

# **CE 435: Environmental Pollution Management**

**January 2018 Semester  
Level-4, Term II**

**CN-4**

**Department of Civil Engineering  
Bangladesh University of Engineering and Technology  
(BUET)**

# **Air Pollution and Meteorology**

Dr. M. Ashraf Ali, CE 435, January 2017  
Semester

# Meteorology

Air quality often depends on the dynamics of the atmosphere (particularly the temperature structure of the atmosphere and wind speed/direction).

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.

The study of the “**lower atmosphere**” is known as “**meteorology**”; study of the “**upper atmosphere**” is known as “**aeronomy**”.

# The Layers of the Atmosphere

The Earth's atmosphere is characterized by variations in temperature and pressure with height. In fact, the variation of average temperature profile with altitude is the basis for distinguishing the layers of the atmosphere.

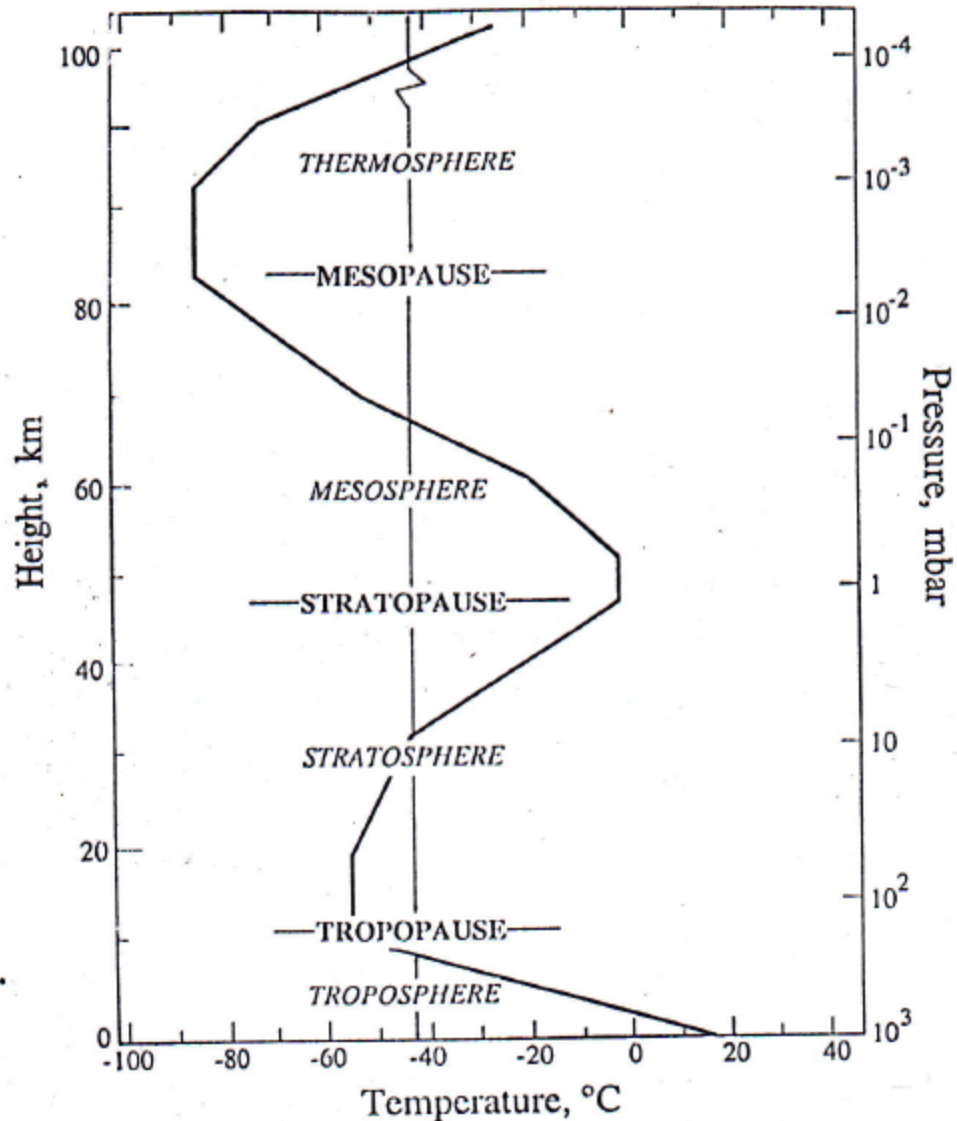




FIGURE 1.1 Layers of the atmosphere.

# Lapse Rates

- The rate of change of temperature of air or a parcel of air (e.g. vehicular emissions) with altitude is usually referred to as “Lapse Rate”.
- 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 temperature of ambient air usually (but not always) decreases with an increase in altitude. This rate of change of temperature is called “ambient or environmental lapse rate ( $\Lambda$ )”

## Lapse Rates (contd.)

- A specific parcel of air (e.g. automobile exhaust) whose temperature is greater than that of the ambient air tends to rise until it reaches a level at which its own temperature and density equal that of the atmosphere that surrounds it.
- Thus, a parcel of artificially heated air (e.g. automobile exhaust) rises, expands, becomes lighter, and cools. The rate at which the temperature of the parcel decreases may be considerably different from the ambient/environmental lapse rate ( $\Lambda$ ). 
- The lapse rate of the rising parcel of air may be determined theoretically. For this calculation, the cooling process within a rising parcel of air is assumed to be “adiabatic” (i.e. occurring without the addition or loss of heat). This is called “adiabatic lapse rate ( $\Gamma$ )” 

# Determination of Adiabatic Lapse Rates ( $\Gamma$ )

- For determination of  $\Gamma$ , we need:
  - (1) Ideal gas law [  $P = (\rho \cdot R \cdot T) / M_a$  ]
  - (2) Hydrostatic equation [  $dP/dz = - \rho \cdot g$  ], and
  - (3) First law of thermodynamics [  $du = dQ - dW$  ]

where,

$\rho$  = mass density of air

$R$  = universal gas constant

$M_a$  = molecular weight of air

$du$  = change in internal energy =  $C_v \cdot dT$

$C_v$  = 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 to to alter the volume of system

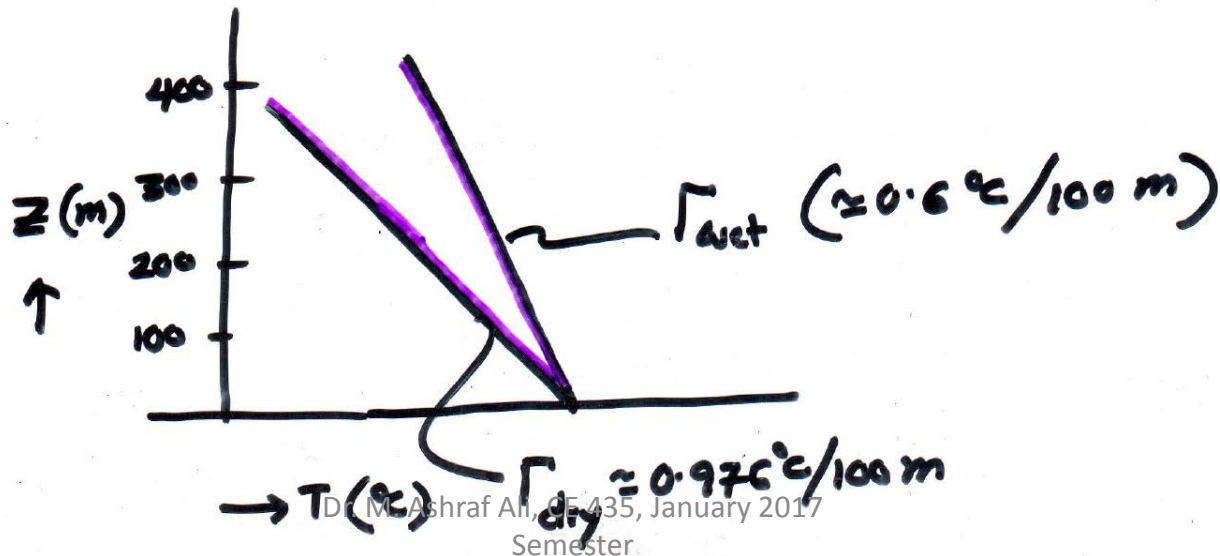
# Determination of Adiabatic Lapse Rates ( $\Gamma$ )

