Atmospheric Gases, Heat, & Pressure – Video Tutorial

The sun heats up the surface of the Earth through the heat transfer method described last week: **radiation**. This radiation consists of ultraviolet, visible, and infrared light. Ultraviolet, or UV, is the shortest in wavelength – Infrared, or IR, the longest.

For every 100 units of heat that radiate towards a particular area of Earth's surface, 16% are absorbed by the atmosphere, specifically by the area known as the **ozone layer**. This layer absorbs mostly the UV radiation. 30% of the incoming radiation is reflected right back to space – most from the upper atmosphere, a small amount from the surface. 51% of the incoming radiation is absorbed at the surface, which raises the temperature of the surface. That higher-temperature surface material reradiates its heat upward in the form of IR radiation. It also conducts some of its heat to the air above it and transfers some it to latent heat of evaporation of water. Some of the reradiated heat escapes to space, but most is held in the lower atmosphere, because the IR radiation, being longer wavelength, is absorbed by greenhouse gases such as water, carbon dioxide, and methane. Eventually the heat of the atmosphere also is transferred back to space from the upper atmosphere.

This image shows the ongoing balance of heat between what arrives and what is returned. If the Sun stopped radiating heat, all Earth's heat would eventually radiate to space, and the surface would get progressively colder and colder until it was unlivable. If there was no ozone layer to trap the UV radiation, the Earth's surface would receive even more heat, and some of that in the harmful light spectrum that damages biological molecules – life would not be able to live on the surface. If the greenhouse gases that absorb the reradiated thermal heat disappeared, Earth's surface would be much colder because it wouldn't have the insulated heat-rich atmospheric layer that currently sits above it.

As you are undoubtedly aware, the amount of greenhouse gases in our atmosphere is increasing. More greenhouse gases means more of the thermal IR heat is absorbed or trapped in the lower atmosphere and a warming of Earth's surface. This list shows the main greenhouse gases at work in our lower atmosphere in decreasing order of importance. Water is the most important. If we set the IR absorption capability of carbon dioxide at 1, for comparison purposes, we can see that methane is an even more powerful absorber than carbon dioxide – 25 times more powerful. Ozone is 2000 times more powerful. *Note: here we're talking about ozone in the lower atmosphere, which is very low in abundance, not the ozone layer. In the lower atmosphere, ozone is produced by car exhaust and a major ingredient of smog. In that capacity, it is a greenhouse gas.* Water is only 1/20th as powerful as carbon dioxide, yet it is considered the most important greenhouse gas on the planet, followed by carbon dioxide. Why is water so important? Volume – there is a LOT more water in the atmosphere than any of the other molecules combined.

This graph shows the levels of carbon dioxide, methane, and nitrous oxides in Earth's atmosphere over the past 2000 years. Notice the large jump after 1750, coincident with the start of the industrial revolution and the burning of fossil fuels.

This next graph shows atmospheric carbon dioxide levels over the past half a million years during which there have been a number of ice ages. The high points on this graph represent the interglacials when the global temperature was at its warmest. The low points show the glacial periods when as much as 30% of Earth's land surface was covered by glaciers. This graph is useful for showing the recent increase in CO2 and how it compares to Earth's recent past.

This graph shows average global surface temperature data for the last century as gathered and published by four different agencies. You can notice from the jagged nature of this graph that average temperature fluctuates greatly over a 5 to 10-year time frame. But you can also see the general upward trend when you look over one hundred years. Since 1900, there has been a 1.2° Celsius increase in global temperature.

The oceans are affected by this process in two key ways:

1) Global warming causes the average ocean temperature to rise and hence sea level.This graph based on tidal data shows that mean sea level has increased almost 9 cm since 1960, when the data was first collected.

2) Increased carbon dioxide emissions means greater CO_2 dissolved in the oceans and leads to greater acidity of the oceans as discussed in the Carbonated Oceans video. As you can see, the majority of carbon dioxide stored in the world's various reservoirs is found in the oceans!

Pause now.

Now let's return to the ozone layer, a major absorber of solar UV radiation. We call the lowest layer of Earth's atmosphere, where all weather occurs, the troposphere. The layer above it is called the stratosphere. The ozone layer resides in the stratosphere. You'll notice that as we move from Earth's surface upward, the temperature drops to a low at the top of the troposphere of about -55°C. The stratosphere on the other hand warms back up again as you move into and above the ozone layer.

