<u>Why We Need to Pay Attention to Ozone</u>

Figure 1: Charlotte, NC Air Quality[1]

This brief paper explains ozone, the ozone layer, the science and importance behind ozone functioning in our environment, and the impacts humans have on the state and flow of ozone. I'll focus on the Charlotte, North Carolina area and its challenges with air quality. Charlotte has been designated as one of the ten most ozone-polluted cities in the country. I'll end this paper with some adaptation and mitigation strategies to offset the bad effects humans have on ozone and ozone has on humans.

What is Ozone and is it Good or Bad?

Ozone (O_3) is a gas that occurs both in the Earth's upper atmosphere and at ground level. Ozone can be "good" or "bad" for our health and the environment, depending on its location in two layers of the atmosphere. The layer closest to the Earth's surface is the troposphere (extending about 6 miles above sea level) where ground-level or "bad" ozone is an air pollutant that is harmful to breathe and it damages crops, trees and other vegetation and is a main ingredient of urban smog. The stratospheric (about 6 to 30 miles from sea level) or "good" ozone protects life on Earth from the sun's harmful ultraviolet (UV) rays.[2]

Ozone is formed in the stratosphere when UV radiation acts on oxygen (O) molecules.[3] Their high-energy UV radiation first causes some molecular oxygen (O_2) to split apart into free oxygen (O) atoms, and these atoms then combine with molecular oxygen to form ozone via the following reactions:

$O_2 + UVB \rightarrow O + O$ (1)

$O + O_2 \rightarrow O_3$ (2)

Not all molecular oxygen is converted to ozone, however, because free oxygen atoms may also combine with ozone molecules, to form two oxygen molecules:

$O + O_3 \rightarrow O_2 + O_2$ (3)

When ozone absorbs ultraviolet B or medium waves (UVB), it is converted back to free oxygen and molecular oxygen:

$O_3 + UVB \rightarrow O + O_2$ (4)

Thus, the amount of ozone in the stratosphere is dynamic due to the continual cycle of reactions of formation (Eqs 1 and 2) and reactions of destruction (Eqs 3 and 4). Ozone concentration in the Northern Hemisphere is highest in summer and lowest in winter; Ozone concentrations are highest at the equator and diminish as latitude increases. Both of these effects are due to overall amounts of solar radiation influenced by seasonal variations. Other chemicals in the stratosphere can upset the normal ozone equilibrium and promote undesirable reactions.

Ground-level ozone forms when nitrogen oxides (NOx) react with volatile organic compounds (VOCs) in the presence of heat and sunlight. VOCs, or hydrocarbons come from man-made sources such as cars, service stations, dry cleaners and factories and natural sources such as trees and other vegetation. hey evaporate easily and typically have a strong smell. Fumes from substances such as gasoline, paint thinners and solvents, printer ink, fragrances in perfumes, soaps, and other consumer products are VOCs. Naturally occurring VOCs from trees and vegetation are sometimes called biogenic emissions, while man-made emissions are referred to as anthropogenic.[4]

NOx is a byproduct of combustion, and comes from coal-fired power plants, industrial boilers, motor vehicles, lawn-care equipment and other sources that burn fuel. In some North Carolina urban areas, up to 70% of ozone-forming NOx comes from motor vehicles.

"Good" ozone is gradually being destroyed by man-made chemicals referred to as ozone-depleting substances (ODS), including chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), halons, methyl bromide, carbon tetrachloride, and methyl chloroform. These substances were formerly used and sometimes still are used in coolants, foaming agents, fire extinguishers, solvents, pesticides, and aerosol propellants. Once released into the air these ozone-depleting substances degrade very slowly. In fact, they can remain intact for years as they move through the troposphere until they reach the stratosphere. There they are broken down by the intensity of the sun's UV rays and release chlorine and bromine molecules, which destroy the "good" ozone. Scientists estimate that one chlorine atom can destroy 100,000 "good" ozone molecules. It can take 10-20 years for cholorofl ourocarbon molecules to get into the stratosphere and then can react with the ozone for up to 120 years. These impacts cause a serious thinning in the stratospheric ozone layer over the South Pole, referred to as "the ozone hole."[5]

