Science-1A Lecture: Week-5, Monday, September 6, 2021

This Lecture is about Global Warming. People can call it Global Climate Change, but it is hard to avoid the fact that it is warming.

Many of you are far better informed on this than your parents or grandparents, but I will write this assuming no significant previous knowledge.

Climate prediction is exceedingly difficult, it depends on a wide variety of data throughout the entire world, including the oceans. Ice and clouds reflect sunlight. Greenhouse gases trap heat. The ocean can slowly absorb heat and carbon dioxide. Ocean circulation is complicated by varying salt content. Still, the best scientists and most powerful computers are working on the problem because of its crucial importance to life on Earth. Earth is nicely positioned in the "Goldilocks zone" around the sun. But it is not impossible that the Earth's climate could go out of control making it uninhabitable like Mars and Venus.

Greenhouse Effect Basics

In class, I bring in a radiant heater like that shown in the picture at the right. It has a coil of resistance wire that glows at about 900 ^{o}C when turned on. At that temperature, we see an mild orange glow, but if we could see infrared light, we would see a very bright infrared light source. The infrared radiation is focused by the metal parabolic reflector into an outwardly directed beam.

I first have a student stand a meter in front of it and testify that they feel warmth. Then I put a picture frame holding a pane of clear glass between the student and the heater, and the student announces that the heat has stopped. **Glass blocks infrared heat waves** even though it freely lets visible light through.

I also bring in an infrared thermometer that can measure temperatures of objects by measuring the infrared heat radiation coming from them. Those thermometers can measure the temperature of ice cubes as well as people and stove tops because all things radiate heat, even dry ice, liquid nitrogen, and the void of outer space. The amount of heat an object radiates is proportional to the 4th power of the kelvin temperature. Since ice is at 273 K and body temperature is 310 K, a person radiates $(310\,\mathrm{K}/273\,\mathrm{K})^4 = 1.663$ times as much heat per unit area as a block of ice. The infrared thermometer measures that heat and calculates the temperature of the object emitting it. My infrared thermometer, is not sensitive enough to measure the temperature of liquid nitrogen at 77 K since its emitted power is only $(77\,\mathrm{K}/295\,\mathrm{K})^4 = 0.0046$ times as much as room temperature. Much more expensive infrared devices are needed to measure such low temperatures.

The soil in a greenhouse is warmed by the entering sunlight to more than the outside temperatures helping the plants grow in cool weather. Without being in a greenhouse, that warm soil would lose its heat to the outside as infrared radiation, but that infrared radiation is trapped inside a greenhouse by its glass so that its plants and soil stay warmer. **That is the "greenhouse effect".**

The Earth's Atmosphere is like a greenhouse

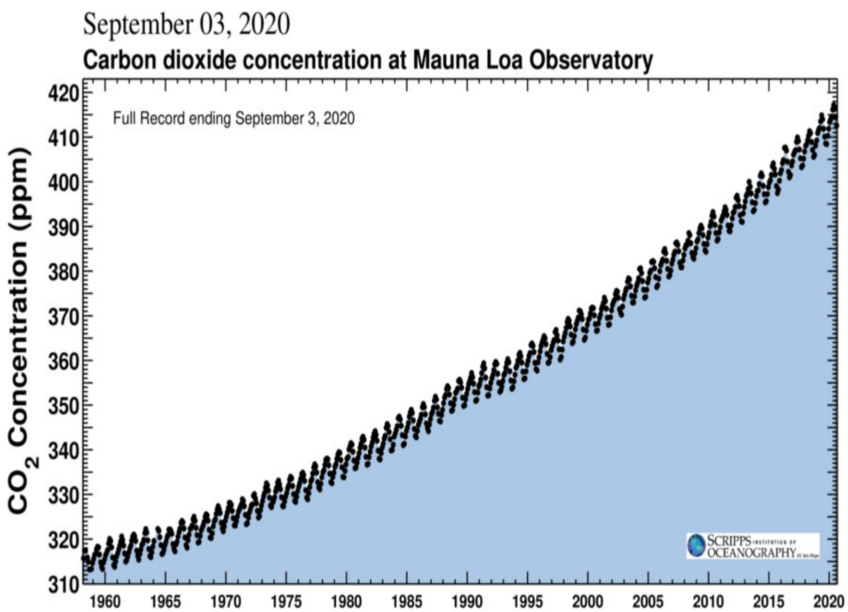
The Earth's atmosphere is not made of glass, but it also lets visible light in and tends to trap infrared radiation from escaping to outer space. The extent to which the atmosphere blocks the escape of infrared radiation depends on certain types of molecules in the atmosphere: primarily water vapor H_2O, carbon dioxide CO_2, and methane CH_4.

There is very little water vapor in the atmosphere above deserts and a great deal above the rainforests, but on the average over the whole earth the water vapor in the atmosphere depends on the average ocean temperature. The ocean has an enormous heat capacity so its average temperature only changes very slowly, raising only about 0.7 ºC over the past 100 years. As a result, the water vapor content of the atmosphere has changed very little.

