Ground Level Ozone
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Very few studies have addressed the problem of accumulating tropospheric ozone, i.e. ground level ozone and its effects. In addition, the media has diverted much of our societies' attention to other environmental issues; such as global warming and ozone depletion in the stratosphere. What has not been as appreciated is that increased ground-level ozone is common downwind of metropolitan areas and it has adverse effects on human health as well as plants.

Ozone is a molecule of oxygen which may be beneficial or harmful to human health and the environment depending on many variables. Ozone is more commonly known for its beneficial function of blocking ultra violet radiation from the sun, which is found in the stratosphere. We call this type of ozone, good ozone, or stratospheric ozone. At the ground level, however, ozone is considered a pollutant, which when it accumulates in the atmosphere at certain concentrations can cause injury to living organisms. We call this type of ozone, ground-level ozone, bad ozone, or tropospheric ozone. Bad ozone has been accumulating in the troposphere and has doubled in concentration since the beginning of the industrial age. The purpose of this paper is to present the variables associated with the formation of ozone, the levels of exposure to ozone that can cause harm, how we can recognize and characterize that harm, and the future consequences of not controlling the anthropogenic causes of ozone production.

Ozone Production
Ozone is produced naturally by the following chemical reactions:

NO_2 + sun light => NO + O
O + O_2 => O_3 (ozone)
O_3 + NO => NO_2 + O_2
NO_2 + sun light => NO + O

Nitrogen dioxide plus sunlight produces nitric oxide plus a free oxygen atom. The free oxygen atom then reacts with an oxygen molecule and produces ozone. Ozone is very unstable and reacts with nitric oxide and forms nitrogen dioxide and an oxygen molecule. In this process, accumulation of ozone does not occur and it is called the "null cycle" of ozone. However, in nature vegetation produces volatile organic compounds (VOCs), including the compounds of isoprene and pinene. These compounds produce some of the aromas we smell from certain plants, e.g., smell of pine, citrus, etc. Vegetation accounts for about 55% to 60% of the VOCs found in the air we breath. When VOCs are available to nitric oxide, they interfere with the reaction of nitric oxide and ozone, the null cycle is broken and the accumulation of ground level ozone begins (see Figure 1).

What is Smog?
Most people living in metropolitan areas are familiar with smog. The term smog comes from a combination of the words smoke and fog. It is the brown haze that can often be seen over city areas that forms during the hot summer months. In general, this smog consists of various amounts of particulate matter, nitrogen dioxide (NO_2), volatile organic VOCs (both from vegetation and anthropogenic sources), and ozone. The constituents of smog come from the burning of hydrocarbon fuels used for transportation (cars, trucks, buses, and trains), heating (homes, businesses, and factories), electrical power plants, and manufacturing processes. The predominant constituents of smog are nitrogen dioxide (NO_2), which is a brownish colored gas and particulates. Usually, smog becomes less noticeable away from the metropolitan areas and into the countryside. Smog is rarely seen in rural areas, but the affects of smog can be worse than in the city areas, as will be discussed below.

