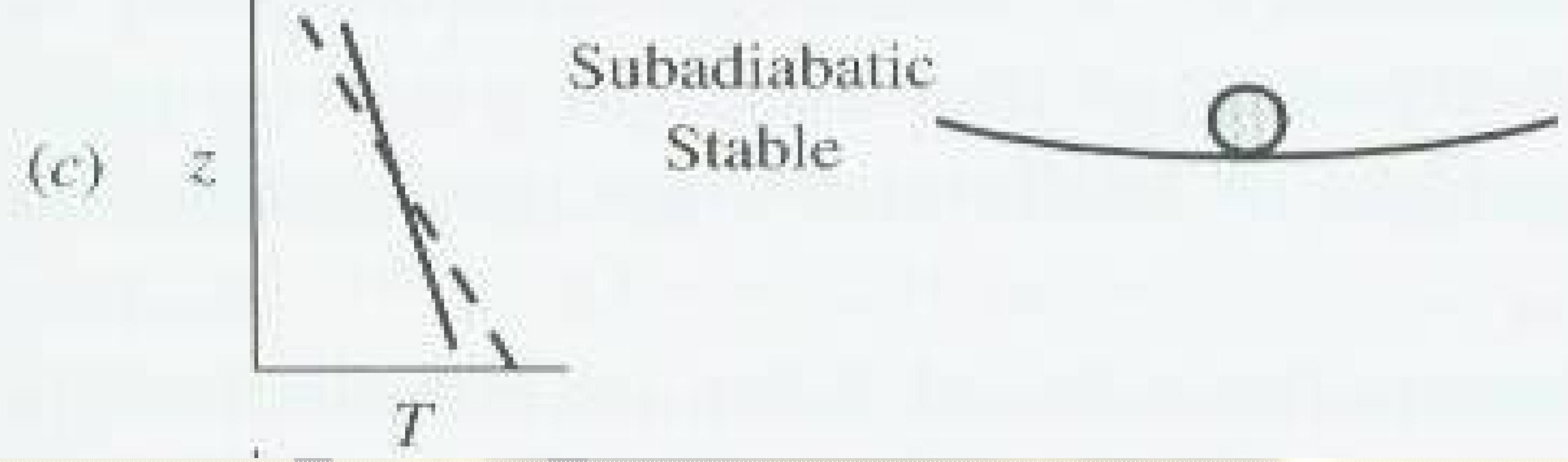
- Rate of change of Temperature is similar (nearly equal) to the adiabatic lapse rate
- Results from:
  - **Cloudy conditions**
  - **Elevated wind speeds**
  - **Day/night transitions**
- Describes good dispersion conditions



- **Neutral**
  - Environmental lapse rate is same as the dry adiabatic lapse rate
  - A parcel of air carried up or down will have same temp as environment at the new height
  - No tendency for further movement

3. Isothermal Lapse Rates (Weakly Stable)

- Characterized by no temperature change with height. (dT/dZ= constant)
- Atmosphere is somewhat stable
- Dispersion conditions are moderate

