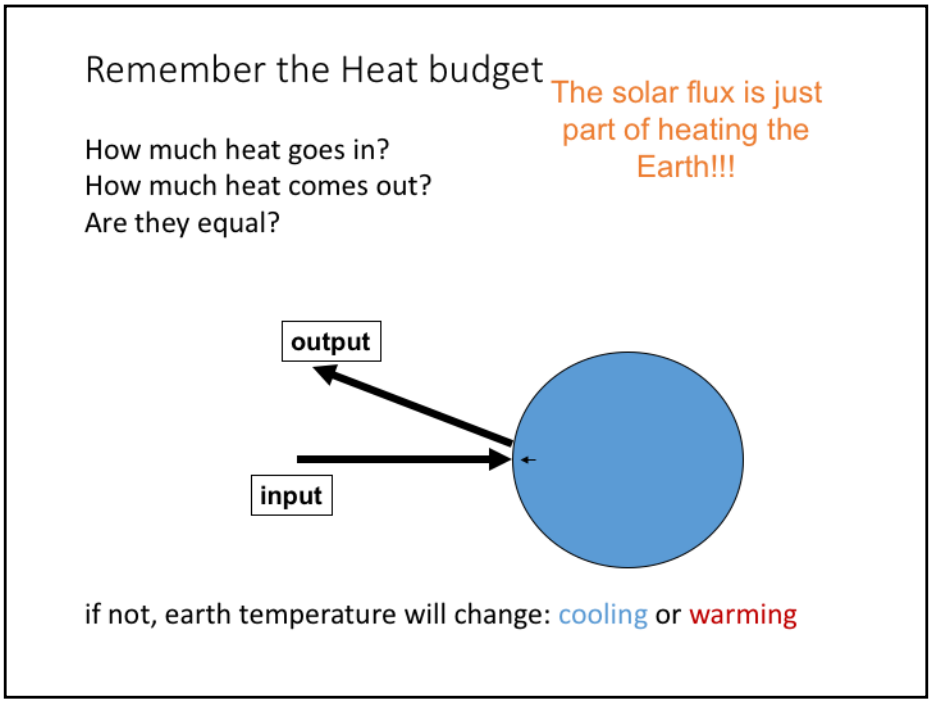
Evidence of climate change

Objectives:

- I understand what causes climate to change
- I can describe both short term (seasonal) and long term (annual) changes in CO_2 concentrations (Keeling Curve)
- I understand what the IPCC is
- I can describe evidence for that suggests current climate is changing: temperature, sea level rise, melting ice, CO_2 increase, CH_4 increase, permafrost thaw, increased growing days

Evidence from glaciers and past climate data shows us that Earth's climate has changed over time.

Today we are going to discuss some of the evidence that suggests that our climate is currently changing now.



Remember when we are talking about changing temperatures in the atmosphere is is all about the balance between incoming and outgoing energy.

Energy must go out, otherwise the Earth would melt!!

Solar flux is a part of the heat budget, but how much stays and how much goes is dependent on other factors.

How does the Earth's climate change?

There are two fundamental ways to change the radiation balance of the Earth.

1] Change the incoming solar radiation

- change Earth's orbit—Milankovitch cycles
- change the Sun itself–solar luminosity has increased 30%; sunspots

2] Change the outgoing solar radiation

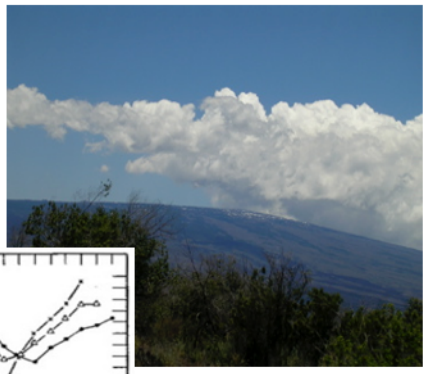
- change Earth's albedo
- change the Greenhouse Effect

We had previously discussed incoming radiation as constant, but it can change. For one, the earth's orbit around the sun changes throughout time---orbit changes from elliptical to circular, tilt changes, and the direction of axis changes. These are known as Milankovitch cycles in influence the incoming radiation.

Additionally, the Sun's radiation has not been the same for all of Earth's history---at the beginning of Earth's history, the sun was about 30% less luminous than today. Sunspots can also lead to slight changes in incoming radiation.

The outgoing radiation is influenced by the albedo of Earth and changes in the Greenhouse effect. We will look primarily at changes to the Greenhouse effect today.

Where climate change science began...



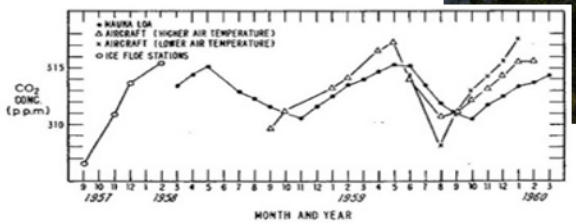


Fig. 1. Variation in concentration of atmospheric carbon dioxide in the Northern Hemisphere.

Tellus XII (1960), 2

Keeling, C.D. 1960.The concentration and isotopic abundance of carbon dioxide in the atmosphere. *Tellus* 12:200-203.

http://scrippsco2.ucsd.edu/talks/cdk_tyler_prize_lecture_2005.pdf

It was in the 1960s when CO2 measurements in the atmosphere first started being measured at Mauna Loa lab.

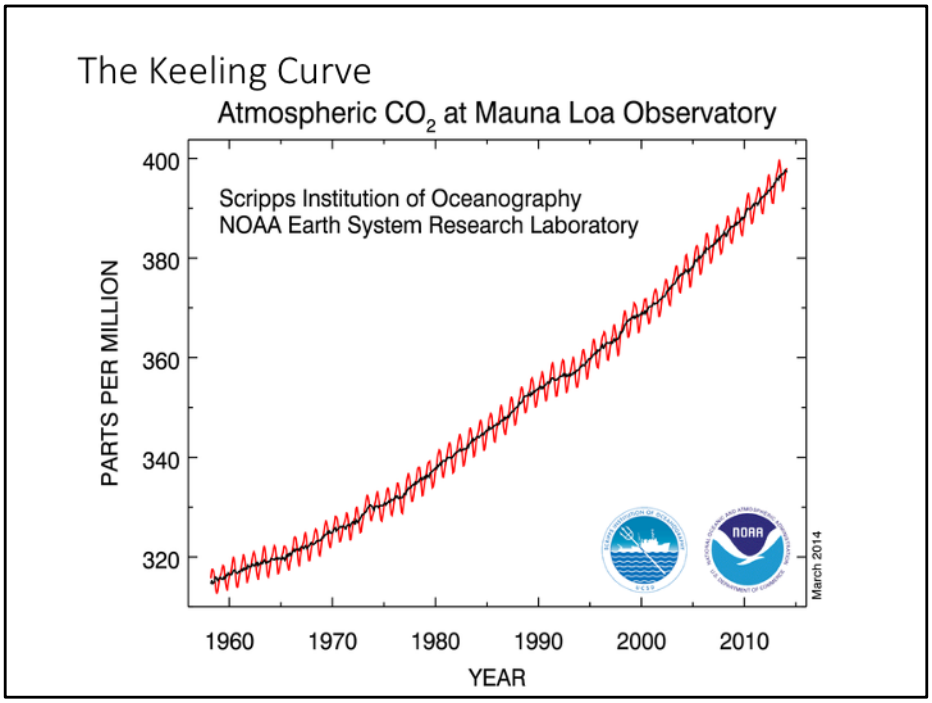
Keeling began to take air samples throughout the day and night and soon detected an intriguing diurnal pattern. **The air contained more CO2 at night than during the day** ---function of plant respiration.

He repeated these measurements in the rain forests of Olympic peninsula and high mountain forests in Arizona. Everywhere the data were the same: strong diurnal behavior with steady values of about 310 ppm in the afternoon. The explanation for the results came from a book on meteorology describing diurnal patterns in turbulence in the atmosphere. In the afternoon Dave Keeling was measuring CO2 concentrations representative of the "free atmosphere", concentrations that prevailed over a large part of the Northern Hemisphere. At night time with a lower boundary layer the CO2 concentration was heavily influenced by respiration from local plants and soils.

Dave Keeling's analytical skills and dedication had paid off with two dramatic discoveries: firstly, of **the natural seasonal "breathing" of the planet** and secondly, of the rise in atmospheric CO2 due to the combustion of fossil fuels by industry and to land use changes. Published in the 1960 Tellus Article, "The concentration and isotopic abundances of carbon dioxide in the atmosphere" (pdf), these significant findings marked the beginning of the now world famous "Keeling Curve" which extends for 55 years and represents one of the most important geophysical records ever made.

In the course of working on a project involving carbon in river water - a project that incidentally required making measurements of CO2 in air - Charles David Keeling made a key discovery. What he discovered was that when he sampled the air remote from forests, cities, and other obvious sources or sinks for CO2, he always got almost the same value of 310 ppm.

By the early 1970s this curve was getting serious attention, and played a key role in launching a research program into the effect of rising CO2 on climate. Since then, the rise has been relentless and shows a remarkably constant relationship with fossil-fuel burning, and can be well accounted for based on the simple premise that 57 percent of fossil-fuel emissions remain airborne.
The Mauna Loa record can now be placed in the context of the variations in CO2 over the past 400,000 years, based on reconstructions from polar ice cores. During ice ages, the CO2 levels were around 200 ppm, and during the warmer interglacial periods, the levels were around 280 ppm.