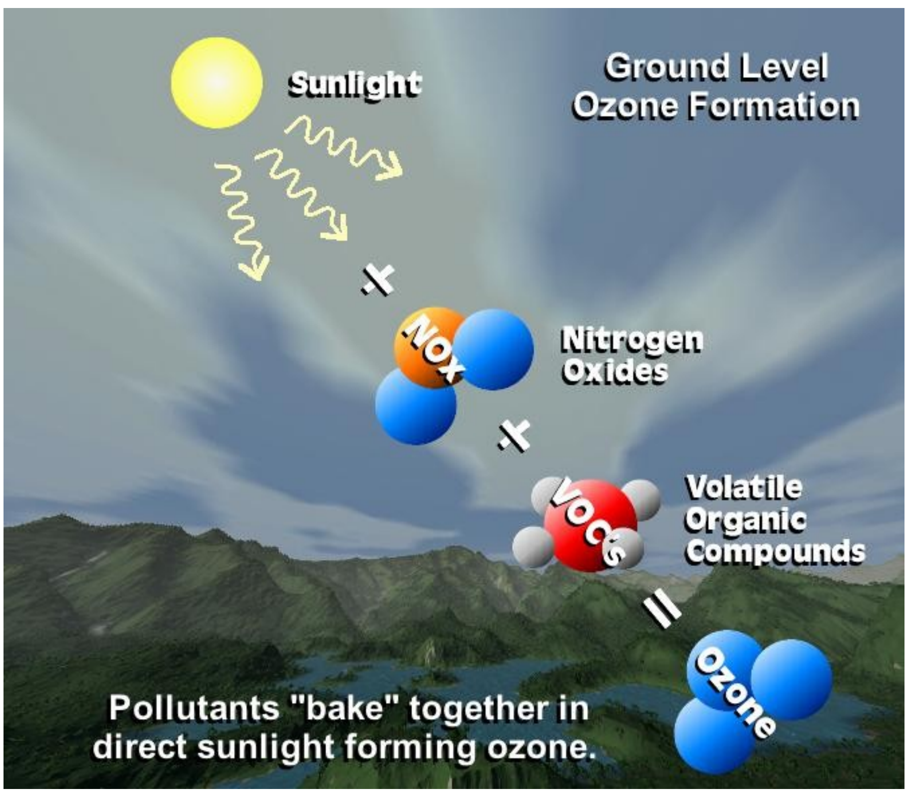

Figure 1. How the secondary air pollutant ozone forms from
http://harmanonearth.wordpress.com/2008/04/16/mccain-lost-in-the-ozone/

Ground Level Ozone
As smog disperses away from the metropolitan areas and into the countryside, the nitrogen oxide encounters increasing levels of VOCs emanating from the more densely vegetated landscape. What results is an ever increasing amount of ground level ozone. Unfortunately, many people believe that the beautiful more rural areas of New York, such as Suffolk County on the east end of Long Island are free of air

pollution. In fact, it is the huge amounts of VOCs coming from the extensive forested areas that react with the nitrogen oxides blown in from the metropolitan areas located upwind that can make ground level ozone levels much higher in the more rural areas by comparison. A look at the ground level ozone concentrations between New York City and Riverhead located on eastern Long Island illustrates this conclusion.

In general, environmental conditions favorable for the formation of ground level ozone are the following:
- Hot, dry and sunny weather;
- Stagnating, high-pressure weather systems.

Some of the characteristics of ground level ozone production are as follows:
- levels peak in the later afternoon at low elevations;
- remain high all day at higher elevations, such as in the mountains;
- increase seasonally from April through September;

Environmental Impacts from Ozone

Bad ozone can impact human health and the environment depending on the exposure concentrations, and the amount of sunlight, with regards to plant injury. In animals, ozone attacks lung tissue through oxidization reactions. It acts as a powerful irritant, and is compared to getting "*sunburn*" on the lungs. Animal toxicology studies have shown that long-term exposure to high levels of ozone can cause structural changes to the lungs.

Human response symptoms to levels of ozone are as follows:
- shortness of breath;
- chest pain when inhaling deeply;
- wheezing and coughing;
- increased susceptibility to respiratory infections;
- inflammation of the lungs and airways;
- increased risk of asthma attacks;
- increased need for medical treatment and hospital admission for people with lung diseases.

Based on these human response factors, the US Environmental Protection Agency has developed the following table where ppb means parts per billion:

Ozone ppb	Levels	Cautionary Statements
0-50	Good	None
51-100*	Moderate	Unusually sensitive people should consider reducing prolonged or heavy exertion outdoors.
101-150	Unhealthy for Sensitive Groups	Active children and adults, and people with lung disease, such as asthma, should reduce prolonged or heavy exertion outdoors.
151-200	Unhealthy	Active children and adults, and people with lung disease, such as asthma, should avoid prolonged or heavy exertion outdoors. Everyone else, especially children, should reduce prolonged or heavy exertion outdoors.

In contrast to the way humans respond, plant's responses to ozone exposure are as follows:
- symptoms of chronic ozone exposure begin to occur in plants at 40 ppb which leads to reduced growth and spotting of leaves (stippling)
- symptoms of acute ozone exposure occurs to plants at >80 ppb and leads to yellowing (chlorosis) bronzing, and eventually leaf death (necrosis)

Plants are used to study the impacts of ozone on our environment because:
- it is not practical to look at people's lungs;
- leaves are replaced each year;
- it is easier to evaluate the source of damage;

It is important to monitor the impacts to plants from ozone because continued exposure on plants will lead to a decrease in food crop production as the world's population continues to increase. To understand the plant's response to ozone exposure we need to consider the following:
- genetic predisposition of plant species and individuals;
- exposure to ozone that exceeds threshold values for injury;
- environmental conditions that favor ozone production.

Firstly, the plant species must be genetically predisposed to be sensitive to ozone. There is a sensitivity gradient; some plants are highly susceptible to ozone injury, some are mildly injured, and some aren't injured at all. Second, the plant must be exposed to ambient levels of ozone that exceed the threshold required for injury. As described above there are two basic types of exposures that can produce injury on plants, chronic and acute. Acute exposures (>80 ppb) are characterized by the presence of a high concentration of ozone for a relatively short period of time. Chronic exposures (40 to 80 ppb) involve lower concentrations that persist or recur over an extended period of time. Thirdly, environmental conditions that favor photosynthesis also promote gas exchange and the uptake of ozone along with carbon dioxide. Conditions of optimum temperature, humidity, illumination, and soil moisture will facilitate photosynthesis and the associated uptake of ozone, causing injury to the plant's leaf cells. Ozone enters the leaf cells following the same path as carbon dioxide does.

