AIR POLLUTION AND CLIMATOLOGY

GEOG/ENST 3331 – Lecture 11

Ahrens: Chapter 18; A&B: Chapter 14; Turco: Chapter 5

Assignment 5

- What gas is the major form of carbon in the atmosphere? What are the two main sinks for removing this carbon from the atmosphere?
- How is the hydrologic cycle linked to other biogeochemical cycles discussed in class? In other words, how would they be affected if the hydrologic cycle were interrupted?

Last week

- Reservoirs
  - Box models and fluxes
- Global chemical cycles
  - Water
  - Carbon
  - Oxygen
  - Nitrogen
  - Sulfur


FUMIFUGIUM:
OR
The Inconveniencie of the AER
AND
SMOAK of LONDON
DISSIPATED.
TOGETHER
With some REMEDIES humbly
PROPOSED
By J. E. Esq;
To His Sacred MAJESTIE,
AND
To the PARLIAMENT now Assembled.

Published by His Majesties Command.

Lucret. l. 5.
Carbonúmque gravis vis, atque odor insinuatur
Quam facile in cerebrum? ——

LONDON,
Printed by W. Godbid for Gabriel Bedel, and Thomas Collins, and are to be sold at their Shop at the Middle Temple Gate neer Temple-Bar. M. DC. LXI.

John Evelyn, 1661
Fumifugium, or,
The inconveniencie of the aer and smoak of London dissipated together

Air Pollution

- Sources and receptors
- Dispersion
- Climate and pollutants
- Case study

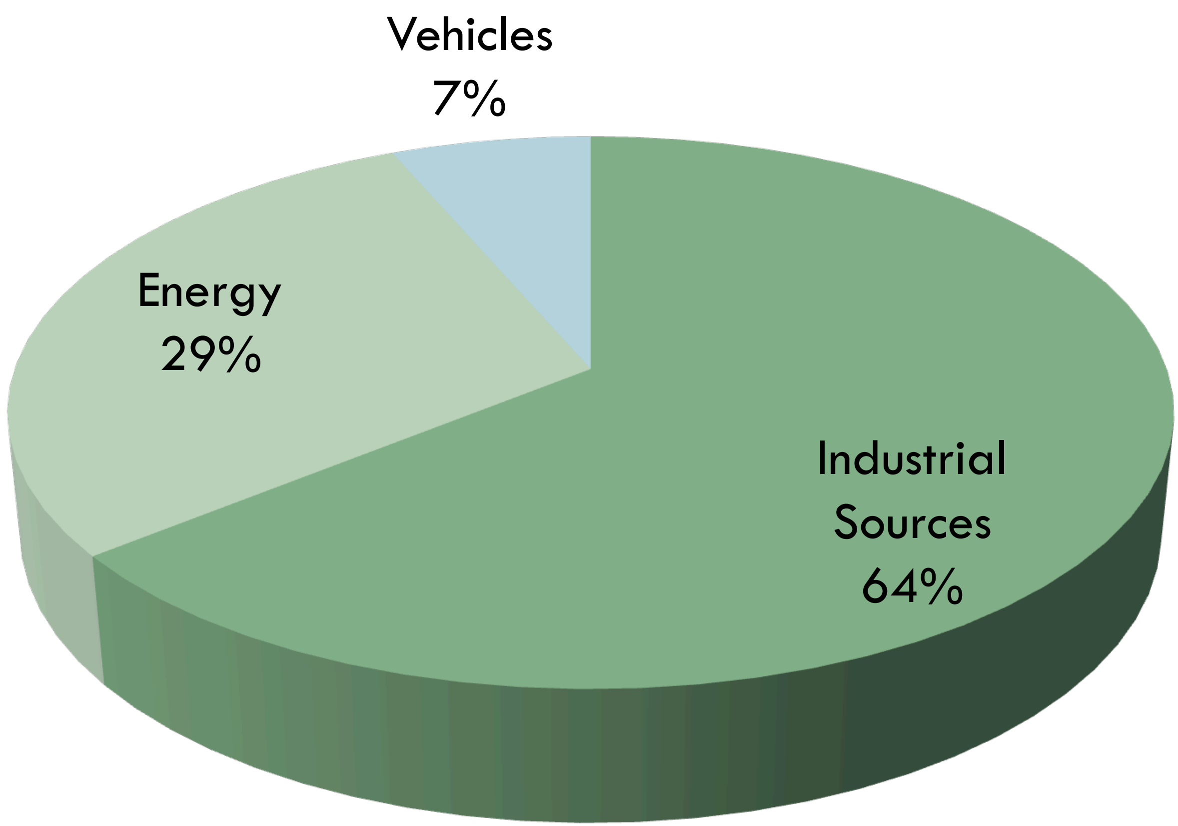
Pollutants

- Direct, harmful effects on living organisms
- Primary pollutants
  - Emitted directly into the environment
- Secondary pollutants
  - Generated in the atmosphere over time
  - Derived from primary pollutants

Primary pollutants

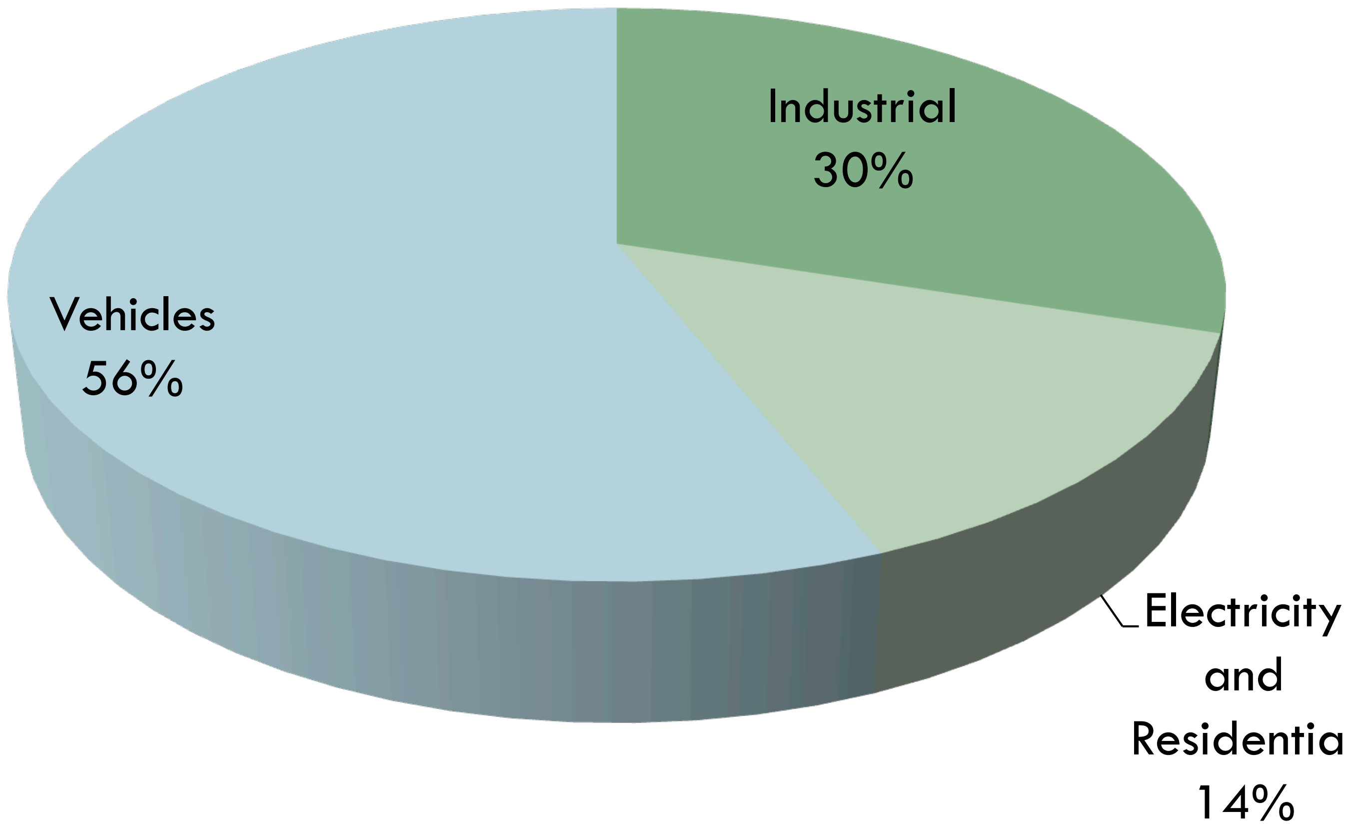
Pollutant	*Full Name*	*Sources*
CO	Carbon Monoxide	Combustion
SO_2	Sulfur dioxide	Coal, oil, smelters, refineries, paper mills
NO_x	Nitrogen oxides	Vehicles, power plants, waste disposal
VOCs	Volatile organic compounds	Industrial processes, vehicles
PM	Particulate matter	Industrial processes, vehicles

