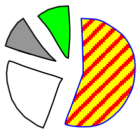
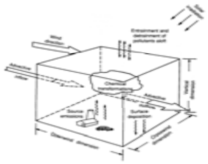
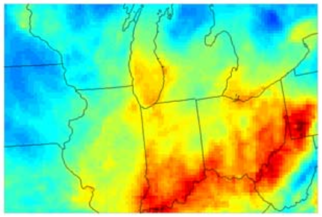
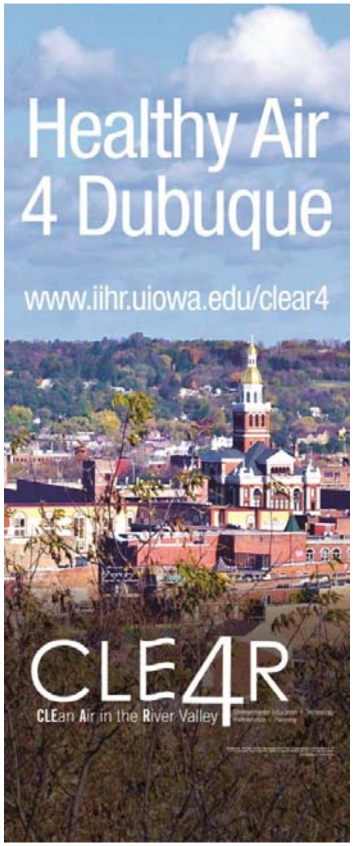





# CLE4R Partner Training
# Segment 1. Intro to Particulate Matter

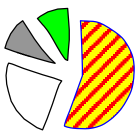

Can Dong can-dong@uiowa.edu
Charles Stanier charles-stanier@uiowa.edu

January 21, 2016

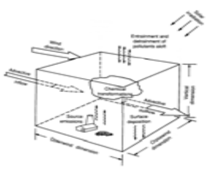


# What we'll cover in this module

- "A" introduction to the health effects of pollution

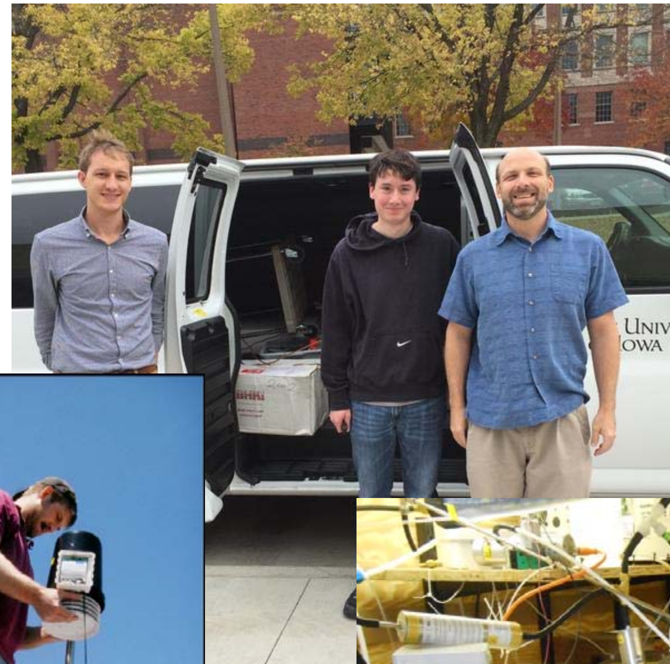


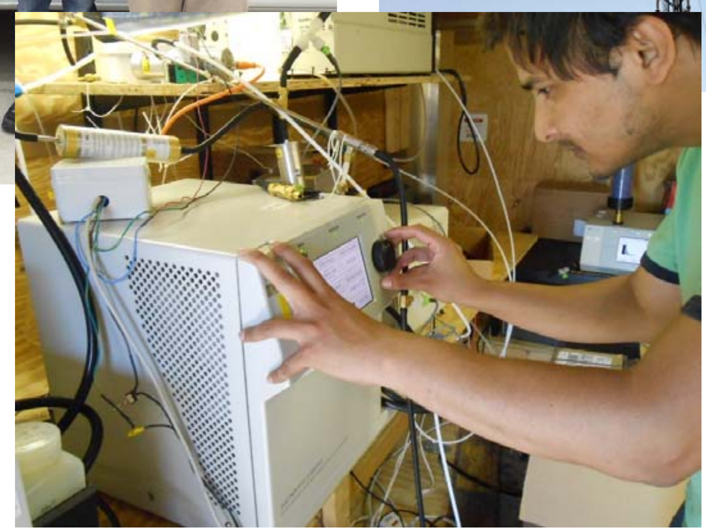
- "B" the chemical constituents that make up clean and polluted air
  - Case Study – Chinese -- health effects and air quality



- "C" the processes that control concentrations in the atmosphere (emissions, chemical transformation, physical transformation, and meteorology)

# Stanier Research Group – University of Iowa



# “Clean” vs. “Not Clean” is Defined by U.S. Law

- Clean Air Act
  - Requires the U.S. EPA to establish health based standards for criteria pollutants
  - National Ambient Air Quality Standards (NAAQS) (referred to as “Standards”)

- NAAQS are set in order to protect the public health and welfare
  - Particulate Matter, Ozone, Lead, Carbon Monoxide (CO), Nitrogen Dioxide ($NO_2$), Sulfur Dioxide ($SO_2$)
  - Particulate matter (PM) broken into two size fractions
    - PM10
    - PM2.5

THE UNIVERSITY OF IOWA

# Particulate Matter: What is It?

**A complex mixture of extremely small particles and liquid droplets**

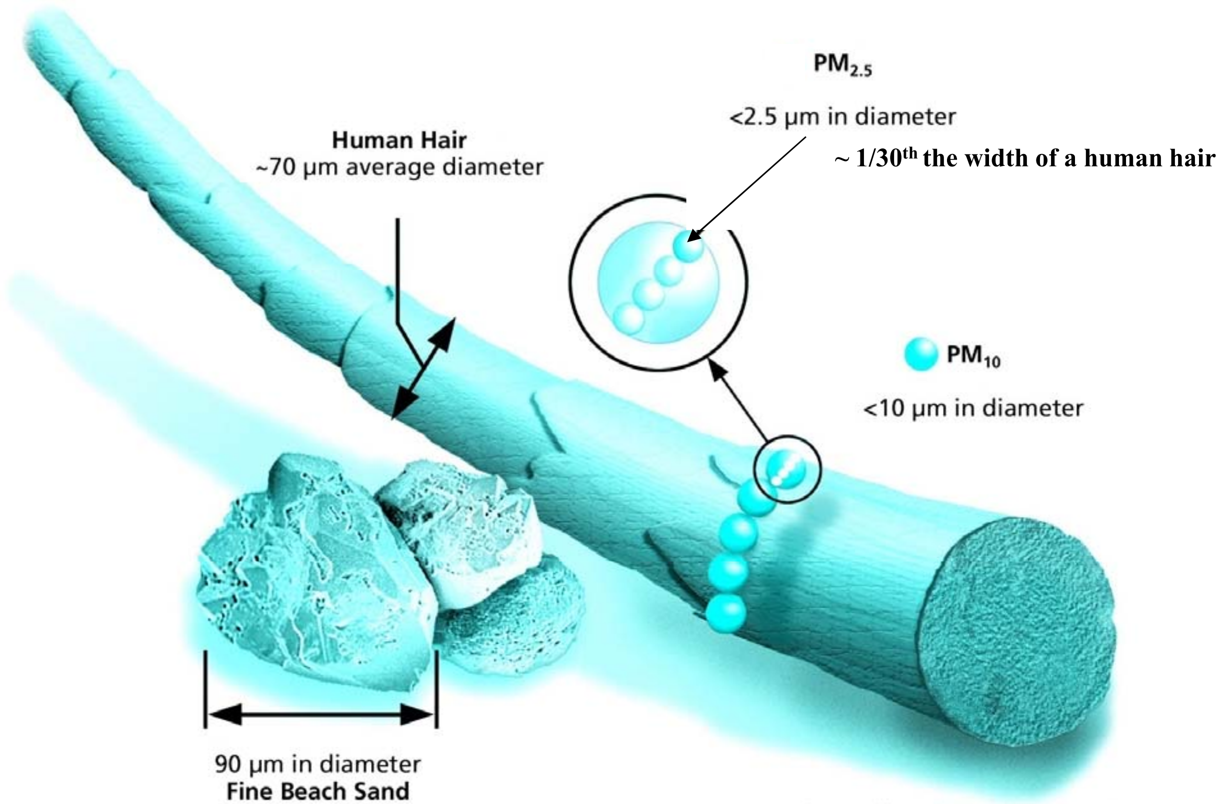
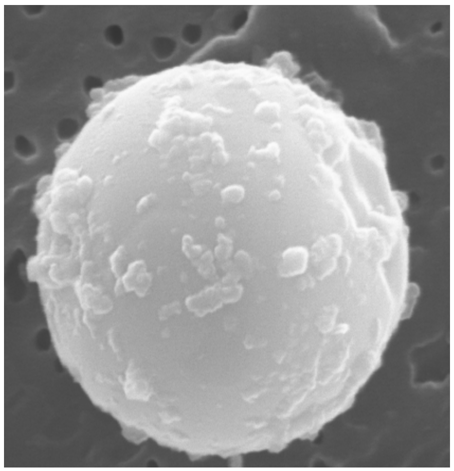
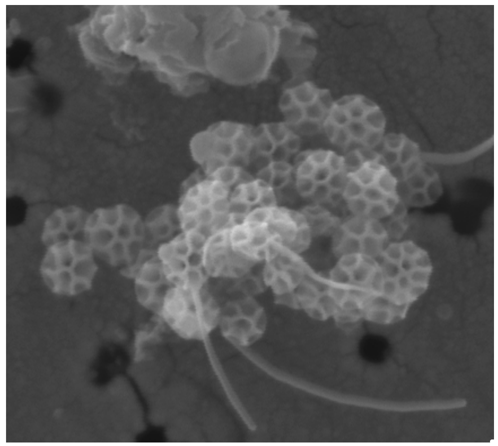
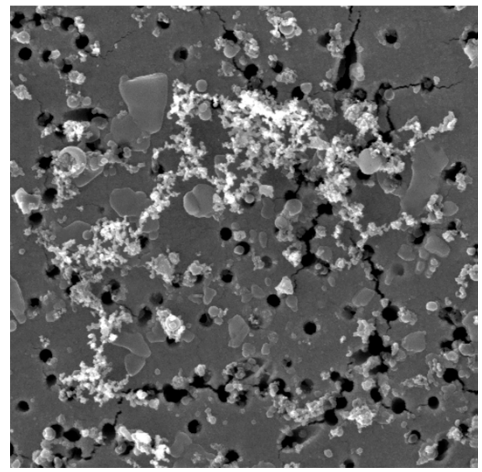


