Air Pollution Meteorology

The solution to pollution is dilution

1

Air Pollution Meteorology

- **Weather**
  - → **Winds and Breezes**
- **Dispersion Processes**
- **Convective Dispersion**
  - → **Air Parcel Dynamics**
  - → **Adiabatic Process**
  - → **Lapse Rate**
  - → **Atmospheric Stability**
  - → **Stability and Dispersion**

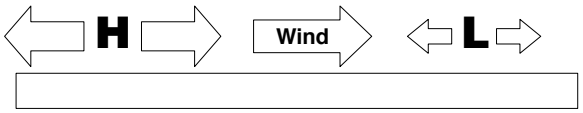
2

- **Temperature Inversions**
  - → **Stability**
  - → **Formation/Types**
  - → **Mixing Height**
- **Daily and Seasonal Smog Variation**
- **Application: Chimney Plumes**
  - → **Plume Type vs. Stability**
  - → **Enhancing Plume Dispersion**

3

Winds

- **Winds blow from high to low atmospheric pressure**



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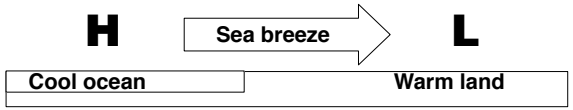
Sea Breeze

- **Sea breezes blow from the cool ocean region toward the warmer land**



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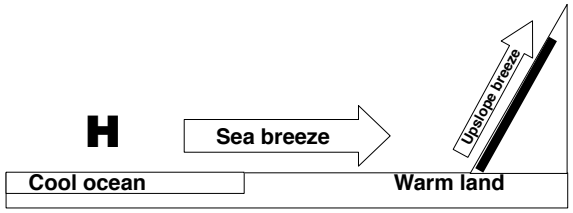

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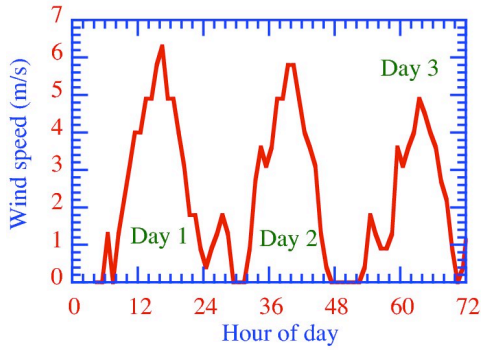


Fig. 6.20

7

Fig. 6.22

Fig. 6.23

8

Dispersion Processes

Defn.: A substance mixes in and becomes diluted within a larger volume of another substance.

Molecular Diffusion
Turbulence
Convection

9

Molecular Diffusion

- **Molecules drift from regions of high concentration to regions of lower concentration**

The larger the concentration gradient, the higher the diffusion rate

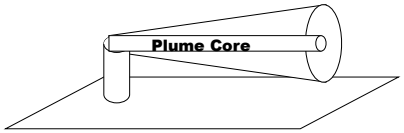
Length scale of motion = molecular — Slow!!

10

Turbulence

- **Bulk air motion in random directions**

Pollution



Strong, gusty winds generate the most turbulence

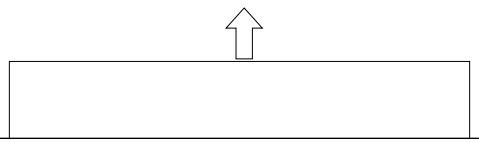
11

Convection

- **Mass transport of pollutants by winds**

→ Advection: horizontal motion

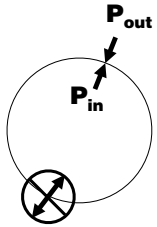
→ Convection: vertical motion



12

Air Parcel Mechanics

- **Air Parcel: a specified volume of air (ex.: bubble, balloon)**



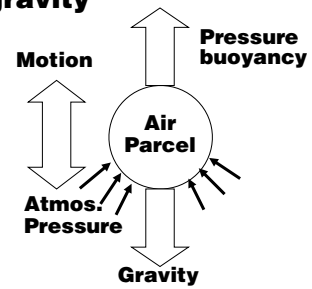
- **Constraints:**
  - → $P_{inside} = P_{outside}$ **at all times**
  - → **No mixing of air across boundary**