Major SO_x Sources



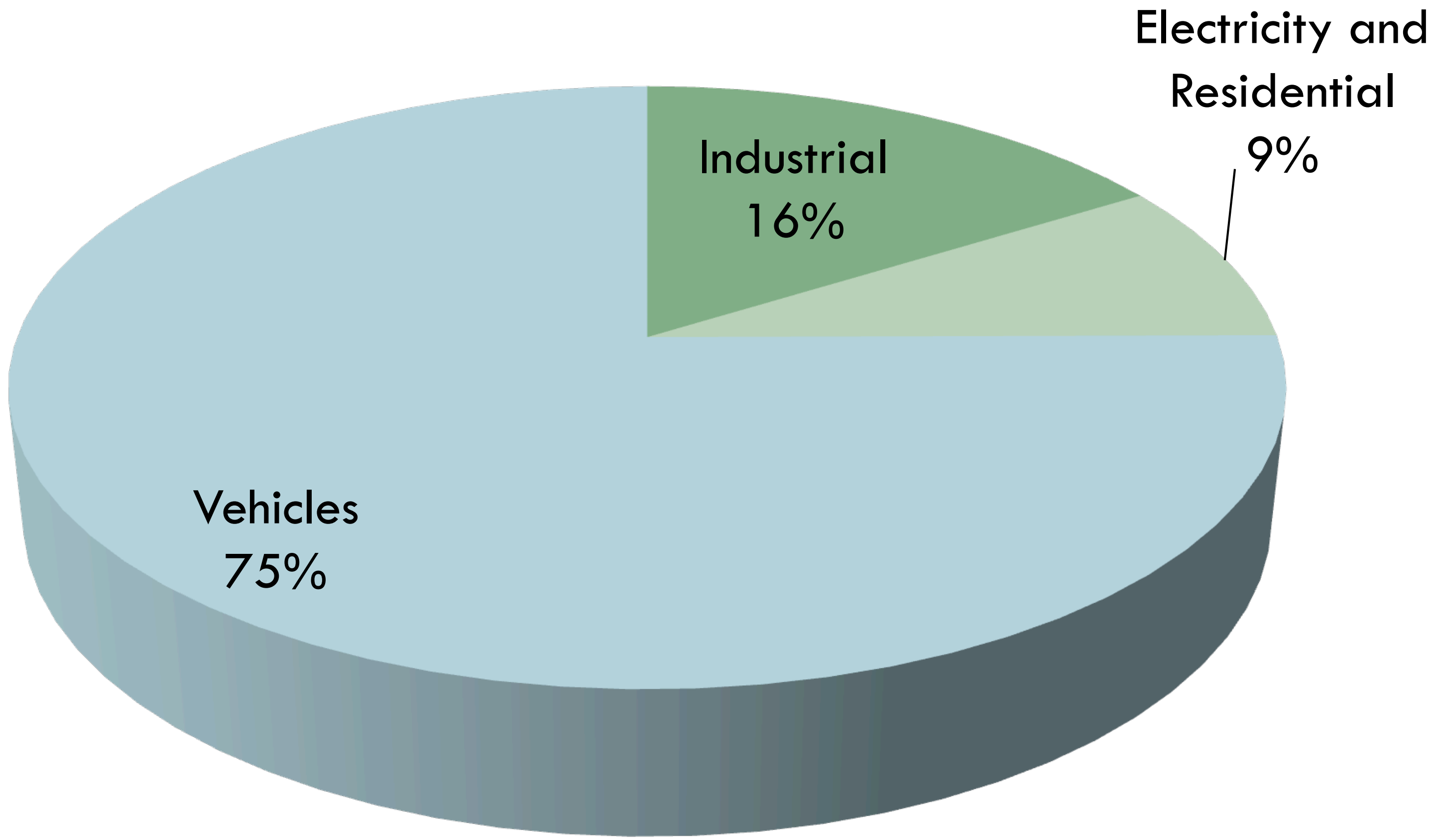
Source: Environment Canada National Pollutant Release Inventory