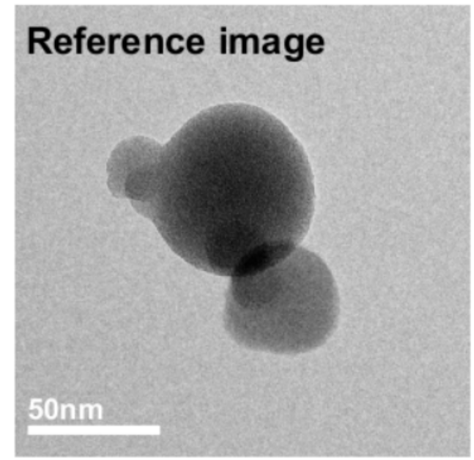

*Image courtesy of EPA, Office of Research and Development*

# What are Atmospheric Aerosol Particles
# What is “Particulate Matter” (PM)?









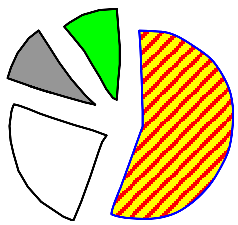

SEM Images:
Gary Casuccio, R.J. Lee Group, Monroeville, PA; Sylvia Lee Joun, University of Iowa

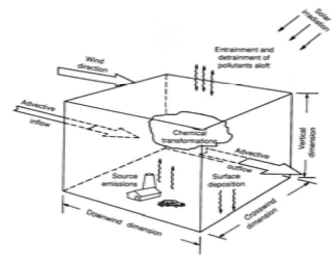
# Health Standards

* Fine Particulate Matter (PM2.5) NAAQS
  * Fine particulate matter first regulated in 1997 (and the limits were 15 and 65, respectively)
  * The 24-hour standard was revised in 2006
  * The Annual standard was revised in 2012

| | 2006 Standards | | 2012 Standards | |
|---|---|---|---|---|
| | Annual | 24-hour | Annual | 24-hour |
| **$PM_{2.5}$ (Fine Particles)** | 15 µg/m3<br>Annual arithmetic mean, averaged over 3 years | **35 µg/m$^3$**<br>24- hour average, 98$^{th}$ percentile, averaged over 3 years | 12 µg/m3<br>Annual arithmetic mean, averaged over 3 years | **35 µg/m$^3$**<br>24- hour average, 98$^{th}$ percentile, averaged over 3 years |

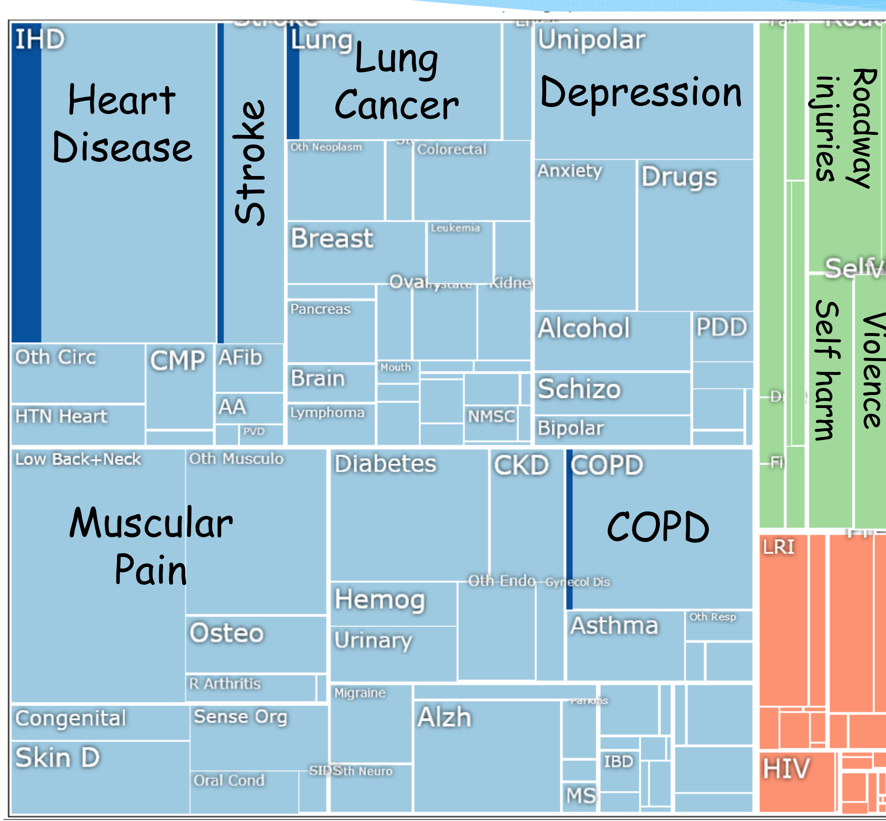
# “A” introduction to the health effects of pollution





# $PM_{2.5}$ is Regulated Because It Causes Disease and Death

Non-communicable diseases




Injuries

Pictorial representation of disability-adjusted years of life lost due to various causes

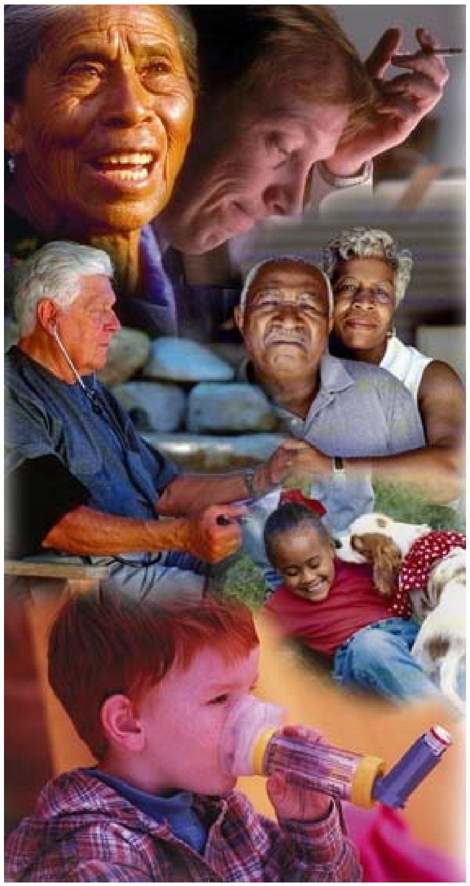
Communicable, maternal, neonatal, and nutritional disorders

Institute for Health Metrics and Evaluation (IHME). **GBD Compare**. Seattle, WA: IHME, University of Washington, 2015. Available from http://vizhub.healthdata.org/gbd-compare. (Accessed Jan 2016)

# $PM_{2.5}$ is Regulated Because

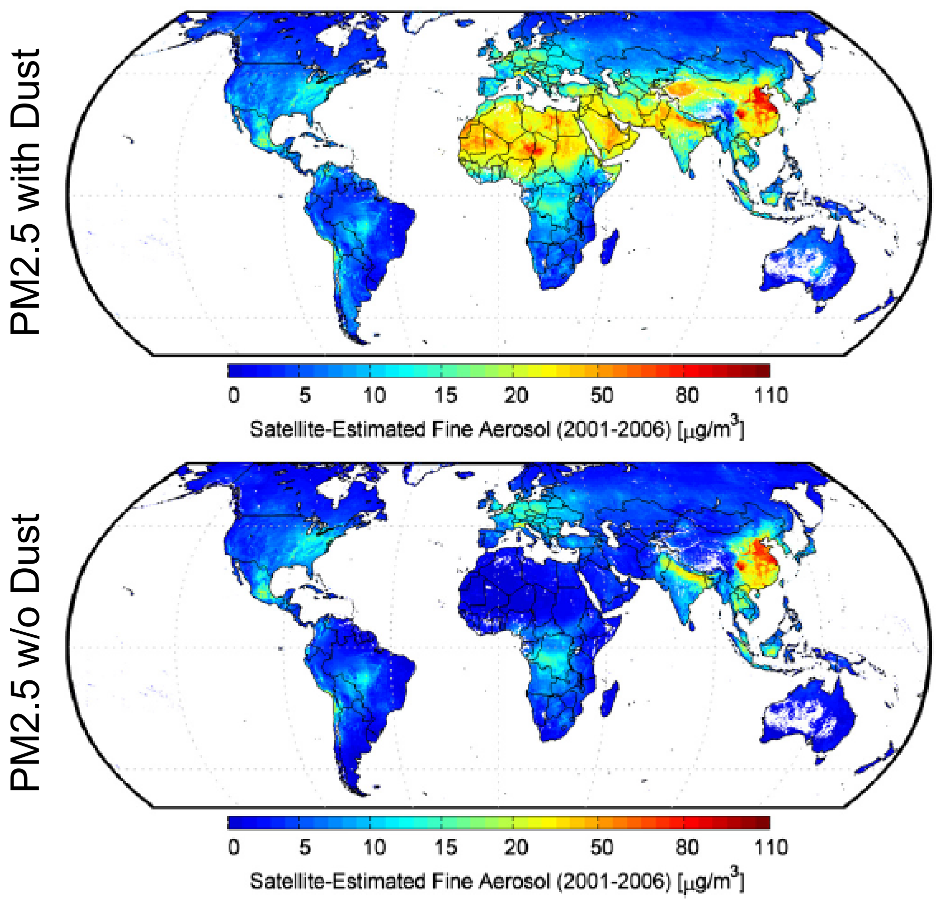
- $PM_{2.5}$ is linked in dozens of studies (both long and short term) to:
  - Symptom aggravation and/or death from cardiac diseases:
    - Cardiac arrhythmias, angina, and cardiac arrest, heart disease
  - Hospital admissions and/or death from respiratory diseases
    - Lung disease, emphysema, Chronic obstructive pulmonary disease (COPD), asthma
  - Progression of atherosclerosis (hardening of arteries)
  - Changes in lung and blood chemistry and biology consistent with many of the above diseases
  - Work absence, disability, and medication use for the above diseases
- And possibly
  - Low birthweight, developmental problems in children, diabetes, neurogegenerative diseases such as Alzheimer's

# Some Groups Are More at Risk



- **People with heart or lung disease**
  - Conditions make them vulnerable
- **Older adults**
  - Greater prevalence of heart and lung disease
- **Children**
  - More likely to be active
  - Breathe more air per pound
  - Bodies still developing

# Globally, aerosol concentrations are estimated by a combination of satellites and computer simulations




Evans et al. Environmental Research (2013).

Aerosol concentrations use 2001-2006 MODIS/MISR composite fields and aerosol properties from GEOS Chem.

