Project GO3

Global Ozone Project Curriculum

Lesson 1:
Air Pollution Basics

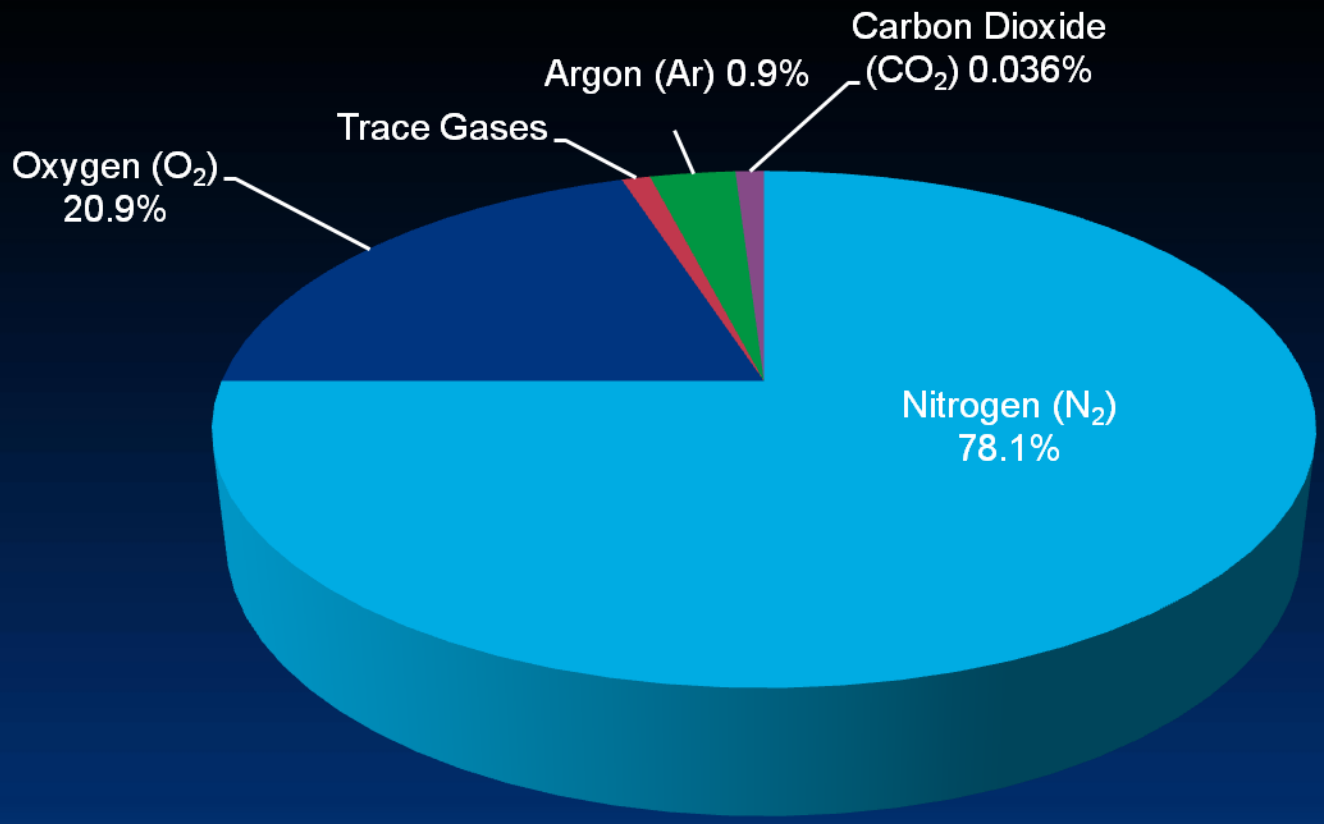
Rev 13
Jessa Ellenburg and John Birks

Learning Objectives

At the end of this lesson students will be able to:

- Explain the role of the *Clean Air Act* and name the *6 major air pollutants* regulated in the US.
- Define the terms *primary* and *secondary pollutants*.
- Identify that there are both *Natural and Anthropogenic sources* of air pollutants and name examples of each.

What is Air Composed of?



Composition of Air

What is Air Pollution?

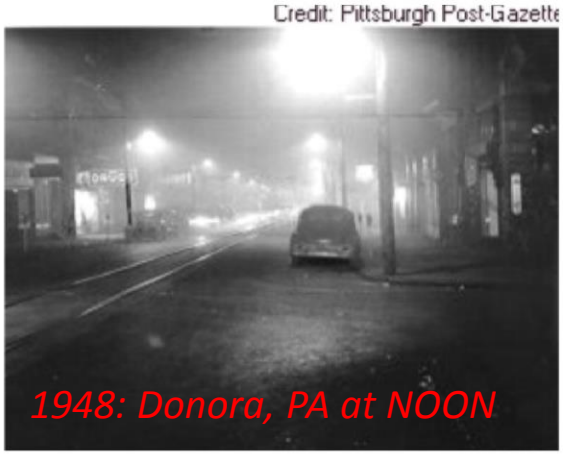
Air Pollutant: Any substance emitted to or produced in the atmosphere as a result of human activity in sufficient quantity to cause harm to plants, animals or materials.

Harm can be direct: human health effects, reduced crop yields, damage to rubber products such as tires, erosion of marble sculpture, etc.

Or indirect: e.g., climate change

Air Pollution + Stagnant Weather Can Spell Disaster

1948 in Donora, PA



An air pollution episode killed 20 people, and half the town's 14,000 residents became ill due to emissions from industrial facilities and stagnant weather conditions.

Air Pollution + Stagnant Weather Can Spell Disaster

1952 in London, England

Nelson's Column in the 1958 smog

Nelson's Column today

An air pollution episode killed between 4,000 and 12,000 people. 100,000 residents became ill due to emissions from industrial facilities and coal burning during stagnant weather conditions.

Clean Air Act

- After the deadly US air pollution event of 1948, it was clear that air quality needed to be regulated to ensure that such severe pollution events didn't happen again.
- The US passed the first Clean Air Act in 1963.
- The Clean Air Act of 1970 gave the US Environmental Protection Agency (EPA) the authority to regulate air pollution and identified *six Criteria Pollutants* to monitor.

Clean Air Act

Six Criteria Air Pollutants to monitor:

- **Ozone (O_3)**
- **Nitrogen Dioxide (NO_2)**
- **Carbon Monoxide (CO)**
- **Particulate Matter ($PM_{2.5}$ and PM_{10})**
- **Lead (Pb)**
- **Sulfur Dioxide (SO_2)**

Examples of Sources for the *Six Criteria Pollutants*

O_3 – Ozone

Ozone: Formed by the interaction of sunlight with other other pollutants: NO, CO, and Volatile Organic Compounds (VOCs)

NO_2 – Nitrogen Dioxide

Car exhaust and Electricity Generation produce NO during combustion, which gets converted into NO_2 in the atmosphere

CO – Carbon Monoxide

All combustion processes such as car exhaust and Electricity Generation

O_3, NO_2, and CO will be discussed further in Lesson 2

Examples of Sources for the *Six Criteria Pollutants*

4

$PM_{2.5,10}$ – Particulate Matter

Car Exhaust, Electricity Generation, Fires, and Road dust

5

Pb – Lead

Iron smelters and other industrial processes.

Before it was banned, leaded gasoline was a major contributor to lead in the atmosphere.

6

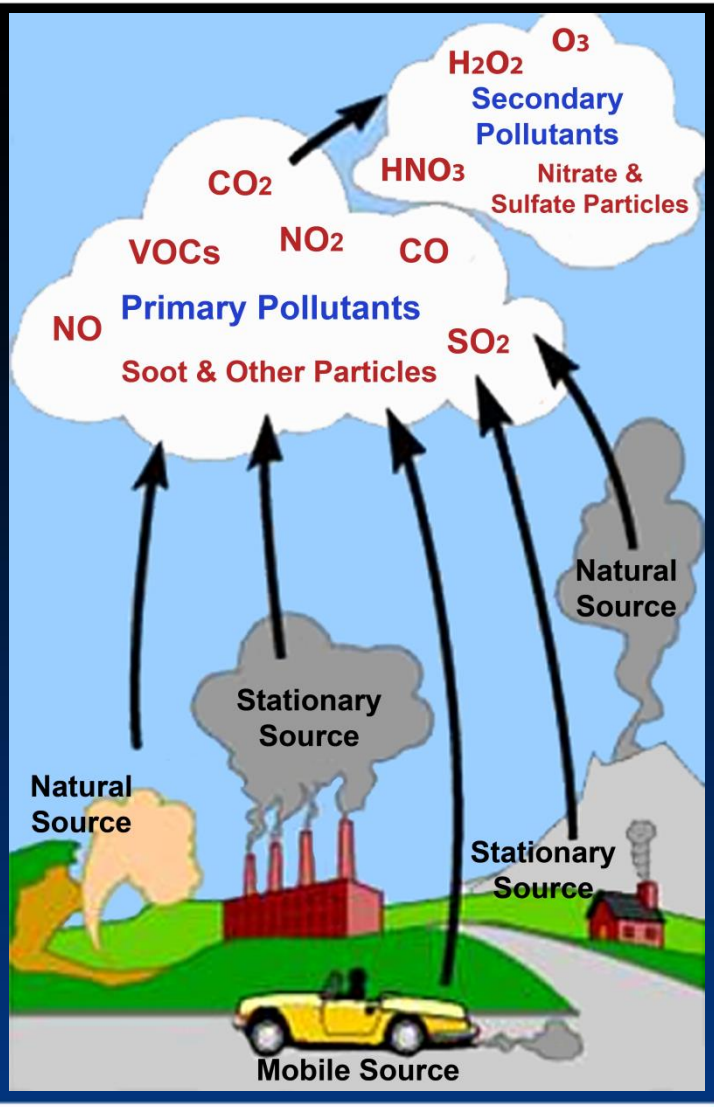
SO_2 – Sulfur Dioxide

Electricity Generation from burning of coal.

O_3, NO_2, and CO will be discussed further in Lesson 2

Primary and Secondary Pollutants

- **Primary Pollutants** are emitted directly from various sources and cause harm in their emitted state.
  - Examples of **Primary Pollutants:** NO, SO_2, CO, CO_2
- **Secondary Pollutants** result from chemical transformations in the atmosphere.
  - Examples of **Secondary Pollutants:** O_3, H_2O_2, HNO_3, H_2SO_4, Nitrate and Sulfate Particles



Natural and Anthropogenic Sources

There can be two sources of these compounds in the air:

Natural

Certain atmospheric gases are created by natural sources like trees, swamps, and oceans.

Anthropogenic

These gases are formed from human activity like cars and power plants.

Examples of Natural Sources

Termites

Believe it or not, termites' digestive systems emit a significant amount of Methane

Lightning

Lightning creates Nitrogen Oxides (NO_x)

Trees

Trees emit Volatile Organic Compounds (VOCs)

Examples of Anthropogenic Sources

Separated into four Categories:

Point

very concentrated sources of pollution

- Power Plants
- Gas Pipelines

Area

more diffuse sources of pollution

- Cows
- Paints, Architectural Coatings

On-Road

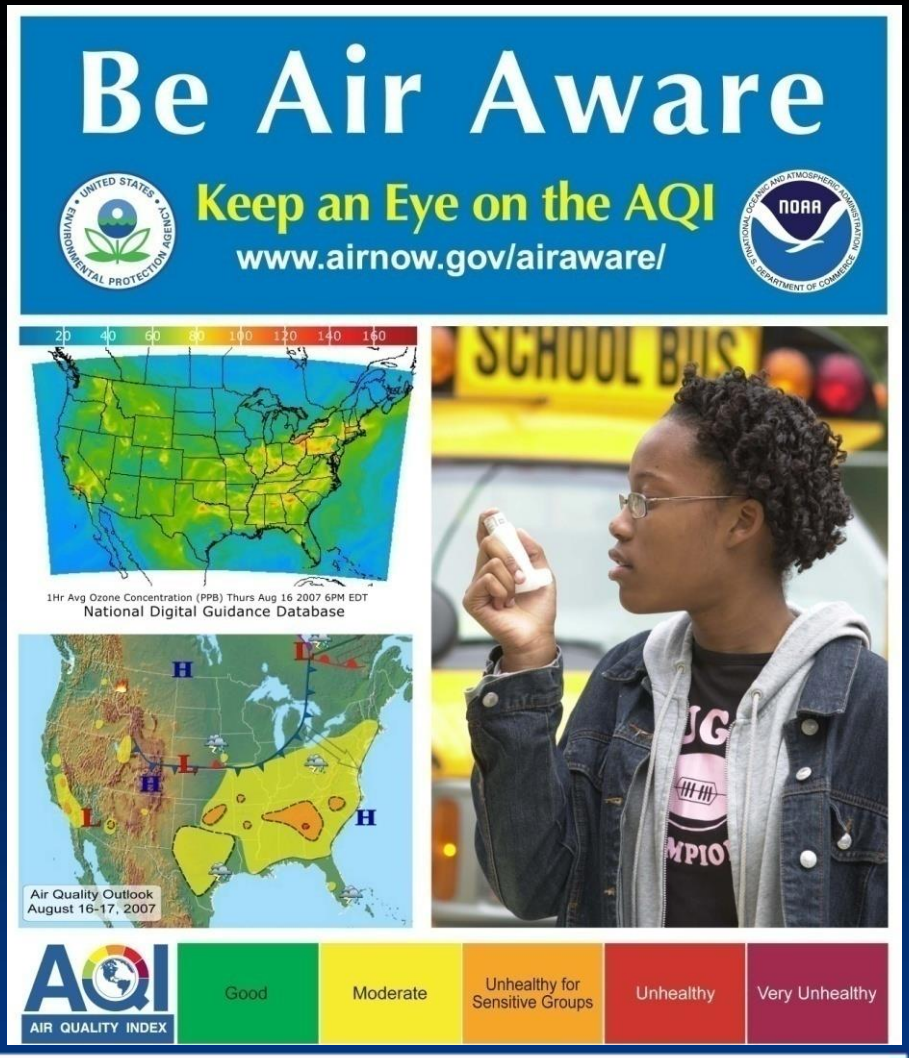
- Cars
- Trucks

Off-Road

- Airplanes
- Construction Equipment
- Lawn Mowers

Air Quality Index

A daily measure of the quality of the air generally published along with weather reports based on the amount of the *six criteria pollutants* in the air.



Air Quality Index

Levels of Health Concern

Numerical Value	Meaning
0-50	**Good** – Air Quality is considered satisfactory, and air pollution poses little or no risk.
51-100	**Moderate** – Air Quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.
101-150	**Unhealthy for Sensitive Groups** – Members of sensitive groups may experience health effects. The general public is not likely to be affected.
151 – 200	**Unhealthy** – Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.
201- 300	**Very Unhealthy** – Health alert: everyone may experience more serious health effects.
> 300	**Hazardous** – Health warnings of emergency conditions. The entire population is more likely to be affected.

A daily measure of the quality of the air generally published along with weather reports based on the amount of the *six criteria pollutants* in the air.

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Global Ozone Project Curriculum

Lesson 2: Ozone Formation in the Troposphere

Rev 13

Learning Objectives

At the end of this lesson students will be able to:

- Identify the difference between ozone in the *stratosphere* and the *troposphere*.
- List the ingredients that result in formation of ground level ozone.
- Describe the role sunlight plays in the formation of ground level ozone.

Our Atmosphere

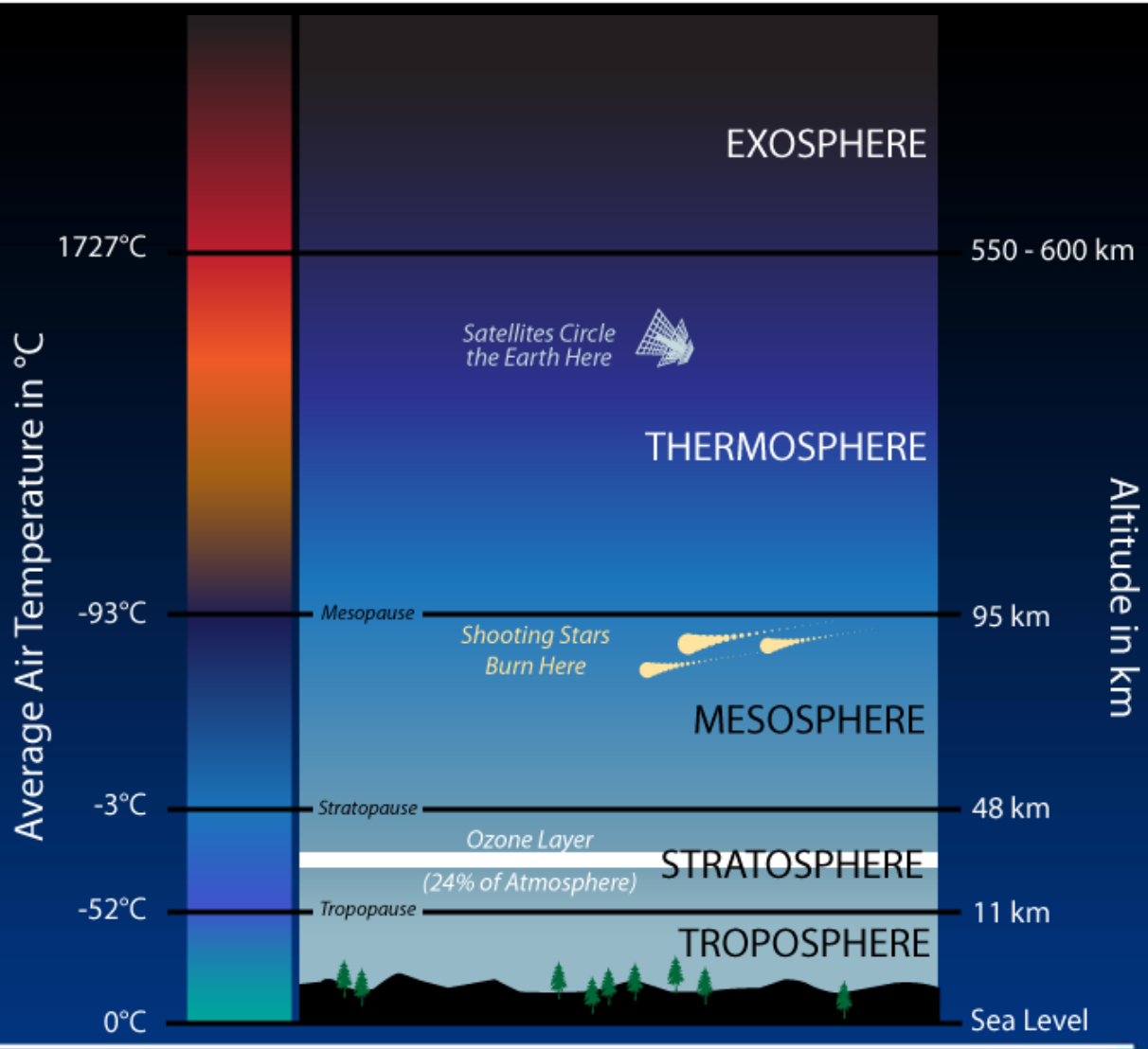
Like the Skin of an Apple

As large as it seems when you look up, our atmosphere is actually very thin, analogous to the skin of an apple. This means that pollutants may have a very significant effect on global atmospheric chemistry.

Layers of the Atmosphere

Notice the change in temperature in relation to altitude.

The production of ozone causes the temperature to rise with increasing altitude in the stratosphere.

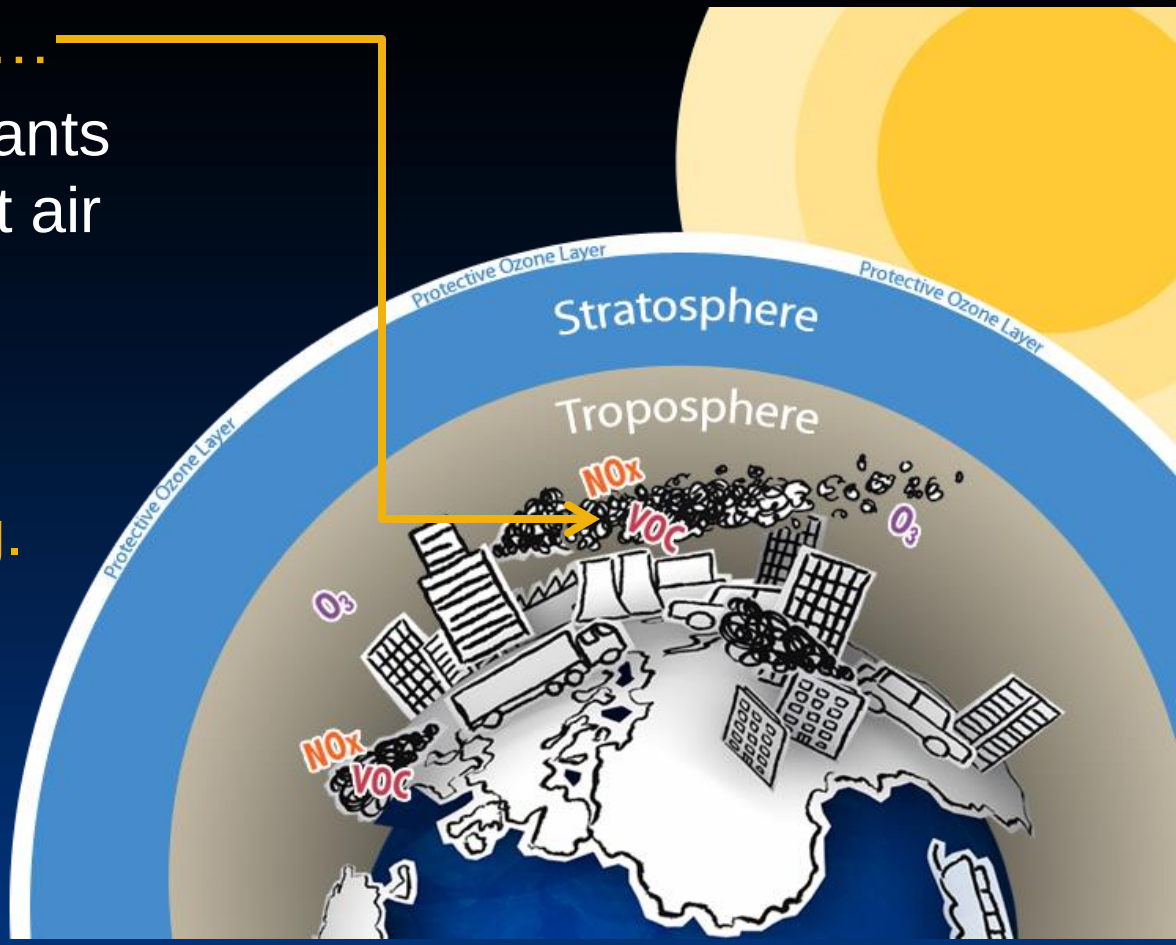


The Difference Between Stratospheric and Tropospheric Ozone

Too much ozone here…

Cars, trucks, power plants and industry all emit air pollution that forms ground-level ozone.

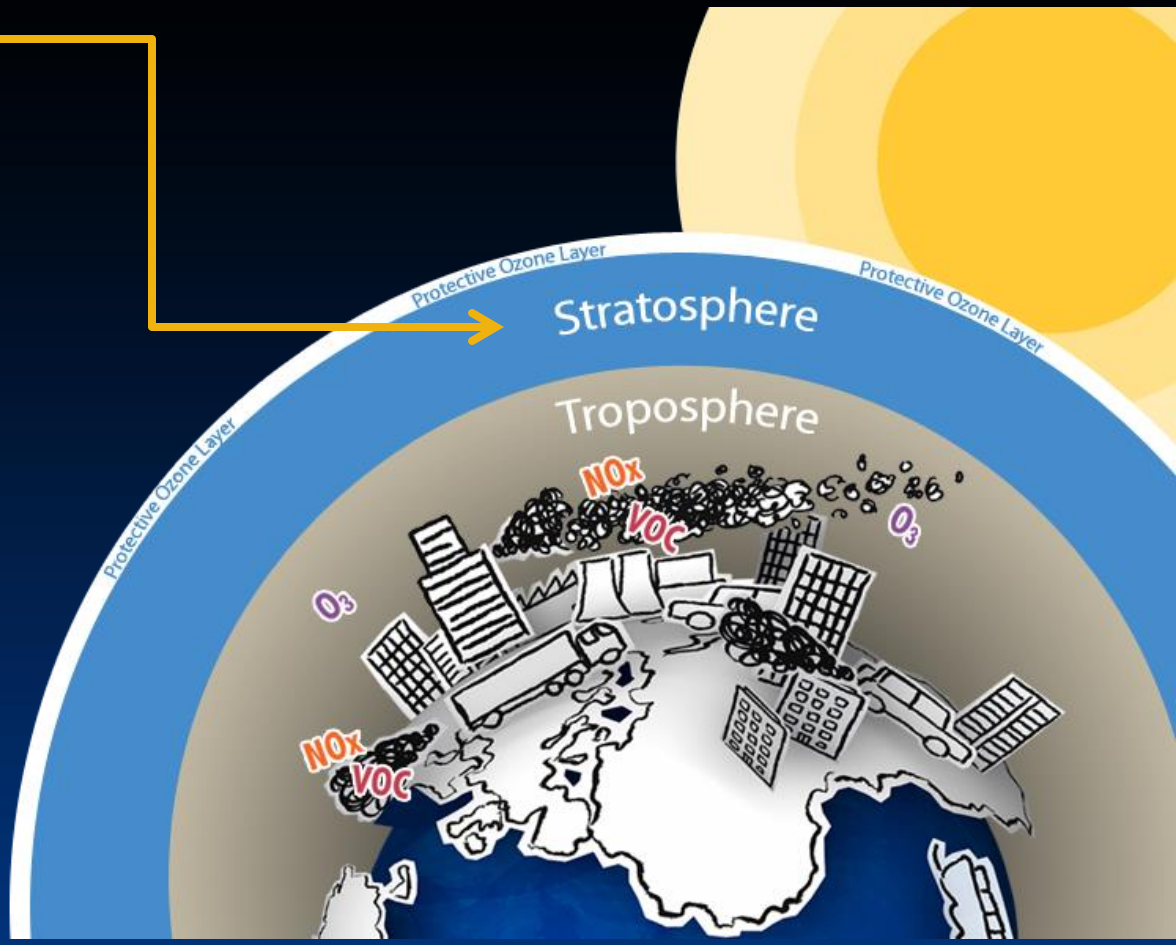
Ozone is a primary component of smog.



The Difference Between Stratospheric and Tropospheric Ozone

Too little there…

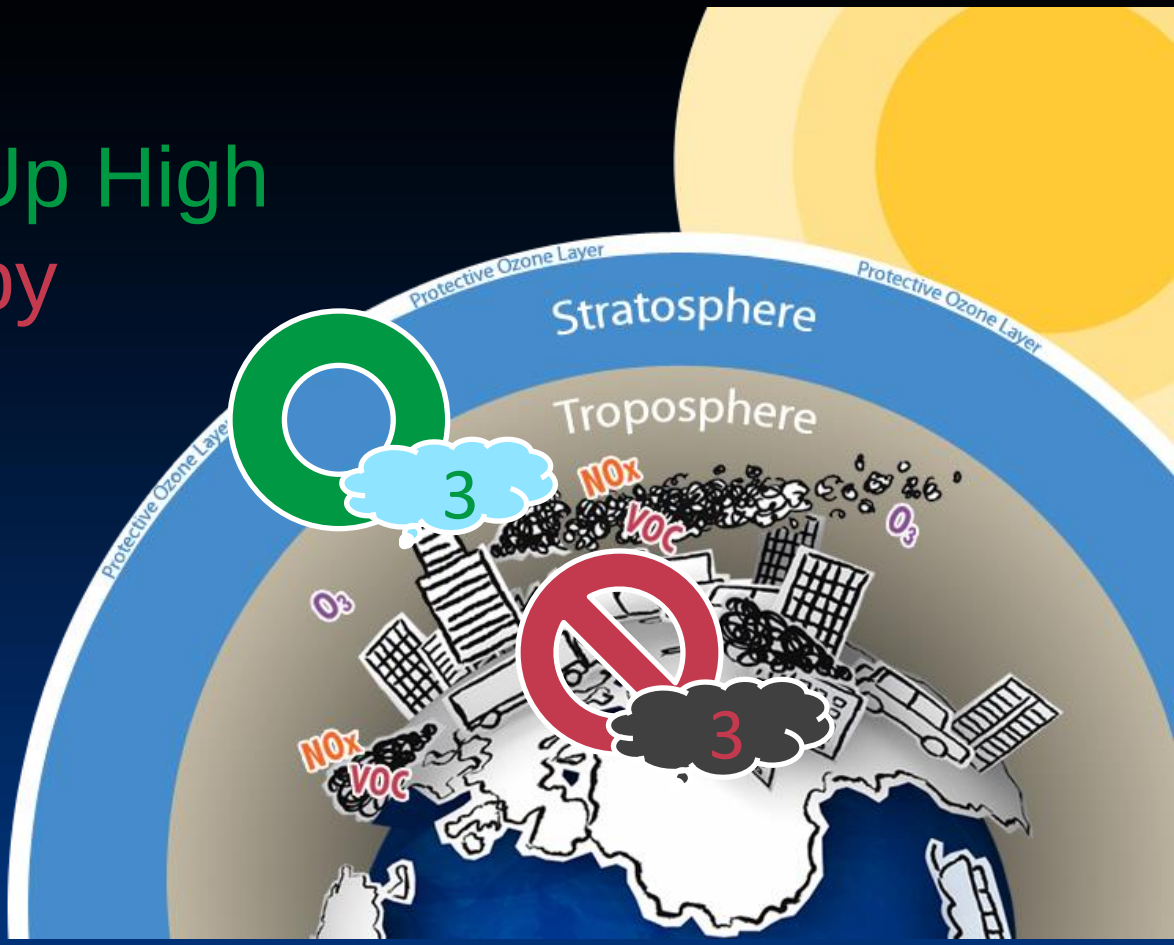
In the past, many popular consumer products like air conditioners, refrigerators and aerosol propellants made use of CFCs. Over time, these chemicals have damaged the Earth's protective ozone layer.



The Difference Between Stratospheric and Tropospheric Ozone

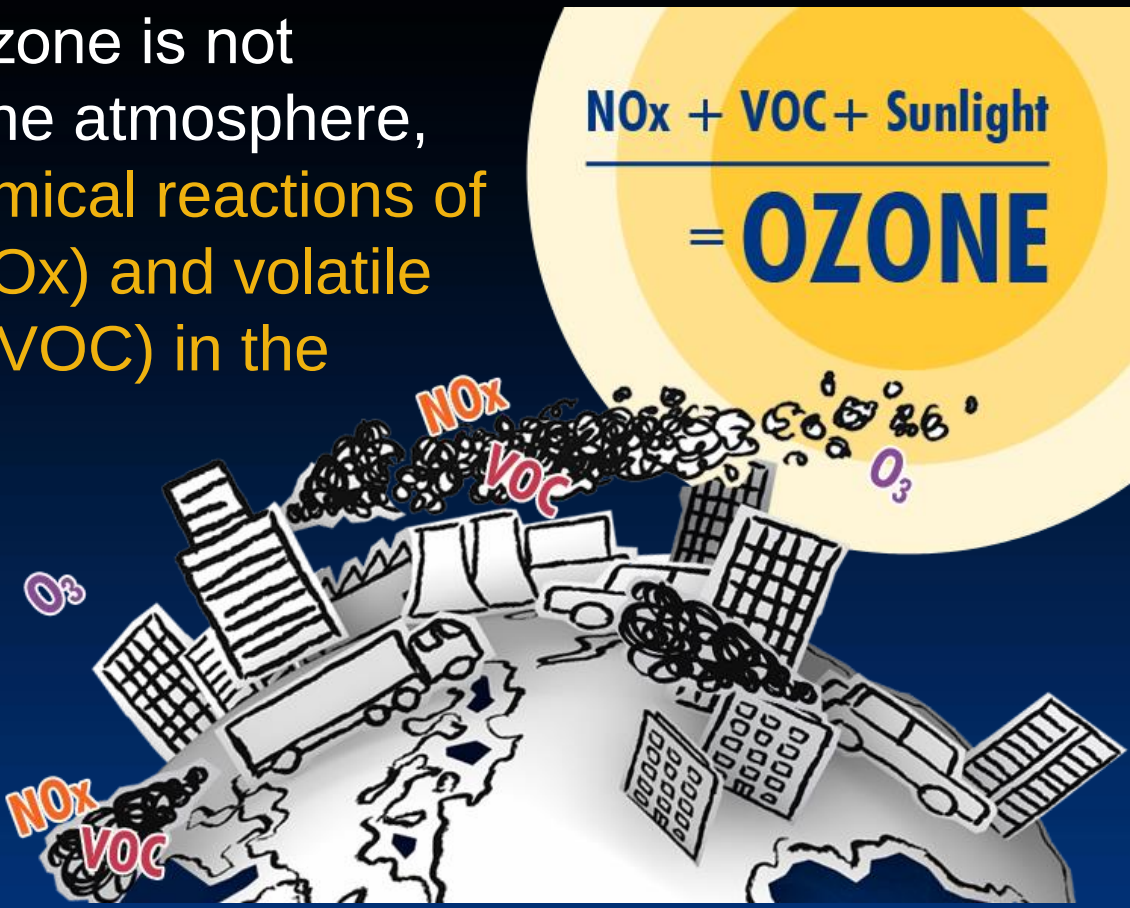
Remember…

Ozone is Good Up High and Bad Nearby

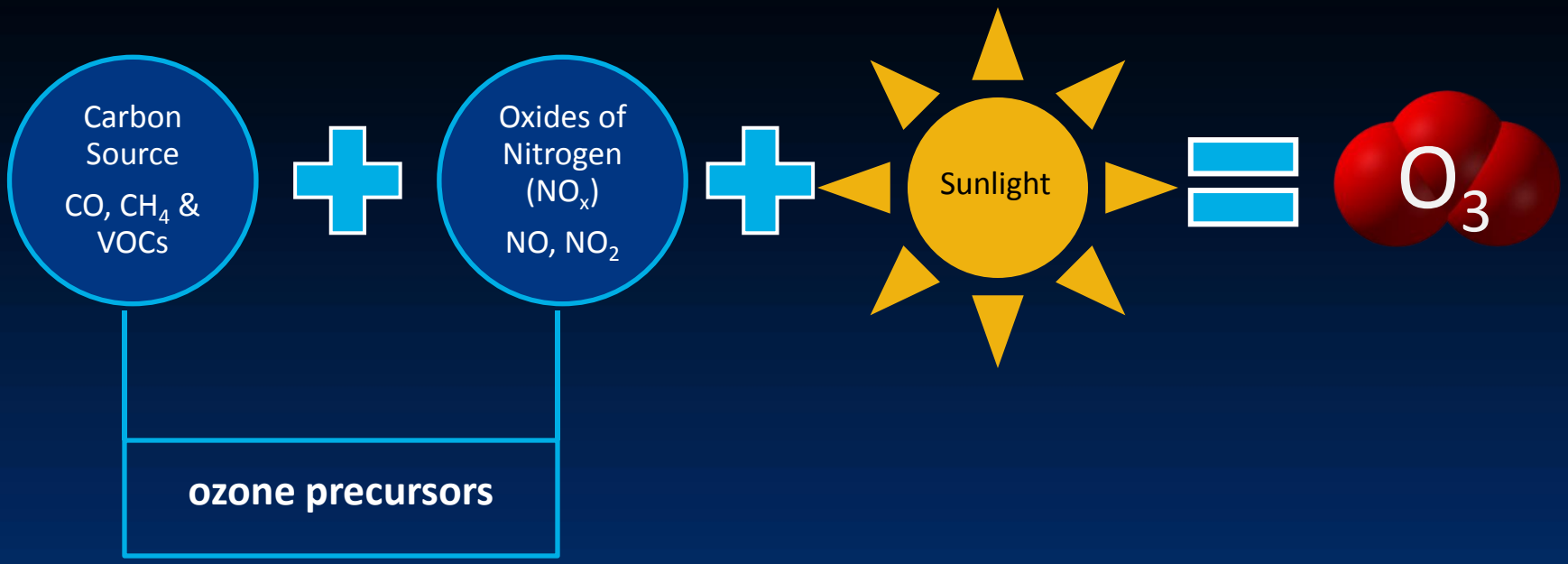


Formation of Ground Level Ozone

Ground level or “bad” ozone is not emitted directly into the atmosphere, but is created by chemical reactions of oxides of nitrogen (NOx) and volatile organic compounds (VOC) in the presence of sunlight.

