Global Warming: Science and Connections.

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Global warming is about the temperature of our earth's atmosphere, land surfaces, and water bodies. It is also about politics, economic interests, and now, also about Oscar winning movies, though this article will touch lightly on these latter issues. For many, global warming is also synonymous with carbon dioxide gas and this is why it is connected with both temperature and public mood. Thoughts on global warming date back to 1824 with Joseph Fourier of France. Svante Arrhenius of Sweden made reasonably accurate calculations about global warming in 1896. Arrhenius thought that a warmer earth would be needed to provide adequate food supplies for everyone.

Sunlight is the primary heat source for our climate. Variations in the sun's output or the sun-earth distance change climate. Most of us are particularly well acquainted with the visible wavelengths of light from the sun that illuminate our daily lives. The visible spectrum spans from blue to red, with green in the middle. For a size comparison, the wavelength of green light is about 100 times smaller than the diameter of a human hair. The sun also emits radiation we don't see directly with our eyes, but can sense in other ways. For example, the ultraviolet portion of the spectrum gives us sunburns. When you close your eyes you can easily sense the direction of the sun from the sunlight at all wavelengths that is absorbed by our skin. The sun emits about 40% of its energy at infrared wavelengths. The surface of the sun emits radiation like a source at a temperature of around 5,800 C, or 10,000 F. Lucky for us the sun is far enough from the earth that our surface temperature is somewhere around a balmy 12 C or around 53 F at ground level.

Let's consider why our surface temperature is around 12 C. Suppose we think about the earth's light balance from the perspective of an observer on the moon. Figure 1 illustrates the balance of incoming sunlight with outgoing reflected sunlight plus infrared light emitted by both the ground and the atmosphere from the moon observer's perspective that sees light at the top of the earth's atmosphere. The earth's infrared light emission leaving through the top of the atmosphere to space is associated with a temperature of -18 C, or 0 F. The earth's surface is warmer than 0 F because it is heated by both sunlight and infrared light emitted by the atmosphere. Conversely, the earth's ground temperature would be around 0 F if the atmosphere did not absorb and emit infrared light because all of the energy exiting the planet in the form of infrared light would leave behind a cooler ground. Referring again to figure 1, the infrared light that leaves the planet actually comes in part from the ground, and in part from the atmosphere at all levels. The atmosphere absorbs some of the infrared light emitted by the ground.

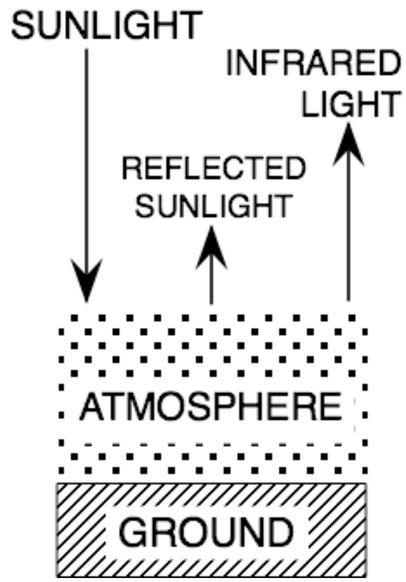

Figure 1. The earth's light balance from an observer on the moon. Incoming sunlight is equal to the sum of the outgoing reflected sunlight plus the infrared light emitted by the ground and atmosphere. Though not shown, the atmosphere also emits infrared light towards the ground. Sunlight is reflected by clouds and gases in the atmosphere as well as by the ground. Not all the infrared light emitted by the ground makes it to space. Some is absorbed by the atmosphere.

Absorption and emission of infrared light are two faces of a very similar coin as discussed here in more detail. Gases that emit and absorb infrared light are referred to as ‘greenhouse’ gases, or perhaps more properly as 'infrared active gases'. The primary list of gases is water vapor, carbon dioxide, methane, and ozone. Figure 2 is an infrared absorption spectrum for these gases. These molecules are infrared active gases because they can vibrate and rotate in many ways when they are stimulated by infrared light in an absorption process that results in the conversion of infrared light to heat. In turn these molecules are prodigious emitters of infrared radiation for reasons discussed next.