See van Donkelaar et al. (2010) Environmental Health Perspectives for PM2.5 method

# USC *Children's Health* Study

- Between about 1995 and 2008, in 6 LA communities studied by Gauderman et al.
  - the average NO2 level decreased by 14 ppb
  - PM2.5 concentrations decreased by about 13 ug/m3
  - PM10 concentrations decreased by about 9 ug/m3

- In the 1990's the study looked at lung capacity in 11-yr old children and then followed these children with followup measurements until they were 15
- This was repeated in ~2008 with a new group of 11-15 year olds
- Comparisons are possible between clean and dirty communities
- Comparisons are possible between the same communities in the polluted state of the 1990s and the clean stat eof the 2000s

Gauderman, W. J., et al. *N. Engl. J. Med.* **2015**, *372* (10), 905–913.

# What does your intuition say? The pollution decrease was associated with

- No statistical difference in the lung capacity of 15 year olds
- 0-2% increase in the lung capacity of 15 year olds in “clean LA” relative to dirty LA
- 2-4% increase in the lung capacity of 15 year olds in “clean LA” relative to dirty LA
- 4-6% increase in the lung capacity of 15 year olds in “clean LA” relative to dirty LA

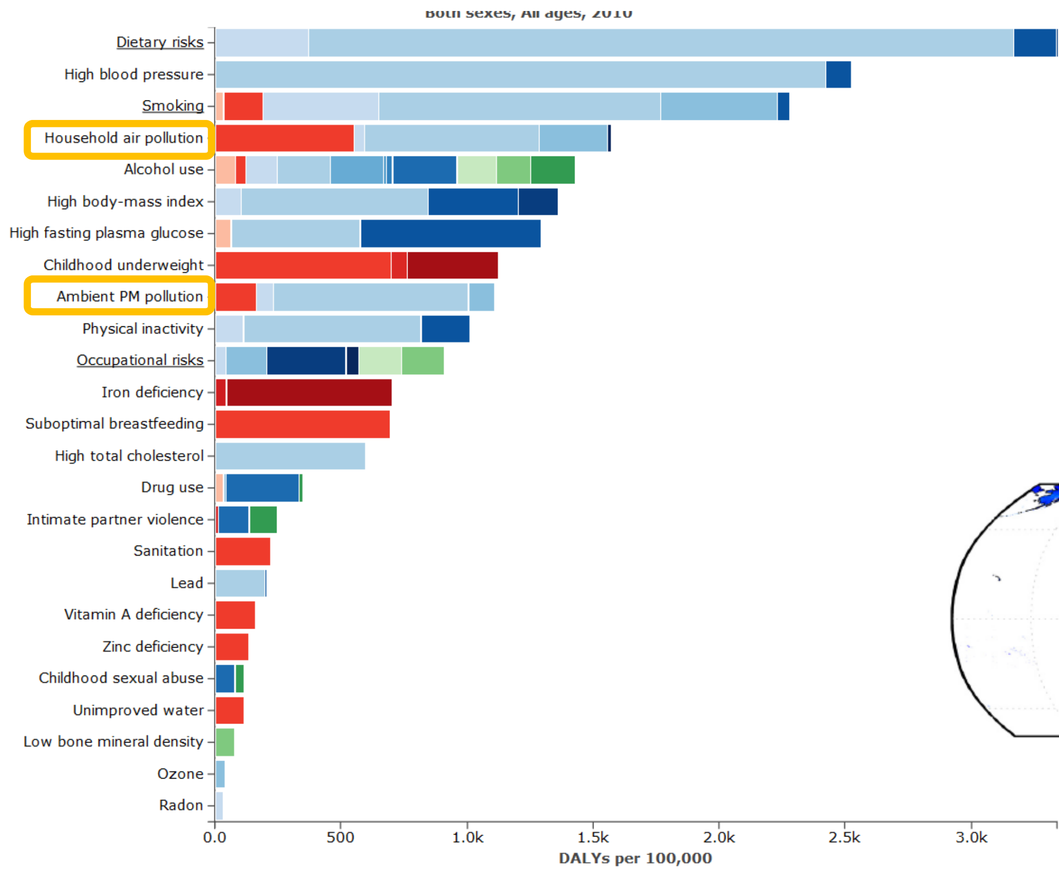
Gauderman, W. J., et al. *N. Engl. J. Med.* **2015**, *372* (10), 905–913.

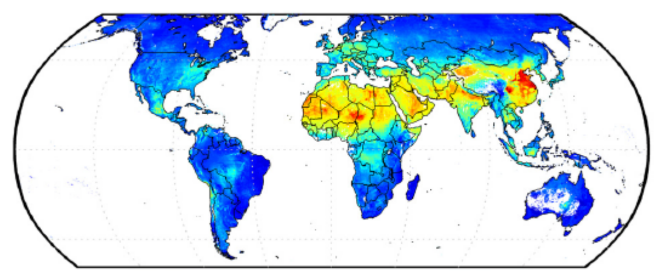
# What does your intuition say?
# The pollution decrease was associated with

- No statistical difference in the lung capacity of 15 year olds
- 0-2% increase in the lung capacity of 15 year olds in "clean LA" relative to dirty LA
- 2-4% increase in the lung capacity of 15 year olds in "clean LA" relative to dirty LA (2.6% increase, highly statistically significant, p-value < 0.001)
- 4-6% increase in the lung capacity of 15 year olds in "clean LA" relative to dirty LA
- (p values < 0.001)
- Also
  - in the recent groups of children, fewer children have doctor-diagnosed low lung capacity. Results hold true across race/ethnicity, community, and asthma/inhaler use status.
  - Growth of children is not accelerated overall. Lung capacity does not predict height.

Gauderman, W. J., et al. *N. Engl. J. Med.* **2015**, *372* (10), 905–913.

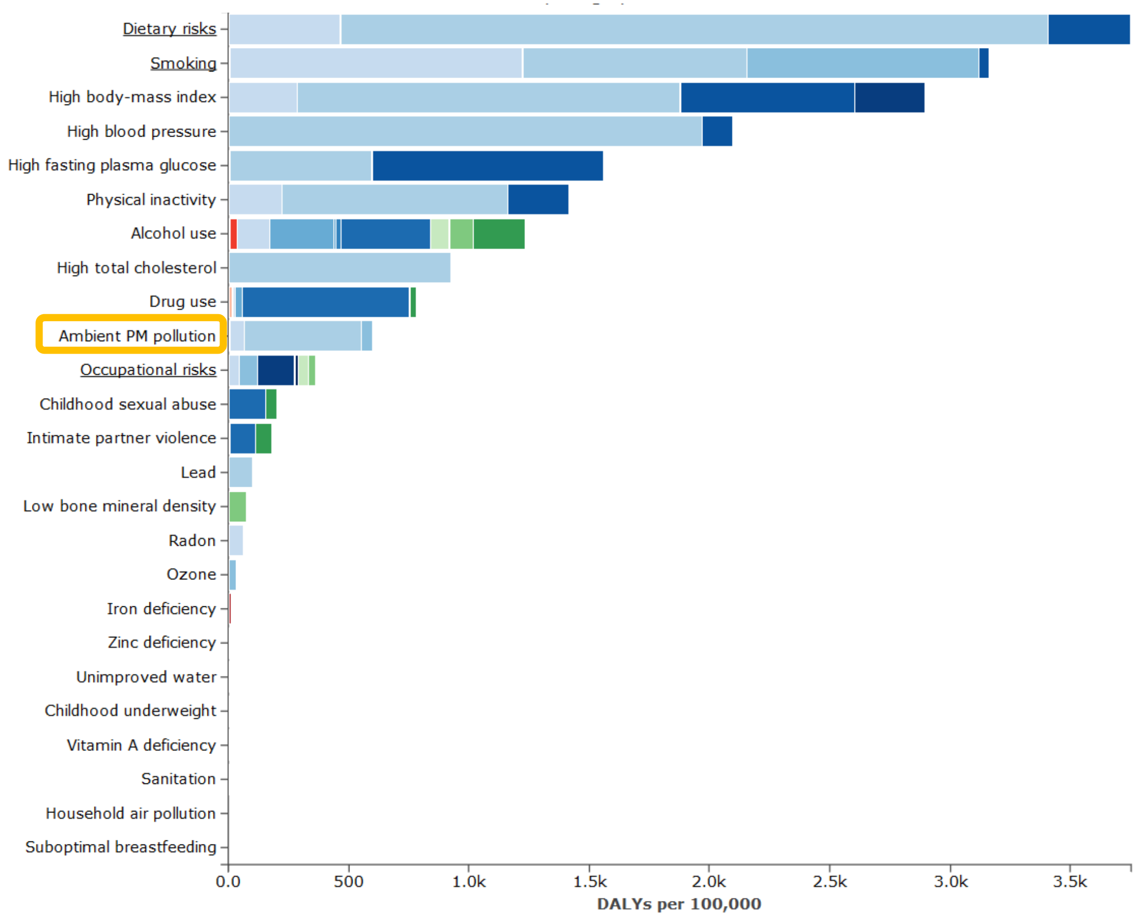
# Globally – ambient air pollution is #9 environmental risk factor http://vizhub.healthdata.org/gbd-compare/



Institute for Health Metrics and Evaluation (IHME). **GBD Compare**. Seattle, WA: IHME, University of Washington, 2015. Available from http://vizhub.healthdata.org/gbd-compare. (Accessed Jan 2016)

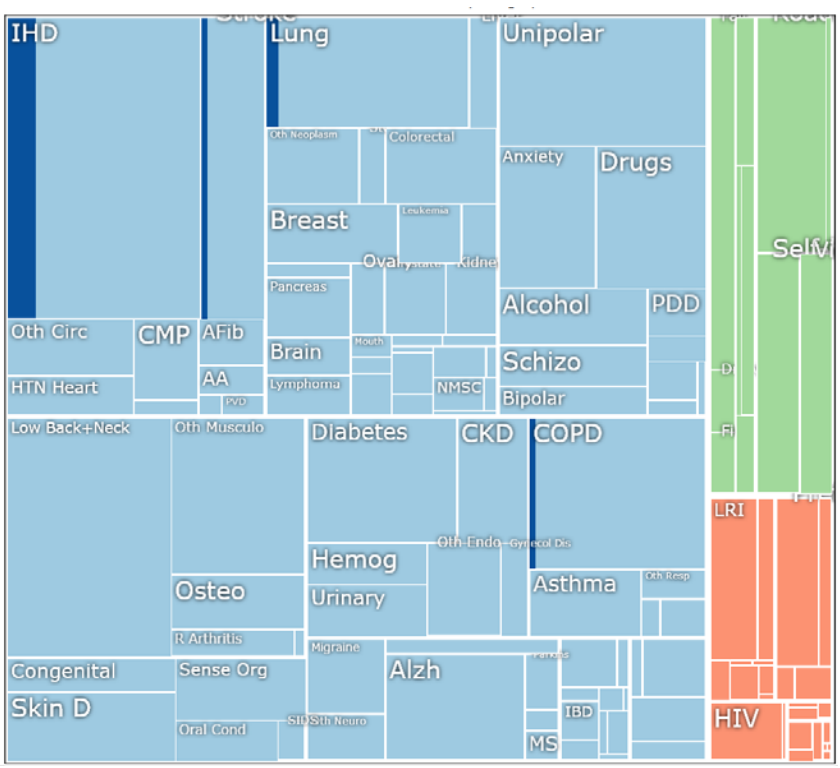
# US – ambient air pollution is #10 environmental risk factor http://vizhub.healthdata.org/gbd-compare/



