Lecture 4
Air Pollution: Particulates

METR113/ENVS113

SPRING 2011

MARCH 15, 2011

Reading
(Books on Course Reserve)

- Jacobson, Chapter 5, Chapter 8.1.9
- Turco, Chapter 6.5, Chapter 9.4
- Web links in following slides …
- Web links in Assignment #2

Terminology

- **Particulates**
  - An air pollutant that is not a gas
  - Liquid or solid
- **Aerosol**
  - “Suspended” particulate
  - Small in size
- **Droplet**
  - Liquid
  - Relevant to air pollutant dissolved in water (acid rain, acid fog)
  - Rain, cloud, fog, haze (“hydrometeors”)

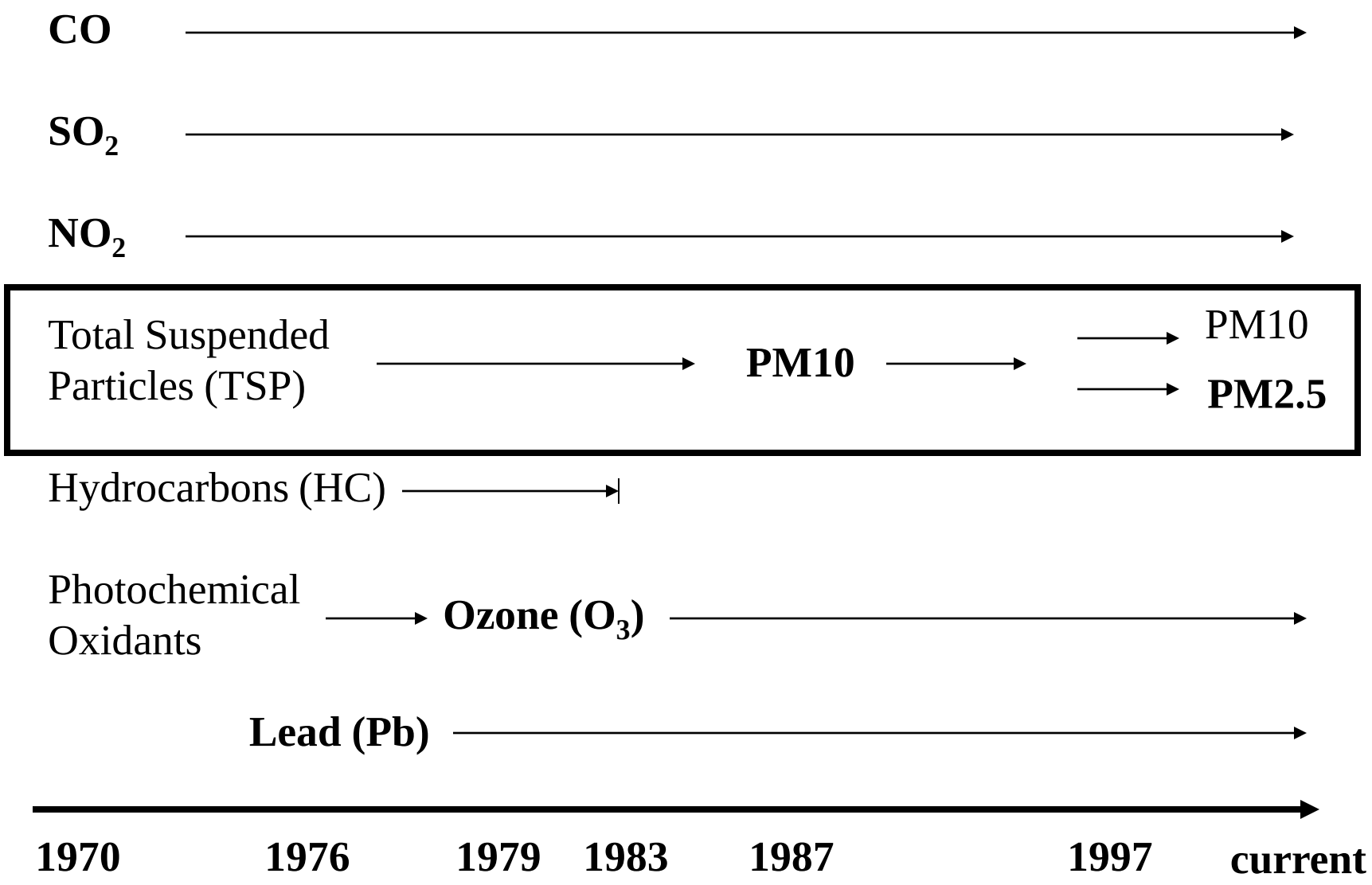
Characterization

- By **size**
  - PM10 – Amount (by mass) of particulate of "diameter" ≤ 10 μm
  - PM2.5 – Amount (by mass) of particulate of "diameter" ≤ 2.5 μm
  - Regulatory (EPA, CARB, etc …) characterizations

- By **chemical make-up** (some important examples …)
  - Sulfates
  - Nitrates
  - PAH (Polycyclic Aromatic Hydrocarbons)
  - Soot ("Black" Carbon, "Elemental" Carbon)
  - Asbestos (an indoor pollutant, not so important in outdoor ambient air)
  - Organic Carbon (includes PAH and others …)
  - Inorganic (Sulfates, Nitrates, Metals, others …)

- By **source**
  - Road dust, Sea spray
  - Diesel particulate matter (regulated by CARB)

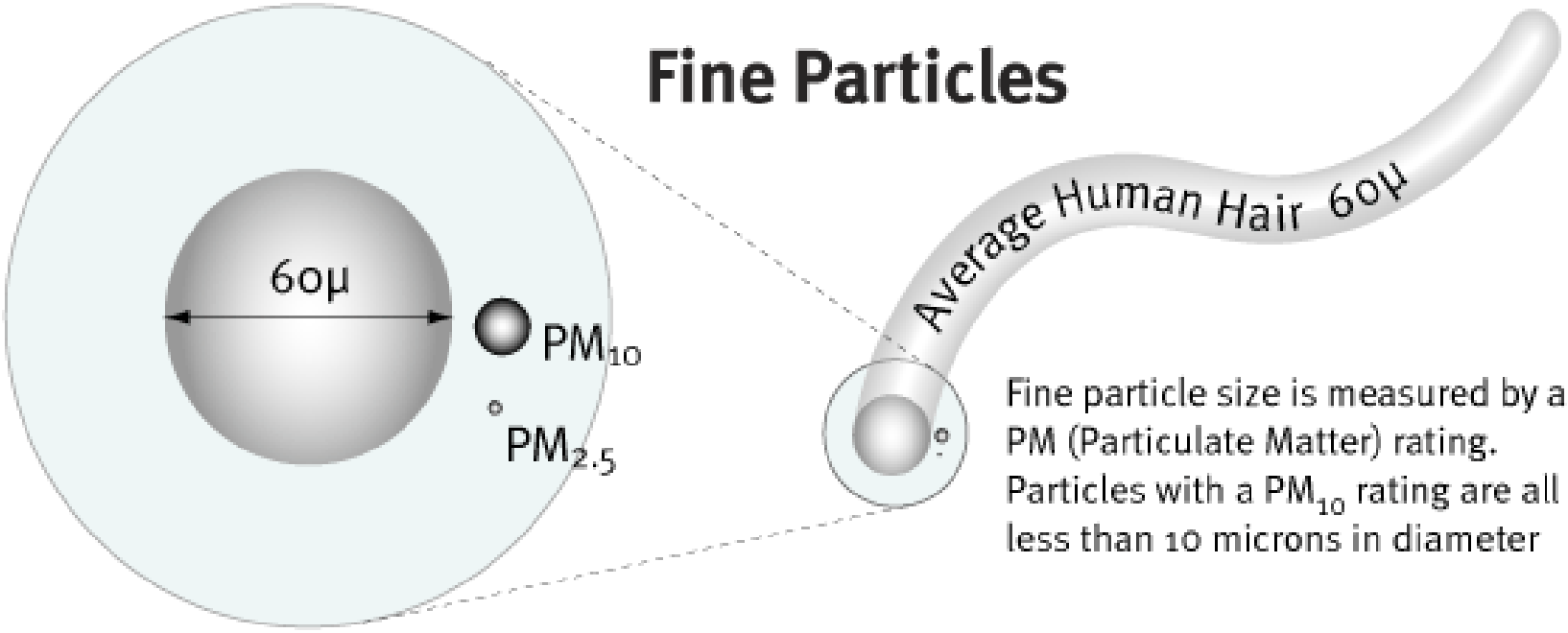
Timeline: Regulation of Criteria Pollutants



