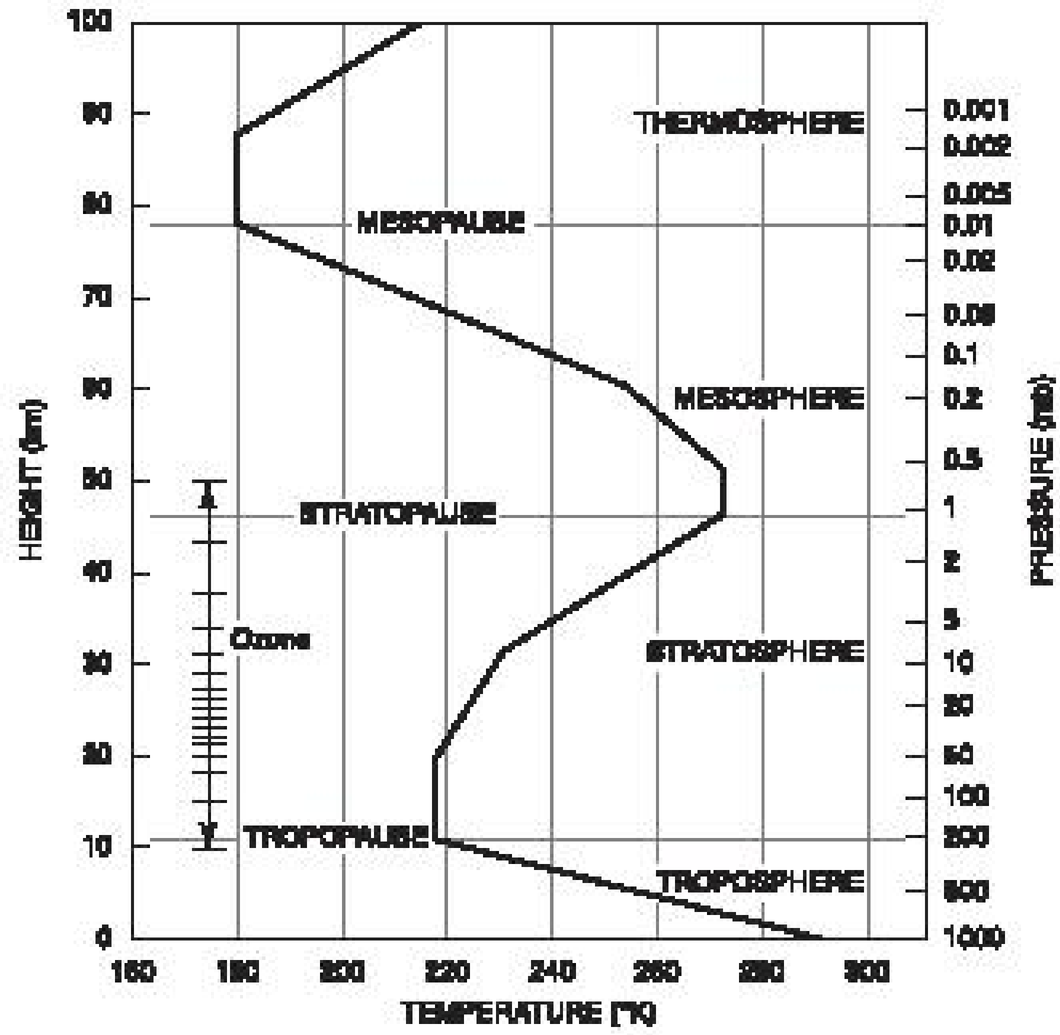
LECTURE 9:
AIR POLLUTION & METEOROLOGY

CE 433

Excerpts from Lecture notes of Professor M. Ashraf Ali, BUET.