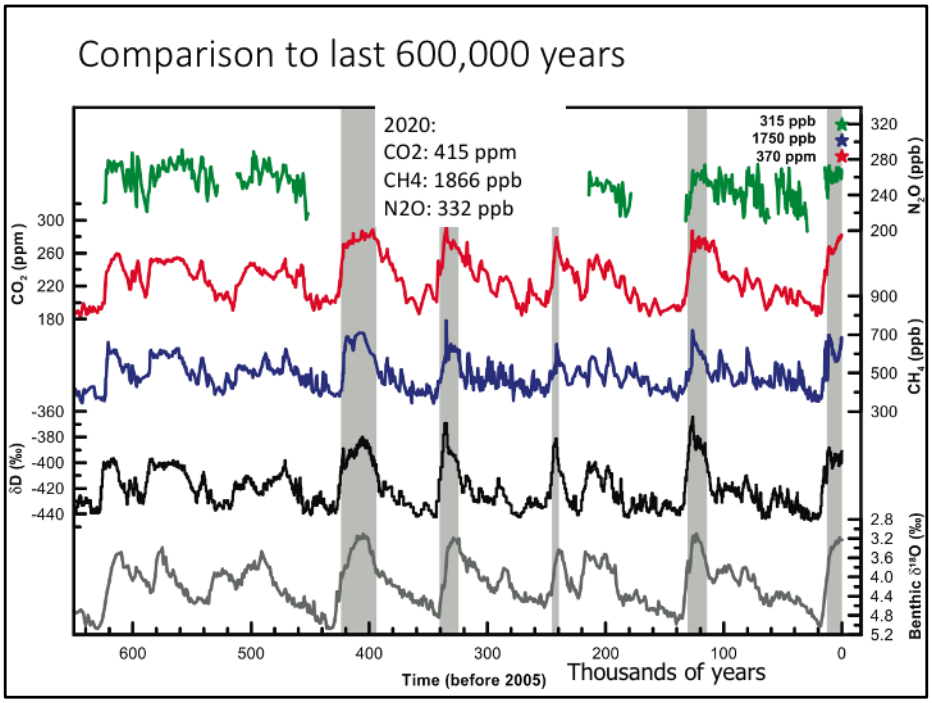


Measurements continued and are still ongoing.

Does CO_2 change over time? Does one line (red or black) represent that change better than another?

If CO_2 does change over time, what do you think contributes to the variation in CO_2?

From 1960-2014, concentrations of CO2 ranged between 300-400 ppm.



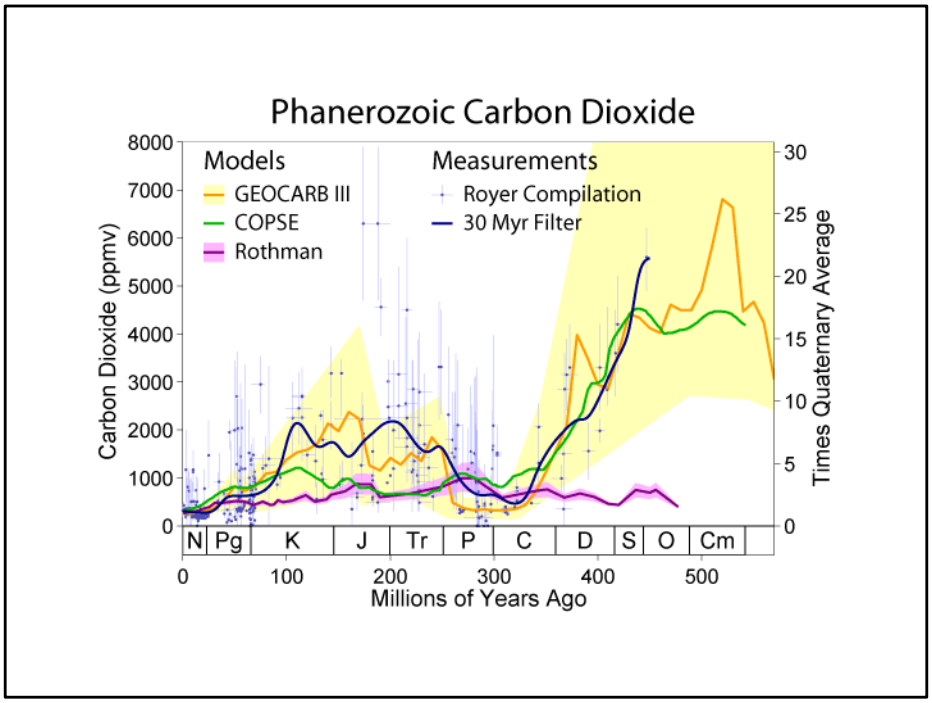
Remember this figure from last class. As increase CO2 in the atmosphere, temperature increases because CO2 is a greenhouse gas.

From 1960-2014, CO2 concentrations ranged from 300-400 ppm

Prior to that, over the last 600,000 years, CO2 concentrations ranged from 180-300 ppm. Note the scale change. A scale change is an indication that CO2 concentrations are changing. And the rate of change. An increase in CO2100 ppm happened over 20,000 years. Over the last 20,000 years the increase is 200 ppm!

Figure 6.3. *Variations of deuterium (δD; black), a proxy for local temperature, and the atmospheric concentrations of the greenhouse gases CO_2 (red), CH_4 (blue), and nitrous oxide (N_2O; green) derived from air trapped within ice cores from Antarctica and from recent atmospheric measurements (Petit et al., 1999; Indermühle et al., 2000; EPICA community members, 2004; Spahni et al., 2005; Siegenthaler et al., 2005a,b). The shading indicates the last interglacial warm periods. Interglacial periods also existed prior to 450 ka,*

but these were apparently colder than the typical interglacials of the latest Quaternary. The length of the current interglacial is not unusual in the context of the last 650 kyr. The stack of 57 globally distributed benthic $\delta^{18}O$ marine records (dark grey), a proxy for global ice volume fluctuations (Lisiecki and Raymo, 2005), is displayed for comparison with the ice core data. Downward trends in the benthic $\delta^{18}O$ curve reflect increasing ice volumes on land. Note that the shaded vertical bars are based on the ice core age model (EPICA community members, 2004), and that the marine record is plotted on its original time scale based on tuning to the orbital parameters (Lisiecki and Raymo, 2005). The stars and labels indicate atmospheric concentrations at year 2000.

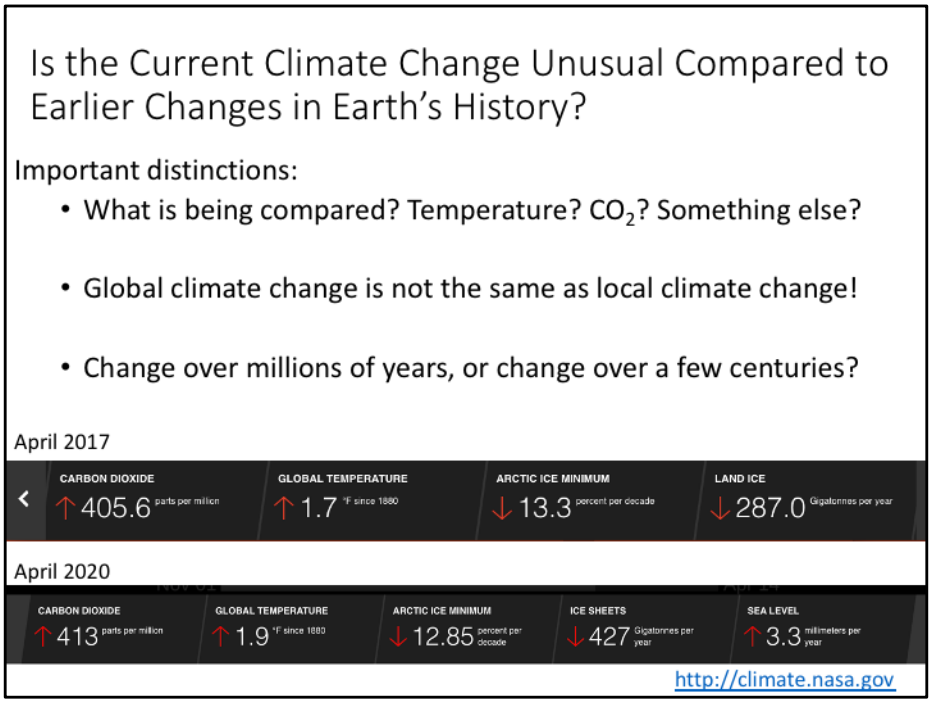


blue line = average of the blue data points. everything else is from models---estimating CO2 concentrations based on climate proxies-the only ones that go back 500 million years are fossils and rocks.

Previously you saw that CO2 currently is much higher than in the last 600,000 years, but CO2 has been even higher over geologic time.

500 million years ago, CO2 could have been 5,000 ppm! However, look at the rate of change between 300-500 million years ago.

POINT = CO2 levels were likely MUCH higher in the past. The position of the continents, degree of weathering, and ocean composition was also much different. CHANGE occurs over long time periods



When we think about current climate change it is compared to earth's history.

When you are talking about past climate change it is usually over millions of years. Now, we are considering rates of change over a few decades.

As we discuss climate change, we will be talking about global averages—this does not mean that everyplace is experiencing the same change. If we talk about temperature increasing globally there will be places where temperature in decreasing. The trend is that globally averages are increasing.

Also remember that climate isn't just temperature, it is also precipitation, humidity, etc.

The bottom two images are some statistics from NASA. The top is from 3 years ago, the bottom is from this year. In 2017 CO2 was at 406, currently 413. In 2017 global temperature had increased 1.7 F, now it has increased 1.9. We will look into these lines of evidence as we continue.

local: caused by changes in ocean circulation
large scale requires global forcing mechanism

IPCC

https://www.youtube.com/watch?v=6yiTZm0y1YA&feature=youtu.be

- International Panel on Climate Change
  - Scientific body set up by the World Meteorological Society and the United Nations Environment Programme
    - Government representatives
    - > 800 scientists who review the work of the entire scientific community
  - Largest collaborative scientific effort in history

- 5th Assessment Report released in 2014
  - http://www.ipcc.ch/report/ar5/wg2/

Scientific evidence for warming of the climate system is unequivocal.

- Intergovernmental Panel on Climate Change

A lot of the data I'm going to show you is from the IPCC report in 2007 and 2014. IPCC takes all the research that has been done and compiles it together to look at global patterns and trends. There are more than 800 scientists who work on this! What you will see is not just my interpretation of data, but the results that 800 experts compiles.

The IPCC presents six main lines of evidence for climate change.

•We have tracked the unprecedented recent rise in atmospheric carbon dioxide and other greenhouse gases since the beginning of the industrial revolution.

•We know from laboratory and atmospheric measurements that greenhouse gases do indeed absorb heat when they are present in the atmosphere.

