

The Formation and Transportation of Ozone to West Point

John Doe
Department of
Columbia University
Environmental Data Analysis
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Episodes of deleterious ozone concentrations were recorded at West Point, New York between the 8/1/93 and 8/17/93. The cause of these high concentrations was determined by analyzing relevant meteorological conditions in regards to ozone formation and transportation. Ozone was formed on hot sunny days in urban areas that produce high levels of the precursor pollutants NO_x and VOCs. This ozone was then transported to West Point by atmospheric currents.

Introduction

The chemical activity of tropospheric ozone poses a potential threat to our environment and us. It is a powerful photochemical oxidant that oxidizes any potential reductant including people, animals, and plants¹. Prolonged exposure at concentrated levels severely limits respiratory function and destroys cell tissue. “Good” levels of Ozone are between 0 and 50 ppm according to the EPA’s Air Quality Control Index². Ozone and pertinent meteorological data was collected at monitoring stations at West Point New York. Figure 1 shows West Point experienced several episodes above the safe threshold during this time.

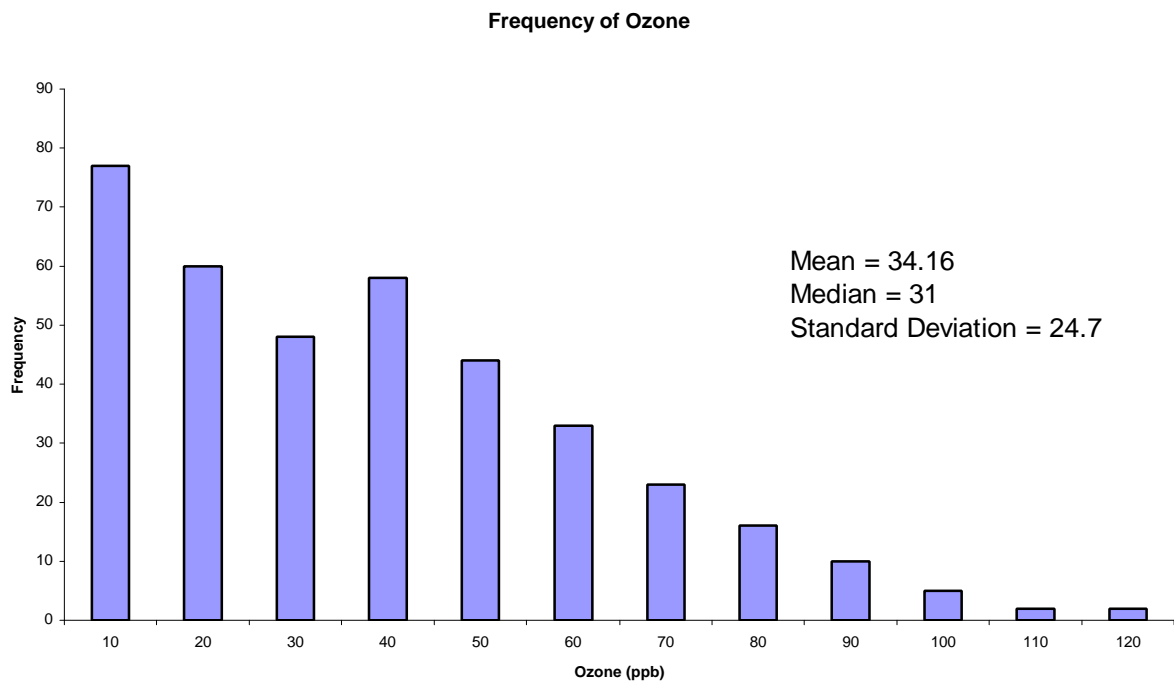


Figure 1. Frequency of Ozone Concentrations at West Point

The purpose of this study is to determine the reasons why West Point experienced such high levels of ozone. Ozone levels are directly related to formation in urban areas and transportation by atmospheric currents.