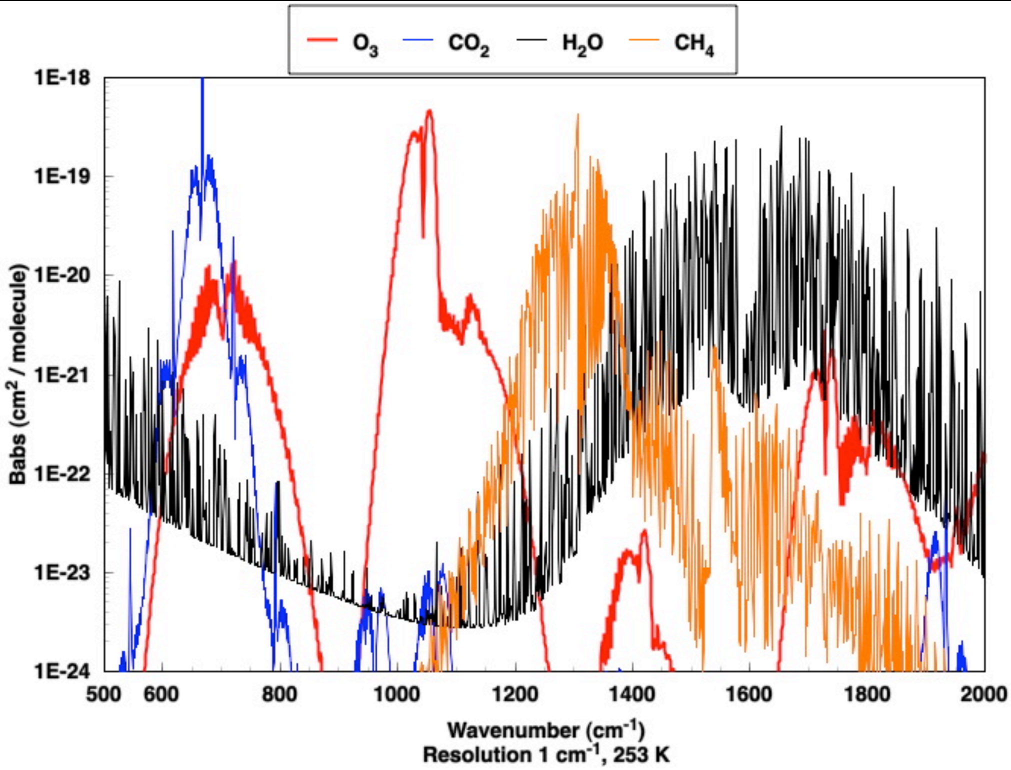

Figure 2. Calculated absorption spectrum of infrared light by the four predominant infrared active gases in the atmosphere. O_3 is ozone, CO_2 is carbon dioxide, H_20 is water vapor, and CH_4 is methane. The horizontal axis units is wavenumbers. For reference, 500 wavenumbers is equal to 20 microns wavelength for the infrared light, a distance that is about 1/3 of the diameter of a human hair. The vertical axis is the absorption strength at a particular wavenumber for a single molecule. The number of molecules of each type in the atmosphere varies greatly with location in the atmosphere and molecule type. The atmosphere uses wavenumbers between 800 and 1400 to cool by emission of infrared light to space, though both ozone and methane have strong absorption in this wavenumber range. We call this the Earth's atmospheric window region. The most striking feature is that water vapor has absorption at all wavenumbers. Note that the main effects of carbon dioxide are between 500 and 800 wavenumbers. The spikes are due to the vibration and rotation states of the molecules while the underlying gentle curve for water vapor is known as continuum absorption.

