Session 1A Part 2:
Air Quality and Meteorology 101

Timothy S. Dye
Clinton P. MacDonald
Dianne S. Miller

Sonoma Technology, Inc.

Air Quality and Meteorology 101

Objectives of this course are to provide

- Insights into the history of Smog
- Familiarity with the major pollutants, formation processes, and emission sources
- Description of the role of weather in Air Quality

Course Topics

- History of Smog
- Major Types of Pollutants
- Emission Sources
- Pollutant Lifecycles and Trends
- Key Weather Features

History of Smog (1 of 7)

Origin: **sm**oke and f**og** = **Smog**

- Ozone, hydrocarbons, nitrogen oxides, particles, and other chemically reactive compounds.
- The word "smog" coined in early 1900s by Harold A. Des Veaux to describe conditions of sooty fog in Britain.
- Also known as "*pea soupers*" and *"great stinking fogs"*.

History of Smog (2 of 7)

AD 61	Rome, the Philosopher Seneca wrote, *"as soon as I had gotten out of the heavy air of Rome and from the stink of the smoky chimneys thereof, which, being stirred, poured forth whatever pestilential vapours and soot they had enclosed in them, I felt an alteration of my disposition."*
1300	England, King Edward II banned coal burning in London while parliament was in session and announced that "*whosoever shall be found guilty of burning coal shall suffer the loss of his head."*
1552	Juan Rodriquez Cabrillo sailed into Los Angeles Bay. Upon observing smoke from Indian fires on shore rise and spread after hitting the inversion, he named it "The Bay of Smokes".
1661	Britain, scientists John Evelyn and John Graunt found that polluted air from industry could affect vegetation and people. They suggested that industries be located in the countryside to minimize effects on health.
1750s	Under stable conditions, London's urban plume of smoke was observed at distances of 100 km

History of Smog (3 of 7)

1943: First recognized episodes of smog occurred in Los Angeles. Visibility was only three blocks and people suffered from itchy eyes, respiratory discomfort, nausea, and vomiting. The phenomenon was termed a "gas attack" and blamed on a nearby butadiene plant.

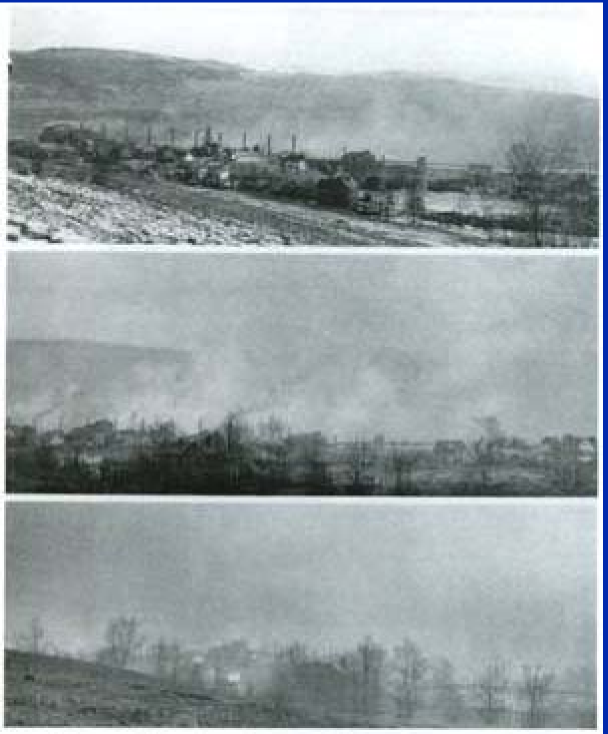
Protests at Pasadena City Hall on November 9, 1954, following fifteen days of smog in October.

History of Smog (4 of 7)

1948 Donora, Pennsylvania, air pollution episode killed 20 people, and half the town's 12,000 residents became ill due to uncontrolled emissions from industrial facilities and stagnant weather.

Credit: Pittsburgh Post-Gazette

1948: Donora, PA at noon.



Views of Donora's steel mill and wire works taken from across the river in Webster, Pennsylvania. All of these photographs are made at noon on various days in 1948. On the worst days, the town was completely obscured by smog.

Source: *When Smoke Ran Like Water,* Devra Davis, Perseus Books

History of Smog (5 of 7)

1952 London, four days in December

- Mix of dense fog and sooty black coal smoke
- Killed thousands of Londoners
- December 4 smoke (PM) was 490 µg/m^3
- December 7 and 8 4460 µg/m^3

"Night at Noon." London's Piccadilly Circus at midday, during another deadly smog episode, this time in the winter of 1955.
Source: *When Smoke Ran Like Water,* Devra Davis, Perseus Books

Central London during the killer smog, December 1952. At this point, visibility is less than 30 feet. During the height of the smog, people could not see their own hands or feet, and buses had to be led by policemen walking with flares.
Source: *When Smoke Ran Like Water,* Devra Davis, Perseus Books

History of Smog (6 of 7)

1966 On Thanksgiving Day, New York City found itself in a sea of smog caused by traffic, industry and power plants, and apartment buildings heating with coal. Weather played a role in trapping pollution beneath a temperature inversion.

A smog emergency was declared for the tri-state area. Motorists were urged to stay home. Incinerators were shut down. Health officials later attributed more than 150 deaths to the pollution.

1966: New York City buried under a sea of smog.

History of Smog (7 of 7)

1960 Air Pollution Potential – forecasting began

1963 National Air Pollution Control Agency – Started as a research body; not very effective

1967 The Air Quality Act of 1967

- Designation of air quality regions
- Regional approach to pollution control

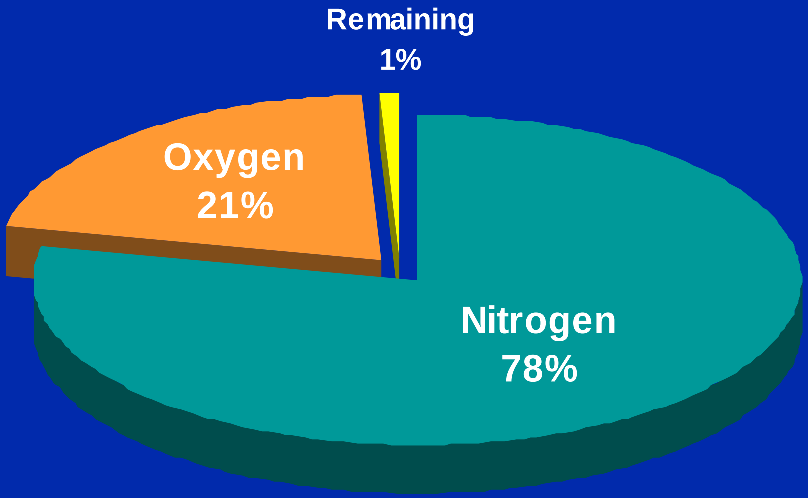
1970 A turning point

- Attitudinal change in U.S. society
- National Environmental Policy Act (January 1)
- Formation of Environmental Protection Agency (July 9)
- Earth Day (April 22)
- Clean Air Act of 1970
  - National Air Quality Standards
  - Statutory deadlines for compliance

Major Types of Pollutants

What is in our air?

- Mixture of invisible gases, particles, and water
- Mostly nitrogen (78%) and oxygen (21%)
- Other
  - – Argon
  - – Water vapor
  - – Carbon dioxide
  - – Ozone
  - – Particulate matter
  - – and many more



Major Types of Pollutants

Categories of pollutants

- Primary – emitted directly from source
- Secondary – formed in atmosphere from reaction of primary pollutants
- Precursors – primary pollutants (gases) that form secondary pollutants

Pollutants originate from

- Combustion of fossil fuels and organic matter
- Evaporation of petroleum products or compounds used in commercial products, services, and manufacturing
- Natural production of smoke from fires, dust from strong winds, and emissions from the biosphere and geosphere

Pollutants – Combustion

- Complete combustion

  Fuel → water and carbon dioxide (CO_2)

- Incomplete combustion

  Fuel → water, CO_2, pollutants

  Pollutants are both gases and particles

Pollutants – Evaporation

- Thousands of chemical compounds
- Liquids evaporating or gases being released
- Some harmful by themselves, some react to produce other pollutants
- Many items you can smell are evaporative pollutants:
  - Gasoline – benzene (sweet odor, toxic, carcinogenic)
  - House cleaners: Pinesol – pinenes (ozone-forming)
  - Bleach – chlorine (toxic, greenhouse gas)
  - Plants – isoprene (ozone-forming)
  - Trees – pinenes, limonene (ozone- and particulate matter forming)
  - Paint – volatile organic compounds (ozone- and particulate matter forming)
  - "New car smell" – complex mixture of VOCs including toluene, acetone, xylenes (toxics, ozone-forming)
  - Aerosol hairspray, deodorant – butane is used as a propellant (ozone-forming)
  - Rubber cement, nail polish – toluene (toxic, ozone-forming)
  - Pressed wood products – formaldehyde (toxic, carcinogenic, ozone-forming)
  - Baking bread, fermenting wine and beer – VOCs and ethanol (ozone-forming)

Pollutants – Natural Production

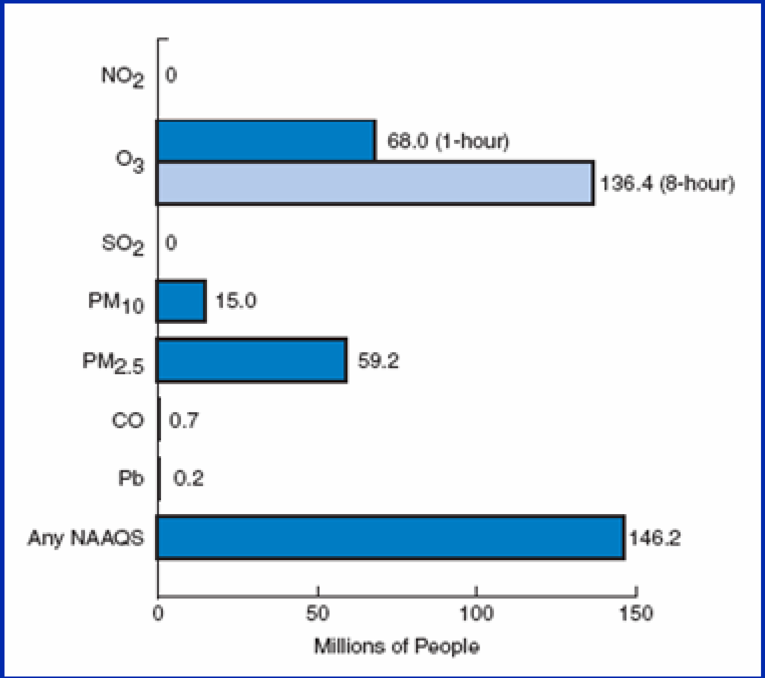
- Fires = combustion – Produce gases and particles
- Winds “pick up” dust, dirt, sand – Create particles of various sizes

- Biosphere – Emits gases from trees, plants, soil, ocean, animals, microbes
- Volcanoes and oil seeps – Produce particles and gases

Pollutants – Criteria

- Response to 1970 Clean Air Act
- Established the National Ambient Air Quality Standards (NAAQS) for six pollutants:
  - Nitrogen dioxide (NO_2)
  - Ozone (O_3)
  - Sulfur dioxide (SO_2)
  - Particulate matter (PM_{10})
  - Particulate matter ($PM_{2.5}$)*
  - Lead (Pb)
  - Carbon monoxide (CO)

People Living in Counties with Air Quality Concentrations above the NAAQS in 2002



Source: U.S. EPA National Air Pollutant Emission Trends, 1900-1998

* established after 1970

Units of Measure

Pollution reported in several ways

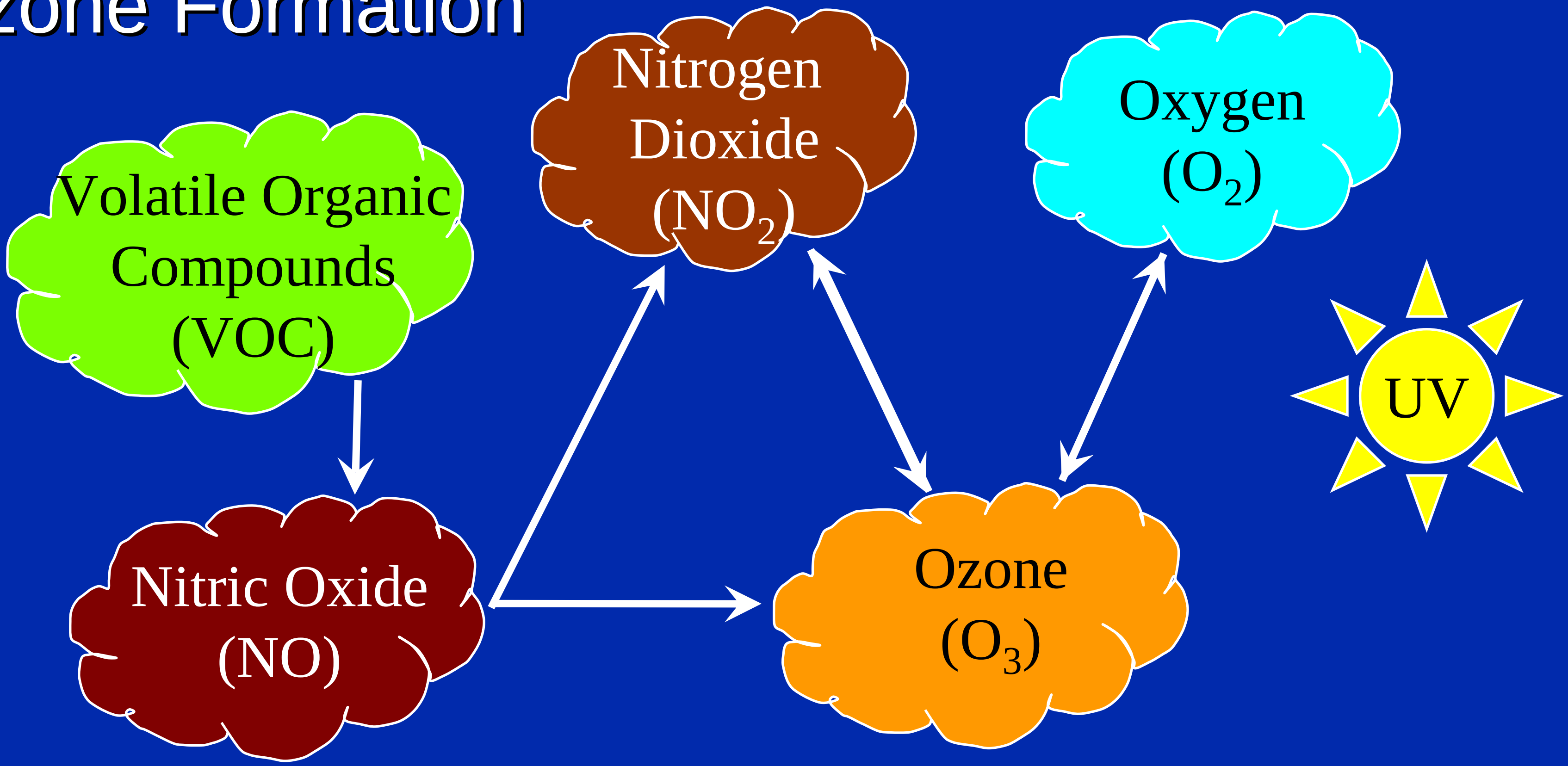
- Concentration
  - Amount of a material in large amount of air
  - Parts per million (ppm) 1 in 1,000,000
  - Parts per billion (ppb) 1 in 1,000,000,000
- Mass
  - Weight of impurity in a volume of air
  - Microgram per cubic meter ($\mu g/m^3$)
- Air Quality Index
  - Health-related physical units removed
  - Good, Moderate, Unhealthy for Sensitive Groups, Unhealthy, Very Unhealthy

Pollutants – Ozone (1 of 3)

- A colorless gas
- Composed of three oxygen atoms
  - Oxygen molecule (O_2) – needed to breathe to sustain life
  - Ozone (O_3) – extra oxygen atom makes ozone very reactive
- Secondary pollutant that forms from precursor gases
  - Nitric oxide – combustion product
  - Volatile organic compounds – evaporative and combustion products

Pollutants – Ozone (2 of 3)

Ozone Formation



Key factors:

- Sunlight (ultraviolet) needed
- Amount of VOC and NO is critical
- Higher temperatures speed up chemical reactions

Pollutants – Ozone (3 of 3)

- Clean-air background levels are 35-40 ppb* (sometimes lower)
- U.S. concentrations range from 0 to 250+ ppb*

- Ozone health concerns
  - A severe irritant (reactive).
  - Inflames and irritates the respiratory tract, particularly during physical activity. Breathing ozone can worsen asthma attacks.
  - Symptoms include breathing difficulty, coughing, and throat irritation.
  - Medical studies have shown that ozone damages lung tissue; complete recovery may take several days after exposure.

* One-hour average

Ozone Experiment

- Create ozone in a bottle
- Materials
  - Oxygen
  - Flask
  - Electrical charge
  - Grounding wire
  - Aluminum foil
  - Rubber band
  - Fruit

- Results
  - Ozone is a clear gas
  - Rubber band oxidation
  - Gas-to-particle conversion

Making ozone in a bottle…

Fill flask with oxygen (O_2)

Apply electricity to break down oxygen molecules (O_2) into atomic oxygen (O), which then combines with existing oxygen molecules to form ozone (O_3)

Ozone reacting in a bottle….

Flask filled with ozone – approximately 1000+ ppb!

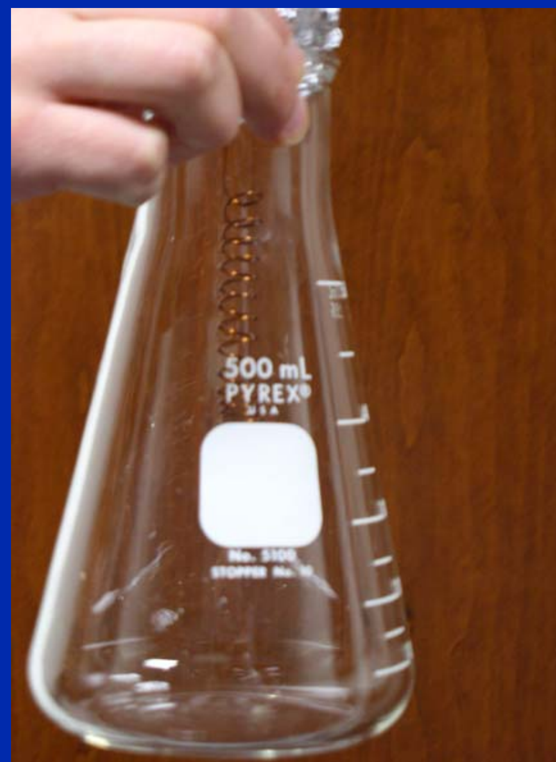
Insert rubber band into ozone-laden flask

Rubber band cracks due to oxidation by ozone within five minutes

Pollutants – Ozone Experiment (4 of 4)

Gas (Ozone, VOC) converting to particles…

An orange serves as the volatile organic compound (terpenes)

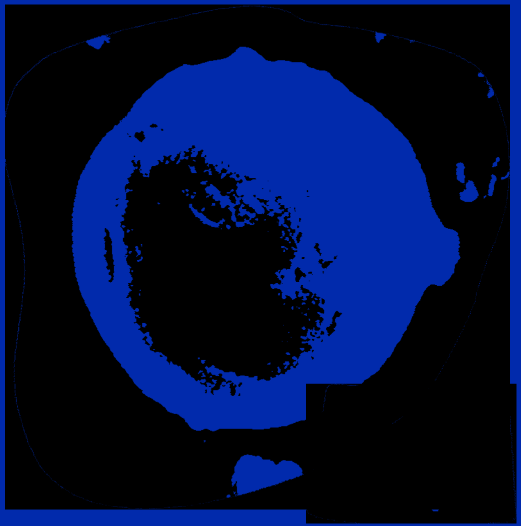


Ozone gas in the bottle with no particles

Inserting a scored orange peel adds VOCs that react with ozone to form particles

Pollutants – Particulate Matter (1 of 7)

- A complex mixture of solid and liquid particles
- Composed of many different compounds
- Both a primary and secondary pollutant
- Sizes vary tremendously
- Forms in many ways
- Clean-air levels are < 5 µg/m^3 *
- Background concentrations can be higher due to dust and smoke
- U.S. concentrations range from 0 to 200+ µg/m^3 *
- Health concerns
  - Can aggravate heart diseases
  - Associated with cardiac arrhythmias and heart attacks
  - Can aggravate lung diseases such as asthma and bronchitis
  - Can also increase susceptibility to respiratory infections

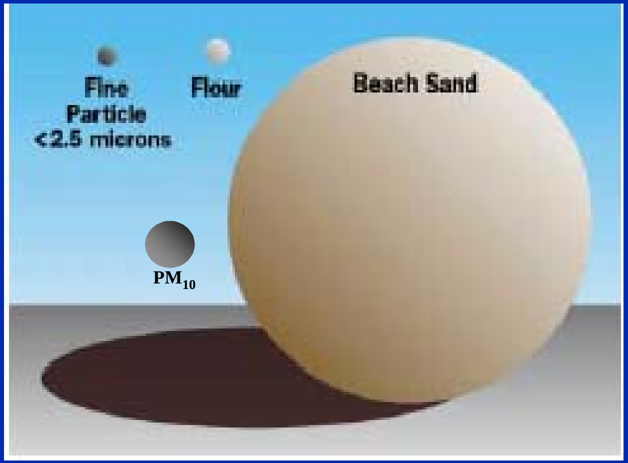


Ultra-fine fly-ash or carbon soot

* 24-hour average

Pollutants – Particulate Matter (2 of 7)

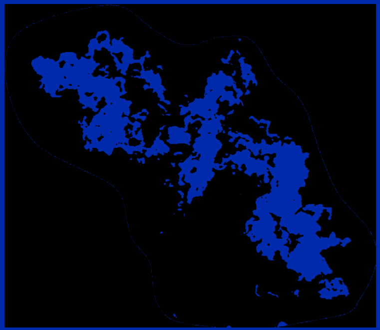
Particles come in different shapes and sizes:



Particle sizes:

- Ultrafine particles (<0.1 µm)
- Fine particles (0.1 to 2.5 µm)
- Coarse particles (2.5 to 10 µm)


Crustal material


Carbon chain agglomerates

Pollutants – Particulate Matter (3a of 7)

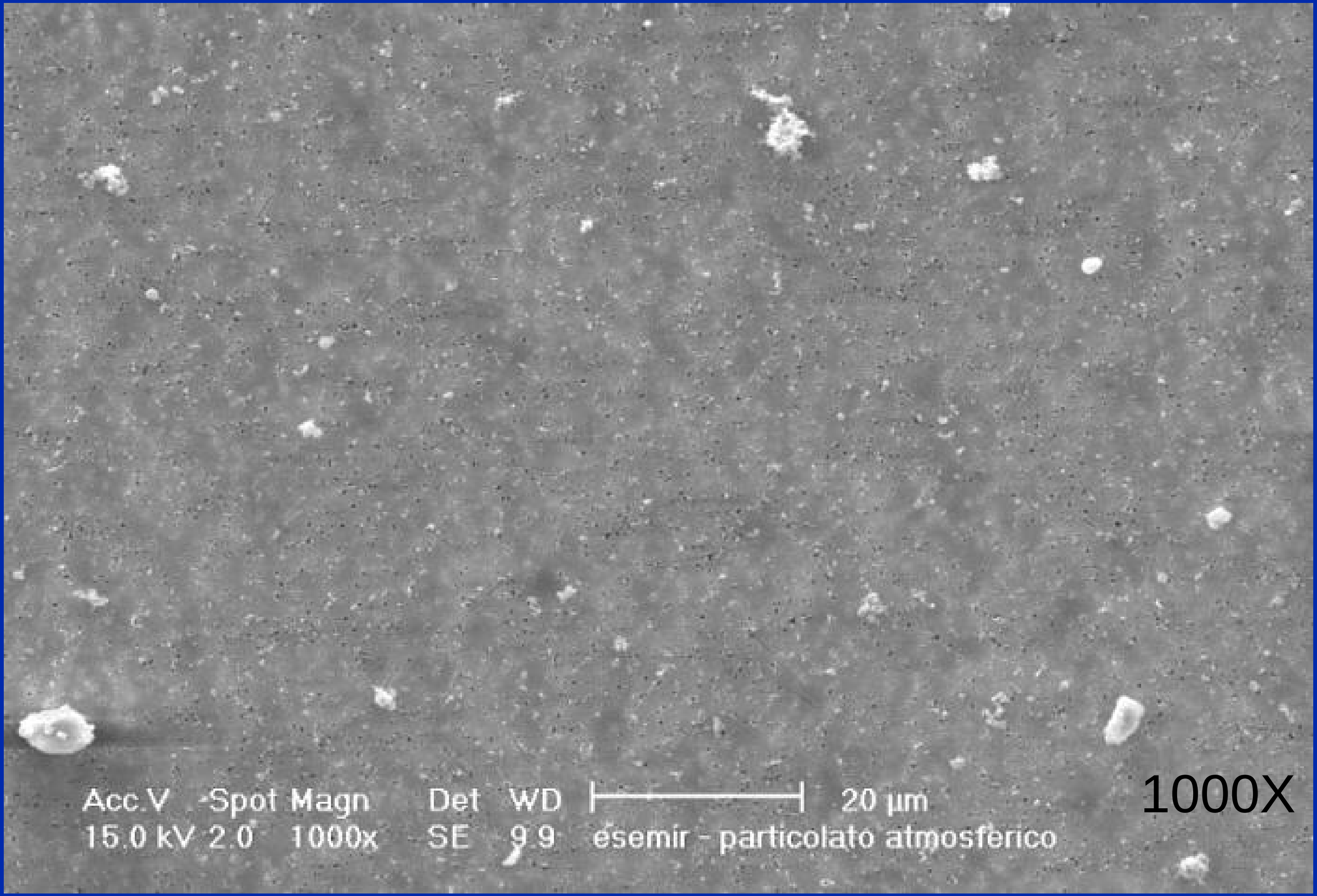
A unused (left) and dirty (right) PM filter

Pollutants – Particulate Matter (3b of 7)

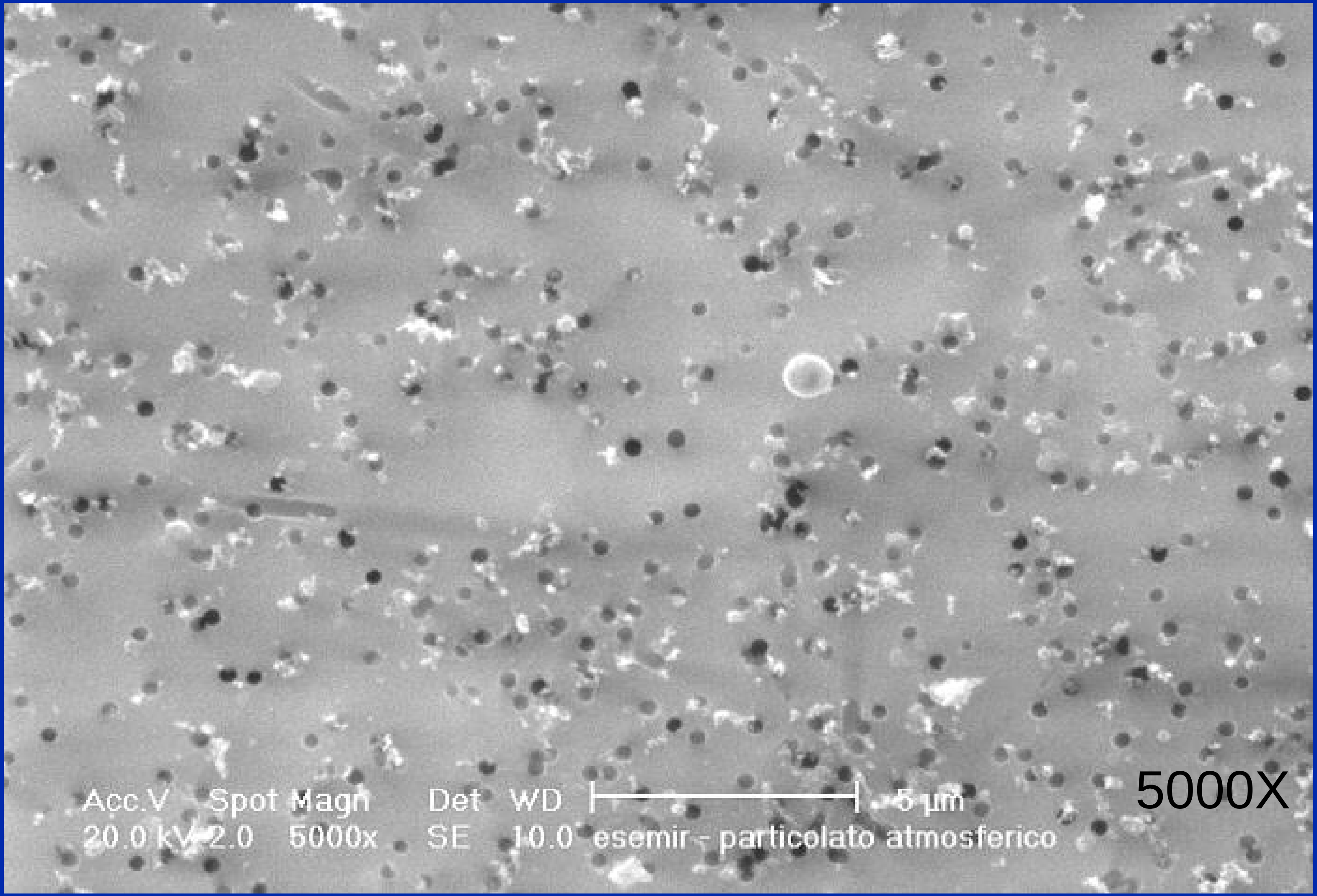
Pollutants – Particulate Matter (3c of 7)

Pollutants – Particulate Matter (3d of 7)

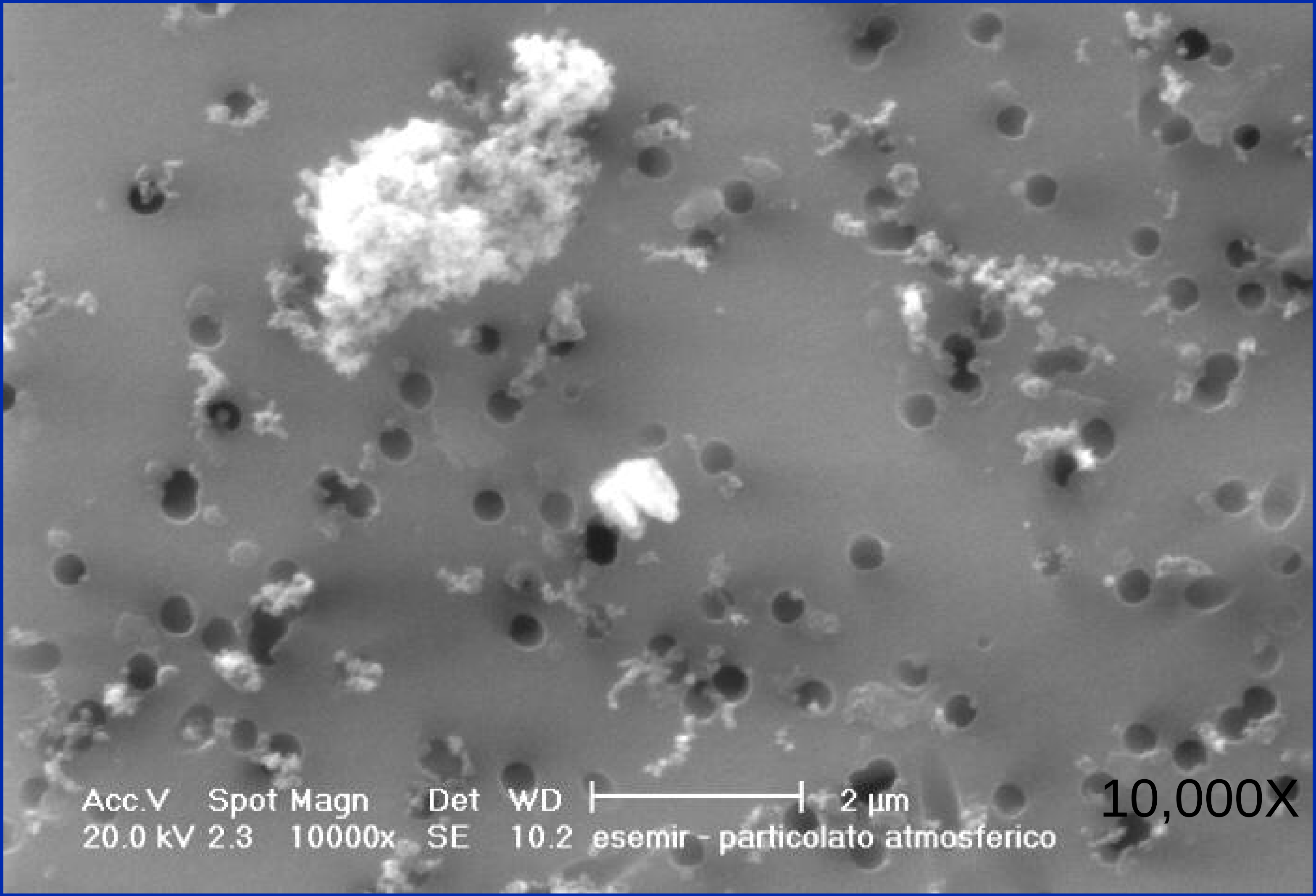
Pollutants – Particulate Matter (3e of 7)



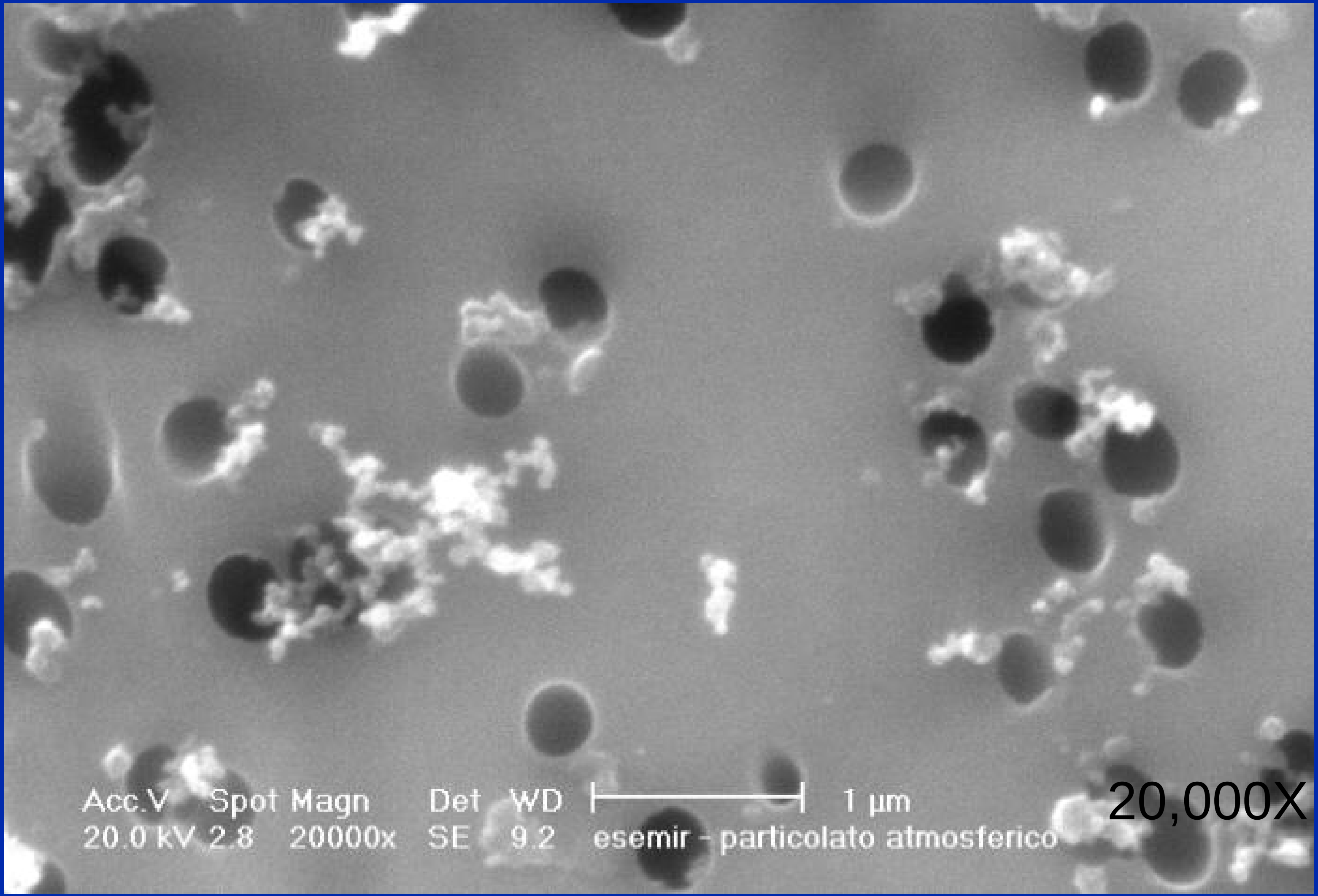
Pollutants – Particulate Matter (3f of 7)



Pollutants – Particulate Matter (3g of 7)



Pollutants – Particulate Matter (3h of 7)



Pollutants – Particulate Matter (4 of 7)

Lava lamp and particles

- Big particles settle out
- Many small particles stay suspended for hours

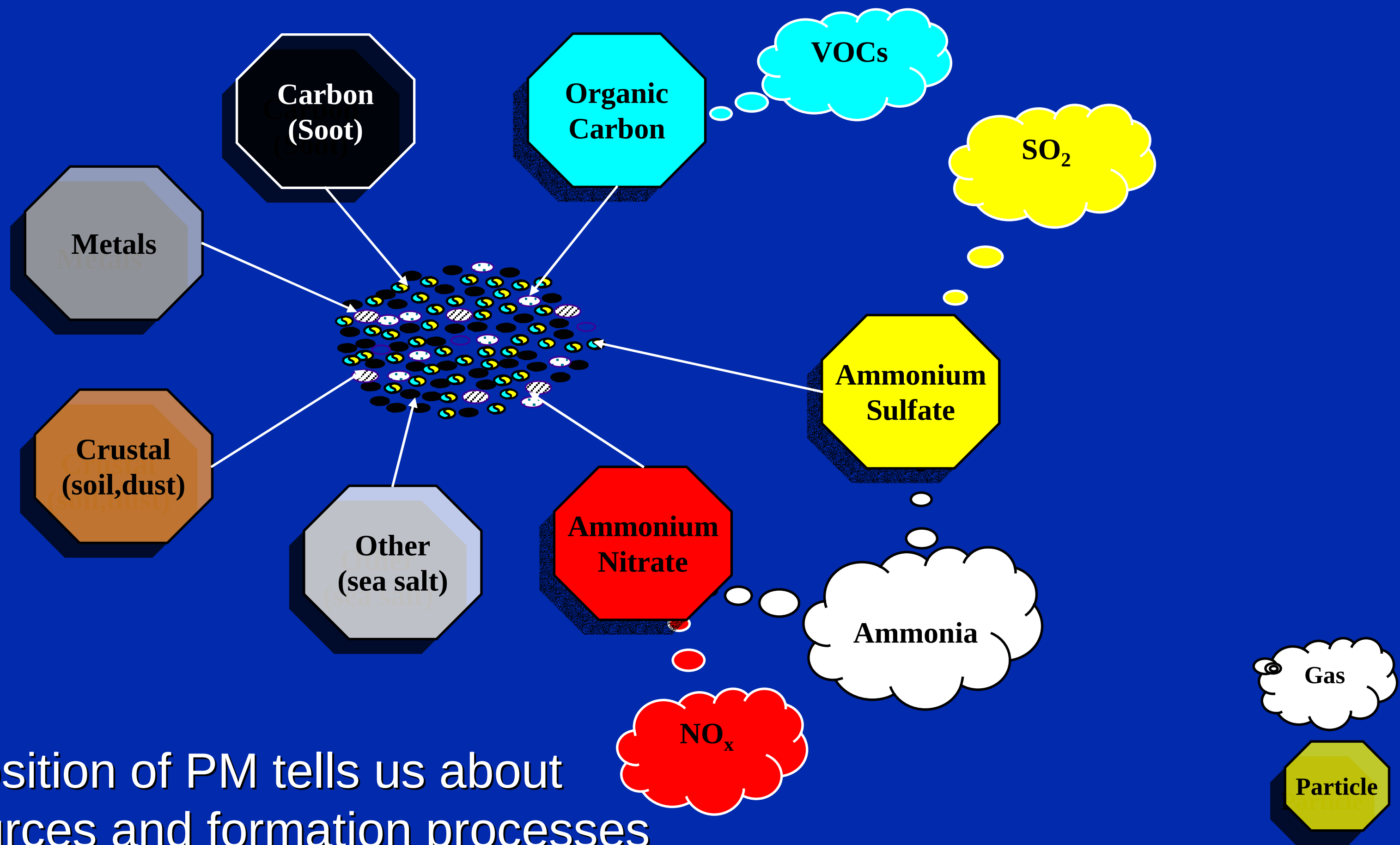
Name	Residence time	Removal process
Ultrafine	days-week	coagulation
Fine ($PM_{2.5}$)	week-month	condensation
Coarse ($PM_{2.5}$ to PM_{10})	hours-day	sedimentation

Pollutants – Particulate Matter (5 of 7)

Many compounds are in PM

Primary Particles
(directly emitted)

Secondary Particles
(from precursor gases)

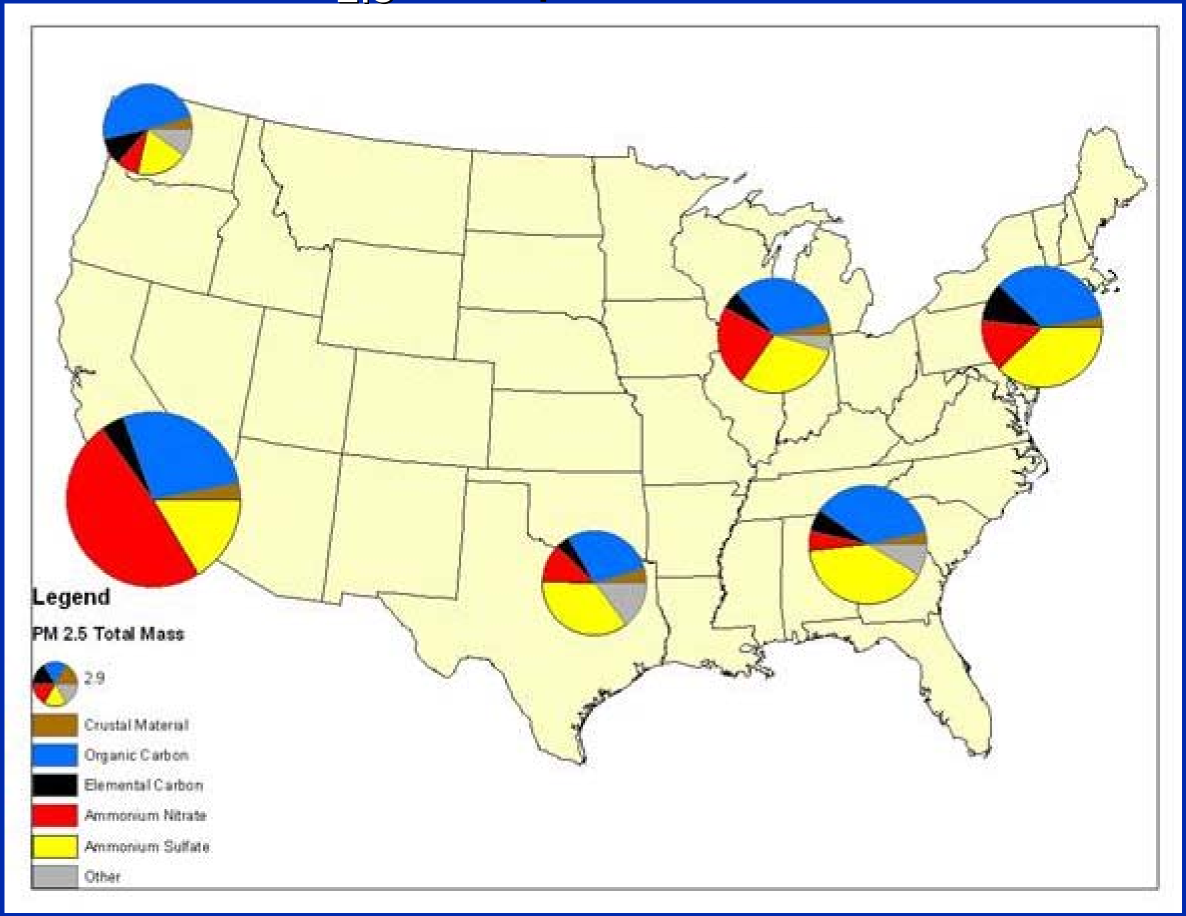


Composition of PM tells us about the sources and formation processes

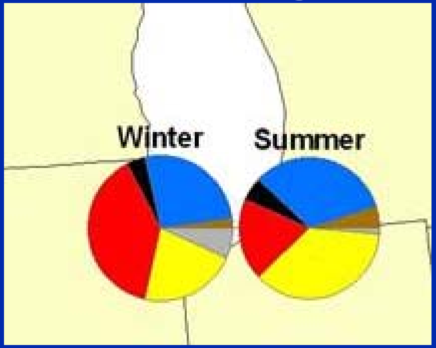
Pollutants – Particulate Matter (6 of 7)

PM varies across the U.S. and by season

$PM_{2.5}$ composition



Chicago



Source: U.S. EPA Air Quality System (AQS)

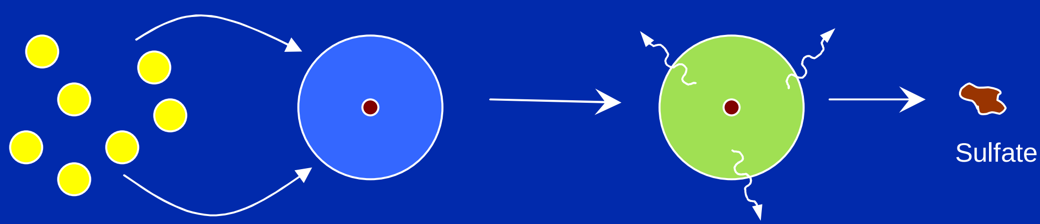
Pollutants – Particulate Matter (7 of 7)

PM Formation

Coagulation: Particles collide and stick together.