13

Parcel Buoyancy

- **Buoyancy: up- or downward force from combination of atmospheric pressure and gravity**

Up- or downward motion of air parcel depends on buoyancy vs. gravity



14

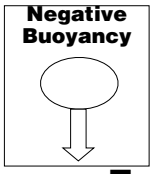
Air Density vs. Temperature

$$\rho \propto \frac{1}{T} \quad \text{for P = constant}$$

Cold air is more dense than warm air

15

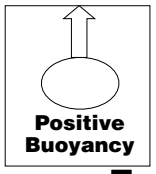
Buoyancy in Fluids



$T_{parcel} < T_{envir}$

Parcel colder than environment

$\rho_{parcel} > \rho_{envir}$



$T_{parcel} > T_{envir}$

Parcel warmer than environment

$\rho_{parcel} < \rho_{envir}$

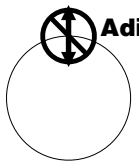
16

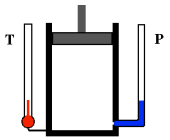
Adiabatic Process

No heat exchanged between a system and its surroundings

Heat

Adiabatic



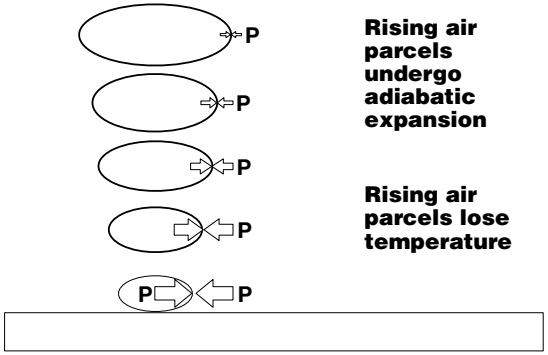


Compression: P⇧, T⇧

Expansion: P⇩, T⇩

17

Parcel Temperature



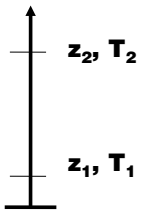
Rising air parcels undergo adiabatic expansion

Rising air parcels lose temperature

18

Lapse Rate

Defn.: Rate at which temperature decreases as altitude increases



Lapse rate = γ or Γ ("gamma")

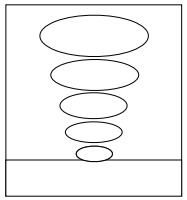
$$-\frac{T_2 - T_1}{z_2 - z_1} = -\frac{\Delta T}{\Delta z}$$

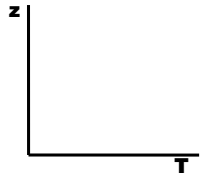
$$= \gamma$$

19

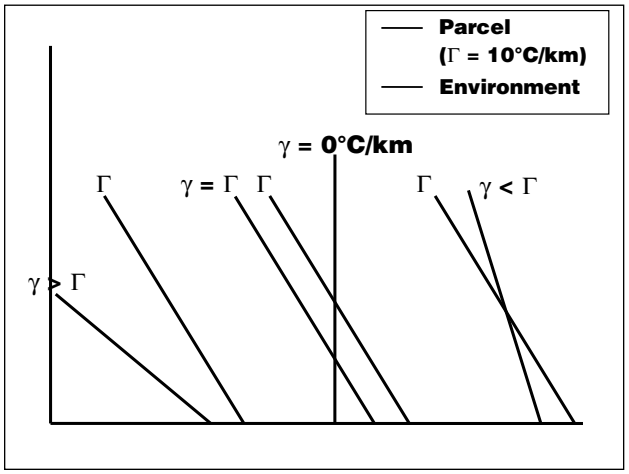
Making Parcels Buoyant

- **Need: parcel temp. > envir. temp.**
  - → **Heat up air parcel at the ground**
  - → **Then, positively buoyant parcel rises**
  - → **But, rising parcel loses temperature through adiabatic expansion...**





