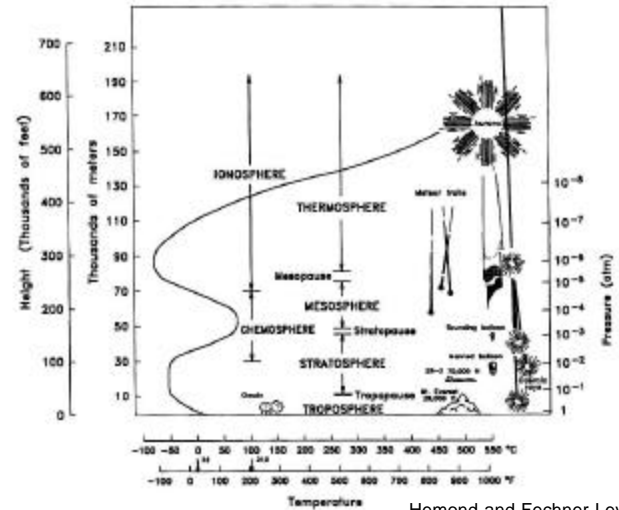


# “The Nature of the Atmosphere”

## Module 4: The Atmosphere, Lecture 1

*Chemical Fate and Transport in the Environment*, 2<sup>nd</sup> edition. H.F. Hemond and E.J. Fechner-Levy. Academic Press. London. 2000.

### Vertical Structure of the Atmosphere



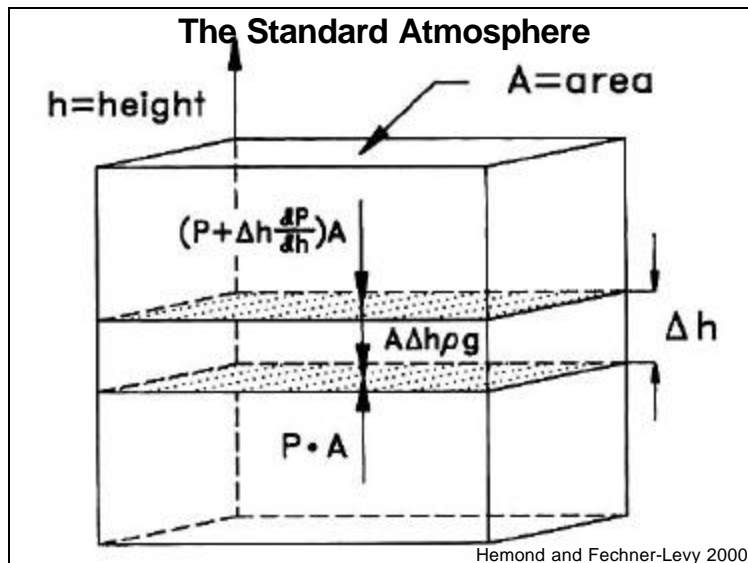
Hemond and Fechner-Levy 2000

### Vertical Structure of the Atmosphere

- Weather phenomena are confined almost to the troposphere (about 30,000 ft).
- Pollutants are also mostly confined to the troposphere, which are removed by various processes before they can mix with the stratosphere.
- Some long-lived pollutants (such as chlorofluorocarbons (CFCs) do mix with stratosphere, along with injected materials (such as volcanic debris and nuclear explosion material)

### The Standard Atmosphere

- The exponential relationship between pressure and altitude arises from the compressibility of air.
- Pressure at the bottom of the standard volume is approximately 1 atm.
- In the standard atmosphere, temperature decreases at the rate of about 6.5°C per 1,000m (3.5°F per 1,000 ft) in the troposphere, after it remains relatively constant in the lower portions of the stratosphere, inhibiting vertical mixing.
- Temperature variations with elevation determine stability and mixing of air pollutants.



Components of Atmospheric Air			
Gas	Formula	Mixing ratio (percentage by volume)	Concentration [ppb by volume, ppb(v)]
Major gases			
Nitrogen	N <sub>2</sub>	78.084	
Oxygen	O <sub>2</sub>	20.946	
Argon	Ar	0.934	
Inert trace gases			
Neon	Ne		18,180
Helium	He		5240
Krypton	Kr		1140
Xenon	Xe		87
Reactive trace gases			
Carbon dioxide	CO <sub>2</sub>		358,000
Methane	CH <sub>4</sub>		1720
Hydrogen	H <sub>2</sub>		500
Nitrous oxide	N <sub>2</sub> O		312
Ozone	O <sub>3</sub>		10–50
Water	H <sub>2</sub> O	0.004–4	
Carbon monoxide	CO		50–150
Nitrogen dioxide	NO <sub>2</sub>		0.1–5
Ammonia	NH <sub>3</sub>		0.1–10
Sulfur dioxide	SO <sub>2</sub>		0.03–30
Hydrogen sulfide	H <sub>2</sub> S		<0.006–0.6

