Astronomy 100
Chapter 19

Earth

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question for you

What has been the most successful way of finding planets around other stars so far?

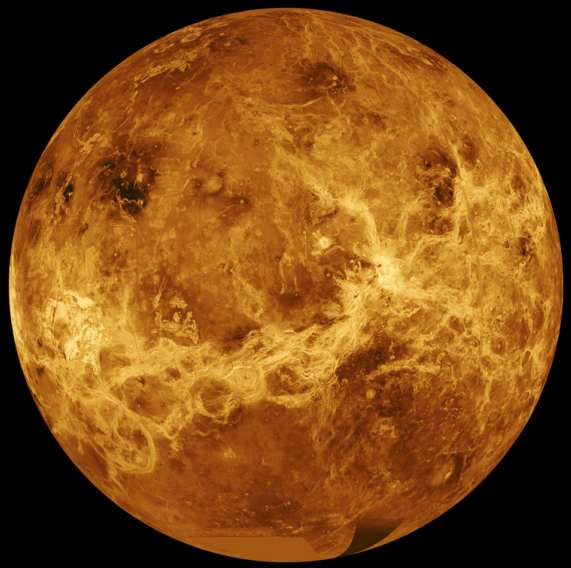
A. Measuring the wobble of stars using astrometry
B. Measuring spectral lines shifting with a period of a few years
C. Measuring light from stars pulsating and brightening regularly
D. Measuring light from the stars dimming at regular intervals
E. I have no idea

Plan for this lesson

- Geologic time
- Geological processes
- Earth's magnetic field
- Oceans and atmosphere

What makes Earth Special?

Venus



Too close to the Sun.
Too hot for water to remain liquid

Earth

Just Right!
Liquid water, life!

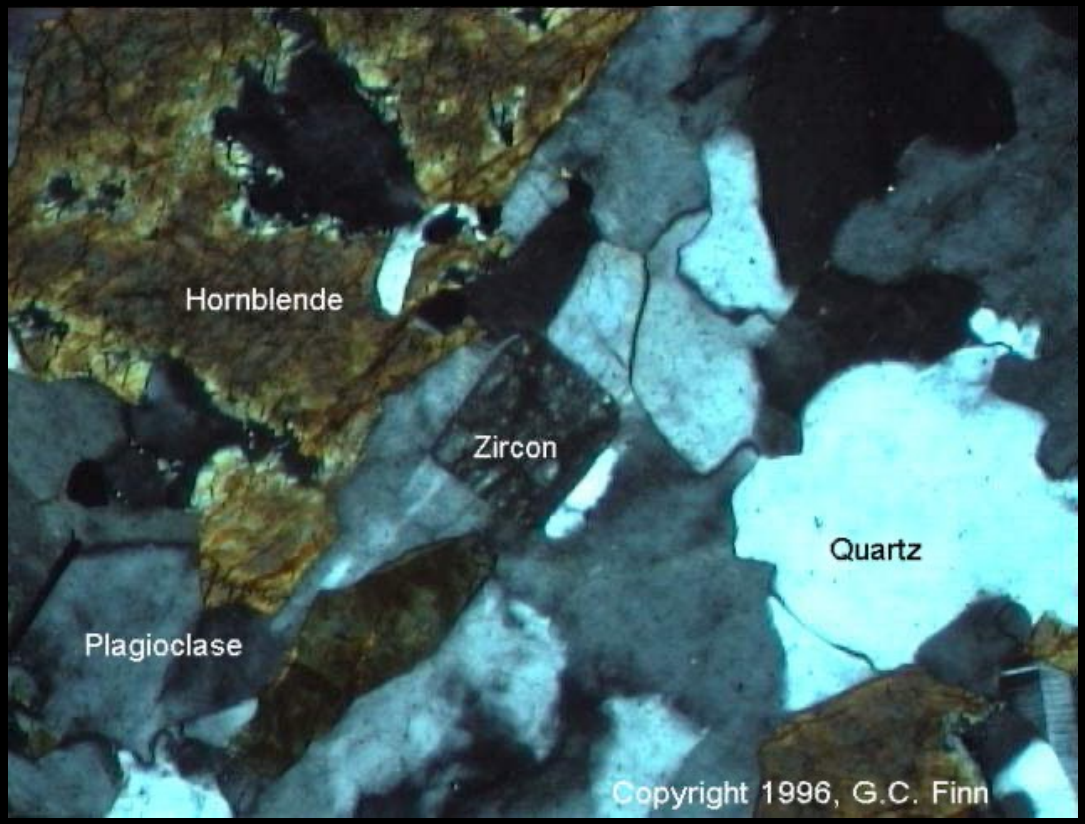
Mars

Too far from the Sun.
Water ice only in polar regions.

Geologic Time

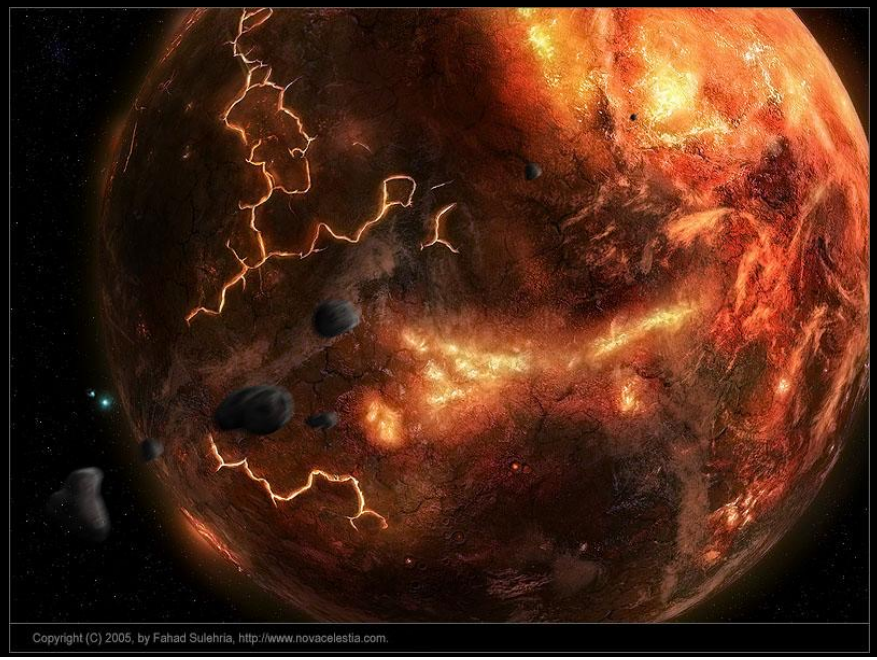
Geologic Time

- Oldest Earth rocks are 4.0 billion years old; meteorites can be even older.
- Earth's geologic history divided into four **eons**: **Hadean, Archean, Proterozoic, and Phanerozoic**.



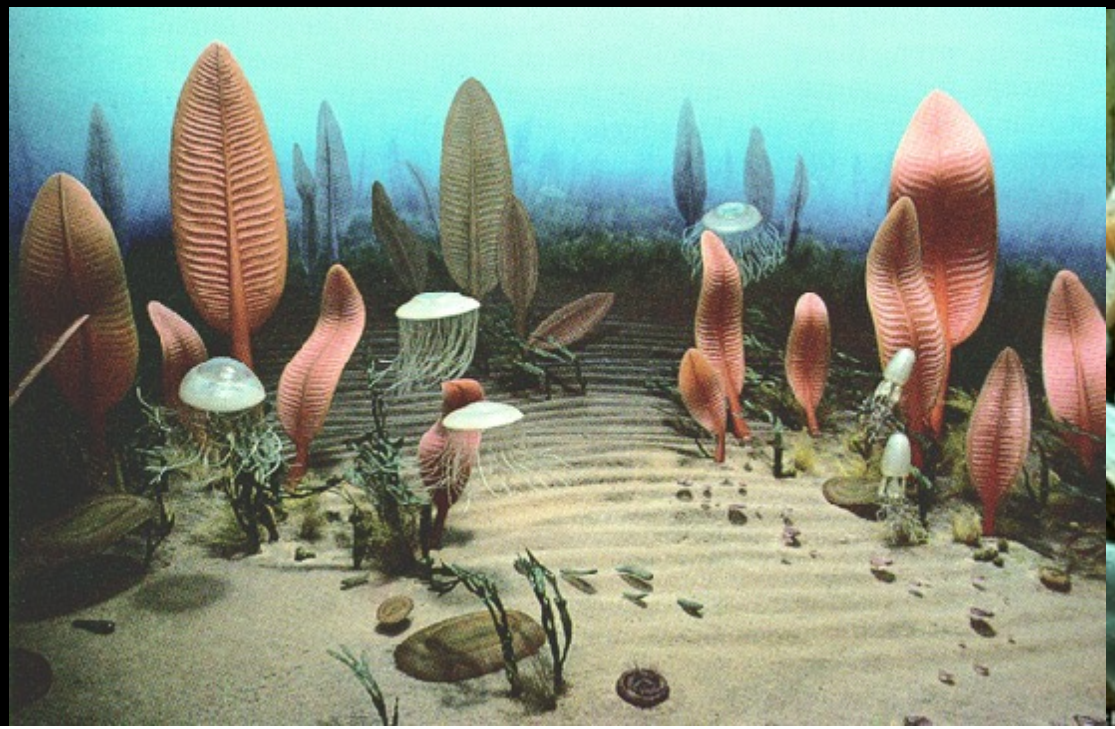
Geologic Time

- **Hadean** (hellish) Earth (till 3.85 billion years ago) during heavy bombardment, continents just beginning to form.
- **Archean** Earth (3.85 – 2.5 billion years ago): life begins, it's three times hotter than present-day Earth, more active plate tectonics.



Geologic Time

- **Proterozoic** Earth (2.5 billion – 540 million years ago): oxygenation of atmosphere, glaciation, evolution of soft-bodied multicellular organisms.
- **Phanerozoic** (540 million years ago till present day): evolution of abundant animal life, Cambrian explosion of biodiversity.



Geological processes

Geologic Processes on Earth

4 geological processes shape Earth's surface:

- Volcanism
- Plate Tectonics
- Erosion
- Impact Cratering

What Drives Geologic Activity on Earth?

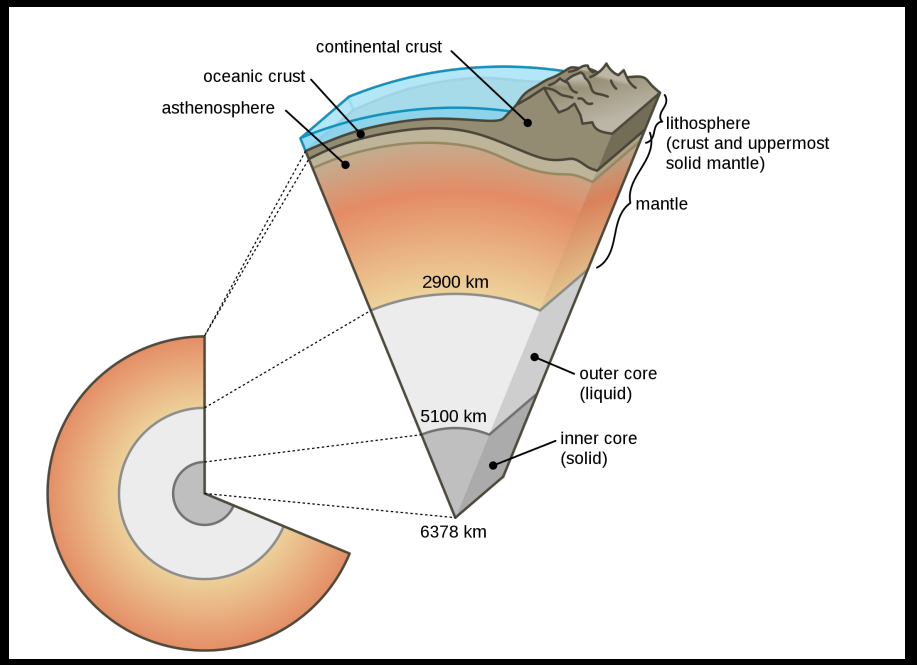
Earth's interior, which is still partially molten (fluid) and hot (from accretion + radioactive decay). Its heat drives geologic activity.

center: 4000-7000 K

Earth's Interior

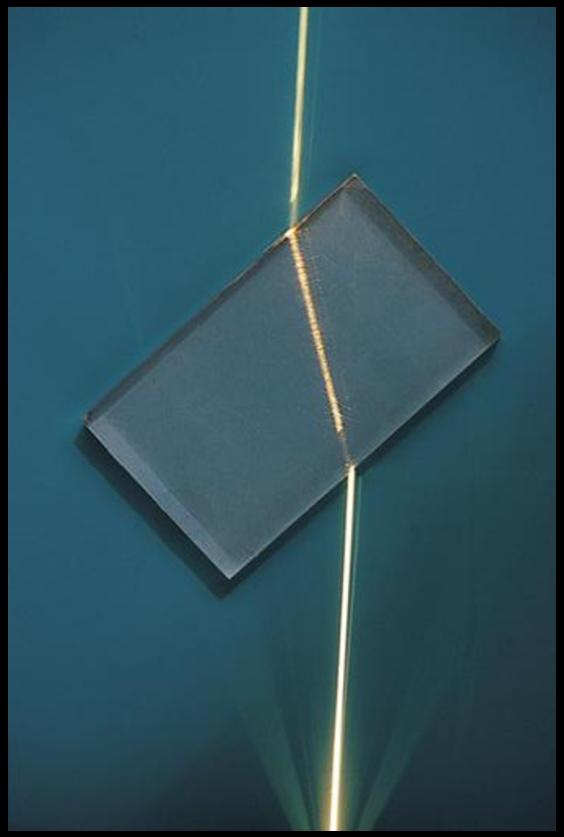
1. Core: solid inner core and molten outer core. Both are made up of iron and nickel.
2. Mantle is mostly solid but highly viscous layer, ~3000 km thick, made of silicate rock.
3. Crust: thin outer layer of igneous, metamorphic, and sedimentary rocks.