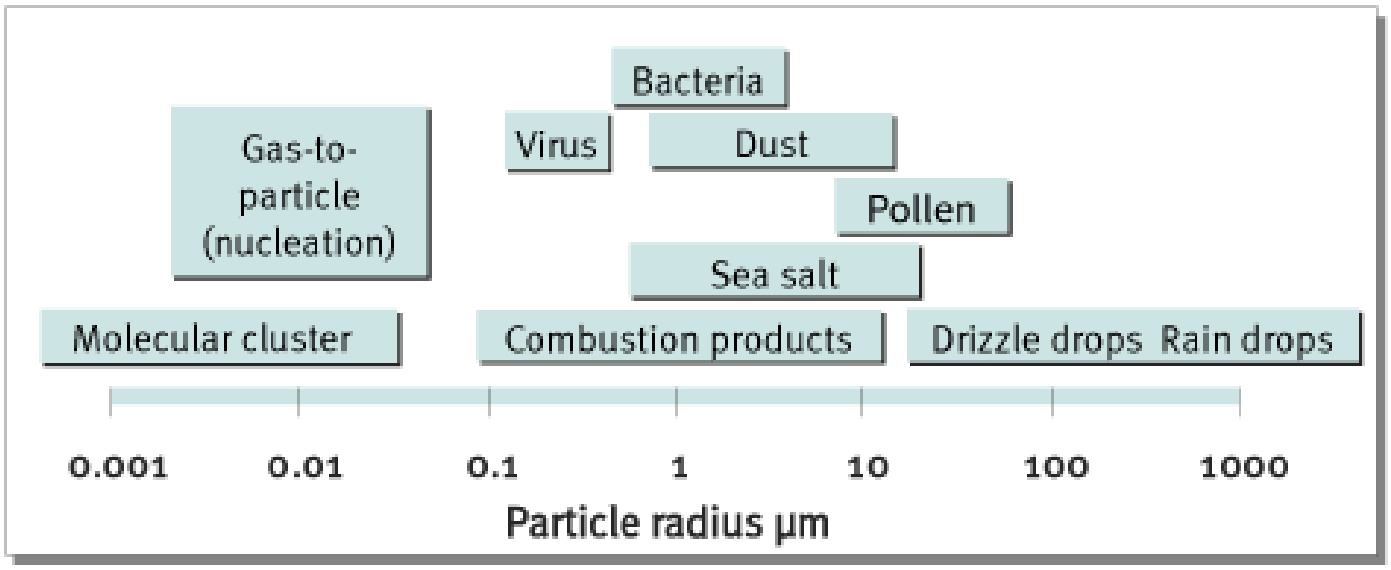
PM10 & PM2.5

- NAAQS and State Ambient Air Standards
- PM10
  - Total particulate mass less than 10 μm in diameter
  - “Respirable” particulate
  - Able to penetrate past nasal cavity into throat and lungs
- PM2.5
  - Total particulate mass less than 2.5 μm in diameter (a subset of PM10)
  - “Fine” particulate
  - Penetrates deep into lungs and may even penetrate into bloodstream
  - Evidence increasingly building that PM2.5 is the main danger to human health (rather than PM10)

Fine Particles

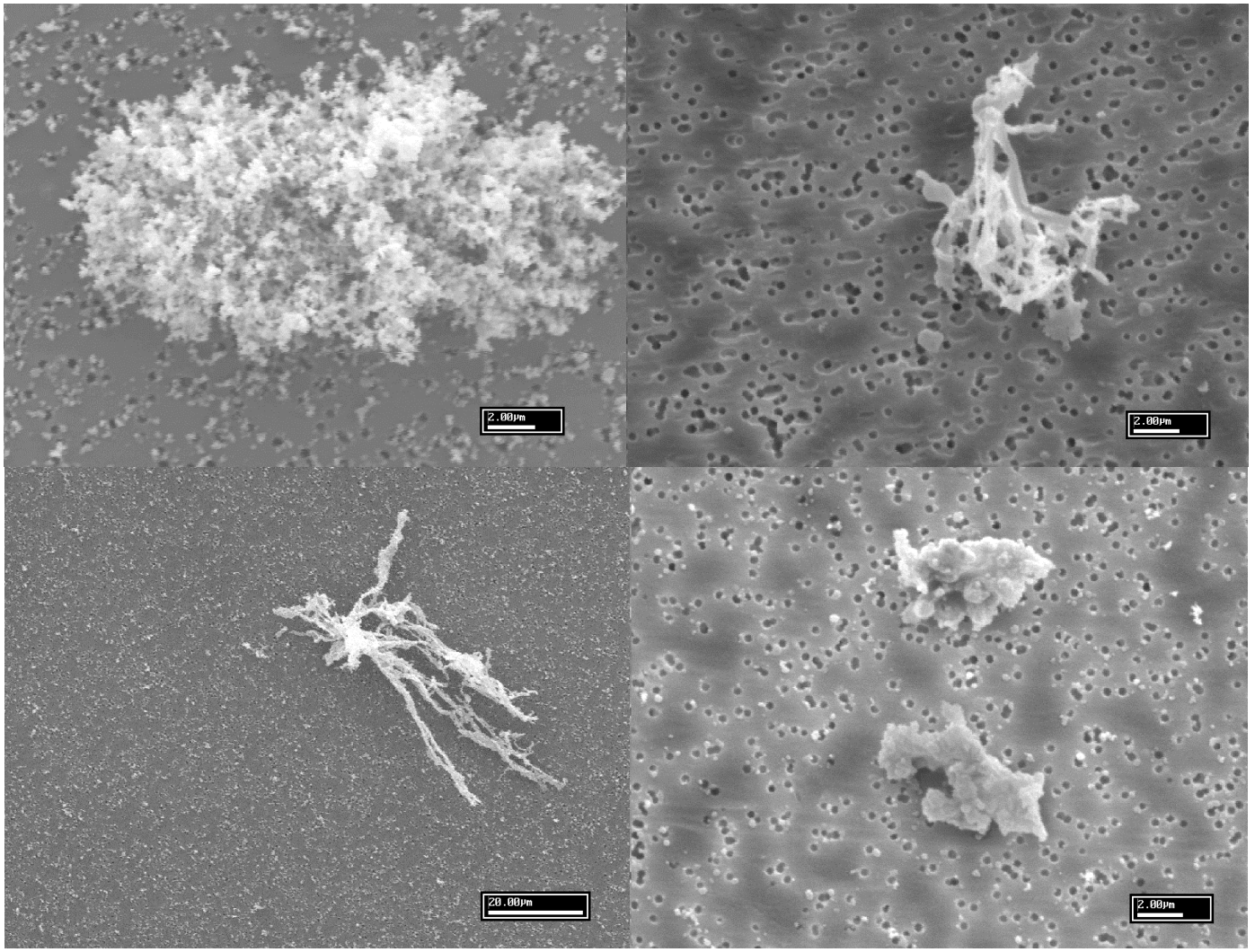


Fine particle size is measured by a PM (Particulate Matter) rating. Particles with a PM_{10} rating are all less than 10 microns in diameter



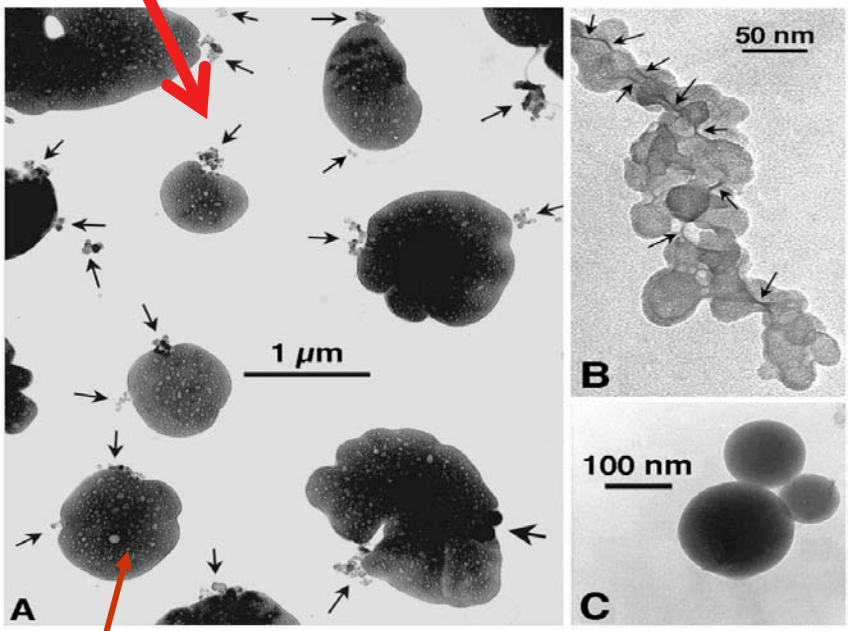
Queensland Government
Environmental Protection Agency