It can be derived that for dry atmosphere,

$$\begin{aligned}\Gamma &= \Gamma_{\text{dry}} = -dT/dz \\ &= 0.976 \text{ }^\circ\text{C}/100 \text{ m} \approx 1 \text{ }^\circ\text{C}/100 \text{ m} \\ &= 9.76 \text{ }^\circ\text{C}/\text{km} = 5.4 \text{ }^\circ\text{F}/1000 \text{ ft}\end{aligned}$$

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. In most atmosphere,

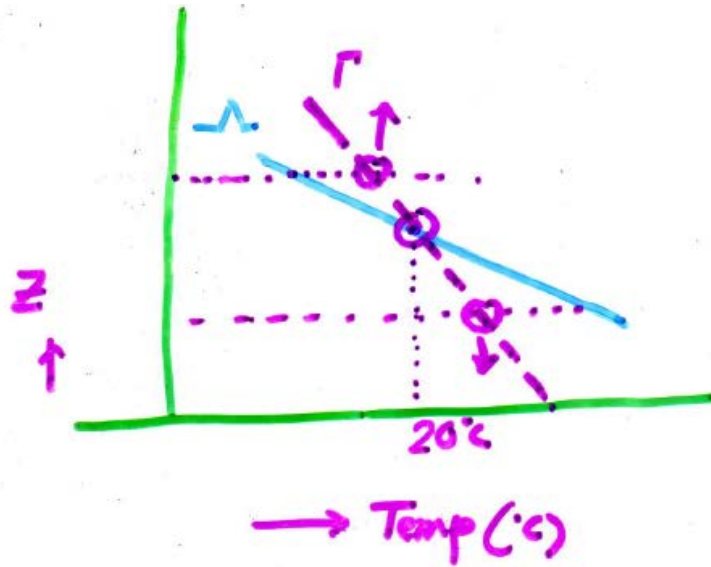
$$\Gamma_{\text{wet}} = 0.6 \text{ }^\circ\text{C}/100 \text{ m}$$



# Atmospheric Stability

- The degree of stability of the atmosphere is determined by the temperature difference between an air parcel and the air surrounding it. This difference can cause the parcel to move vertically (i.e., it may rise or fall).
- In **stable** conditions, this vertical movement is discouraged, whereas in **unstable** conditions the air parcel tends to move upward or downward and to continue that movement.
- When conditions neither encourage nor discourage movement, they are considered **neutral**.
- **The atmospheric stability (i.e. stable, unstable or neutral condition) could be determined by comparing “adiabatic” and “ambient/environmental” lapse rates.**

# Atmospheric Stability: Unstable Atmosphere

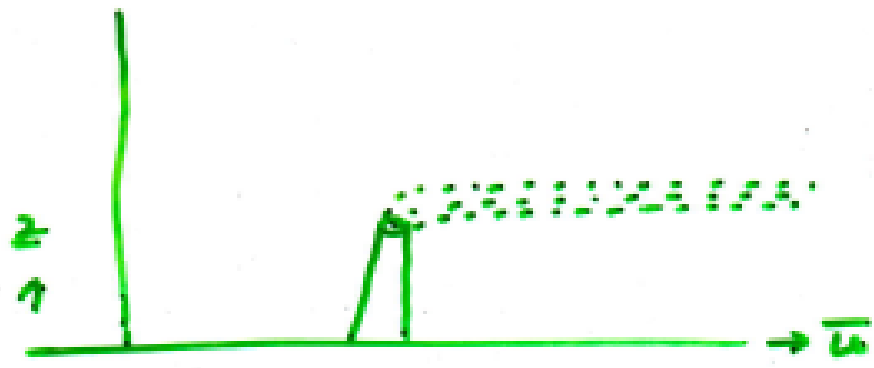
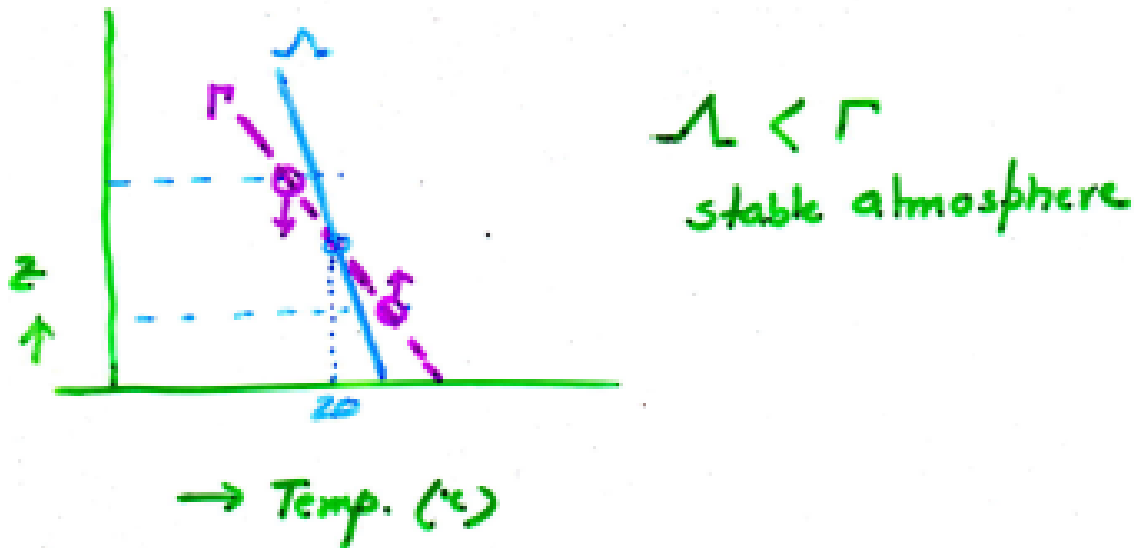


$\gamma > \Gamma$   
Unstable  
atmosphere



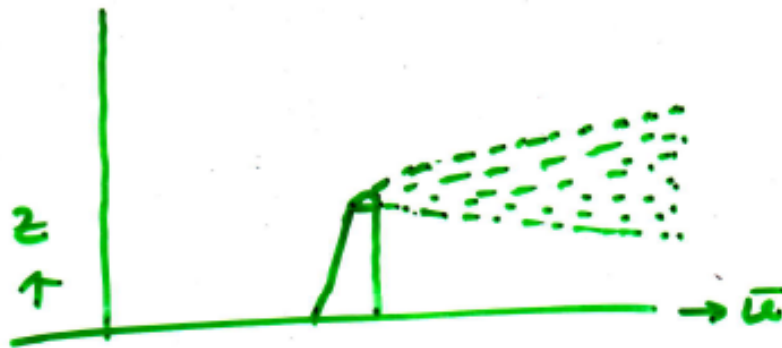
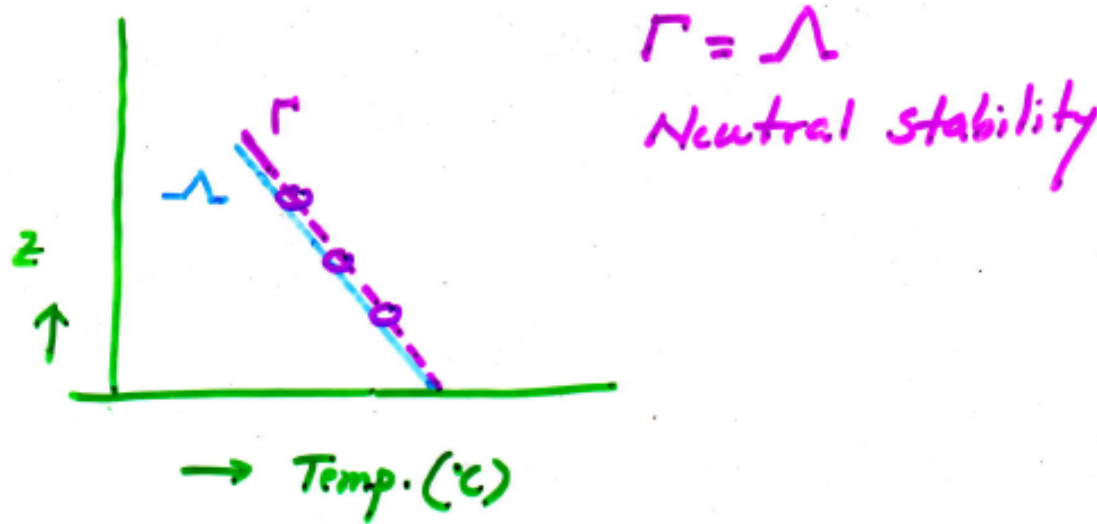
"Looping"