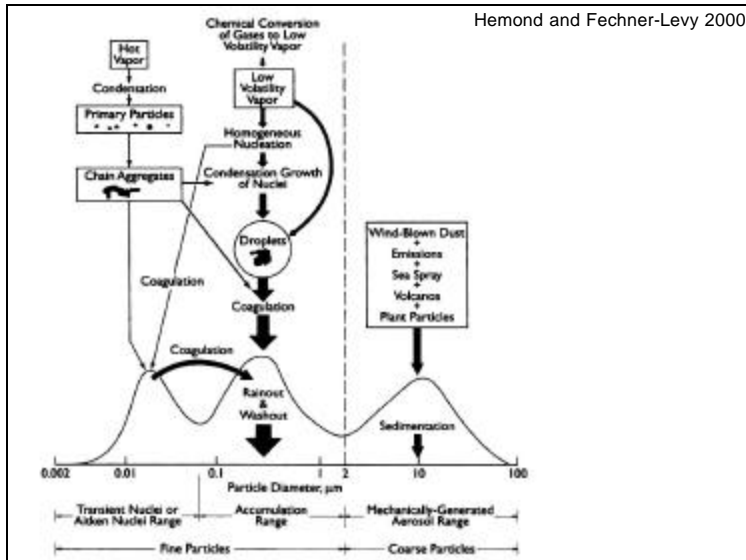
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## 4.1.2 Sources of Pollutant Chemicals in the Atmosphere

- Human activities contribute large fluxes of gases and particulates to the atmosphere.
- Many sources are associated with fuel combustion. Other sources include volatile chemical evaporation, vapor emissions from metallurgical operations, and fugitive dust losses from mechanical activities.
- The annual Toxic Release Inventory indicates emissions of toxicants from different industrial operations and locations.
- Fine particulates (PM<sub>2.5</sub>) receive special consideration as they can enter the lungs and be a public health concern (especially in conjunction with certain gaseous pollutants).

U.S. National Air Emissions as Reported by Facilities to the Toxics Release Inventory <sup>a</sup>	
Chemical	1996 Air emissions (million lb)
Methanol	206
Ammonia	155
Toluene	125
Xylenes	83
Carbon disulfide	73
n-Hexane	72
Chlorine	66
Hydrochloric acid	65
Methyl ethyl ketone	59
Dichloromethane	53
Styrene	42
Trichloroethylene	21
Benzene	8
Manganese	7
Zinc	2
CFC-12	1
CFC-11	0.7
Lead	0.6
Arsenic	0.04
Mercury	0.01
Cadmium	0.005

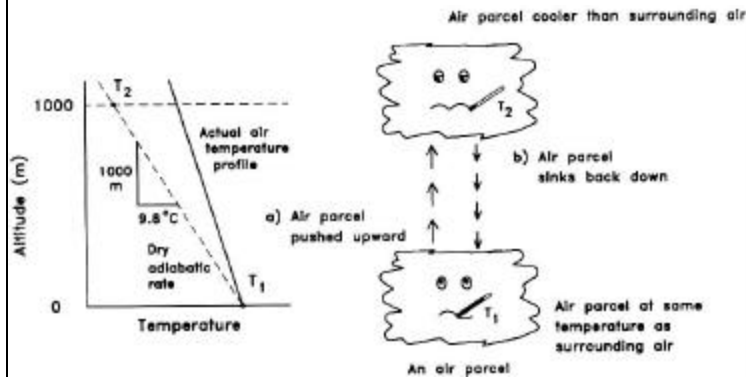
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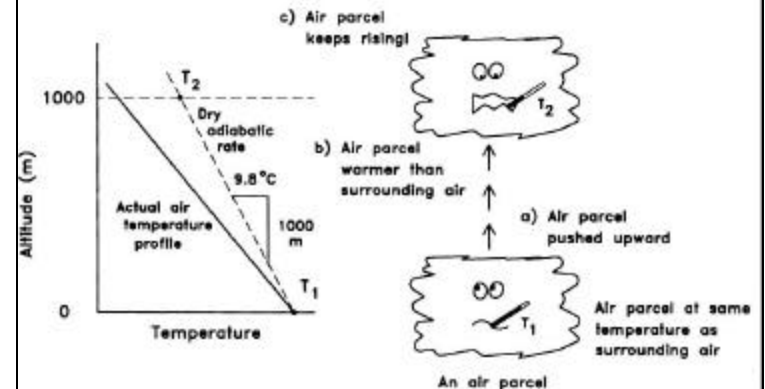
## 4.2 Atmospheric Stability