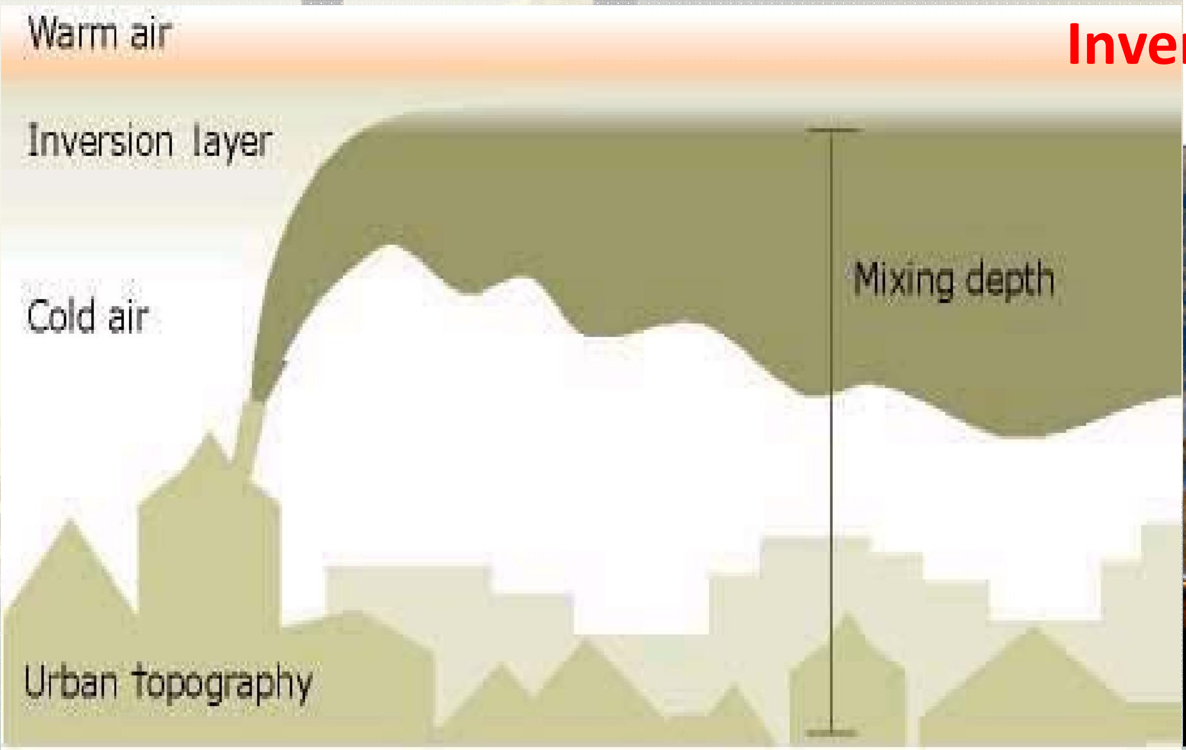


4. Sub adiabatic --- Weakly Stable

- Environmental lapse rate < Γ
- greater temp. gradient
- No tendency for further vertical movement due to temp. differences
- Any parcel of air will return to its original position
- Parcel is colder than air above – moves back

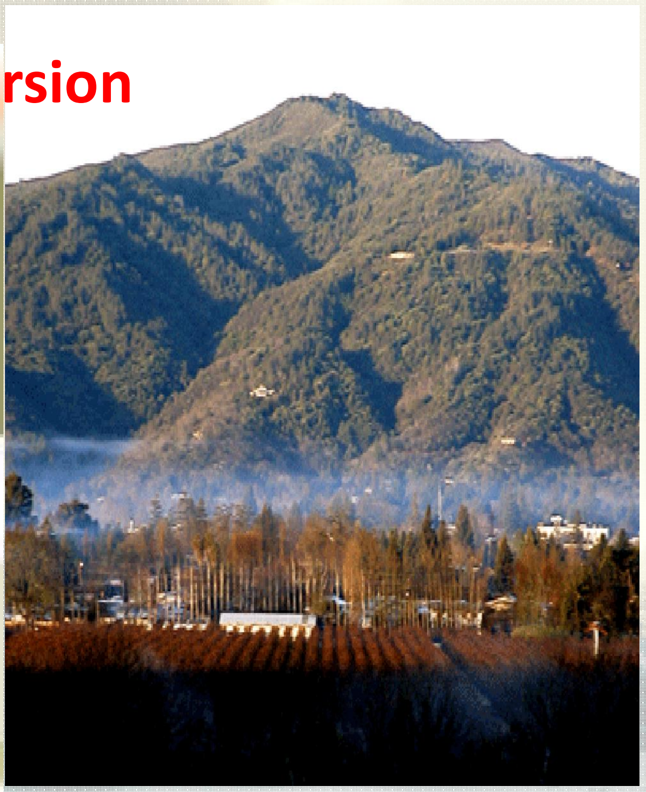
5. Inverted Lapse Rates (Inversion -Strongly Stable)

- Characterized by increasing temperature with height.



