



Last Lecture – Global change

Global change

- What is Global Change?
- What drives Global Change?

Global change

- What is Global Change?
- What drives Global Change?
 - Solid earth
 - Atmosphere
 - Life
 - Continents
 - Sea level
 - Rocks
 - Biogeochemical
 - Hydrologic
 - Carbon

Global change

- What is weather?
- What is climate?

Global change

- Transformations or modifications of physical or biological components of Earth system
- Gradual vs catastrophic change
- Unidirectional vs cyclic changes

Steady State

- What is steady state?
- What does thermodynamics say about Earth's future?

Steady State

- Heat is created inside our Earth from radioactive decay. As radioactive elements are used up, there will be less energy inside the Earth.
- Eventually Earth will lose its tectonic activity.

Entropy

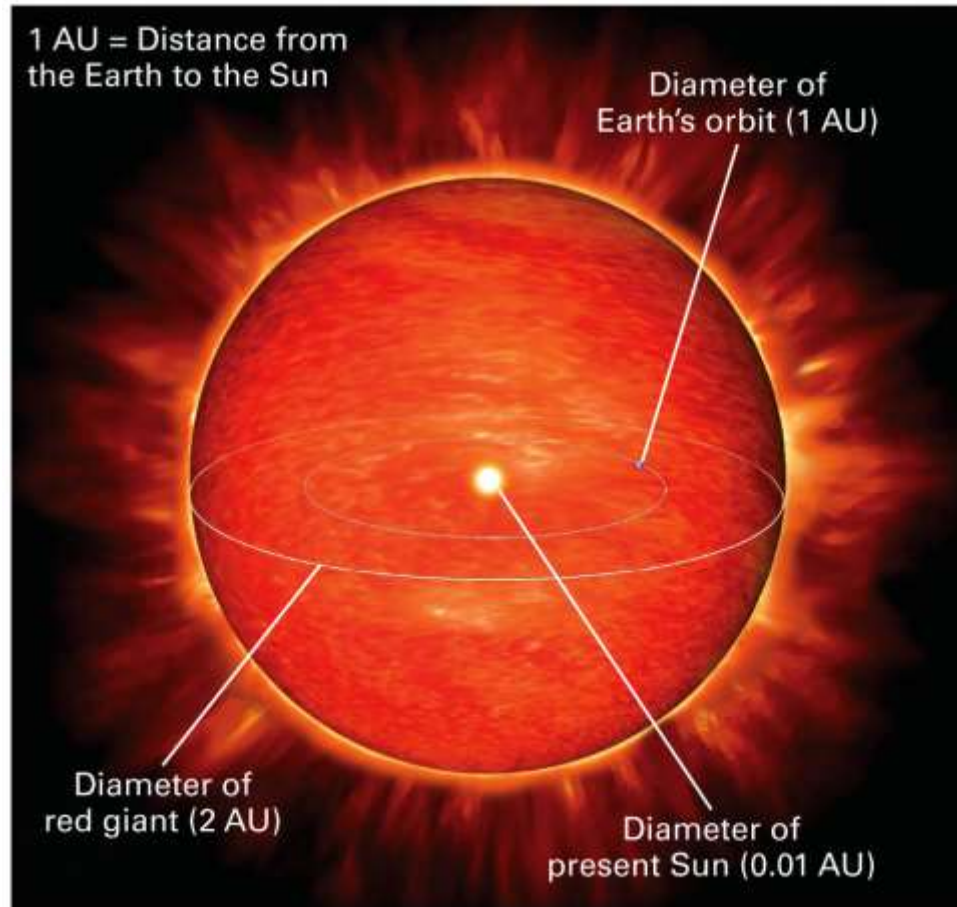
- Entropy is a cost to create “order” from chaos
- Heat death of the universe!
- Each time a reaction happens, some of its energy is lost to entropy.
- Eventually all energy which could be used for work will be lost.

Geologic/Universe time is not human time



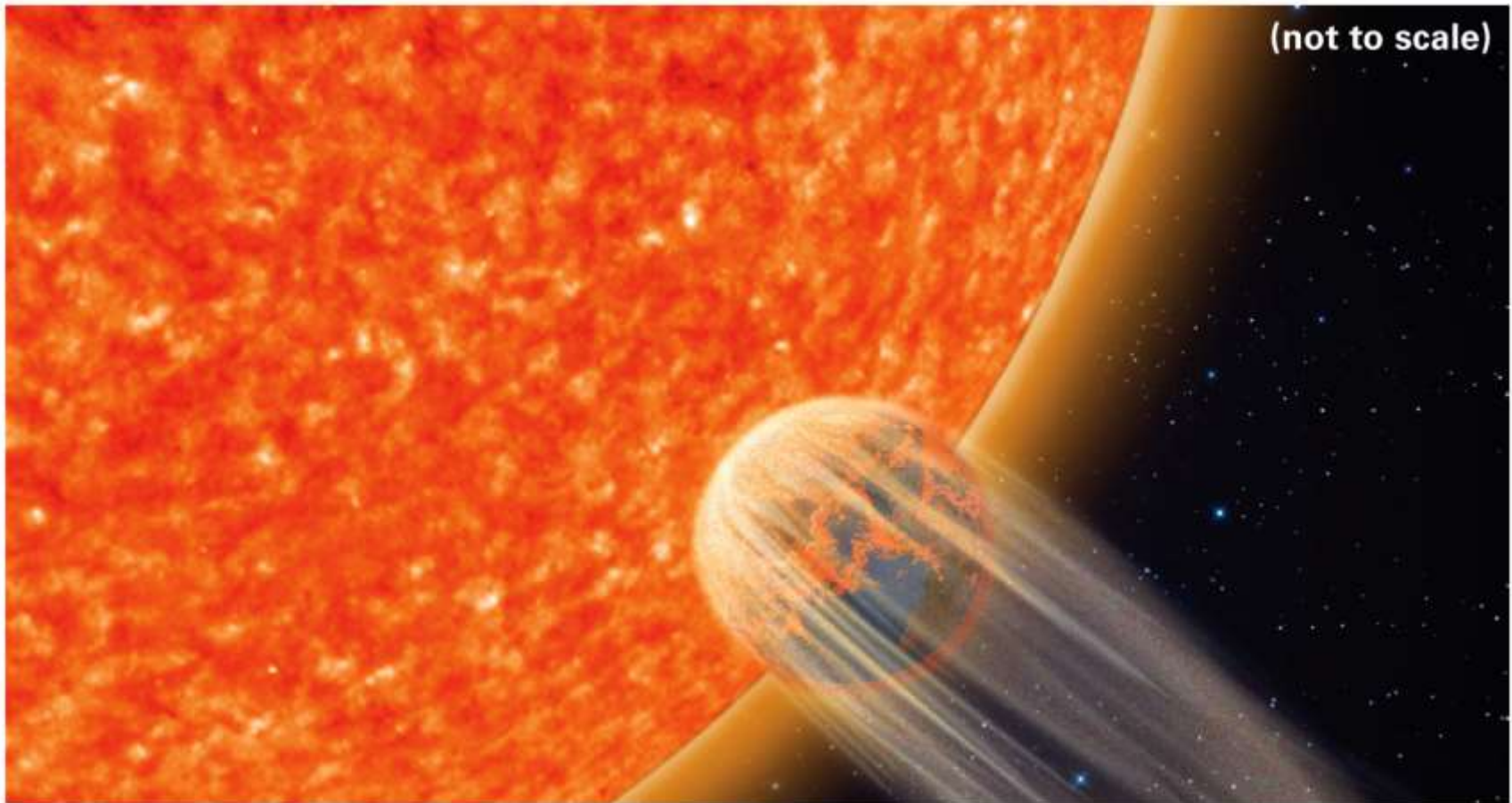
Copyright © 2016 W. W. Norton & Company, Inc.

Geologic/Universe time is not human time



Copyright © 2016 W. W. Norton & Company, Inc.

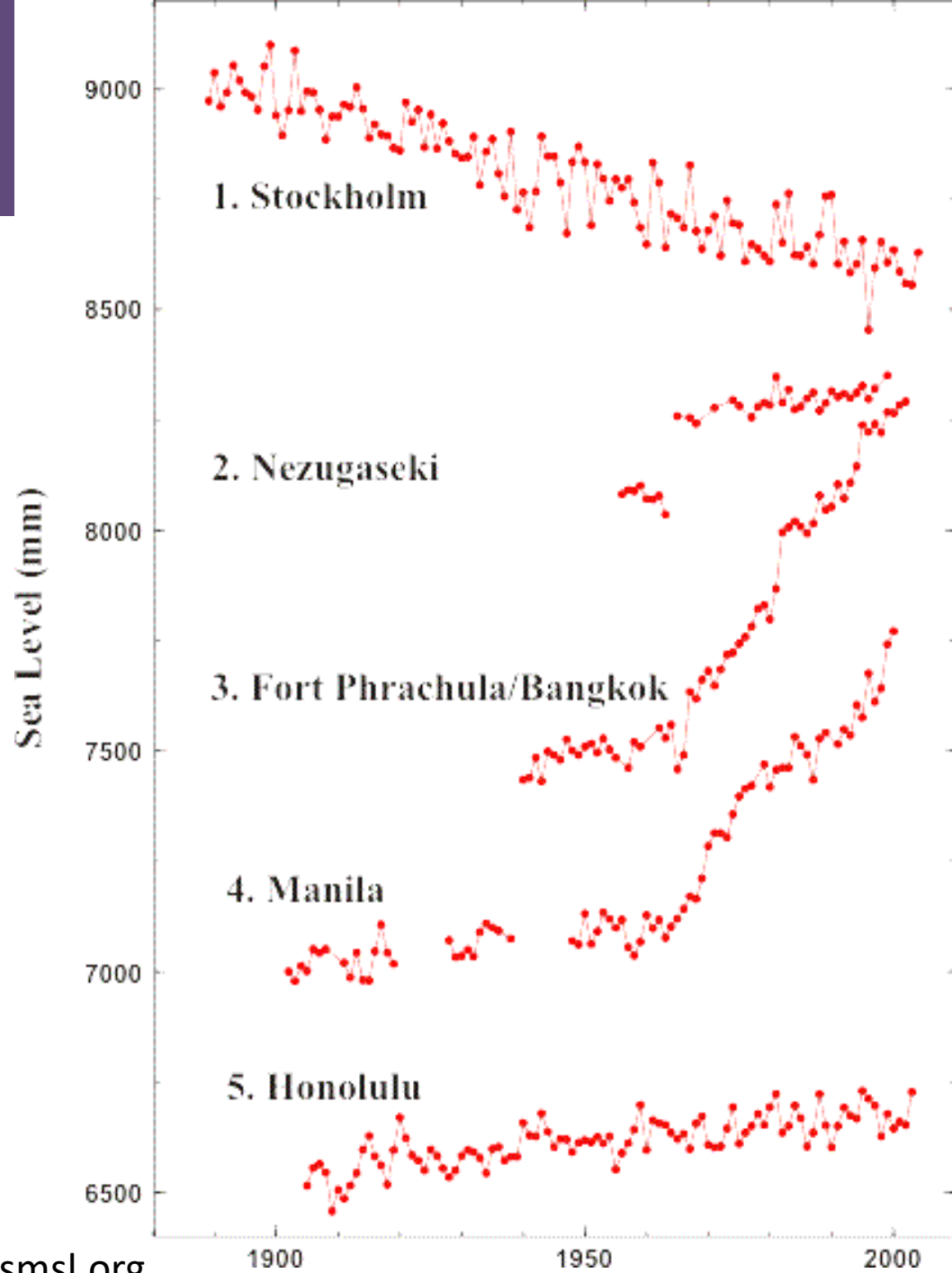
Geologic/Universe time is not human time



Measuring sea level

- What is 'sea level'?
- How do we measure it?

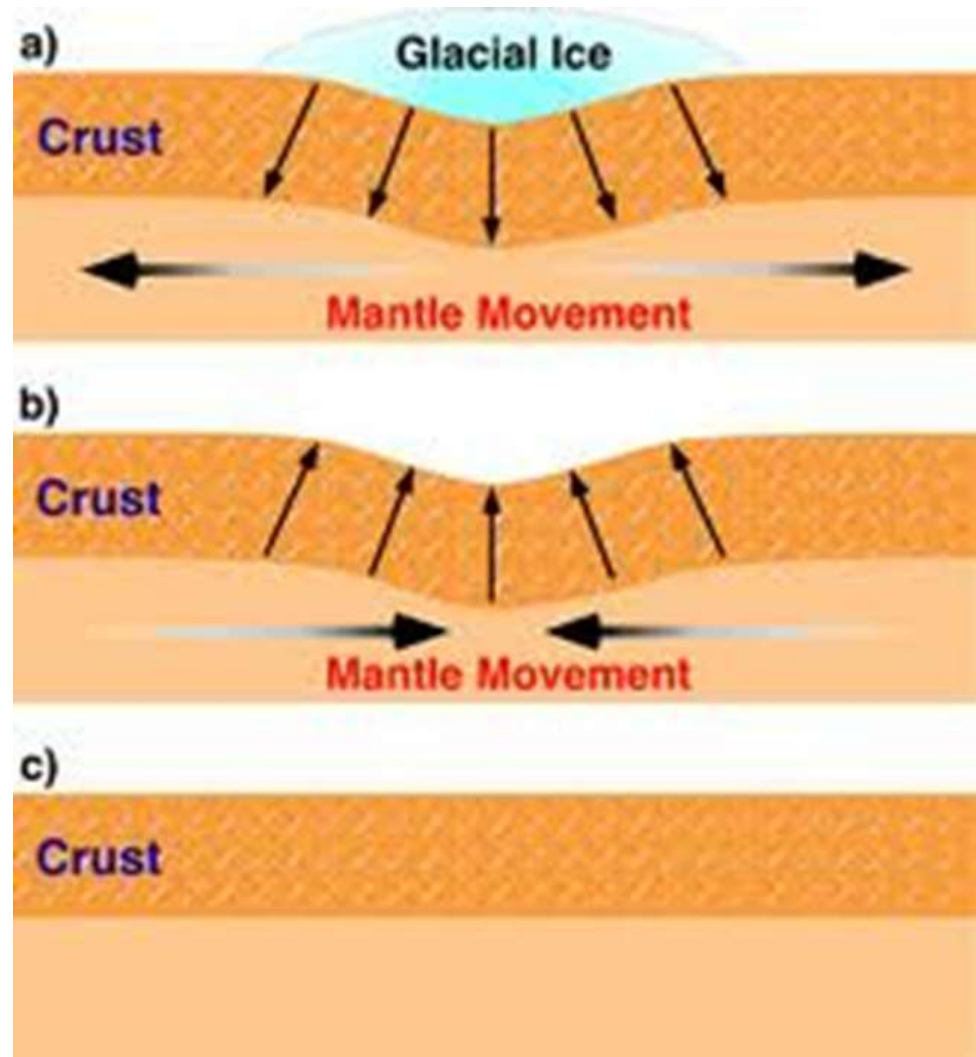
Examples of tide gauge records



Isostatic vs eustatic sea level change

- Isostatic (local) sea level varies due to:
 - Movement of land surface e.g. loading, plate tectonics
 - Atmospheric pressure
 - Ocean currents
 - Temperature of local water currents
- Eustatic (global) sea level varies due to:
 - Change in mass of ocean water e.g. ice sheet melting, or increased evaporation
 - Change in volume of ocean basins (over millions of years)
 - Density changes of water (thermal expansion or contraction)