Methods

The Data collected at West Point from 8/1/93 through 8/17/93 consisted of hourly Ozone concentration and related meteorological conditions. The conditions were then graphically analyzed by time series plots, scatter plots, and histograms to find the mechanism related to the presence of unhealthy ozone.

Results

Various mechanisms of ozone formation and transportation contribute to the concentrations at West Point. To evaluate the participation of each parameter, temporal ozone concentrations are compared to the corresponding temperature, solar radiation, wind speed, and wind direction. There was no data for 8/5/93.

Results of Ozone Formation Parameters

Figure 2 shows the direct correlation between ozone and temperature. The highest levels of ozone correspond to the highest temperatures.

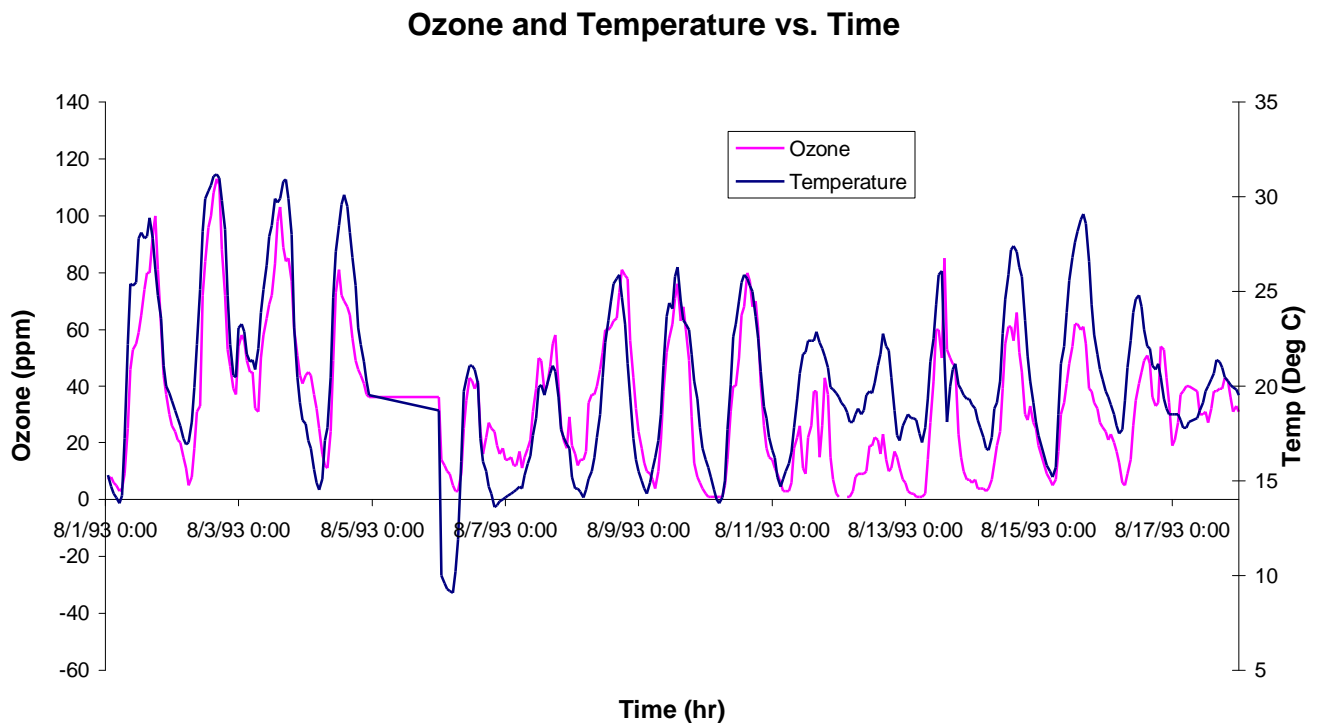


Figure 2. Temporal Ozone Concentrations and the Corresponding Temperature

Figure 3 shows how Ozone and Solar Radiation vary over time. The highest levels of ozone appear a few hours after the maximum solar radiation.

