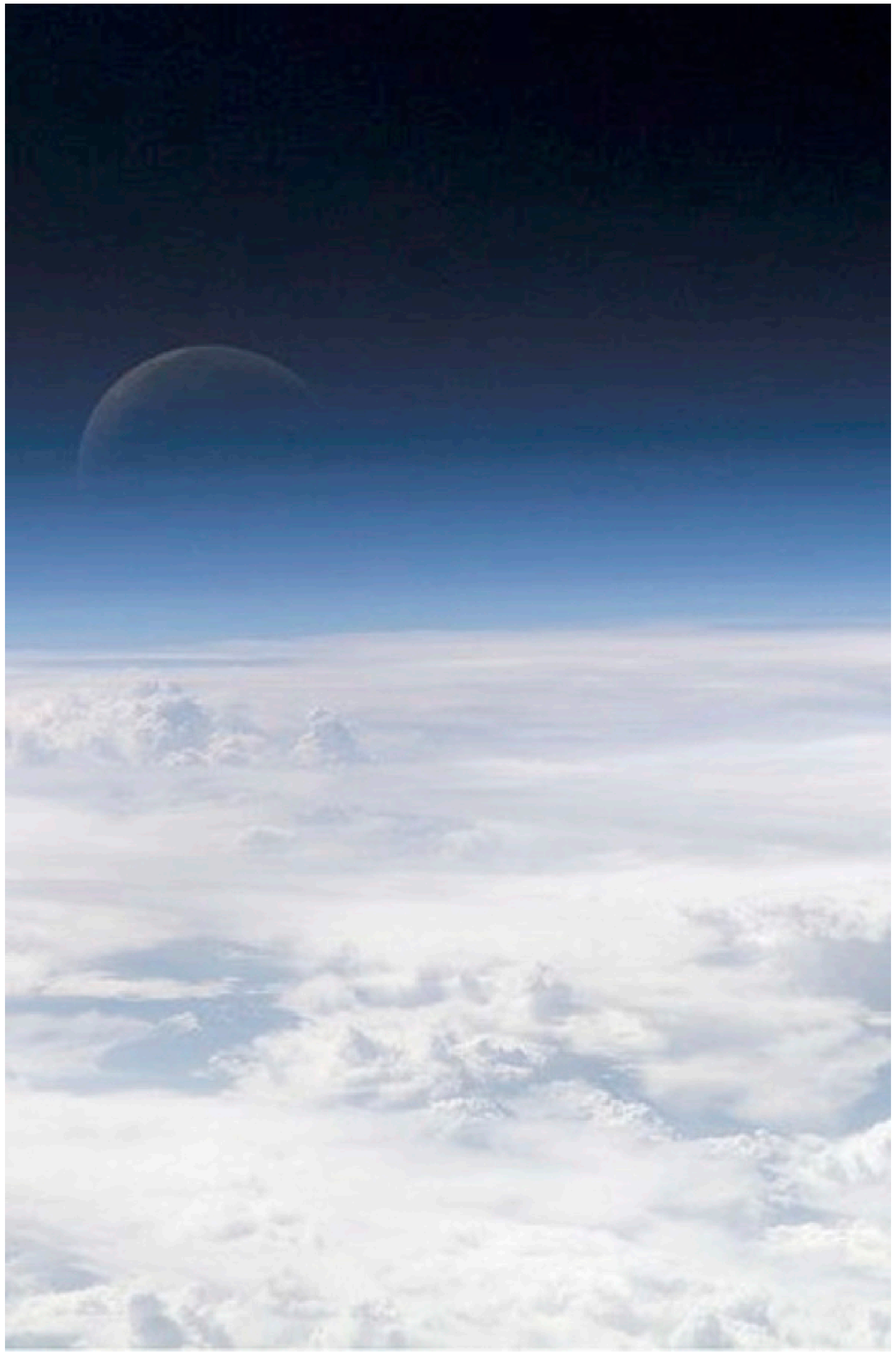
Chapter 11

Atmosphere

Chapter Objectives:

1. Understand the composition and structure of the Earth's atmosphere.
2. Describe the difference between weather and climate.
3. Describe the changes to the Earth's atmosphere over the last million years. Discuss how natural changes in the Earth's orbital parameters affect this (Milankovitch Cycles).
4. Discuss the Coriolis Effect and describe how it affects wind patterns.
5. List and describe greenhouse gases. Discuss sources and sinks for these gases, describing both natural and anthropogenic sources.
6. Describe the heat island effect. Discuss its impact on the environment.
7. List the major anthropogenic air pollutants and describe their effects on the environment.
8. Describe the role of ozone in both the troposphere and the stratosphere. Discuss efforts to control it in the troposphere and to prevent its loss in the stratosphere.
9. Describe positive and negative feedback cycles in the atmosphere and discuss how they would affect the average temperature.



Atmosphere Connections

Each day, Earth's 7.2 billion people interact with the atmosphere in many ways. Jet pilots, for example, fly through the atmosphere and must be intimately familiar with weather patterns. Satellite TV stations send signals through the atmosphere that bounce off satellites and then back through the atmosphere to satellite dishes scattered far and wide. Many of these interactions are invisible and involve gases, heat, or energy waves. The most basic of these interactions is, of course, breathing. In fact, right now as you read these words, you are inhaling oxygen (O_2) and exhaling carbon dioxide (CO_2). We humans need a steady supply of "clean" air.