The Layers of the Atmosphere



The Layers of the Atmosphere

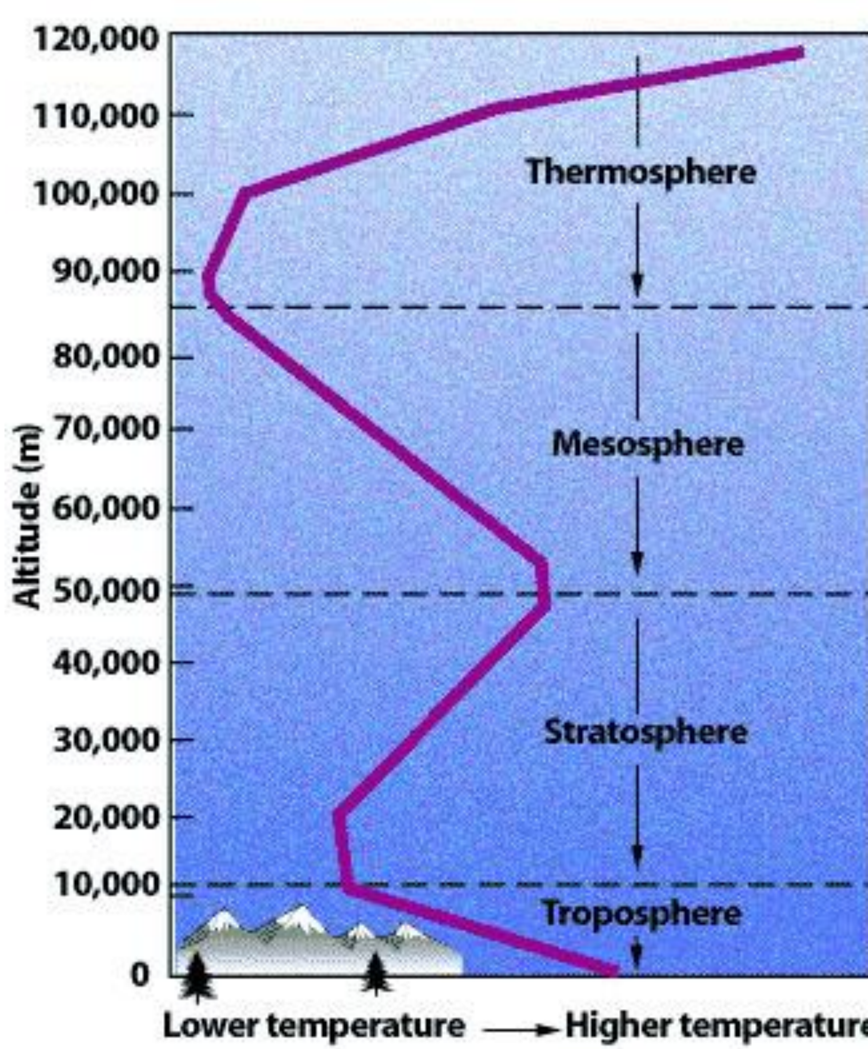
- The atmosphere is generally divided into
  - Lower atmosphere, and
  - Upper atmosphere
- The lower atmosphere is generally considered to extend up to the top of the “stratosphere”, an altitude of about 50 km
- Study of lower atmosphere is generally considered to extend up to the top of the “Stratosphere”, an altitude of about 50 km.
- Study of lower atmosphere is known as “Meteorology”. Study of the upper atmosphere is called “Aeronomy”.
- The earth’s atmosphere is characterized by variations of temperature and pressure with height. In fact, the variation of the average temperature profile with altitude is the basis for distinguishing the layers of the atmosphere.

Air Pollution and Meteorology

- Air Quality often depends on the dynamics of the atmosphere, the study of which is called “meteorology”.
- <u>Lapse Rates:</u>

The ease with which pollutants can disperse in the atmosphere is largely determined by the rate of change of air temperature with altitude.

In the troposphere, the temp of ambient air usually decreases with an increase in altitude. This rate of temp change is called “lapse rate” (or ambient lapse rate, Λ)



Air Pollution and Meteorology

- A specific parcel of air whose temp. is greater than that of the ambient air tends to rise until it reaches a level at which its own temperature and density equals to that of the atmosphere that surround it.
- Thus a parcel of artificially heated air (e.g. automobile exhaust) rises, expands, becomes lighter and cools. The rate at which the temp of the parcel decreases (i.e. lapse rate) may be considerably different from the ambient lapse rate (Λ) of the air. The lapse rate for the rising parcel of air may be determined theoretically. For this calculation, the cooling process within rising parcel of air is assumed to be "adiabatic" (ie. Occurring without the addition or loss of heat). This is called "adiabatic lapse rate" (Γ).

Determination of Adiabatic lapse rate

- "Γ" serves as a reference temp profile against which we compare actual profiles.