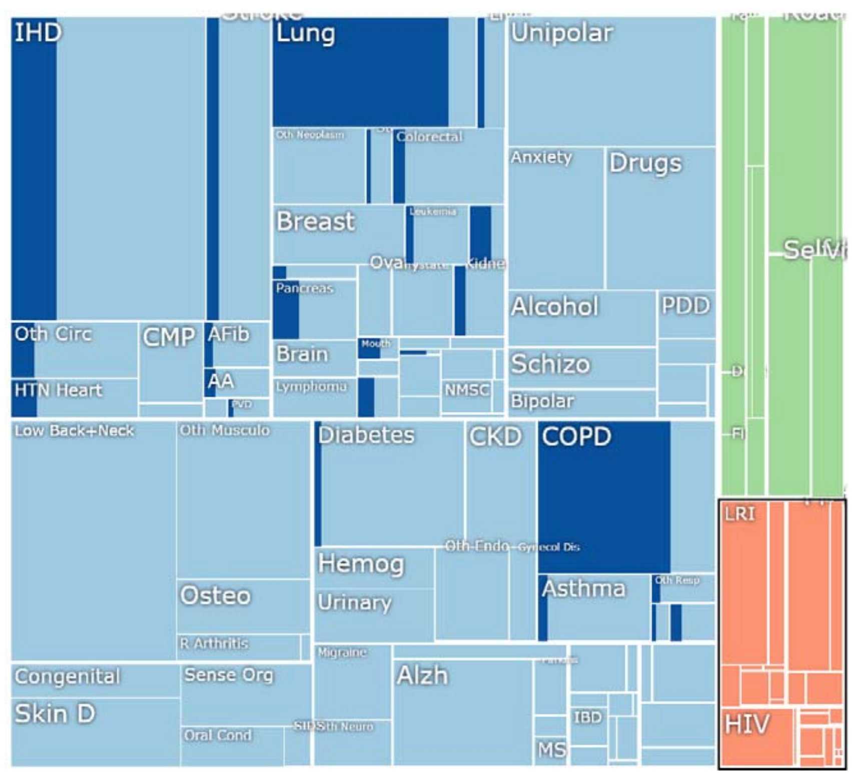

Institute for Health Metrics and Evaluation (IHME). **GBD Compare**. Seattle, WA: IHME, University of Washington, 2015. Available from http://vizhub.healthdata.org/gbd-compare. (Accessed Jan 2016)