Rowland and Molina[6] won the Nobel Prize in Chemistry in 1995 for their finding that CFCs could damage the stratosphere ozone layer through the release of chlorine atoms and, as a result, UV radiation would increase and cause more skin cancer. CFCs are viewed as dangerous because they act as transport agents that continuously move chlorine atoms into the atmosphere. Other scientists reasoned that any substance carrying reactive halogens (halons, methyl chloroform, carbon tetraflouride, and methyl bromide) to the stratosphere had the potential to deplete ozone.

$$Cl + O_3 \rightarrow ClO + O_2 \quad (5)$$

$$ClO + O \rightarrow Cl + O_2 \quad (6)$$

These reactions destroy ozone and reduce the likelihood that it will be formed because atomic oxygen (O) is removed, as well.

Solar radiation emits electromagnetic waves with a wide range of energies and wavelengths. Visible light is that part of the electromagnetic spectrum that can be detected by the eye. Ultraviolet light (UV) wavelengths are slightly shorter than the wavelengths of violet light, which are the shortest wavelengths visible to the human eye. UVB radiation consists of wavelengths that range from 280-315 nonometers (0.28-0.32 μm). Since energy is inversely related to wavelength, UVB is more energetic and therefore more dangerous but UVA can also cause damage to humans, especially through sun burn.

Sunlight, temperature, atmospheric stability, and wind conditions all affect the formation and accumulation of ground-level ozone. Ultraviolet radiation from sunlight drives the reaction between NOx and VOCs to form ozone, so ozone pollution increases on clear or partly cloudy days. Like many chemical reactions, ozone formation increases as temperatures rise. In addition, temperature affects ozone-forming emissions (e.g., evaporative emissions of VOCs and biogenic emissions increase with high temperatures). Atmospheric stability (temperature change by height) controls the amount of vertical air mixing that takes place. Strong stability tends to reduce mixing (dilution) of ground-level ozone and ozone-forming emissions. During atmospheric inversions, air higher in the atmosphere is warmer than air below, preventing lower air from rising and mixing. Inversions thus concentrate air closer to the surface, sometimes resulting in higher ozone levels. Wind conditions affect the dispersal and dilution of air and pollutants. Calm or light winds allow more pollution to concentrate in an area. Upper-level winds are also important because they can transport ozone great distances during the overnight period. Ozone concentrations tend to be highest on sunny, hot days with little to no wind.[7]

Effects of Ozone and UV

Upon penetrating the atmosphere and being absorbed by biological tissues, UV radiation damages protein and DNA molecules at the surfaces of all living things. If the full amount of UV radiation falling on the stratosphere reached Earth's surface, it is doubtful that any life could survive. This is not occurring because most UV radiation (more than 99%) is absorbed by ozone in the stratosphere. For this reason, the stratospheric ozone is referred to as the **ozone shield.**

Ozone pollution can damage plant tissues, reducing growth rates and agricultural yields. It interferes with the ability of plants to produce and store food, making them more susceptible to disease, insects, other pollutants, and harsh weather. Ground-level ozone damages the foliage of trees and other plants, impacting the landscape of cities, national parks and forests, and recreation areas. UV can also damage sensitive crops, such as soybeans, and reduce crop yields. Some scientists suggest that marine phytoplankton, which are the base of the ocean food chain, are already under stress from UV radiation. This stress could have adverse consequences for human food supplies from the oceans.

Ozone is a strong respiratory irritant, and can cause serious health problems, especially for sensitive groups: children, people with asthma and other respiratory ailments, and anyone who works or exercises vigorously outdoors. Symptoms of ozone exposure can include coughing, throat irritation, chest pain, rapid and shallow breathing, and asthma attacks. Emergency room visits for asthma have increased as much as 36 percent on high ozone days, according to some studies. High childhood exposure to ozone pollution may reduce lifetime lung function.

