OH-THREE AND ME: Sources, Impacts and Levels of Ozone

OBJECTIVES

Students will do the following:

1. Understand how Ozone (O_3) relates to the environment and differences between ground level and stratospheric O_3.

2. Understand the different sources of precursors that form ground level O_3.

3. Collect information about the emissions of precursors of ground level O_3 and the changing trends in ground level O_3 concentrations in the United States using hands-on data exploration tools.

SUBJECTS: Environmental science, biology, chemistry,

TIME: 90-120 minutes

MATERIALS

Access to computers and internet recommended;

Handouts

Crossword or word search puzzles (Sample and resources included)

BACKGROUND MATERIAL

What is O_3?

Ozone (O_3) is a gas that occurs in two layers of the atmosphere, the stratosphere and the troposphere. The stratospheric or "good" O_3 layer, extends upward from about 10 to 30 miles above the earth's surface. The O_3 in the stratosphere is naturally occurring and protects life on earth from the sun's harmful ultraviolet rays. In modern times there has been a depletion of O_3 in the stratosphere resulting from emissions of chlorofluorocarbons (CFCs), a phenomenon known as the ozone hole.

However, O_3 found in the troposphere, the layer of the atmosphere that extends from the earth's surface to about 10 miles up, is deemed ground level or "bad" O_3. At the ground level, O_3 is an air pollutant that is a result of anthropogenic activity. O_3 damages human health, vegetation, materials such as rubber tires, and is a key ingredient of smog. Smog refers to a combination of smoke and fog that impacts visibility and human health. Ground level O_3 is regulated by the USEPA working with state and local agencies with a goal of meeting National Ambient Air Quality Standards (NAAQS).

Sources and Mode of Formation of Ground Level O_3

How Does O_3 Form?

O_3 has the same chemical structure (O_3) whether it occurs miles above the earth or at ground level. Ground level O_3 is typically not emitted directly. It is considered a secondary pollutant as it

is formed through sunlight driven chemical reactions that involve precursor (define precursor) pollutants such as volatile organic compounds (VOCs) and nitrogen oxides (NOX).

- Basic equation for O3 formation: **NO_x + VOCs + Sunlight = O3.**

What are the different sources of precursors of ground level O3?

- NO_x, (nitrogen oxide gases) is the generic term for a group of highly reactive gases, all of which contain nitrogen and oxygen in varying proportions. Many of the nitrogen oxides are colorless and odorless. The primary sources of NO_x are motor vehicles, electric utilities, and other industrial, commercial, and residential sources that burn fuels. In the United States, the distribution of sources for year 2011 is as follows:
    - Automobiles and other mobile sources contribute 57% of all NOx emissions
    - Industrial and other fuel combustion sources account for 33% of NO_x emissions. Example sources under these sectors include boilers, incinerators, diesel engines, iron and steel mills, petroleum refineries, and cement, glass and nitric acid manufacturing facilities.
    - Natural sources of NO_x include lightning in the atmosphere, forest and grass fires, volcanic activity and microbial activity. Microbial activity and fires alone account for about 9% of all NOx emissions.
- VOCs are a class of organic compounds and consist of more than one chemical compound VOCs are emitted from industrial, commercial, household and even natural sources. In the United States, the distribution of sources for year 2011 are as follows:
    - Natural sources contribute to the largest fraction of VOC emissions (70%). This includes natural emissions from trees and vegetation. The single most important VOC from natural sources is thought to be isoprene which is a colorless liquid, which easily vaporizes on hot summer days. Isoprene has been shown to protect plants from heat stress and large temperature fluctuations. Forest and grassland fires contribute to an additional 8% of VOC emissions.
    - Mobile sources contribute 8% of all VOC emissions. Emissions can either result from exhaust from the tailpipe of vehicles or from evaporation of fuels (gasoline, diesel and even biofuels) from onroad and noroad equipment including sources located at gas stations and petroleum terminals. Industrial sources contribute to only about 6% of VOCs emissions in the United States and are primarily related to manufacturing and usage of products such as paints, adhesives, coatings and fragrants. These products are widely used to develop films for products ranging from metal cans, wooden and metal furniture, and even painting aircrafts.
    - Solvent usage also contributes to about 5% of VOCs. These emissions are typically from ingredients in household products including: paints, varnishes, wax, fuels, cleaning, disinfecting, cosmetic, degreasing, and hobby products. Some VOCs are safe to handle and have little known health effects, while other VOCs are highly toxic, having adverse effects beyond their role in O_3 production.