20



21

Atmospheric Stability

- **Related to behavior of an air parcel after it has been disturbed**
- **Indicates atmosphere's ability to mix vertically**
- **Related to air parcel buoyancy after parcel is disturbed**

22

Stability Behavior

Behavior after disturbance of equilibrium characterizes stability

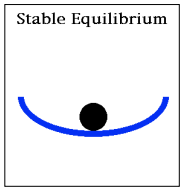
Stable
Unstable
Neutral

23

Stability Behavior

Behavior after disturbance of equilibrium characterizes stability

Stable

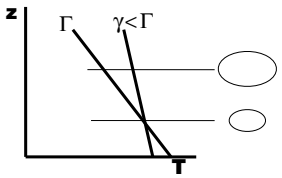


24

Stability Behavior

Stable equilibrium: suppresses disturbances; restores original configuration of system

Stable

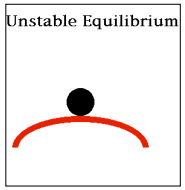


25

Stability Behavior

Behavior after disturbance of equilibrium characterizes stability

Unstable

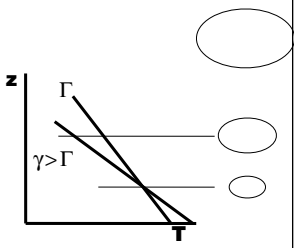


26

Stability Behavior

Unstable: encourages or accelerates disturbances

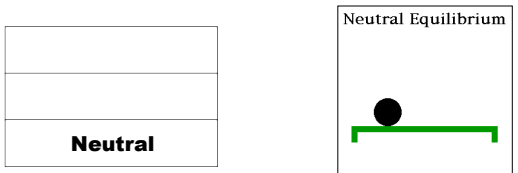
Unstable



27

Stability Behavior

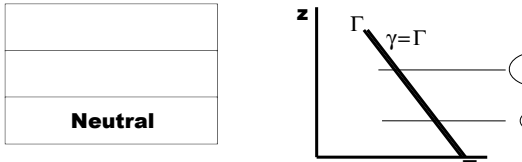
Behavior after disturbance of equilibrium characterizes stability



28

Stability Behavior

Neutral: neither suppresses nor accelerates disturbances; new equilibrium configuration results



29

Stability Criteria

Stable: $\gamma < \Gamma$

Unstable: $\gamma > \Gamma$

Neutral: $\gamma = \Gamma$

30

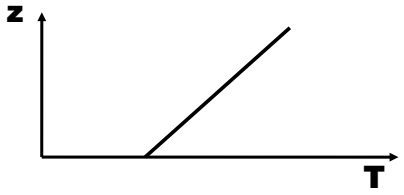
Stability vs. Dispersion

- **Turbulence gives parcel an initial push**
- **Stability vs. vertical mixing:**
  - → **Stable—vertical motion suppressed—vertical dispersion discouraged**
  - → **Unstable—vertical motion encouraged—vertical dispersion enhanced**

31

Temperature Inversions

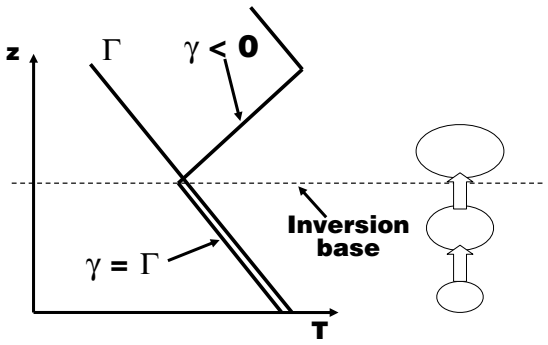
☞**Defn.: Temperature increases with increasing altitude ($\gamma < 0$)**