The process by which humans inhale O_2 and exhale CO_2 is known as respiration. This exchange of gases is the respiratory system's means of getting oxygen to the blood. Without air, a person will die faster than if they were deprived of any other human need, such as food, water, or cellphones. Most of us can only hold our breath for about a minute. After 30 seconds, it begins to get uncomfortable. After 3 to 5 minutes, hypoxia, or oxygen deprivation sets in, brain cells begin to die and you're on your way to being dead. Note: This is not part of your lab assignment.

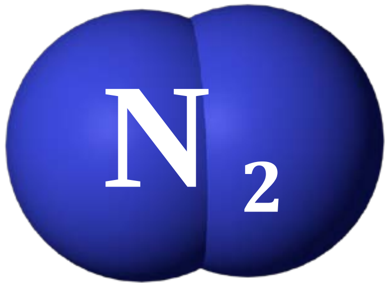
Breathing is not the only way in which humans interact with the atmosphere. A good example of this is sneezing, which is a reflex response usually to the presence of atmospheric particulates, such as pollen or dust, in your nose. We also sneeze when we are sick with a cold, or sometimes when light and pressure changes suddenly. Sneezing sprays the atmosphere around you with microscopic bacteria and fluid at a speed close to the fastest baseball pitchers, about 100 miles per hour.

Not all of our bodily interaction with the atmosphere occurs in an obvious manner. When we sweat, water is excreted to the surface of our skin through pores. This moisture evaporates into the air by absorbing heat from our body, thereby cooling our body in a more efficient manner than conduction. This evaporation increases the humidity of the air around us, thus affecting the composition of that air. Of course, the amount of the humidity increase is small, and as anyone who lives in an environment that is already moist knows, will depend upon what the relative humidity in the surroundings is to start.

Atmospheric Composition

The air you are breathing is actually a mixture of gases. This mixture of gases is known as the atmosphere. The word "atmosphere", by the way, comes from the Latin "atmosphaera", which was cobbled together from the Greek word "atmos", meaning "vapor", and the Latin word "sphaera" translated as sphere. Quite literally then, the atmosphere is the "vapor-sphere".

This gaseous composition of the atmosphere is usually expressed by percentage volume, that is, each gas's relative part of the total mixture. For example, 78% of the atmosphere is made of the gas nitrogen (N_2), 21% is composed of oxygen (O_2), and .9% is made up of argon (Ar). These three gases together make up 99.9% of the atmosphere. Other gases that make up the atmosphere include water vapor (H_20), carbon dioxide (CO_2), neon (Ne), helium (He), methane (CH_4), krypton (Kr), and hydrogen (H_2). These gases, along with many others, are referred to as trace gases, in that there are small traces of them in the atmosphere. The concentration of gases in the atmosphere normally is measured in parts per thousand (ppt), parts per million (ppm) or parts per billion (ppb).



The atmosphere also contains solid material in addition to the gases above. This solid material is very small, between .1 and 25 thousandths of a millimeter, or micrometer and is known as particulates. To give you some idea how small particulates are, a single grain of table salt is about 100 micrometers in size, which corresponds to a mass of material that is 1/1000 to ¼ the size of a grain of table salt. In addition to gases and solids, liquids also exist in the atmosphere. The most common one of these is water. Water exists in the atmosphere as clouds, rain, and fog, all of which are visible and, therefore, familiar. See Appendix B for the composition of the atmosphere and the cumulative volume of each compound.

Layers of the Atmosphere

Appendix B shows that the atmosphere contains gases, suspended liquids, and solids that entirely surround Earth. Earth's gravity pulls these gases, liquids, and solids toward the surface. Since gases are compressible, it is not surprising that there are more gases closer to the surface and fewer as you move away. Therefore, the Earth's atmosphere is denser at the surface and gradually thins as altitude increases.

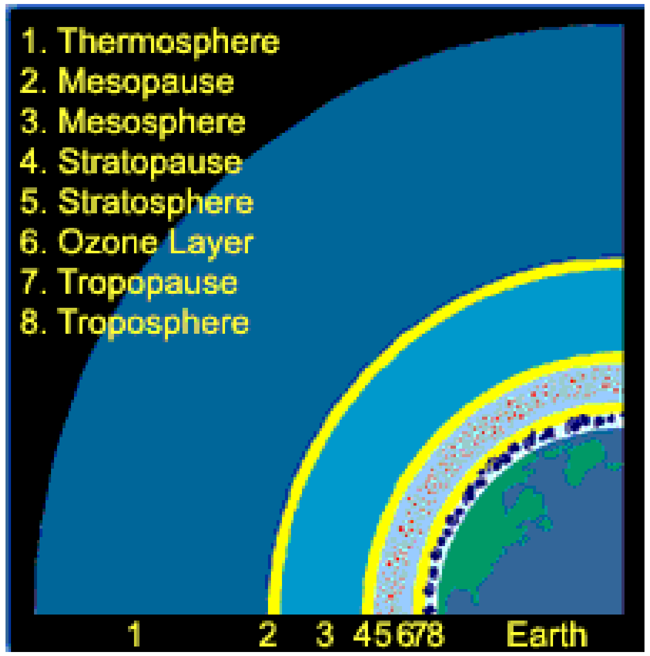


Fig. 1: Layers of the atmosphere (NASA)

The atmosphere begins at the surface of the planet and extends outward some 6,000 miles (10,000 km) into space. From the surface to an altitude of 50 miles (80 km) the chemical composition of the atmosphere is highly uniform. Due to this uniformity, this section of atmosphere is known as the homosphere. The homosphere, or lower atmosphere, is divided into various layers. The troposphere is the layer closest to the surface, extending outward an average of 11 miles (18 km). It is defined by a decreasing temperature profile with height, i.e it gets colder as you go up. Beyond the troposphere is the stratosphere, which extends from 11 to around 30 miles above the surface. Because of ozone in this layer that absorbs UV radiation, the temperature increases with height. Above the stratosphere is the mesosphere, which starts at around 30 miles and extends outward to 50 miles from the surface. This layer has a temperature profile that decreases with height.

