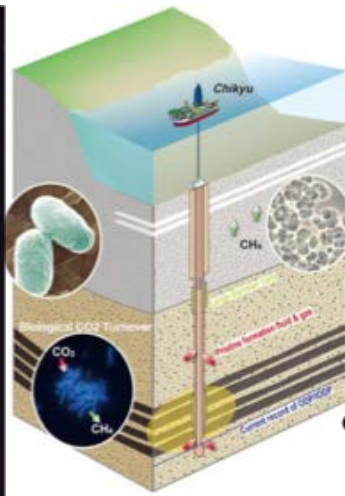
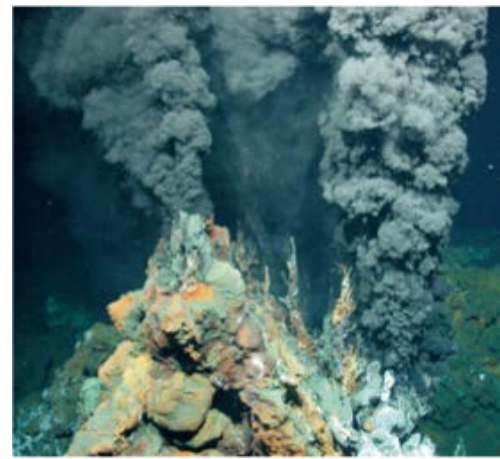
An aerial photograph of a dry, cracked landscape, likely a salt flat or a dried-up lake bed. The ground is covered in a complex network of dark, irregular cracks that form a mosaic-like pattern. The overall color palette is dominated by shades of blue, from light cyan to deep navy, which is applied as a color overlay to the original photograph. The text is overlaid on the left side of the image.

Climate Science 101: Warmer Things

Meghana Ranganathan and Ellen Lalk



Research: methane production by microbes kilometers below the ocean floor



Introductions: Ellen Lalk

1st year PhD student in Chemical Oceanography



Rémi Bigonneau

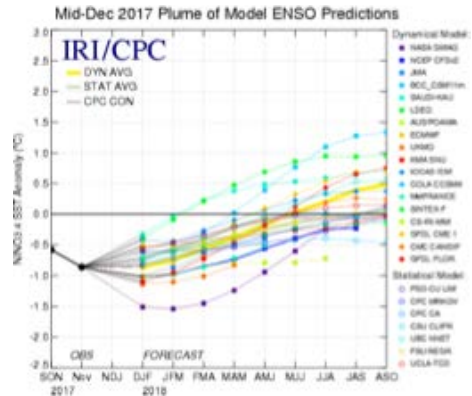
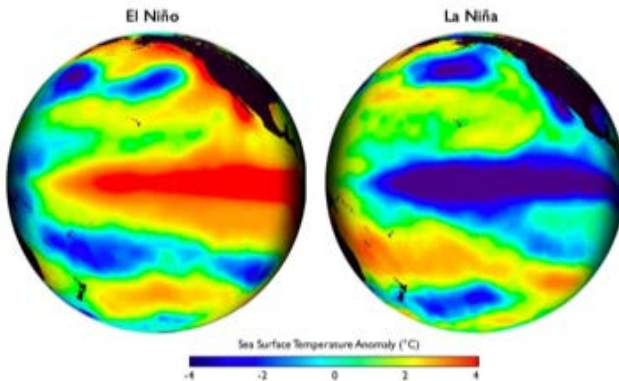
Penguin enthusiast



Previously studied Chemistry and Archaeology at WUSTL



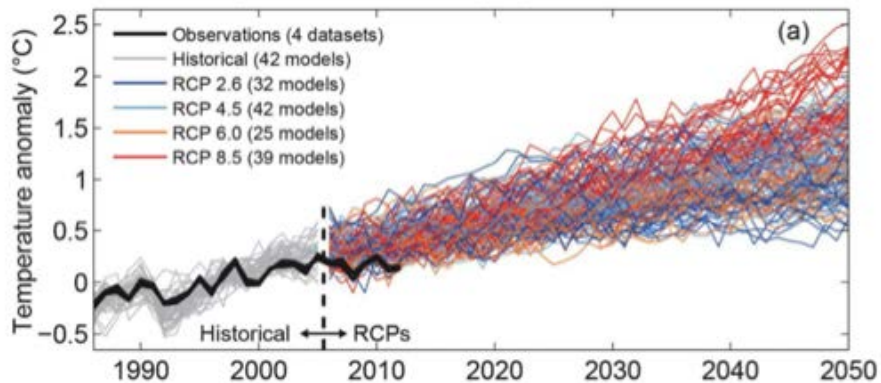
Past Research: evaluating ENSO forecasts at Columbia/IRI



Introductions: Meghana Ranganathan



Global mean temperature near-term projections relative to 1986–2005



1st Year PhD Student in Atmospheric Science

Current research: using neural networks and machine learning to quantify climate uncertainty

Images:

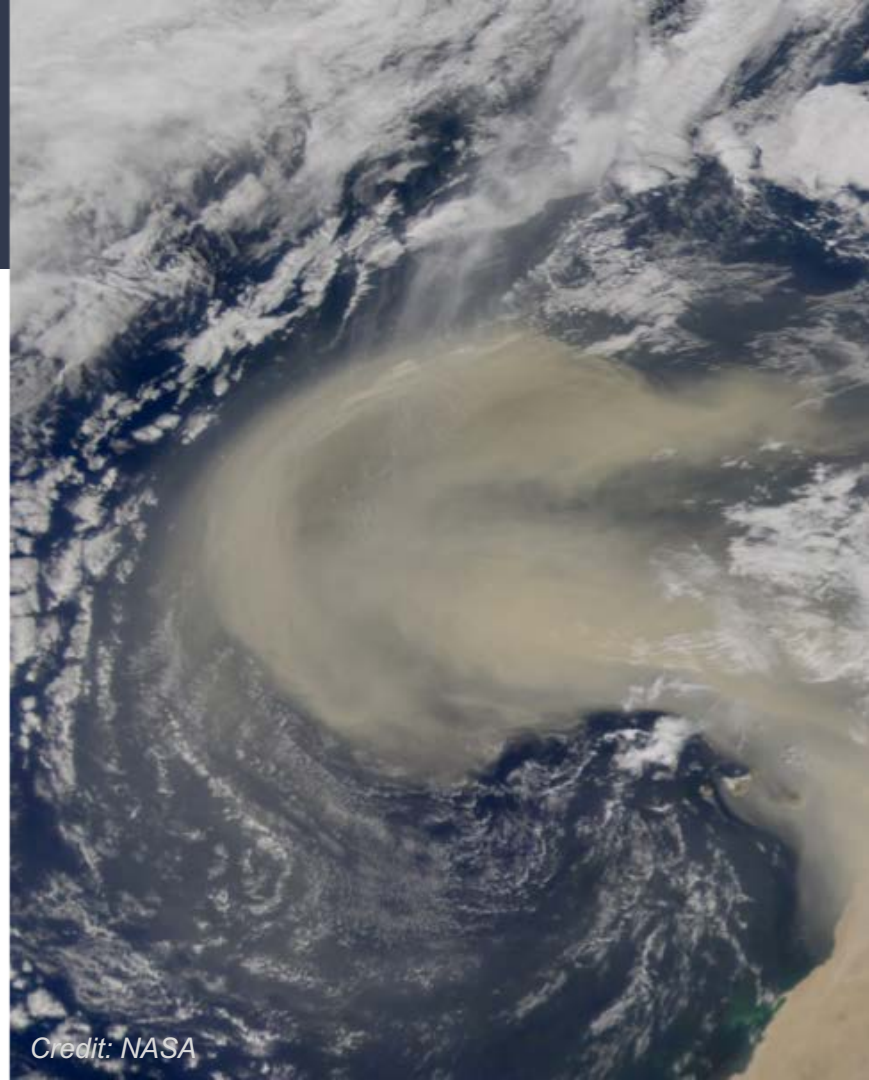
- http://insideclimatenews.org/sites/default/files/styles/cn_full_wrap_wide/public/Climate%20chart_0.png?itok=GqFt5ALQ
- <https://iri.columbia.edu/wp-content/uploads/2017/12/figure4-1.gif>
- <https://blog.wdtinc.com/hubfs/blog-files/el-nino-vs-lanina-noaa.jpg?t=1513787240214>

Topic Overview

1. What is “climate”
2. What Affects Earth’s Temperature
3. A Look Into Past Climate
4. Environmental Changes from Climate Change

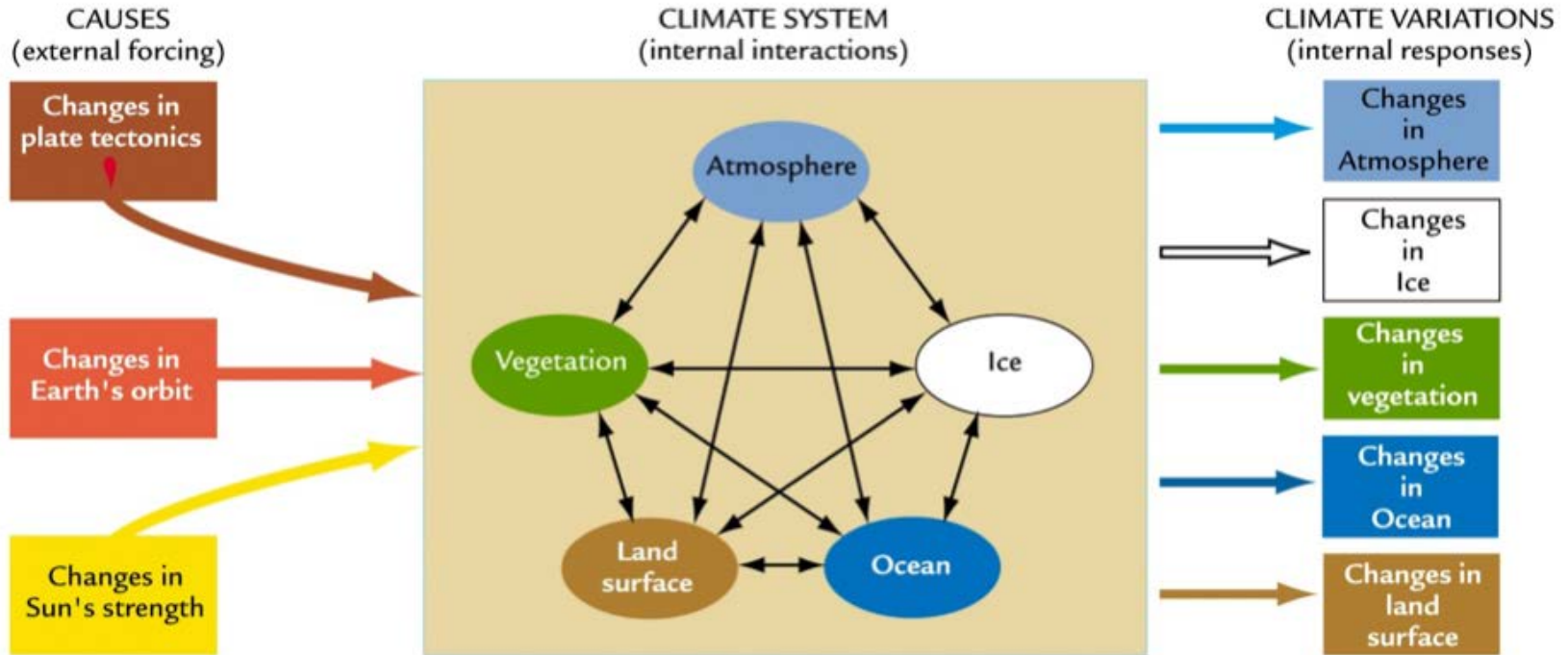
Definitions

1. **Weather:** Things like precipitation, wind, and humidity that we experience at a given time in a specific location
2. **Climate:** average weather over a long period of time for a given region; the statistics of weather
3. **Climate Variability:** natural variation in climate that occurs over months or decades
4. **Climate Change:** a systematic change in long term state over multiple decades