Condensation: Gases condense onto a small solid particle to form a liquid droplet.

Cloud/Fog Processes: Gases dissolve in a water droplet and chemically react. A particle exists when the water evaporates.



Chemical Reaction: Gases react to form particles.

Pollutants – Visibility (1 of 3)

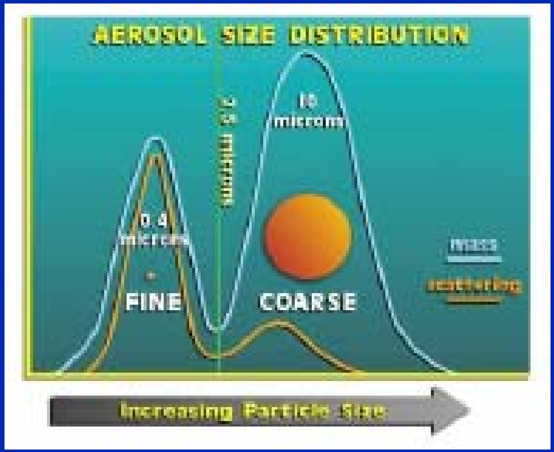
- PM affects visibility
- Visibility is the greatest distance one can see and identify with the unaided eye a dark object against the sky (daytime) or a moderately intense light source (night)
- Haze is particles suspended in air reducing visibility
- Visibility is affected by
  - Viewing and sun angle
  - Humidity
  - Particle size, type, and concentration

Pollutants – Visibility (2 of 3)

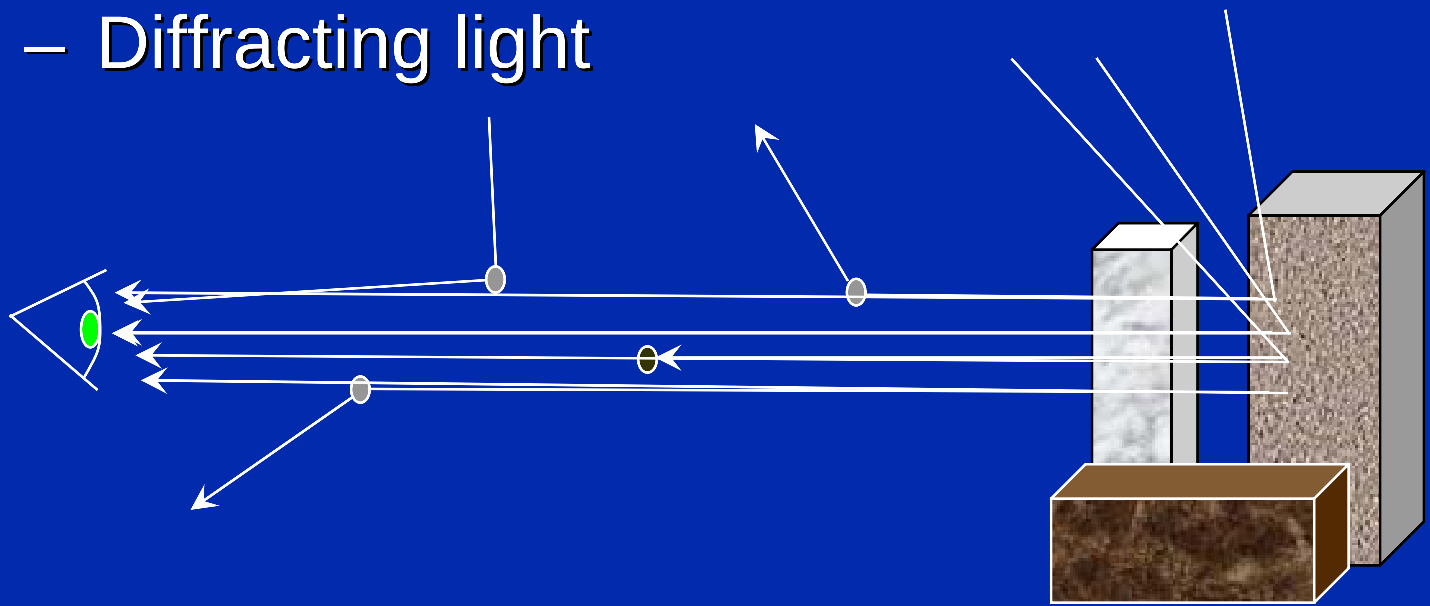
How do particles affect visibility?

Particles interrupt light transmission by:

- Absorbing light
- Scattering light
- Diffracting light



Introduction to Visibility, Malm



Pollutants – Visibility (3 of 3)

Examples of PM affecting visibility


Burlington, VT October 9, 2001


Chicago Aug 16, 2000`
$PM_{2.5}$ < 10 ug/m^3


Glacier National Park
$PM_{2.5}$ 7.6 ug/m3


Burlington, VT June 15, 2001

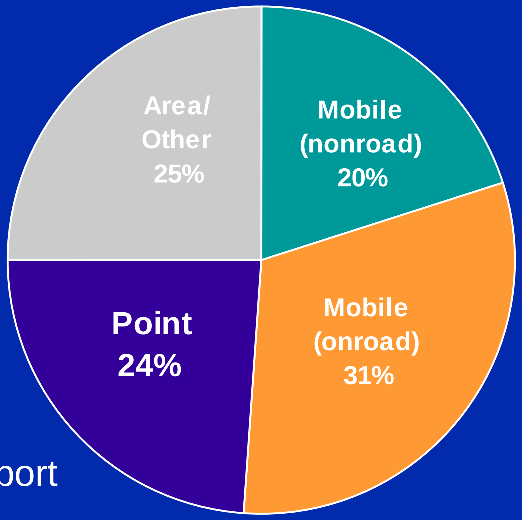

Chicago, August 26, 2000
$PM_{2.5}$ = 35 ug/m^3


Glacier National Park
$PM_{2.5}$ 21.7 ug/m3

Source: www.mwhazecam.net, www.hazecam.net, and *Introduction to Visibility, Malm*

Pollutants – Toxics (1 of 2)

- Air toxics (hazardous air pollutants) are known or suspected to cause cancer or other serious health effects.
- 188 hazardous air pollutants include
  - –Benzene (motor fuel, oil refineries, chemical processes
  - –Perchlorethylene (dry cleaning, degreasing)
  - –Chloroform (solvent in adhesive and pesticides, byproduct of chlorination processes)



National Air Toxics Emission Sources, 1996

Source: U.S. EPA trends report

Pollutants – Toxics (2 of 2)

- Different than criteria pollutants
  - No set criteria (yet) for health concern (except lead)
  - A challenge to monitor
    - Usually not available in real-time
    - Example: Dioxin requires 28 days of sampling to get measurable amounts
  - Often localized near source
  - Difficult to forecast due to
    - Lack of real-time data
    - Local nature

Pollutants – Recap

- Ozone
  - Reactive, invisible gas
  - Secondary pollutant
  - Forms from NO_x and VOCs
- PM
  - Small solid and liquid particles
  - Composed of many compounds
  - Fine particles ($PM_{2.5}$) affect visibility and persist in the atmosphere
- Air toxics
  - Many compounds
  - Growing concern
  - Not yet ready to forecast

Emissions – Categories of Sources (1 of 4)

Point – generally a major facility emitting pollutants from identifiable sources (pipe or smoke stack). Facilities are typically permitted.

Emissions – Categories of Sources (2 of 4)

Area – any low-level source of air pollution released over a diffuse area (not a point) such as consumer products, architectural coatings, waste treatment facilities, animal feeding operations, construction, open burning, residential wood burning, swimming pools, and charbroilers

Emissions – Categories of Sources (3 of 4)

Mobile

- On-road is any moving source of air pollution such as cars, trucks, motorcycles, and buses
- Non-road sources include pollutants emitted by combustion engines on farm and construction equipment, locomotives, commercial marine vessels, recreational watercraft, airplanes, snow mobiles, agricultural equipment, and lawn and garden equipment

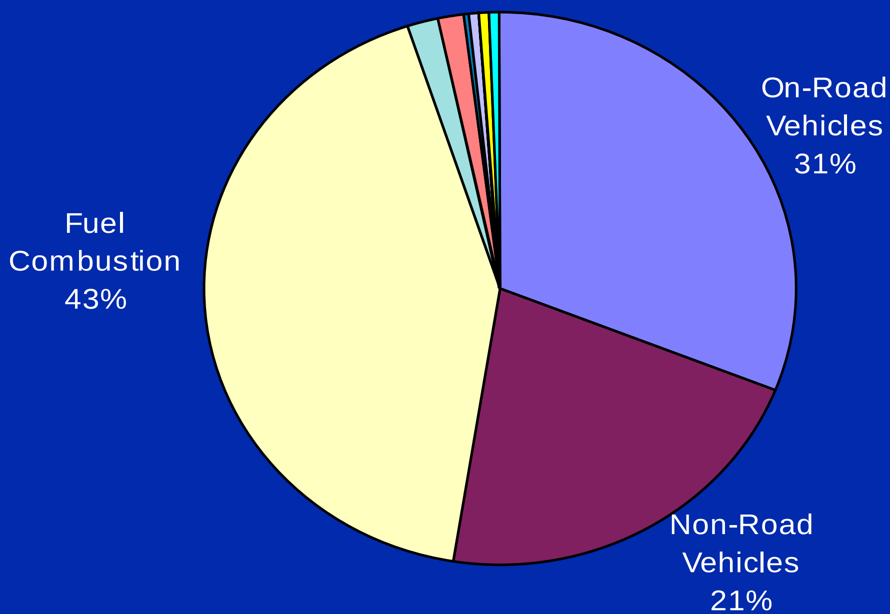
Emissions – Categories of Sources (4 of 4)

Natural – biogenic and geogenic emissions from wildfires, wind blown dust, plants, trees, grasses, volcanoes, geysers, seeps, soil, and lightning

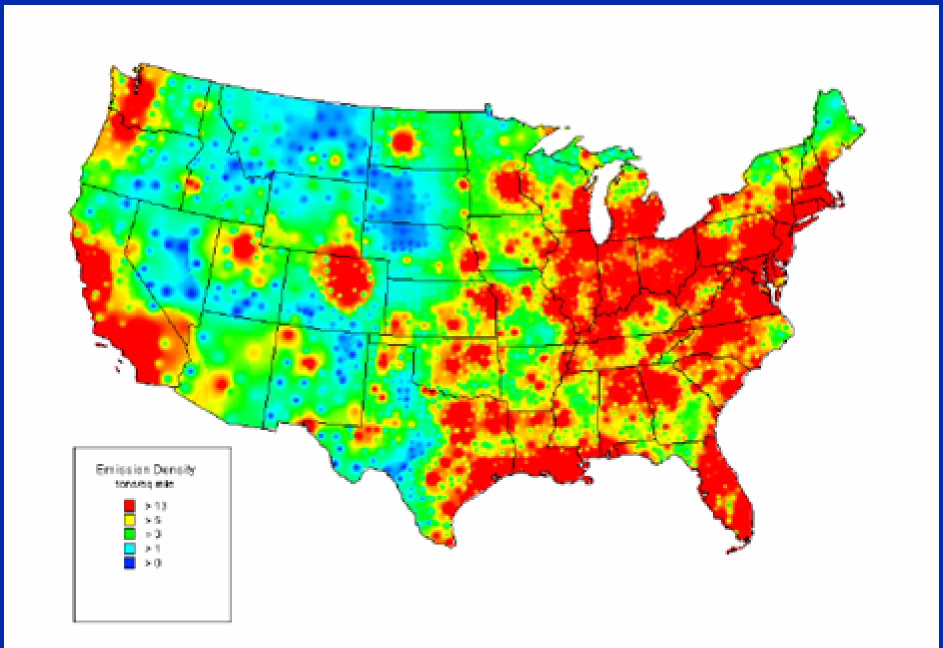
Emissions – NO_x (1 of 2)

- Nitrogen oxides are composed of nitrogen oxide (NO) and nitrogen dioxide (NO_2)
- Importance
  - Precursor to ozone
  - Precursor to $PM_{2.5}$ (ammonium nitrate)
  - NO_2 is a criteria pollutant
- Major sources
  - Vehicles, trucks, boats, engines (52%)
  - Coal, oil, gas, residential wood combustion (43%)

Emissions – NO_x (2 of 2)



1998 Nitrogen Oxide Emissions Density

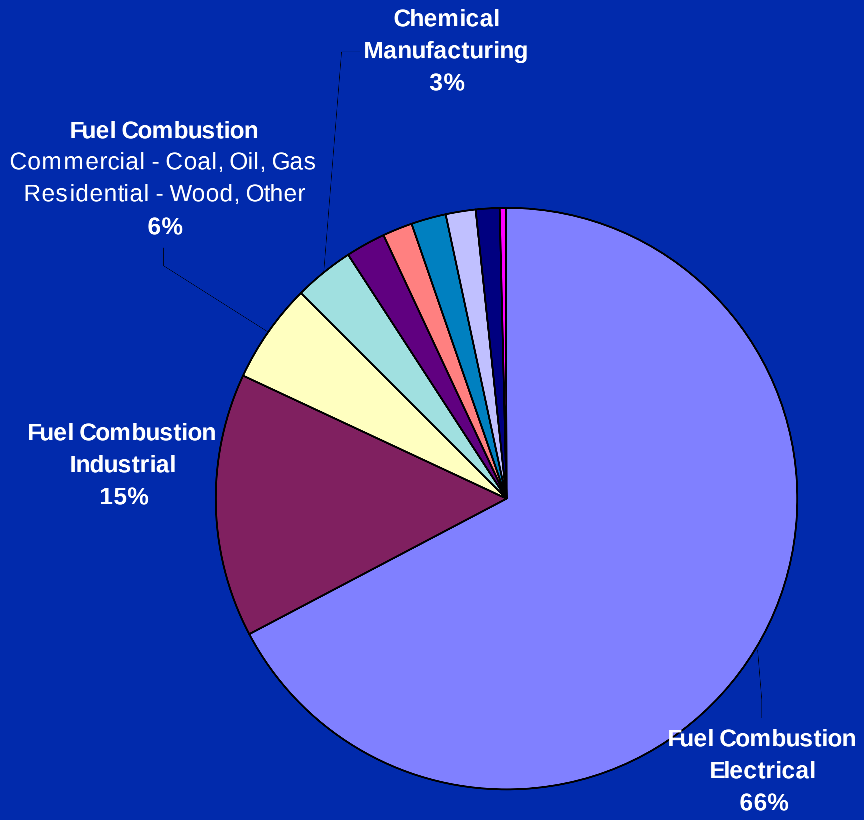


Source: U.S. EPA National Air Pollutant Emission Trends, 1900-1998

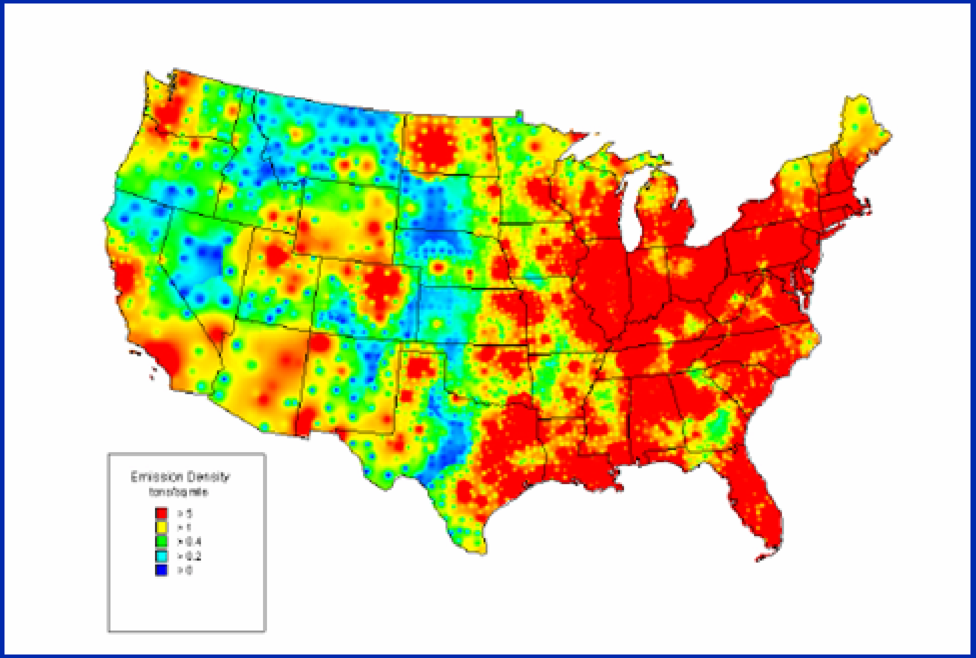
Emissions – SO_2 (1 of 2)

- Sulfur dioxide (SO_2) gas is formed from burning fuel containing sulfur (mainly coal and oil).
- Importance:
  - Precursor to $PM_{2.5}$ (ammonium sulfates)
  - SO_2 is a criteria pollutant
- Major sources
  - Electrical and industrial fuel combustion (81%)
  - Commercial and residential fuel combustion of coal, oil, gas (6%)

Emissions – SO_2 (2 of 2)



1998 Sulfur Dioxide Emissions Density

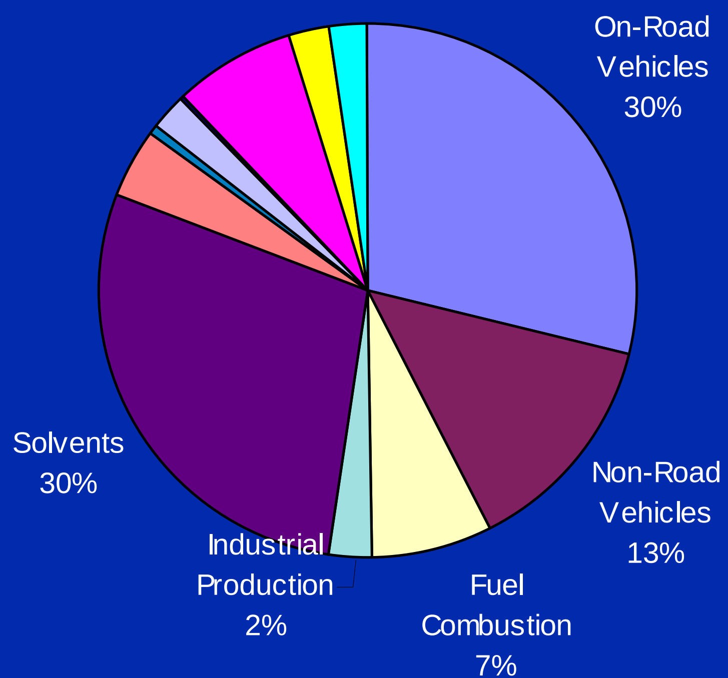


Source: U.S. EPA National Air Pollutant Emission Trends, 1900-1998

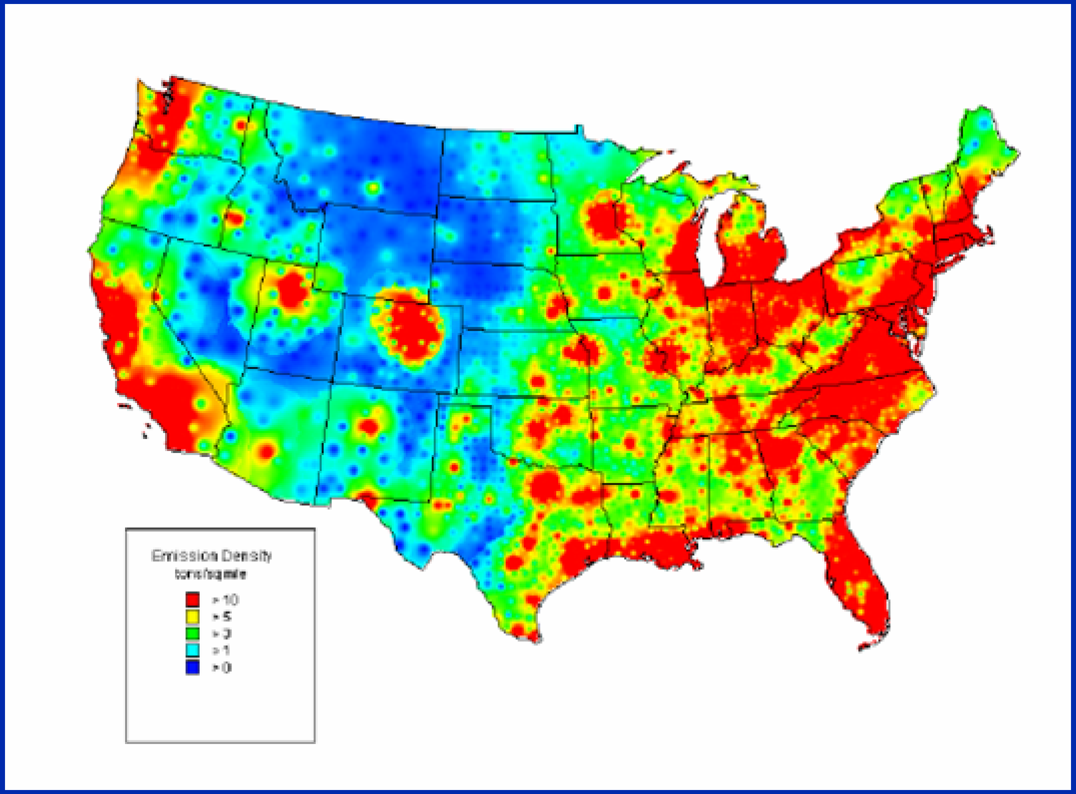
Emissions – VOCs (1 of 2)