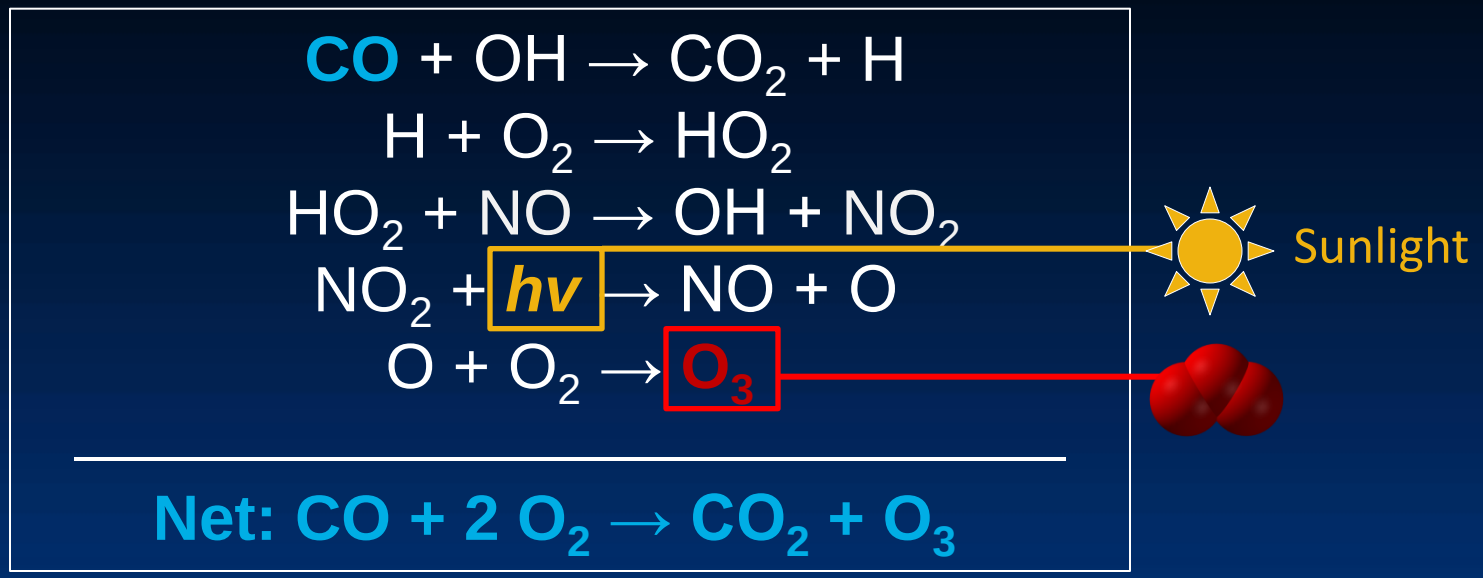


Ground Level Ozone Ingredients



A Closer Look at CO

The series of reactions with CO that leads to the formation of ground level ozone:



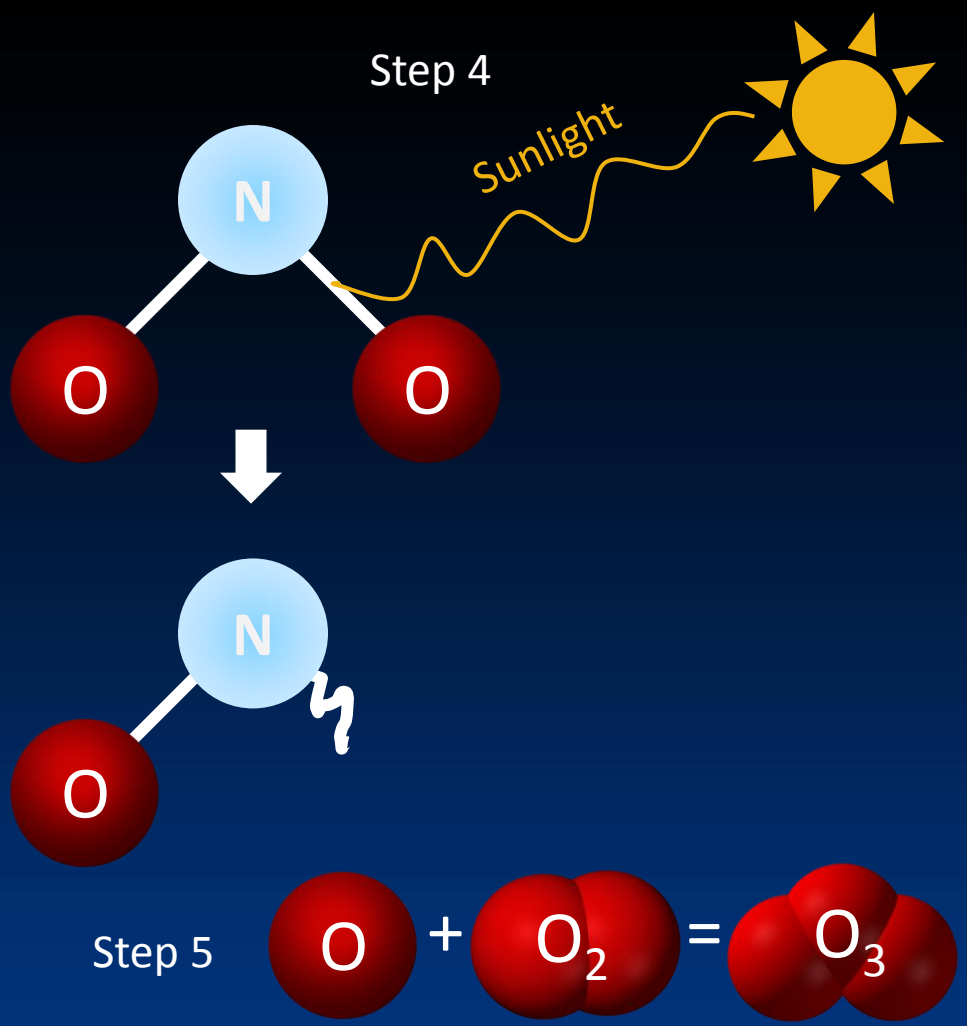
(we will explore this in more depth in later sections)

The Role of Sunlight in the Formation of Ozone

Let's take a closer look at steps 4 and 5 in the equation with CO as the precursor:

1. $CO + OH \rightarrow CO_2 + H$
2. $H + O_2 \rightarrow HO_2$
3. $HO_2 + NO \rightarrow OH + NO_2$
4. **$NO_2 + h\nu \rightarrow NO + O$**
5. **$O + O_2 \rightarrow O_3$**

This is one of the reasons that sunlight is needed to produce ozone. Sunlight also is needed to make the OH radical.



Formation of Ozone (O_3)

The Single Oxygen Atom is Lonely

A single Oxygen atom (O) in the atmosphere will quickly find an O_2 and bind with it to form Ozone (O_3). O_2 is obviously quite abundant in the troposphere, but a single O is extremely rare.

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Lesson 3:
Carbon Sources - Carbon Monoxide

Rev 13

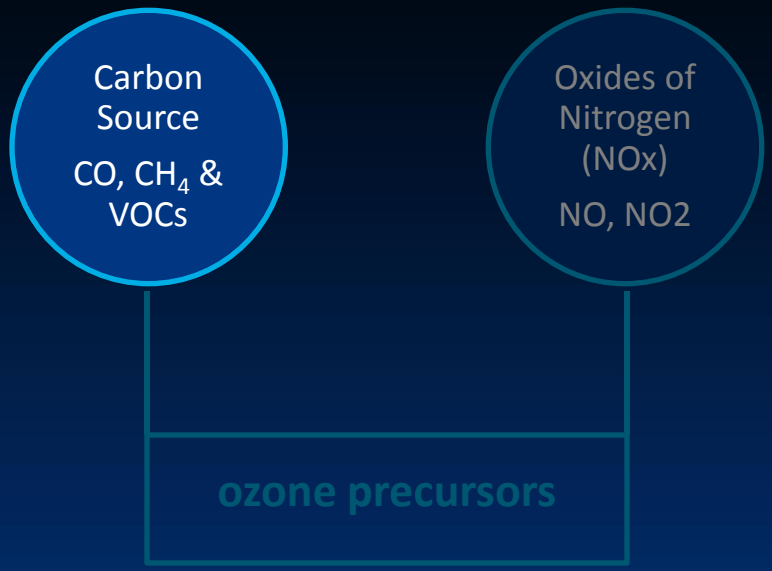
Learning Objectives

At the end of this lesson students will be able to:

- Identify three main examples of carbon sources that lead to the formation of ground level ozone.
- Understand the sources of carbon globally that contribute to the formation of ground level ozone.
- Identify examples of natural and anthropogenic sources of carbon in the atmosphere.

Exploration of Precursors in Depth

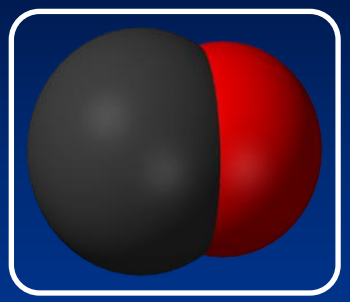
Carbon Sources: CO, CH_4, VOCs



- Examples of carbon sources
- Breakdown of anthropogenic sources (cars, power plants, etc.)
- Breakdown of natural sources (swamps, trees, etc.)

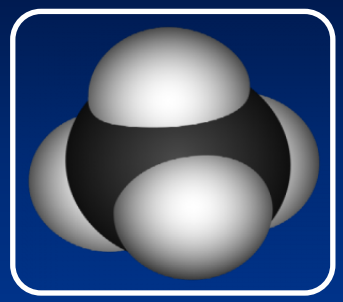
Examples of Carbon Sources

Ozone needs carbon sources in order to form. Here are some examples of those sources



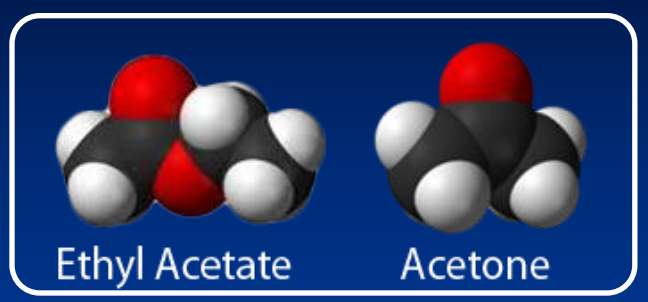
CO

(Carbon Monoxide)



CH_4

(Methane)



VOCs

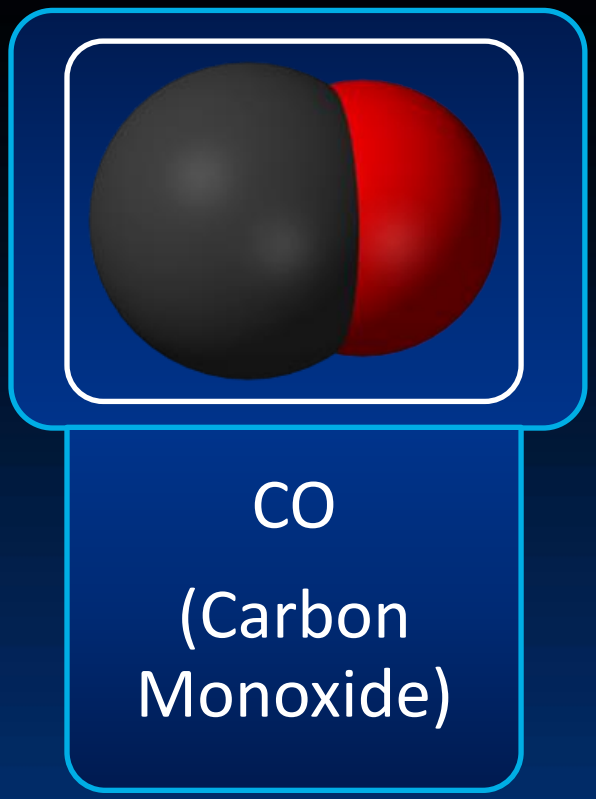
(Volatile Organic Compounds)

Do you notice what all the molecules have in common?

Carbon Monoxide (CO)

Lesson 3 : Carbon Sources - Carbon Monoxide

A Closer Look at a Carbon Source – CO (Carbon Monoxide)



We will look at:

- CO's role in ozone formation
- Global anthropogenic and natural sources of CO
- A breakdown of anthropogenic sources of CO, globally and in the USA
- Other interesting information about CO

A Closer Look at CO

The series of reactions with CO that lead to the formation of ground level ozone

$$CO + OH \rightarrow CO_2 + H$$
$$H + O_2 \rightarrow HO_2$$
$$HO_2 + NO \rightarrow OH + NO_2$$
$$NO_2 + h\nu \rightarrow NO + O$$
$$O + O_2 \rightarrow O_3$$

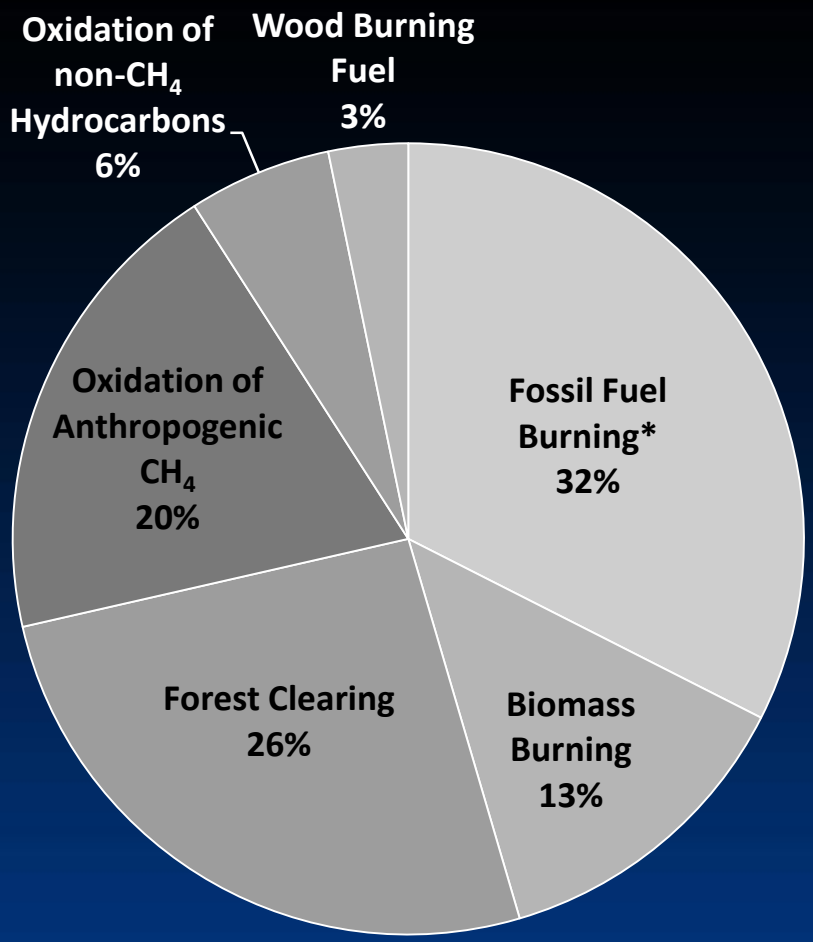
$$\text{Net: } CO + 2\,O_2 \rightarrow CO_2 + O_3$$

(we will explore this in more depth in later sections)

Global Anthropogenic Sources of CO

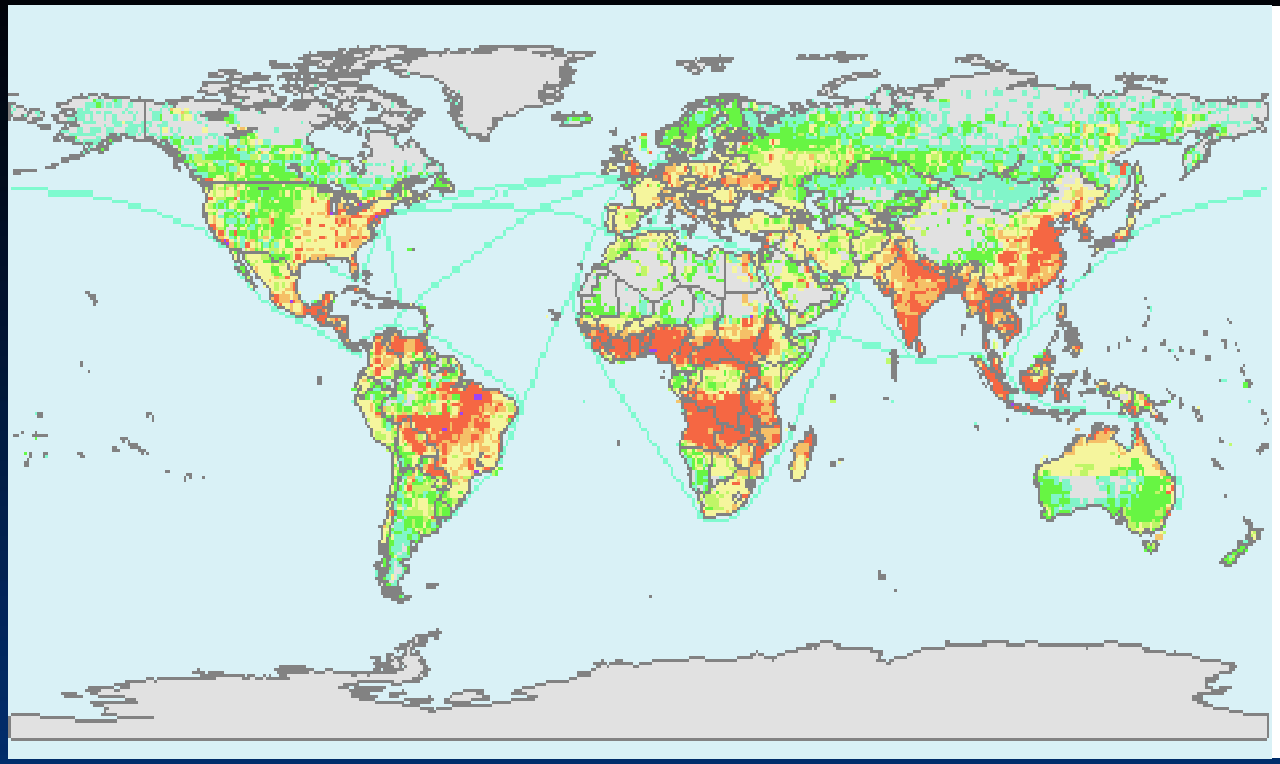
Lesson 3 : Carbon Sources - Carbon Monoxide

Breakdown of Global Anthropogenic Sources of CO



*Includes automobile emissions

Global Anthropogenic CO Emissions Density



Legend

CO Total 2000

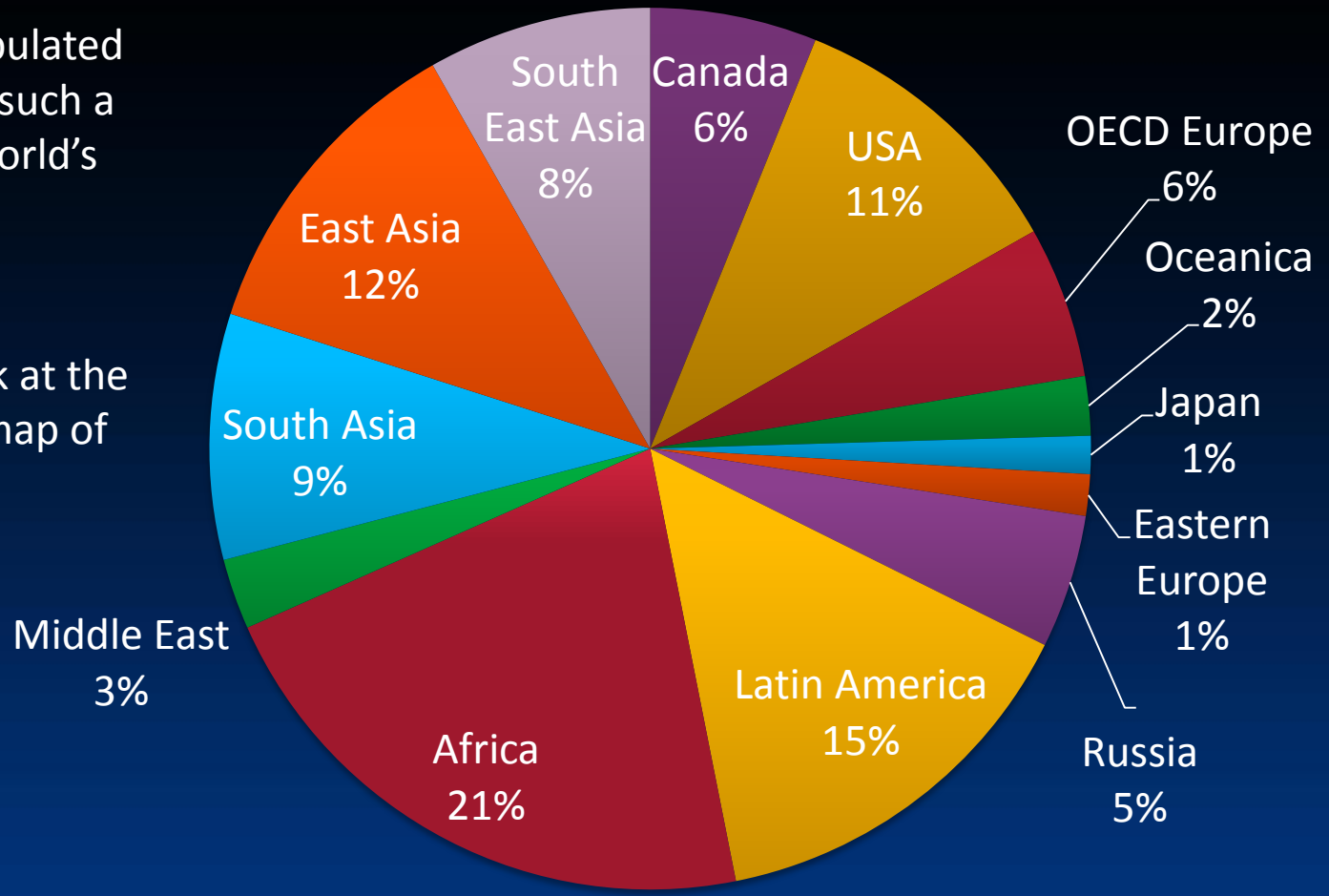
- 0 – 2 Gg CO per cell
- 2 – 10
- 10 – 20
- 20 – 100
- 100 – 200
- 200 – 1000
- 1000 – 10,000 Gg CO per cell

Units = Gigagrams of Carbon
(1 Gigagram = 10^9 grams = 1,000,000,000 grams)

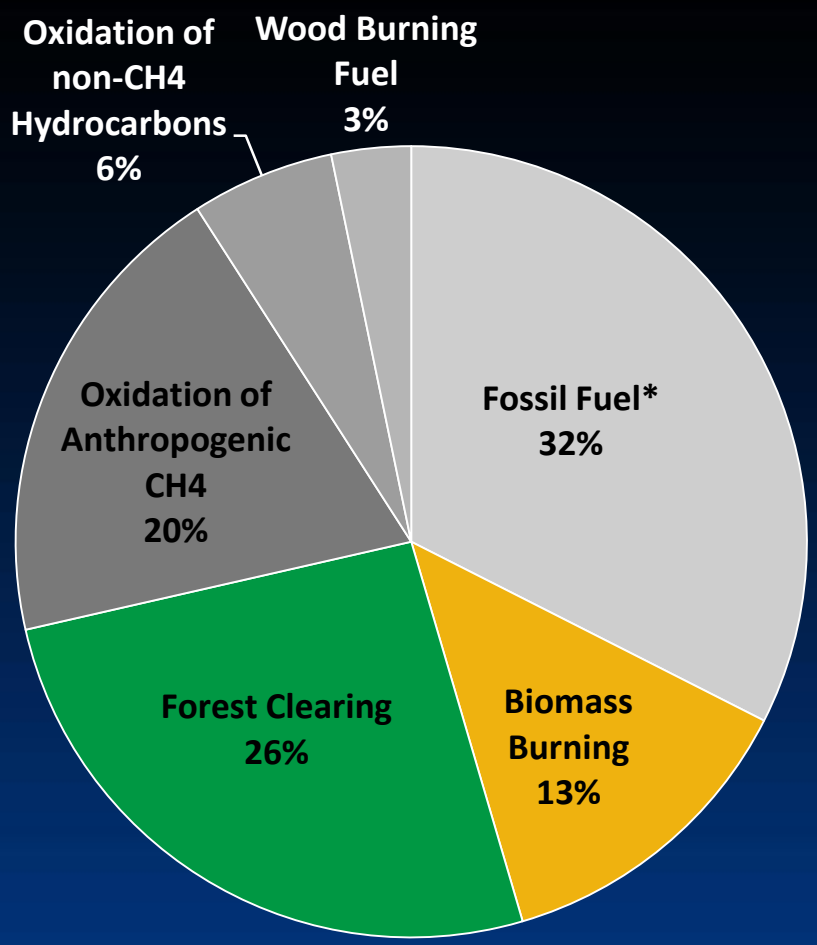
Regional Breakdown of Total Global Anthropogenic CO Emissions

Why would Africa, a relatively sparsely populated continent, contribute such a large portion of the world's anthropogenic CO emissions?

Also take another look at the slide showing global map of CO emissions density.



Let's Take a Closer Look at Forest Clearing and Biomass Burning



*Includes automobile emissions

Biomass Burning: Every year farmers across the globe burn their crops at the end of the season to clear dead vegetation and kill pests.

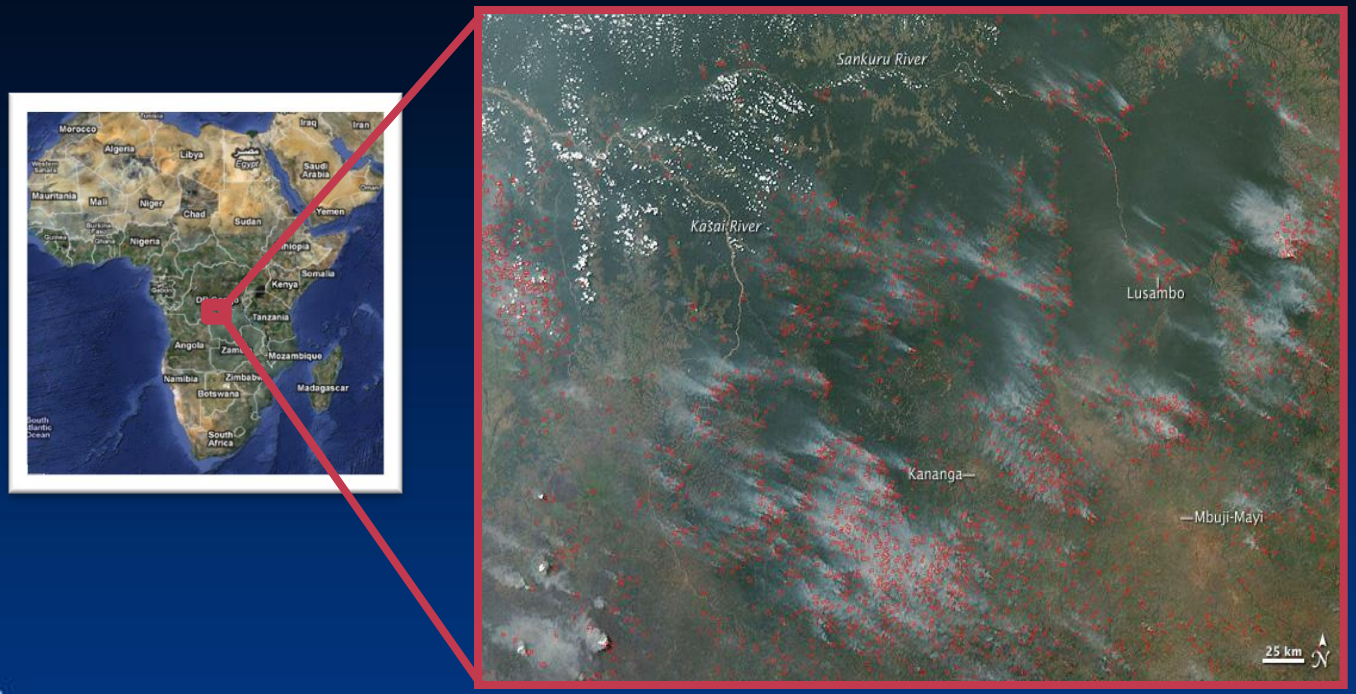
Forest Clearing: People clear forests by setting fires for animal pastures and crops (including "slash and burn" practices in the Amazon), to produce new farm land.

These activities release a significant amount of CO – recall Africa's disproportionate contribution to global CO.

Forest Clearing and Biomass Burning as Sources of CO

NASA Satellite Image of Fires Burning in Africa (in the Democratic Republic of the Congo)

The red dots indicate the locations of active fires burning



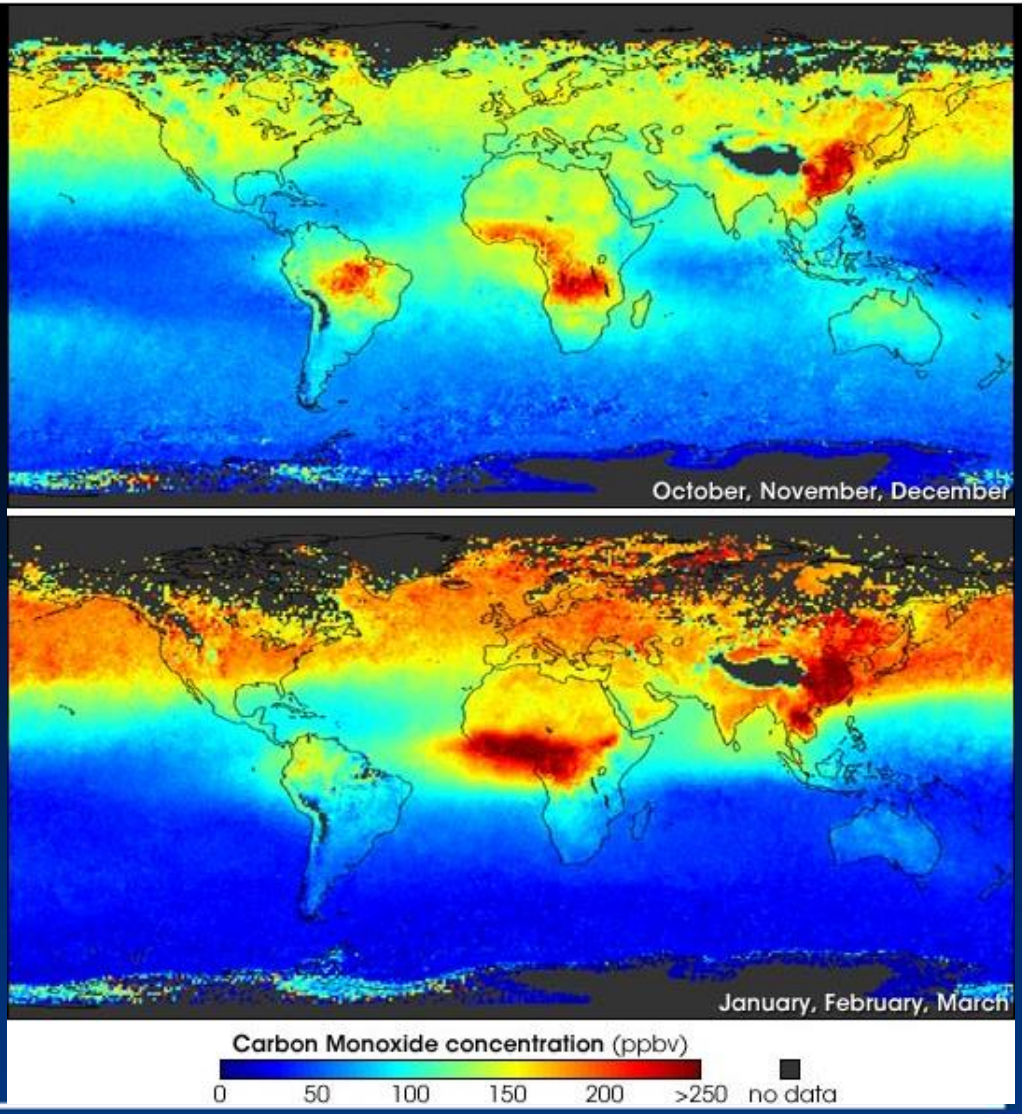
Forest Clearing and Biomass Burning as Sources of CO

NASA Satellite Image of Fires Burning in Burma/Thailand/Laos

The red dots indicate the locations of active fires burning

NASA Satellite Images of CO Concentration

- Fires from crop burning, forest clearing, and natural wildfires follow seasonal patterns as shown in these images.
- NASA Satellites measure CO in the atmosphere so we can better understand the concentrations and movements of CO around the globe.

