



ESA21

Environmental Science Activities for the 21st Century

The Atmosphere

Ozone Depletion

From the notes in the Layers of the Atmosphere, we learned that the homosphere, or lower atmosphere, is divided into three layers. The troposphere, closest to the earth, is where daily weather phenomenon occurs and where air pollution and acid rain is distributed. Now, it's time to set our sites a little higher, specifically to the stratosphere. The stratosphere sits some 11 to 30 miles from the earth's surface. As 90% of the gas molecules in the atmosphere are within the first ten miles, the air in the stratosphere is very thin.

Despite the thinness of the stratosphere, however, there is one gas located there which performs a critical function to life on earth. The gas is ozone, or O_3 . Ozone filters ultraviolet radiation from the sun. Various forms of energy have different wavelengths. The wavelength of light energy, for example, is shorter than that of heat energy. Ultraviolet, or UV, energy has a wavelength that is shorter than light energy. Even UV energy itself is divided into three types, based on wavelength with UVC being the shortest, UVA the longest and UVB in the middle.

Humans need a small amount of ultraviolet radiation to maintain health. Ultraviolet radiation activates vitamin D in the human body, which assists the intestines in absorbing minerals. Humans, as well as other life forms, can tolerate radiation through the UVA range, but radiation with shorter wavelengths, such as UVB and UVC is harmful. Oxygen molecules absorb the shortest and most harmful UVC radiation and ozone absorbs most of the remainder before it reaches the earth's surface. Ozone, a molecule containing three oxygen atoms, is made when the shortest wavelengths of UVC are absorbed by oxygen and break apart into two oxygen atoms. These atoms then combine with O_2 molecules to form stratospheric ozone and it is these O_3 molecules that shield the surface from too much ultraviolet radiation.

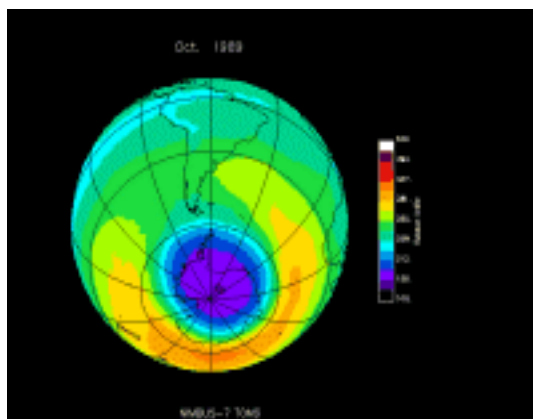


Fig. 1: Data image showing Antarctic ozone hole (NASA)

Stratospheric ozone depletion occurs when O_3 molecules interact with chlorine-based compounds such as chlorofluorocarbons, also known as CFCs, and halons. Chlorofluorocarbons are synthetic compounds containing chlorine, fluorine, and carbon. CFCs have been used in a wide variety of consumer and commercial applications such as refrigeration, air conditioning, foam production, aerosol propellants, and circuit board cleaning. Halons are another class of synthetic chemicals that are used to extinguish fires.

Both CFCs and halons are extremely long-lived and stable chemicals that can remain chemically active in the atmosphere for decades. Not only do CFCs and halons destroy the molecular bonds of the O_3 molecule, but also a single chlorine molecule can eliminate as many as 100,000 ozone molecules. Halons contain bromine and are even more potent ozone destroyers than CFCs.

The result of ozone destruction is a gradual thinning of the stratospheric ozone layer. Over the past 20 years, ozone levels above the Antarctic have dropped by almost 50%, resulting in an “ozone hole”. Every year, beginning in September, ozone levels in the stratosphere above the Antarctic begin to decline. As they decline, more and more ultraviolet radiation reaches the earth’s surface. Scientists believe that a 1% drop in ozone accounts for a 2% increase in ultraviolet radiation at the earth’s surface.

Over time the Antarctic ozone hole has gotten larger. In September 2003, the World Meteorological Association reported that the 2003 hole equaled the all time record set in September 2000. Over the past decade, stratospheric ozone levels have begun to decrease in the Arctic as well, though scientists believe that a “hole” like that at the South Pole is not likely to develop. Nonetheless, there have been short period with significant ozone loss in the Arctic, such as in the winter of 1998-99. A small amount of ozone loss, about 3%, appears to be occurring around the mid-latitudes.¹

Increasing ultraviolet radiation at the surface results in effects on human health, natural ecosystems, and crops. The human effects of increasing ultraviolet radiation include increase in skin cancer cases, development of cataracts, and suppression of human immune systems. Effects on natural ecosystems include decrease in photosynthetic productivity and adaptive strategies. Phytoplankton in the oceans, for example, are thought to stay further away from the ocean surface in response to changing ultraviolet light concentrations. The crop productivity of certain crops can be adversely affected by changes in UV concentrations at the surface.

The Montreal Protocol, adopted in 1987, required nations to freeze production levels of CFCs. Additional agreements enacted since 1987 accelerated the CFC phase out timetable to December 31, 1995. Atmospheric concentrations of chlorofluorocarbons peaked in 1994 and began to decrease in 1995, marking the first time that a atmospheric concentrations of chlorine began to decrease. Chlorine concentrations in July 2002, were about 5% less than the 1994 peak. However, the amount of atmospheric bromine continues to increase, albeit at a slower rate.