- Volatile organic compounds (also called hydrocarbons) are composed of hundreds of gases. Many odors detected are from evaporative pollutants.
- Importance
  - Precursor to ozone
  - Precursor to $PM_{2.5}$ (organic carbon)
  - Include toxic compounds
- Major sources
  - Vehicles, trucks, boats, engines (43%)
  - Solvents (30%)

Emissions – VOCs (2 of 2)



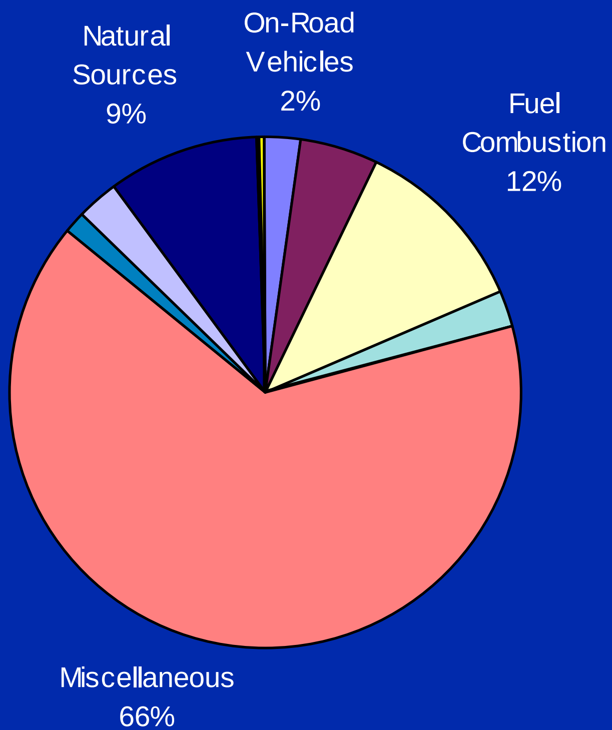
1998 Volatile Organic Compound Emissions Density



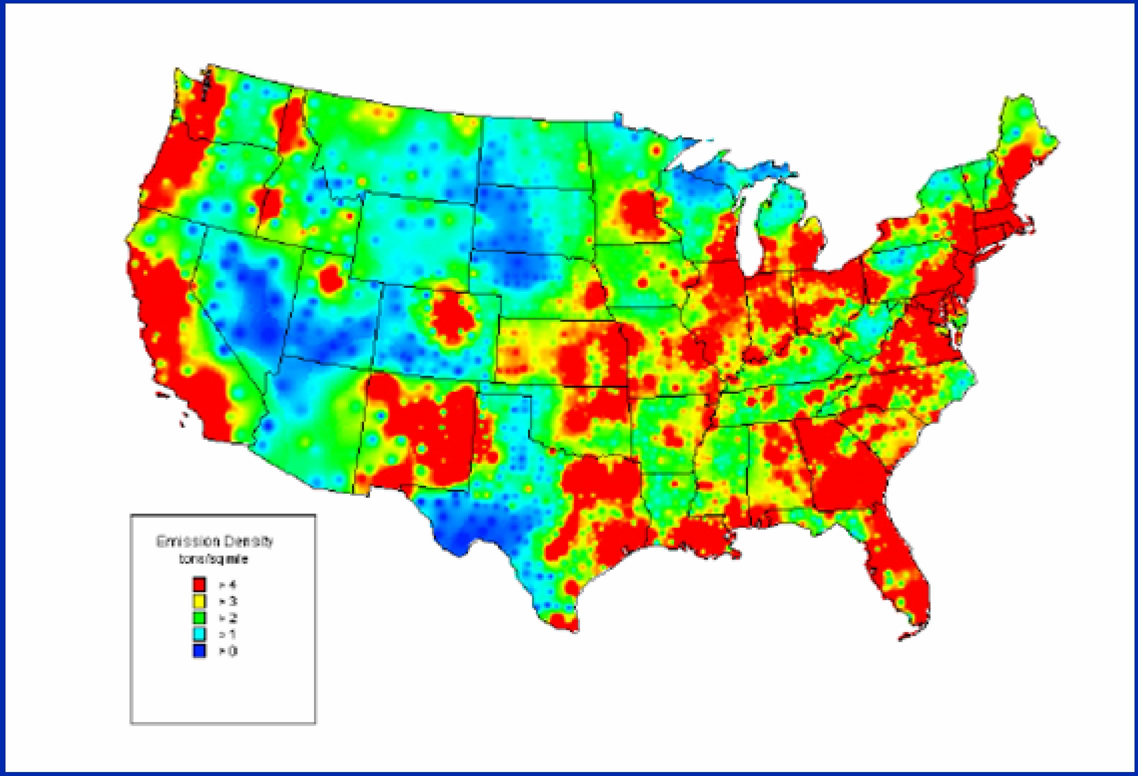
Emissions – Primary $PM_{2.5}$ (1 of 2)

- Particulate matter (less than 2.5 µm) is composed of solid and liquid compounds directly emitted into the air.
- Importance
  - Primary emissions of $PM_{2.5}$
  - Reduces visibility
- Major sources (primary emissions)
  - Miscellaneous: agriculture crops and livestock activity, wildfires and managed burns; and dust from unpaved roads, construction (66%)
  - Wind-blown dust (9%)

Emissions – Primary $PM_{2.5}$ (2 of 2)

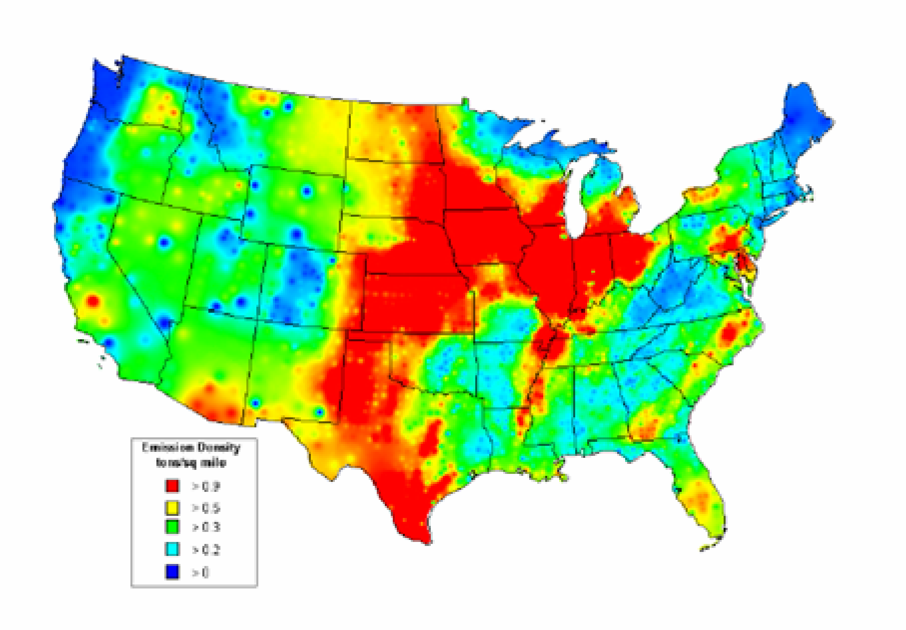


1998 Primary Particulate Matter ($PM_{2.5}$) Emissions Density

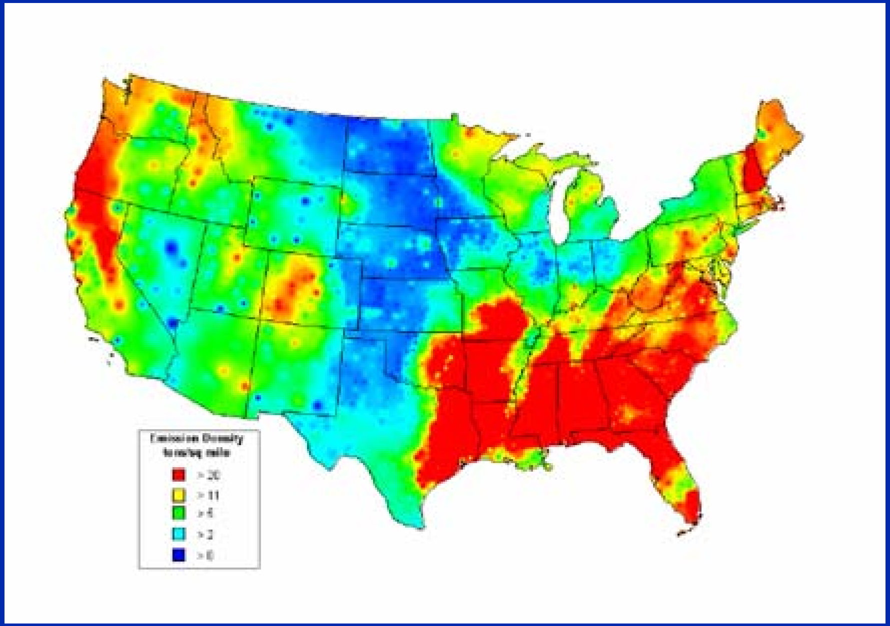


Emissions – Biogenic

Nitrogen oxides 1997



Volatile organic compounds 1997



Pollutant Lifecycles and Trends

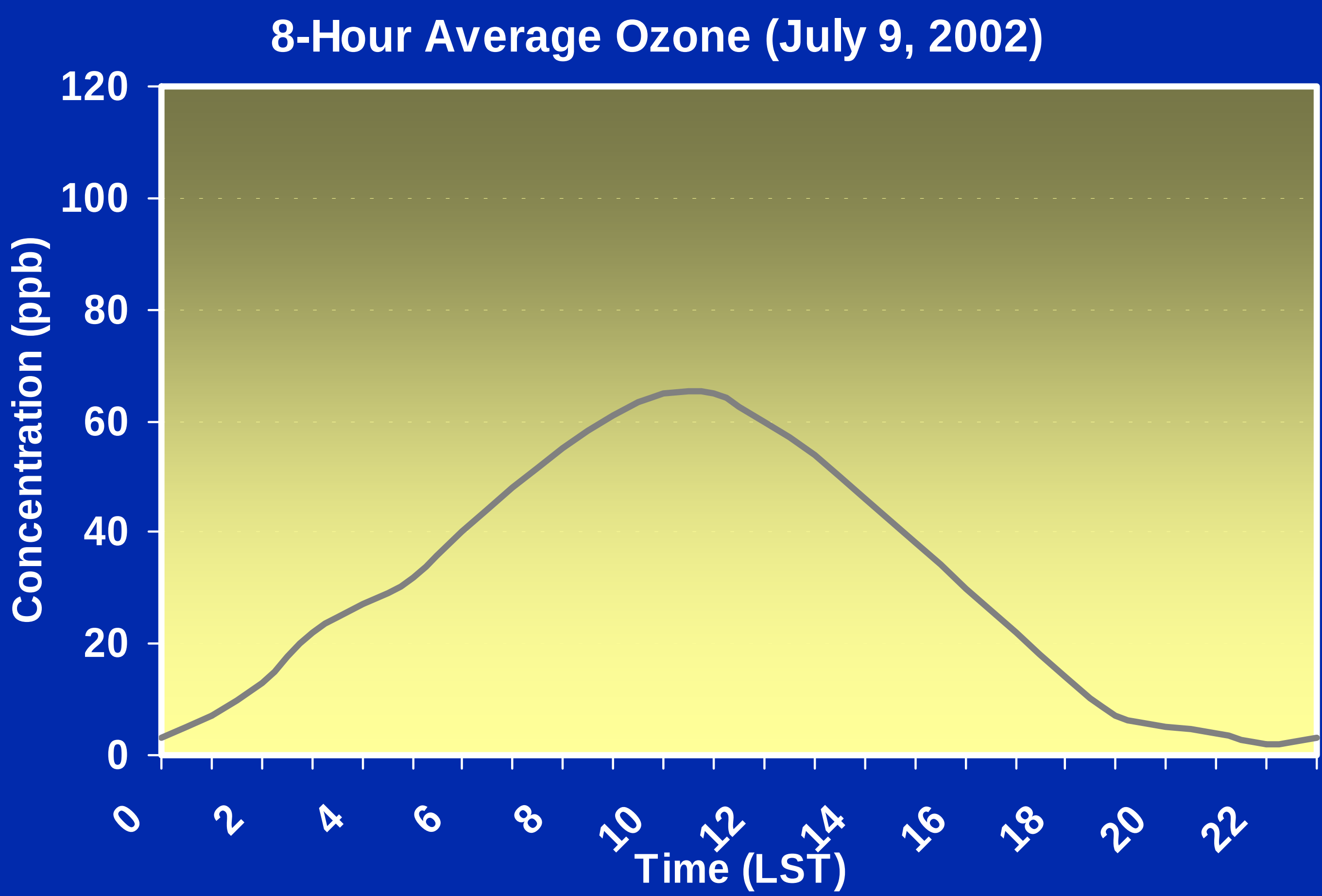
- Lifecyles are daily and episodic changes in pollution levels.
- Trends are longer-term changes in air pollution that are caused by population and emission changes.
- Importance
  - Daily forecasting (changes, evolution)
  - Communication (message, exposure)
- Four time periods
  - Day/night (diurnal) and multi-day
  - Seasonal
  - Yearly
  - Long-term

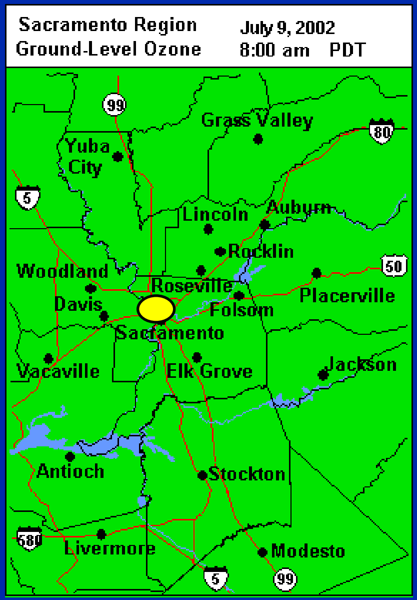
Lifecycles – Day/Night (1 of 3)

- Day/night and multi-day changes
- Local ozone/ $PM_{2.5}$ measurements at a site affected by:
  - Weather
  - Season
  - Emissions (regional and local)
  - Site location

Lifecycles – Day/Night (2 of 3)

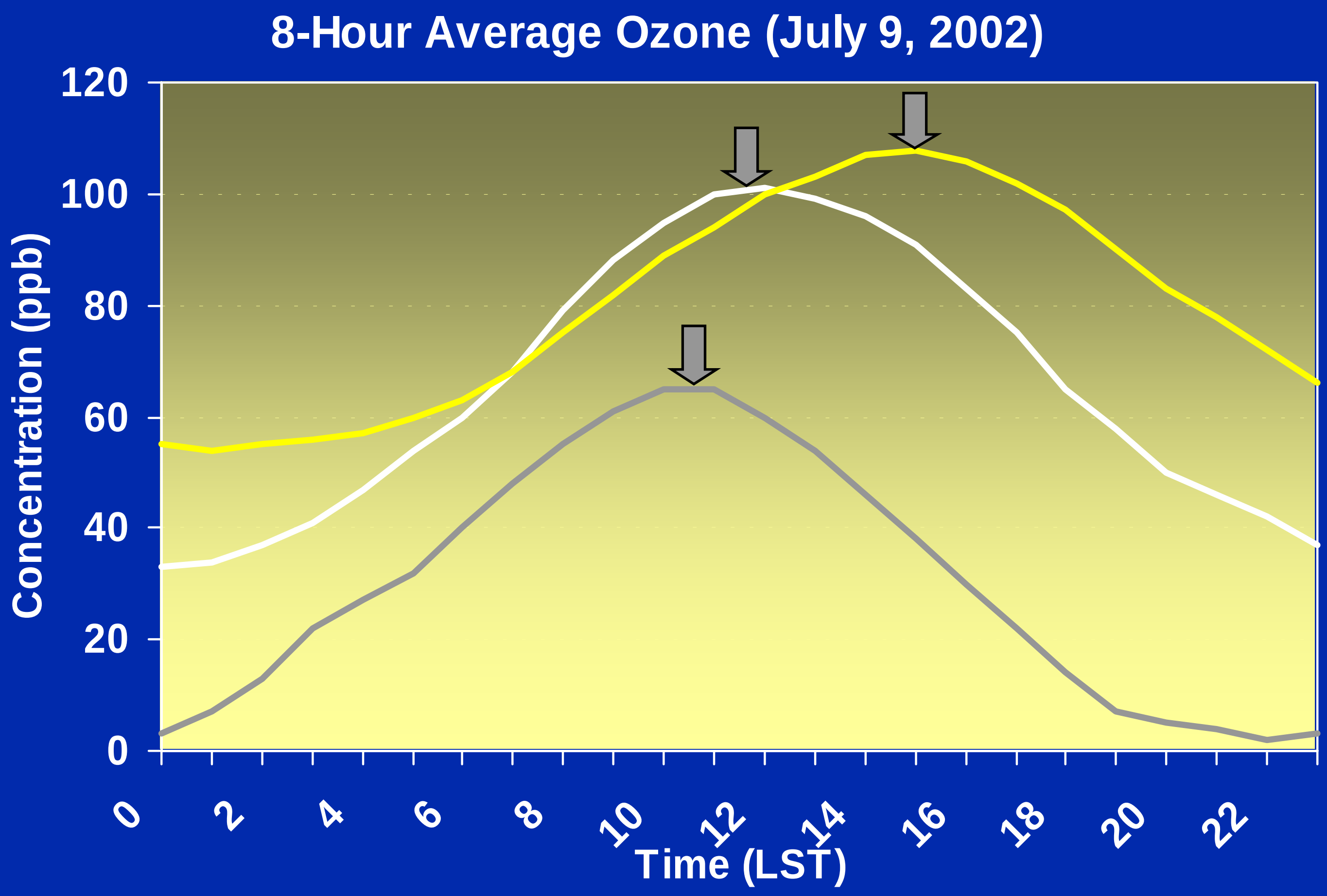
Ozone example

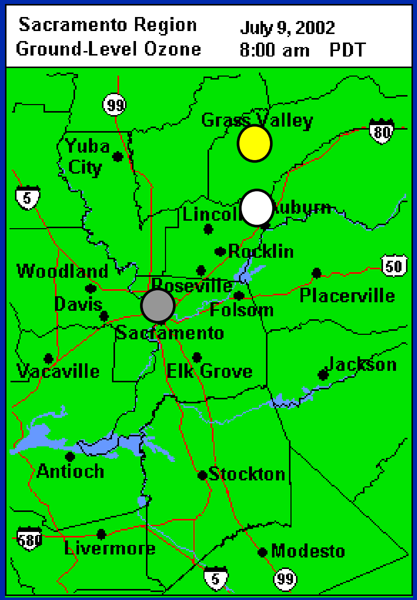




Lifecycles – Day/Night (3 of 3)