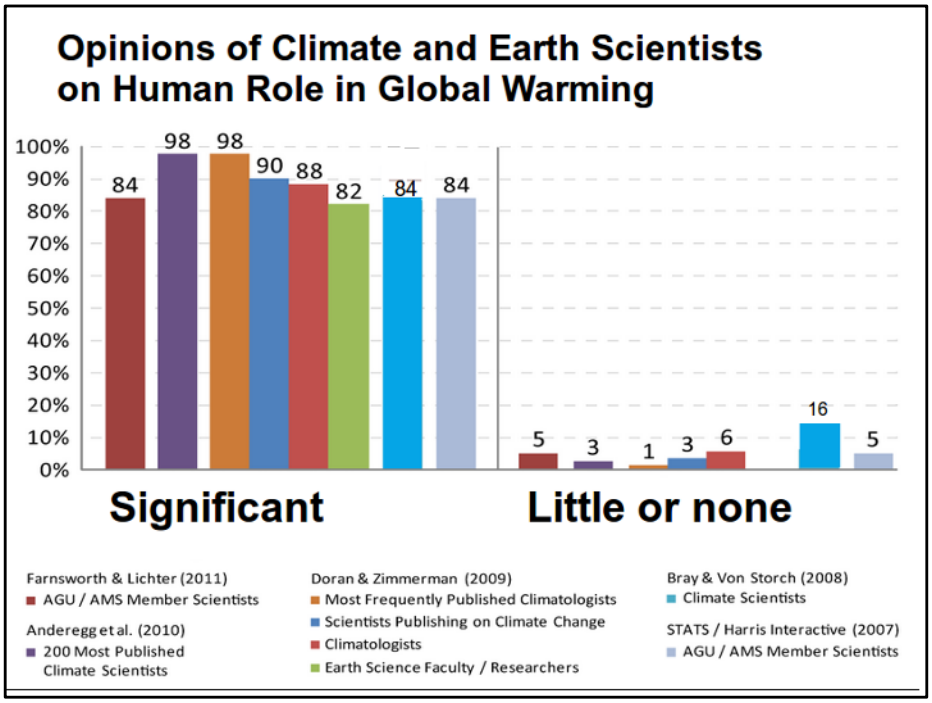
•We have tracked significant increase in global temperatures of 0.85°C and sea level rise of 20 cm over the past century.

•We have analyzed the effects of natural events such as sunspots and volcanic eruptions on the climate, and though these are essential to understand the pattern of temperature changes over the past 150 years, they cannot explain the overall warming trend.

•We have observed significant changes in the Earth's climate system including reduced snowfall in the Northern Hemisphere, retreat of sea ice in the Arctic, retreating glaciers on all continents, and shrinking of the area covered by permafrost and the increasing depth of its active layer. All of which are consistent with a warming global climate.

•We continually track global weather and have seen significant shifts in weather patterns and an increase in extreme events. Patterns of precipitation (rainfall and snowfall) have changed, with parts of North and South America, Europe and northern and central Asia becoming wetter, while the Sahel region of central Africa, southern Africa, the Mediterranean and southern Asia have become drier. Intense rainfall has become more frequent, along with major flooding. We're also seeing more heat waves. According to the US National Oceanic and Atmospheric Administration (NOAA) between 1880 and the beginning of 2014, the 13 warmest years on record have all occurred within the past 16 years.

Here are the 6 main lines of evidence that climate is currently changing, according to the IPCC.

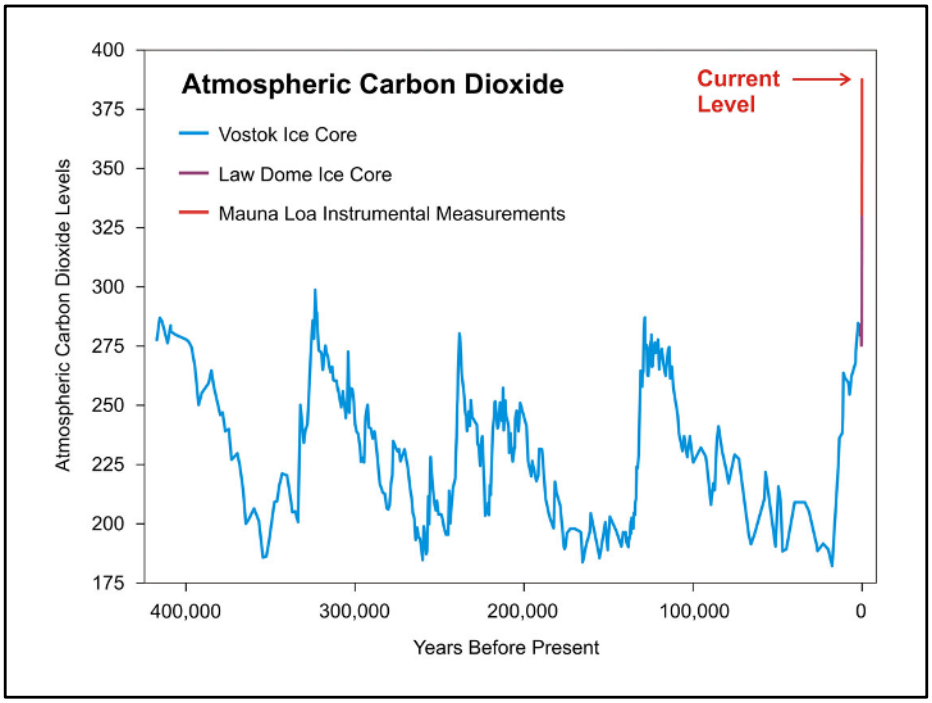


Again, I want to reiterate that I am not just telling you my opinions on climate change. I am presenting to you data from the larger scientific community about climate change.

And the term opinions should't be used here. We are looking at data. Therefore it is more about agreeing or disagreeing with data.

This graph is showing you based on polling of researchers in the climate and earth science fields how many state that humans have played a role in current global warming. Those in the earth science and climate fields-the majority agree that humans are influencing current global warming.

Remember—global warming is not the same as climate change. Global warming is that the global average temperature is increasing . Climate change includes that, but also precipitation.



Now onto the lines of evidence that climate is changing. Let's come back to CO2.

Just a reminder of the concentrations back 400,000 years—this is coming from ice core data. Current CO2 concentrations are significantly higher than over the past 400,000 years and the rate of change over the last 20,000 years is greater than over the last 400,000 years.

Evidence for Anthropogenic rise in CO_2

- Increase in CO_2 mirrors exponential rise in burning fossil fuels
- During the previous 420,000 years, CO_2 concentration never rose above 300 ppm
  - Current levels = 400 ppm
- Decrease in atmospheric $^{13}C/^{12}C$ ratio after Industrial Revolution
  - Fossil fuels enriched in ^{12}C
- Observed increase in CO_2 per year ~ half of what should be observed
  - Natural carbon reservoirs absorbing CO_2 (sink), not producing it (source)

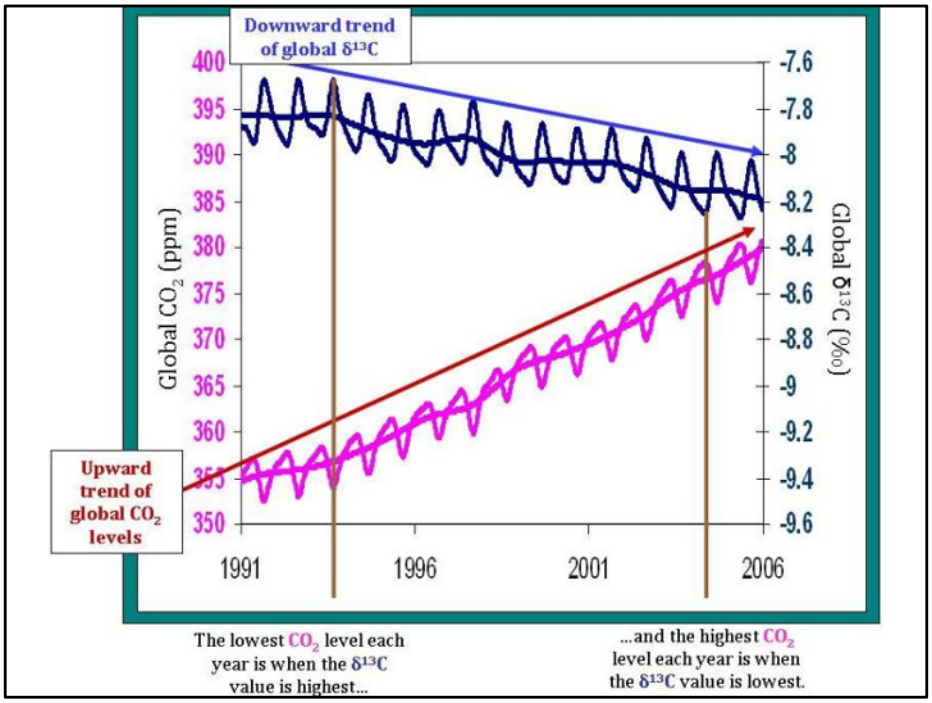
What is influencing the CO2 increase?

CO2 can come from volcanoes, it can come from respiration.

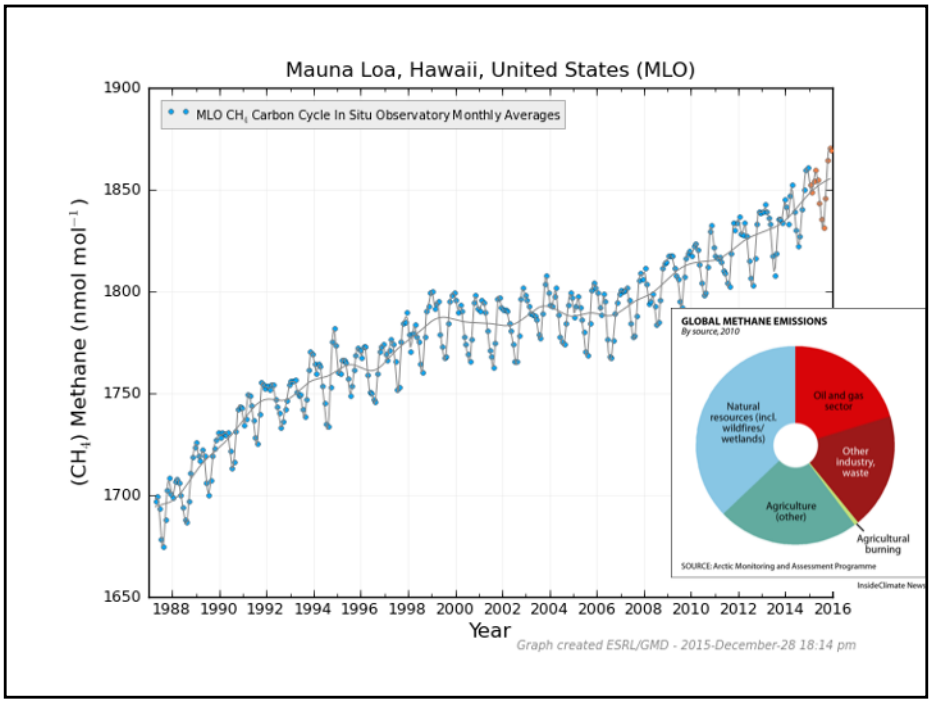
The increase since the industrial revolution mirrors the rise in burning fossil fuels.