Winter inversion layer trapping smoke from home fires

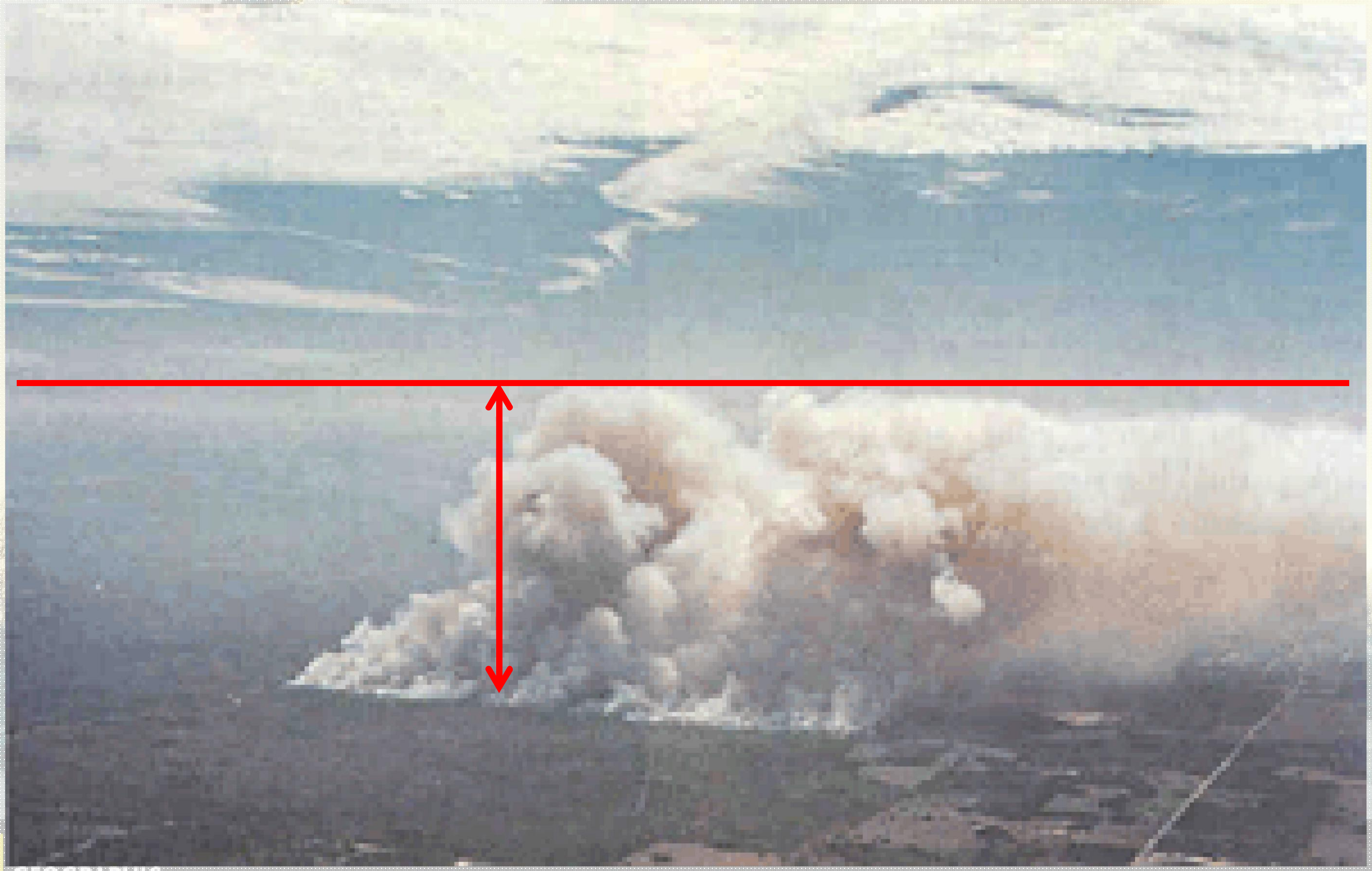
Inversion



- Inversion --- Strongly Stable
  - Environmental lapse rate is negative
  - Temp. increases with height
  - No tendency for further vertical movement due to temp. differences
  - Any parcel of air will return to its original position
  - Parcel is colder than air above – moves back
  - Concentrates pollutants