Ash, Combusted Plant Fiber, Elongated Ash, Soil Dust

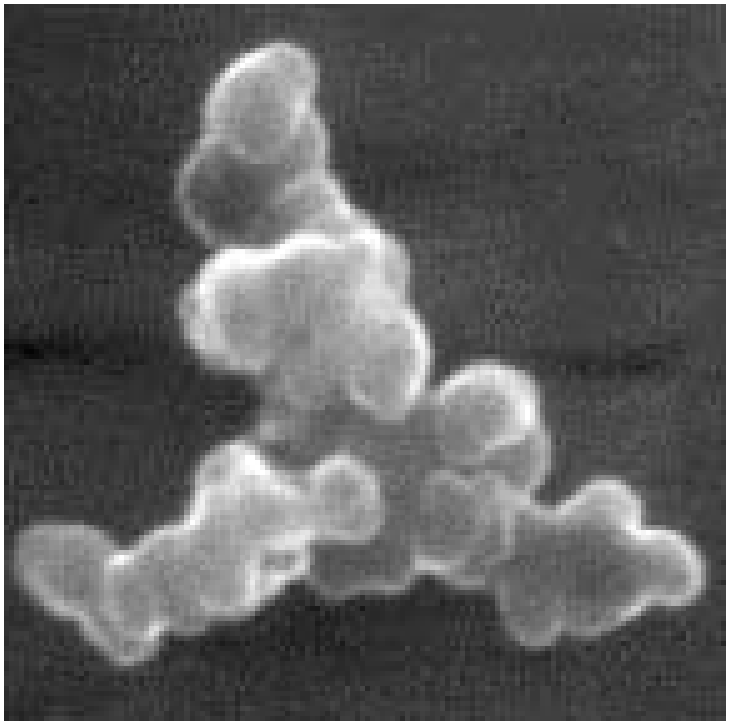


Soot Particles

Soot inclusion

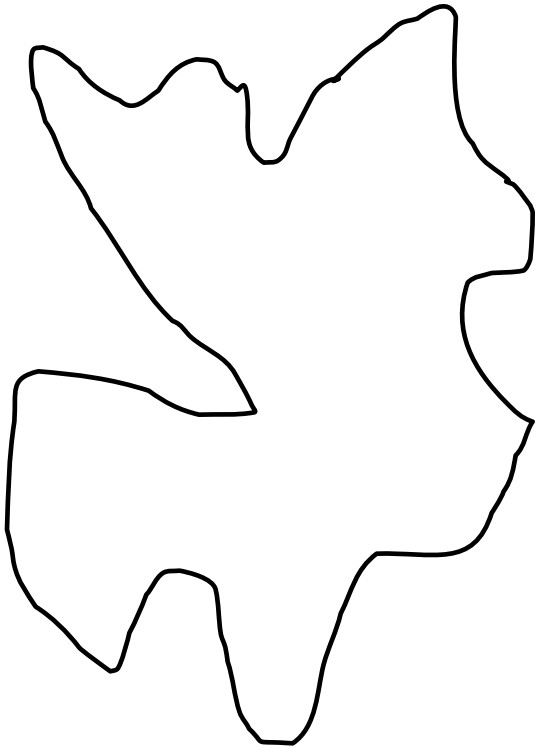


Coated Soot Particle

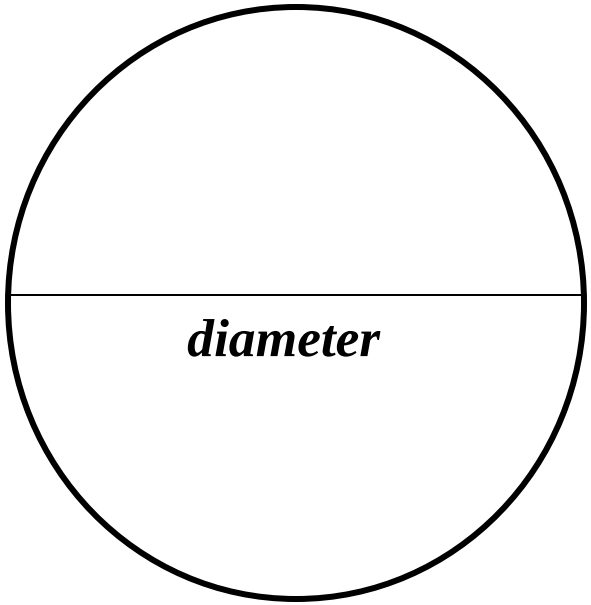


Ammonia sulfate particles

Particle “Size”



actual particle



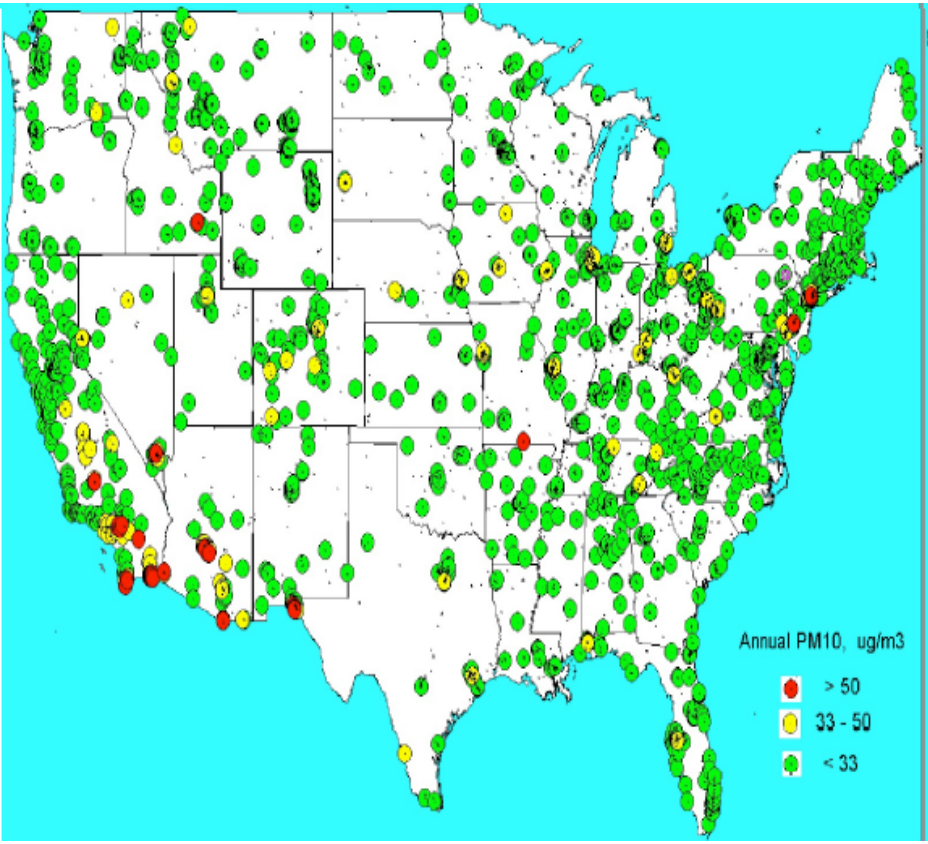
idealized particle

Note: Above pictures are 2-D, but real particles are 3-D

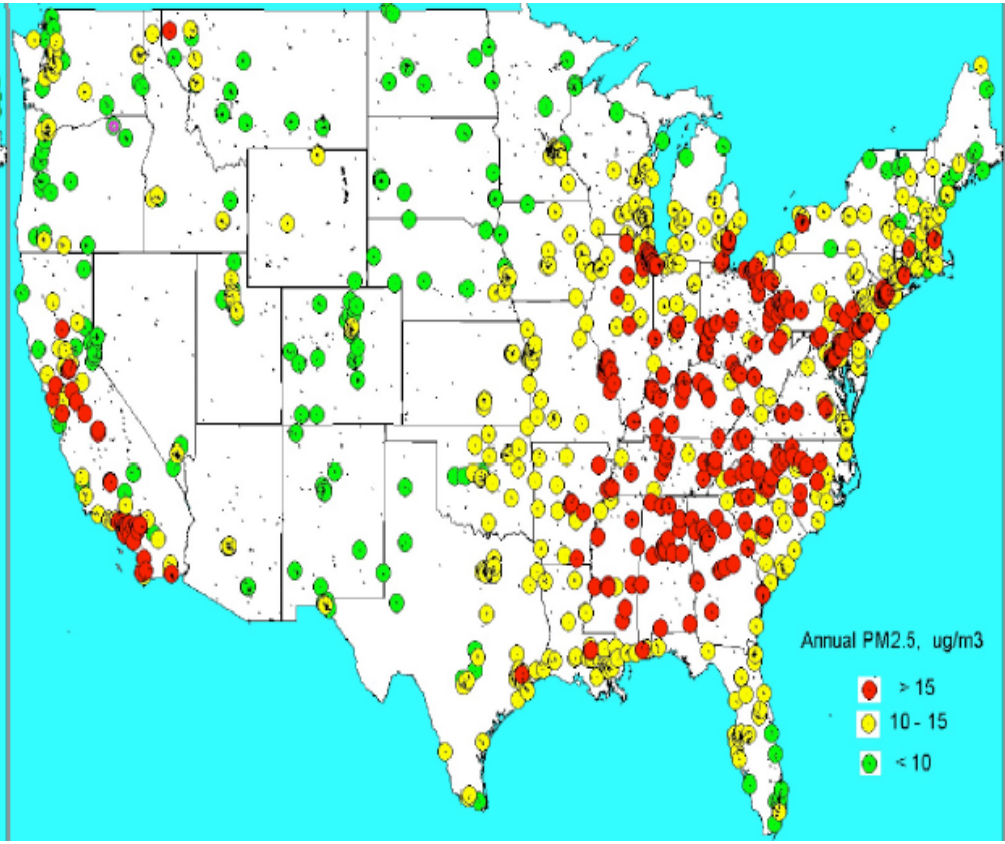
Annual Average PM10 and PM2.5 Concentration

(not sure for what year, but recent …)

PM10 (particles > 10 μm)



