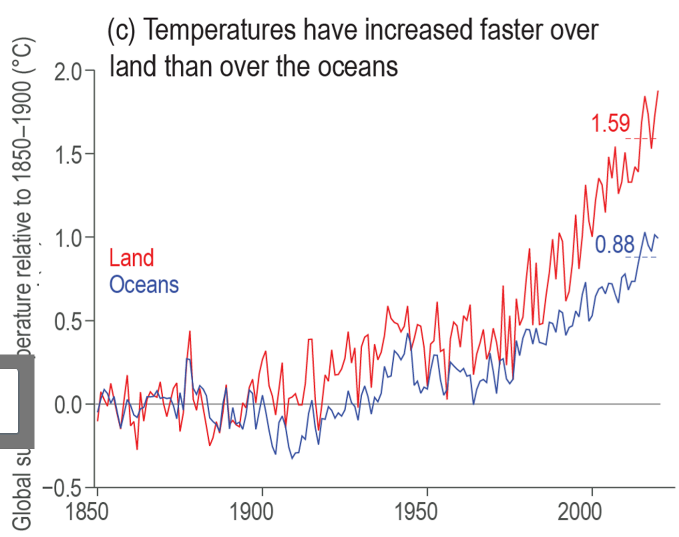
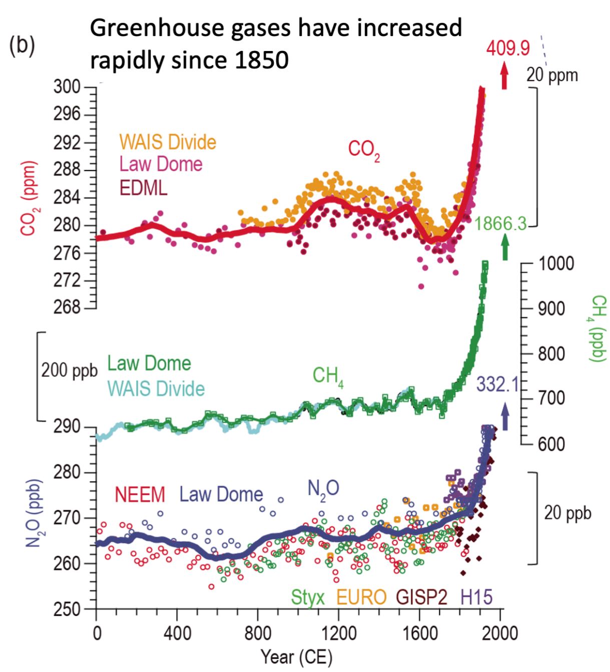
# Lecture 22: Climate Change

