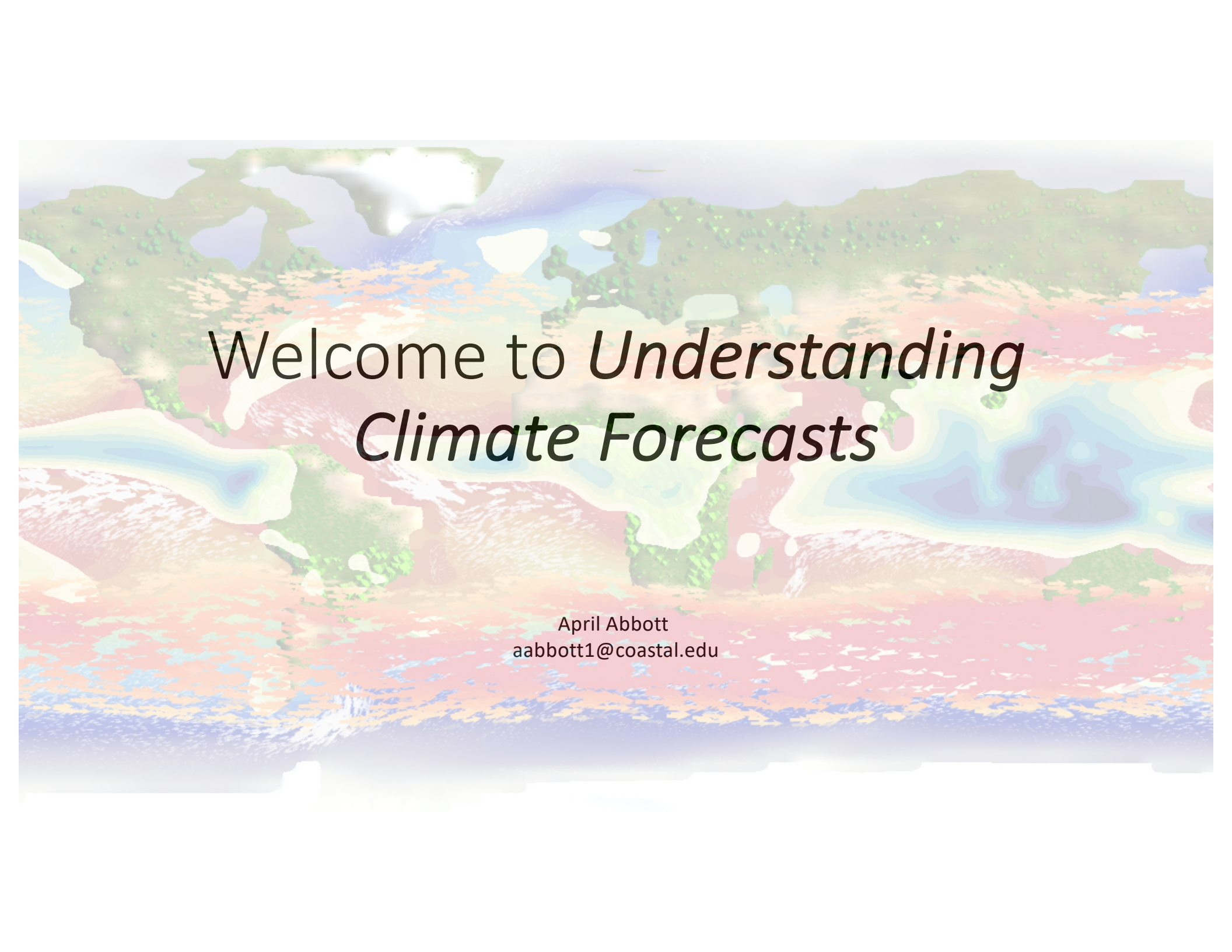




Welcome to *Understanding Climate Forecasts*

April Abbott
aabbott1@coastal.edu

Let's talk models

- What is hysteresis? What is a tipping point?
- Is abrupt change common in Earth's system?
- How does climate modelling work?

