DePaul University
UNIVERSITY LIBRARIES

DePaul Discoveries

Volume 5 | Issue 1 Article 18

2016

Using a High-Altitude Balloon Platform to Observe and Measure Ozone Uptake over Agricultural Landscapes in Central Illinois

Cody Sabo
DePaul University, codyjohnsabo@gmail.com

Recommended Citation

Sabo, Cody (2016) "Using a High-Altitude Balloon Platform to Observe and Measure Ozone Uptake over Agricultural Landscapes in Central Illinois," *DePaul Discoveries*: Vol. 5: Iss. 1, Article 18.
Available at: https://via.library.depaul.edu/depaul-disc/vol5/iss1/18

Using a High-Altitude Balloon Platform to Observe and Measure Ozone Uptake over Agricultural Landscapes in Central Illinois

Acknowledgements

I would like to thank the Undergraduate Summer Research Program for providing me with financial assistance in completing this project. I would also like to thank my faculty research advisers Dr. Mark Potosnak and Dr. Bernhard Beck-Winchatz for their assistance in conducting this study. I also want to acknowledge Mike Cole and Mary Babiez for helping out with several launches. Finally, I would like to thank Paul Ritter from Pontiac High School for allowing us to use the school's property as a launch site throughout the summer.

Using a High-Altitude Balloon Platform to Observe and Measure Ozone Uptake over Agricultural Landscapes in Central Illinois

Cody Sabo*

Department of Environmental Science and Studies

Mark Potosnak, PhD; Faculty Advisor

Department of Environmental Science and Studies

ABSTRACT An increase in the amount of factories and machines that emit greenhouse gases (GHGs) has caused the concentration of GHGs to rise steeply since the industrial era. These emissions create compounds that react with sunlight to form ozone, a GHG. Ozone not only traps heat in the atmosphere causing long-term global issues, but it also causes direct harm to both plants and animals. The damage that ozone causes to plants is due to plants taking the gas up through their stomata. Measuring ozone uptake has traditionally been a difficult and expensive process. This study proposes a novel approach towards measuring ozone uptake using a high-altitude balloon (HAB). It was hypothesized that the HAB would be an effective method for measuring ozone uptake. Similarly to carbon dioxide studies performed by previous DePaul University students, the methods of this experiment involve launching a HAB carrying an ozone monitor and using the measured ozone concentrations to calculate ozone exchange values for each launch day. The data acquired from the HAB launches were not consistent with surface uptake. It was concluded that the HAB method was an ineffective method for measuring ozone uptake. This was due to the fact that ozone is both created and destroyed in the atmosphere through a series of chemical reactions as opposed to having a simple relationship with surface exchange via plants. Due to these complications, ozone production and destruction values were calculated for different altitude intervals throughout the atmosphere.

INTRODUCTION

The concentration of most anthropogenic greenhouse gases (GHGs) in the atmosphere has continued to rise since the dawn of the industrial era. This is due to an increase in the number of factories and machines that emit GHGs. The major problem associated with GHG emissions is that they can trap heat in the atmosphere which contributes to global warming. Among the gases emitted by industrial activity are carbon dioxide, methane, and nitrous oxide. Precursors to ozone, a GHG, are also emitted. While ozone is vital in the stratosphere, where it absorbs much of the ultraviolet radiation from the sun, it functions as a pollutant in the troposphere. This is because it causes direct harm to both plants and humans.

The plant damage caused by ozone not only results in economic issues related to agriculture, but also in the exacerbation of global warming

---

* Corresponding Author *codyjohnsabo@gmail.com*
Research Completed in Summer 2015

because plants serve as a sink that takes carbon dioxide out of the atmosphere. Sitch et al. (2007) found a significant suppression of the global land carbon sink because increases in ozone affect plant productivity. It is estimated that background ozone concentration in the Midwest has risen from approximately 25 ppb in 1850 to 40 ppb in 2000 (Gauss et al. 2001). More recently, national rural ozone concentration in the United States has dropped by approximately 20% (Environmental Protection Agency). However, the net increase in ozone concentration has led to crop damage, particularly to the soybean crop in the Midwest. Morgan et al. found that chronic ozone exposure of 70 ppb decreased average soybean shoot biomass by 34% (2003). The dramatic increase in ozone since the last century is due to an increase in industrial activity. This increase in industry has resulted in greater quantities of nitrogen oxides and hydrocarbons being released into the atmosphere. These compounds go through photochemical reactions in the presence of sunlight to drive ozone formation (Jacob 1999). This simplified version of the ozone formation process is shown below.

$$NO_x + C_xH_x + Sunlight \rightarrow$$

$$O_3\ (and\ other\ products)$$

Among the major effects that ozone has on plants are decrease in leaf size, decrease in leaf area, decrease in overall growth, decrease in net primary productivity (NPP), and decrease in water use efficiency (Karnosky et al. 2003). NPP is the net amount of carbon that the plant fixes in photosynthesis.