Recall that isotopes can trace processes. Fossil fuel burning has an isotopic signature for carbon. Fossil fuels lead to the CO2 in the atmosphere being enriched in C12.

It is important to note that as CO2 is increasing in the atmosphere, there are processes consuming/using it (known as a sink).

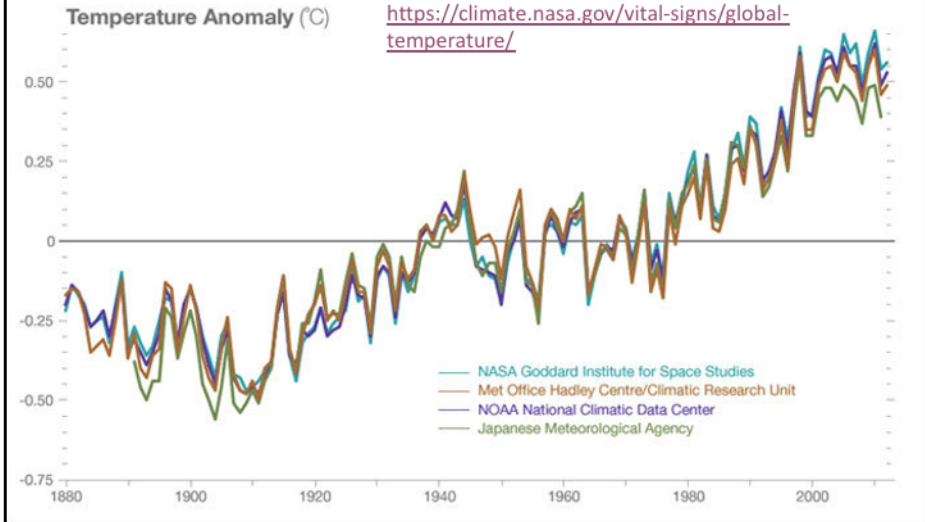


This is showing the CO2 increase (pink) since 1991 with the carbon isotopes of CO2 in blue. The isotopes of CO2 are decreasing as CO2 increasing—further evidence that CO2 in the atmosphere is coming from fossil fuels. Other sources of CO2 have positive isotopic signatures.



CO2 is not the only greenhouse gas that is increasing—methane is as well.

Methane comes from a combination of natural processes, agriculture, oil and gas and industry.



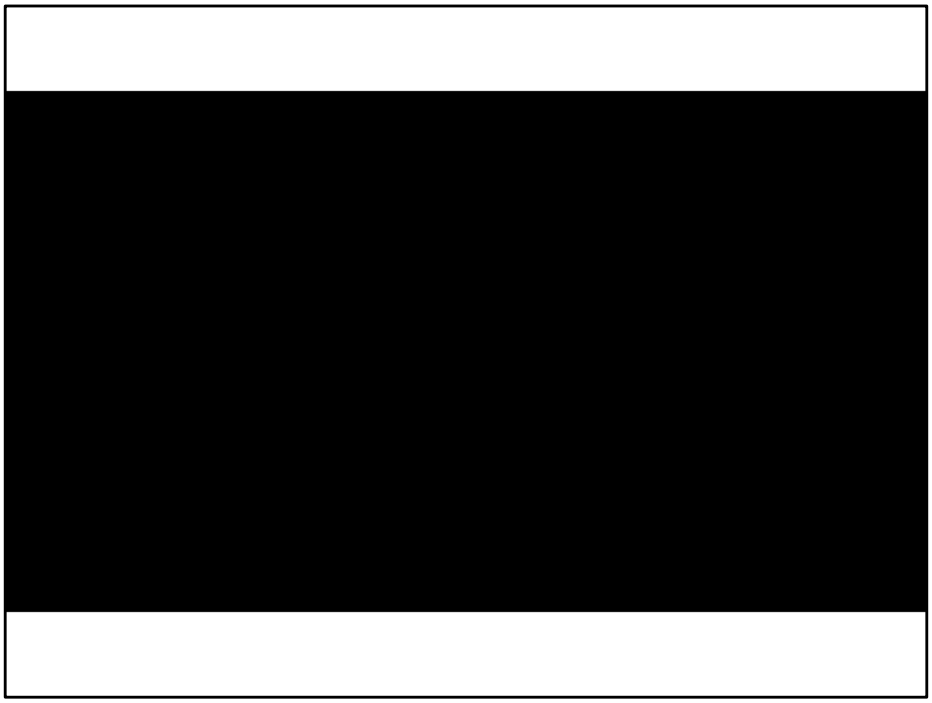
Temperature data from four international science institutions. All show rapid warming in the past few decades and that the last decade has been the warmest on record. Data sources: NASA's Goddard Institute for Space Studies, NOAA National Climatic Data Center, Met Office Hadley Centre/Climatic Research Unit and the Japanese Meteorological Agency.

As greenhouse gases increase, temperature will as well because the incoming radiation is trapped in our atmosphere.

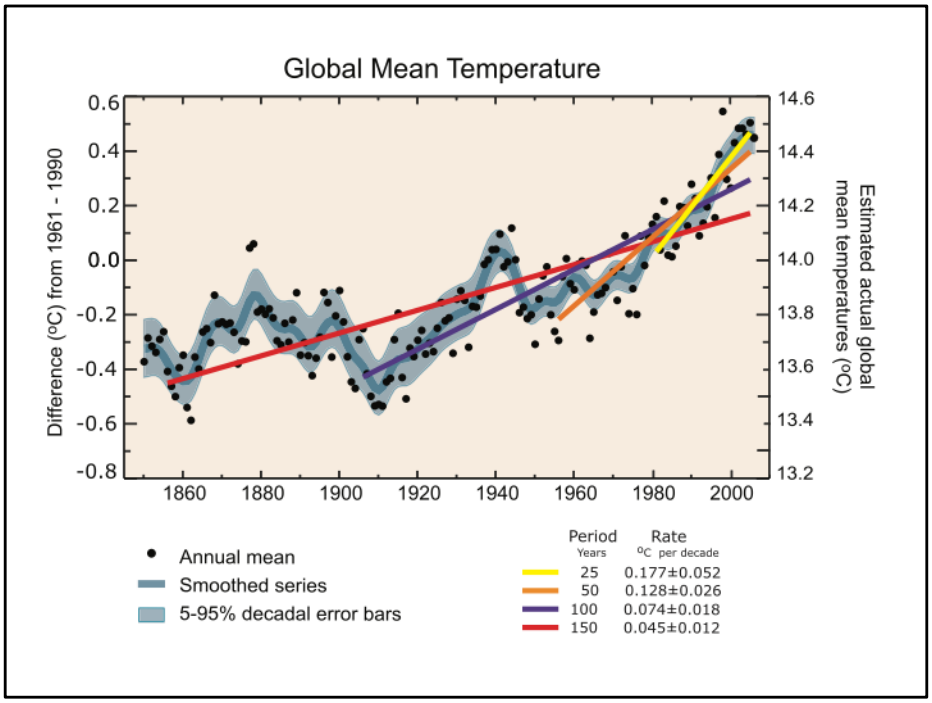
This graph illustrates the change in global surface temperature relative to 1951-1980 average temperatures.

Each line represents a temperature records from different science institutions. I like to show this to illustrate that when we are talking about global temperature change, it isn't just one person standing outside taking measurements. But these are measurements from multiple places integrated together.

While there are some variations between NASA temperature records with Japanese, overall the trends are the same.

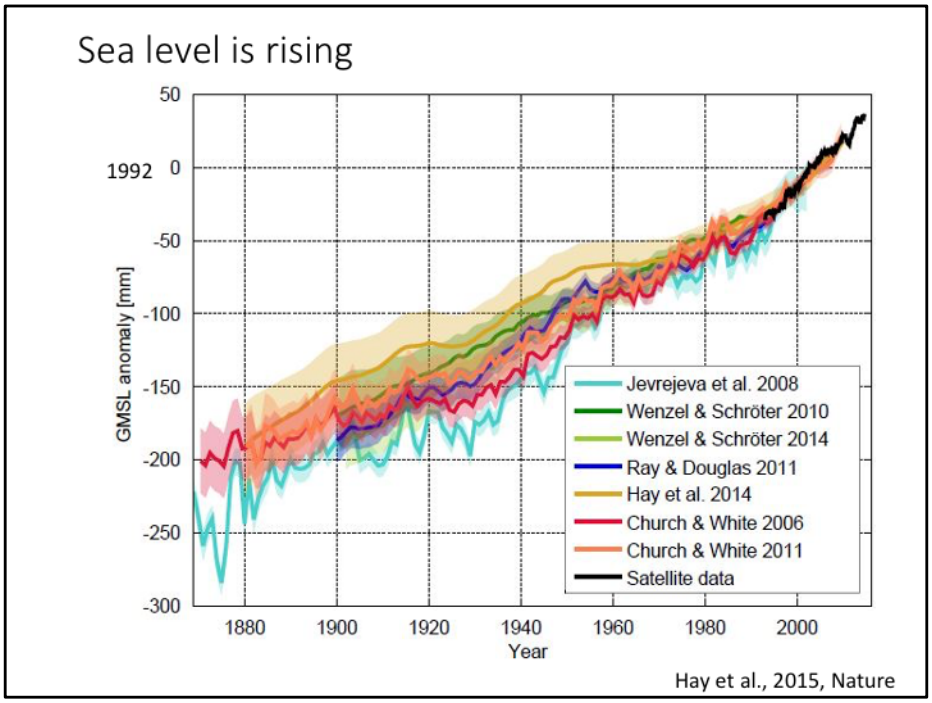


This video shows temperature anomalies (greater than or less than 1950s average) globally. Not every location is experiencing the same temperature change, but overall the temperatures are increasing throughout time.