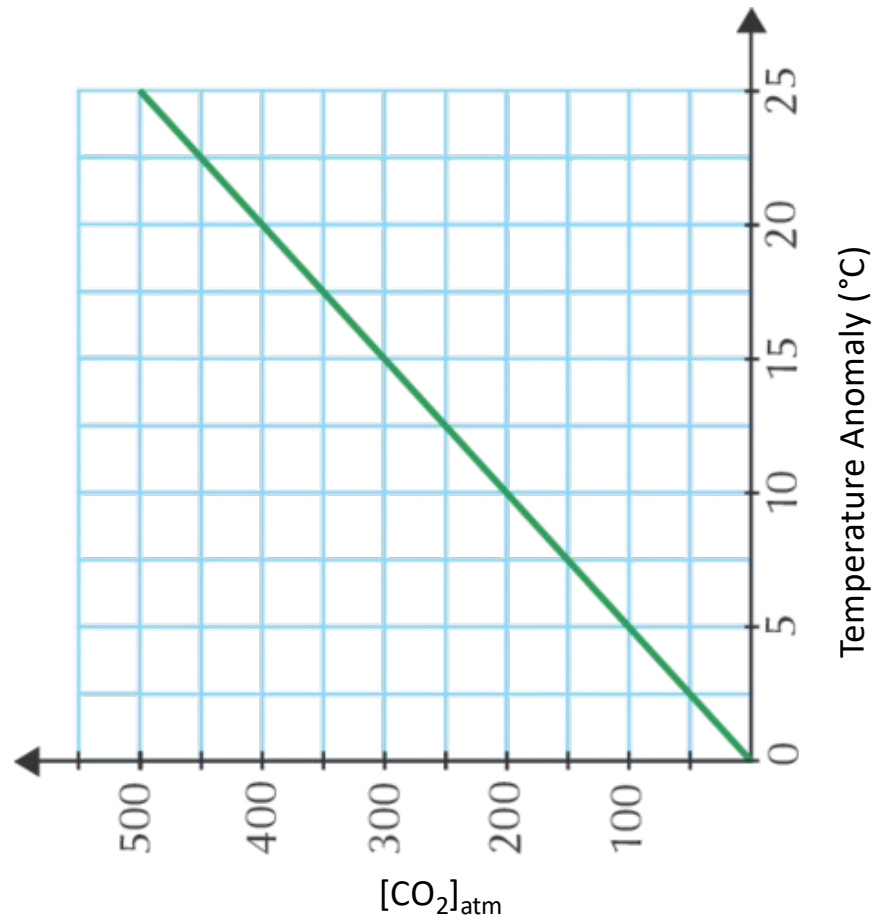


Non-Linear Change

- What do we mean by non-linear change?
- Are there examples of non-linear change in Earth's past?
- Why do we care?
- How can we predict future changes?

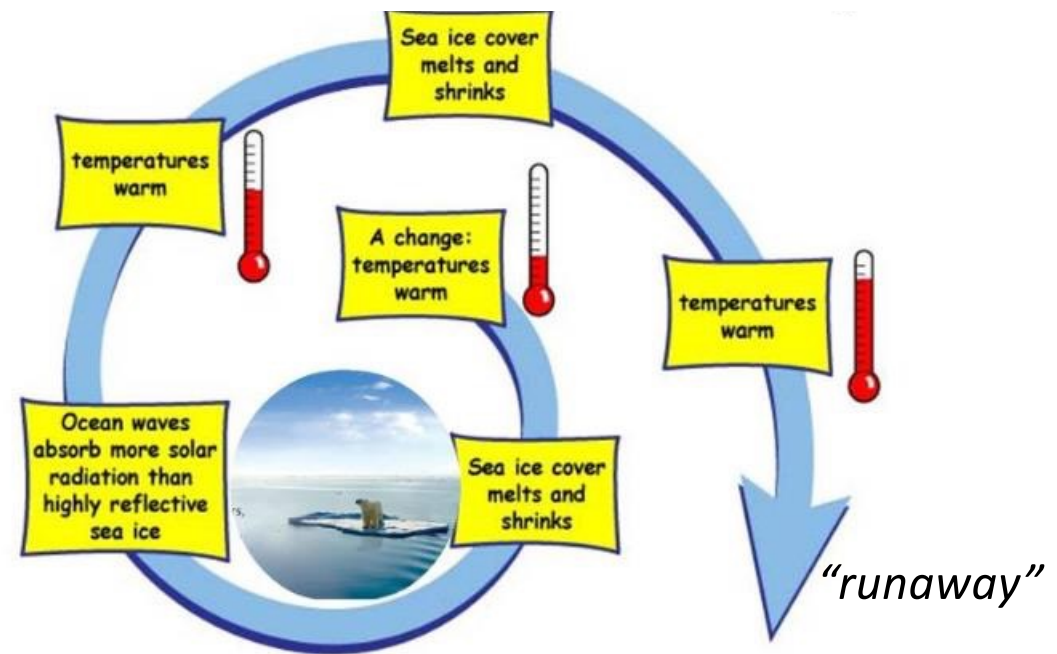
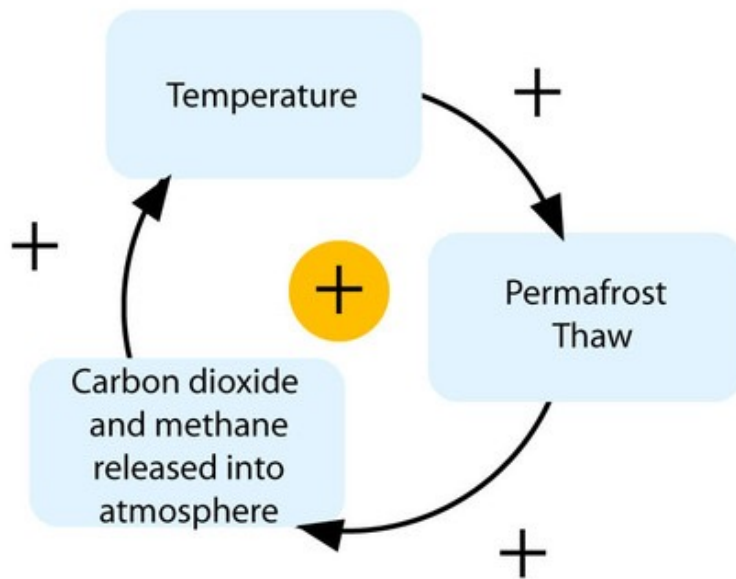