Commented [JH1]: Is this 8% in addition to the 70%?

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How does weather impact ground level O_3 formation?

- Ground level O_3 formation is strongly correlated to presence of sunlight. Hence peak concentrations are generally recorded during the day and during warm sunny weather. O_3 trends vary diurnally, seasonally and inter-annually.
    - Formation of O_3 results from addition of atomic oxygen (O) to an oxygen molecule (O_2) to form an ozone molecule (O_3). However, this reaction requires a third body which is provided by different trace gases; consisting primarily of nitrogen or oxygen molecules. Solar radiation enables breakdown of NOx and releases a single atom of oxygen. This single oxygen is highly oxidative and can initiate a complex cycle of chemical reactions in the atmosphere in the presence of VOCs.
    - While O_3 is produced during the day in the presence of sunlight, it can be destroyed through chemical reactions during day and night. Hence, the concentrations of O_3 show large variations throughout the day and across days in a year.
- There are weather factors involved with the formation of "bad" or ground level O_3, including: cloud cover, wind direction, and wind speeds. If the weather conditions are conducive, and there are ample amounts of NO_x and VOCs, harmful concentrations of ground level O_3 can form in the air.
    - Sunlight and warm temperatures enhance O_3 concentrations during the day.
        - Peak O_3 concentrations in urban areas are typically observed in early afternoon for an hour or two in summer. While afternoon peaks are common in winter, these peaks are typically much smaller than those observed in winter.
    - Typically the ground warms air that is right above it. The warm air then rises in the atmosphere causing the air to "mix" and dilute the concentration of O_3. However, in the case of an inversion when cooler air sits below warm air, the atmospheric conditions are not conducive for mixing. Inversions are common in the valleys located in mountainous areas (such as the Los Angeles basin which sits between mountains).
    - Winds can move parcels of air from places where precursors are emitted to other locations. This can cause elevated concentrations in rural areas or often in places located inland where sea breezes in the morning move O_3 from cities located along the coast.
    - Cloudy, cool, rainy and windy conditions limit production of O_3.

Commented [JH2]:

Commented [MOU3R2]:

Where is Ground Level O_3 Typically Found?

Ground level O_3 is ubiquitous and is found everywhere in low concentrations. Many urban areas tend to have high levels of ground level O_3, especially during warm weather. Even rural areas are often subjected to increased O_3 levels because winds can carry O_3, and the pollutants that form it, hundreds of miles away from the original sources. The process of prevailing winds carrying

ground level O_3 away from the original source is called transport. For example, if wind transports NO_x to a rural area, filled with trees that are naturally releasing VOCs, a large amount of ground level O_3 can form in the rural area. Regardless of how the ground level O_3 is formed, it poses health threats to all the people, animals and plants in the area. A map of current O_3 levels can be accessed at https://www.airnow.gov/index.cfm?action=airnow.mapcenter&mapcenter=1

Impacts of Ground Level O_3

What are the impacts of ground level O_3?

Ground level O_3 causes injury to both the environment and human health.

- Exposure to ground level O_3 can cause irritation to the human respiratory system. For example, it can reduce lung function, aggravate asthma, inflame and damage cells that line lungs, aggravate chronic lung diseases, and cause permanent lung damage.
    - Acute (short-term) effects mainly include reduced lung function, respiratory symptoms and airway inflammation. Epidemiological studies indicate that O_3 levels have been linked to increase in daily emergency hospital visits, increase in asthma medication intake and school absences. People who live in areas where O_3 levels are frequently high may find that their initial symptoms go away over time, but O_3 can continue to cause lung damage even when the symptoms have disappeared.
    - Chronic (long-term) effects include morphological changes in the airways mainly in children and young adults and potentially increase the incidence and prevalence of asthma.
- The impact of elevated O_3 concentrations is on terrestrial ecosystems is well documented. O_3 affects sensitive vegetation and ecosystems, including forests, parks, wildlife refuges and wilderness areas. Elevated O_3 can also cause damage during the growing season of crops and reduce crop quality and yield.
- Rubber, textile dyes, fibers, and certain paints may be weakened or damaged by exposure to O_3. Some elastic materials can become brittle and crack, while paints and fabric dyes may fade more quickly.

Concentrations of Ground Level O_3

How do Scientists Know what Levels of O_3 are Harmful?