Research into ozone damage to plants has revealed that certain plants are more or less susceptible to injury. These plants have been categorized by the National Park Service into three groups as follows:

- Bioindicators
- Sensitive
- Suspected sensitive

Bioindicators are plant species for ozone injury that meet all or most of the following criteria:

- species exhibit foliar symptoms in the field at ambient ozone concentrations that can be easily recognized as ozone injury by subject matter experts
- species ozone sensitivity has been confirmed at realistic ozone concentrations in exposure chambers
- species that are widely distributed regionally
- species that are easily identified in the field

Some Long Island bioindicators include Sweet-Gum, Tulip Tree (yellow-poplar), Black Locust, Winged Sumac, Tall Milkweed, Common milkweed, Black Cherry, and Northern fox grape

Species considered sensitive are those that typically exhibit foliar injury at or near ambient ozone concentrations in fumigation chambers and/or species for which ozone foliar injury symptoms in the field have been documented by more than one observer.

Species suspected of being sensitive to ozone are species for which there is some evidence of sensitivity, but species does not meet criteria for sensitive species (i.e., sensitive species typically exhibit foliar injury at or near ambient ozone concentrations in fumigation chambers and/or are species for which ozone foliar injury symptoms in the field have been documented by more than one observer). Suspect species are also those species for which evidence from different observers is conflicting.

For the purpose of this lesson, only bioindicators should be used in assessing ozone damage as they are plants that are easily identifiable in the field and in most cases the injury can be recognized after some guided field training.

Identification of Leaf Damage from Ozone

- look for ozone injury during the mid to late summer;
- find an opening with full sunlight exposure;
- select areas with no obvious conditions that would cause mimicking symptoms of ozone injury, i.e., near roadways, where herbicides or other chemicals have been applied or disposed;
- look for symptoms on mature leaves that are in full sunlight.
- Look for injury on the more mature foliage. There should be an increase in severity of injury from the youngest to the oldest leaves.

The damage can be identified by observing the leaves looking for stipples (small darkly pigmented areas ~2-4 mm diameter), bronzing and reddening, chlorosis (yellowing), and necrosis (leaf death). Use the following link to understand the characteristics of stippling and practice estimating the percentages of damage. For ozone leaf damage training go to http://www.nature.nps.gov/air/edu/O3Training/index.cfm

Climate Change Effects

Surface concentrations of ozone air pollution begin to increase seasonally from April through September in the eastern regions of the United States. This is the time period of increased amounts of sunlight, higher temperatures, and commonly occurring stagnating high-pressure systems (Bermuda Highs) over vast regions of the Midwest and Mid-Atlantic States. Under these atmospheric conditions ozone air pollution reaches its highest levels during the hottest and most sunlit months of the year. Depending upon weather patterns, the concentrations of ozone air pollution though usually higher in the summer, can vary year to year. (Sachs, 2007)

Ozone is being monitored in various locations throughout the country. In New York, each New York State Department of Environmental Conservation (NYSDEC) Region has several ozone monitoring stations. On Long Island, there are three in Suffolk County (Riverhead, Holtsville and Babylon) and none in Nassau County (Eisenhower Park does not monitor ozone). See Figure 2 next page. The data from each of these stations can be accessed at the following link http://www.dec.ny.gov/airmon/index.php.

In 2005 the American Lung Association reported that Suffolk County had second highest ozone in state and was given a grade of “F”. The table below shows the breakdown of the range of ozone concentrations and the number of days exceeding those values.

- Orange Ozone (85 – 104 ppb) : 23 days
- Red Ozone (105 – 124 ppb) : 9 days
- Purple Ozone (125 – 374 ppb):1 day

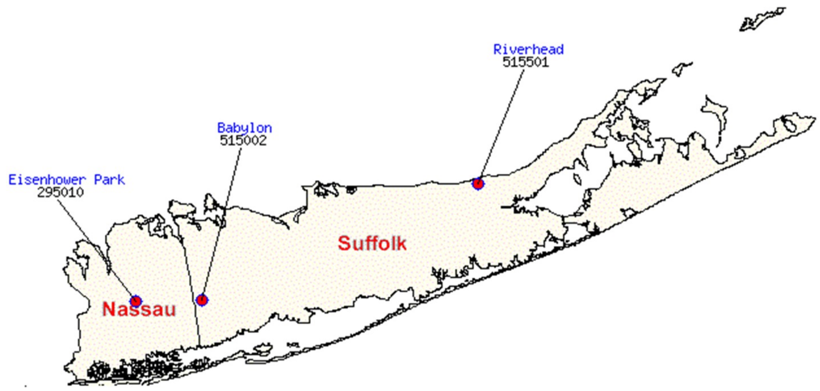

Figure 2 Map of Nassau and Suffolk Counties on Long Island New York showing the DEC air monitoring sites on Long Island. The site at Holtsville is under the Suffolk County label. From http://www.dec.ny.gov/airmon/

