TeachEngineering

STEM Curriculum for K-12

AN INTRODUCTION TO AIR QUALITY

Learning Goals

After this lesson, you will be able to…

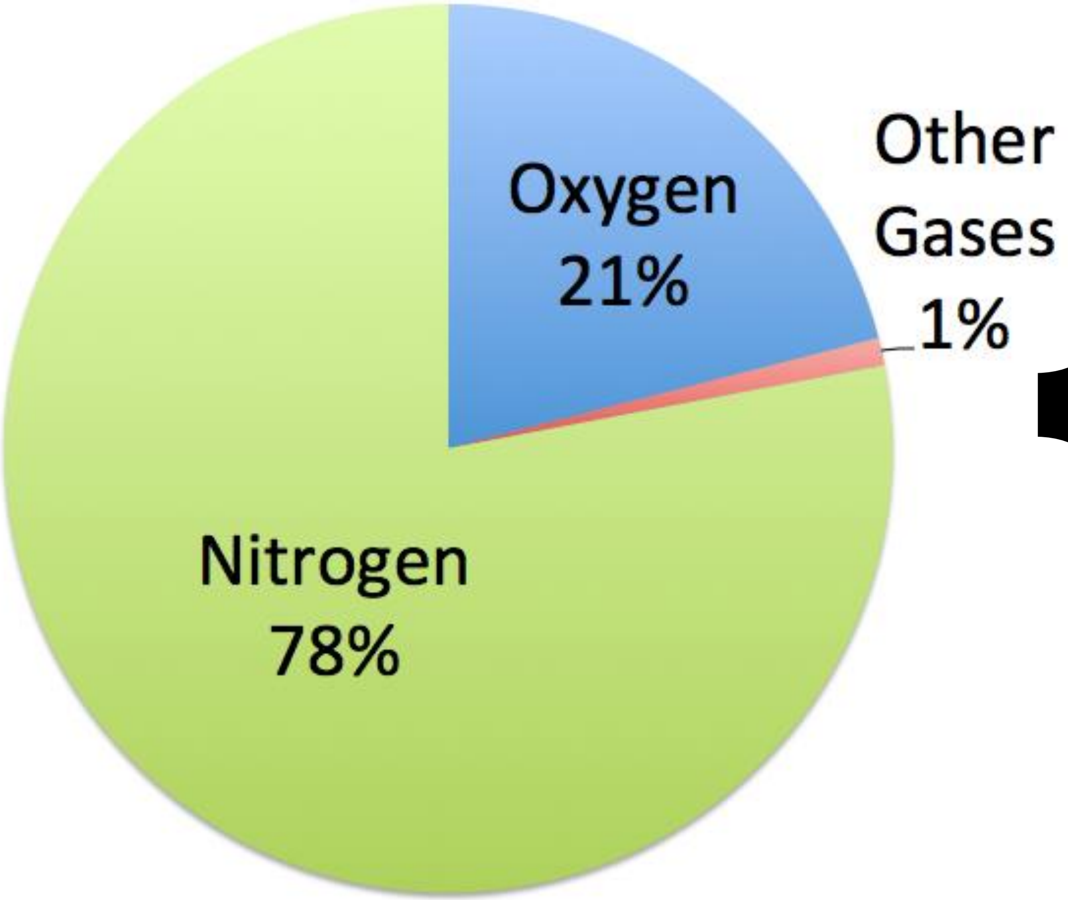
- List and describe the three primary reasons to study air quality: health effects, climate change and aesthetics
- Explain the differences between primary and secondary pollutants, and gas-phase and particulate pollutants
- Explain the different sources of CO & CO_2 (biological and combustion), VOCs (combustion and volatilization), and NO_2 (combustion).

What sets the Earth apart from other planets and makes it possible for us to live here?

the atmosphere

Radius=6000 km	Radius=75mm
Atm=12 km	Skin=0.5mm
Radius/atm=500	Radius/skin=150

What gases make up our atmosphere?

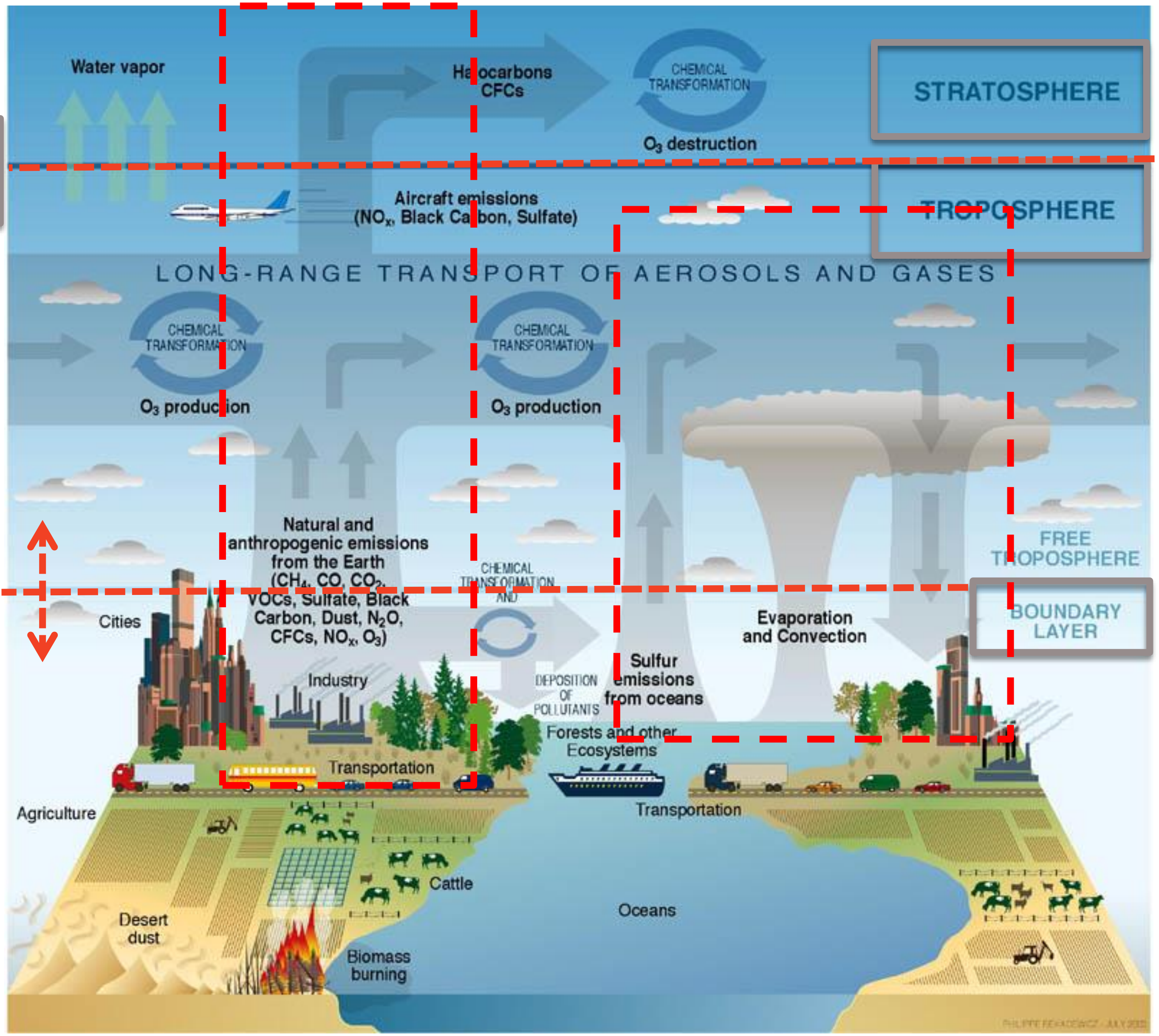


Including but not limited to:
argon (0.93%)
carbon dioxide (0.043%)
water vapor
hydrogen
neon
helium
methane

Our atmosphere is divided into layers

TROPOPAUSE (boundary)

But there is also circulation and movement between the layers



The Earth's atmospheric conditions vary from the surface to space—it's a complex system

TeachEngineering

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What do you think of when you hear "**air quality**"?

Sandstorm in Morocco

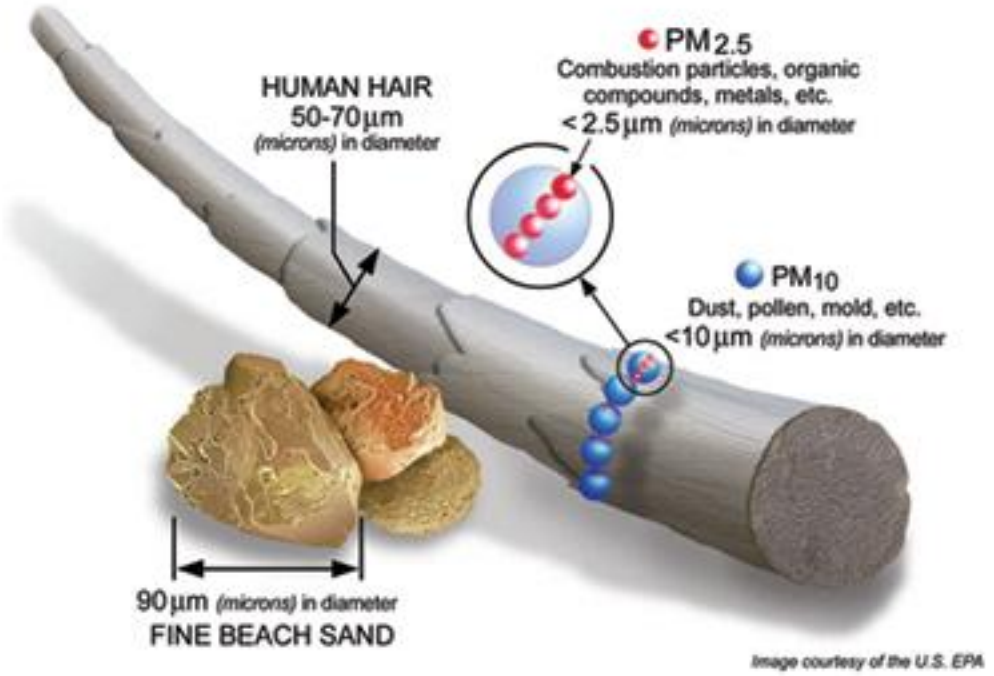
Smog in Malaysia

Clear day in Los Angeles

Is air quality the same all over the planet? Why or why not?

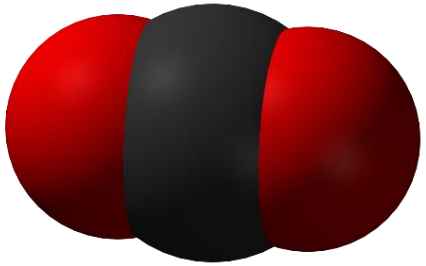
Types of Air Pollution

Particulate Matter (PM)

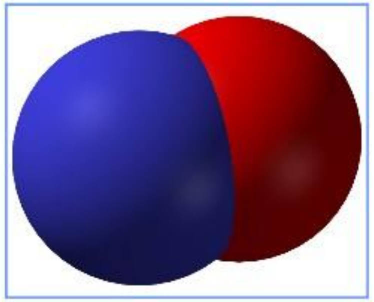


Note: Particulates may also be liquid, or a mixture of solid and liquid.