- **Inversions are extremely stable**

32

Temperature Inversion Aloft



33

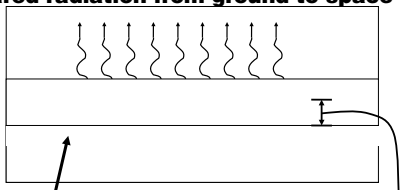
Inversion Types

- Radiation Inversion
- Advection Inversion
- Regional Subsidence Inversion
- Large-scale Subsidence Inversion

34

Radiation Inversion

Infrared radiation from ground to space

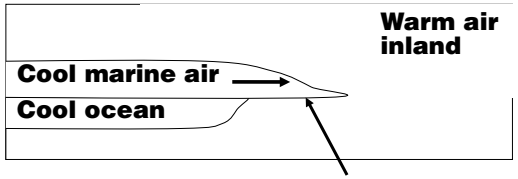


Ground cools off at night
— Cools air next to it

Shallow

35

Advection Inversion

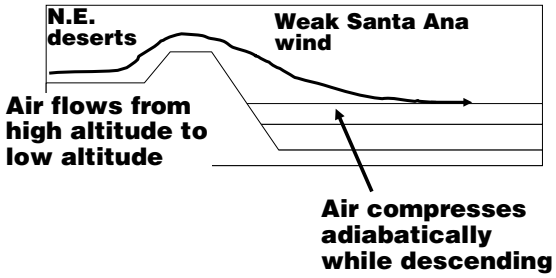


Cool air flows
underneath warm air

☞ In Southern California,
called the “Marine Layer”

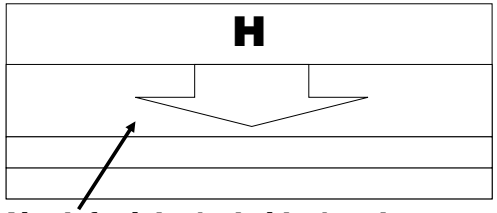
36

Regional Subsidence Inversion



37

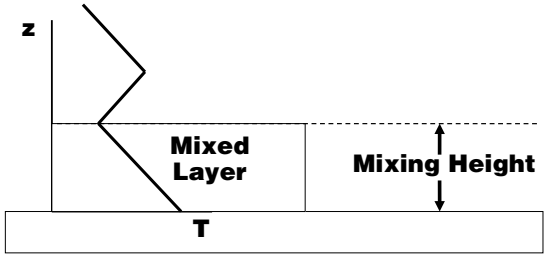
Large-scale Subsidence Inversion



- L.A. has a semi-permanent large-scale subsidence inversion

38

Mixing Heights

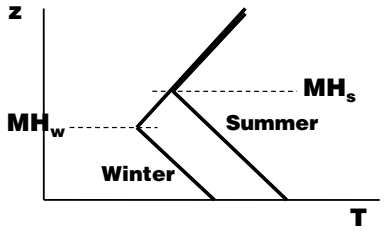


$$\text{Pollution concentration} \propto \frac{1}{\text{Mixing Height}}$$

39

Mixing Height vs. Season

MH ∝ ground temperature



40

Mixing Height vs. Time of Day

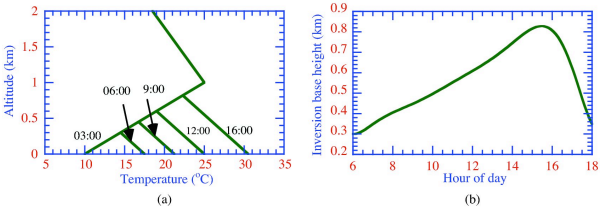
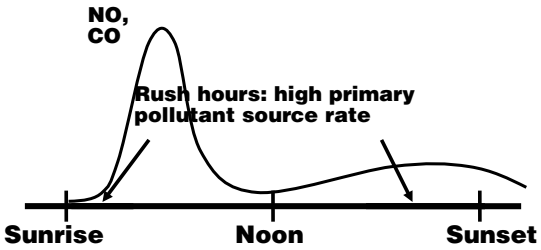