Above 50 miles, the chemical composition of the atmosphere changes with altitude. This layer is known as the upper atmosphere or heterosphere. This upper layer is also known as the thermosphere and it extends outward several thousand miles with no real boundary between the upper atmosphere and space. The temperature in this layer increases with height due to frictional heating from incoming solar particles.

Though the atmosphere extends outward several thousand miles, one half of the gas molecules that comprise the atmosphere are located within the first 3.5 miles (5.6 km), or 18,840 feet. Fully 90% of the molecules are within the first 10 miles (16 kilometers), or 52,580 feet, and some 97% of gas molecules are packed within the first 18 miles (30 km). Gravity keeps the atmosphere very close to the surface, and this packing of most of the atmosphere this low is one reason why humans do not travel much above 12,000 feet above sea level.

Weather Versus Climate

The troposphere is an extremely dynamic and ever-changing system. Every day, the light, clouds, and heat energy in the troposphere go through a million variations. These changes affect daily life in thousands of subtle and direct ways, and for generations, humans have been fascinated by the troposphere’s daily changes. On some days it is rainy, and some days, sunny. Some days are hot, and some are cold. Sometimes the wind blows with intense ferocity.

Before proceeding, let’s make a clear distinction between two words that are often interchanged in everyday conversation. Daily changes in the troposphere are known as weather. Long term, average conditions are referred to as climate. Weather is more extreme than climate, meaning that daily ranges of temperature, precipitation, pressure, and wind are greater than the long-term extremes of climate. Since climate refers to long-term average conditions, it is more moderate.

As an example, the average climate for Arkansas in March is for a daily high of 50 °F, a low of 30 °F, and .15 inches of rain. This does not mean that you will be guaranteed this every day. On March 2, 2013, the weather was a high of 33 °F, a low of 25 °F, and a light dusting of snow. The next day, the high was 47 °F, the low was 34 °F, and it was sunny all day. As this shows, weather changes much more rapidly than climate. Climate also changes, but on a much longer time scale. This type of change will be studied more closely later in this chapter.

Human Changes to the Atmosphere - Indoors

In addition to the natural changes that occur in the atmosphere, many of the activities we humans engage in can change the atmosphere, principally by altering the chemistry or gaseous composition of the atmosphere. Many human activities release trace amounts of gases or particulates that can result in a variety of impacts on human health and the environment that are far greater than the breathing, sneezing, and sweating mentioned in the introduction. Where these changes take place is very important, as anyone who has been in a small room with a lit cigarette can tell you.

For example, there are many technologies or devices that burn wood, coal, or oil inside buildings such as wood stoves, boilers, furnaces, ovens and heaters. When these devices are used, they must be properly vented to the outside because the gases that result from combustion can have a serious impact on the ability of humans to breathe. Primarily, these devices release carbon dioxide and water vapor. While water vapor is not harmful, the carbon dioxide is, as is the decrease in available oxygen. However, there are other chemicals released that are also harmful.

Carbon monoxide is one such gas that often results from combustion, and it is becoming more common for carbon monoxide monitors or alarms to be installed within homes and buildings. Carbon monoxide, or CO, is a colorless, odorless gas that results from incomplete combustion or burning of fuel. Normally, the atmosphere contains a very small amount of carbon monoxide, about 200 parts per billion (ppb), or .02 parts per million (ppm). If the concentration of carbon monoxide in the air you breathe increases slightly to 9 parts per million, you may begin to have difficulty breathing. A healthy person may be just barely affected by CO exposure of 9 ppm, but older individuals and asthmatics, whose lung function may be already compromised, are likely to feel a greater level of effect.

Carbon monoxide reduces the ability of the body's blood to absorb oxygen. It is also colorless and odorless making detection difficult. Inhaling low levels of carbon monoxide can result in fatigue and chest pain, particularly in individuals with chronic heart disease. Increased exposure to CO can result in headaches, dizziness, sleepiness, nausea, vomiting, and disorientation. At very high levels, inhalation of carbon monoxide can cause loss of consciousness and death. Every year, several hundred lives are lost in the U.S. as a result of carbon monoxide inhalation.

An increase from 0.02 to 9 ppm in carbon monoxide may seem like a large relative increase, but a change of this magnitude is a change of only 0.000088% in the total concentration of gases in the air you breathe. Thus, a small relative change in the composition of gases in the atmosphere can have a big impact on our health. Unvented kerosene space heaters will vary the CO levels between 0.5 and 50 ppm. Chimney smoke from a wood stove contains 5,000 ppm of CO. Undiluted warm car exhaust contains about 7,000 ppm of CO, and undiluted cigarette smoke about 30,000 ppm of CO.[1] These are all good reasons to have CO monitors in your home.

In addition to carbon monoxide, there are many other chemicals, substances, and gases which can be harmful to human health. With the development of more energy efficient buildings over the last several years that limit the number of air exchanges with the outside, the importance on monitoring these has grown. The inability of these indoor air pollutants to be easily dispersed or diluted in these buildings means that concentrations can often be many times higher than outdoors. Pollutants found indoors include asbestos, biological contaminants, formaldehyde, fumes from household products, lead, nitrogen dioxide, particulates, pesticides, radon, and tobacco smoke.