The United States Environmental Protection Agency (US EPA) has gathered a great deal of information about the health effects of O_3. This information comes from a number of sources including: studies that examine health statistics and O_3 levels within communities, and through controlled testing of human volunteers to determine how O_3 affects lung function. Though scientists' understanding of ozone's effects has increased substantially in recent years, many important questions still exist. Several studies are focusing on impact of repeated short-term exposure of high levels of O_3 on long-term lung function in both children and adults. Scientists are continuing to study these and other questions to gain a better understanding of ozone's

Commented [JH4]: This seems like a stretch to me. What reference are you using for this part?

Commented [JH6]: It might be good to define concentration here and get students used to hearing this word since it is more precise than levels

effects and make necessary revisions of safety guidelines to better protect public health and the environment.

The Clean Air Act (last amended in 1990) directs US EPA to set National Ambient Air Quality Standards (NAAQS) for air pollutants that are considered harmful to public health and the environment. The Clean Air Act established two types of national air quality standards. ***Primary standards*** set limits to protect public health, including the health of at-risk populations such as people with pre-existing heart or lung disease, children, and older adults. ***Secondary standards*** set limits to protect public welfare, including protection against visibility impairment, damage to animals, crops, vegetation, and buildings. Ground level O3 concentration is regulated by NAAQS.

Is there an Unhealthy Level of Ground Level O3?

An unhealthy level of ground level O3 is indicated by the NAAQS. The standards were recently revised in 2015. The primary and secondary standards for O3 are set at 70 ppb; averaged over a time period of 8 hours. Prior to year 2015, the primary and secondary standards were set at 75 ppb (established in 2008). When O3 levels surpass these set standards, unhealthy conditions are present.

Add a discussion of the Air Quality Index (AQI)

Has the NAAQS changed for ground level O3?

The Clean Air Act mandates the NAAQS undergo a periodic review of the science upon which the standards are based and update the standards accordingly. The NAAQS for O3 were first established in the 1970s and have since then been updated six times; with the most recent update in 2015. The history of the O3 NAAQS is available at https://www.epa.gov/O3-pollution/table-historical-O3-national-ambient-air-quality-standards-naaqs

Ground level O3 concentrations are much lower today than in the 1970's. How did this happen?

US EPA's national and regional regulations and programs initiated by State and Local governments have been instrumental in reducing emissions of pollutants that form ground level O3. Since the Clean Air Act was instituted, several actions have been taken in the form of vehicle and transportation standards, emission controls for industrial sources, regional haze and visibility rules, and regular reviews of the NAAQS.

The large number of sources of O3 precursors, role of natural and physical processes in O3 distribution, production and destruction, and complex chemistry, means that control of O3 is not straightforward. The only practical management strategy is to control the precursor emissions from human activities that lead to O3 formation. Hence, US EPA works with different states and tribal areas and obtains information from air quality monitors to see if ozone levels are within healthy limits. An area is considered as attainment or nonattainment by comparing the measurements collected from the air quality monitors with NAAQS. If the air quality in a geographic area meets or does better than the national standard, it is called an attainment area;

areas that don't meet the national standard are called nonattainment areas. The nonattainment areas then examine historical trends in air quality data, emissions from precursors, local weather conditions, and topography and then evaluate different measures to reduce O_3 formation in their area.

More interesting facts

Why don't we mix the layers and use the "bad" ground level O_3 to plug the holes in the "good" O_3 layer? Wouldn't that solve both problems?

Yes, theoretically that would solve both problems, but unfortunately that cannot be done.

Commented [JH7]: Insert a brief statement explaining the ozone hole for those who may not be familiar with it

First, the air in the troposphere and the stratosphere cannot simply be mixed. The troposphere is the layer of the atmosphere at the earth's surface and contains 75% of all the air found in our atmosphere and 99% of the water vapor. The air in the troposphere is in constant motion, with both horizontal and vertical air currents and is responsible for weather conditions. The troposphere is capped by a thin layer known as the tropopause, which is a region of stable temperature that helps to confine most weather phenomena (as well as "bad" O_3) to the troposphere.

The stratosphere is the second layer in the atmosphere from the earth's surface and in the lower part contains the O_3 layer. The O_3 layer prevents harmful ultraviolet radiation from reaching the earth's surface by absorbing the rays and thereby warming the air above it. The warm air tends to remain in the upper stratosphere, and cool air remains lower. The layering of warm and cool air prevents vertical mixing, so the air moves only in a horizontal direction, making the stratosphere very stable, but also acting like a giant lid. This is helpful to commercial airlines that often fly in the lower stratosphere because the air is relatively warm and stable, but not helpful to be able to mix O_3 between the stratosphere and the troposphere.