- For determination of Γ, we need:
  - i) Ideal gas law
  - Ii) Hydrostatic Equation
  - Iii) 1st law of thermodynamics

Considering air as an ideal gas, we can write

$$P = \frac{rRT}{M_a} \quad \text{...(1)}$$

ρ = mass density of air (kg/m^3)
R = universal gas constant = 8.134 J/° K/mole
M_a = Mol weight of air = 28.97 g/mol

Determination of Adiabatic lapse rate

- The pressure at any height is due to the weight of air above. Change in pressure with height is given by “hydrostatic equation” as follows:

- $$\frac{dP}{dz} = -rg \quad \frac{dP}{dz} = -\frac{gM_aP}{RT} \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

- Combining (1) and (2) ,

- $$\frac{dP}{dz} = -\frac{gM_aP}{RT} \quad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Determination of Adiabatic lapse rate

- Now from first law of thermodynamics:

$$du = dQ - dW \text{ ……………………(4)}$$

Where, du = change in internal energy = $C_v.dT$

C_v = heat capacity of system at constant volume

dQ = heat input to the system across its boundaries

= 0 for adiabatic condition

dW = energy lost by the system to the surroundings as a result of work done ot alter the volume of system = P.dV

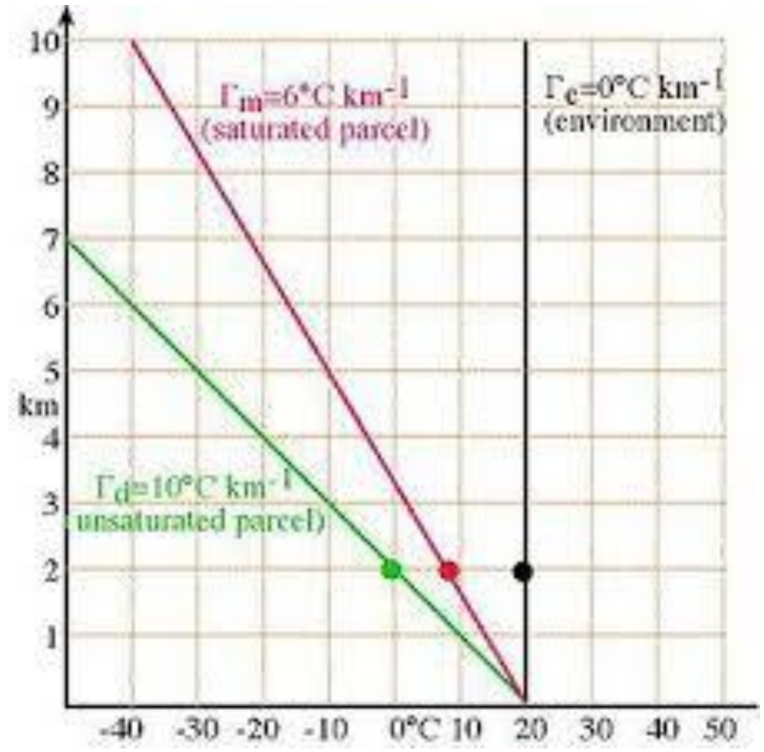
Adiabatic lapse rate

- Γ = 0.976 ° c /100 m
  = 9.76 ° c /km
  = 5.4 ° F /1000 ft

→ Dry adiabatic lapse rate.
(often taken as 1 ° c /100 m)

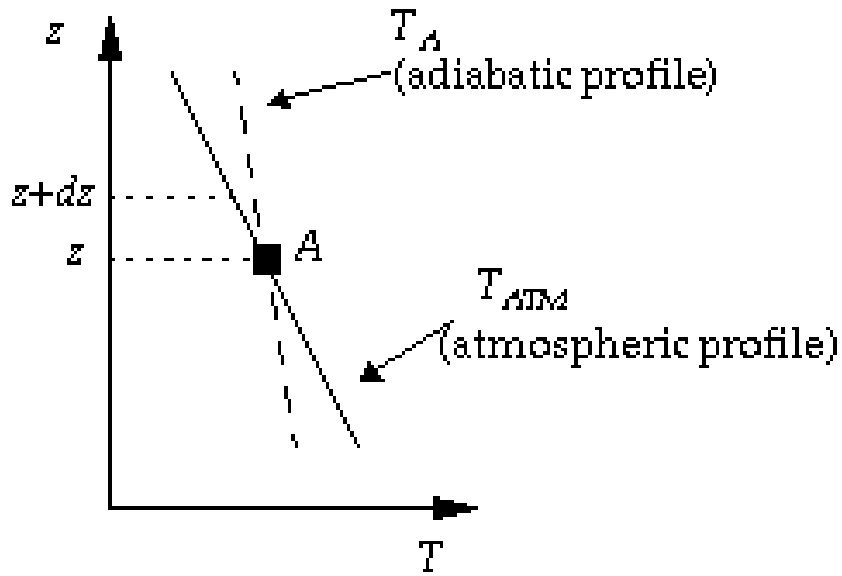
- In moist atmosphere, because of the release of latent heat of vaporization, a saturated parcel cools on rising at a slower rate than a dry parcel.

