

ESA21

Environmental Science Activities for the 21st Century

Ozone: Stratospheric Ozone

Ultraviolet Light

Introduction

Last week, we studied ground-level ozone. We discovered that our modern way-of-life produces ozone in great quantities, which can be extremely harmful to the environment since it is a chemical poison to many life forms, including humans. This week, we are going to investigate stratospheric ozone. As we read last week, this ozone is responsible for filtering out ultraviolet radiation from sunlight and reducing levels of it found at the Earth's surface. This action is extremely important to life forms found in our ecosystems, since this high-energy form of ionizing radiation can have damaging effects.

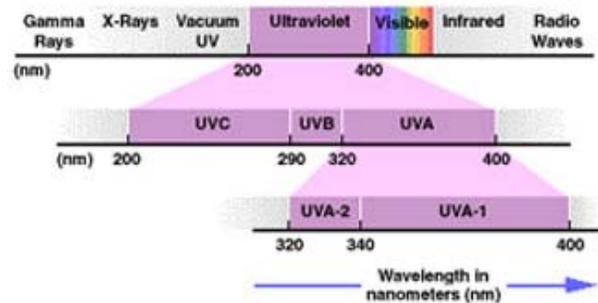


Fig. 1: Ultraviolet region UVA, UVB, and UVC. UVA radiation is between 320-400 NM UVB radiation ranges between 290-320 NM UVC ranges between 200-290 NM

While our eyes allow us to estimate the amount of visible light that comes from the Sun, we are generally unaware of the amount of non-visible light that it is striking the Earth. The diagram at the right shows the wavelength range of light that is emitted by the Sun. As we can see, the visible part of the spectrum is an extremely tiny portion of the total range. While most of the Sun's energy is in this range, there is still a significant portion of the Sun's energy that is emitted in the infrared and ultraviolet range. While a great deal of the infrared radiation is absorbed by the many greenhouse gases in the atmosphere, the only thing standing between us and the ultraviolet radiation is stratospheric ozone.

Why do we need to filter out a lot of this UV radiation? The amount of energy that can be absorbed from electromagnetic radiation depends inversely on the wavelength of the radiation. The shorter the wavelength of the radiation is, the greater the amount of radiation that can be absorbed. We do need some UV radiation exposure during our day. Our bodies naturally produce Vitamin D when exposed to UV radiation. However, UV radiation can be extremely harmful to organisms in large quantities. The large amount of energy that can be absorbed from it is enough to ionize many atoms, including those found in the DNA in your cells. Because of this, there is a much greater risk of contracting skin cancer if you are exposed to high doses of UV radiation.

UV radiation is also linked to many other harmful effects. It can cause cataracts, which may cause blindness for both humans and animals. It damages plants at the cellular level, leading to damaged leaves and eventual death. In the oceans, it can wipe out large numbers of tiny organisms called plankton. These organisms are important because they are major source of food for many marine animals and because they absorb so much carbon dioxide. Without them, we would see a great die off of fish and marine mammals and an increase in the amount of atmospheric carbon dioxide.

Ozone and Ultraviolet Light

Interaction

The increasing concern over increased UV radiation at the Earth's surface is due to the depletion of stratospheric ozone. Under normal condition, most of the UV radiation that strikes our atmosphere is

absorbed in a layer of the atmosphere that lies between 15 and 30 kilometers above the Earth's surface where there is a significant amount of ozone gas. This is known as the ozone layer.

The process by which ozone (O_3) is created and absorbs the ultraviolet radiation is shown at the right. When radiation below 200 nanometers (NM) strikes molecular oxygen (O_2), it breaks it apart into two atoms of oxygen. These oxygen atoms are then free to combine with other molecules of oxygen to create ozone. This process is reversed when UV radiation in the UVB range is absorbed by ozone. This high-energy radiation breaks the bonds of the molecule, creating a molecule and a single atom of oxygen. This free oxygen atom then combines with an ozone molecule, causing it break down into two molecules of oxygen.