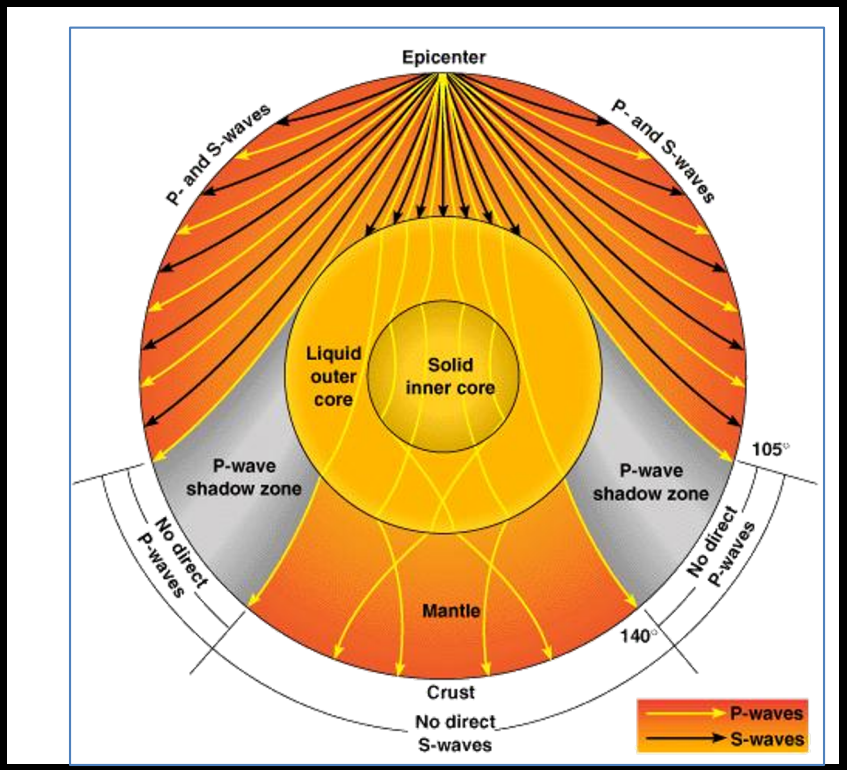
Crust + upper mantle comprise the **lithosphere**.



How do we Know?

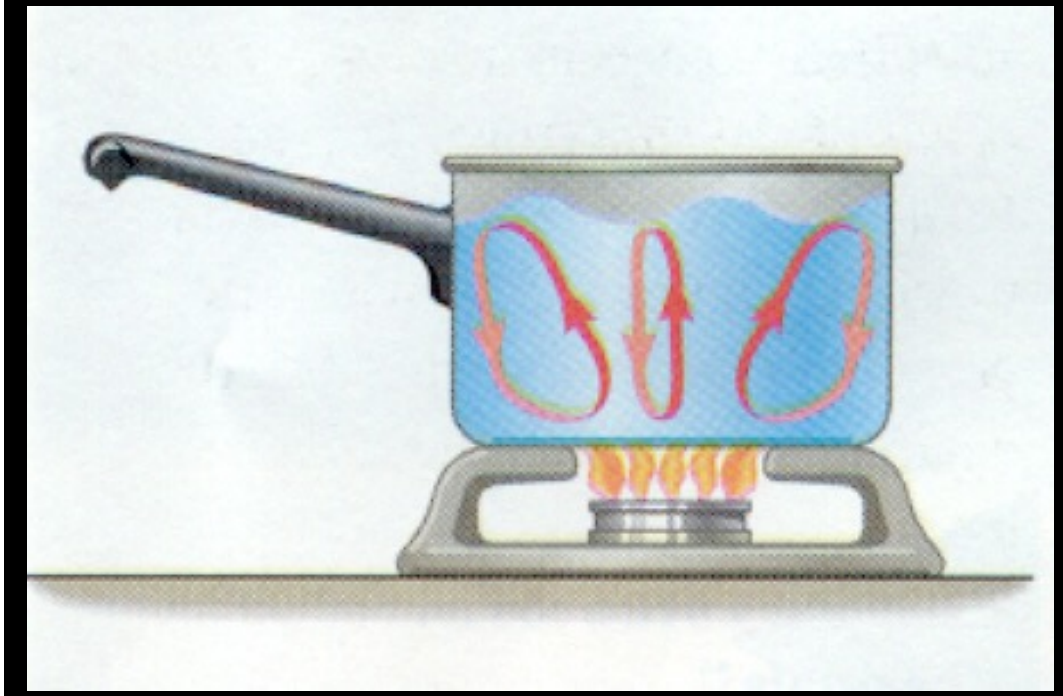
When a wave crosses a boundary (for example, between solid and liquid), it refracts (changes direction).





Convection

Currents always tend to transport heat from hotter to cooler regions, since heated fluid is less dense and rises, while cold fluid is denser and sinks.



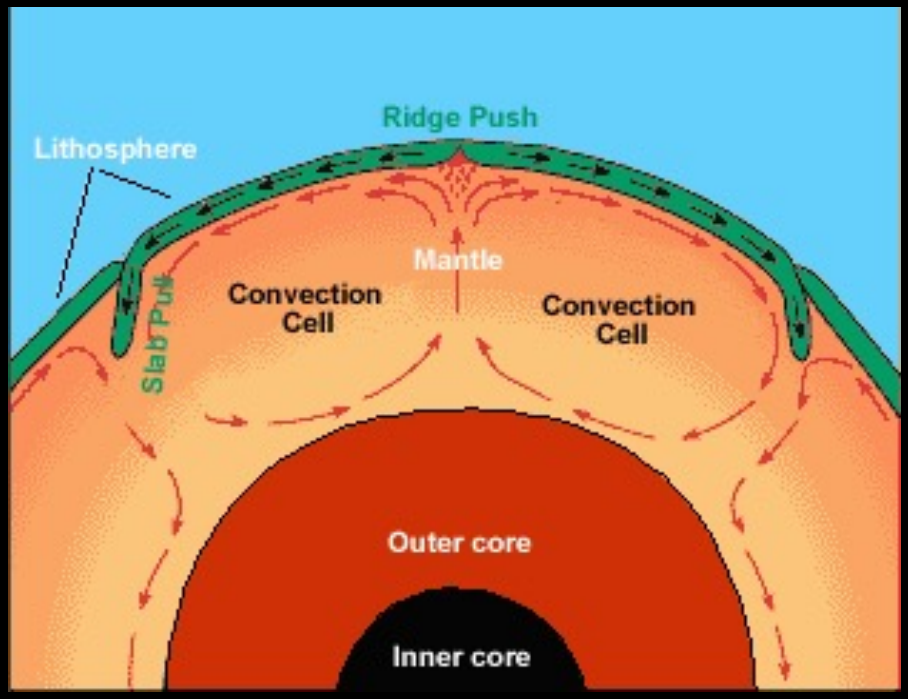
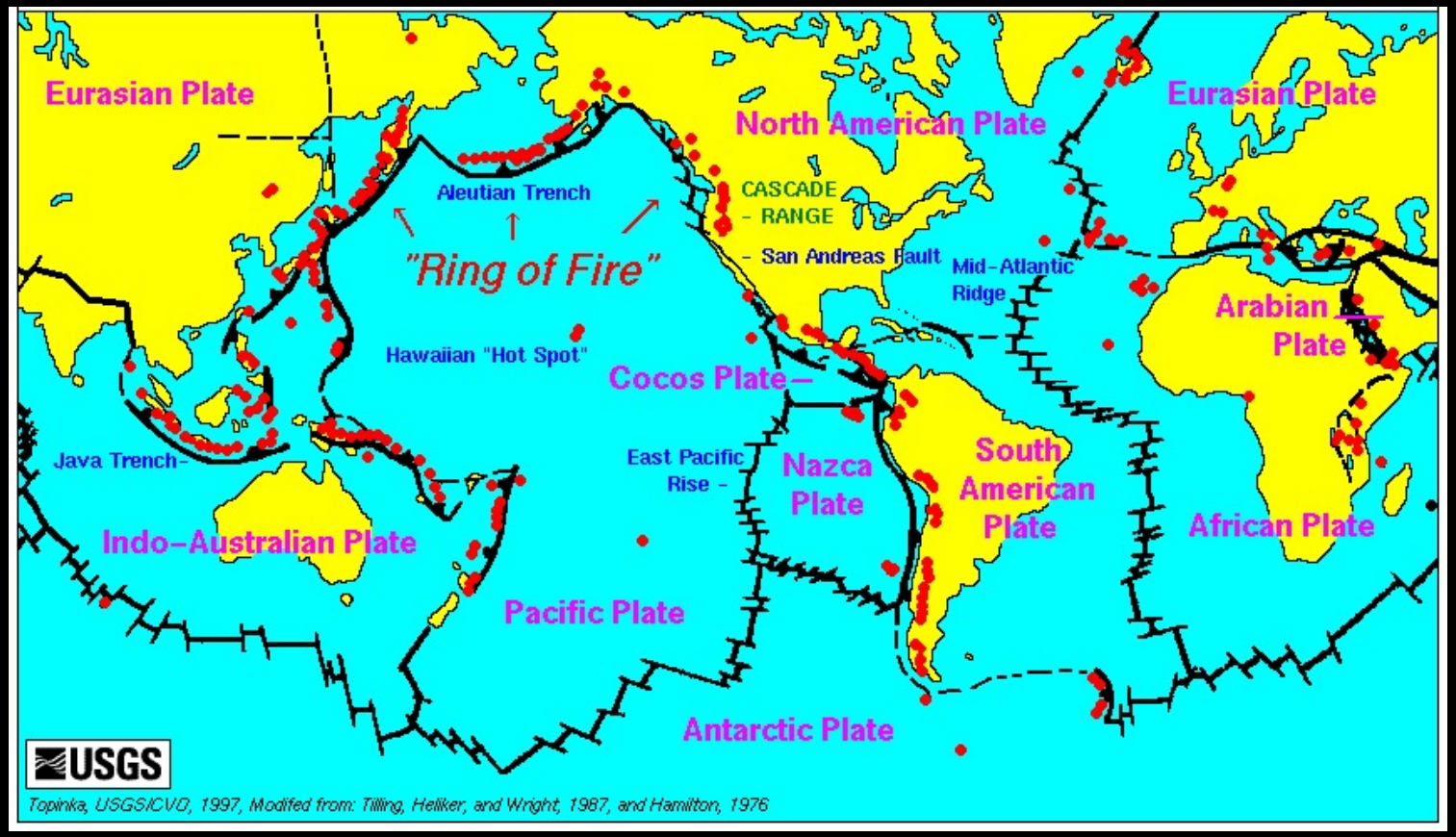