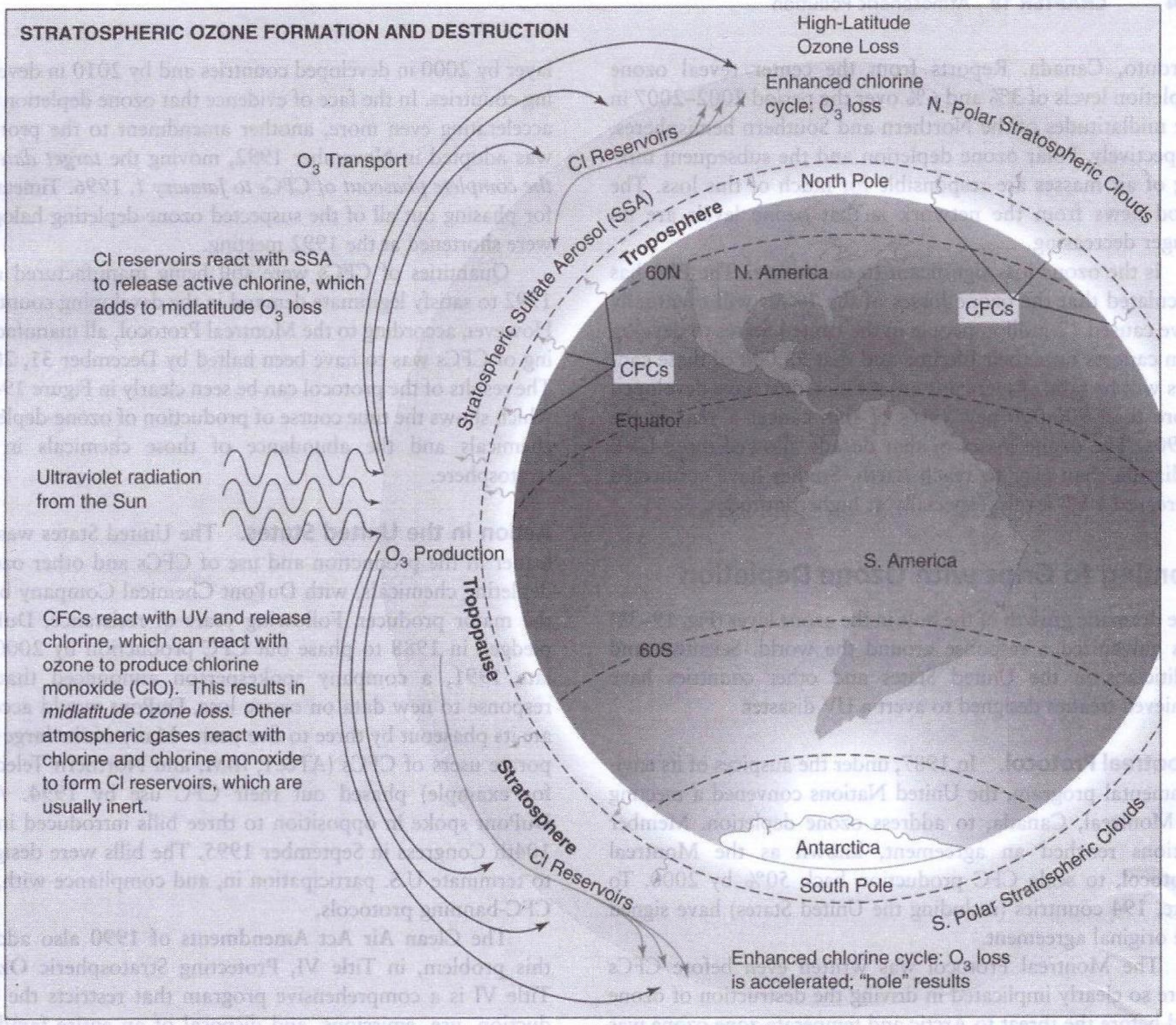

Figure 2: Stratospheric ozone formation and destruction. UV radiation stimulates ozone production at the lower latitudes, and ozone-rich air migrates to high latitudes. At the same time, CFCs and other compounds carry halogens into the stratosphere where they are broken down by UV radiation, to release chlorine and bromine. Ozone is subject to high-latitude loss during winter, as the chlorine cycle is enhanced by the polar stratosphere clouds. Mid-latitude losses occur as chlorine reservoirs are stimulated to release chlorine by reacting with stratosphere sulfate aerosol.[8]