Determining the extent to which ozone is affecting a particular plant is not as easy as measuring ozone concentration outside the leaf. This is because the negative effects of ozone are most closely related to stomatal uptake into the leaf (Klinberg et. al. 2011). In a study performed by Panek et. al. (2004), it was found that periods of peak ozone concentration do not align with periods of peak ozone uptake. This shows that there is no simple correlation between ozone uptake and ozone concentration.

Traditional methods for measuring ozone uptake in the field range from using satellites (Lynch 2009) to estimating ozone uptake based on the stomatal conductance (Panek 2004). The former method is extremely costly and the latter is an indirect method of modeling ozone uptake. It is proposed that an alternate method for assessing ozone uptake is using a high altitude weather balloon (HAB). Recent studies by DePaul University students have shown that HABs are an adequate method for documenting carbon dioxide flux in central Illinois. They were able to measure seasonal carbon dioxide flux patterns that agreed with expected patterns (Pocs 2014, Bouche 2015). The HAB is cheap, quick, and can document carbon dioxide exchanges with agricultural crops over large spatial areas. While these studies have shown how the balloon method could work to document carbon dioxide flux, no such HAB studies have been performed to record ozone uptake.

The goal of this study was to measure ozone uptake in central Illinois using a HAB platform. These results would verify that the HAB platform is a successful method for measuring ozone uptake. Information from this experiment could possibly provide agronomists with an inexpensive method for measuring ozone uptake and thus determining how ozone is negatively affecting crops. It was hypothesized that the HAB would be able to measure surface ozone uptake because similar methods have already been used to successfully calculate carbon dioxide flux (Pocs 2014, Bouche 2015).

METHODS

HAB LAUNCH DESCRIPTION

This project was based upon one reported previously (Bouche, 2015), with the major difference being that Bouche's study focused on carbon dioxide flux and the focus of this study was on ozone uptake.

Ozone uptake data were acquired on five different launch days between June and September in central Illinois using a HAB carrying a flight package. The flight package contained a latex balloon (150 or 200 g), a parachute, and four payloads that were strung together using masonry cord (Figure 1). Tanks of industrial grade helium purchased from

American Gas (Dundee, IL) were used to fill the balloon until it achieved a lift of approximately 5 kg. This lift allowed the flight package to achieve an ascent rate of between 4.5 and 6.5 m s^{-1}. The parachute was attached to the balloon by two 18 ft lines. The parachute slowed the descent of the payloads to roughly 7.5 m s^{-1} to ensure a safe landing. Below the parachute, a Stratostar GPS command module (Noblesville, IN) was connected by 6 ft lines. The Stratostar GPS was used as the primary source of tracking data so that the payloads could be followed by the tracking vehicle and retrieved upon landing. A Model 205 Ozone Monitor (2B Technologies, Boulder, CO) was connected to the Stratostar GPS by 8 ft lines. The Model 205 Ozone Monitor uses UV light absorption measurements to acquire ozone concentration values. These ozone concentration data were logged in the device's internal memory along with cell pressure, cell temperature, and timestamps. A ham radio was connected to the ozone monitor by 8 ft lines. The ham radio was used as a secondary tracking device in case of primary device failure. The ham radio functioned by sending location data through the internet via a network of amateur ham radio operators (Automatic Packet Reporting System, http://aprs.fi).

The balloon and payloads were launched into the atmosphere twice during each launch day with approximately three hours in between launches. Prior to launching the balloon, a flight prediction was acquired using HABHub, software created by the UK High Altitude Society (https://ukhas.org.uk/). This prediction software uses wind data from the National Oceanic and Atmospheric Administration Global Forecast System (NOAA GFS) Model. This flight prediction was used first to gauge whether or not the conditions on a potential launch day were sufficient for success. If the prediction showed that the flight package was likely to land too far away from the launch site or in an area with too much tree cover, launches were canceled. The five days that were ultimately used for testing were June 19th, July 2nd, July 15th, August 13th, and September 12th. If conditions were appropriate for a launch, the prediction was used so that the tracking vehicle could immediately head towards the anticipated landing zone post-launch. This helped make the package retrieval process efficient.