You can go around the world and look at the amount of sunlight and infrared light at the ground by visiting the website http://cmdl1.cmdl.noaa.gov:8000/www/all/rad/. Figure 3 is an example of a tour that considers two locations, Trinidad Head near the coast of northern California, and one in Antarctica near the south pole after the sun has set for the season. The amount of sunlight varies faithfully with season. Locations where the sky is warm and/or filled with clouds result in the largest amounts of infrared light. Without this infrared light shining down on us from the atmosphere the earth would be too cold to support our lives. On cloudy days the amount of infrared light is even larger because clouds emit a lot. That's why it is often warmer on a cloudy night than a clear night. It is as if clouds and infrared active gases in the atmosphere act as flashlights for infrared light. Each infrared-active gas molecule and cloud ice crystal, snowflake, or water droplet acts as a tiny flashlight. The analogy for the battery that drives these flashlights is the thermal energy of the local environment that provides the stimulus for molecular transitions that produce infrared light. Closer to home, figure 4 shows the infrared spectrum of light emitted by the atmosphere as measured during my Atmospheric Radiation course at UNR.

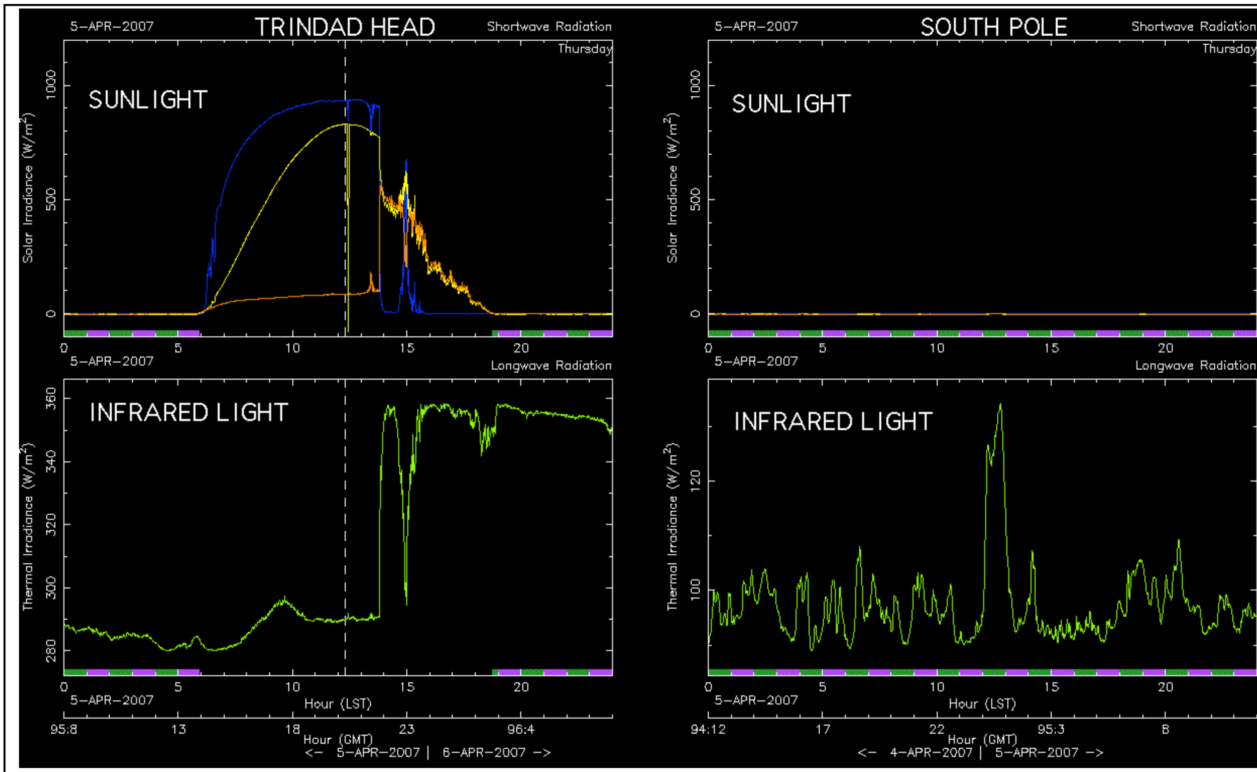

Figure 3. Measured sunlight and infrared light on the 5th of April, 2007 at Trinidad Head near the coast of northern California (left), and near the south pole (right). This is the infrared light emitted by the atmosphere to the earth's surface. Notice at Trinidad Head the sunlight starts increasing at dawn and peaks at around noon. Later in the afternoon, it becomes partly cloudy and at sunlight varies because some of it is scattered to back to space by clouds. Notice also the infrared light at this location has a pronounced increase in the afternoon when the cloudiness arrives. The morning infrared light at Trinidad head is from infrared light emission by gases in the atmosphere, while clouds augment the afternoon infrared emission. By contrast, no sunlight is observed at the south pole station. The only warming light comes from infrared emission by the atmosphere. The increase around noon is likely due to the passage of a cloud. Notice that the amount of infrared light at Trinidad Head exceeds the amount at the south pole by about a factor of 3. The atmosphere above Trinidad Head is much warmer than at the south pole. Infrared light is observed both day and night and this is the essence of the 'greenhouse effect'.