If you have camped in the desert, you know that although it can be extremely hot in the daytime, it rapidly cools at night as the heat radiates to outer space through the dry atmosphere above.

Carbon Dioxide Increase

Human burning of fossil fuels over the past few hundred years has accelerated, raising the carbon dioxide content of the atmosphere from 280 parts per million (280 CO_2 molecules per million air molecules) to its current value of 415 ppm. The graph at the right shows the change since 1960.

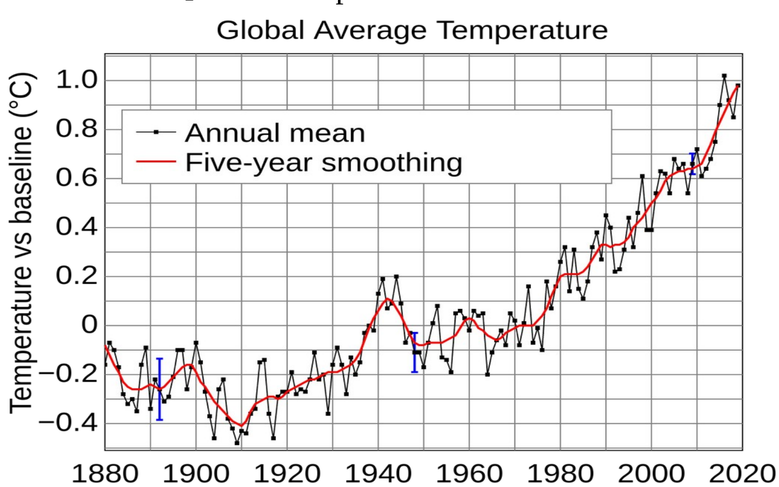


The wiggles in the CO_2 curve are caused by the seasonal vegetation growth being greater in the Northern Hemisphere. The CO_2 values dip each summer as trees take in CO_2 while growing.

An earlier edition of our textbook erroneously claimed that since the water vapor effect was greater than the carbon-dioxide effect our production of CO_2 was not very important. Wrong!!! The temperature rise from the human-caused CO_2 increase will gradually raise the ocean temperatures causing the water vapor effect to also increase. The CO_2 drives the process.

Global Temperature Rise

The average Earth temperature, including the oceans, is very difficult to determine, but the graph at the right is the result of a careful analysis.



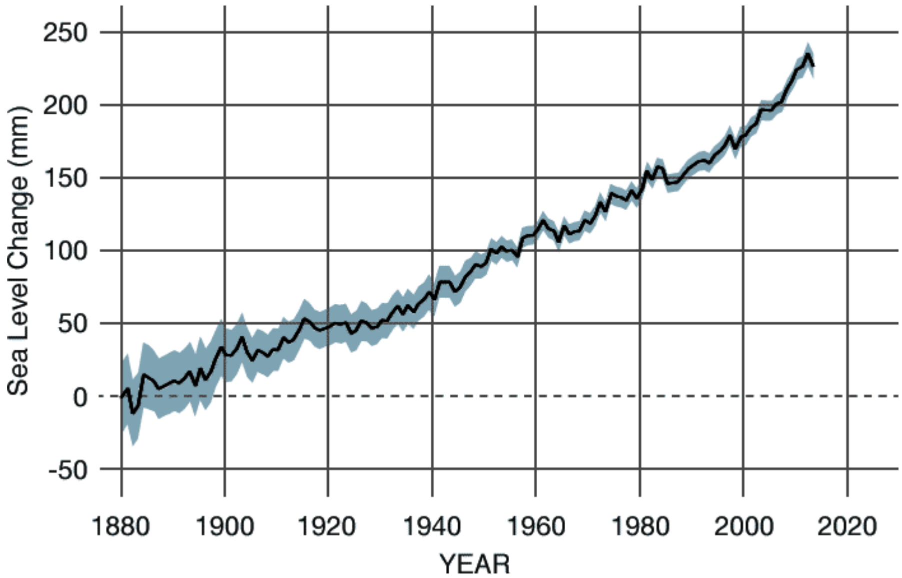
This rise may not seem significant, but it leads to melting of glaciers and the polar ice caps.

The melting of the Arctic and Antarctic ice is nicely reported in an interactive web page at *https://nsidc.org/arcticseaicenews/charctic-interactive-sea-ice-graph/* .

Sea Level Rise

You can do a simple experiment to show that melting of floating ice does not cause a water level rise. Just fill a glass about 3/4 full with water, add a couple of ice cubes that can float freely, and mark the water level. When the ice cubes have melted, the water level will still be at your mark. **Melting of floating ice does not raise water level.**

The ice of the Arctic Ocean is floating so as it melts, the ocean level will not rise, but the ice on Greenland and on the Antarctic Continent is not floating. As those melt, the ocean level will rise.



Although the rise in ocean level is very difficult to sort out from tidal and wave effects, the graph on the right is the result of a thorough analysis.