# Atmospheric Stability: Stable Atmosphere



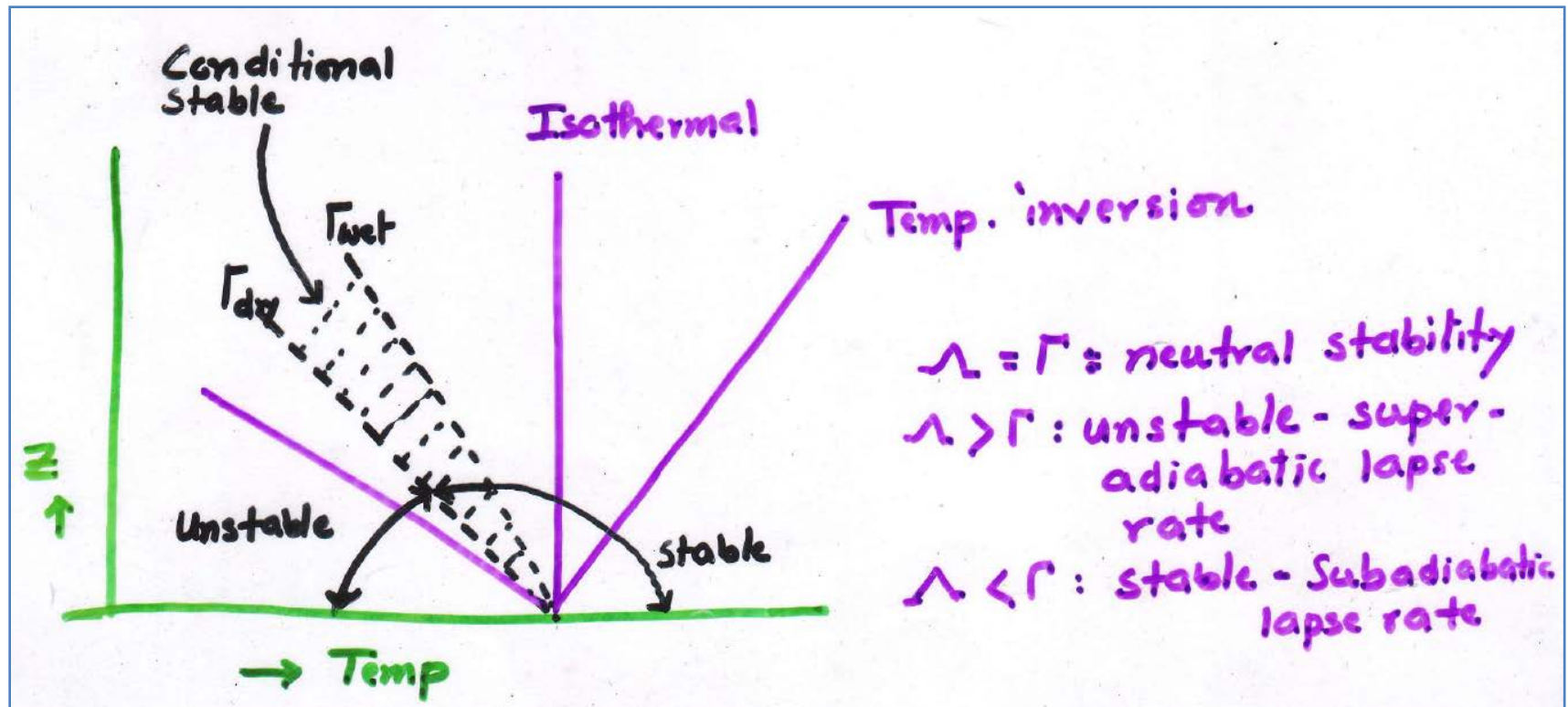
"Fanning"

# Atmospheric Stability: Neutral Atmosphere



"Coning"

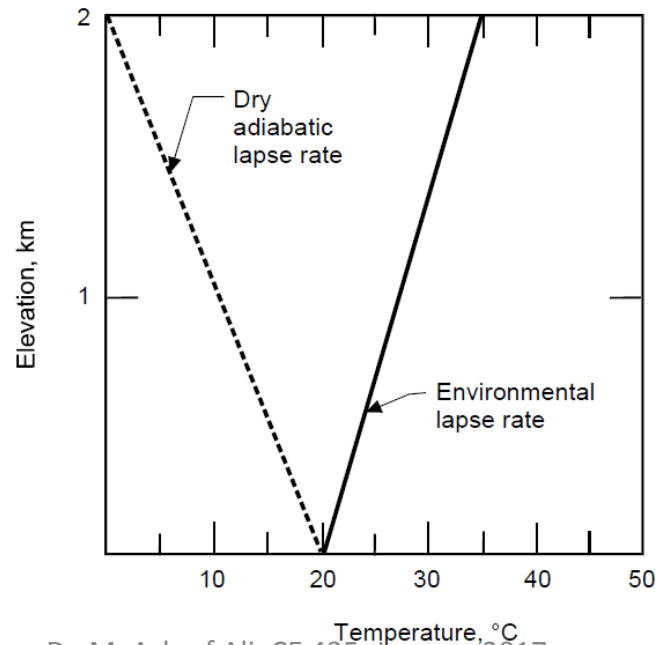
# Atmospheric Stability (contd.)