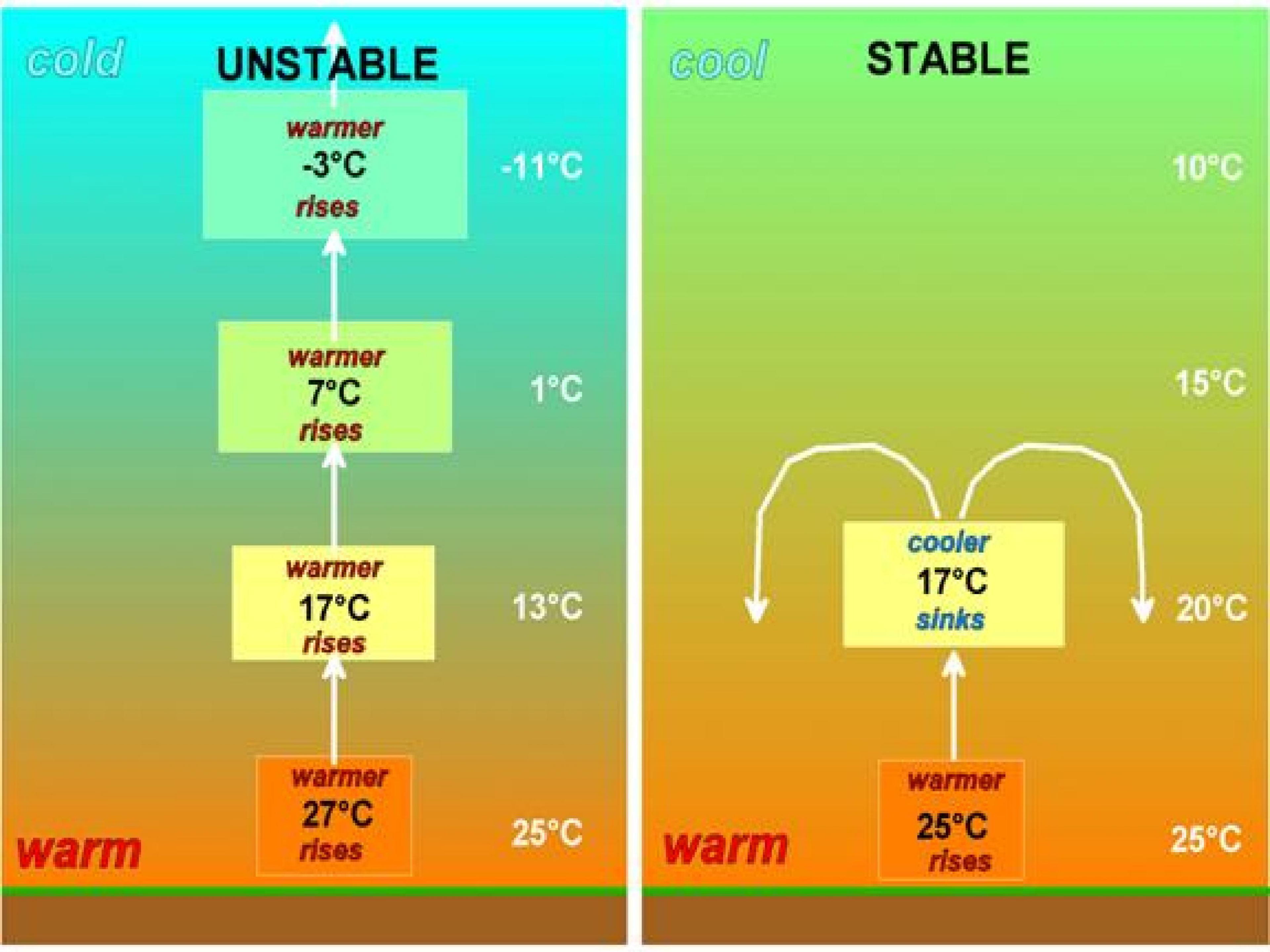
Stable Atmosphere

Stable Atmosphere



Unstable Atmosphere

Unstable Atmosphere


cold
UNSTABLE
warmer
-3°C
rises
-11°C
warmer
7°C
rises
1°C
warmer
17°C
rises
13°C
warmer
27°C
rises
25°C
warm
cool
STABLE
10°C
15°C
cooler
17°C
sinks
20°C
warmer
25°C
rises
25°C
warm

VERTICAL DISPERSION OF POLLUTANTS

As a parcel of air in the earth's atmosphere rises through the atmosphere, it experiences decreasing pressure and thus expands.