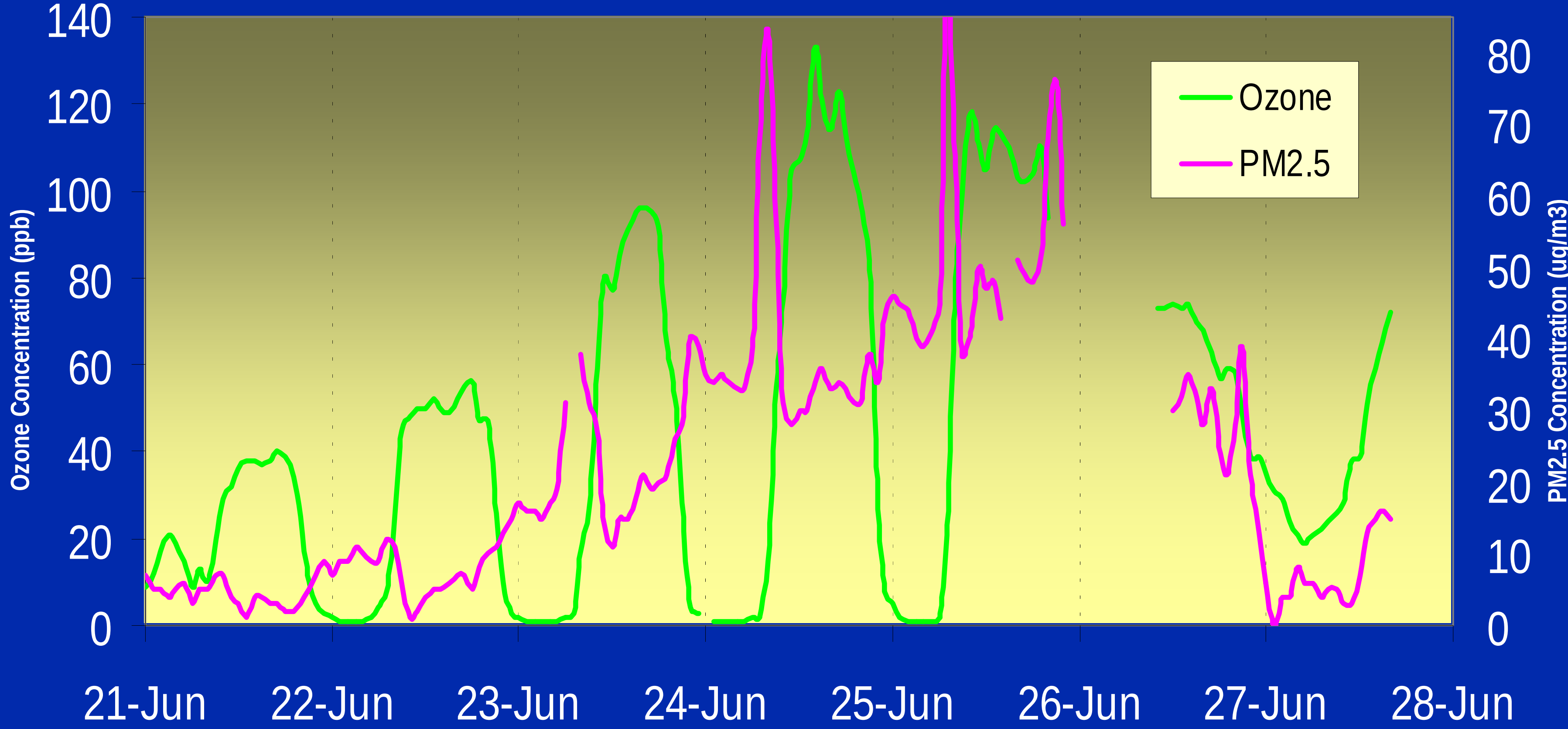
Ozone example





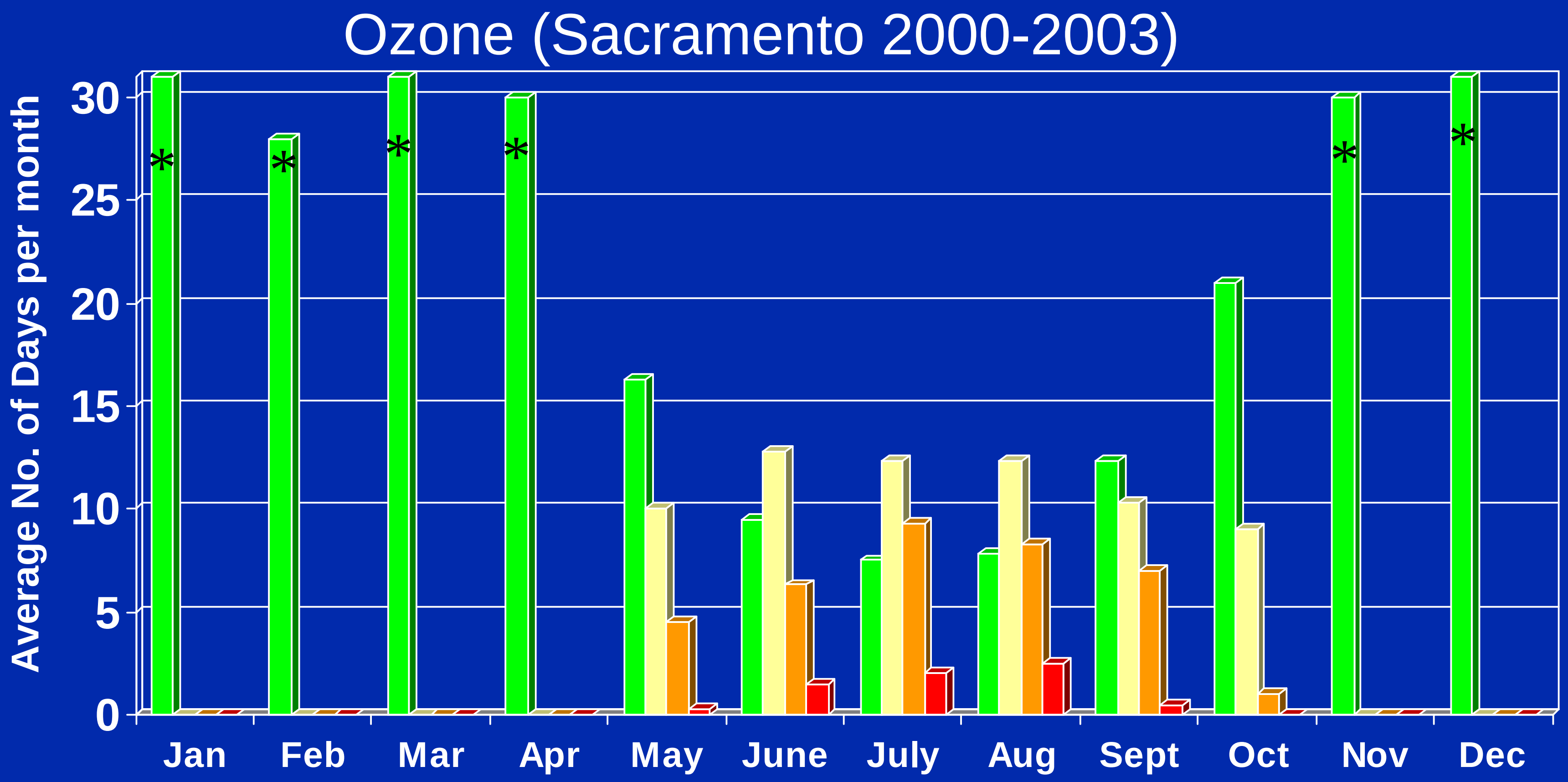
Lifecycles – Multi-day

Combined Ozone and $PM_{2.5}$



Seasonal – Ozone

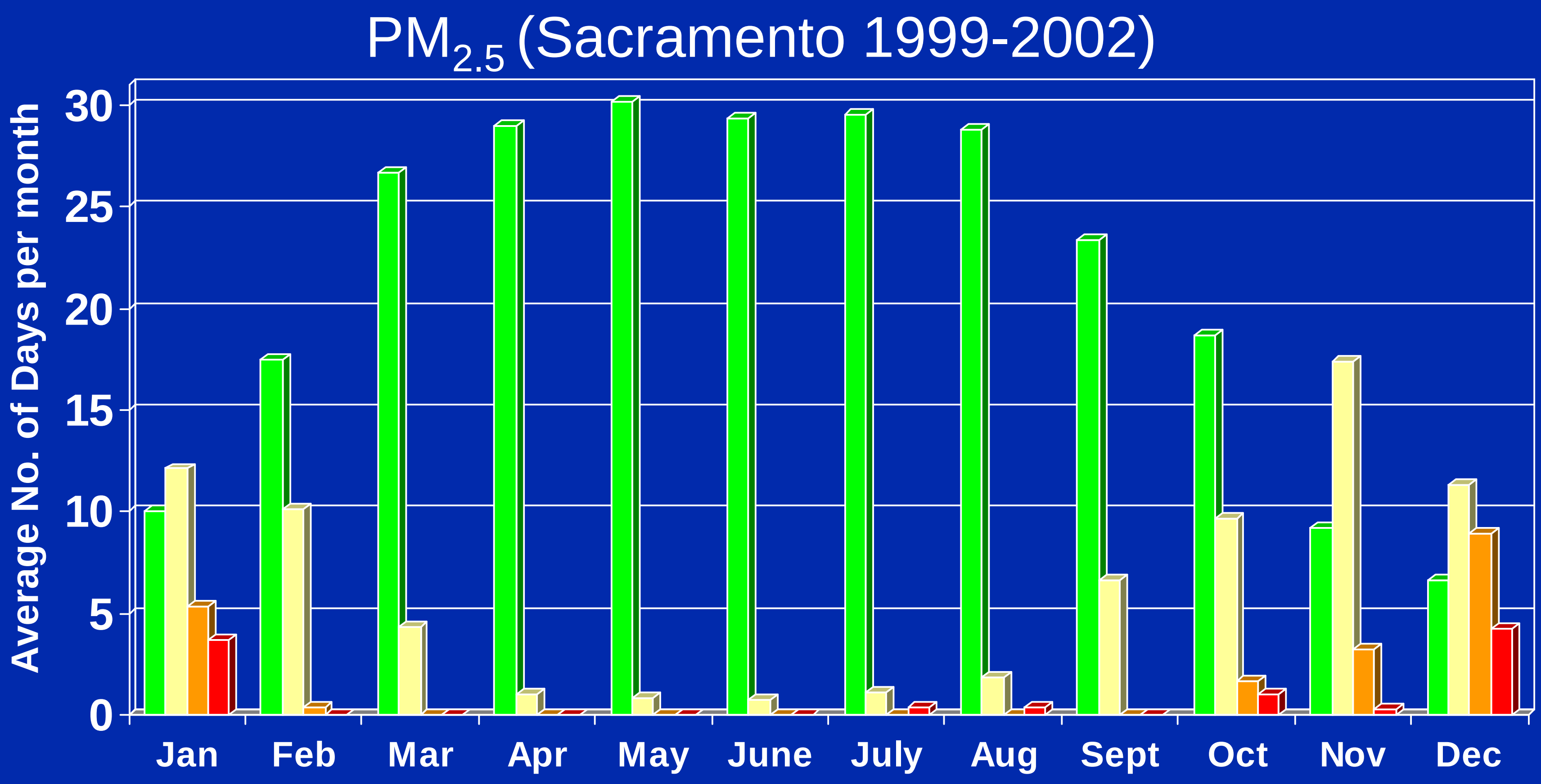
AQI Frequency for ozone



* All days in January, February, March, April, November, and December were assumed to have "Good" ozone AQI

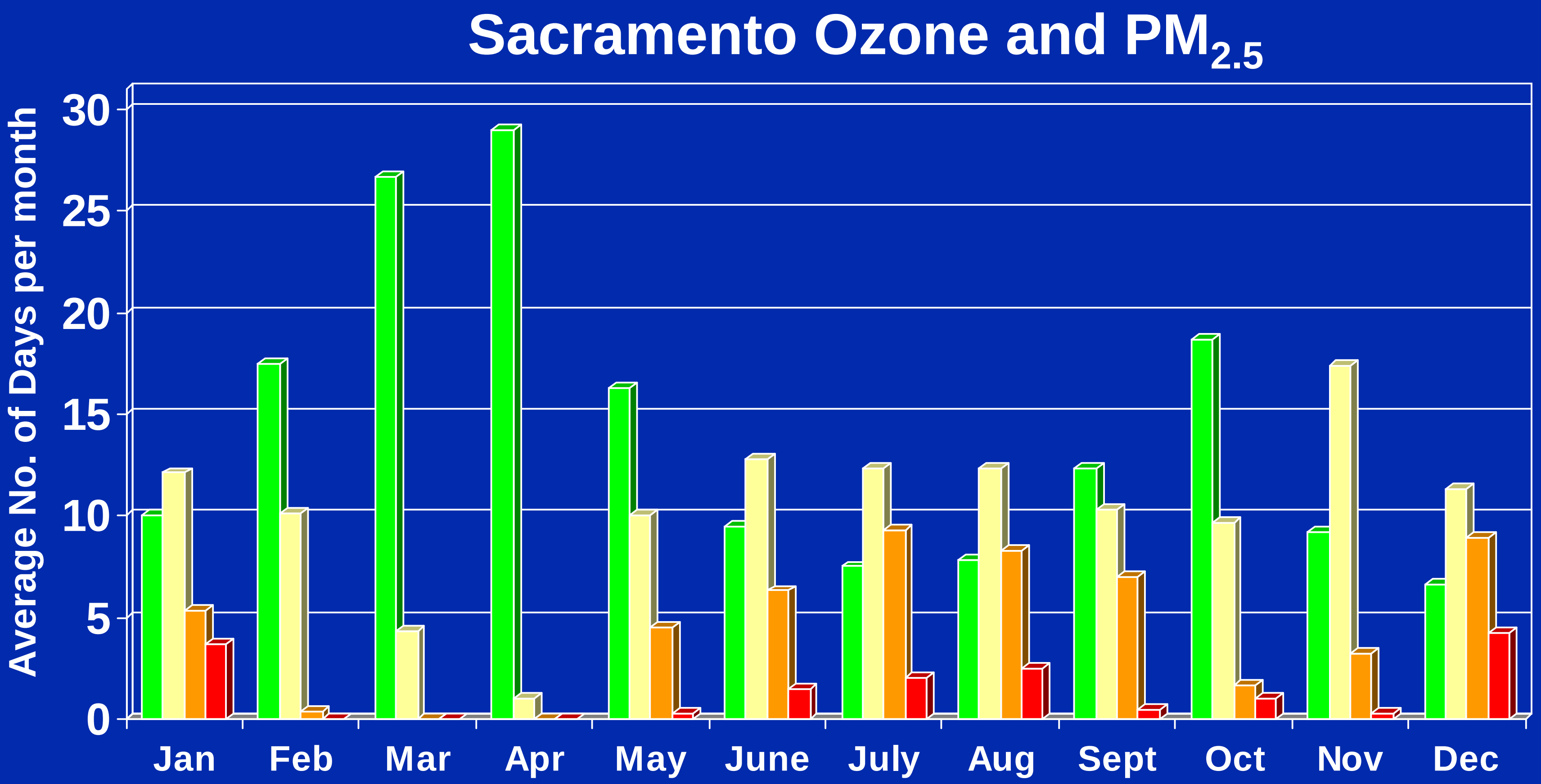
Seasonal – $PM_{2.5}$

AQI Frequency for ozone



Seasonal – Ozone and $PM_{2.5}$

AQI Frequency for Ozone and $PM_{2.5}$



Yearly Trends (1 of 4)

Yearly pollution trends affected by

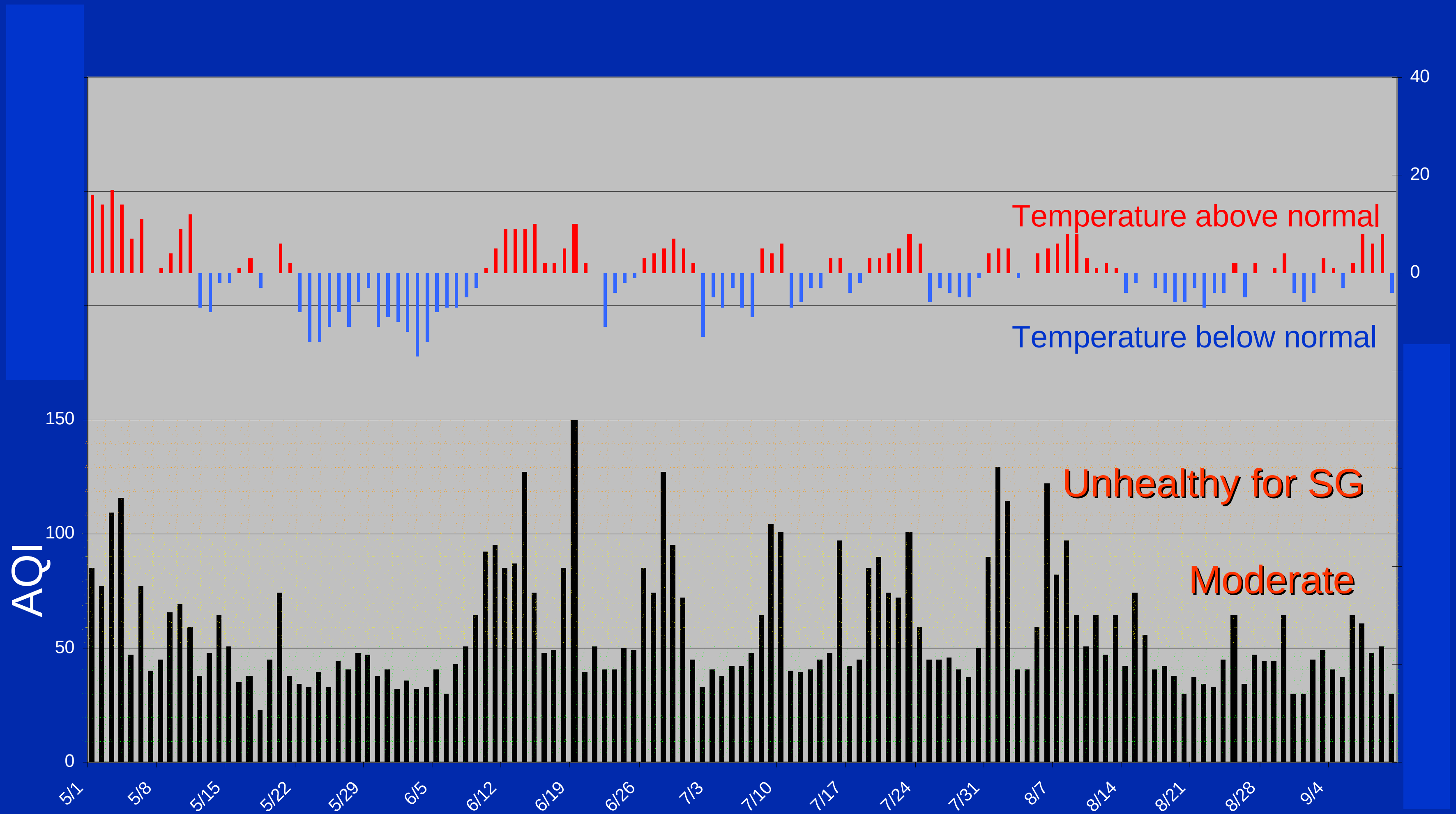
- Season (temperature, precipitation, clouds)
- Emissions changes (substantial)

Example: Columbus, OH

	2001	2002	2003
Number of USG days	9	28	6
Days with above normal temperature	64	93	40

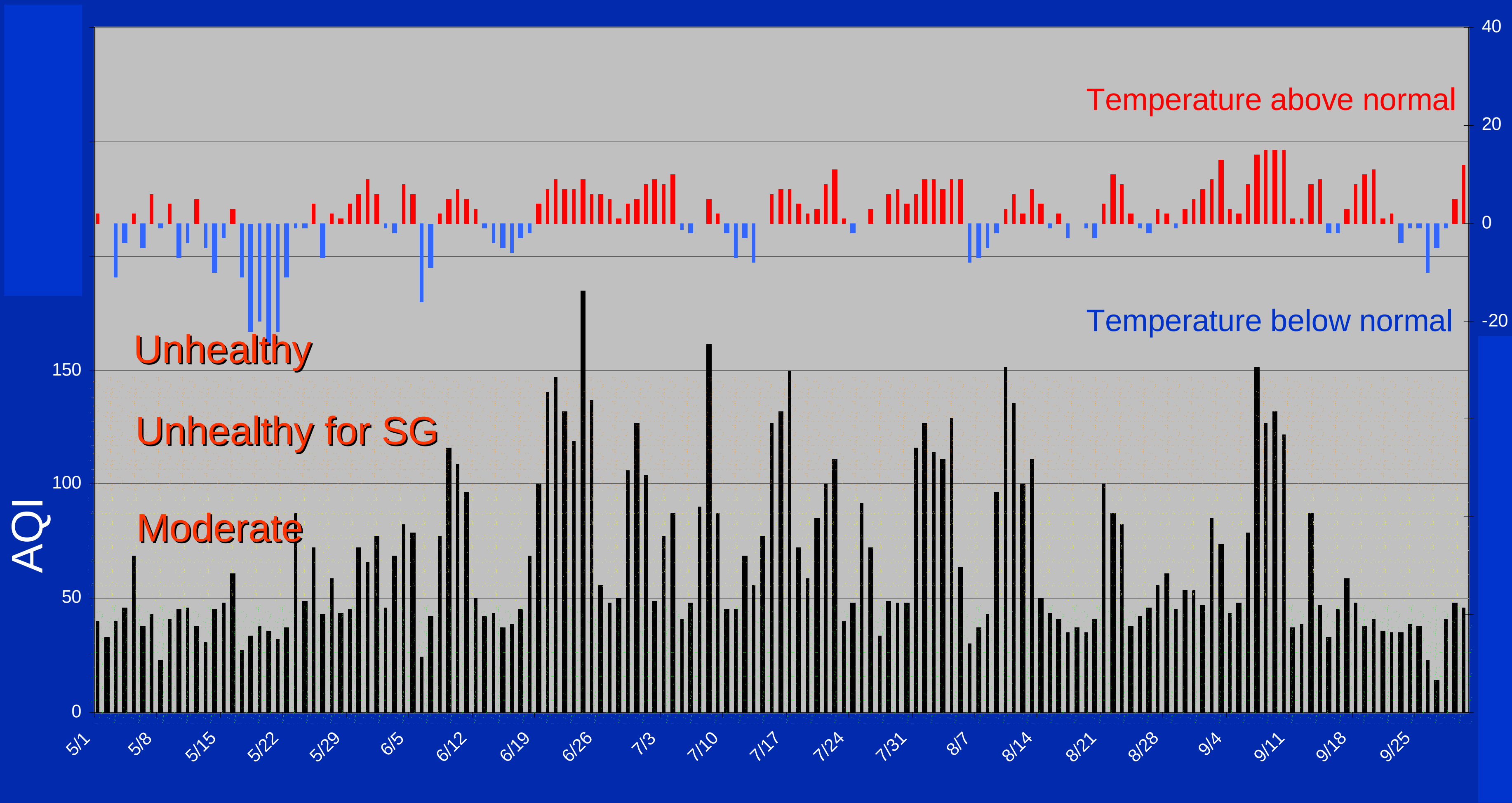
Yearly Trends (2 of 4)