Short-term, infrequent exposure to ozone can result in throat and eye irritation, difficulty drawing a deep breath, and coughing. Long-term and repeated exposure to ozone concentrations above the Federal standard can result in reduction of lung function as the cells lining the lungs are damaged. Repeated cycles of damage and healing may result in scarring of lung tissue and permanently reduced lung function. Health studies have indicated that high ambient ozone concentrations may impair lung function growth in children, resulting in reduced lung function in adulthood.[9] As lung function declines in older adults, individuals whose lung function is already below normal may be especially vulnerable to respiratory problems.[10]

Asthmatics and other individuals with respiratory disease are especially at risk from elevated ozone concentrations. Ozone can worsen, and may trigger, asthma attacks. Ozone may also contribute to the development of asthma. A recent study found a strong association between elevated ambient ozone levels and the development of asthma in physically active children.[11]

All children are at risk from ozone exposure because they often spend a large part of the summer playing outdoors, their lungs are still developing, they breathe more air per pound of body weight, and they are less likely to notice symptoms. Children and adults who frequently exercise outdoors are particularly vulnerable to ozone's negative health effects, because they may be repeatedly exposed to elevated ozone concentrations while breathing at an increased respiratory rate.[12]

Ozone depletion can cause increased amounts of UV radiation to reach the Earth which can lead to more cases of skin cancer, cataracts, and impaired immune systems. Overexposure to UV is believed to be contributing to the increase in melanoma, the most fatal of all skin cancers. Since 1990, the risk of developing melanoma has more than doubled.

The nitrogen oxides that contribute to ozone pollution also fall back to the earth as nitrogen compounds, contributing to nutrient pollution of streams, rivers, and estuaries. As much as half of the nitrogen pollution in North Carolina's coastal waters may come from air pollution. Nutrient pollution contributes to algal blooms, reduced oxygen content of water, and fish kills.

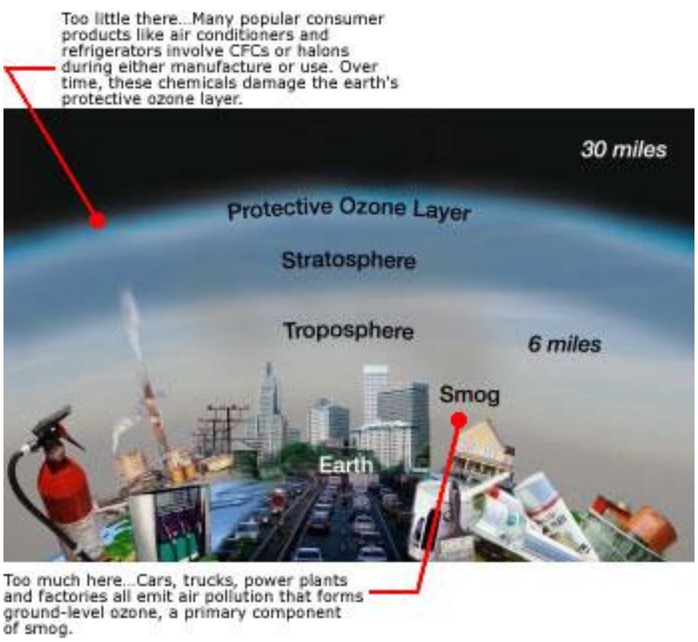

Figure 3: Demonstration of ozone impacts at different levels of the atmosphere.[13]