Fig. 6.14

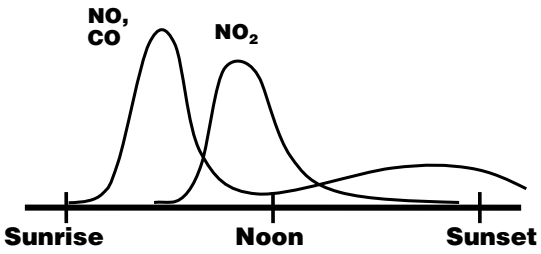
41

Daily Smog Variation



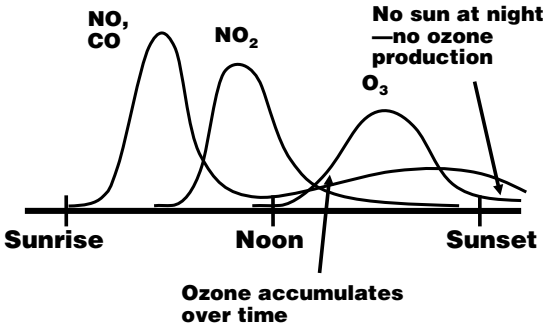
42

Daily Smog Variation



43

Daily Smog Variation



44

Daily Meteorology

Daytime, afternoon: Coast → (Sea breeze) → Inland

- **Inversions affect daily concentration**
  - ➔ **Large-scale subsidence inversion**
  - ➔ **Marine layer inversion**
  - ➔ **Diurnal variation of mixing height**

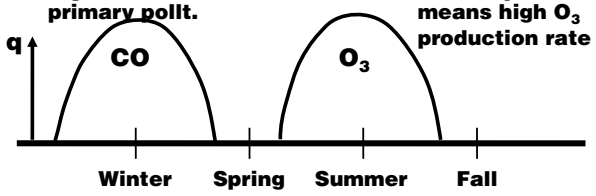
45

Seasonal Variation

	Sunlight Intensity	Air Temperature
Winter	Low	Cold
Summer	High	Warm

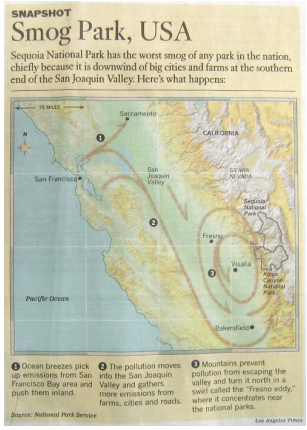
Low MH means high concen. of primary pollt.

High sun intensity means high O_3 production rate



Seasonal Meteorology

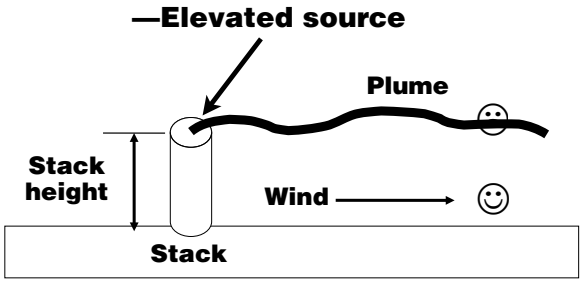
- **Winter**
  - ➔ **Low morning mixing height → high [CO] early in morning**
  - ➔ **Occasional storm helps clear the air**
- **Summer**
  - ➔ **Inversions very strong (LSSI + MI)**
  - ➔ **Warm, sunny afternoons → high [O_3]**