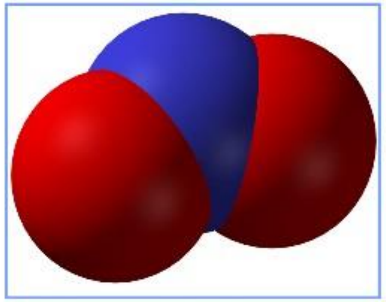
Gas Phase



carbon dioxide (CO_2)



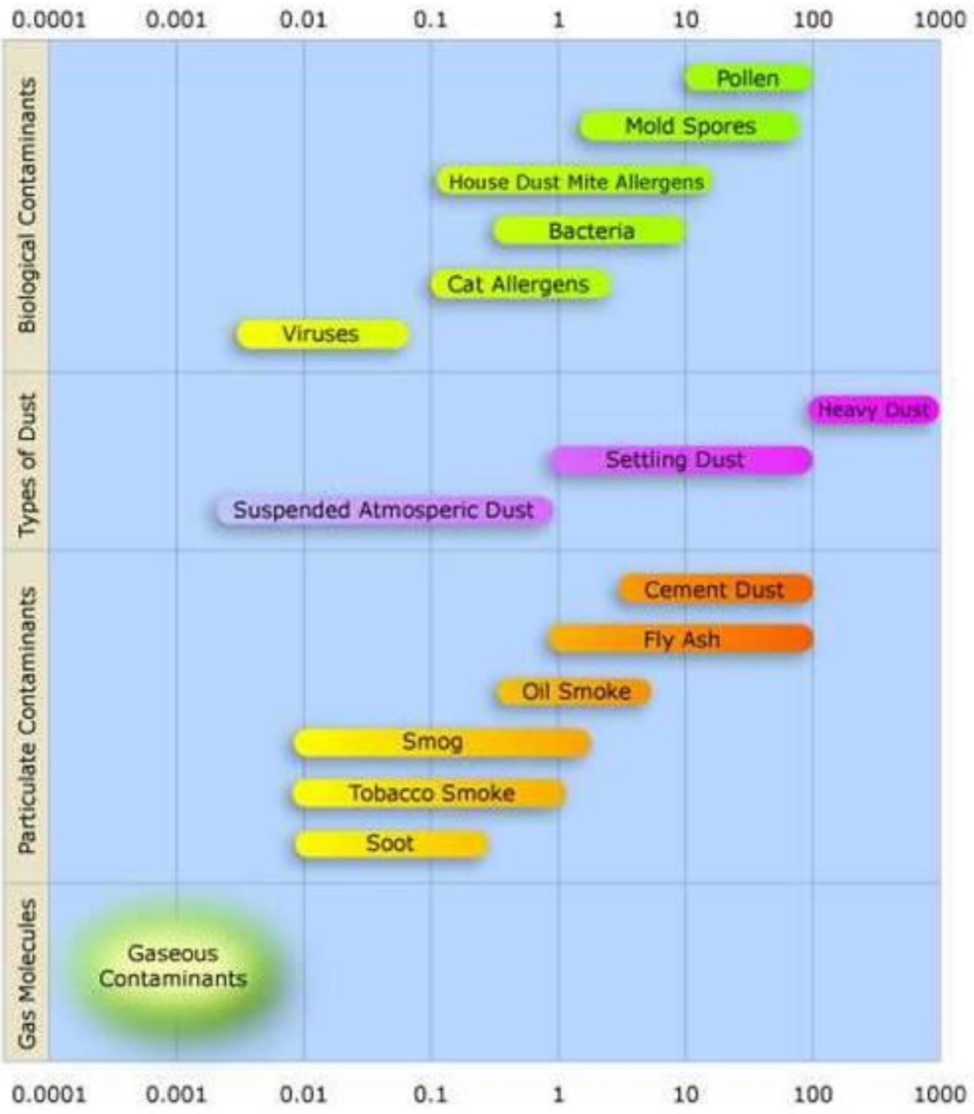
Nitric Oxide, NO



Nitrogen Dioxide, NO_2

Pollutant Size and Classification

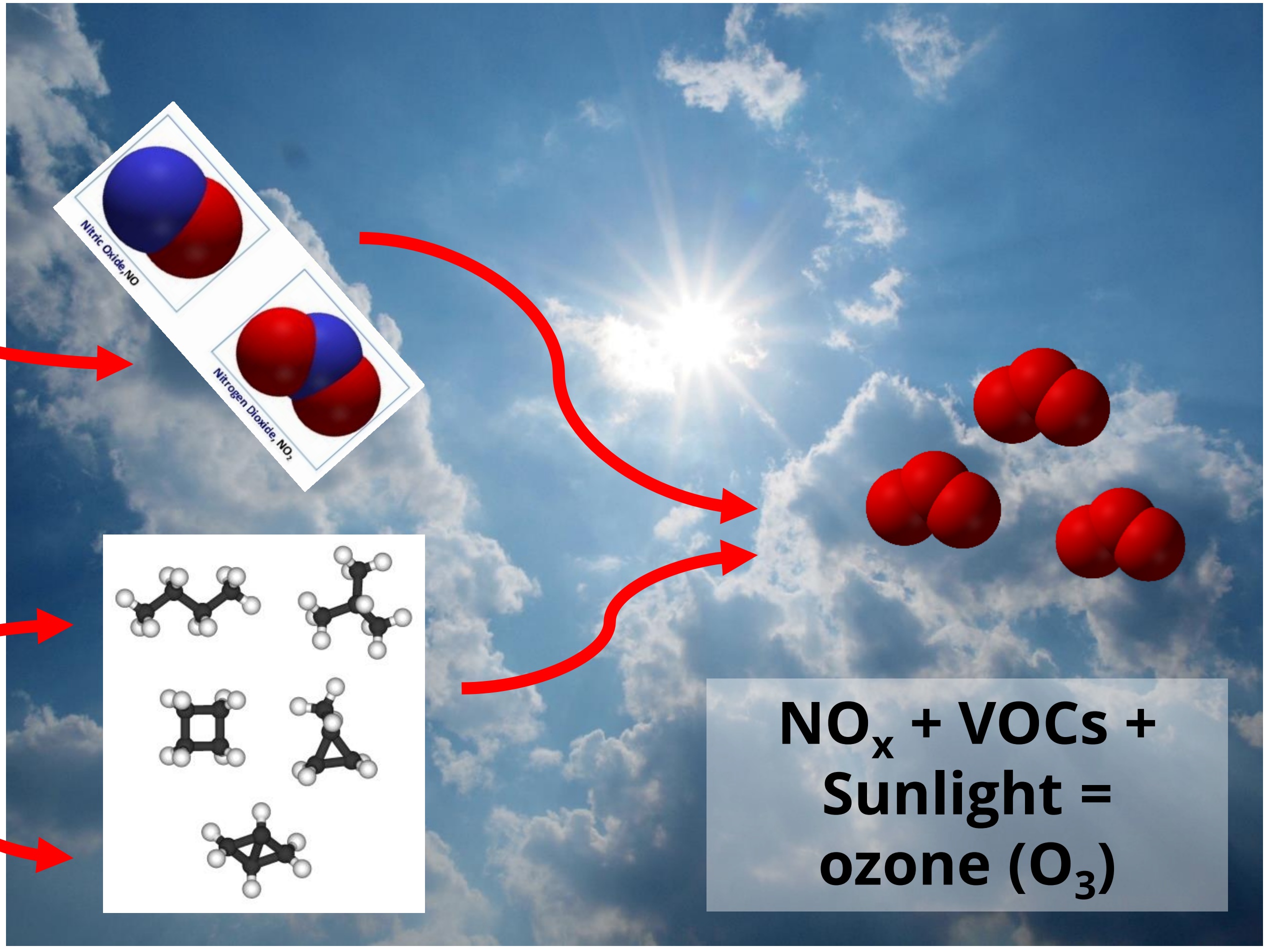
- PM_{10} (< 10 µm)
- $PM_{2.5}$ (<2.5 µm)
- PM_1 (<1 µm)
- Gaseous contaminants



units = microns (1,000,000 microns = 1 meter)

Primary vs. Secondary Emissions

Ozone Formation…



Our Focus: Gas Phase

- **Carbon dioxide (CO_2)**
  - Sources: biological respiration, combustion (complete)
- **Nitrogen dioxide (NO_2)**
  - Sources: combustion (high temperature)
- **Volatile organic compounds (VOCs)**
  - Sources: combustion (incomplete), any organic compound capable of volatizing at room temperature and pressures (such as cleaning products, paint, etc.)
- **Carbon Monoxide (CO)**
  - Sources: combustion (incomplete), photochemical reactions in the atmosphere, producing chemicals

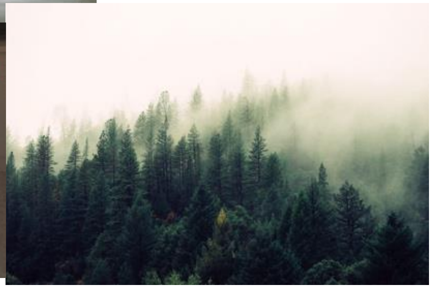
$O2 + CO + \text{sunlight} \rightarrow O3 + CO_2$
(greenhouse gas formation)

$N_2 + O_2 \rightarrow NO$ & NO_2
(high temperatures can break up N2 in the air)

Carbon Fuel + $O_2 \rightarrow H_2O + CO_2$
(complete combustion)

Incomplete or inefficient combustion
→ **uncombusted VOCs**

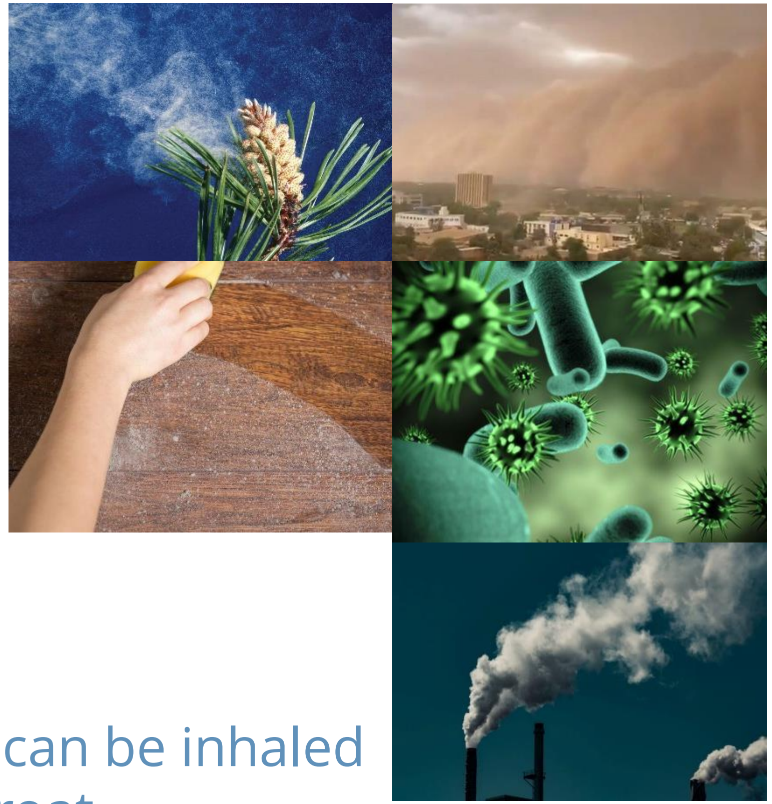
other VOCs



Our Focus: Particulate Matter

The sources of particulate matter include:

- **Primary**: incomplete combustion, automobile emissions, dust, cooking
- **Secondary**: chemical reactions in the atmosphere



- **PM_{10} (< 10 µm)**
  - Examples: pollen, heavy dust, ash
- **$PM_{2.5}$ (< 2.5 µm)**
  - Examples: house and settling dust, bacteria, mold spores
- **PM_1 (< 1 µm)**
  - Examples: tobacco smoke, smog, soot, viruses

Health Impacts:

- All PM that is 10 microns or smaller can be inhaled
- PM_{10} irritates the eyes, nose, and throat
- $PM_{2.5}$ and PM_1 can enter the bloodstream through the alveoli in the lungs

What are the main causes of air pollution?