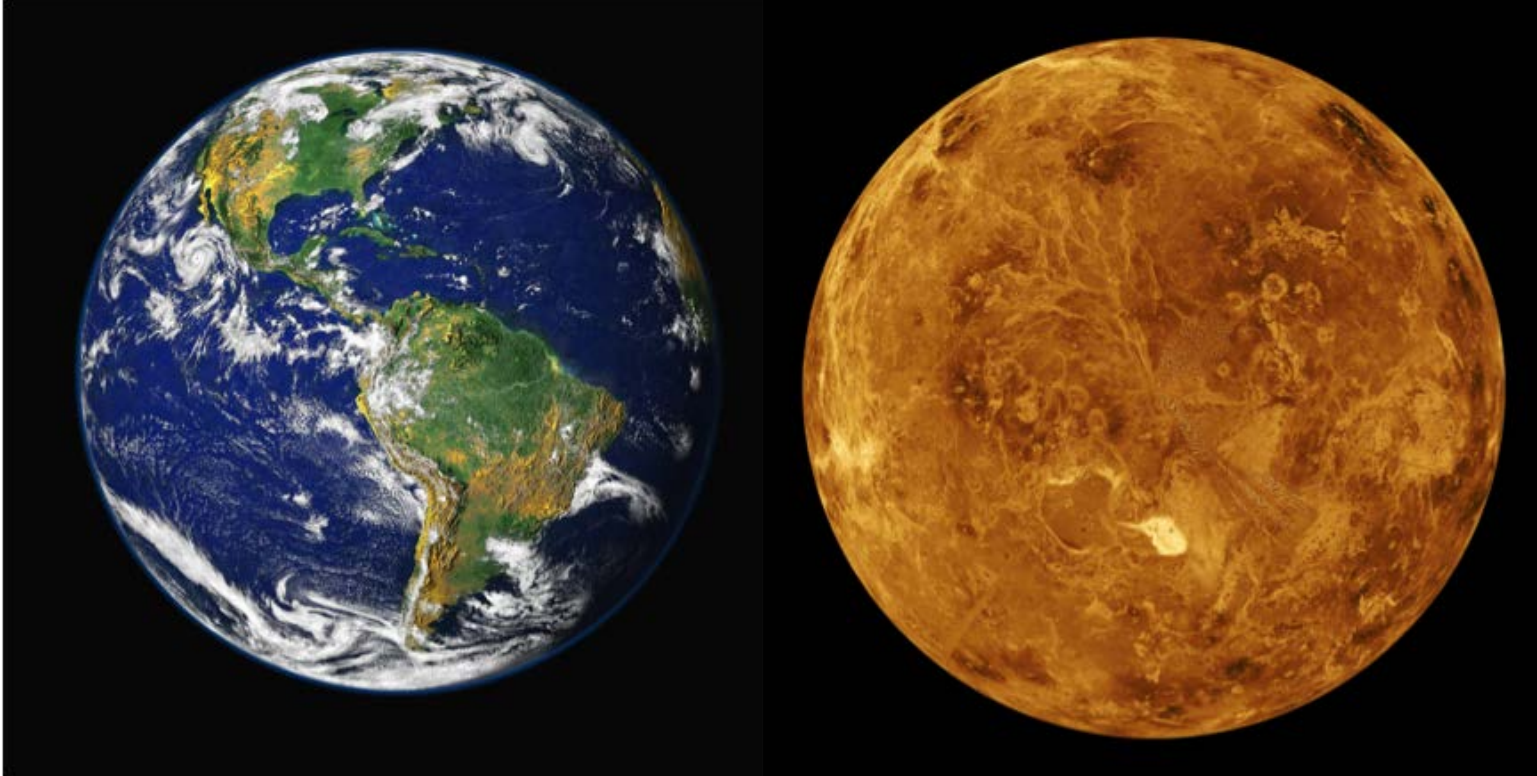


Credit: NASA

The Climate System: Overview

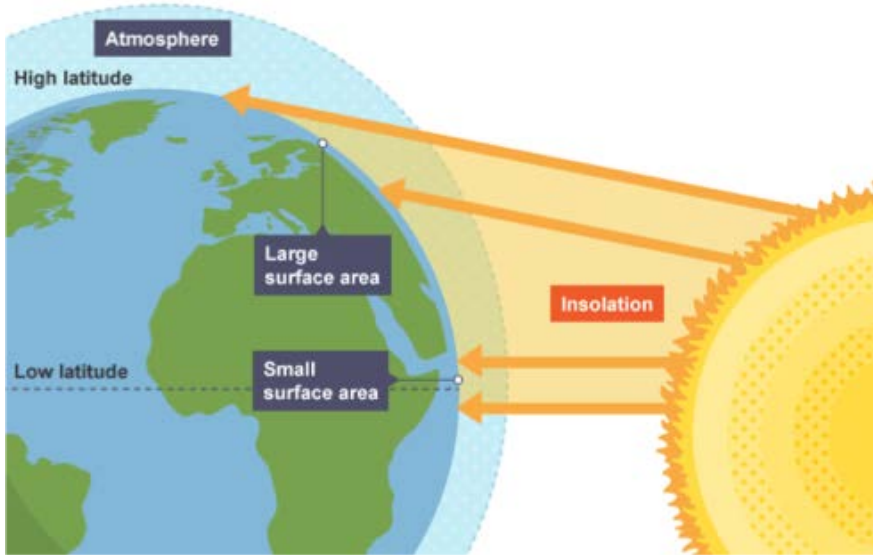


Sun: What Factors Affect Earth's Temperature?

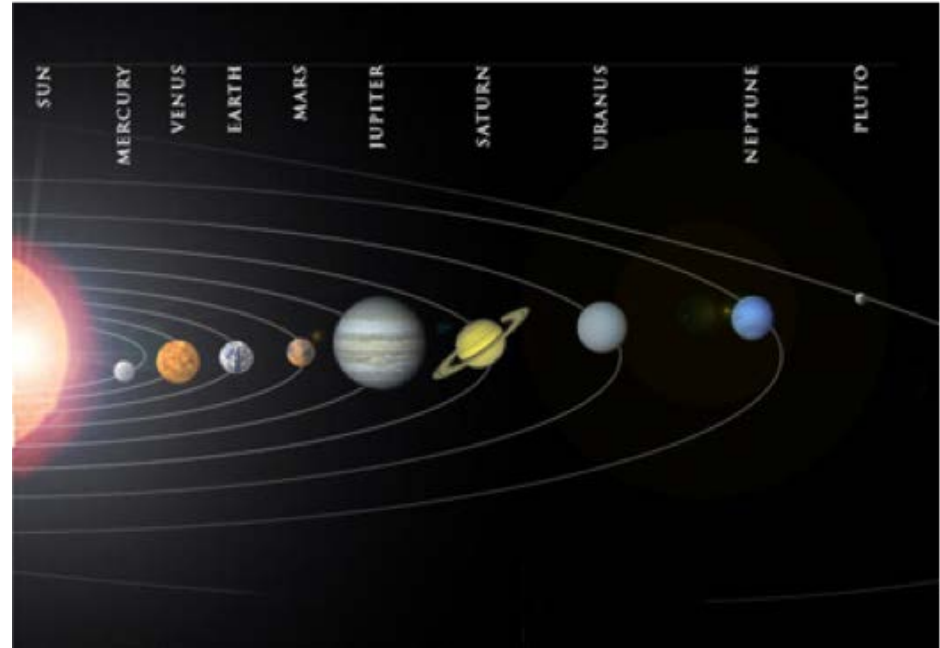


Images:
<https://static.pexels.com/photos/2422/sky-earth-galaxy-universe.jpg>
<https://www.nasa.gov/sites/default/files/thumbnails/image/pia00271.jpg>

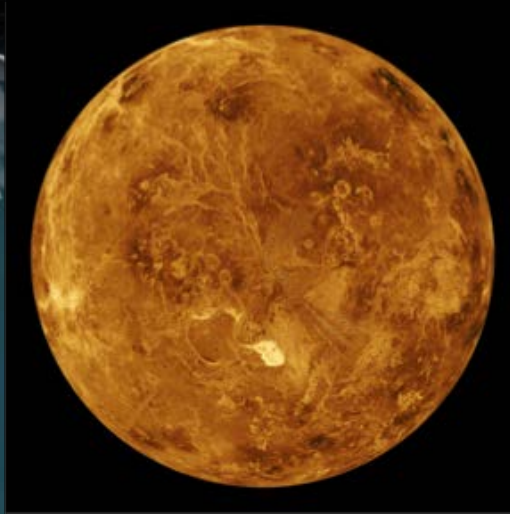
Factor 1: Insolation



$$\text{Flux} = \frac{\text{Energy}}{\text{Time} \times \text{Area}}$$



Factor 2: Albedo



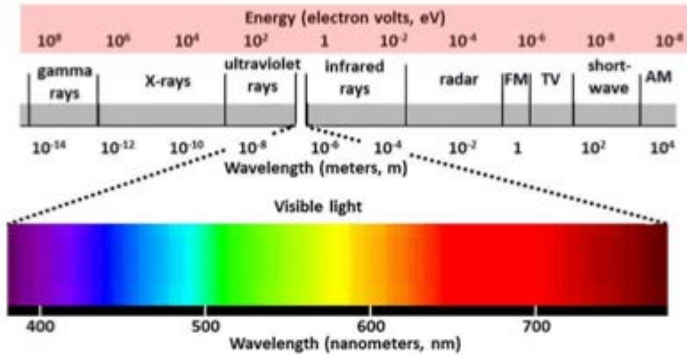
Grass: $\alpha = 0.20$
Antarctica: $\alpha = 0.81$
Clouds: $\alpha = 0.80 - 0.85$
Earth: $\alpha = 0.30$
Venus: $\alpha = 0.80$