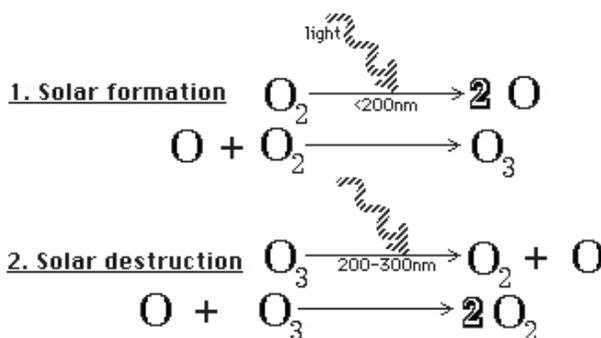


Fig. 2: The formation and destruction of stratospheric ozone

In the absence of man-made chemicals, these processes occur so as to continually create and breakdown ozone. However, in the presence of certain chemicals, this balance is upset, and more ozone is broken down than is created. This causes an overall reduction in the amount of ozone, which reduces our atmosphere's ability to absorb UV radiation.

Learn more about how man-made chemicals destroy the ozone layer and view an animation of the process by viewing the [Stratospheric Ozone](#) page from project LEARN. Supplemental information on stratospheric ozone can be viewed on EPA's [Ozone Depletion](#) site.

	<p>Topic: Ozone Layer Date: May 30, 2000 Summary: NPR's Richard Harris reports that another significant ozone hole formed over the Arctic this year. This loss of ozone lets more damaging ultraviolet light reach the Earth's surface. At a news conference today, scientists attributed this year's ozone loss to clouds in the stratosphere, which persisted into the spring (http://www.npr.org). (3:30) Link: http://www.npr.org/ramfiles/atc/20000530.atc.12.ram</p>
<p>Listen</p> <p>Requires RealPlayer</p>	

Internet Addresses of Linked Sites

Project LEARN Stratospheric Ozone: http://www.ucar.edu/learn/1_6_1.htm

EPA Ozone Depletion: <http://www.epa.gov/ozone/science/>

UV Index and Dobson Units

Measurements

In this week's lab, we are going to look at the relationship between the amount of UV radiation that gets to the Earth's surface and the amount of stratospheric ozone. In order to do this, we first need to decide upon what we will be measuring.

As we saw previously, the UV portion of the spectrum comprises many wavelengths. One way to measure the amount of UV radiation would be to pick a particular wavelength in that spectrum range and to measure its amplitude. While this method will give us detailed information about how this portion of the spectrum is affected, it would be problematic since it would not involve sampling of the entire range. There might be processes that actually affect the amount of radiation in other parts of the UV spectrum without affecting the one particular wavelength that we chose. A better method of measuring the amount of UV radiation would involve sampling all wavelengths. This is done with the UV index, which is a weighted sum of the amount of energy being delivered in the UV range. This sum is weighted to take into

account the fact that different wavelengths of ultraviolet radiation do more damage to human skin than others.

We also need to measure the amount of ozone in the stratosphere. This is not as easy as it sounds. Ozone is spread out over the entire region of the stratosphere. At different heights above the surface, there are different concentrations. Therefore, just as with wavelength, if we were to sample at just one height, we would not get an accurate picture of the total amount of ozone. The way that has been decided upon by the scientific community is to calculate the thickness of ozone that would result from compressing all of the ozone in the stratosphere into a single layer at a temperature of 0 Celsius and one atmosphere of pressure. The thickness of this layer is measured in Dobson units (100 DU is about 1 millimeter).

Other Factors

UV Radiation

While the amount of ozone in the stratosphere gets most of the headlines, the amount of UV radiation at the surface does depend on other factors. These factors concern the angle at which sunlight is striking the Earth, how much atmosphere is above the surface, and the type of weather and surroundings. The factors below are taken from the EPA's brochure "The Sun, UV, and You".

Time of Day - The Sun is at its highest in the sky around noon. At this time, the Sun's rays have the least distance to travel through the atmosphere and UVB levels are at their highest. In the early morning and late afternoon, the sun's rays pass through the atmosphere at an angle and their intensity is greatly reduced.

Time of Year - The Sun's angle varies with the seasons, causing the intensity of UV rays to change. UV intensity tends to be highest during the summer months.