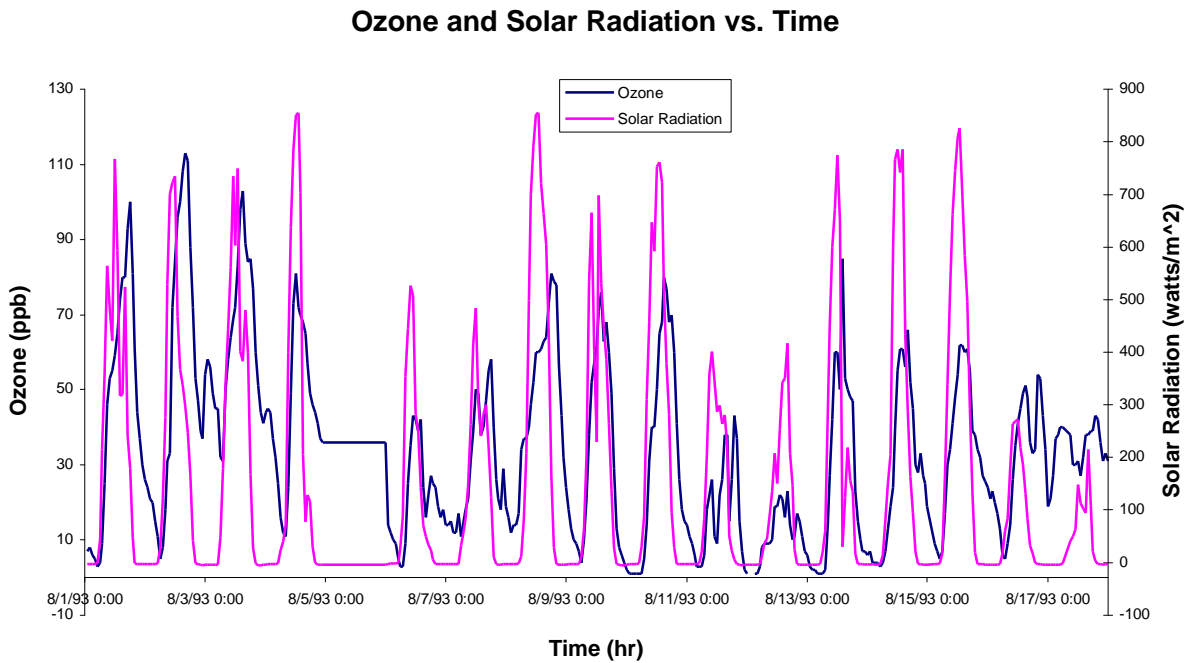


Figure 3. Temporal Ozone and the corresponding Solar Radiation.

Figure 4 shows the daily results of maximum ozone compared to the maximum solar radiation and the corresponding temperature. The highest levels of ozone correspond to high solar radiation.