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

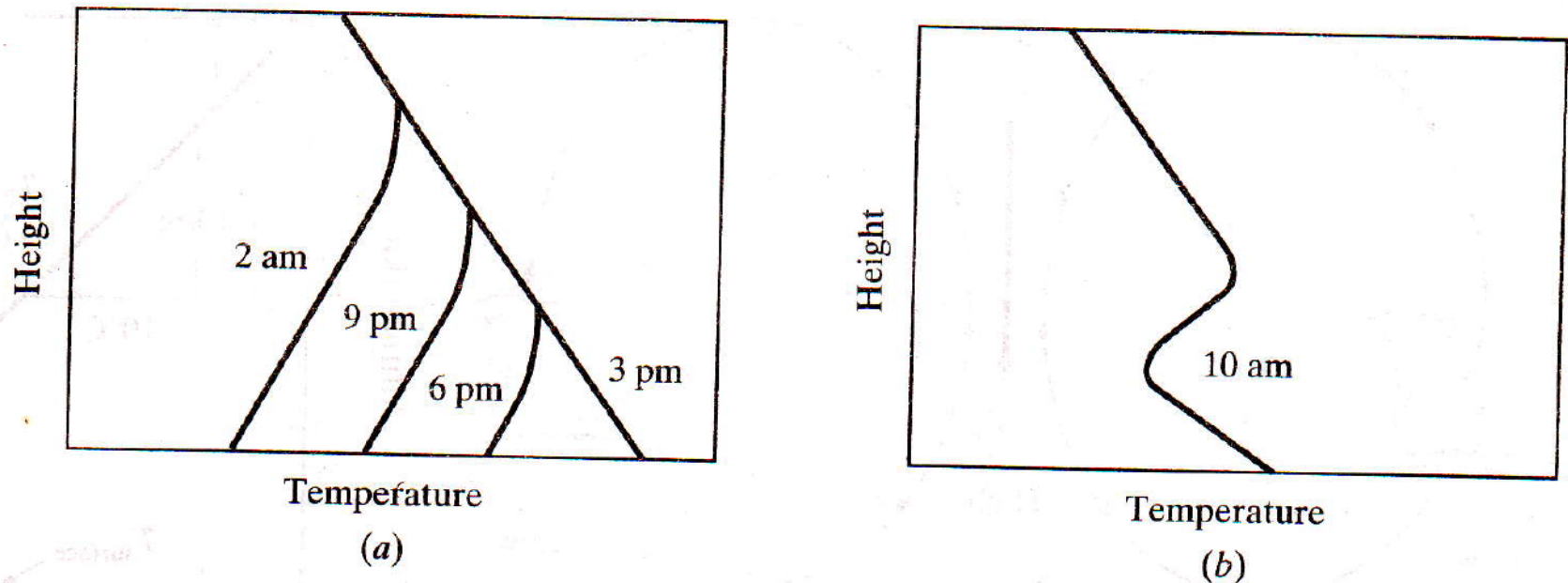
# Temperature Inversions

- An “inversion” occurs when air temperature increases with altitude. This situation occurs frequently but is generally confined to a relatively shallow layer. High concentrations of air pollutants are often associated with **inversions since they inhibit plume dispersion.**
- The two common types of inversions are: (a) Radiation inversion, and (b) Subsidence inversion. Other inversion types include “frontal inversion” and “advection inversion”.



# Temperature Inversions (contd.)

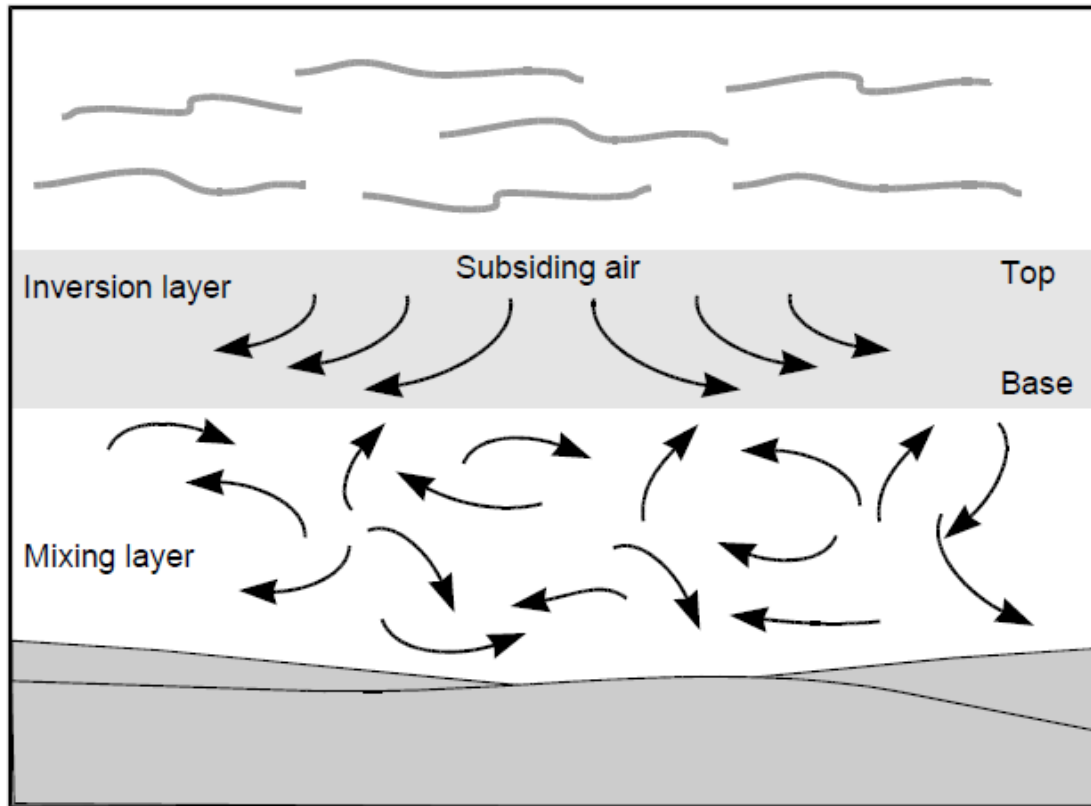
- **Radiation Inversion:** Due to unequal cooling of the earth and the air above it. Usually a nocturnal phenomenon that breaks up easily with the rays of the morning sun. Radiation inversion prompts the formation of fog and simultaneously traps gases and particulates.



**FIGURE 7.39** Development of a radiation inversion (a), and the subsequent erosion of the inversion (b). The times are representative only. The breakup of the inversion in the morning leads to a process called fumigation.

# Temperature Inversions (contd.)

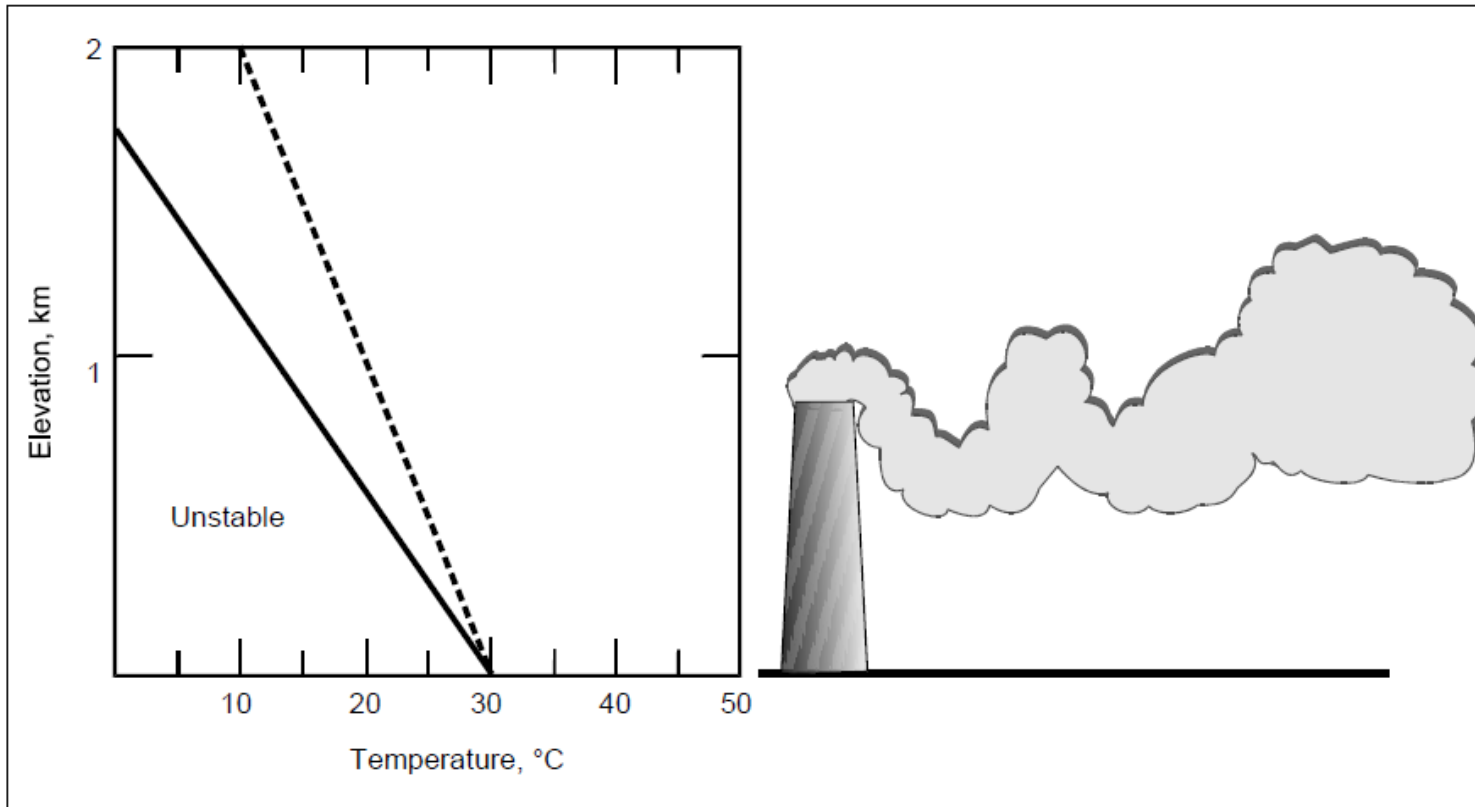
- **Subsidence Inversion:** Usually associated with a high pressure system. As the high pressure air descends, it is compressed and heated, forming a blanket of warm air over the cooler air below and thus creating an inversion that prevents further vertical movement of air.