Albedo is α , where $0 < \alpha < 1$

Factor 3: Atmosphere

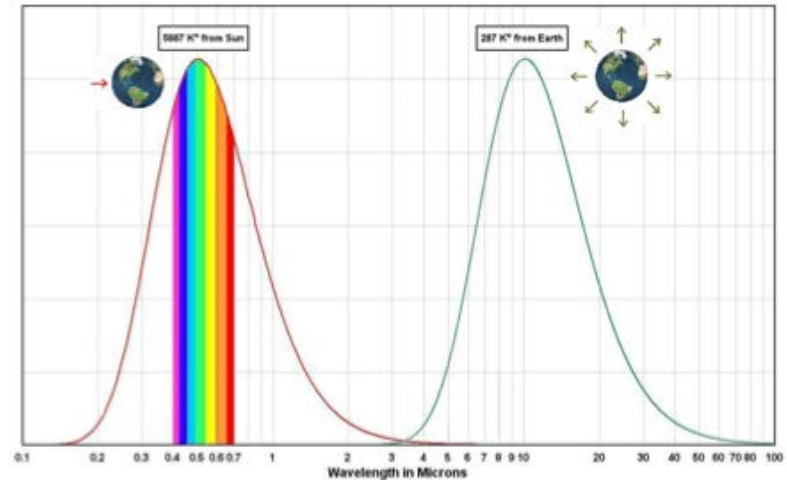
A **black body** absorbs all incoming radiation

$$F = \sigma T^4$$

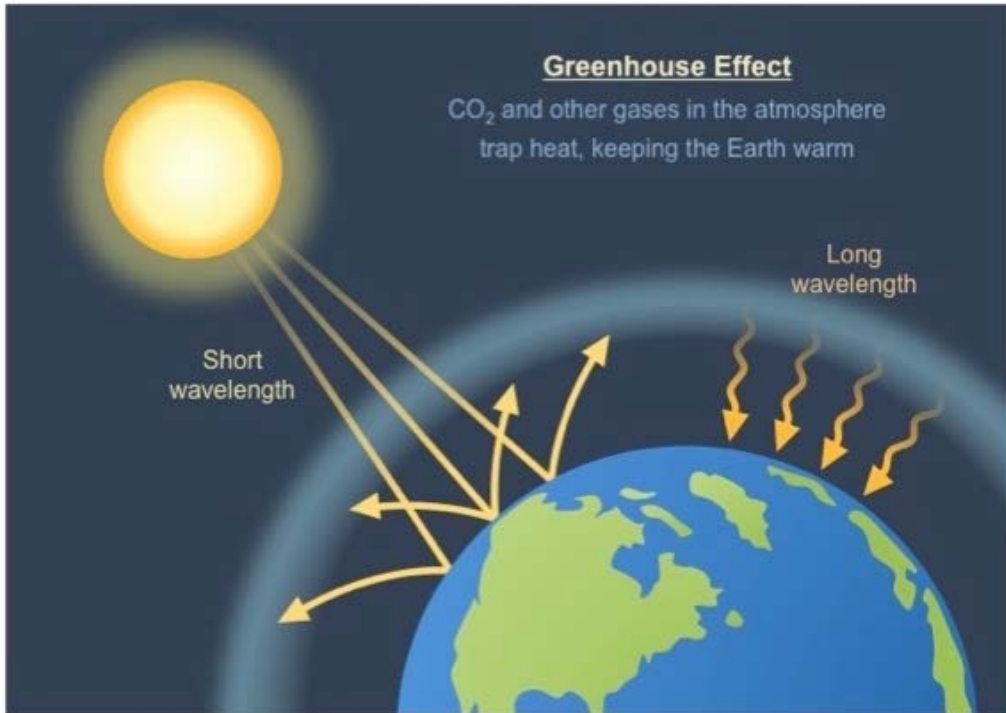


TRUE black bodies don't exist - instead they have albedo:

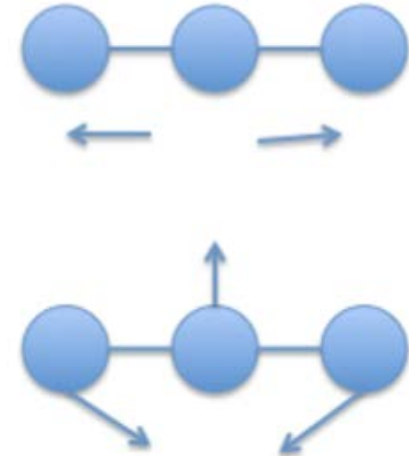
$$F = (1 - \alpha)\sigma T^4$$



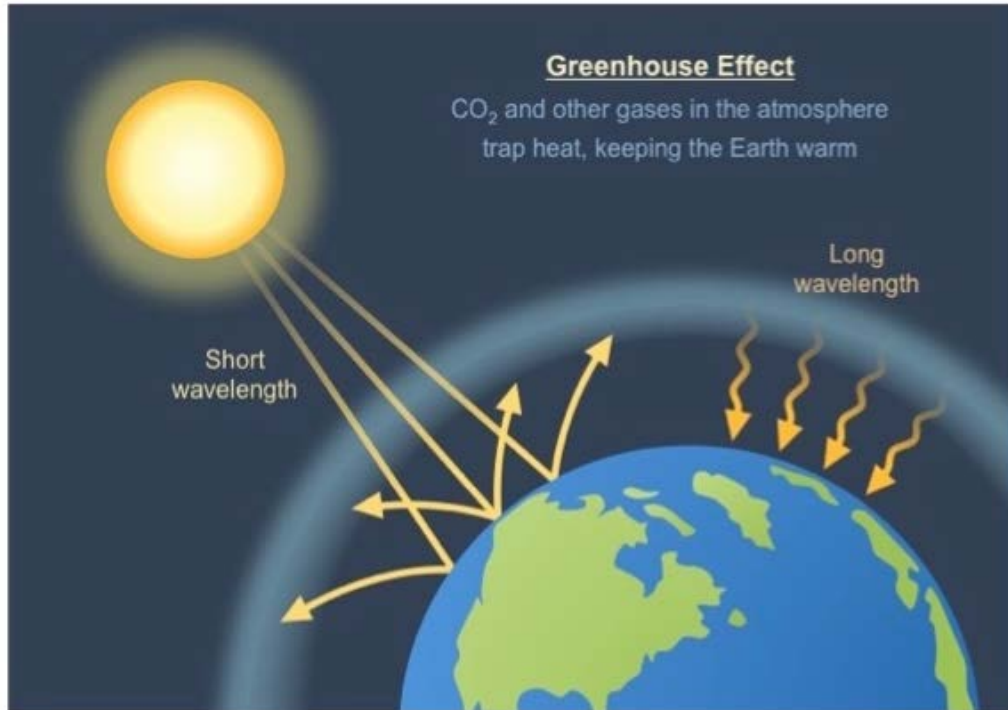
Factor 3: Atmosphere



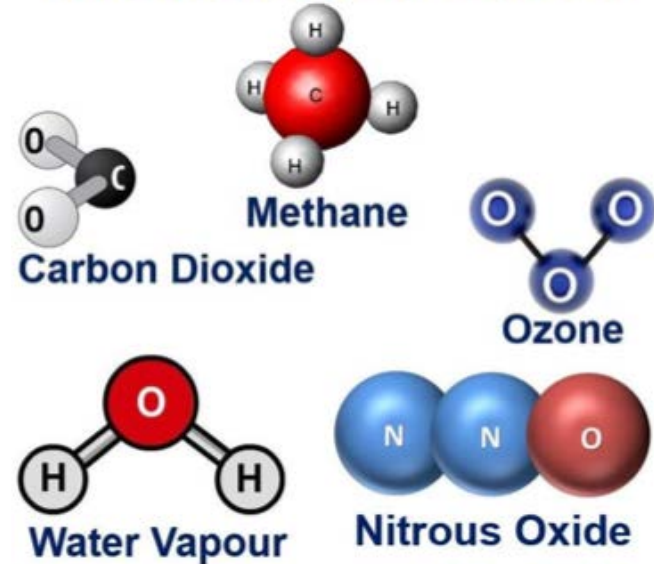
Some reflected energy gets trapped in the atmosphere by **greenhouse gases**. Why are some gases greenhouse gases?



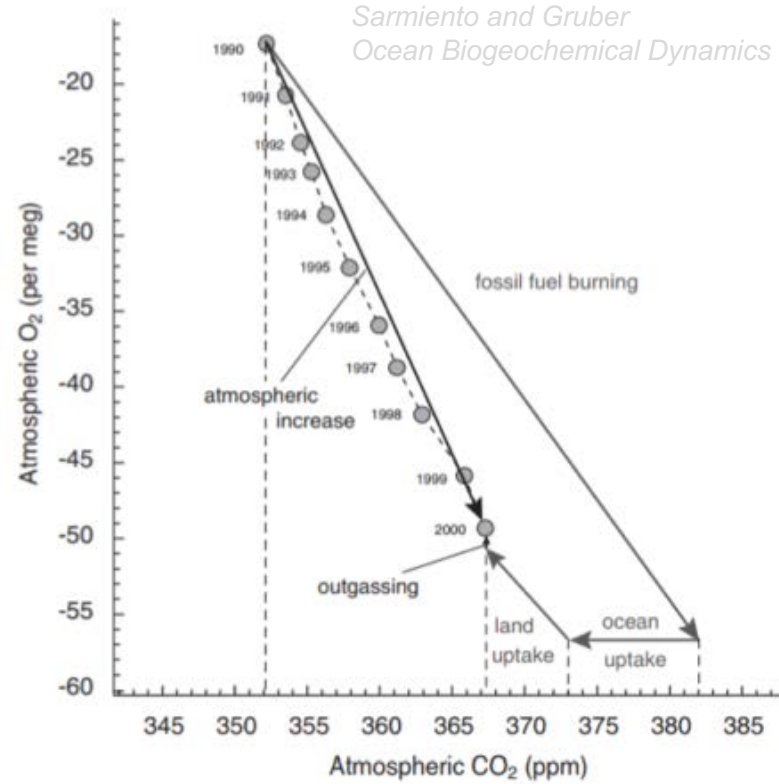
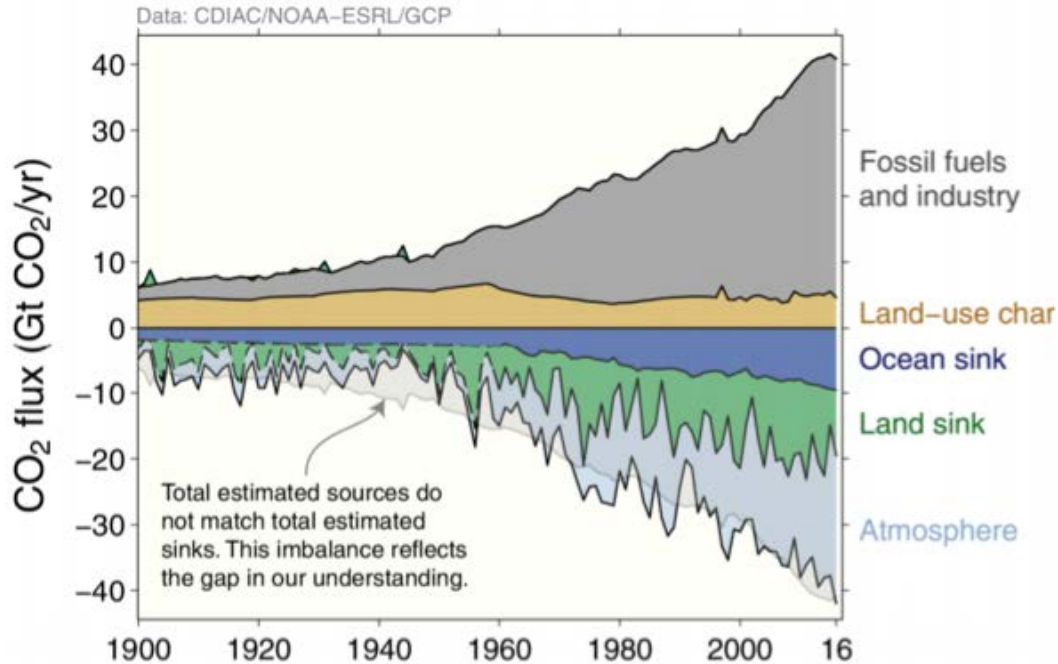
Factor 3: Atmosphere