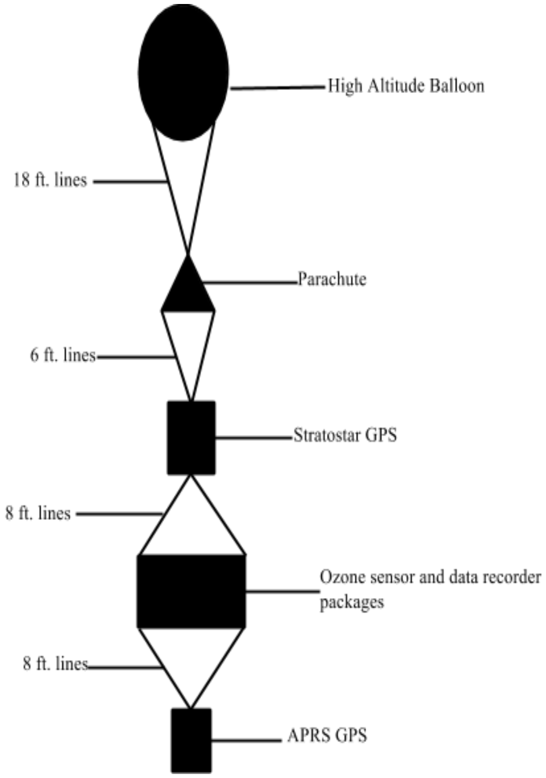

Figure 1. Diagram showing the various components of the flight package. The lengths of the lines between packages shown are approximate and may have varied by a few feet on the various launch dates. The flights were often jointly performed with an additional package for carbon dioxide.

CALCULATIONS

The HAB was launched from Pontiac Township High School located in Pontiac, IL (40°53'16.9"N 88°37'06.2"W) for every launch. The data acquired from the launch provided an ozone profile showing how ozone concentration varied with altitude for two flights on a given launch day. Microsoft Excel was used to analyze these data in order to obtain column ozone exchange values for each flight day. Column ozone exchange refers to the net amount of ozone that is being exchanged with the surface below in a square meter column of air ascending to a certain altitude. The ozone monitor recorded ozone concentration values for the entire flight, which involved the ascent to upwards of 12 km and the descent. Out of this raw data, only the first 4500 m of the ascent were analyzed. First, the ozone concentration data were placed into 300 m bins and the concentrations were averaged. This resulted in 13 different average ozone concentration values for the first 4500 m of the flight, as described below. The temperature was assumed to be constant throughout the entire flight so that the hydrostatic equation could be applied. The scale height used in the hydrostatic equation was provided by Stratostar measurements of altitude via GPS and pressure from the simultaneous carbon dioxide study (Bouche 2015). The data for these studies were measured simultaneously, with both ozone and carbon dioxide gas detectors being a part of the same flight package. The resulting temperature from the hydrostatic equation was then substituted into the ideal gas law. The ideal gas law was used to find the average density of the air (n_a/V) where n_a is the moles of air and V is a unit volume of the air in m^3. This average density value for air was multiplied by the difference in the concentration of ozone measured between the two flights in nmol of ozone per mole of air, which resulted in a mole per volume difference. This value was then divided by the change in time (Δt, s) between the two launches so that an uptake value could be calculated. This uptake value was multiplied by the height of the averaging bin (300 m) in order to convert from volume (m^3) to area (m^2). This resulted in a value for ozone uptake in nmol m^{-2} s^{-1} for each altitude bin. These bins were then summed as shown. The summation began at 600 m (300-600 m) and ended at 4500 m, represented by i=1 and 14 respectively, so that one column ozone exchange value could be determined for each launch date.

$$\sum_{i=1}^{14} \frac{\frac{n_a}{V}\,(C_2 - C_1)}{\Delta t} \times 300$$

In order to measure how ozone concentration varied over different altitude intervals, rates of ozone production/destruction (ppb/hr) were calculated for the different altitude bins used for the column ozone exchange calculations. The averaged 300 m binned data for ozone concentrations were divided by the time between flights for each bin ($(C_2 - C_1)/\Delta t$). This resulted in 13 different ozone concentration rate of change values that were each representative of different heights in the atmosphere.