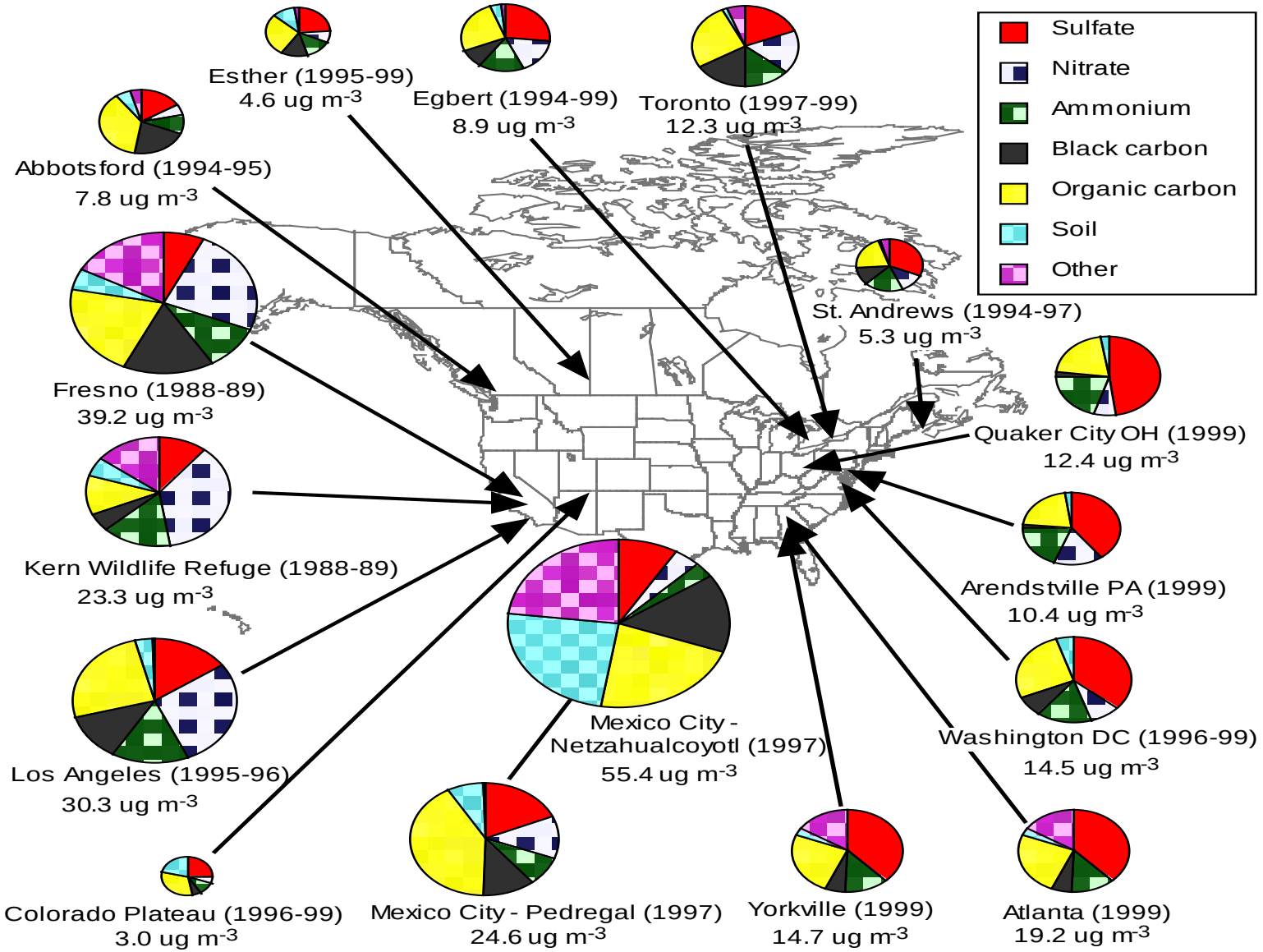
PM2.5 (particles > 2.5 μm)



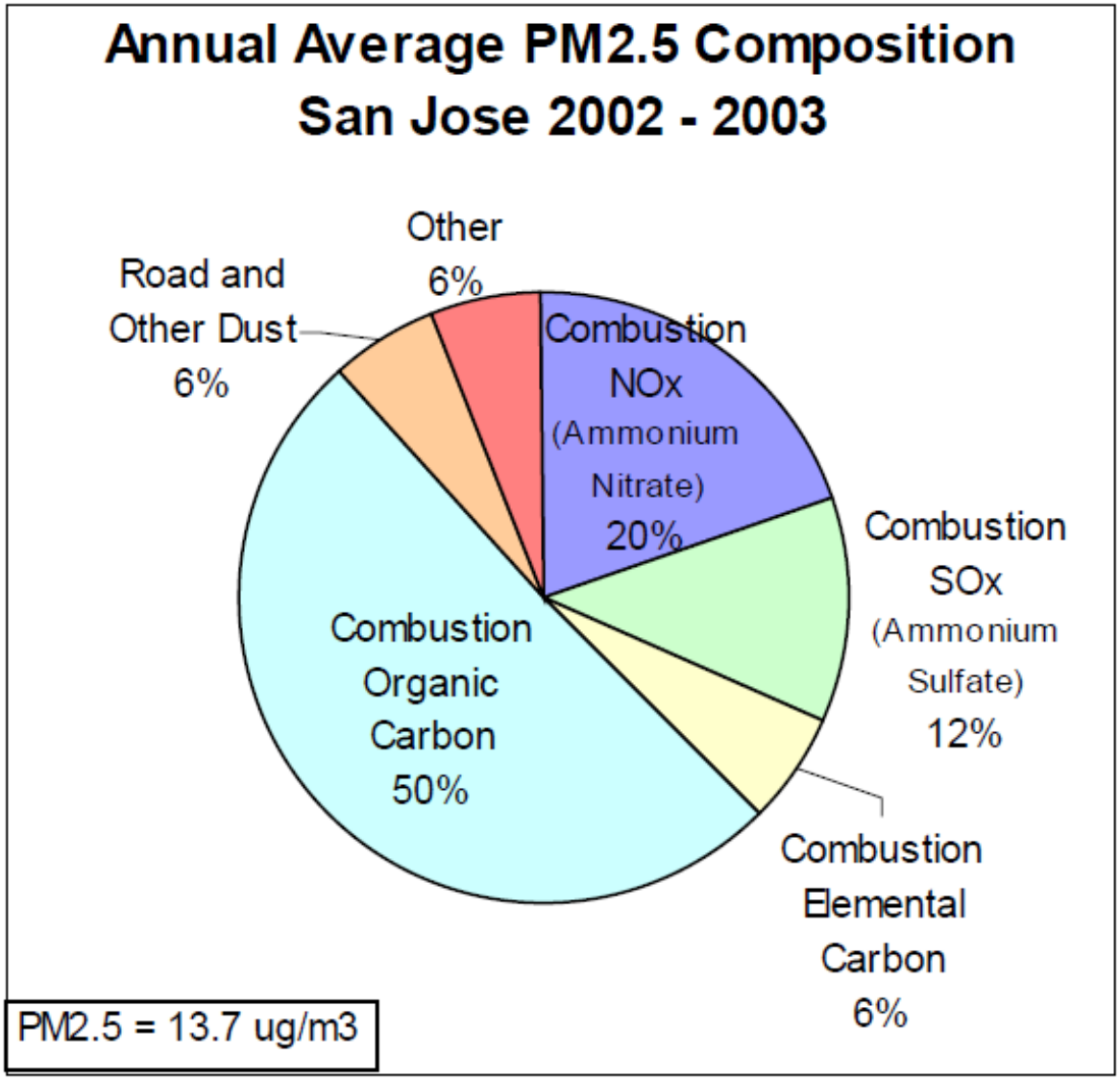
Red circles indicate violations of national air quality standard (NAAQS):

~~50 μg m^{-3} for PM10~~ (no longer exists) **15 μg m^{-3} for PM2.5**

Composition of PM2.5 (1)



Composition of PM2.5 (2)



Composition of PM2.5 (3)

From measurements (previous slides) six main categories make up PM2.5 composition in polluted air …

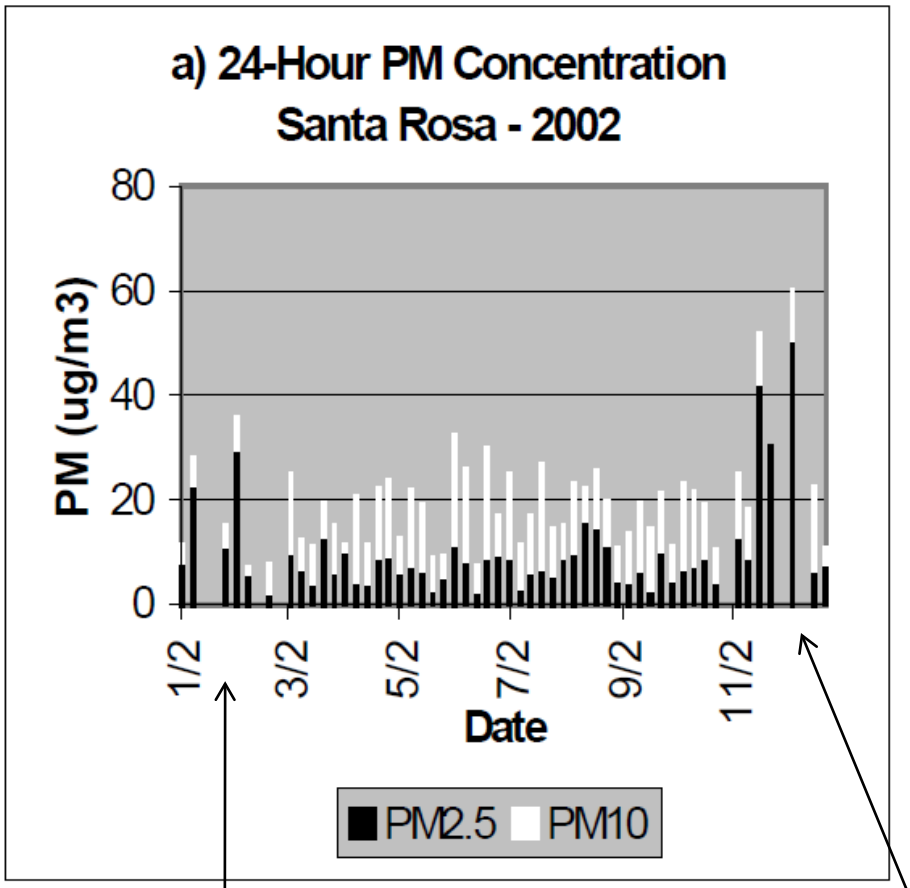
1. Sulfates
2. Nitrates (includes ammonium nitrate, also called “ammonium”)
3. Elemental Carbon (“black” carbon, “soot”)
4. Organic Carbon
5. Dust/Soil
6. Others (includes metals)