Isostatic sea level change: Glacial loading and rebound

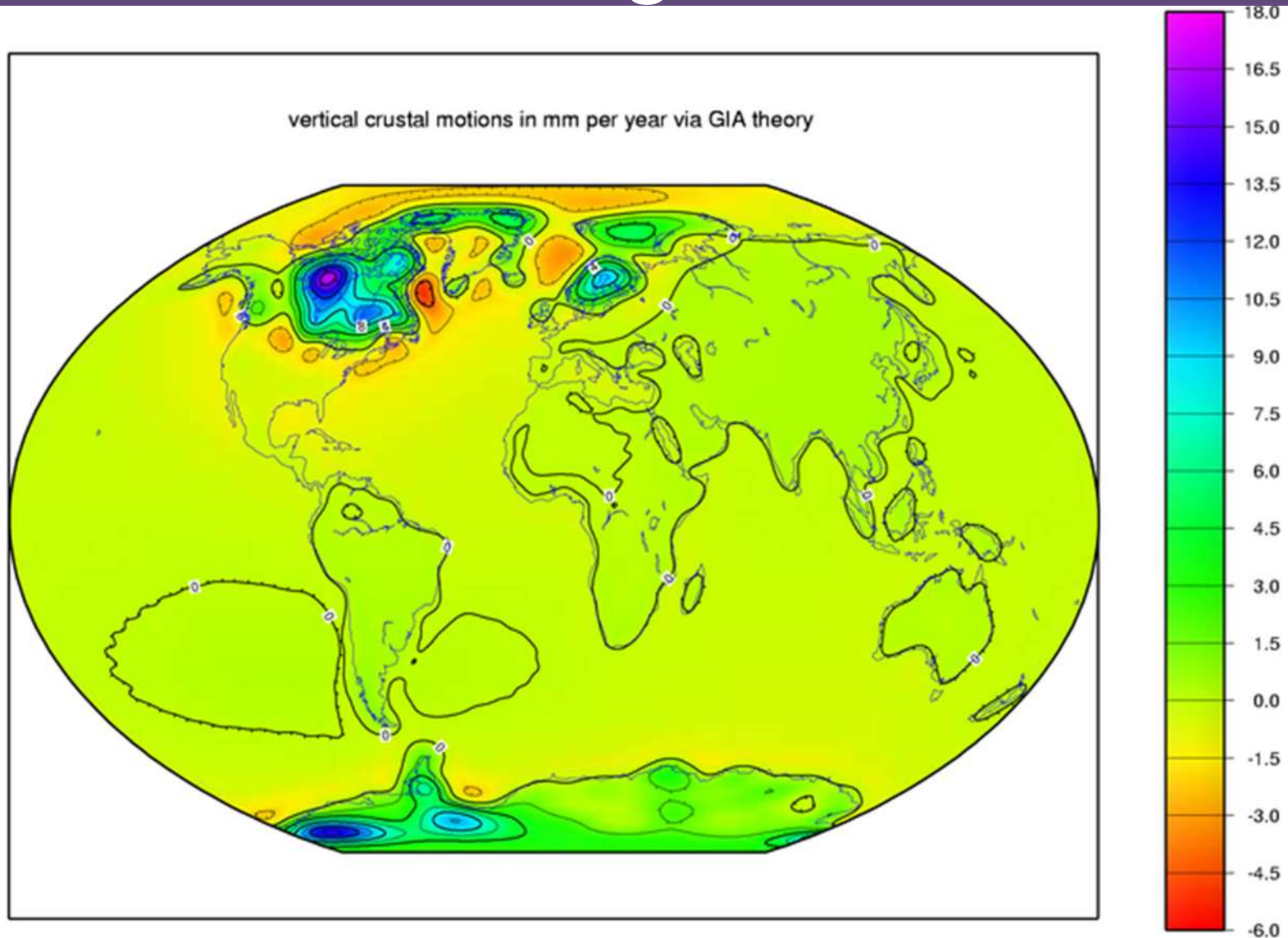


Isostatic sea level change: Glacial loading and rebound



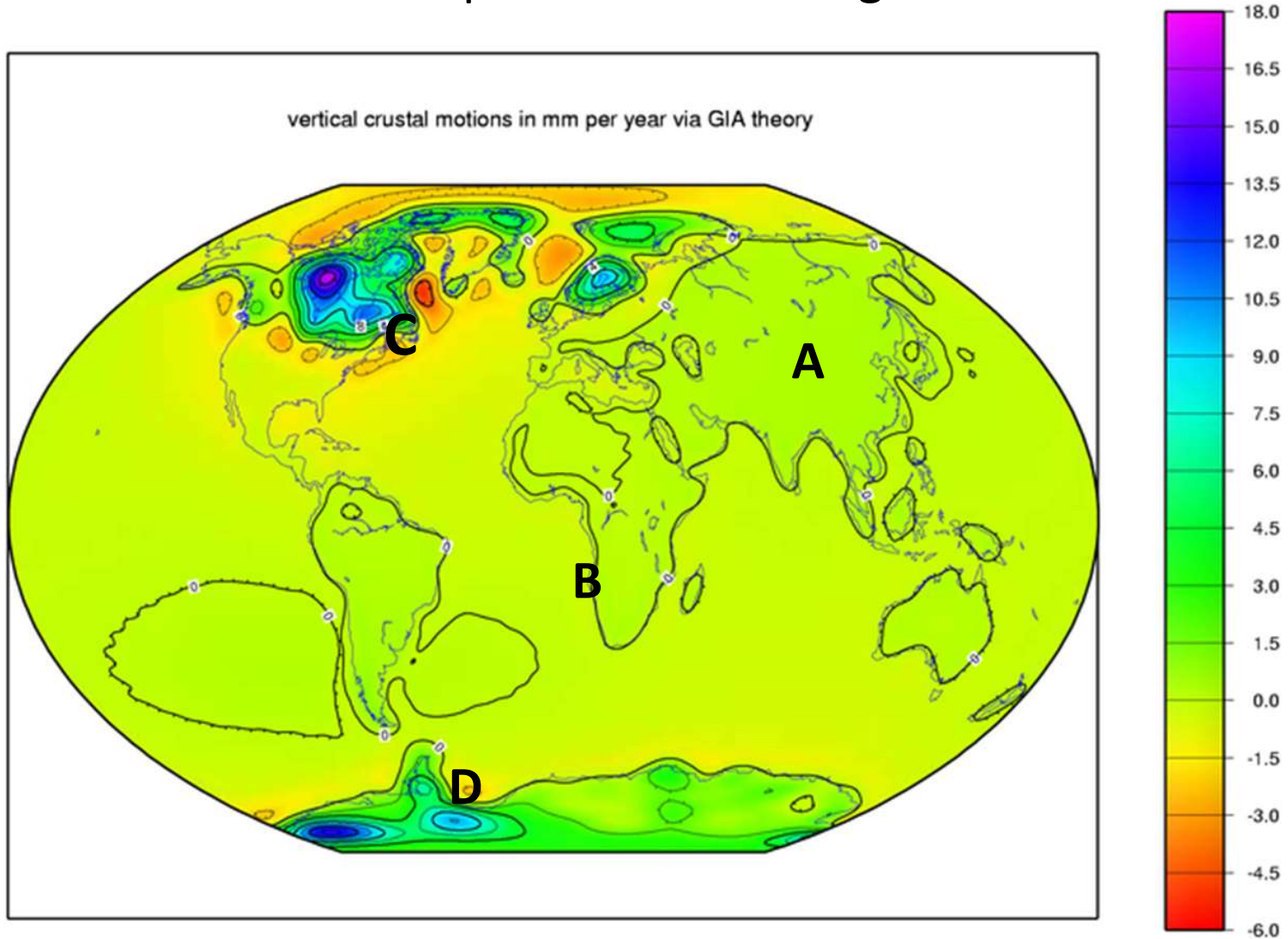
Mike Beauregard from Nunavut, Canada

Isostatic sea level change: Glacial loading and rebound



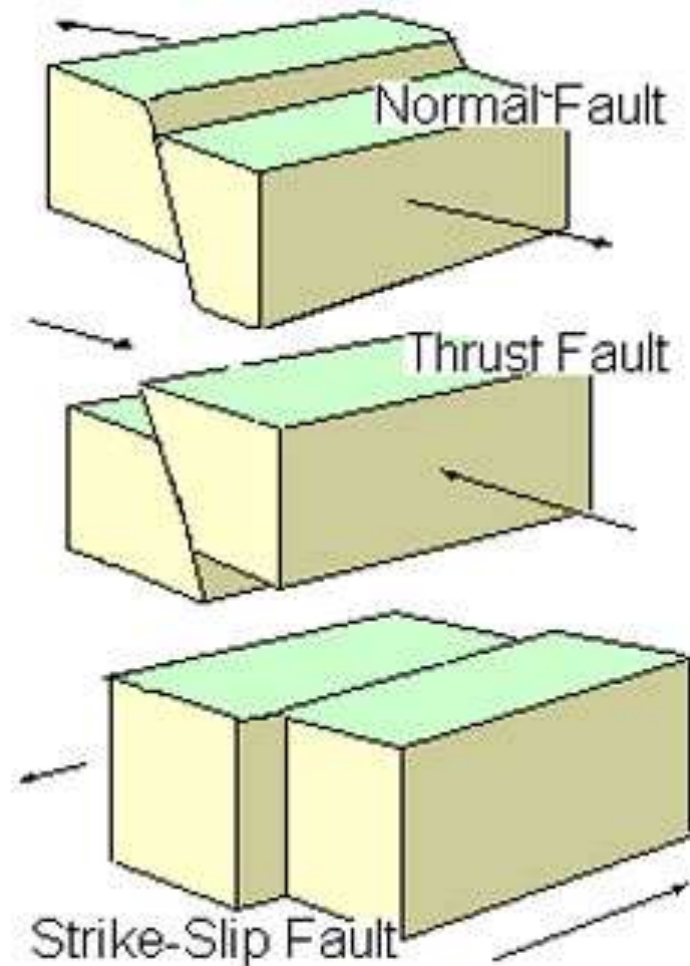
Isostatic sea level change: Glacial loading and rebound

Where would be the best place to measure global sea level changes?



Isostatic sea level change: Plate tectonics

- Plate boundaries sometimes occur close to the edges of continents
- Some areas uplifting = local sea level fall
- Some areas subsiding = local sea level rise
- Earthquakes result in sudden changes in sea level



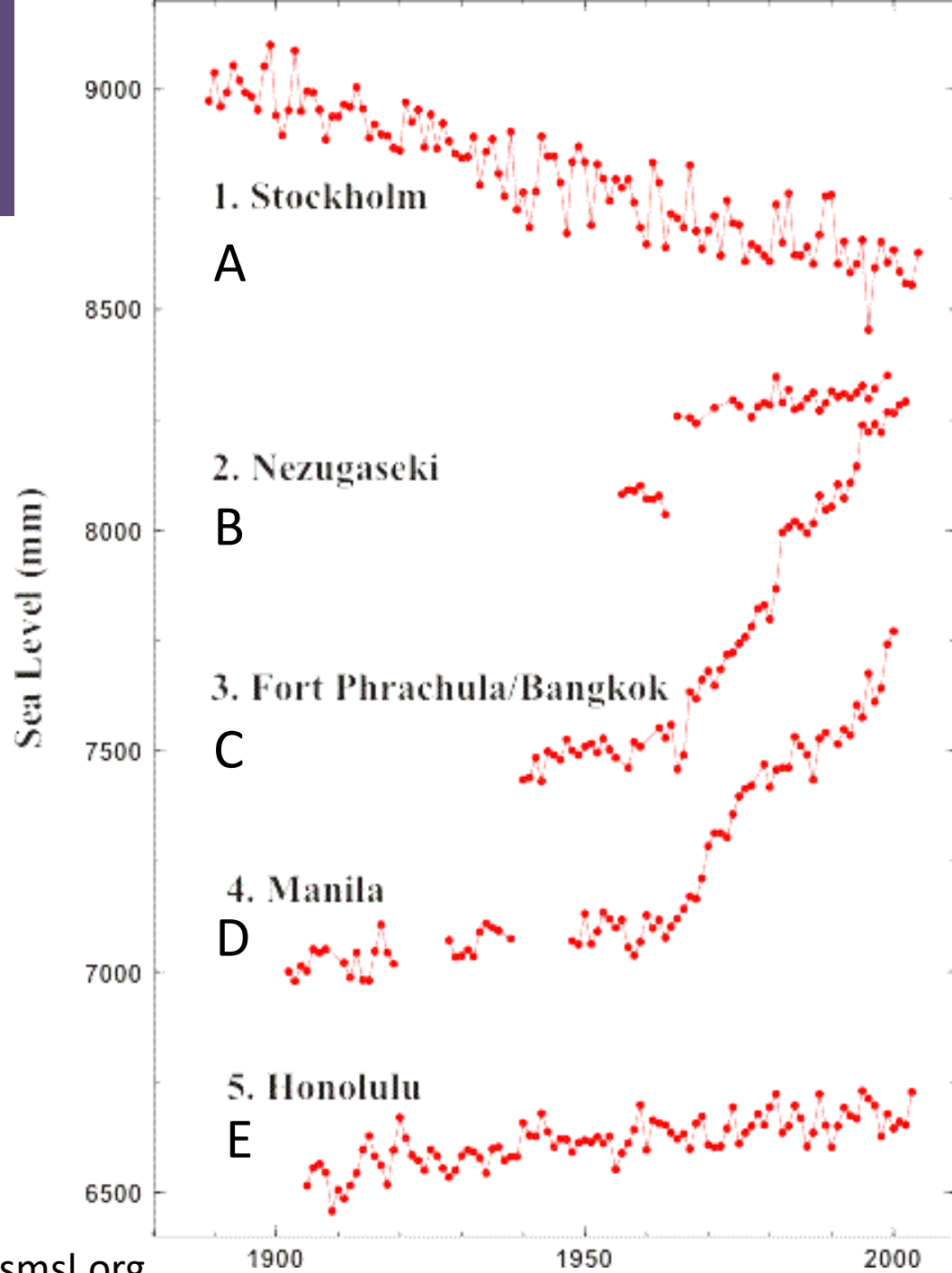
Isostatic sea level change: Plate tectonics

e.g. 3m rise in the land level after 8.0 magnitude earthquake in Solomon islands in 2007 left huge areas of coral reef exposed



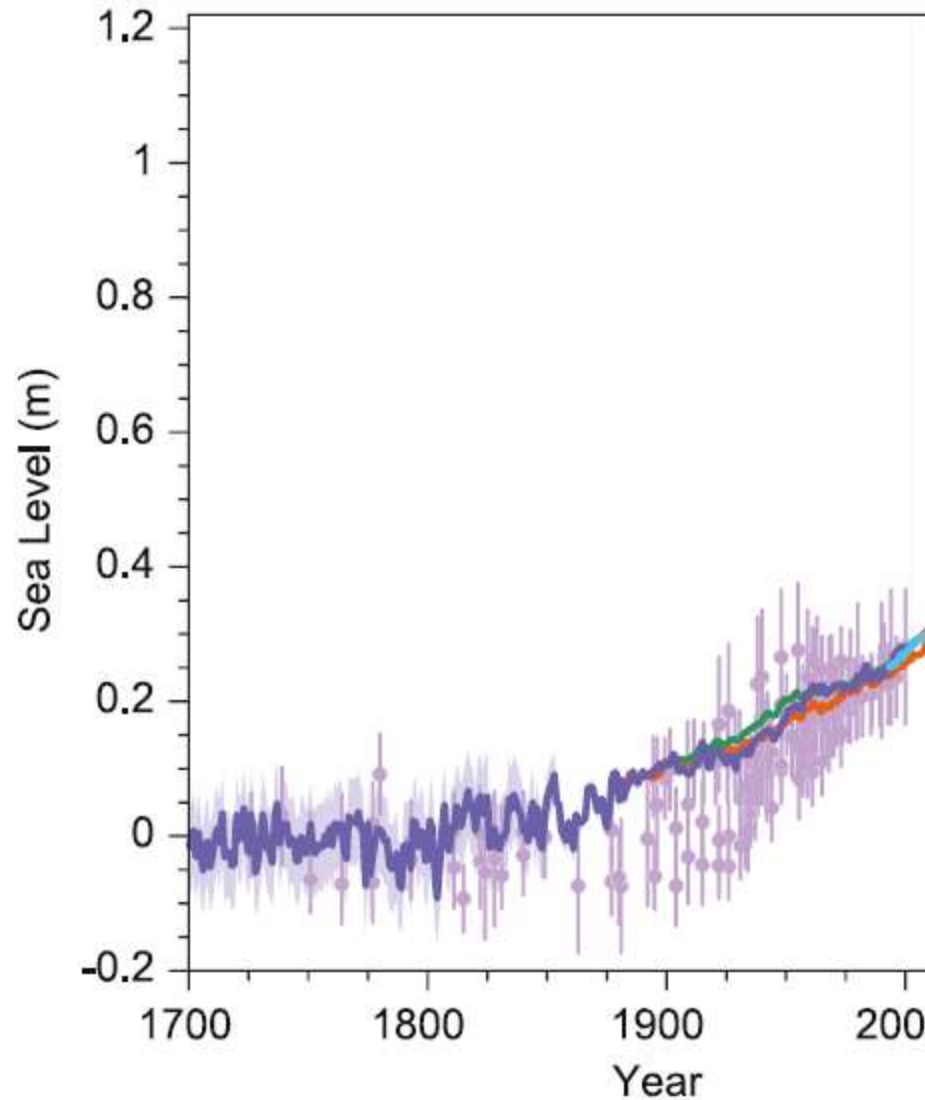
Examples of tide gauge records

Which of these locations might have experienced an earthquake?