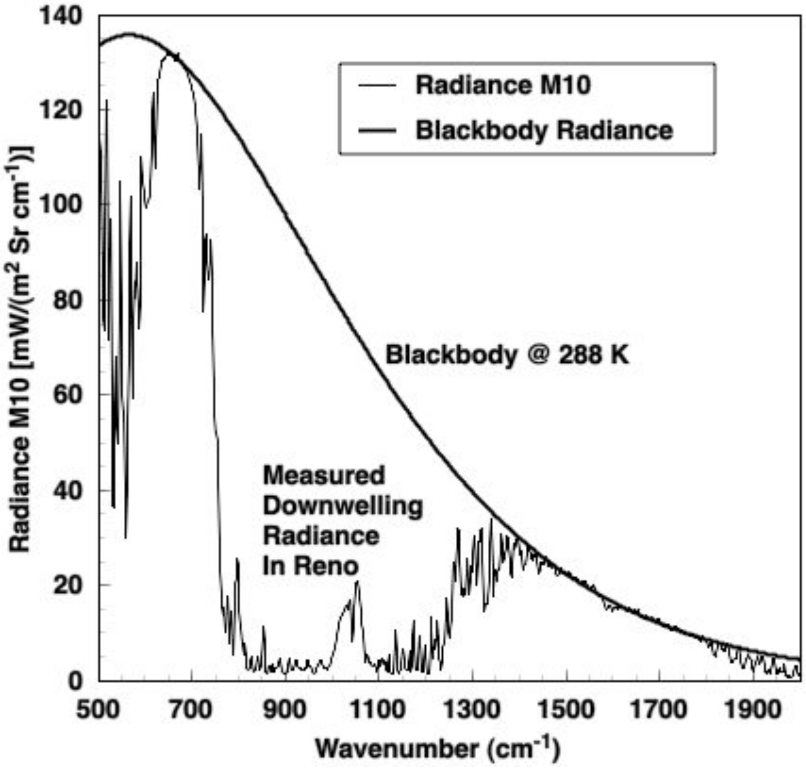

Figure 4. Spectrum of infrared light emitted by the atmosphere and measured at the surface during UNR class, looking up with a Fourier transform infrared spectrometer (the mathematical analysis method used in this instrument refers to its inventor, the same Joseph Fourier of France that was discussed in the first paragraph of this article.). The horizontal axis is in wavenumber units, as discussed also in the caption of figure 2. The infrared light near 700 wavenumbers is due to carbon dioxide gas in the atmosphere, while that from 1300 to 1900 is due mostly to water vapor. The extra amount above the baseline from 1000 to 1100 wavenumbers is the infrared emission by ozone in the stratosphere. The atmosphere doesn't emit that much radiation from 800 to 1400 wavenumbers, and so it also doesn't absorb much radiation in this wavenumber range either. Infrared light emitted by the earth's surface in this wavenumber range can efficiently penetrate the atmosphere and leave the planet, helping to cool the earth. The envelope curve labeled 'Blackbody Radiance' is a theoretical curve for the emission by a perfect infrared emitter at a temperature of 288 Kelvin. At wavenumbers where the measurements fit to this theoretical curve, such as near 700, and between 1500 and 1700 wavenumbers, the carbon dioxide and water vapor molecules in the atmosphere absorb and emit infrared light so strongly all the infrared light comes from the immediate vicinity of the instrument. Peaks in the carbon dioxide and ozone gas spectra in Figure 2 can be seen as relative peaks in this measured emission spectrum.

Gasoline and diesel powered vehicles, coal fired power plants, and living animals use organic molecules as fuel and give off, among other things, carbon dioxide and water vapor. Plants, rocks, and oceans are depositories for some of the carbon dioxide. The National Oceanic and Atmospheric Administration have been making carbon dioxide measurements at Mauna Loa

Hawaii since 1959. Carbon dioxide levels from before that time are inferred from measurements of air bubbles trapped in ice cores. Currently, out of 1 million air molecules, 380 are carbon dioxide. 15 years ago when I first started teaching at UNR, the number was around 365, and in the year 1750 prior to the industrial revolution, the number was closer to 280. This number keeps going up because we keep burning coal, oil, wood, and cow dung, and because nature also dishes out carbon dioxide from volcanoes. The global warming fuss is really about a few potent molecules.