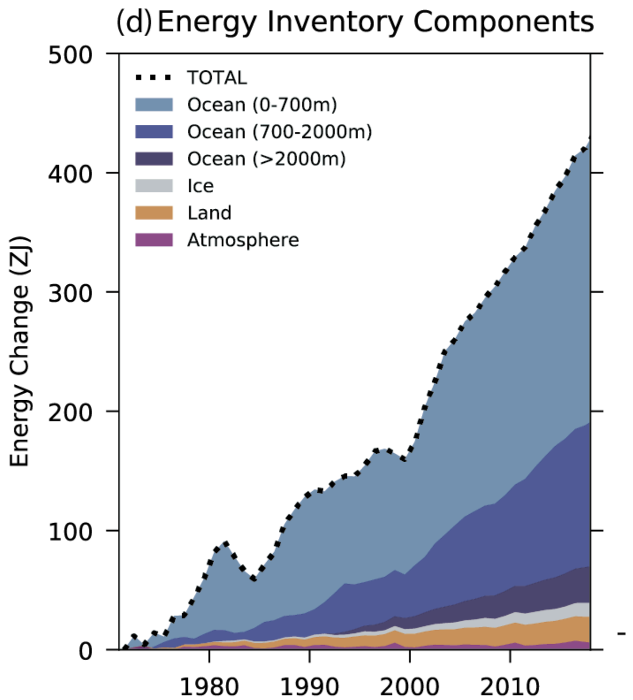
Lecture 22: Climate Change in the Ocean

In the past 150 years, the climate on earth has been changing due to rapid changes in the atmosphere. Since records have begun being kept in the 1880s, the temperature of the earth has warmed at a faster rate than ever before. There are a number of lines of evidence that demonstrate how quickly climate has been changing in the past century. One of the most compelling is the rapid acceleration of temperature increase coincident with unprecedented increases in greenhouse gases in the atmosphere. Look at the two figures below (both taken from the IPCC 6$^{th}$ Climate Assessment Report). On the left is a timeseries of global surface temperatures since 1850. The red line is land temperatures, blue shows temperatures over the ocean (do you recall why land would be heating faster than the ocean?). Now look over to the figure on the right which shows greenhouse gas concentrations over the same time. Since the industrial revolution, greenhouse gas emissions from human sources have caused a rapid acceleration in greenhouse gases, which have caused an overall increase in global temperature.