Second, the "good" O_3 that occurs naturally in the stratosphere is gradually being destroyed by man-made chemicals and we can't make enough O_3 to replace what has been destroyed. The O_3 depleting substances can remain intact for years while moving through the troposphere until they reach the stratosphere. There they are broken down by the intensity of the sun's ultraviolet rays and release chlorine and bromine molecules, which destroy "good" O_3. One chlorine or bromine molecule can destroy 100,000 O_3 molecules, causing O_3 to disappear much faster than nature (or man) could ever replace it. We can't make enough O_3 to replace what's been destroyed, but provided that we stop producing O_3 depleting substances, natural O_3 production reactions could return the O_3 layer to normal levels. Nations have taken major strides in reducing emissions of O_3 depleting substances through a multi-national agreement called the Montreal Protocol that came into force in 1989.

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PROCEDURE

I. Preliminary Lecture

Setting the Stage

The background information should be used to establish basic concepts through PowerPoint presentations (see sample in Appendix 3) and online videos. The Background Material above can also be provided as a factsheet at the end of the class. The lecture session is estimated to last between 30-45 minutes. Following this session, two activities will be held in class:

A. Recap of the background information using either a crossword puzzle or a word search puzzle. The expected time for this activity is 10 minutes

B. Hands-on data exploration to identify variations and trends in ground level O_3 in the United States and correlate with trends in emissions of precursor pollutants (NOx and VOCs). This activity can last anywhere between 30-60 minutes and additional time can be allotted for in-class presentations.

Recommended resources for background information

- http://ciese.org/curriculum/airproj/ozoneprimer/
- https://www.epa.gov/ozone-pollution

Recommended videos:

- http://www3.epa.gov/airnow/airnow/ozone/03.html
- https://www.youtube.com/watch?v=THYoUULn_2U

II. Activity A: Recap of Background Information

Setting the Stage

Teachers can choose either a crossword puzzle or a word search. Students can work on their puzzles independently or work in teams of two. This activity should occur after the background information is presented. Suggested resources are recommended below. Sample puzzles are provided in Appendix 1.

Recommended resources to create crossword or word search puzzle:

- http://www.puzzle-maker.com/CW/
- http://puzzlemaker.discoveryeducation.com/WordSearchSetupForm.asp

Follow up

The answers to the puzzles should be discussed in class before moving to Activity B. Teachers should reiterate the different sources of precursors to O_3 formation and impact of weather conditions.

III. Activity B: Data Exploration

Setting the Stage

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This activity is aimed at familiarizing students with national and regional trends in ground level O_3 concentrations. The students will access information on trends in emissions of precursors; namely of NOx and VOCs. The goal is to use this information to explain the observed trends in ground level O_3. A classroom discussion can then be used to compare and contrast trends between different regions in the United States.

Access to the webpages listed in data sources should be setup before class. If internet connection is unavailable, teachers can print out figures from these web links and distribute it to the students. It is recommended that students be divided into teams of 2-3. Distribute the Activity B Handout for students to follow instructions and answer leading questions. Teachers can modify the worksheet based on time availability and level of understanding they seek to establish in-class. Each group should be assigned a state to explore and the related US EPA region that the state belongs to. Ensure that the states cover a wide geographic range (e.g. coastal versus interior, mountainous versus flatland, low versus high population). The data exploration will be driven by the students.

Data sources

- **Ground level O_3 trends:** https://www3.epa.gov/airtrends/index.html
- **Current air quality conditions:** https://www.airnow.gov/index.cfm?action=airnow.mapcenter&mapcenter=1
- **Air emissions sources data**: https://www3.epa.gov/air/emissions/index.htm

IV. Follow-up

At least 20 minutes should be provided at the end to facilitate in-class discussion to tie back Activities A and B with background information. Teachers should also setup a large United States map to facilitate in-class discussion. If this is unavailable, the chalkboard can also be used to note down trends in O_3 concentrations and emissions of NOx and VOCs for different states. The goal for the follow up is to establish differences in regional and temporal trends in ground level O_3 concentrations and trends in precursor emissions. If time permits, students should be directed to brainstorm about identifying sources that can be controlled, potential solutions to emissions control, costs involved and effort to deploy solutions regionally.