Pollutants come from:

- Combustion
- Compound volatilization
  - Anthropogenic sources: industrial activity or manufacturing
  - Natural sources: trees (VOCs)
- Mechanical generation
  - Such as dust

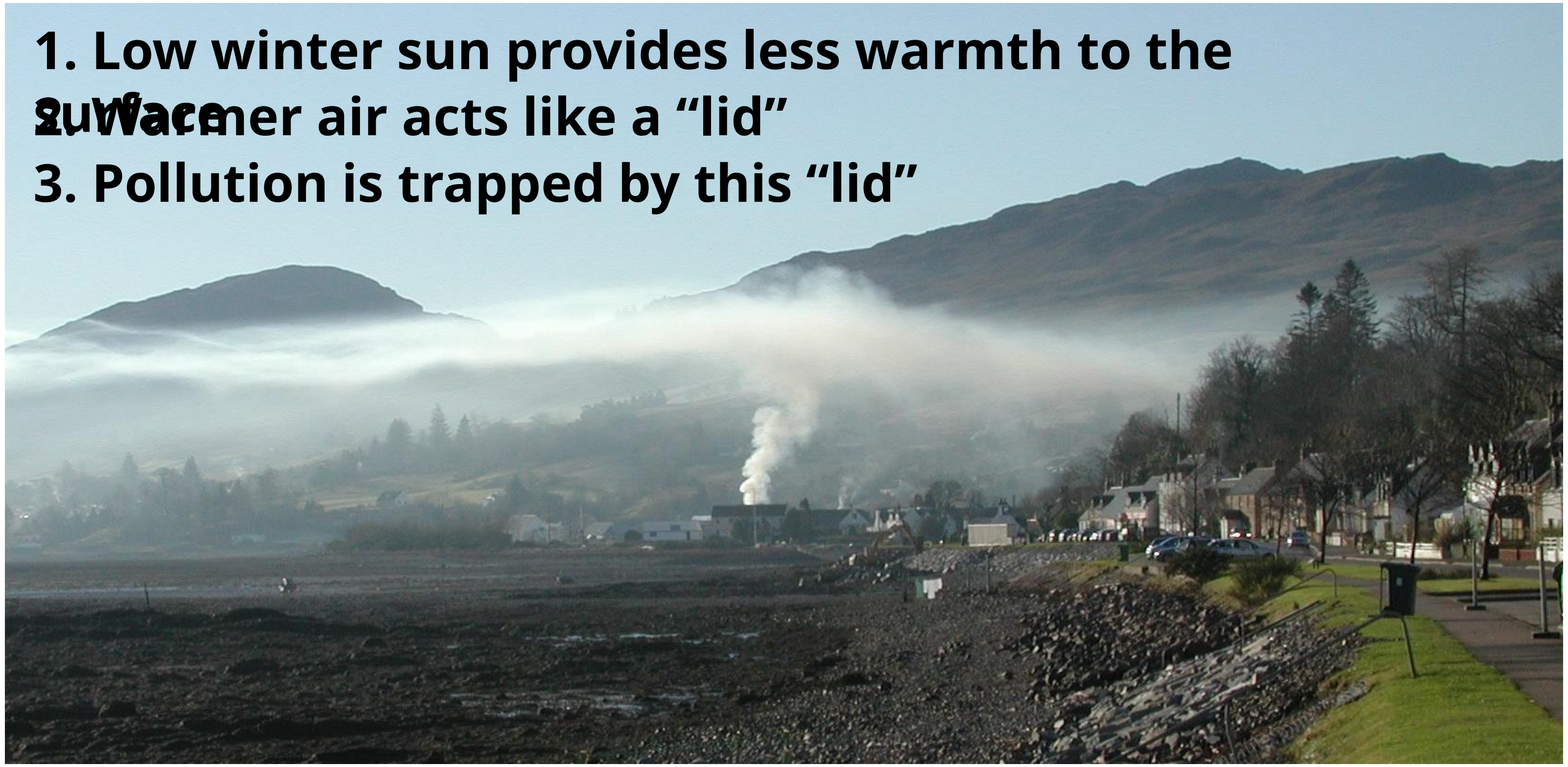
Then, meteorological conditions and atmospheric dynamics impact whether or not the emissions disperse

~~*“the solution to pollution is dilution”*~~

Temperature inversions affect dilution and how pollutants disperse

Why "inversion"?

- Normally, warm air at the Earth's surface rises up, causing ***mixing*** throughout the atmosphere
- Instead, we have warm air on top, which traps the old air and pollutants, causing an inversion
- Inversions are usually worst in the early morning hours



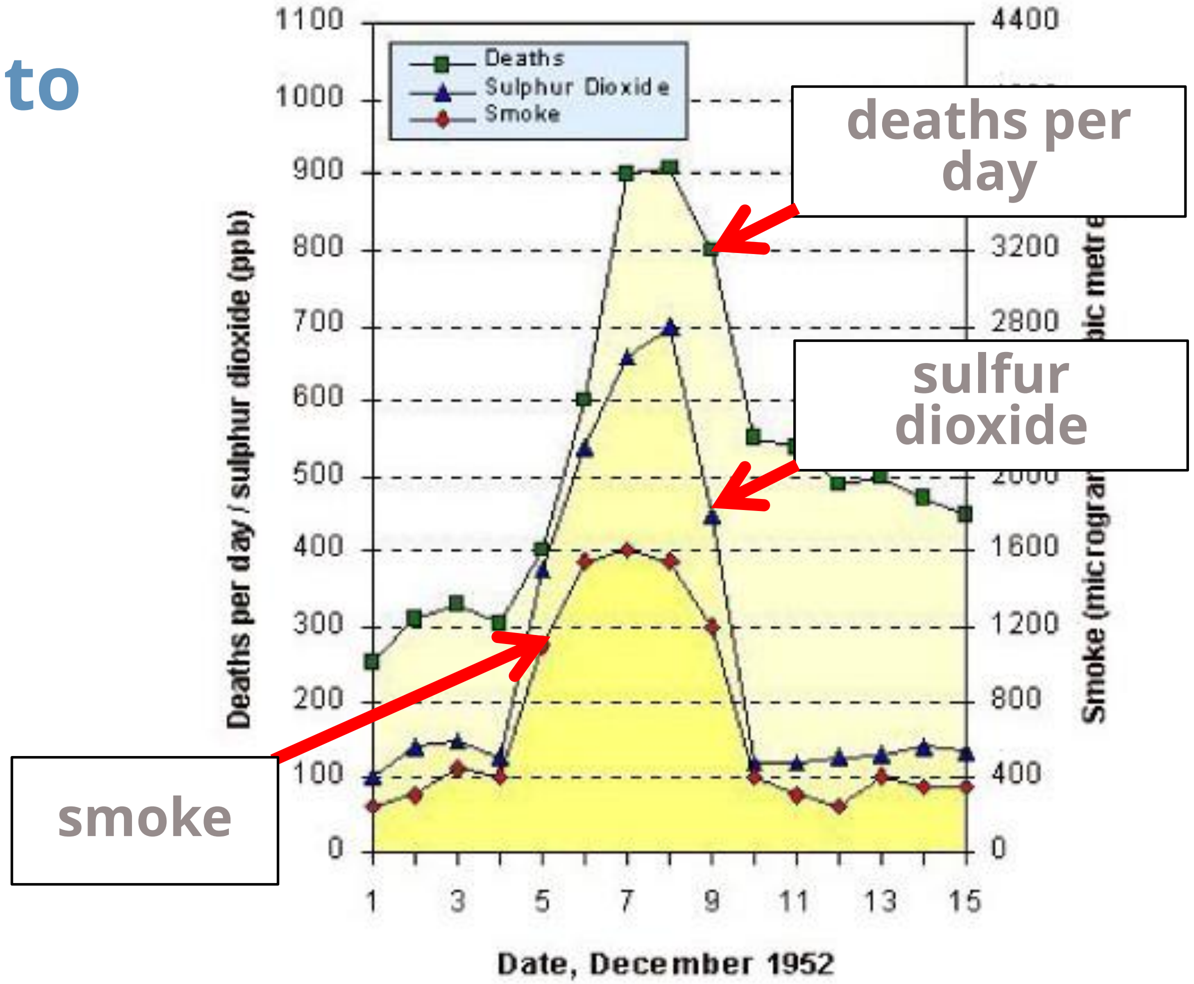

THE BIGGER PICTURE

Why does air quality matter?

- Health impacts (breathing)
- Climate change
- Aesthetics (visibility and odor)

Outdoor Air Pollution > Health Impacts

- Air pollution can be **harmful to human health**
- A 1952 London smog event **killed 4,000+ people**



The relationship between smoke, sulphur dioxide (in parts per billion – ppb) and number of deaths during the Great London Smog, December 1952. (After Wilkins, 1954, p. 170)

How do we protect U.S. citizens' health?

"The mission of EPA is to protect human health and the environment."

- **Human health** is the primary focus, and regulations are based on scientific literature and studies on health and safety, which are continuo
- For example…
  - 1963 Clean Air Act
  - National Ambient Air Quality Standards (NAASQs)
    - Primary standards (CO, O_3, NO_x SO_2, Pb, and $PM_{2.5}$ & PM_{10})
    - Secondary standards for ecological health
      (Note: These are different from primary and secondary pollutants)
  - Hazardous air pollutants (HAPs)

  - **LIMITATIONS:** For outdoor air quality only; OSHA oversees indoor *workplace* air quality

Indoor Air Pollution > Health Impacts

- ~3 billion people cook and heat their homes using *solid fuels*
  - *Solid fu*els include wood, crop wastes, charcoal, coal and dung
- Inefficient cooking technologies (open fires and leaky stoves) and solid fuels produce small soot particles that penetrate deep into the lungs, leading to pneumonia, stroke, heart and lung disease and lung cancer

Traditional cookstoves

New stove!

- **More than 4 million people die prematurely every year from illnesses that are caused by indoor air pollution created by cooking with solid fuels**

Source: World Health Organization

Climate Change and Air Pollution

The Earth's surface radiates heat into the atmosphere. Then that heat is either…

A. absorbed by a GHG and radiated into space

B. escapes into space

C. absorbed by a GHG and radiated back to Earth

- More greenhouse gases (GHG) = less heat escaping & more radiated back to the Earth
- Due to air pollution generated by humans, **GHG concentrations are increasing**
- Examples of greenhouse gases…
  - Water vapor, CFCs, nitrous oxide (N_2O)
  - *Carbon dioxide (CO_2), methane (CH_4), ozone (O_3)

*We are able to measure these with the Pod

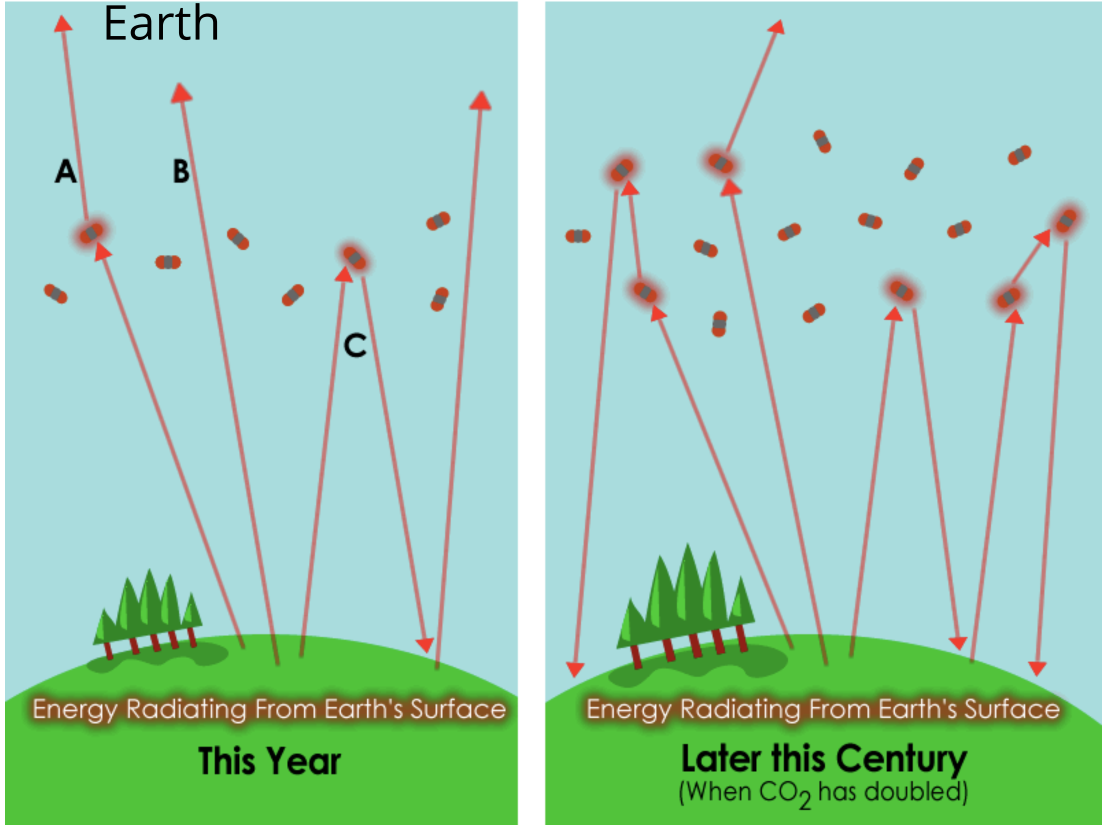


Figure courtesy of Lisa Gardiner/Windows to the Universe

Air Pollution > Aesthetic Impacts

- Poor air quality results in decreased *visibility*, which is especially an issue for tourism in national parks or other pristine areas
- Imagine if the haze below were present in Rocky Mountain National Park

The difference between a clear day and an extremely smoggy day in Beijing.