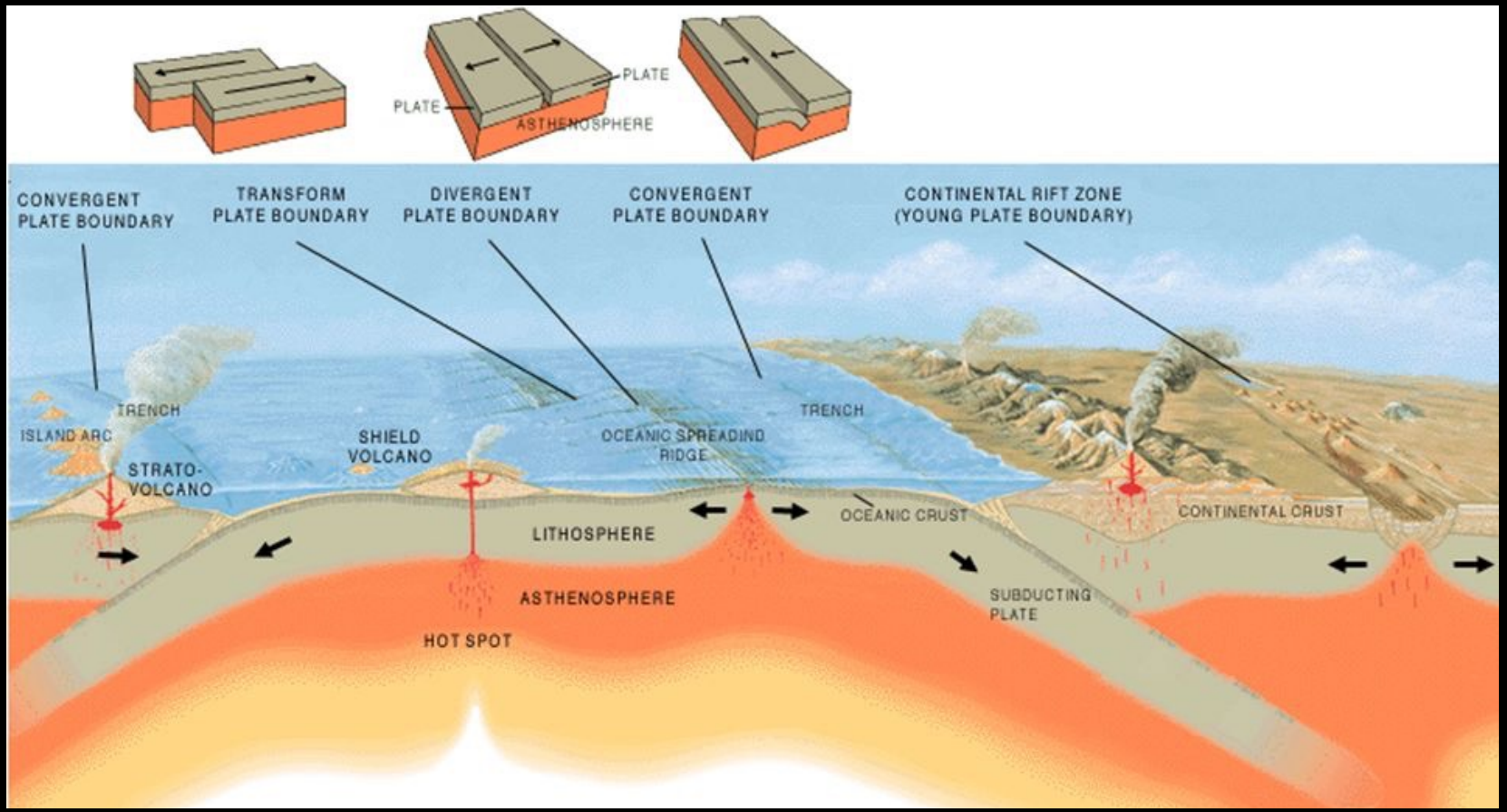
Plate Tectonics

- Motion of rocky plates in the lithosphere "floating" on the more fluid mantle.
- Earth's surface broken into **12 tectonic plates**.
- Boundaries of plates most active zones.



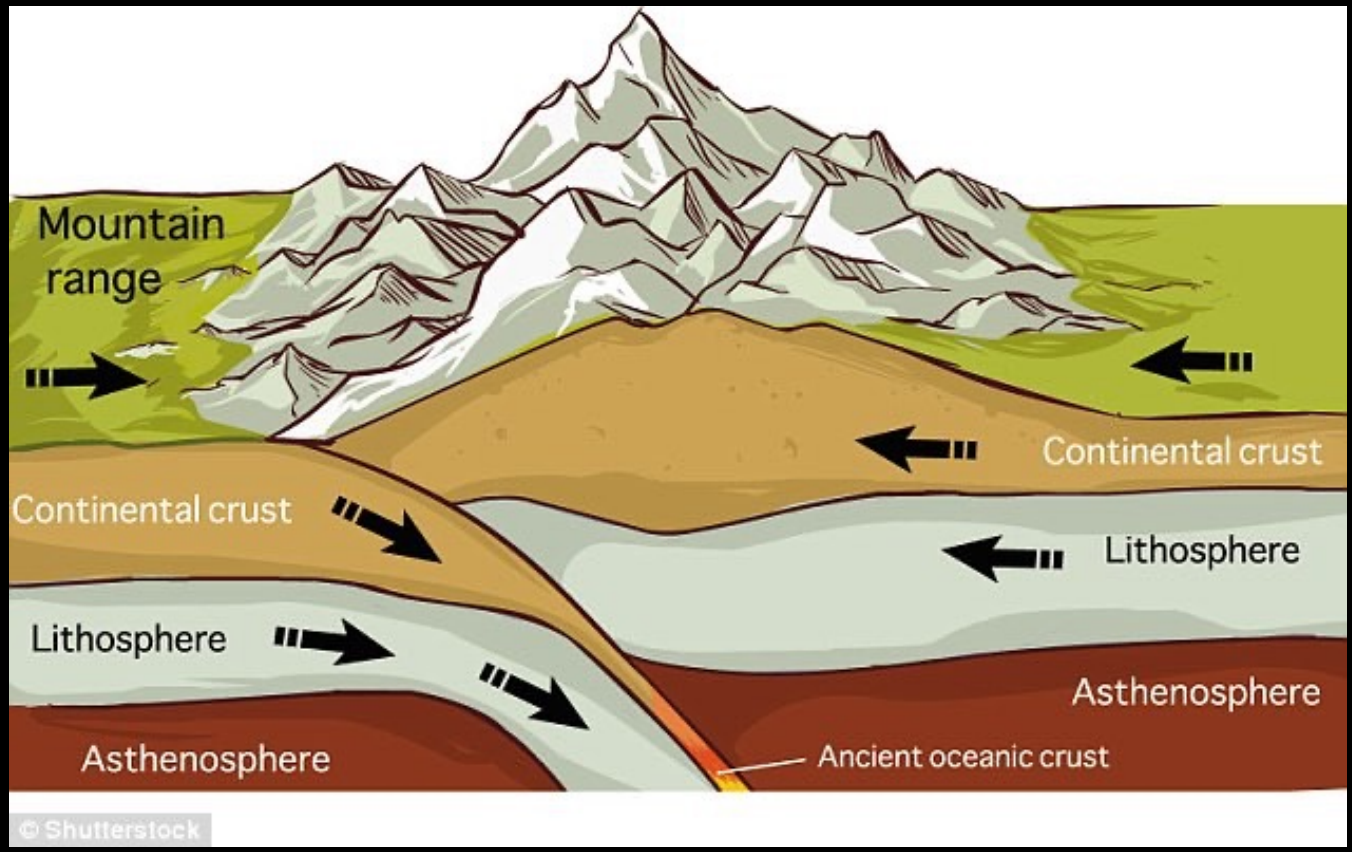
Interactions of tectonic plates

- At **convergent** boundaries, plates are colliding.
- At **divergent** boundaries, plates are moving apart from one another.
- At **transform** boundaries, plates are sliding past each another.



Subduction zones

At subduction zones, oceanic plate (denser) dives under continental plate (less dense). Subduction zones are locations of high volcanic and earthquake activity.



Volcanism

- Flow of molten lava to Earth's surface.
- Creation of new land masses.
- Partly responsible for Earth's atmosphere (outgassing).

Plate Tectonics

- Reshaping of continents: **continental drift**.
- Formation of mountains.

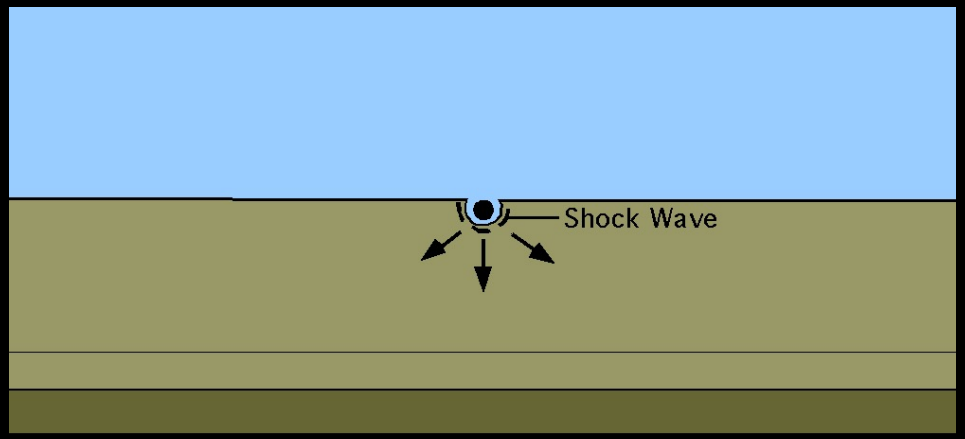
starting ~300 million years ago...
https://dinosaurpictures.org/ancient-earth

Erosion

- **Water and wind** erosion result in the weathering and transport of solids.
- Given enough time, erosion flattens mountains.

Impact Cratering

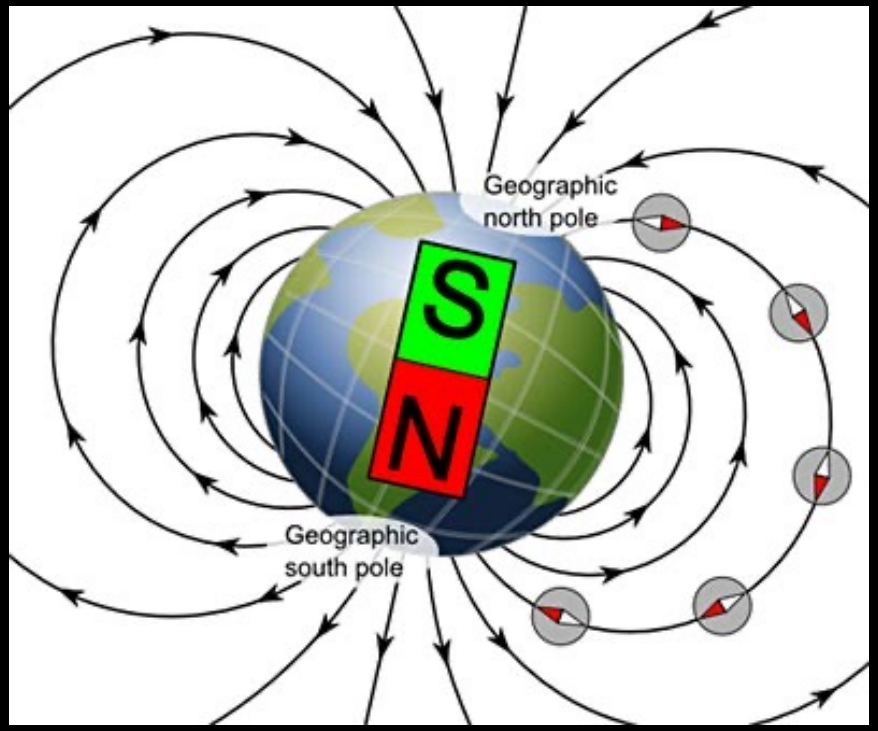
- Early in the Solar System, comets were responsible for bringing water to Earth.
- Subsequently responsible for mass extinctions, including dinosaurs.
- Still occurs today, with much less frequency