# Atmospheric Stability and Plume Behavior

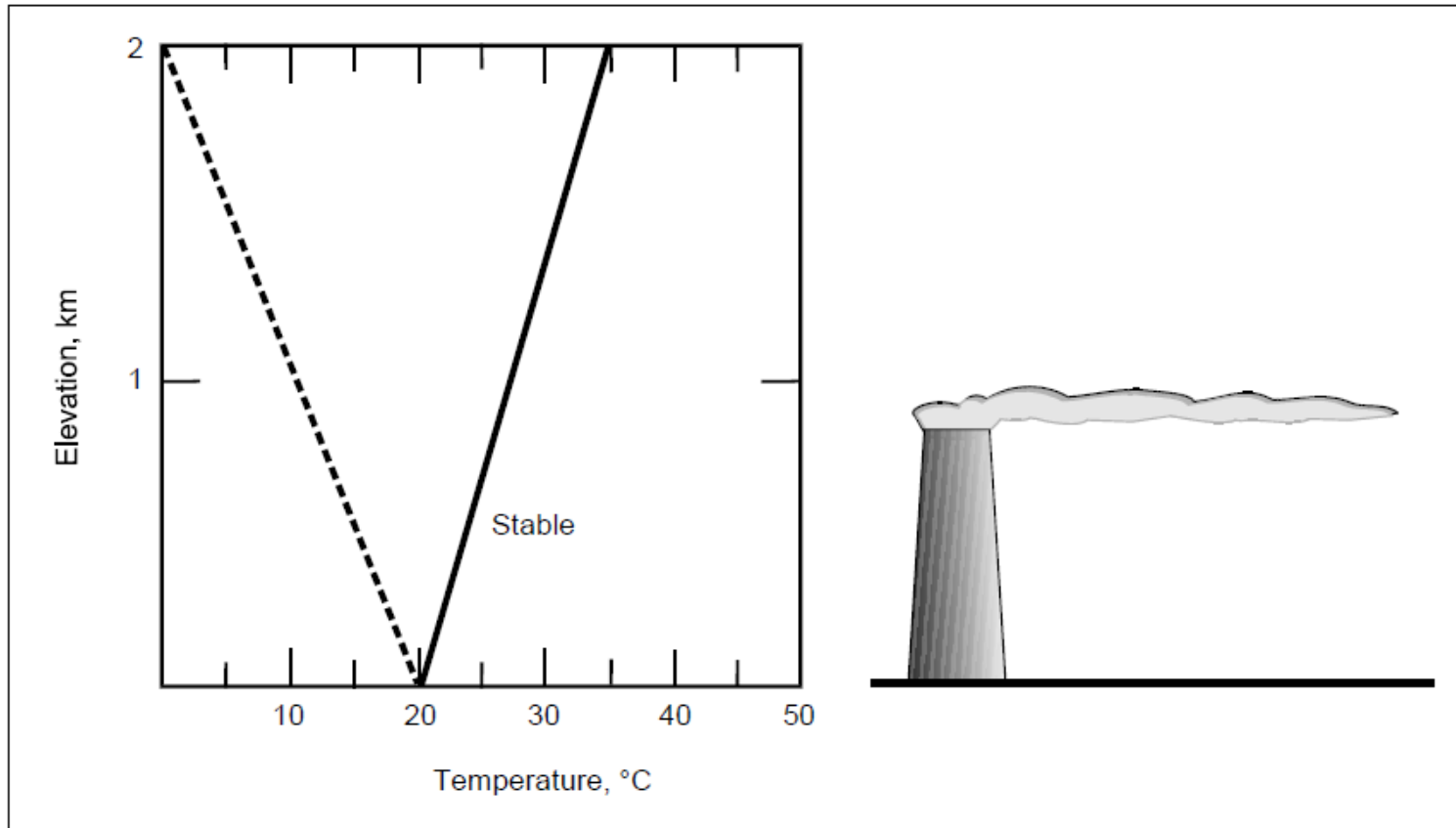
- By comparing the ambient/environmental lapse rate ( $\Lambda$ ) with adiabatic lapse rate ( $\Gamma$ ), it may be possible to predict what would happen to gases emitted from a stack.

## (a) Unstable Atmosphere: “Looping” plume



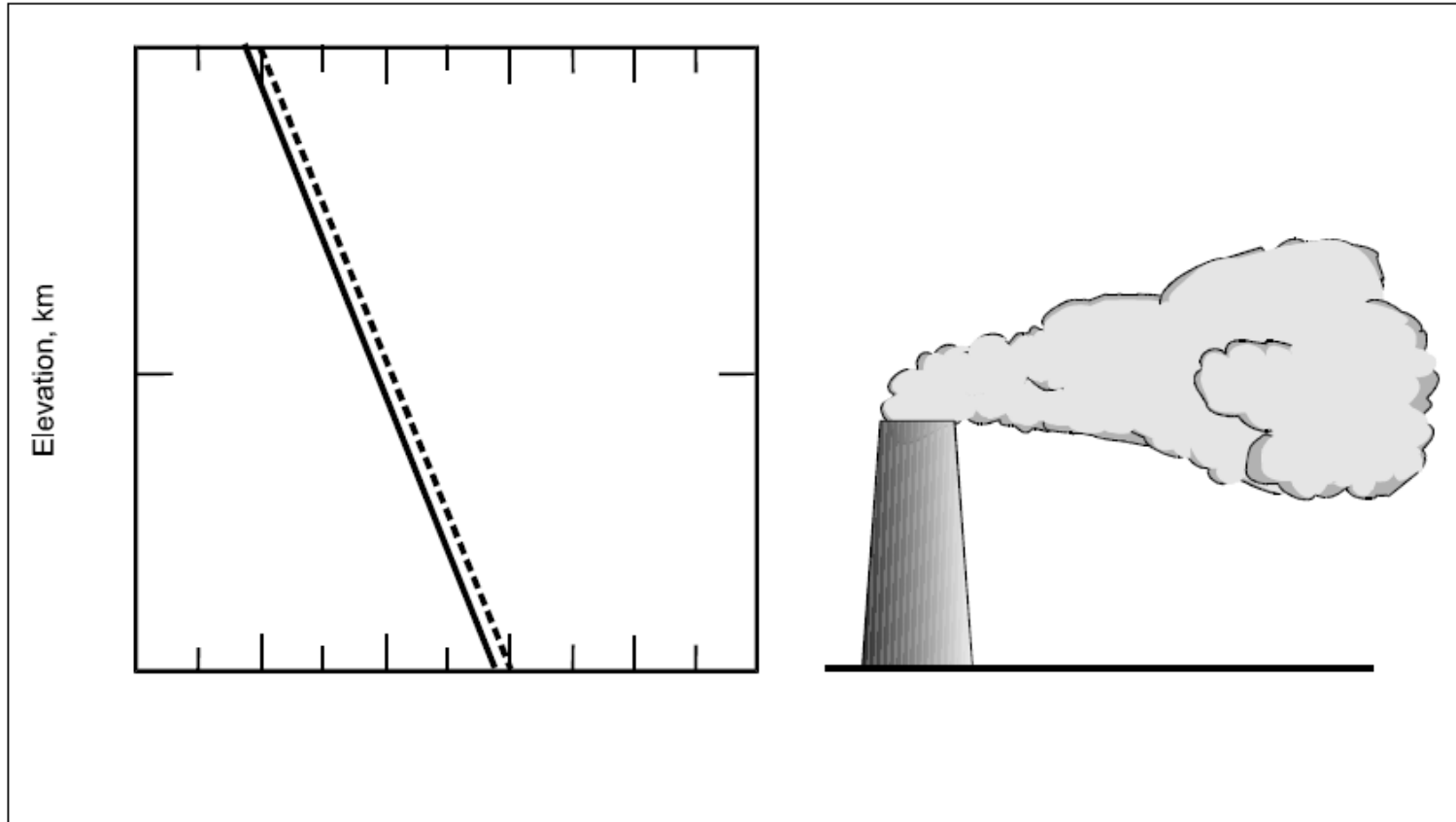
# Atmospheric Stability and Plume Behavior