- Poor air quality can also cause *unpleasant odors*, especially in areas of high industrial activity

AIR QUALITY MONITORING TECHNOLOGIES

A Quick Note about Common Units…

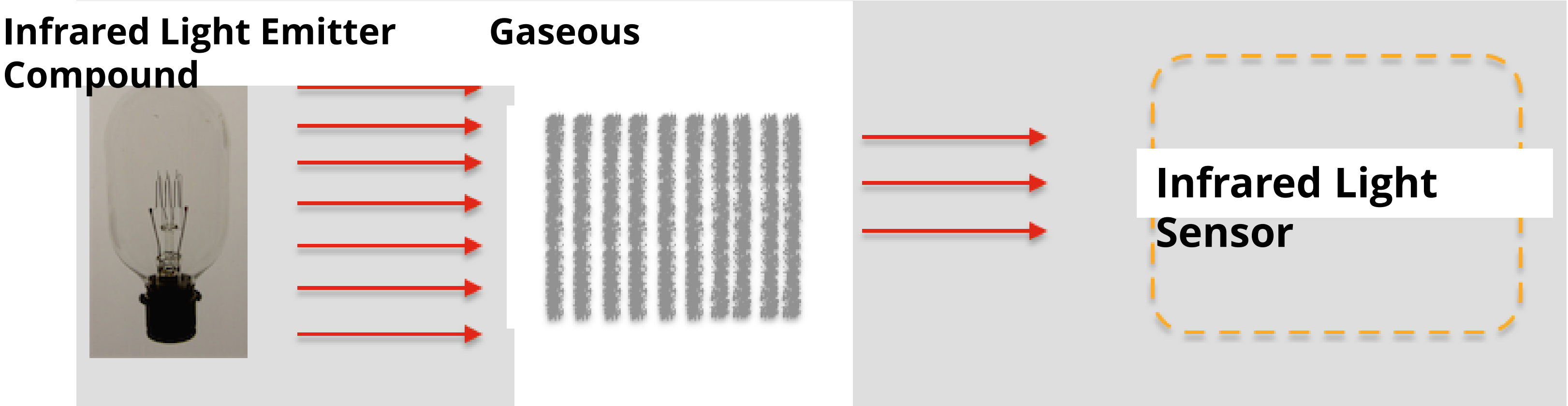
For AQ studies, we need to know ***concentration***:

- **ppm or ppb**
  - = parts per million or parts per billion
  - EXAMPLE: Imagine you have 1 million water bottles and 400 are filled with CO_2 while the rest are filled with air—by volume you have 400 ppm of CO_2

- **μg/m^3**
  - = micrograms of pollutant per meter cubed of air
  - This is the total weight of particulates (for example) that you have, per meter cubed of air

What are we measuring?

- **Optical properties:** such as absorbance



Some gases absorb light, so less light makes it to the detector, which we can measure in order to figure out how much of the gas we have.

- **Physical properties:** such as weight or size

- **A change:** Burn it and measure the resulting energy, or gases react with the surface of a sensor and we measure the reaction

Conventional Monitoring Equipment

- **Conventional monitoring equipment**
  - High cost ($5,000 - $100,000)
  - High accuracy, high precision
  - Necessary for scientific research and regulatory purposes (states must prove they are meeting EPA regulations)

Picarro Cavity Ring-Down Spectroscopy (CRDS) instrument, as used in greenhouse gas measurement stations worldwide

Measures: CO, CO2, CH4, H2O and other species

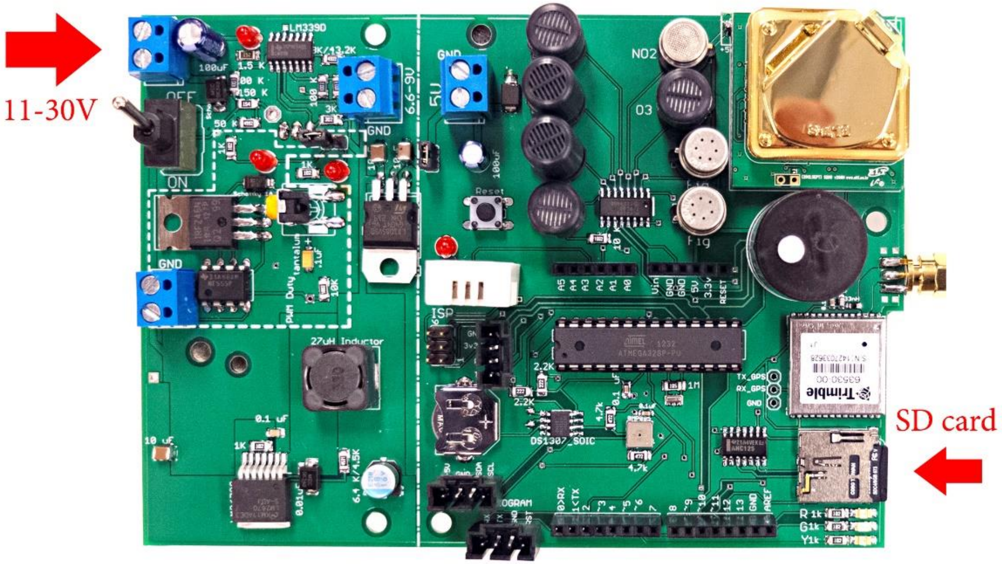
Continuous Air Monitoring Project
Colorado Department of Public Health and the Environment, Denver CO

Measures: CO, PM10, PM2.5, NO2, O3, SO2, NO, TEMP, WD, WS

Next-Generation Monitoring Equipment

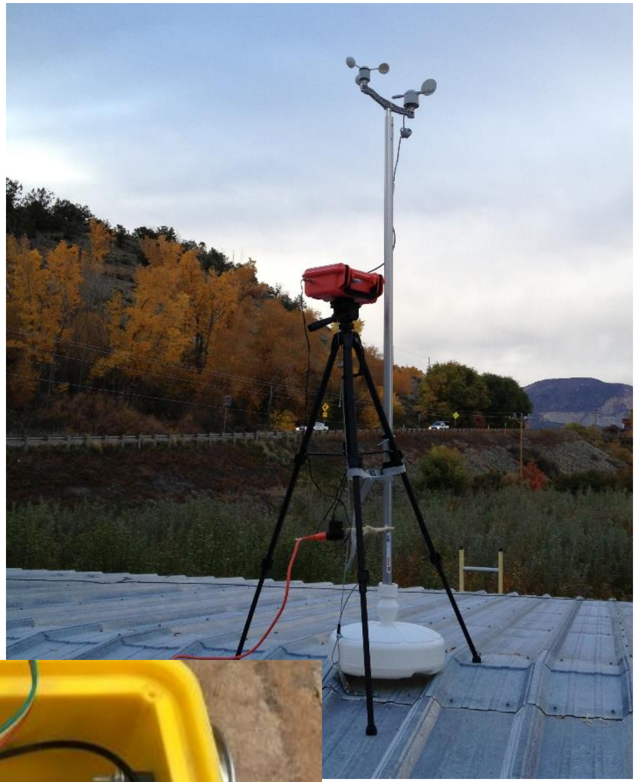
The "next-generation movement" — the future of air quality monitoring!

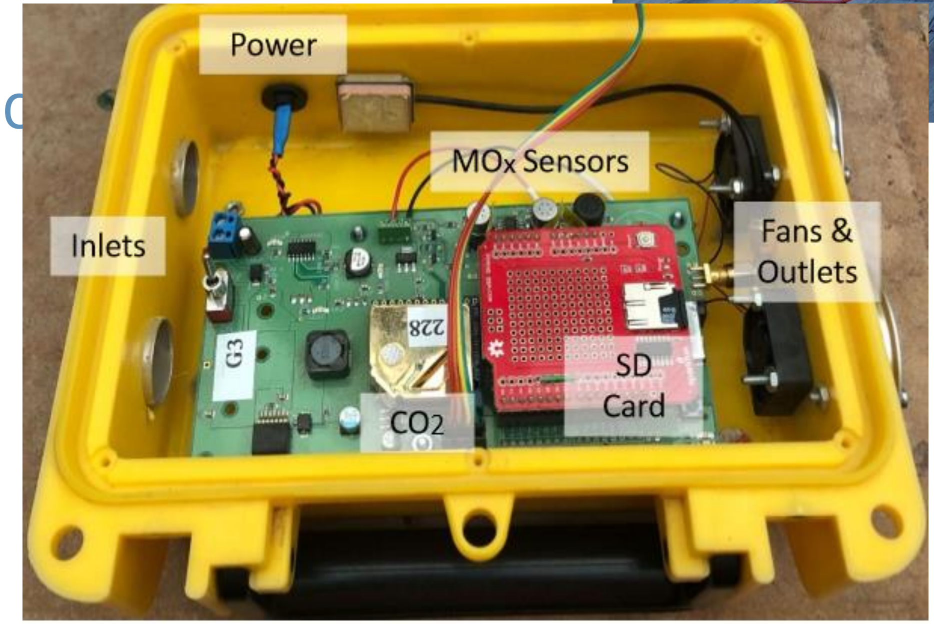
- Low-cost monitors enable researchers to gather more data by using multiple monitors at once (this provides better data on the *spatial variability* of pollutants)
- Low-cost monitors also make monitoring accessible to more people: "**citizen science**"
- They are still under development, require further validation, can be fairly accurate (time-intensive), and are useful for focused projects and hands-on teaching and learning



Pods

- **Continuous monitoring:**
  - Indoor or outdoor
  - Mobile or stationary
- **Total cost** < $1000 per device, open-source design
- **Measures:**
  - CO_2, total VOCs, PM, and CO
  - Temperature, humidity, wind speec wind direction and GPS locations
- **Sensors used:**
  - Metal oxide semi-conductor
  - Electrochemical
  - Non-dispersive infrared