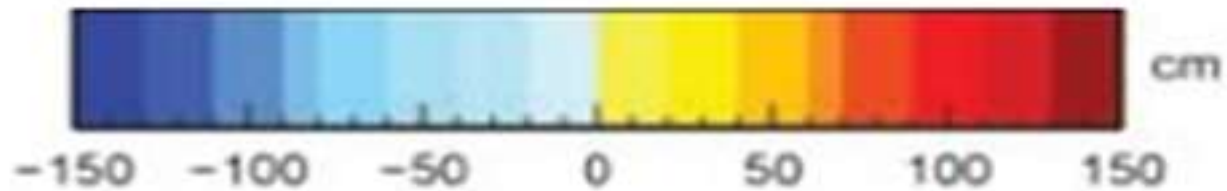
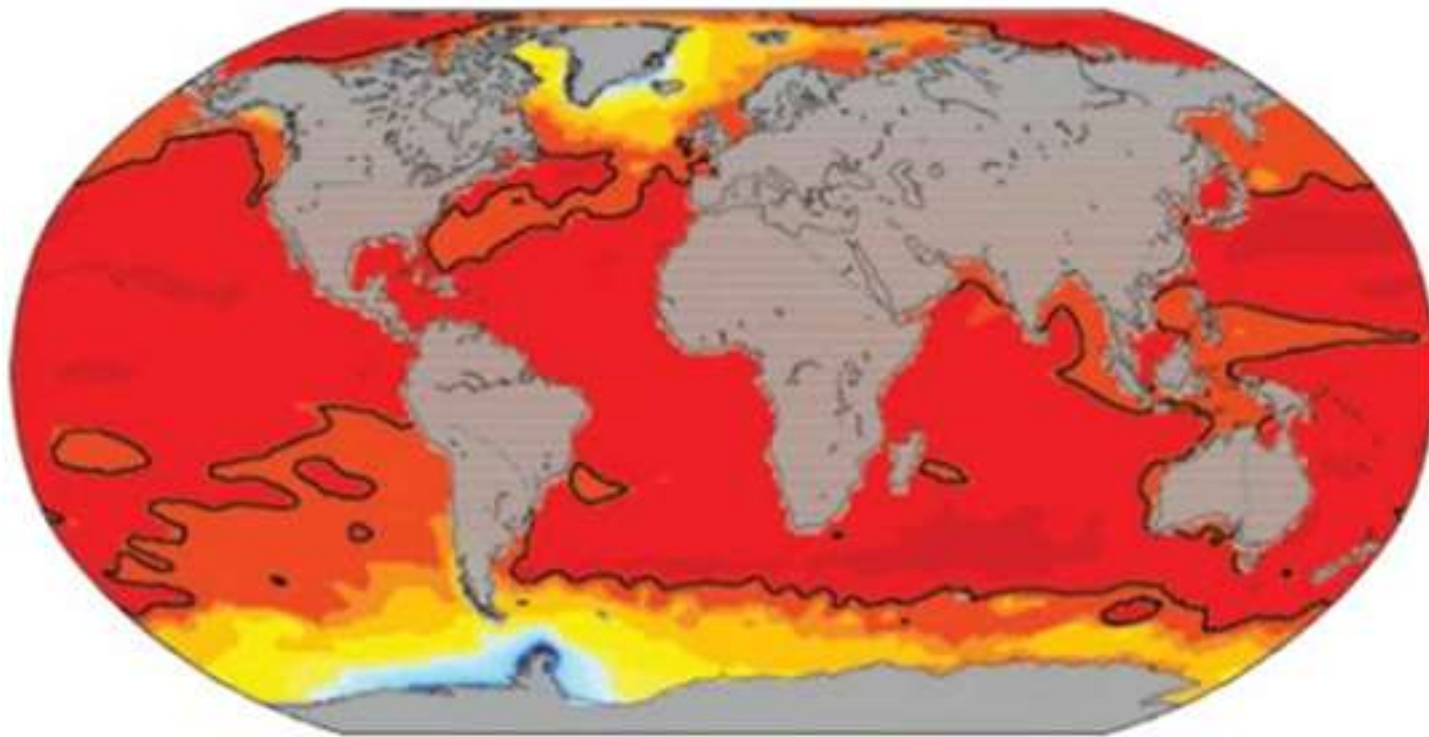
Observed eustatic (global) sea level rise

Reconstructed
sea level for past
300 years
accounting for
isostatic factors

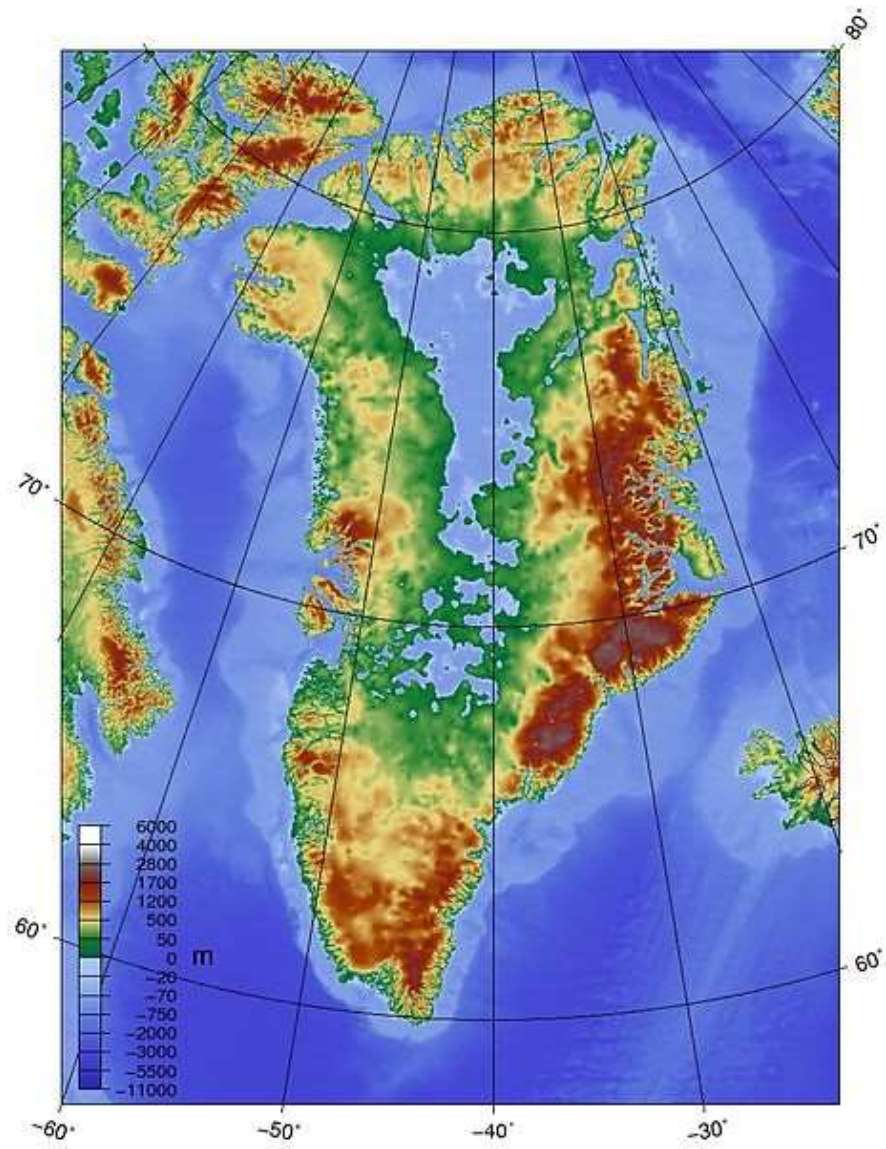


Future sea level rise

High End (average = 89 cm)

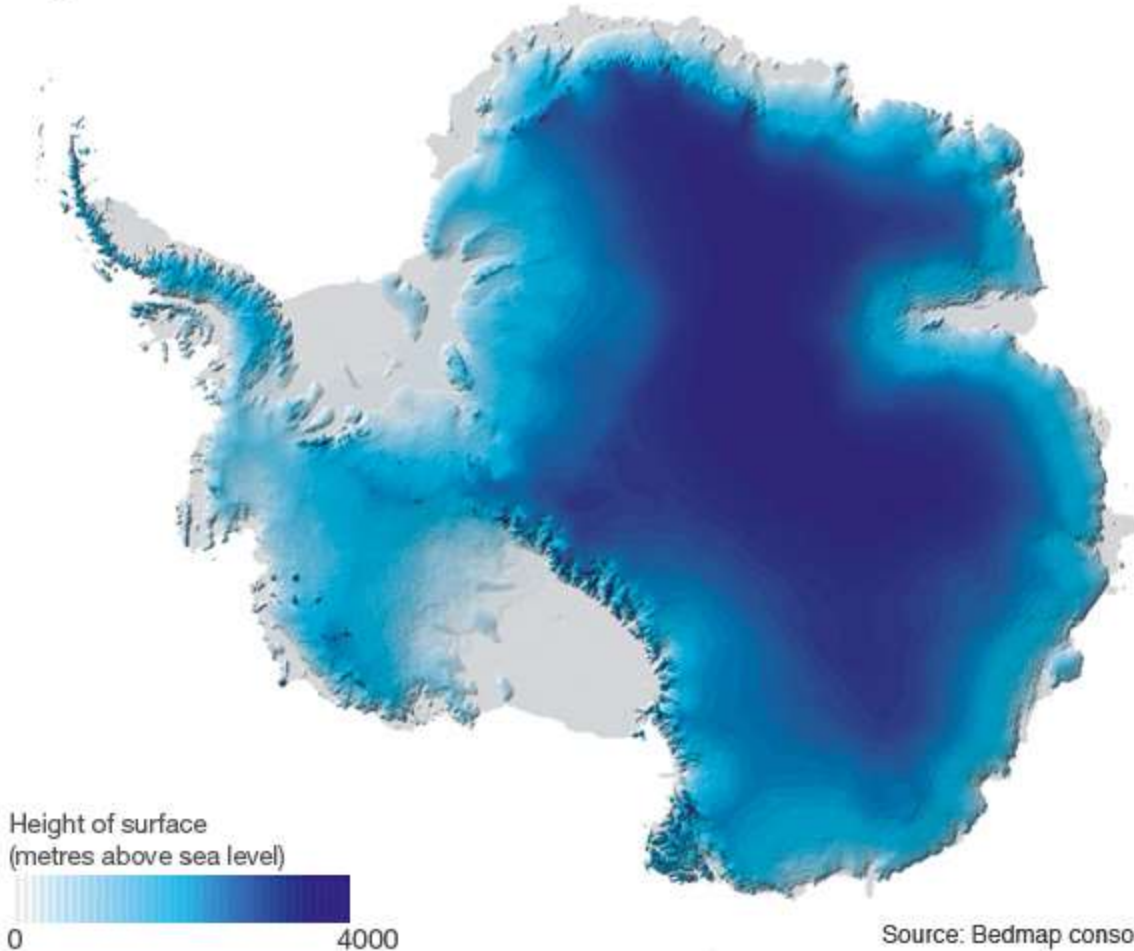


Greenland Ice Sheet



Antarctic Ice Sheet

Shape of the Antarctic ice surface

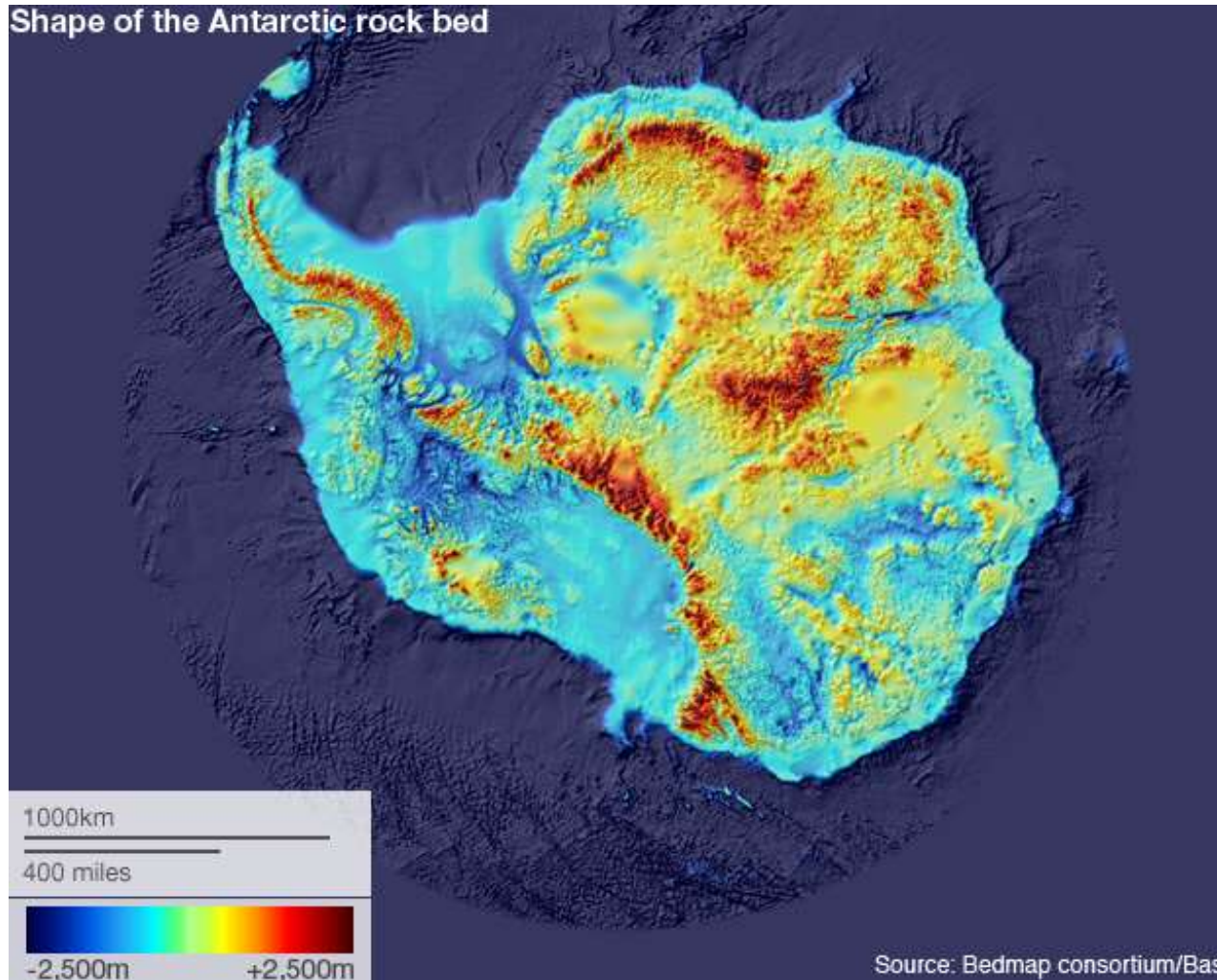


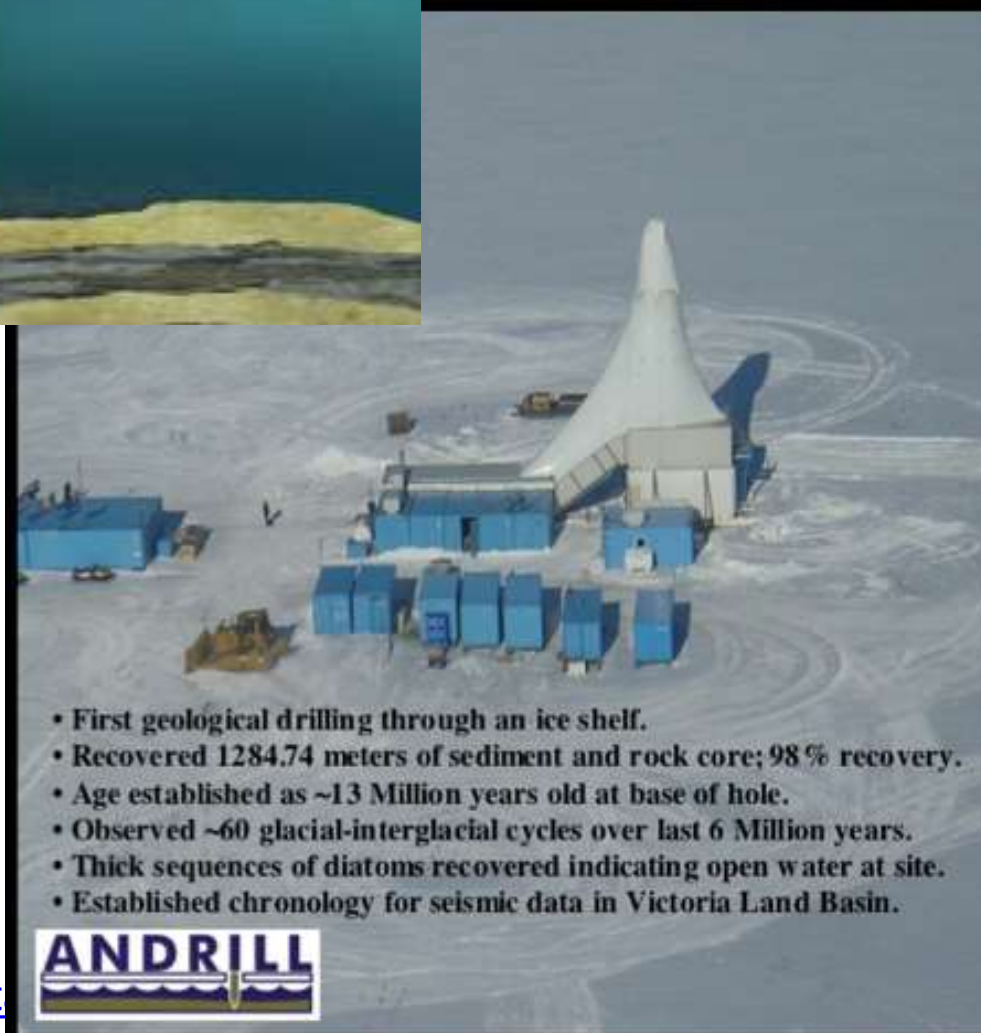
- 12.3 million km²
- Thickness = 2 km
- Volume ~ 26.5 million km³
- Sea level rise equivalent of up to 73m
- Ice up to 1 million years old

Antarctic Ice Sheet

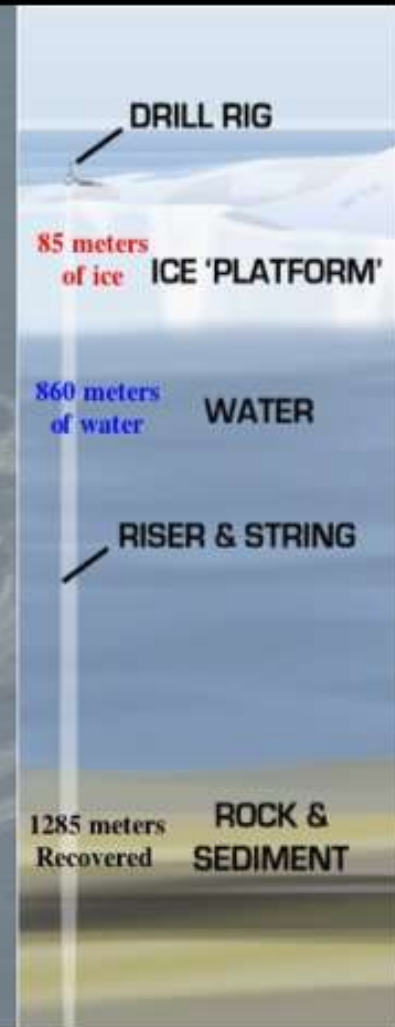
How do we work out how stable the Antarctic ice sheet is?