## (b) Stable Atmosphere: “Fanning” plume



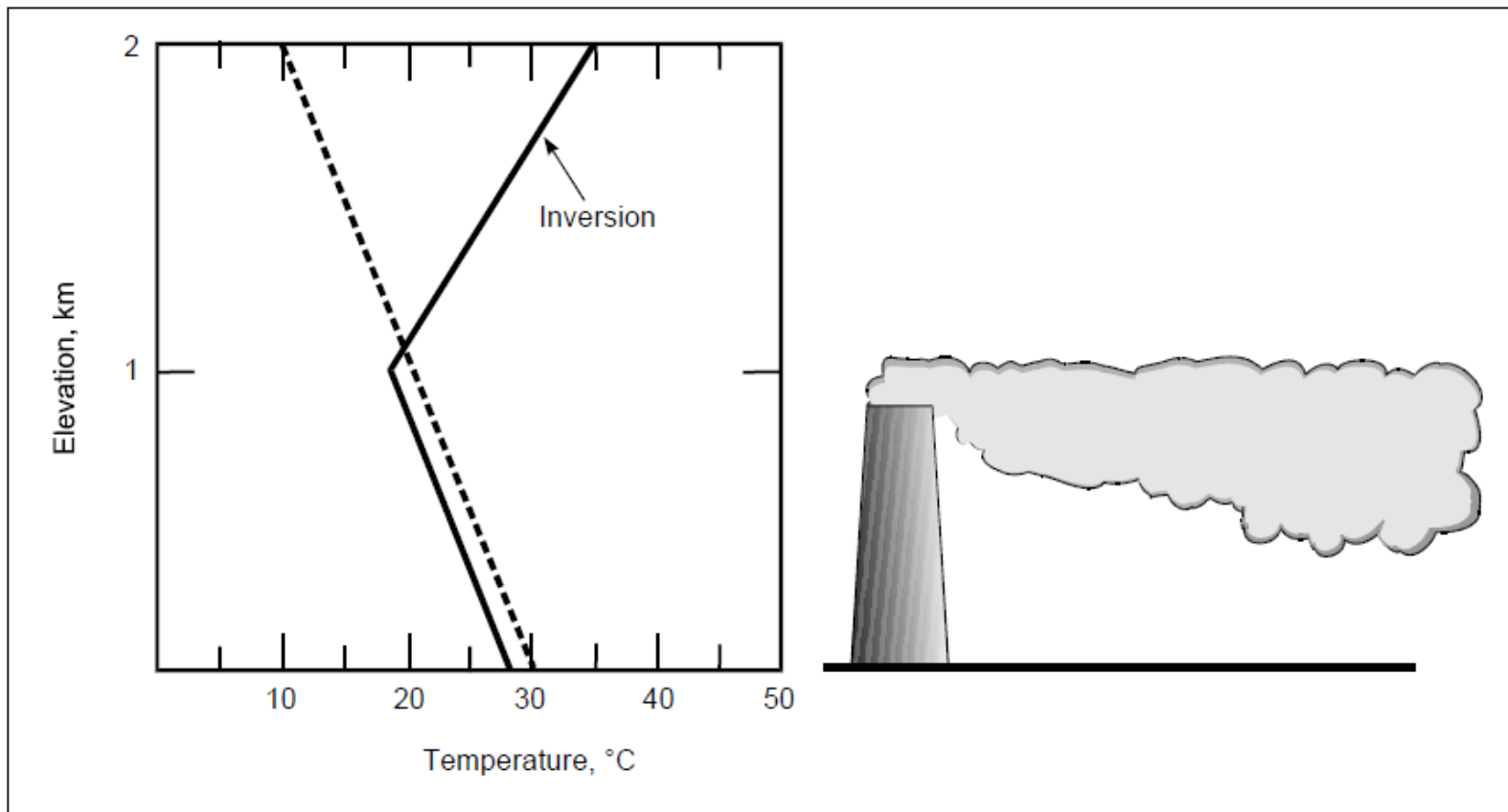
# Atmospheric Stability and Plume Behavior

## (c) Neutral Atmosphere: “Coning” plume



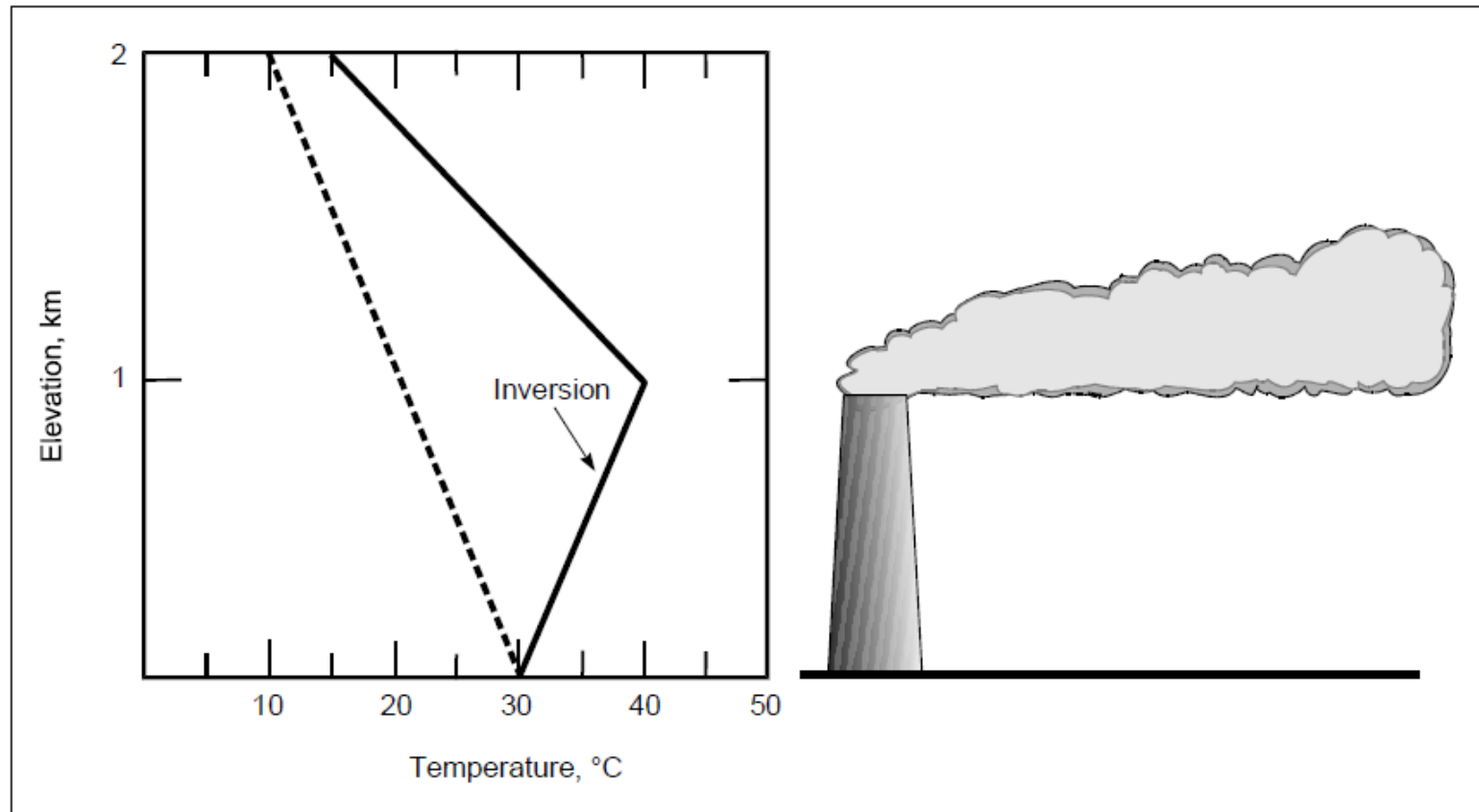
# Atmospheric Stability and Plume Behavior