# Contrast with smoking is important (US Data)

Ambient Air Pollution

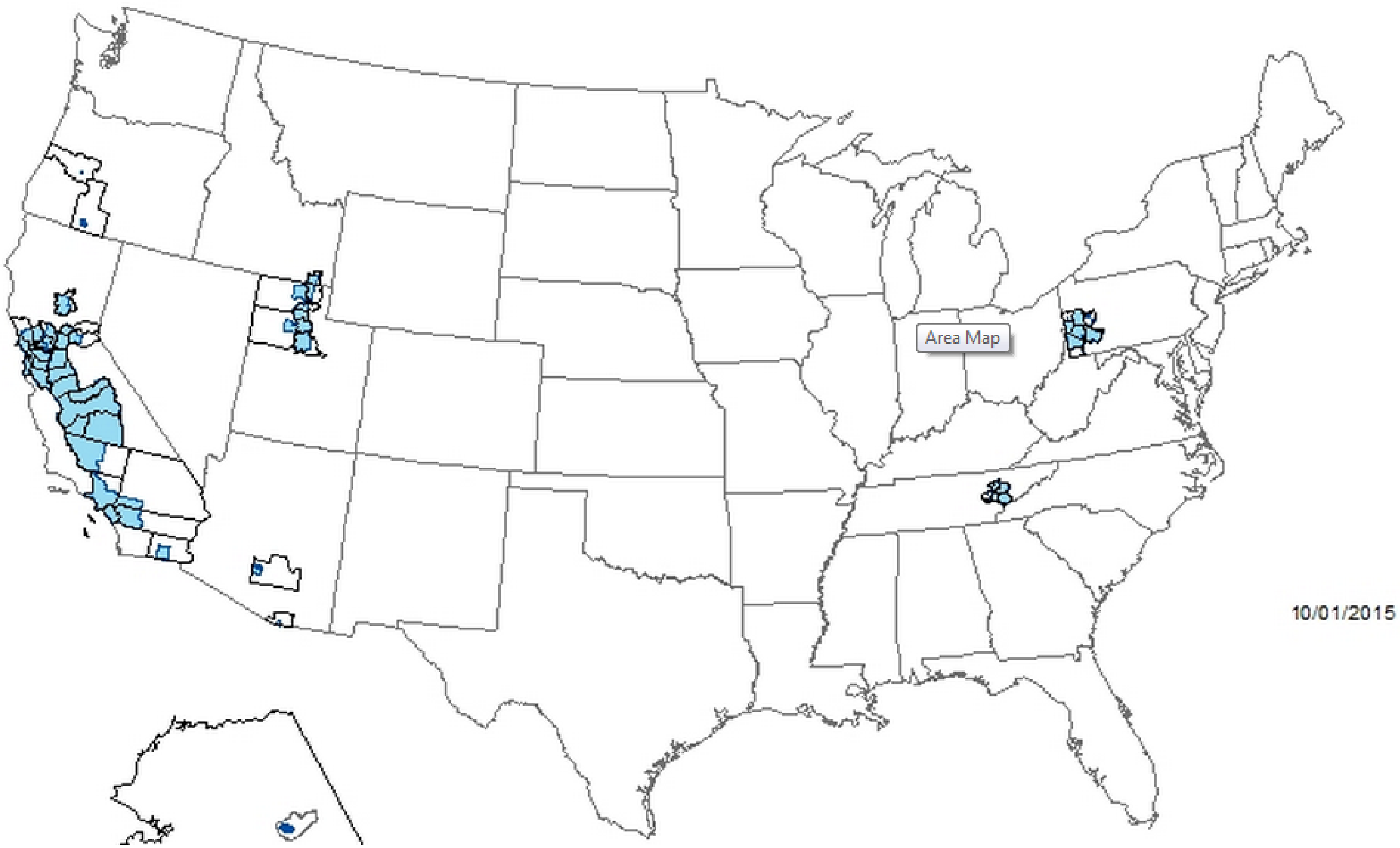



Smoking



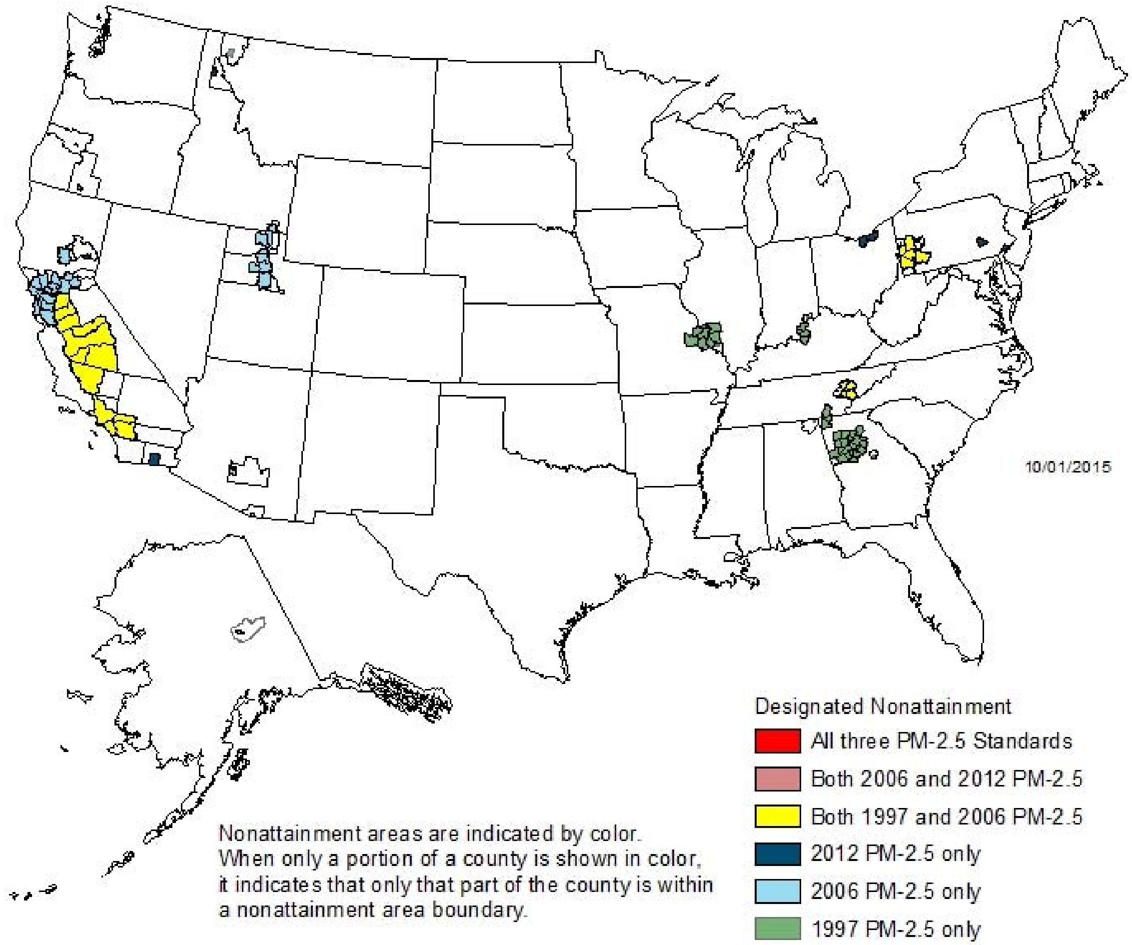

**GBD Compare**. Full citation on other slides

# PM-2.5 Nonattainment Areas (2006 Standard)

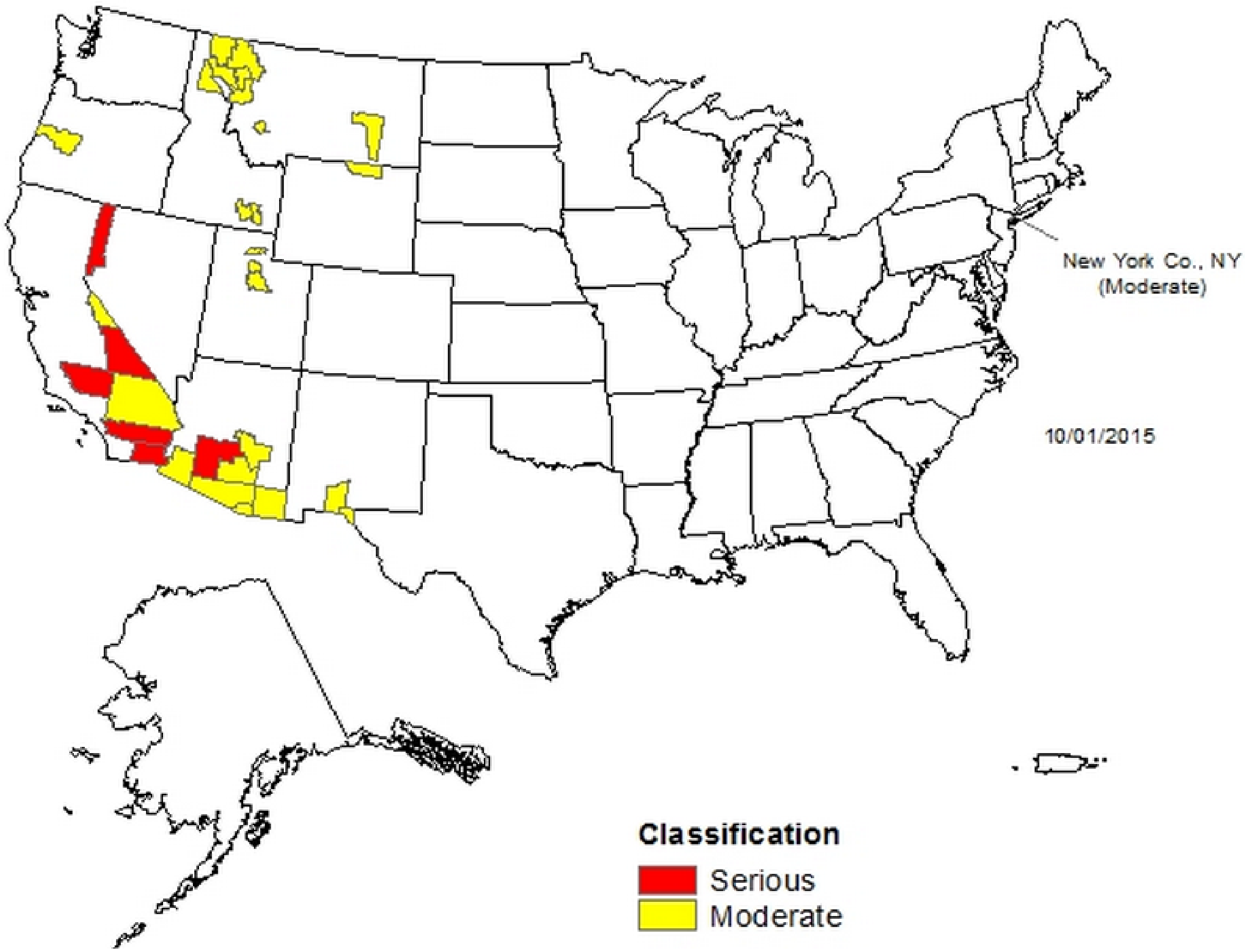



Areas exceeding an annual average of 12 µg/m3

**Counties Designated Nonattainment**
**for PM-2.5 (1997, 2006, and/or 2012 Standards)**



## Counties Designated Nonattainment for PM-10



# Quiz Question

- The EPA Estimate of Direct Compliance Costs of the Clean Air Act, averaged over the US, in the year 2010, were
  - $5-10 per household per year
  - $10-50 per household per year
  - $50-100 per household per year
  - $100-$500 per household per year
  - $500-$1000 per household per year
  - $1000-$5000 per household per year
  - $5000-$10,000 per household per year
  - $10,000-$50,000 per household per year

# Quiz Question

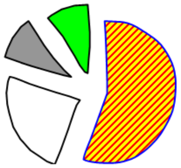
- The EPA Estimate of Direct Compliance Costs of the Clean Air Act, averaged over the US, in the year 2010, were
  - $5-10 per household per year
  - $10-50 per household per year
  - $50-100 per household per year
  - $100-$500 per household per year ($446 per year)
  - $500-$1000 per household per year
  - $1000-$5000 per household per year
  - $5000-$10,000 per household per year
  - $10,000-$50,000 per household per year

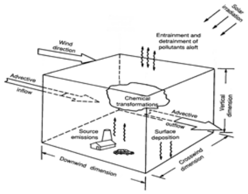
# Quiz Question

- The EPA Estimate of Benefits of the Clean Air Act, averaged over the US, in the year 2010, were. Note the estimate is based on a "Value of Statistical Life" where avoided premature mortality is valued at $253 per day
  - $5-10 per household per year
  - $10-50 per household per year
  - $50-100 per household per year
  - $100-$500 per household per year
  - $500-$1000 per household per year
  - $1000-$5000 per household per year
  - $5000-$10,000 per household per year
  - $10,000-$50,000 per household per year

# Quiz Question

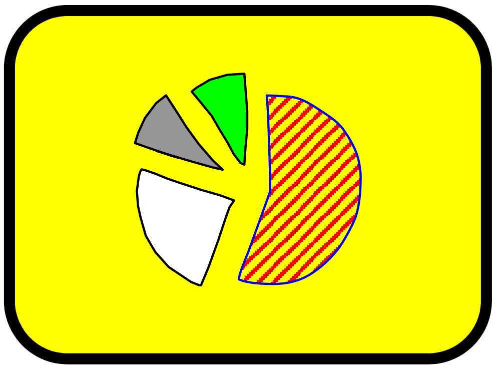
- The EPA Estimate of Benefits of the Clean Air Act, averaged over the US, in the year 2010, were. Note the estimate is based on a "Value of Statistical Life" where avoided premature mortality is valued at $253 per day
  - $5-10 per household per year
  - $10-50 per household per year
  - $50-100 per household per year
  - $100-$500 per household per year
  - $500-$1000 per household per year
  - $1000-$5000 per household per year
  - $5000-$10,000 per household per year
  - $10,000-$50,000 per household per year ($10,928 per year)

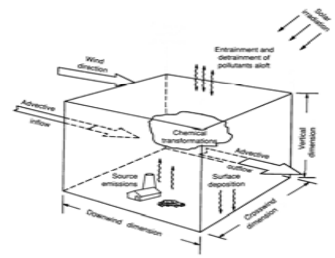





- The Clean Air Act sets standards for the concentration of 6 pollutants – ozone ($O_3$), lead, sulfur dioxide ($SO_2$), Nitrogen Dioxide (NO2), Carbon Monoxide (CO), and Particulate Matter (PM)
  - PM is divided into two size classifications PM2.5, and PM10
- There are significant respiratory and cardiovascular health benefits to low PM and significant risks to high PM
- The health effects of PM are robust and are supported by the number of studies that have found association, and the variation in the types of studies (long term, short term, natural experiment, case crossover, biomarkers, lung function, etc.)

# “B” chemical constituents that make up clean and polluted air





# Classification of Major Air Pollutants

- **NAAQSs**
  - **Six Criteria Pollutants [Nitrogen Dioxide ($NO_2$), Ozone, Sulfur Dioxide, Carbon Monoxide, Lead, PM]**
  - **Non-Criteria Pollutants**
- **Chemical Properties**
  - **Inorganic**
  - **Organic**
- **Chemical Groups**
  - **Sulfur-Containing Compounds ($SO_2$, $H_2SO_4$)**
  - **Nitrogen-Containing Compounds (NO, $NO_2$, $HNO_3$)**
  - **Carbon-Containing Compounds ($CH_4$, Alkanes, Alkenes, Alcohols)**
  - **Halogen-Containing Compounds (CFCs, $CH_3Cl$, $CH_3Br$)**
  - **Atmospheric Oxidants ($O_3$, $H_2O_2$, OH radical, $NO_3$ radical)**
  - **PM (sulfate, nitrate, OC, EC, dust, sea-salt)**
  - **Air Toxics (Lead, Mercury, Asbestos, Dioxins, Benzene)**
- **Residence Time (or Lifetime)**
  - **Long-Lived Species (CFCs, $CH_4$, $N_2O$)**
  - **Moderately Long-Lived Species (CO, $SO_2$, $NO_x$, PM, Tropospheric Ozone)**
  - **Short-Lived Species (Radicals: OH, $NO_3$, $HO_2$)**