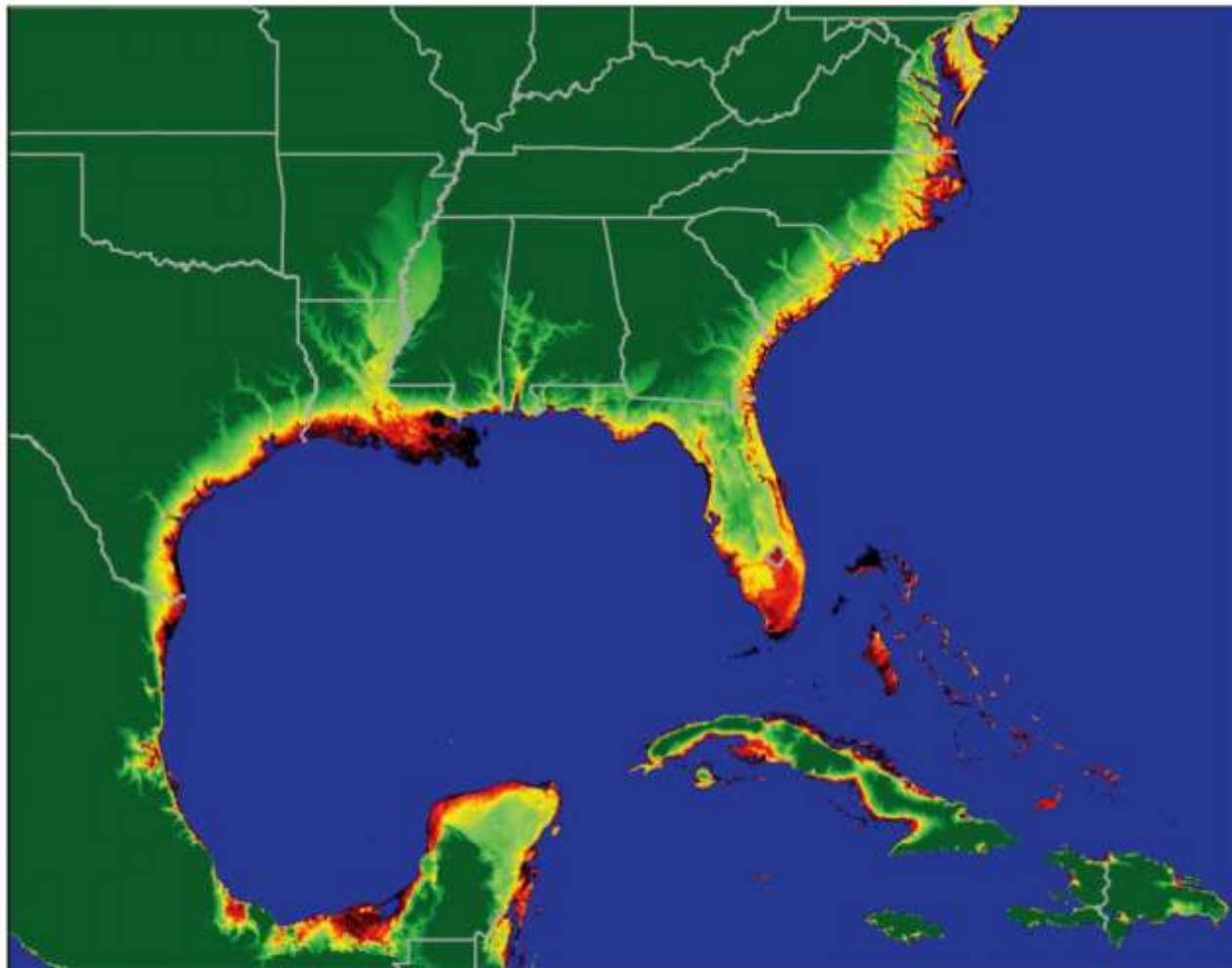
Shape of the Antarctic rock bed





- First geological drilling through an ice shelf.
- Recovered 1284.74 meters of sediment and rock core; 98 % recovery.
- Age established as ~13 Million years old at base of hole.
- Observed ~60 glacial-interglacial cycles over last 6 Million years.
- Thick sequences of diatoms recovered indicating open water at site.
- Established chronology for seismic data in Victoria Land Basin.



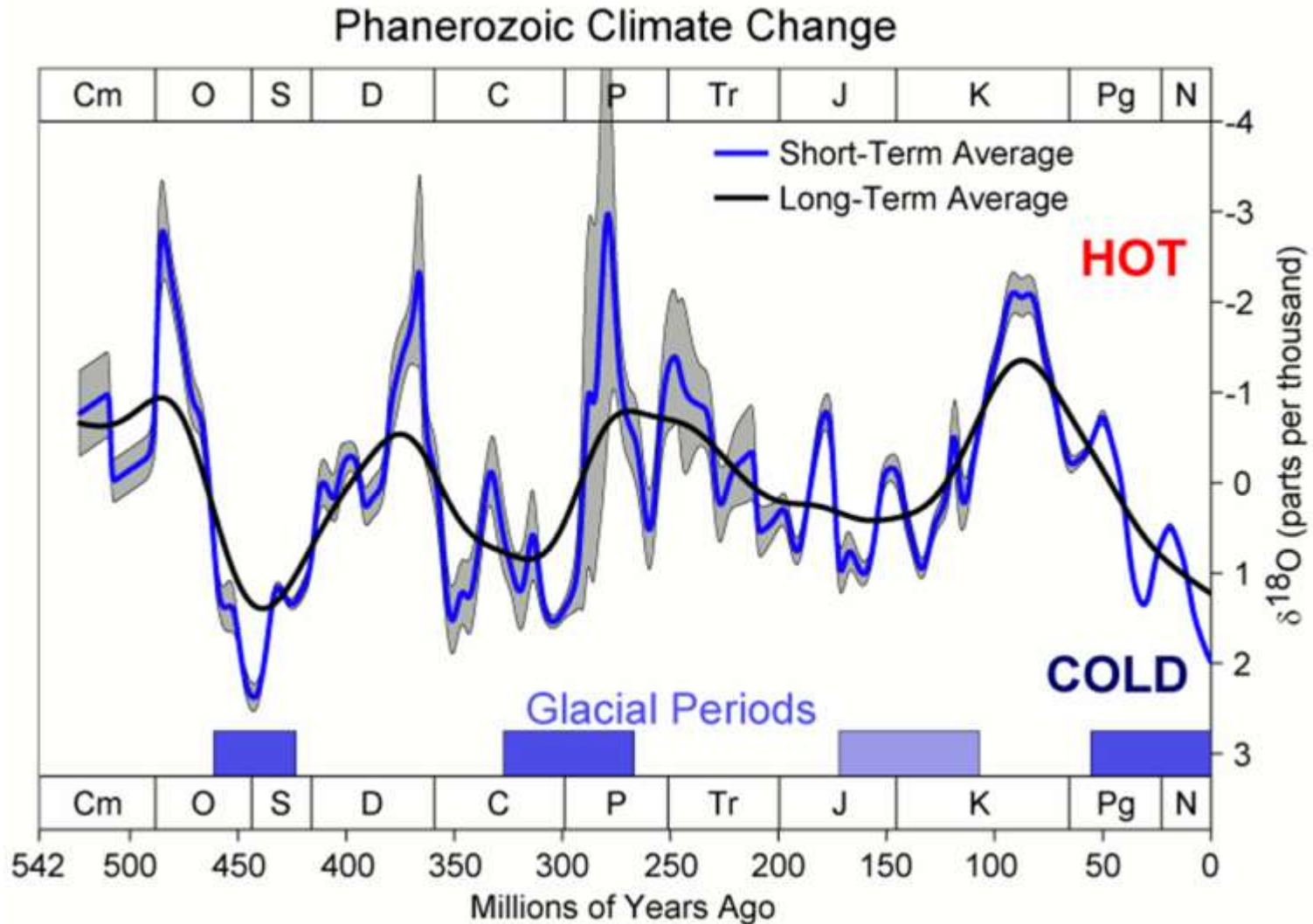


Height above sea level (m)



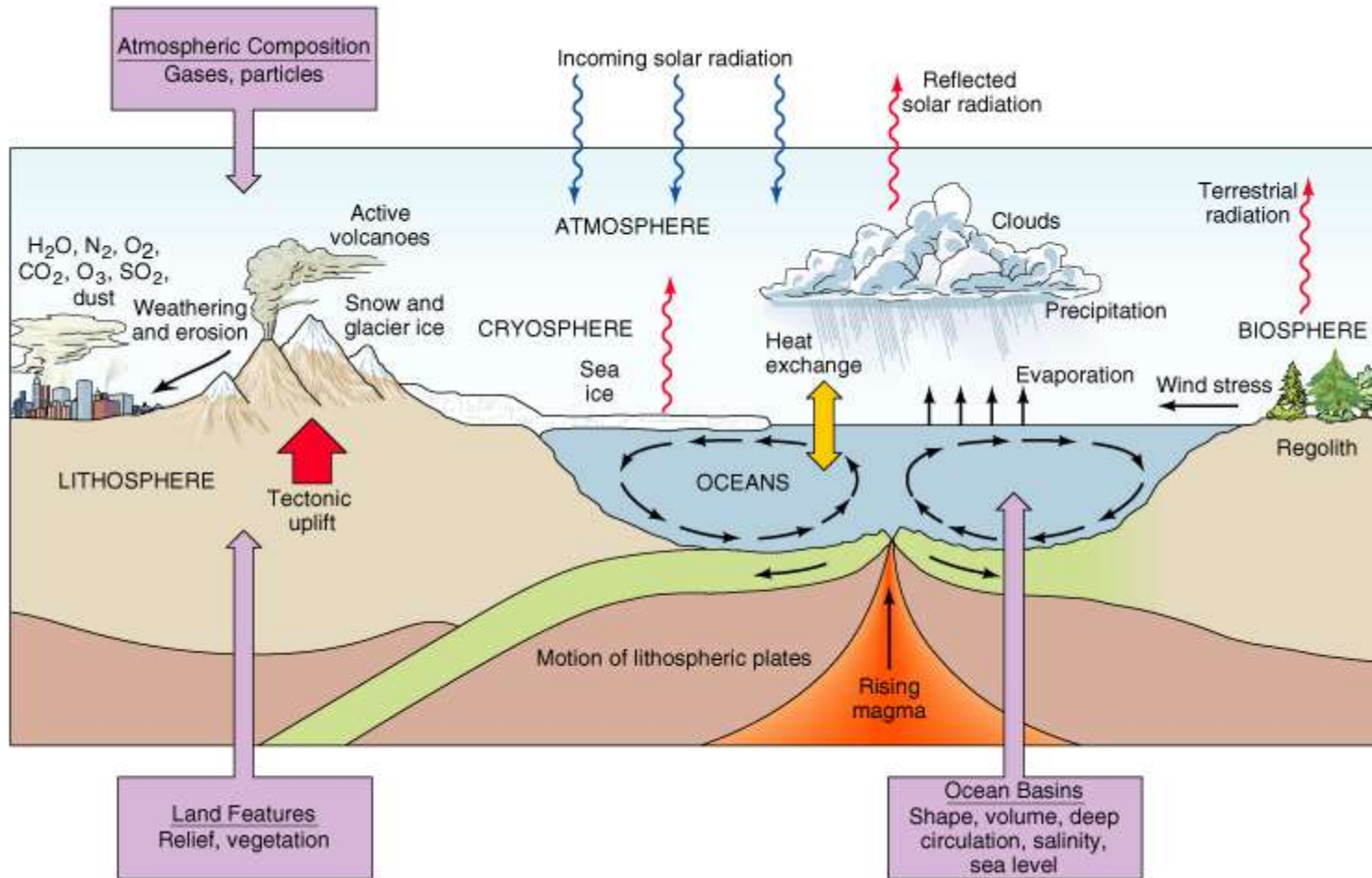
Global climate change

- Has happened repeatedly over Earth's history



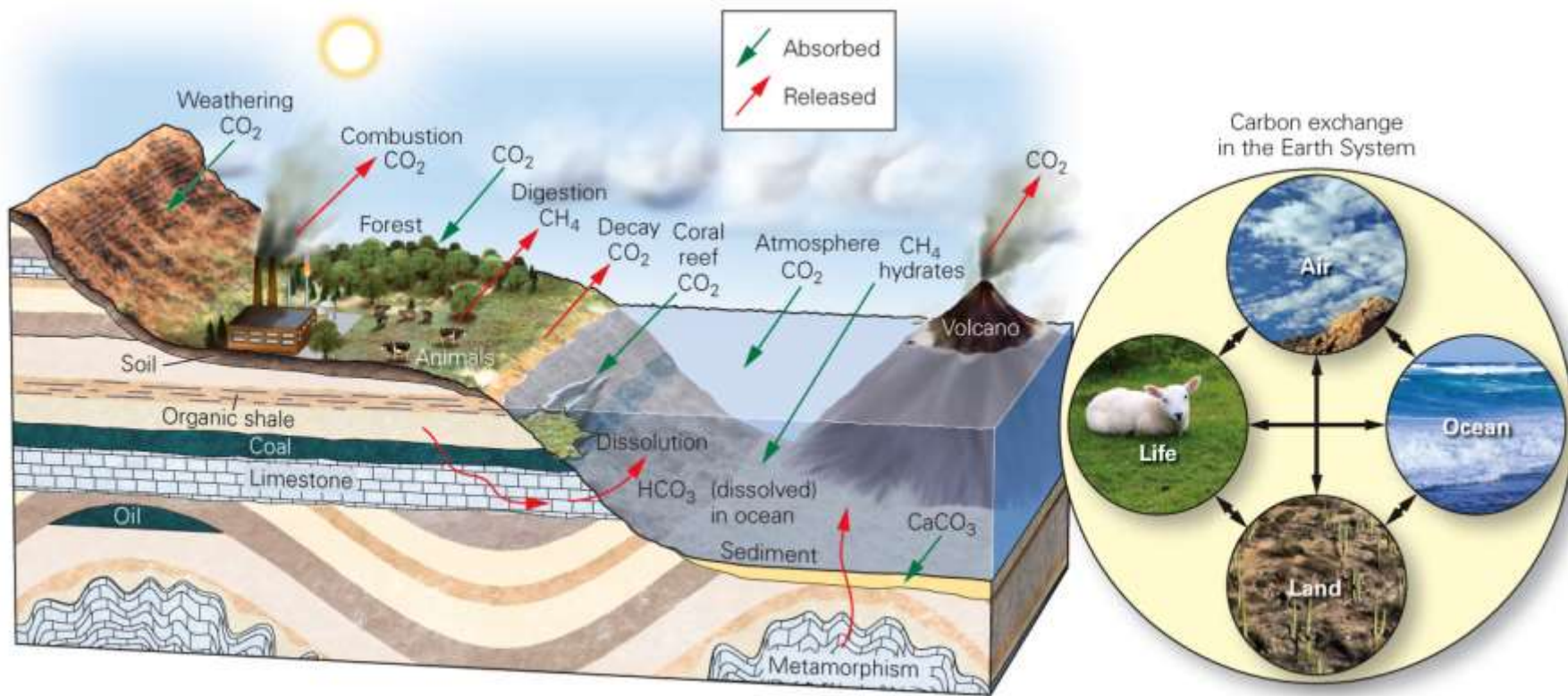
“The Climate System”

Characterized by CHANGE



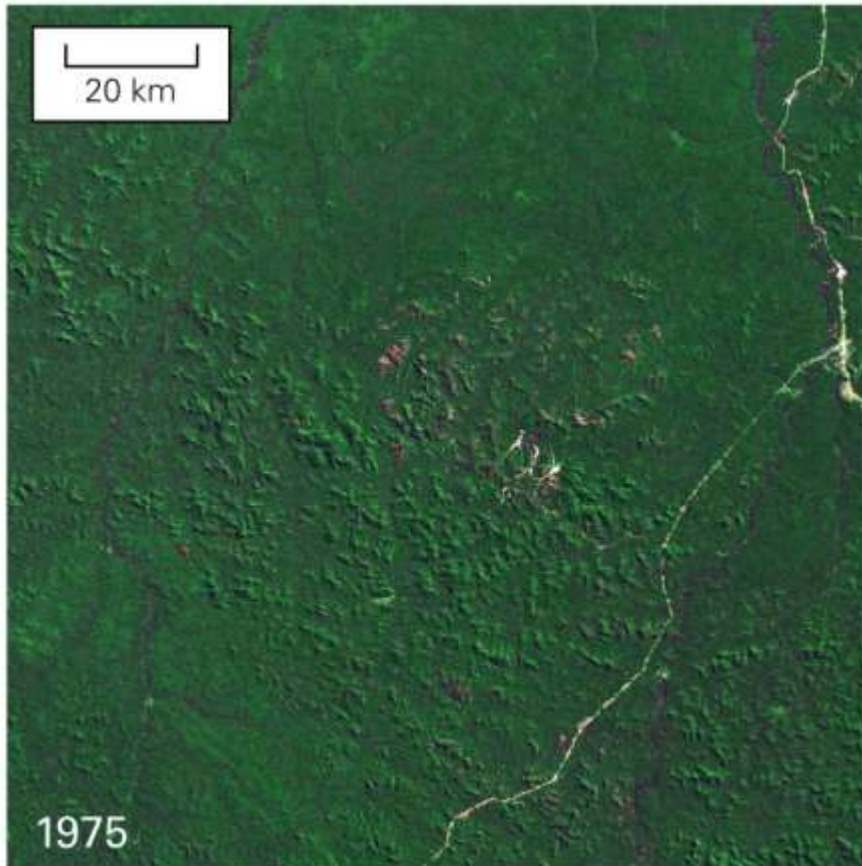
“The Climate System”

Characterized by CHANGE



Past Climate: how do we know?