Major NO_x Sources

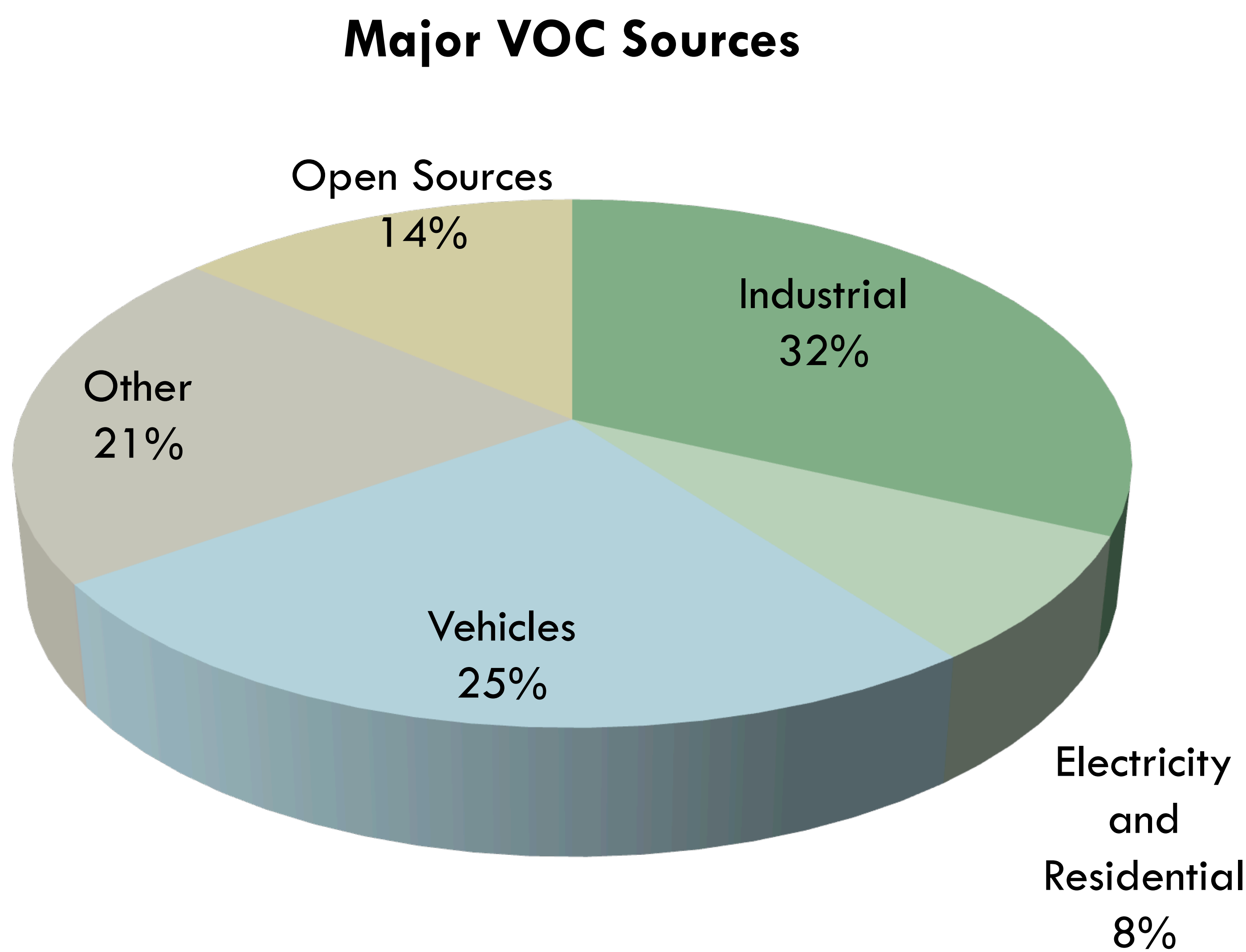


Source: Environment Canada National Pollutant Release Inventory

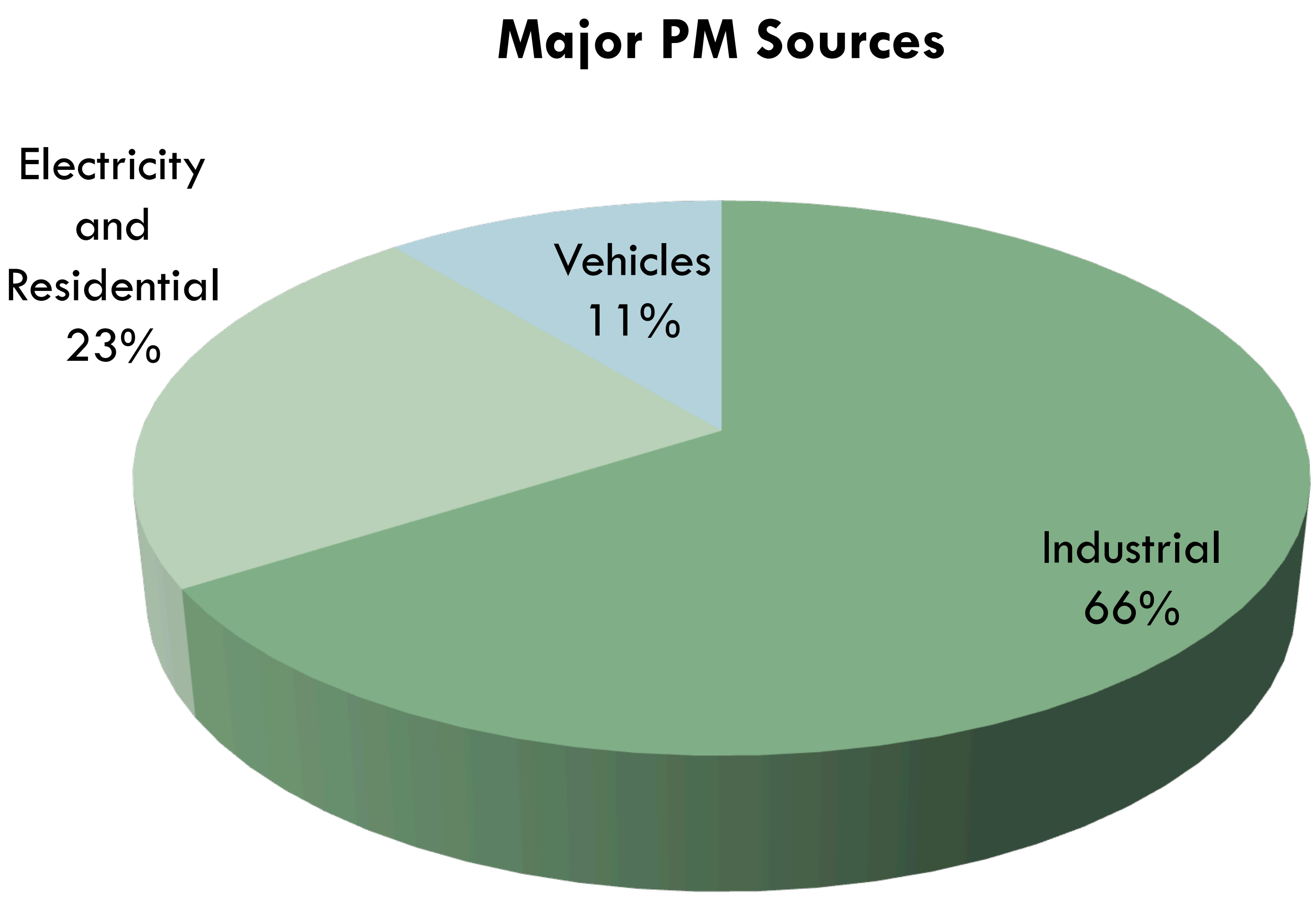
Major CO Sources



Source: Environment Canada National Pollutant Release Inventory



Source: Environment Canada National Pollutant Release Inventory



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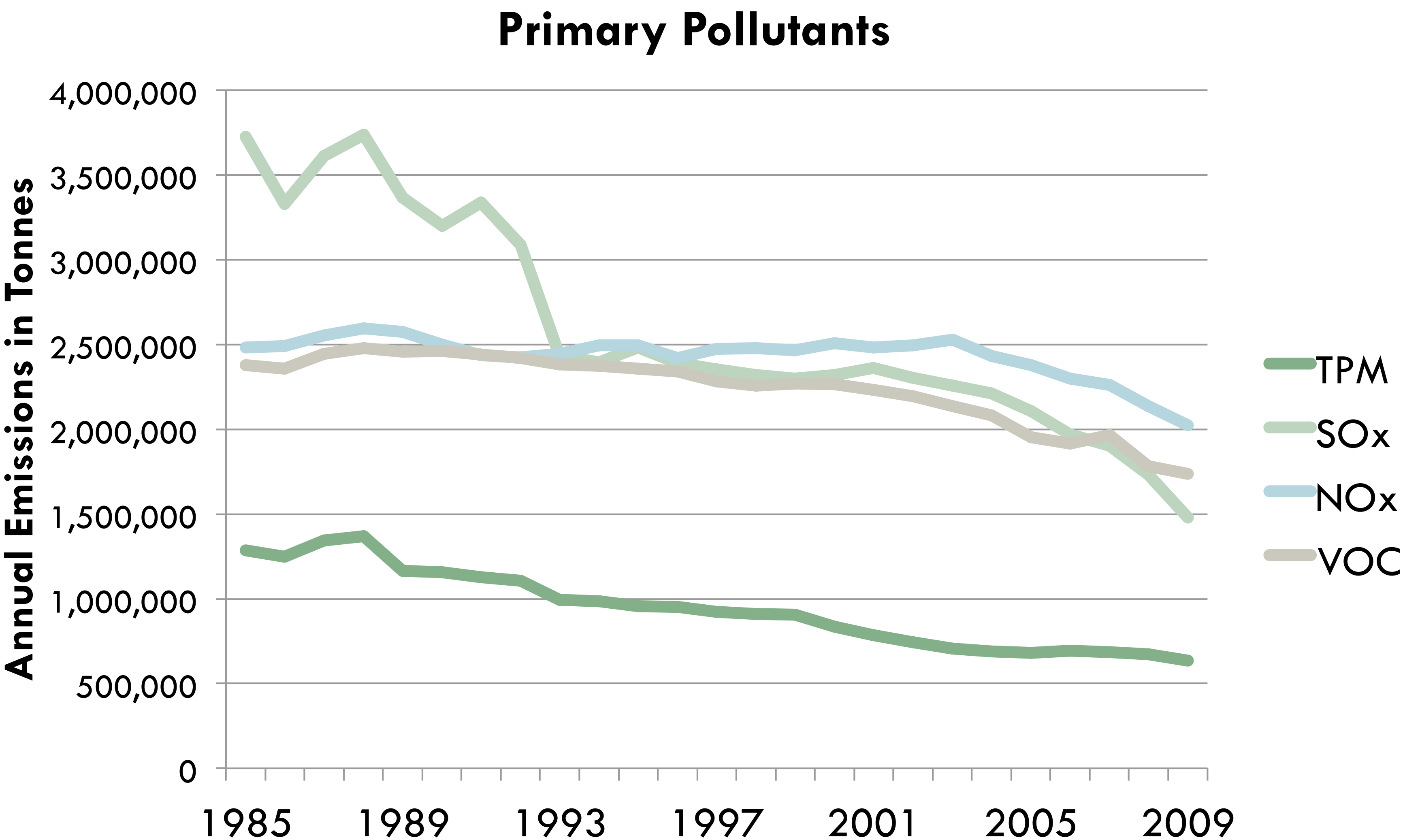


Source: Environment Canada National Pollutant Release Inventory

Secondary pollutants

Pollutant	*Full Name*	*Source*
O_3	Ozone	NO_x, VOCs
Smog		O_3, SO_2
PM	Particulate matter	Primary pollutants
VOCs	Volatile organic compounds	Primary pollutants

Characterizing Sources

- Point source
  - Localized, e.g. smokestack
    - SO_x
- Distributed source
  - Relatively large, continuous, e.g. agriculture, landfill
    - VOCs
  - Cluster of point sources, e.g. road network
    - No_x
  - Is Thunder Bay a Point source or Distributed source?

Characterizing Receptors

- Areas receiving pollutants
- Impacts depend on
  - Vulnerability
  - Concentration and total amount of pollutant received
    - Size
    - Distance from source
    - Dispersal of pollutant
- Role of atmospheric processes

Pollutant dispersion

- "The solution to pollution is dilution"
- Contributing processes:
  - Diffusion, Turbulence, Advection, Convection

Diffusion

- "Drunken walk" – Random movement of gas molecules
- Spatial distribution of a gas in the air becomes more uniform as time passes

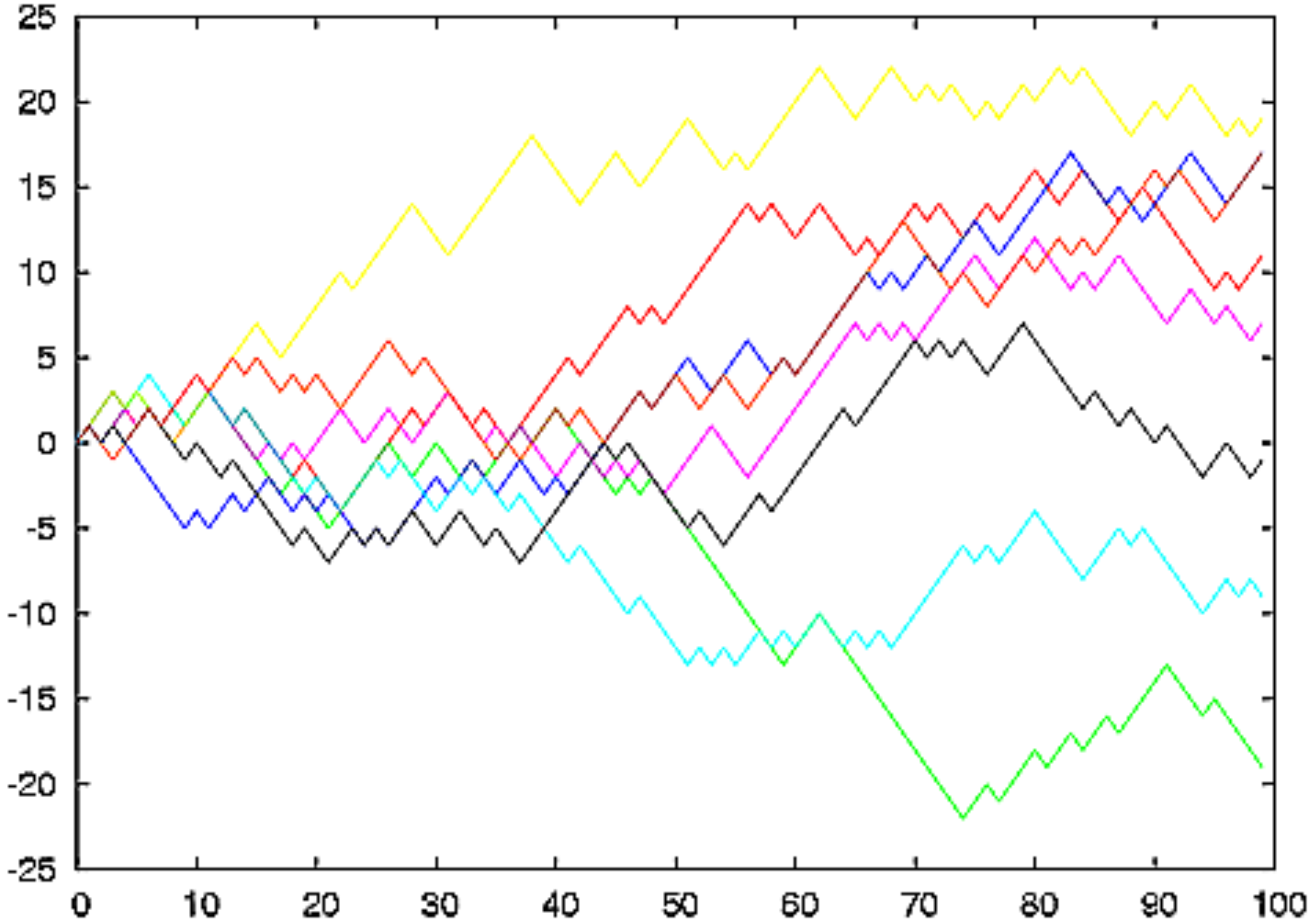
Diffusion

- Movement of a gas molecule through the air is random
  - "Drunken walk"
  - The net distance that a gas molecule travels *away from the starting point* increases as time passes

- The spatial distribution of a gas in the air becomes more uniform as time passes