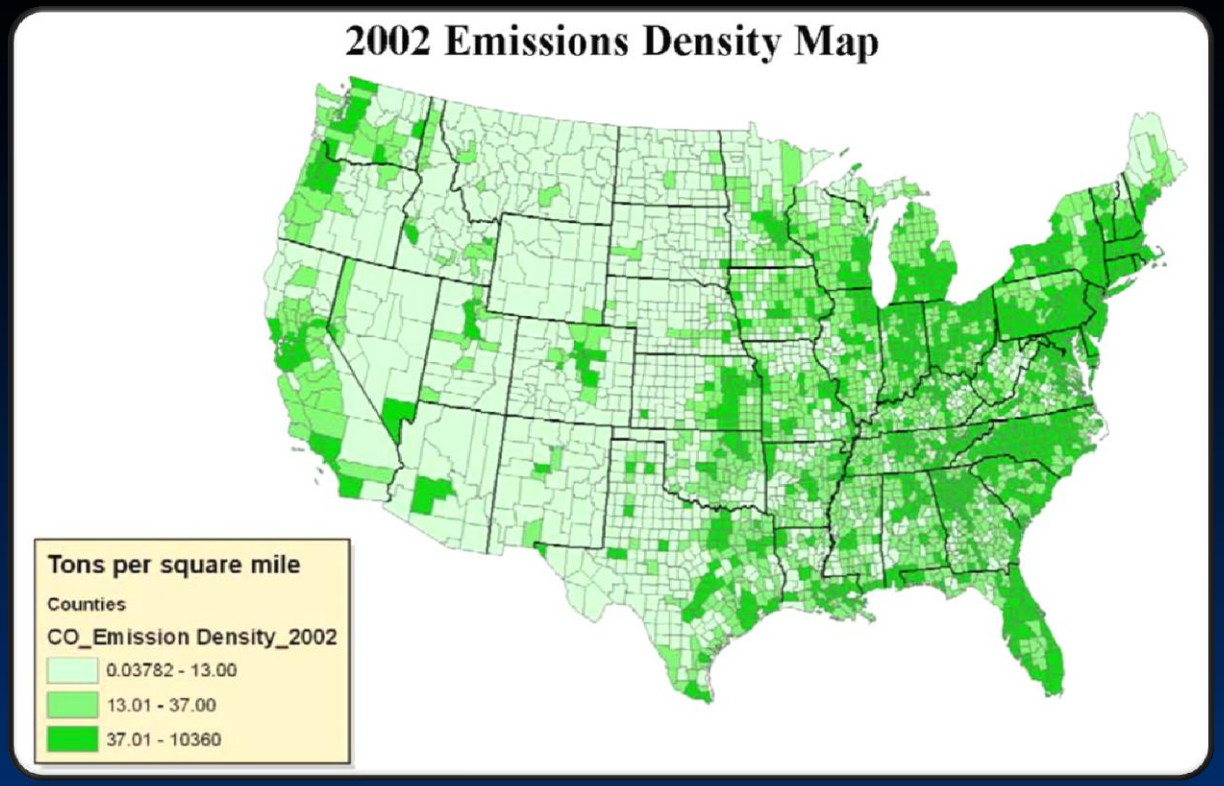


Anthropogenic Sources of CO in the United States

Lesson 3 : Carbon Sources - Carbon Monoxide

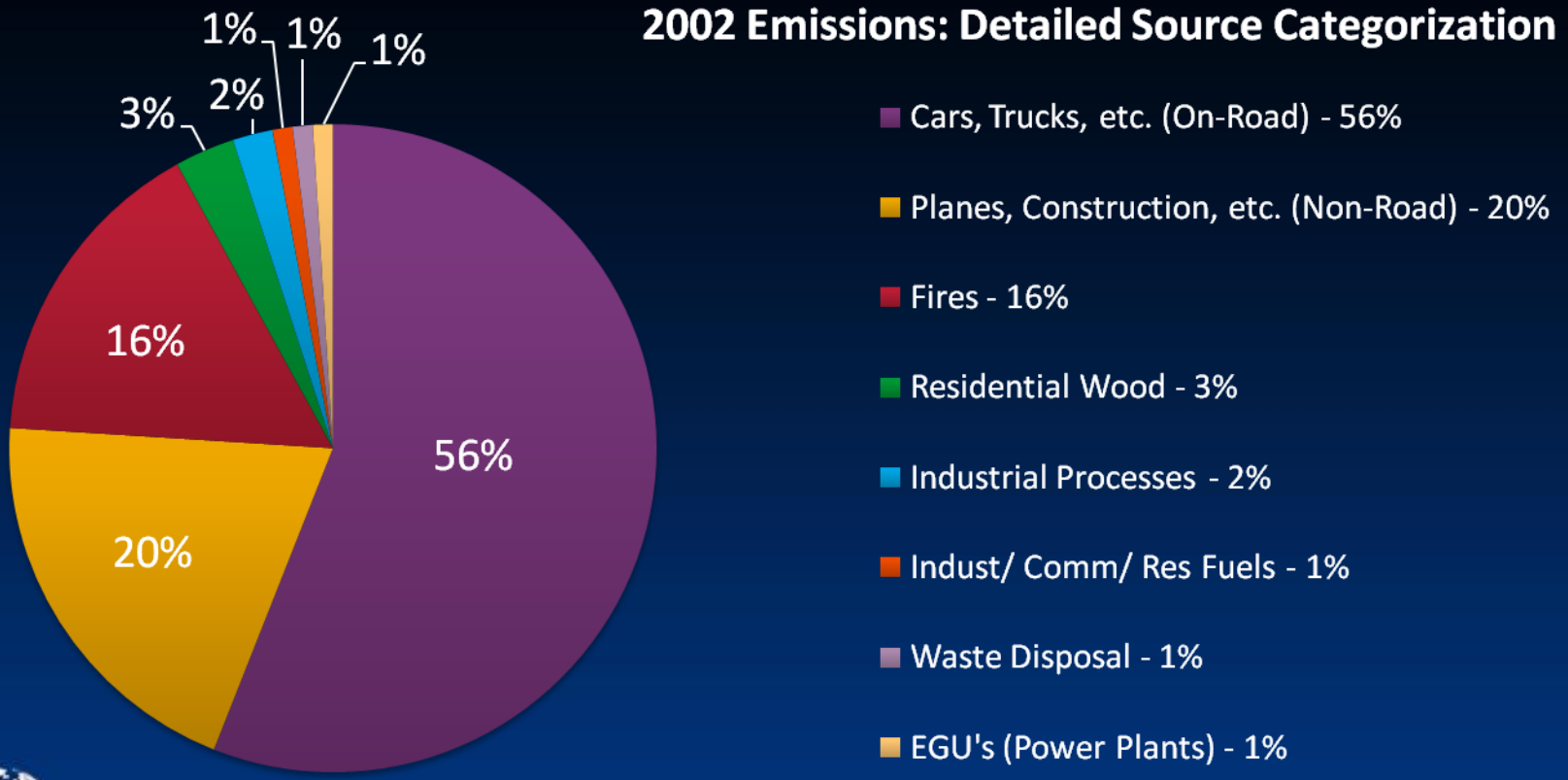
CO Emission Inventory for the United States

- Emission Inventories are created to tally the amount of CO emitted by each region of the county, in this case by county.
- If you live in the US, what is your county's CO Emission Density?



Breakdown of Anthropogenic Sources of CO in the **United States**

What are the top three sources of CO in the US?

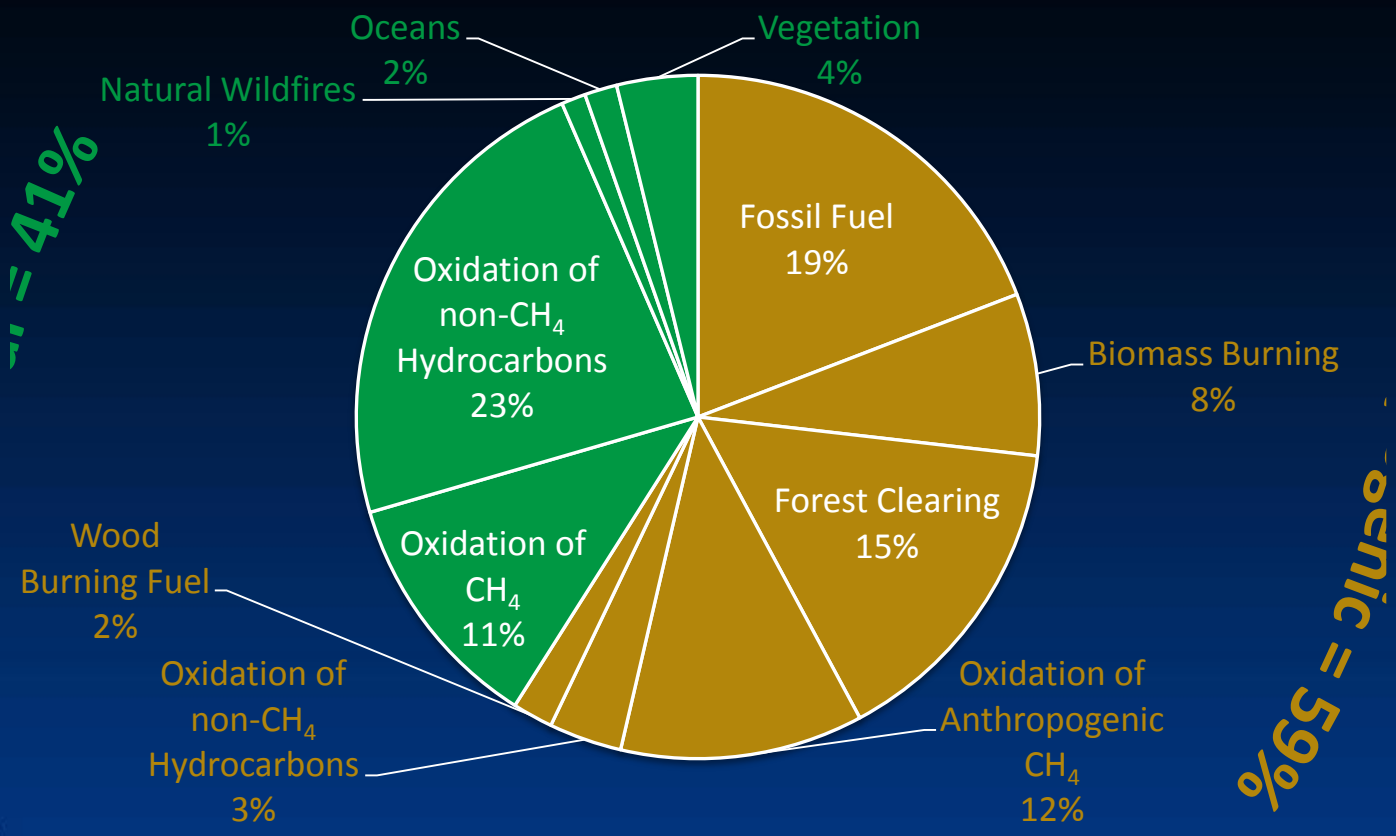


Natural Sources of CO

Lesson 3 : Carbon Sources - Carbon Monoxide

Breakdown of Natural and Anthropogenic Sources of CO in the **World**

Let's Look at a Global Total of CO Emissions – Including Natural and Anthropogenic Sources



Project GO 3

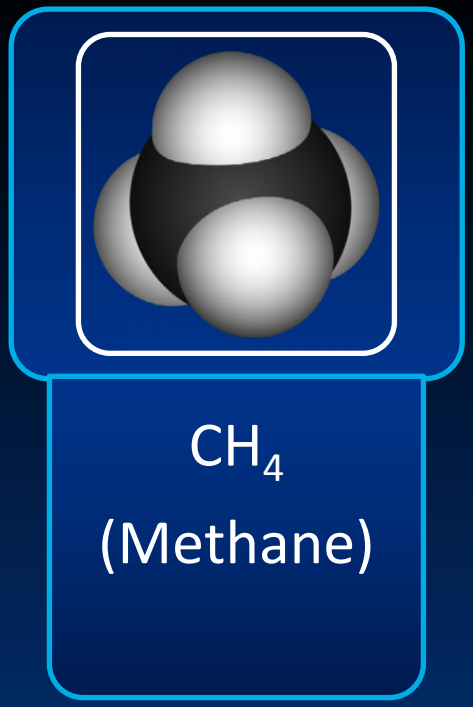
Lesson 4:
Methane (CH_4)

Learning Objectives

At the end of this lesson students will be able to:

- Identify three main examples of methane sources that lead to the formation of ground level ozone.
- Understand the sources of methane globally that contribute to the formation of ground level ozone.
- Identify examples of natural and anthropogenic sources of methane in the atmosphere.

Let's Take a Closer Look at One Last Carbon Source – CH_4 (Methane)



We will look at:

- CH_4's role in ozone formation
- Global anthropogenic and natural sources of CH_4
- Other interesting information about CH_4

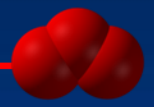
A Closer Look at CH_4

The Series of Reactions with CH_4 that Lead to the Formation of Ground Level Ozone

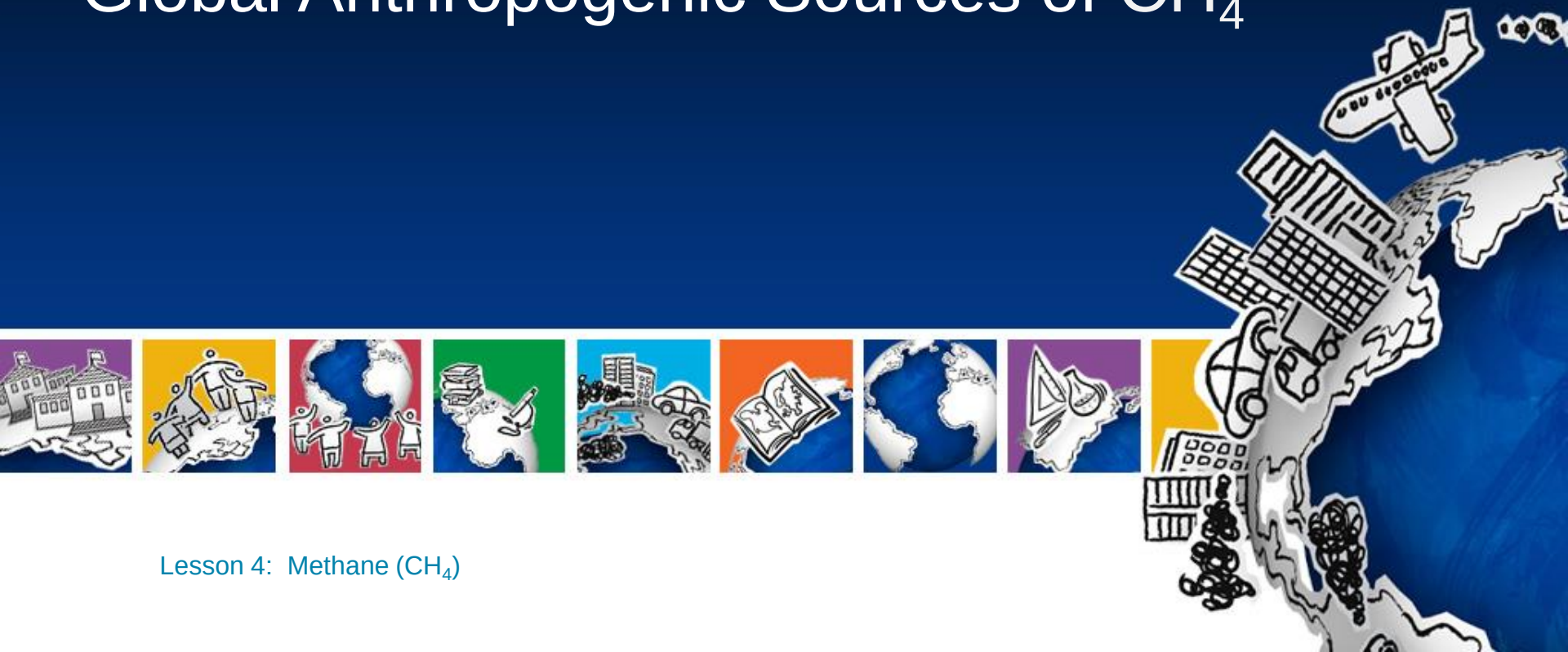
$$CH_4 + OH \rightarrow CH_3 + H_2O$$
$$CH_3 + O_2 \rightarrow CH_3O_2$$
$$CH_3O_2 + NO \rightarrow CH_3O + NO_2$$
$$CH_3O + O_2 \rightarrow CH_2O + HO_2$$
$$HO_2 + NO \rightarrow OH + NO_2$$
$$(NO_2 + h\nu \rightarrow NO + O) \text{ Twice}$$
$$(O + O_2 \rightarrow O_3) \text{ Twice}$$

Sunlight

Net: $CH_4 + 4\ O_2 \rightarrow CH_2O + H_2O + 2\ O_3$



Global Anthropogenic Sources of CH_4

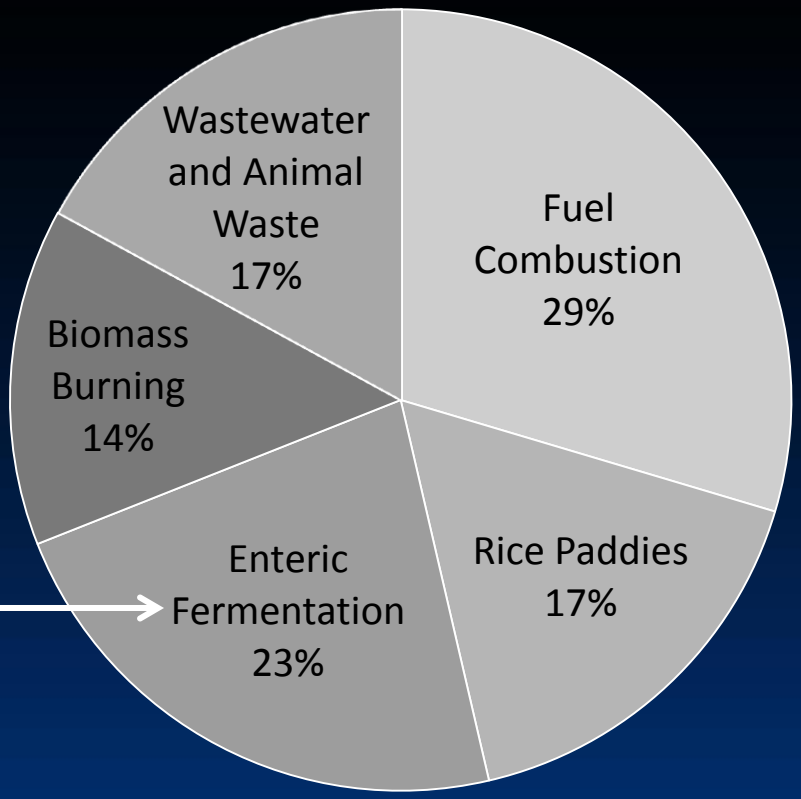


Lesson 4: Methane (CH_4)

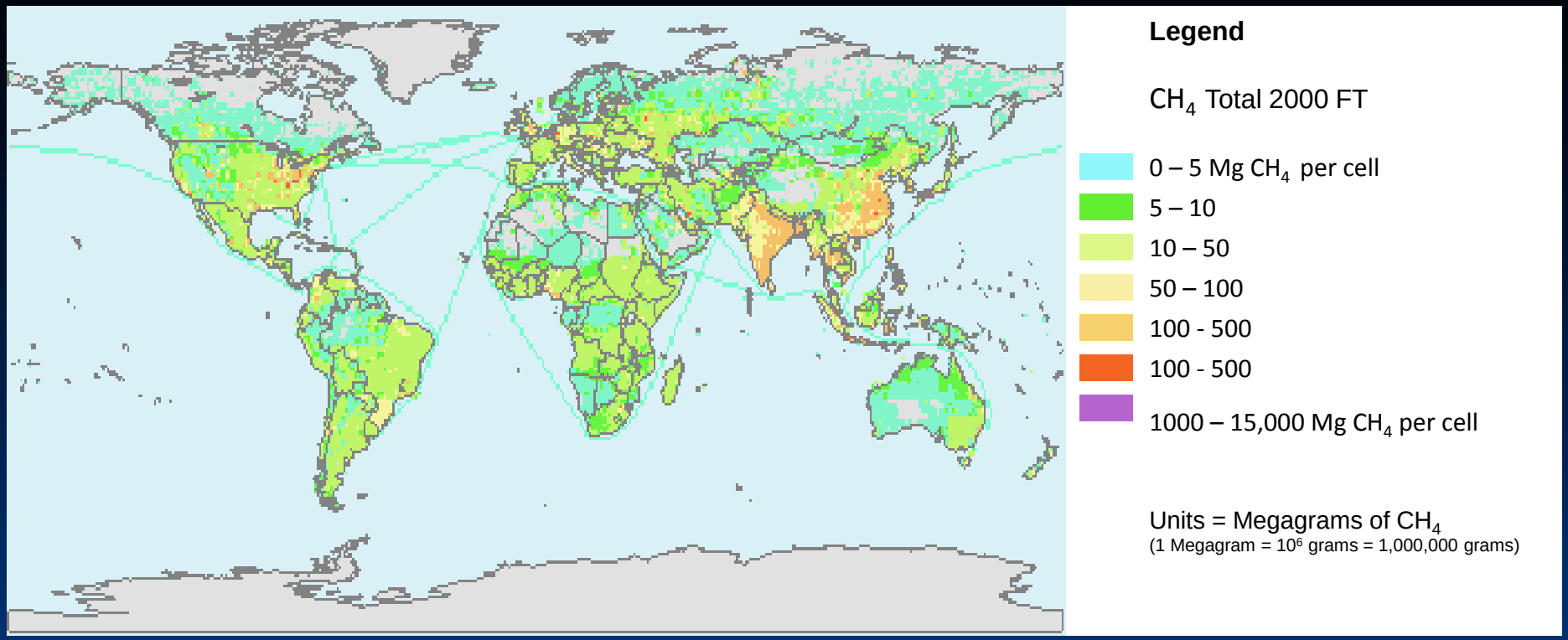
Breakdown of Global Anthropogenic Sources of CH_4

What is Enteric Fermentation?

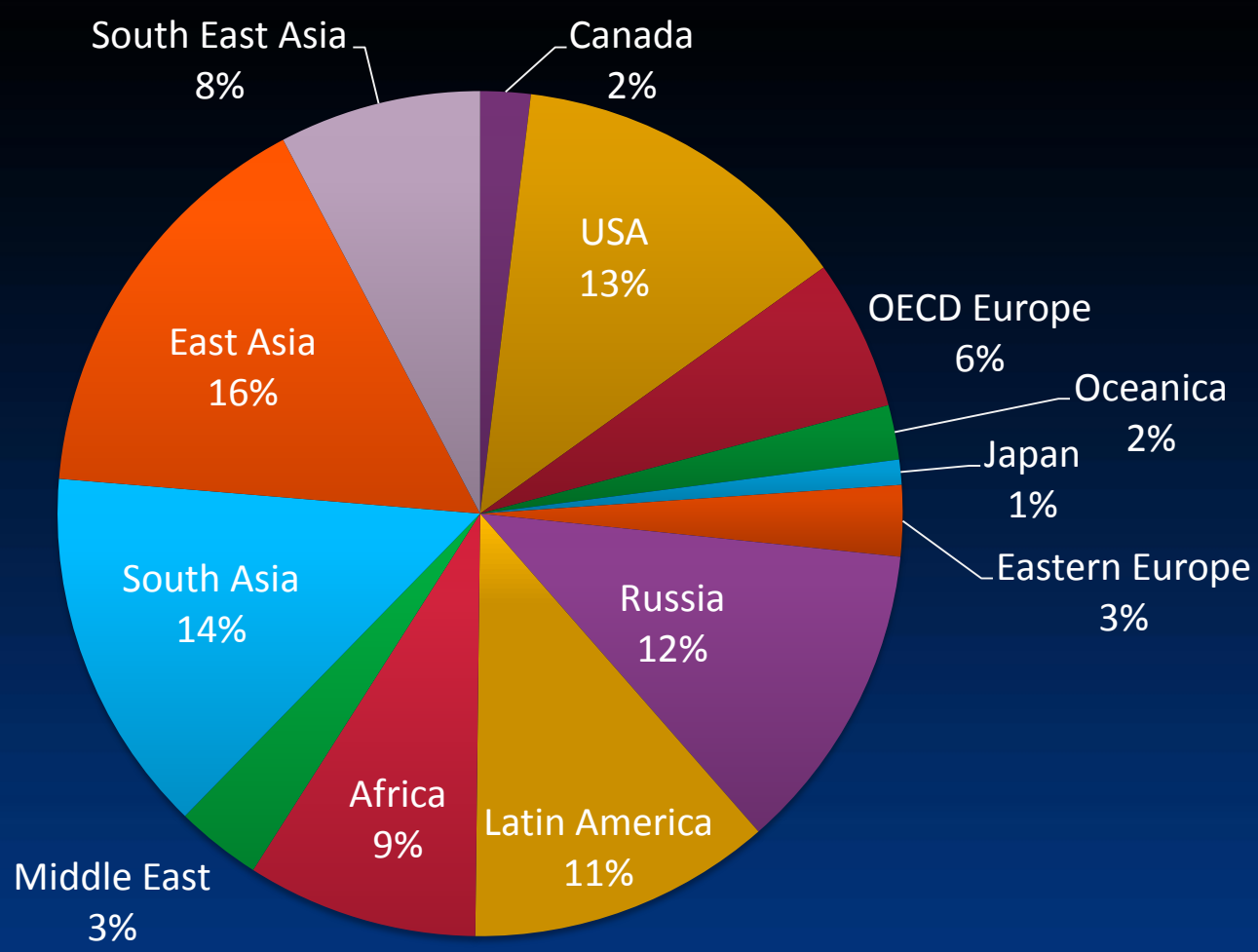
Hint:



Global Anthropogenic CH_4 Emissions Density



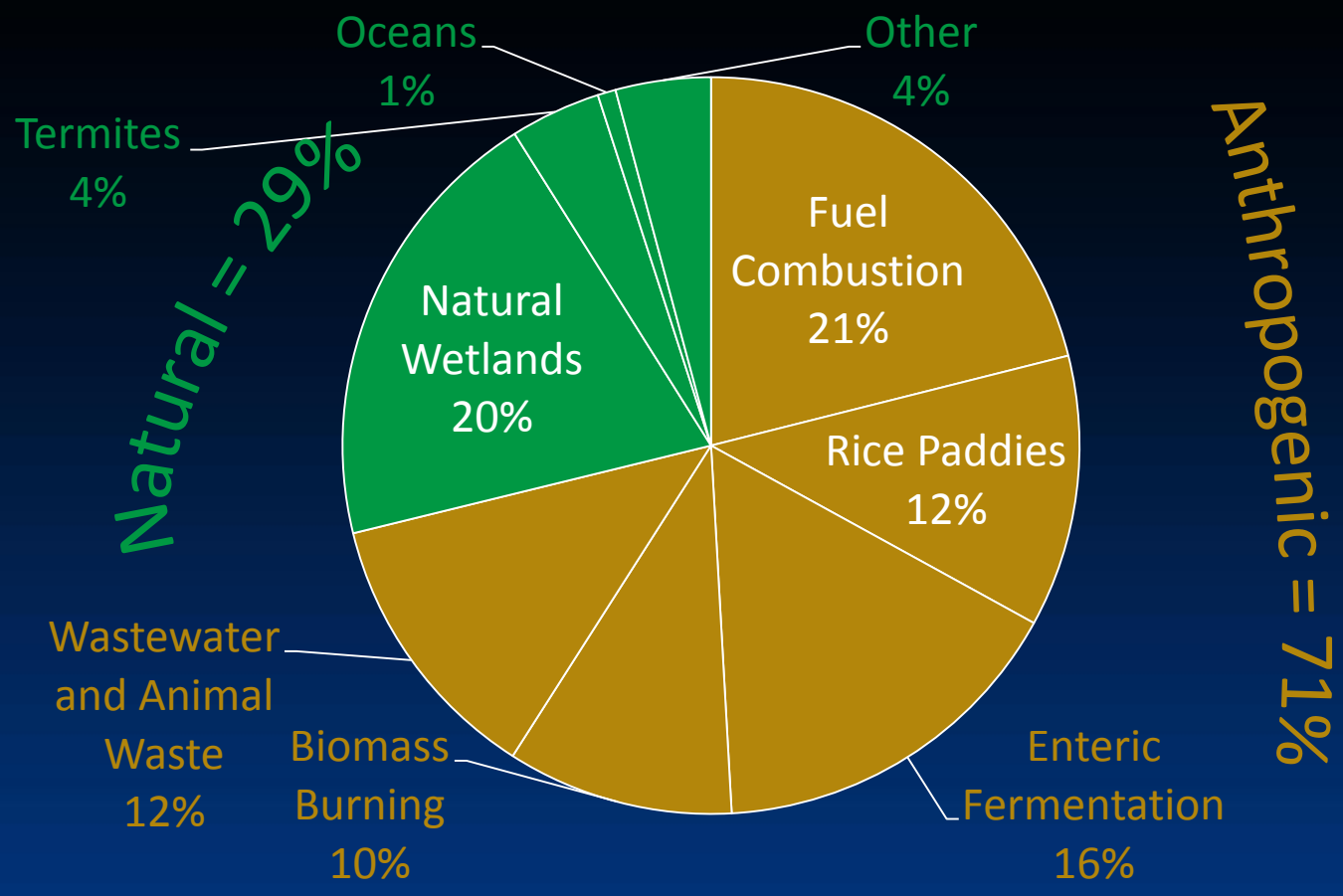
Regional Breakdown of Total Global Anthropogenic CH_4 Emissions



Natural Sources of CH_4

Lesson 4: Methane (CH_4)

There are Significant Natural Sources of CH_4



Project GO3

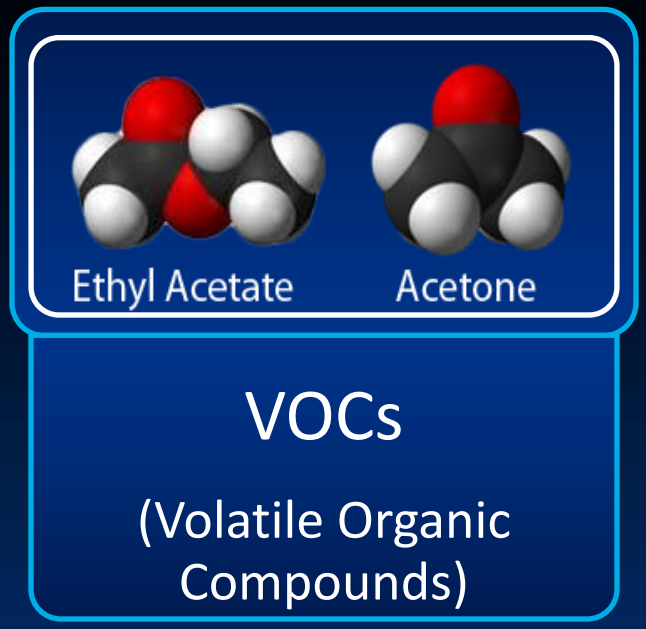
Lesson 5:
Volatile Organic Compounds (VOCs)

Learning Objectives

At the end of this lesson students will be able to:

- Identify three main examples of VOCs sources that lead to the formation of ground level ozone.
- Understand the sources of VOCs globally that contribute to the formation of ground level ozone.
- Identify examples of natural and anthropogenic sources of VOCs in the atmosphere.

A Closer Look at Another Carbon Source - VOCs



We will look at:

- VOCs' role in ozone formation
- Global anthropogenic and natural sources of VOCs
- A breakdown of anthropogenic sources of VOCs, globally and in the USA
- Other interesting information about VOCs

First of all, what are VOCs?

VOCs are chemical compounds containing carbon that vaporize easily and enter the atmosphere.

They can be released directly into the air, or by incomplete combustion in the burning of fossil fuels in automobile engines and power plants.

Vapors from Paint Thinner

Gasoline Vapors

Vapor Video

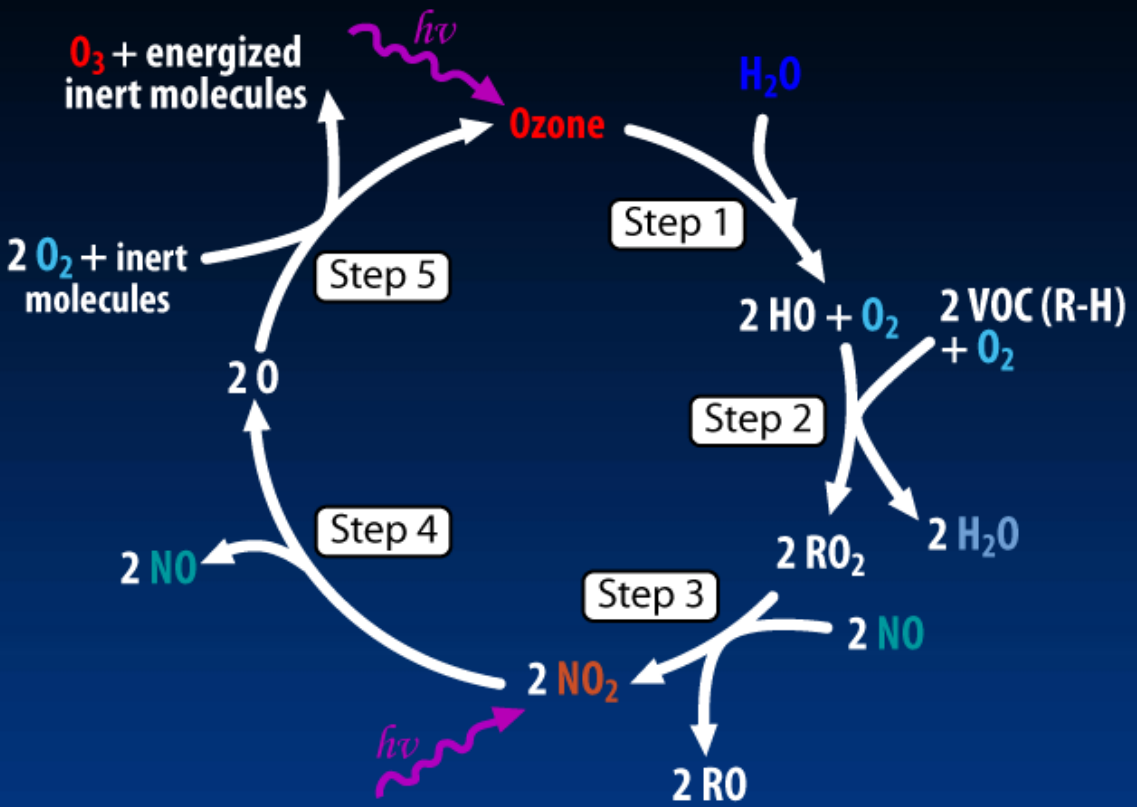
We can't see many of the VOCs released into the atmosphere.

This infrared video shows the vapors (VOCs) that are released when a gas tank is filled.

Click on the image or on the link to watch the video: YouTube Vapor Video

Series of Reactions with VOCs

The series of reactions with VOCs that leads to the formation of ground level ozone is… well…a little bit complicated!

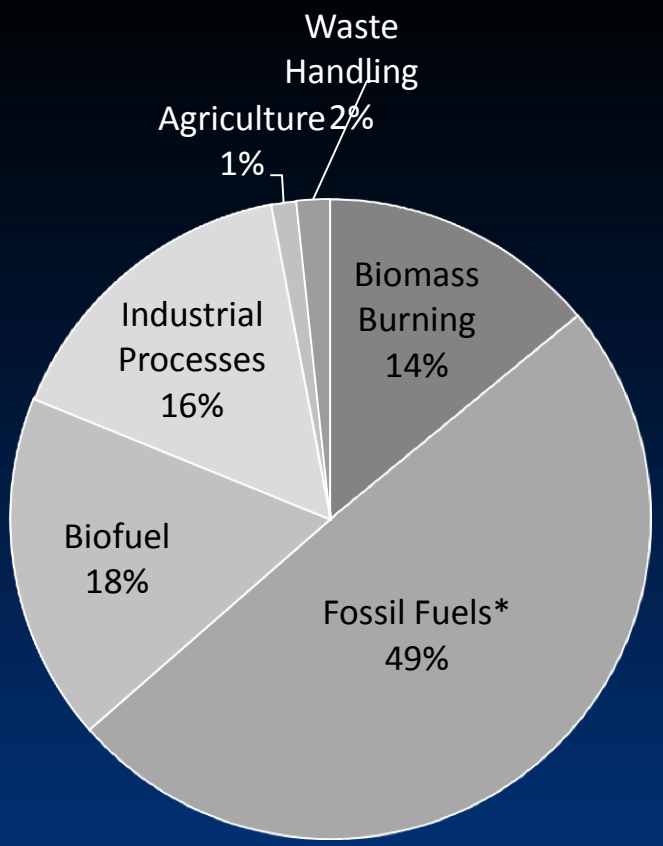


Global Anthropogenic Sources of VOCs

Breakdown of Global Anthropogenic Sources of VOCs

How does this breakdown differ from the CO sources?