V. Extension

This lesson is primarily targeted towards understanding O_3 pollution in the United States. The lesson could be extended in two directions. The first extension is a broader discussion of emissions of precursors by using US EPA's dataset that reports long-term emissions trends (see https://www.epa.gov/air-emissions-inventories/air-pollutant-emissions-trends-data). The second extension could be related to discussion of sources, mechanisms and impacts of stratospheric ozone depletion, concept of ozone depleting potential and the role of the multi-national Montreal Protocol in combating ozone depletion.

RESOURCES

Tropospheric ozone formation:

"Ground-level ozone in the 21st century: future trends, impacts and policy implications" (2008), The Royal Society Science Policy Report 15/08. Available at http://www.accent-network.org/accent_documents/ozone%20report%20web%20pdf%20final.pdf

National Ambient Air Quality Standards:

History of the O3 NAAQS: https://www.epa.gov/O3-pollution/table-historical-O3-national-ambient-air-quality-standards-naaqs

NAAQS Table: https://www.epa.gov/criteria-air-pollutants/naaqs-table

General background information

http://ciese.org/curriculum/airproj/ozoneprimer/

https://www.epa.gov/ozone-pollution

Videos for background information:

http://www3.epa.gov/airnow/airnow/ozone/o3.html

https://www.youtube.com/watch?v=THYoUULn_2U

Resources to create crossword or word search puzzle:

http://www.puzzle-maker.com/CW/

http://puzzlemaker.discoveryeducation.com/WordSearchSetupForm.asp

Data sources

Ground level O3 trends: https://www3.epa.gov/airtrends/index.html

Current air quality conditions:
https://www.airnow.gov/index.cfm?action=airnow.mapcenter&mapcenter=1

Air emissions sources data: https://www3.epa.gov/air/emissions/index.htm

Long-term emissions trends:https://www.epa.gov/air-emissions-inventories/air-pollutant-emissions-trends-data

Air Quality Trends: *https://www3.epa.gov/airtrends/index.html*

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Stratospheric ozone depletion:

https://www.ucar.edu/learn/1_6_1.htm
https://www.ucar.edu/learn/1_6_2_25t.htm
http://mynasadata.larc.nasa.gov/las2/UI.vm

Appendix I: Sample puzzles

***Sample word puzzle*:**

A word search puzzle is meant for students to recap the key terminology associated with ground level O_3. The recommended puzzle maker can be used to modify the complexity of the puzzle if desired. Students will have to look for words within the word jumble.