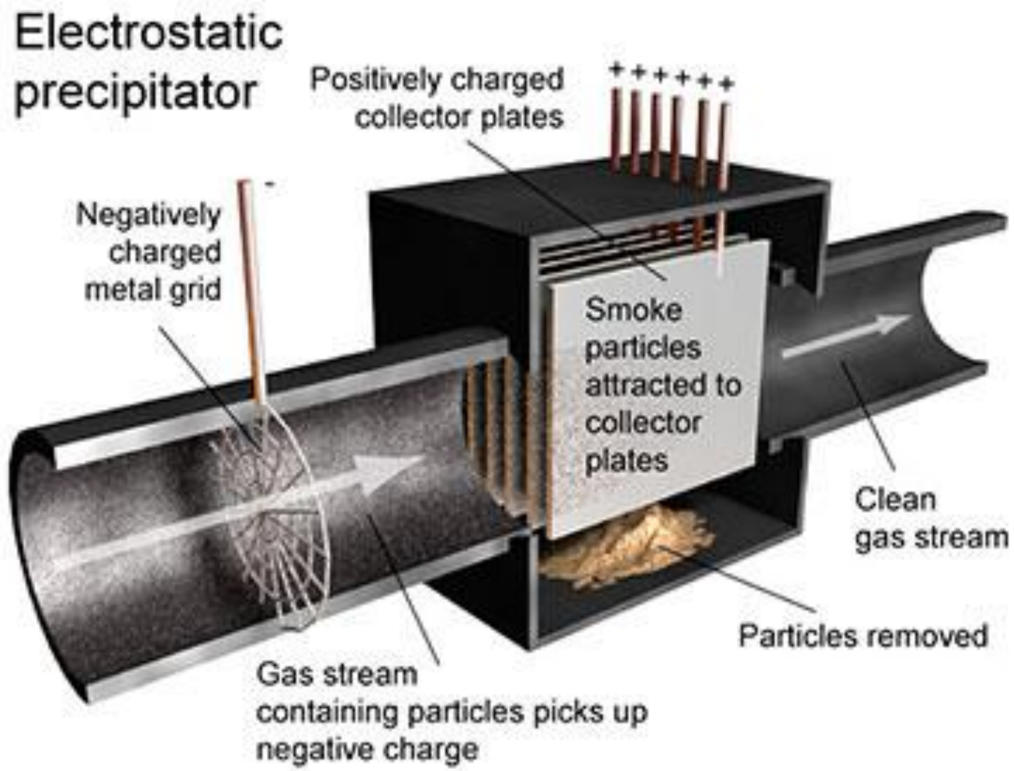


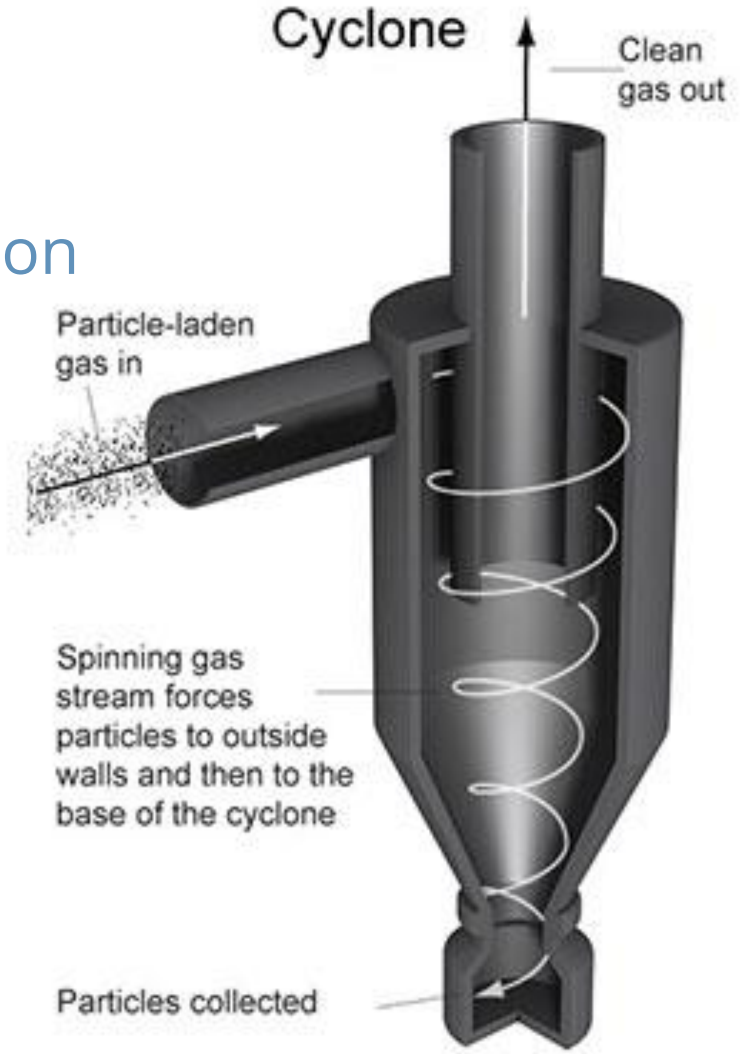
CONTROL TECHNOLOGIES

Control Technologies Overview

How do we remove particles?

- Essentially, we need to somehow trap or filter them
- Effectiveness depends on particle size and composition



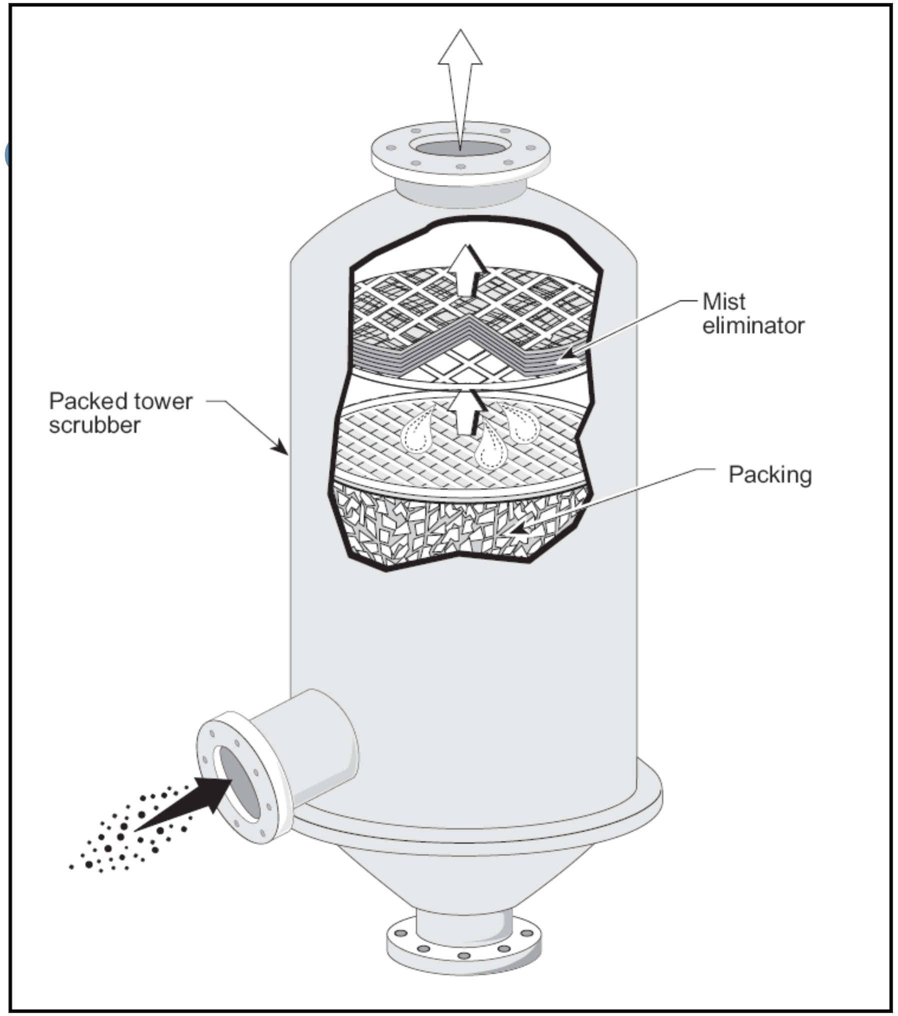


Control Technologies Overview

How do we remove gases?

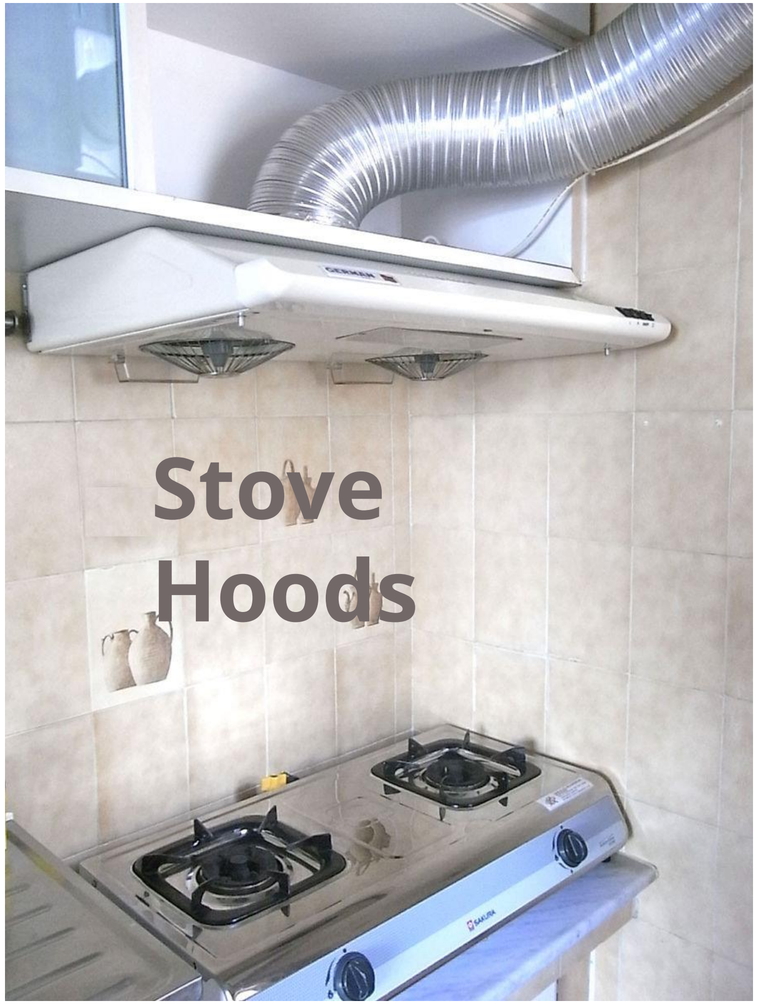
- Essentially, we need to capture them or change their composition
- Effectiveness depends on target compound

Flaring



Scrubber

Control Technologies in Daily Life



Stove Hoods

HVAC Filters

Catalytic Converters

Control Technologies Overview

What else can we do?

Mitigation: Changing behavior or practices to minimize what is emitted in the first place

Example: OzoneAware campaign →

- Example recommendations:
  - No idling
  - Take public transit
  - Mow after dark

What are they trying to mitigate?

Conclusions

We care about air quality because of…

- Health, climate change and aesthetics

Air pollution comes from…

- Combustion, mechanical production, and volatilization

Engineers use a wide variety of monitoring technologies to understand what is in our air

Engineers develop and implement control technologies and mitigation strategies to improve air quality

Any question?

What could you investigate with this tool?

What are you are curious about?