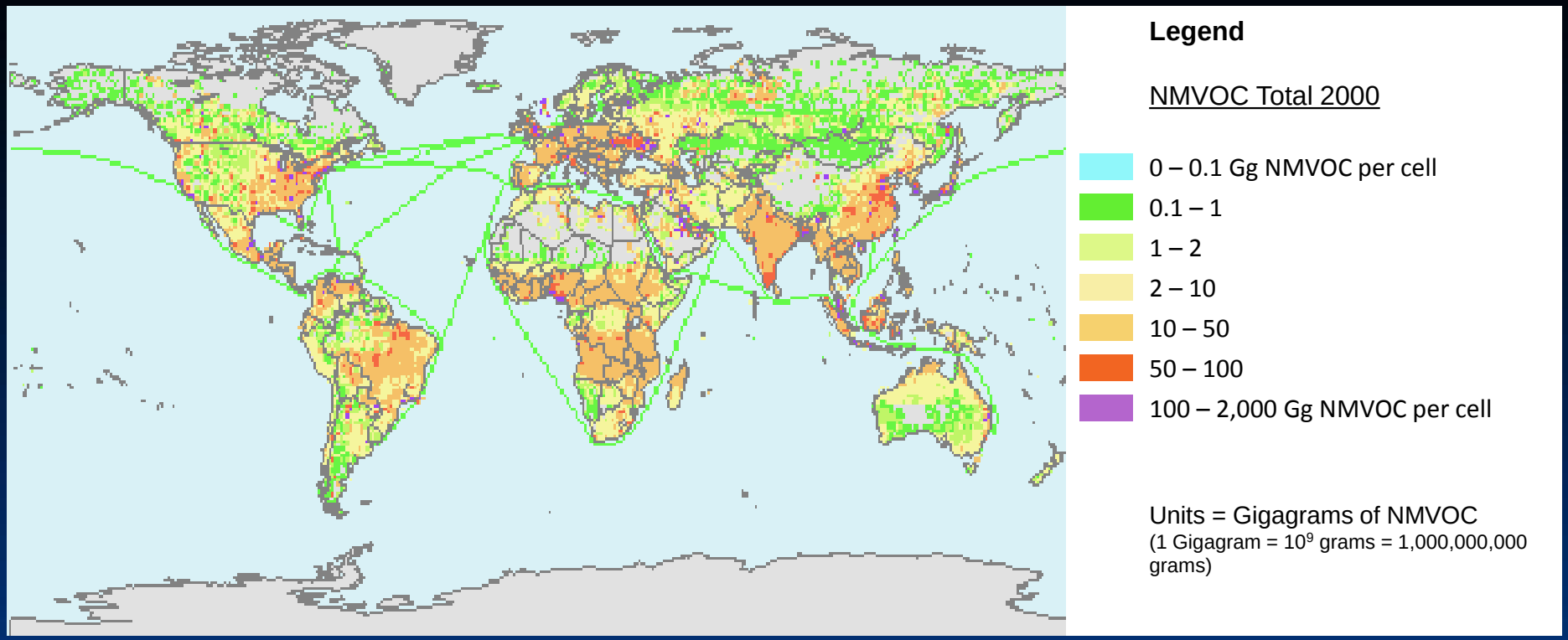
What is the main source of anthropogenic VOCs?



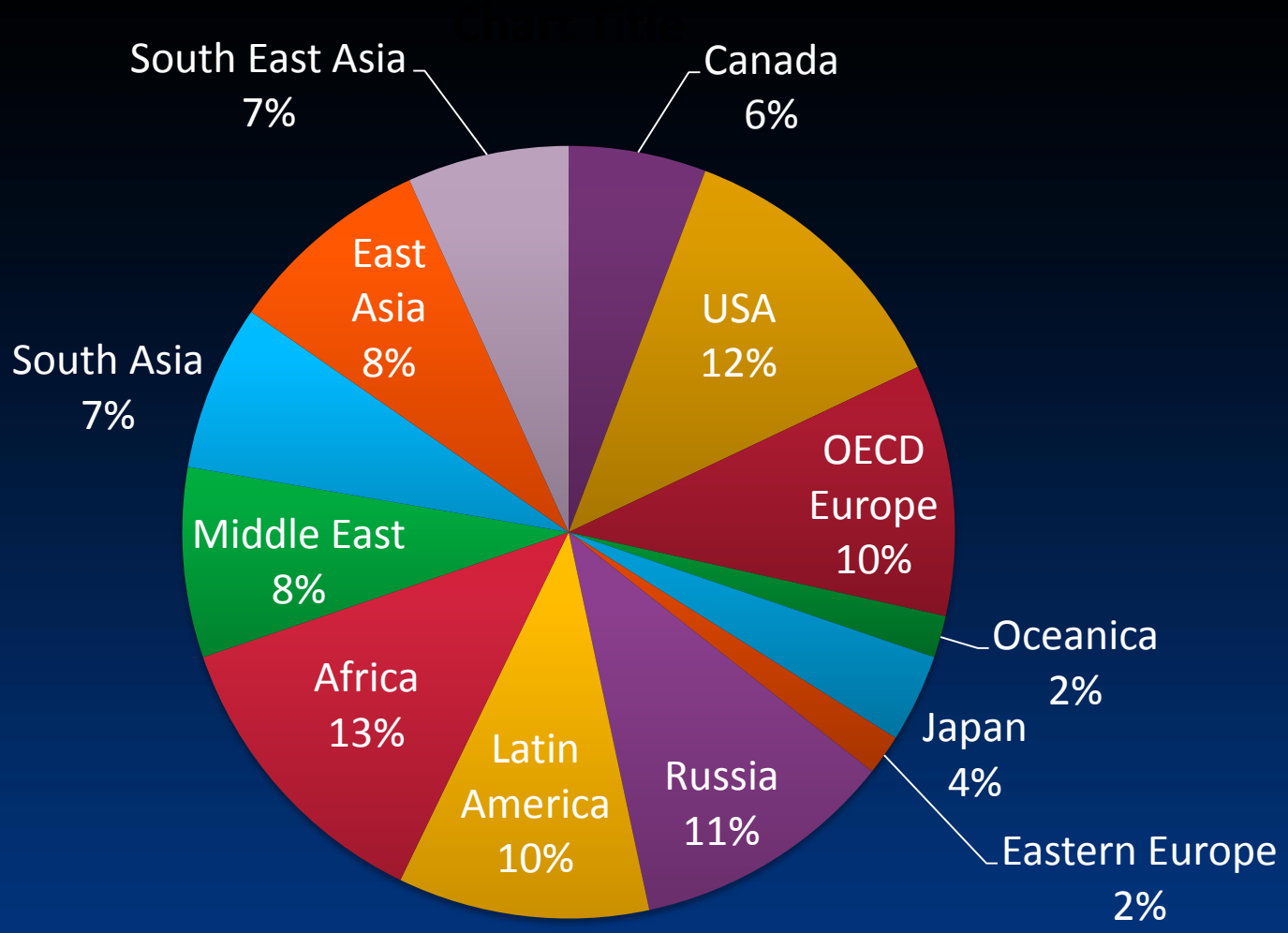
*Includes automobile emissions

Global Anthropogenic Non-Methane VOC (NMVOC*) Emissions Density

**NMVOC = Non-Methane VOCs, which are VOCs excluding methane, which is discussed separately*



Regional Breakdown of Total Global Anthropogenic NMVOC Emissions

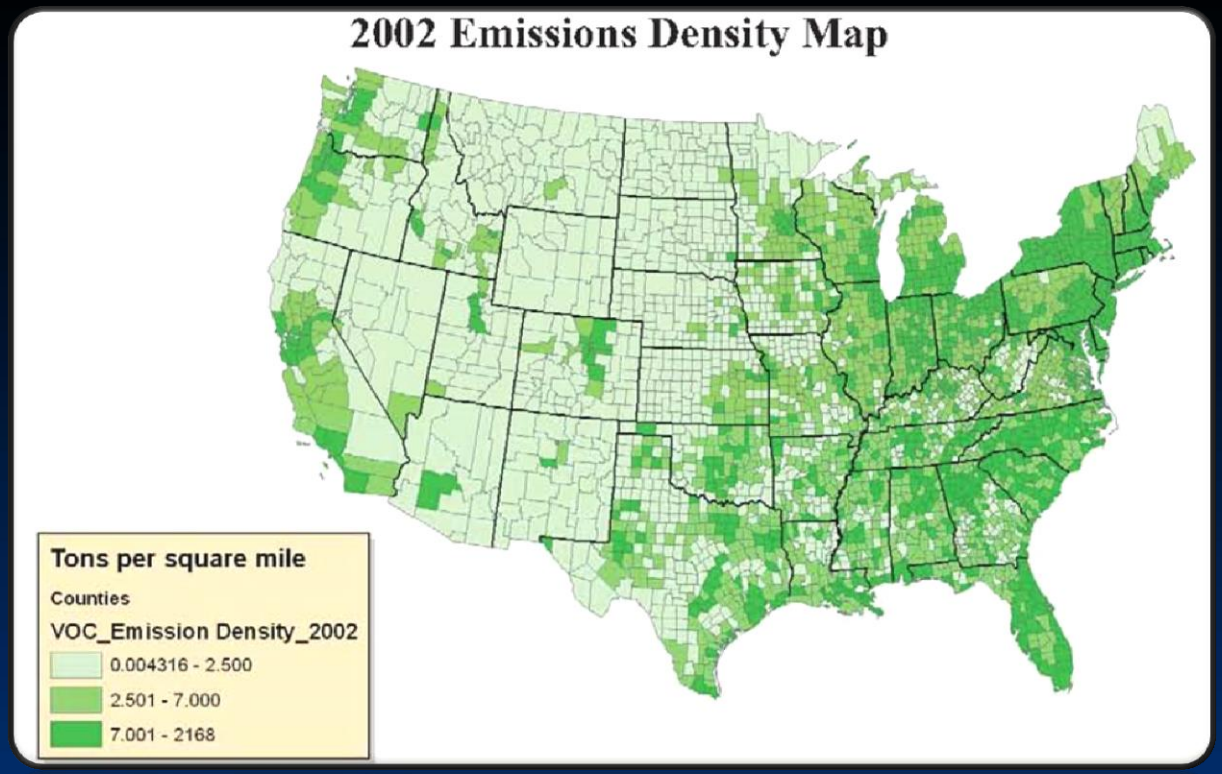


Anthropogenic Sources of VOCs in the United States

Lesson 5: Volatile Organic Compounds (VOCs)

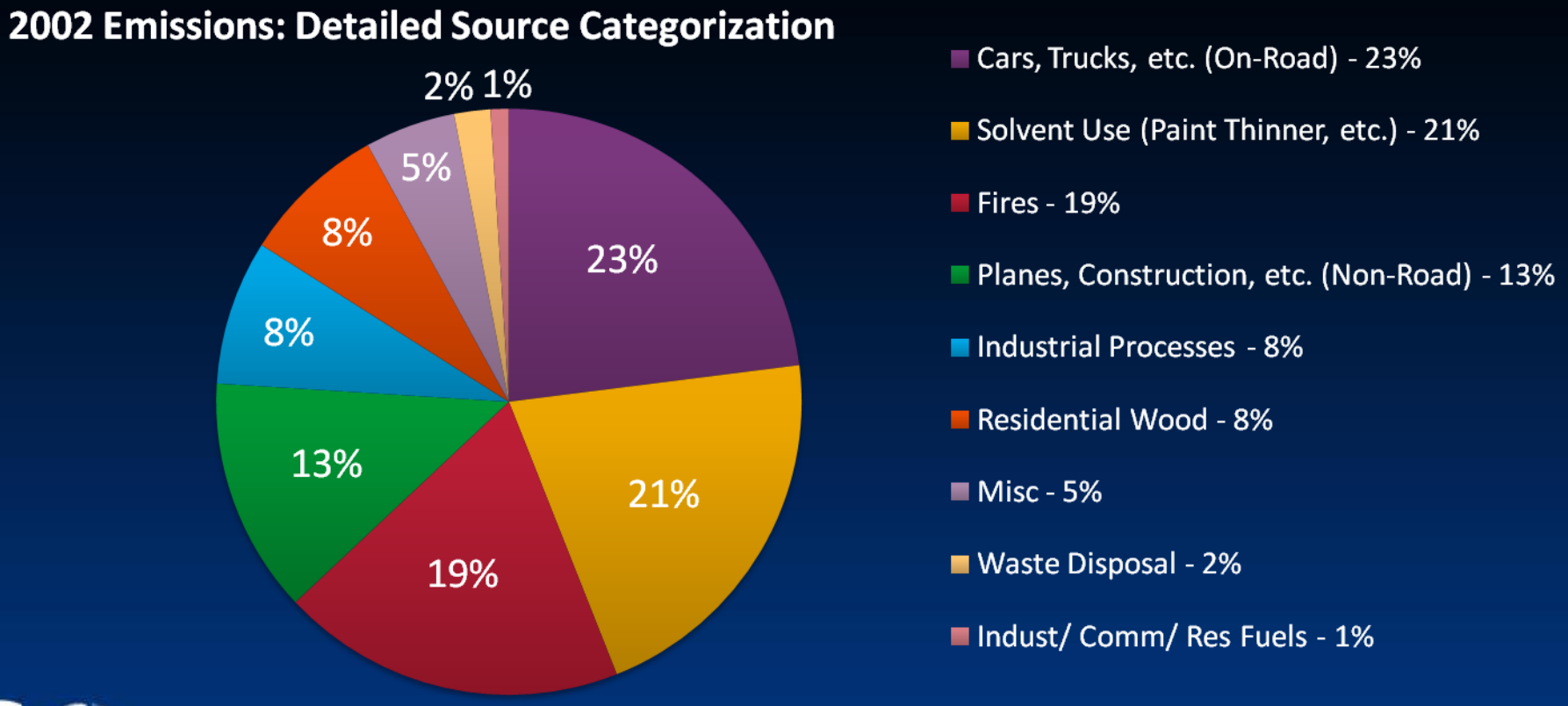
VOC Emission Inventory for the United States

- Emission Inventories are created to tally the amount of VOCs emitted by each region of the county, in this case by county.
- If you live in the US, what is your county's VOC Emission Density?



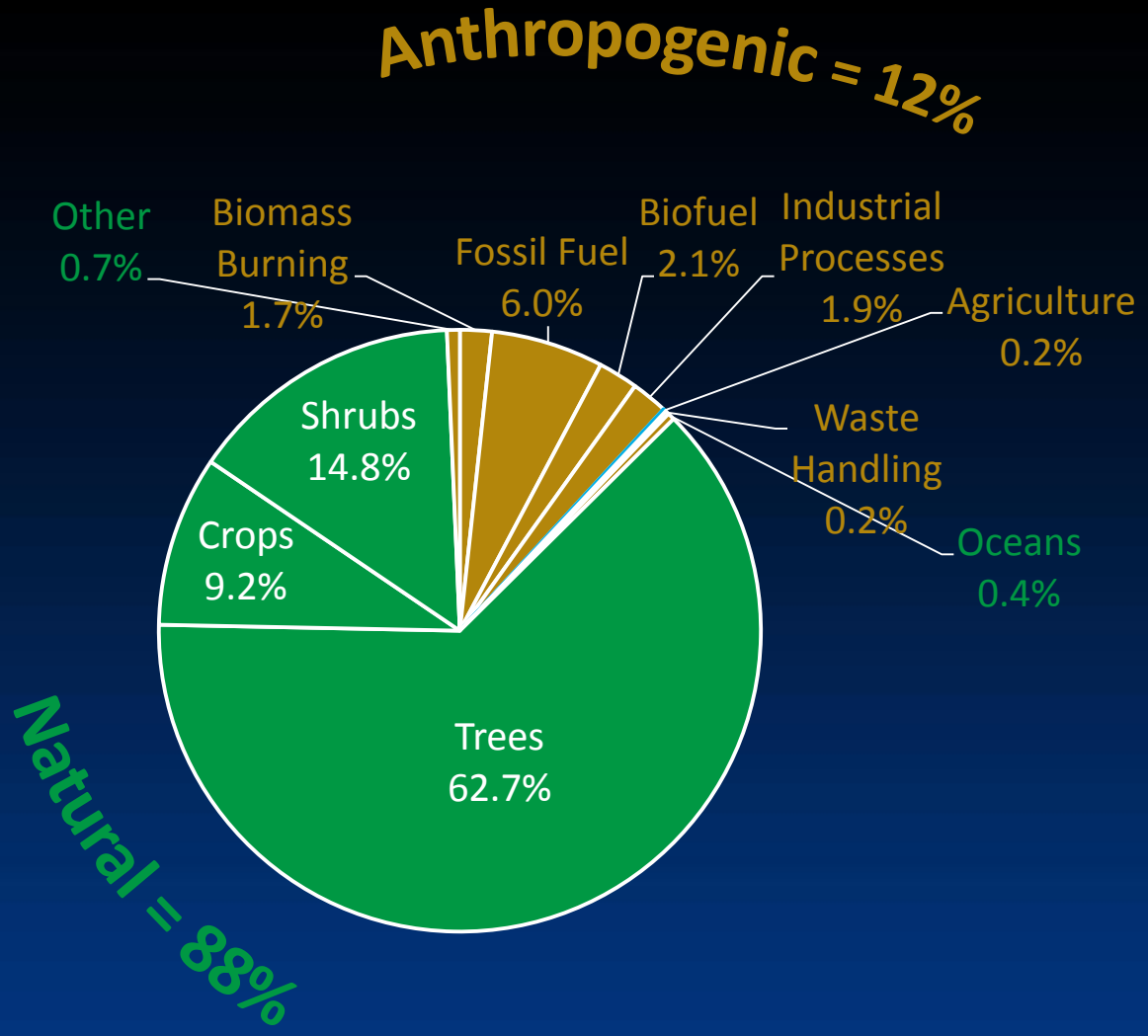
Breakdown of Anthropogenic Sources of VOCs in the **United States**

What are the top three sources of VOCs in the US?



Natural Sources of VOCs

There are Significant Natural Sources of VOCs

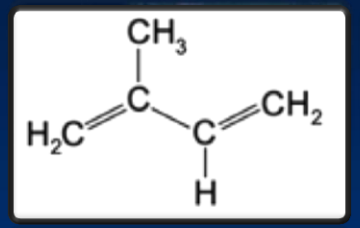


What are the Natural Sources of VOCs?

Trees emit VOCs in the form of isoprene and monoterpenes, which give them their characteristic smell.

Trees emit VOCs for a variety of reasons:

- To repel harmful insects and animals.
- To attract pollinators.
- As a stress response.



Isoprene, one of the VOCs emitted by trees

Kudzu – Another Natural Source of VOCs

The invasive vine Kudzu produces isoprene, a “growing” problem for ozone formation in the Southeastern US

If natural sources emit 88% of the world's VOCs…

Why should we be concerned with the amount we emit?

Natural vs. Anthropogenic

Recall that trees are a huge source of VOCs. However, as the image above of the world's forests reveals, these emissions are spread out over the entire earth.

Anthropogenic sources are much more concentrated than natural sources, resulting in concentrated "chemical soups" and unhealthy conditions.

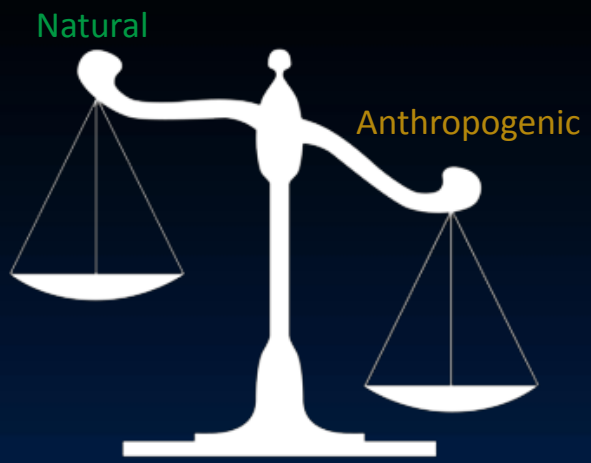
Atmospheric “Balance”

The delicate balance of the compounds in the atmosphere developed over millions of years.

There are two main reasons human activity is negatively affecting the environment:

1. Human activity can tip the delicate balance, causing pollutants to interact in different ways than they would naturally (we will look into this more in later slides).

2. The natural sources of the compounds cover the entire planet, in contrast with human pollution, which is extremely concentrated in small areas.



Project G3

Global Ozone Project Curriculum

Lesson 6:
Oxides of Nitrogen (NO_x)

Rev 13

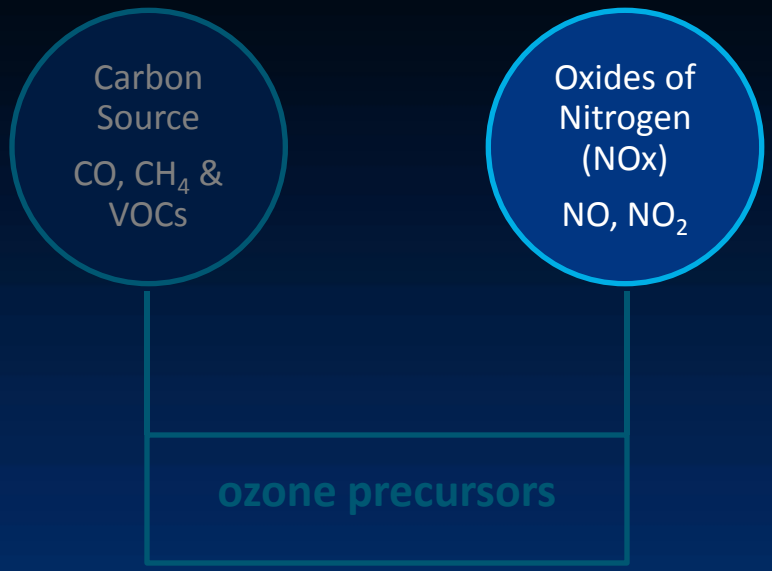
Learning Objectives

At the end of this lesson students will be able to:

- Identify the two forms of nitrogen that make up NO_x and lead to the formation of ground level ozone.
- Understand the sources of NO_x globally that contribute to the formation of ground level ozone.
- Identify examples of natural and anthropogenic sources of NO_x in the atmosphere.
- Describe the role of NO_x as a *"Chemical Switch".*

Exploration of Precursors in Depth

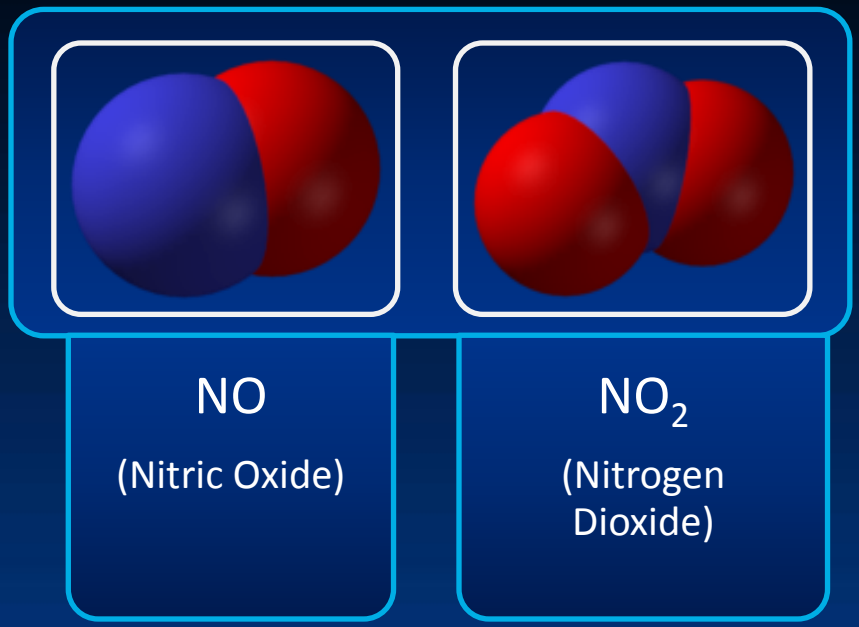
Oxides of Nitrogen (NO_x): NO, NO_2



- Examples of nitrogen sources
- Breakdown of anthropogenic sources (cars, power plants, etc.)
- Breakdown of natural sources (swamps, trees, etc.)

Examples of NO_x

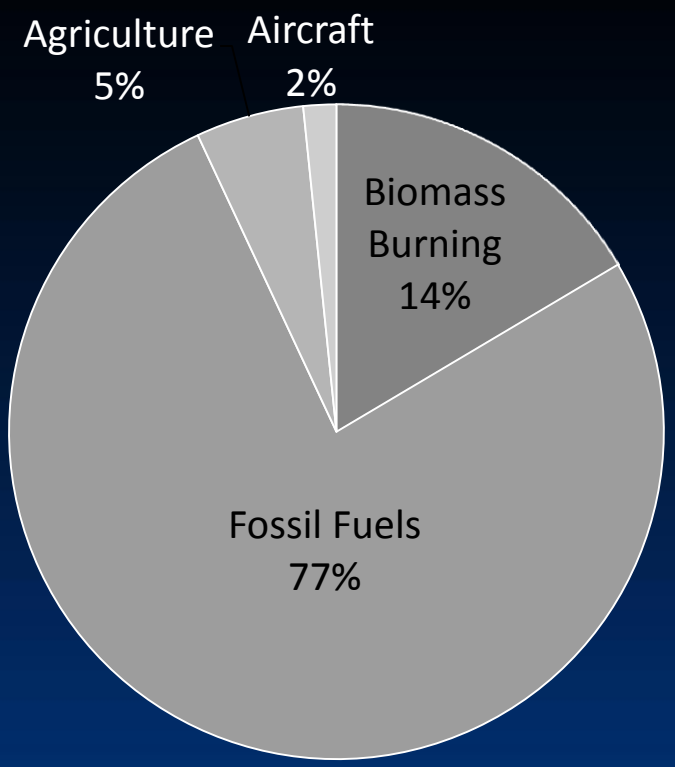
Ozone needs oxides of nitrogen in order to form. Here are the two NO_x compounds:



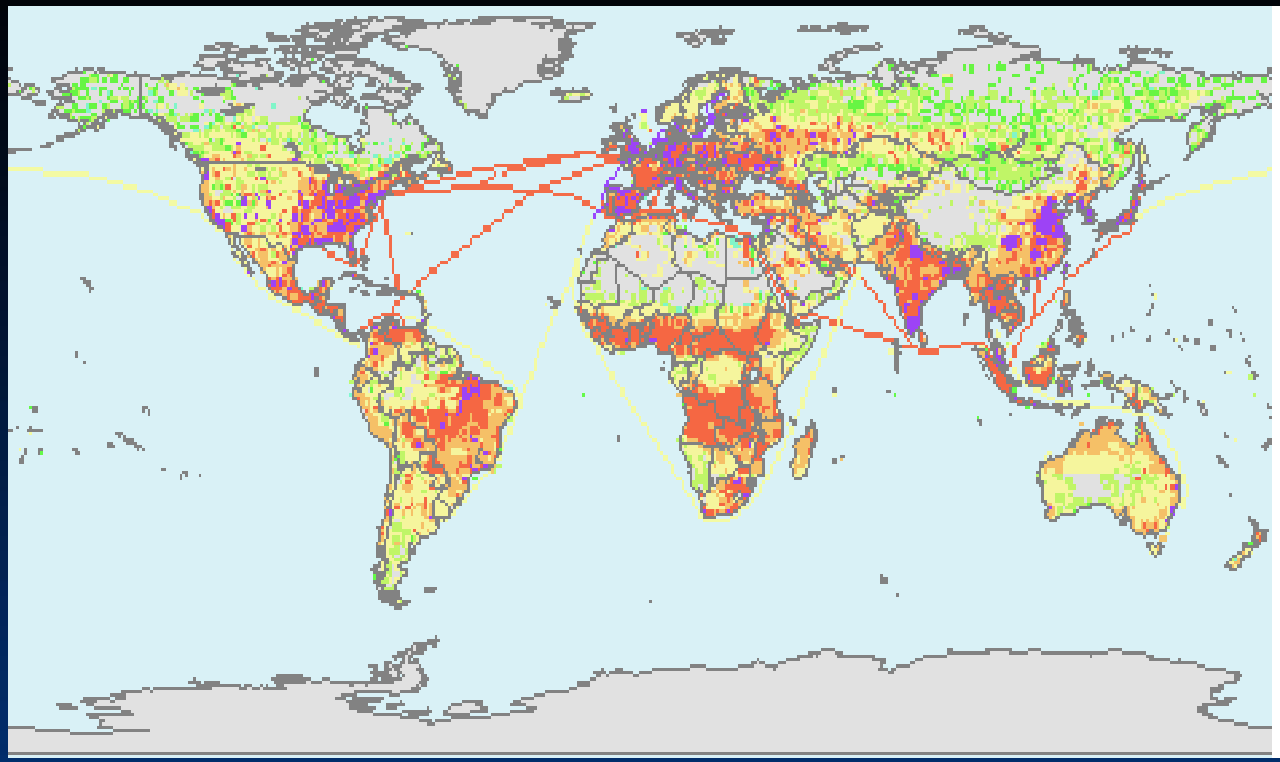
Global Anthropogenic Sources of NO_x

Breakdown of Global Anthropogenic Sources of NO_x

Does anything about this breakdown jump out at you?