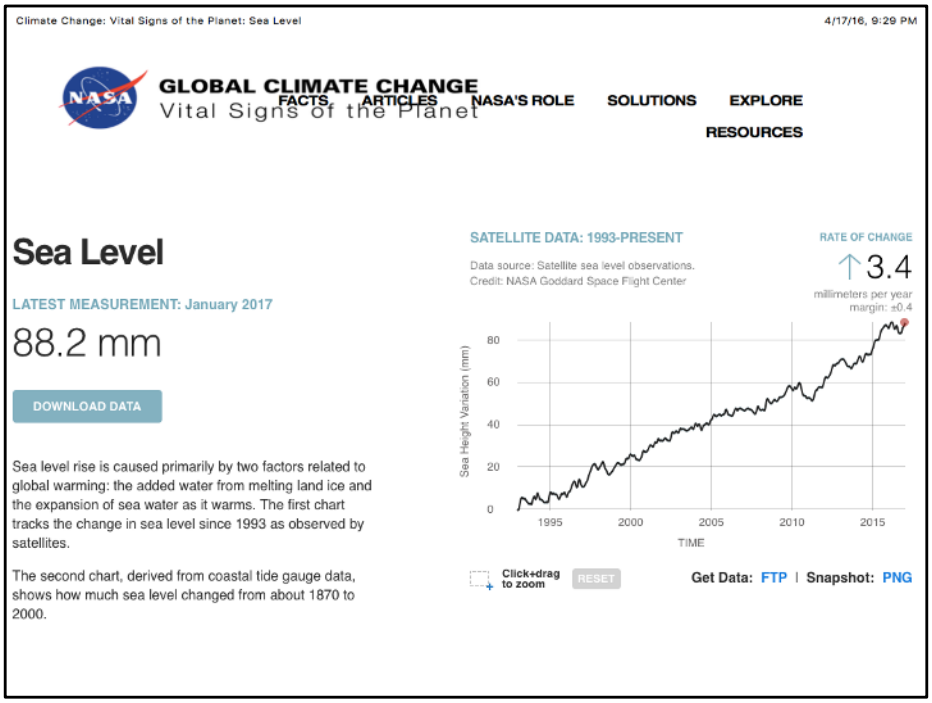
Scale matters when interpreting rate of change.

Overall the rate of change has been 0.045 C / decade for the last 150 years, but if you change the timeframe to the last 50 years it is 0.128 C/decade

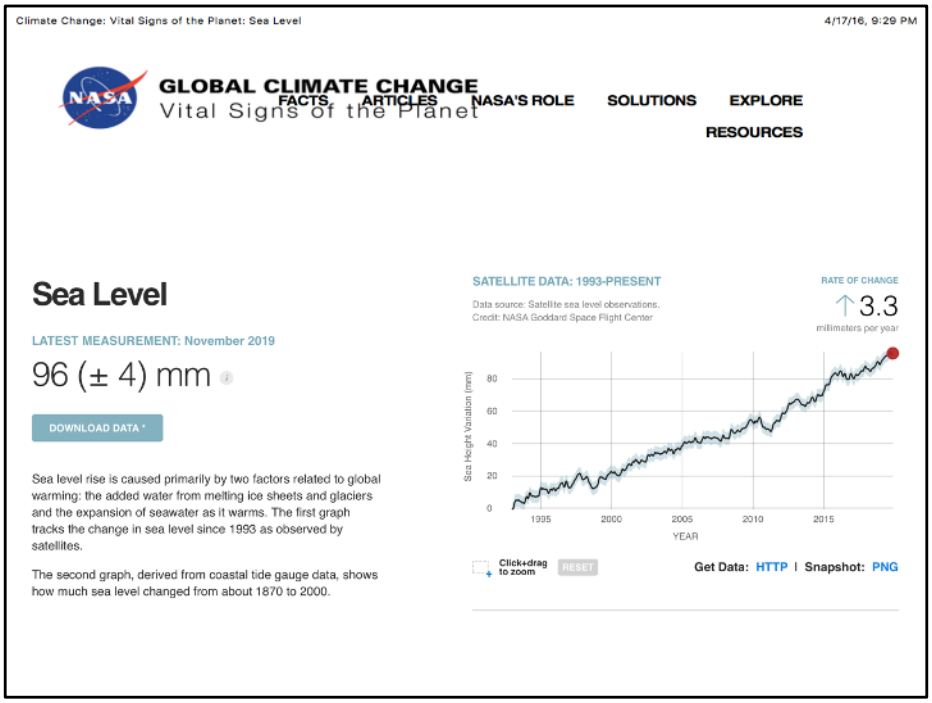


Since the late 1800s, sea level has been rising. These measurements are relative to sea level in 1992. 1992 is known as the satellite era—when sea level measurements are being taken by satellites.

Again, this is data from multiple sources compiled together. There is slight disagreement between the magnitude of change for past sea level change, but the trend is still the same.

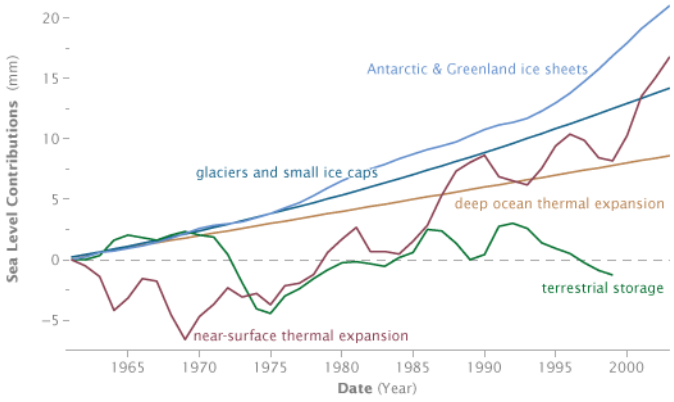


This data is from January 2017---since 1993, sea level rose 88.2 mm, at a rate of 3.4 mm/year



Two years later, the most recent sea level rise data show total rise since 1993 as 96 mm, and the rate being the same as previously.

The two major causes of global sea level rise
*Loss of **land-based** ice due to increased melting.*
Thermal expansion of the oceans (water expands as it warms)



NASA

Sea level rise is because of multiple factors.

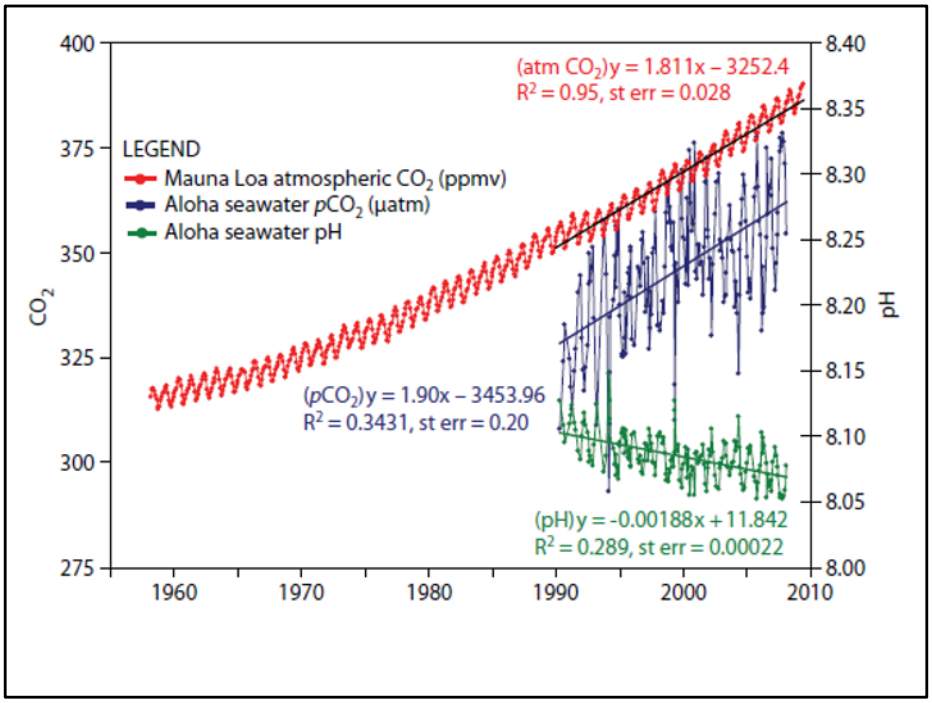
This graph shows sea level contributions over time.

Mostly ice sheets melting lead to sea level rise.

Melting of small land ice also leads to sea level rise

As does thermal expansion. As water warms, it expands, contributing to rise.

Why is sea ice not on here? Sea ice is already part of the volume of the ocean, so if it melts it doesn't contribute to sea level rise. However, sea ice melting would lead to albedo changes.



Not only is sea level rising, but there is a change to the pH of the ocean water due to increase in CO2.

As CO2 in the atmosphere increases, the pCO2 in water also increases due to exchange of water with the atmosphere

As CO2 in the water increases, the pH of water decreases. I'll go through this more on the next slide.

- CO_2 dissolves in water to form carbonic acid. In the oceans, carbonic acid releases hydrogen ions (H+), reducing pH, and bicarbonate ions (HCO3-).

$$CO_2 + H_2O \Rightarrow H^+ + HCO_3^-$$

- The additional hydrogen ions released by carbonic acid bind to carbonate ions (CO_3^{2-}), forming additional HCO_3^-.

$$H^+ + CO_3^{2-} \Rightarrow HCO_3^-$$

- This reduces the concentration of CO_3^{2-}, making it harder for marine creatures to take up CO_3^{2-} to form the calcium carbonate needed to build their exoskeletons.

$$Ca^{2+} + CO_3^{2-} \Rightarrow CaCO_3$$

- The two main forms of calcium carbonate used by marine creatures are calcite and aragonite. Decreasing the amount of carbonate ions in the water makes conditions more difficult for both calcite users (phytoplankton, foraminifera and coccolithophore algae), and aragonite users (corals, shellfish, pteropods and heteropods).