In addition, the US Environmental Protection Agency (USEPA) assess ozone compliance with their regulations an 8-hour average of ozone on the fourth highest day in the year. The following graph in Figure 3 illustrates the number of USEPA regulatory exceedances on Long Island between 1997 and 2007. Although the trend does appear to be decreasing for Long Island during this time period, there are many variables that affect ground level ozone production. With an increasing number of cars and trucks on today’s roads and the issue of global climate change, the ozone levels in the NY metropolitan area, and others, are likely to increase.

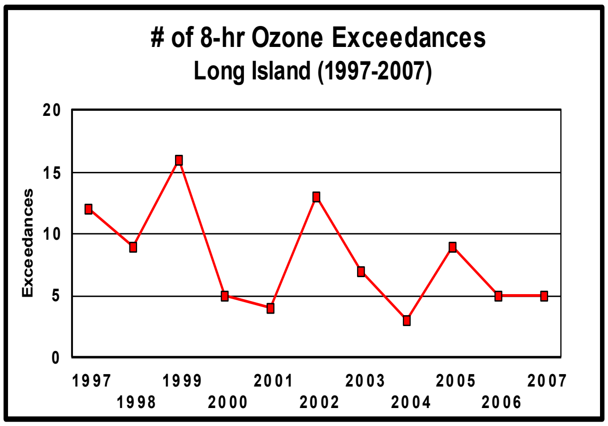

Figure 3 from Gaza, 2007

There is ongoing research into the long term combined effects of carbon dioxide and ground level ozone using a global model to predict world food production (Reilly *et al*, 2007). The model takes into account vegetation response and the world economy. One of the biggest concerns for the future is the impact that ozone will have on crop production. As discussed earlier, certain plants are susceptible to ground level ozone damage, which stunts growth and productivity. Increased CO_2 may lead some plants to be more productive. If, however, global air pollution controls are not in put into place to reduce ozone production the increased ground level ozone associated with increased air pollution and global warming associated with increased greenhouse gasses is predicted to lead to reduced food production even while the population increases (Reilly *et al*, 2007).

Ozone internet resources:

http://www.lungusa.org/site/pp.asp?c=dvLUK9O0E&b=50328
http://www.epa.gov/groundlevelozone/
http://www.atmosphere.mpg.de/enid/23c.html
http://www.fs.fed.us/r8/foresthealth/pubs/ozone/r8-pr25/ozoneh2.htm
http://www.ciese.org/curriculum/airproj/ozoneprimer.html
http://www.dec.ny.gov/airmon/index.php
http://www.nature.nps.gov/air/edu/O3Training/index.cfm

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http://earthobservatory.nasa.gov/Library/OzoneWeBreathe/printall.php

Gaza, R. 2007. D.E.C. representative for Long Island Ground level Ozone census.

Kohut, Robert, 2005, Handbook For Assessment if Foliar Ozone Injury on Vegetation in the National Parks.
http://science.nature.nps.gov/im/monitor/protocols/OzoneInjuryAssessment.pdf

Ozone Sensitive Plant Species on National Park Service and U.S. Fish and Wildlife Service Lands: Results of a June 24-25, 2003 Workshop Baltimore, Maryland.
http://handsontheland.org/monitoring/projects/ozone/O3SensitiveSpp-on-NPS-FWS-Lands.pdf

J. Reilly, S. Paltsev, B. Felzer, X. Wang, D. Kicklighter, J. Melillo, R. Prinn, M. Sarofim, A. Sokolov and C. Wang, 2007, Global economic effects of changes in crops, pasture, and forests due to changing climate, carbon dioxide, and ozone *Energy Policy*, 35, 5370-5383 (See news report on this article http://web.mit.edu/newsoffice/2007/ozone-1026.html)

Sachs, Susan and Ladd, Irene, Implementation Guide:Using Sensitive Plants as Bioindicators of ground level ozone pollution.
http://handsontheland.org/monitoring/projects/ozone/implementation_guide.pdf

United States Department of Agriculture, How to Identify Ozone Injury on Eastern Forest Plants.
http://www.fs.fed.us/r8/foresthealth/pubs/ozone/r8-pr25/ozoneh2.htm