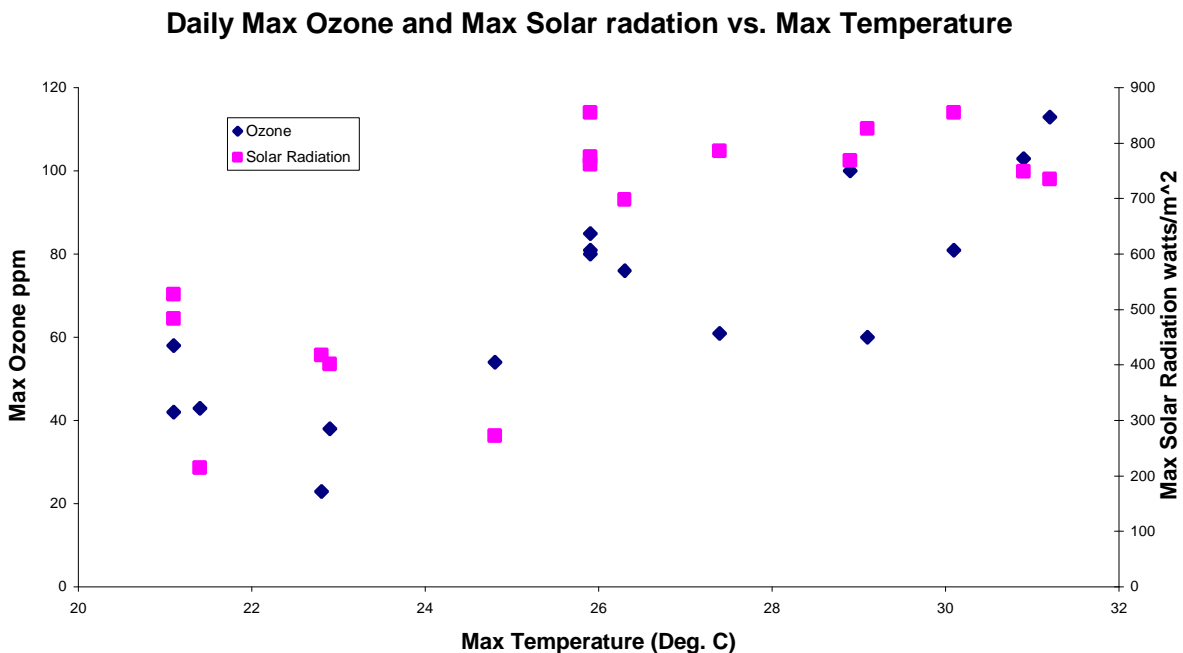


Figure 4. The Maximum Daily Ozone and Maximum Solar Radiation and the corresponding Maximum Temperature

Results of Ozone Transportation Parameters

Figure 5 shows how Ozone and Wind Speed changes with time. The higher levels of ozone are associated with the greatest magnitude of wind velocity.