RESULTS/DISCUSSION

One of the initial goals of this experiment was to measure surface ozone uptake, which may also be referred to as column ozone exchange. Column ozone exchange values for each launch data are shown in Table 1 and column ozone exchange profile data is presented in Figure 2. The lack of a clear trend between the charts was the first major indicator that the methods may not have work as planned. If the initial hypothesis were to be supported, the data should have all looked similar to that from the August 13th launch. On that day, it appeared as if ozone molecules were being taken up at the surface and produced higher up in the atmosphere. This would suggest that ozone was being taken up by crops at low altitudes and created due to chemical reactions of pollutants at higher altitudes. Data from June 19th, July 2nd, and September 12th appear to follow similar trends, but none supports the hypothesis of surface ozone uptake. These three launch dates show that column ozone exchange appeared to be positive at low and high altitudes, while being negative in the middle. Ozone should not be produced by crops, so low-altitude production was due to air chemistry. The data from September 12th further deviate from the anticipated trend because there was a positive ozone column exchange throughout the entire 4500 m.

Column ozone exchange was the focus of this study due to the success of the preceding carbon dioxide studies (Pocs 2014, Bouche 2015). It was thought that similar methods of data analysis would be sufficient for both studies. This turned out to be a false assumption because near-surface ozone and near-surface carbon dioxide behave differently. Near-surface carbon dioxide is relatively simple in the sense that it has a clear source and sink and is chemically stable in the atmosphere.

Table 1. Column ozone exchange values for each launch.

Flight Date	**Column Ozone Exchange from 600-4500 m (nmol m^{-2} s^{-1})**
June 19th	14.06
July 2nd	-34.97
July 15th	280.4
August 13th	28.35
September 12th	-9.214