SNAPSHOT

Smog Park, USA

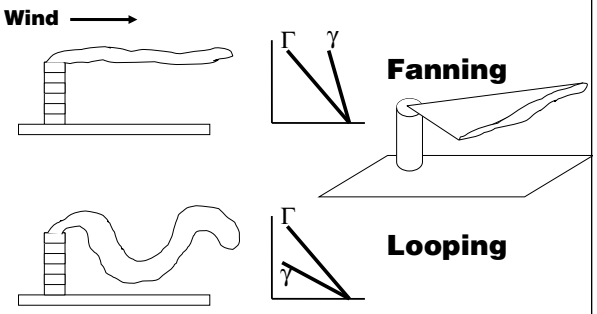
Sequoia National Park has the worst smog of any park in the nation, chiefly because it is downwind of big cities and farms at the southern end of the San Joaquin Valley. Here's what happens:

Chimney Plume Dispersion



49

Chimney Plume Types



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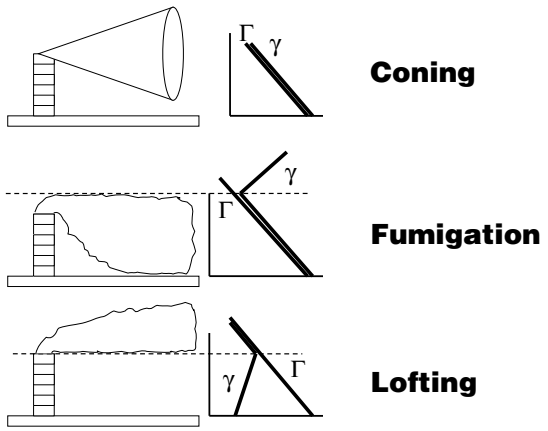
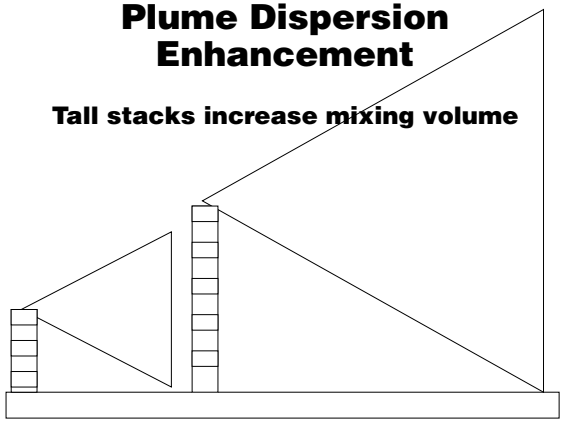


51

Plume Dispersion Enhancement

Tall stacks increase mixing volume



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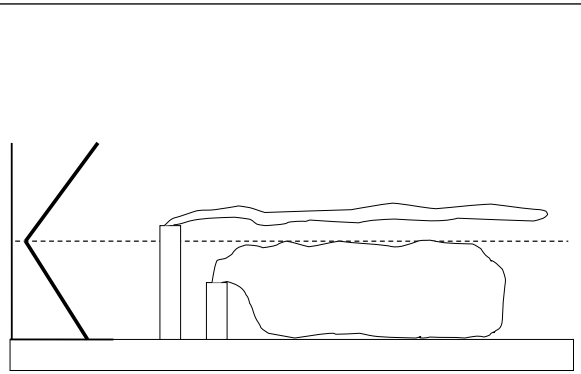

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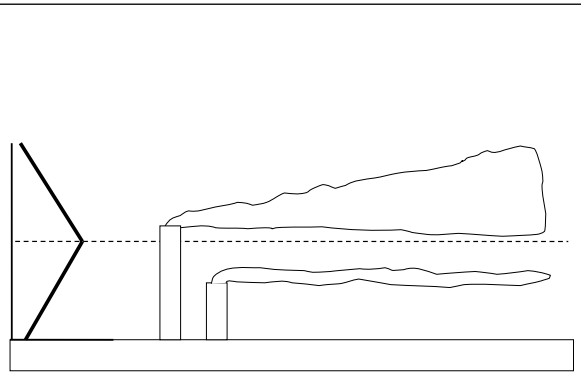

54

Artificial Enhancement