Global Anthropogenic NO_x Emissions Density



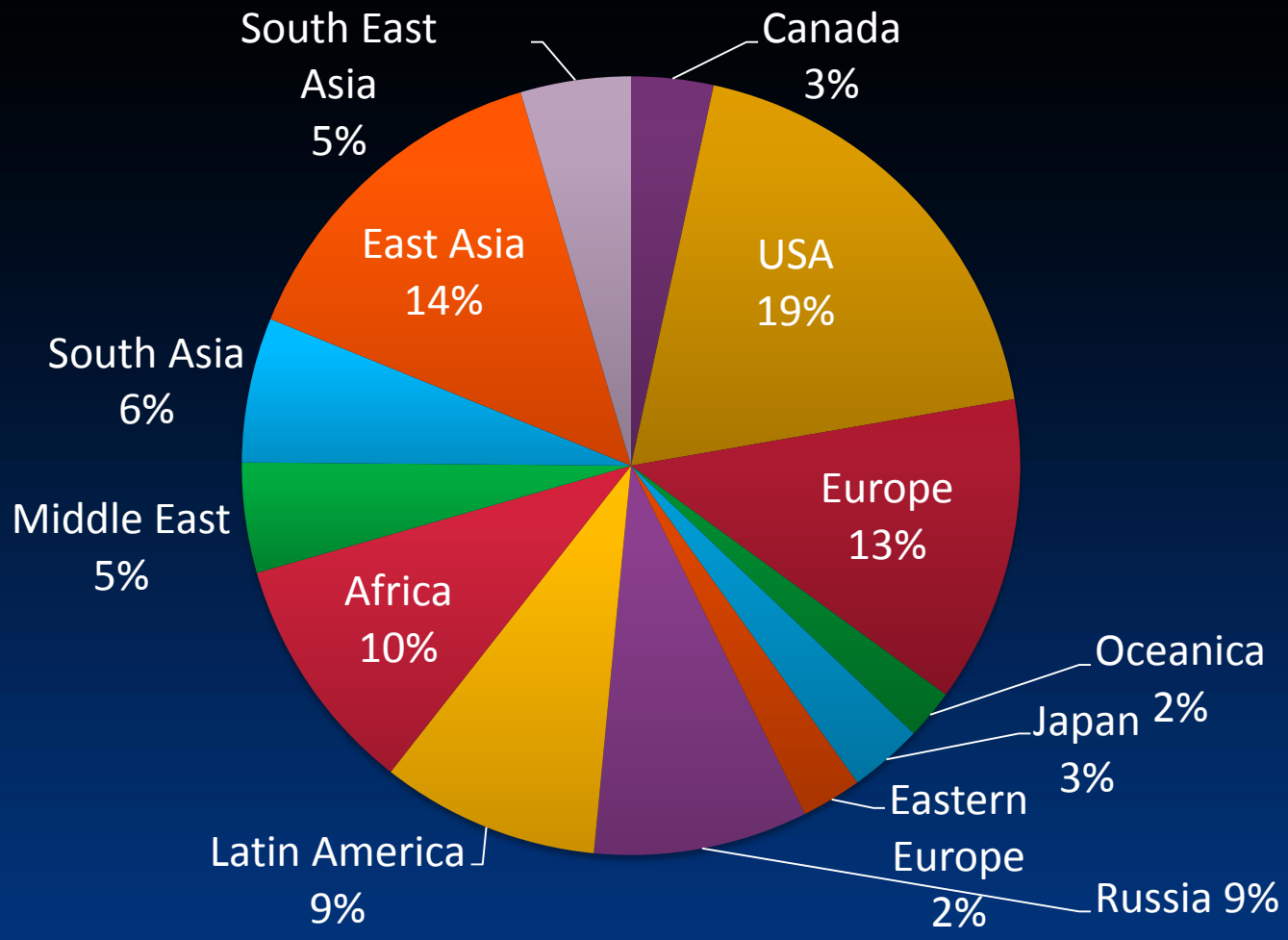
Legend

NO_x Total 2000 FT

- 0 – 3 Mg NO_x per cell
- 3 – 30
- 30 – 300
- 300 – 3,000
- 3,000 – 10,000
- 10,000 – 30,000
- 30,000 – 900,000 Mg NO_x per cell

Units = Megagrams of NO_x
(1 Megagram = 10^6 grams = 1,000,000 grams)

Regional Breakdown of Total Global Anthropogenic NO_x Emissions

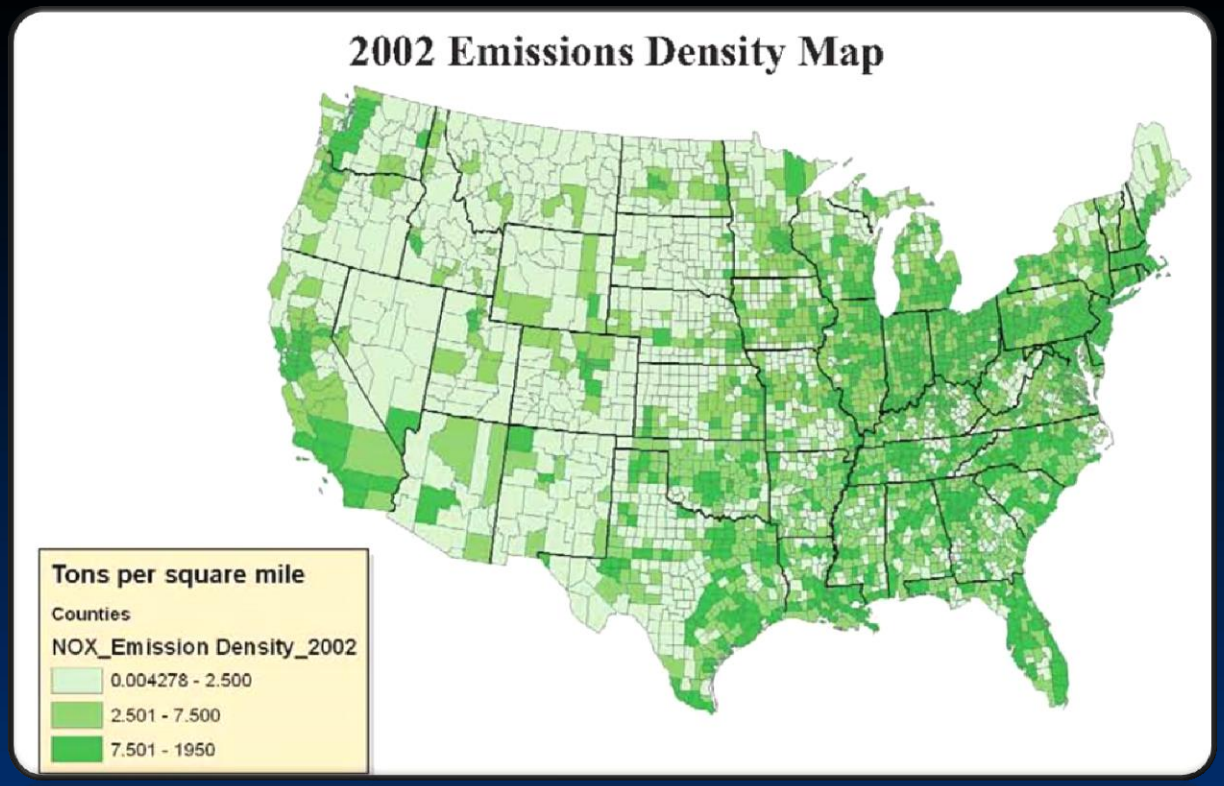


Anthropogenic Sources of NO_x in the United States

Lesson 6: Oxides of Nitrogen (NO_x)

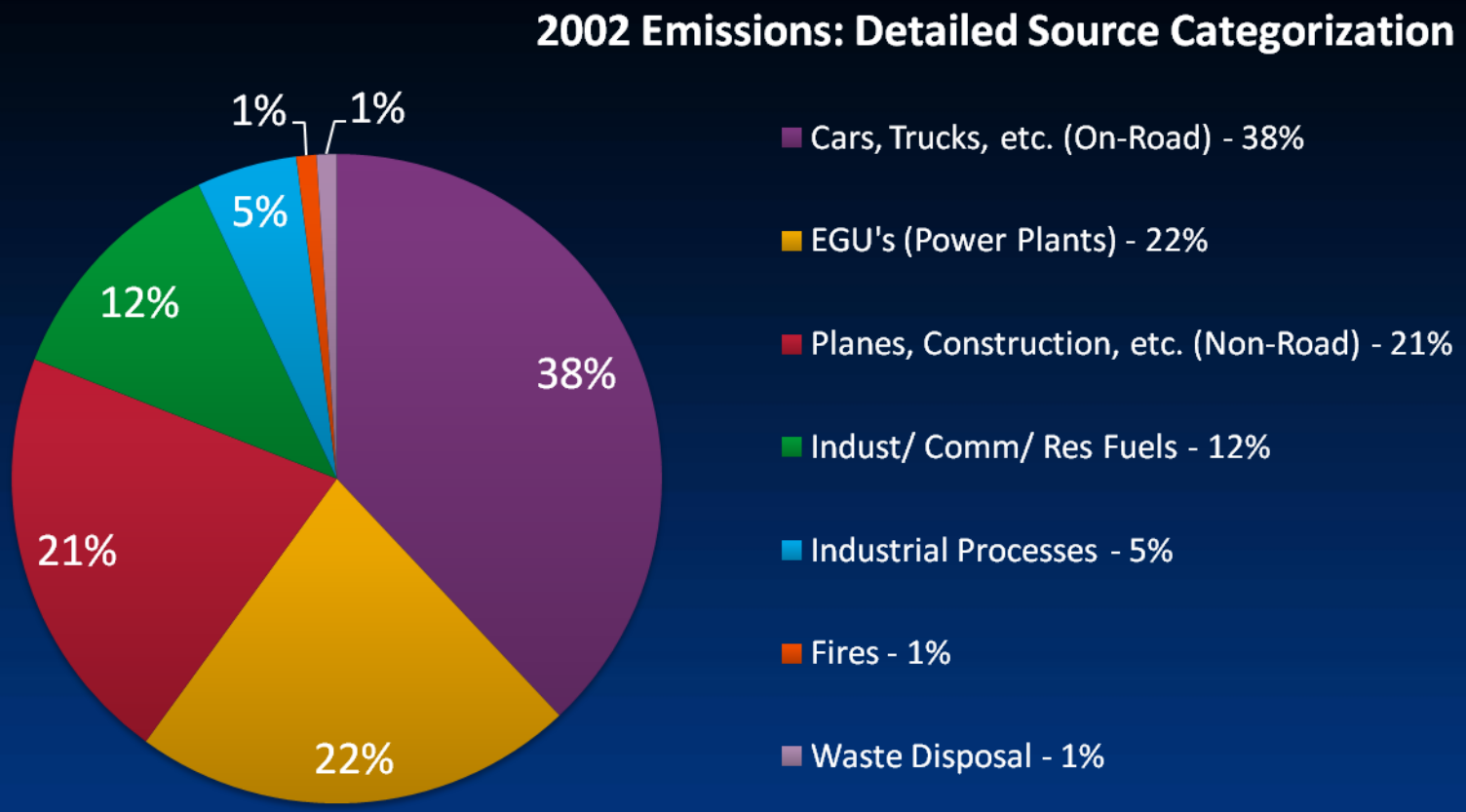
NO_x Emission Inventory for the United States

- Emission Inventories are created to tally the amount of NOx emitted by each region of the county, in this case by county.
- If you live in the US, what is your county's NOx Emission Density?



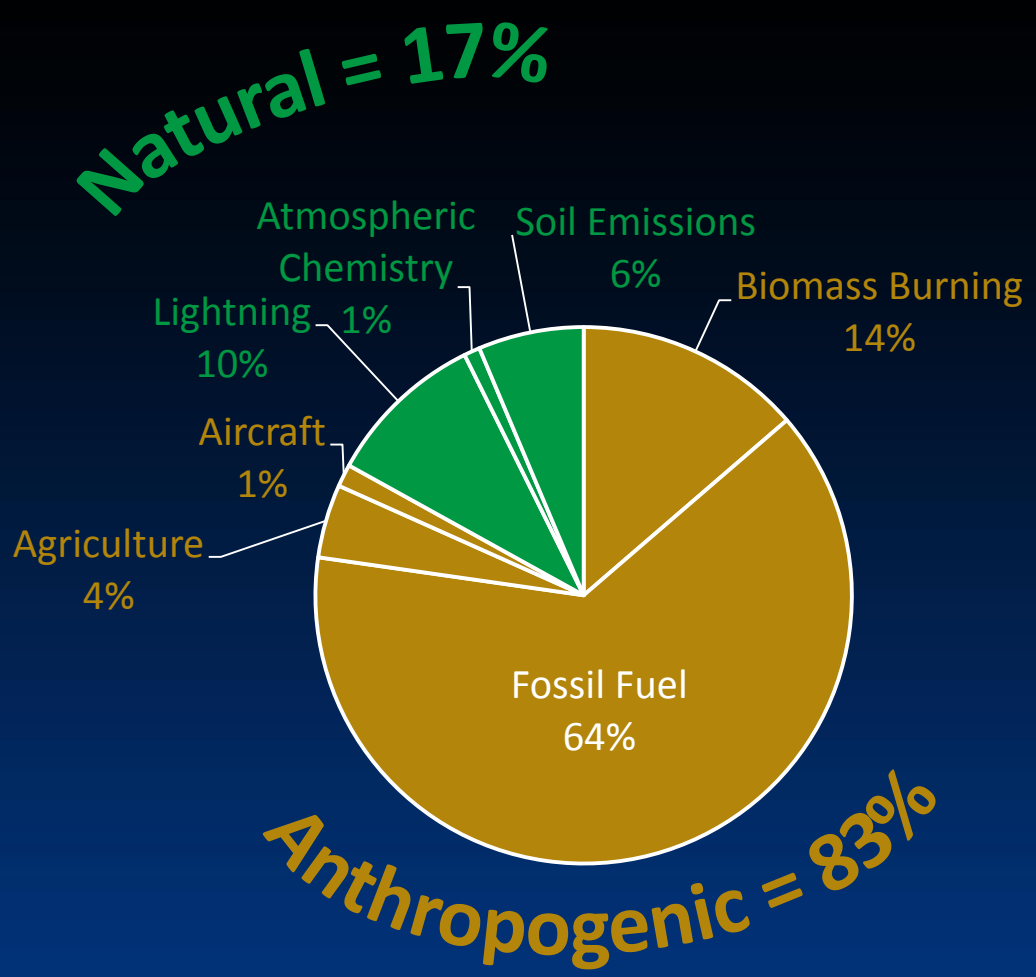
Breakdown of Anthropogenic Sources of NO_x in the **United States**

What are the top three sources of NO_x in the US?

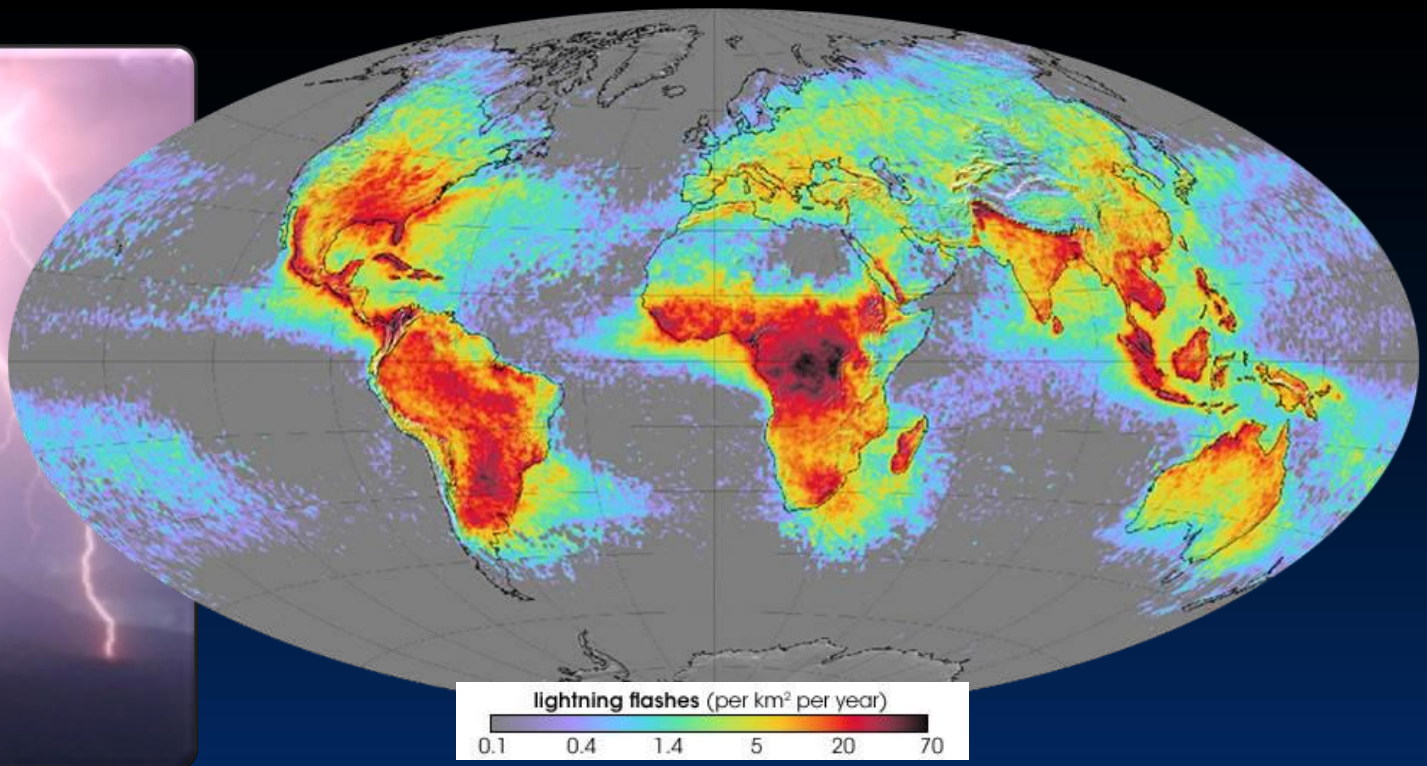


Natural Sources of NO_x

Anthropogenic Emissions Contribute the Vast Majority of NO_x Globally



Let's Look at One of the Most Significant Natural Source of NO_x Globally: Lightning



This image shows how lighting strikes are distributed around the world.
The units are in lightning flashes per square kilometer per year.
This gives us an idea of where on the earth NO_x is created from lightning.

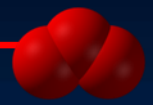
NO_x as a "Chemical Switch"

Before Anthropogenic Emissions…

… there was a relatively low concentration of NO_x in the air.

Low Concentration of NO_x:

$$CO + OH \rightarrow CO_2 + H$$
$$H + O_2 \rightarrow HO_2$$
$$HO_2 + O_3 \rightarrow OH + 2O_2$$



Net: $CO + O_3 \rightarrow CO_2 + O_2$

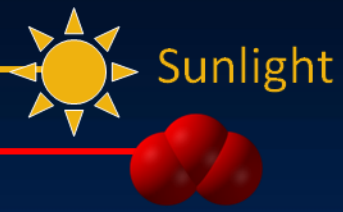
With a low concentration of NO_x in the Atmosphere, the series of reactions actually leads to the destruction of ozone!

Anthropogenic Emissions have Tipped the Atmospheric Balance…

… and Now these Compounds Interact in Ways they Don't Normally.

High Concentration of NO_x:

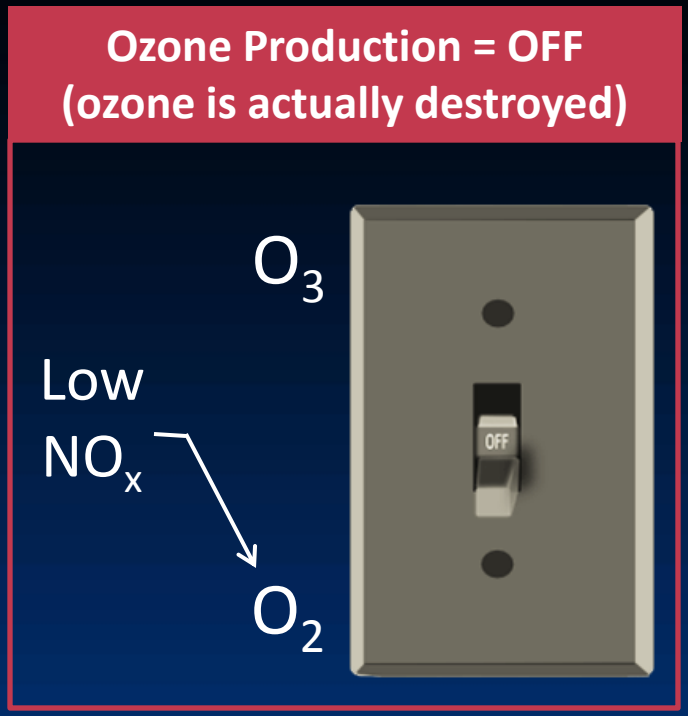
$$CO + OH \rightarrow CO_2 + H$$
$$H + O_2 \rightarrow HO_2$$
$$HO_2 + NO \rightarrow OH + NO_2$$
$$NO_2 + h\nu \rightarrow NO + O$$
$$O + O_2 \rightarrow O_3$$

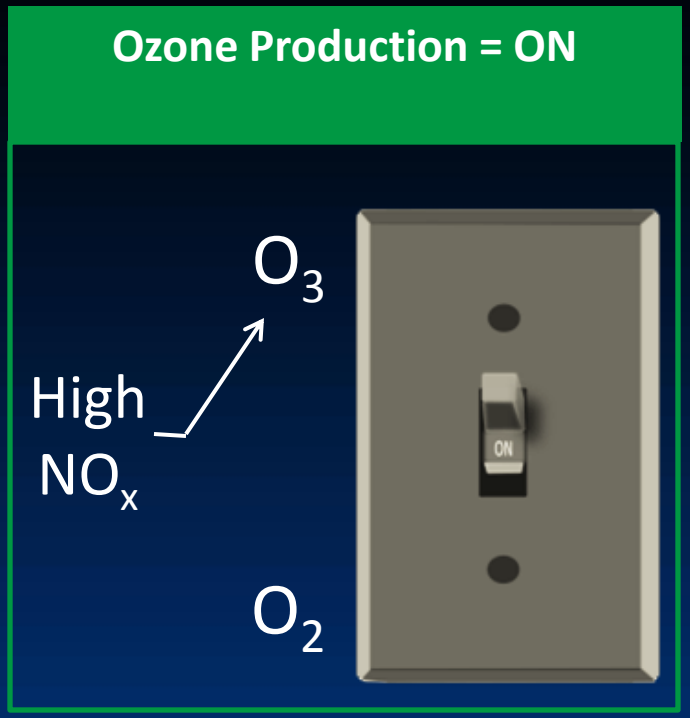


Net: $CO + 2\ O_2 \rightarrow CO_2 + \mathbf{O_3}$

With a high concentration of NO_x in the Atmosphere, the series of reactions leads to the formation of ozone

The Concentration of NO_x in the Atmosphere Can be Thought of as a "Chemical Switch"





Project GO3

Global Ozone Project Curriculum

Lesson 7:
Sunlight and Weather

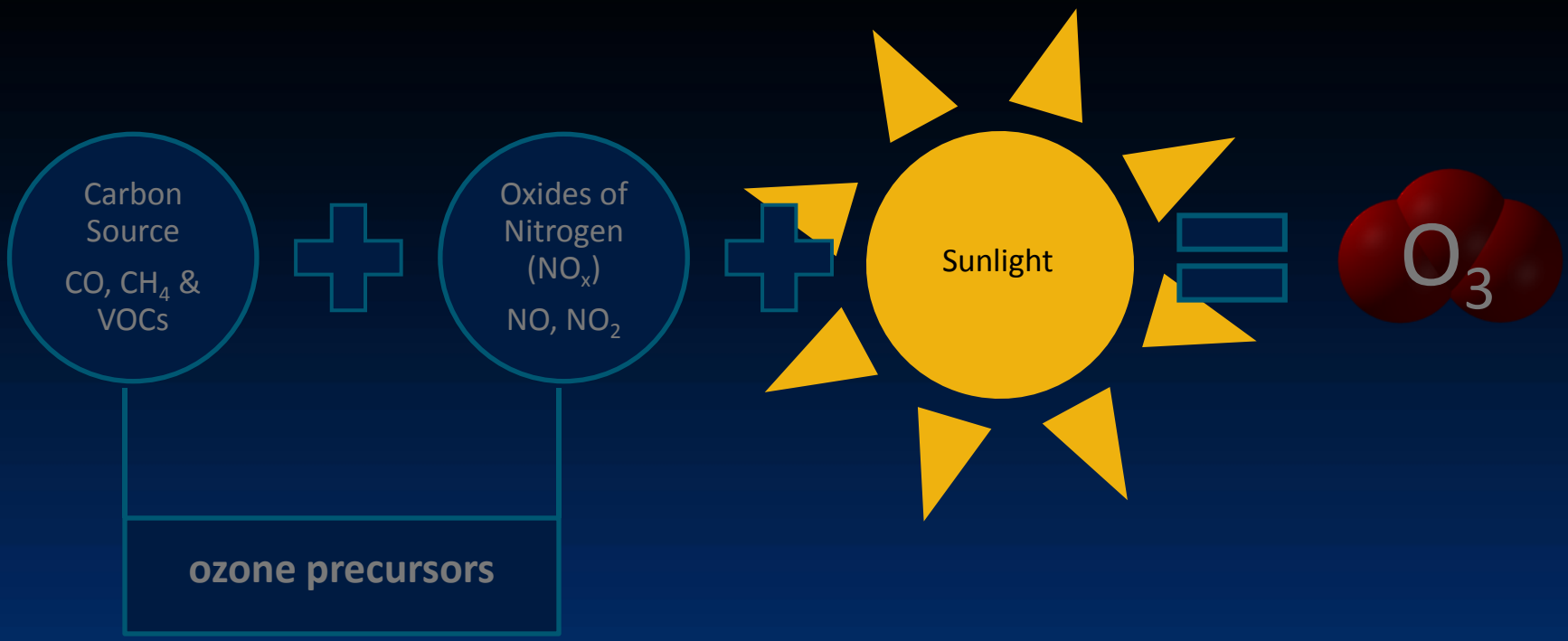
Rev 13

Learning Objectives

At the end of this lesson students will be able to:

- Describe the role of sunlight in the formation of ground level ozone.
- Explain ozone transport locally and globally.
- Identify the role of temperature, humidity, rain, and temperature inversions play in ground level ozone concentrations.
- Describe the seasonality of ground level ozone.

Ground Level Ozone Ingredients

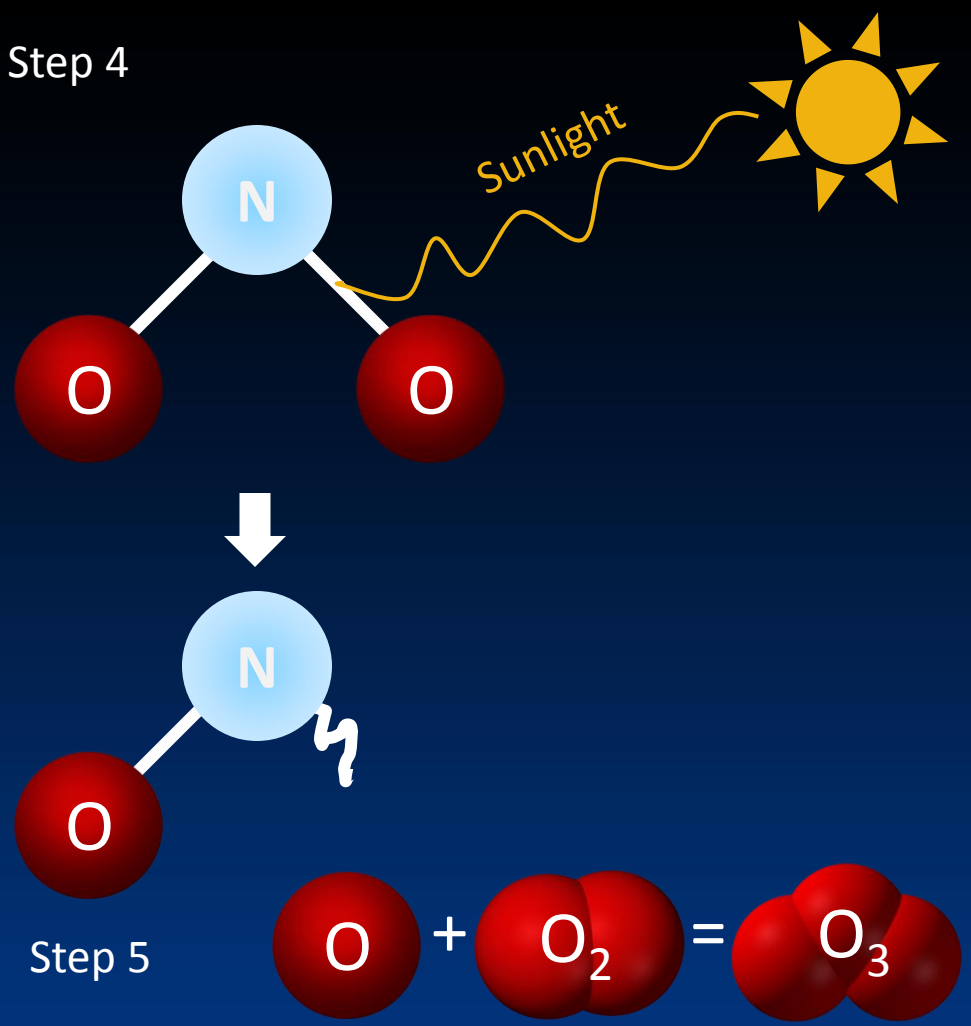


The Role of Sunlight in the Formation of Ozone

Let's take a closer look at steps 4 and 5 in the equation with CO as the precursor:

1. $CO + OH \rightarrow CO_2 + H$
2. $H + O_2 \rightarrow HO_2$
3. $HO_2 + NO \rightarrow OH + NO_2$
4. **$NO_2 + h\nu \rightarrow NO + O$**
5. **$O + O_2 \rightarrow O_3$**

This is why sunlight is needed to produce ozone

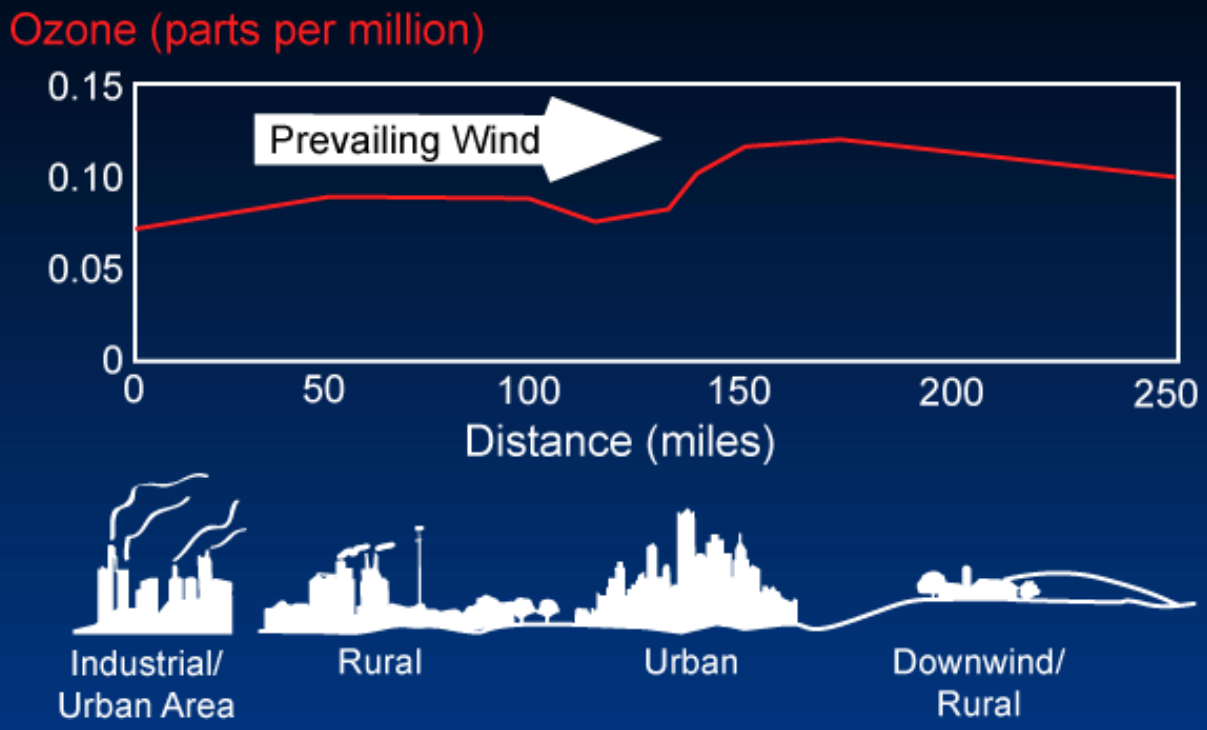


How Weather Affects Ozone Production and Transport

Lesson 7: Sunlight and Weather

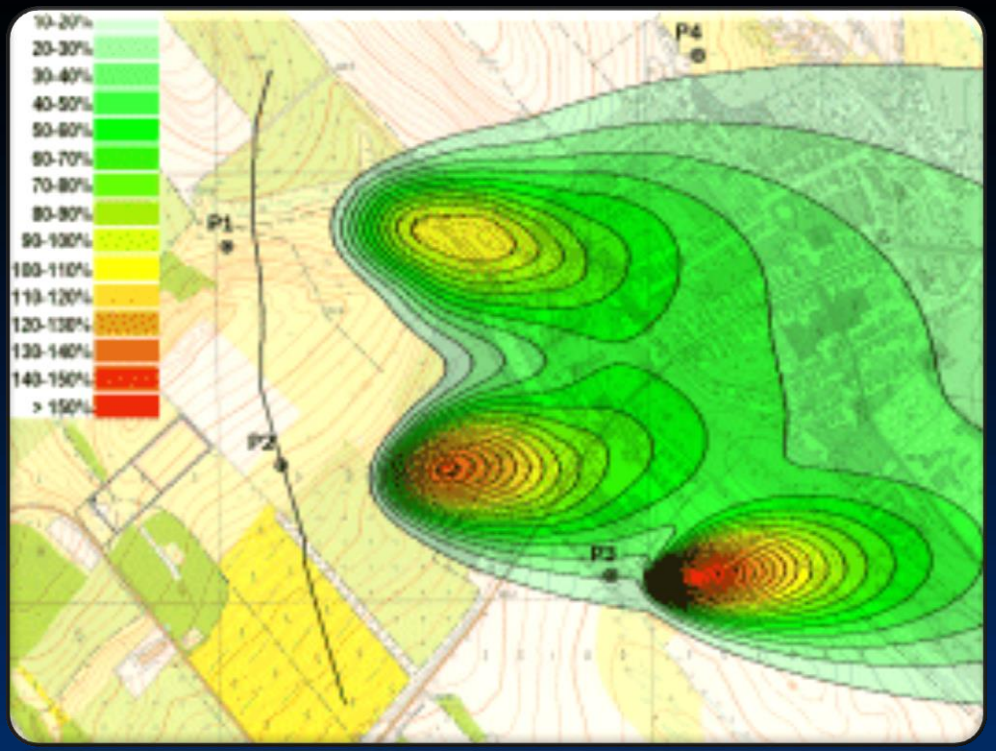
Ozone Transport Downwind

Rural areas can suffer from high ozone that is transported by the wind from large cities. It can also take time for ozone to form, so a city might not see much ozone, but the town downwind of it will see the highest concentrations. This also depends on geographical situation.



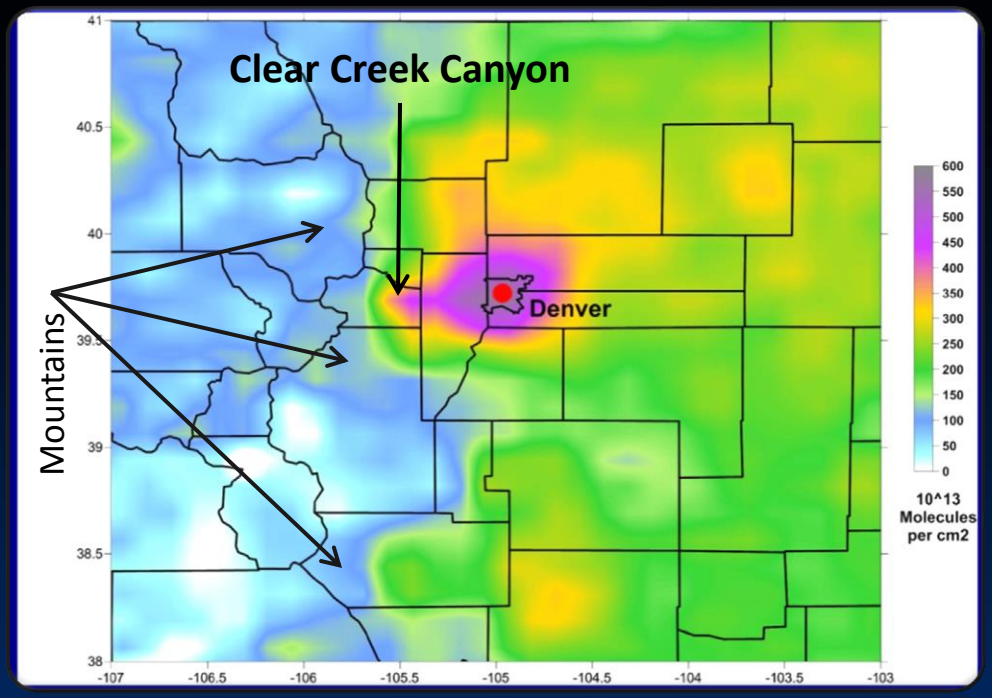
Pollutant Transport Computer Models

Computer models can help us understand the transport of pollutants; this is a snapshot of a model analyzing the transport of pollutants from point sources.

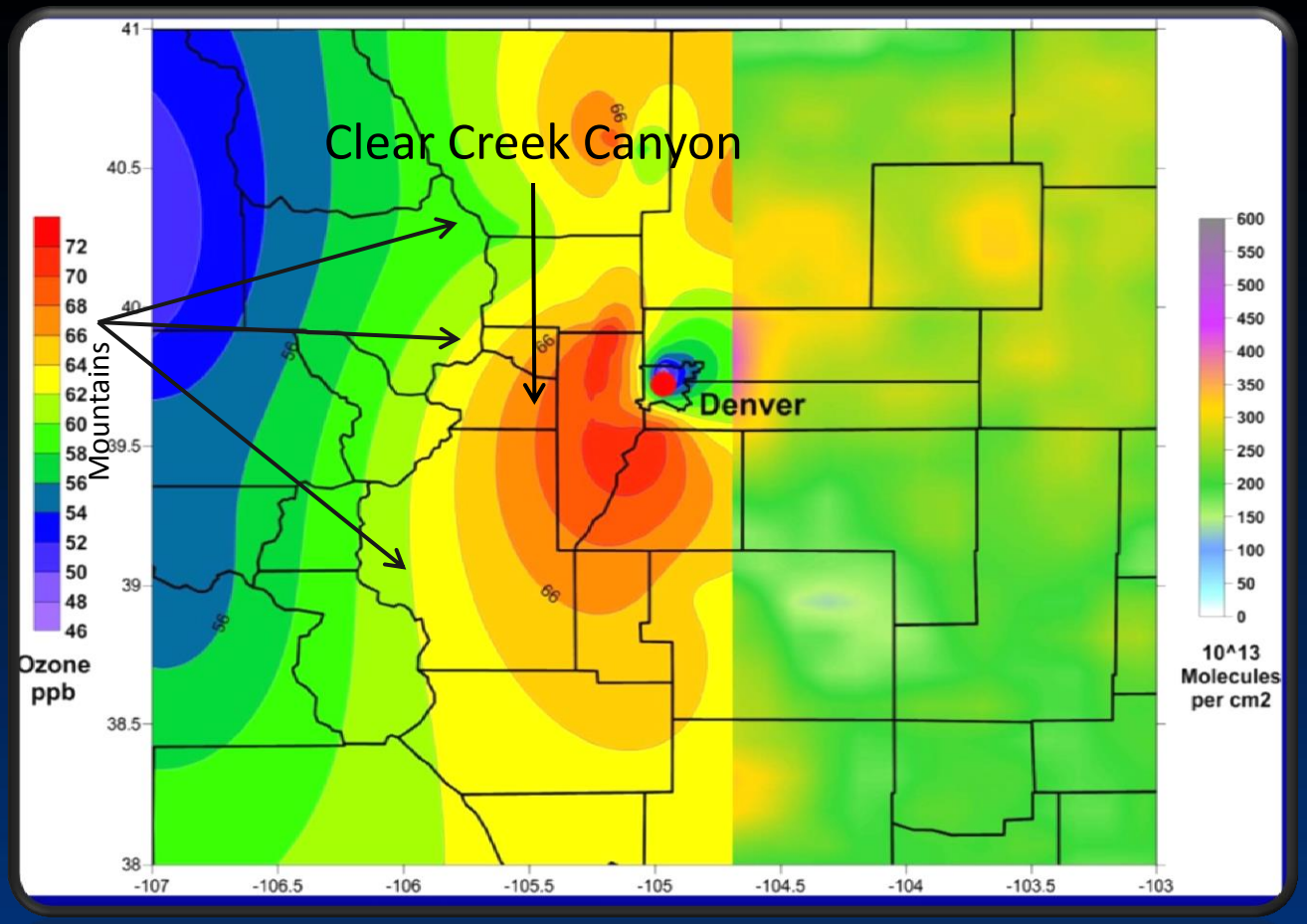


Local Conditions and Weather Phenomena Affects Ozone Formation

- Data collected with a satellite shows Northern Colorado's (USA) average concentration of NO_x for July of 2006. A local upslope phenomenon brings Denver's NO_x up into the mountains, shown here moving up a canyon to the west of Denver.
- This transport of NO_x affects ozone concentration along the mountain range, as shown in the next slide.