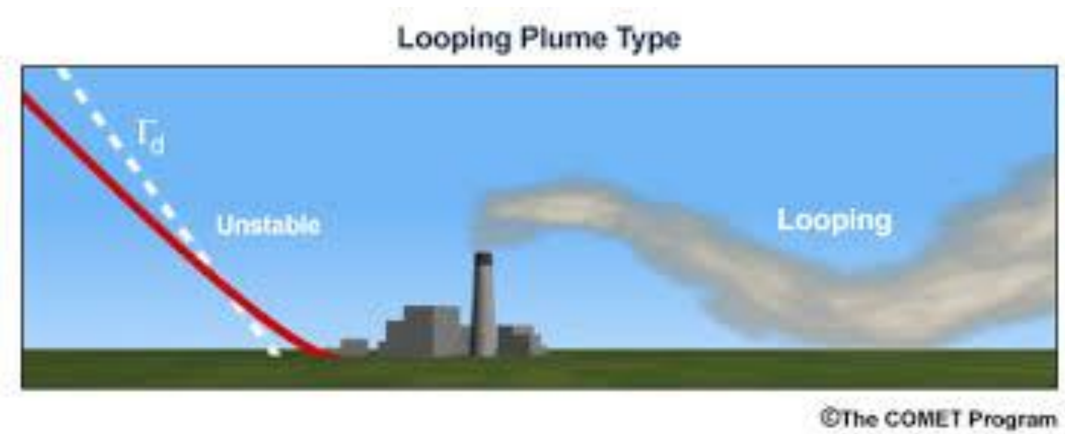
- So, $\Gamma_{dry} > \Gamma_{wet}$



Atmospheric stability

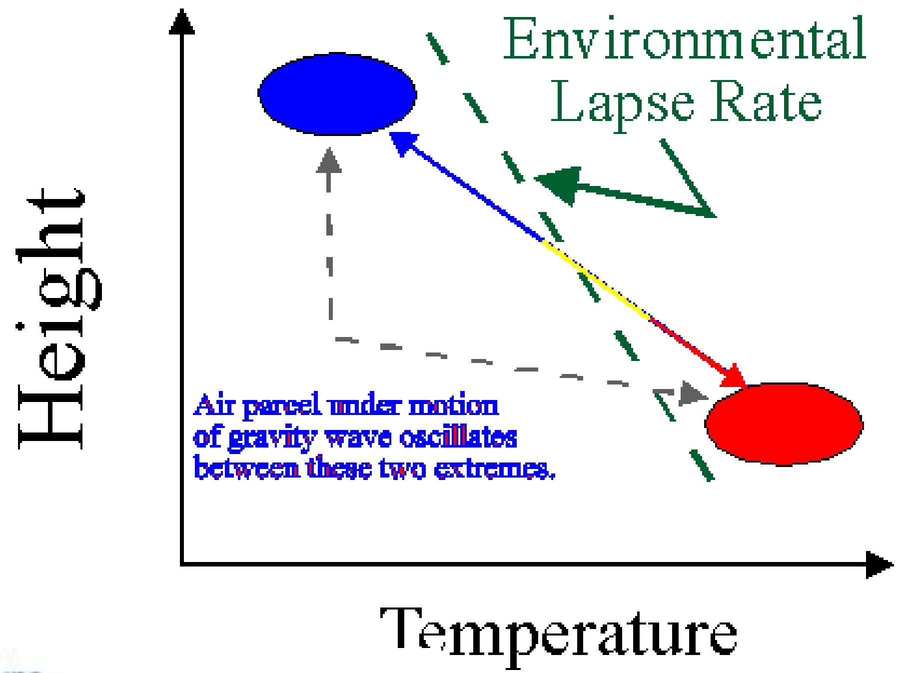
- Unstable atmosphere
- $\Lambda > \Gamma$