The atmosphere is complicated for many reasons. Here is an example that weaves a connection between global warming and ozone depletion. Ozone is a reactive gas formed when three oxygen atoms bond together. Ozone in the stratosphere absorbs UV light that would otherwise kill plants and animals on earth by sunburn. The issue with ozone depletion is that chlorofluorocarbons destroy stratospheric ozone, so their use in propellants in spray cans and in refrigerators has been phased out in many places. However, ozone near the ground from air pollution is a lung irritant and is destructive to plants. Both ozone and chlorofluorocarbons are also infrared active gases that contribute to global warming, albeit with less gusto than other molecules like water vapor and carbon dioxide.

Consider now the very important water vapor molecule. Water vapor gives way to water droplets and ice crystals, which give way to rain and snow as precipitation. It takes energy to drive evaporation, and when evaporation occurs the faster moving molecules are removed from the liquid or frozen water, leaving behind cooler water, or a cooler you when the energy source for driving evaporation is your internal body heat. Later, when water vapor molecules in the atmosphere condense to form water droplets or ice crystals, roughly the same amount of energy is released to the surrounding air in the form of heat that encourages air parcels to be more buoyant, to rise to higher locations in the atmosphere where it is colder, and to make more condensation. Water vapor is THE most important infrared active gas in our atmosphere because it absorbs and emits infrared light at most wavelengths associated with earth's infrared light. Clouds are also very active infrared absorbers and emitters, and they also scatter a lot of sunlight back to space that would otherwise heat the surface. Snow is one of the brightest surfaces on the planet when considering the reflection of sunlight, and is one of many very dark surfaces when considering the absorption of infrared light. Carbon dioxide and methane may affect the amount of water vapor in the atmosphere because they produce infrared light that can be absorbed to drive evaporation.