Latitude - The sun's rays are strongest at the equator, where the sun is most directly overhead and UV rays must travel the least distance through the atmosphere. Ozone also is naturally thinner in the tropics compared to the mid- and high-latitudes, so there is less ozone to absorb the UV radiation as it passes through the atmosphere. At higher latitudes the sun is lower in the sky, so UV rays must travel a greater distance through ozone-rich portions of the atmosphere and, in turn, expose those latitudes to less UV radiation.

Altitude - UV intensity increases with altitude because there is less atmosphere to absorb the damaging rays. Thus, when you go to higher altitudes, your risk of overexposure increases.

Weather Conditions - Cloud cover reduces UV levels, but not completely. Depending on the thickness of the cloud cover, it is possible to burn—and increase your risk of long-term skin and eye damage—on a cloudy summer day, even if it does not feel very warm.

Reflection - Some surfaces, such as snow, sand, grass, or water can reflect much of the UV radiation that reaches them. Because of this reflection, UV intensity can be deceptively high even in shaded areas..

For a complete guide to UV exposure, read the EPA's [brochure](#) on the subject. Clicking on this link will open a new window. Please close it when you are finished reading the PDF file.

Internet Addresses of Linked Sites

The Sun, UV, and You (EPA): <http://www.epa.gov/sunwise/doc/sunuvu.pdf>

Ozone vs. UV Index

Activity

As we can see, there are several factors other than ozone that affect the amount of UV radiation found at the Earth's surface. Therefore, if we wish to study the relationship between stratospheric ozone and UV

radiation, we will need to find some way to hold these other factors constant. In most areas of the world, this will prove extremely daunting. By restricting ourselves to one location to do our evaluation, we will be fixing the altitude. However, this will be about the only thing that we will fix. At no locations will the Sun always be at the same angle every day; at almost all, the Sun's angle will vary throughout the entire day. Outside of desert locations, the weather will make day-to-day measurements highly variable. Even something as simple as the local reflectivity can vary radically, as foliage changes color or new dust gets deposited.

With this in mind, there is one location that would better than most others to carry out such a study: the South Pole. While the angle of the Sun's rays does change throughout the year, it is constant throughout the day (the South Pole experiences a 6 month period of daylight followed by a 6 month period of night as the Sun makes a 360 degree circle around the horizon each day at the same angle above the horizon). The South Pole is also in the middle of a very arid desert, getting less than an inch of precipitation a year. And with a landscape that is only snow and ice, the albedo (reflectivity) is extremely constant. The last reason to use the South Pole to do our study is that we have about 5 years' worth of UV Index and stratospheric ozone data to use from this location for our study.

Choosing Dates

You will be examining data from the South Pole over several sequential years (1996 - 2003) for this activity. It is important to remember that the Sun is either below the horizon or just above the horizon for much of the year in this location. Since we are going to be measuring the ultraviolet radiation coming from the Sun, it is best to investigate dates during which the Sun is well above the horizon and shining on a flat, horizontal surface. The best times for this occur between November 1 and February 14 of each year. Your instructor might want to assign you certain dates. If not, it is advisable to use dates from each year that fall within this time frame.

As mentioned above, one of the factors that affects the amount of UV radiation that is measured at the Earth's surface is the angle at which sunlight strikes the Earth. The picture at the right shows sunlight (yellow) coming through the Earth's atmosphere at two different angles and striking UV detectors. You will note that the greater the angle θ , the farther the sunlight must travel through the ozone layer (blue), which effectively makes the ozone layer thicker than it actually is. You will also note that the steeper angle corresponds to the sunlight's energy being spread over a greater area. Thus, the detector will measure a smaller amount of UV radiation, as the spreading of the energy means less will strike the detector's surface.

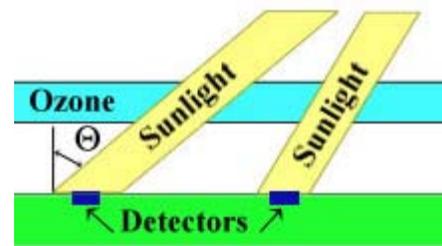


Fig. 3: Diagram of sunlight striking the Earth at two different angles

One way to take this effect of the sunlight's angle of incidence into consideration is to limit your data to when the Sun is at the same position in the sky. You can do this by selecting the same set of days from each year's worth of data. For instance, if you only look at data from February 1st in any of the years between 1996 and 2003, then you can be assured that the Sun will always be at the same angle of incidence. Since the angle of the Sun is not that much different on January 31st or February 2nd, you could also consider using data from these days each year. However, doing so will severely limit the amount of data that you can use in this activity.