Eight random walks from zero

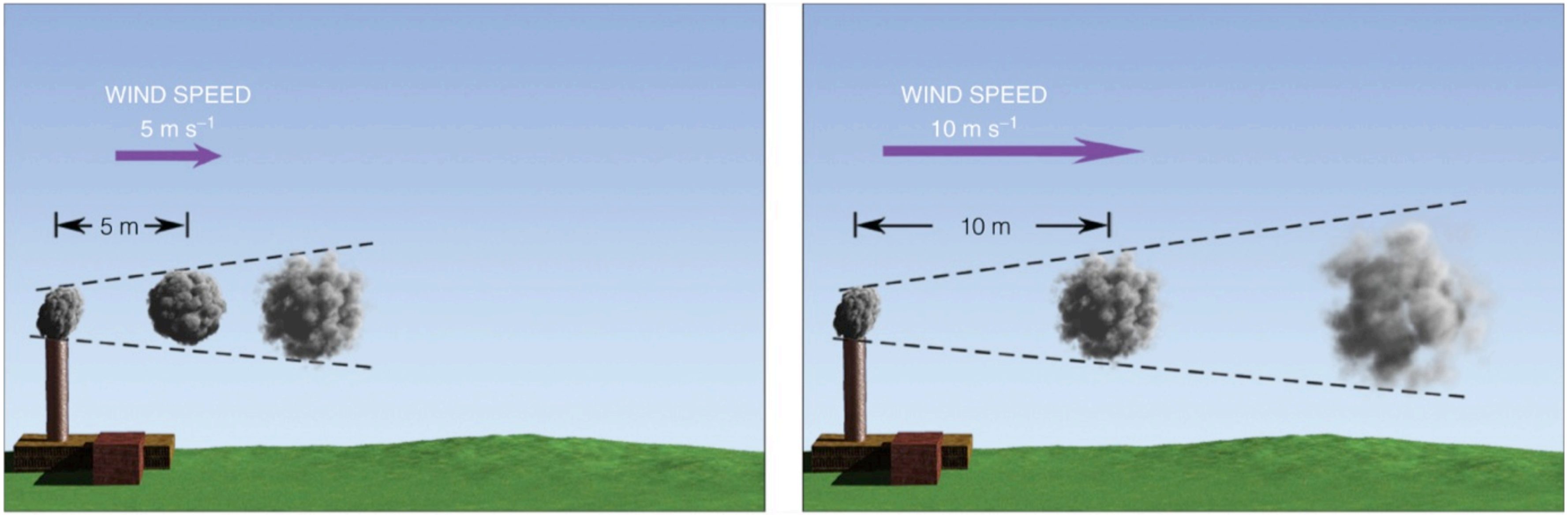
Source: *Chemistry Daily*



time

Horizontal dispersal: advection

- Long range transport via winds
- Faster winds increases horizontal dispersal
  - Also increases turbulent mixing

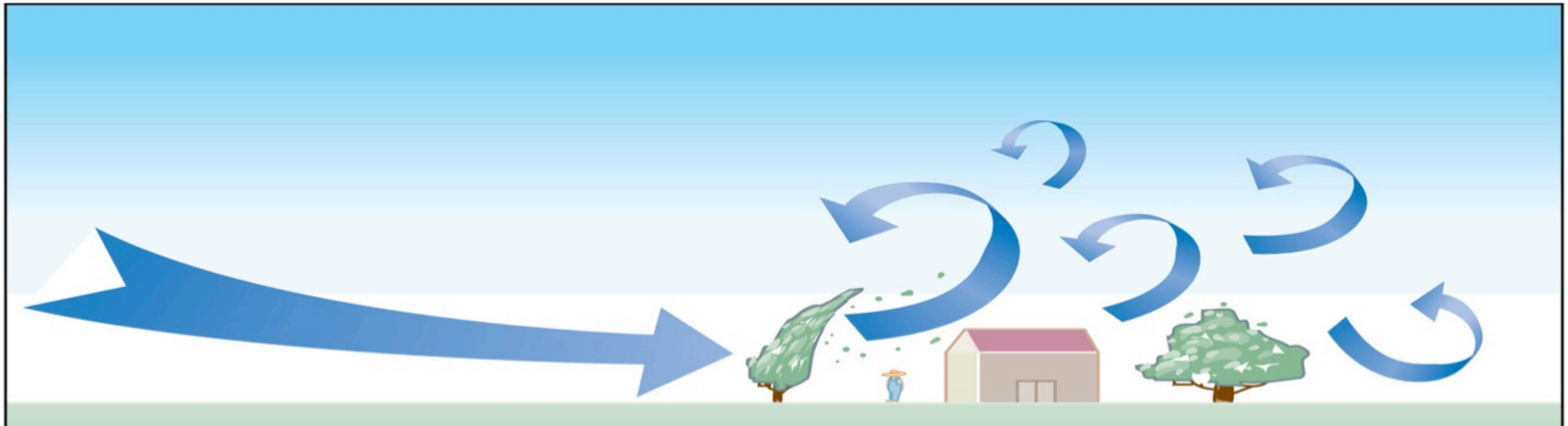


(a) (b)

Ahrens: Figure 18.11

Vertical dispersal: Turbulence

- Atmospheric turbulence (eddies) contributes vertical mixing
- Caused by friction
  - Greater surface roughness means greater turbulence
- Pollutants disperse faster if turbulence aids diffusion



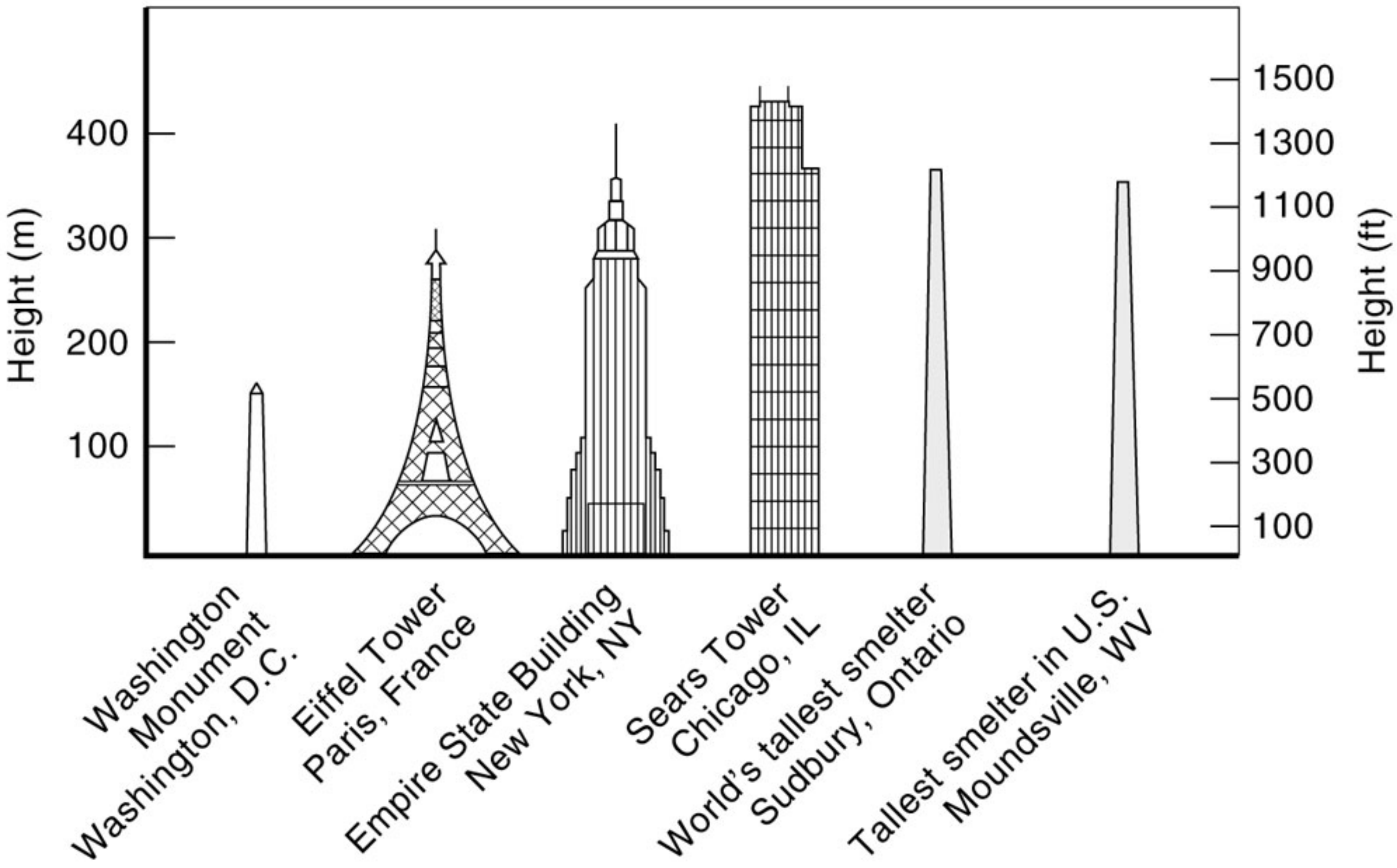
A&B: Fig. 3-13

Effect of chimney height

- Faster winds
  - Pollutants carried farther, sooner
  - Pollutants disperse more rapidly

- Farther away from surface
  - More time before surface receptors are affected
    - Greater distance travelled
    - Lower received concentration
  - "Superstacks" –answer to Sudbury's pollution problem?