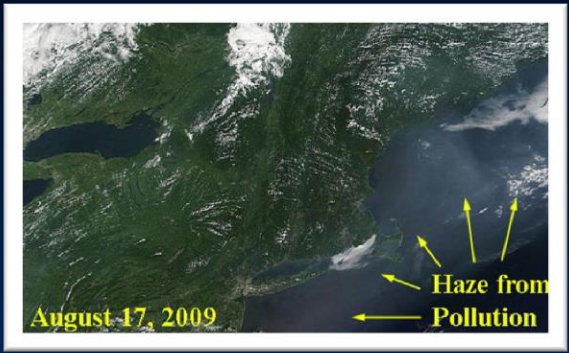


Denver's Upslope Phenomenon Results in High Ozone Along the Mountain Range

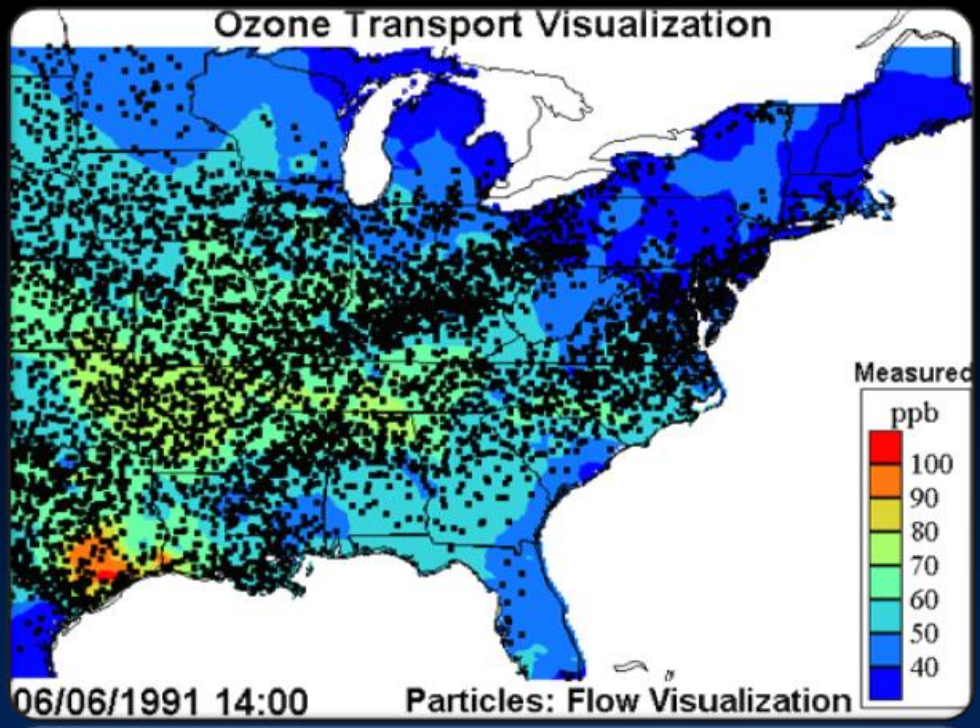


Ozone Transport Visualization

Ozone Transport Visualization of how wind patterns can affect ozone concentrations



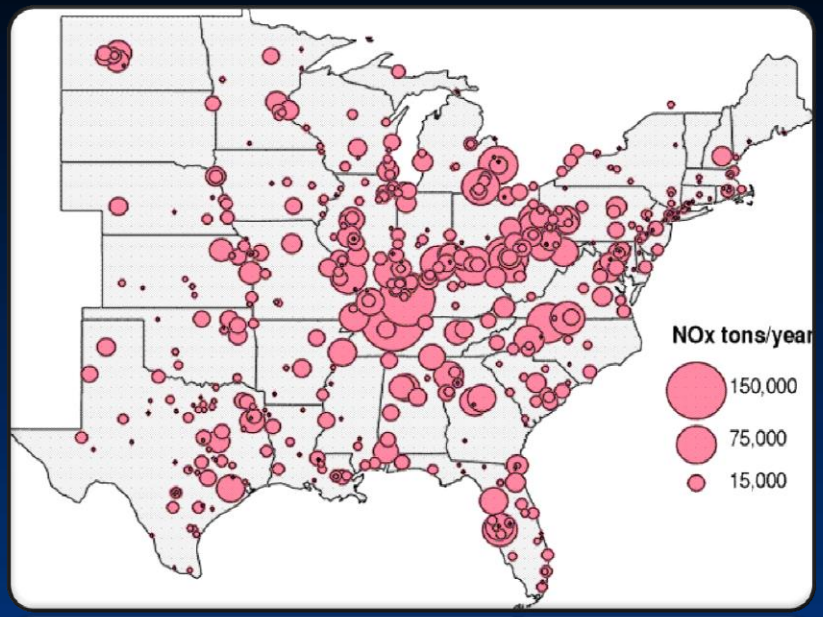
Pollution Coming off of the Northeast Coast of the US



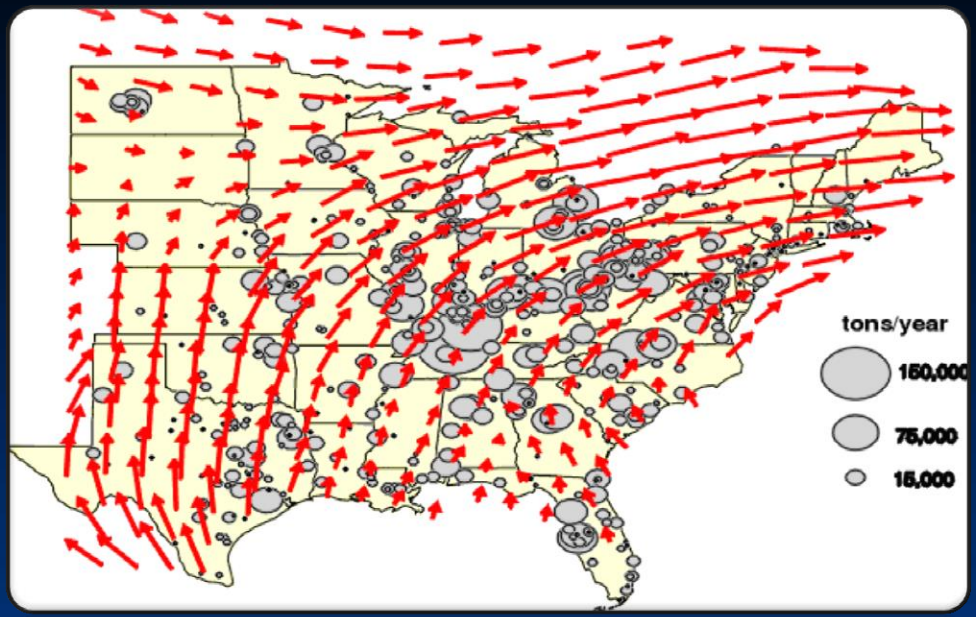
Click on the link to see the animation: YouTube Ozone Transport Video

Analyzing Ozone Transport Using Wind Speed and Direction Arrows

This map shows point sources of NO_x in tons per year

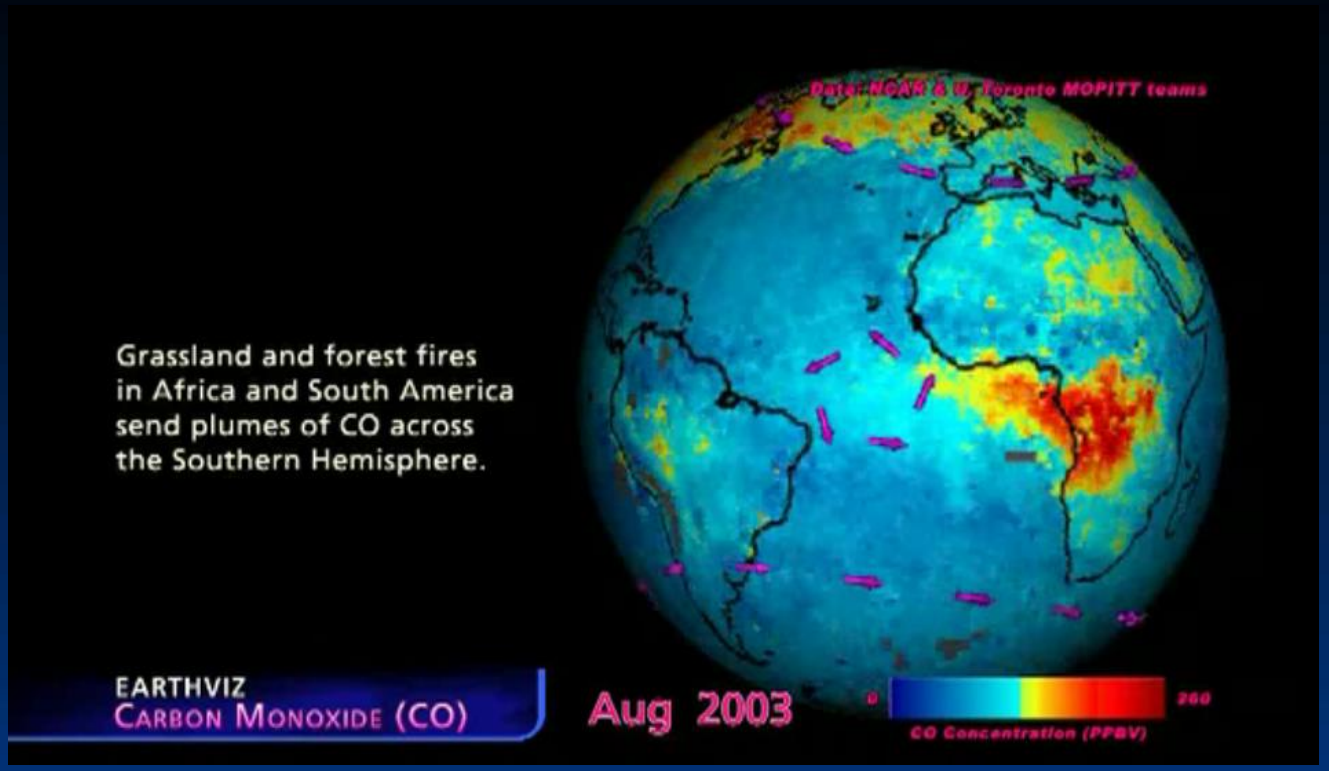


This map shows wind speed and direction overlaid on the point source map (the size of the arrows indicates wind speed, bigger arrows = higher speeds). The wind pattern shown corresponds to the highest ozone days in the Northeastern United States.



Ozone and Other Pollutants Can Circle the Globe

This animation shows CO circling the earth, with ozone following similar patterns. Also, as discussed, ozone concentration is affected by the concentration of CO in the atmosphere.



Click this link to see the animation: YouTube CO Video

Humidity and Temperature Effects on Ozone Formation

Recall the chemical reactions that take place during ozone formation:

$$CO + OH \rightarrow CO_2 + H$$
$$H + O_2 \rightarrow HO_2$$
$$HO_2 + NO \rightarrow OH + NO_2$$
$$NO_2 + h\nu \rightarrow NO + O$$
$$O + O_2 \rightarrow O_3$$

$$\text{Net: } CO + 2\,O_2 \rightarrow CO_2 + O_3$$

OH is called the **Hydroxyl Radical** and is formed from water in the air (humidity). As humidity increases, so does the abundance of hydroxyl radicals. More ozone can be produced if there are more hydroxyl radicals in the air, thus:

Humidity ↑ Ozone ↑

High temperatures cause these reactions to speed up, thus:

Temperature ↑ Ozone ↑

Ozone and Rain

Ozone concentration in the air is not significantly decreased by rain itself, but can be decreased due to its partner – clouds. The clouds cover the sun and reduce the amount of sunlight needed to form ozone.

Unlike Ozone, SO_2 and NO_2 are soluble in water and react with rain drops to form Sulfuric and Nitric Acid, which is better known as **acid rain**.

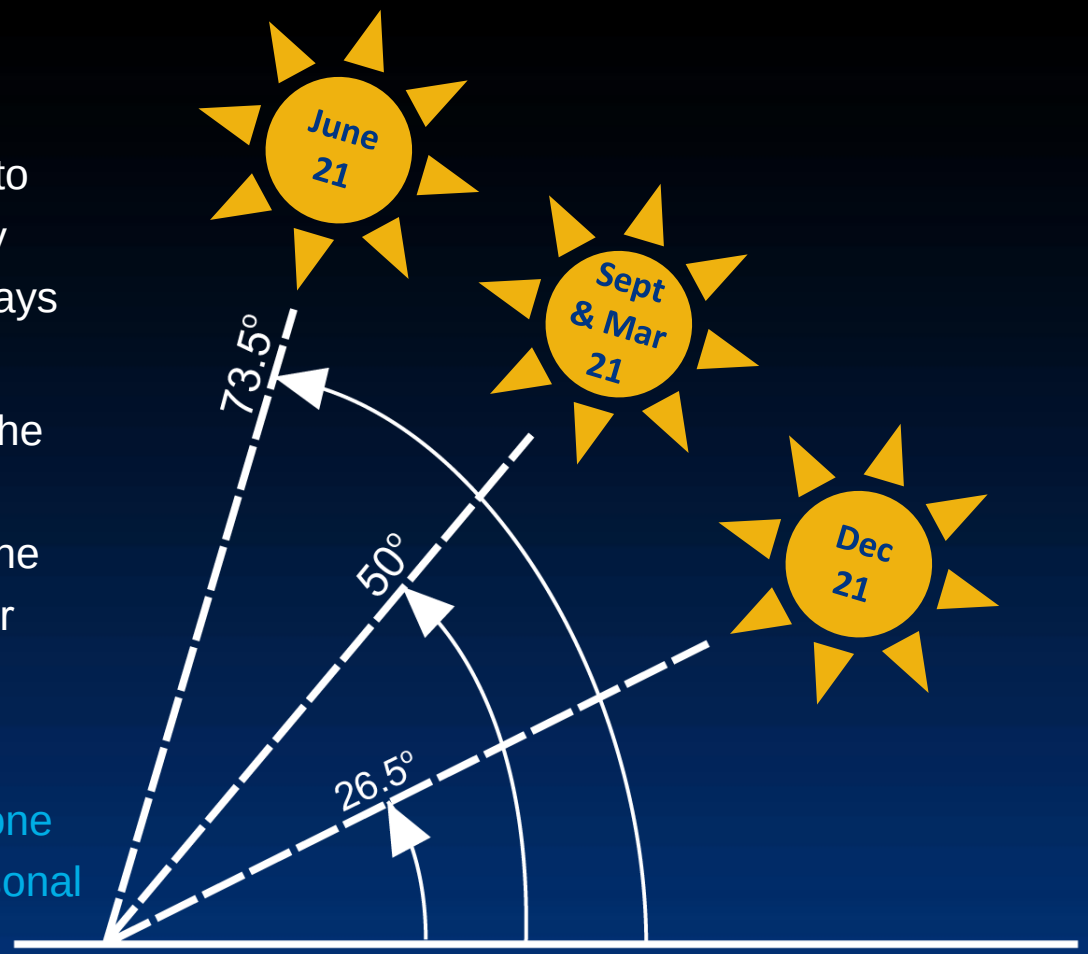
Rain = Clouds = Less Sunlight & UV Rays = Less Ozone

Ozone and the Seasons

Ozone formation is affected by the changing seasons. This is due to the position of the sun in the sky and the angle at which the UV rays hit the Earth's surface.

It also depends on the location, as the sun's position in the sky doesn't change much at latitudes near the equator. This is why it's hot year round at those latitudes.

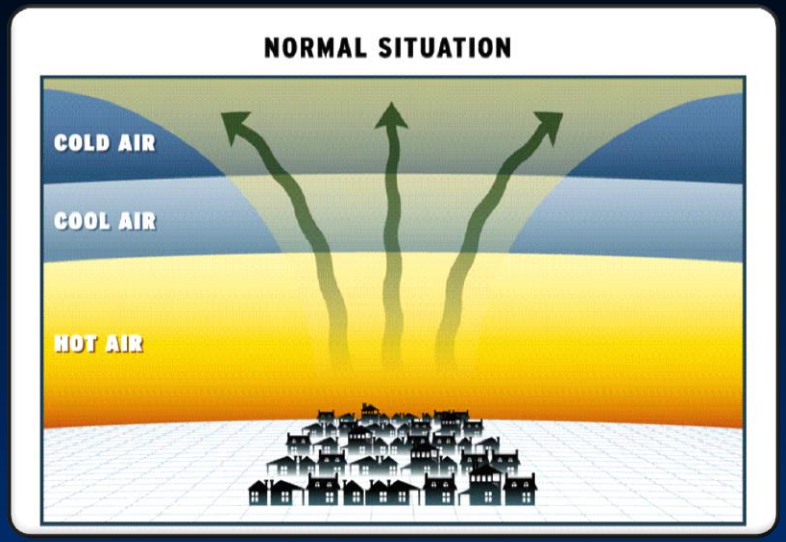
QUESTION: At what latitudes is ozone formation most affected by seasonal changes?



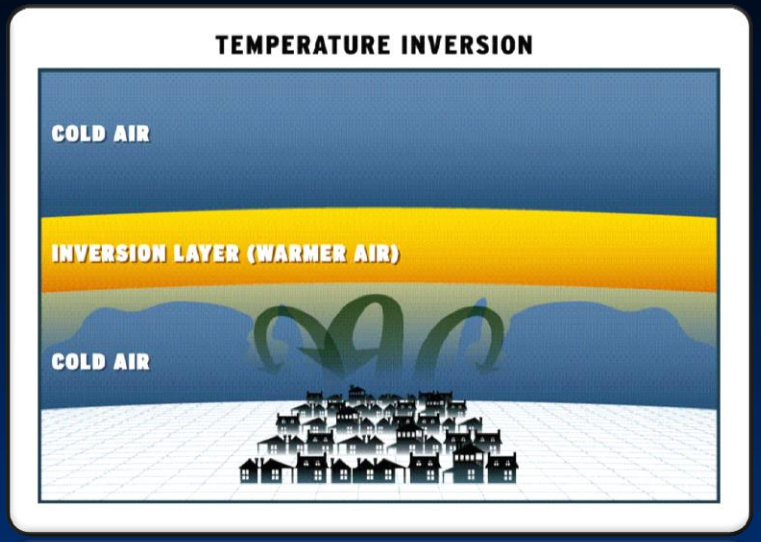
When the sun hits the earth at the 26.5 degree angle during the winter, its intensity is spread over more area and thus reduced. (This diagram shows the sun's angles for the Northern US.) Try this with a flashlight!

Temperature Inversions Can Trap Air Pollution at Ground Level

In the normal situation, hot air rises as shown below.



During a temperature inversion, the cold air stays near the ground, because cold air sinks and stays there.



Temperature Inversions Can Trap Air Pollution at Ground Level

What a temperature inversion can look like: all the pollutants are trapped near the ground

Project GO3

Global Ozone Project Curriculum

Lesson 8:
Harmful Effects of Ground Level Ozone

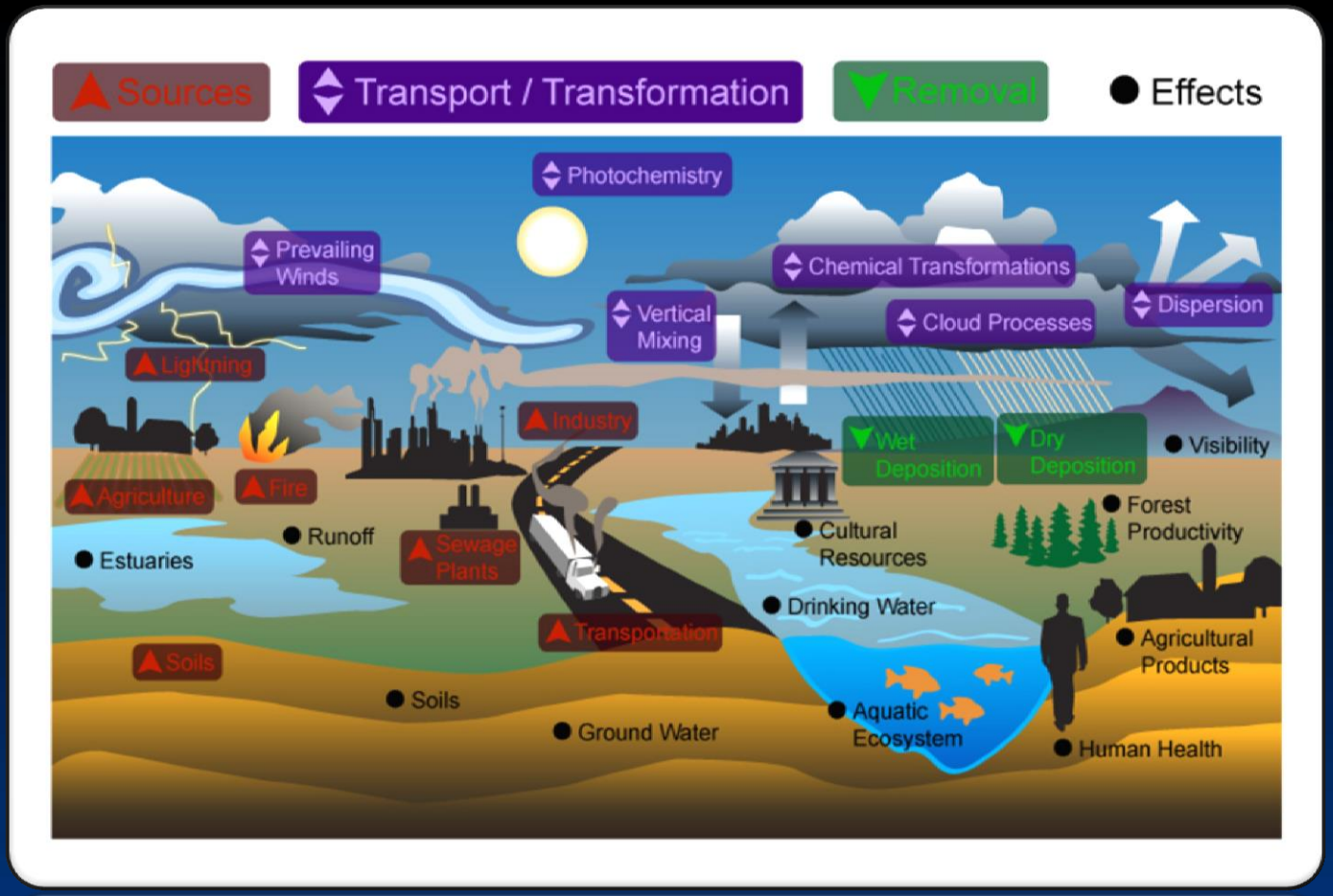
Rev 13

Learning Objectives

At the end of this lesson students will be able to:

- Describe ground level ozone's effect on humans and plants.
- Identify ozone as a greenhouse gas.

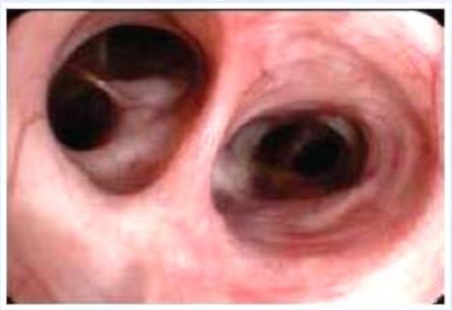
The Pathways and Effects of Air Pollution



Effects of Ozone on Lungs

Ozone can inflame the lungs when breathed which is particularly harmful for people who have asthma, because inhaling ozone can trigger an asthma attack.

34.1 Million People in the US Have Asthma



Ozone can inflame the lung's lining. These photos show a healthy lung airway (left) and an inflamed lung airway (right).
Photos courtesy of PENTAX Medical Company.

Approximately 300 million people in the World Have Asthma

Ozone and the Air Quality Index

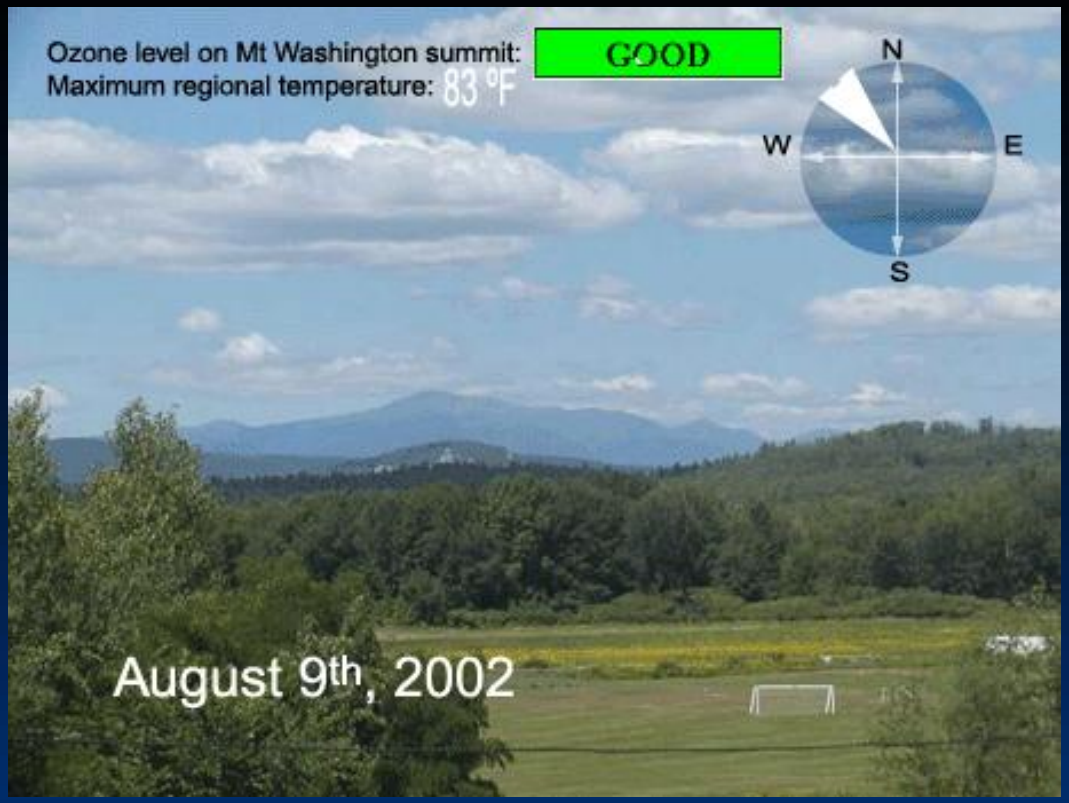
Ozone 8-hr Avg. Concentration*	0 – 59ppb	60 -75ppb	76-95ppb	96-115 ppb	116-374 ppb	375ppb +
AQI Values**	0 - 50	51 - 100	101 - 150	151 – 200	201- 300	300 - 500
Level of Concern & Cautionary Statements	• **Good** Air Little or no health risk.	• **Moderate** People unusually sensitive may be mildly affected.	• **Unhealthy for Sensitive Groups** People with respiratory or heart disease, the elderly and children should limit prolonged exertion.	• **Unhealthy** People with respiratory or heart disease, the elderly and children should avoid prolonged exertion, everyone else should limit prolonged exertion.	• **Very Unhealthy** People with respiratory or heart disease, the elderly and children should avoid any outdoor activity, everyone else should avoid prolonged exertion.	• **Hazardous** Everyone should avoid any outdoor exertion; people with respiratory or heart disease, the elderly and children should remain indoors.

* The top value is obtained by averaging ozone concentration over 8 hours

** The AQI value is typically the number published in your local newspaper or weather report that indicates the air quality. If the primary pollutant listed is ozone, you can back-calculate the ozone in ppb from the AQI. To do this calculation go to: http://airnow.gov/index.cfm?action=aqi_calc.aqi_conc_calc

Ozone and Visibility

Ozone is commonly associated with poor visibility in areas with high ozone levels.

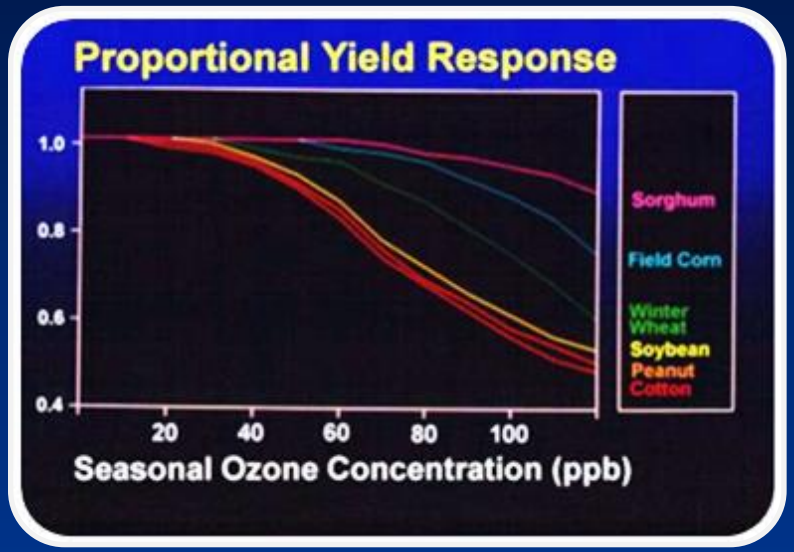


View the slide in slideshow mode or click on the link to see the animation: Haze Animation

Effects of Ozone on Crop Production

15 ppb 80 ppb 100 ppb

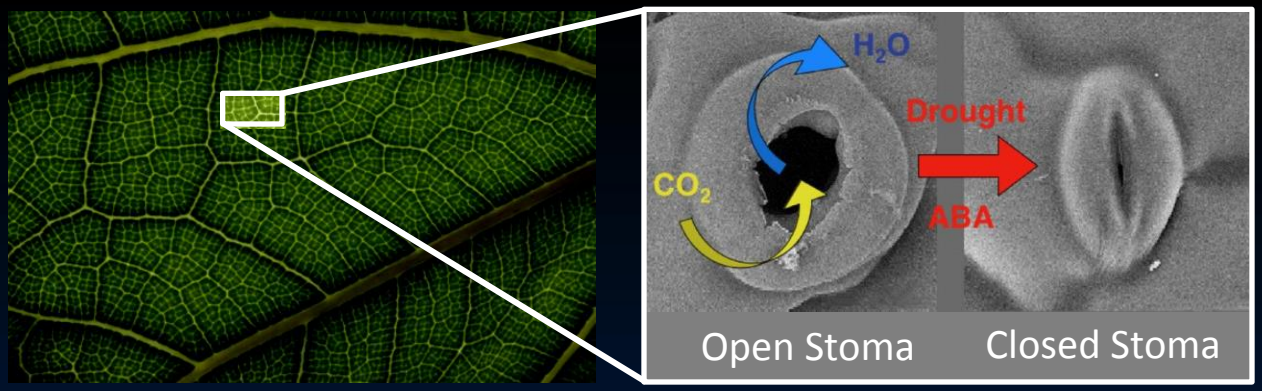
Effects of Ozone on Crop Production



This chart shows crop reductions for various crops as a function of increased ozone levels.

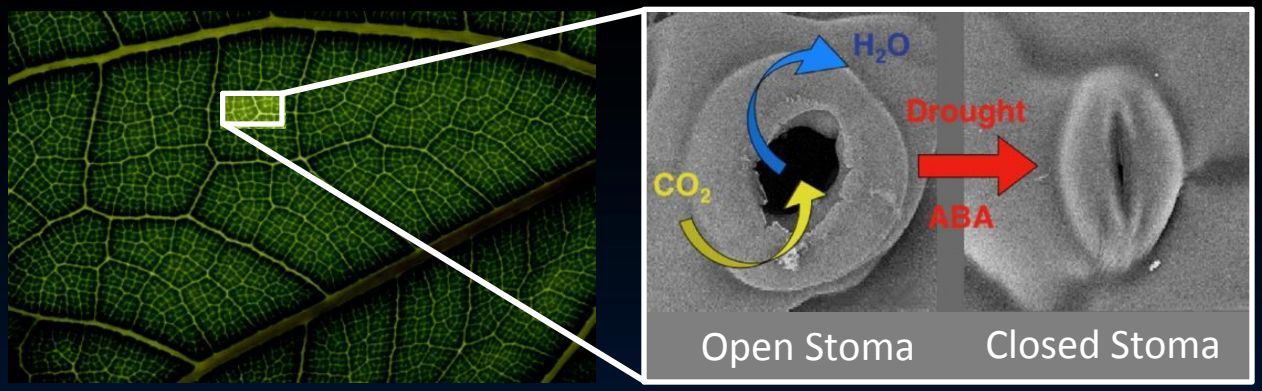
QUESTION: Which crop is the most sensitive?

How Ozone Enters Plants



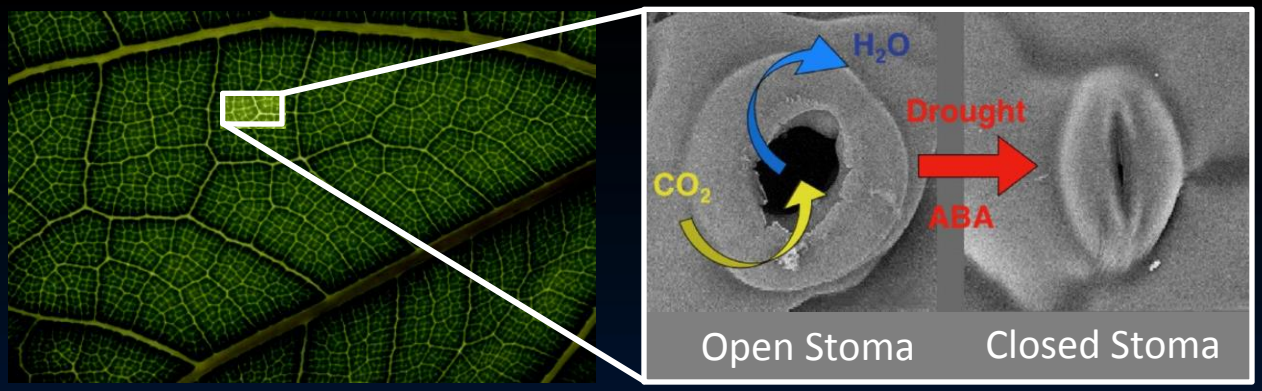
1. The plant opens and closes its **stomata** (the plural of stoma) while performing its normal processes. Under normal conditions the stomata open and close to exchange water and carbon dioxide. The stomata always close when there is a drought, or the plant is stressed.