This puzzle was ***Created by Puzzlemaker at DiscoveryEducation.com***

```
T R K C K U N T C T
R U X Z L A U H O Y
K B R O A U A G V S
G B I Q N R F I E J
G E S E E R T L K P
D R O Y V E C N S X
V V O A I I T U T M
V B Q U H P I S I T
S E V E N T Y N X O
J H V E I D P G O Q
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GROUND NAAQS NOX RUBBER SEVENTY
SUNLIGHT TREES VEHICLES VOC
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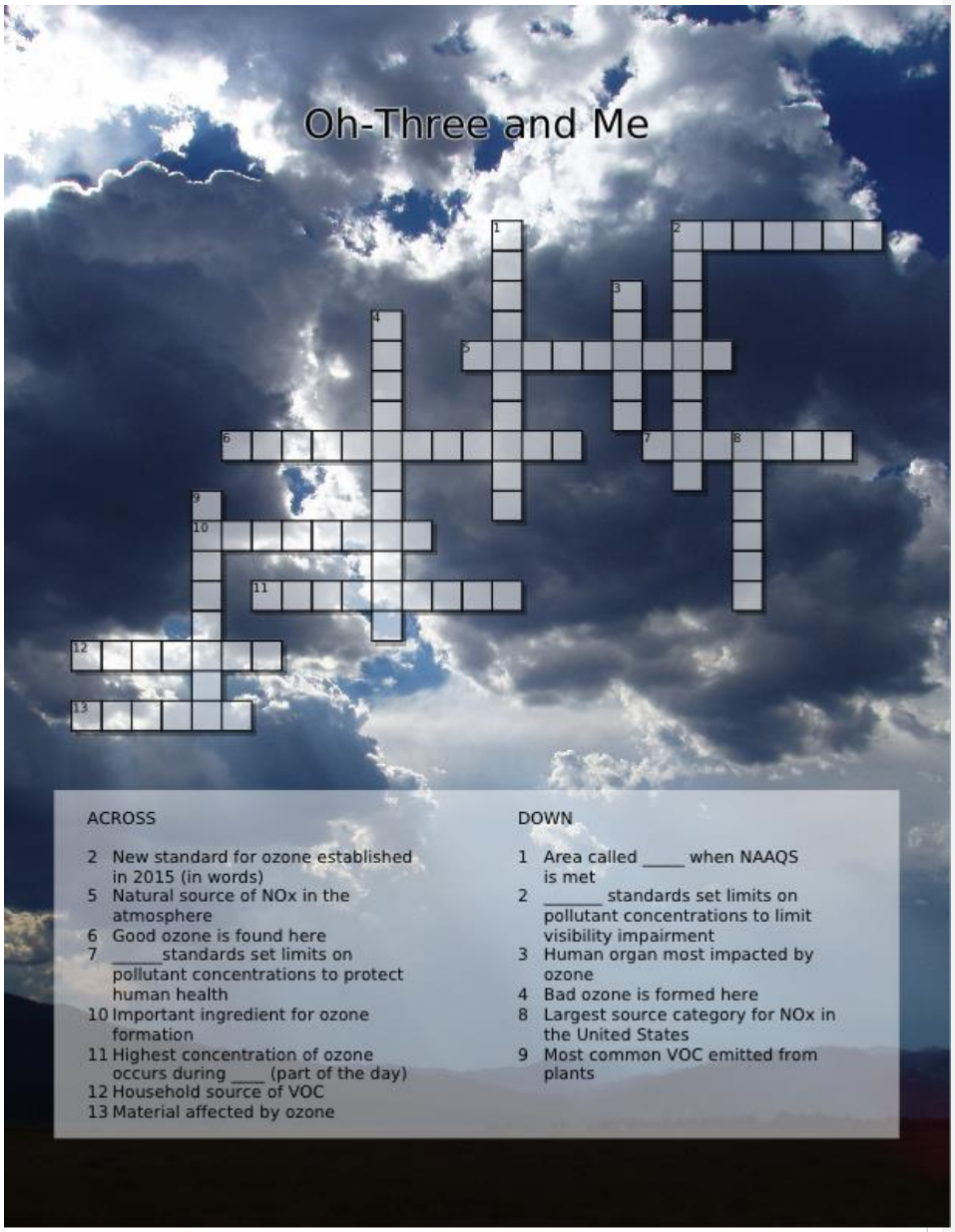
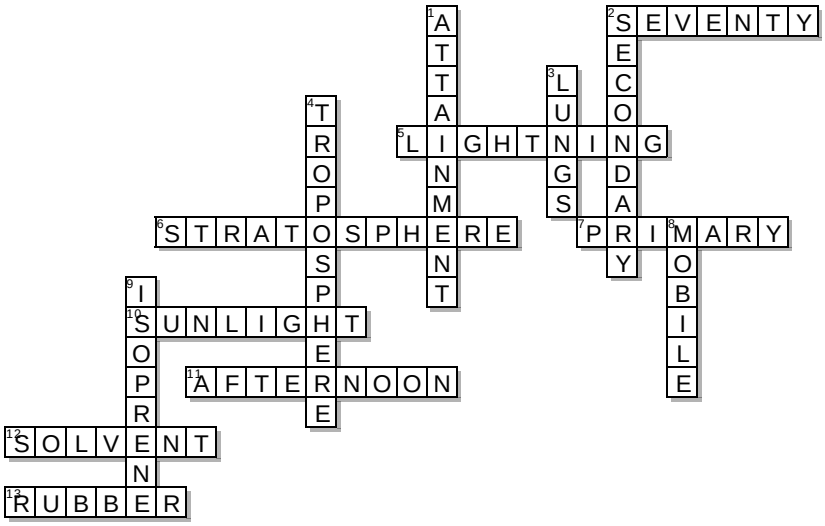


Oh-Three and Me: Sources, Impacts and Levels of Ozone

This puzzle was ***Created by Instant Online Puzzle-Maker at Puzzle-Maker.com***

Oh-Three and Me



Appendix II: Activity B: Handout for data exploration

Exercise 1: Exploring trends in ground level O_3 concentrations

Let's access the AirTrends page: https://www3.epa.gov/airtrends/index.html. This webpage is managed by US EPA and reports trends in concentrations of different pollutants as it relates to air quality. Our interest is in ground-level O_3. Click on the link named ozone (O_3); which is listed about midway on the webpage.

Answer the following questions based on the information available on the webpage:

1. US EPA develops trends in O_3 concentration using a nationwide network of monitoring sites. Monitoring data provides insight into the inter-annual and inter-regional trends in air quality. National trends are calculated by averaging the measurements from all measurement sites.
    a. First year of O_3 monitoring reported - _____
    b. Number of monitoring sites considered for reporting national trend - _____
    c. Has the number of measurement sites increased since 1980? _____
2. How have O_3 concentrations varied nationally since the 1980's? Could you provide reasons to explain such trends?
3. How does the national trend compare to the most recent NAAQS for O_3? (Hint: 1 ppm = 1000 ppb)
4. Let's focus on regional data now. Scroll further down on the webpage and select your region from the box. Results will appear below the map of the United States:
    a. What is the name of the State and Region you were assigned? _____
    b. Has there been a reduction in ground level ozone concentrations since 2000? If yes, how large is the reduction?
    c. How does the regional reduction in O_3 concentrations compare with the national average between 2000-2016?

The US EPA's AirTrends page provides a lot of information on O_3 levels at national, regional and local scales until the year 2016. However, to see the most recent data for ground level O_3, we need to access another resource called AirNow. Click on https://www.airnow.gov/index.cfm?action=airnow.main and then on the tab that reads "More maps". The current conditions for air quality including O_3 for mainland United States is provided at this webpage.