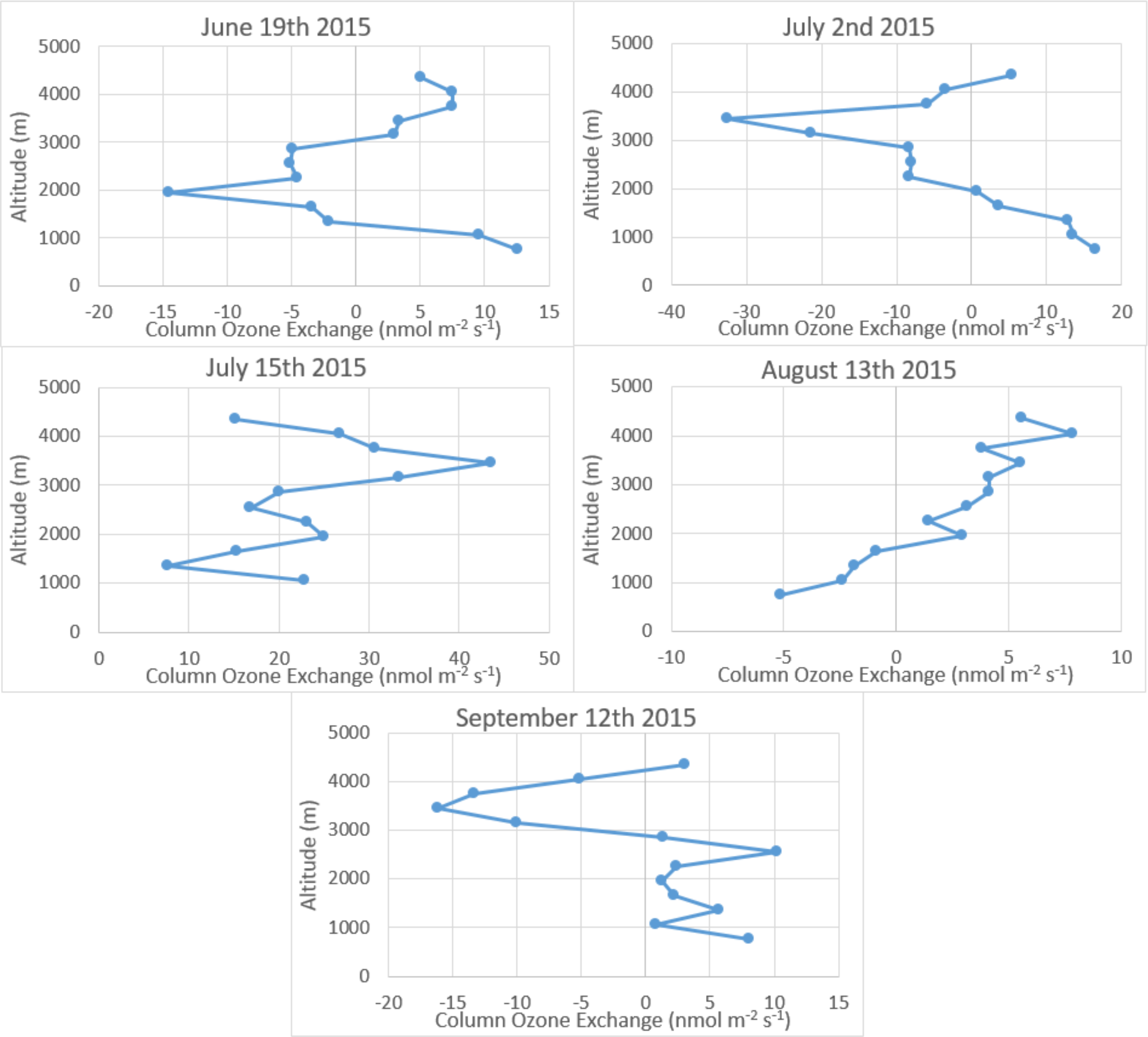

Figure 2. Summary of the various launches throughout the summer showing how column ozone exchange (nmol m^{-2} s^{-1}) varied with altitude (m). Launches on June 19th, July 2nd, and September 12th appear to follow similar trends, while the July 15th and August 13th launches are quite different.

The major source of carbon dioxide is the burning of fossil fuels and the major sink is the Earth's surface, where carbon dioxide enters either plants or bodies of water. It was clear that the only major sink for carbon dioxide would be the crops below the launches, because the studies took place over vast areas of corn and soybean crops in central Illinois.

However, ozone does not have the same clear relationship with Earth's surface as carbon disoxide has. Ozone is both produced and destroyed in the atmosphere due to complex chemical reactions. Therefore, assuming that an entire column of air behaves as if it has a clear interaction with the surface was not a reasonable premise. Although it is clear that ozone uptake can be measured by certain methods that focus on the plants themselves (Panek et. al 2004), using a HAB for ozone uptake measurements was not an appropriate method, thus disproving the initial hypothesis.

After these data were analyzed and the chemistry of ozone was researched, it became apparent that different methods of data analysis could be used to acquire useful information from this experiment. Although it would be invalid to assume that a column of ozone behaves uniformly, it would still be effective to examine how each altitude bin of ozone behaves over time. This would allow one to conclude whether ozone is produced or destroyed for each altitude interval using units of ppb/hr, which are more appropriate for atmospheric chemistry. These ozone production or destruction values were charted for the various altitudes (Figure 3) of the balloon's flight. Figure 3 shows production or destruction values and ozone concentrations for the July 2nd launch. Ozone was being destroyed between approximately 2000 and 4250 meters and it was being produced everywhere else. The chart on the left in Figure 3 shows the ozone concentration values throughout both of the flights on July 2nd. It is important to note that the ozone monitor provided negative ozone concentrations during certain portions of the balloon's second flight. This was an issue during each of the launches, which could have led to further issues in observing trends in column ozone exchange. The ozone monitor measured values that could be trusted near the surface because most of the data were in a range that one would expect.

A nearby air monitoring site, Bondville Environmental and Atmospheric Research Site, was located approximately 55 miles away from the launching site for this study. Ozone data measured from the Bondville site were recorded by the EPA air quality monitoring network (http://www3.epa.gov/airdata/ad_rep_mon.html). These data were analyzed and it was determined that the average 8 hour maximum ozone concentration for June, July, and August 2015 was 44.1 ppb with a standard deviation of 8.8. The average value of the lowest altitude bin (600-900 m.) data for each flight of this study was 42.7 ppb with a standard deviation of 10.3. The similarity in these average ozone concentration values indicated that the monitor was likely functioning correctly at lower altitudes.

Another supporting piece of evidence that showed that the instrument was functioning properly at lower altitudes was the fact that the ozone concentrations on July 2nd were relatively uniform for the first 1500 m. This stability would be expected throughout the mixed boundary layer so the measured data fit the expected trend. It is assumed that the instrument failed at higher altitudes due to the substantially lower pressure higher in the atmosphere.

It is thought that there may have been an issue with the pump that draws air into the ozone monitor at high altitudes because because of the ambient low pressure. The instrument functions by constantly drawing the air into two separate tubes. One of these tubes contains air that has been scrubbed of ozone so that the other tube can be measured spectrophotomically and compared to the tube that doesn't contain ozone. If the pump was failing or the pressure measurement faulty, then the measurements would not have been accurate and could have resulted in negative values. In the future, it would be worthwhile to further examine what could be causing these negative ozone concentration values or to attempt to use a different ozone monitor.