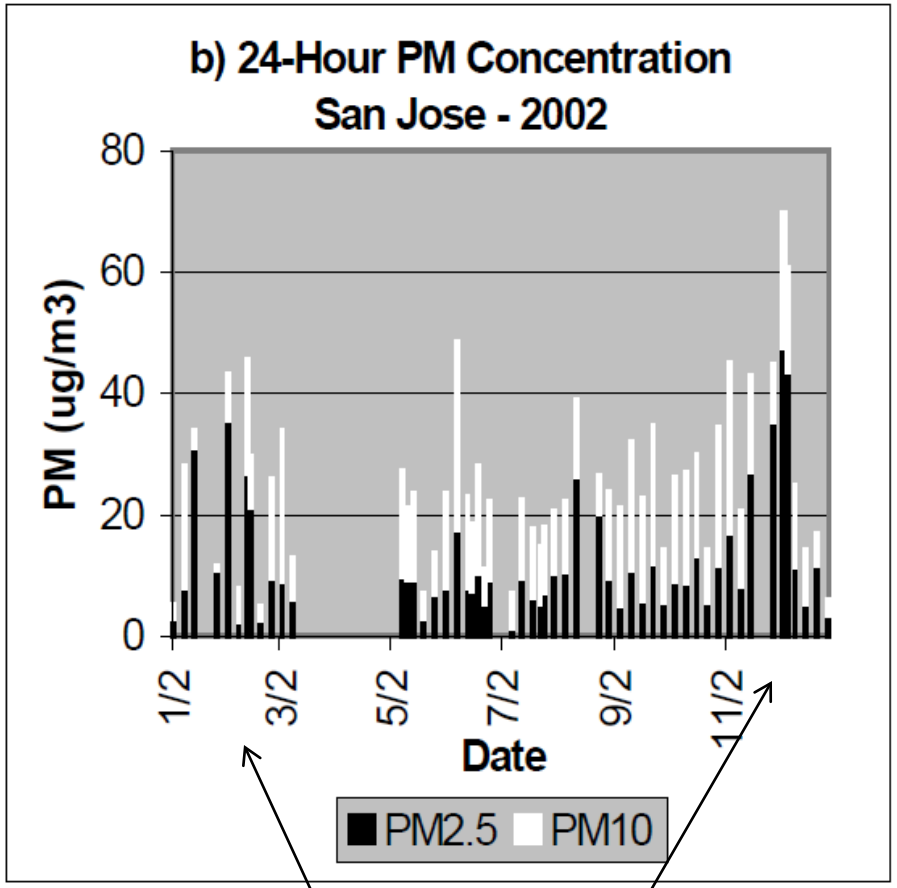
Secondary Aerosols

(Sulfate, Nitrate & a portion of Organic Carbon)

- A “secondary” aerosol
- That is … forms in the atmosphere from emitted “precursor” gases
- As opposed to “primary” aerosols (emitted directly from source)
- Precursor gases
  - Sulfate: Precursor is sulfur dioxide (SO_2)
  - Nitrate: Precursor is nitrogen oxides (NO_x)
  - Ammonium Nitrate: NO_x and Ammonia (NH_3)
  - Secondary Organic Carbon: Volatile Organic Compounds (VOCs), Reactive Organic Gases (ROGs)

Figure L-2 (a and b). Seasonal Variation in PM10 and PM2.5 Concentrations.

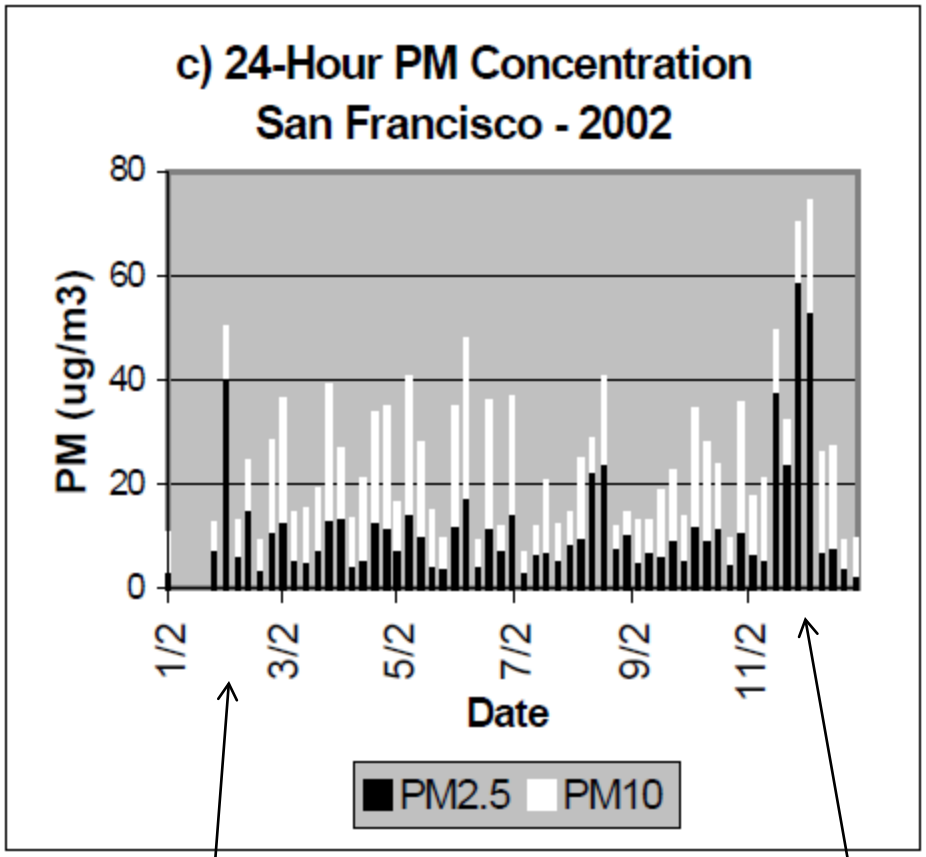


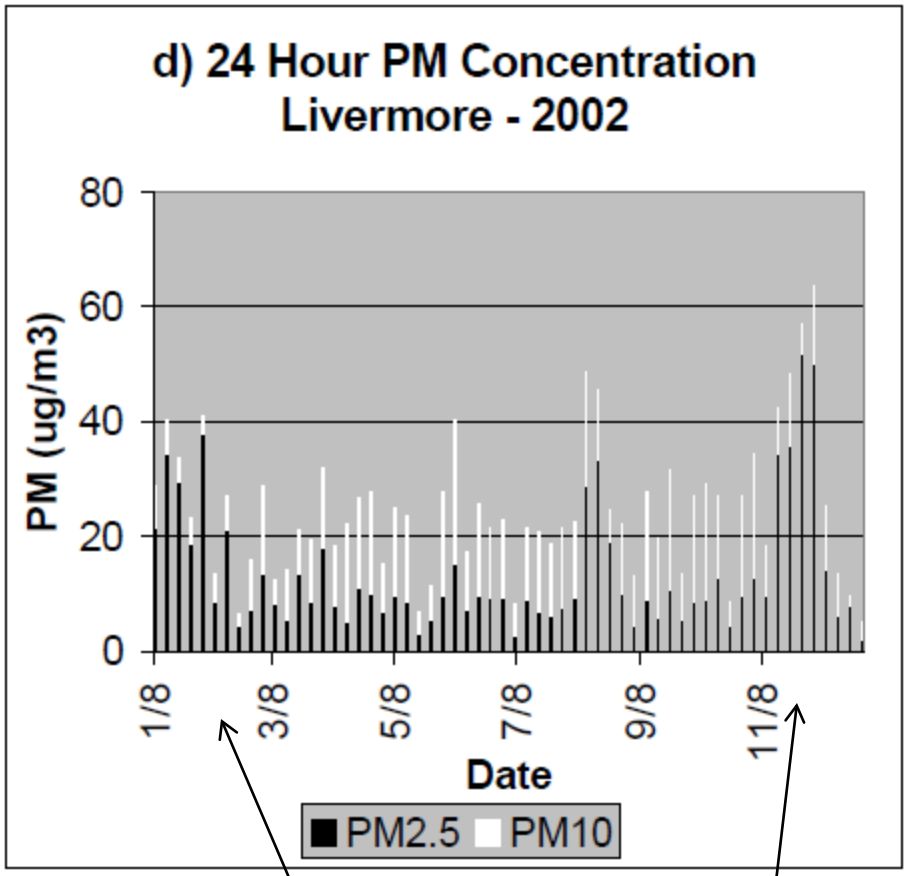


PM2.5 generally more of a problem in winter

- colder air, slower winds … less dispersion of pollution
- colder temperatures favor nitrate and sulfate formation

Figure L-2 (c and d). Seasonal Variation in PM10 and PM2.5 Concentrations.