How Ozone Enters Plants



2. When the plant's stomata are open ozone can get into the plant.

How Ozone Enters Plants



3. When the plant detects that ozone is entering the stomata, it closes its stomata so that no more ozone can get in.

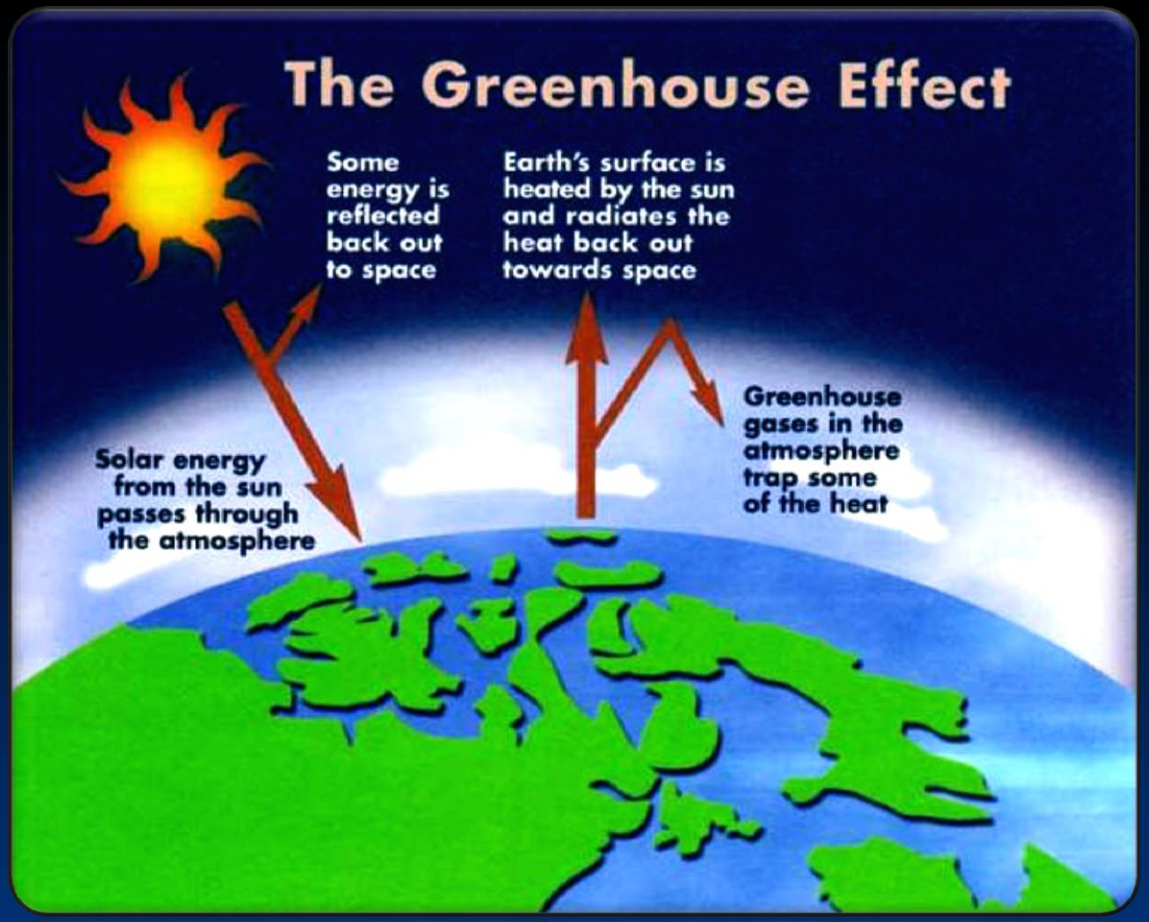
How Ozone Enters Plants

Ozone damage causes **stipple**, which always occurs on the top surface of the leaf and in between the veins

4. When the stomata are closed so that no more ozone can get in, it's like what happens to a plant during a drought. When the stomata are closed, the plant can't get the CO_2 it needs to keep it healthy, leading to plant death around the stomata.

QUESTION: Can ozone damage happen during a drought? Why or why not?

Ozone is a Greenhouse Gas and Contributes to Global Warming

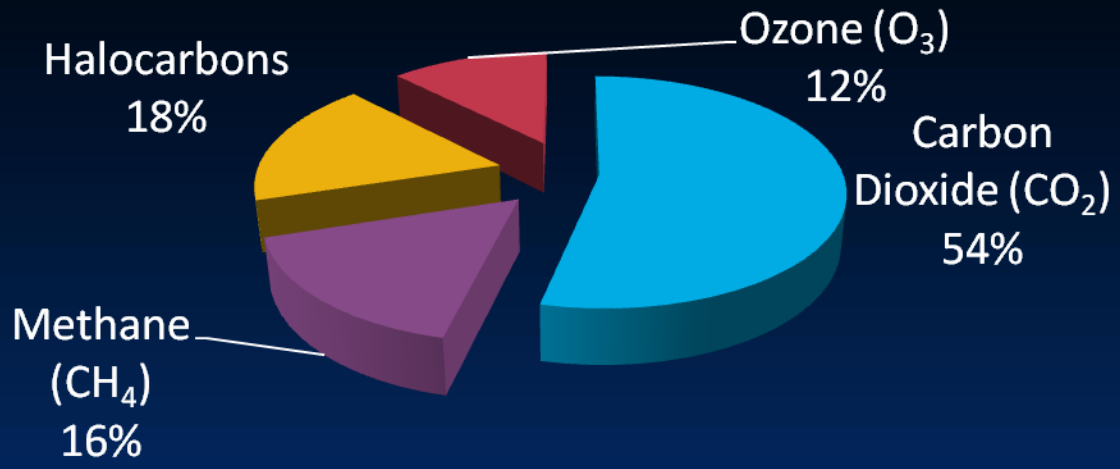


Interesting Fact:

Without any CO_2 or other greenhouse gases, our planet would be a frozen planet. However, because of the presence of greenhouse gases the temperature near the earth's surface is warmer, making lakes and liquid oceans possible. Life as we know it depends on the greenhouse effect. But, scientists now agree that air pollutants are causing a dangerous additional "global warming".

Major Global Warming Gases

The four main anthropogenic global warming gases are listed below, along with their percentage contribution to global warming.



QUESTION: What happens to the rate of ozone formation as the planet warms? Does it increase or decrease? Why?

Project GO3

Global Ozone Project Curriculum

Lesson 9:
Stratospheric Ozone and the Ozone Hole

Rev 13

Learning Objectives

At the end of this lesson the students will be able to:

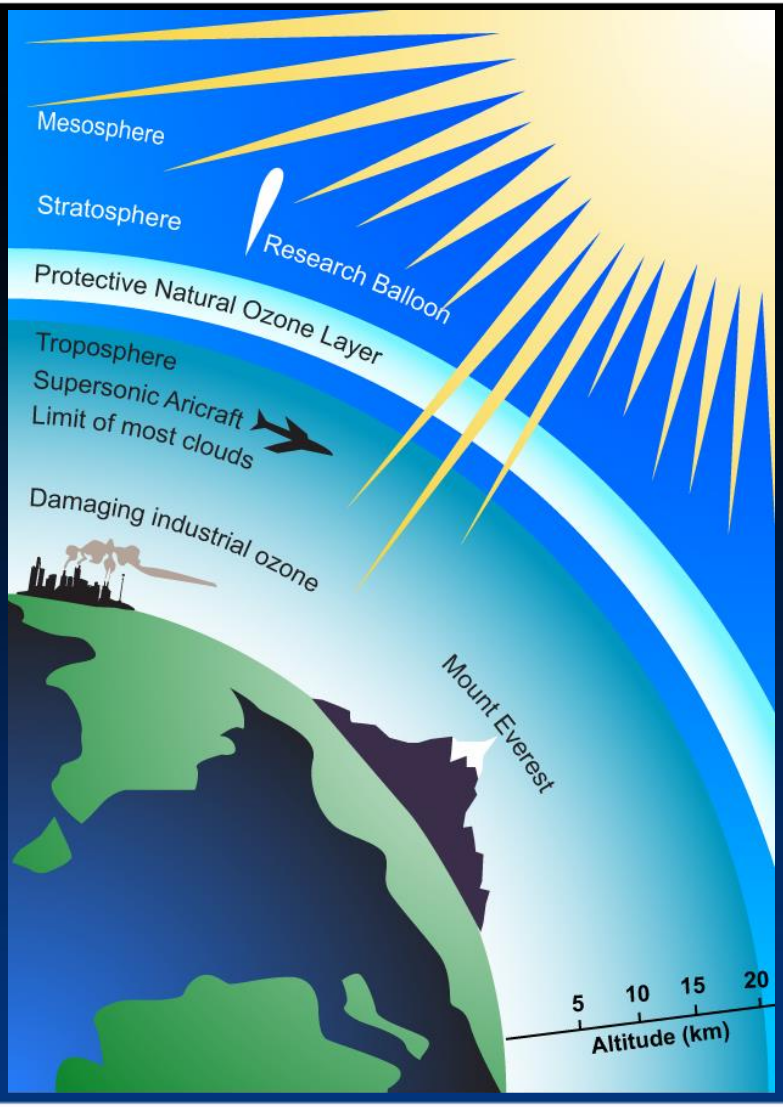
- Identify the main causes of stratospheric ozone depletion.
- Explain Dobson Units and how they are used to describe the thickness of the ozone layer.
- Describe why the ozone hole occurs over Antarctica.
- Discuss the requirements of the Montreal Protocol.

The Stratospheric Ozone Layer: a Giant Umbrella for Earth

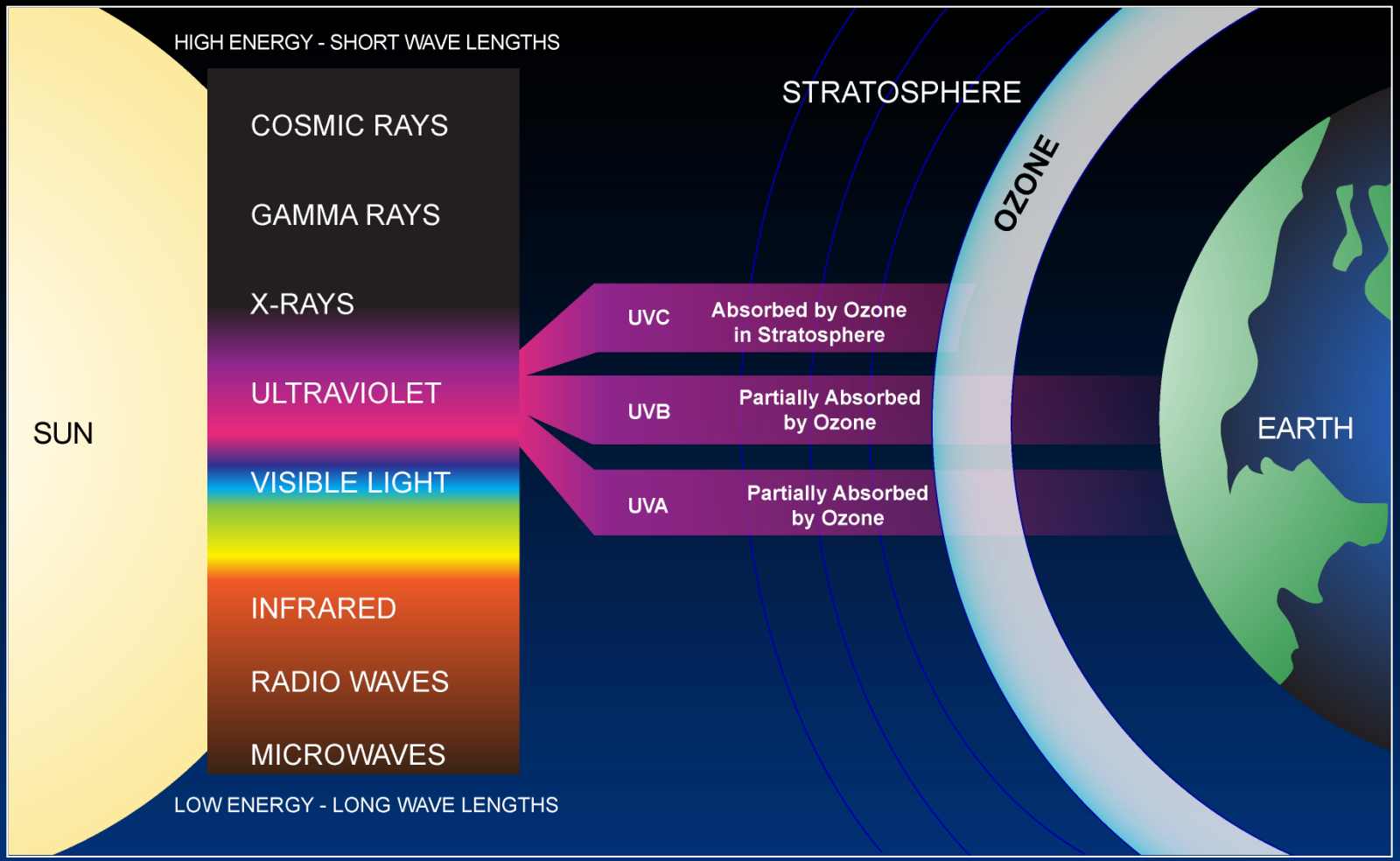
The Stratospheric Ozone Layer: Location in the Atmosphere

OZONE LAYER

20-40 KM ABOVE EARTH'S SURFACE

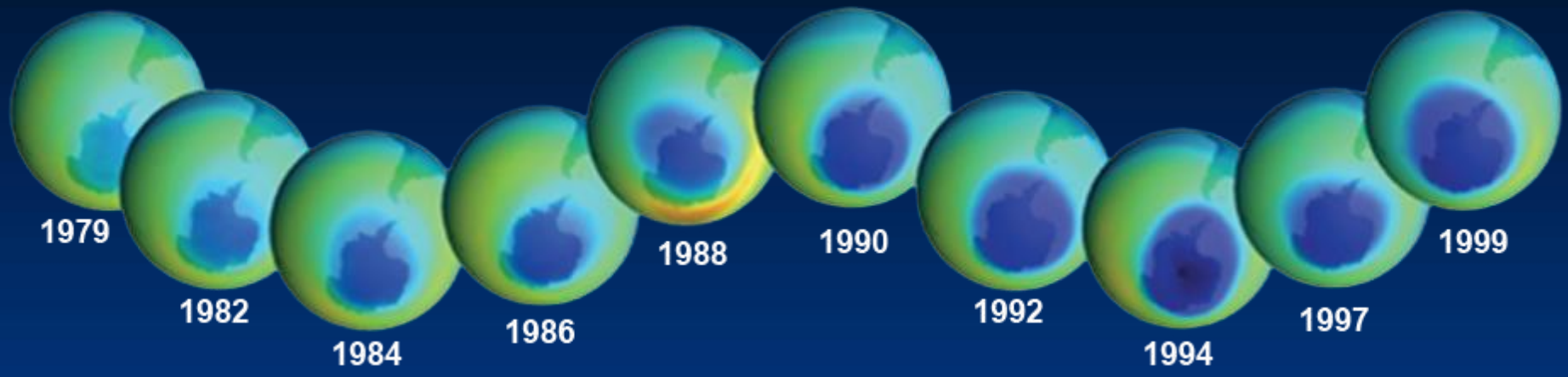


The Stratospheric Ozone Layer: Filters Out Many of the Sun's Harmful Rays



Thinning of the Ozone Layer Over Antarctica

These satellite images illustrate the development of the ozone hole during the 1980s and 1990s. Dark blue colors correspond to the thinnest ozone, while light blue, green, and yellow indicate thicker ozone. (Image courtesy of the NASA GSFC Scientific Visualization Studio.)



Thinning of the Ozone Layer Over Antarctica

The ozone “hole” is not exactly a hole, it actually refers to the thinning of the ozone layer. The extent of ozone thinning covers the entire continent of Antarctica.

To put the area of ozone thinning into perspective, this is a comparison of the sizes of the US and Antarctica.

The Thickness of the Ozone

- Seen from space, the edge of the Earth is blurred by the pale blue atmosphere.
- Most dense at the surface, the atmosphere thins with altitude, until it gradually merges with the vacuum of outer space.
- Total ozone is measured through the entire atmospheric column, from the surface to the edge of space.

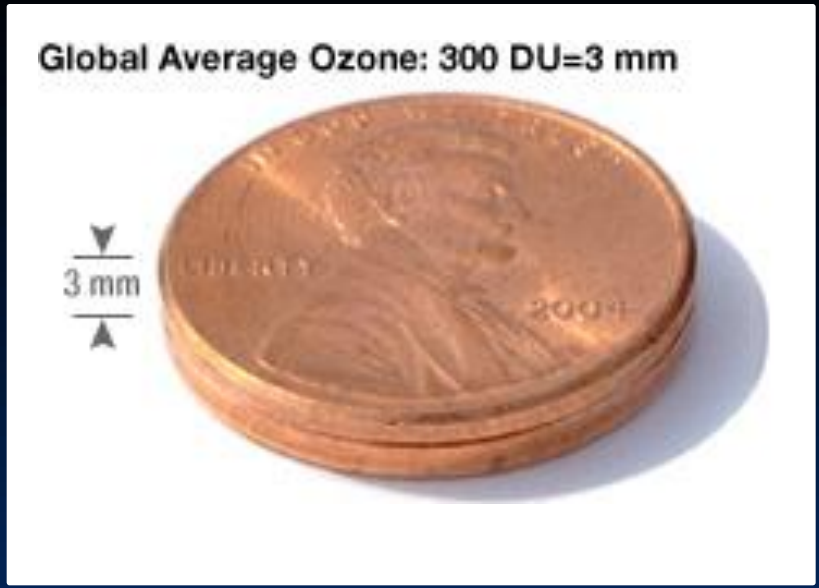
The Thickness of the Ozone Layer is Measured in Dobson Units

If you compressed the total amount of ozone throughout the height of the atmosphere to a pressure of 1 atmosphere and measured its height in millimeters then …

- 1 mm = 100 Dobson Units
- 3 mm = 300 Dobson Units
- 5 mm = 500 Dobson Units

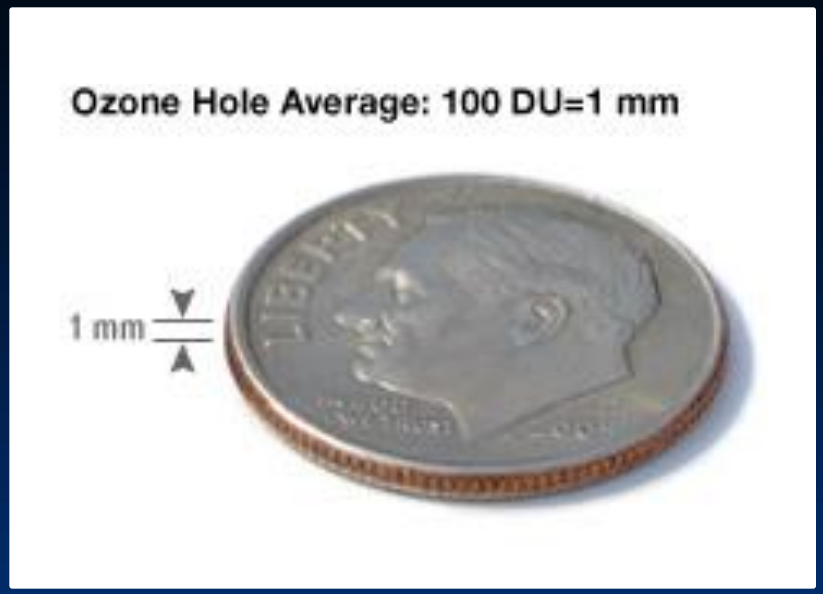
The Global Average Ozone is 300 DU

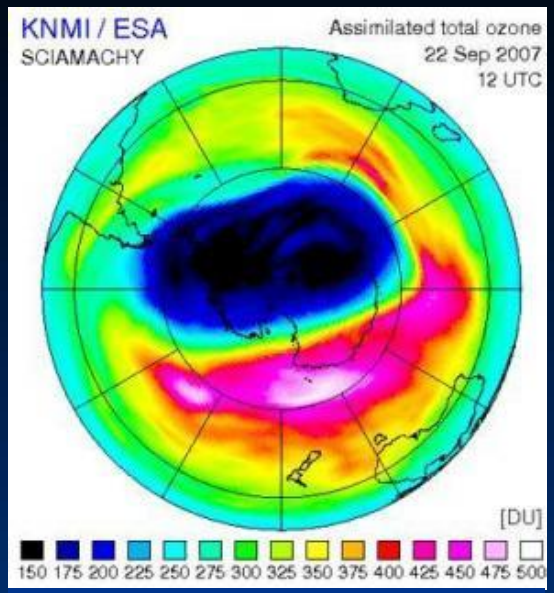
The global average ozone of 300 DB would be 3 mm if compressed to one atmosphere of pressure - the approximate thickness of two pennies



The Global Average Ozone is 300 DU

In the ozone “hole”, the layer would only be about 1mm thick

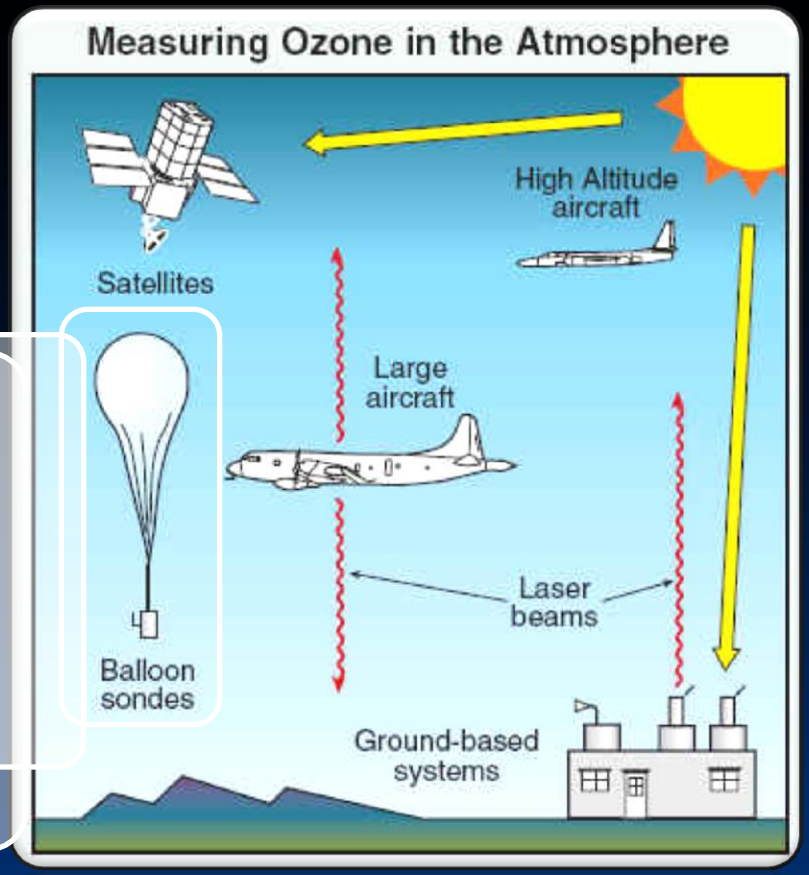




Ozone hole over Antarctica measured in September 2007 by Envisat. (Credit: KNMI - ESA)

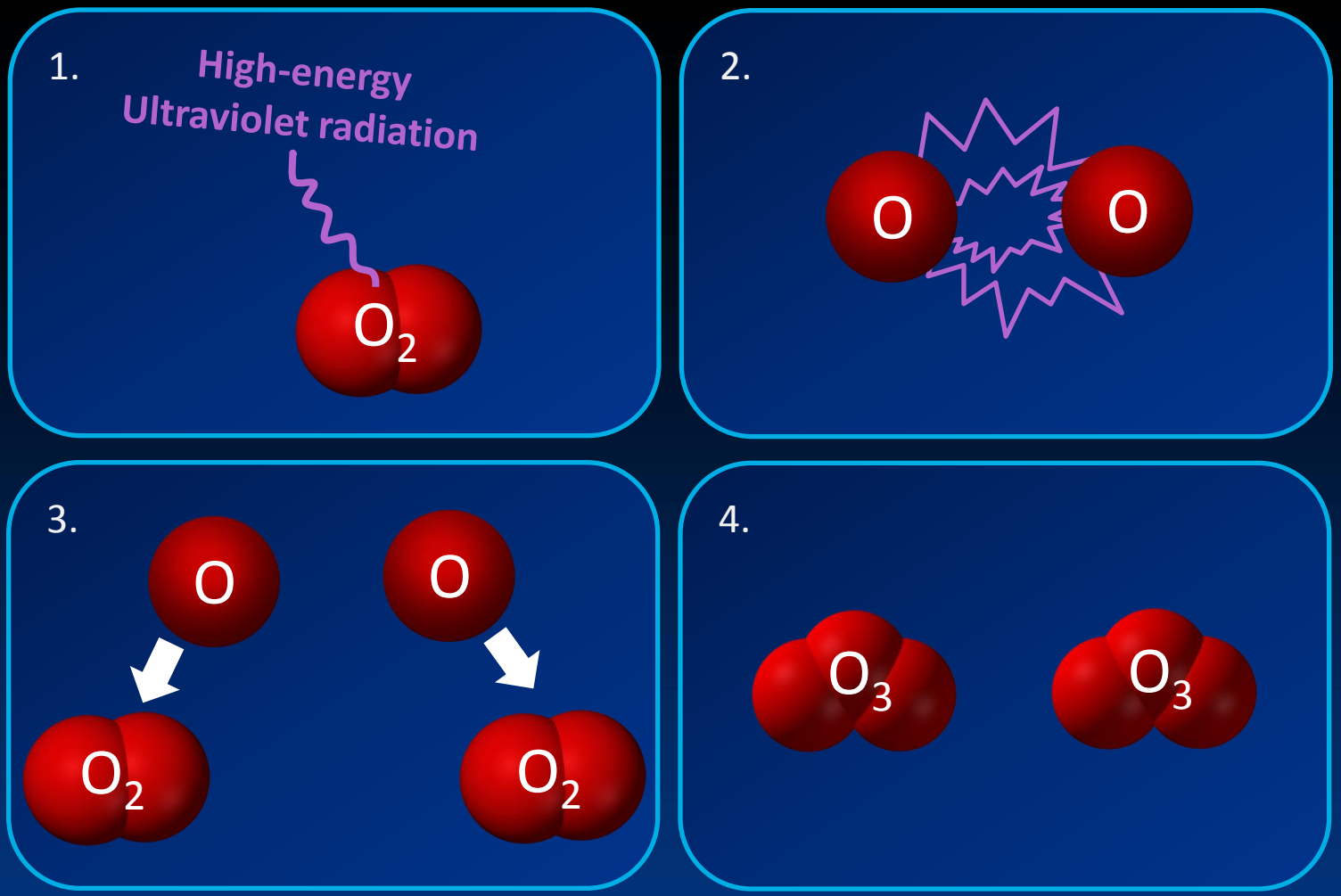
Methods of Measuring Ozone in the Stratosphere

Scientists have many different methods of measuring the amount of ozone in the stratosphere



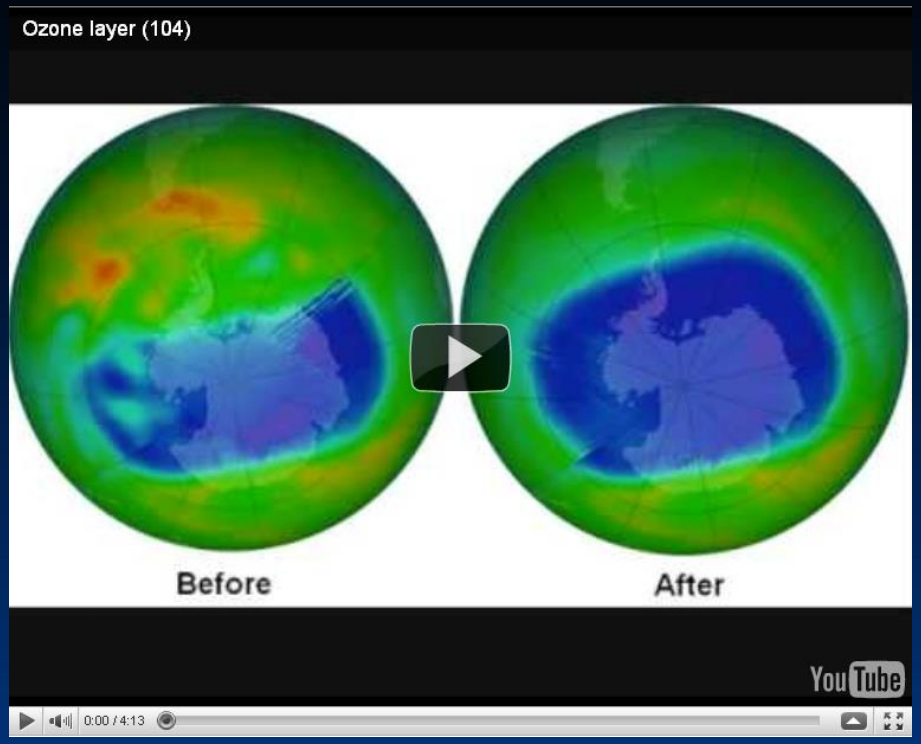
Scientists launch a balloon sonde in Antarctica

Formation of Ozone in the Stratosphere



Video

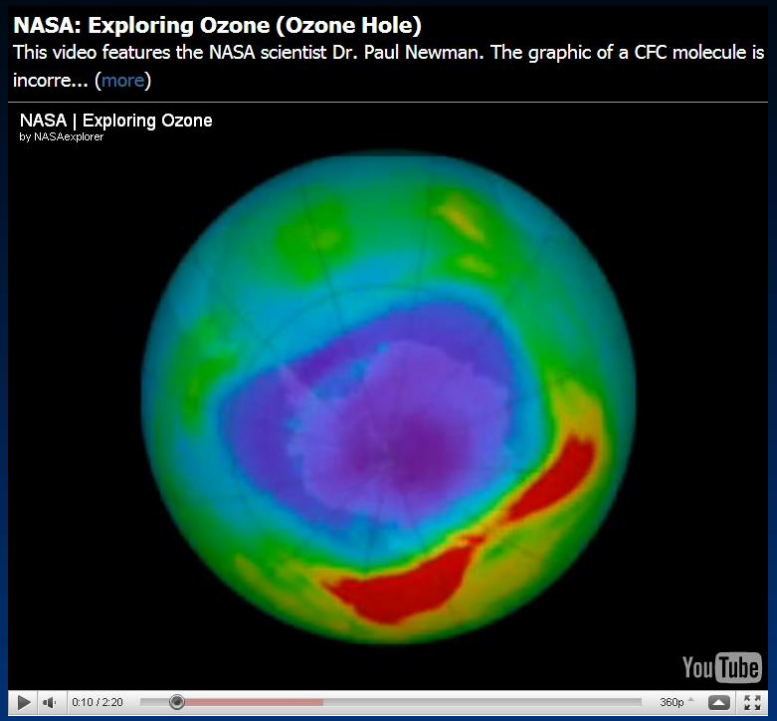
Explaining Ozone Destruction: Click on the link below to see a video about the Earth's protective ozone layer.



Click on the link to view the video: YouTube Ozone Destruction Video

NASA Video

Why the Ozone Hole Occurs Over Antarctica: Click on the link below to view a NASA video explaining the Antarctic "Ozone Hole".



Click on the link to view the video: YouTube Antarctic Ozone Video

Ozone Depleting Substances

Common Ozone-Depleting Substances and Some Alternatives‡

Substance	Uses	Ozone-Depleting Potential*	Global Warming Potential**
Chlorofluorocarbons (CFCs)	Refrigerants, cleaning solvents, aerosol propellants, and blowing agents for plastic foam manufacture.	0.6 – 1.0	4,680 – 10,720
Halons	Fire extinguishers/fire suppression systems, explosion protection.	3 – 10	1,620 – 7,030
Carbon tetrachloride (CCl_4)	Production of CFCs (feedstock), solvent/diluents, fire extinguishers.	1.1	1,380
Methyl chloroform ($CHCl_3$)	Industrial solvent for cleaning, inks, correction fluid.	0.1	144
Methyl bromide (CH_3Br)	Fumigant used to control soil-borne pests and diseases in crops prior to planting and in commodities such as stored grains. Fumigants are substances that give off fumes; they are often used as disinfectants or to kill pests.	0.6	5
Hydrochlorofluorocarbons (HCFCs)	Transitional CFC replacements used as refrigerants, solvents, blowing agents for plastic foam manufacture, and fire extinguishers. HCFCs deplete stratospheric ozone, but to a much lesser extent than CFCs; however, they are greenhouse gases.	0.01 – 0.5	76 – 2,270
Hydrofluorocarbons (HFCs)	CFC replacements used as refrigerants, aerosol propellants, solvents, and fire extinguishers. HFCs do not deplete stratospheric ozone, but they are greenhouse gases.	0	122 – 14,130

‡ This is a limited list and does not represent all of the alternatives approved by EPA's Significant New Alternatives Policy (SNAP) program. For a complete list, see: www.epa.gov/ozone/snap/lists/index.html.

* Ozone-depleting potential (ODP) is the ratio of the impact on ozone caused by a chemical compared to the impact of a similar mass of CFC-11. The ODP of CFC-11 is 1.0.

** Global warming potential (GWP) is the ratio of the warming caused by a substance compared to the warming caused by a similar mass of carbon dioxide. The GWP of carbon dioxide is 1.0.

Brief Timeline of Major Events in the Discovery of the Ozone Hole

Interesting Fact: Even though NASA had been measuring worldwide ozone since 1974, they initially "missed" detecting the ozone hole, because their computer was programmed to discard all ozone data that was below 180 Dobson Units. It was previously thought to be impossible for the ozone layer to be thinner than 180 Dobson Units, so NASA initially thought the data was incorrect.