Past Climate: how do we know?

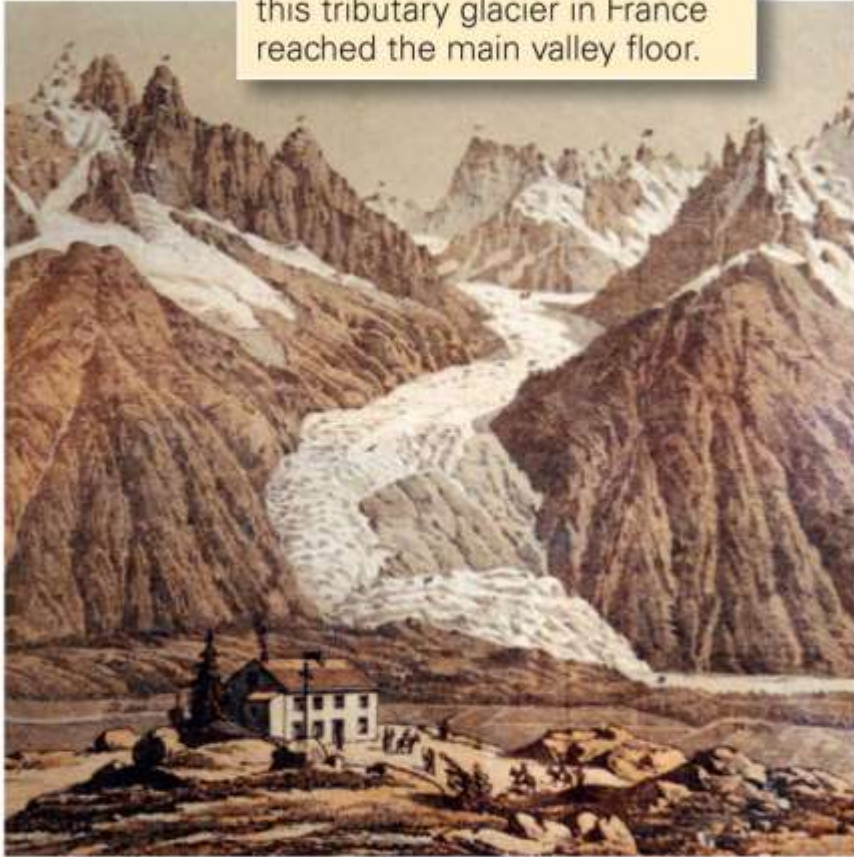


Past Climate: how do we know?



Past Climate: how do we know?

At the end of the Little Ice Age, this tributary glacier in France reached the main valley floor.



Today, glaciers extend only part-way down the side valleys.



Past Climate: how do we know?

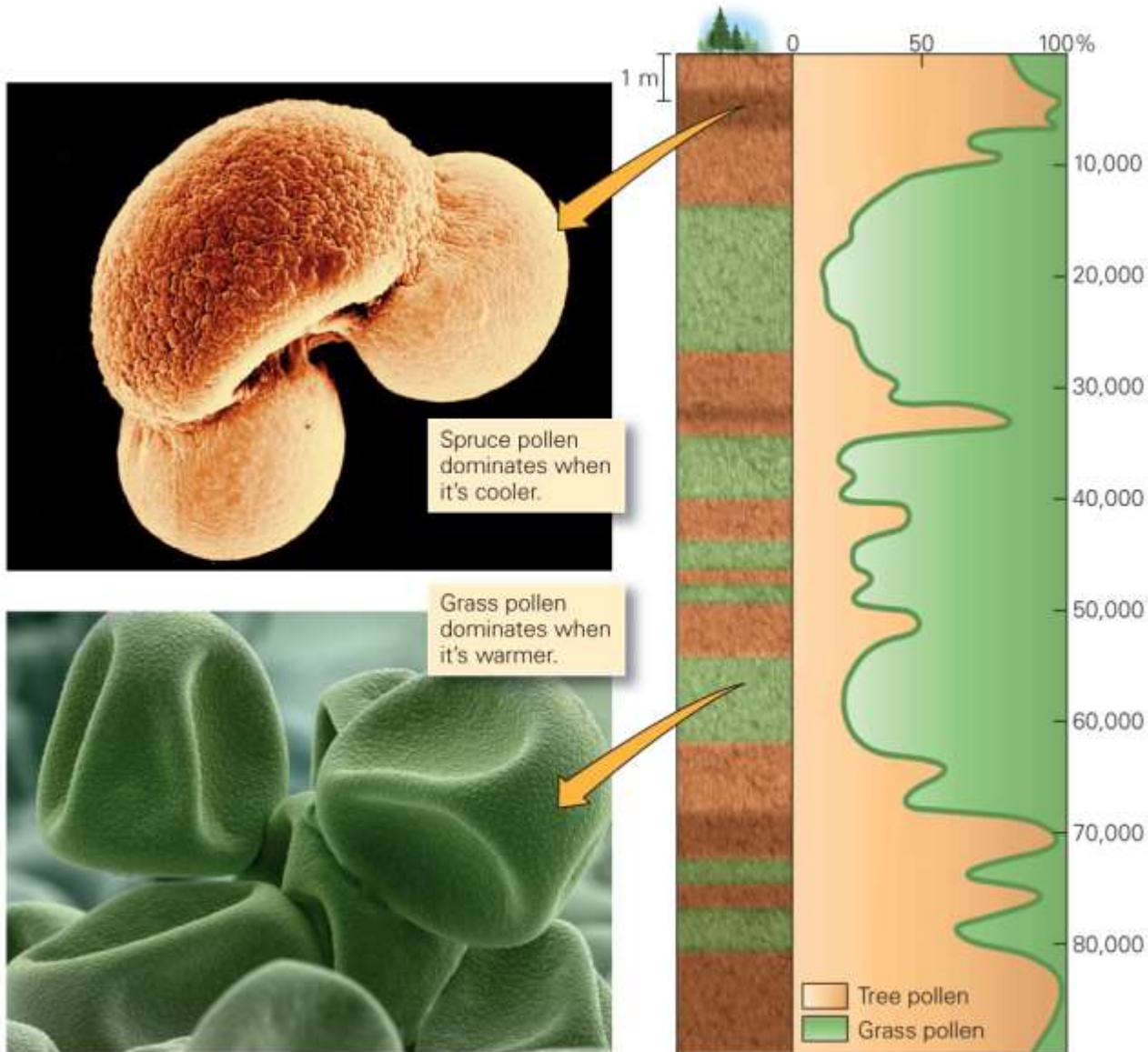


Past Climate: how do we know?

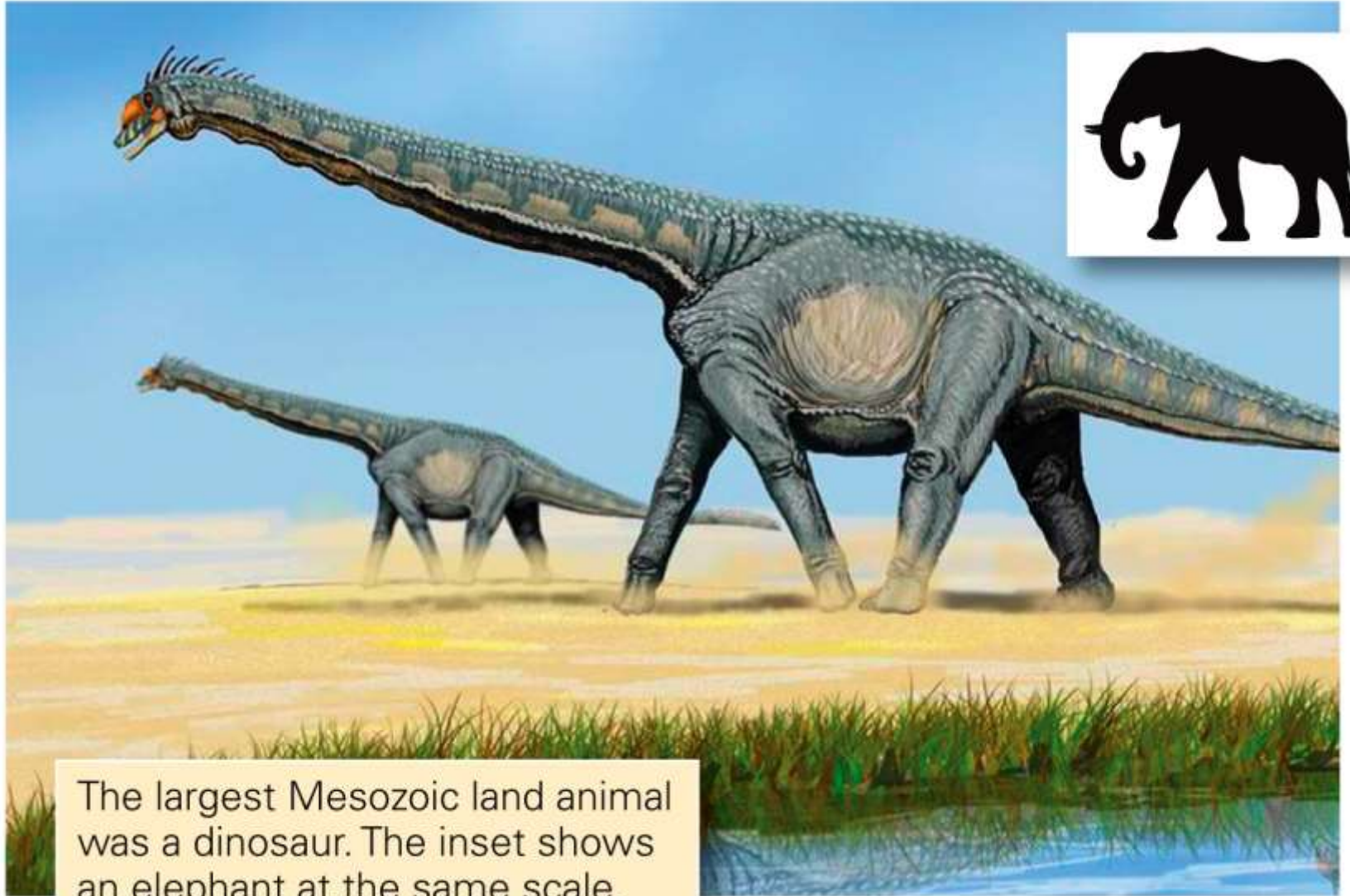
1. Instrumental Record
(recent, ~1800s to present)
2. Geologic Record
 - fossils
 - landscape features (sand dunes, dry lakes/rivers, moraines etc)
3. Proxy Records
“records of natural events that are controlled by, and closely mimic, climate”



Geologic Record



Geologic Record



The largest Mesozoic land animal was a dinosaur. The inset shows an elephant at the same scale.

Past Climate: Proxy Records

Natural “layered” records e.g.

- a) Tree rings
- b) Lake/ocean sediment
- c) Ice cores
- d) Others include cave deposits, corals etc



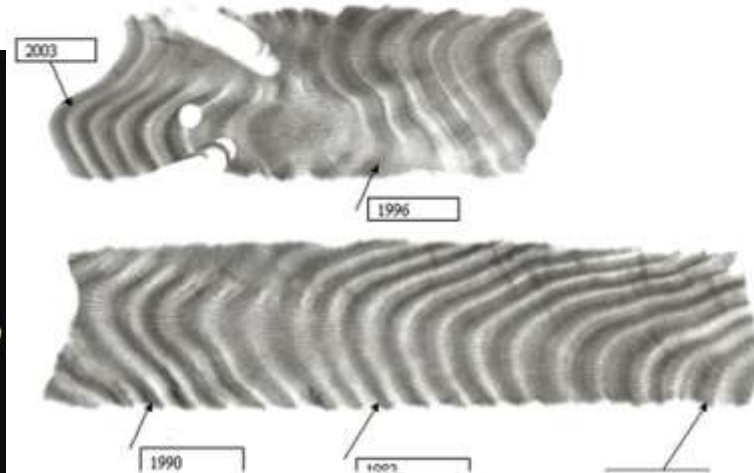
<http://www.theage.com.au/news/national/great-barrier-reef-hurt-by-farming/2007/05/31/1180205427882.html>



www.cr.nps.gov/worldheritage/caca.htm



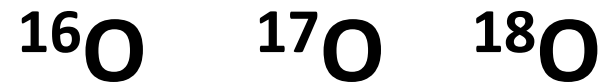
<http://www.ncdc.noaa.gov/paleo/pubs/partin2007/stalagmite.jpg>



<http://www3.aims.gov.au/pages/research/organic-geochemistry/cccgag/imagesD1/coral-density-bands-dated-480.jpg>

Evaporating water

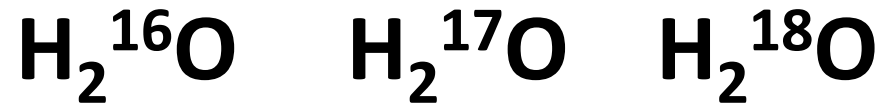
Three stable oxygen isotopes:



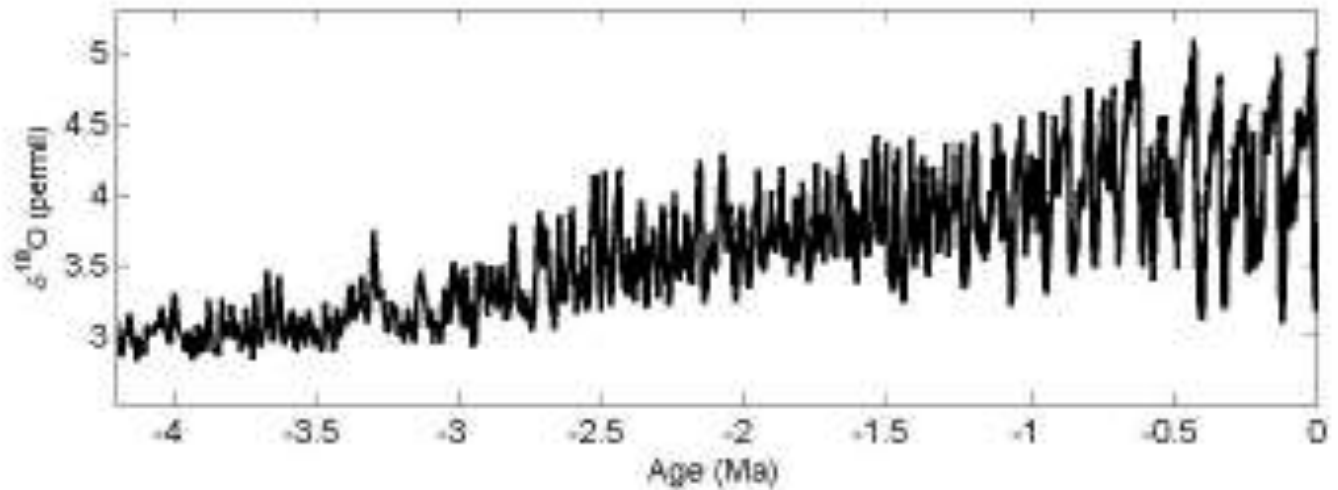
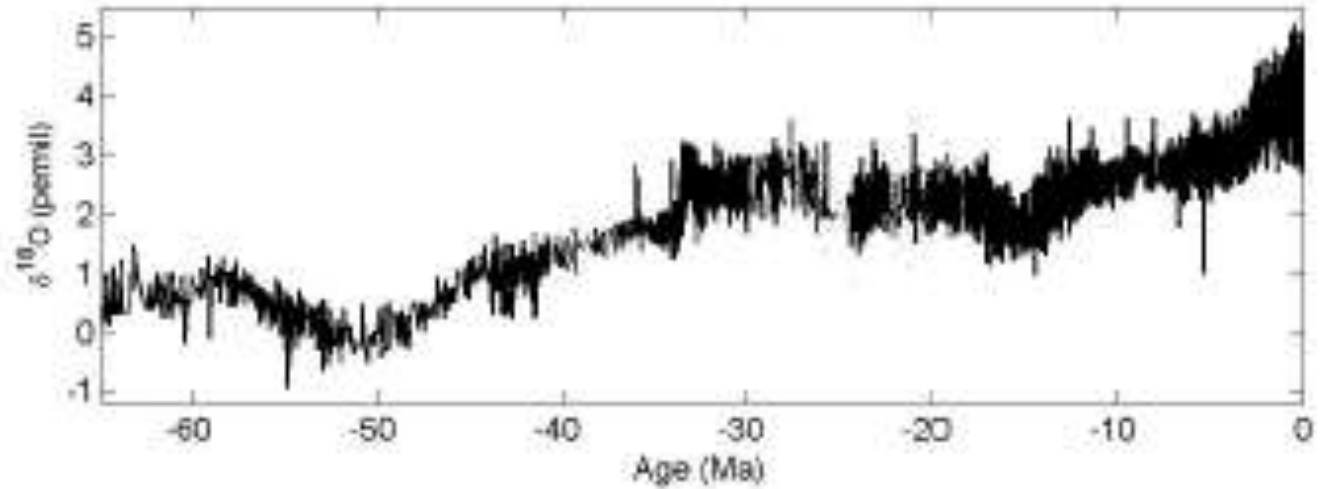
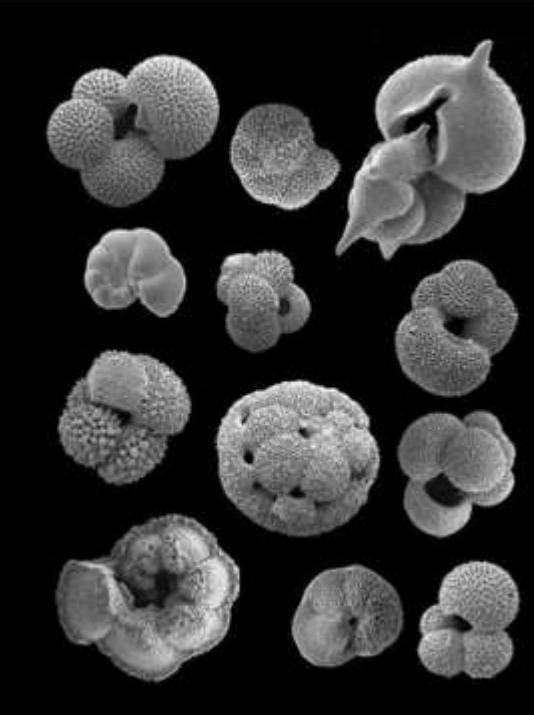
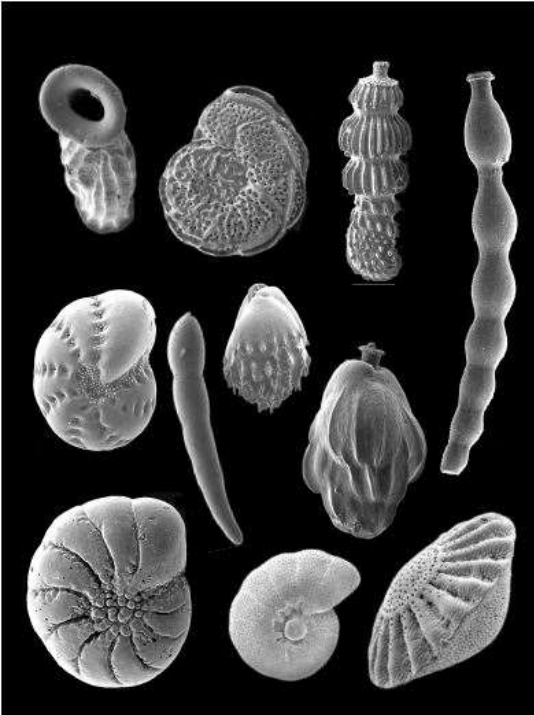
How does evaporation work?