**(d) Inversion: Smokestack under inversion layer:  
“Fumigating” plume**



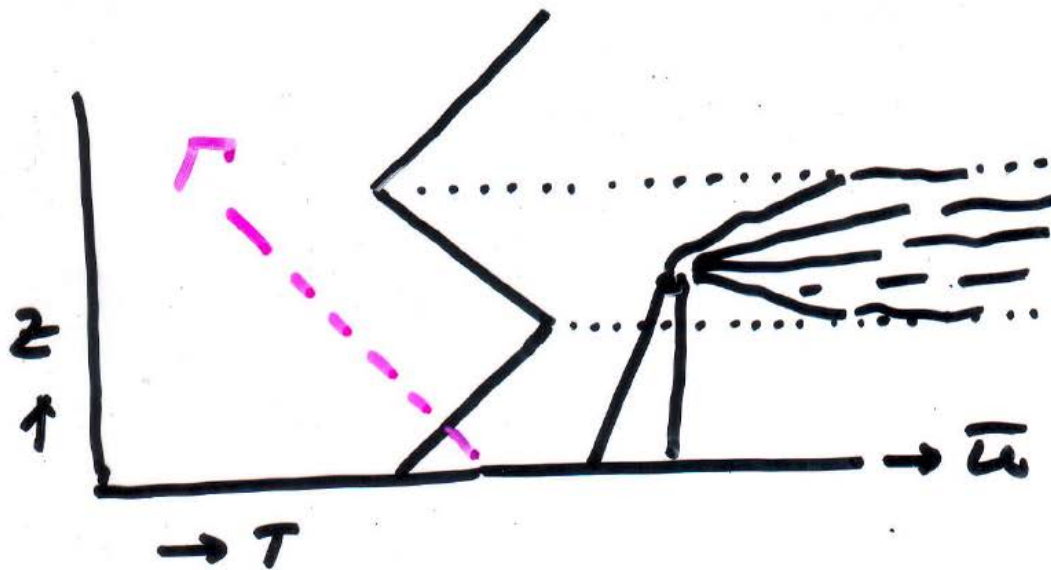
# Atmospheric Stability and Plume Behavior

**(e) Inversion: Smokestack above inversion layer:  
“Lofting” plume**



# Atmospheric Stability and Plume Behavior

(f) Smokestack between two inversion layers:  
"Trapping" plume



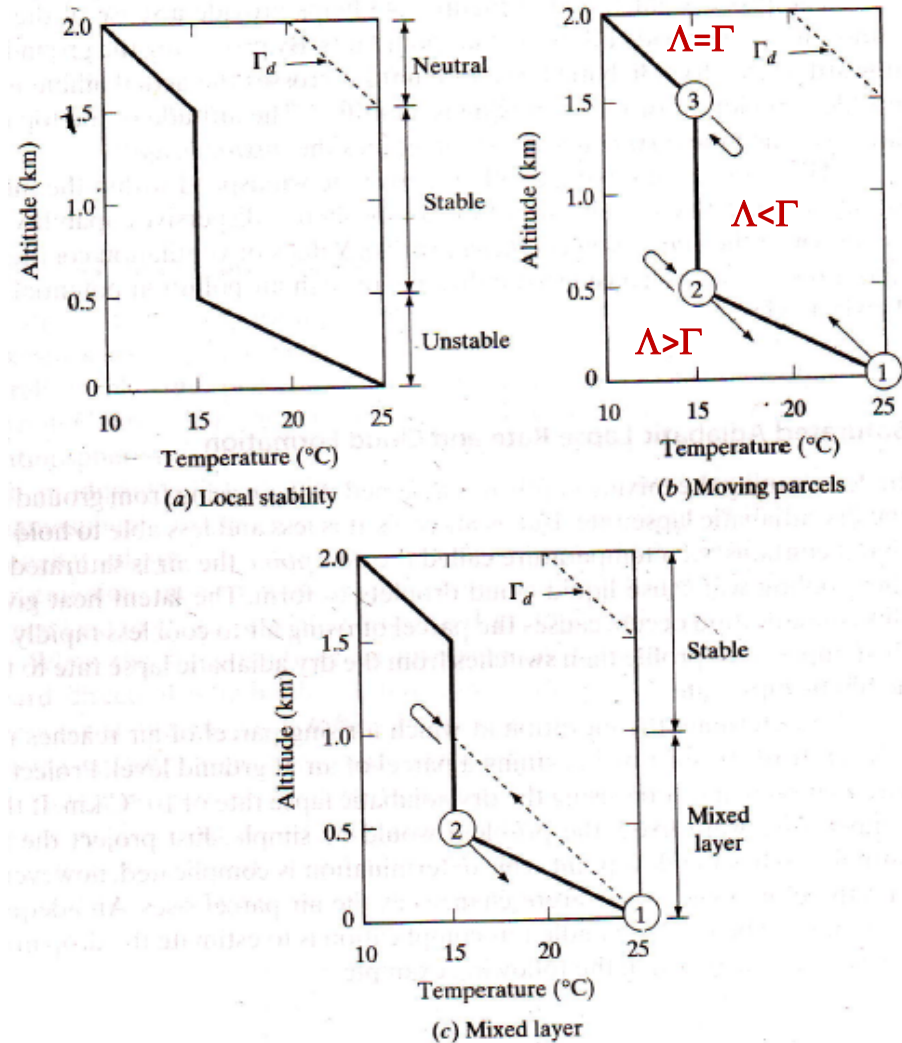
(f) Smokestack  
between two  
stable layers  
"Trapping"

# Atmospheric Stability and Plume Behavior

- **“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 pollutants 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.