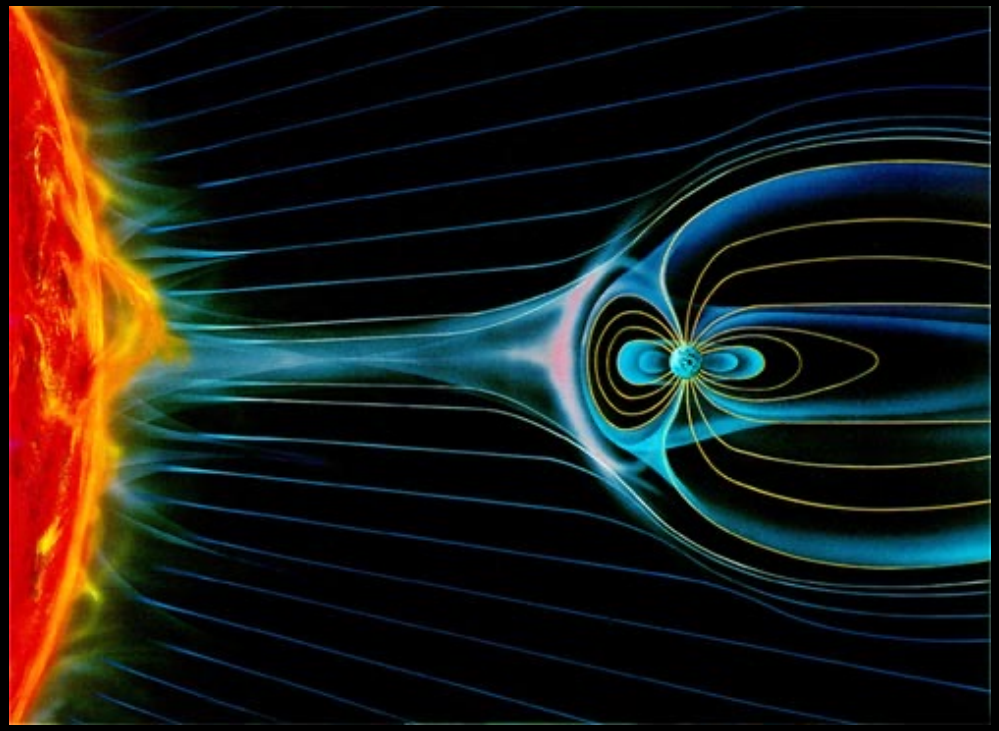


Earth's magnetic field

Earth's magnetic field

- Created by the currents in Earth's molten core.
- Protects atmosphere from bombardment by solar wind particles.





Why is a magnetic field essential for life?

- Compare Earth (strong magnetic field) with Mars (very weak magnetic field):
  - Earth's surface protected from solar radiation. Martian surface is not.
  - Earth has retained its atmosphere and its oceans. Martian oceans thought to have evaporated and been stripped away from the atmosphere by the solar wind.

Oceans and Atmosphere

If Earth formed in the warm inner solar system, how did it end up with an atmosphere and oceans of liquid water?

Oceans and Atmosphere

- Jovian planets knocked many icy planetesimals into inner solar system.
- Some planetesimals were incorporated into formation of the Earth, trapping gases in Earth's interior.
- Repeated comet impacts are thought to have supplied the water for Earth's oceans.

Oceans and Atmosphere

- Volcanism and outgassing supplied many of the components of the early atmosphere.
- Early life modified Earth's atmosphere, consuming carbon dioxide and creating oxygen.
- Earth may have been habitable very early in its history.

Let's talk about climate change…

United Nations Intergovernmental Panel on Climate Change (IPCC), publishes a report every 6 years, see 2020 (http://www.ipcc.ch/).

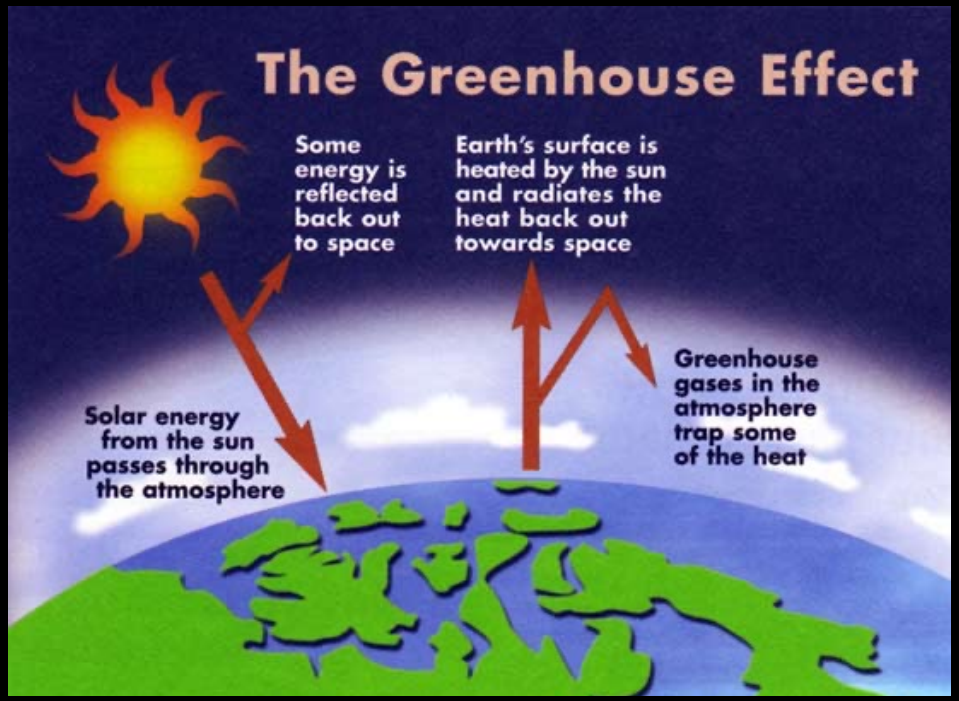
Climate vs. Weather

- **Weather** are conditions of the atmosphere over a short period of time.
- **Climate** is how the atmosphere behaves over long periods of time.

Earth's "thermostat"

Greenhouse effect

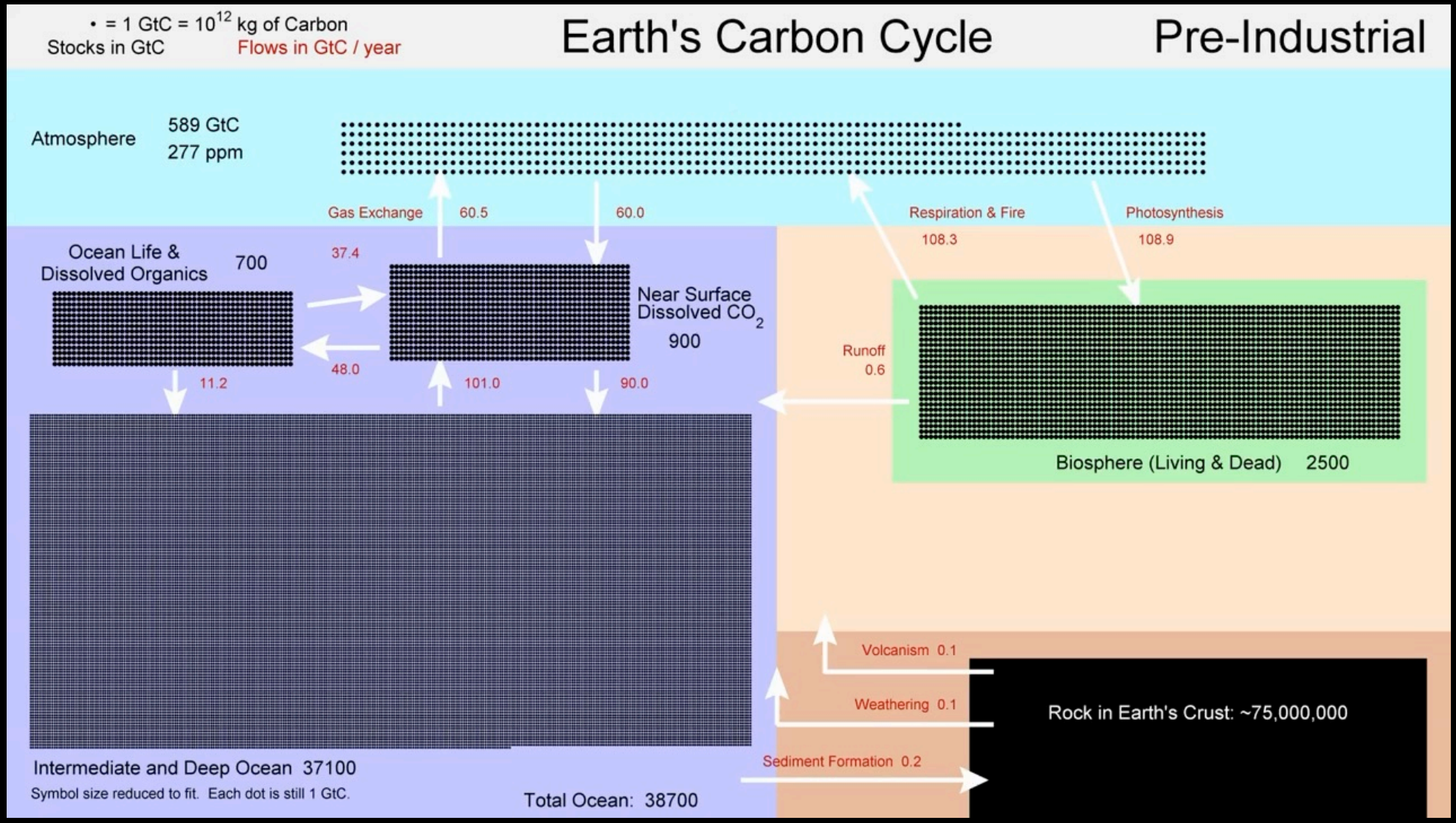
- Earth's climate has been relatively stable for billions of years, despite changes in the Sun's brightness.
- **Greenhouse gases** (carbon dioxide, water vapor, methane) reflect and trap radiated heat, stabilizing Earth's climate.



Carbon cycle = Earth's thermostat

- The Earth warms up a bit
- Carbonate minerals form in the oceans at a more rapid rate (this rate is very sensitive to temperature), pulling CO_2 out of the atmosphere at a faster rate
- Atmospheric CO_2 reduced
- Greenhouse effect weakens, counteracts the initial warming
- The Earth cools down

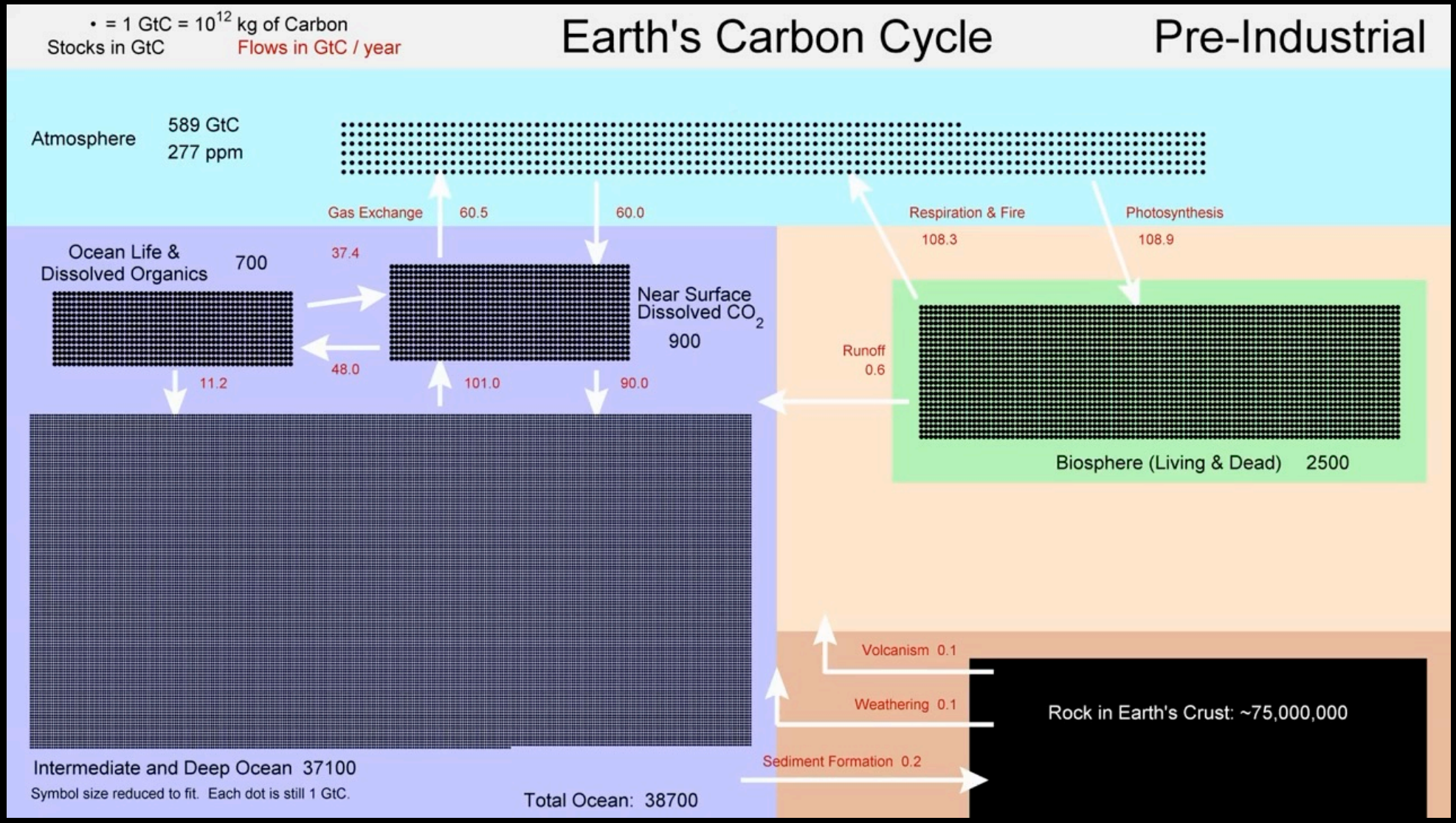
Carbon cycle



question for you

What are possible ways to break this thermostat?