Indoor pollution occurs in a wide range of indoor environments including homes, schools, factories, office buildings, and commercial workplaces. Excessive noise, dust, odors and fumes can all serve to lower worker productivity and adversely affect human health. The Occupational Safety and Health Administration (OSHA) regulates indoor pollution within workplaces and the U.S. Environmental Protection Agency (EPA) focuses on indoor air problems within homes.

Indoor air pollution can affect human health in many ways, ranging from headaches and breathing difficulties to death. Some of these affects exhibit themselves immediately after exposure. For example, if you mix bleach and ammonia, you will produce chlorine gas which can kill you instantly. Others occur after long periods of exposure, such as the toxic effect of low level radon that can slowly cause cancer and death. Each person has a different level of susceptibility to indoor air pollution. Some individuals are hardly bothered while others have acute sensitivity to the smallest levels. Many variables, in combination, determine likely health impacts from exposure. These include a person's age, existing lung function, the concentration of pollutants, and the duration of exposure.

Within residential buildings, a variety of technologies are used to control indoor pollution. These include measurement & monitoring devices such as carbon monoxide and radon detectors, ventilation improvements, and home air cleaning equipment and systems. Because there are many more indoor pollutants within workplaces, particularly shops and factories, there are a large number of commercial scale indoor air technologies. These include filters, humidifiers and dehumidifiers, dust collection systems, fume extractors, and ventilation systems.

Human Changes to the Atmosphere - Outdoors

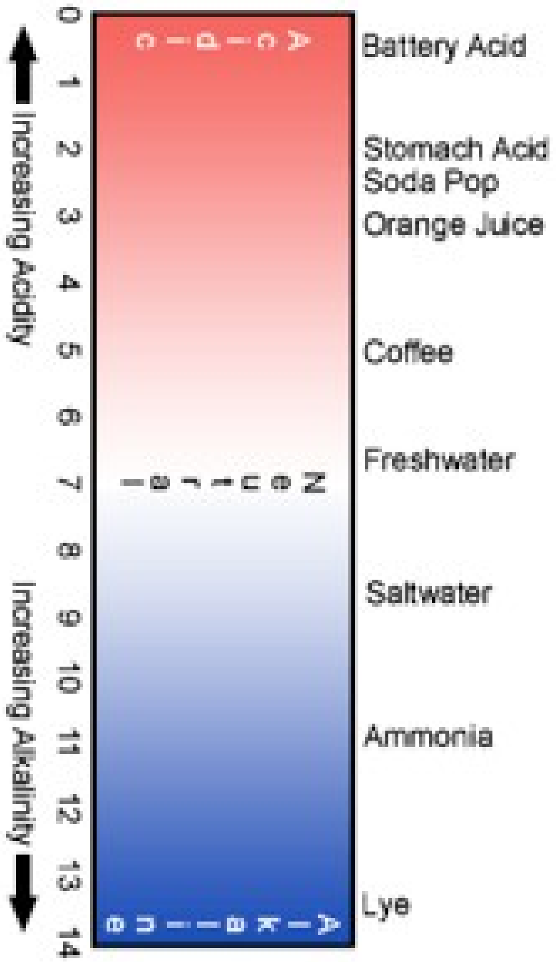
Changes in atmospheric chemistry that result in impacts on human health or the environment can often occur outside as well. These changes are typically known as air pollution, of which there are two principal kinds: 1) pollution that is released from a single, identifiable source, known as a point source and 2) pollution that comes from a large number of dispersed sources, known as non-point or area sources of pollution.

Point sources of air pollution include toxic trace compounds emitted from specific industries. This type of pollution, known as local air toxics, presents an air quality problem in the vicinity of these industries. These pollutants include heavy metals such as beryllium, cadmium, and mercury, organic compounds such as aldehydes and furans and radioactive particles and gases. Occasionally, large-scale toxic emissions from industrial facilities, such as the industrial accident in 1984 in Bhopal, India, are severely harmful on human health. Other localized air quality concerns include noxious odors from industrial facilities, landfills and sewage treatment facilities.

A number of processes and technologies are used to control local air pollutants and odors. Of particular importance is detection equipment and systems as many of these compounds are highly toxic to humans. Processes include distillation, extraction, incineration, control, biofiltration, and removal. Technologies include toxic gas analyzers, monitors and detectors, hood fans, exhaust systems, chemicals and scrubbers.