Many scientists believe that the stratospheric ozone layer will be somewhat “mended” by the year 2050, though uncertainty remains. In the mean time, it is difficult to predict, with any reasonable accuracy, the amount of ozone depletion that might continue to take place, how much additional UVB will reach the earth’s surface in the next fifty years, and the potential impacts of this increased radiation on terrestrial and aquatic ecosystems as well as on human health.

Activity

While we often talk about the “Ozone Hole” over the Antarctic, we rarely talk about what ozone levels are like above our own heads. While the thinning of the ozone layer over the South Pole points to potential problems that we might experience here one day, it would be nice to know what our current situation is. In this week’s activity, we will do just this with the aid of data from 4 different satellites that have been monitoring ozone levels around the world for the last several decades.

The Total Ozone Mapping Spectrometer (TOMS) Program was started in 1978 to provide scientists with a global view of the stratospheric ozone layer. Until this time, the only measurements that had been taken of it were from ground-based instruments that were limited to the thickness of the layer directly above the instrument. With the placement of the TOMS instrument on the Nimbus-7 satellite, we began period of being able to “see” the entirety of the layer in real time. Since that first instrument, there have been three additional instruments placed on orbiting satellites: the Russian Meteor-3, the Japanese Advanced Earth Observing Satellite (ADEOS), and the NASA Earth Probe satellite. With the exception of an 18-month gap in 1994-1995,

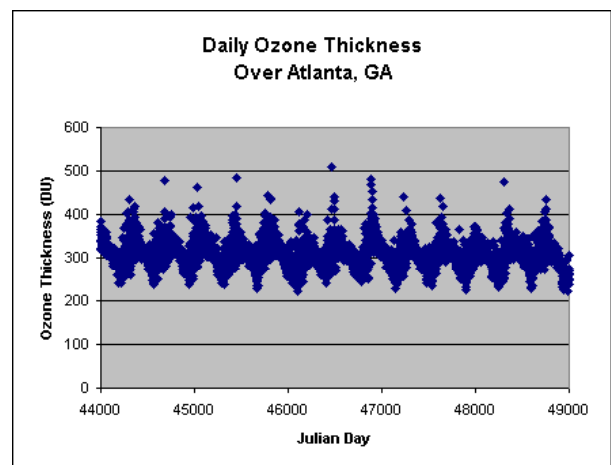


Fig. 2: TOMS data over Atlanta (13 year period)

we have a continuous data set for ozone measurements².

The data from these satellites is available to the public from NASA. It can be accessed in a variety of forms, both graphically and numerically. For instance, if one so desires, they can access the ozone thickness reading for all locations on the Earth for almost every day since 1978 (see Figure 2 for an example of one sites data). If one were to do this, they could definitely check the hypothesis that the ozone thickness has been declining worldwide over that time period. We are not going to do that here, as it would take too much time to complete.

Instead, we are going to look at the average monthly data for latitudinal bands. This will be done for several reasons. By averaging the data over a month's period of time, we will be eliminating the daily variability in the data. After all, what we are looking for is a change in a longtime trend. In a similar fashion, zonally averaging the data gets rid of small variations that might occur in space. Some localized atmospheric phenomenon might cause a blip in the data that will not show up in the zonally averaged data.

Your instructor will advise you on which locations and months you are to investigate. You should only compare data from the same month each year, as seasonal variations cause the ozone thickness to cycle annually. The data you are going to use can be found at the [NASA TOMS](http://toms.gsfc.nasa.gov) site. Under the title of "Data Product: Zonal Mean", you are able to select from which satellite you wish to retrieve data. You need to select "Monthly" before you push the Request button. From this site, you need to retrieve the data for the appropriate months and locations and place it in the appropriate slots on the Activity Sheet below. Once you are finished doing this, you need to answer the questions on the sheet.

References

- 1 UNEP/WMO "Scientific Assessment of Ozone Depletion: 2002" Executive Summary, Final.
- 2 http://pao.gsfc.nasa.gov/gsfsc/service/gallery/fact_sheets/earthsci/toms.htm, September 17, 2004.
- 3 <http://toms.gsfc.nasa.gov/ozone/ozoneother.html>, September 17, 2004

ESA21: Environmental Science Activities

Activity Sheet
Ozone Depletion

Name: _____

Month = _____

Latitude Range = _____

Year	Thickness	Year	Thickness	Year	Thickness	Year	Thickness
1979		1985		1991		1998	
1980		1986		1992		1999	
1981		1987		1993		2000	
1982		1988		1994		2001	
1983		1989		1996		2002	
1984		1990		1997		2003	

1. Plot the data in the table above and perform a linear regression (best fit line). Is the trend of the data decreasing, increasing, or staying the same? Does this fit what you expected? Why or why not?
2. Notice the variability of the data from year to year. Is this larger or smaller than you would have expected? Does its size make you trust or doubt your result in question 1? Why?
3. The amount of stratospheric ozone is affected by the amount of solar radiation. In particular, an increase in the amount of high-energy solar particles striking the atmosphere results in an increase in the creation of ozone. Because of this, one expects to see variability in the ozone data that matches the 11-year sunspot cycle. Do you see evidence for this in your data? If so, how does it affect your result in question 1?