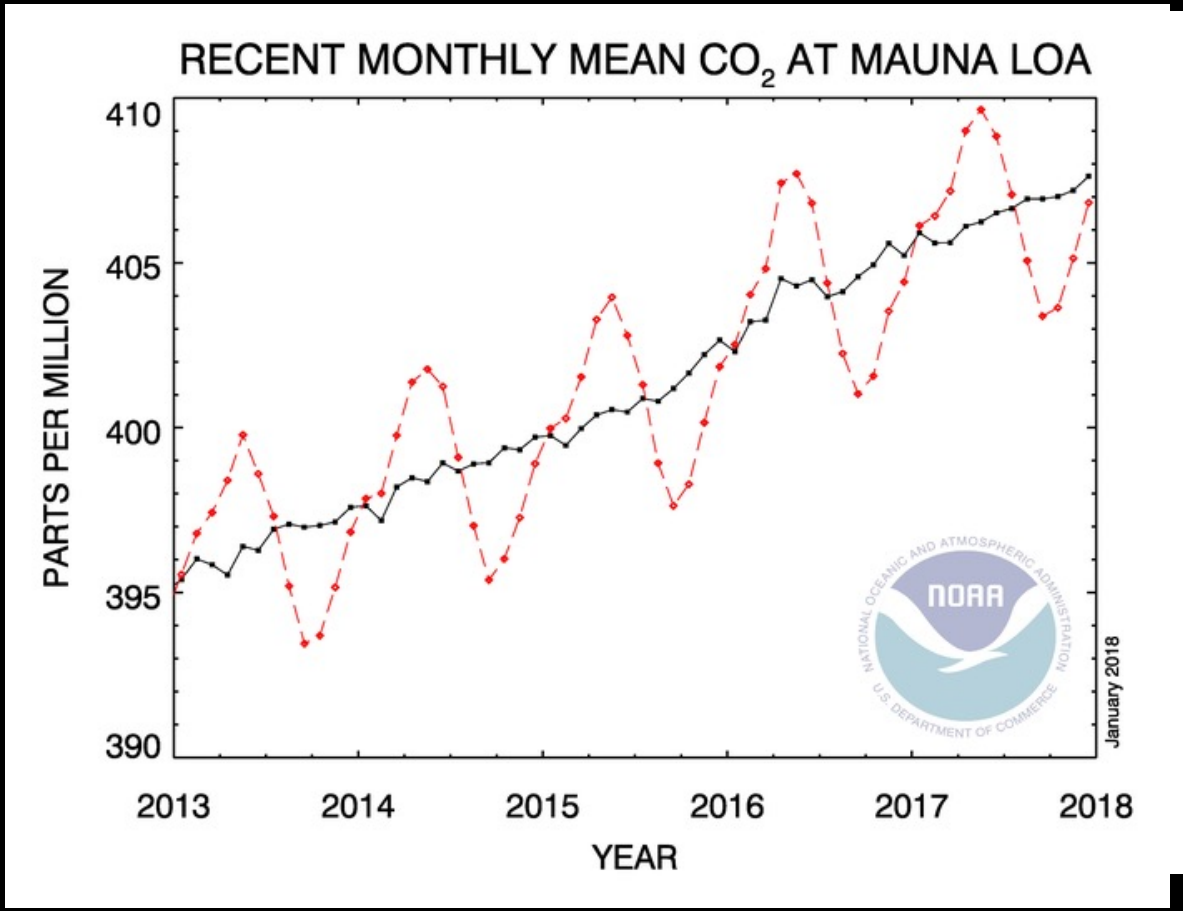
Carbon cycle



The Data

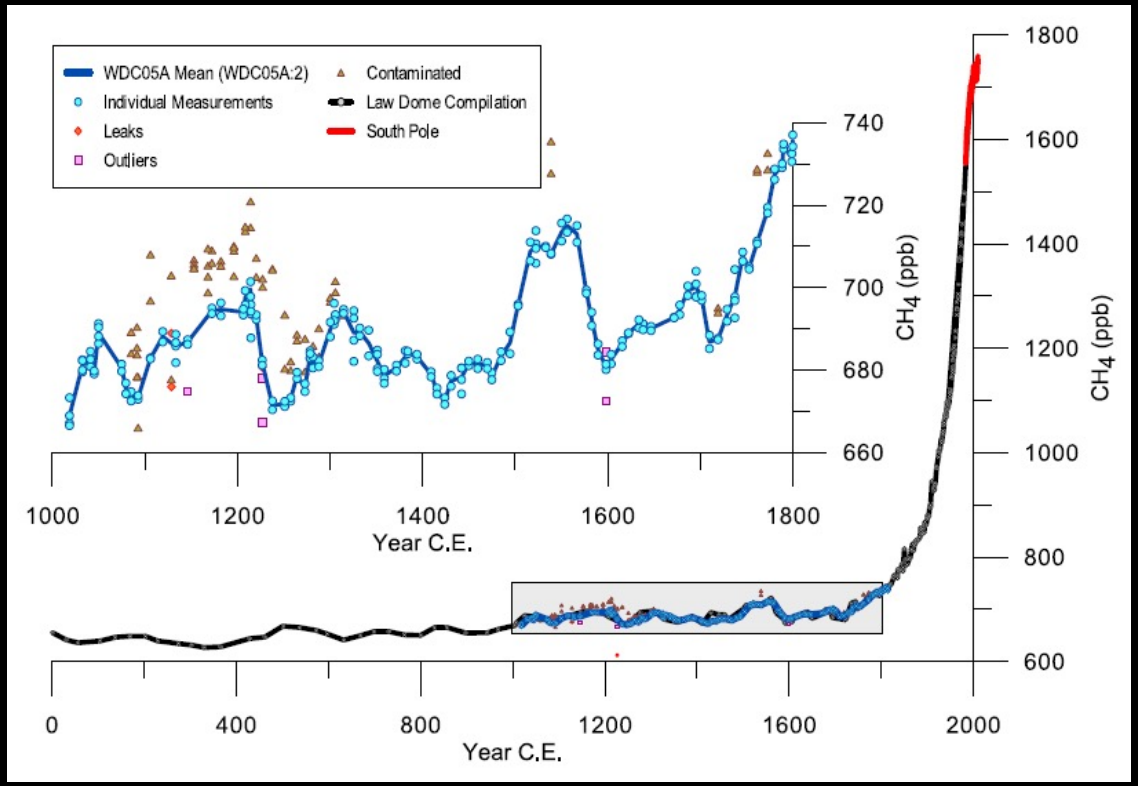
Atmospheric CO_2

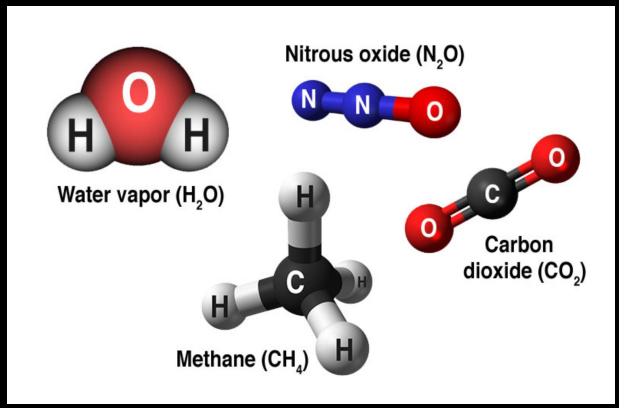
Atmospheric CO_2 exceeded 400 ppm for the first time in history in May 2015.



Changes in atmospheric composition

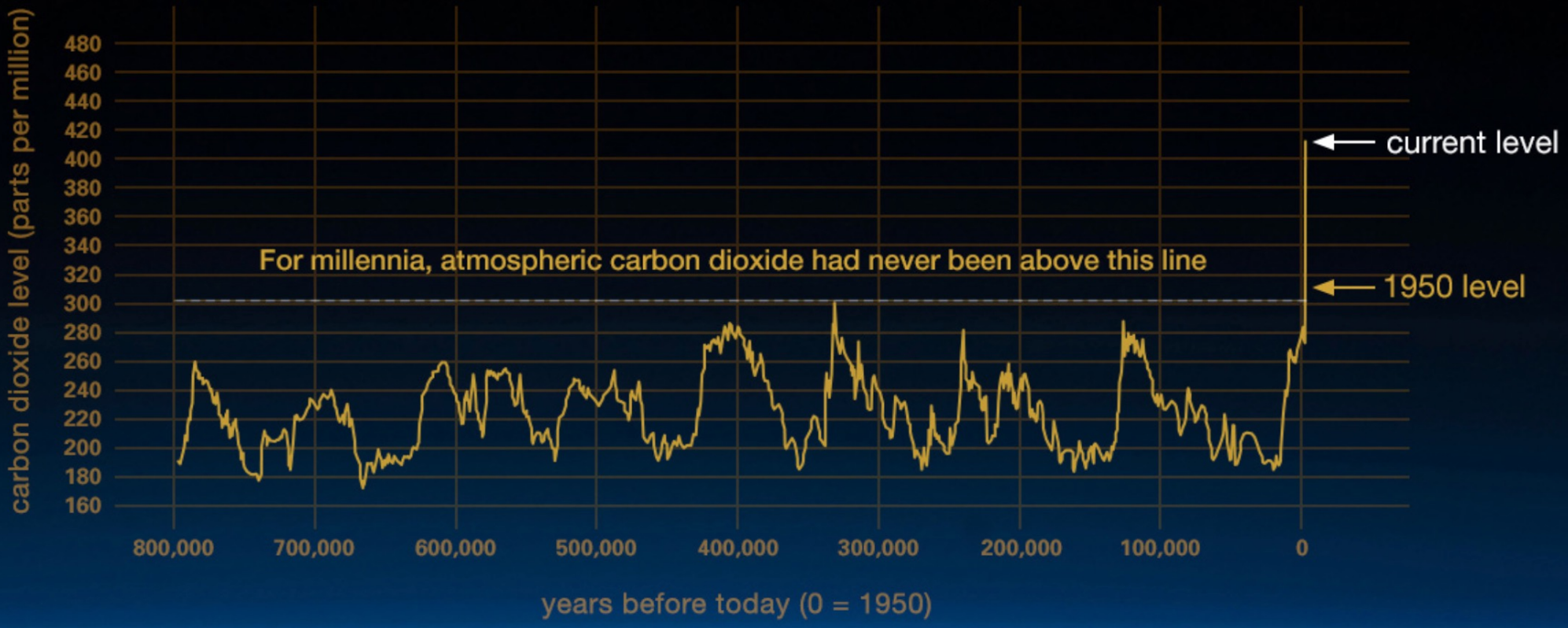
Methane is 72 times more effective as a greenhouse gas than CO_2. Atmospheric methane exceeded 1800 ppb in 2020.