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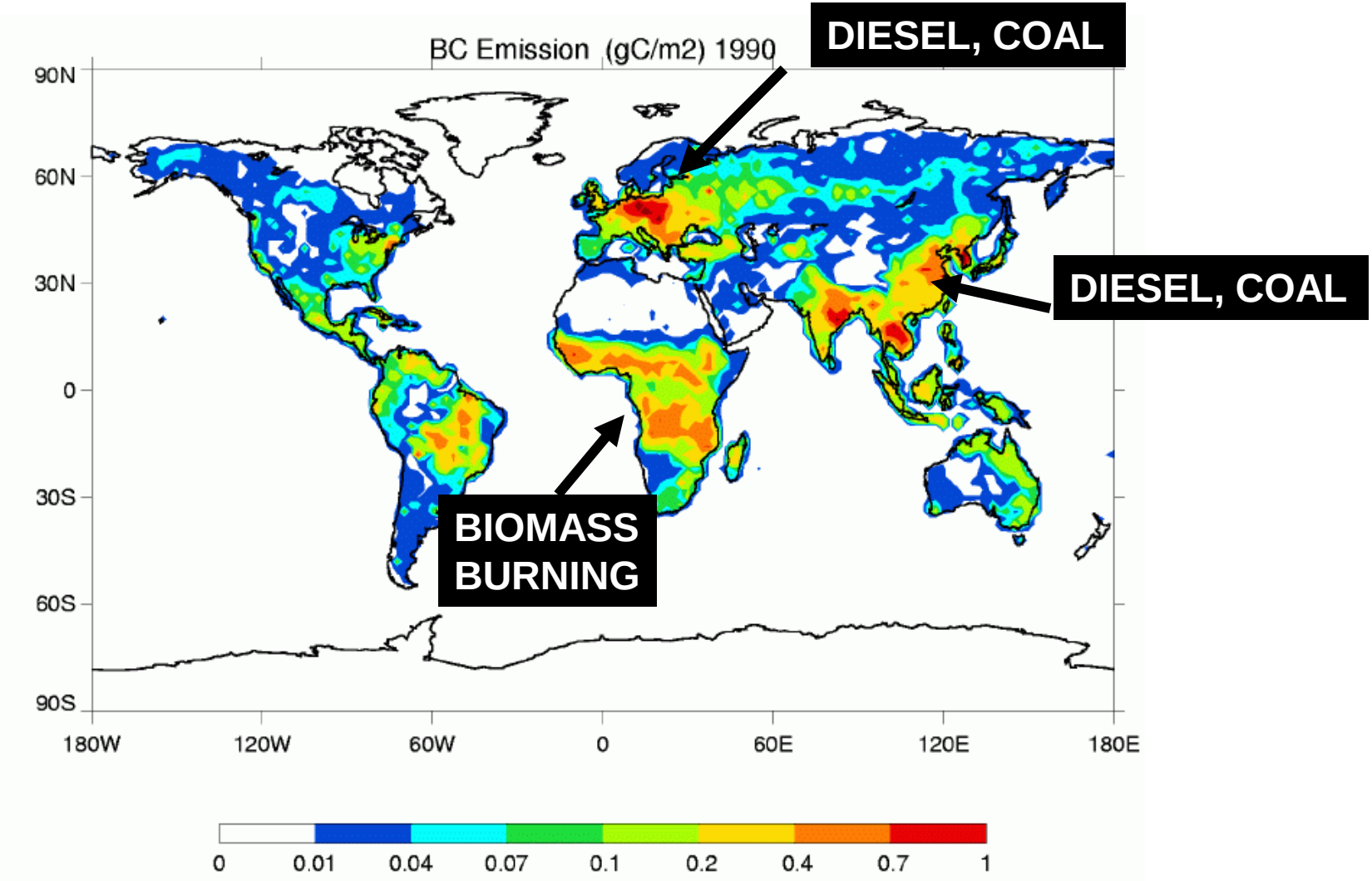
PM2.5 Emissions

- **Direct Emissions** (PM2.5 emitted from source, leads to “primary” PM2.5)
  - Diesel Combustion (esp. trucks, construction equipment, ships, others …)
  - Wood & Other Controlled Burning (Residential, Controlled Fires, Agricultural Burning)
  - Road Dust
- **Indirect Emissions** (Emissions of Precursor Gases leading to “secondary” PM2.5)
  - NO_x: Combustion Sources (Cars, Trucks, Factories, etc …)
  - SO_2: Coal (outside CA); Shipping (in CA, Bunker Fuel – heavy sulfur content)
  - NH_4 (Ammonia): In CA – Livestock!
  - Organic Gases (VOCs, ROGs)
  - Form secondary PM2.5 (sulfates, nitrates, secondary part of organic carbon)
- **Some links**
  - http://www.epa.gov/oms/invntory/overview/pollutants/pm.htm
  - http://www.epa.gov/air/emissions/pm.htm#pmnat
  - Chapter 2 of http://www.arb.ca.gov/aqd/almanac/almanac.htm

Black Carbon Emissions
(also called soot, elemental carbon)



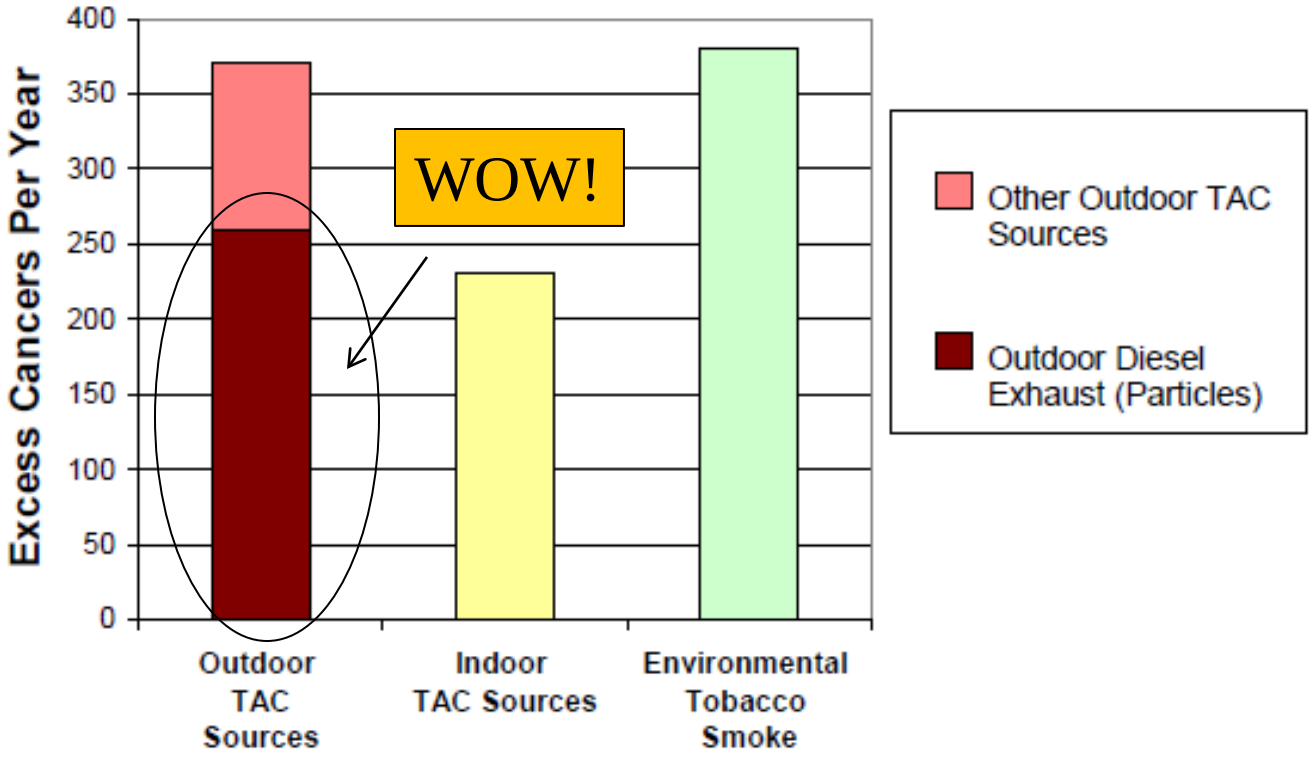
Diesel Particulate Matter (DPM)

- A particularly dangerous portion of PM2.5

- Comprised mostly of
  - Soot (“elemental carbon”)
  - Many different forms of “organic carbon”

- Sources: Diesel fueled engines (stationary and mobile)
  - Heavy-duty trucks
  - Construction equipment
  - Others …

Figure ES-2:
Estimated Potential Cancer Burden from Air Toxics in California by Source



Note: TAC = "Toxic Air Contaminant", which is comprised of many air pollutants that are toxic
http://www.arb.ca.gov/research/apr/reports/l3041.pdf

Some articles and websites (Diesel Particulate) …

- http://www.ens-newswire.com/ens/feb2006/2006-02-22-03.html
- Summary of above article …
  1. Diesel particulates cause high cancer risk.
  2. Risk is greater than other TACs combined (see also previous slide).
  3. CARB diesel engine retrofit program for trucks and buses (http://www.arb.ca.gov/msprog/onrdiesel/onrdiesel.htm)
- http://www.arb.ca.gov/research/diesel/diesel-health.htm
- http://www.arb.ca.gov/research/diesel/diesel.htm
- http://www.arb.ca.gov/diesel/diesel.htm

Homework:

Due Date: 4/7 (Day of Exam #3)

Watch the following video …
http://video.google.com/videoplay?docid=3665914907157343039#
(Alternatively, google "Arden Pope video". You will then get a link to a google video (64 min) dated March 31, 2007 entitled "Air Pollution and Health – A Presentation from C. Arden Pope")

Answer the following (turn in 1-2 page summary on exam day):

1. Background: What is an "epidemiological study" and a "cohort study"? (You need to look this up on your own … not in video.)