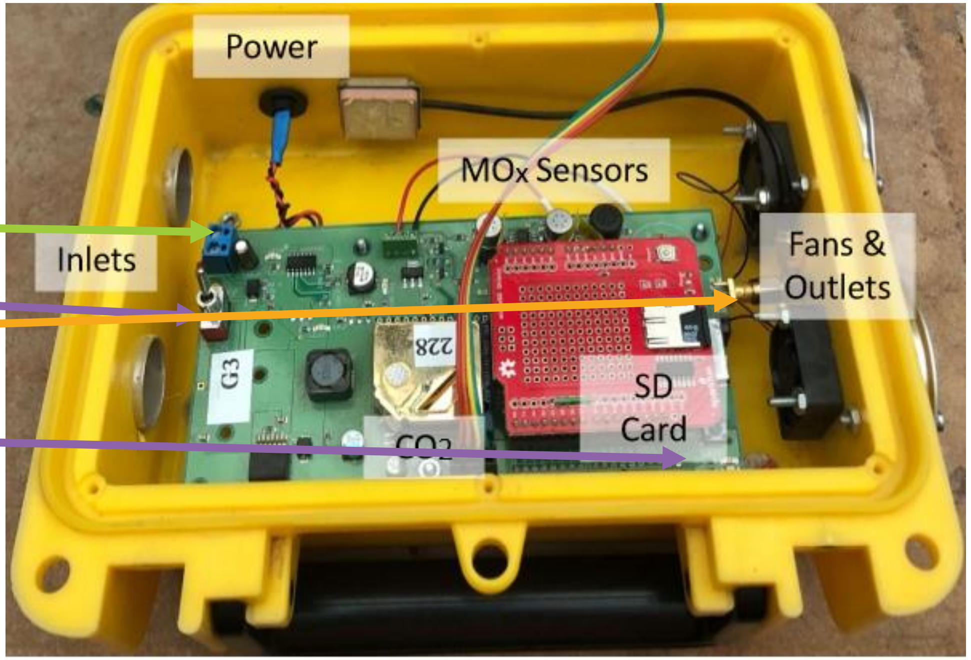
APPENDIX SLIDES

Appendix 1: More Information on the Technology (Pods)

- **Operational Info:** How the Pods work, how you can look at data
- **Sensors:** How they work
- **Calibration:** Raw vs. calibrated data

Operational Info

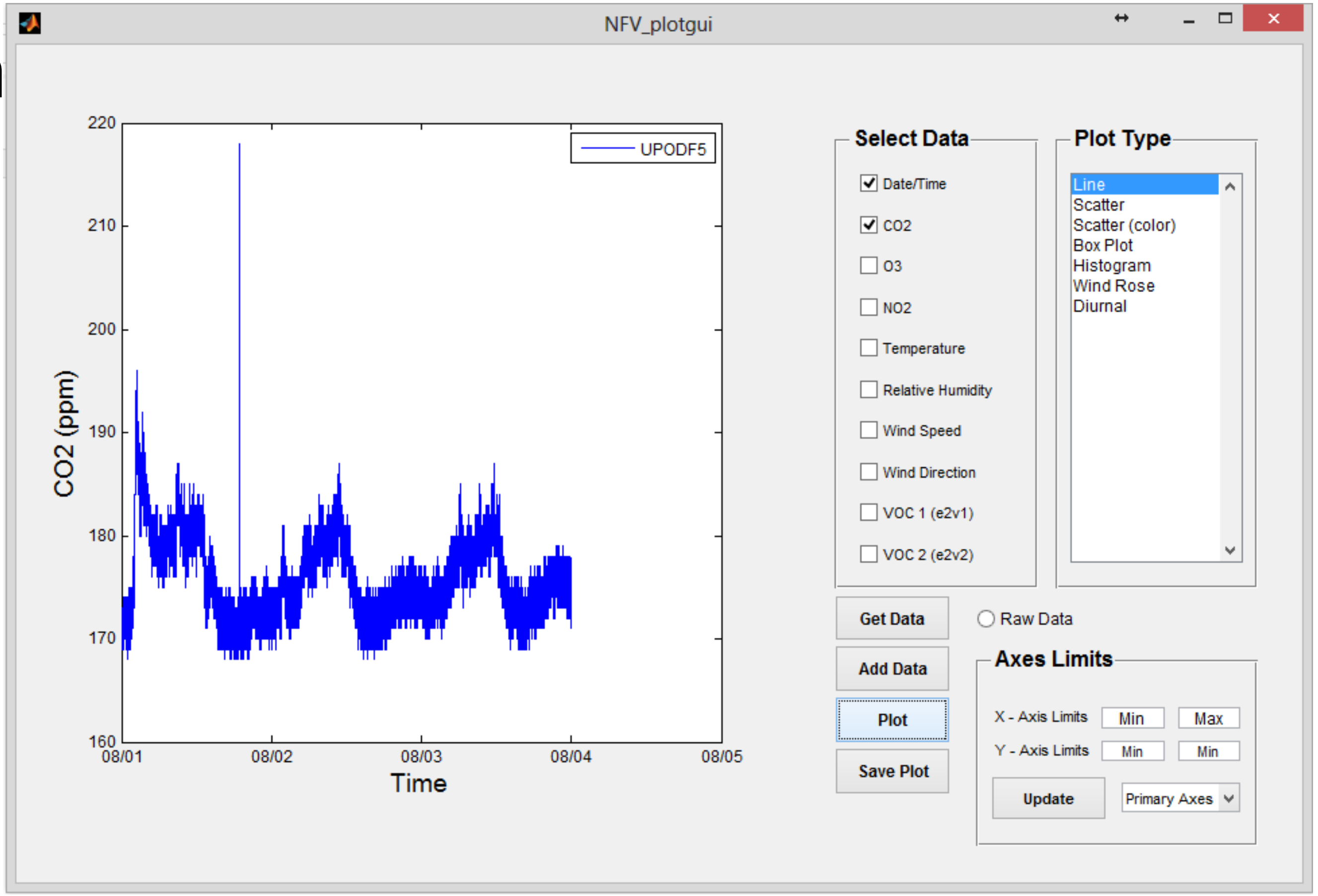
- Pods record data every ~5-25 seconds, depending on the settings
- Data is recorded to a mini–SD card on the board (bottom right corner of image)
- Powered by using a power adapter OR a battery
- **Checks:**
  - Is this light on?
  - Is the switch flipped down?
  - Are the fans running?
  - Is this light flashing every 5-15 seconds?
  - If so, then the pod is collecting data



FYI: plenty of space on the SD card

Operational Info

Data files can be viewed in Excel OR in "Plotter Tool"



- **Excel** gives you:
  - More flexibility
  - More analysis tools (statistics)
- **Plotter Tool**:
  - Reduces the time required to load data files into Excel
  - Able to plot large amounts of data
  - *Problems*: If the data file did not write perfectly, it will not load (for example, stray characters)
  - Downloadable for free from wiki site at: **Citizenscienceairqualitymonitoring.pbworks.com**

The Sensors

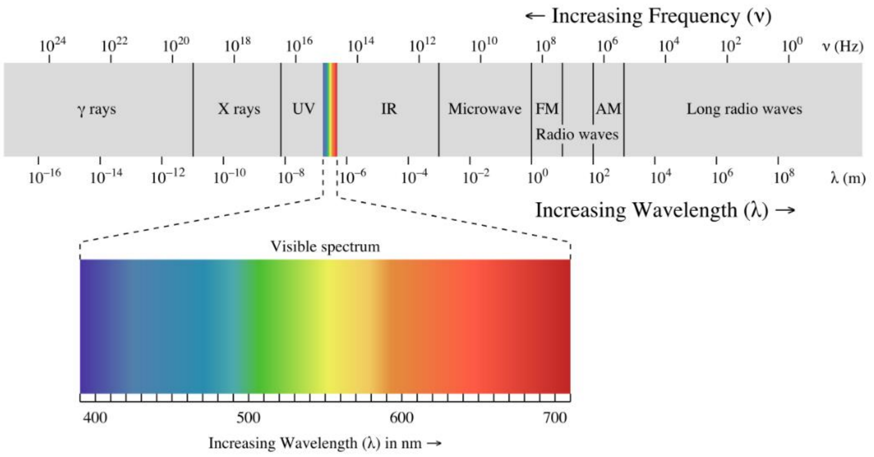
Metal Oxide Semi-Conductor

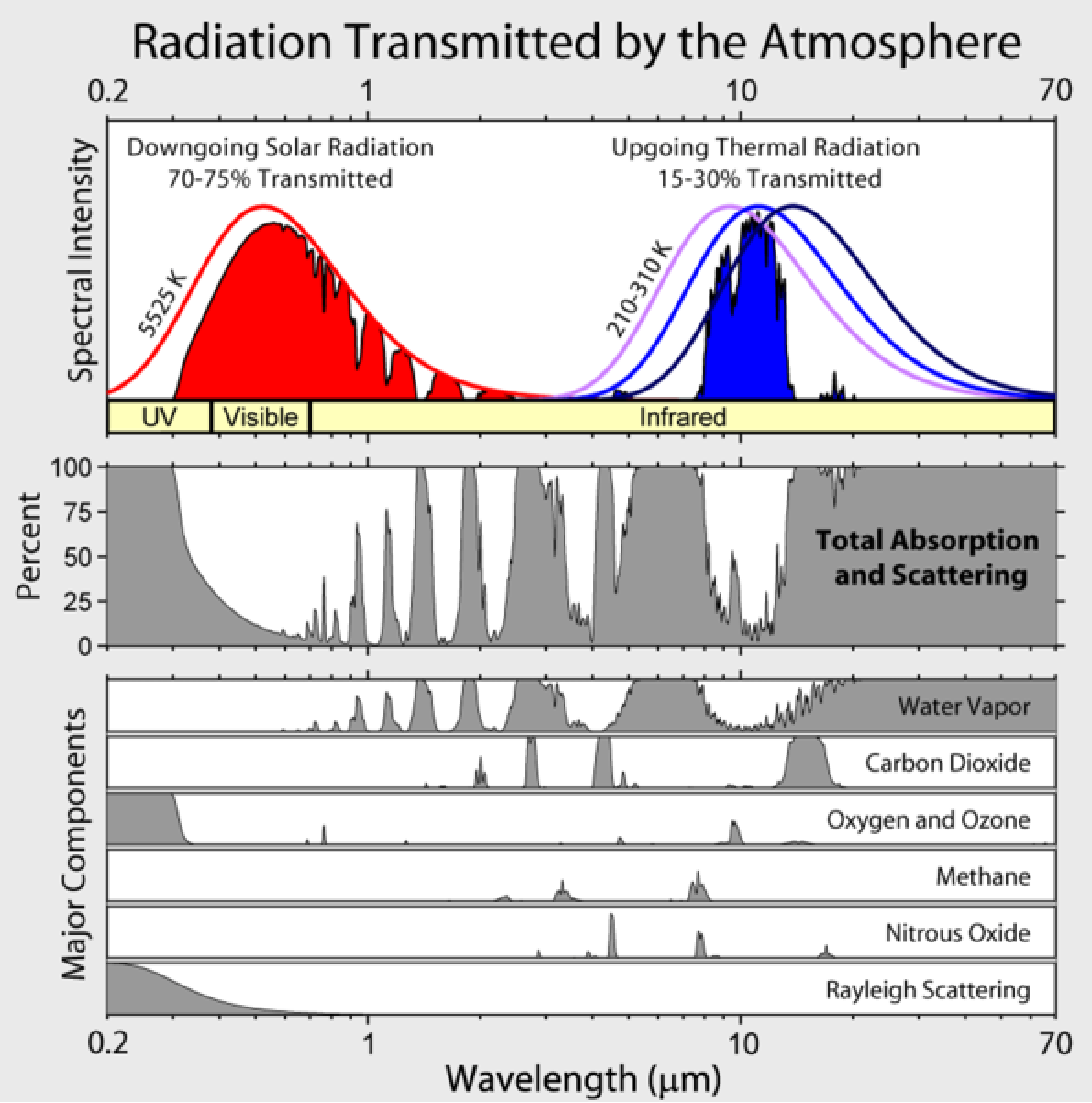
- *Pros*: affordable (≈$5-10), easy to implement, easy to use, available for a variety of pollutants
- *Cons*: temperature and humidity effects, cross-sensitivities, requires intensive sensor characterization and data processing

The Sensors

Non-Dispersive Infrared

- Slightly more expensive ($40)
- Less subject to temperature and humidity effects
- Utilizes *optical properties* to measure
  gas concentration (light absorbance by a gas, at specific wavelengths)





An Important Note about Data Analysis and Calibration

- **Raw sensor data directly from the Pod is in the form of voltages**
- **Calibration enables us to convert the voltages to concentration values**
- **Analyzing raw signal is possible and useful, especially for:**
  - **short-term class activities/demos (it is immediately available)**
  - **indoor data**
  - **or when you are seeing substantial amounts of pollutants**