1928 — The first CFCs are made by DuPont

1956 — The British Antarctic Survey begins making ground-based measurements of ozone over Antarctica

1974 — Scientists Molina and Rowland publish a study that shows CFCs have the potential to destroy ozone

1978 — NASA begins to make worldwide ozone measurements by satellite

1985 — British Antarctic Survey scientists Farman, Gardiner, and Shanklin publish a paper describing the ozone hole based on their ground-based measurements

1986 — NASA confirms the ozone hole with satellite data

Montreal Protocol

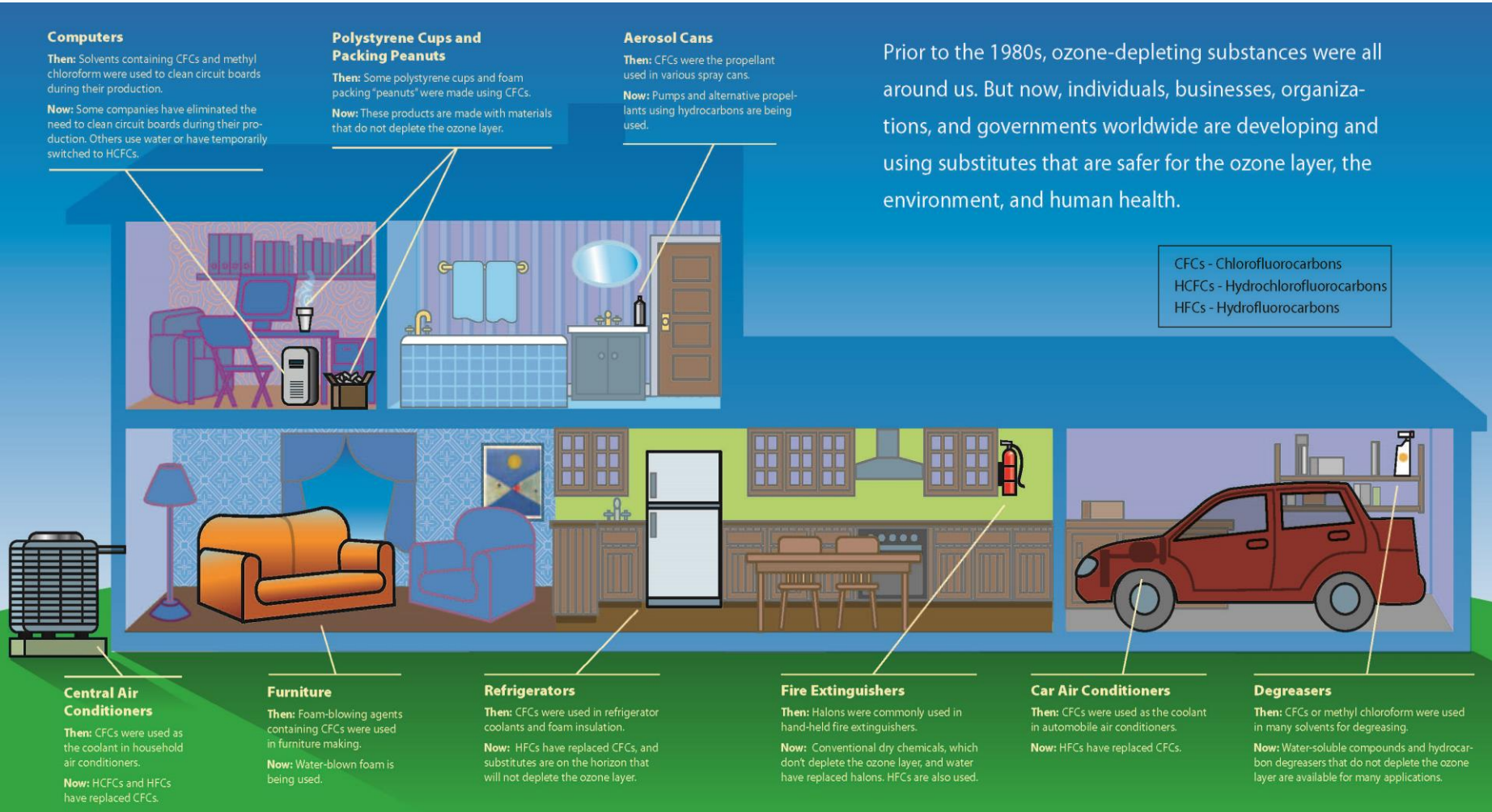
The **Montreal Protocol on Substances That Deplete the Ozone Layer** is an international treaty designed to protect the ozone layer by phasing out the production of a number of substances (CFCs and related compounds) responsible for ozone depletion. It outlines two timelines, one for developed countries and one for developing countries.

Due to its widespread adoption and implementation it has been hailed as an example of exceptional international co-operation with Kofi Annan, the Former Secretary General of the United Nations, quoted as saying that the Montreal Protocol is "perhaps the single most successful international agreement to date“.

Montreal Protocol

Summary of Montreal Protocol control measures		
Ozone depleting substances	Developed countries	Developing countries
Chlorofluorocarbons (CFCs)	Phased out end of 1995[a]	Total phase out by 2010
Halons	Phased out end of 1993	Total phase out by 2010
Carbon tetrachloride	Phased out end of 1995[a]	Total phase out by 2010
Methyl chloroform	Phased out end of 1995[a]	Total phase out by 2015
Hydrochlorofluorocarbons (HCFCs)	Freeze from beginning of 1996[b] 35% reduction by 2004 75% reduction by 2010 90% reduction by 2015 Total phase out by 2020[c]	Freeze in 2013 at a base level calculated as the average of 2009 and 2010 consumption levels 10% reduction by 2015 35% reduction by 2020 67.5% reduction by 2025 Total phase out by 2030[d]
Hydrobromofluorocarbons (HBFCs)	Phased out end of 1995	Phased out end of 1995
Methyl bromide (horticultural uses)	Freeze in 1995 at 1991 base level[e] 25% reduction by 1999 50% reduction by 2001 70% reduction by 2003 Total phase out by 2005	Freeze in 2002 at average 1995-1998 base level[e] 20% reduction by 2005 Total phase out by 2015
Bromochloromethane (BCM)	Phase out by 2002	Phase out by 2002

Examples of Where Ozone Depleting Substances Can be Used Around the Home



Project GO3

Global Ozone Project Curriculum

Lesson 10:
How an Ozone Monitor Works

Rev 13

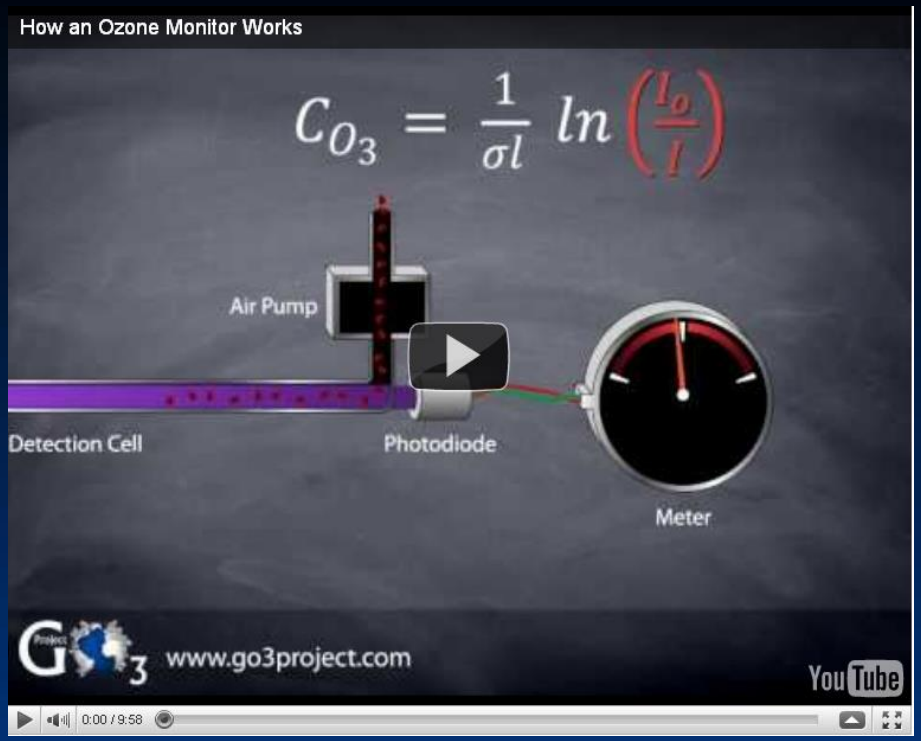
Learning Objectives

At the end of this lesson students will be able to:

- Define UV absorbance and explain how it is used to detect ozone.
- Describe the important terms in the mathematical equation for ozone concentration.

Ozone Monitor Video

Please Click on the Link Below for a Video Describing How an Ozone Monitor Works



Click on the link to view the video: Ozone Monitor Video

Project G O3

Global Ozone Project Curriculum

Lesson 11: Data Collection and Integration

Rev 13

Learning Objectives

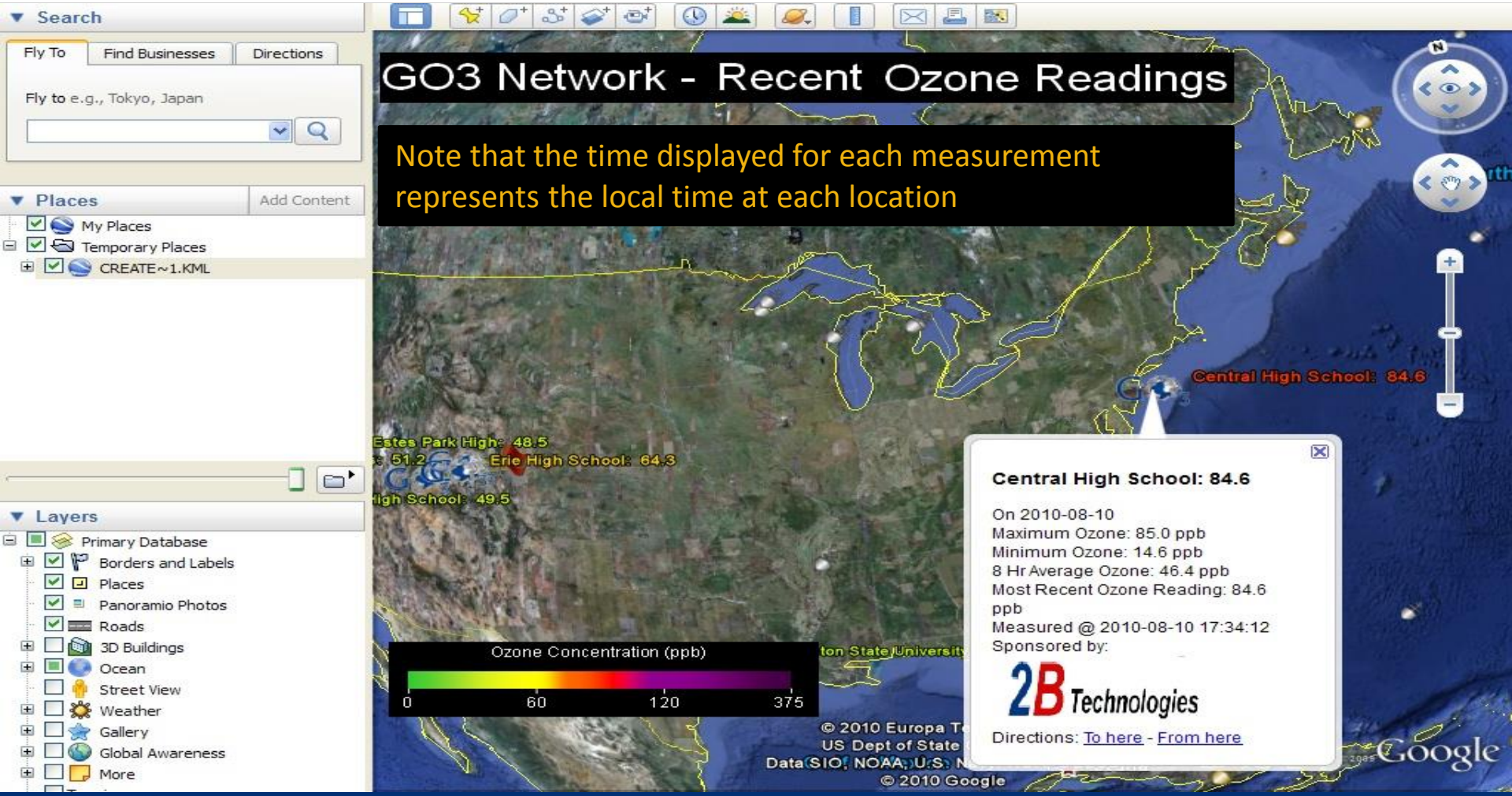
At the end of this lesson students will be able to:

- Plot and analyze ozone data to identify interesting trends and events.

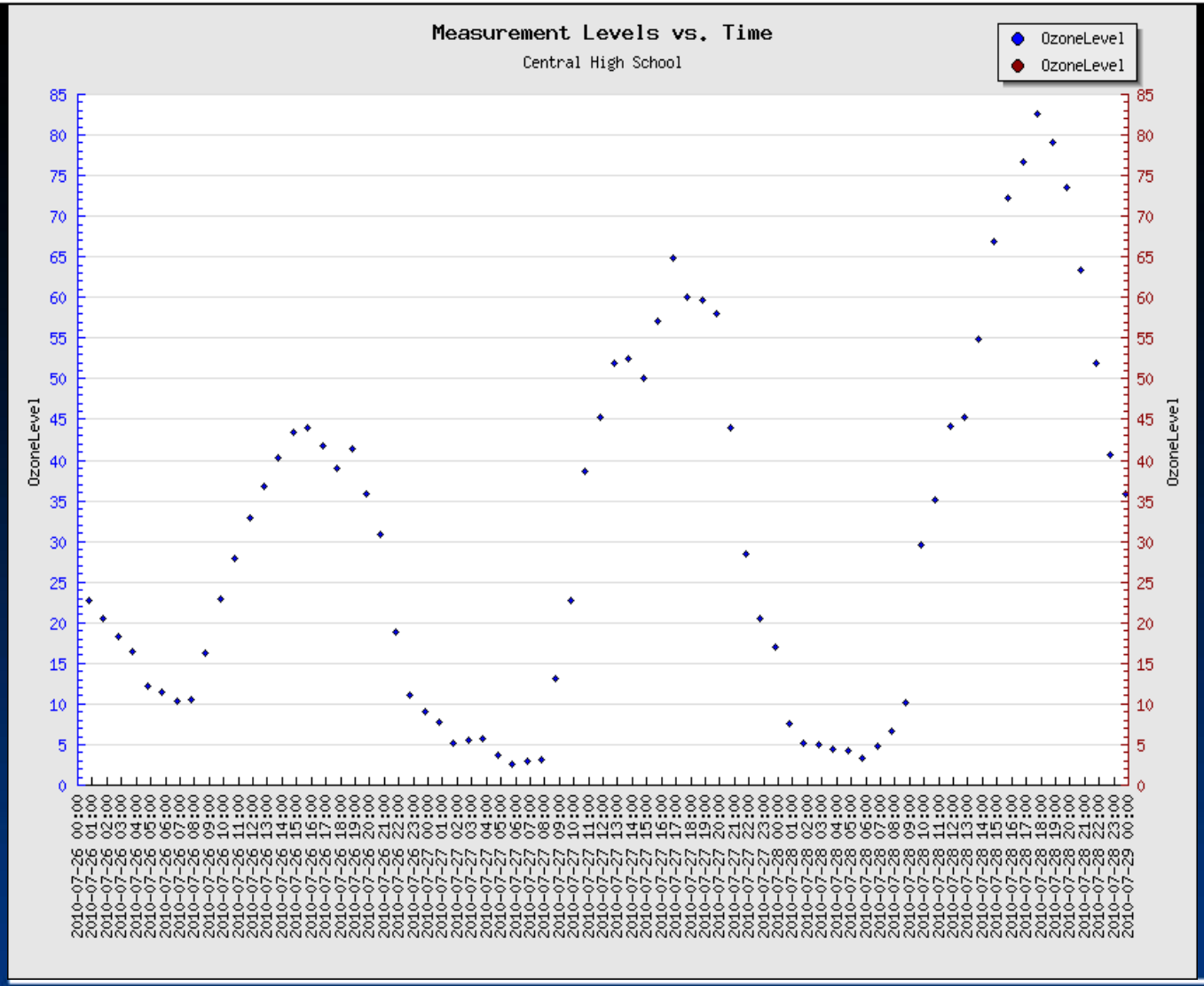
Graphing Your Ozone Data

Go to www.go3project.com and click on the Ozone tab – you can choose to either graph the data or open it in a Google Earth file.

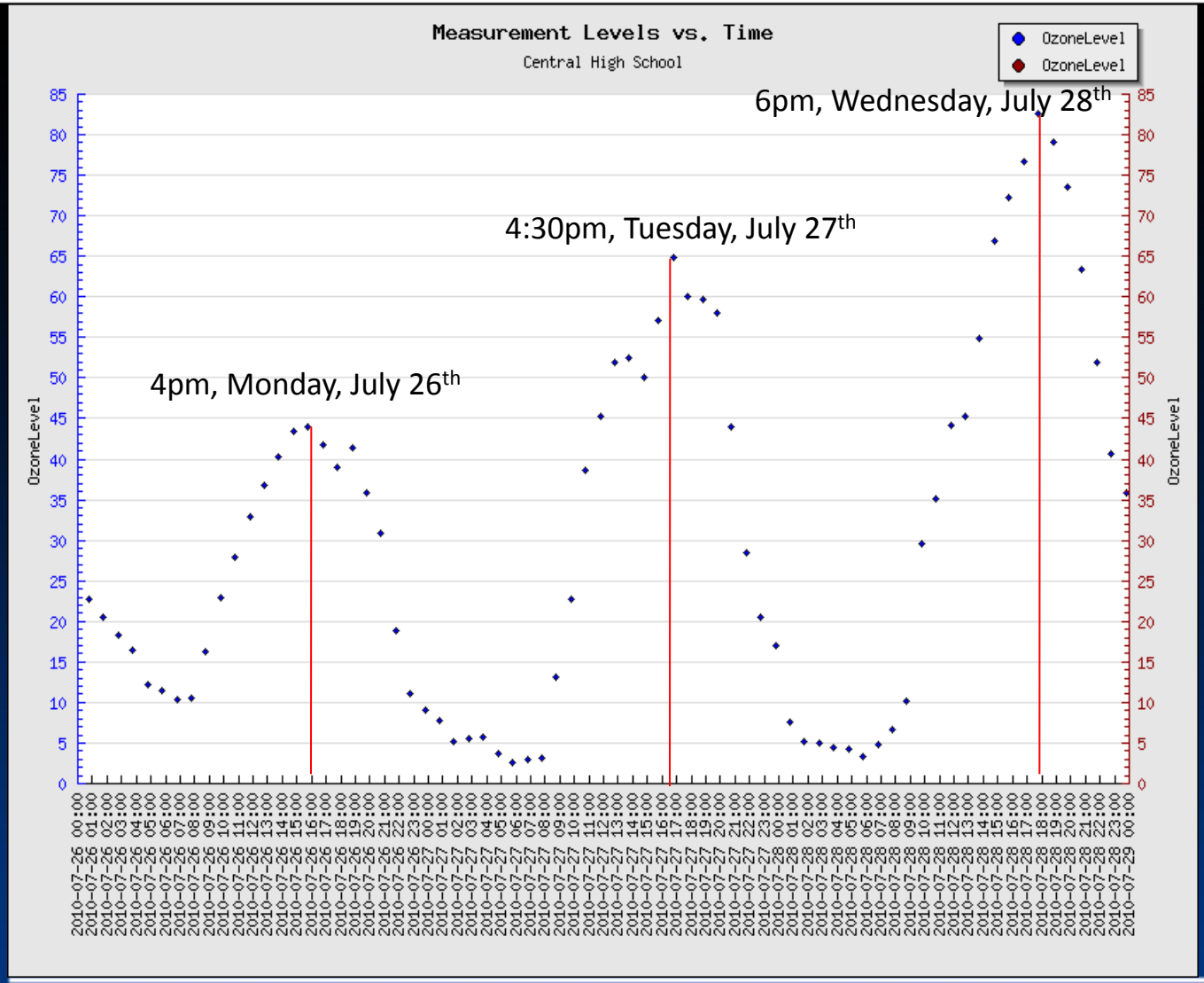
Google Earth Display of GO3 Data



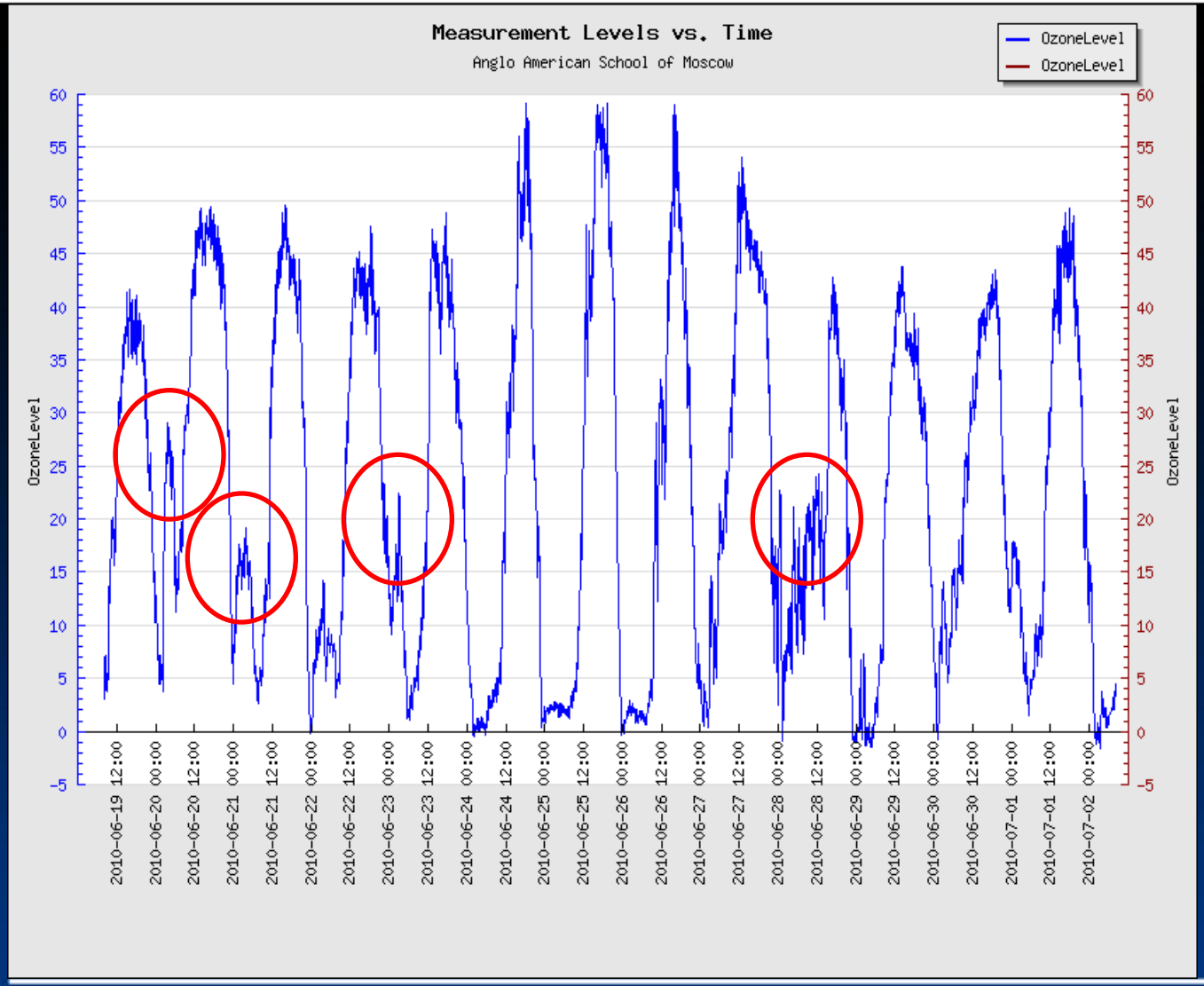
Graph of GO3 Ozone Data



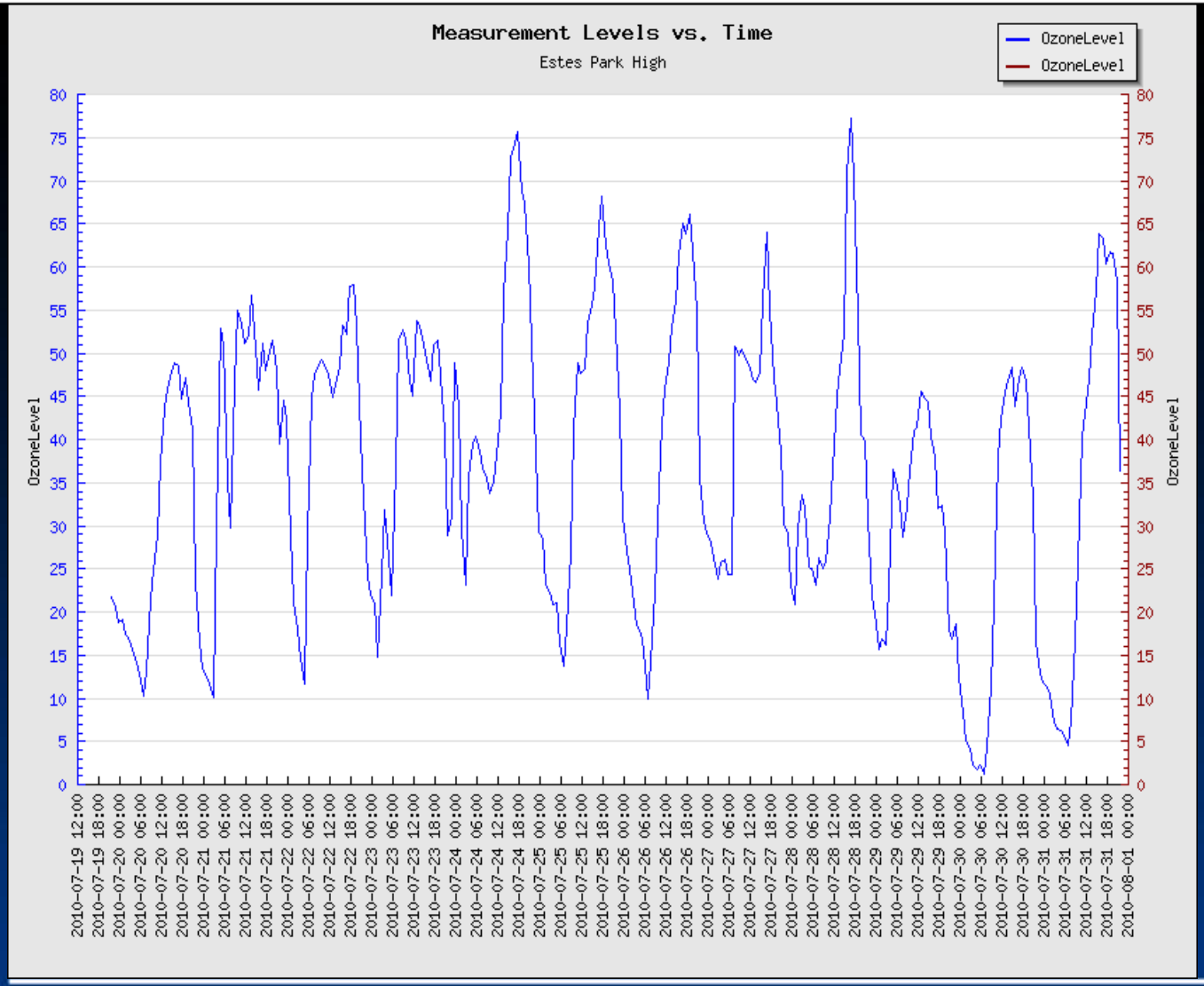
Timing of Daily Peaks in Ozone



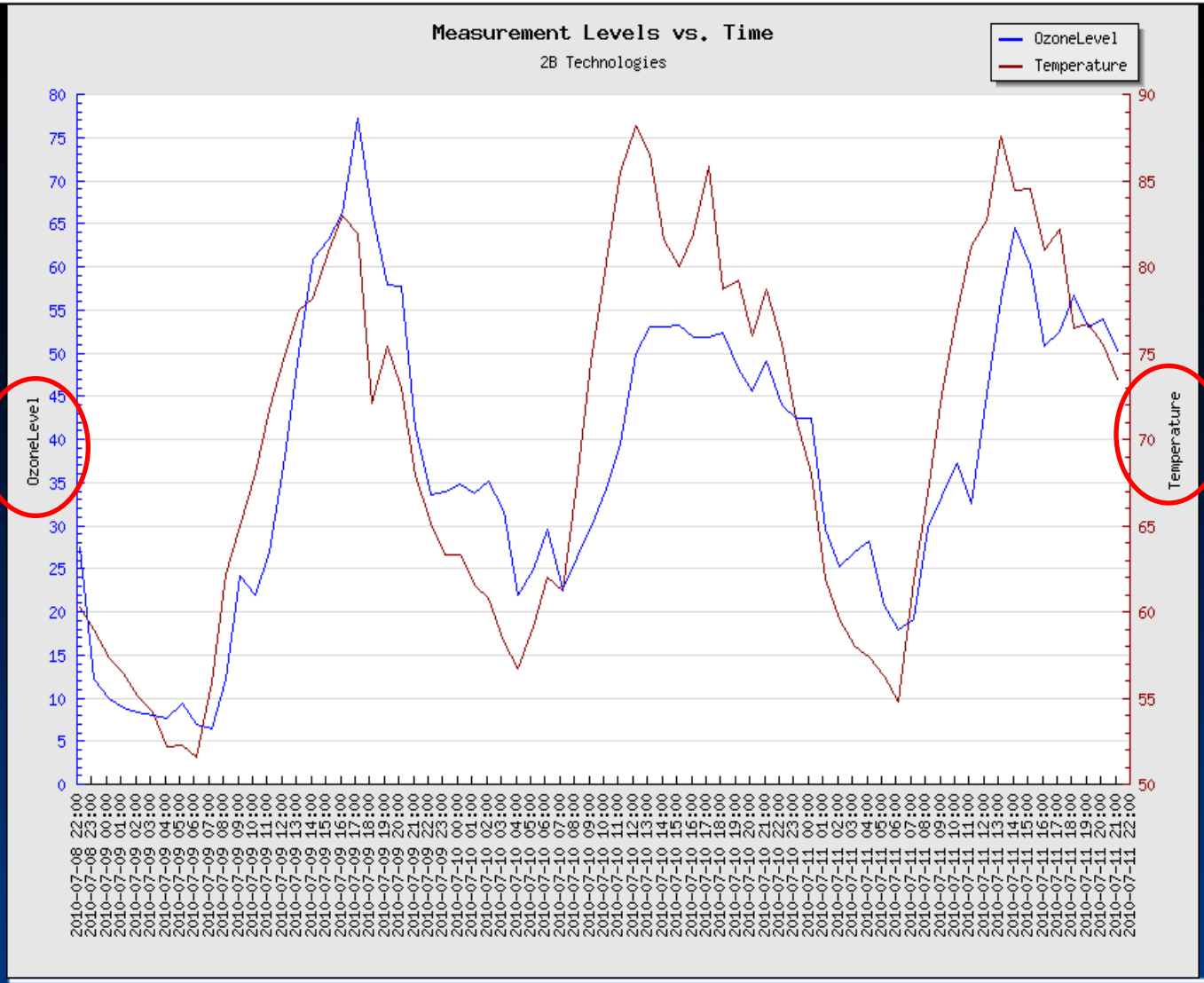
Ozone “Spikes” at Night



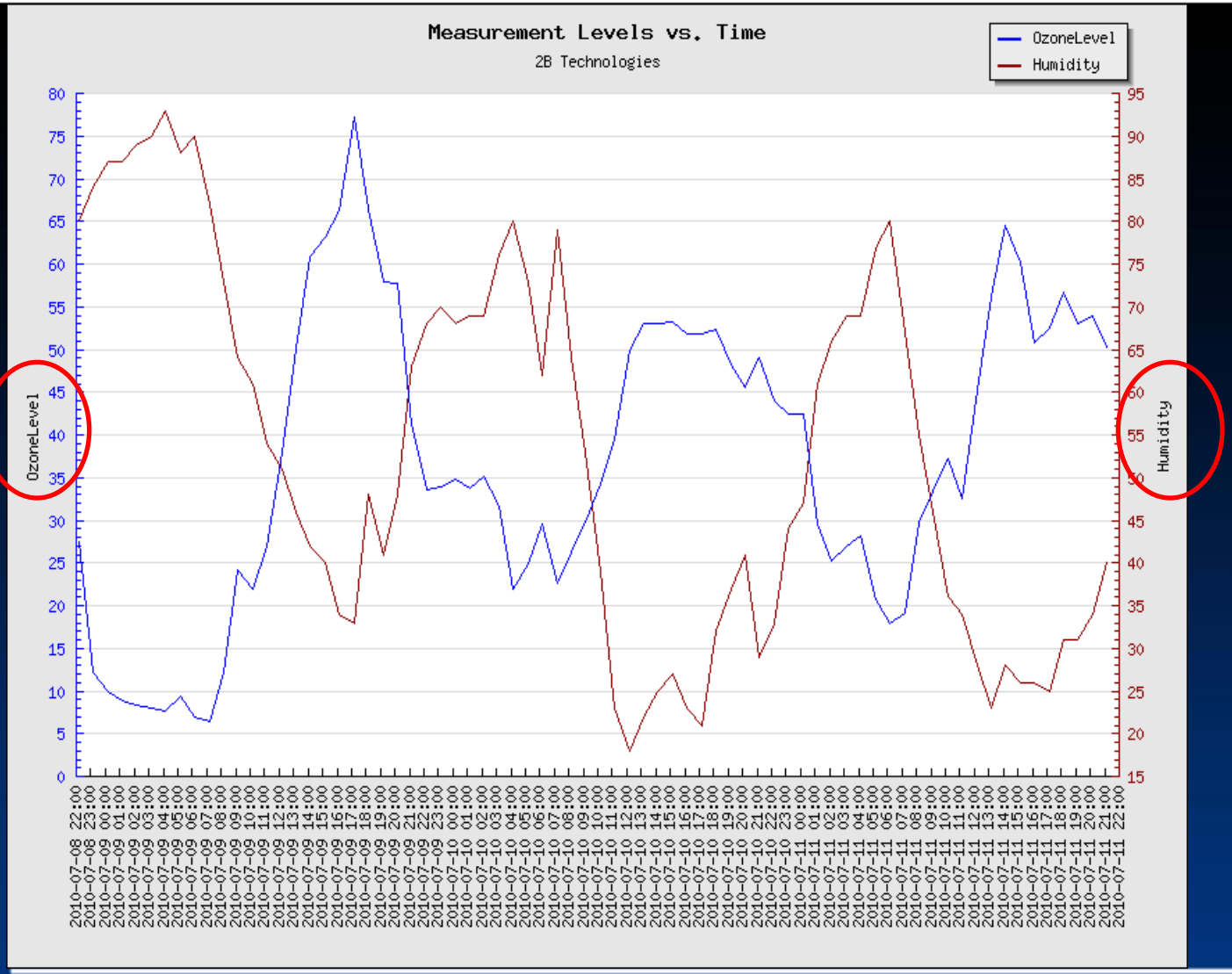
Background Levels of Ozone



Graphing Ozone and Temperature



Graphing Ozone and Humidity



Project GO3

Global Ozone Project Curriculum

Lesson 12: Sustainable Technologies and Renewable Energies

UNDER CONSTRUCTION

Rev 13

Project GO3

Global Ozone Project Curriculum

Lesson 13: What Can You Do?

UNDER CONSTRUCTION

Rev 13