2. Summarize the epidemiological cohort studies presented by Dr. Pope in the video that link PM2.5 to adverse health effects.
   a) What were the specific studies?
   b) How were they designed.
   c) What were the findings (specific health effects)

There will also be a multiple choice question about this …

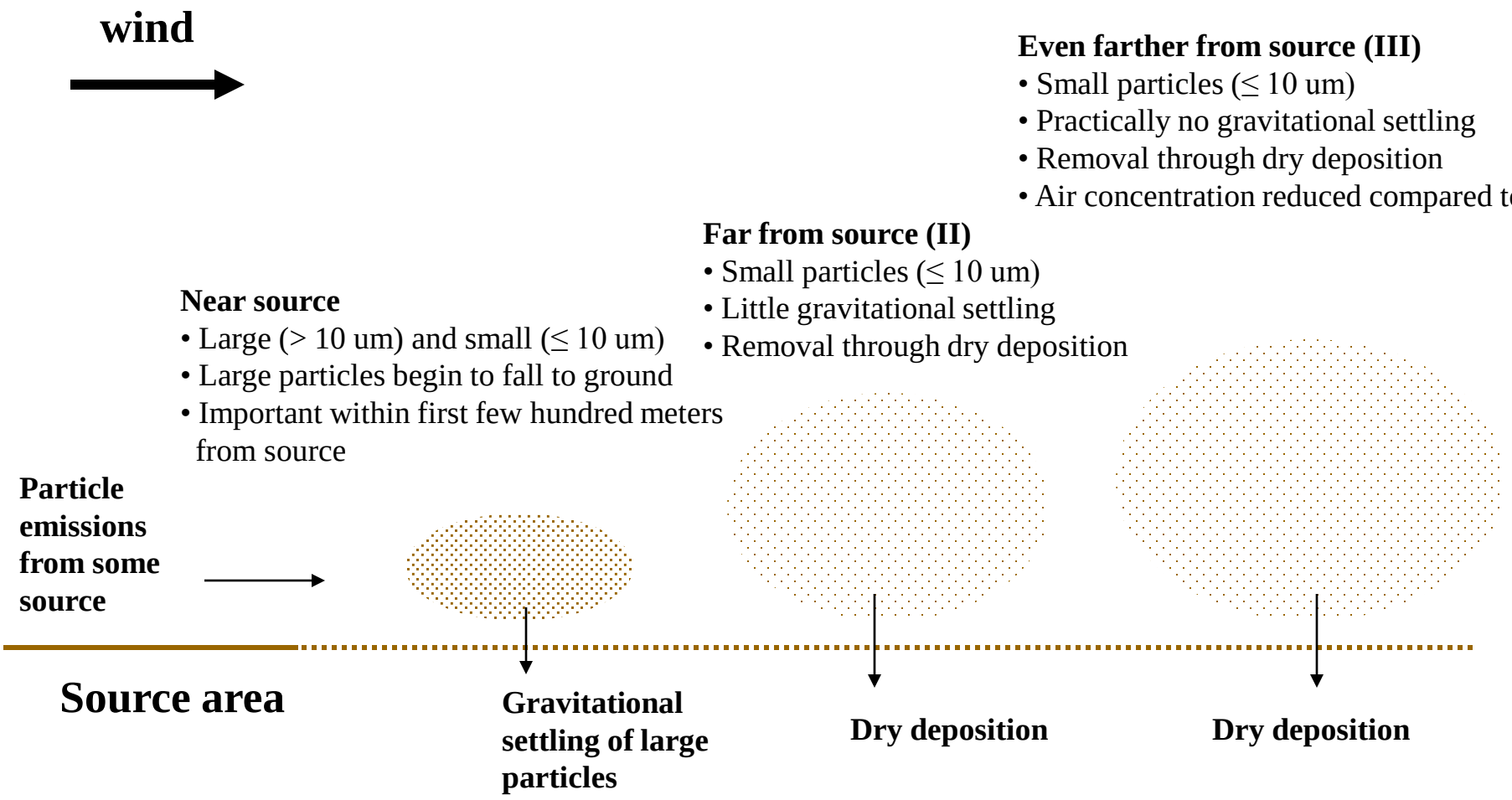
3. How did these studies affect development and other issues surrounding the PM2.5 NAAQS standards during the 1990s and early 2000s?

Meteorological Effects: PM2.5

- Gravitational Settling & Deposition
- Visibility Reduction
- Regionally High PM2.5 concentrations
  (Inversion Layers, Wind Transport & Topography)

See portions of Jacobson, Chapters 6 and 7 for reading support …

Particle transport and sinks



Summary

- **Large particles (> 10 um)**
  - o Removed very efficiently (i.e. near source)
  - o Removed by gravitational settling

- **Small particles (≤ 10 um)**
  - o Removed very slowly (very persistent in air)
  - o PM2.5 especially persistent, since it is smaller
  - o Removed through dry deposition

Air Pollution in Urban Area (Mexico City)

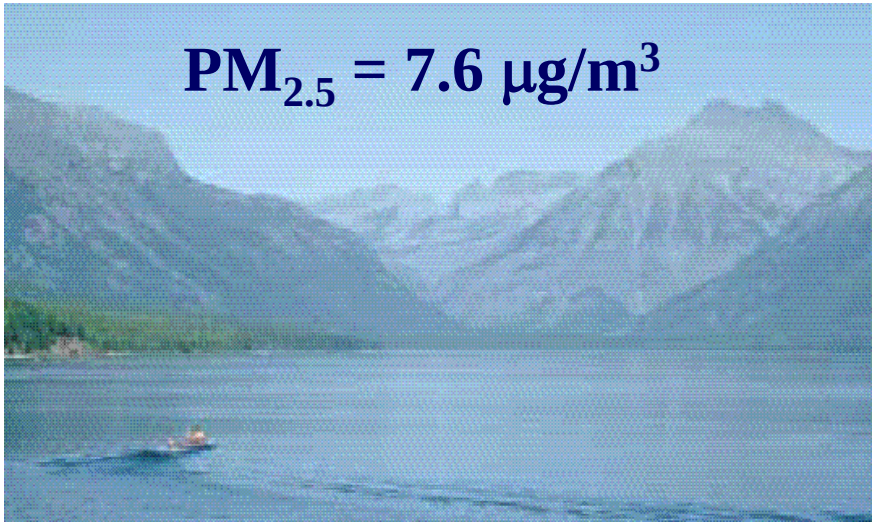
Air Pollution in Urban Area (Mexico City)

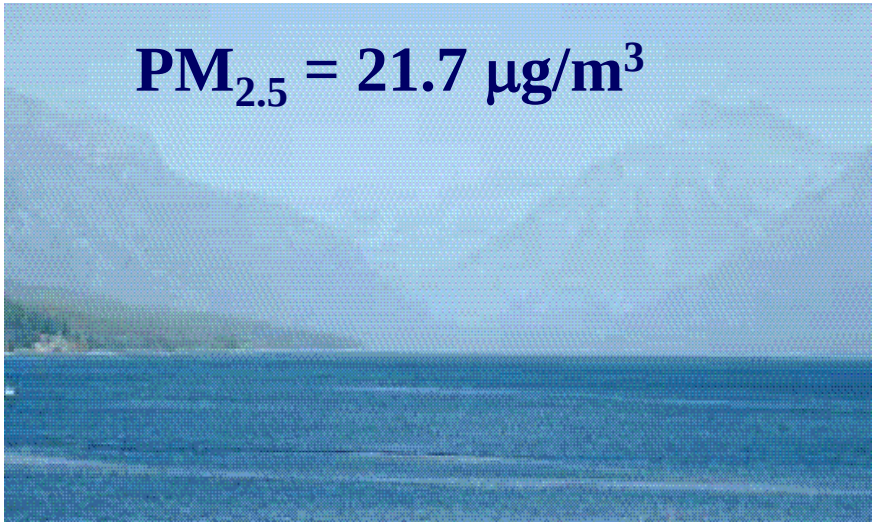
*** visibility reduction mostly due to PM2.5**