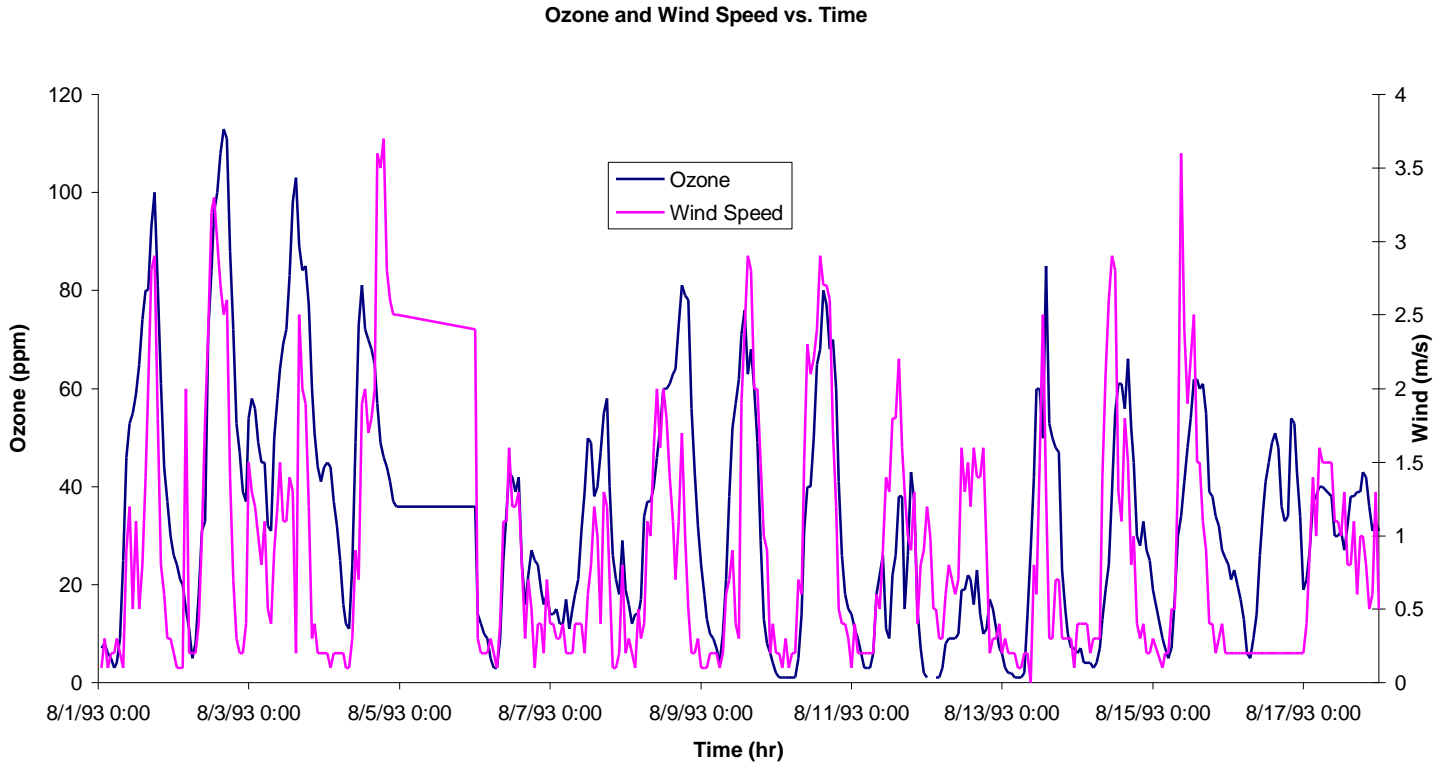


Figure 5. How Wind speed affects Ozone Concentration

Figure 6 shows a radial histogram of the prevailing wind directions. The wind directions at West Point blow Southeast and Northwest.

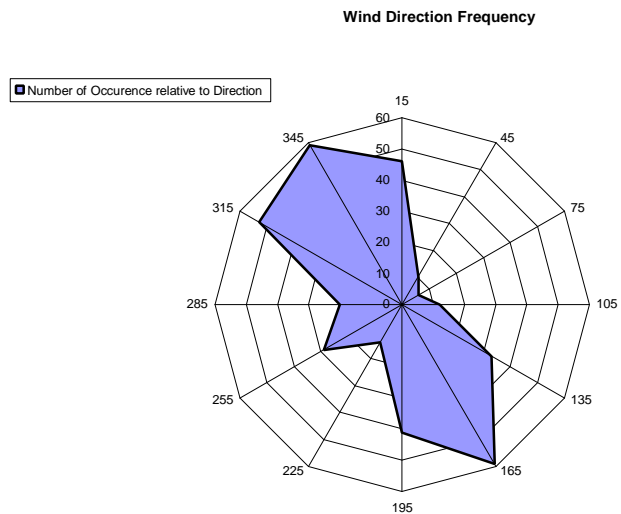


Figure 6. The Prevailing Wind Directions

Figure 7 shows the result of the temporal ozone concentration and the corresponding wind direction and magnitude for 8/10/93. The highest ozone concentrations result when the wind blows hard from the Southeast in the afternoon