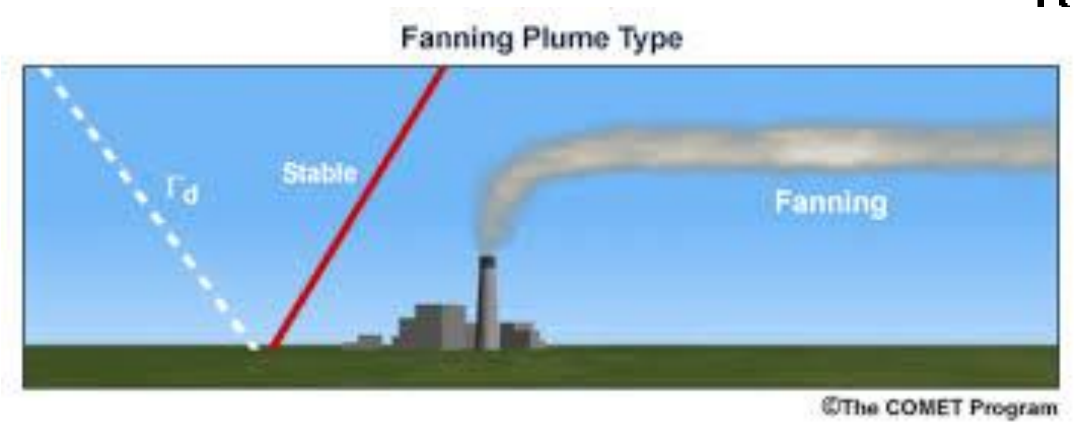




Atmospheric Stability

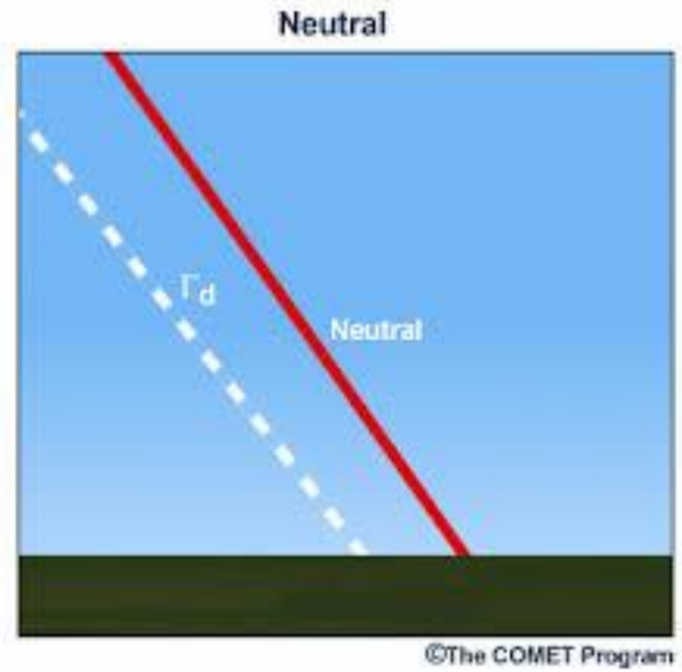
- Stable Atmosphere
- $\Lambda < \Gamma$