Credit: Yang Zhang, NC State

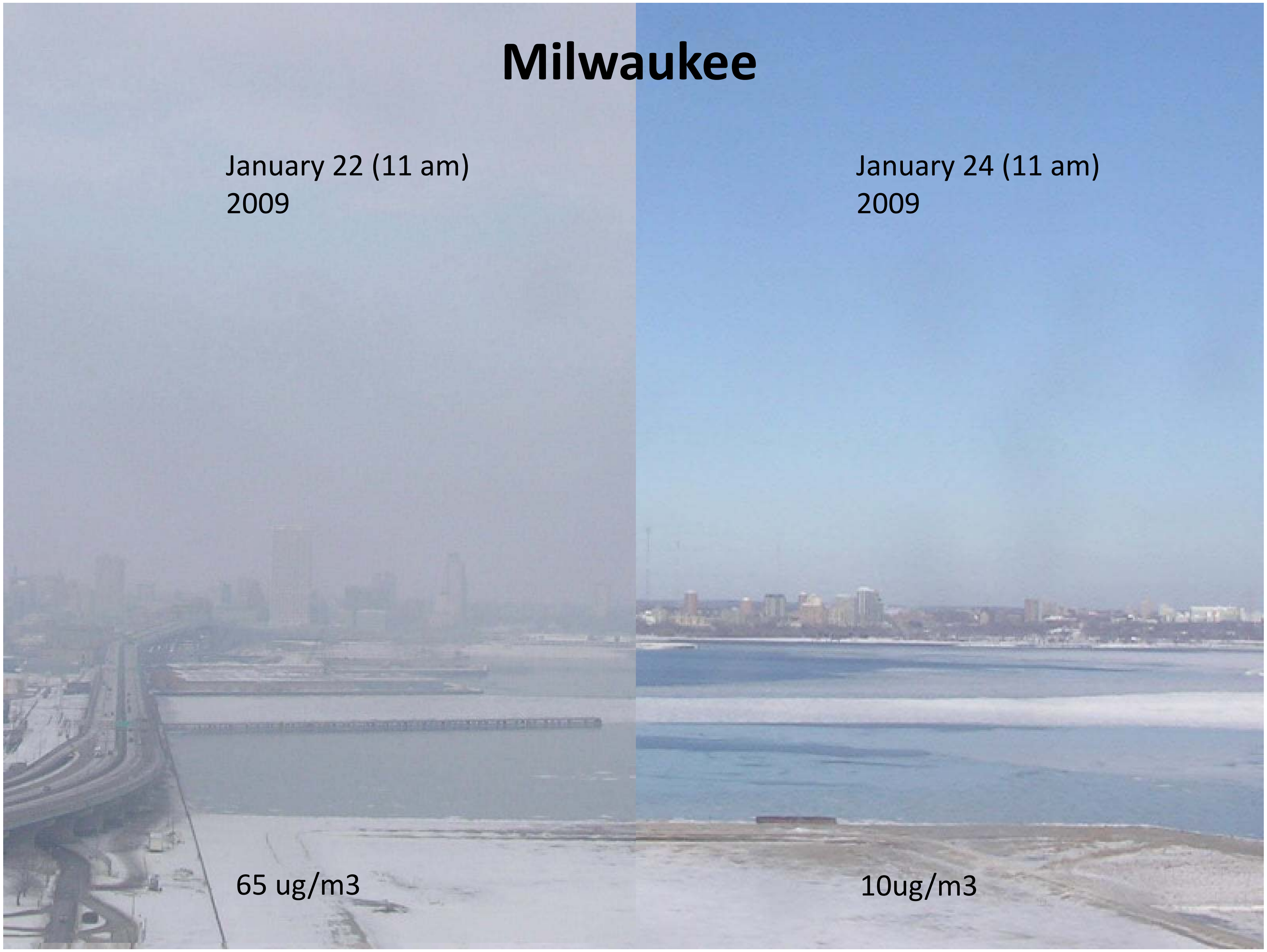
# $O_3$: Good Up High and Bad Nearby

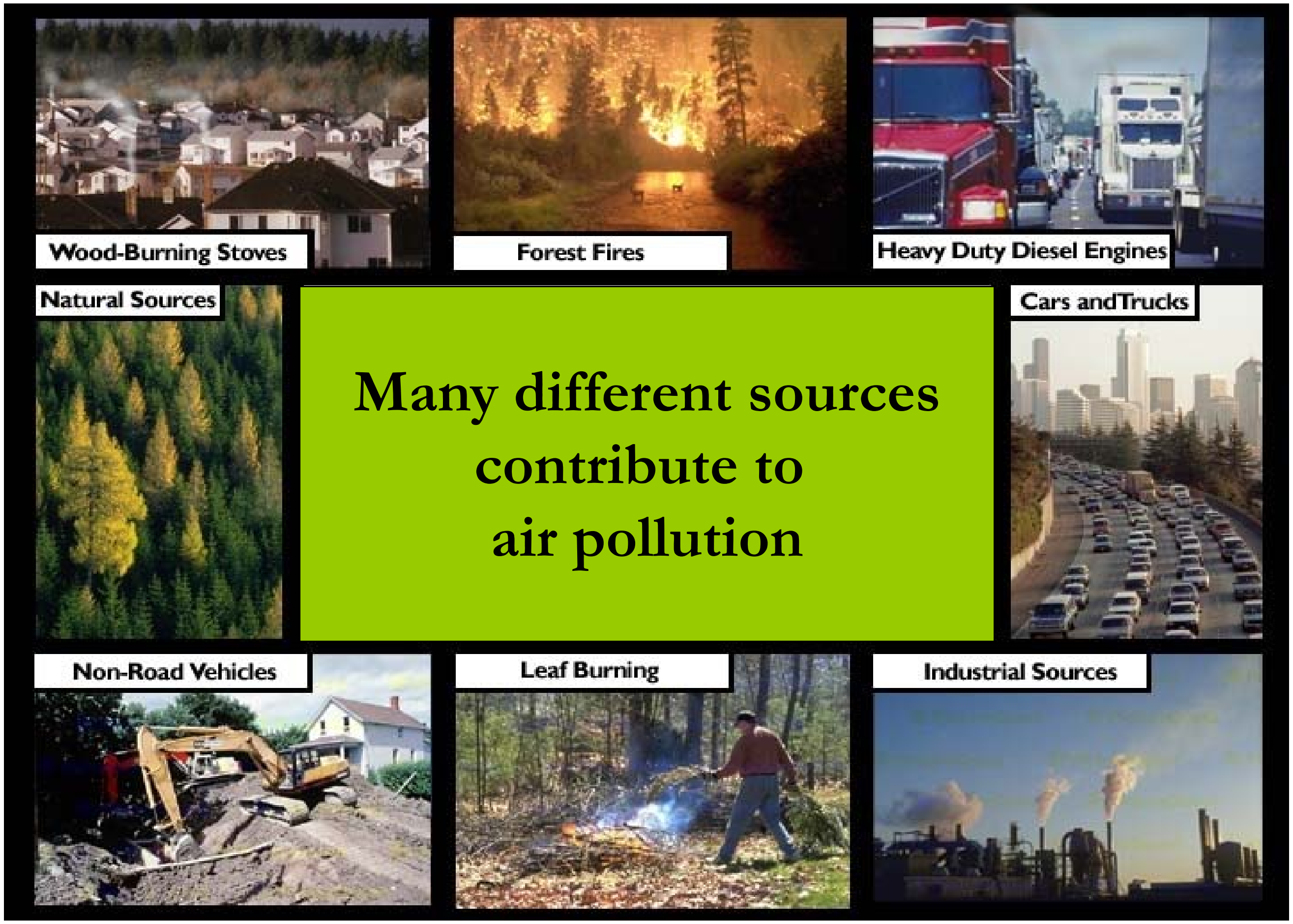
- **Tropospheric Ozone** (ground-level) – Bad, it is harmful to breathe and it damages crops, trees and other vegetation
- **Stratospheric Ozone** – Good, it protects life on Earth from the sun's harmful ultraviolet (UV) rays
- **Depletion of Good Ozone** – caused by ozone-depleting substances (e.g., chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), methyl bromide ($CH_3Br$))
- **Health Effects of Ozone Depletion** - increased amounts of UV radiation to reach the Earth which can lead to more cases of skin cancer, cataracts, and impaired immune systems
- **Environmental Effects** - UV can also damage sensitive crops, such as soybeans, and reduce crop yields

NAAQS: 70 ppb (8 hour average). Recently decreased from 75 ppb.