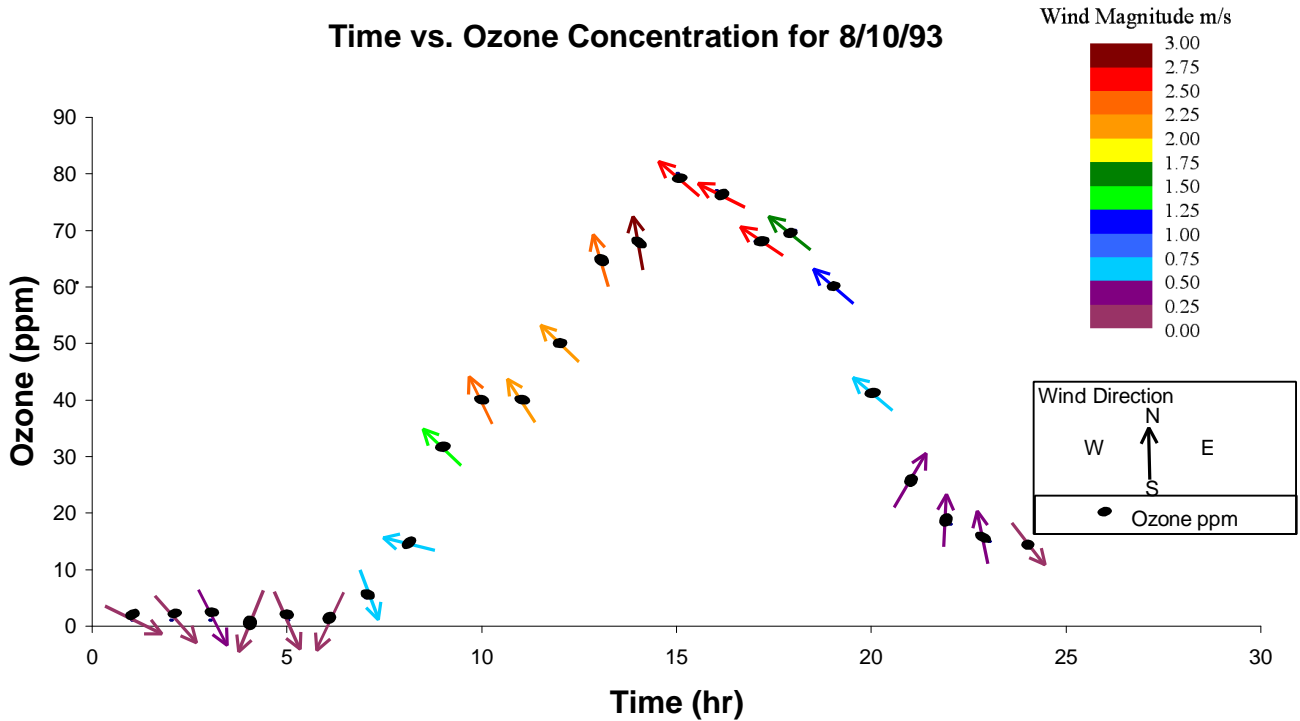


Figure 7. Temporal Ozone Concentration versus Wind magnitude and direction

Figure 8 shows the ozone concentration versus the Southeast vectorized wind (See the appendix for vectorization procedure).

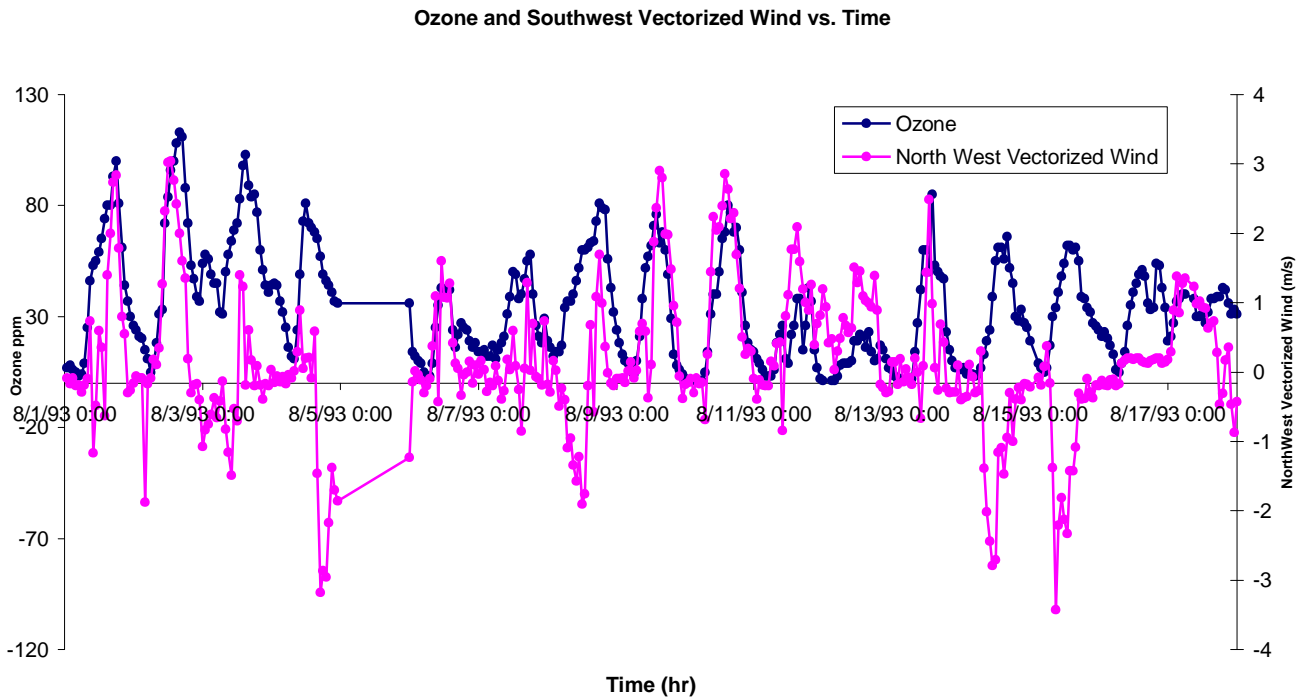
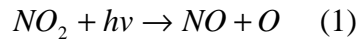