This expansion lowers the temperature of the air parcel, and therefore the air cools as it rises.

The rate at which dry air cools as it rises is called the dry adiabatic lapse rate and is independent of the ambient air temperature.

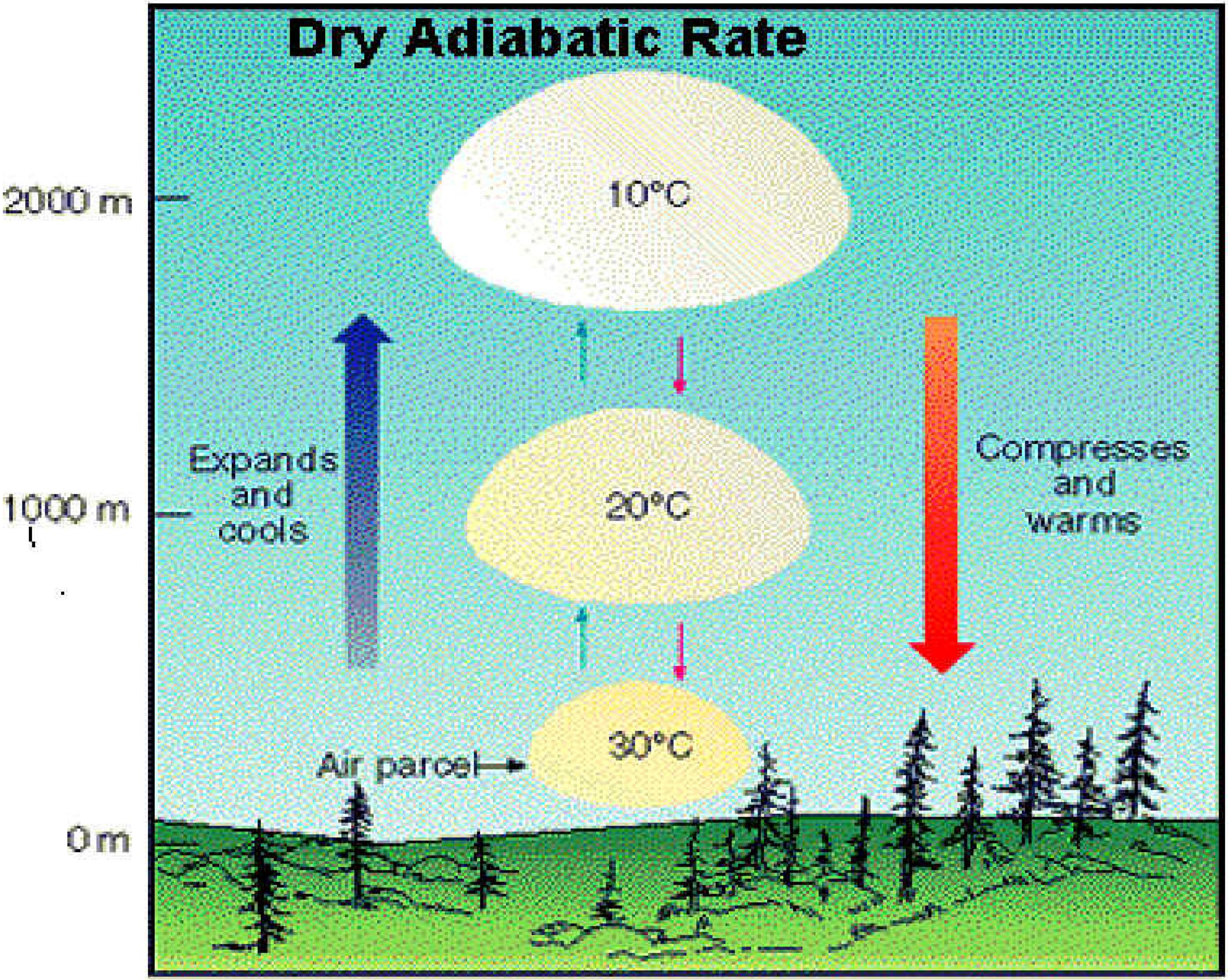
The term "adiabatic" means that there is no heat exchange between the rising parcel of air under consideration and the surrounding air.