1. Click on the Tab "Current Ozone". What is the air quality index (AQI) for ozone in the State of your interest?

Commented [JH8]: Perhaps we should include something about the AQI in the background materials

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2. Click on the Tab "Ozone Loop". If you look closely at the upper left part of the map, you can see the time stamp for which the animation is being generated. How does the AQI for O3 vary for the day? Describe how the temporal variations in O3 vary for your State and the rest of United States.

Exercise 2: Exploring emissions sources of NOx and VOCs

We now have information about how O3 has varied nationally and regionally in the United States since the 1980's. We also identified the current conditions of O3 across United States. O3 is a secondary air pollutant; which means it depends on emissions of other pollutants in order to form. Of particular interest are nitrogen oxides (NOx) and volatile organic compounds (VOCs). In this exercise we will explore different sources of emissions of these two precursor pollutants. Emissions data is provided by US EPA at https://www3.epa.gov/air/emissions/index.htm. This provides information related to emissions related to six criteria air pollutants. Typically, US EPA reports emissions every three years for different sources and pollutants.

1. Click on Ground-level Ozone Precursor: Nitrogen Oxides (NOx). This webpage provides national, state and local summaries of trends in NOx emissions. Scroll to the end of the webpage and select the State of interest. Answer the following questions:
    a. Which source sector is the largest contributor of NOx emissions in 2011?
    b. Which source sector is the smallest contributor of NOX emissions in 2011?
    c. How does the distribution of emissions sources in the State compare with national scale?
    d. Repeat the exercise by choosing another neighboring state that is in the same region that you explored in Exercise 1.

2. Go back to the main webpage and then click on Ground-level Ozone Precursor: Volatile Organic Compounds (VOCs). This webpage provides national, state and local summaries of trends in VOC emissions. Scroll to the end of the webpage and select the State of interest. Answer the following questions:
    a. Which source sector is the largest contributor of VOC emissions in 2011?
    b. Which source setor is the smallest contributor of VOC emissions in 2011?
    c. How does the distribution of emissions sources in the State compare with national scale?
    d. Repeat the exercise by choosing another neighboring state that is in the same region that you explored in Exercise 1.