Greenhouse Gases



CO2 Sources and Sinks



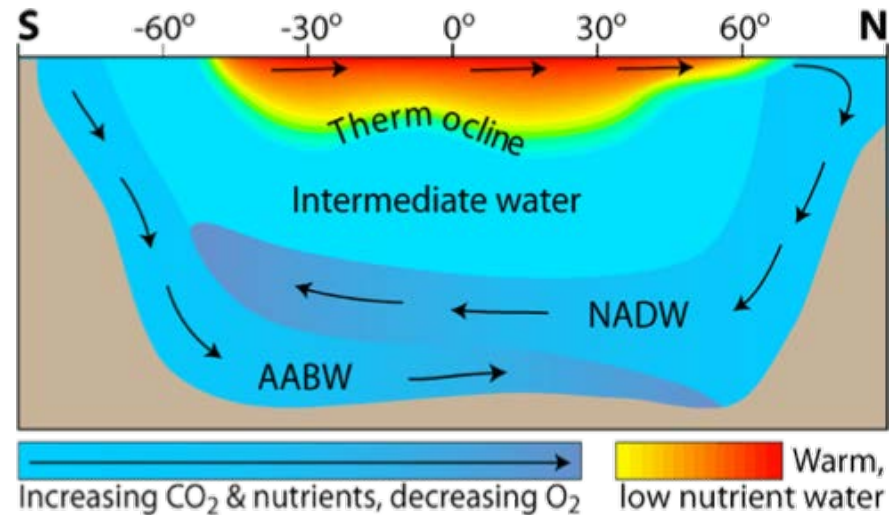
Factor 4: The Ocean

The ocean acts like a giant sponge, absorbing:

- ¼ of anthropogenic CO₂ emission
- 90% of additional warming due to the greenhouse effect

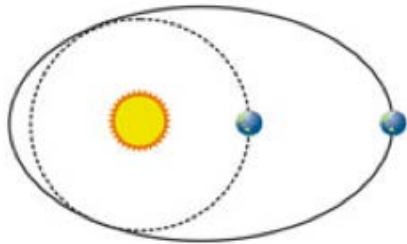
The surface ocean moves North, cool, traps more gas from the atmosphere, and then sinks to the deep

The ocean recirculates and eventually these buried emissions will resurface

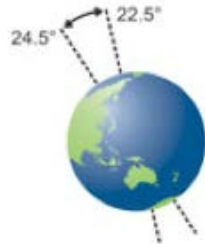


Factor 5: Orbital Changes (Milankovitch Cycles)

Milankovitch Cycles



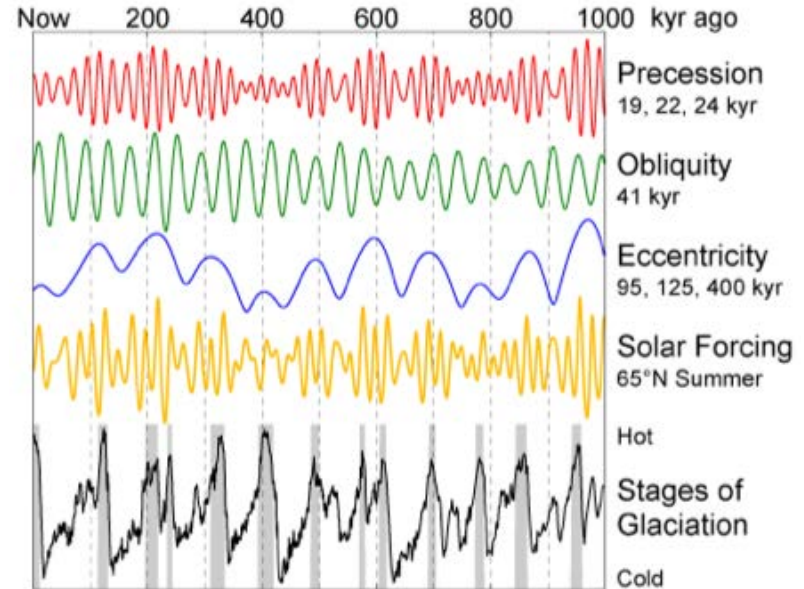
Eccentricity



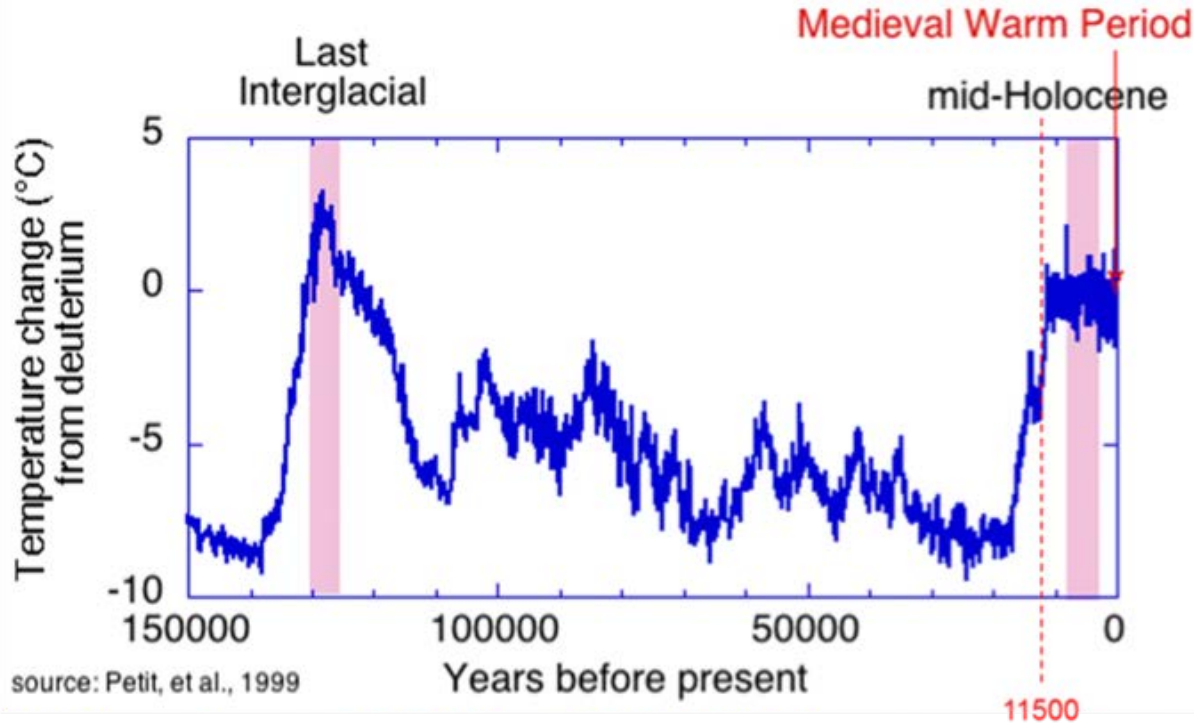
Obliquity



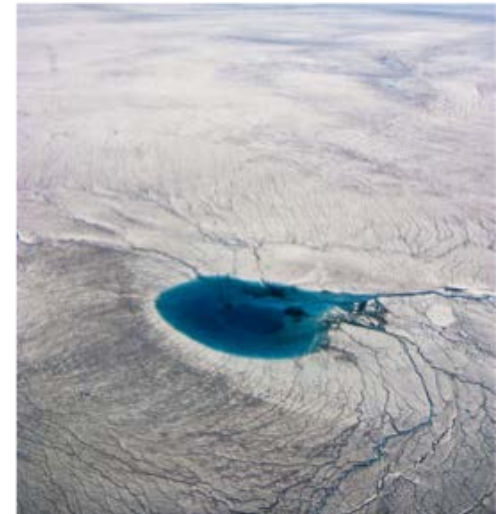
Precession



Example: Eemian Period



What made the Eemian period so much warmer than today?
-Milankovitch Cycles!
-Feedbacks!

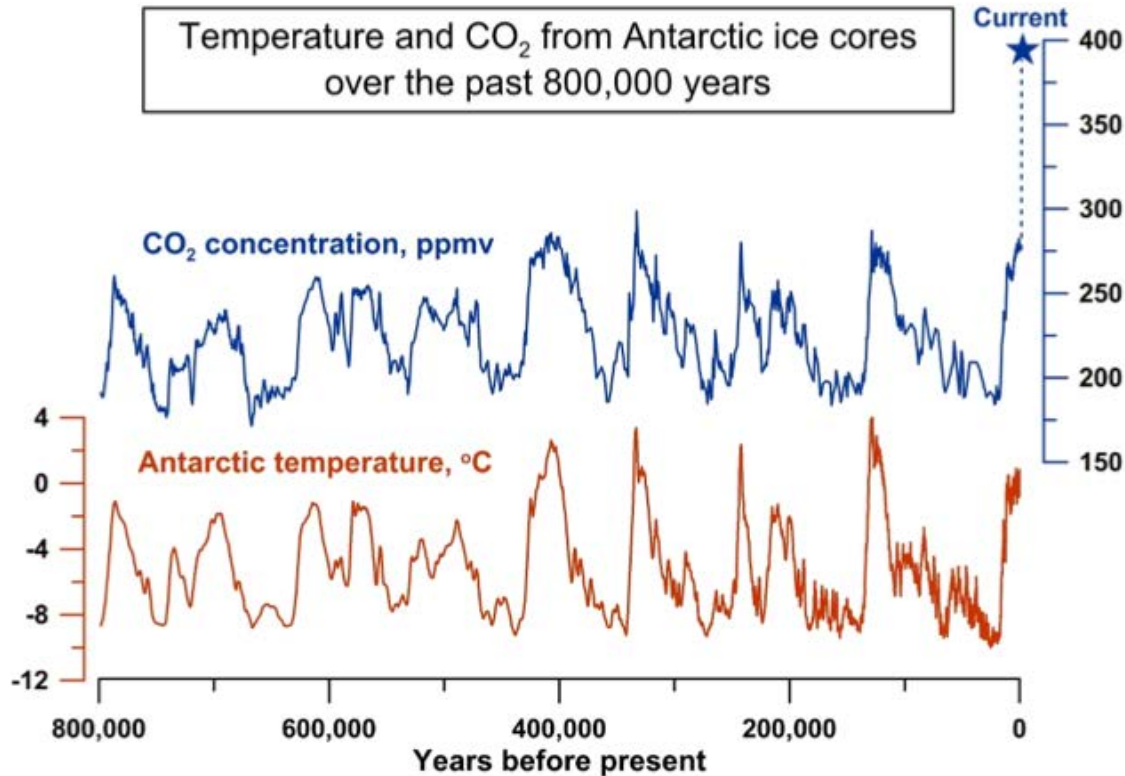


<http://www.ncdc.noaa.gov/paleo/globalwarming/paleobefore.html>

Images:
<https://i.pinimg.com/originals/aa/1b/e9/aa1be9c5cba3b9a63979a3e4a2bfb6f4.jpg>
<https://6000generations.files.wordpress.com/2013/05/eemian-and-holocene-interglacials.png>