Acid Rain

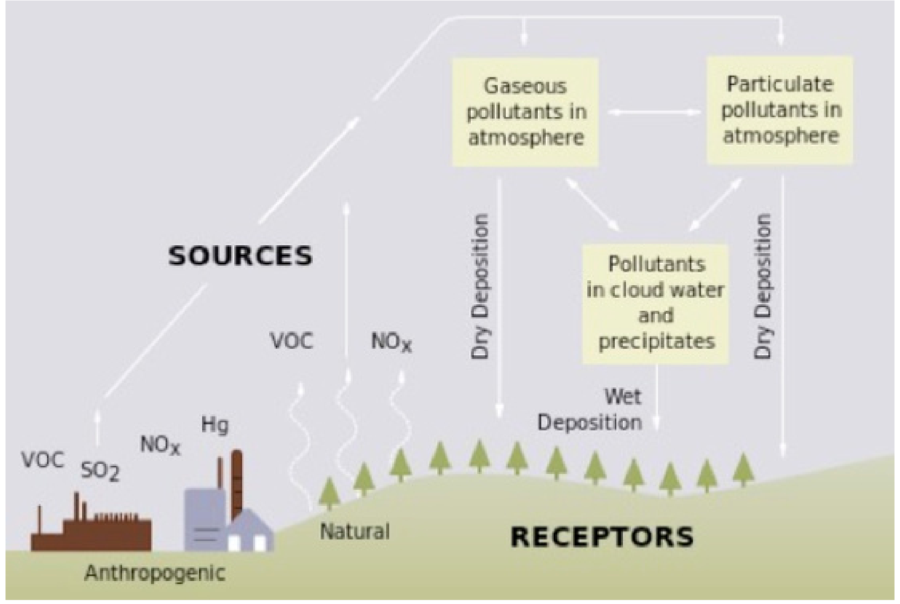
Oftentimes, the pollutants that are released do not just affect the local region. When pollutants are gaseous and able to diffuse well in the atmosphere, they can radically change the atmosphere thousands of miles away. One example of this is when gaseous acids are released into the environment. Acidity is measured on the pH scale ranges from 0 to 14 with 0 being acid, 7 as neutral, and 14 as alkaline. The pH scale measures the concentration of hydrogen ions in solution, which indicates acidity. The pH scale is also logarithmic, so that a change in one unit represents a tenfold change in acidity, thus a solution of pH 4 is 10 times as acidic as one with pH 5 and 100 times as acidic as pH 6.



"Natural" or unpolluted rainfall is slightly acidic and has a pH of between 5.6 and 5.8. The reason for this is that naturally found gaseous molecules dissolve into water and turn it acidic. For example, when carbon dioxide dissolves into water, it interacts with ions in the water to form a very weak carbonic acid (H_2CO_3). You are probably very familiar with this acid, as it is in all carbonated soft drinks. However, in those solutions, the acid is not particularly weak, as the concentration of carbon dioxide that has been pumped at very high pressure into the sodas is much higher than what is found in the atmosphere or rain water. In fact, the amount is so high that it is not sustainable, which is why bubbles form in the soda, which releases carbon dioxide. If you leave the soda out for a long time, enough carbon dioxide will escape such that the acidity of the drink will decrease significantly. This is why flat soda has a very different taste, as it is no longer as acidic.

When fossil fuels, such as coal, are burned, sulfur dioxide (SO_2) and nitrogen oxide (NO_x) are released into the troposphere. The primary source of acid, SO_2, is from electrical power plants (predominantly coal-burning), whereas NO_x comes from industrial boilers, mineral smelting plants, and automobiles as well as electrical power plants. Since they are gases, they cannot be filtered out of the exhaust in the same way that solid particles can be. There are some measures that can be taken to reduce their output, but these measures take time and money to institute. Once airborne, these acidic gases mix with precipitation such as rain, sleet, and snow and fall back to Earth as “acid” rain.

Acid rain can affect both terrestrial and aquatic ecosystems, but the effects can vary depending on local conditions. The American Midwest, for example, has naturally alkaline soils that can buffer acid fallout. Likewise, some lakes lie on limestone, sandstone, or other alkaline formations that help neutralize acidity. On the other hand, some regions where lakes and soils lie on granite or glacial tills have low pH values to start, and thus, are greatly affected by acid rain.



Forests can be greatly affected by this. Extensive stretches of forests in Switzerland and Germany have been damaged or destroyed by acid rain. Extensive vegetation dieback and soil erosion have occurred in the Canadian province of Ontario and acid rain has been implicated in tree damage reaching all the way south along the Appalachian Mountains to Georgia.

Aquatic effects from acid rain result from increasing acidity of rivers, lakes, and streams. Aquatic ecosystems have a preferred and tolerated range for acidity and if levels exceed the tolerated range plants, insects, and fish can disappear. In Scandinavia, as well as the Eastern U.S. seaboard, many waterways have been affected. Some have been declared technically "dead" or placed on the critical list.

Materials and structures are also affected by acid rain. The most common problem is corrosion of buildings and statues made of marble and limestone. Steel structures are also susceptible to corrosion resulting from acid rain. In Poland, where there are few or no emissions controls on smokestacks, and where they burn large quantities of high sulfur coal, acid deposition is beginning to erode railroad tracks.

One of the difficulties involved in dealing with acidic deposition is that it often falls in different areas or countries from where it originated. Sulfur dioxide emissions can travel up to 2,000 kilometers in a few days. Most of the acidic deposition in the Eastern United States, for example, is the result of coal burning power plants in the Midwest. Acidic deposition has become a significant trans-boundary issue. Both Sweden and Norway claim that most of the SO_2 they receive comes from other countries, most notably Poland.

A range of specific control technologies exists for both sulfur dioxide and nitrogen oxides. Since sulfur dioxide is produced primarily from the combustion of coal, there are a number of technologies designed to burn coal cleaner. These include more efficient boilers, cleaning technologies, and fluidized combustion beds. Other technologies designed to reduce SO_2 and NO_x emissions include limestone injection burners, reburners, flue gas de-sulphurizers, in-duct sprayers, and low NO_x burners. See the DOE’s Clean Coal and Natural Gas Power Systems Initiative (Chapter 7) for more details.

In addition, technologies exist for both wet and dry deposition, monitoring, and measurement as well as materials protection. Monitoring and measurement technologies include rain gauges and pH analyzers. Materials protection technologies include waxes, special coatings, and paints.