Remember that pH = -log [H+]

As H+ increases, pH decreases.

Is the Amount of Snow and Ice on the Earth Decreasing?

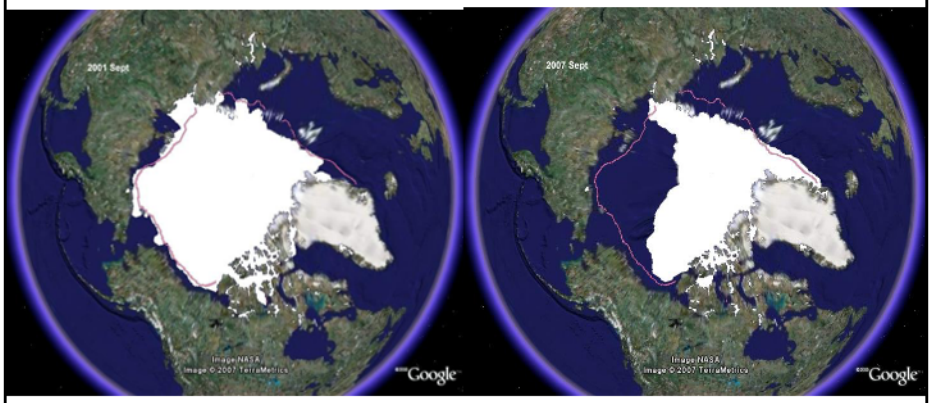
- Yes.
- Sea ice is shrinking, especially in summer.
- Coastal ice sheets [Greenland, Antarctica] are thinning and contributing to sea level rise
- Permafrost is thawing.
- Snow and Mountain glaciers are retreating.

Sea level rise is directly linked to loss of ice

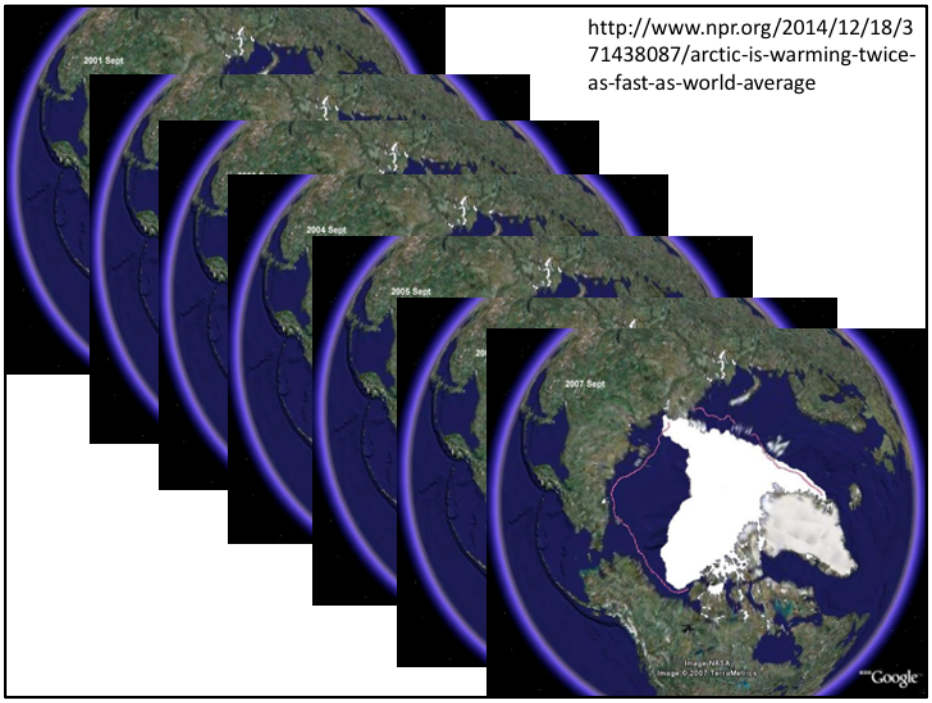
Sea ice melting doesn't influence sea level rise as it is already part of the volume.

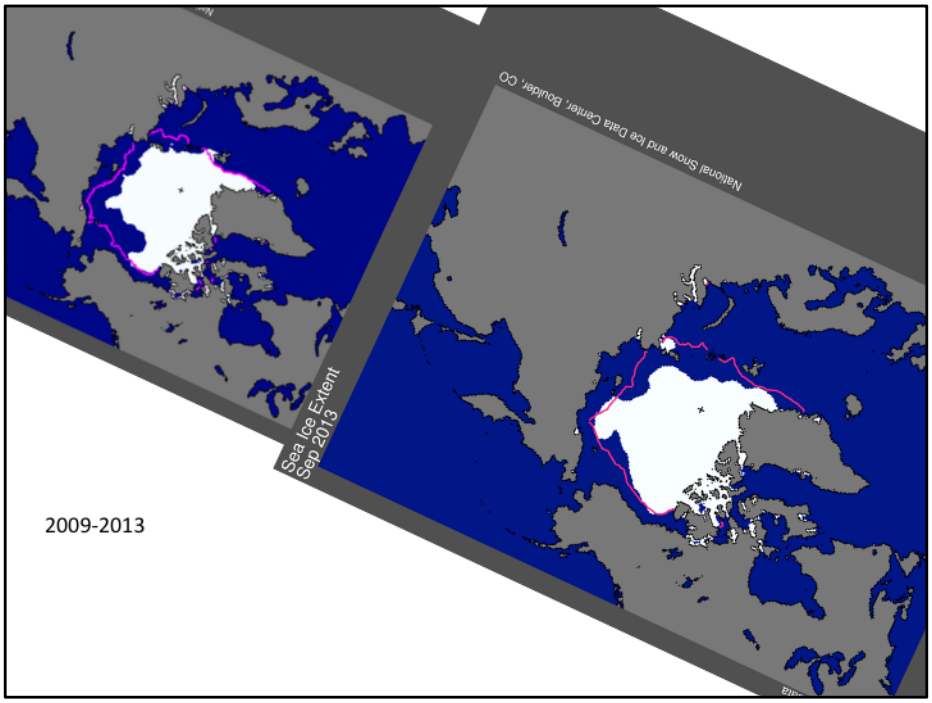
But as land ice melts, the water makes its way to the ocean.

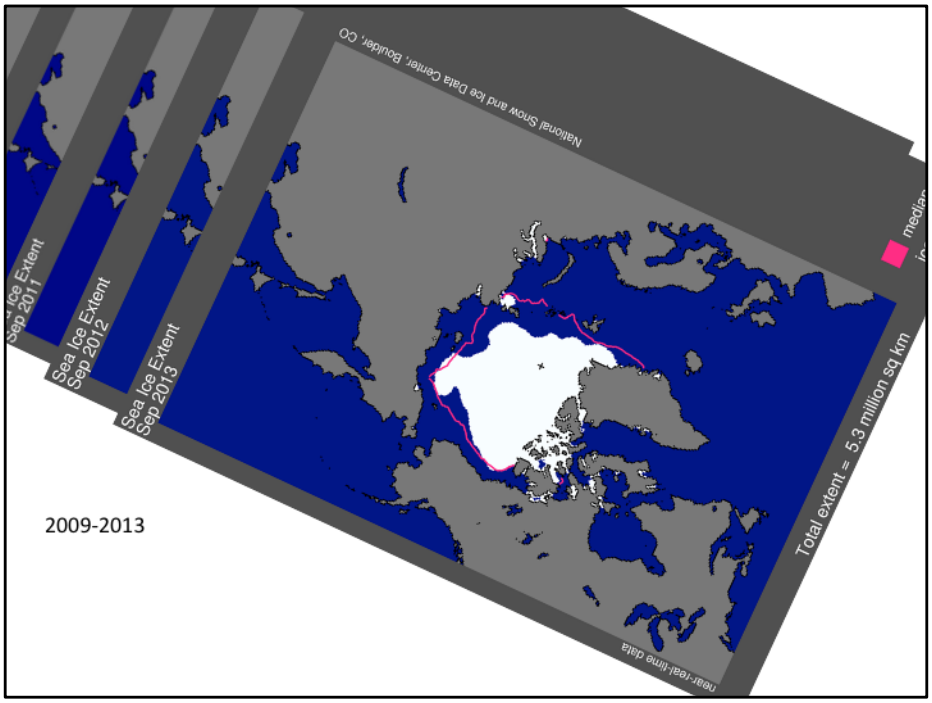
http://www.npr.org/2014/12/18/371438087/arctic-is-warming-twice-as-fast-as-world-average

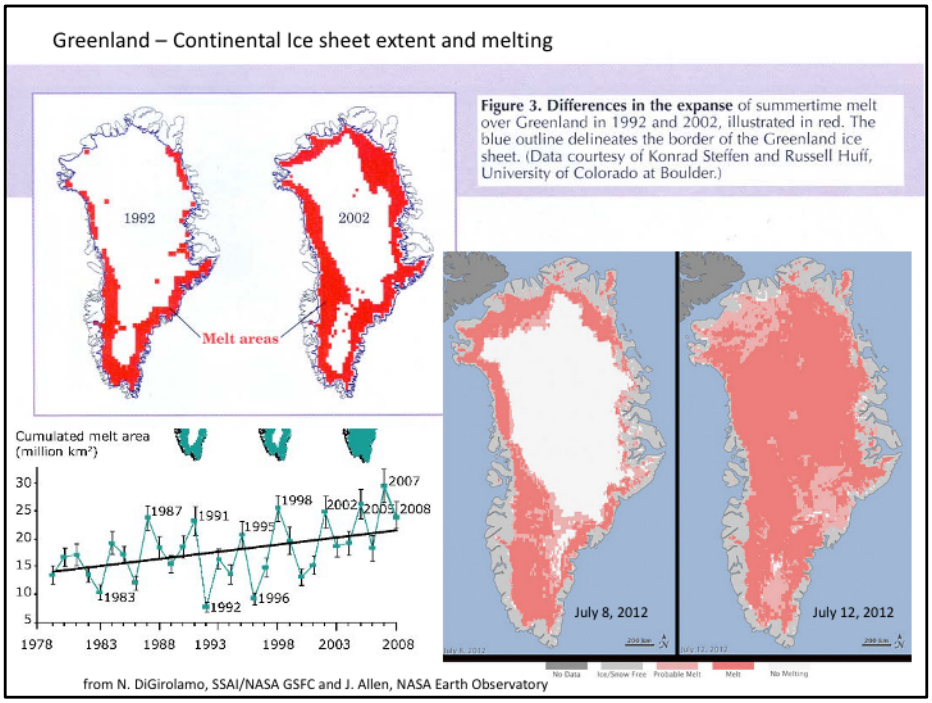


2001 vs. 2007 sea ice melt


http://www.npr.org/2014/12/18/371438087/arctic-is-warming-twice-as-fast-as-world-average
2001 Sept
2004 Sept
2005 Sept
2007 Sept
Google