Evaporating water

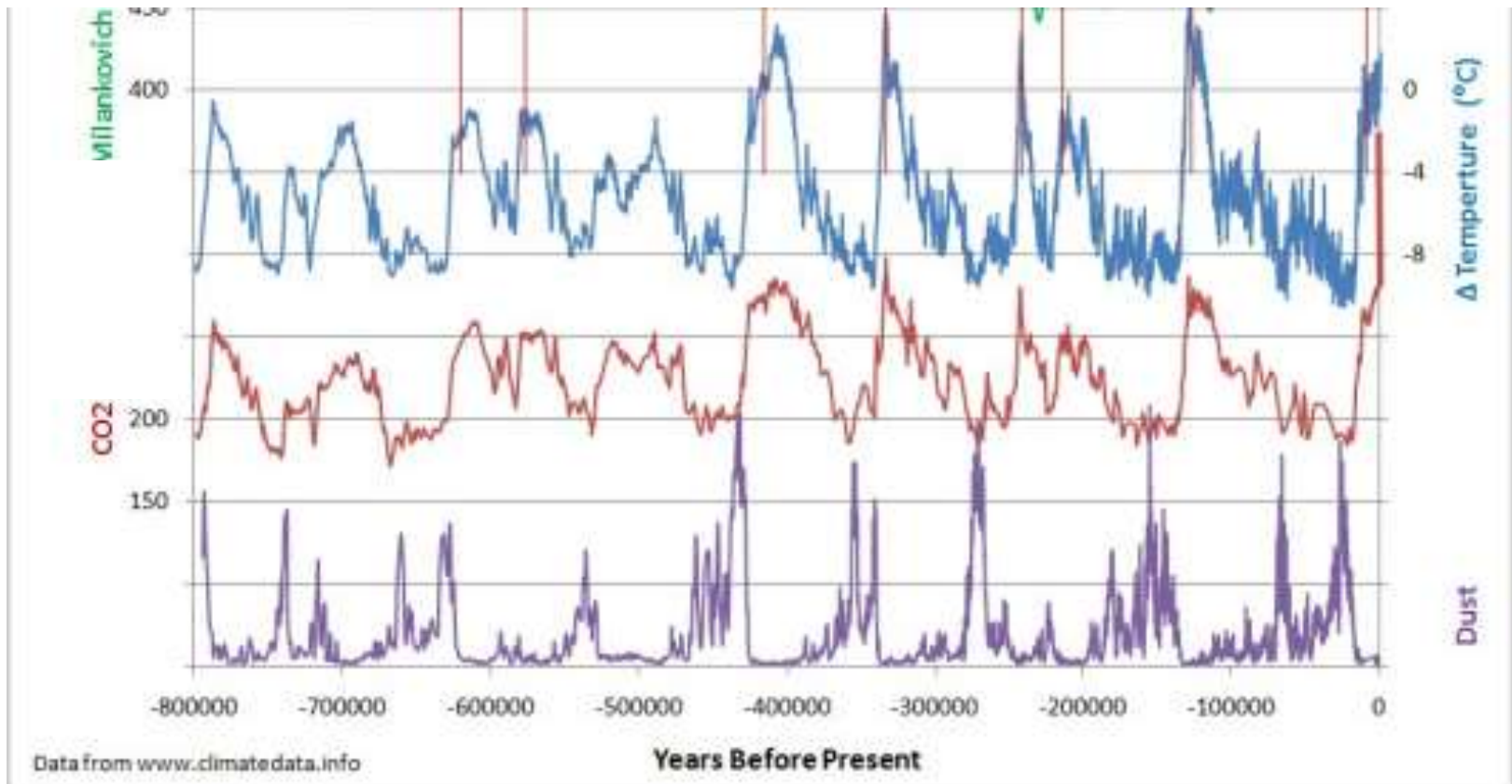
Which water will require more energy to evaporate?



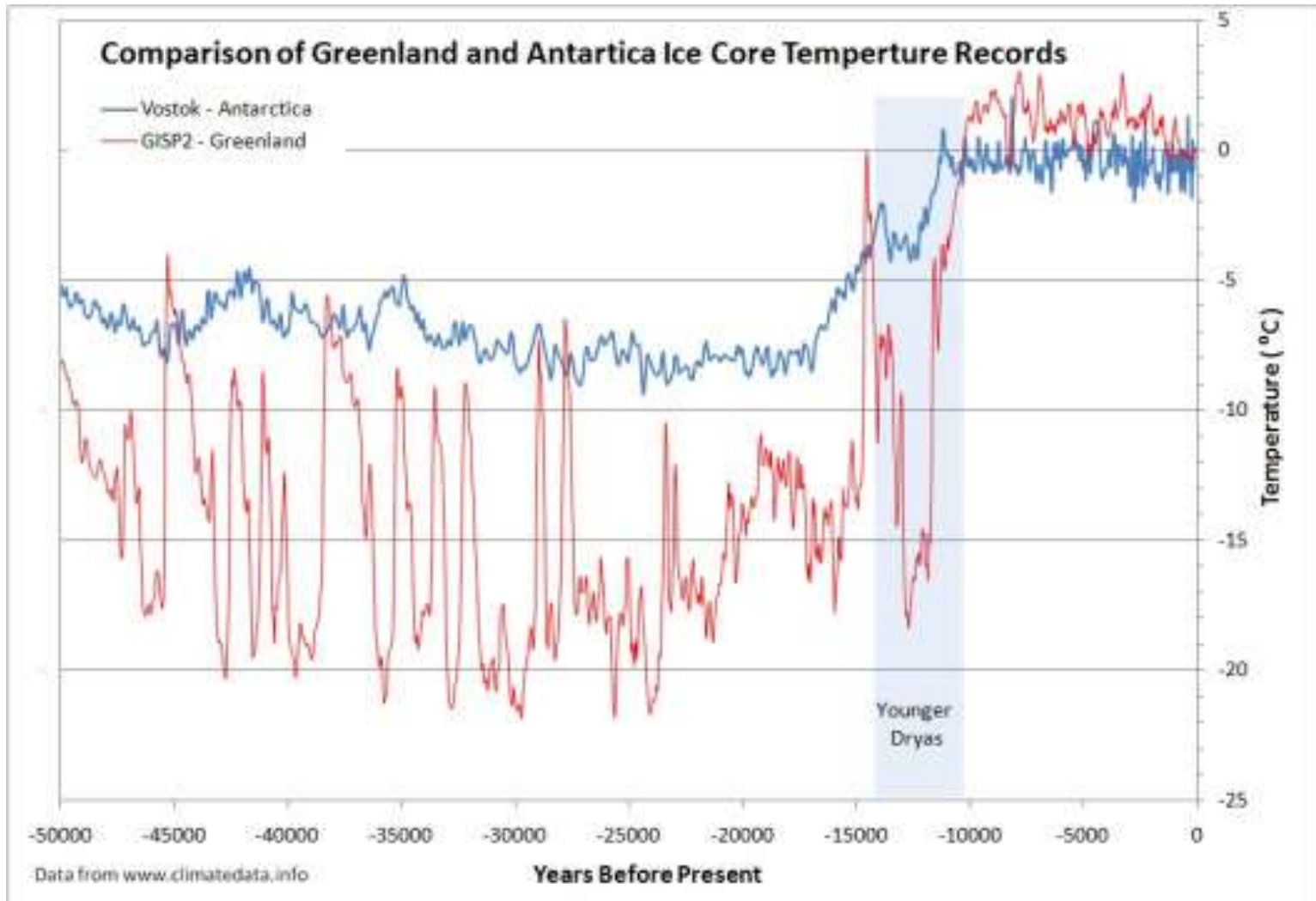
Ocean $\delta^{18}\text{O}$ record



Ice core records: Antarctica



Ice core records: Greenland



Why climate changes

1. Variations in solar output
2. Distribution of continents, mountains and oceans
3. Surface characteristics
4. Changes in greenhouse gas concentrations
5. Aerosols – affect transmission and absorption of solar and infrared radiation
6. Changes in Earth's orbit (Milankovitch cycles)
7. Feedback processes: positive = amplifying, negative = stabilizing

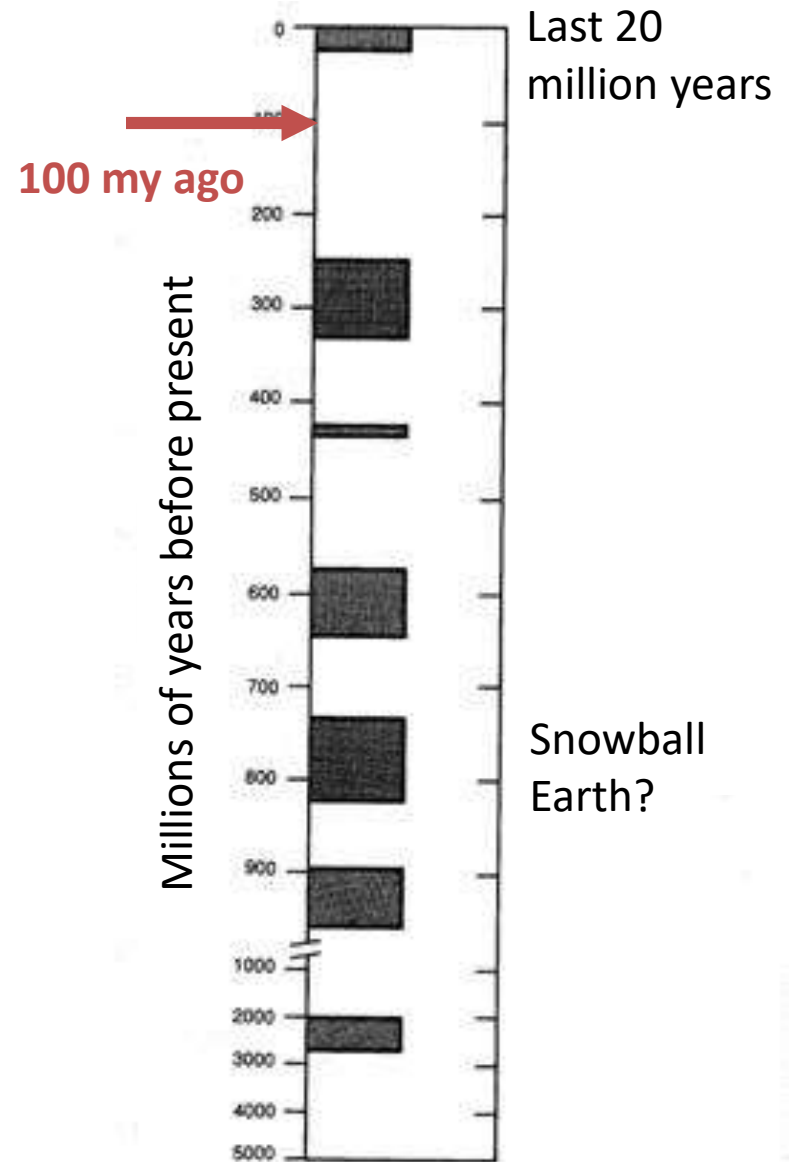
Single celled organisms changed climate



History of climate over last 100 Myrs

Earth is presently in a cool period – dark bands show times when large ice sheets were present on continents.

However, during much of Earth's history, there is no evidence for ice ages – warmer oceans, warmer conditions and higher sea levels.