Temperature departure from normal vs. maximum AQI 2001



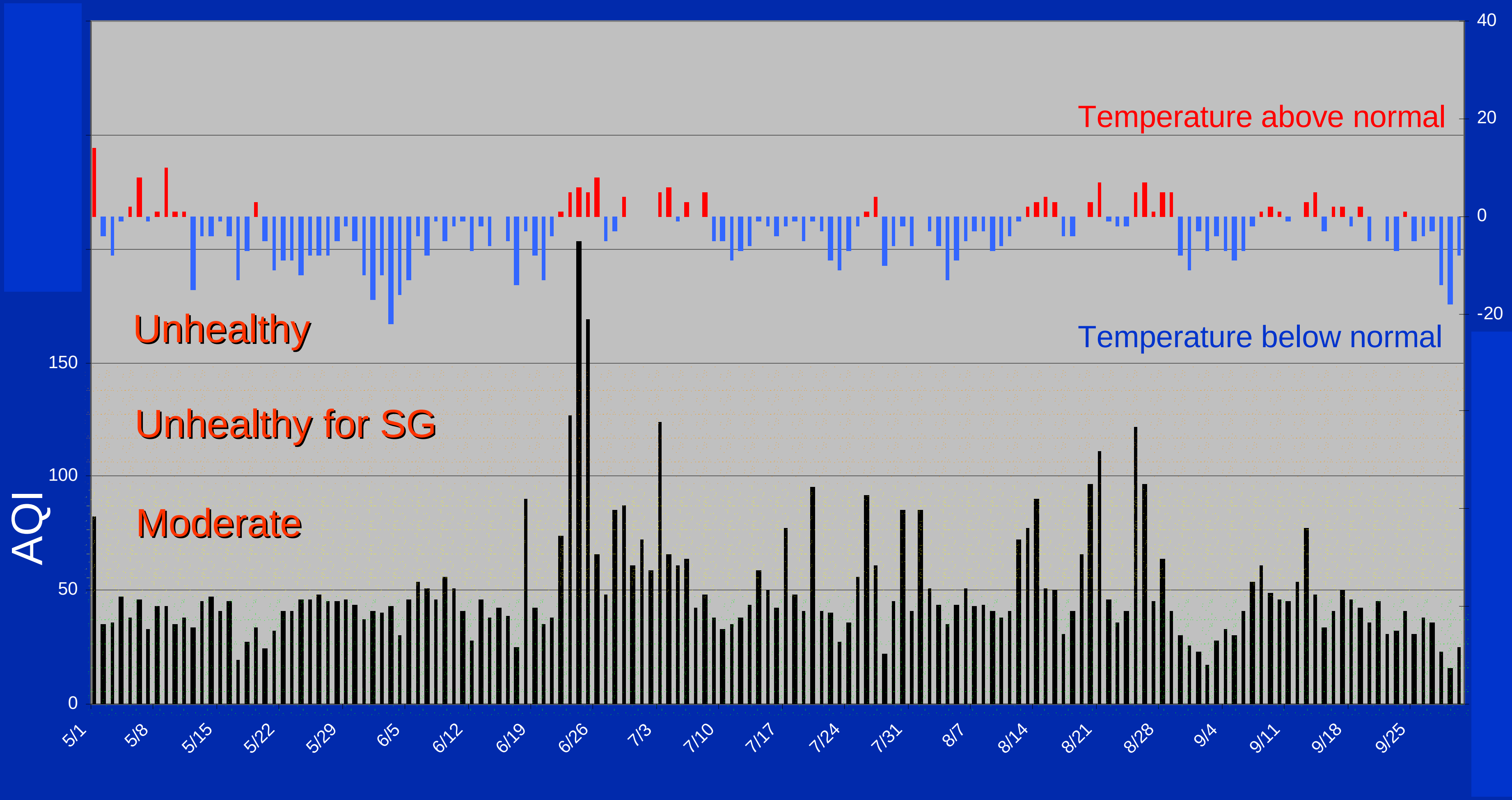
Yearly Trends (3 of 4)

Temperature departure from normal vs. maximum AQI 2002



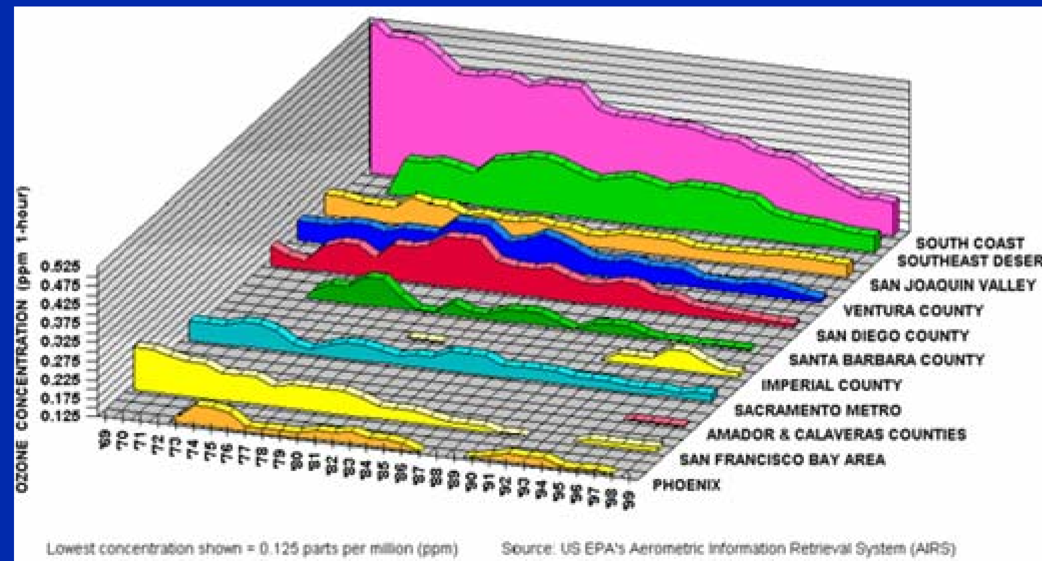
Yearly Trends (4 of 4)

Temperature departure from normal vs. maximum AQI 2003



Long-Term Trends

- Long-term trends – 5 or more years



- Affected by
  - Emissions changes
  - Year-to-year weather changes
  - Monitor characteristics changes (location, environment)
  - Metric used to evaluate trends

Emissions and Trends – Recap

- Emissions
  - Point, area, mobile, natural
  - Sources are everywhere
  - Major pollutants: NO_x, VOCs, SO_2, PM
- Trends
  - Diurnal (day/night) – forecasting/communication
  - Seasonal – planning
  - Yearly – communication
  - Long-term – “are we making a difference”

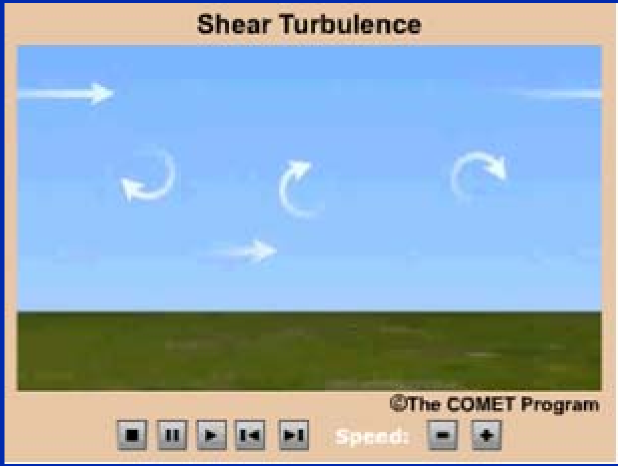
Key Weather Features

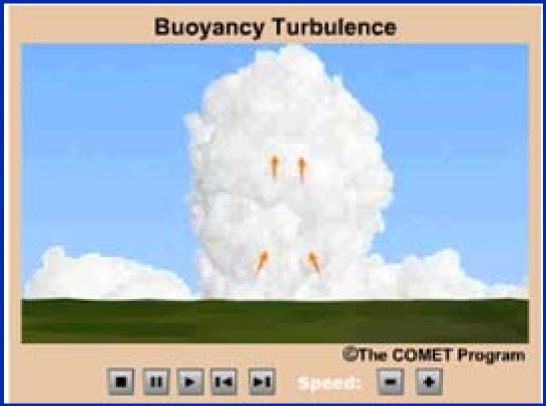
- "The solution to pollution is dilution (and less contribution)"
- Discuss how weather features influence air quality
  - Winds
  - Inversions
  - Fronts and air masses
  - Sunlight, clouds, precipitation

Winds – Dispersion

How do winds affect pollution?

- Disperse pollutants – the spreading of atmospheric constituents.
- Dispersion is a dilution process
  - Molecular Diffusion (not efficient)
  - Atmospheric turbulence
    - Mechanical
    - Shear
    - Buoyancy (convective)





Resource: meted.ucar.edu/dispersion/basics/navmenu0.htm

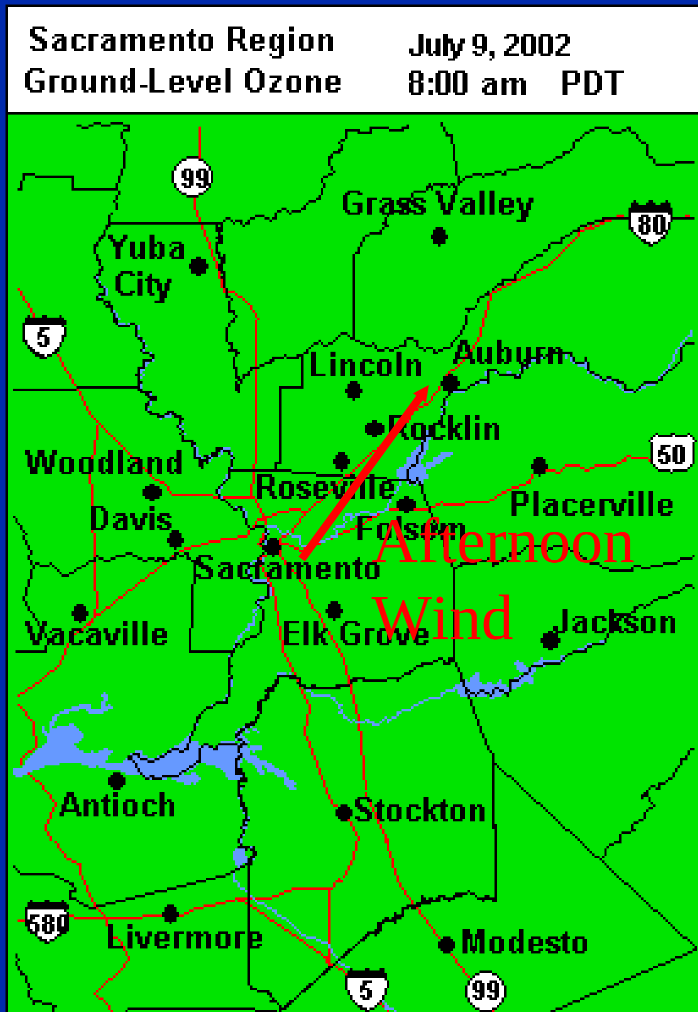
Winds – Transport

How do winds affect pollution?

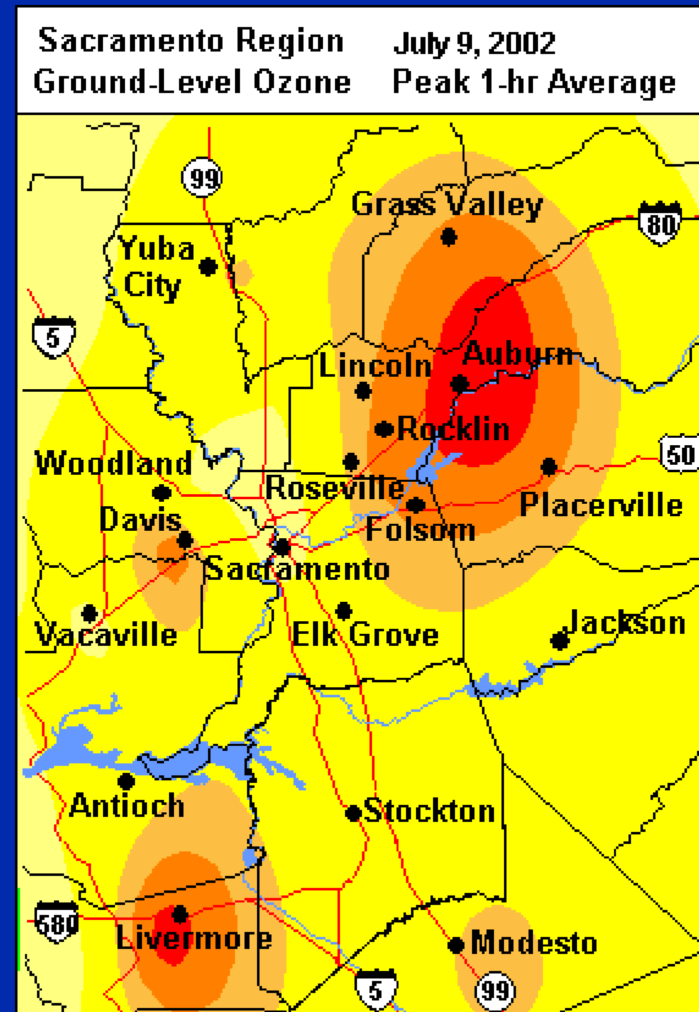
- Pollutant transport – Movement of pollutants from one area to another by the wind
- Types
  - Neighborhood scale: monitor to monitor
  - Regional scale: city to city and state to state
  - National scale: country to country.
  - Global scale: continent to continent

Transport of pollution from the Los Angeles Basin to the Mojave Desert (Courtesy of Don Blumenthal)

Neighborhood Scale (1 of 2)

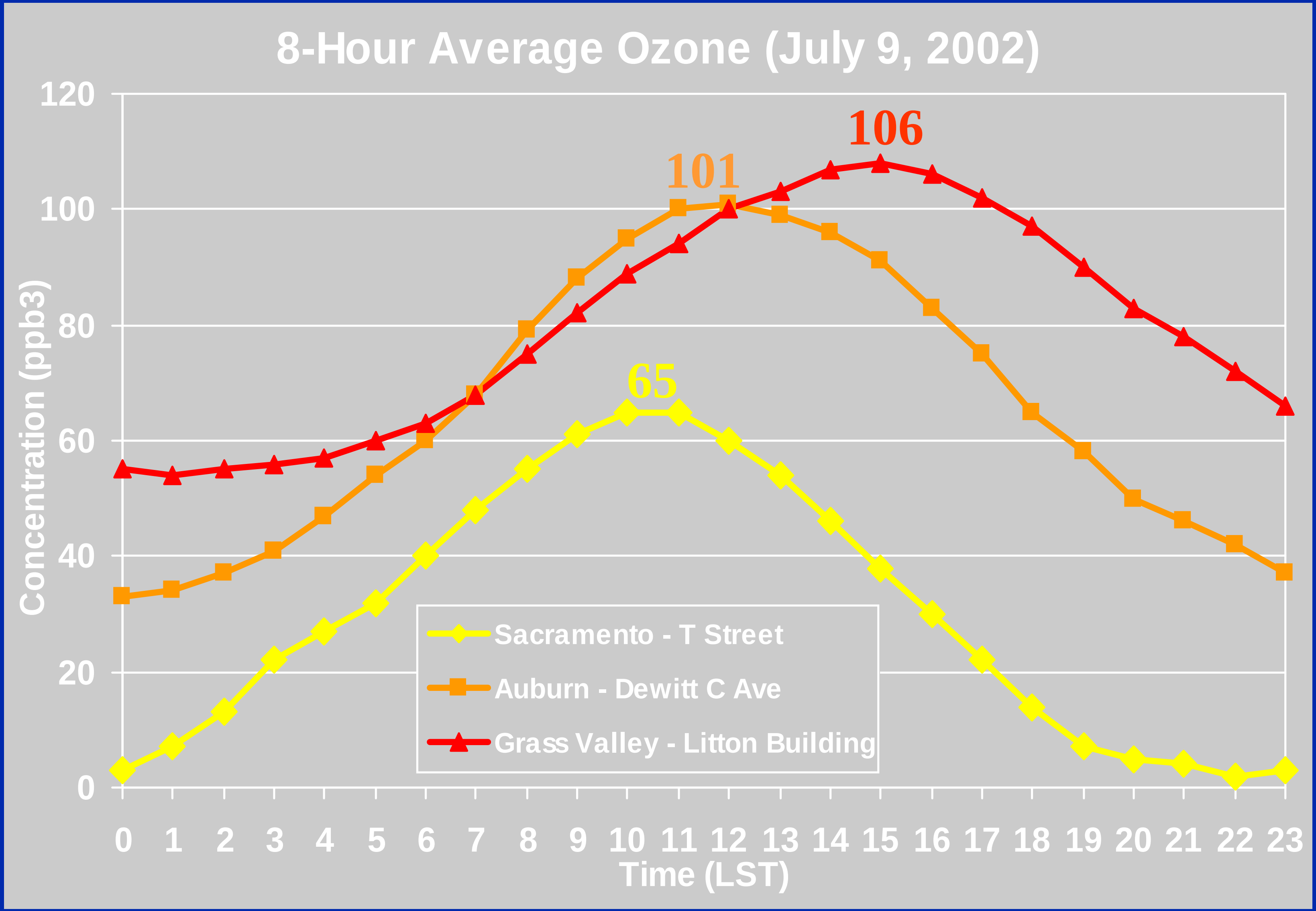


8-hr running averages



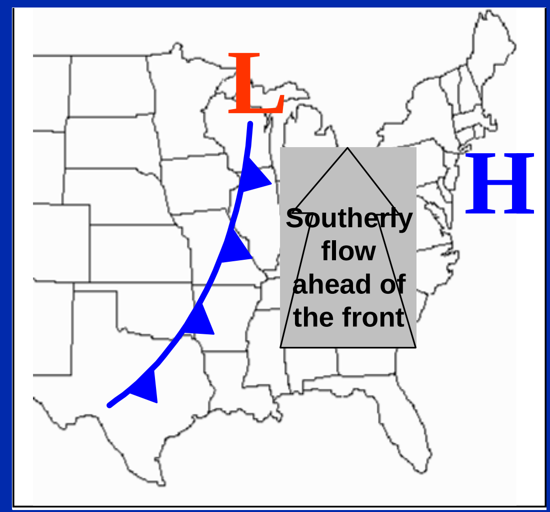
Peak 1-hr average

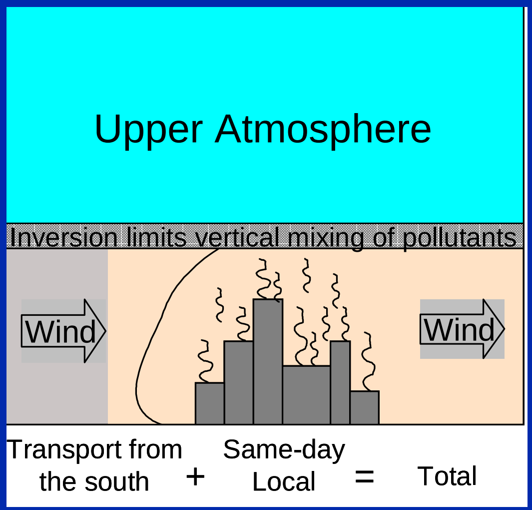
Neighborhood Scale (2 of 2)

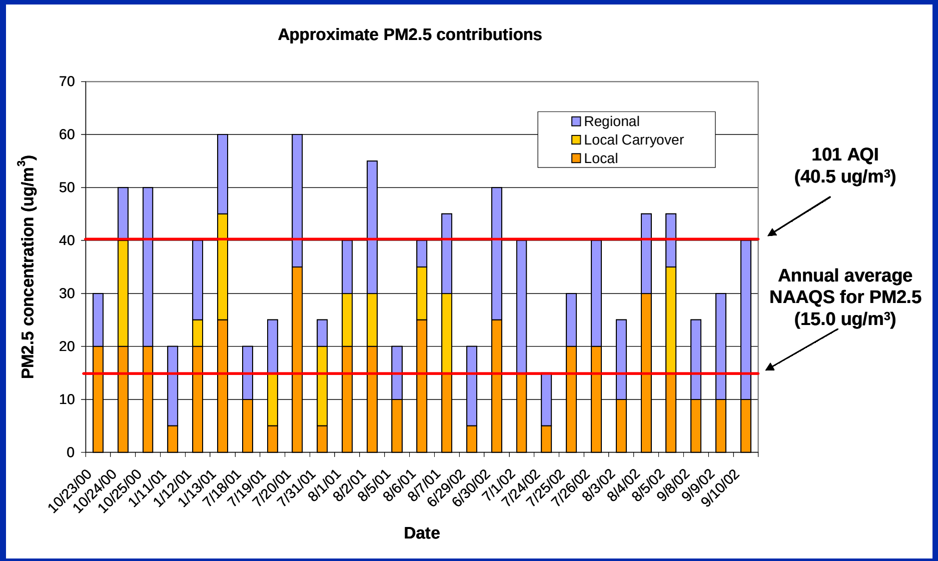


Regional Scale

High pollutant concentrations upstream can be transported into a different area and can cause substantial increases in air quality concentrations than would otherwise occur

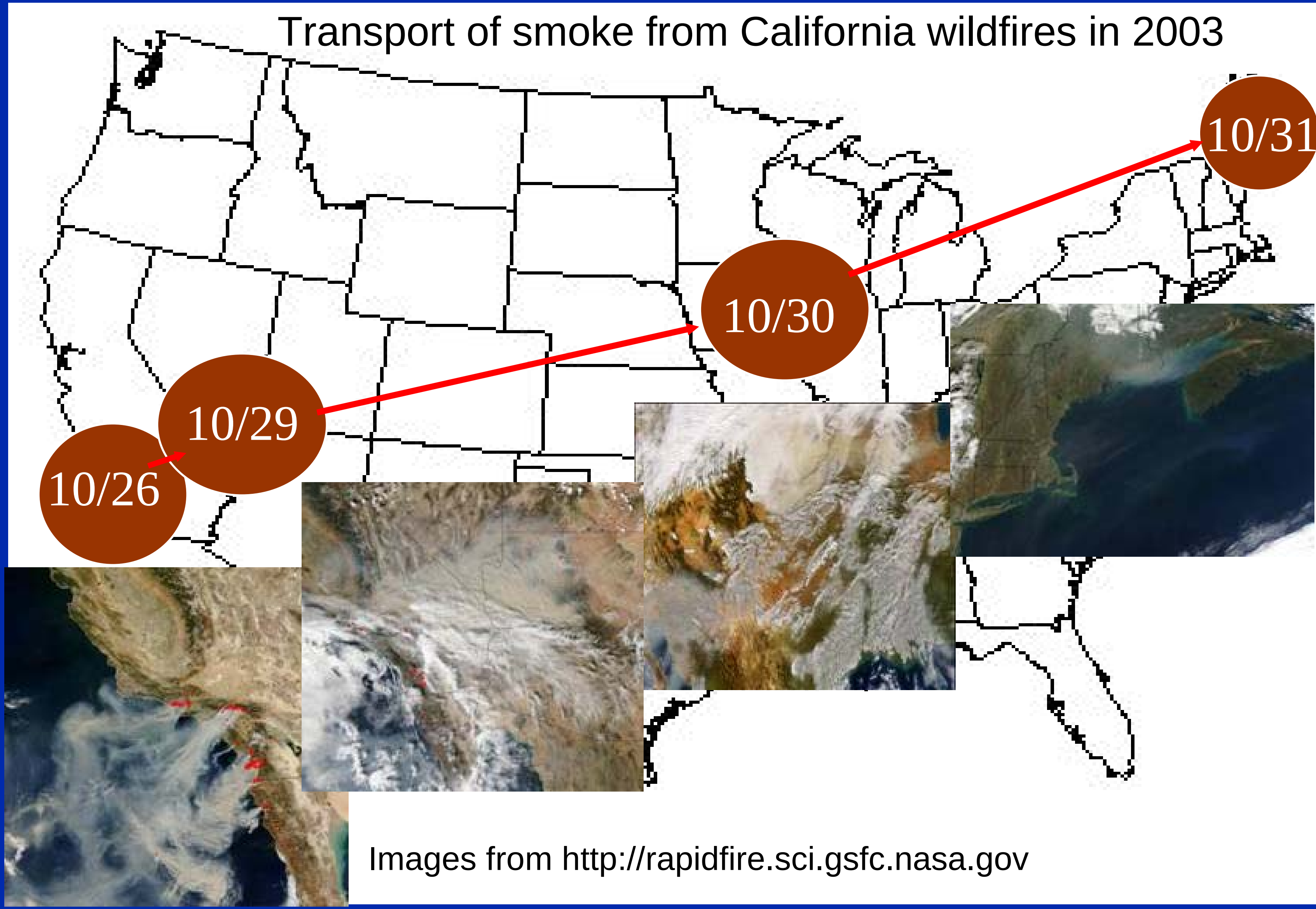






Source: Chinkin et. al., 2003

National Scale



Images from http://rapidfire.sci.gsfc.nasa.gov

Global Scale

April 20,1998

Asian dust transport across the Pacific

Image from http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/OCDST/asian_dust_sequence.html#apr_20 and
"The Asian Dust Events of April 1998" by Husar and 28 co-authors (Journal of Geophysical Research - Atmospheres, 106 (D16), 18317-18330, August 27, 2001) discusses these events.