In the ozone layer, the sun's radiation, which is ultraviolet, collides with the oxygen molecules – O-2 – and splits them. These split molecules immediately recombine with a nearby oxygen molecule and create O-3 – ozone. Ozone is also naturally broken down in the stratosphere by sunlight and unnaturally by a chemical reaction with various compounds containing nitrogen, hydrogen and chlorine – otherwise known as chlorofluorcarbons. Normally there is a balance between the amount of ozone being produced and the amount of ozone being destroyed so that the total concentration of ozone in the ozone layer remains relatively constant. However, the addition of ozone-destroying compounds, like chlorofluorcarbons, has led to a diminishing of the ozone layer over many parts of the Earth's surface. An international effort to eliminate these compounds from production has made a big impact, and the reduction of the ozone layer is diminishing.

The **solar constant** describes the maximum amount of Sun's radiation that could be absorbed by Earth's surface if there were no atmosphere to remove it en route and if that radiation was directed straight down on the surface at a 90 degree angle. The solar constant is 2 calories of heat per cm^2 per minute. Just how much heat is that? Well, assuming we really did have no atmosphere and were directly under the Sun's rays, such that they hit us at a 90-degree angle, how much heat would be transferred to the surface of a football field in a single hour? We take 2 calories of heat per square centimeter per minute and multiply it by the area of the football field in square centimeters and then multiply it by the number of minutes in one hour. That gives us 6.42 billion calories or 6.42 million kilocalories – the food calories that we are more familiar with.

A few things to keep in mind about this number. First, on any day, there will only be one latitude on Earth's surface with a 90 degree angle of incoming radiation. As the Earth orbits the Sun that latitude of 90-degree-straight-on-sunlight migrates between the equator at equinoxes, the tropic of cancer at the June solstice, and the tropic of Capricorn at the December solstice. As this image from an equinox shows, when you're at any other latitude on that day, because of the spherical shape of the Earth, the sun's rays are NOT coming in at a 90-degree angle, and hence some of that sunlight reflects off the surface and isn't available, what IS available is spread over a large surface area because of the angle, AND more of the atmosphere must be travelled through. In fact, all of that diminishing of the solar constant increases as you move away from the equator and toward the poles. As a result, the most sunlight reaches the equator, the least, the poles. This map shows the average annual temperature on the planet – red as the hottest, purple as the coldest -- hottest at the equator and coldest at the poles.

This graph shows the actual value of incoming radiation in watts per square meter per year by latitude, not the same unit we've been working with, but a comparable one. The lines confirm that the area between 25 degrees North and South of the equator – the tropical and equatorial zones – get the highest incoming heat with numbers as high as 0.5 calories per square centimeter per minute just to use our familiar unit. These values are ¼ that of the solar constant. That gives you an idea of how much of an impact the atmosphere has. You can also see that less than 0.1 is available at the poles. That tells you how much of impact the angle of sunlight hitting the surface has. When compared with the outgoing heat from thermal radiation, there's a net gain of heat between 38 degrees north and south, and a net loss of heat as you move poleward from there. The equatorial regions should be getting hotter and hotter each day as they accumulate heat, and the poles colder and colder. But that difference is not increasing daily – the equator isn't getting hotter. The poles aren't getting colder. What happens to the excess heat at the equator? Some of it is delivered to the poles to make up for what's lost there. What are the mechanisms for this heat transfer? Currents – moving packets of air and water.

Pause now.

Earth's atmosphere, when totally dry (no evaporated water) is composed of approximately 78% nitrogen gas, and 21% oxygen gas. All other gases, including the greenhouse gases mentioned earlier, are found in abundances of less than 1%. For example, carbon dioxide, even in its ever-increasing abundance, is still only 0.040% of the atmosphere (as of February 2015). Water is a little different. As discussed in the relative humidity video tutorial, wet air can change those percentages, as water can be present in amounts of 4% or less. When air is warm, it has a greater capacity for water.

The atmosphere is made of gases. **Atmospheric pressure** is the pressure you feel from the weight of all the gases above you. It probably seems as though air weighs nothing. But in fact, the overall weight of air at sea level is 14.7 pounds per square inch. 14.7 lbs is a lot of weight. We don't feel that weight because it's pushing against us on all sides. Hold out your arm. There are 14.7 lbs pushing on it from above, below, and the side. That's why we don't sink down under that weight. It supports us from every direction. To prove that, fill a glass with water and cover it with a note card. Then flip the glass over quickly. The card will be pushed upward against the glass by the same air pressure. As long as the force of the weight of your water isn't greater than 14.7 lbs, the water will stay in the glass.