Now we consider the 'greenhouse effect'. Suppose we instantly doubled the number of carbon dioxide molecules in the atmosphere. Not much would happen to the amount of sunlight absorbed at the earth's surface, but the atmosphere would now absorb and emit more infrared light, making more light available to heat the ground (see figure 1 and its discussion). The earth's land and ocean surfaces effectively absorb infrared radiation. These surfaces respond by evaporating more water vapor, and by heating. Land surfaces heat in a fairly predictable manner, but when oceans are heated they respond by circulating the water around as they try to make the temperature the same everywhere. This behavior of sunlight and infrared light is known as the 'greenhouse effect'. I prefer to call it the 'atmosphere effect'. The atmosphere and greenhouses are similar because sunlight enters both of them. However, greenhouses are warm because they suppress air motion. Think about why you roll down the window in your car. In contrast, the atmosphere's invisible agent is the absorption and emission of infrared light.

Here is a subtle point that people erroneously use to cast doubt on global warming. The issue is that not all infrared wavelengths associated with carbon dioxide absorption and emission will behave the same way. The claim is that carbon dioxide so strongly absorbs infrared light that adding more carbon dioxide does nothing. However, what happens in reality is that emission and absorption will substantially increase at certain wavelengths, and not others. It's not that people shouldn't be skeptical of global warming, but poor science doesn't justify skepticism.

Earth's climate has been through some interesting gyrations over the past several hundred million years. Inferences are that 300 million years ago, oxygen was 35% of the atmosphere instead of 20% as it is now. Think of the fire danger with so much oxygen around to feed flames. It may have been that at one time, with all the continents huddling near the equator, deposition of atmospheric carbon dioxide into rocks and oceans was very effective to the point that a vast ice age ensued, only to be warmed out of existence by eruptions of infrared active gases by volcanoes. The development of agriculture in the last 8,000 years may have produced enough methane and carbon dioxide to prevent us from sliding back into an ice age. Sudden changes in ocean circulations driven by spatial differences in temperature and salinity can turn off warm water circulation from near the equator to the higher latitudes, in a relative instant plunging parts of the Northern hemisphere into cold. Changes in the level of carbon dioxide and methane over the last 700,000 years are linked in lock step with atmospheric temperature changes. Changes in atmospheric composition will likely be associated with a wide range of interesting phenomena. You can learn more by attending atmospheric sciences and geography courses at both the undergraduate and graduate level at UNR.

When we jump to the conclusion that single weather events are due to a warmer earth, we are perhaps mislead, for soon a cold event will come along and displace our point of view. The sum of all weather events is climate and that is where we focus to understand our long-term outlook. In other countries like Germany, Austria, Switzerland, and Scandinavia, global warming is taught in schools as a fact of our future. These countries engage in economic planning, for example, to predict which ski areas will be viable in 20 years. However, it is a stretch to imply that all citizens in these countries uniformly accept a particular point of view on global warming. Of course, there are more pressing concerns than where we ski.

The U.S. has a history of turning issues into opportunities, and if we turn our focus to alternative energy sources there is no doubt that our formidable economic engines and brain-power can make money and a comfortable life for both our citizens and others around the world, and reduce our environmental pollution at the same time. It is about investment, like the loss-leader approach taken by one automobile company to sell their fuel efficient hybrid below cost to grow their market potential, while still selling other autos and large fuel inefficient vehicles to cover their investment costs. One perspective is that we should burn all our coal first before thinking about energy alternatives. However, we already produce the largest amount of infrared active gases of any country. Another perspective is that we should conserve our fossil fuels and develop energy alternatives.

Reading list: **N**=Neutral about global warming. **A** = agrees global warming is man made and real. **D** = disagrees with man-made global warming.

1. Clouds in a glass of beer: Simple experiments in atmospheric physics by Craig Bohren. **N**
2. What light through yonder window breaks? By Craig Bohren. **N**
3. Kicking the Carbon Habit by William Sweet. **A**
4. Global Warming: The complete briefing, by John Houghton. **A**
5. Unstoppable Global Warming: Every 1,500 years, by Fred Singer and Dennis Avery. **D**

Movies:

1. An Inconvenient Truth by Al Gore. **A**
2. The Great Global Warming Swindle by TotalDrivel, available from http://www.youtube.com/watch?v=XttV2C6B8pU. **D**