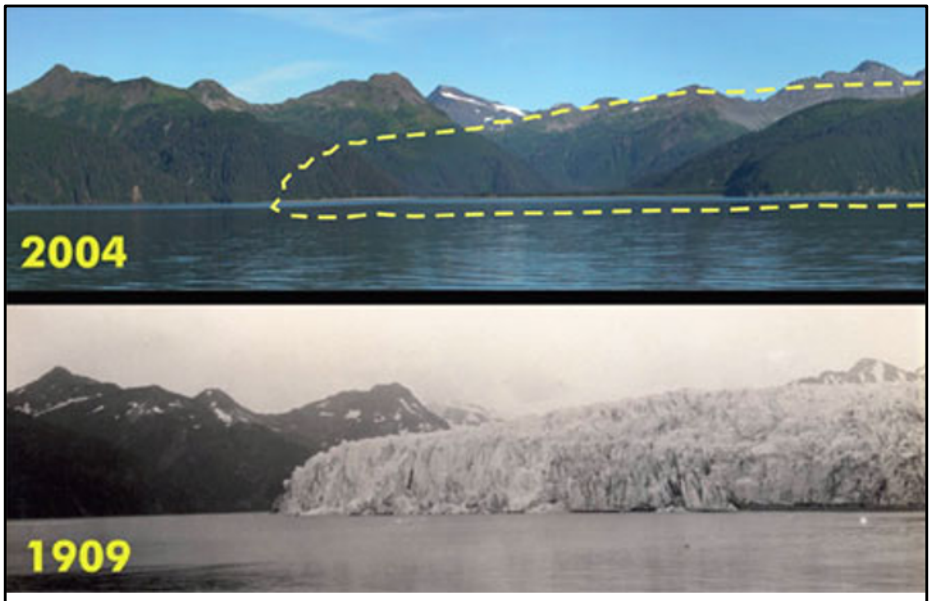

National Snow and Ice Data Center, Boulder, CO
Sea Ice Extent
Sep 2013
2009-2013


National Snow and Ice Data Center, Boulder, CO
Sea Ice Extent
Sep 2013
Sea Ice Extent
Sep 2012
Total extent = 5.3 million sq km
near-real-time data
2009-2013



Looked at this before---added in one other figure-cumulated melt area over time.

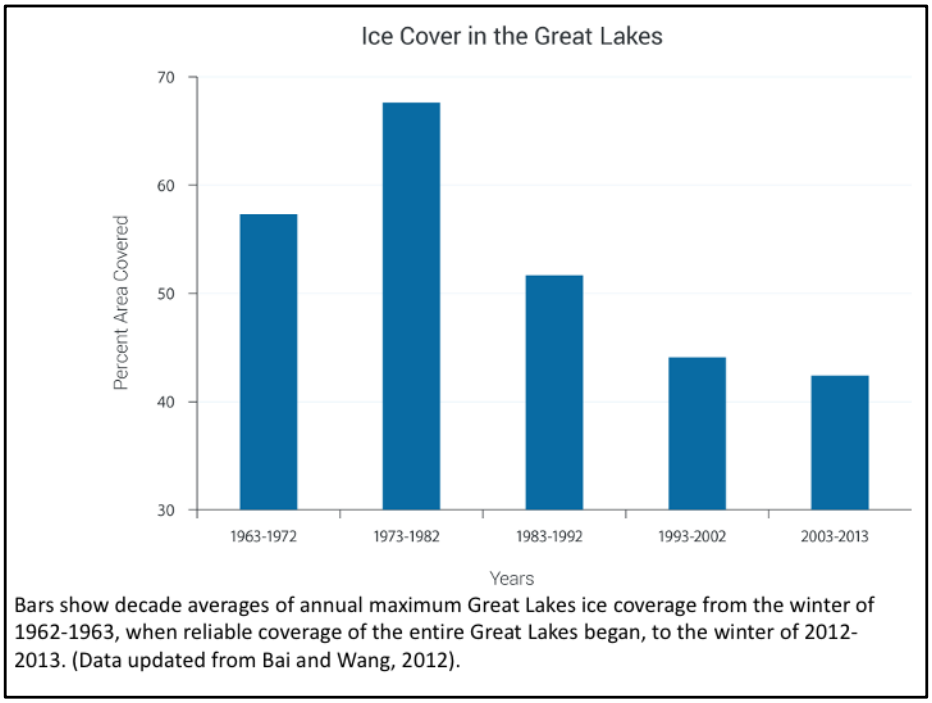
bottom from N. DiGirolamo, SSAI/NASA GSFC and J. Allen, NASA Earth Observatory
graph from European Environmental Agency



McCarty Glacier in Alaska. Evidence of global warming

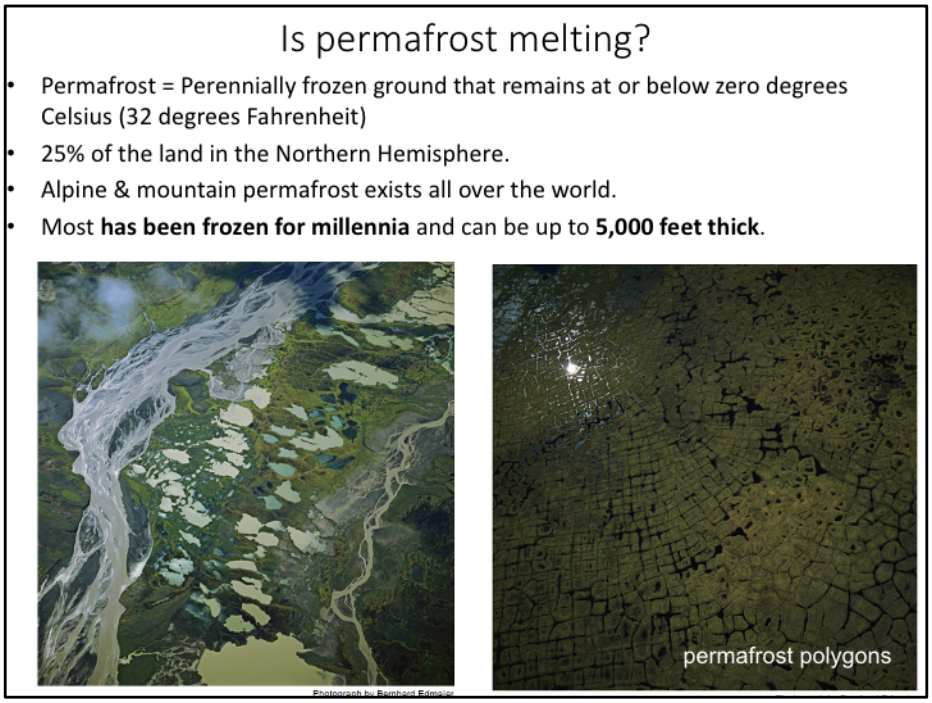
USGS photo library, Robert A. Rohde, and Global Warming Art (www.globalwarmingart.com).

Glaciers are retreating



Bars show decade averages of annual maximum Great Lakes ice coverage from the winter of 1962-1963, when reliable coverage of the entire Great Lakes began, to the winter of 2012-2013. (Data updated from Bai and Wang, 2012).

Ice cover on lakes is also decreasing.



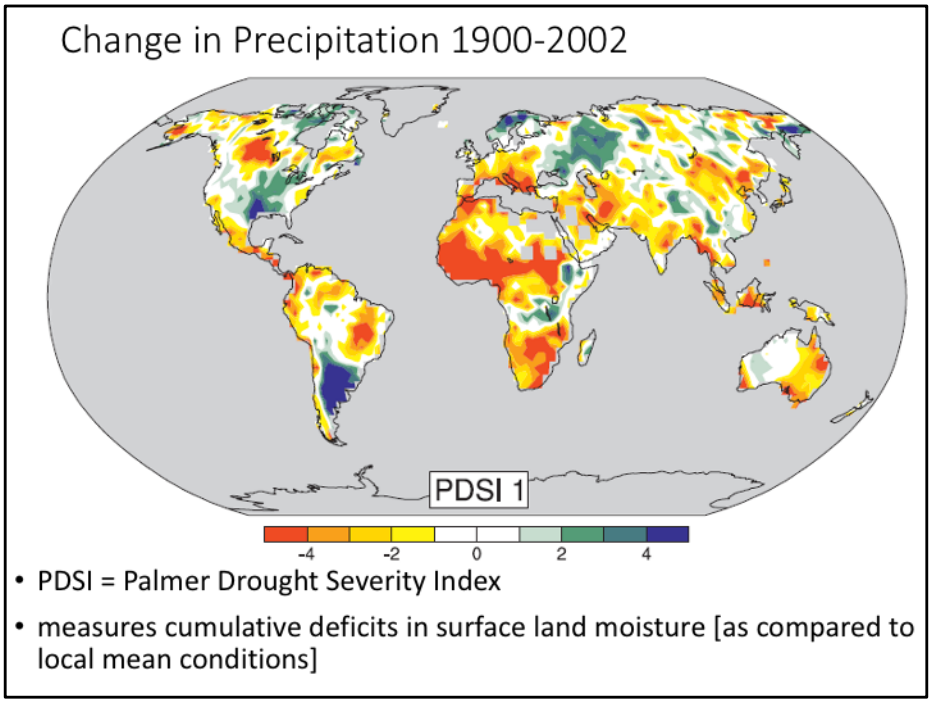
Permafrost is also thawing (or melting)

left: Permafrost terrain encompasses vast reaches of the Northern Hemisphere. In Iceland's central highlands, braids of summer meltwater flow from a nearby glacier and flank a cluster of ragged ponds. Perched on impermeable ground, the shallow pools spread, likely shaped by prevailing winds.
right:
Ice wedges penetrate deep into frozen soil, chiseling tundra into room-size polygons—a signature texture of permafrost landscapes. Climate change may be marking the Canadian Arctic, too, as meltwater erodes the edges of some polygons and deepens pools in their centers.