3. Could you think of three possible ways to reduce emissions of pollutants that are precursors to O3 formation? Discuss your findings and propose your recommendations to the rest of your class.

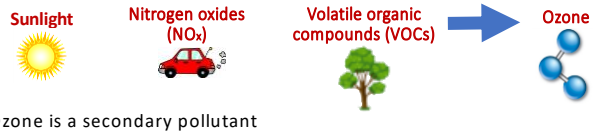
Once you complete the exercise, go ahead and post your results on the poster/ board.

Appendix III: Sample Power Point Presentation

Ozone and Air Quality

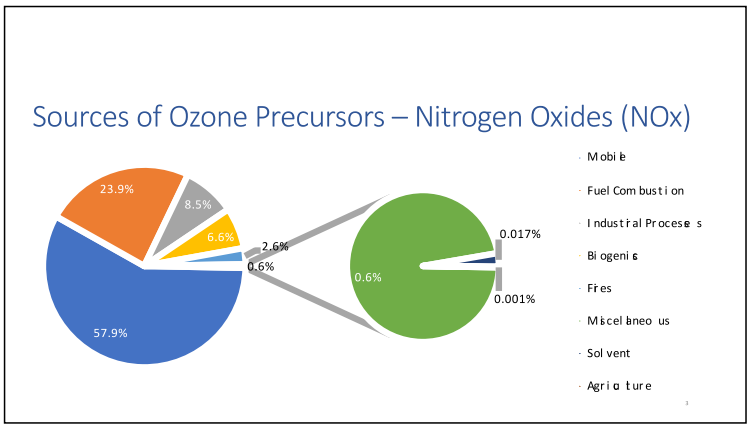
- Ozone (O_3) = three atoms of oxygen
- Occurs freely in the stratosphere, located 6-30 miles from ground surface ("good" ozone)
  - Protects life on earth by blocking UV radiation from the sun
- Ground-level ozone largely man made ("bad" ozone)
  - Adversely impacts human health, ecosystems and materials

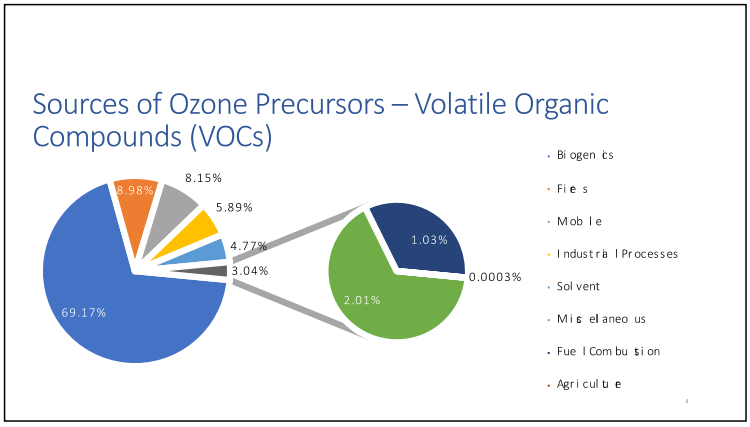
Mode of Ozone formation



- Ozone is a secondary pollutant
  - Formed through chemical reactions between pollutants (namely nitrogen oxides and volatile organic compounds)
  - Formation of ozone is photochemical since it requires sunlight

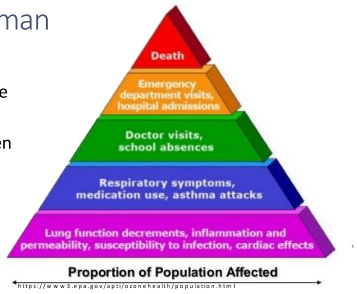
1


Sources of Ozone Precursors – Nitrogen Oxides (NOx)
23.9%
8.5%
6.6%
2.6%
0.6%
57.9%
0.6%
0.017%
0.001%
Mobile
Fuel Combustion
Industrial Processes
Biogenics
Fires
Miscellaneous
Solvent
Agriculture


Sources of Ozone Precursors – Volatile Organic Compounds (VOCs)
8.98%
8.15%
5.89%
4.77%
3.04%
69.17%
1.03%
0.0003%
2.01%
Biogenics
Fires
Mobile
Industrial Processes
Solvent
Miscellaneous
Fuel Combustion
Agriculture

Impacts of Ozone on Human Health

- Exposure to ozone has the most negative impact on the respiratory system
- Increased incidence of asthma in children and young adults



Impacts of Ozone on Ecosystems

- Affects sensitive vegetation and ecosystems including parks, forests and wilderness areas
  - Loss of diversity reported for black cherry, white pine and many others
- Impacts insects and interferes with production of larvae

Oh-Three and Me: Sources, Impacts and Levels of Ozone

Measuring Ozone in the Air

https://www3.epa.gov/airtrends/ozone.html

- Ozone monitors measure concentrations (mass per unit volume) in the air
  - Monitors are deployed across United States as shown in the map
- Regulated by the National Ambient Air Quality Standards
  - Set at 70 ppb (averaged over 8 hour)
  - Based on health statistics and controlled studies on human health
  - Revised six times since first established in the 1970s

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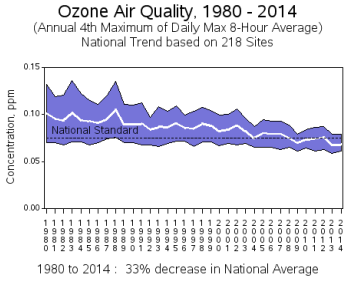
Regulations have resulted in a reduction in ground level ozone concentrations

https://www3.epa.gov/airtrends/ozone.html



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