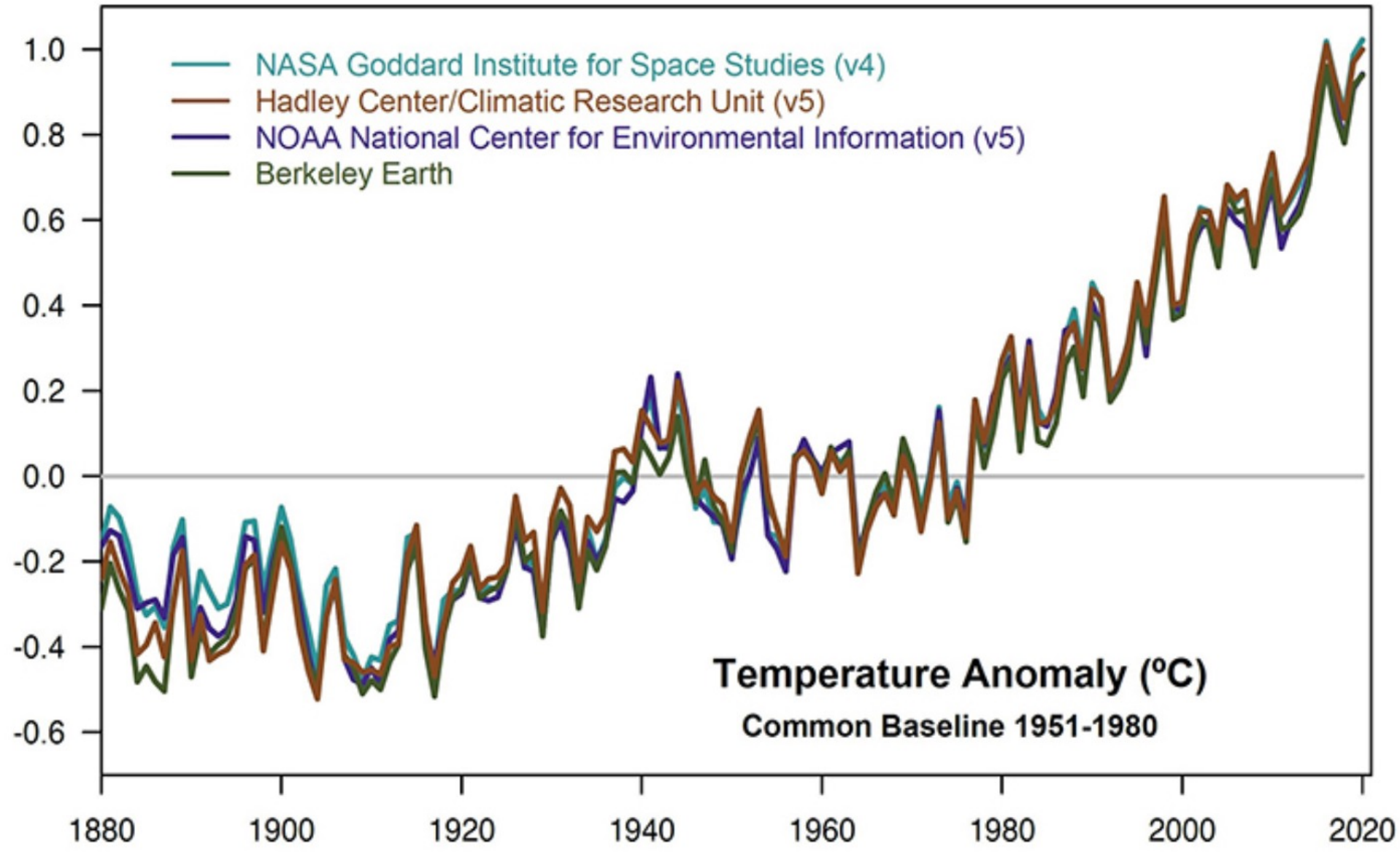


How unusual is today?

NOAA measurements of atmospheric CO_2 show highest levels in last 650,000 years!

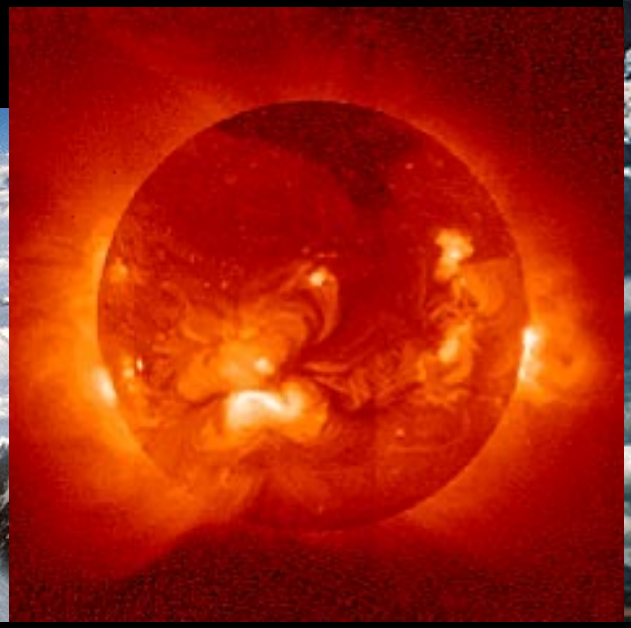


Global rise in temperatures



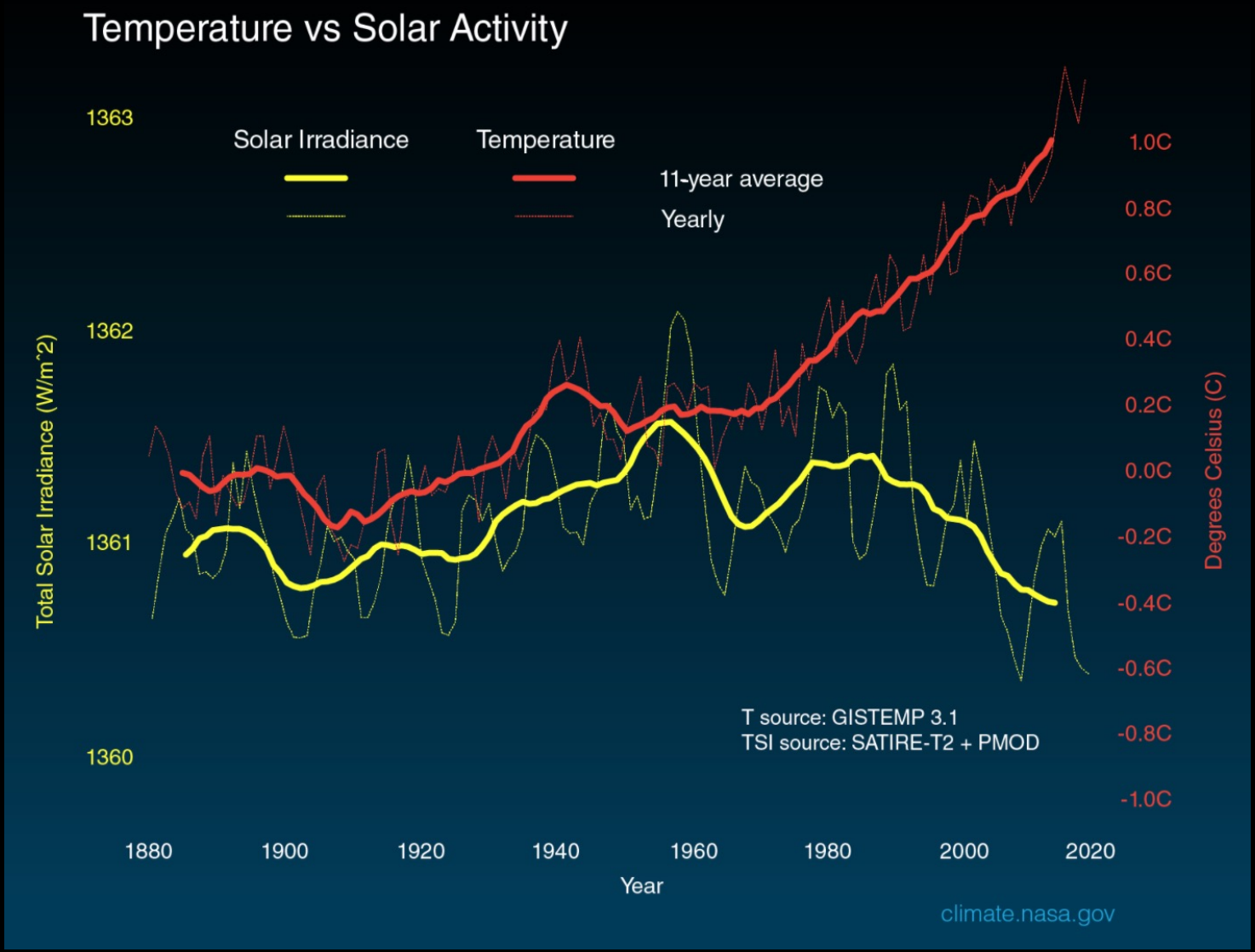
Global warming

- **Global temperatures have steadily risen by about 1 °C (1.8 °F) during the last 100 years…**
- Causes for temperature change could be:
  - Slight change in Sun's power output
  - Glacial cycles
  - Increased volcanism
  - Human activity



The cause?

It's not the Sun...



question for you

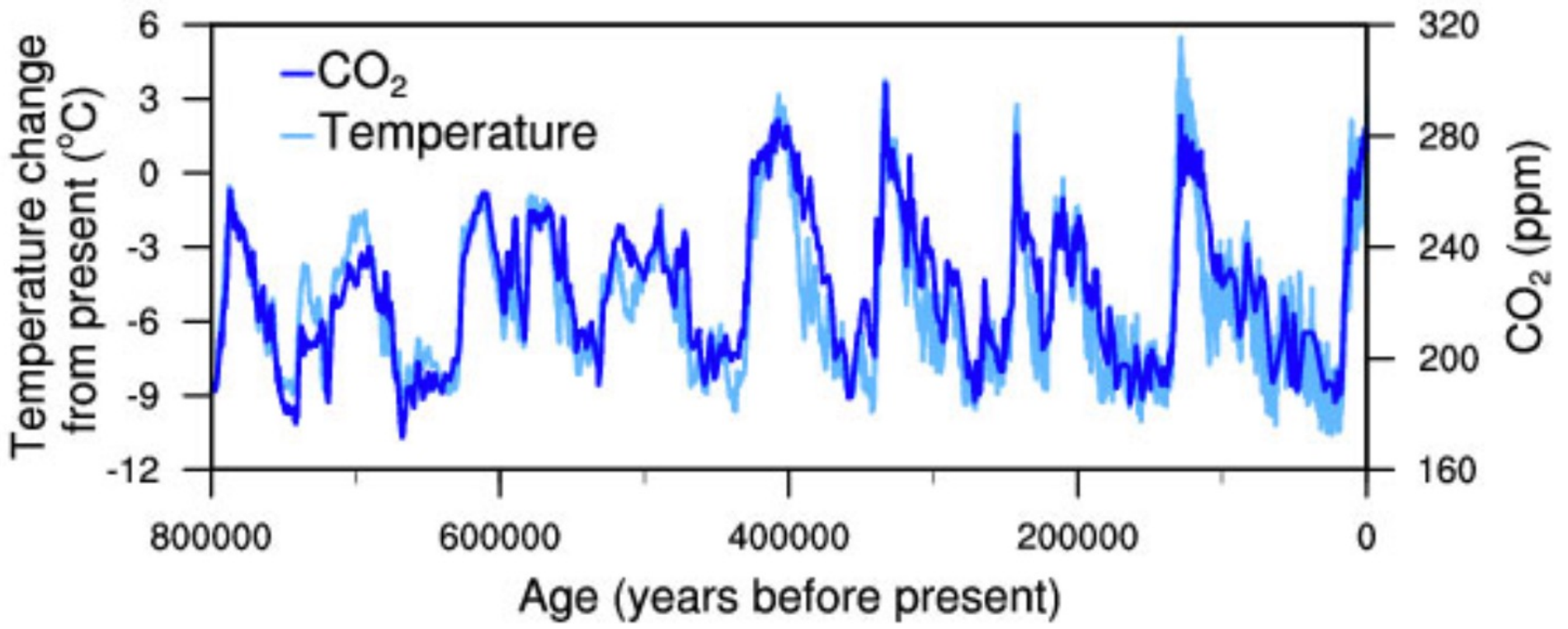
How would you test whether it's us?