Atmosphere and Light

Life on this planet relies on energy from the Sun. While there is plenty of energy being emitted from the interior of Earth, it is far short of that required to sustain the level of life on or near the surface. In order for the Sun’s energy to get to us, it must travel through the near vacuum of space and then pass through our atmosphere to reach the surface where it is needed. While it sounds simple enough, it is complicated by the fact that all of this energy is not visible for us to see with the naked eye. Instead, we must use specialized equipment that can measure the Sun’s energy in non-visible ranges, which makes its study limited. Thus, in order to delve further, we need to know something about light.

Since the time of James Maxwell, we have understood that light travels as a wave. We are all familiar with waves, as we make them every day. The sounds that we make when we talk travel through the atmosphere in waves called, not surprisingly, sound waves. If you drop an object into a pool of water, you create surface waves that travel out from the site of the disturbance. If you’re a sports fan, you might think of how crowds in stadiums sometime make a “human” wave. While it is not a physical wave, it does share many of the same characteristics, such as having a crest, which is the top of the wave, and a trough, which is the bottom. The distance from one crest to the next is called wavelength.

Light is a disturbance in the electric and magnetic fields (hence, an electromagnetic wave), and it can be comprised of many different wavelengths. Your eyes see a certain range of light, which is actually quite small. There are many other ranges, as discussed in Chapter 10. Some of these you can also sense, although not with your eyes. If you’ve ever been sunburned or gotten a tan, it was ultraviolet radiation that caused the temporary changes to your skin. When you feel the heat coming from a warm object, it is infrared radiation that you sensing. Other ranges are not as immediately sensed, although they do interact with your body. For instance, you do not sense X-rays or gamma rays, but if you receive too much exposure to them, the cells in your body will absorb the energy and either be killed or ionized.

The light coming from the Sun does not have all of these different waves in equal proportions. The vast majority of the Sun’s emitted energy is in the visible range, as we discussed in Chapters 2 and 10. In traveling through space, very little of this light is absorbed. At the upper atmosphere of Earth, the intensity (power per unit area) of this light is approximately 1370 W per meter. As it goes through our atmosphere, different ranges of the light interact in unique ways with the air molecules and particles. Some light is scattered, some is reflected, some is absorbed, and some is transmitted with little to no attenuation. For example, the sky appears blue because blue light is scattered more than red light by the nitrogen in our atmosphere. White clouds and ice reflect more visible light back into space than dark clouds or green grass. On average, about half of the light that is incident on the upper atmosphere makes it to the surface of Earth, i.e. there is about 700 W/m incident on the ground.

In the next two sections, we will discuss two large environmental issues that occur in this area of light-atmosphere interaction. These two issues are often confused for being one in the same, but they are really two unique problems.

Stratospheric Ozone Depletion

As we stated previously, the stratosphere is located between 11 to 30 miles from Earth’s surface. As 90% of the gas molecules in the atmosphere are within the first ten miles, the density of air in the stratosphere is very low, and it would be impossible for you to breath on your own at this altitude.

Despite the scarcity of molecules in this layer, the stratosphere contains one specific molecule that performs a critical function to life on Earth: ozone. As we stated earlier, this molecule absorbs ultraviolet radiation, a high energy form of light (short wavelength, high energy absorption) that can cause burns and cancer to plants and animals exposed to it for a long time. To distinguish the more harmful forms of UV from milder forms, we often break it into three ranges, with UVC being the shortest in wavelength (most energy absorbed), UVA the longest (least energy absorbed), 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 0_2 molecules to form stratospheric ozone, and it is these O_3 molecules that shield the surface from too much ultraviolet radiation.

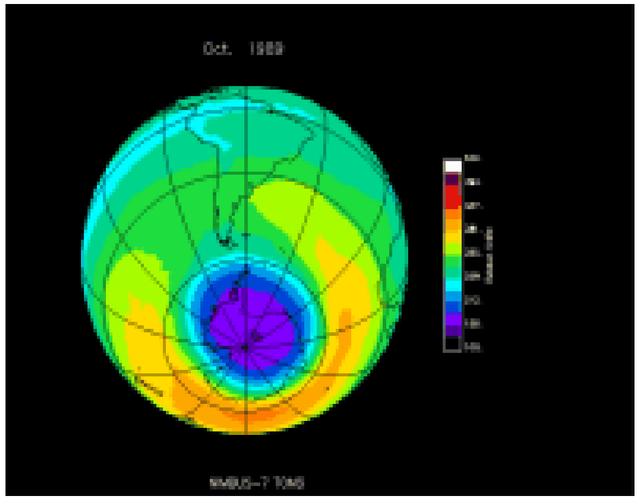


Fig. 2: Data image showing Antarctic ozone hole (NASA)

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.

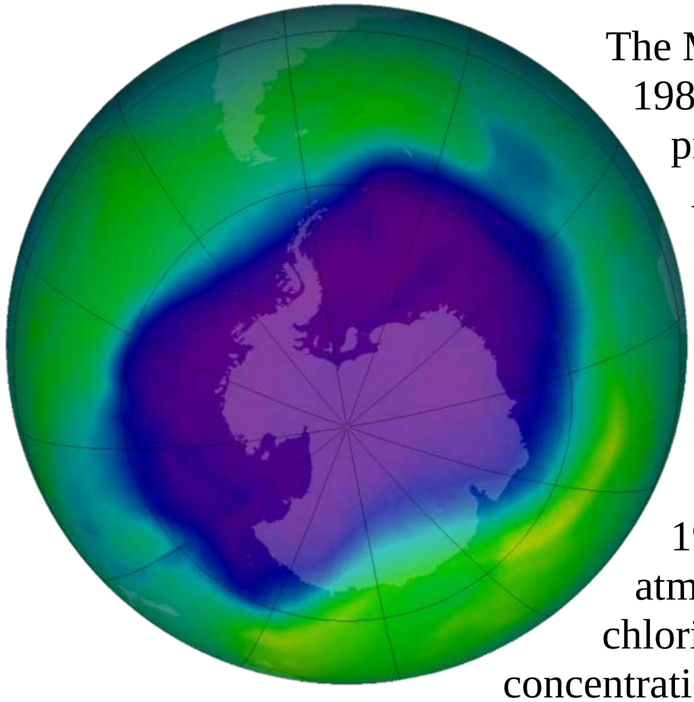
Both CFCs and halons are extremely long-lived and stable chemicals that can remain chemically active in the atmosphere for decades. Not only do CFCs and halons destroy the molecular bonds of the O_3 molecule, but also a single chlorine molecule can eliminate as many as 100,000 ozone molecules before it washes out of the system. 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 40 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 2006, NASA measured thinning levels that set an all-time record. Stratospheric ozone levels also have decreased over the Arctic, 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.[2]