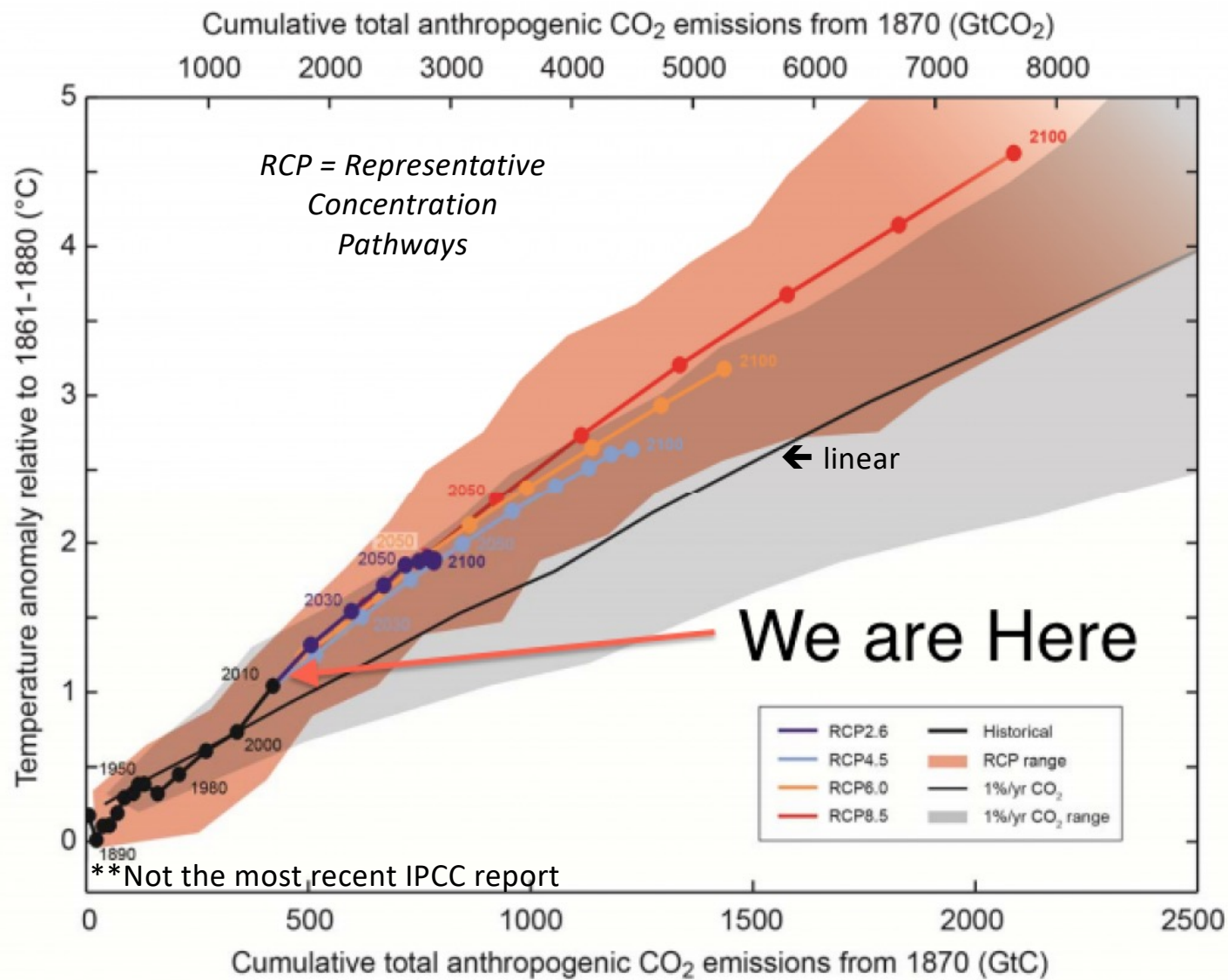
What it is not:



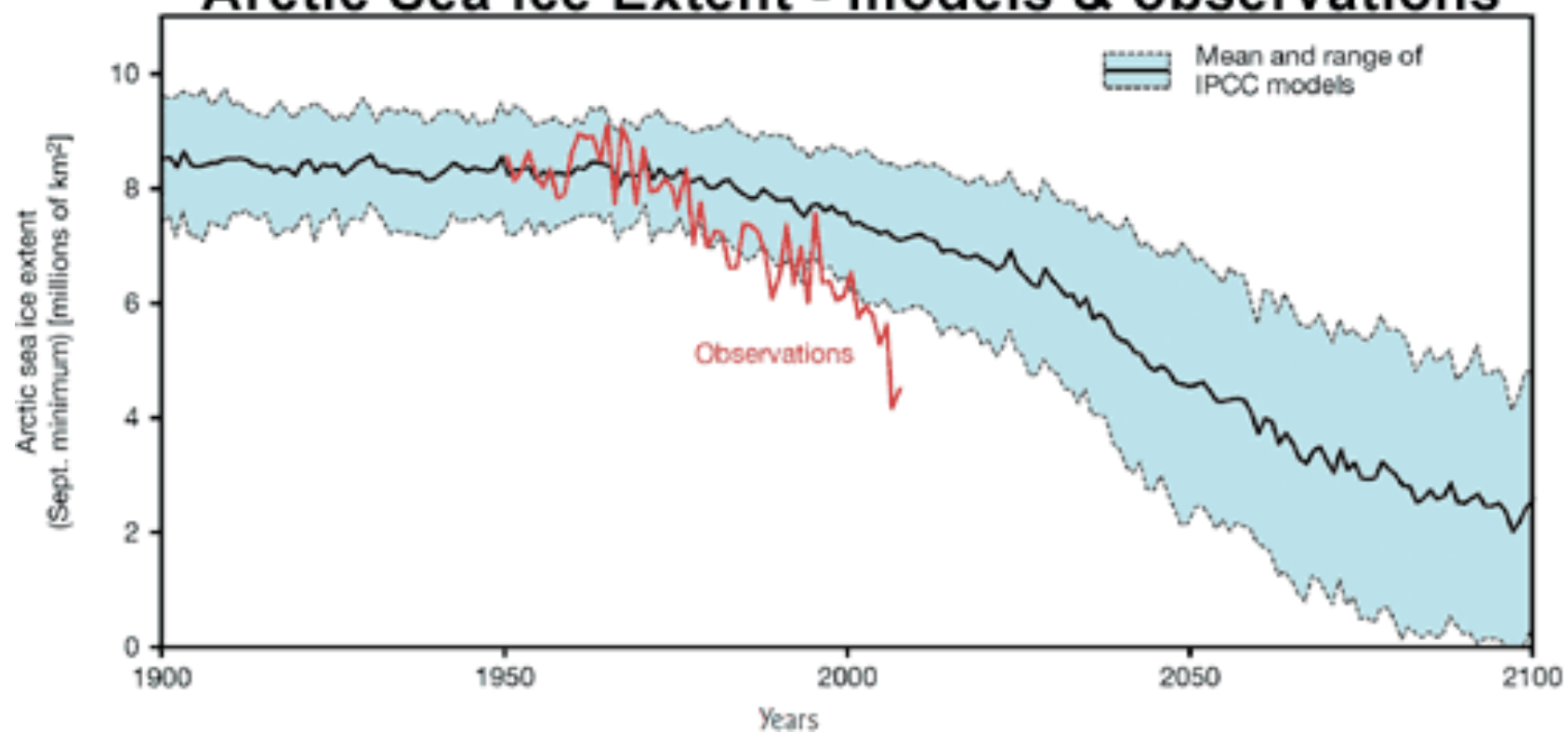
What cause it? Feedbacks!