The dry adiabatic lapse rate may be calculated from basic physical principles.

$$dT/dz|_{\text{dry-adiabatic}} = -9.8°\text{C/km},$$

where T = temperature and z = altitude.

The actual measured rate at which air cools as it rises is called the ambient or prevailing lapse rate. **i.e. ELR(Environmental Lapse Rate)**


Dry Adiabatic Rate
2000 m
1000 m
0 m
10°C
20°C
30°C
Expands
and
cools
Compresses
and
warms
Air parcel

- **The dry adiabatic lapse rate is a fixed rate, entirely independent of ambient air temperature.**
- A parcel of dry air moving upward in the atmosphere, then, will always cool at the rate of 9.8°C/1000 m, regardless of its initial temperature or the temperature of the surrounding air.

- **Problem:**
- Determine whether the atmosphere is unstable, neutral or stable for the following case.
- Initial Temperature = 125 ^{o}C
- Final Temperature = - 65 ^{o}C
- Initial Height = 200 m
- Final Height = 21000 m

- **Solution:**
- Since no wind direction information is given, the stability is determined from the environmental temperature gradient dT/dz.
- $dT/dZ = (125-(-65))/(200 - 21000)$

  $= 190/(-20800)$

  $= -0.914^{0}C/100$

→the **atmosphere is slightly stable - near neutral condition** .

Example 2.

Z(m)	T(ºC)
2	-3.05
318	-6.21

$$\frac{\Delta T}{\Delta z} = \frac{T_2 - T_1}{z_2 - z_1} = \frac{-6.21 - (-3.05)}{318 - 2} = -0.0100 \text{ °C/m}$$

$$= -1.00 \text{ °C/100 m}$$

Since lapse rate = Γ, atmosphere is <u>neutral</u>

Example 3.

Z(m)	T(ºC)
10	5.11
202	1.09

$$\frac{\Delta T}{\Delta z} = \frac{T_2 - T_1}{z_2 - z_1} = \frac{1.09 - 5.11}{202 - 10} = -0.0209\ {}^\circ\text{C/m}$$

$$= -2.09\ {}^\circ\text{C/100 m}$$

Since lapse rate is more negative than Γ, (-1.00 ºC/100 m), atmosphere is unstable

Example 4.

[More Problems]

Z(m)	T(ºC)
18	14.03
286	12.56

$$\frac{\Delta T}{\Delta z} = \frac{T_2 - T_1}{z_2 - z_1} = \frac{12.56 - 14.03}{286 - 18} = -0.0055\ ^{\circ}\text{C/m}$$

$$= -0.55\ ^{\circ}\text{C/100 m}$$

Since lapse rate more positive than Γ, atmosphere is stable

Objective Questions

Q1. Meteorology is science of ____________________.

Q2. Knowledge of air pollution meteorology is essential in order to understand the __________________________________of air pollutants.

Q3. If ELR is greater than DALR atmospheric condition is ________________.

Q4. If ELR is equal to DALR atmospheric condition is ________________.

Q5. If ELR is less than DALR atmospheric condition is ________________.

Q6. If ELR is very very less than DALR atmospheric condition is ________________.

Q7. ____________________ stability condition is most favorable for dispersion of pollutants.

Q8. The environmental, or prevailing, lapse rate can be determined from the ___________________________.

Q9. The dry adiabatic lapse rate is _______________.

Q12. The actual temperature profile of the ambient air can be used to determine the_______________________ lapse rate.

Theory Questions

Q1. Define meteorology and discuss importance of the same.

Q2. Explain stability conditions?

Q3. What is adiabatic cooling?

Q4. Define the following

1. ELR
2. Atmospheric Stability condition
3. Lapse rate

Q5. Write a note on

1.DALR 2. Pasquill's Stability classes