Wind – Dust

How do winds affect pollution?

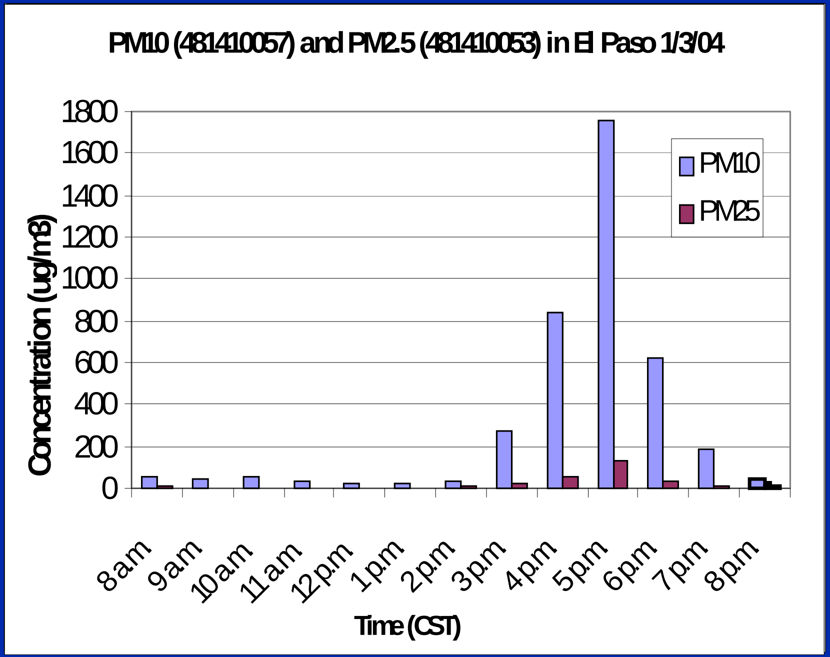
- Create pollution – wind-blown dust
- Two requirements
  - Dusty land/soil
  - Winds 17 mph can loft dust

Threshold Dust-lofting Wind Speed for Different Desert Environments

Land Environment	Threshold Wind Speed
Fine to medium sand in dune-covered areas	10-15 mph
Sandy areas with poorly developed desert pavement	20 mph
Fine material, desert flats	20-25 mph
Alluvial fans and crusted salt flats (dry lake beds)	30-35 mph
Well-developed desert pavement	40 mph

Source: http://meted.ucar.edu/mesoprim/dust/frameset.htm

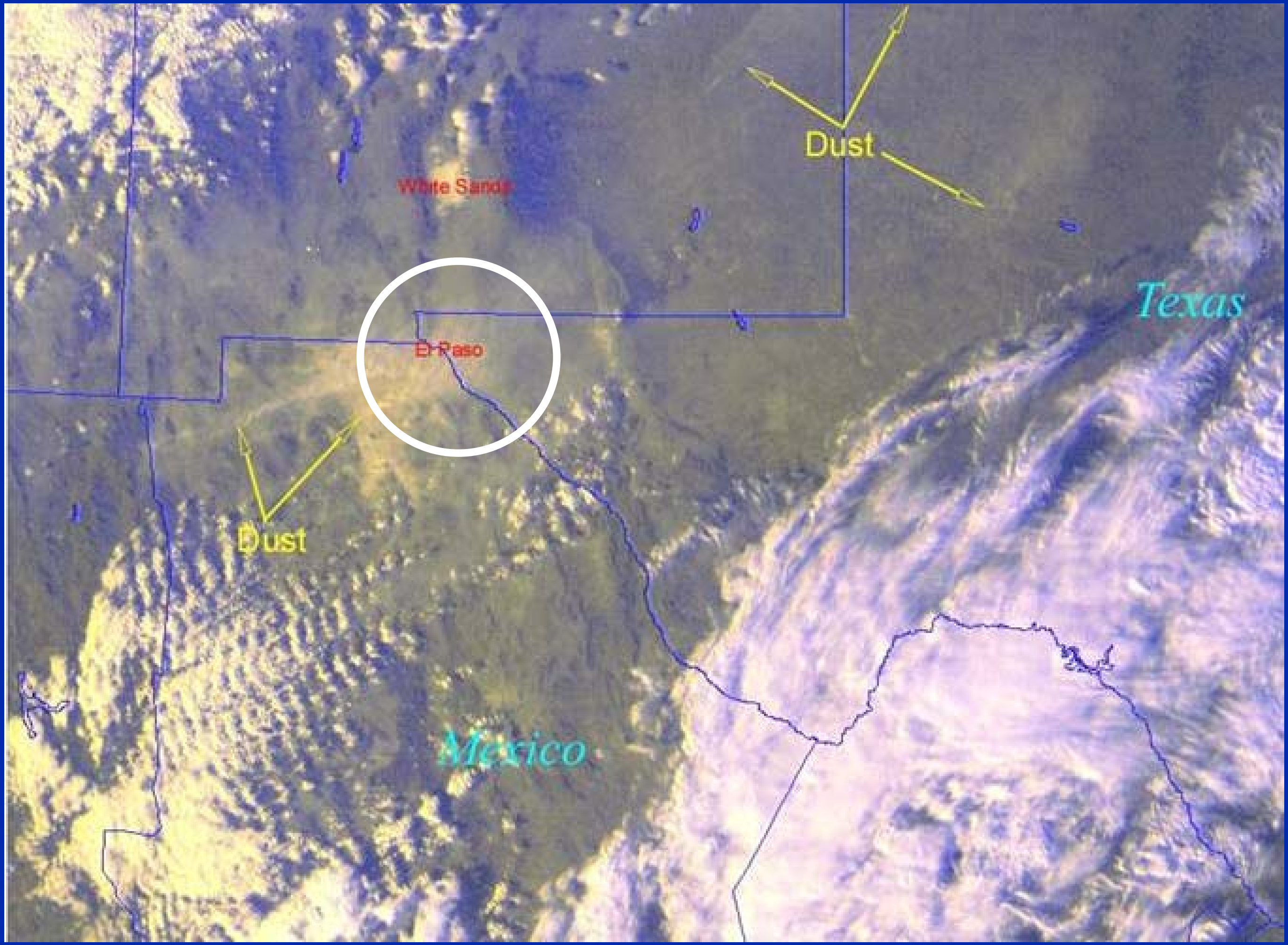
Dust (1 of 2)



Dust event January 3, 2004, 11:00 a.m. to 5:30 p.m., El Paso, Texas

Source: TCEQ

Dust (2 of 2)



Dust event January 3, 2004, 11:00 a.m. to 5:30 p.m., El Paso, Texas

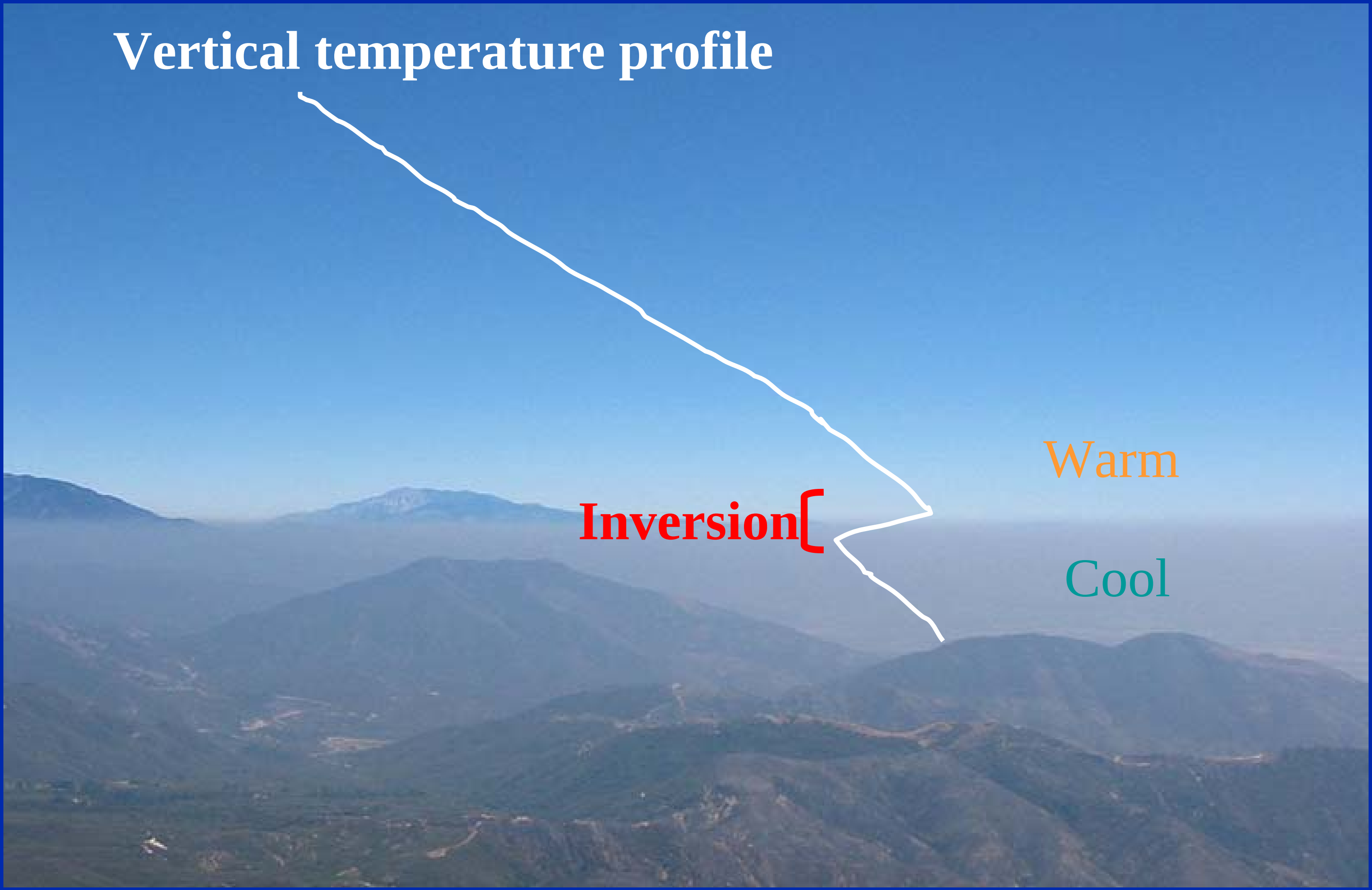
Source: TCEQ

Inversions

- Inversions occur when temperature increases with height.
- Inversions are important because they suppress vertical dispersion of pollution and often trap pollution near the surface where we live.

Dense fog over the Los Angeles Civic Center, 1955. Note that the buildings project above the base of the inversion layer, while the smog remains below.

Inversion – Example

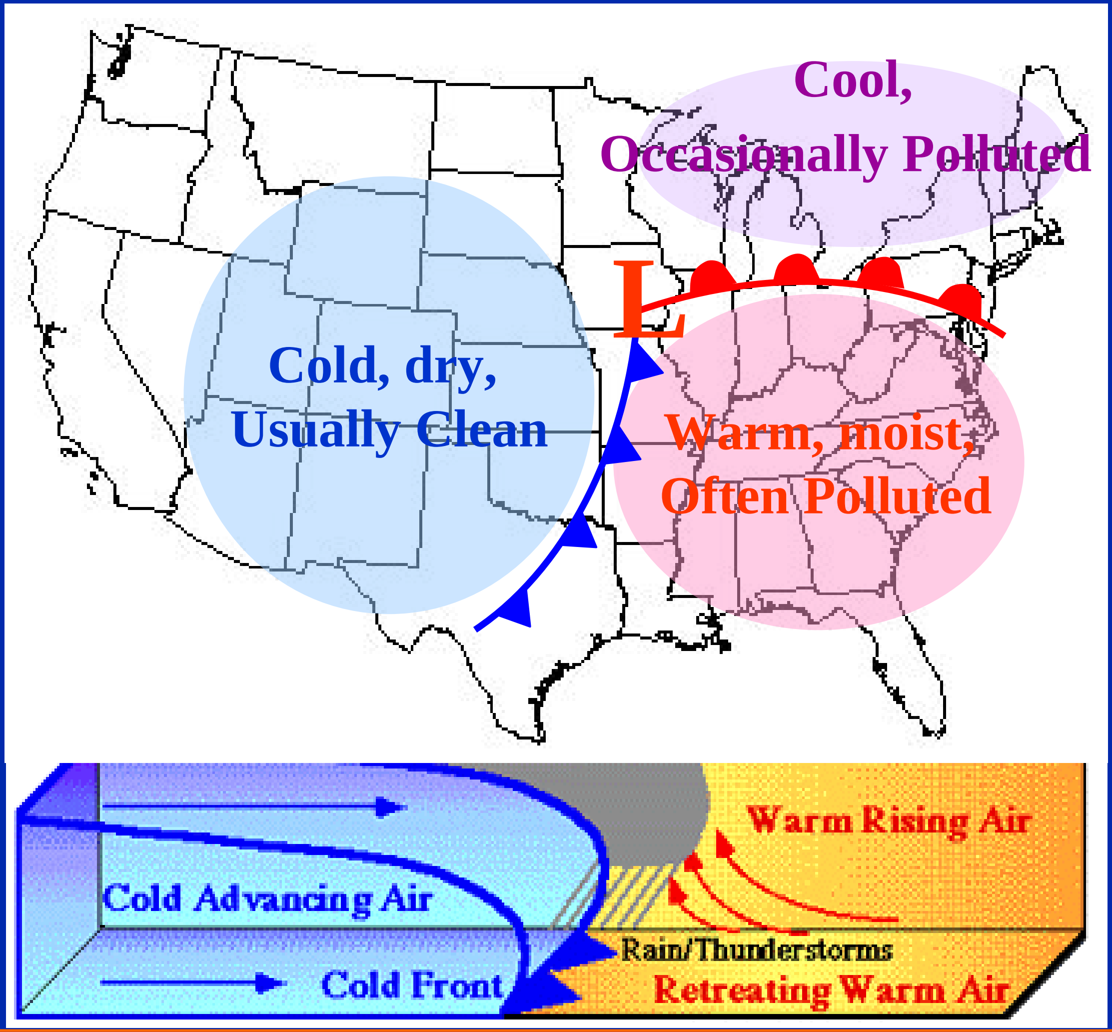


Inversions – Types

- Subsidence
  - Created by sinking air associated with ridges
  - Can limit daytime mixing depth and play important role in daytime pollutant concentrations
- Nocturnal
  - Created by cooling ground at night
  - Strongest with clear skies, light winds, and long nights
  - Can trap emissions, released during the overnight hours, close to the ground
- Advection
  - Created when warm air aloft moves over cooler air below
  - Can occur ahead of an approaching cold front
  - Can cause poor air quality, despite the lack of an aloft ridge

Fronts and Airmasses

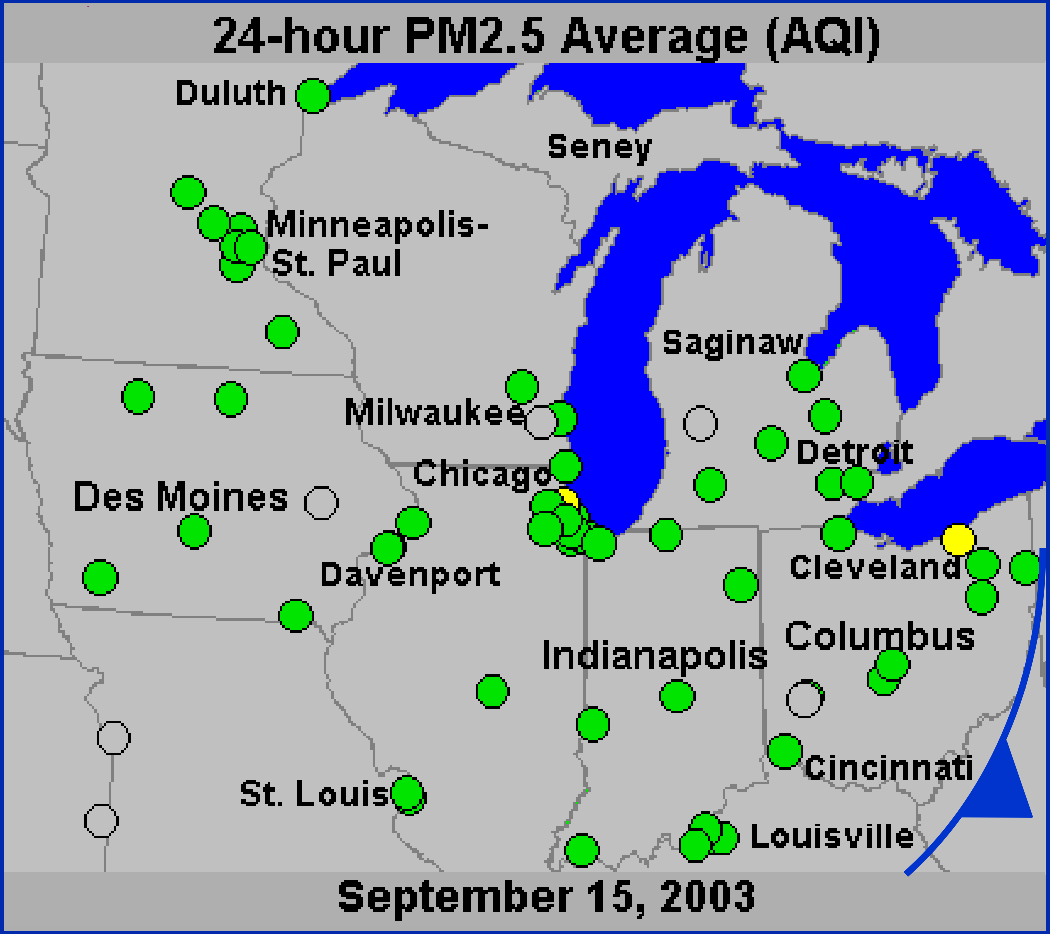
Fronts are regions where an atmospheric variable (temperature, dew point, etc.) changes rapidly across a small horizontal distance and divide **Airmasses**



Fronts

What do they do to air quality?