Atmospheric Stability

- Neutral Atmosphere
- $\Lambda = \Gamma$



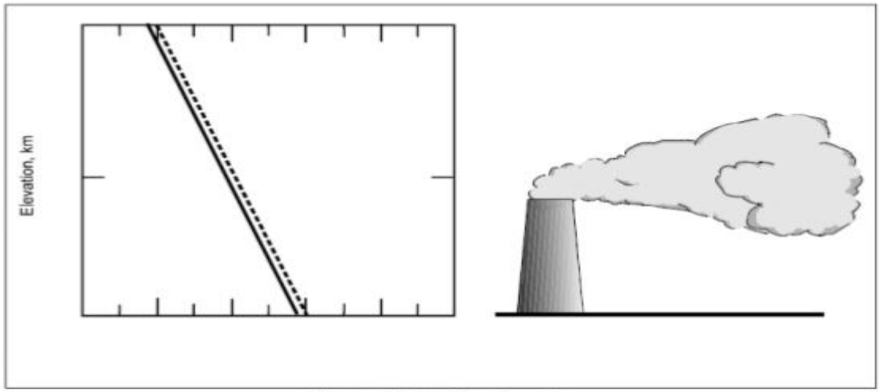
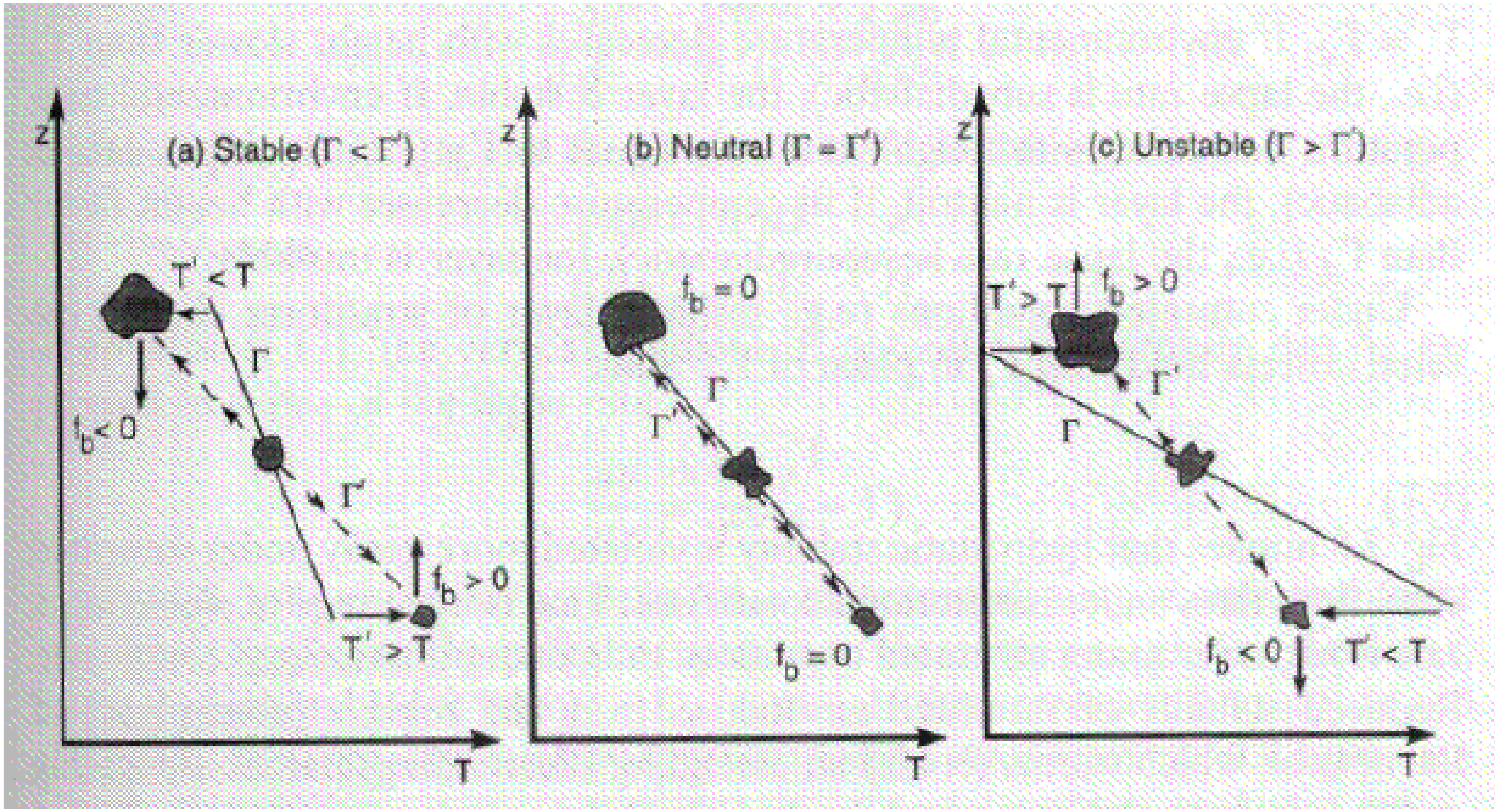