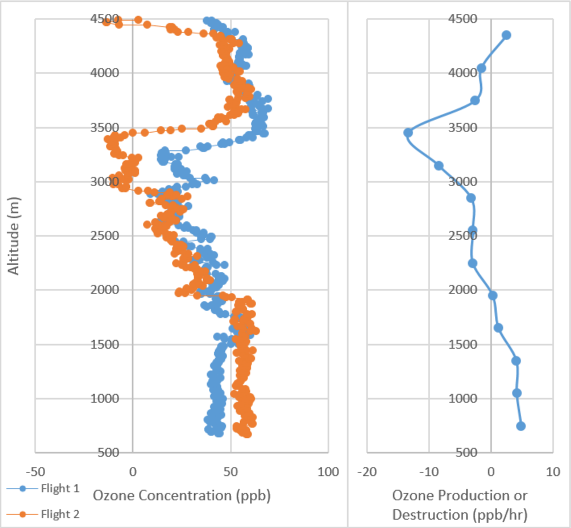

Figure 3. Charts showing how ozone concentration (ppb) and ozone production (positive values) or destruction (negative values) varied with altitude on the July 2nd flights (ppb/hr). The first flight took place 3.18 hours before the second flight.

CONCLUSION

This experiment relied on the premise that near-surface ozone and near-surface carbon dioxide behaved similarly enough to merit using similar methods to measure the surface exchange of both gases. However, the success of the carbon dioxide study in measuring carbon dioxide flux with a HAB did not translate to this study. A likely explanation for this is that ozone is too heavily influenced by atmospheric chemistry. Although the main hypothesis of this study was incorrect, the study showed a new way in which a HAB could be used to measure atmospheric gases. It is thought that a HAB could be used as a tool to investigate air chemistry. The methods may be effective for looking at ozone production or destruction (ppb/hr) values for different altitude intervals throughout the atmosphere, which was a calculation that was performed in this study.

ACKNOWLEDGEMENTS

I would like to thank the Undergraduate Summer Research Program for providing me with financial assistance while completing this project. I would also like to thank my faculty research advisors Dr. Mark Potosnak and Dr. Bernhard Beck-Winchatz for their assistance in conducting this study. I also want to acknowledge Mike Cole and Mary Babiez for helping out with several launches. Finally, I would like to thank Paul Ritter from Pontiac High School for allowing us to use the school's property as a launch site throughout the summer.

AUTHOR CONTRIBUTIONS

C.S. participated in all aspects of this study under the guidance of faculty advisor M.P.

REFERENCES

Bouche, Angela M. (2015) A High-Altitude Balloon Platform for Determining Regional Uptake of Carbon Dioxide over Agricultural Landscapes. DePaul Discoveries: Vol. 4: Iss. 1, Article 3.

Jacob, D. J. (1999). Introduction to atmospheric chemistry. Princeton University Press.

Klingberg, J., Engardt, M., Uddling, J., Karlsson, P., & Pleijel, H. (2011). Ozone risk for vegetation in the future climate of Europe based on stomatal ozone uptake calculations. Tellus: Series A, 63(1), 174-187. doi:10.1111/j.1600-0870.2010.00465.x

Lynch, P. (2009, August 4). Satellite Measurements Help Reveal Ozone

Damage to Important Crops. Retrieved February 8, 2015, from http://www.nasa.gov/topics/earth/features/soybeans.html

Morgan, P. B., Ainsworth, E., & Long, S. P. (2003). How does elevated ozone impact soybean? A meta-analysis of photosynthesis, growth and yield. Plant, Cell and Environment Plant Cell Environ, 26(8), 1317-1328.

Panek, J. (2004). Ozone uptake, water loss and carbon exchange dynamics in annually drought-stressed Pinus ponderosa forests: Measured trends and parameters for uptake modeling. Tree Physiology, 24, 277-290.

Pocs, M. (2014). A High-altitude Balloon Platform for Exploring the Terrestrial Carbon Cycle. DePaul Discoveries, 3(1). Retrieved February 9, 2015, from http://via.library.depaul.edu/depaul-disc/vol3/iss1/2/

Sitch, S., Cox, P. M., Collins, W. J., & Huntingford, C. (2007). Indirect radiative forcing of climate change through ozone effects on the land-carbon sink. Nature, 448(7155), 791-794. doi:10.1038/nature06059

Trends in Ozone Adjusted for Weather Conditions. (n.d.). Retrieved from https://www3.epa.gov/airtrends/weather.html