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 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.

Greenhouse Effect/Climate Change/Global Warming

The terms "Greenhouse Effect", "Climate Change", and "Global Warming" are often used interchangeably, yet they really refer to three separate and distinct processes. In this section, we'll examine all three and assess whether the Earth's atmosphere is getting warmer.

To start, let's look at how our atmosphere is heated. The Sun generates about 3.9 x 10^{26} J of energy every second, which allows it to maintain a temperature of 5780 K. This massive amount is what is currently being output, and as was pointed out in Chapter 2, small variations in the surface temperature corresponds to significant changes in the amount of energy output to space. Studies have shown that there is some variation over time scales of centuries, but they are very small[3].

Because of this temperature, the Sun transmits most of this energy in wavelengths of between 400 to 700 nanometers, which is the spectrum of visible light. This energy is sent into space in all directions, and Earth intercepts only a small portion of it, about one part in two billion. Yet one part in two billion is a tremendous amount, some 2 x 10^{17} J per second. Remember that only about a half of this energy makes it to the surface without being reflected. Once the Sun's energy reaches the Earth's surface, it is absorbed and the temperature of the Earth's surface increases. If you remember our discussion of Wien's Law from thermodynamics, then you know that this energy will be re-radiated at wavelengths that depend on the temperature of the surface. Since the surface temperature is about 300 K, the energy is transmitted back up into the atmosphere in the form of infrared radiation, which has a longer wavelength than light energy.

There can be a significant amount of variation in the above based upon a variety of factors. The Earth's orbit around the Sun is elliptical, which means that we intercept more energy when we are closer to the Sun and less when we are further away. The amount of energy re-radiated into space depends on the type of surface (desert, water, ice, plant-filled, asphalt). Since the types of surface are not evenly distributed around the globe, the amount of energy absorbed versus reflected varies with what type of surface it being exposed.

Because of these factors, the amount of energy absorbed and re-radiated depends upon the orbital dynamics of Earth, which are changing very, very slowly. The shape of our elliptical orbit varies over time scales of 100,000 years. The amount of tilt of our rotational axis with respect to our orbit varies from 22.1^o to 24.5^o over a time scale of 40,000 years. The direction of our rotational axis moves in a circle over a time scale of 26,000 years. These changes in orbital parameters cause long term cycles of temperature variation known as the Milankovitch cycles after their founder, Milutin Milankovitch[4]. These are responsible for the cyclical ice ages Earth has experienced, but as noted, they are very long term and do not affect short term changes.

Certain gases like water vapor, carbon dioxide (CO_2), and methane (CH_4) allow visible light to pass through with little attenuation. However, they absorb the infrared radiation released by the Earth's surface. As this absorption takes place, the Earth's atmosphere is warmed. This ability to absorb this re-radiated infrared energy while allowing visible light to pass through is known as the Greenhouse Effect. Gases like water vapor, carbon dioxide, and methane, along with others such as nitrous oxide (N_20), chlorofluorocarbons (CFCs), hydrocholorfluorocarbons (HCFCs), and a few other synthetic compounds, are called greenhouse gases because of their ability to do this.

Though there are relatively little of these greenhouse gases in the atmosphere (less than 1% of the atmosphere's total volume), these gases are responsible for heating the atmosphere. The global average surface temperature on Earth is about 15^{o}C, or about 59 ^{o}Fahrenheit. The average surface temperature of the Moon, which is roughly the same distance from the Sun as Earth, is about -18 ^{o}C, or about 0 ^{o}F. The reason why the Moon is so much colder is because the Moon does not have an atmosphere, and therefore, no greenhouse gases to trap extra heat. If there were no greenhouse gases on Earth, our average surface temperature would be roughly the same as that of the Moon.

Eventually all the heat that is absorbed by the Earth's greenhouse gases is returned to space. Greenhouse gases merely slowdown or delay the outward transmission of heat from the Earth’s surface. The slower the transmission, the warmer it is near the surface. Water vapor has the biggest effect, owing mostly to its high concentration at certain locations. Humid locations usually have smaller differences in day and night temperatures, while deserts have the greatest variations.

The Milankovitch cycles, along with the variations in energy output from the Sun, are examples of natural climate change. They will occur no matter what else happens on Earth. The term “anthropogenic climate change” refers to changes in the climate that are the result of mankind’s activity. In the past, this was inexactly termed “global warming”. However, we have found that, as the overall temperature of Earth changes, certain locations on Earth will get cooler, at least on short time scales. Therefore, scientists have begun to move away from the term global warming in favor of climate change.