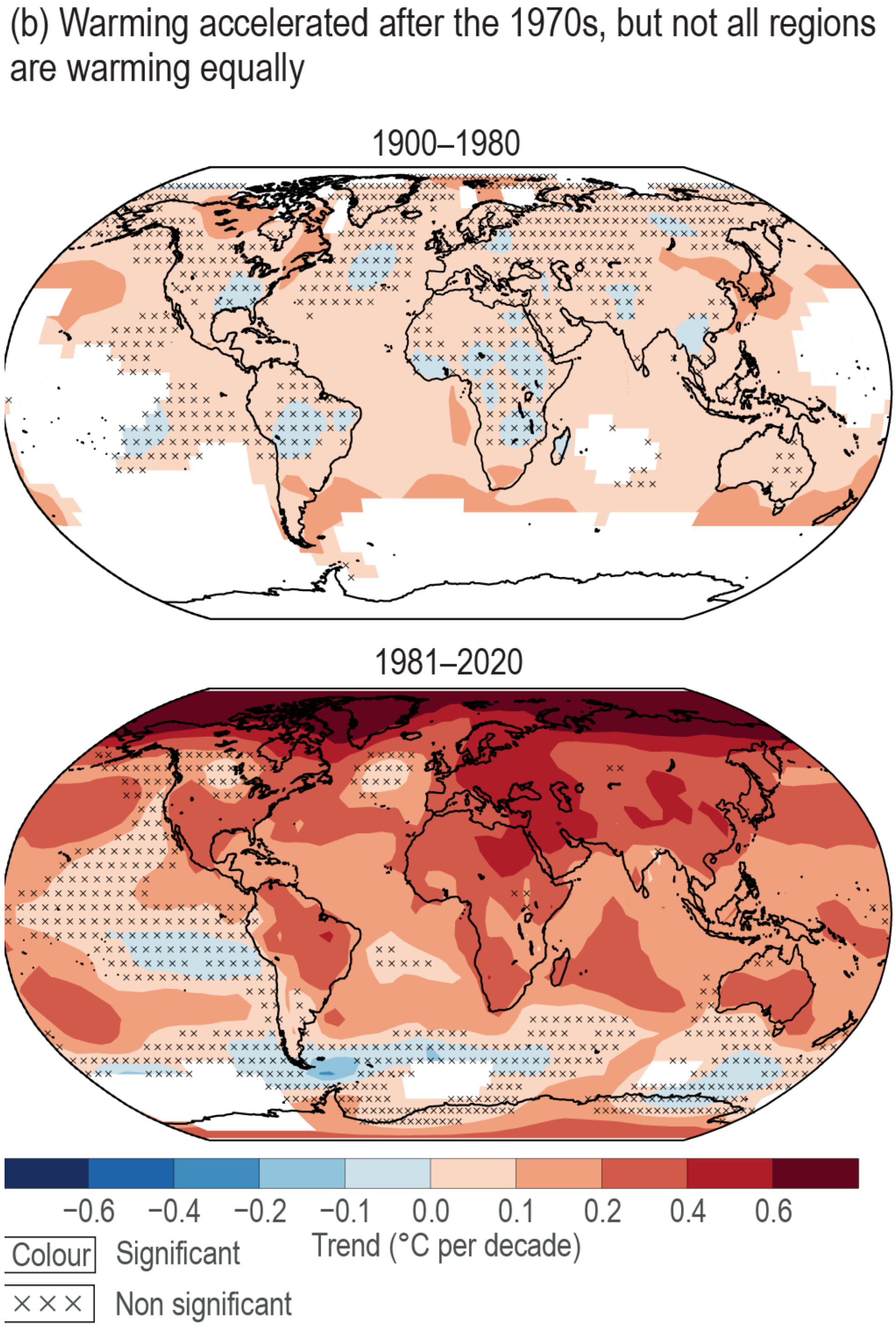



Revisiting the graph above on the left – the temperatures above the ocean have increased less than over land. Why? You know the answer – it is because of the high heat capacity of water (one of those special properties that makes water so unique). Another thing that high heat capacity has allowed for, is the absorption of lots and lots of heat in the ocean. If it wasn't for the storage of heat in the ocean, our planet would have warmed much more by now than it has. The graph below shows the amount of excess energy that has been taken up by various components of the planet. The blue areas represent the energy that has been taken up in various parts of the ocean, compared to that taken up by ice, land or the atmosphere. Imagine if the ocean wasn't so great at absorbing energy! Now – when you learned about all the the amazing properties of water, you also learned that warmer water is less dense and takes up a greater volume. Looking at the figure below, and considering just how much water is out there in the oceans, think about what even a small increase in the water volume might mean (hint – the ocean gets bigger! More on that in a subsequent lecture).




The temperature trend shown in the top figure above is a global average. The effects of climate change have not been equal and consistent everywhere (I hope you can probably think of a few reasons why this would be the case based on previous lectures). The maps below show the changes in global surface temperatures across the globe for the 1900s to 1980 in the top map, and since 1980 in the bottom map. The darker the red color indicates a greater increase in temperature at that location for that time. The blue colors are the opposite. A few things are obvious: 1. the most recent 40 years have increased in temperature much more than the 80 years prior, 2. The arctic region has warmed the most in the past 40 years, 3. There are parts of the earth that are warming more and faster than other places, 4. There is a lot more warming than there is cooling.




As you can see from the map above, the polar regions, and the arctic in particular, has warmed incredibly fast in the past few decades. As you know from earlier in the course, one major difference between the Arctic and the Antarctic is that the Arctic is an ocean region surrounded by land; while the Antarctic is a continent. Each year, the ice covering the Arctic Ocean grows through the winter as darkness dominates, with the maximum coverage of ice around March. Through the summer, as solar radiation returns and warmer conditions occur that ice melts, with the minimum extent of ice happening in September. Since 1987, satellites have been used to measure the extent of summer sea ice in the Arctic. These satellites have recorded a striking loss over time of Arctic sea ice. Check out

[this video (https://youtu.be/AuwOwqzT6rk)](https://youtu.be/AuwOwqzT6rk)

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to see a timeseries of the observed sea ice coverage since 1987, and a graph showing the decline over time to almost half of what it was when we started watching with satellites. Arctic sea ice is not only being lost, it is becoming younger. This is because sea ice not only melts, it can drift out of the ocean basin and be lost. As noted above, each year new ice is formed in the winter and it melts or flows out in the summer. There is a gyre in the Arctic Ocean that tends to hold ice over time so that it accumulates over multiple years. This ‘old’ ice is thicker, less saline, and less likely to melt. Watch
**this video** (https://youtu.be/1soac0qun0g)