- Neutral stability occurs when the actual vertical temperature gradient (the actual lapse rate) is equal to the adiabatic lapse rate.
- The adiabatic lapse rate is the rate at which the temperature of an air parcel changes in response to the compression or expansion associated with elevation change (assuming no heat exchange occurs between the air parcel and its surroundings).
- The adiabatic lapse rate for a dry atmosphere (may contain water vapor but no liquid moisture is present) is about  $9.8^{\circ}\text{C}$  per 1,000 m ( $5.4^{\circ}\text{F}$  per 1,000 ft).

**Stable Atmosphere:** the actual temperature profile is less than the adiabatic rate. When an air parcel is pushed upward (such as by turbulence), it moves to warmer, less dense air, and then sinks back down. This suppress vertical mixing.

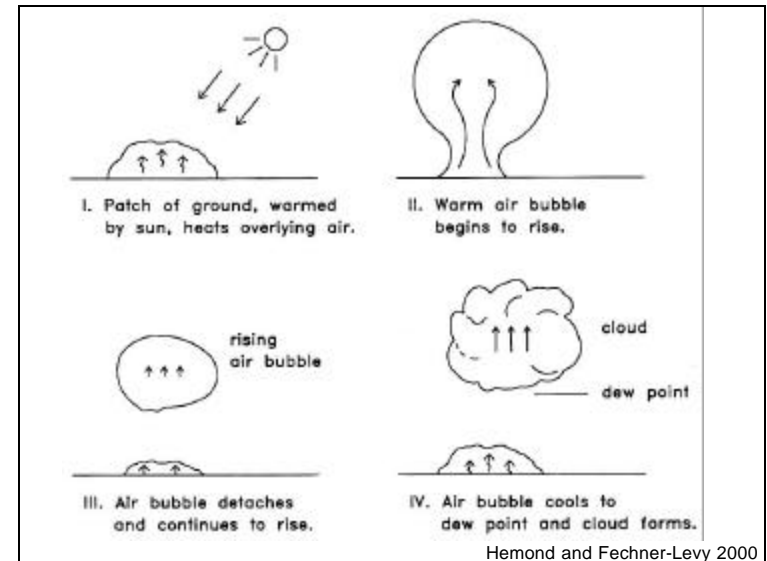


**Unstable Atmosphere:** the actual temperature profile is greater than the adiabatic rate. When an air parcel is pushed upward it moves to cooler, more dense air, and keeps rising. This causes an "infinite" vertical mixing depth.

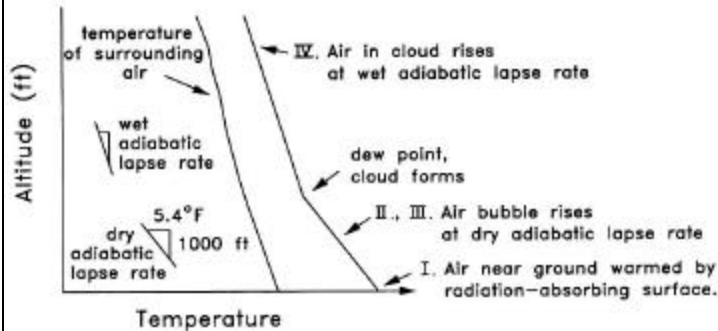


## 4.2.2 Wet Adiabatic Lapse Rates

- When condensed moisture is in the atmosphere, the normal lapse rate is more complex, due to the energy needed to convert liquid water into water vapor (589 calories per gram at 15°C).
- Heat released by condensation mitigates the adiabatic cooling effect, resulting in the parcel of air being warmer than it would be if it was dry.
- The wet adiabatic rate is in the range of 3.6 to 5.5°C per 1,000m, depending on temperature and pressure. The actual values are selected from charts.
- In most cases, both adiabatic lapse rates are present in an atmosphere.



**Cumulus cloud formation:** the rising bubble of air (a “thermal”) reaches its dew point and a cloud begins to form. It now cools at the wet adiabatic lapse rate, which is less than the dry adiabatic lapse rate, and accentuates the tendency of the air bubble to rise farther.