- Positive (exaggerate the initial change; self perpetuating)
- Negative (mitigate the initial perturbation)

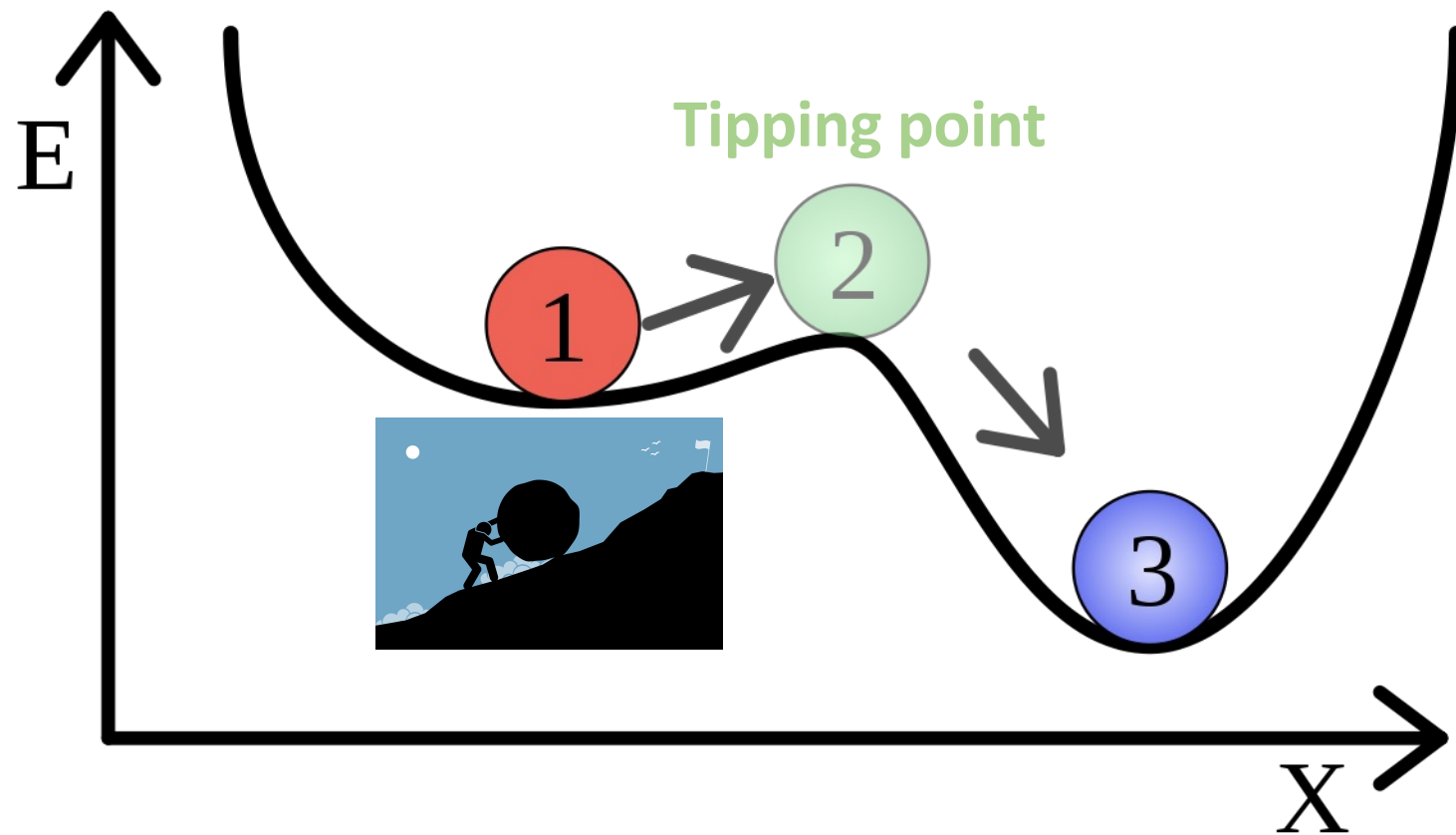




Arctic Sea Ice Extent - models & observations



Alternate Steady State? (hysteresis)



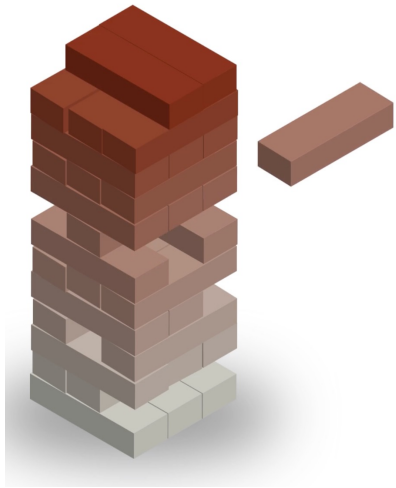
What is a tipping point? (and do we know where they are?)

“A tipping point is the point at which small changes become significant enough to **cause a