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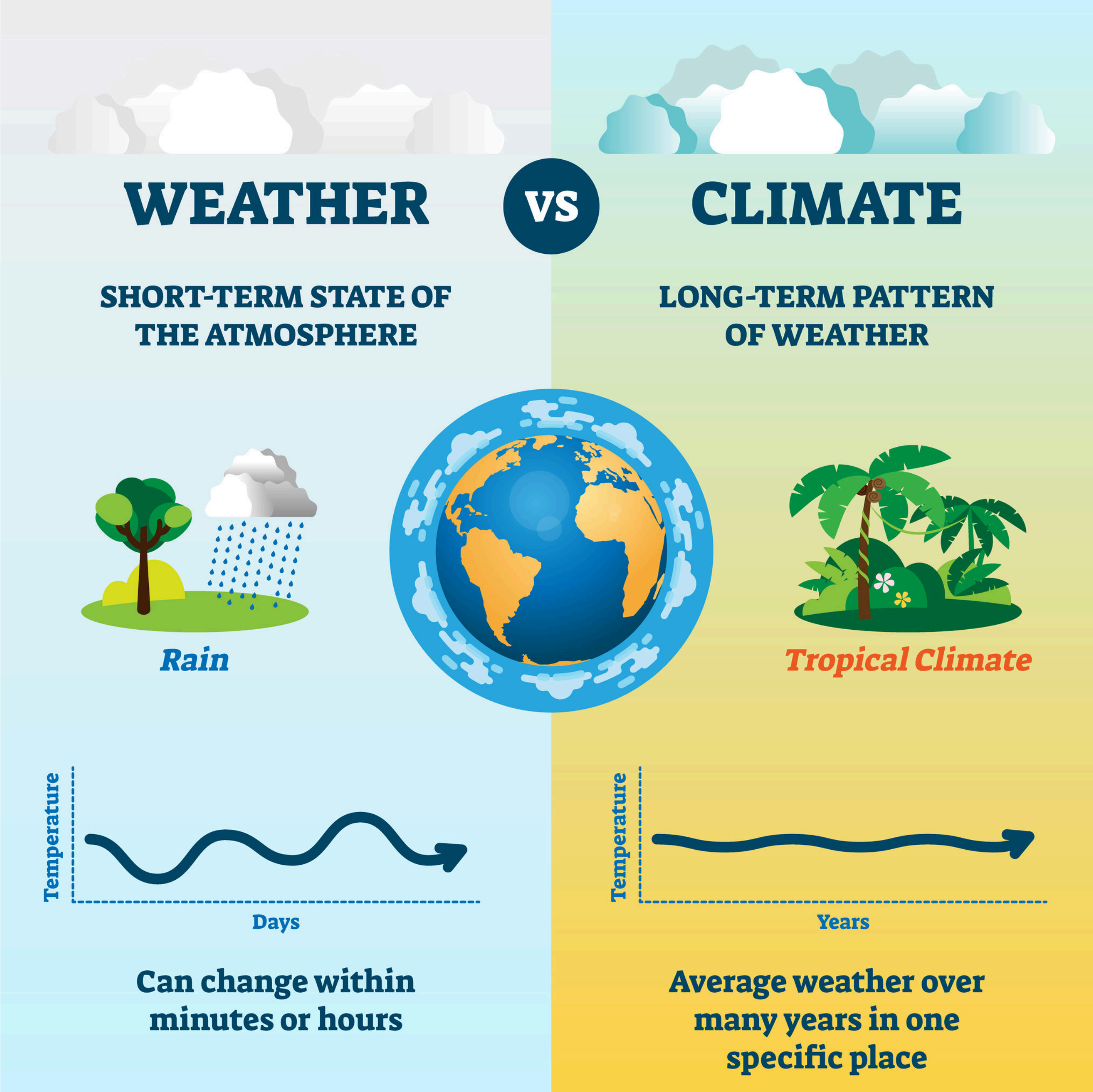
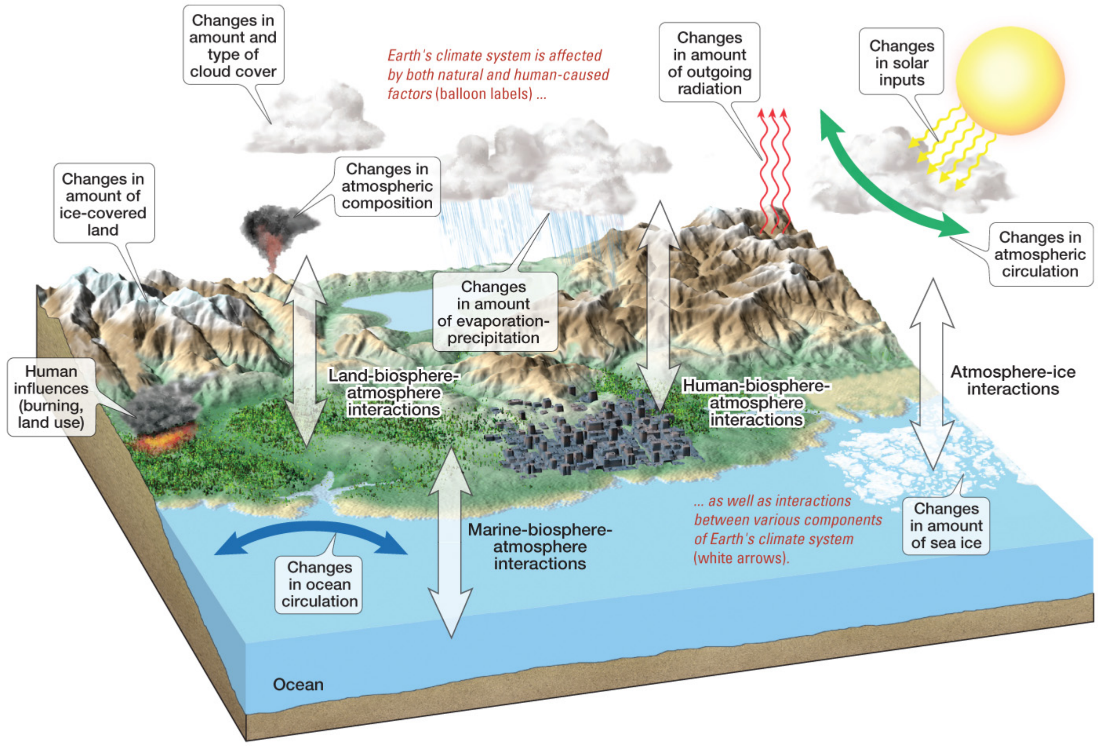
to see a nice animation of how the ice in the Arctic changes through the years, and how the age has changed over time (the more white the ice, the older it is in the video).