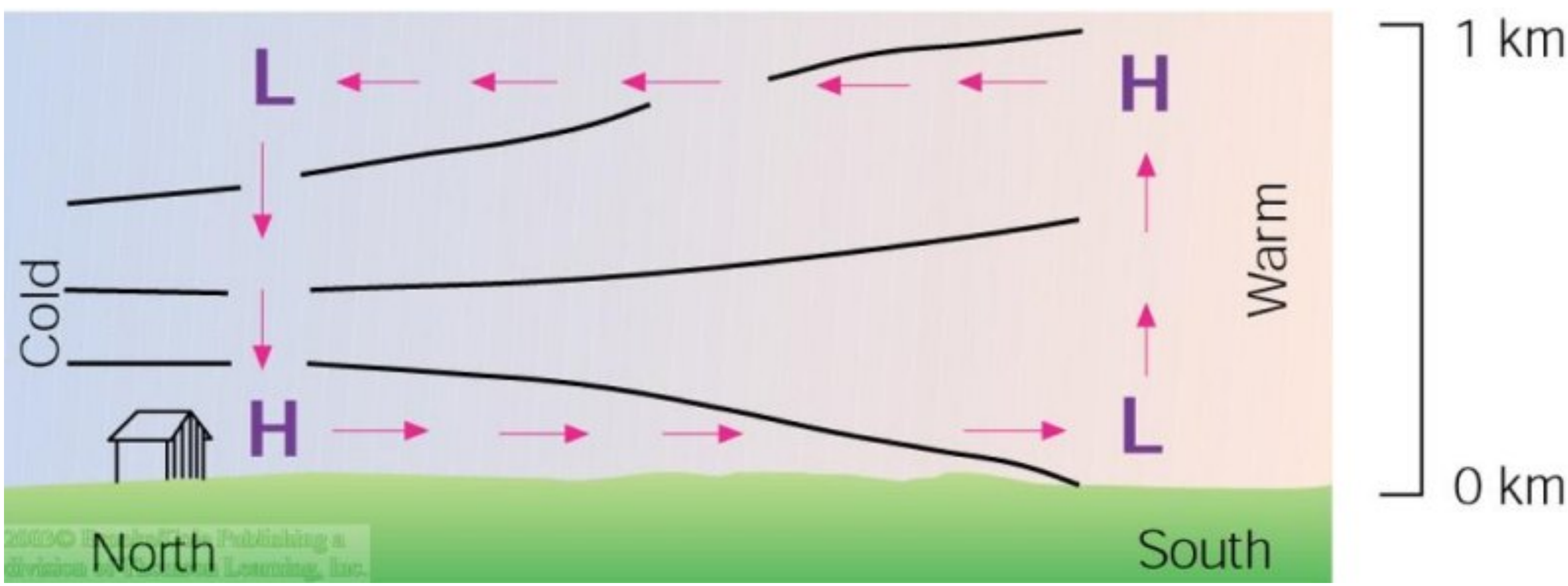
Tall stacks



H&K: Figure 8.19

Vertical dispersal: Convection

- Vertical mixing driven by surface heating
- Creates a 'mixed layer' of air near the surface
- Varies with surface temperature and atmospheric stability

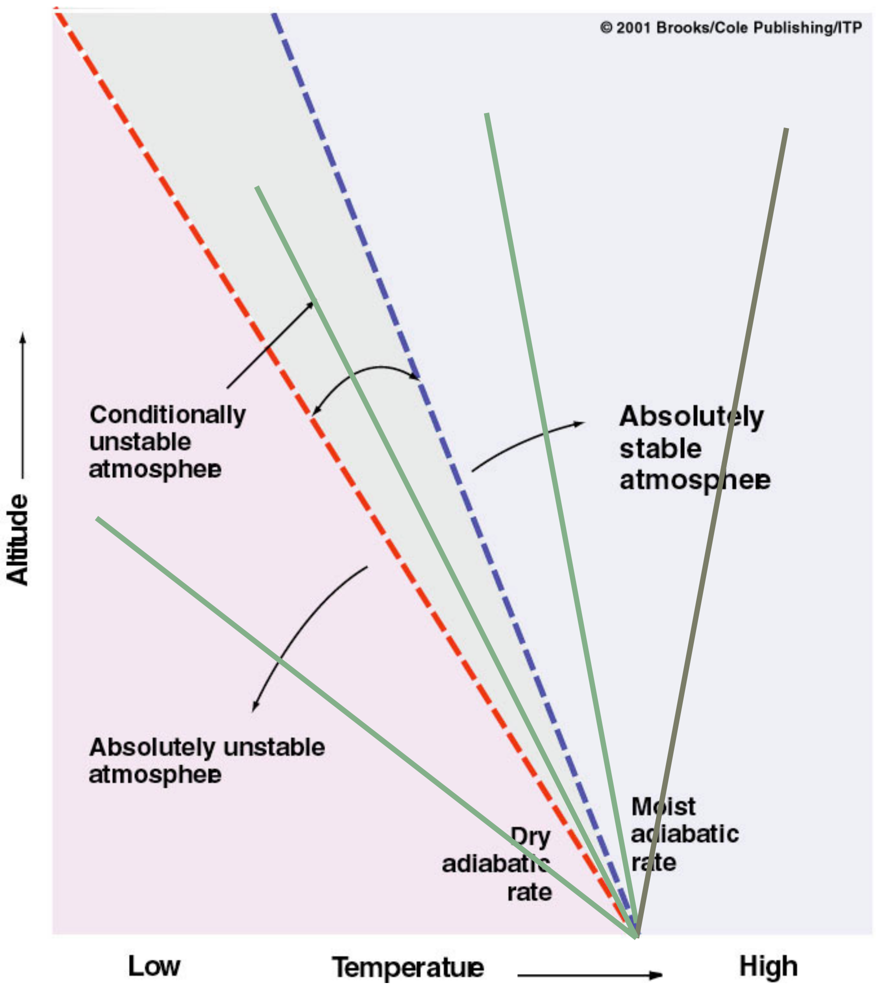


Ahrens: Fig. 9.12

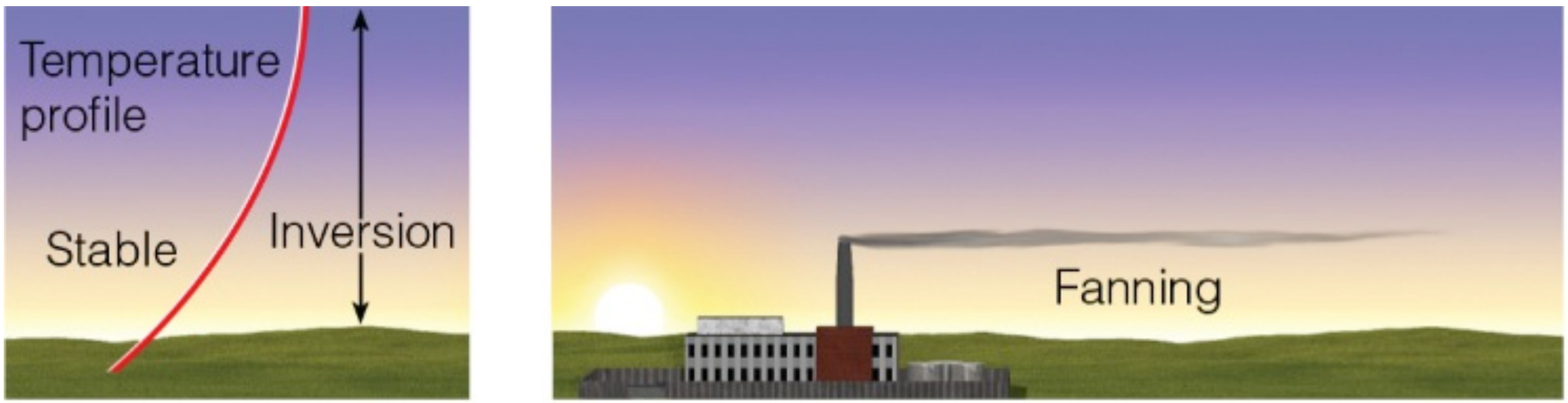
Atmospheric stability

- Unstable conditions enhance vertical mixing
- Stable conditions suppress vertical mixing

Atmospheric Stability



- Dry adiabatic lapse rate
  - 10°C/km
- Saturated adiabatic lapse rate
  - 5-6°C/km
- Environmental conditions



(a)

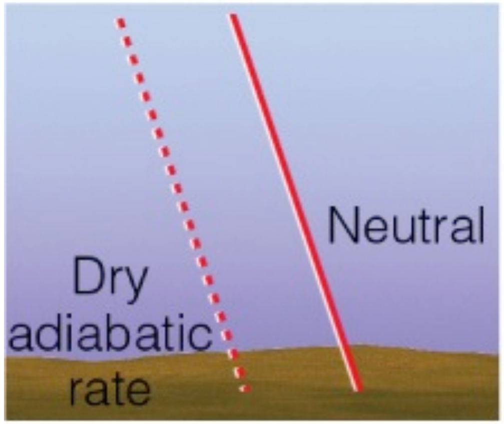
- Inversions common at night
- The smoke does not mix well and follows the prevailing wind.
    - ‘Fanning’
    - ‘Pooling’ if insufficient wind

(b)

- ❑Inversion gradually disappears due to surface heating
    - ❑Stable air over unstable air
- ❑Lots of mixing but only downward
    - ❑'Fumigation'

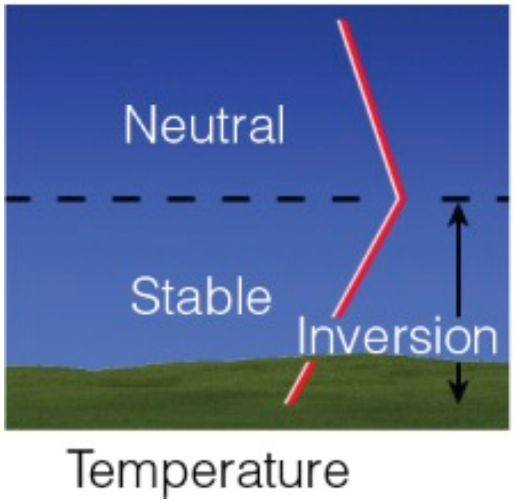
(c)

- Temperature structure is unstable throughout.
- Distribution of smoke follows convective cells.
    - ‘Looping’