Figure 5. How Southwest Wind Velocities affect ozone concentrations

High wind velocities blowing primarily from the Southeast cause the highest levels of ozone. However, it should be noted that there are a few instances where Northwesterly winds cause high levels of ozone.

Discussion

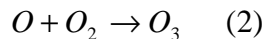
Formation and Transportation are the two key aspects of ozone presence at West Point. Formation will be discussed first. The reactions of NO_x and VOCs and create ozone in the presence of heat and sunlight. These precursor pollutants are usually created in densely populated areas like cities. NO_x is emitted from motor vehicles, power plants, and other sources of combustion. VOCs are emitted from a variety of sources, including motor vehicles, chemical plants, refineries, factories, consumer and commercial products, and other industrial sources¹. Nitrogen dioxide is photodissociated by the sun's electromagnetic radiation in the following reaction:



$h = \text{Planck's constant}$

$\nu = \text{frequency}$

The monatomic oxygen produced in equation 1 then combines with molecular oxygen to form ozone in the following reaction:



The complete reaction involving both NO_x and VOCs is complicated and will not be discussed. A complete discussion of these reactions is described in Cooper and Alley³.

The reactions that form ozone are a function of temperature and solar radiation. Figures 2 and 3 show the highest levels of ozone are strongly correlated to high temperature and solar radiation respectively. The formation of ozone with high temperature suggests that the reaction is endothermic. The increased thermal agitation could make nitrogen dioxide more susceptible to photochemical disassociation. Obviously, the greater amount of solar radiation allows more NO_x to dissociate, which in turn produces more ozone. It appears that the kinetics of the photochemical reaction is important. The peak ozone concentrations do not appear until the afternoon, a few hours after the peak amounts of solar radiation. Figure 4 shows that the higher levels of daily maximum ozone are strongly correlated to the higher levels of maximum solar radiation and higher temperatures. This means problem levels of ozone are formed on hot sunny days where there are substantial amounts of precursor pollutants.

West Point is not densely populated and could not produce the significant amount of precursor pollutants to account for the levels of ozone experienced. This suggests ozone was formed in areas of higher population and was transported by atmospheric currents. This is in agreement with Figure 5. The ozone levels stay relatively low until the wind picks up and transports ozone in from another source.

To determine the sources of ozone formation, the frequency of wind directions are examined. Figure 6 shows the prevailing wind directions are Southeast and Northwest. This would be consistent with land-sea breeze patterns. These patterns can be attributed to the different specific heats of land and water. The sun heats land air faster and it rises. This creates a pressure gradient, which causes the sea air to flow inland. At night, the reverse process happens⁴. Land-sea breeze patterns suggest the ozone is formed Southeast of West Point. The highest population direction in this direction is New York City.