Meteorologists devised the units of atmospheres and bars to help compare pressures at various levels in the atmosphere. At sea level, the pressure is approximately 1 atmosphere – otherwise stated as 1 bar or 1,000 millibars. As we move up a mountain or fly in a plane and move higher into the atmosphere, there is less weight or pressure above us. We might not be able to feel this change in pressure, but our bodies do respond to it. Fewer molecules around us of gas means less oxygen to breathe, so we have to pressurize the insides of airplanes and carry extra oxygen in case the fuselage is punctured. Potato chips and water are bagged and bottled at the same pressure as the air around them. That way the pressure of the air inside matches that of the air outside, and the bags or bottles retain their shapes. When we carry potato chips that were bagged at sea level UP to the mountains, where the outside pressure is lower, the inside pressure is now much greater than the surroundings, and the bags expand and can pop. Similarly, if we fill a water bottle in the mountains, and then bring it back to sea level where the air pressure is higher, the bottles will compress, because the inside air pressure isn't great enough to withstand the outside pressure.

Air rises and falls on our planet as it changes its density – a concept we've talked about many times in past videos. What would change the density of air? Two things – temperature and water content. If I heat up air, the molecules get a higher kinetic energy, and if they have space to move, they'll move outwards and the entire air mass will expand. That makes it less dense. If we cool air, its molecules would lose kinetic energy and slow down. They could now get closer together. They would contract and becomes more dense. How does water fit in? The water molecule, at 18 grams per mole is less dense than the nitrogen and oxygen molecules. So as water evaporates and enters the air, it displaces a nitrogen or oxygen (kicks it out so to speak), and makes the overall air mass weigh less – thus it's less dense. Remove the water, and the nitrogen and oxygen return, and the air becomes denser. So the densest air on the planet is cold and dry – the least dense is warm and wet.

If air becomes less dense than the air around it, it will rise, and the surrounding air will fill in that space. If air becomes more dense than the air below it, the denser air will sink. So what happens to air as it rises and falls? As air rises, it reaches areas of lower pressure in the upper atmosphere. Like the potato chips bagged at sea level, this causes the air to expand outwards. That creates an adiabatic temperature change. You can experience this first hand when you release air from your bike tires. In the tires, the air is under high pressure. When you release the air from that high pressure, it expands and immediately loses kinetic energy and cools down. You can feel that cold air on your hand.

Conversely, when dense air sinks, it's like bringing the water bottle down the mountain – it compresses under the higher pressure at sea level. That compression also creates an adiabatic temperature change. This time it causes the molecules to collide more with each other because there's less space. The molecules speed up, gaining kinetic energy, and the temperature rises. You can feel this when you pump up a bike tire. You are putting air into a higher pressure environment and the air and the tire heat up.

Now let's go one step further – when air rises, it expands and cools. But we also know that cool air has a lower capacity for water. Relative humidity of this air will rise until it reaches 100%. If there are solid particles available for the water to precipitate on, we'll get rain. Conversely, when air sinks, it contracts and warms. Its capacity for water increases. Its relative humidity decreases. No risk of rain. Lots of potential for increased evaporation.

You'll also notice, from this picture, that as the low density air rises, it creates a bit of a vacuum effect on the surface below. There's not as much air pressure on the surface anymore, because the weight of the air pushing down is less. This creates a surface LOW PRESSURE system. Conversely, when denser air sinks, it adds more weight to the air pushing down, and we get a slightly higher air pressure on the surface. We call this a HIGH PRESSURE system.

Winds are what we call the air that moves along the surface of the Earth, not up or down, FROM a high pressure system TOWARDS a low pressure system. You can also think of it as the low pressure system sucking the air away from the high pressure system where it's collecting. The greater the pressure difference between these two systems, the faster the winds!

Pause now.

For more information and more detail, continue on to the next video in this series.

[End credits]

<u>Air-Sea Interactions Series:</u>
Part I: Seasons
Part II: Relative Humidity
Part III: Atmospheric Gases, Heats, and Pressures
Part IV: Atmospheric Circulation
Part V: Weather Phenomena

Atmospheric Gases, Heats, and Pressures
Geoscience Video Tutorial
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