It is important, when we talk about climate change, that we fully appreciate the distinction between climate and weather. Weather is the short-term (minutes to weeks) conditions of the atmosphere; whereas climate is the long term average conditions of weather over time and space. For example, the weather on this day in early December of this year might be calm, relatively warm, and sunny. The climatic conditions for this time of year might be different if we look across many years and days within the month. You can think of climate as the conditions you would expect for a given location and time. For example, in New Jersey in August, we typically expect hot and humid conditions. That climatic average doesn’t mean that there might not be an unusually cold day in August. Another important distinction to discuss is the difference between global warming and climate change. When we talk about global warming, we are specifically talking about an overall warming of the planet on average (like the data shown above). Climate change is more than just temperature – it includes changes in regional climatic conditions that includes temperature, humidity, sea level, rainfall, wind, and extreme weather events.

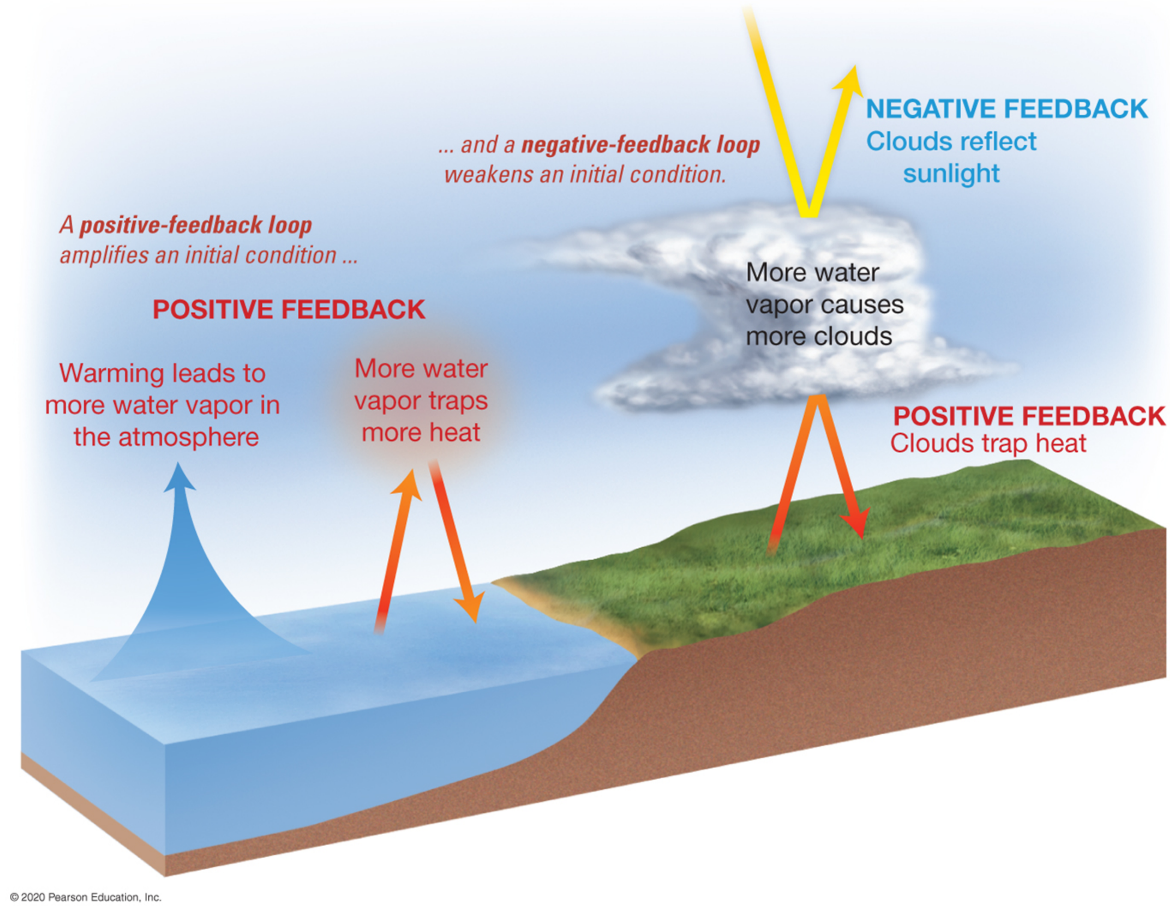



Fully understanding the Earth's climate and how it is changing requires us to look at more than just the atmosphere. The climate is influenced by the atmosphere, the hydrosphere (the water components), the lithosphere (we learned a bit about this already), the biosphere (the biological components), and the cryosphere (these are the cold parts -the ice and snow). The exchange of moisture and energy among these five spheres controls the climate system on Earth. These exchanges of moisture and energy connect the atmosphere (where weather happens) with the other parts of the planet so that they all work as one interconnected unit. You can see in the figure below that the ocean is the biggest part of the Earth's climate system, and it is important to understand that when changes happen in one part of the climate system, those changes are translated to the other speres because of how connected the system is.