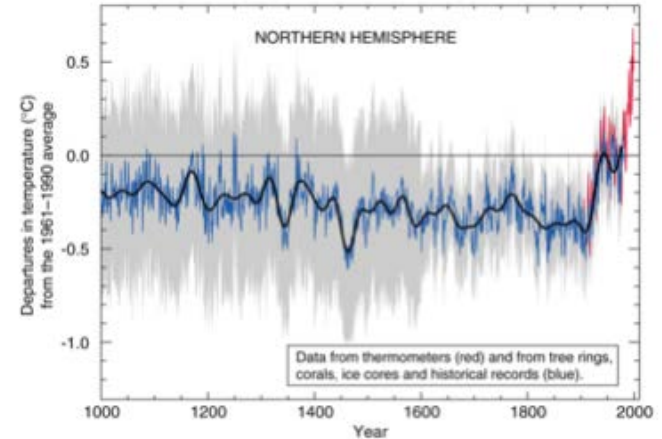
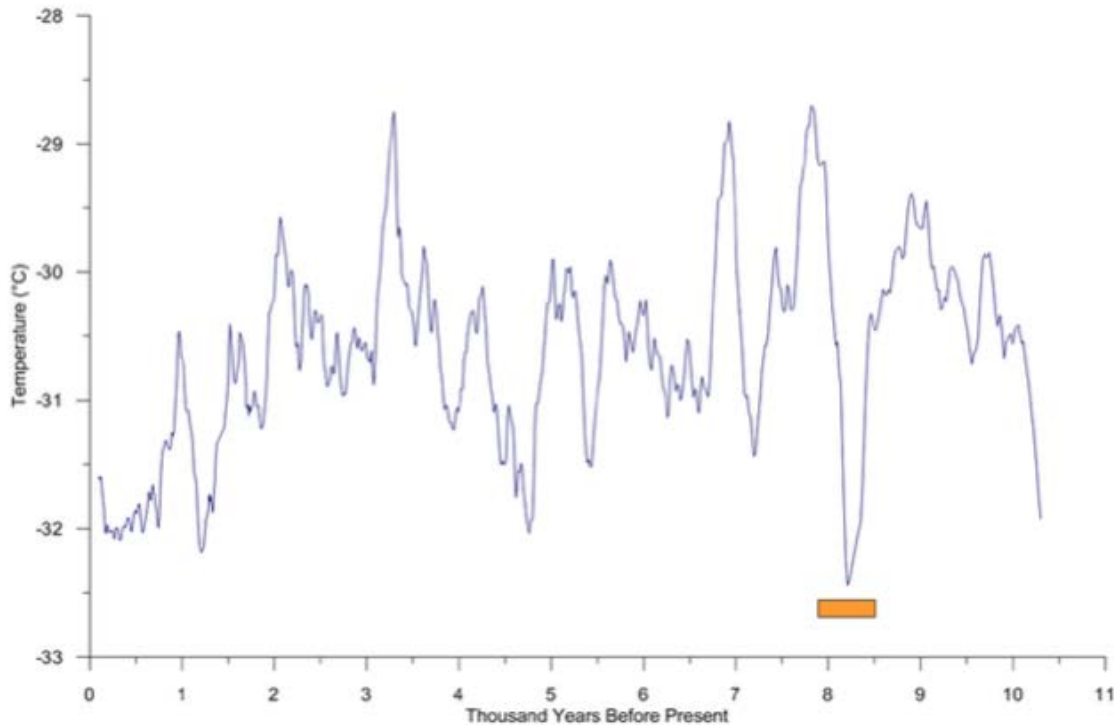
What does the past tell us?

Temperature and CO₂ from Antarctic ice cores over the past 800,000 years



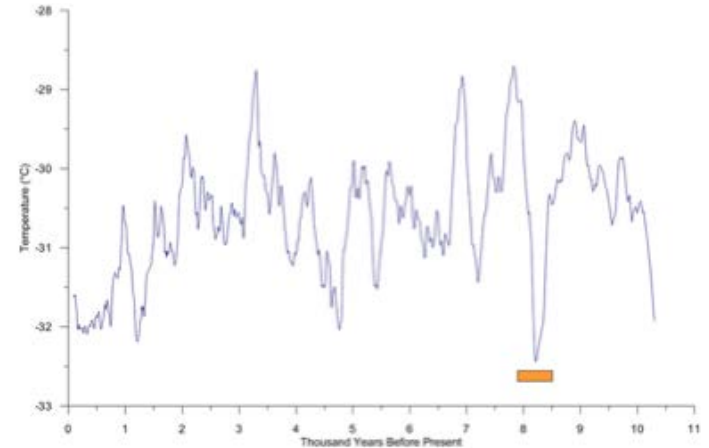
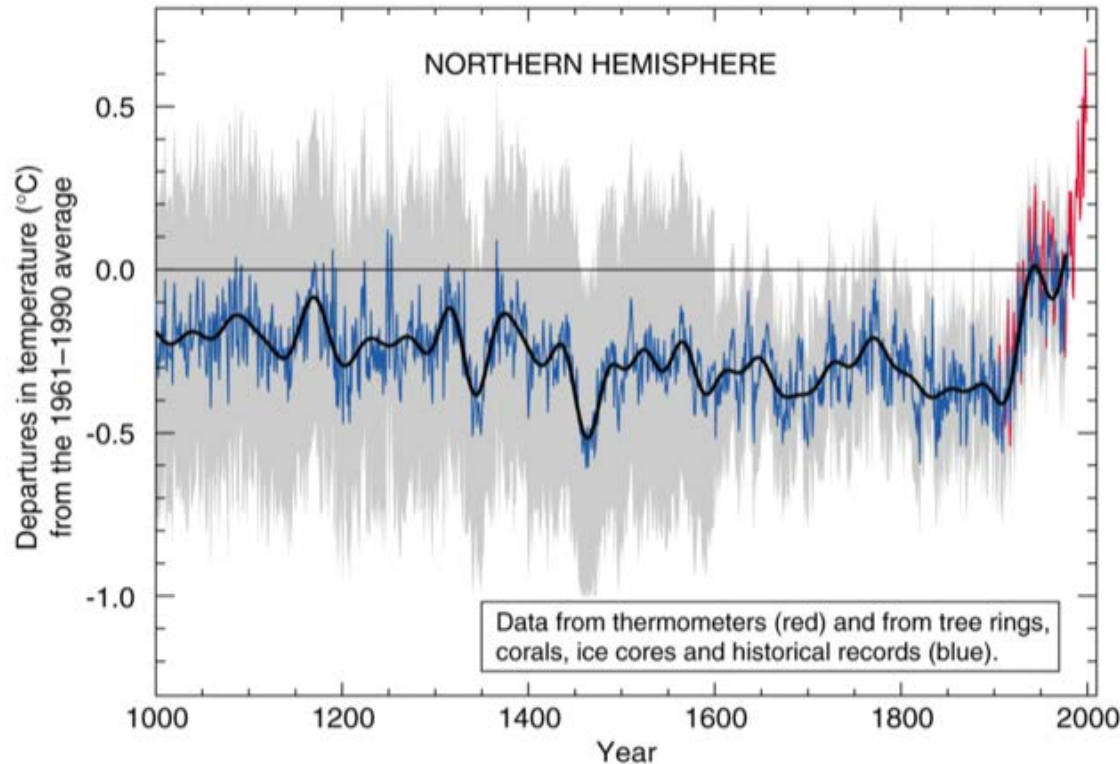
Images: <https://simpleclimate.files.wordpress.com/2012/04/edc.jpg>
http://www.cosmographicresearch.org/Images/glacial_maximum_map2.jpg

Modern Climate: The Hockey Stick



Is Earth more vulnerable to abrupt climate change now than before?

Modern Climate: The Hockey Stick



Is Earth more vulnerable to abrupt climate change now than before?

Images: <http://news.psu.edu/sites/default/files/styles/threshold-992/public/hockeystick.gif?itok=d3wv1Cuj>
https://upload.wikimedia.org/wikipedia/commons/thumb/2/2d/Greenland_gisp2_alley.png/640px-Greenland_gisp2_alley.png

Climate change causes 5 critical environmental changes

1. Warming temperatures of the Earth's surface and oceans
2. Changes in the global water cycle
3. Declining glaciers and snowpack
4. Sea level rise
5. Ocean acidification

1.

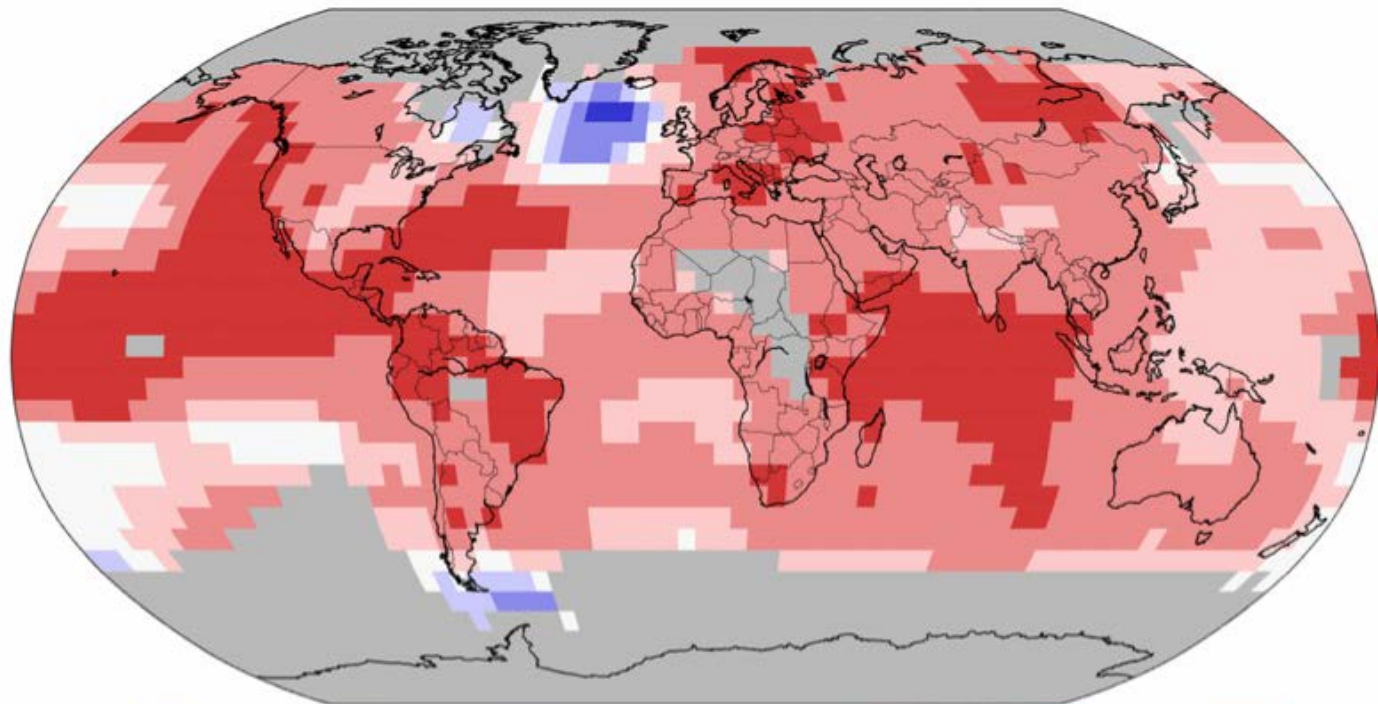
Surface and Ocean Temperature Change

Warming is occurring almost twice as fast as the rate of warming in the previous century