North Carolina and Ozone

The Federal standard for ground-level ozone is 0.075 parts per million (ppm), averaged over an 8-hour period. This is often referred to as the "8-hour standard" and replaces an older "1-hour standard" of 0.125 ppm. Levels of 0.076 ppm and above exceed the Federal ground-level ozone standard.[14] Because hot, sunny conditions are needed for elevated ozone levels, ozone is only a problem during the warm-weather months. For example, the ozone forecast season, when N.C. Division of Air Quality forecasts daily ozone levels, is April 1 to October 31. Ozone begins forming in the morning and formation increases as temperatures increase during the day. Ozone accumulates through the day, especially when winds are calm. In most areas of North Carolina, ozone levels peak during mid-afternoon through early evening, when temperatures are hottest. Ozone levels decrease as the sun sets, drop at night and are lowest around dawn. However, at high elevations (above 4,000 feet) in the mountains, ozone levels can remain high throughout the day and actually reach their highest values overnight. See Table 1 for the Air Quality Index designations.

Table 1: Air Quality Index (AQI) Scale[15]

Good (**Green**): 0-50[16]
Moderate (Yellow): 51-100
Unhealthy for Sensitive Groups (**Orange**): 101-150
Unhealthy (**Red**): 151-200
Very Unhealthy (**Purple**): 201-300
Hazordous: 301-500+

For example, in Charlotte:[17]
8/08/11 89
8/09/11 89
8/10/11 90

Charlotte has an air quality index of 8.6 compared to the national average of 82.8 (100=best).[18] These data are based on ozone alert days and the number of pollutants in the air, as reported by EPA. The American Lung Association's State of the Air Report[19] shows the Charlotte area as the 10th most ozone-polluted city in the nation. The city shows unusually high incidents of pediatric asthma, adult asthma, chronic bronchitis, emphysema and poverty.[20] See Table 2 for the list of 10-most ozone-polluted cities.

Table 2: 10-most Ozone-Polluted Cities

1. Los Angeles-Long Beach-Riverside, California
2. Bakersfield-Delano, California
3. Visalia-Porterville, California
4. Fresno-Madera, California
5. Sacramento-Arden-Arcade-Yuba City, California-Nevada
6. Hanford-Corcoran, California
7. San Diego-Carlsbad-San Arcos, California
8. Houston-Baytown-Huntsville, Texas
9. Merced, California
10. Charlotte-Gastonia-Salisbury, North Carolina

Thus, ozone status and its dynamics are critical to people living in the region. What can be done to mitigate or adapt to these conditions?

What to Do To Mitigate and Adapt

On Ozone Action Days of Code Orange and above, people should try to schedule exercise for the morning, and avoid strenuous exercise in the afternoon. Although ozone levels are generally not as low at dusk as in the morning, ozone levels during dusk and evening are usually safe for exercise. On Code Green days, one is safe exercising any time of the day, and most people are safe exercising on Code Yellow days as well. On "high" Code Yellow days when the AQI is predicted to be close to 100, very sensitive people may need to limit or avoid afternoon exertion.

Efforts to control ozone focus on NOx because most of it comes from man-made sources that can be controlled. Reducing VOCs is less effective because pines, oaks and other trees that are so abundant in the South emit large amounts of hydrocarbons. Most of the ozone in urban areas comes from local sources. However, winds can carry ozone from cities to surrounding rural areas and even to other states. Much of the ozone pollution at high elevations in the mountains of Western North Carolina is transported by winds from other states. In mountain valleys, however, ozone-forming pollution can come from both local and out-of-state sources.

Several major countries and regions (e.g., US, Canada, EU, Soviet Union, Germany) agreed to reduce the use of chloroflourocarbons and halons.[21] These initial efforts have continued with the addition of added bans and reductions on chemicals such as methyl chloroform and leading to complete bans on certain chemicals such as 1996 ban in the United States for all chlorofluorocarbons.[22] These moves are producing some positive outcomes. For example, Figure 4 shows the size of the ozone hole over time which indicates that the ozone hole is stabilizing. The graph shows a steady increase in the size of the ozone hole from 1980 to 2000. The ban on the use of chlorofluorocarbons and other ozone-destroying chemicals appears to have had a positive effect. The trend since 2000 appears to be stable or declining.[23]

Even though we have reduced or eliminated the use of many ODSs, their use in the past can still affect the protective ozone layer. Research indicates that depletion of the "good" ozone layer is being reduced worldwide. Thinning of the protective ozone layer can be observed using satellite measurements, particularly over the Polar Regions.(See Figure 4).