Changes to the climate system are typically large scale, highly complicated, and involve feedback loops. These feedback loops are important mechanisms that modify initial changes by feeding them back and though other parts of the system. An example of some feedback loops are shown below. On the left, you see a positive feedback loop where the initial change of warming over the ocean causes more water vapor to be generated. That water vapor acts as a greenhouse gas, trapping heat which causes a positive feedback loop by further heating the ocean, which then generates more water vapor. These positive feedback loops tend to amplify initial changes and cause them to continue in the direction of the initial change. An example of a negative feedback loop is shown on the right where heating causes water vapor as before, but in the negative feedback loop case, that water vapor may condense to clouds which reflect heat and thus cause cooling which counteracts the initial change and weakens the initial condition. In general, positive feedback loops tend to be reinforcing loops that make an initial change continue; whereas negative feedback loops tend to be balancing and tend to diminish the initial change. We talked above about the loss of Arctic sea ice due to increased temperature. Would this be a positive or negative feedback loop? Sea ice is highly reflective and tends to act in the same way (but much more effectively) as clouds in reflecting heat (a negative feedback). The loss of ice therefore sets up a positive feedback. As it turns out, this is a very strong positive feedback wherein the warming ocean causes loss of the ice, which then accelerates warming because the reflective capacity (the balancing negative feedback) is lost. This is why the changes in the Arctic have been so drastic and rapid in the past few decades.




Greenhouse gas emissions set up an important feedback loop that controls the climate system. Gases in the atmosphere are important – without them we can't breathe, and there would be no way to warm the Earth and life would not exist. However, too much of a good thing can be a problem. Look back up to the first figure in this lecture. On the right are timeseries graphs of some important greenhouse gases. You might notice that they fluctuate over time. There is a certain amount of natural fluctuation in those gases due to climate system processes and feedbacks. In fact, there are natural oscillations in atmospheric gases every ~100,000 years (these generally follow ice age and interglacial cycles). However, when you look at the far right of those figures at the top of the lecture, you will see a sharp increase in greenhouse gases in the past century. $CO_2$ (and other greenhouse gases) are at their highest levels in at least 400,000 years. It is that rapid and human-induced increase in greenhouse gases and the feedback loop they create that is causing climate change and global warming.

How do we know about ancient climate and atmospheric conditions relative to today's conditions? There is a super interesting field of science called paelo-reconstruction that allows us to use various tools to look back at ancient climate conditions. For example, some scientists use ice cores to find and examine air from thousands of centuries ago. This is possible because air is snow becomes trapped as it is compressed to ice. Those air bubbles in the ice are a mini time capsule of ancient atmosphere composition. Other things that can be used to reconstruct climate conditions from before we had fancy equipment like satellites and robots are tree rings, corals, clams (corals and certain clam species live a very long time and the chemistry of their shells allow us to look back in time at the ocean conditions they were growing in). These climate reconstructions are important science tools that allow us to better understand the link between $CO_2$ and surface temperature. It provides a way to evaluate what natural climate variations look like and what causes them. We use reconstructions to see

how fast the climate system respond (the feedbacks), how the biosphere copes with climate change, and how are climate change and sea level linked. Watch
[**this video** (https://youtu.be/cQVPMpt8HhM)](https://youtu.be/cQVPMpt8HhM)