The scientific method

🍎 **observation** → 💡 hypothesis→ 🪐 prediction

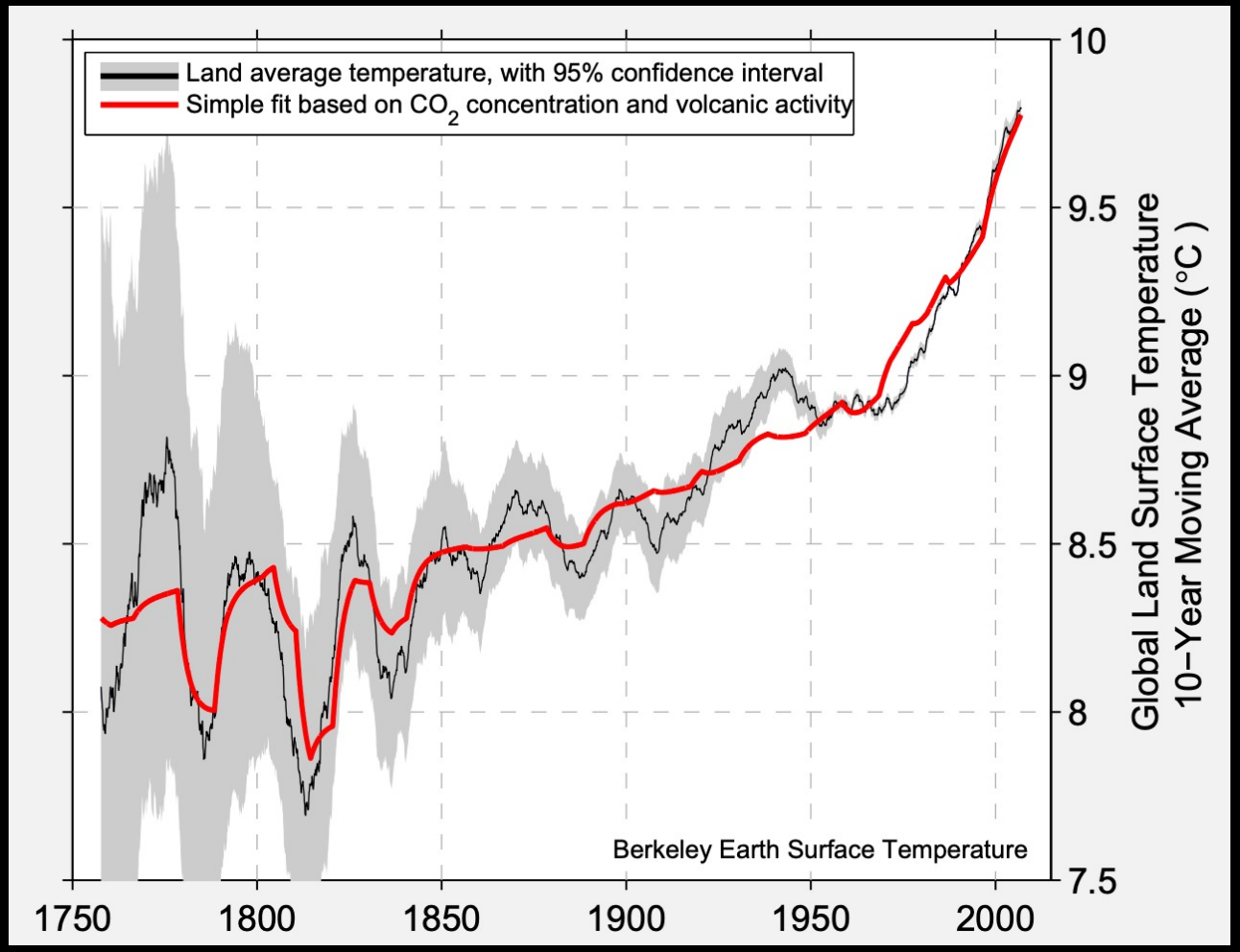
→ 🔭 test → **theory (model)**

NOAA ice core data show a correlation between atmospheric CO2 and temperature



Temperature change (light blue) and carbon dioxide change (dark blue) measured from the EPICA Dome C ice core in Antarctica (Jouzel et al. 2007; Lüthi et al. 2008).

If we try to guess the temperature trends from CO2 measurements, it works.



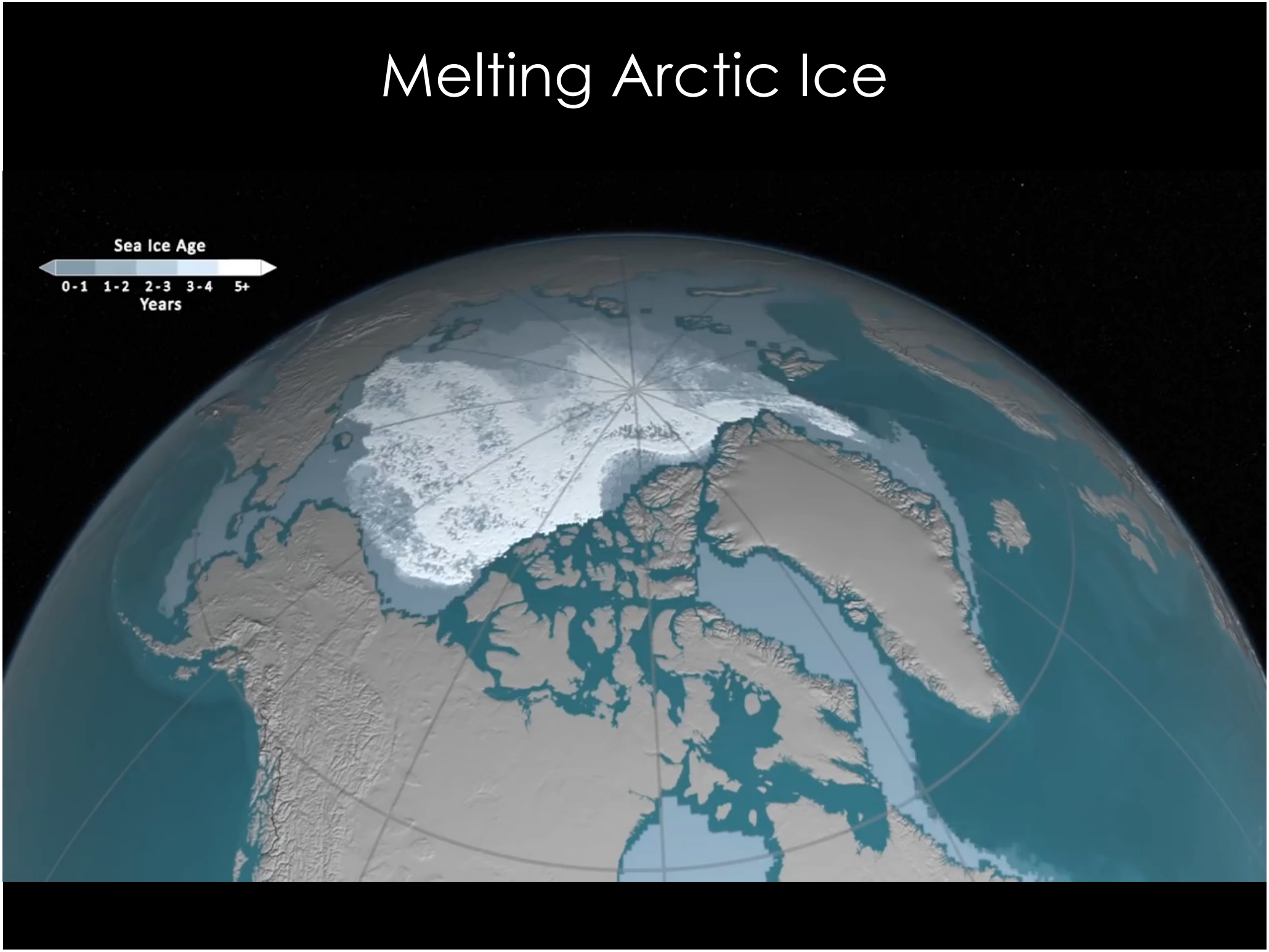
http://berkeleyearth.org/data-visualization/

The Future

Acidification and warming of oceans

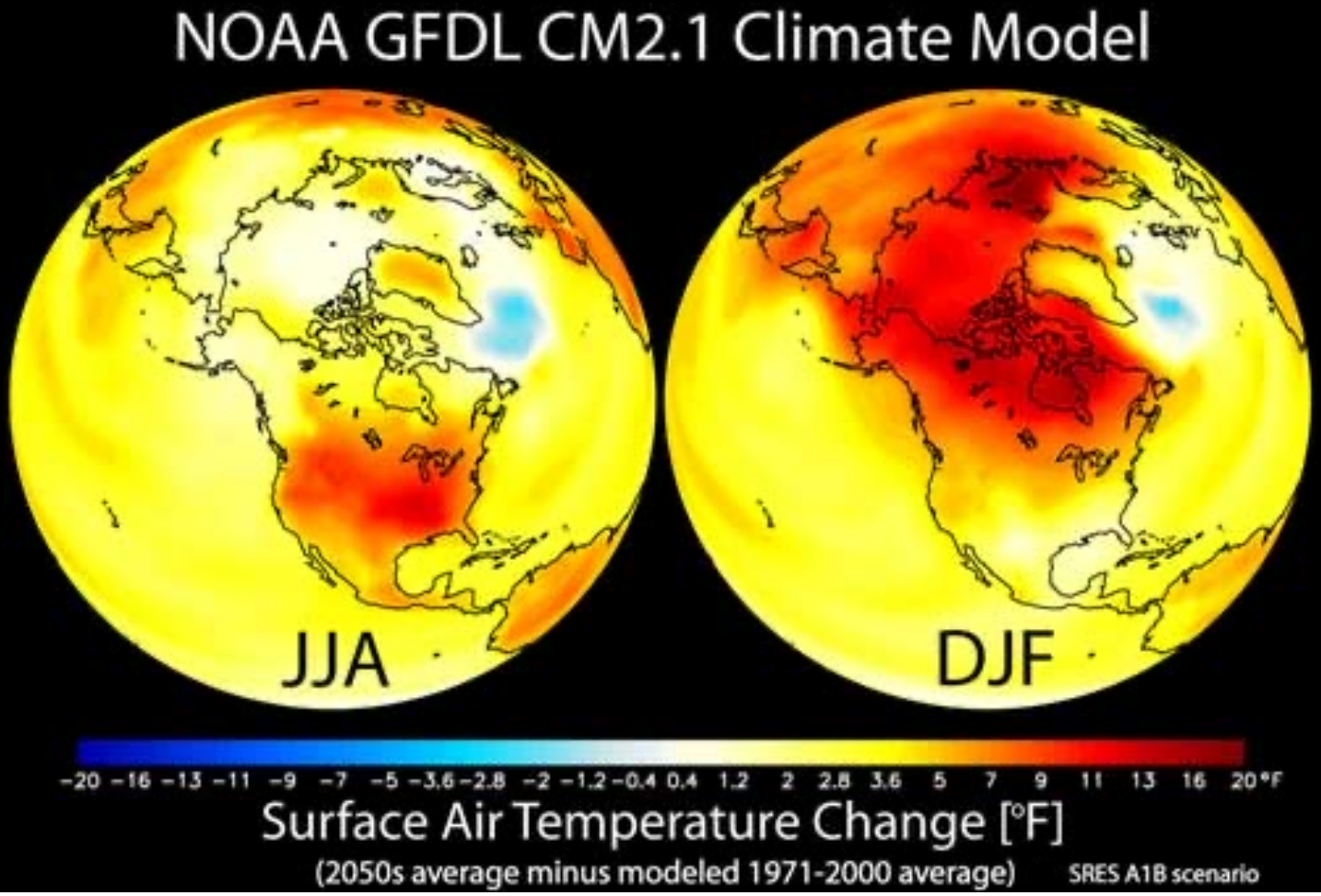
Oceans are absorbing excess CO2, and becoming more acidic. They are also warming up.