The 250 mm rise is not very much, but it is increasing more rapidly than in the past. This rise is a combination of added water from melting land ice and the thermal expansion of the upper levels of ocean. Thermal expansion is the effect of hotter molecules taking up more space as they move faster and bump harder into their neighbors.

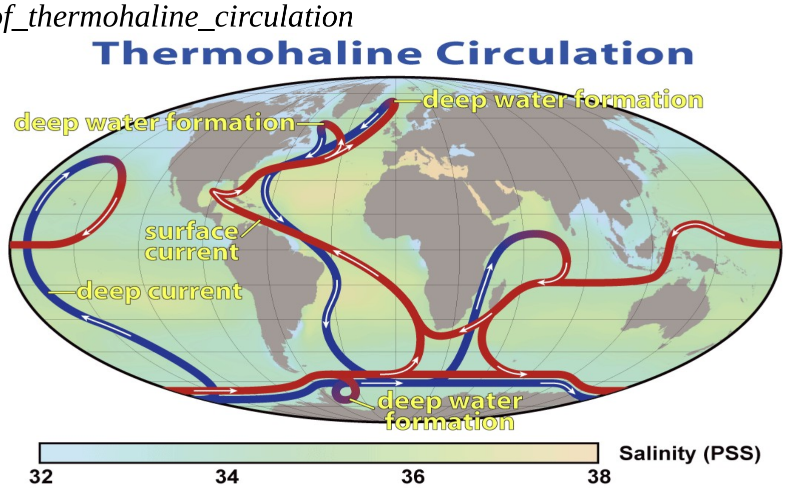
Coastal flooding is caused by waves and storm surges on top of the average ocean level. Prediction of the amount of damage caused by sea level rise is very difficult, but the trend seems to be increasing so that by the year 2100, its effects will be very obvious.

Ocean Acidification

The carbon dioxide increase can be absorbed by the ocean, but that process is extremely slow, taking perhaps hundreds of years. But as it absorbs CO_2, however, it becomes more acidic (lower pH). The protective $CaCO_3$ sea shells of many ocean species are able to exist because of the current pH level of the ocean. Making it more acidic will tend to dissolve $CaCO_3$. We will talk more about the chemistry of ocean acidification in the chemistry part of our course.

The Shutdown of the Thermohaline Circulation

https://en.wikipedia.org/wiki/Shutdown_of_thermohaline_circulation



As explained in this Wikipedia article, there are flowing "rivers" of ocean water with increased salinity that mix the surface ocean water with the deep ocean water. These affect weather along the Atlantic coast, Europe and elsewhere in the world. Warmer waters from a melting Arctic ice cap might disrupt that circulation leading to serious weather disruption.

Alteration of the Jet Stream
The jet stream is a flow of air at about 12 km altitude the circulates above the parts of the northern and southern hemispheres of the Earth. As storm fronts move across the United States from West to East, they are following pressure patterns connected with the Jet Stream. See "What is the Jet Stream" at *https://www.youtube.com/watch?v=o203JXAnSA0* for a short video.

The Wikipedia article at *https://en.wikipedia.org/wiki/Jet_stream* not only explains more about the Jet Stream, but also discusses how climate change affects it.

The warming of the polar ice cap tends to increase the meandering of the jet stream. That causes weather patterns to change more slowly. Heat spells and cold snaps will last longer. When we would commonly have a heat spell last for only a few days, now it might last for a week or two. The same is true for cold weather. As an extreme weather situation lasts longer, its temperatures can go to greater extremes.

The net effect is that the warming of the polar regions will lead to greater extremes of weather for the United States.

What can be done?
The coal and oil we take out of the ground was deposited over millions of years, and we are converting it to carbon dioxide in just a few decades. That is the crux of the problem with our extensive use of fossil fuels. So reducing our consumption of coal and oil is an obvious need.

The following is just a list of a few things being considered.

One solution is to use less energy – less flying, less driving, less eating of meat, and continued improvements in home insulation.

Larger power grids spanning the entire the US, Canada and Mexico can help.

Solar and wind energy generation are the obvious major candidates for helping wean ourselves from fossil fuels, but as the saying goes "the sun does not always shine and the wind does not always blow."

Electricity normally needs to be used as it is generated, although we have already mentioned how moving water between the Courtright and Wishon reservoirs is one method of electricity storage. Batteries are another method of storage, but they are expensive and need to be replaced every 6-10 years. There are serious efforts at making large-scale battery storage practical. One effort is the Tesla Powerwall. See *https://en.wikipedia.org/wiki/Tesla_Powerwall* .

Storage by converting extra electricity to hydrogen and oxygen gas using electrolysis is another, but so far no process has been developed to do that with sufficient efficiency.

Electric cars still need electric energy, but home solar systems might be able to do most of the recharging of electric cars.

Hydrogen-powered cars still need hydrogen fuel which must be produced from water or fossil fuels using a considerable amount of additional energy.

Supporters of nuclear energy push it to supplement solar and wind energy generation, and urge the building of more nuclear power plants. Near the end of the semester, we will discuss the downside of nuclear energy.

We will certainly need to be less wasteful and more tolerant of some inconvenience.