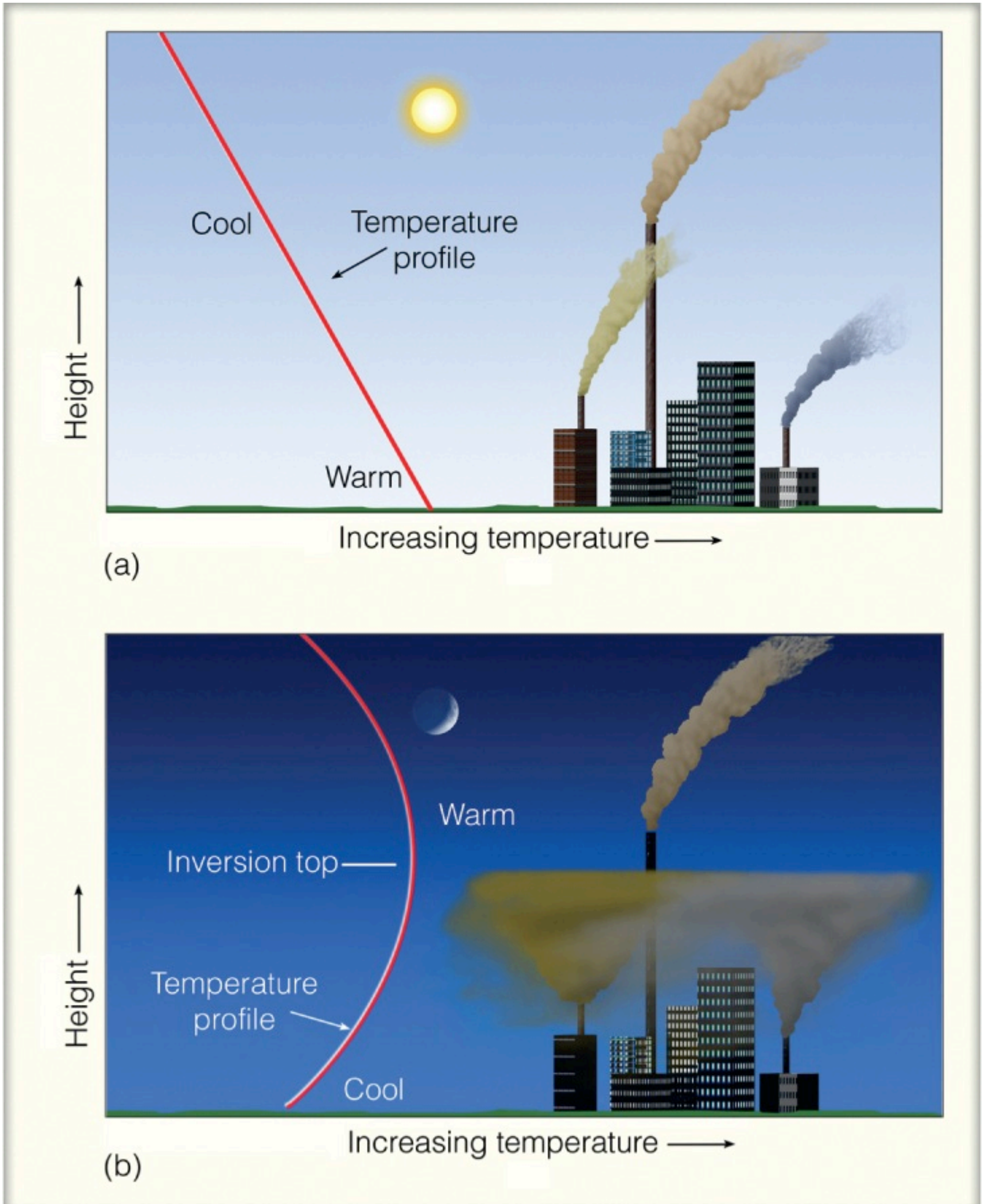
(d)

- ❑Mixing leads to neutral stability
- ❑Distribution of smoke in a narrow cone.
  - ❑'Coning'



(e)

- ❑Inversion gradually re-appears due to surface cooling
- ❑Unstable (or neutral) air above stable air
- ❑Downward mixing is suppressed
    - ❑'Lofting'

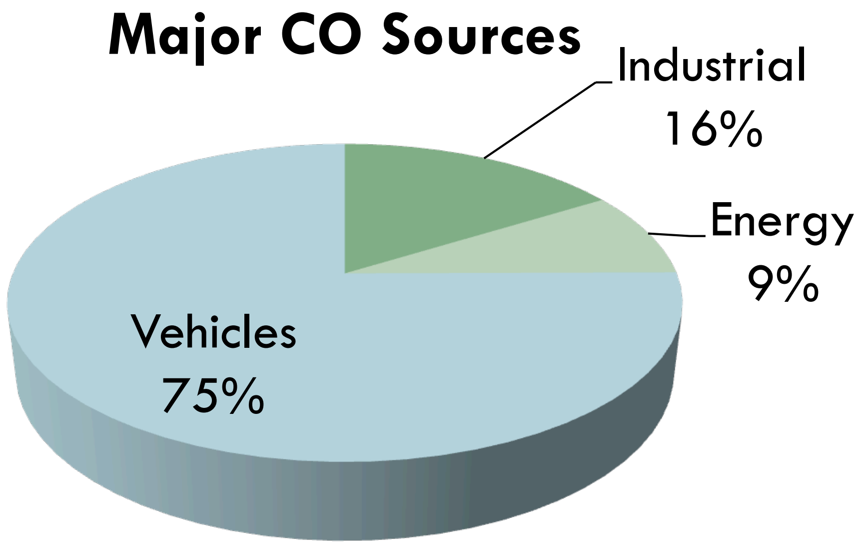


- Importance of the location and height of the smoke stack.
- A lower stack causes *fanning* or *pooling* of pollutants.
- Higher stacks cause *lofting* and pollution does not penetrate to surface levels.

Ahrens: Figure 18.12

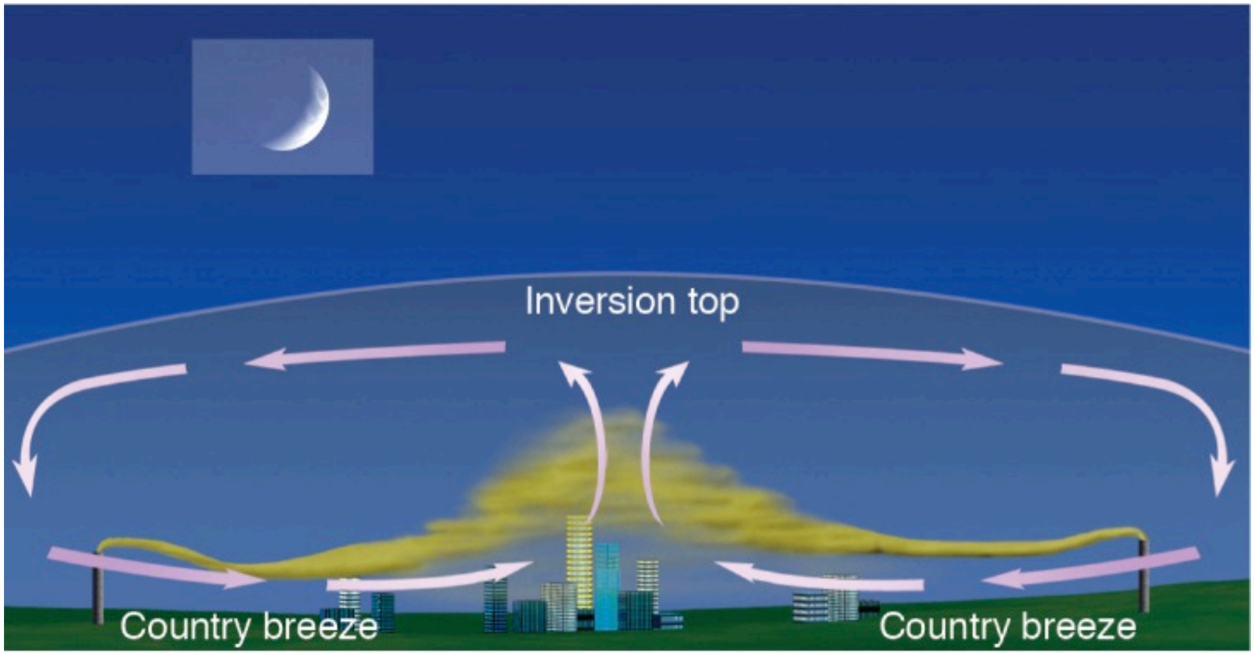
Ground plumes

- Many pollutant sources are at ground level
- Height of plume depends on distance and stability
- Can be a serious problem for toxic pollutants
  - E.g. CO



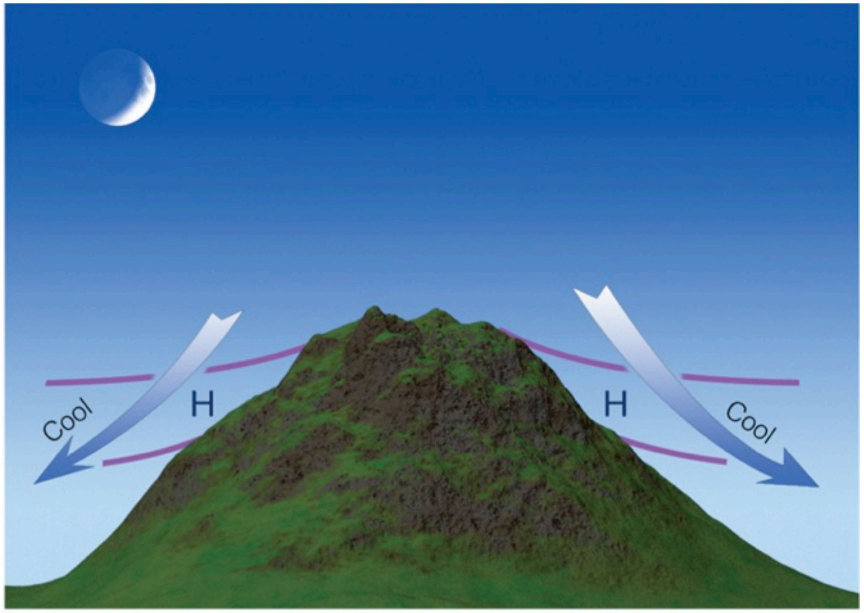
Country breeze

- Urban heat island
  - Cities retain more heat than surroundings
  - Induces a ‘country breeze’ at night
- Focuses pollutants and causes increase in vertical extent