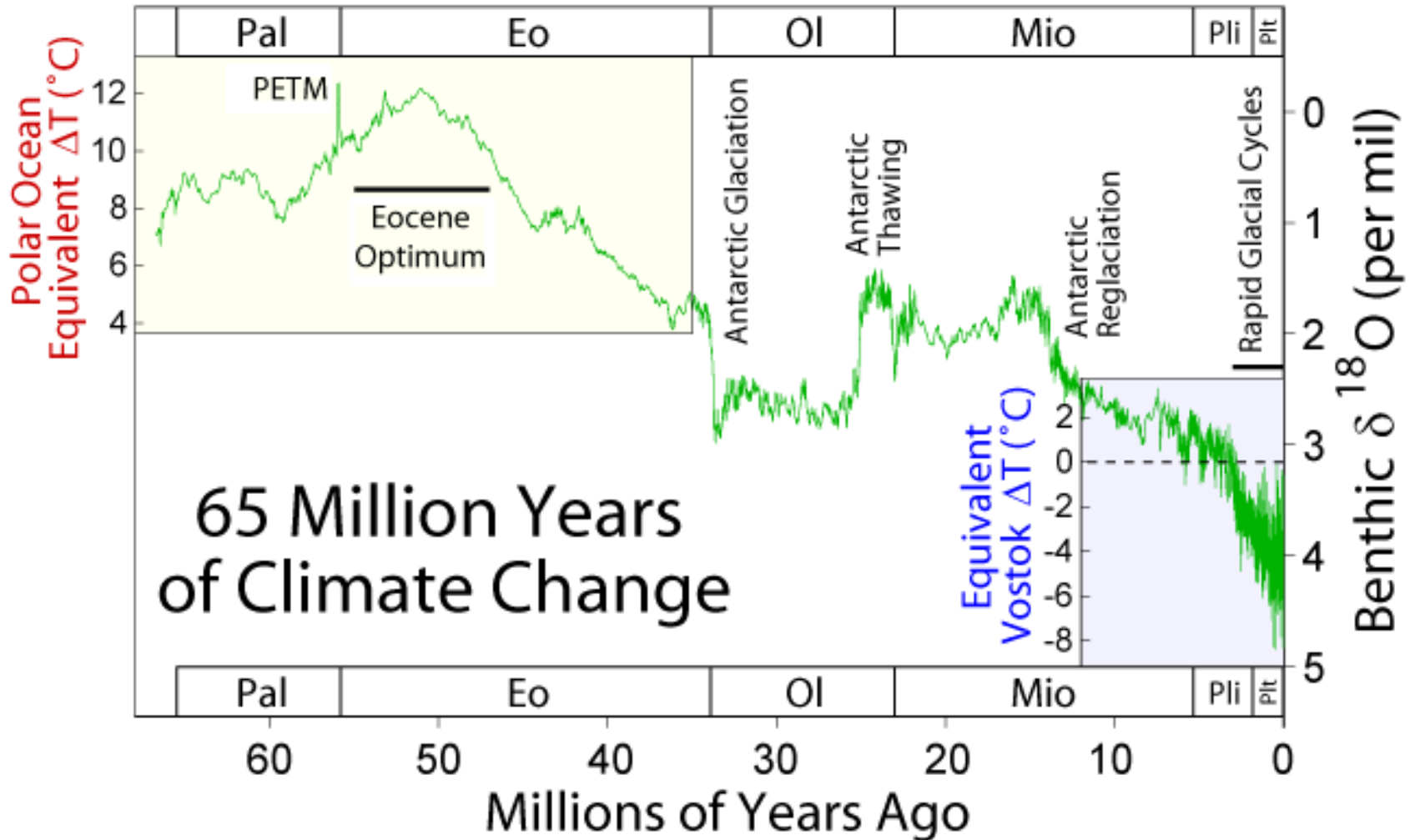
Middle Cretaceous – 100 Myrs ago

Around 100 million years ago

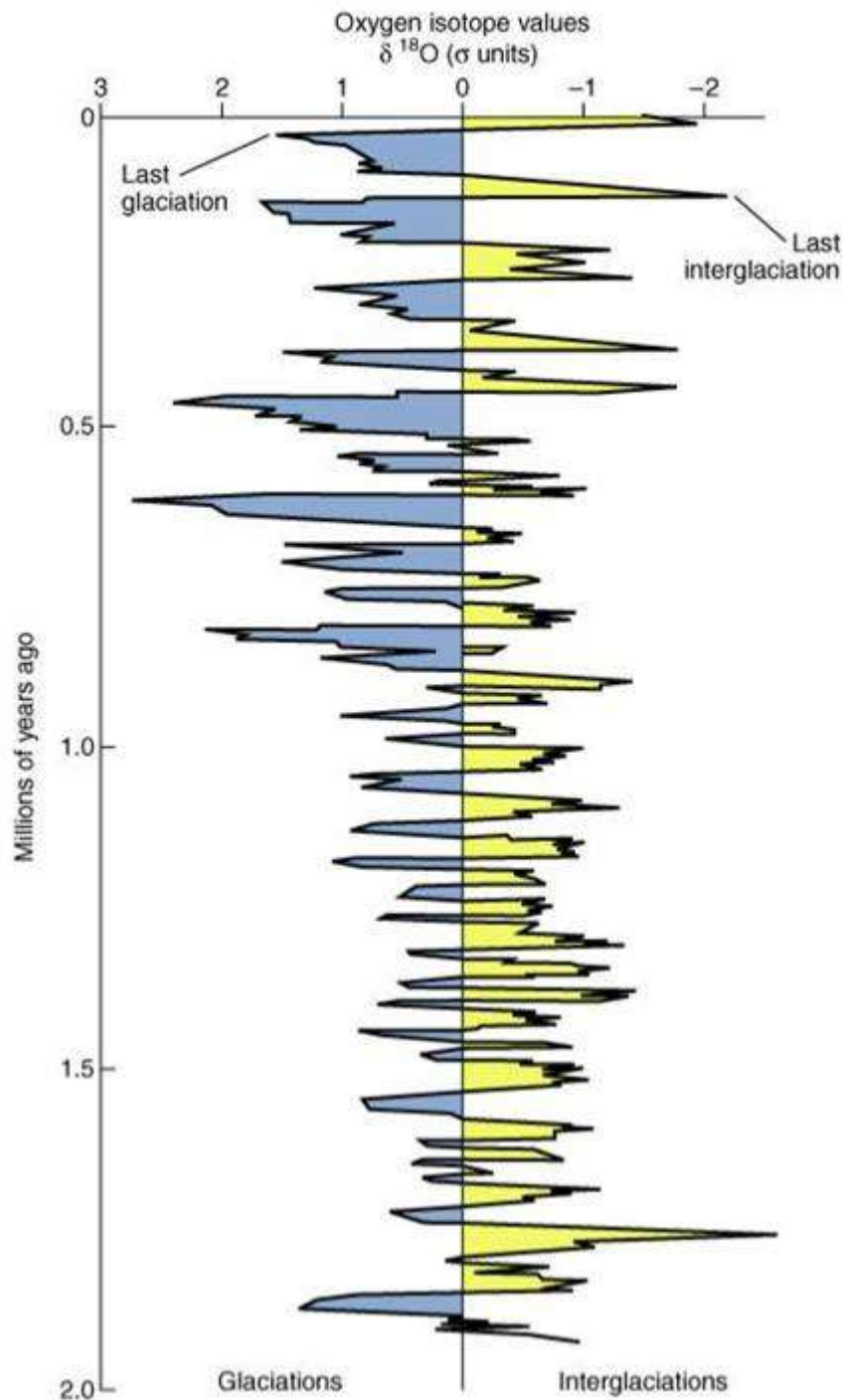


Antarctica during Cretaceous

Last 65 million years



Last 2 Myrs

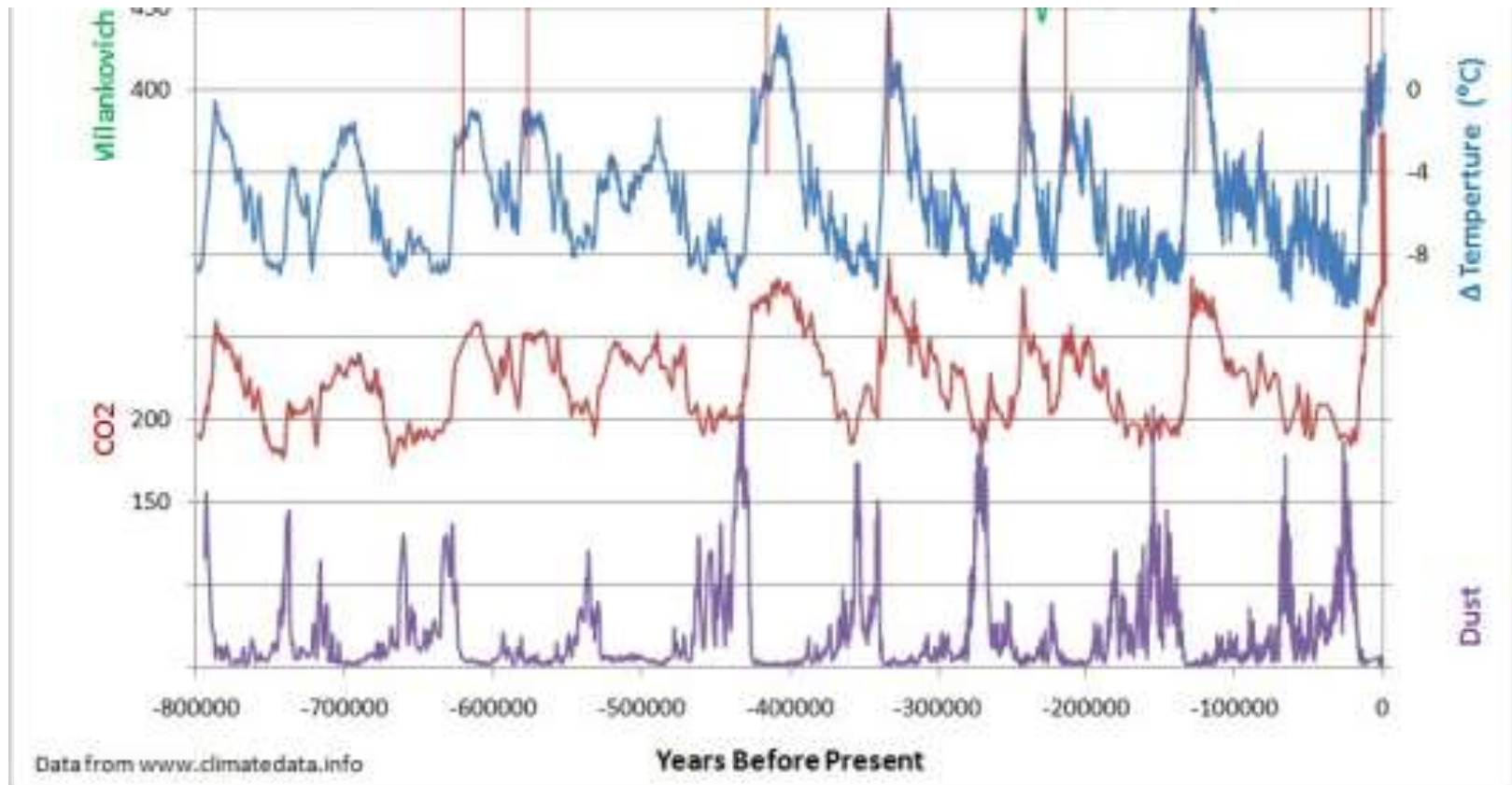


Shows cold glacial (blue) and warm interglacial (yellow) periods

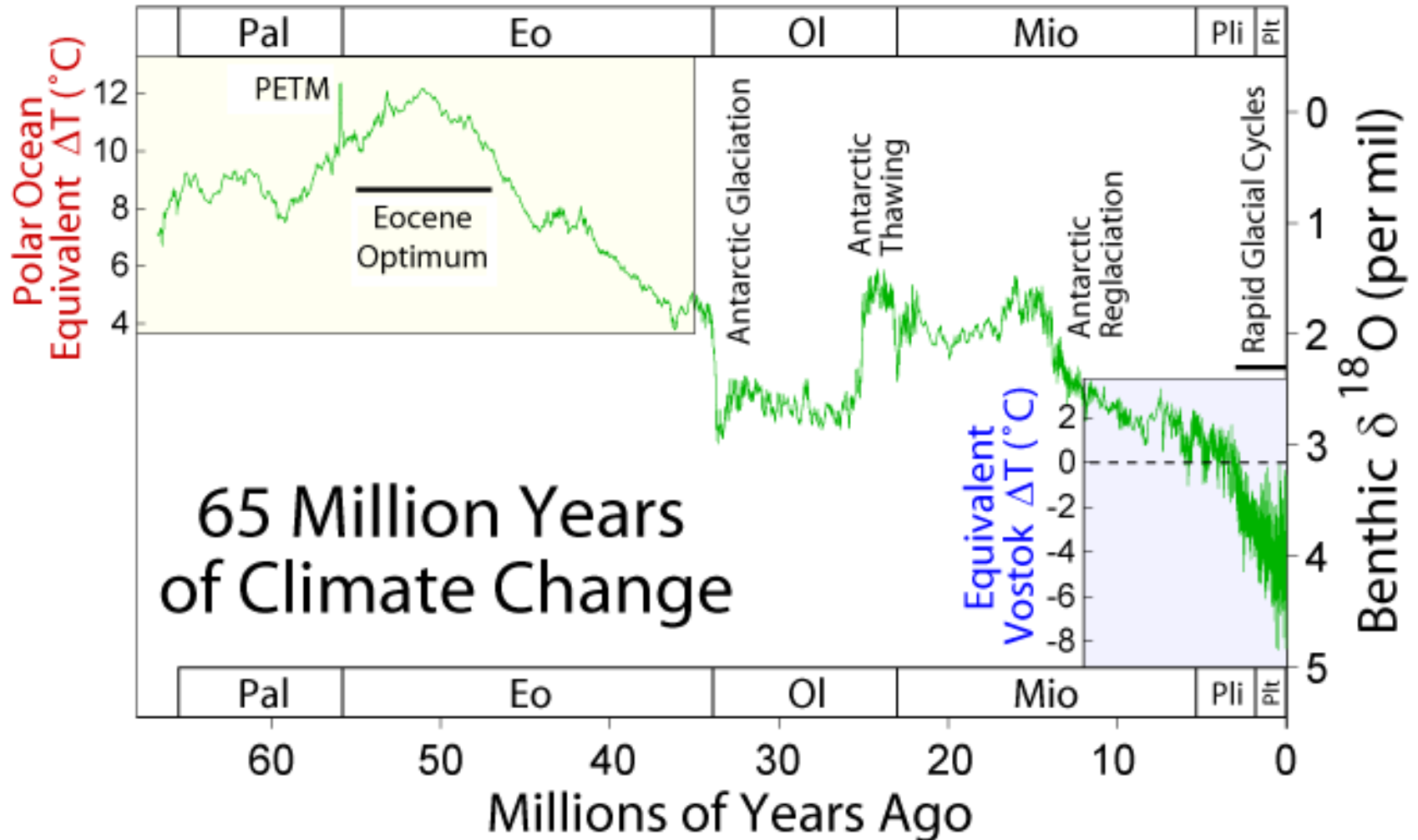
Ice ages every $\sim 100,000$ years for the most recent 800,000 years with gradual cooling then rapid warming

Climate changes due to Milankovitch cycles and amplifying climate feedbacks e.g. increased CO_2

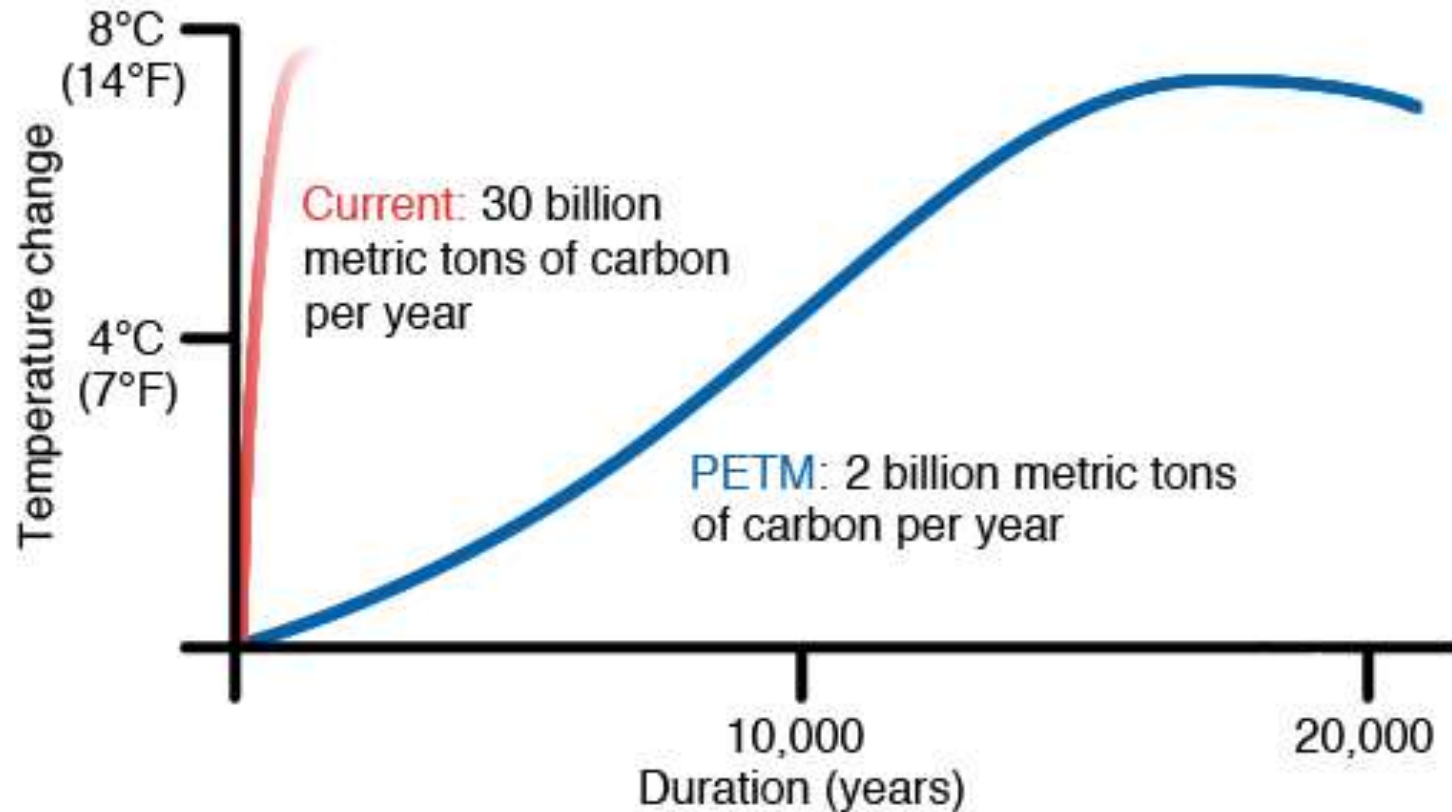
Ice core records and the carbon cycle



Case study: Paleocene-Eocene Thermal Maximum



Learning from the past: Paleocene-Eocene Thermal Maximum

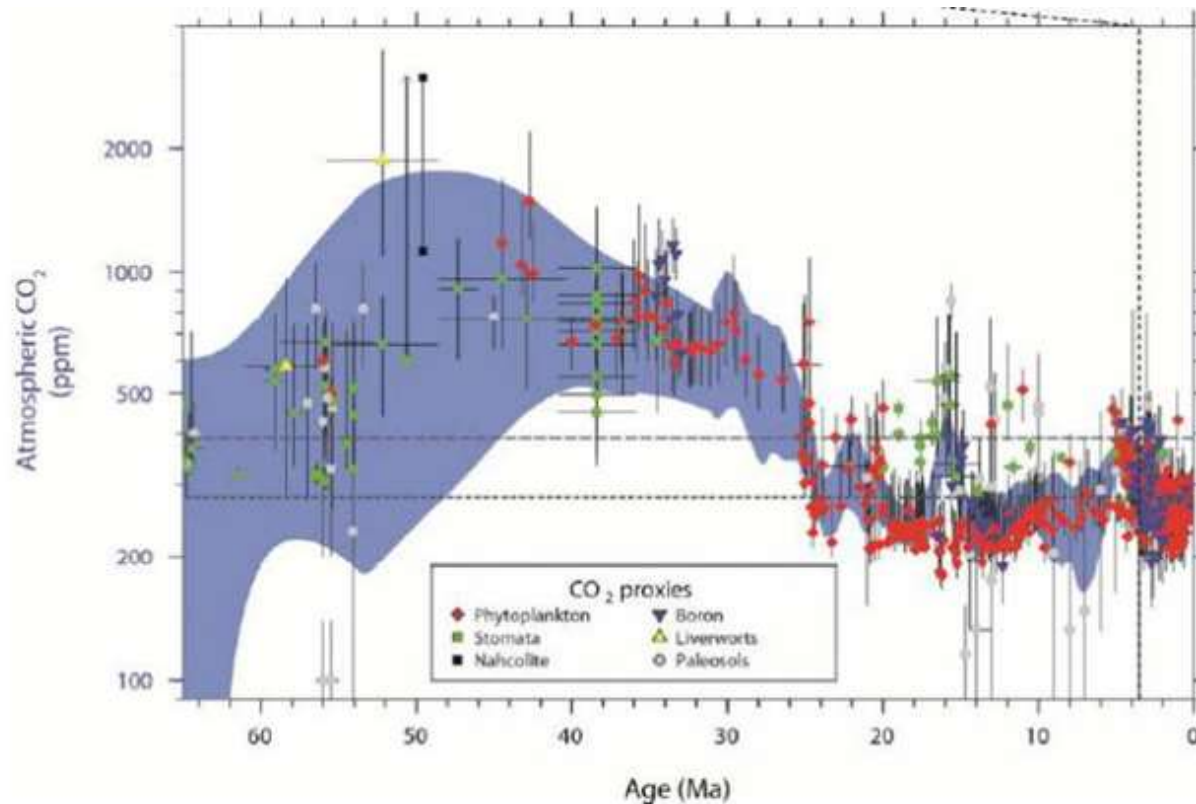


Learning from the past: Paleocene-Eocene Thermal Maximum

	PETM	Current Warming
Cause	Continental drift, volcanoes, methane hydrate melting, fires, permafrost melting	Anthropogenic burning of fossil fuels (oil, coal, natural gas, etc)
CO₂ emissions	Around 5 billion tons per year	At least 30 billion tons per year
Rate of warming	0.025°C per 100 years	1 to 4°C per 100 years
Environmental impact	Ocean circulation reversed, oceans acidified, permafrost melted, peatlands and forests burned in wildfires	Observed impacts: significant sea ice decline, extreme drought, more wildfires, increase in glacier melt, more catastrophic floods, ocean acidification, sea level rise, shoreline erosion Potential impacts: degraded air and water quality, permafrost melting, global ocean circulation changes, more violent winter storms and spring tornado seasons, more intense hurricanes
Ecosystem & human impact	Migration of land mammals, extinction of some benthic foraminifera, coral bleaching	Observed impacts: Famine and malnutrition due to drought, coral bleaching, species endangerment (e.g. polar bears, marine turtles, North Atlantic whales, giant pandas, orangutans, elephants) Potential impacts: increased mortality from extreme weather and malnutrition, increase in disease vectors, decrease in agricultural yield, mass wildlife migration and extinction, total societal collapse