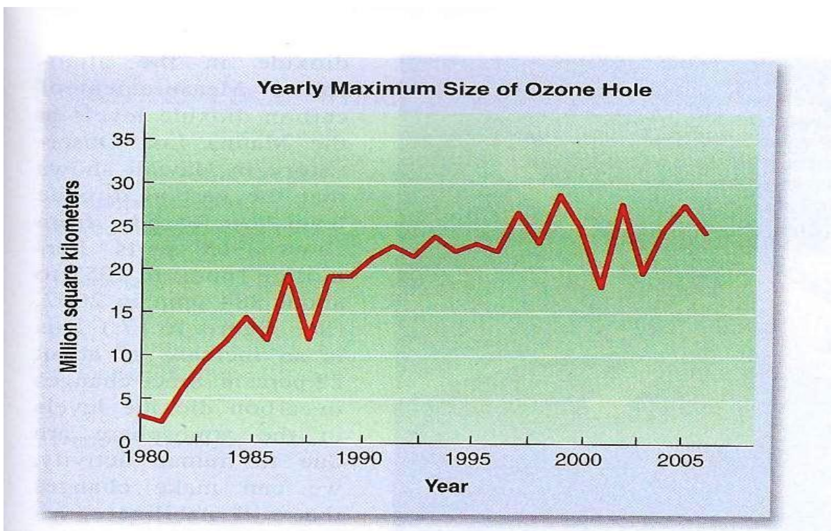

Figure 4: Size of Ozone Hole.

The EPA has established regulations to phase out ozone-depleting chemicals in the United States. Warning labels must be placed on all products containing CFCs or similar substances and nonessential uses of ozone-depleting products are prohibited. Releases into the air of refrigerants used in car and home air conditioning units and appliances are also prohibited. Some substitutes to ozone-depleting products have been produced and others are being developed. If the United States and other countries stop producing ozone-depleting substances, natural ozone production should return the ozone layer to normal levels by about 2050.

Ozone is a secondary pollutant thus the only way to control ozone levels is to control compounds that lead to its formation. Because the biggest source of ozone pollution in most areas is cars and trucks, taking steps to reduce driving one's car will be most helpful. Conserving electricity will reduce ozone pollution resulting from power plant emissions.

The UV Index shows that melanoma incidence in the US is increasing, 8.7/100,000 people in 1975 to 17.7/100,000.[24] Much more has to be done with preventing sun burn and more serious outcomes of UV exposure. People have many myths about sun tanning, so communication is essential. For example, some believe that a suntan is healthy, establishing a base suntan protects you from sun to damage. This is false. A tan results from the body defending itself against further damage from UV radiation. Any change in one's skin's natural color is a sign of damage to the skin.[25]

A final approach is to hold our Congress accountable for its environmental attitudes. Many members of congress are proposing to weaken or block enforcement of the Clean Air Act, including taking away EPA legal authority and funding. The American Lung Association released a bipartisan poll that showed Americans support efforts for even tougher air quality standards and oppose Congressional action that interferes with the EPA's ability to update clean air standards.

ENDNOTES

[1] http://maps.co.mecklenburg.nc.us/website/airquality/default.php?tab=Visibility%20Camera Accessed July 9, 2011.