Land & Ocean Temperature Percentiles Jan–Dec 2015

NOAA's National Centers for Environmental Information

Data Source: GHCN–M version 3.3.0 & ERSST version 4.0.0



Record Coldest



Much Cooler than Average



Cooler than Average



Near Average



Warmer than Average



Much Warmer than Average



Record Warmest



Ocean Temperature and Coral Habitats



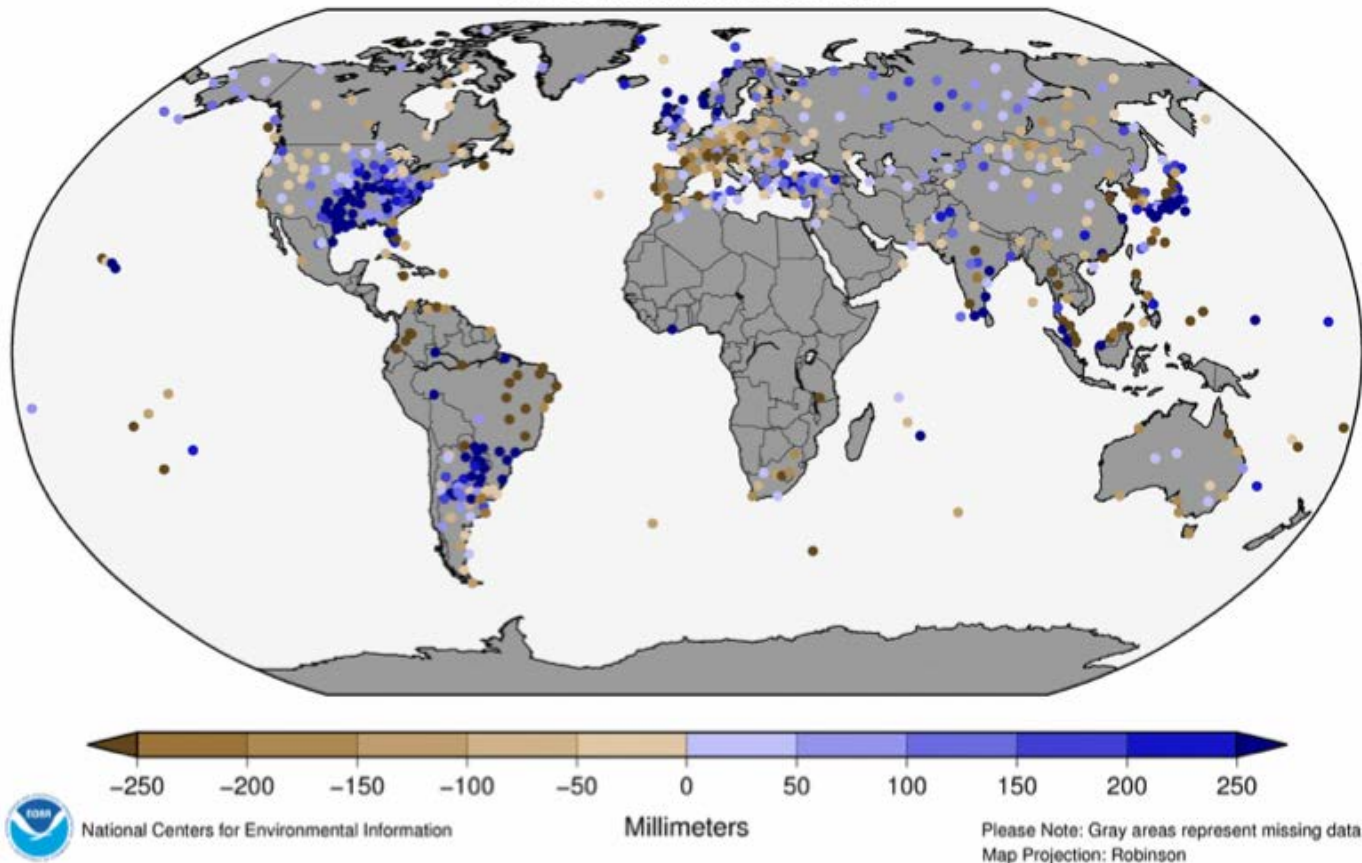
2.

Changes in the Global Water Cycle

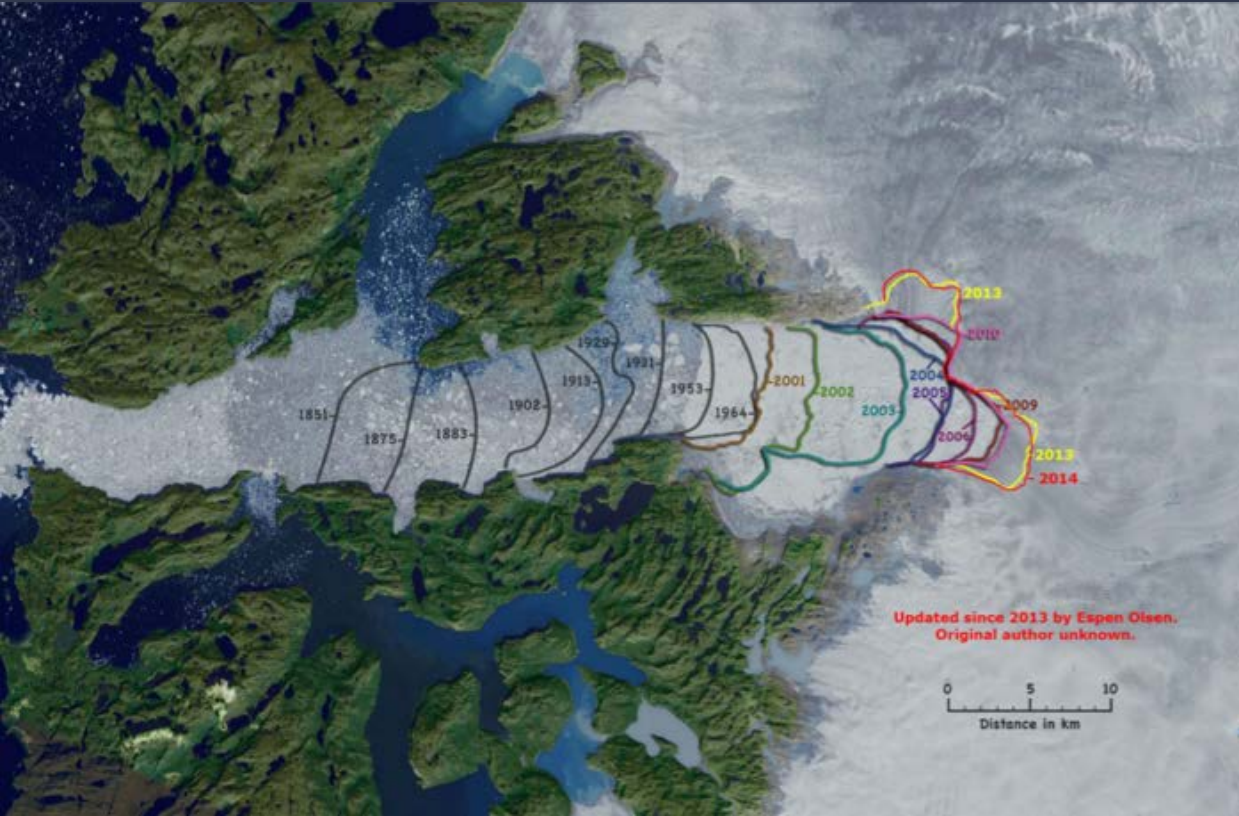
- As the atmosphere warms it is able to hold more water vapor
- The past century has experienced distinct geographical changes in total annual precipitation

Land-Only Precipitation Anomalies Jan-Dec 2015 (with respect to a 1961-1990 base period)

Data Source: GHCN-M version 2

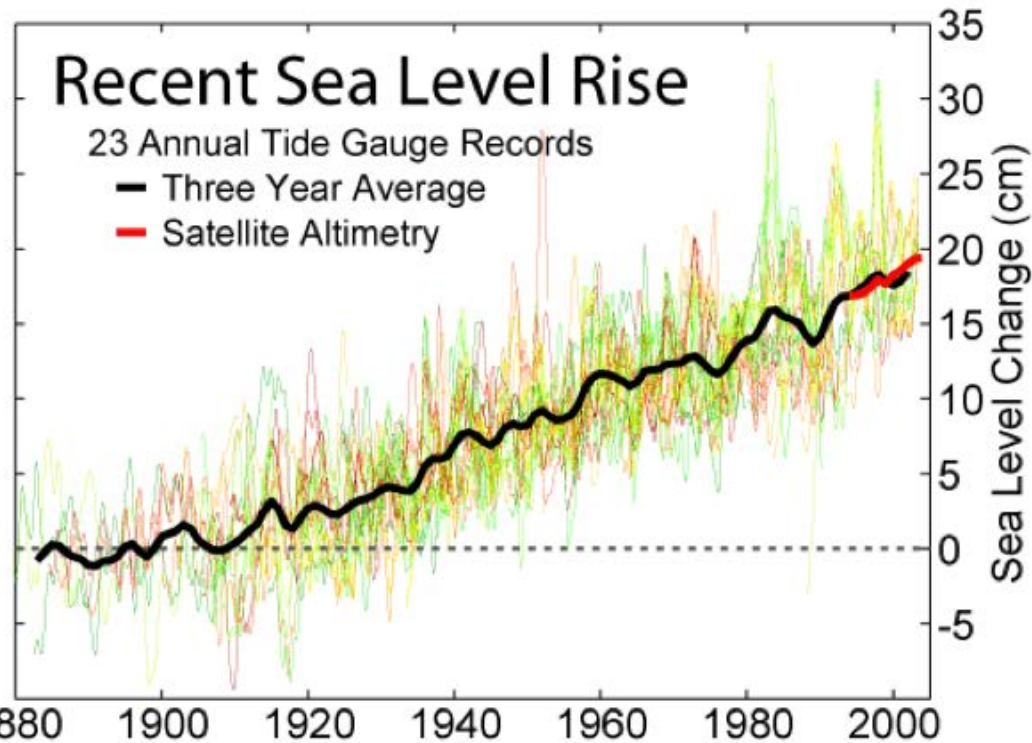


3. Glacier and Snowpack Decline



- Across the globe nearly all glaciers are decreasing in area
- Melt water affects seawater level and salinity
- Earlier spring runoff
- More frequent and severe flooding