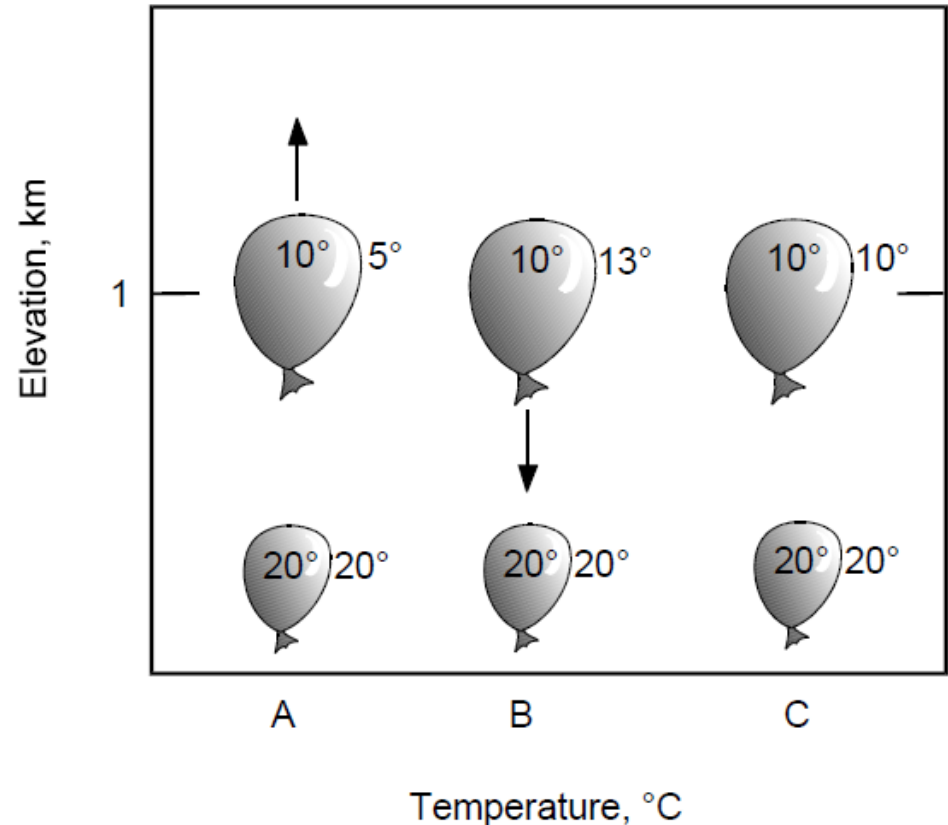
# Atmospheric Stability and Mixing Depths/Height

- 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 (**mixing depth**).
- As estimate of this dilution process can be obtained by estimating the mixing depth/height.



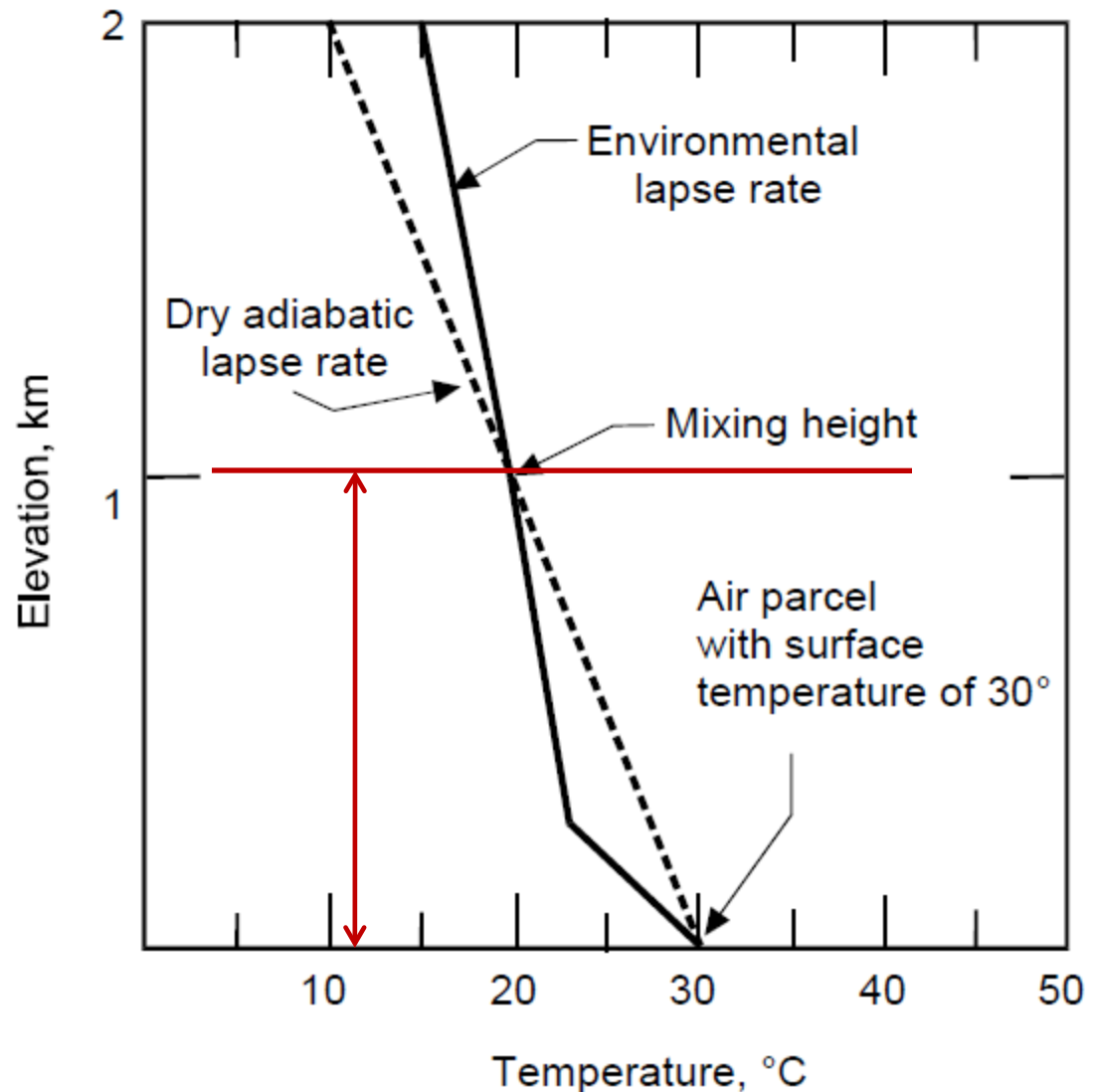
# Atmospheric Stability and Mixing Depth/Height

- The balloons are filled at ground level with air at 20 °C, and then lifted manually to a height of 1 km. The air in the balloons will expand and cool to about 10 °C.
- Whether the balloons rise or fall upon release depends on the surrounding air temperature and density.



# Estimation of Mixing Depth/Height

- The point at which the parcel cooling at the dry adiabatic lapse rate intersects the ambient temperature profile “line” is known as the “mixing depth”



# Ventilation Coefficient (VC):

## An estimate of the dilution potential of a plume

**Ventilation Coefficient (VC) = Mixing depth (m) \* Avg. wind speed within mixing depth (m/s)**

**Ventilation Coefficient is used as an indicator of the atmosphere's dispersive capability.**

**If, Ventilation Coefficient < 6,000 m<sup>2</sup>/s, air pollution potential is considered to be high.**

# Example Problem

(1) Suppose the ambient atmospheric temperature profile of an area is given by the following equation:

$$T (\text{°C}) = 30 - 0.005 z; \quad \text{where, } z = \text{altitude in m}$$

If temperature of a plume emitted at the ground surface is 34 °C and average wind speed is 5.7 m/s, estimate the ventilation coefficient and comment on the pollution potential of the area.

# Atmospheric Stability Classes

**TABLE 7.8** ATMOSPHERIC STABILITY CLASSIFICATIONS

Class	Description	Surface wind speed <sup>a</sup> (m/s)	Day solar insolation			Night cloudiness <sup>e</sup>	
			Strong <sup>b</sup>	Moderate <sup>c</sup>	Slight <sup>d</sup>	Cloudy ( $\geq 4/8$ )	Clear ( $\leq 3/8$ )
A	Very unstable	<2	A	A-B <sup>f</sup>	B	E	F
B	Moderately unstable	2-3	A-B	B	C	E	F
C	Slightly unstable	3-5	B	B-C	C	D	E
D	Neutral	5-6	C	C-D	D	D	D
E	Slightly stable	>6	C	D	D	D	D
F	Stable						

<sup>a</sup> Surface wind speed is measured at 10 m above the ground

<sup>b</sup> Corresponds to clear summer day with sun higher than 60° above the horizon

<sup>c</sup> Corresponds to a summer day with a few broken clouds, of a clear day with sun 35-60° above horizon

<sup>d</sup> Corresponds to a fall afternoon, or a cloudy summer day, or a clear summer day with sun 15-35° above horizon

<sup>e</sup> Cloudiness is defined as the fraction of sky covered by clouds

<sup>f</sup> For A-B, B-C, or C-D conditions, average the values obtained for each

Source: Turner (1970)