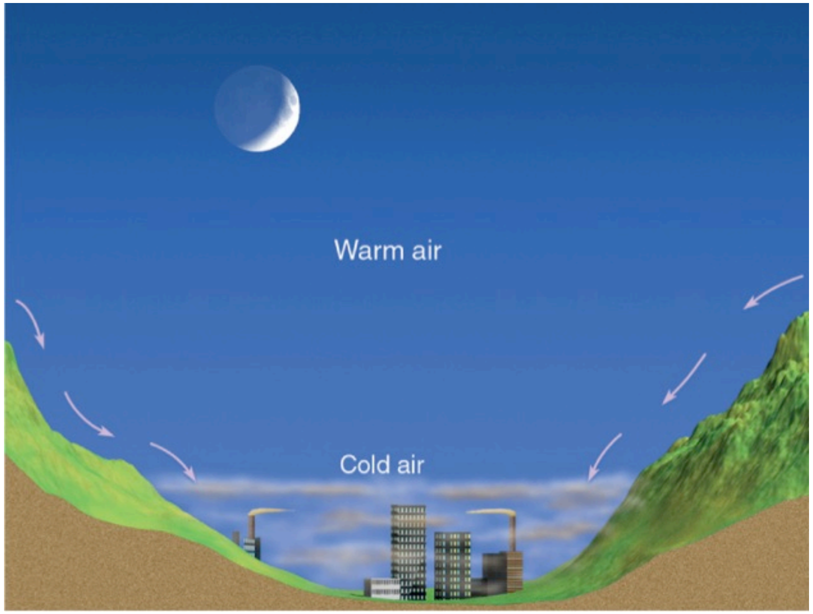
Ahrens: Fig. 18.16

Mountain breeze



Mountain breeze

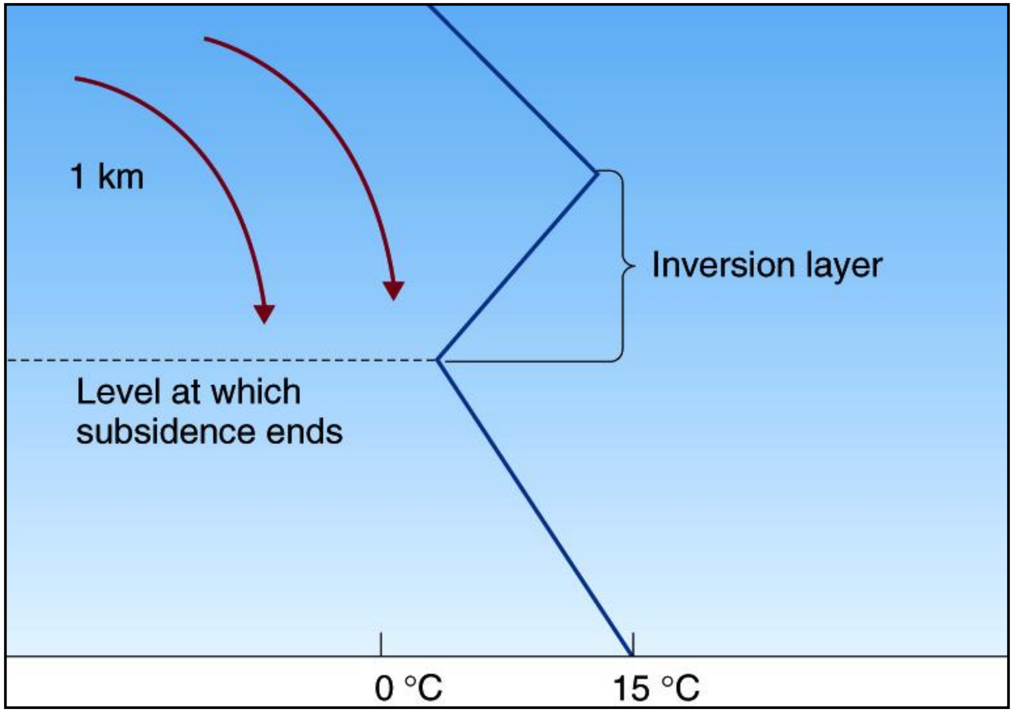
Ahrens: Figure 9.18



Ahrens: Figure 18.16

Subsidence inversion

- Warm air is less dense
- Lee side wind may be unable to push aside cold air

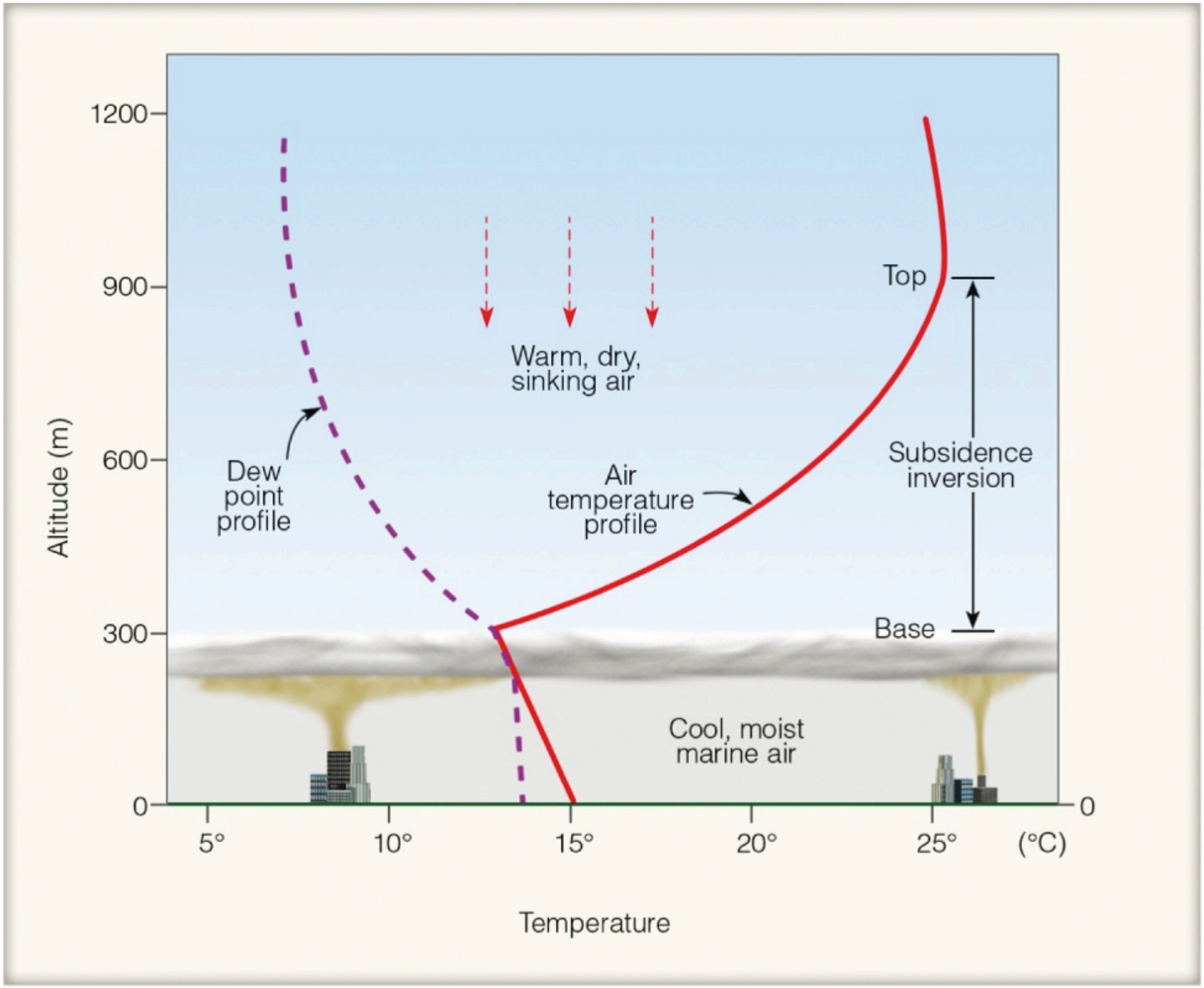


Marine inversion

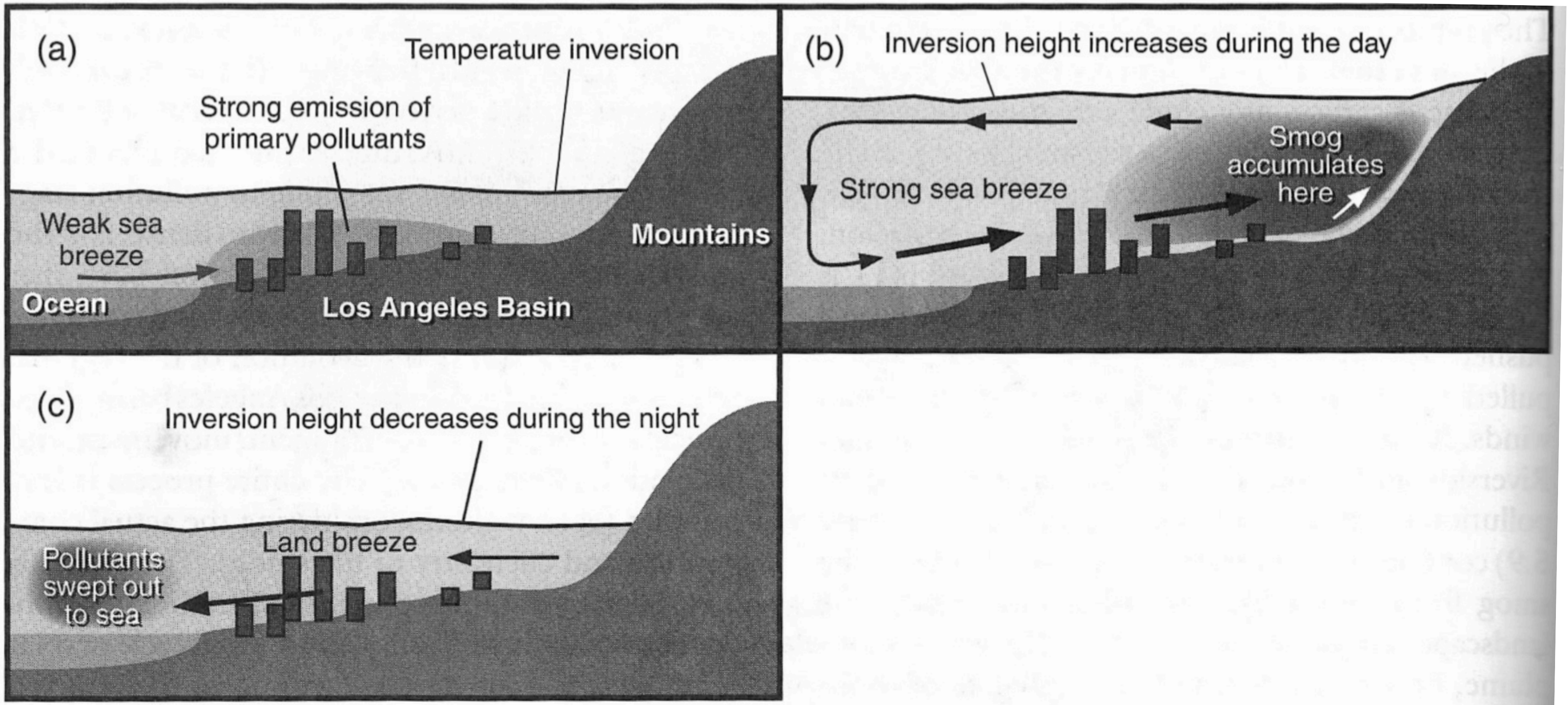
Sea breeze brings in cool air underlying rising warm air