How does mankind change the ability of the Earth’s atmosphere to absorb outgoing thermal energy from the Earth’s surface? Over the last 150 years, human activities, most notably the burning of fossil fuels such as coal, petroleum, and natural gas, have released large quantities of “greenhouse” gases, such as carbon dioxide and methane. These accumulating amounts of greenhouse gases are slowing changing the chemical composition of the global atmosphere, as well as the atmosphere’s radiative, or heat absorbing, properties.

Ice cores and tree growth show that the global atmosphere contained 288 parts per million of carbon dioxide in 1860. Recent measurements (Figure 3) indicate that the atmospheric concentration of CO_2 is now close to 400 parts per million, a relative increase in the amount of atmospheric carbon dioxide of 39%. The reason that 1860 is used as the base year for greenhouse gas concentrations is that large-scale industrialization, driven mainly by coal powered steam engines, did not get off the ground until after 1860. The pre-1860 atmosphere, therefore, is considered to be representative of the atmosphere in its “natural” state.

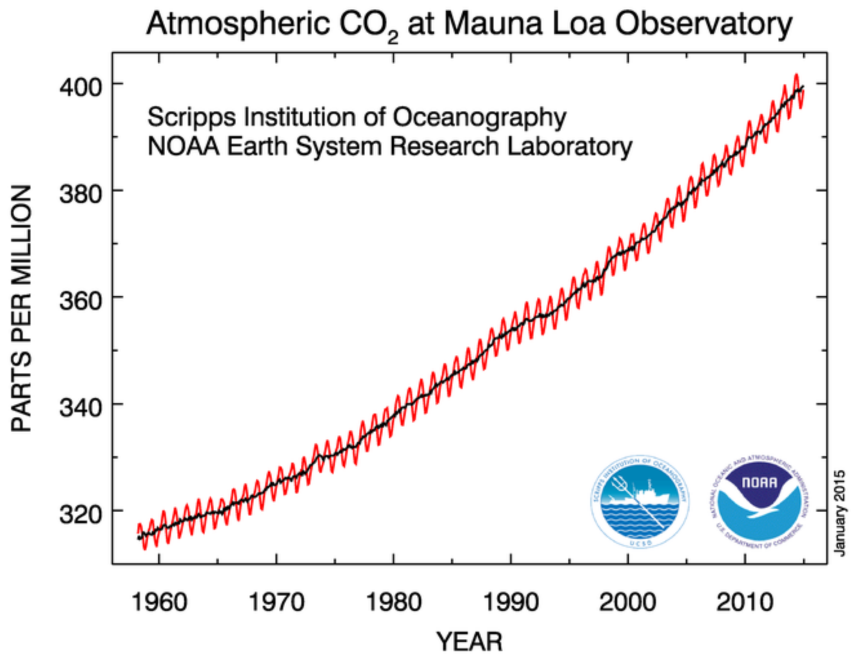


Fig. 3: Yearly CO2 Observations (NOAA)

The pre-industrial concentration of methane was 848 parts per billion (ppb). Atmospheric concentrations now are about 1800 ppb, a relative increase of over 100%, or a doubling of the atmospheric concentration[5]. The current atmospheric concentration of nitrous oxide is 315 parts ppb, a 10% increase over the 1860 concentration of 285 ppb. The synthetic greenhouse gases, CFCs, HFCs, PFCs, and SF6, were not present in the pre-industrial atmosphere at all. Current levels of chlorofluorocarbons are 533 parts per billion, HFCs at 154 parts per trillion (ppt), PFCs at 79ppt and sulphur hexafluoride at 5 ppt.

Slowly, the ability of the Earth's atmosphere to absorb heat from the surface has increased and, with it, the temperature of the atmosphere. The last decade was the warmest on record since the invention of thermometers[6]. Every major organization of scientific who study Earth (American Geophysical Union, American Meteorological Society, the National Research Council, the World Meteorological Society, and the Intergovernmental Panel on Climate Change, to name a few) have all stated that human activities are altering the chemistry of the atmosphere and have resulted in an excess warming of the lower atmosphere above what would naturally be occurring. In November of 2007, the Nobel Peace Prize committee recognized the IPCC and former Vice President Al Gore for "their efforts to build up and disseminate greater knowledge about man-made climate change and to lay the foundations for the measures that are needed to counteract such change."

However, the overwhelming data supporting anthropogenic climate change has not resulted in much action to slow down or stop its effects. The major reason is that this will require a significant investment in new technologies and a radical change in how most developed countries do business. Furthermore, well-funded skeptics have come forward to claim that anthropogenic climate change is having little to no effect on the average global temperature and that any increase in temperatures is due to other factors such as increases in cosmic radiation or the Milankovitch cycles. Although there is no basis for such claims, this has not stopped these skeptics from getting a lot of press and money from organizations and individuals who have a lot to lose if governments were to begin taking serious action to reduce greenhouse gases.

Discussion Questions

1. What direction do winds blow around a high pressure system in the Northern Hemisphere? In the Southern Hemisphere?

2. What is the difference between climate and weather?

3. When do clouds form?

4. Should we eliminate all greenhouse gases from the atmosphere?

5. What is the problem with chlorofluorocarbons?

6. In the 1980's, Senator William Proxmire gave a Golden Fleece Award to the government for funding a research project that studied cattle flatulance. Was he right to do so?

7. What is the problem with the ozone hole over the Antarctic?

8. Is there a relationship between the hole in the stratospheric ozone layer and the question of global

9. Are trees sources or sinks for greenhouse gases? What about you?

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