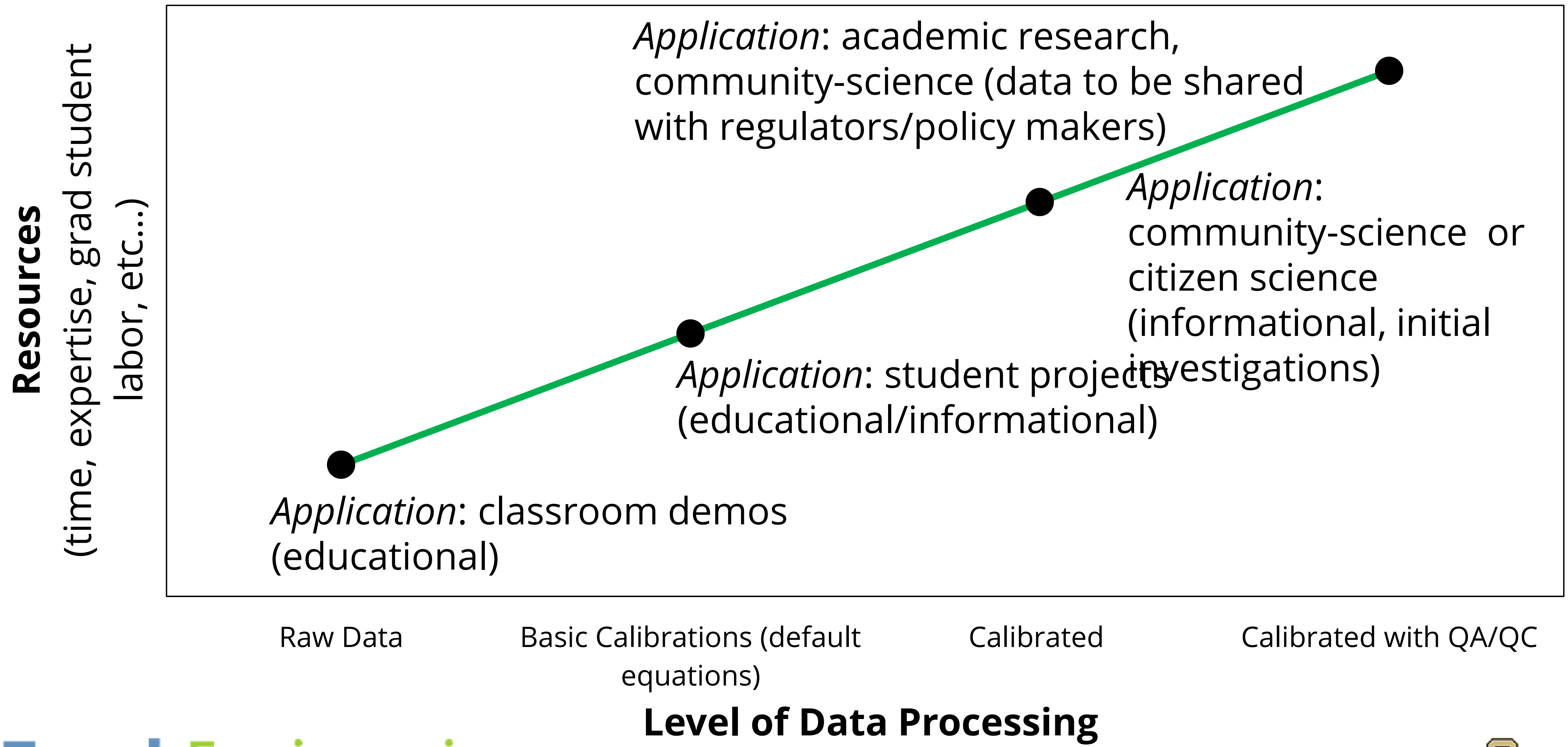
Why is this? The change in pollutant is likely going to be more significant than the change in temperature or humidity, which means the data trends will be driven by pollutants and *qualitative* analysis is possible (or examining relative changes rather than numerical concentrations)

An Important Note about Data Analysis and Calibration

- Calibrated data is in the form of concentration (such as ppm or ppb)
- Analyzing calibrated data is necessary, especially:
  - If you are trying to *quantitative* analysis
  - If you are collecting data in an environment with large changes in temperature or humidity
  - If you wish to share your data beyond your project

Also, different levels of calibrated data exist; see the next slide →

Different Levels of Data Quality



Appendix 2: Data Examples

- **Calibration example**
- **Carbon dioxide data example**
- **Ozone data example**

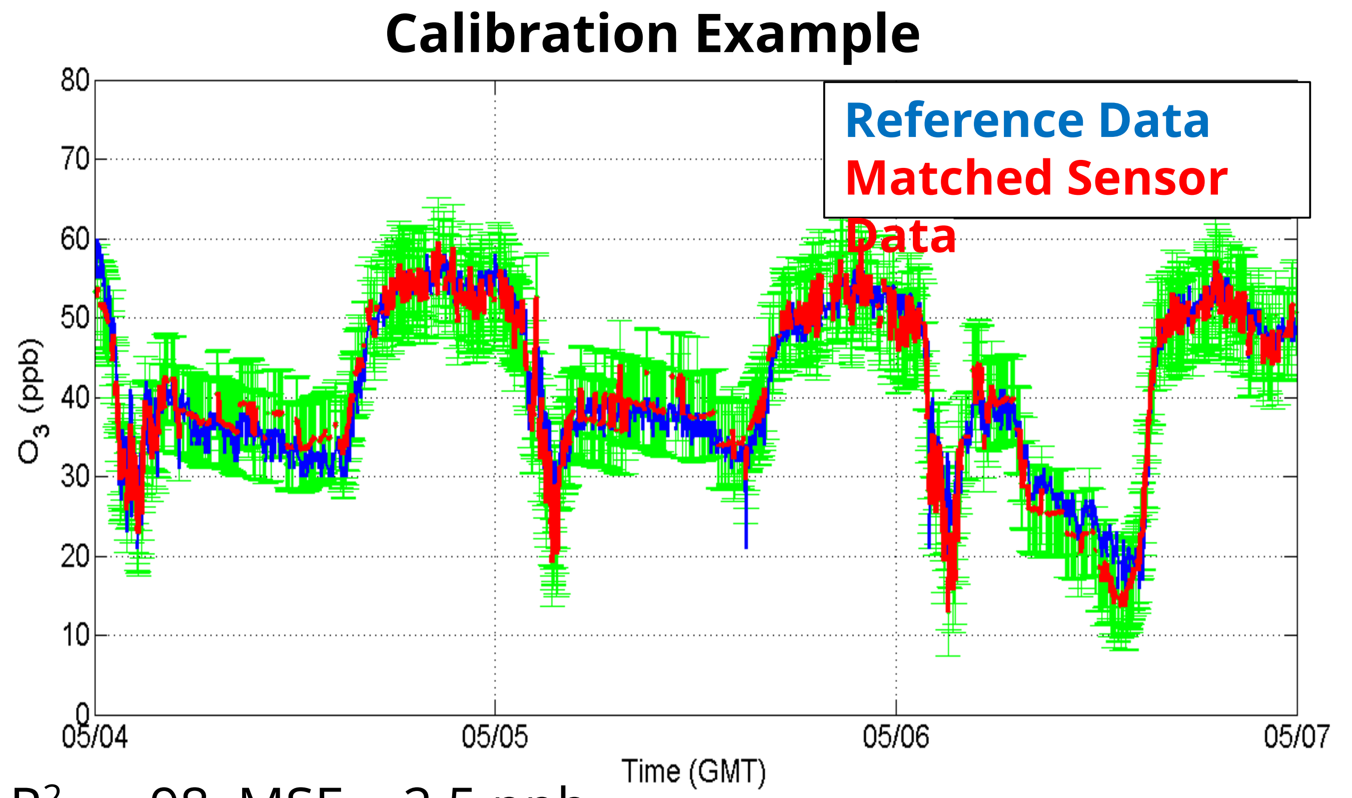
Data Examples

What a calibration looks like…

Similar to *y* = *mx +*b***

We use linear equations or models to convert our data

y (concentration)* = m_1*voltage + m_2*temperature + m_3*humidity + *b



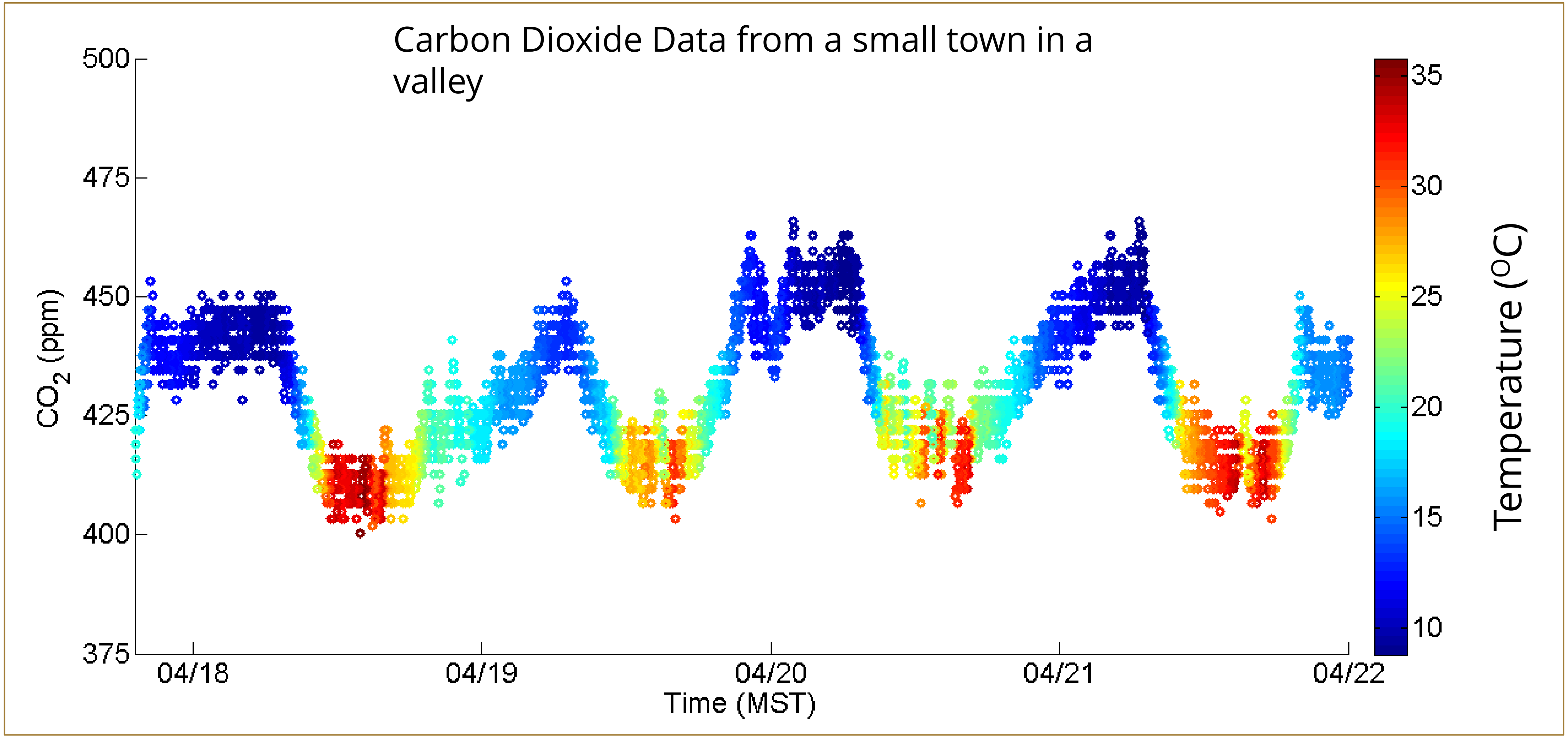
R^2 = .98, MSE = 2.5 ppb

- To calibrate our sensors we need both an *independent* variable and *dependent* variable
- We get the *dependent* variable from a higher quality monitor that we want our data to match
- Then we can solve for our *coefficients* (slopes and y-intercept)
- Then we can use this model to predict the concentration or dependent variable for new data collected in the field

Data Examples

What can we learn from this data?