[2] The discovery of UV radiation was associated with the observation that silver salts darken when exposed to sunlight. In 1801, the German physicist Johann Wilhelm Ritter made the hallmark observation that invisible rays just beyond the violet end of the visible spectrum were especially effective at lightening silver chloride-soaked paper. He called them "oxidizing rays" to emphasize chemical reactivity and to distinguish them from "heat rays" at the other end of the visible spectrum. The simpler term "chemical rays" was adopted shortly thereafter, and it remained popular throughout the 19th century. The terms chemical and heat rays were eventually dropped in favor of ultraviolet and infrared radiation, respectively. The discovery of the ultraviolet radiation below 200 µm, named vacuum ultraviolet because it is strongly absorbed by air, was made in 1893 by the German physicist Victor Schumann. P.E. Hockberger (2002). "A history of ultraviolet photobiology for humans, animals and microorganisms". Photochem. Photobiol. **76** (6): 561–579. T. Lyman. (1914). "Victor Schumann". Astrophysical Journal **38**: 1–4.

[3] R.T. Wrigth and D.B. Boorse (2010). Environmental science: toward a sustainable future. Eleventh Edition. Pearson Edition: 511-512.

[4] EPA (2003) Ozone: Good up high, bad nearby. Office of Air and Radiation. Washington, DC: United States Environmental Protection Agency.

[5] EPA (2003) op cit.

[6] M.J. Molina and F.S. Rowland (1974). Stratospheric sink for Chlorofluoro-methanes: Chlorine-atom catalyzed distribution of ozone. Nature. 249: 810-812.

[7] EPA (2003) op cit.

[8] R.T. Wrigth and D.B. Boorse (2010). Op cit. 513.

[9] EPA (2003) op cit.

[10] D. Reed, D Foley, et al. (1998), Predictors of Healthy Aging in Men with High Life Expectancies. American Journal of Public Health, 88: 1463-1468. Also, see Module 3: **Module 3: Normal Change of Aging**
http://www.ageworks.com/course_demo/513/module3/module3.htm Accessed July 9, 2011

[11] McConnell et al. (2002). Asthma in exercising children exposed to ozone: a cohort study. Lancet 359: 386-391.

[12] McConnell et al. (2002) Op cit.

[13] EPA (2003) op cit.

[14] Parts per million, or ppm, is a ratio that describes how many parts of something you have per one million equally-sized parts of something else. So, with the 8-hour standard, the maximum healthy concentration of ground-level ozone is less than 1/10th of one part of ozone per one million parts of air.

[15] http://weather.weatherbug.com/NC/Charlotte-weather/air-quality.html Accessed July 9, 2011

[16] QI refers to the Air Quality Index.
An AQI of 100 is equivalent to the National Ambient Air Quality Standard (NAAQS). An AQI greater than 100 is considered to be above the national standard or NAAQS. An AQI Calculation Table (http://daq.state.nc.us/airaware/ozone/codecalc.shtml)is available online to convert raw ozone concentrations to the Air Quality Index. The weather conditions listed above are common weather types associated with the respective air quality levels. A combination of part or of all these weather conditions could lead to a certain level of observed air quality. Accessed July 9, 2011.

[17] http://daq.state.nc.us/monitor/monitoring_plan/ Accessed July 9, 2011.

[18] http://www.bestplaces.net/health/city/north_carolina/charlotte Accessed July 9, 2011.
[19] American Lung Association (2011). State of the Air Report. Washington, DC: American Lung Association. http://www.lungusa.org/assets/documents/publications/state-of-the-air/state-of-the-air-2011-report-embargoed.pdf Accessed July 8, 2011.
[20] Ibid: 13
[21] Montreal Protocol 1987 was ratified by the U.S. Senate in 1988. http://www.eoearth.org/article/Montreal_Protocol_on_Substances_that_Deplete_the_Ozone_Layer Accessed July 8, 2011
[22] R. E. Benedick, (1998) Ozone Diplomacy – New Directions for Safeguarding the Planet. Enlarged Edition. Boston, MA: Harvard University Press.
[23] E.D. Enger and B. F. Smith (2010) Environmental science: A study of interrelationships. Twelfth Edition. NY, NY: McGraw Hill: 379.
[24] National Cancer Institute, SEER Program quoted in EPA (2004). A guide to the UV Index. Washington, DC: EPA:2.
[25] Ibid: 6.