What we've learned from paleoclimate

- World has been warmer and colder than today in Earth's history
- But... human civilization is very much “adapted” to the current, very stable climate
- The RATE of climate change over the next 100 years is greatest threat - likely 10 times faster than any other change in the last 65 million years

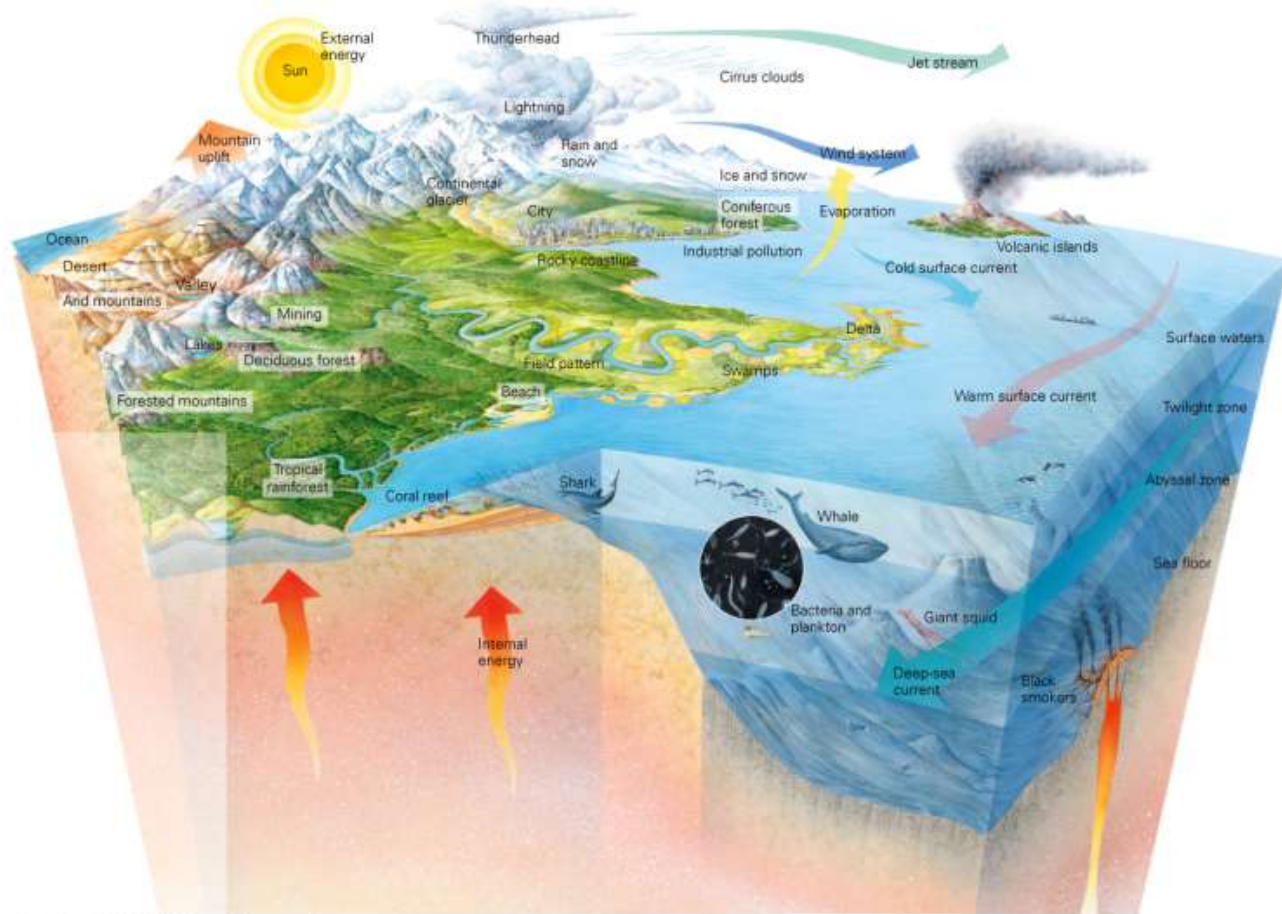


Climate change is natural

“This much CO2 in the air is not natural”

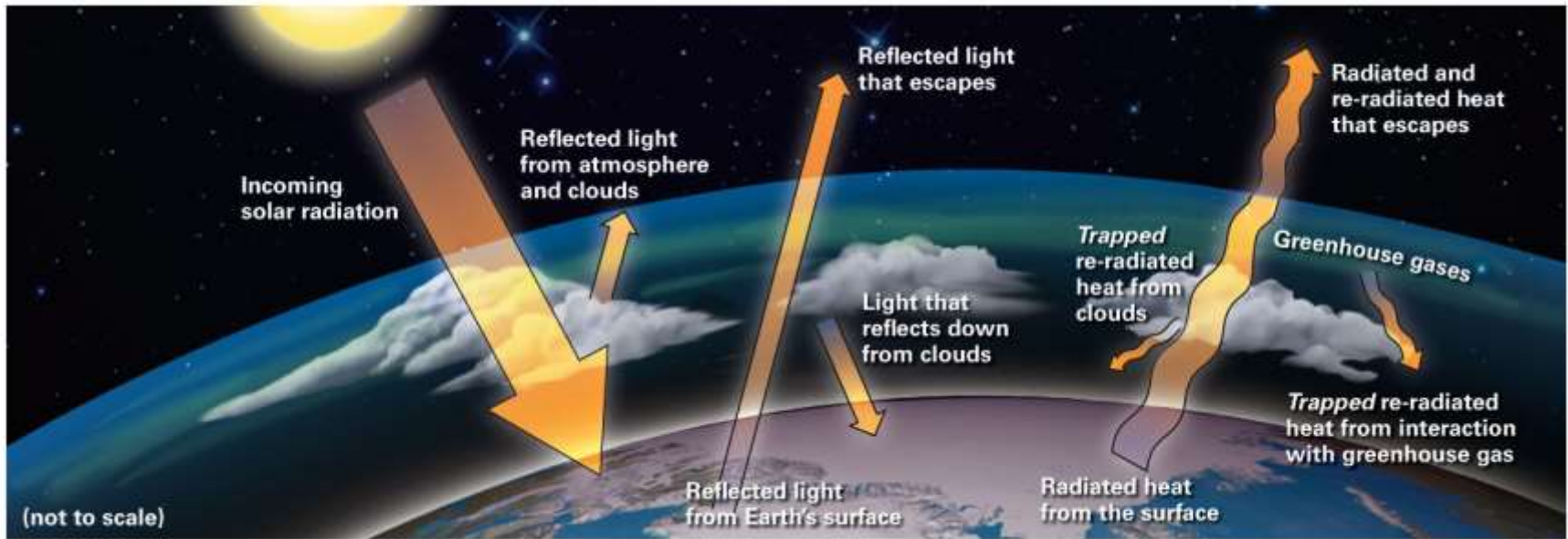
- Scientifically, humans are natural.
- Other realms of knowledge may have different ideas about the origin of humans.
- In the sciences current evidence indicates that humans originated from an evolutionary process. Therefore human activity is the result of a natural process.
- To scientists, placing humanity and human activities “above” natural processes is not consistent with a data driven approach to thinking.

Interactions between geosphere and rest of Earth system



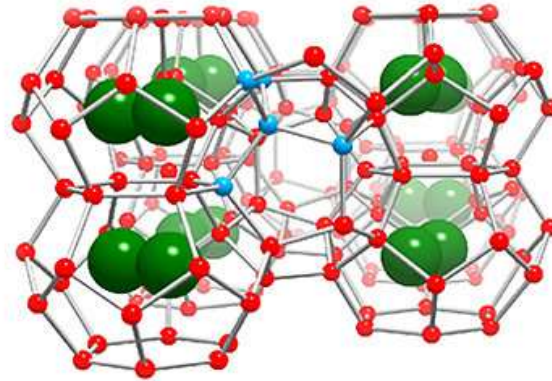
Copyright © 2016 W. W. Norton & Company, Inc.

Interactions between geosphere and rest of Earth system



Copyright © 2016 W. W. Norton & Company, Inc.

Clathrate Hydrates



Clathrate Hydrate



Have we reached a point of no return?



Who cares?



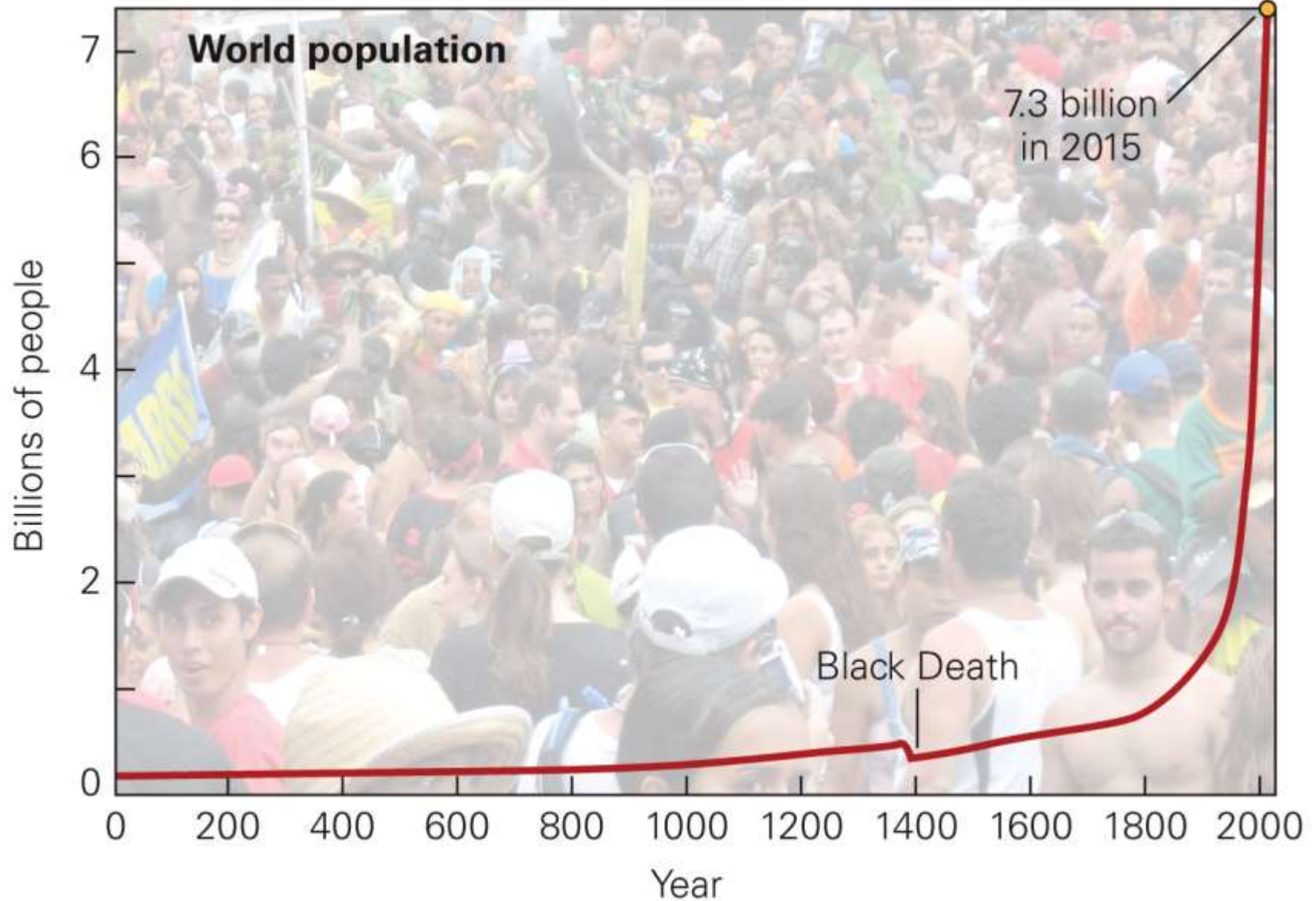
The Earth has a way of handling climate change.

Who cares?



The Earth is a ball of rocks. It doesn't need to "handle" anything.

Who cares?



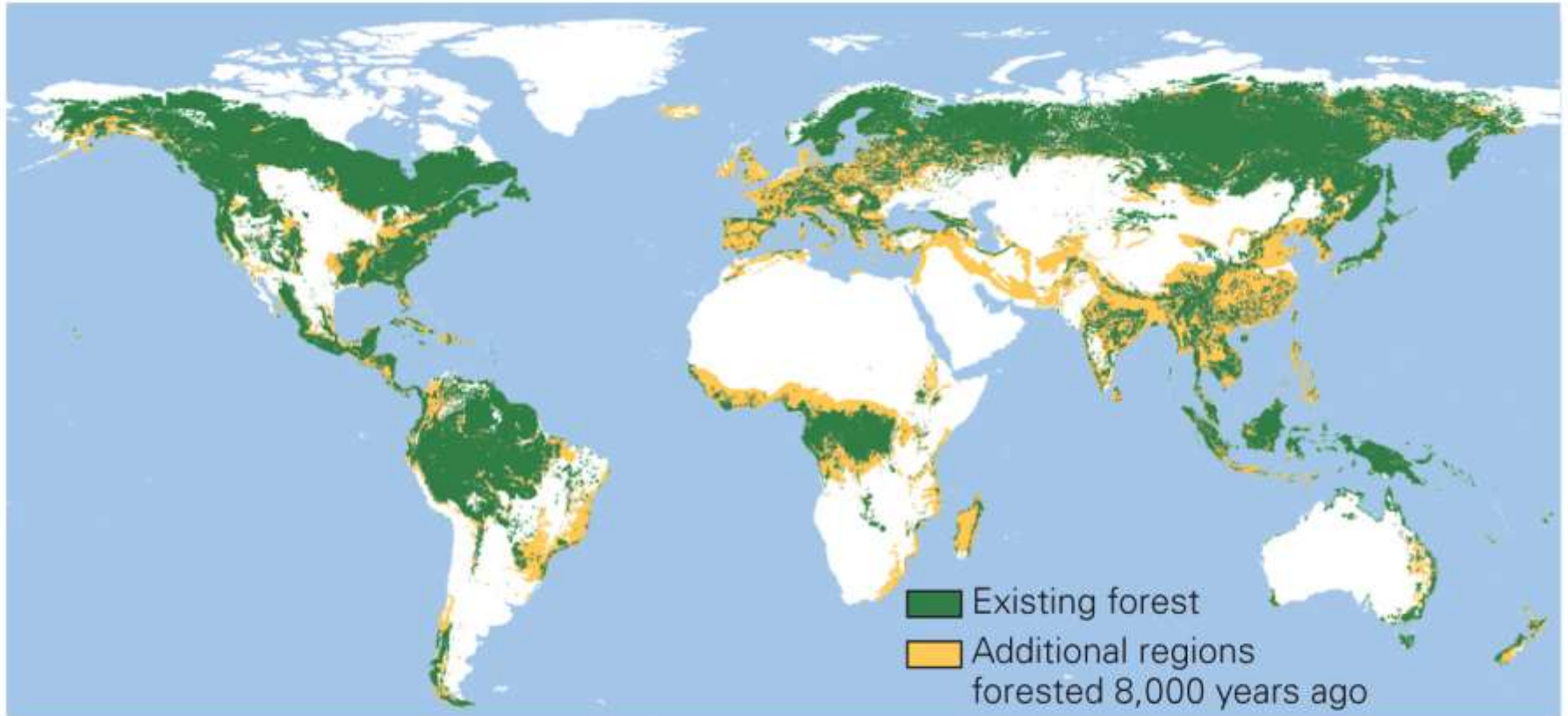
Will 1 day of over eating have health implications?



Will 1 day of over spending have wallet implications?



Will 1 day of over eating have health implications?



Also ozone layer