- They can cause rapid changes in air quality levels within a few hours of passage
- Weak fronts can have little to no impact of their own; however, enhanced convection that occurs near them can reduce air quality
- A stationary front positioned near an area is often associated with high $PM_{2.5}$ levels



Sunlight/Clouds/Precipitation

Affect on $PM_{2.5}$ and ozone and why

	$PM_{2.5}$	Ozone
Sunlight	↑ Photochemistry	↑ Photochemistry
Clouds	↑ Aqueous Chemistry ↓ Reduce Photochemistry	↓ Reduce Photochemistry
Precipitation	↔ Minor direct impact	↔ Minor direct impact

Key Weather Features – Summary

- Winds
  - Disperse pollution
  - Transport pollution
  - Create dust
- Inversions
  - Trap pollution
- Fronts and airmasses
  - Boundaries of pollution
- Sunlight and clouds
  - Influence pollutant chemistry
- Precipitation
  - No direct impact on $PM_{2.5}$ or ozone but can wash out PM_{10}

Summary of Air Quality and Meteorology 101

- Smog – A long polluted history, but improving
- Types of pollutants
  - Primary
  - Secondary
- Pollution is everywhere…
- Ozone – a colorless, reactive gas
- PM – many small liquid and solid particles
- Visibility impaired by particles
- Emission from many sources

Summary of Air Quality and Meteorology 101

- Lifecycles and trends
  - Day-night changes
  - Seasonal considerations
  - Long-term trends
- Solution to pollution is both
  - dilution and
  - less contribution
- Winds disperse, transport, and create pollution
- Inversions decrease dispersion
- Fronts – define a change in air mass
- Sunlight, clouds, and precipitation affect pollution in many different ways

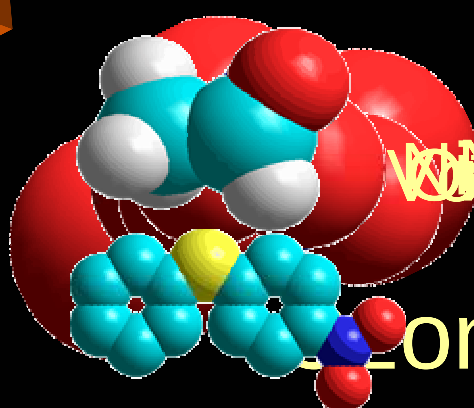
Factoids

- An increase in temperature of 18°F can cause over a two-fold increase in biogenic VOC and NO emissions. (http://www.epa.gov/ttn/chief/trends/trends98/chapter6.pdf, U.S. EPA National Air Pollutant Emission Trends: 1900-1998 (March 2000) EPA 454/R-00-002)
- One part per billion is equivalent to a pinch of salt in 10 tons of potato chips. A part per billion is also one part (salt) per billion parts (chips) or one drop of impurity in 500 barrels of water. (http://ace.orst.edu/info/extoxnet/tibs/partperm.htm).
- Spilling a “shot glass” (1oz.) of gasoline that evaporates produces the same VOC emissions as a car driving 56 miles (STI).
- In one day, one acre of eucalyptus trees emits more VOC emissions than a car driving over 7,700 miles (STI).
- The term “ozone” was suggested by Christian F. Schoenbein in 1840 as an atmospheric constituent gas with a certain odor; the Greek word “to smell” is ozein.

Factoids

- "Innovative" solutions proposed by the public for the Los Angeles' smog problem:
  - Tearing a hole in the atmospheric inversion layer that traps smog—thereby allowing it to escape—by firing cannons through the inversion layer from Mt. Wilson, dropping hot water on it from balloons, or burning a hole through it using giant mirrors focusing the sun's rays.
  - Installing spray towers off the coast to wash air at night as it flows offshore.
  - Seeding clouds to produce cleansing rains.
  - Planting smog-absorbing vegetation on mountain sides surrounding the Los Angeles Basin. (Source: http://www.aqmd.gov/news1/History.htm)
- Moving air takes energy. The polluted air mass out of Los Angeles County alone (up to 1000 feet) weighs 650 million tons. Electric fans needed to push the air out each day would require the electrical output of the Hoover Dam for eight years. (Dr. Arie Haagen-Smit who discovered the nature and causes of photochemical smog. Source: http://www.aqmd.gov/news1/History.htm)

A day in the life of an Ozone molecule

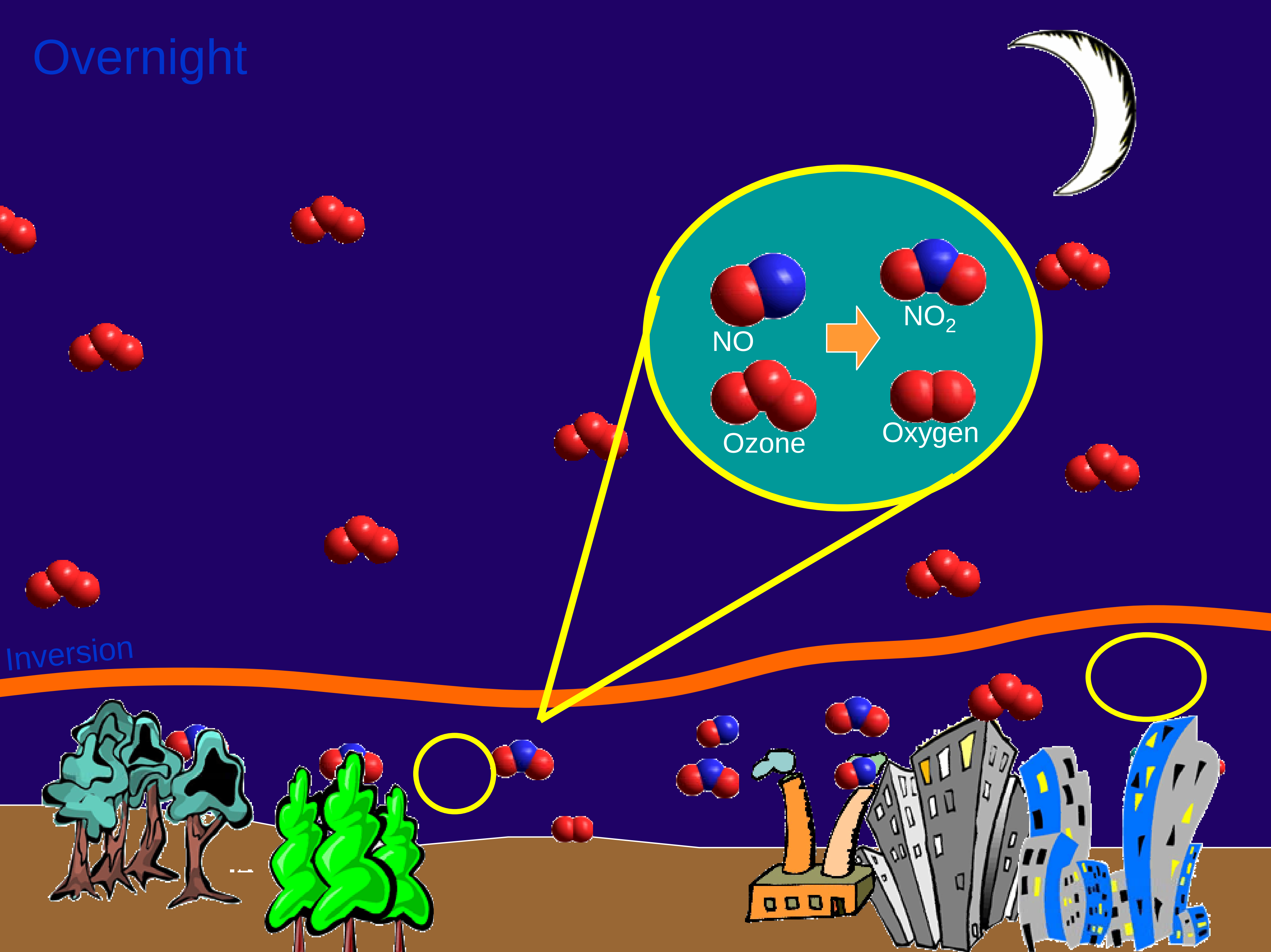


Volatile Organic Compounds as VOCs

Nitrogen Dioxide as NO_2

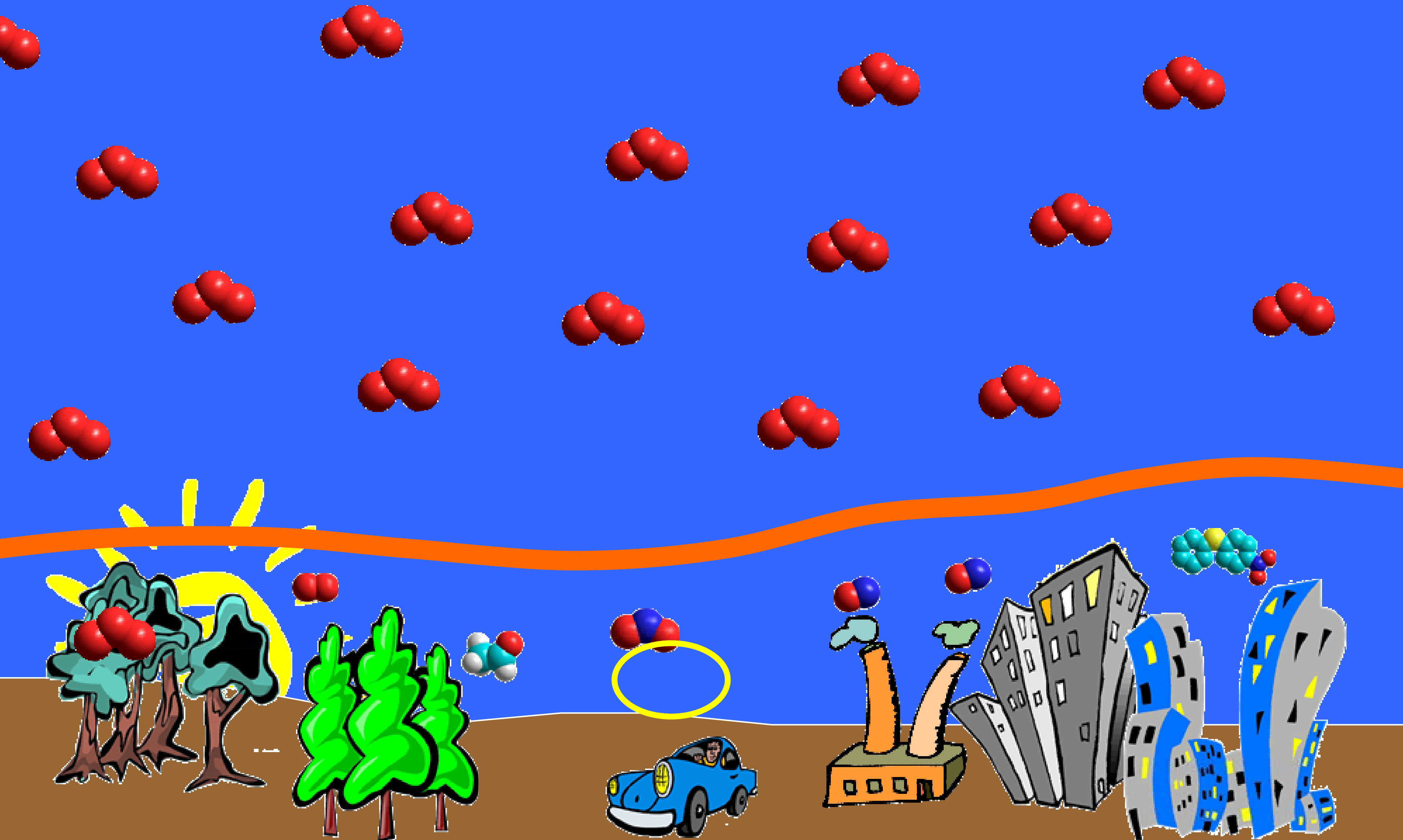
Oxygen gas as O_2

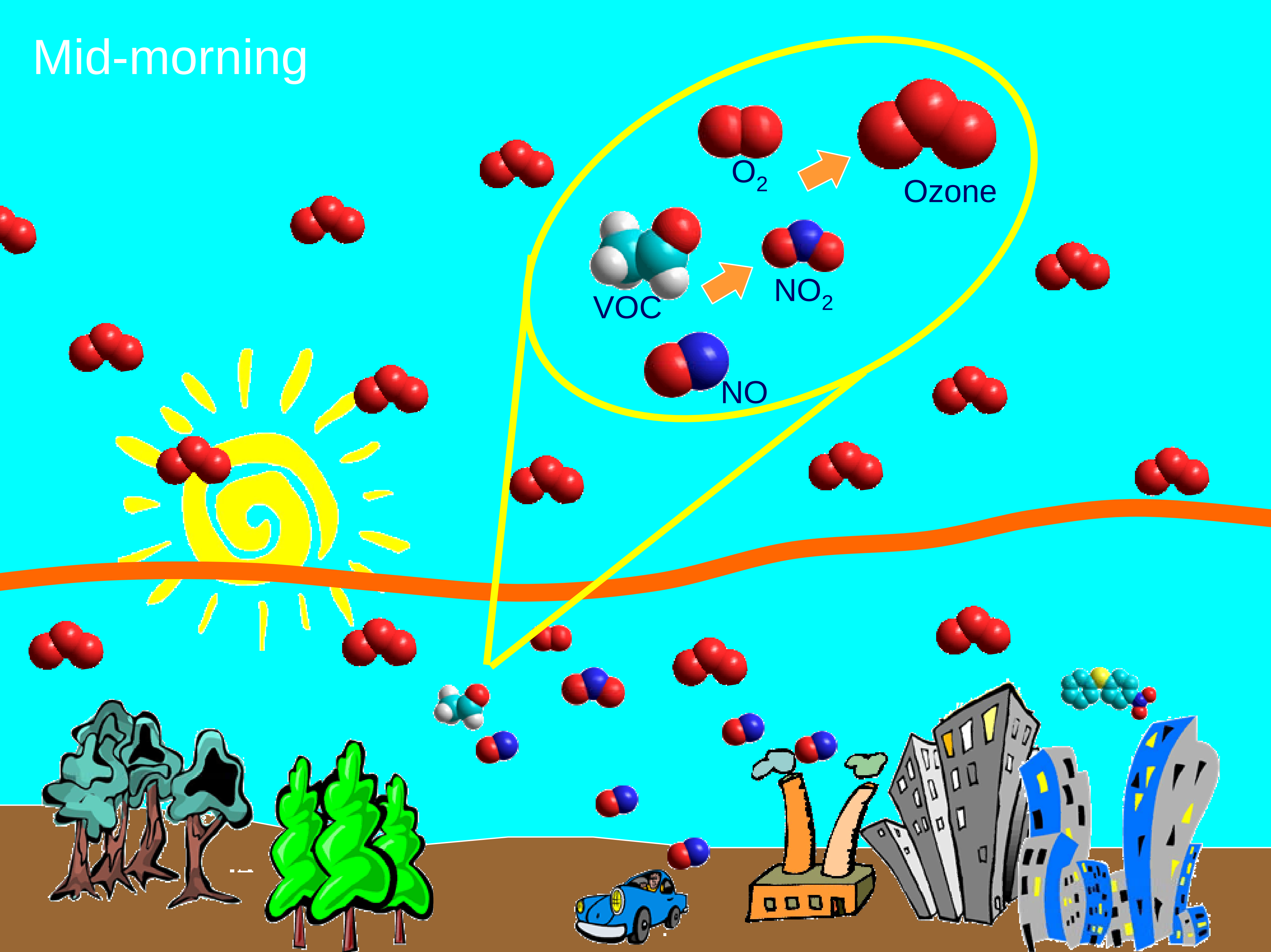
Ozone as O_3



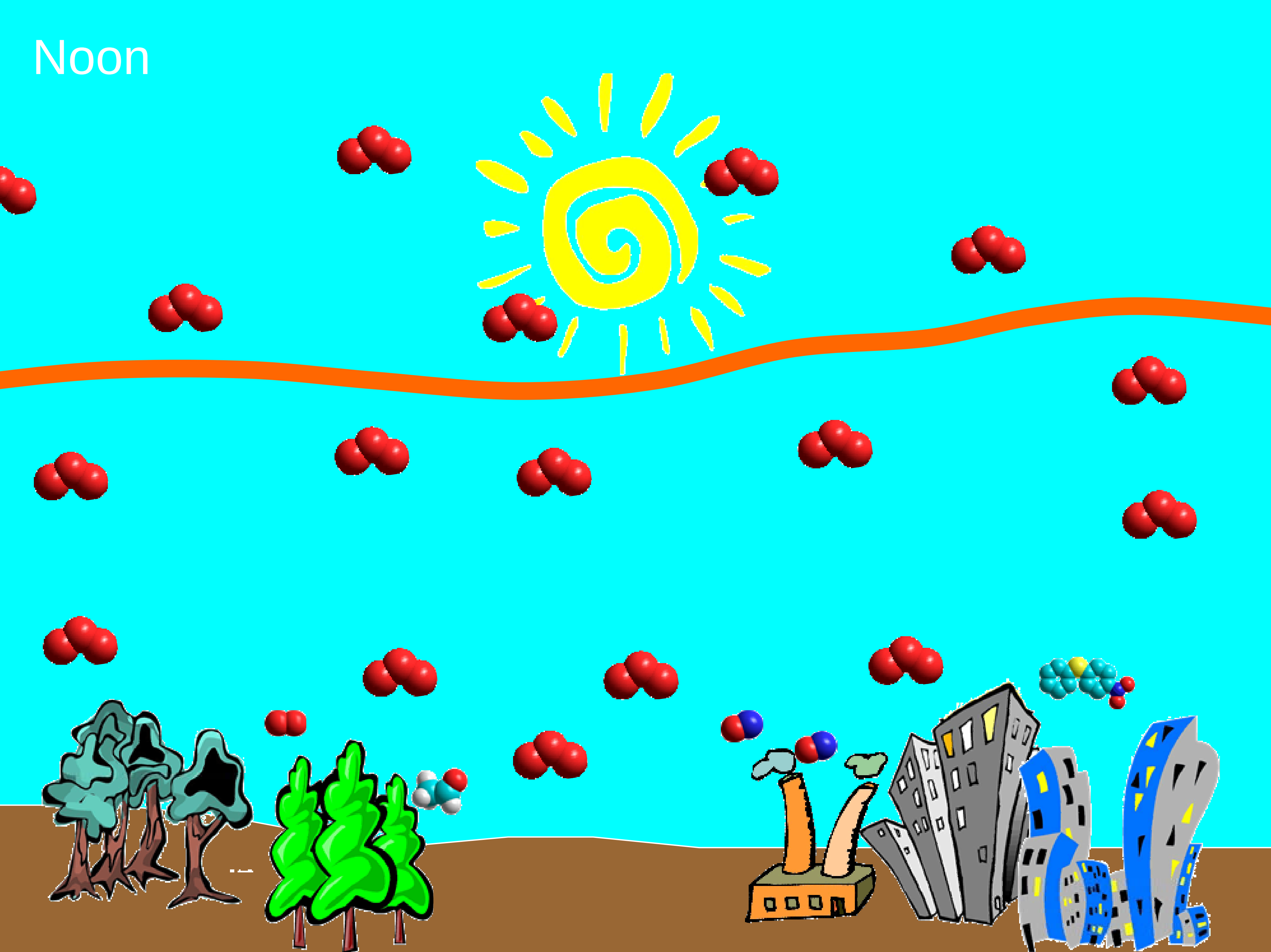
Overnight
NO
NO_2
Ozone
Oxygen
Inversion

Dawn

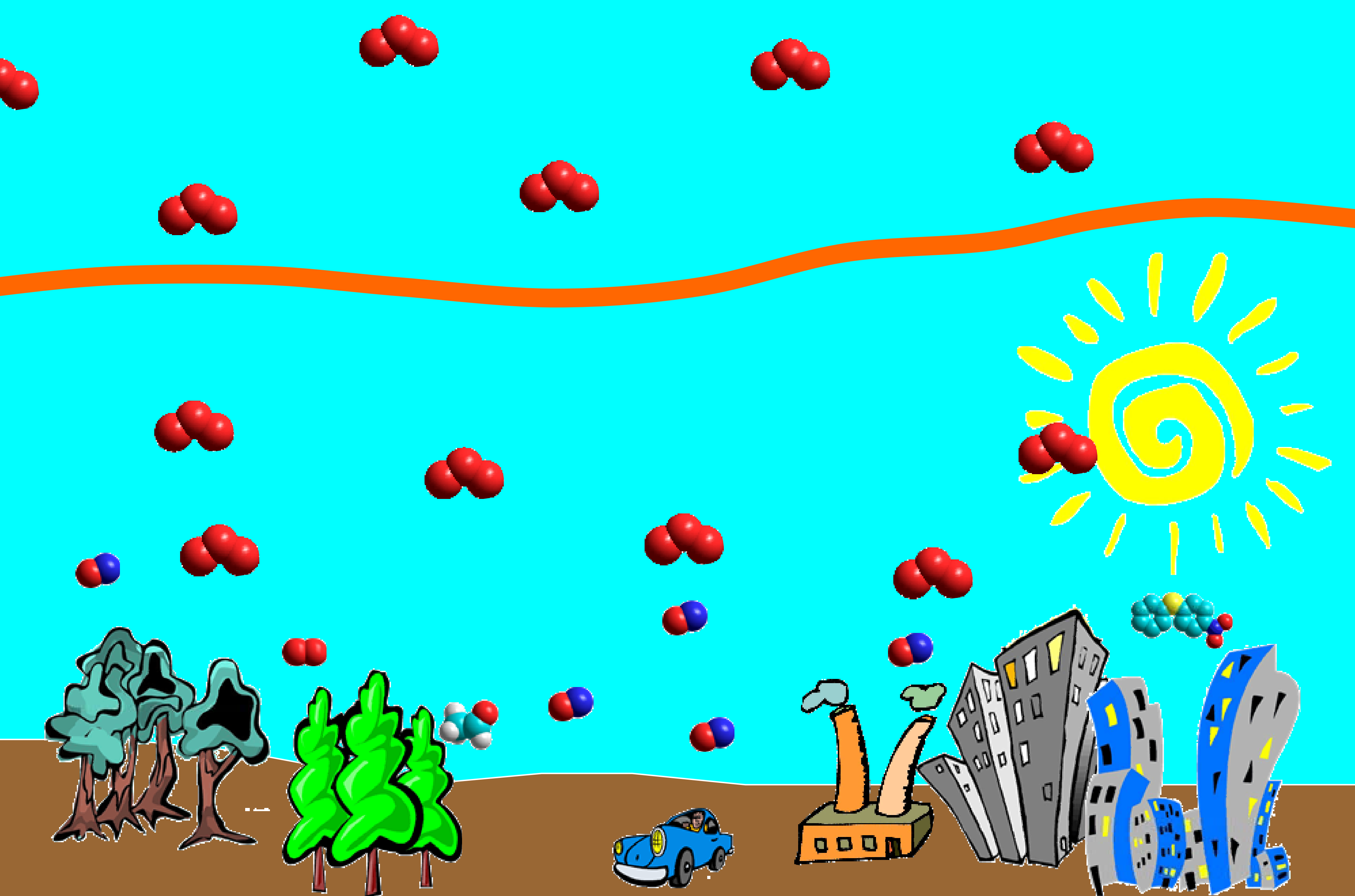




Mid-morning
O_2
Ozone
VOC
NO_2
NO


Noon

Late Afternoon



Evening