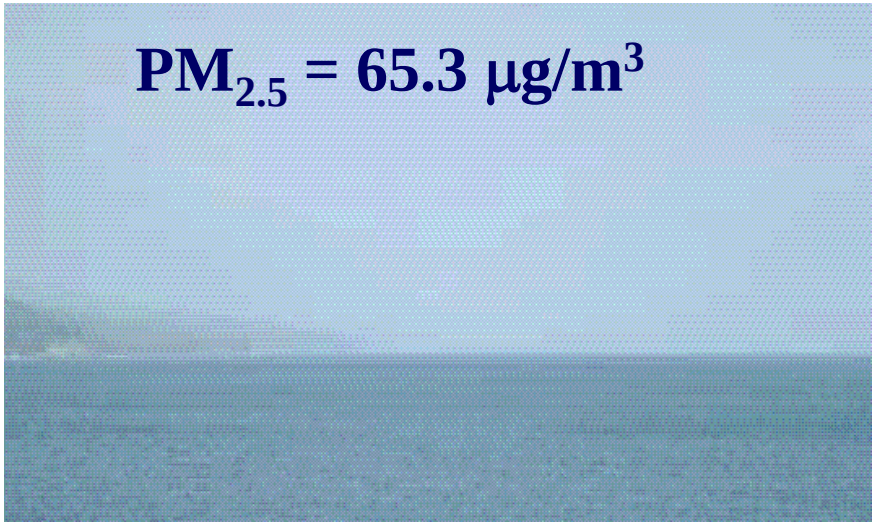
Air Pollution in Urban Area (Los Angeles)

Particles and Visibility

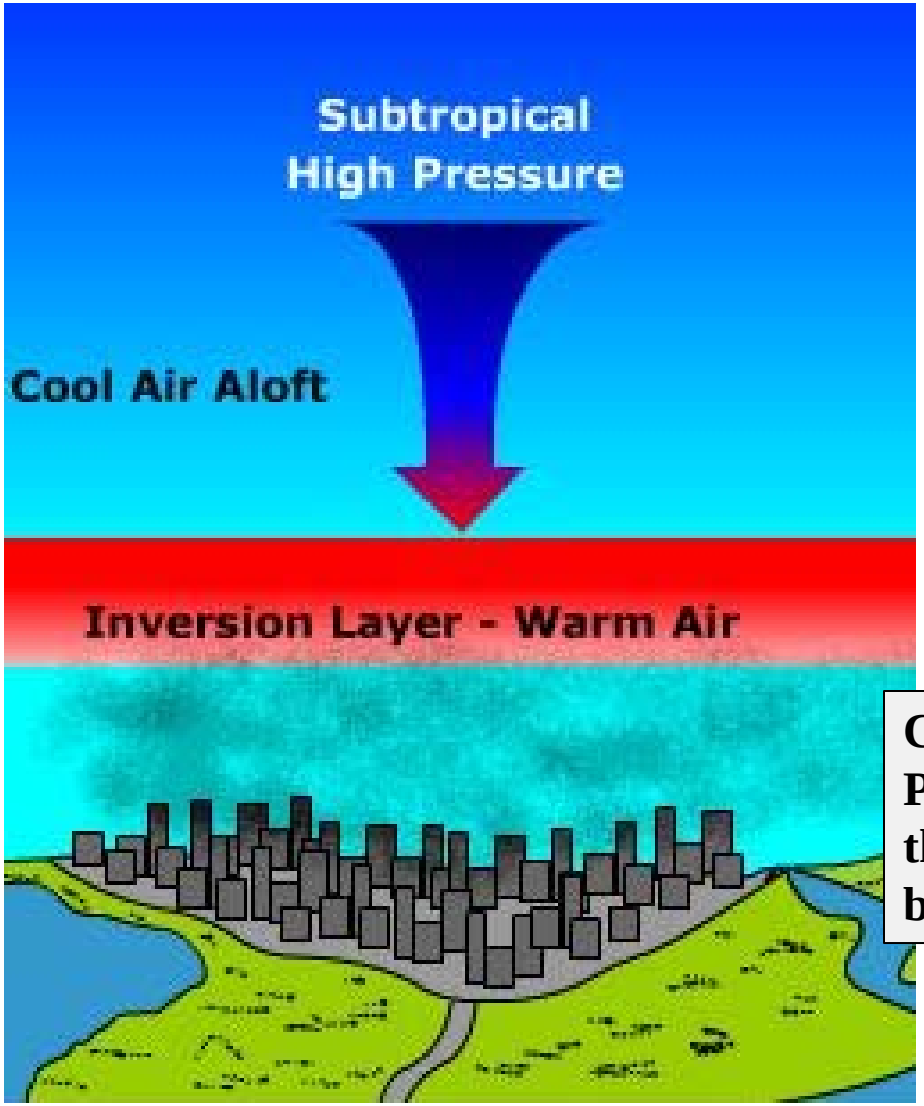
(Photos below generated by computer simulation)





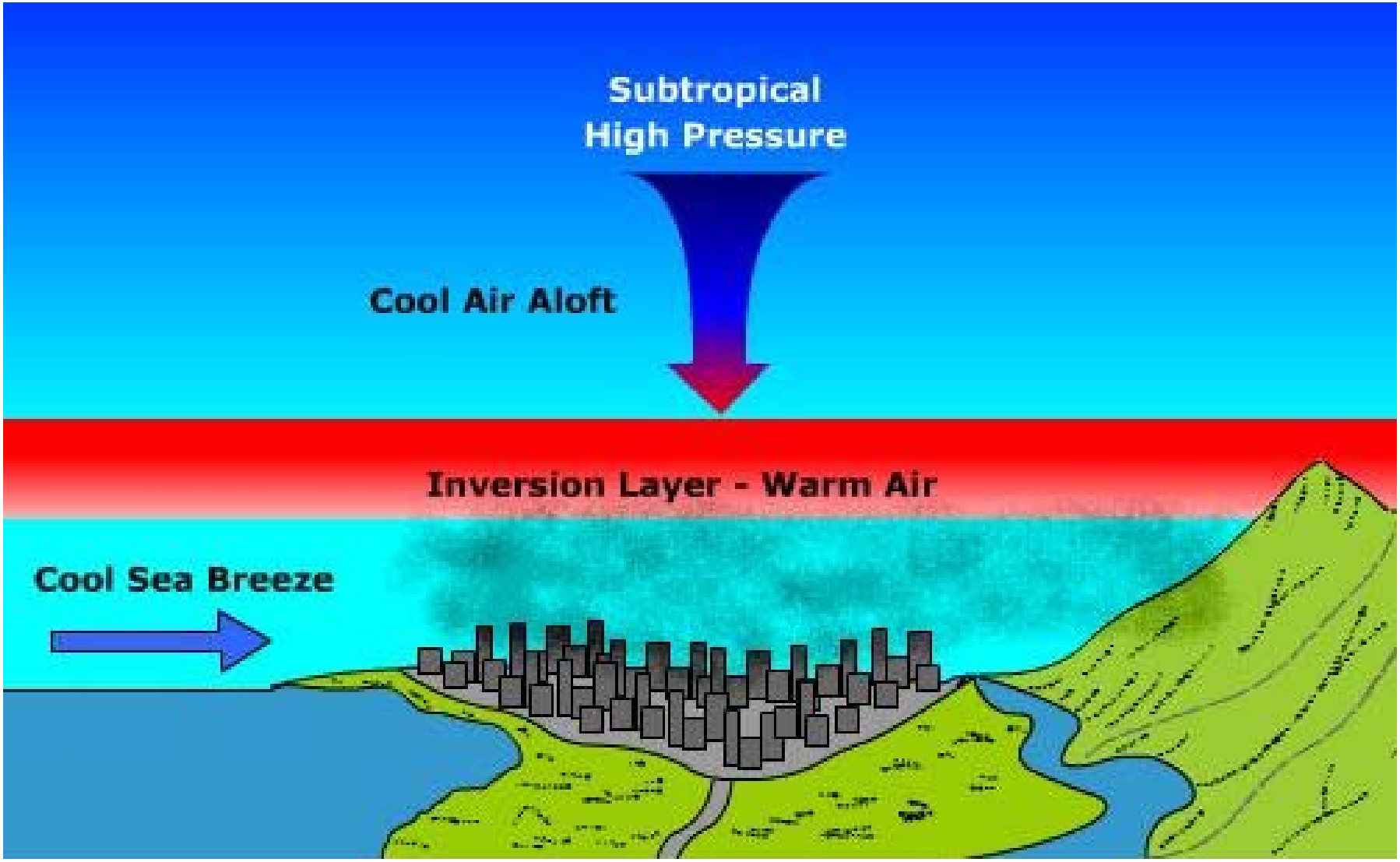


What is an “inversion layer”?



Cool Air Below.
Pollutants prevented from rising through inversion. Trapped below … high concentrations.

Situation made worse by winds blowing inland and further trapping by topography …



A Multiple Choice Exam Question

Which of the following best characterizes direct PM2.5 emissions in California?

a) Emissions of NOx from passenger car tailpipes
b) Emissions of particulate from heavy-duty diesel powered trucks
c) Emissions from dust lifted off the ground from road traffic
d) Emissions of particulate from cargo ship traffic

Another Multiple Choice Exam Question …

An inversion layer is a layer in the atmosphere in which the air is _____.
Inversion layers are important because _____.

a) Warmer than the air below; they trap pollutants below the inversion thereby increasing concentrations
b) Warmer that the air below; they speed up chemical reactions that form air pollution.
c) Colder than the air below; they trap pollutants below the inversion thereby increasing concentrations
d) Colder than the air below; they speed up chemical reactions that form air pollution.

Yet Another (!) Multiple Choice Exam Question …

Which gives a correct definition of "secondary" PM2.5?

a) PM2.5 that is of relatively less concern in terms of health risk compared to "primary" PM2.5.
b) PM2.5 for which there is only a secondary NAAQS or state ambient air standard.
c) PM2.5 not emitted to the atmosphere, but is instead formed in the atmosphere from chemical reactions.