Ahrens:

Ch. 5, Fig. 1



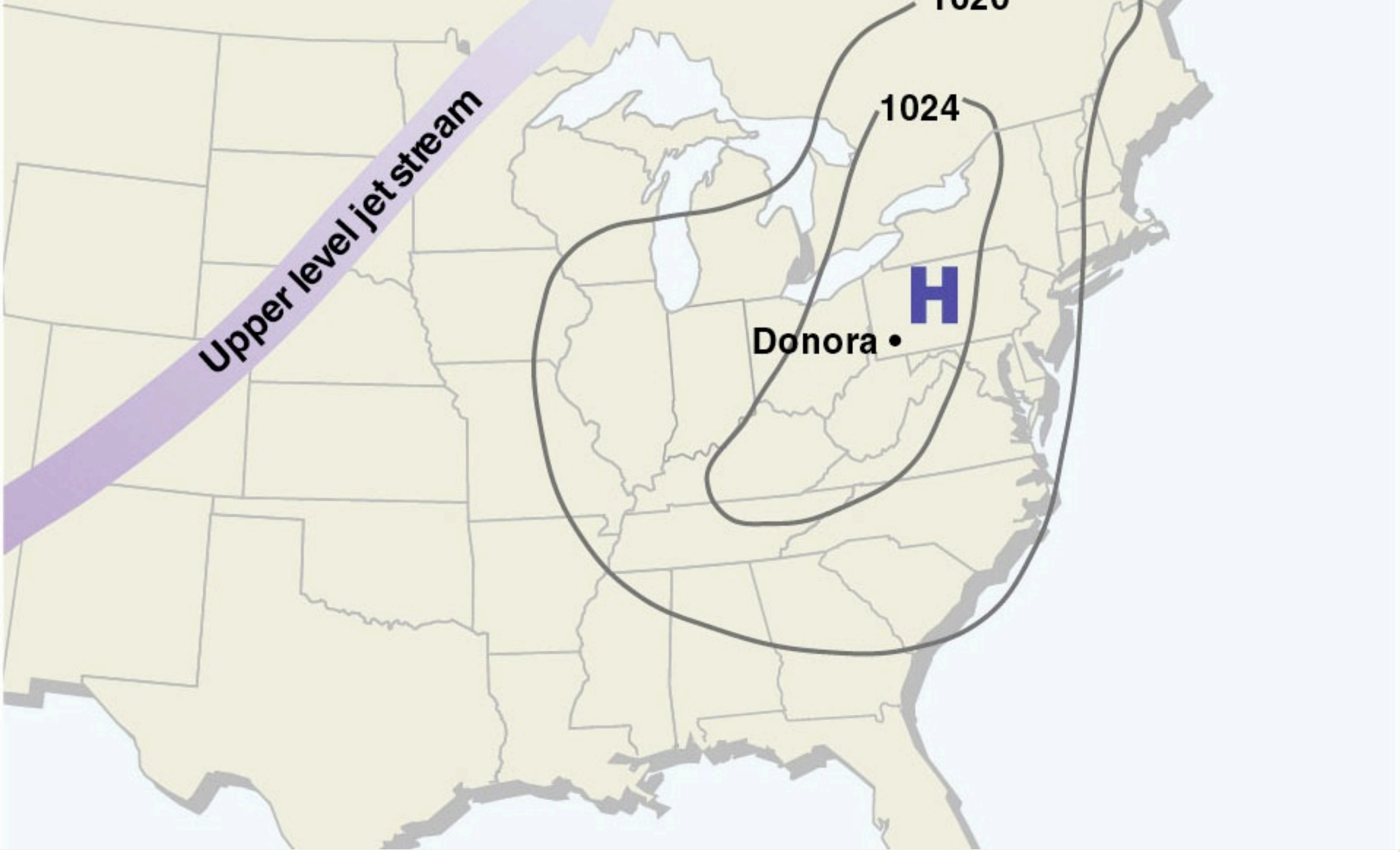
Los Angeles: the Bay of Smoke



Turco: Fig. 5.12

Case Study: Five days in Donora

- City in Pennsylvania
- 1948: population 14 000
- "Mill town"
  - Steel, zinc smelters
  - High emissions of SO_2, NO_x, F



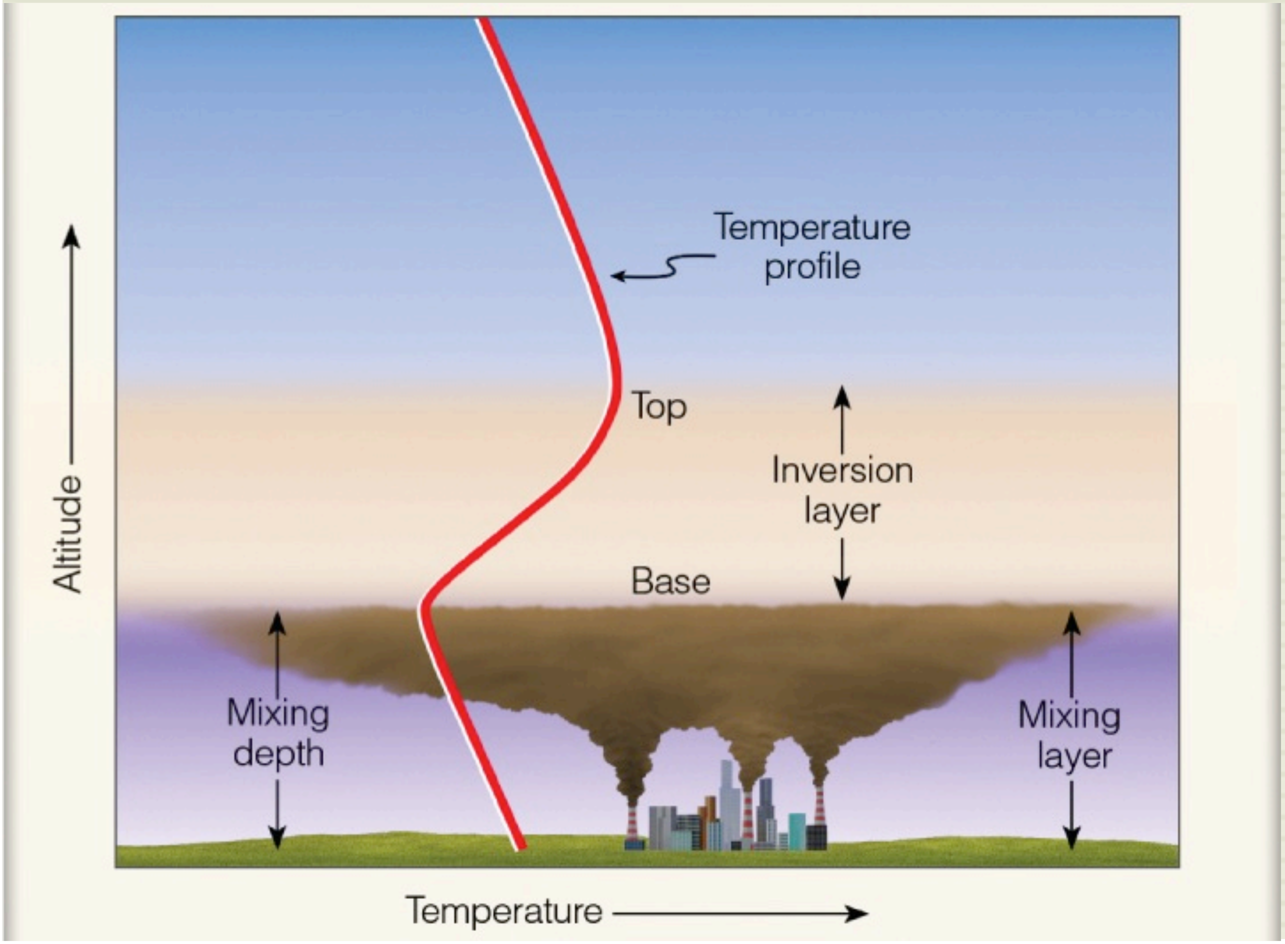
Donora, Pennsylvania

Persistent high pressure system for 5 consecutive days in 1948

Weak pressure gradients and light winds

High pressure in Donora

- Descending air
  - Traps pollutants near the surface
  - Low horizontal winds near the centre
- Clear conditions
  - Promotes radiative heating and night-time cooling
- Fog formed morning of first day
  - Valley location didn’t help; extra cool air at night
  - Blocked sunlight from reaching surface and prolonged temperature inversion



Inversion layer

Ahrens: Figure 18.13

High pressure in Donora

- Factories continued operation
  - SO_2 and particulates
- Toxic fog got thicker and thicker over five day period
- 22 deaths in community of 14 000
- Finally, storm cleared the air

- 10 years later, still experienced higher than normal mortality rates

Next lecture

- Air quality

- Ahrens: Chapter 18
- A&B: Chapter 14
- Turco: Chapter 5