Figure 7 shows as the wind blows hardest from the Southeast the levels of ozone increase. This indicates that New York City is the area of ozone formation and this ozone is transported by the land-sea breeze patterns. However, Figure 8 displays that there are a few instances where the wind blows in the opposite direction and there is still high ozone concentration. This insinuates that New York City is not the only place of ozone formation. Figure 9 gives some geographic possibilities of ozone sources that would be consistent with the vectorized plot.

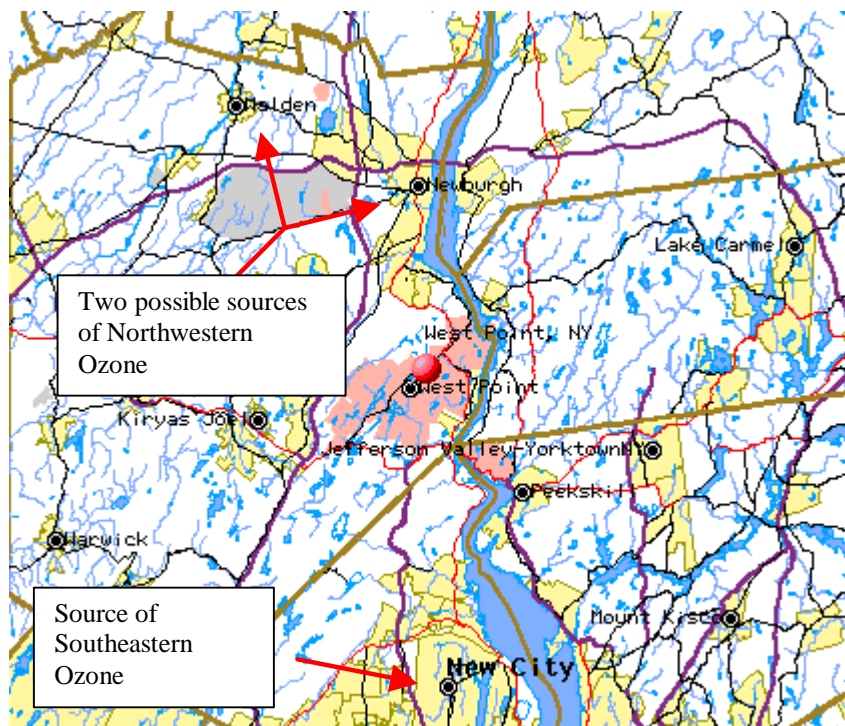


Figure 9. Other Possible Sources of Ozone

Ozone at West Point is due predominantly to formation in New York City and transportation by Southeast winds. It is occasionally it may form in Walden and Newburgh and be blown in by Northwest winds. The dominant factors influencing ozone concentration at West Point are the levels of NOx and VOCs, temperature, solar radiation, and atmospheric transport patterns. Our Society only has control of NOx and VOCs levels. Mother nature is still in charge of the other variables. Our remedial approach should be there could be no transportation without formation. Ozone

concentrations at West Point can be controlled by strict air pollution regulations, which would reduce levels of the precursor pollutants NO_x and VOCs.

Reference:

1. Committee on Tropospheric Ozone Formation and Measurement. 1991. *Rethinking the Urban Ozone Problem in Urban and Regional Air Pollution*. National Academy Press, Washington, D.C. pp. 22, 23-28.
2. Stute, M. 1999. Environmental Data Analysis. Ozone Lecture 1: *Tropospheric Ozone*. http://www.ldeo.columbia.edu/~martins/eda/ozone_lec1.html
3. Cooper, D., Alley, F. 1994. Air Pollution Control. Waveland Press, Inc. USA. pp. 485-511.
4. Miller, G.1998. Living in the Environment. Wadsworth Publishing. USA. pp. 163.