larger, more critical change that can be abrupt, irreversible, and lead to cascading effects**. The concept of tipping points was introduced by the IPCC 20 years ago, but then it was thought they would only occur if global warming reached 5°C. Recent IPCC assessments, however, suggested that **tipping points could be reached between 1°C and 2°C of warming.**”

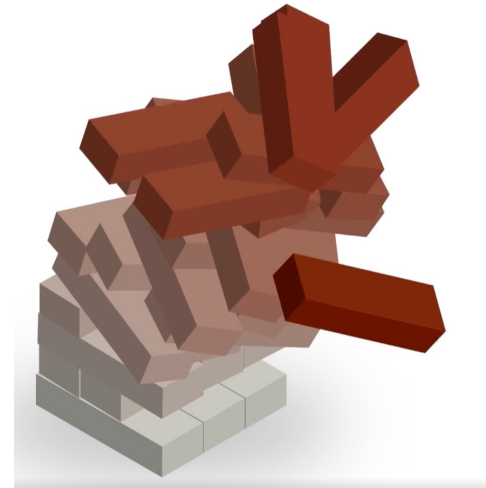
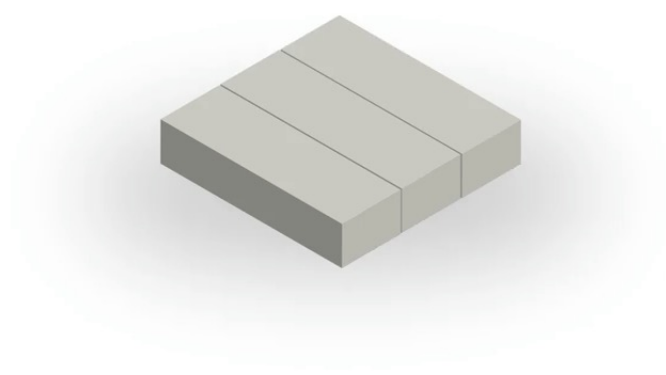