Another way to take this affect into consideration is to account for the variances in angles mathematically.

If the sunlight is striking the ozone layer at an angle θ from the vertical, and the ozone layer has a thickness D , then the sunlight is actually traveling through an amount of ozone that is given by the formula

$$\text{Ozone amount} = D/\cos \theta$$

At the same time, the energy of the sunlight is being spread out over a greater area than it would be if it

were striking the Earth at a normal angle. The detector, which is sitting flat, will measure an intensity of radiation that is reduced because of this. If we let I be the intensity of radiation measured by the detector, the actual intensity of the sunlight is given by

$$\text{Actual intensity} = I/\cos \theta$$

Thus, we can take into account the effects of the sunlight coming in from various angles by multiplying all measured ozone thicknesses and UV intensities by the same factor, which is the reciprocal of the cosine of the angle that the sunlight strikes the ground with respect to the vertical. Using the position of the Sun on the various days as seen from the South Pole, we have created a [table](#) of these factors for each day for you to use.

UV and Ozone Databases

The data that we are going to use this week comes from two different sources. The stratospheric ozone data comes from the NASA Total Ozone Mapping Spectrometer (TOMS) satellite. This satellite has recorded the ozone thickness over the entire almost every day for the last 7 years. Luckily, the friendly people at NASA have built a nice search engine that allows one to extract ozone thickness data from any location at any time. This search engine is found at the address

http://toms.gsfc.nasa.gov/teacher/ozone_overhead.html

The UV data comes from an NSF-sponsored monitoring unit at the Scott-Amundson station at the South Pole. Biospherical Instrument, Inc. in San Diego has developed an interactive database for the NSF that allows one to retrieve UV Index data for this site. This database can be found at

<http://www.biospherical.com/nsf/student/CSVRequest.asp>

Clicking on either of these links will bring up a window that has the interface required to retrieve the data from each site. From these interfaces, we are going to want to retrieve ozone thickness and UV Index data for dates that you have decided upon. To do this, follow the directions below.

Retrieving UV Index Data (http://www.biospherical.com/nsf/student/CSVRequest.asp):	
1.	Select your Start Date.
2.	Select your End Date .
3.	Select the South Pole as your site from the pull-down menu.
4.	Select the Irradiance Data that you want. Choose the UV Index data only (ozone does not absorb UVA).
5.	Select "Retrieve Only Noontime Scans". This will ensure that the data was taken at the same time every day.
6.	Click on Submit.
Retrieving Ozone Thickness Data (http://toms.gsfc.nasa.gov/teacher/ozone_overhead.html):	
1.	Enter -90 for the Latitude and 0 for the Longitude.
2.	Select a set of Year, Month, and Day that corresponds to your first UV Index data point.
3.	Click on Submit, and write down the value for the Ozone Thickness in Dobson Units.
4.	Click on the Back button at the top of the browser to take you back to the first page.
5.	Repeat with the same Latitude and Longitude, but a different Year, Month, and Day.

Activity Sheet Directions

Before entering you data onto the activity sheet, be sure to multiply both the UV Index data and the Ozone Thickness data by the appropriate factor for that day (see [factor table](#)). Enter the UV data (from the NSF site) and the Ozone thickness data (from the NASA TOMS satellite) in the appropriate cells in the table. Once all the data has been entered, make a plot of UV Index vs. Stratospheric Ozone Thickness. As plotting requires both measurements for a given day, you cannot plot days where you only have one measurement (either the UV Index or Stratospheric Ozone Thickness) for that day. If ozone does absorb ultraviolet radiation, then this data should show that the UV Index decreases as the ozone thickness increases. This will be seen from a plot of your data.

Analysis:

Describe the relationship between the UV Index and the stratospheric ozone thickness. Explain why this is or isn't the relationship you expected.

Over the last several decades, there has been a measured thinning of the stratospheric ozone layer over most of the world. If the relationship that you found is correct, what would this mean for ecosystems worldwide (what would you expect to be occurring in these ecosystems)?