Why is thawing permafrost a problem?

- = a carbon reservoir
- holds plant and animal material that would be decomposed by microbes at warmer temps
  - this would release CO_2 and CH_4
  - CH_4 is 20x more powerful greenhouse gas than CO_2
- The amount of CH_4 held in permafrost is HUGE but often not accounted for in climate models
  - 500-1000 billion metric tons estimated
  - atmosphere currently holds 800 billion metric tons
  - 75X the annual GLOBAL fossil fuel emissions.

Positive feedback cycle—increasing temperatures lead to thawing permafrost. Thawing permafrost increases greenhouse gas concentrations. Increasing greenhouse gas concentrations leads to warmer temperatures. Warmer temperatures leads to more thawing permafrost.

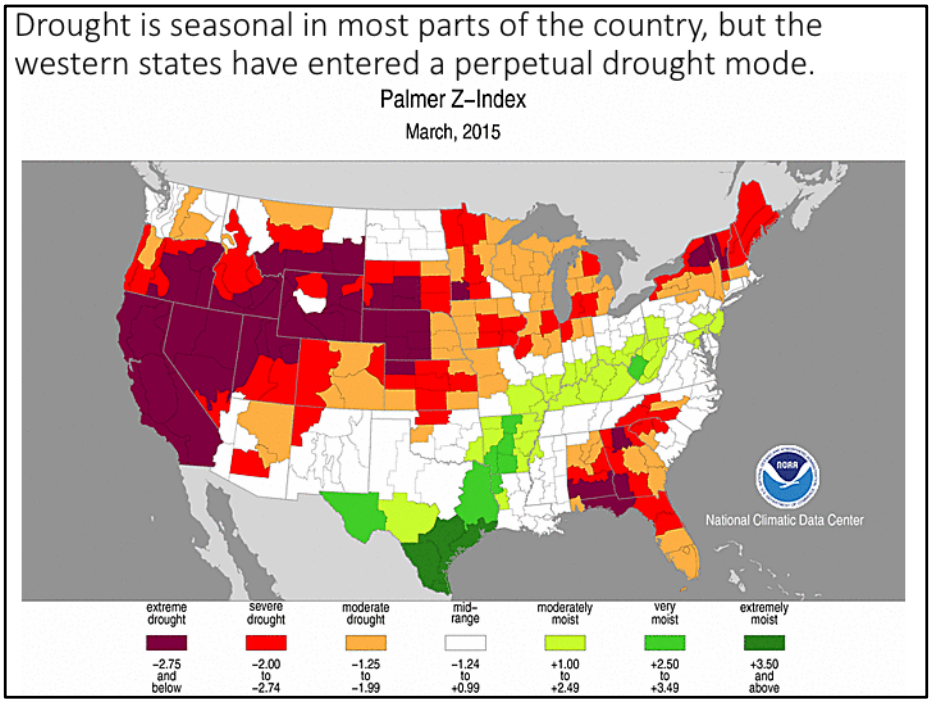


Precipitation is also a part of climate change. This image is showing you the palmer drought severity index.

moisture deficits in red (i.e. dry and droughts) , moisture surplus in blue (i.e. wetter than usual).

Not all locations are experiencing droughts. Not all locations are experiencing wetter than usual conditions.

Drought is seasonal in most parts of the country, but the western states have entered a perpetual drought mode.



Zoom into the US.

THE WALL STREET JOURNAL.

BLACK FRIDAY SALE

U.S.

Forest Fires Spread by Drought Strike Southern Appalachians

Dozens of wildfires threaten homes and tax firefighters as they evacuate people from the region

Climate | Nov. 15, 2016 09:39AM EST

Record-Breaking Drought and Wildfires Plaque Southeast

The Washington Post

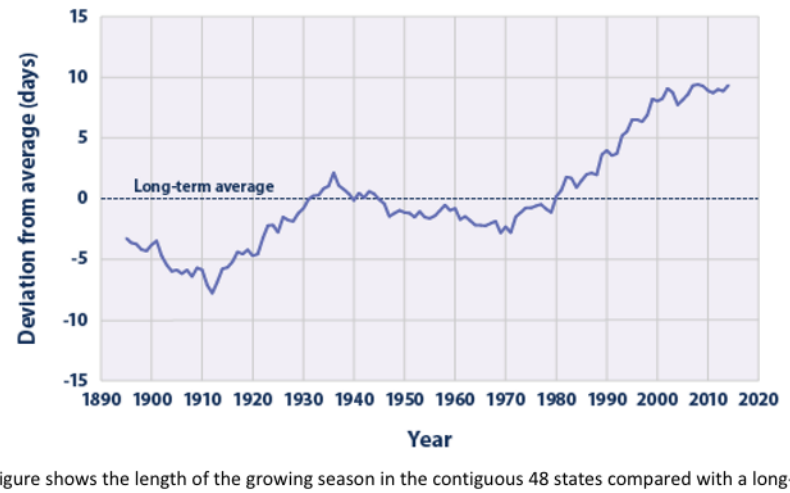
2017 MOTOR TREND CAR OF THE YEAR.

Health & Science

A giant reservoir that supplies a California county's drinking water is nearly empty

Drought has lots of implications for wildfires and drinking water supplies.

Figure 1. Length of Growing Season in the Contiguous 48 States, 1895–2014

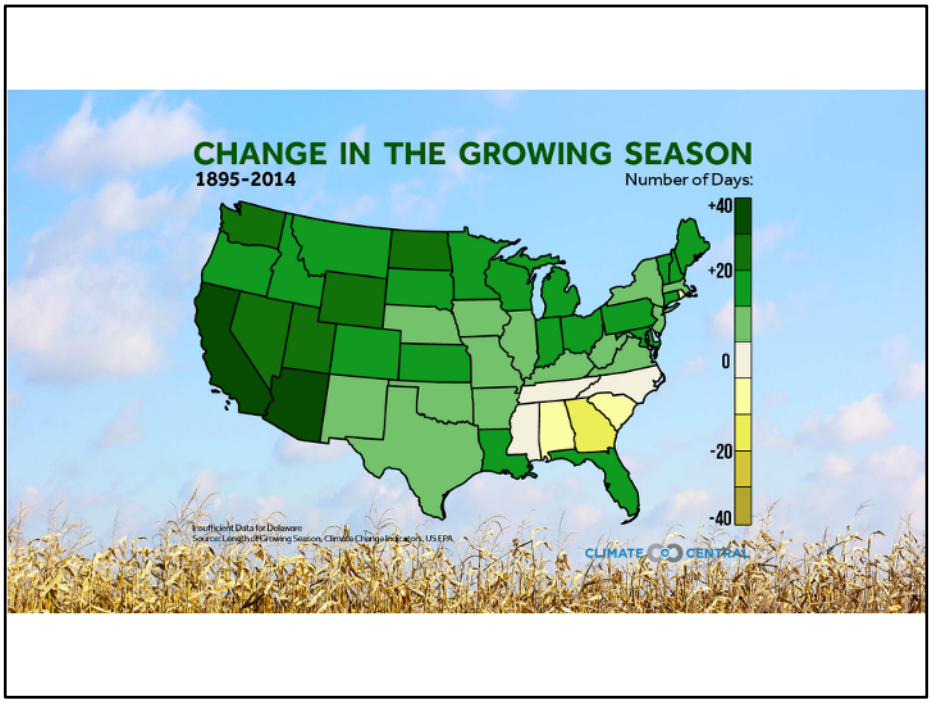


This figure shows the length of the growing season in the contiguous 48 states compared with a long-term average. For each year, the line represents the number of days shorter or longer than average. The line was smoothed using an 11-year moving average. Choosing a different long-term average for comparison would not change the shape of the data over time.

Data source: Kunkel, 2015[2]

Here you are looking at growing season length relative to average in 1940. Since the 1980s, growing season has been increasing.

Note that in our discussion of evidence for climate change I have been trying not to discuss consequences and not labeling things as “good” and “bad”. We are just looking at the data to see if climate change is occurring. A lot of times climate change is then discussed as being “bad” because there are a lot of negative consequences (sea level rise influencing coastal communities, etc.), but a longer growing season can be a positive thing! (except however if there is also a drought).



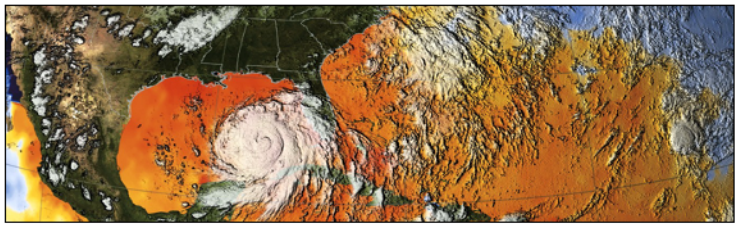
Not all states are experiencing a longer growing seasons. Most are, with the exception of the southeast. Remember-averages mean that not every place experiences the same.

Hurricanes and climate change

Trends in storm activity may reflect climate change.

TOP YEARS FOR TROPICAL STORMS AND HURRICANES

year	# named storms
1. 2005	28
2. 1933	20
3. 2012/2011/2012/1995/1887	19
4. 1969	18
5. 2008/2003/1936	16
6. 2007/2004/2001/2000	15



Extreme weather conditions are often discussed in conjunction with climate change. However, remember that weather is not the same as climate change. To discuss if weather is related to climate change would need to look at either increase/decrease of events or change in magnitude.

For hurricanes, storm activity MAY reflect climate change, but only if you look at long term data.

warmer oceans = more evap = more moisture in the atmosphere = wetter weather and stronger storms

Hurricanes and Climate Change

- Does this reflect Climate Change?
  - If oceans are getting warmer, more energy for hurricanes
  - But also may increase shearing winds that break up storms

- Study published Sept. 4, 2008 (Nature):
  - Studied intensity strongest storms since 1981
  - No increase in overall number [except for specific years]
  - Clear increase in strong storms (categories 4 and 5)