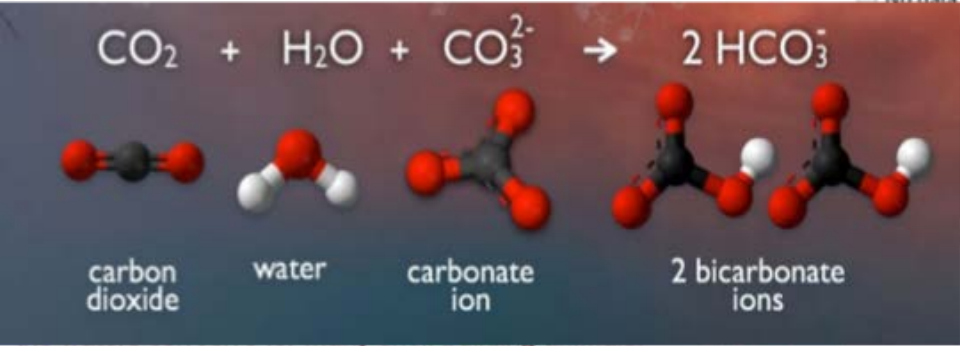
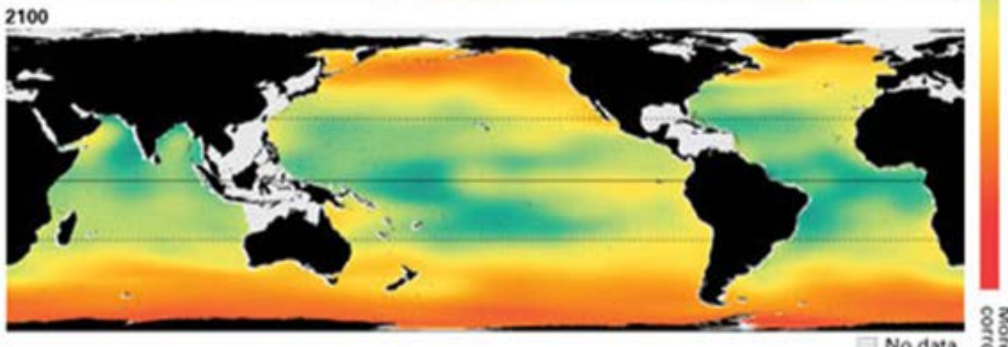
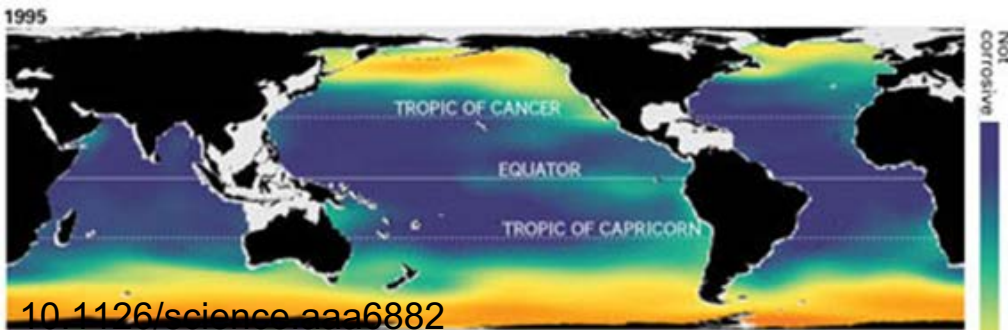
4. Sea Level Rise



- Warmer water expands, so the ocean increases in volume
- Melting glaciers and snowpack
- A 2 m sea level rise would swamp 187 million people
 - This is an upper bound prediction for 2100

Sea Level Rise: Boston





5. Ocean Acidification

The surface ocean equilibrates with the atmosphere

Increase of pCO₂ in the atmosphere consumes the carbonate ion, which decreases its saturation state

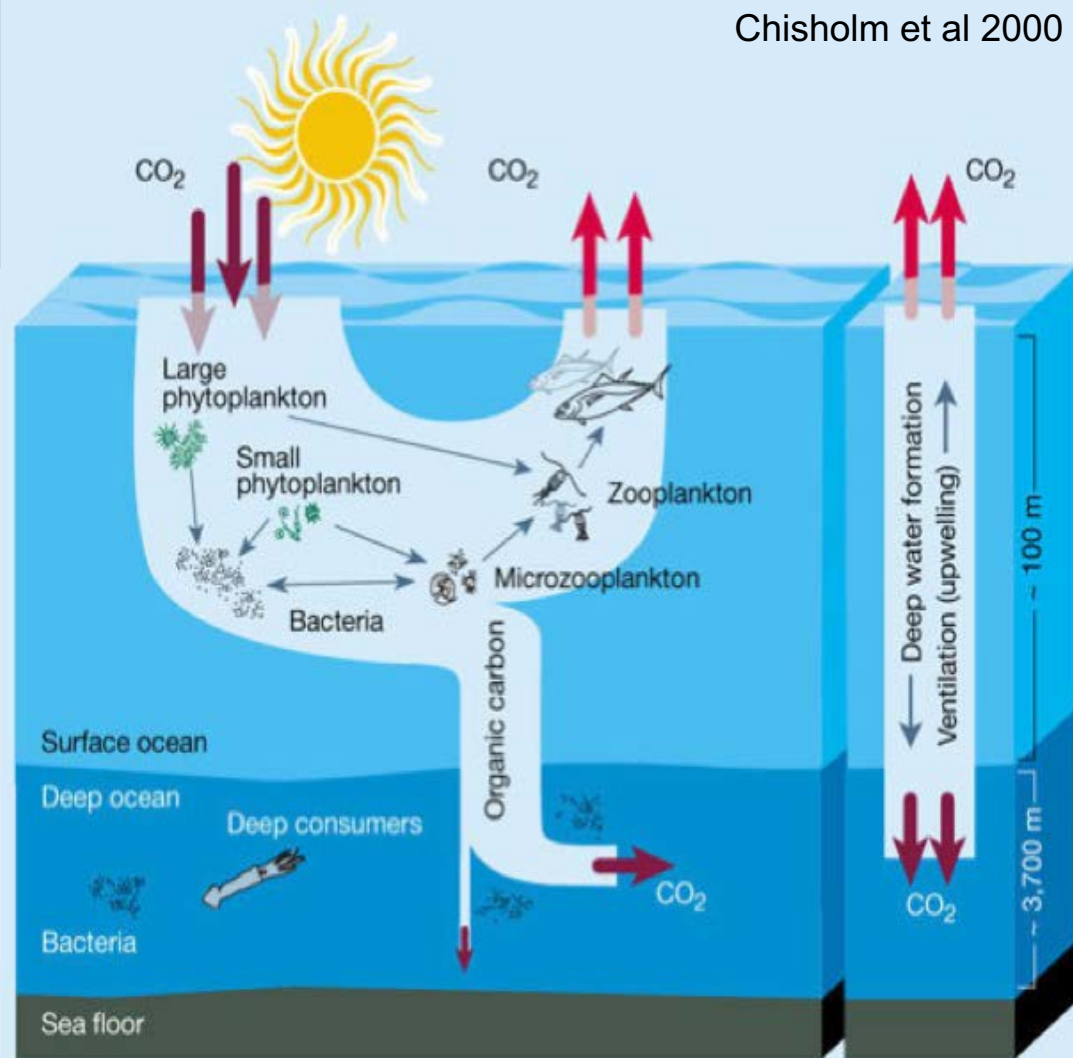
This impedes the effectiveness of the carbonate pump

The Biological Pump

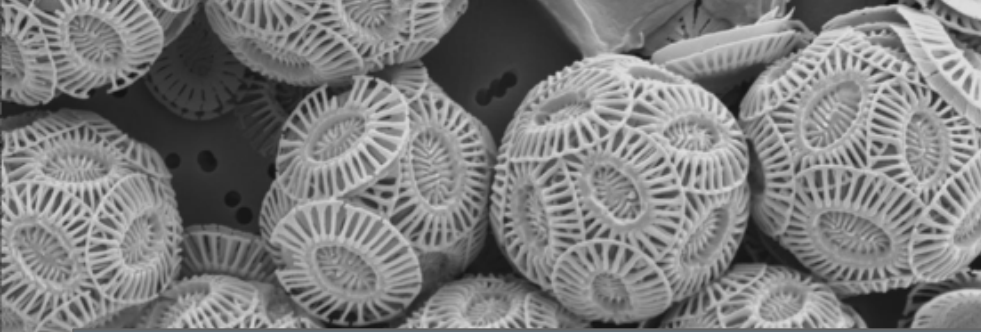
Contributors:

- Soft Tissue Pump
 - Organic matter formed by photosynthesis
 - Dead cells and fecal pellets aggregate and sink
- Carbonate Pump
 - CaCO_3 shells formed by plankton and mollusks

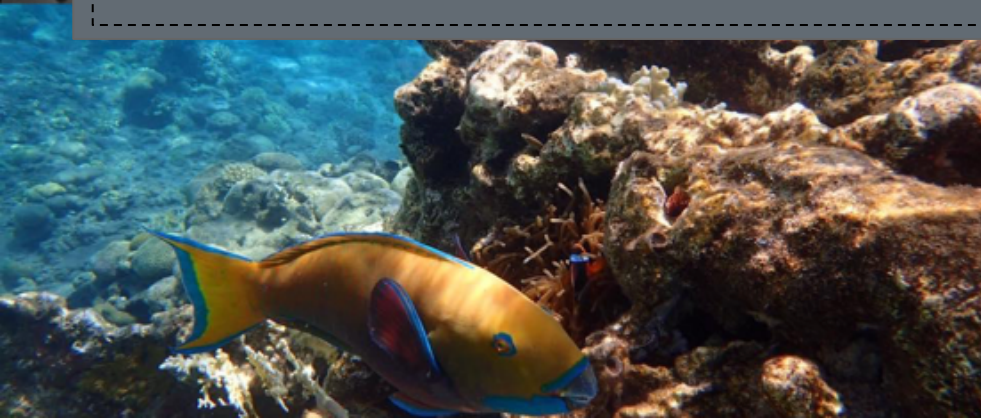
Important sink of CO_2 from the atmosphere!!!







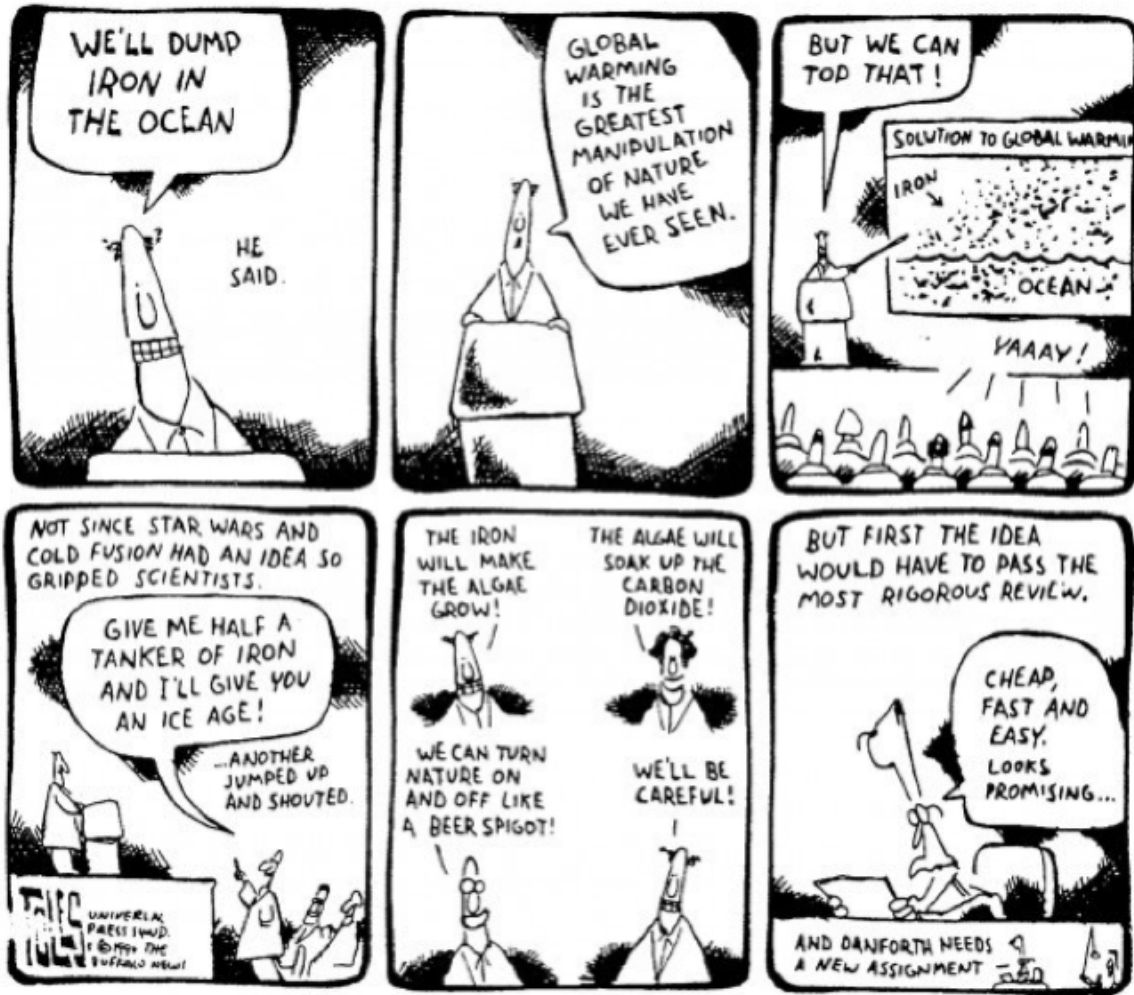
Ocean acidification= less carbonate formation
Dissolution of coral environments
Less Biodiversity



Potential Solutions to Ocean Acidification?