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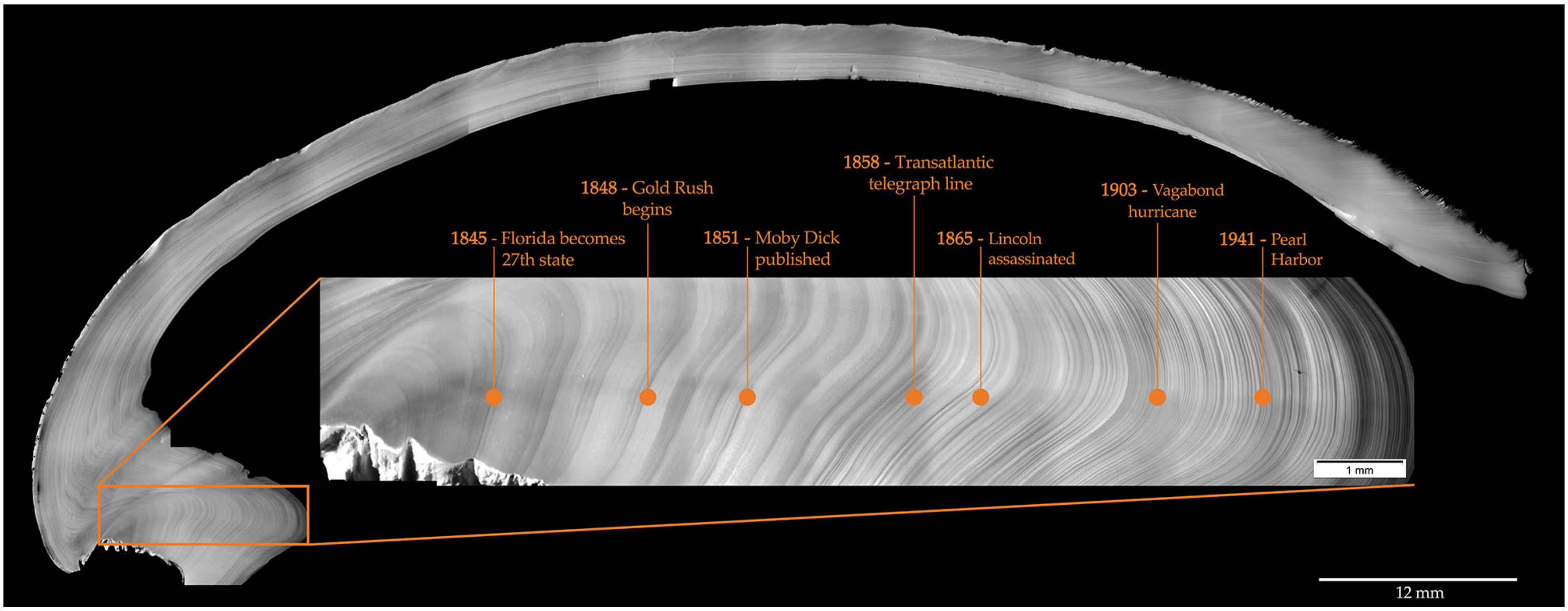
to learn about the amazing ice core program in the US. And the image below shows a time history recorded in a clam (you are looking at a cut cross-section of the shell) caught in the ocean off New Jersey – these amazing clams live centuries!




As we learn more and more about ancient atmosphere, ocean, and climate, we gain a better understanding of the rapid and dramatic changes we are seeing on the planet today. Importantly, we are learning about where the tipping points and feedback loops are and how they are creating unexpected switches and accelerations to changes we are seeing in the climate system. Ocean acidification and sea level rise are examples – more about those in other lectures. Another example is changes to global thermohaline circulation. As you learned previously, the global conveyor belt is an important global ocean current system that connects the deep ocean and surface ocean, and helps redistribute heat around the globe. Scientists have recently observed small changes to the major currents that could signal a change in this important climate feedback loop. If the conveyor belt were to slow or shut down completely, it would set off a massive positive feedback loop. Interestingly, climate reconstructions have allowed us to look back in time to when a similar process is believed to have causes the Younger Dryas cold event (~12,000 yrs ago), when meltwater from Lake Agassiz suddenly spilled into the north Atlantic. Observing that historical shift is helping scientists understand what might be happening on the planet today.