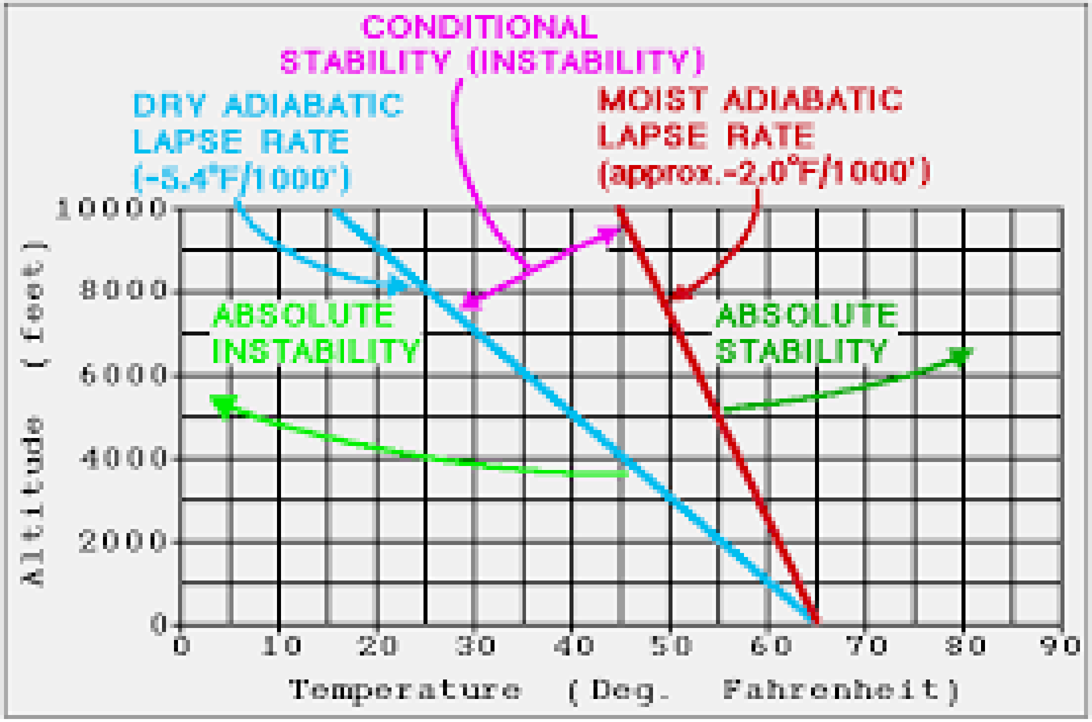
Figure 4-21. Coning plume

Atmospheric Stability



Temperature Inversion

- Since $\Gamma_{dry} > \Gamma_{wet}$, a moist atmosphere is inherently less stable than a dry atmosphere. Thus a stable situation with reference to Γ_{dry} may actually be unstable for upward displacement of a saturated air parcel.