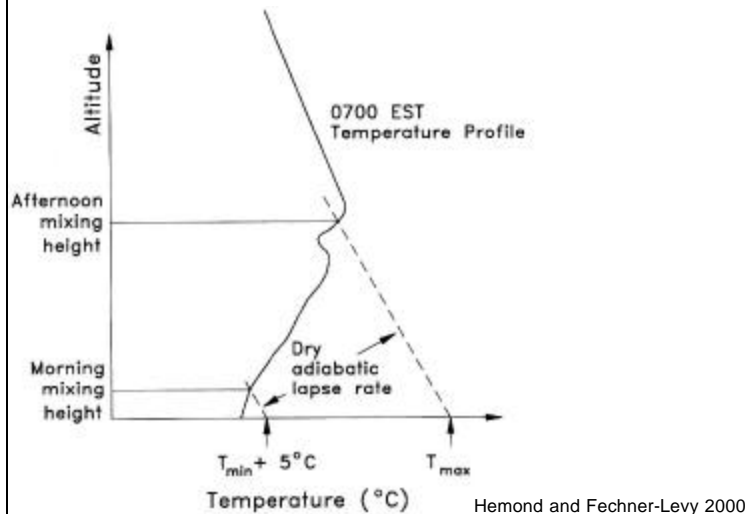


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## 4.2.3 Mixing Height

- During the day, solar radiation warms the ground, which in turn warms the air near the ground.
- This warm air rises until it reaches a height where its temperature (and therefore density) is equal to the surrounding air.
- This height is termed the mixing height.
- The layer of air below this height is the boundary layer within which atmospheric mixing is aided by buoyancy.

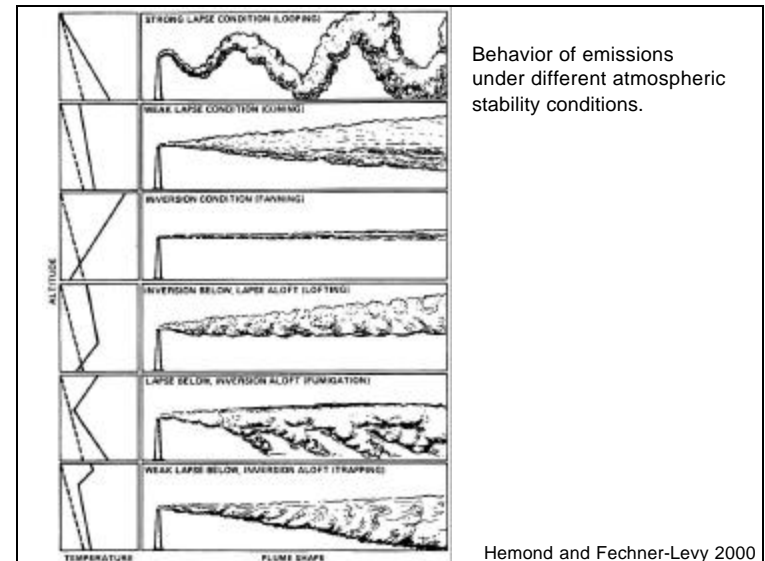
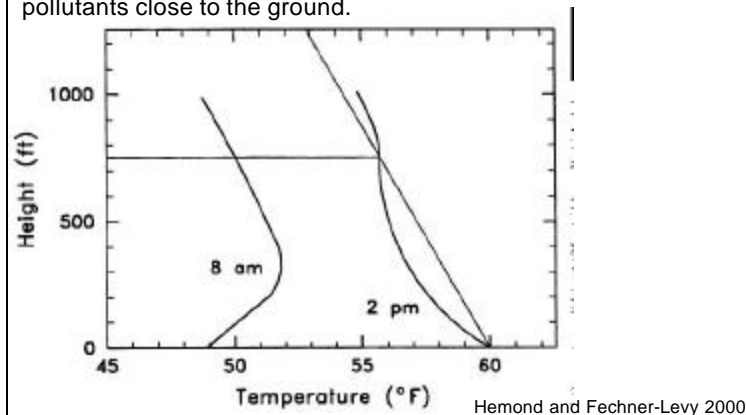
Mixing Height



## Example 4-3

- What is the mixing height associated with the following temperature profile at 2 and at 8 PM (assuming “dry” air).
- Draw a line with a slope equal to the dry adiabatic lapse rate beginning at the temperature and elevation of the ground surface.

The elevation where the line intersects the actual temperature profile at 2 pm is about 750 ft. Pollutants released at the surface in the afternoon will not easily mix above this height. At 8 am, the mixing height is zero, and inversion conditions prevail, trapping pollutants close to the ground.



#### 4.3.4 Local Effects

- At small scales, local topography may have significant effects of wind currents, atmospheric stability, and diffusion.
- “Urban canyons” tend to confine pollutants in restricted areas.
- Ocean currents and valleys also cause local warming and cooling and cause local effects on pollutant transport.