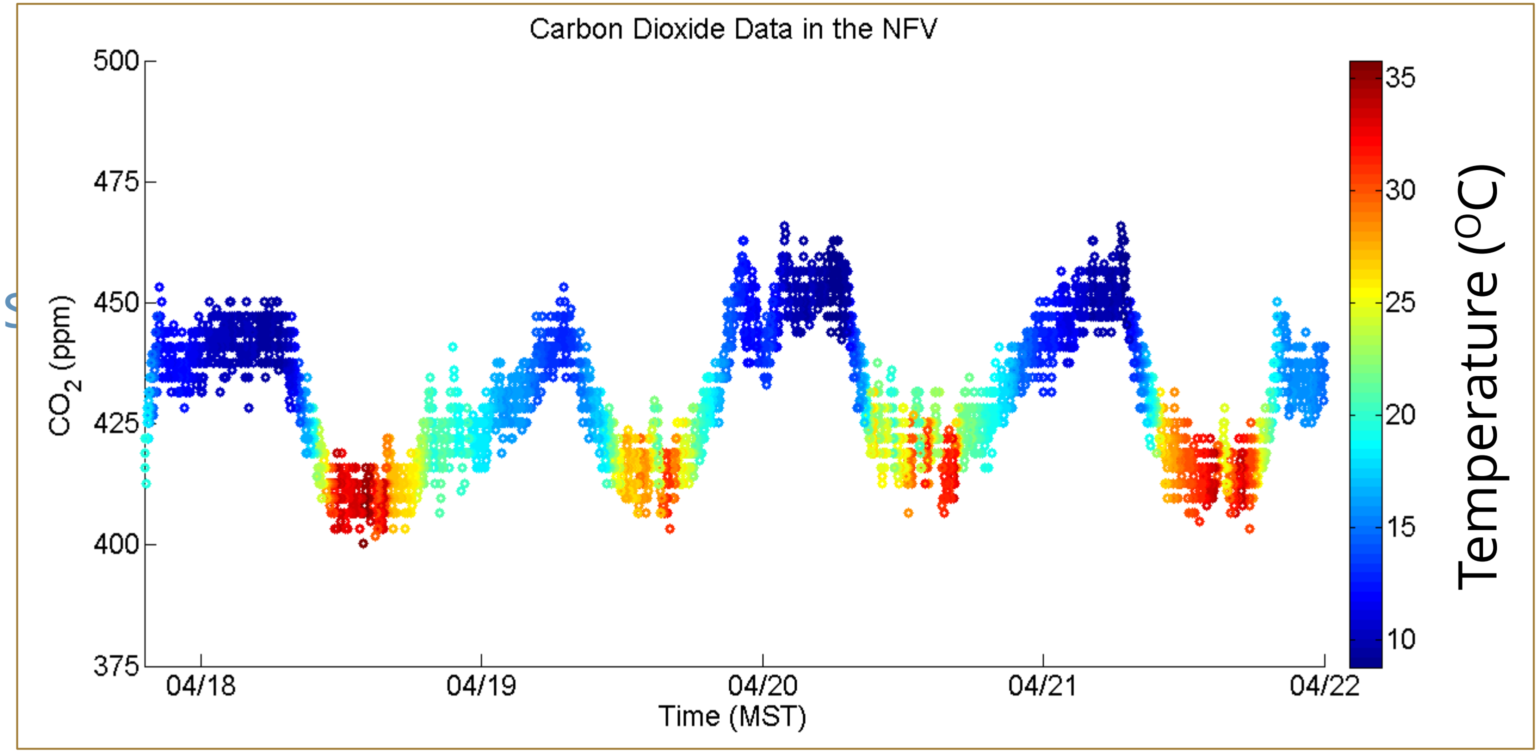
- **Do you see a daily pattern?**
- **How does the pattern relate to temperature?**



Data Examples

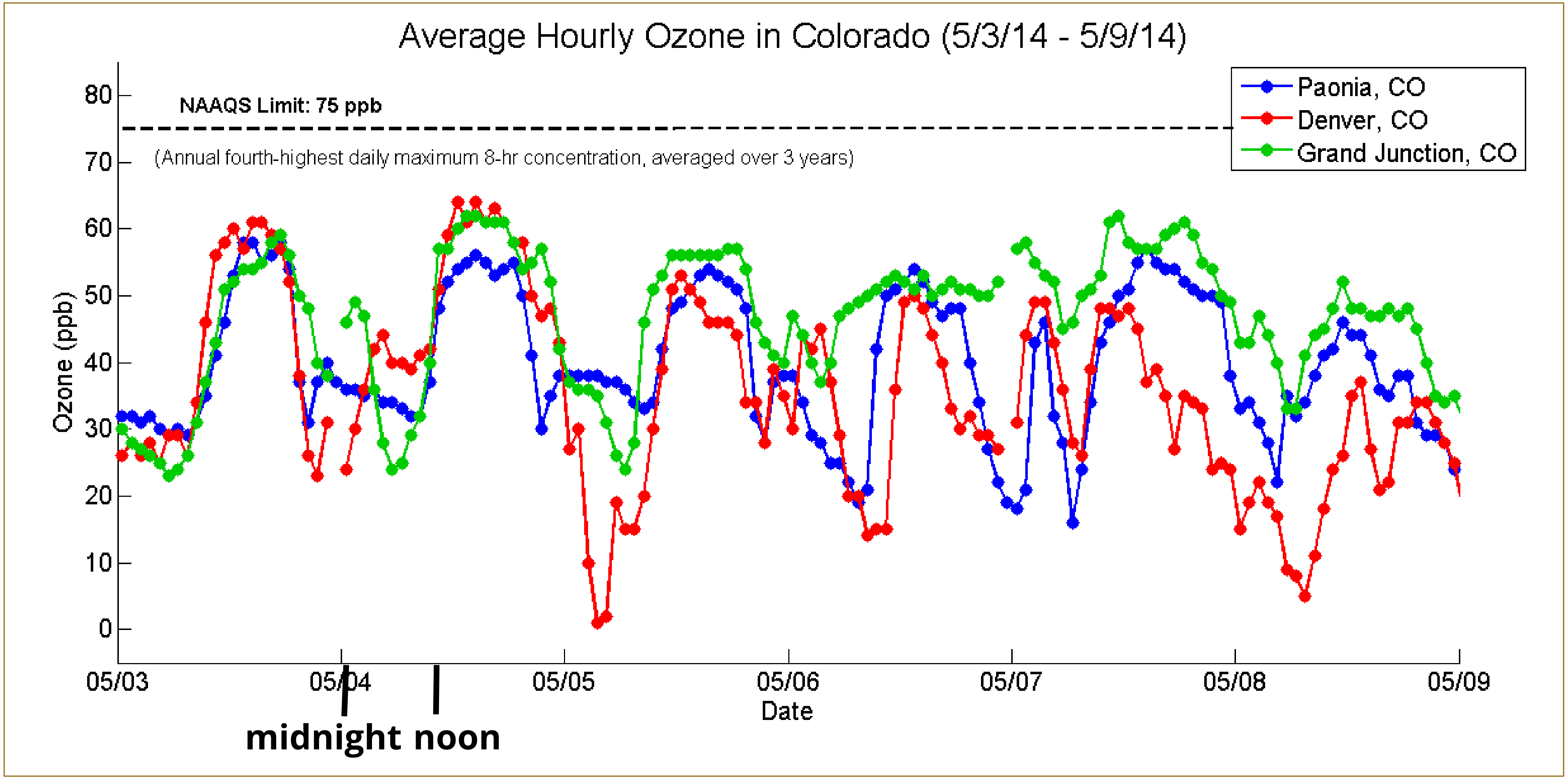
- **Observations**
  - CO2 is highest when temperature is at its lowest
  - CO2 peaks at night
  - Following the warmest day, there is the lowest night time CO2

- **Possible Explanations**
  - Boundary layer
  - Temperature inversions
  - Emissions from home heating



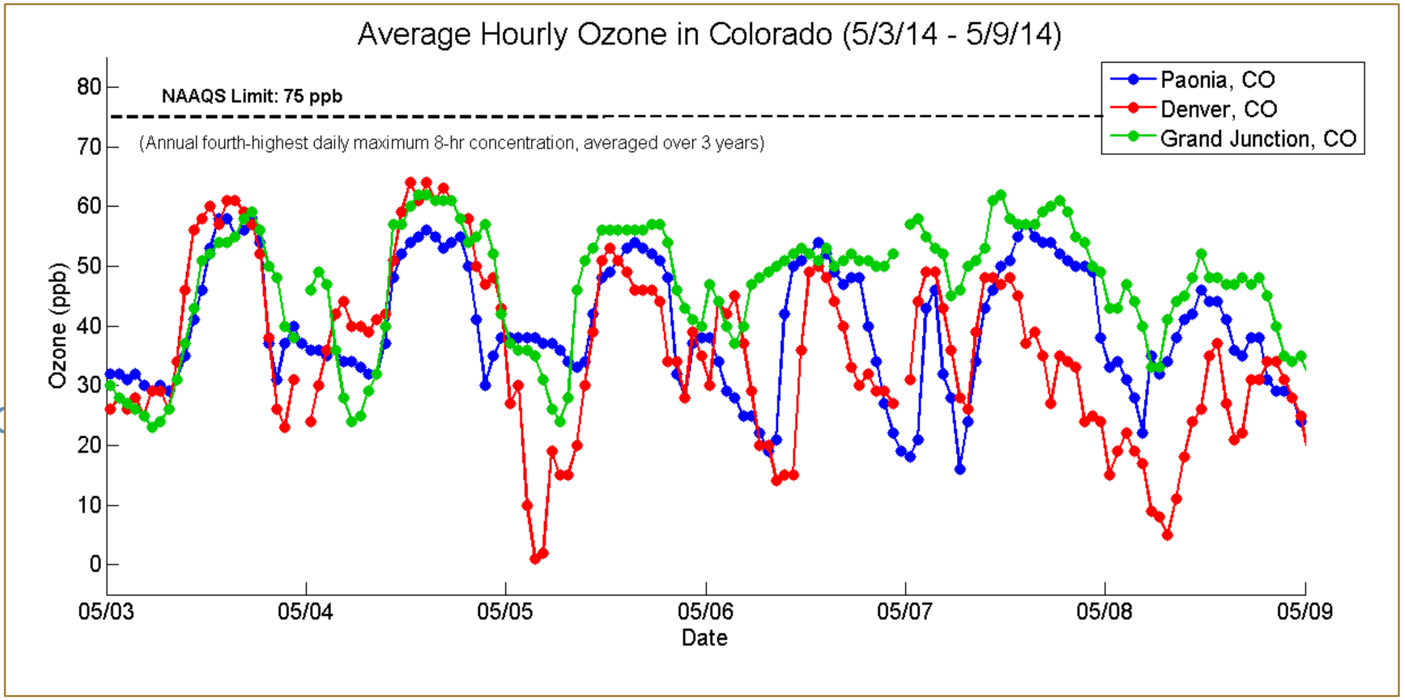
Data Examples

How can you explain the diurnal trend in the beginning of this data set? Any interesting observations?



Data Examples

- **Diurnal Trend**
  - The chemistry of ozone formation requires **sunlight**
  - Ozone is continually being formed and broken down
    - **Sunlight** – formation is favored
    - **No sunlight** – destruction is favored
  - Destruction of ozone requires NOx; if not enough NOx, ozone can "hang around"



- **Observations**
  - Little variance between three locations
  - Ozone typically peaks in urban areas in the summer (thus, lack of sunlight might be limiting production in Denver)
  - Background ozone = 30-40 ppb, in uninhabited areas (naturally occurring VOCs can assist in its production)
  - Ozone is more of a regional issue than a local one because it takes more time to form and decay