**Source: http://www.epa.gov/oar/oaqps/gooduphigh/ozone.html#good** Credit: Yang Zhang, NC State

# Milwaukee

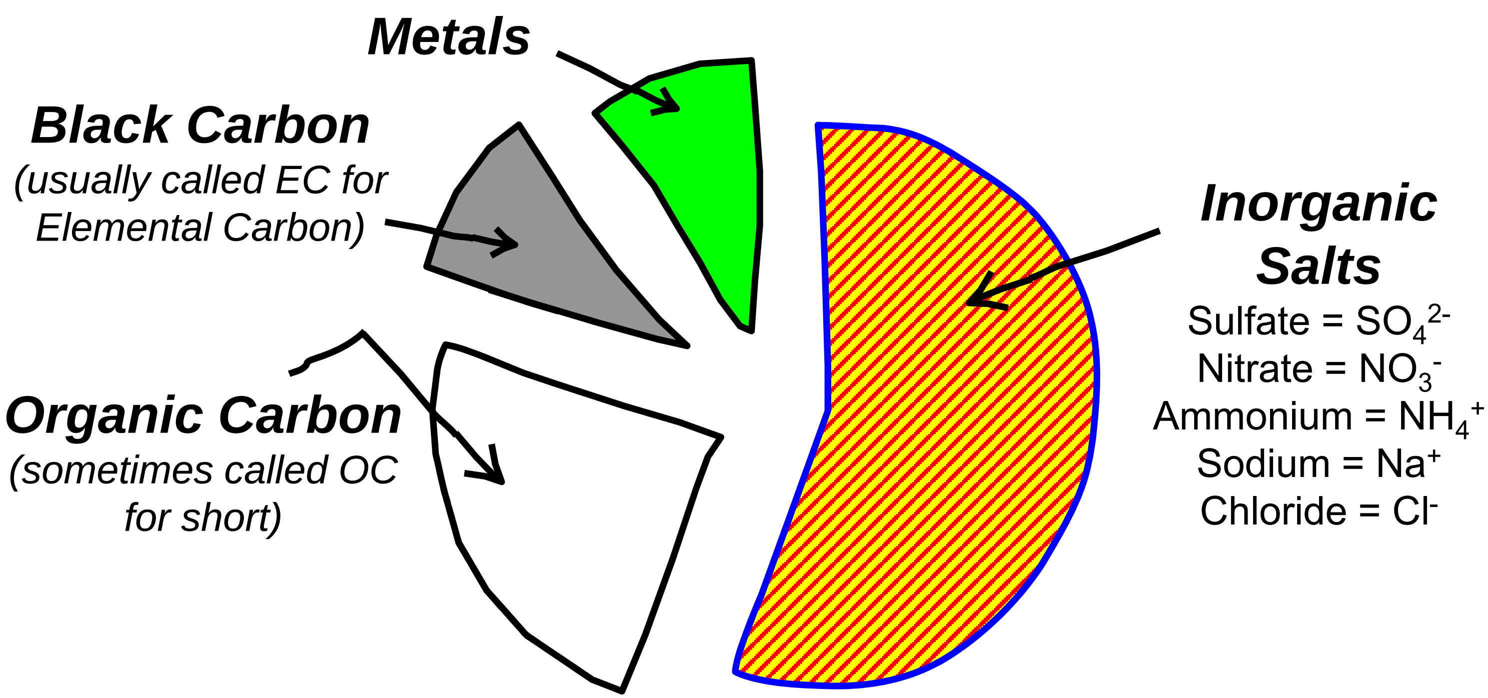




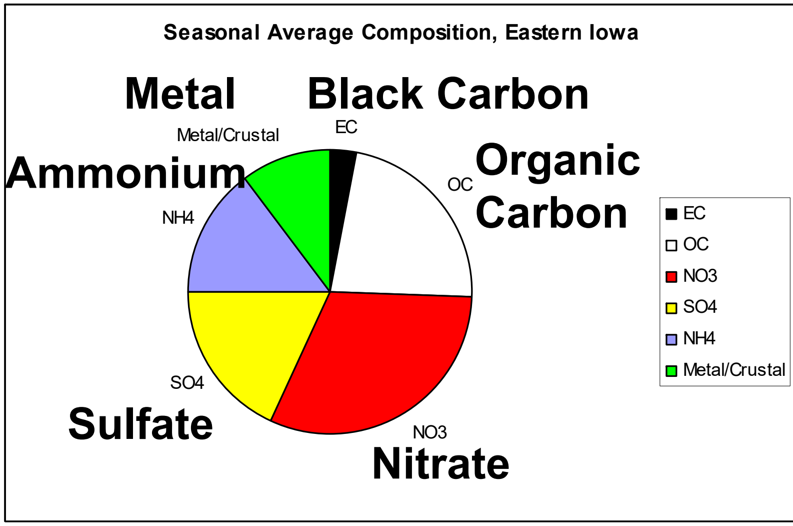



Source: Jim McGraw, IDNR

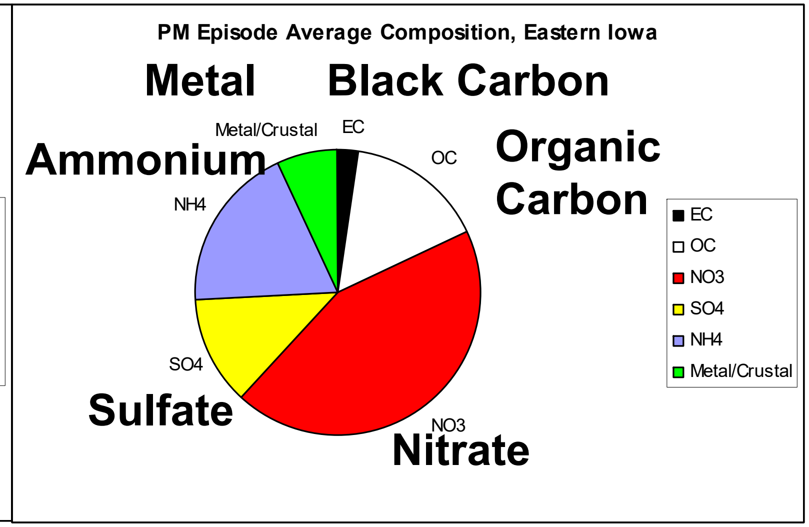
# Typical Chemical Makeup



# Winter Composition, Eastern Iowa




# Winter <u>Episode</u> Composition, Eastern Iowa




Average of Cedar Rapids, Des Moines, and Davenport
From section 5 Feb 2009 "Understanding Episodes…" Stanier et al.

# #1 Chemical Contribution = “Salts”

**Ammonium Nitrate**

**Ammonium Sulfate**

- **Formed IN THE ATMOSPHERE – called Secondary Particulate Matter**
- Ultimate sources
  - Ammonia
  - Nitrogen Oxides (NOx, NO and $NO_2$)
  - Sulfur Dioxide

Image Sources
www.hottdealss.com/Ammonium%20nitrate.html
www.irmteam.com/html/prod_210024sfluid.html

# #2 Chemical Contribution = Carbonaceous Materials



Organic Carbon (OC)

Black Carbon (EC)

- Primary and Secondary
- Ultimate Sources: Incomplete Combustion, Solvent and Fuel Vapors, Vegetation

- Primary
- Ultimate Source:

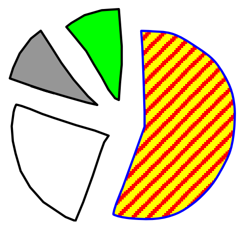
Incomplete Combustion

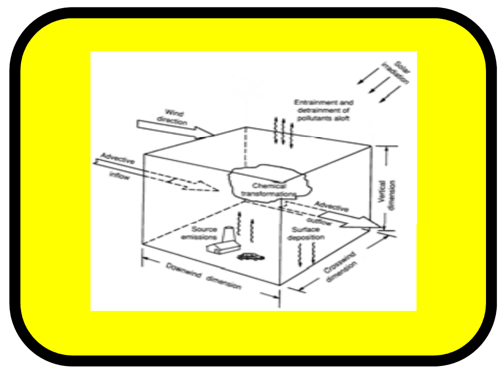
Image Sources www.honorrunchem.com/Sodium_Benzoate.html
www.jiaodakaida.com/cpshow.php?id=57
www.allproducts.com/manufacture100/sfsd/product1.html

# Quick Review…

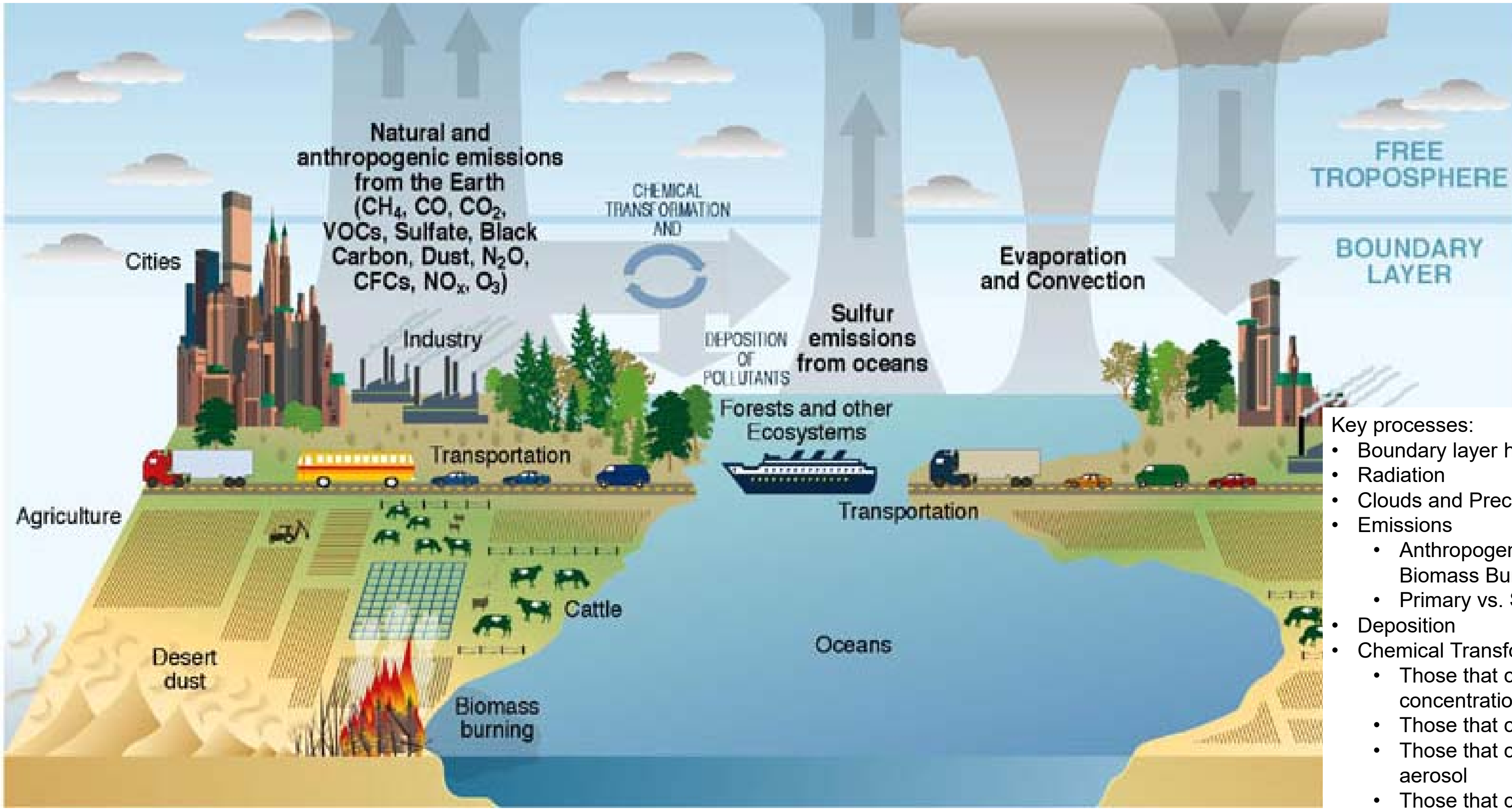
| **PM2.5 Species** | **Primary or Secondary?** | **Notes** |
|---|---|---|
| Nitrate | Secondary | #1 in winter<br>Ultimate source: NOx from combustion |
| Organic Carbon (OC) | Secondary and Primary | #2 year round<br>Variety of sources |
| Sulfate | Secondary | #1 in summer<br>Ultimate source: Sulfur dioxide (SO2) from combustion |
| Ammonium | Characteristics of both secondary and primary | Important year round<br>Ultimate source: ammonia gas emissions from fertilizer, manure, automobiles, and wastewater |
| Metals | Primary | Road and soil dust; Combustion; Industrial emissions; Tire and brake wear |
| Black Carbon (EC) | Primary | Incomplete Combustion |

# “C” the processes that control concentrations in the atmosphere





# Air Pollution Processes



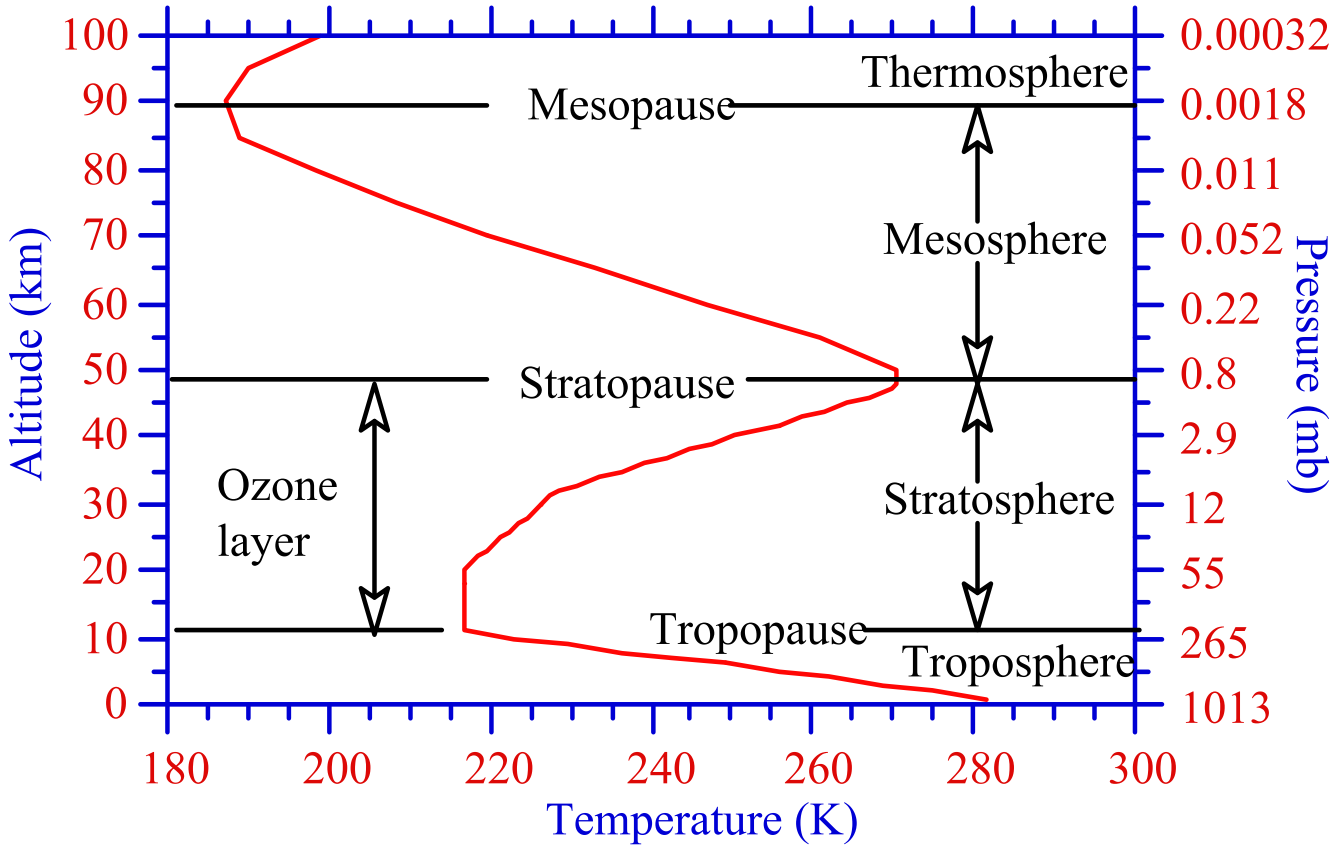

Key processes:

- Boundary layer height / mixing height
- Radiation
- Clouds and Precipitation
- Emissions
  - Anthropogenic vs. Biogenic vs. Biomass Burning
  - Primary vs. Secondary
- Deposition
- Chemical Transformations
  - Those that control ozone concentrations
  - Those that create sulfate aerosol
  - Those that create secondary organic aerosol
  - Those that create ammonium nitrate aerosol
- Aerosol Thermodynamics



http://www.climatescience.gov/Library/stratplan2003/final/ccspstratplan2003-chap3.htm

# Temperature Versus Altitude






Credit: Yang Zhang, NC State

# Structure of Troposphere

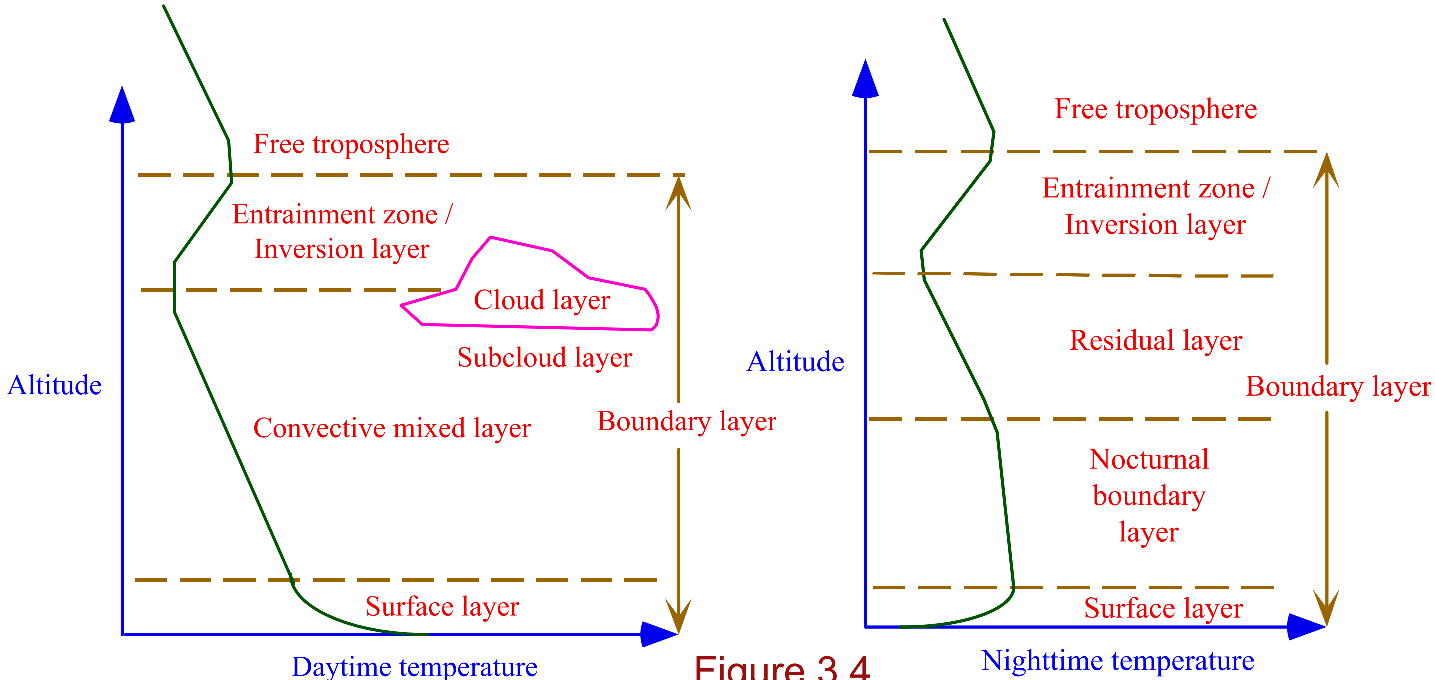



Figure 3.4

**Free Troposphere– between the PBL and the tropopause, temperature decreases with increasing altitude**
**Planetary Boundary Layer (PBL) – from the surface to between 500 and 3000 m altitude, pollution builds up**

- **Surface layer: bottom 10% of the PBL, from ground to 50 to 300 m, strong change of wind speed with height (wind shear)**
- **Convective mixed layer: just above the surface layer, upward/downward motions occur, allowing air and pollutants to mix**
- **Entrainment zone/Inversion layer: the region from the top of the mixed layer to that of the PBL, temperature increases with increasing height (inversion). Some mixing (entrainment) between the inversion and convective mixed layer also occurs**
- **Nocturnal boundary layer: the portion of the daytime mixed layer that loses its buoyancy at night**



Credit: Yang Zhang, NC State

# Change in Mixing Depth, Los Angeles, Dec. 19, 2000

Noon Late afternoon

Figure 6.15

# Stability in Unsaturated Air

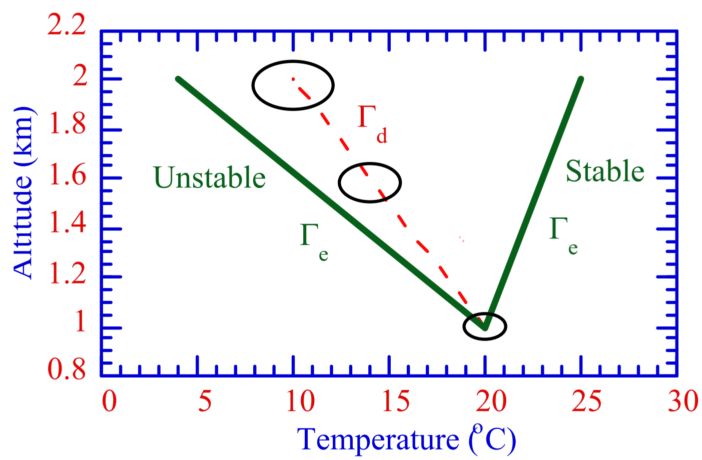



Fig. 6.8

**Stability – a measure of whether pollutants emitted will convectively rise and disperse or build up in conc. near the surface.**

**In stable air – The rising parcel is cooler and more dense than the surrounding air, as of a result, it sinks, compresses, and warms until its temp (and density) equals that of the surrounding air. Stable air is associated with near-surface pollution buildup.**

**In unstable air– The rising parcel is warmer and less dense than the surrounding air, as of a result, it continues to accelerate until it reaches a layer with a new environmental lapse rate, at which the air has the same temp (and density) as the parcel. Unstable air is associated with near-surface pollution cleansing.**

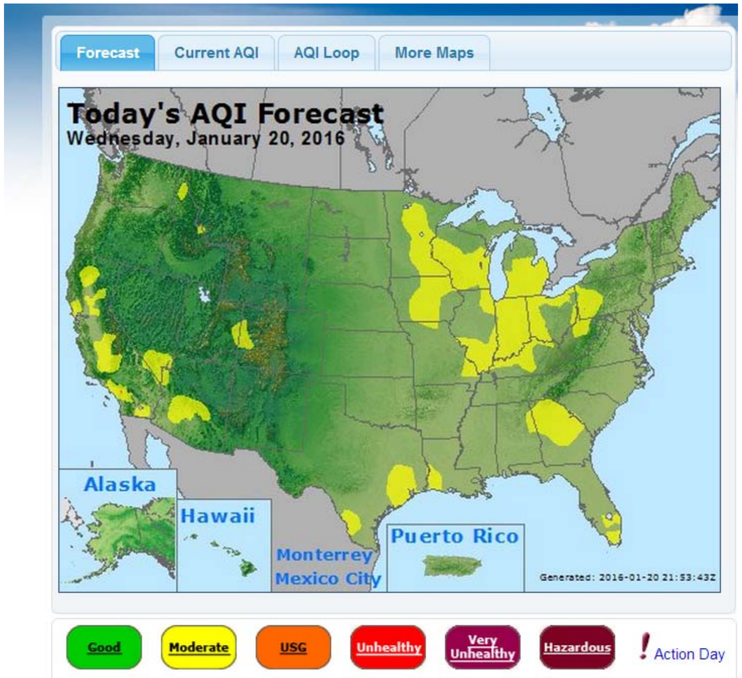
**In neutral air - the parcel neither accelerates nor decelerates, but continues along the direction of its initial perturbation at a constant velocity. Neutral air results in pollution dilution slower than in unstable air but faster than in stable air.**

**$\Gamma_d$ – dry (or unsaturated) adiabatic lapse rate, = 9.8 K (or °C) km$^{-1}$**
**$\Gamma_w$ – wet (or saturated, or pseudoadiabatic) lapse rate.**
**$\Gamma_e$ – environmental lapse rate, = $-\Delta T/\Delta z$.**

Credit: Yang Zhang, NC State

# Air Quality Index

| Air Quality Index (AQI) Values | Levels of Health Concern | Colors | 24 hr ave PM2.5 |
|---|---|---|---|
| *When the AQI is in this range:* | *..air quality conditions are:* | *...as symbolized by this color:* | *ug/m3* |
| 0-50 | Good | Green | 0 - 12 |
| 51-100 | Moderate | Yellow | 12.1 -35.4 |
| 101-150 | Unhealthy for Sensitive Groups | Orange | 35.5 – 55.4 |
| 151 to 200 | Unhealthy | Red | 55.5 – 150.4 |
| 201 to 300 | Very Unhealthy | Purple | 150.5 – 250.4 |
| 301 to 500 | Hazardous | Maroon | 250.5 – 500.4 |




**Air Quality Index (AQI) is used by government agencies to tell the public how clean or polluted the air currently is.**

http://www.airnow.gov/