- Geoengineering
 - Iron Fertilization
 - Adding alkalinityThese have significant economic and ecological costs.

Best solution:
Stop adding CO2 to the atmosphere



The Aral Sea:
anthropogenic
environmental
and climate
change





Anthropogenic Impacts:

- Increases of agriculture in the 20th century used up all the water coming down the mountains before it could reach the sea
- Farmers grew water intensive crops
- Excessive use of agricultural pesticides
- Island in the center was used at a biological weapons development site (smallpox, plague, etc)



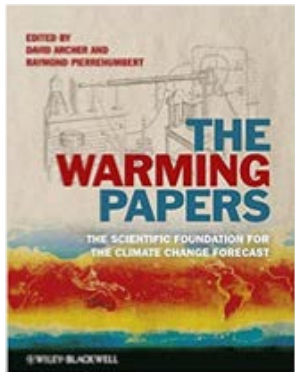
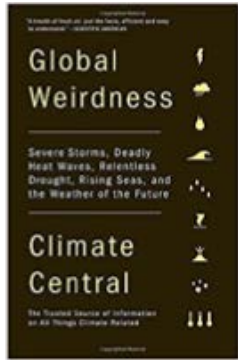
Climate Change Effects:

- Sea surface temperature (SST) changes
- **Hotter summers, colder winters**
- Exposed seabed results in dust storms
 - Issue for respiratory health
- Rising salinity kills fish
 - Decimates fishing villages
 - Destroys fishing and canning industry
 - Cultural loss of traditional food

Books

Organizations

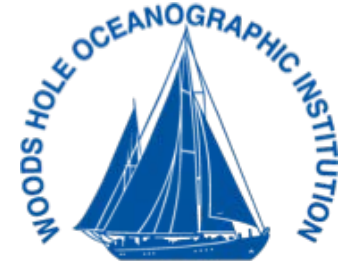
Documentaries



Protecting nature. Preserving life.



EARTHJUSTICE



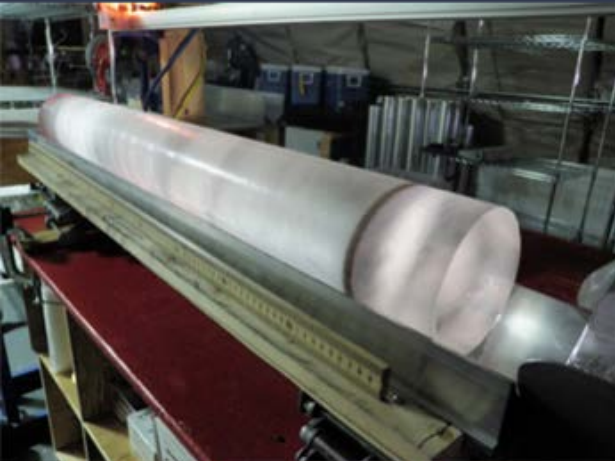
1930



THE SOLUTIONS PROJECT

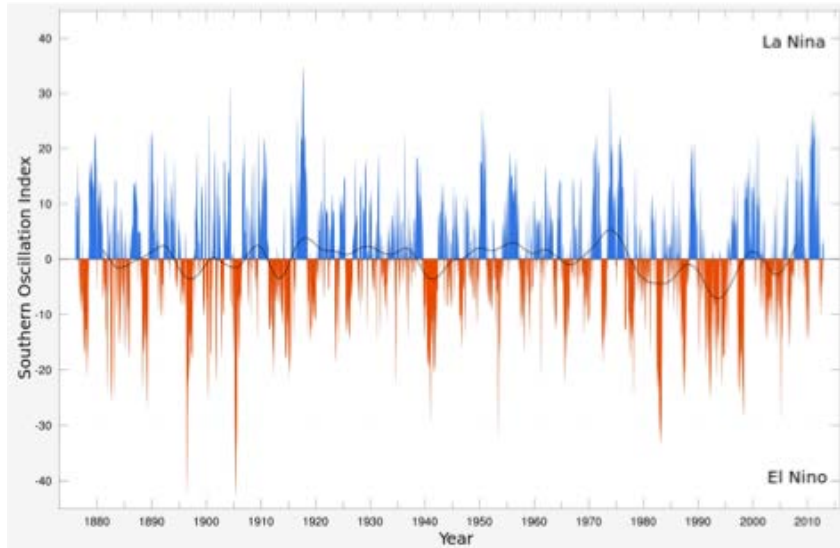
EXTRA SLIDES

How Do We Know About Past Climates?

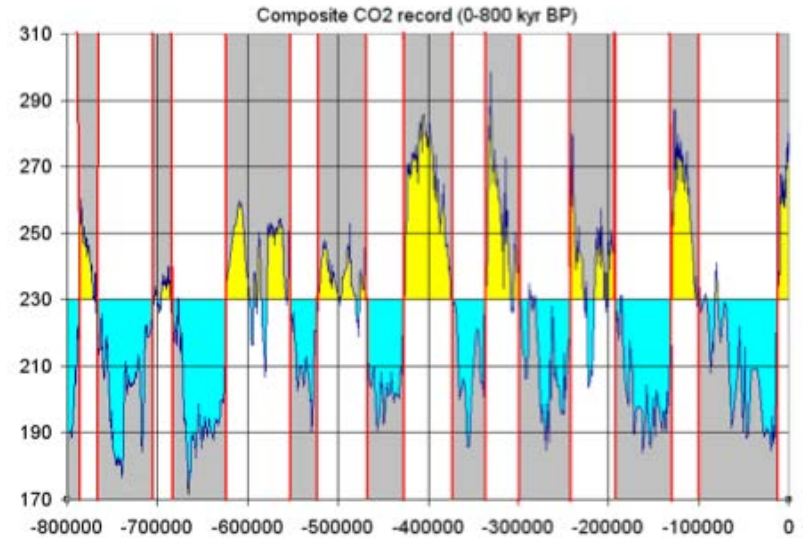


Images: https://climate.nasa.gov/internal_resources/1205/
[https://upload.wikimedia.org/wikipedia/commons/thumb/2/2e/Cor
al_Outcrop_Flynn_Reef.jpg/1200px-
Coral_Outcrop_Flynn_Reef.jpg](https://upload.wikimedia.org/wikipedia/commons/thumb/2/2e/Cor_al_Outcrop_Flynn_Reef.jpg/1200px-Coral_Outcrop_Flynn_Reef.jpg)
<https://dsmag.com/wp-content/uploads/2016/09/Tree-Rings.jpg>
[https://eapsweb.mit.edu/sites/default/files/8679459790_36196d6
197_b.jpg](https://eapsweb.mit.edu/sites/default/files/8679459790_36196d6197_b.jpg)
[http://static.wixstatic.com/media/c309ff_2bc8d6f43cac442aaefe1
ee0eeb34a6e.jpg/v1/fill/w_396,h_296,al_c.lg_1,q_80/c309ff_2bc
8d6f43cac442aaefe1ee0eeb34a6e.webp](http://static.wixstatic.com/media/c309ff_2bc8d6f43cac442aaefe1ee0eeb34a6e.jpg/v1/fill/w_396,h_296,al_c.lg_1,q_80/c309ff_2bc8d6f43cac442aaefe1ee0eeb34a6e.webp)

Climate Cycle Examples



El Nino Southern Oscillation (ENSO)
Timescale of 2-4 years



Glacial-Interglacial Cycles
Timescale of 20,000 years

Factor 3: Atmosphere

Greenhouse Gases

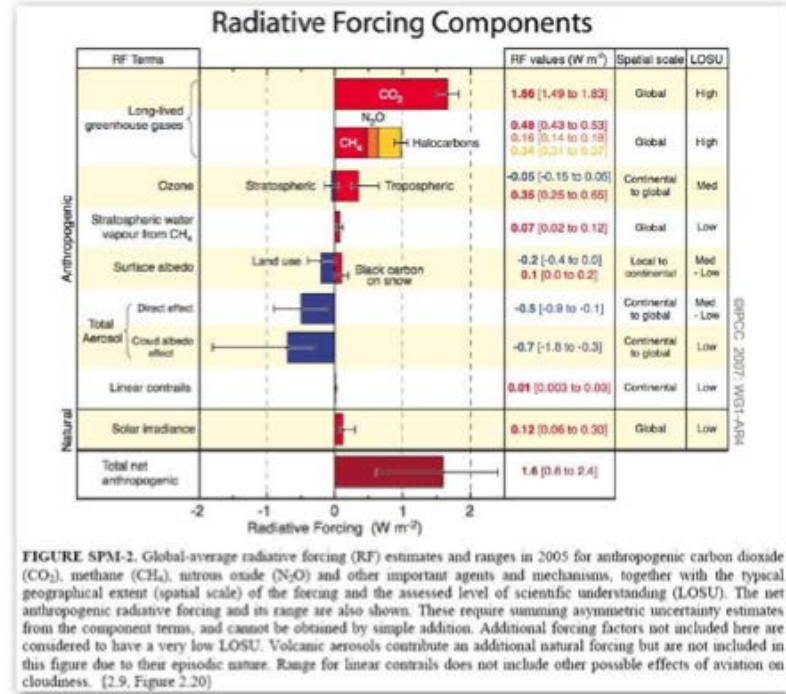
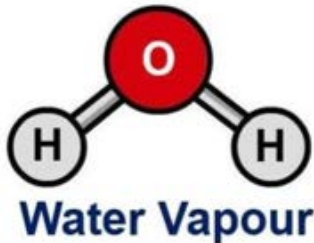
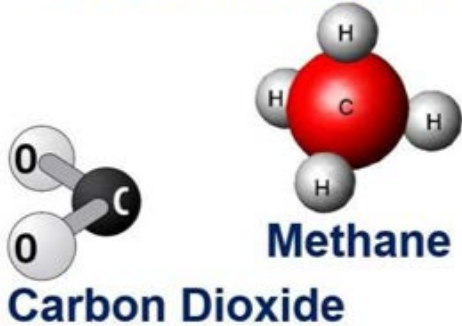


FIGURE SPM-2. Global-average radiative forcing (RF) estimates and ranges in 2005 for anthropogenic carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O) and other important agents and mechanisms, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU). The net anthropogenic radiative forcing and its range are also shown. These require summing asymmetric uncertainty estimates from the component terms, and cannot be obtained by simple addition. Additional forcing factors not included here are considered to have a very low LOSU. Volcanic aerosols contribute an additional natural forcing but are not included in this figure due to their episodic nature. Range for linear contrasts does not include other possible effects of aviation on cloudiness. [2.9, Figure 2.20]