Melting Arctic Ice



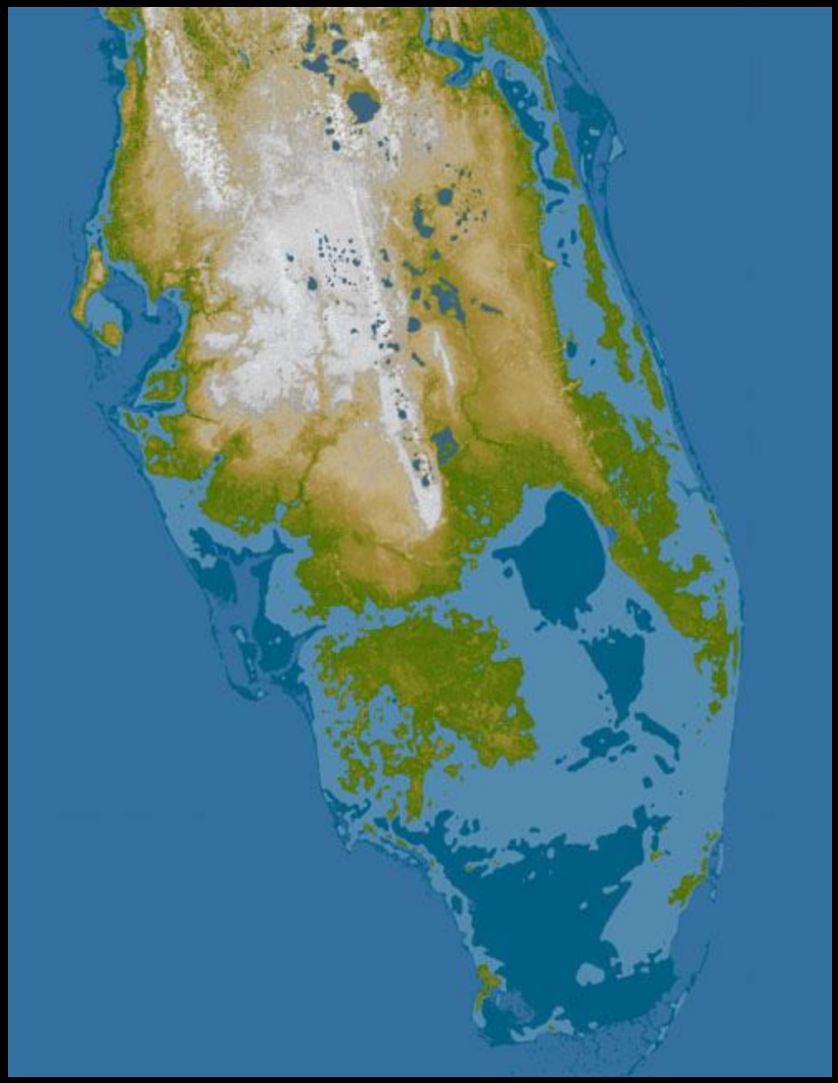
NOAA Contributions to IPCC Report

- Projected change in annual mean surface air temperature from the late 20th century (1971-2000 average) to the middle 21st century (2051-2060 average)



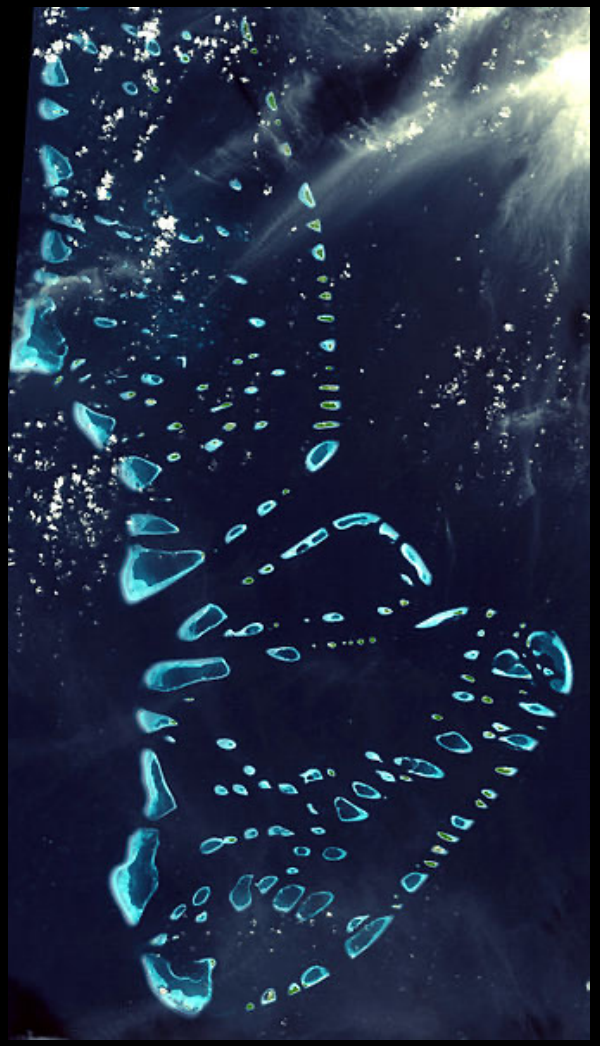
Vanishing Coastlines

- 634 million people live worldwide within 30 ft of sea level.
- Two-thirds of world's cities with more than 5 million people located in coastal areas.
- A 10-m rise in sea level in Florida shown on the right.

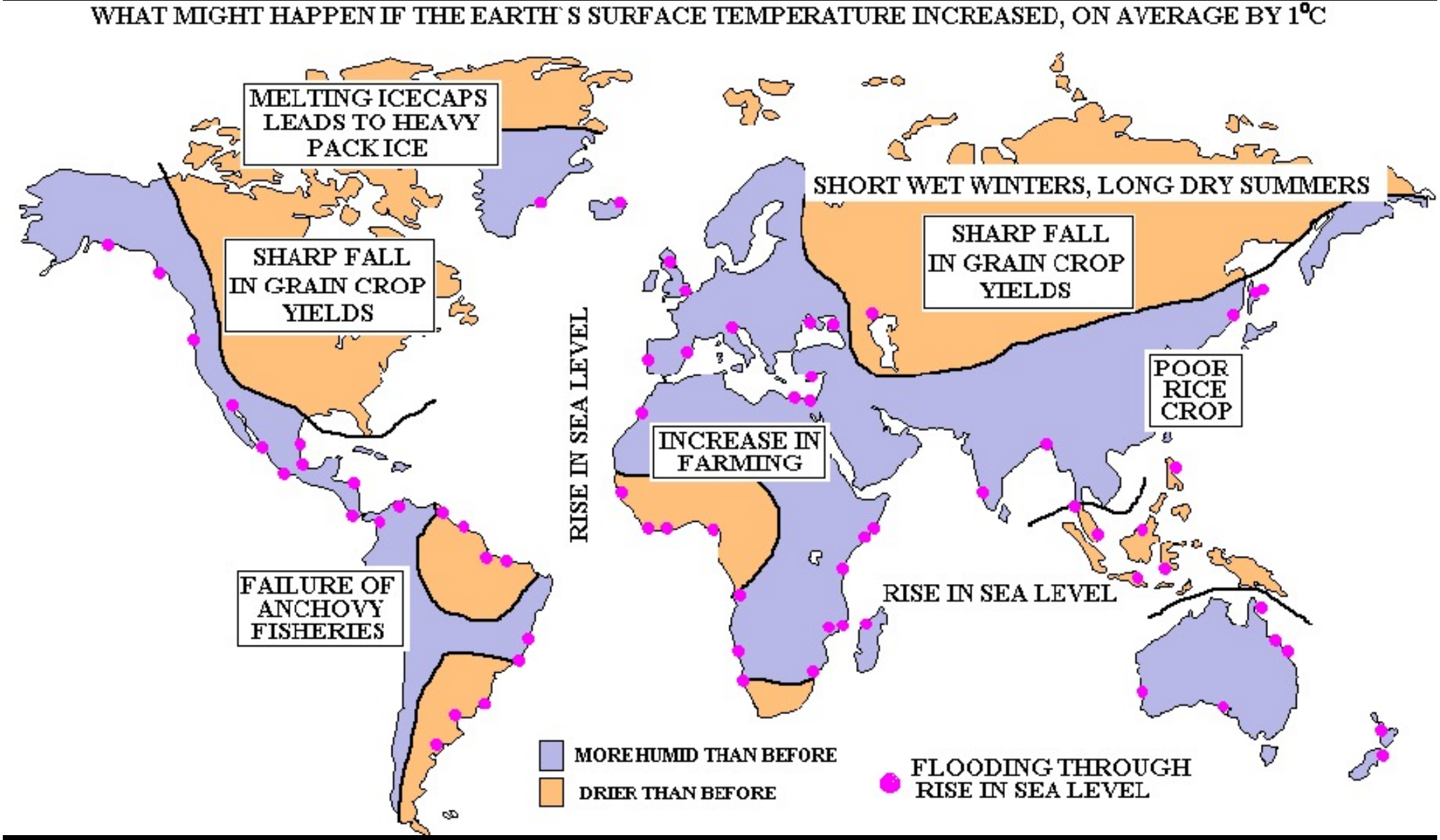


Vanishing Countries

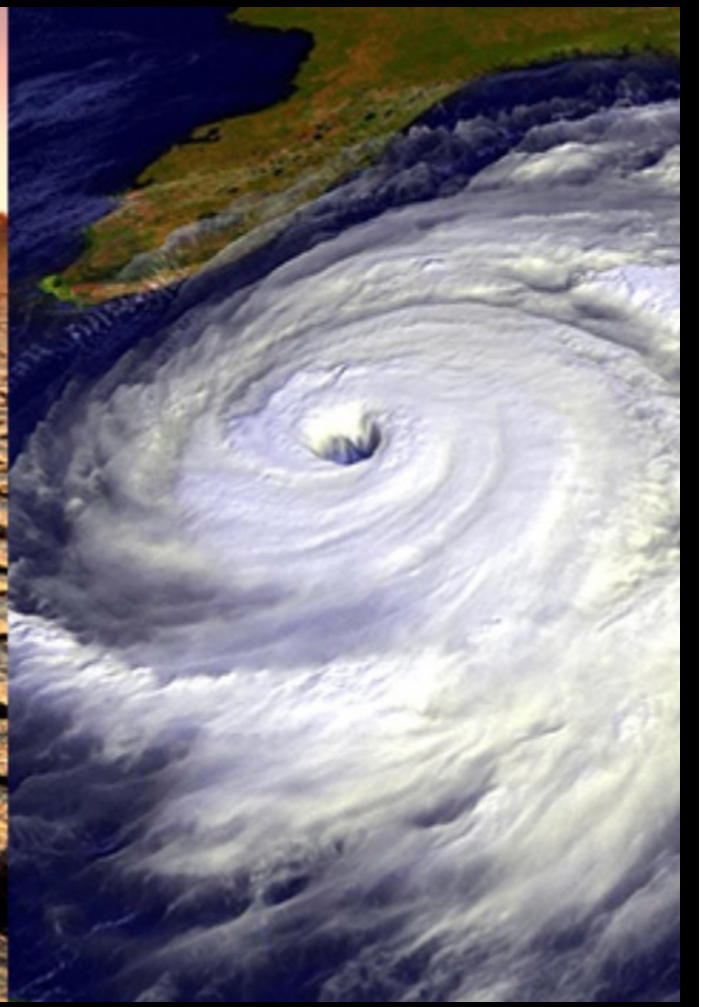
- Highest (natural) point in Republic of Maldives is 2.3 m above sea level.
- More than 80% of the land is below 1.0 m above sea level.
- Island nation will "disappear" in the next 100 years.



Precipitation and extreme weather



Disruption of a delicate balance: Into the Unkown…



question for you

What should we do about it?

What did we learn in Chapter 19?

- Four geologic processes on Earth: Plate tectonics, volcanism, erosion, impact cratering.
- Plate tectonics and volcanism driven by convection of heat from Earth's interior.
- Differentiation is the separation of elements by density when the interior of a planet is molten.
- Earth's magnetic field is generated in the fluid outer core.
- Changes in Earth's orbit cause cyclical changes to climate, including ice ages.

What did we learn in Chapter 19?

- Earth's geologic history divided into four eons: Hadean, Archean, Proterozoic, Phanerozoic.
- Most of the water now found in Earth's oceans brought by comet impacts.
- Earth's early atmosphere was mostly carbon dioxide and sulfur outgassed from volcanoes.
- Greenhouse gases in Earth's atmosphere (carbon dioxide, methane, water vapor) increase the average temperature on the surface of the Earth.
- The planetary CO_2 cycle is able to regulate, on long time scales, the temperature of the Earth.

What did we learn in Chapter 19?

- Climate change is a result of human action, and is causing a rise in global temperatures due to the increase of the carbon dioxide content of Earth's atmosphere.
- Consequences of climate change are
  - Rise in sea levels, vanishing coastlines
  - Hotter, drier summers
  - Severe weather events.