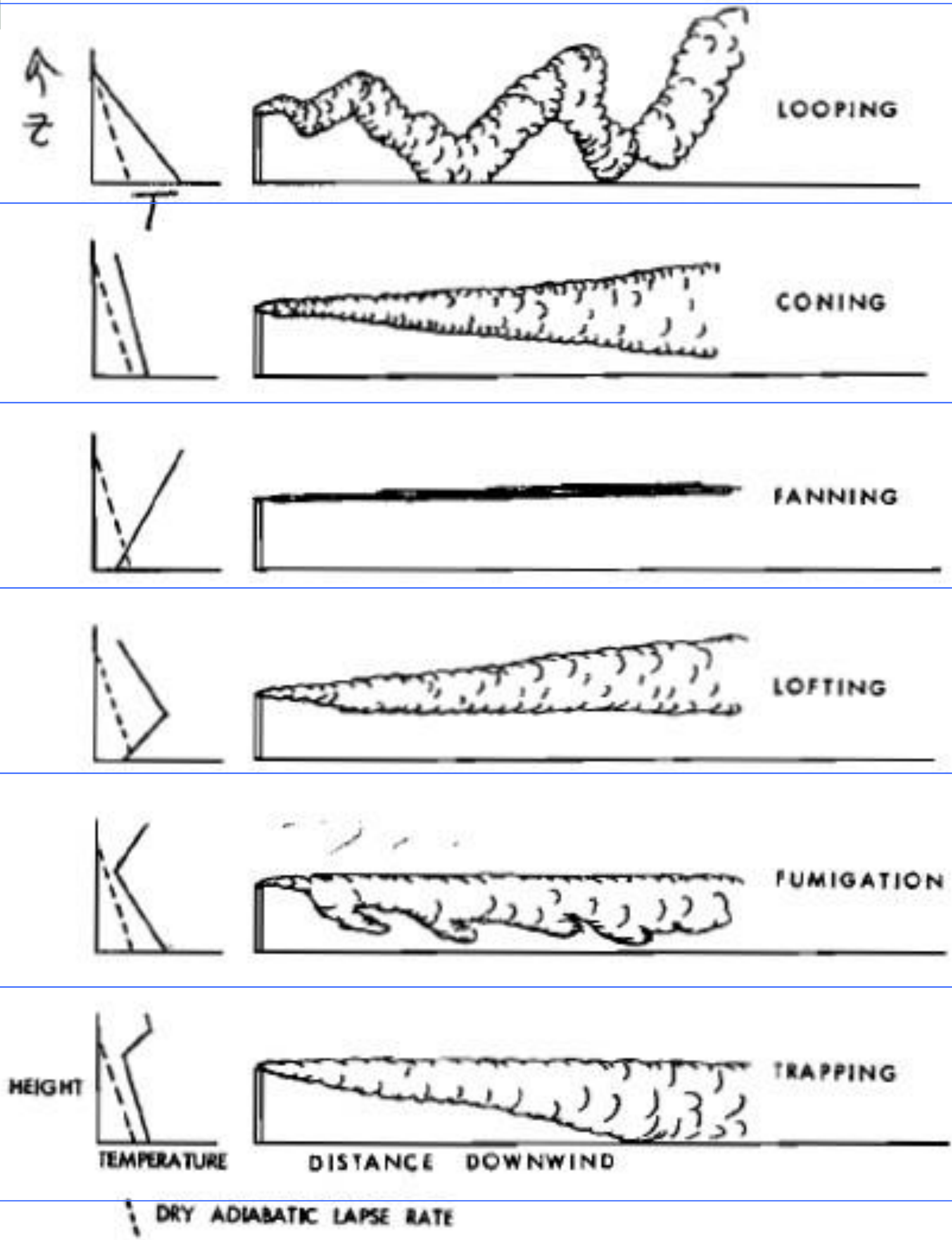
Temperature Inversion

- Radiation Inversion: Arises from unequal cooling rates of the earth and the air above the earth. Usually a nocturnal phenomenon that breaks up easily with the rays of the morning sun. Radiation inversion prompts the formation of fog and simultaneously traps gases and particulates, creating a concentration of pollutants.

- Subsidence Inversion: Usually associated with a high pressure system. As the high pressure air descends, it is compressed and heated, forming a blanket of warm air over the cooler air below and thus creating an inversion that prevents further vertical movement of air.

Lapse Rates and Dispersion

- By comparing the ambient lapse rate to the adiabatic lapse rate, it may be possible to predict what will happen to gases emitted from a stack.



Unstable atmosphere

Neutrally stable atmosphere

Stable atmosphere

Smokestack above inversion layer

Inversion: Smokestack under inversion layer

Smokestack between two stable layers

Lapse Rates and Dispersion

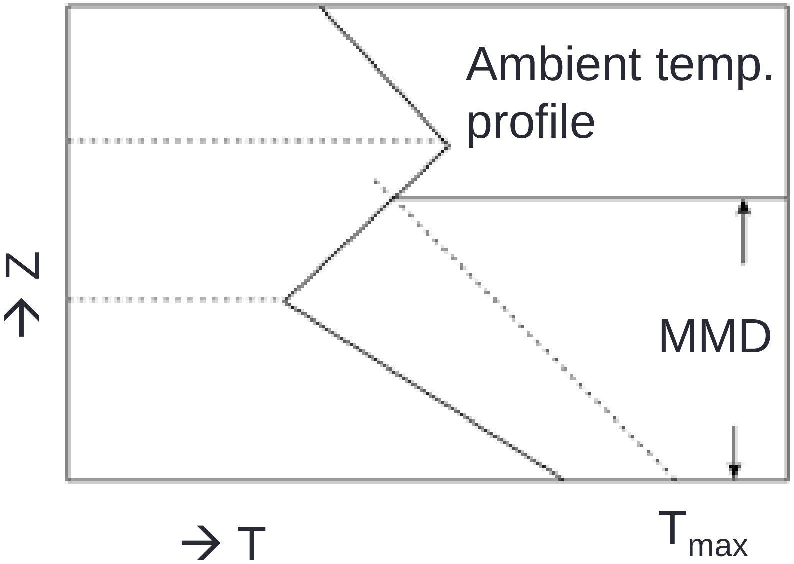
- Fumigating plumes can lead to greatly elevated down-wind, ground level concentration
- Lofting plumes are helpful in terms of exposure to people at ground level.
- Thus a common approach to air pollution control has been to build taller stacks to emit pollutant, above inversion layers. However, pollutants released from tall stacks can travel long distances, so that effects such as acid deposition can be felt hundreds of miles from the source.

Atmospheric Stability and Mixing Depth

- The amount of air available to dilute pollutants is related to the wind speed and to the extent to which emissions can rise into the atmosphere.
- An estimate of this (dilution process) can be obtained by determining “maximum mixing depth”

Estimation of Maximum mixing depth and ventilation coefficient

- Following the logic presented earlier, the maximum mixing depth can be estimated by plotting maximum surface temperature and drawing a line parallel to the dry adiabatic lapse rate from the point of maximum surface temperature to the point at which the line intersects the ambient or natural temperature profile (usually of early morning or night)



Ventilation Coefficient (m^2/s) = MMD (m) * Avg wind speed within mixing depth (m/s)

This parameter is used as an indicator of the atmosphere's dispersive capability

If ventilation coefficient< 6000 m^2/s, air pollution potential is considered to be high.

Problem

- Suppose the ambient atmospheric temp profile of an area is given by the following equation:
- $\Lambda(^\circ C) = 30 - 0.005z$, when z = altitude in m.
- If maximum surface temperature is 34° C and average wind speed is 5.7 m/s, estimate the ventilation coefficient and comment on the pollution potential.