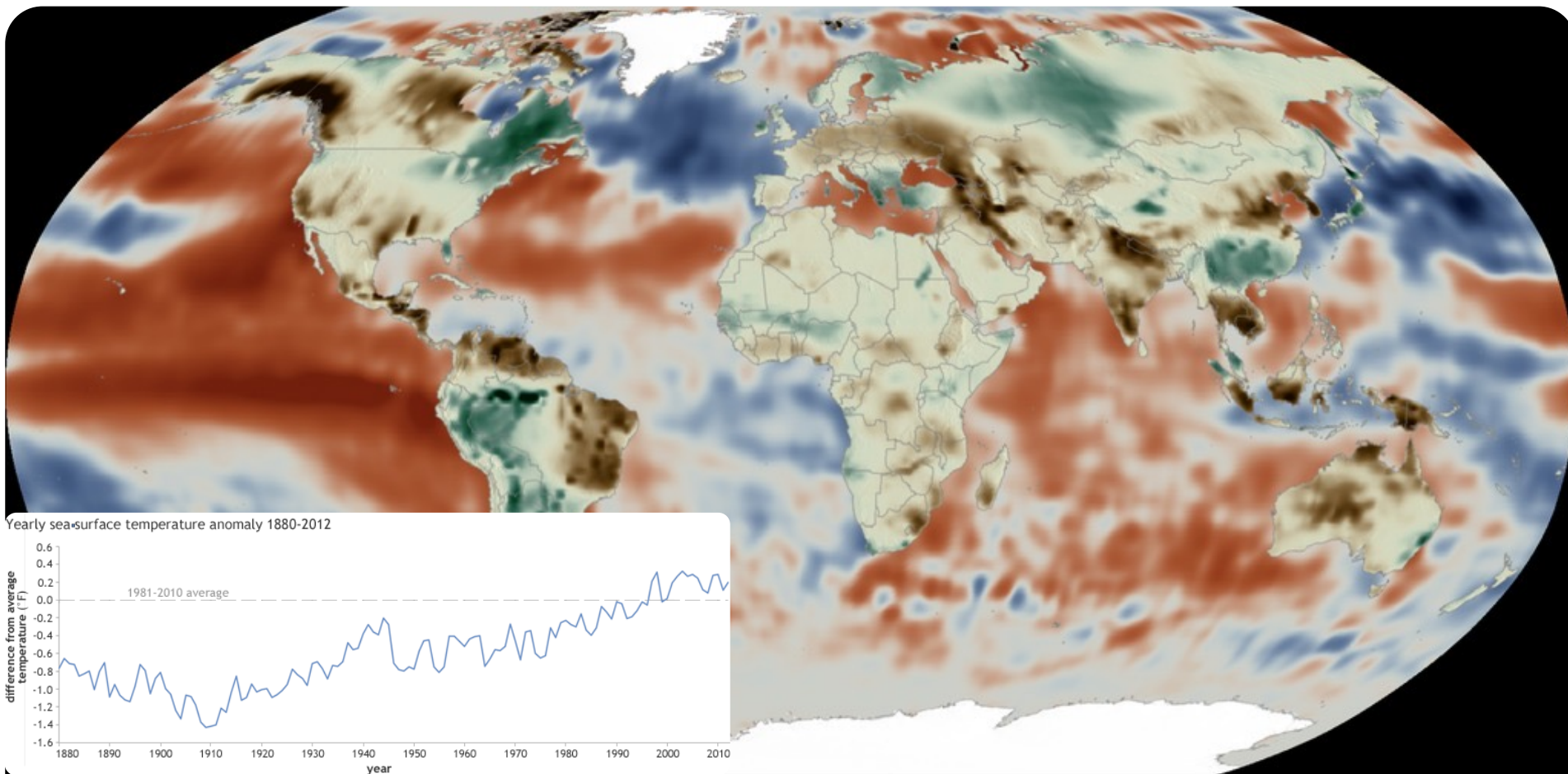
Prof. Richard Alley seminar

https://www.youtube.com/watch?v=o4oMsfa_30Q

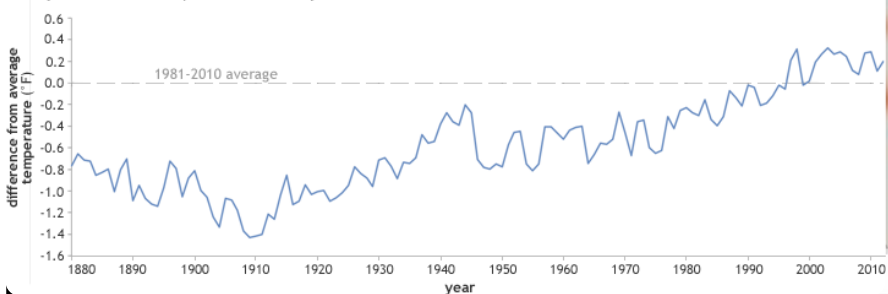


CB

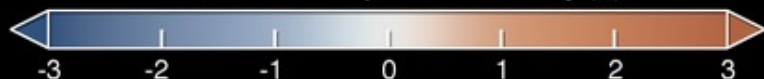




Yearly sea surface temperature anomaly 1880-2012



Sea Surface Temperature Anomaly (K)



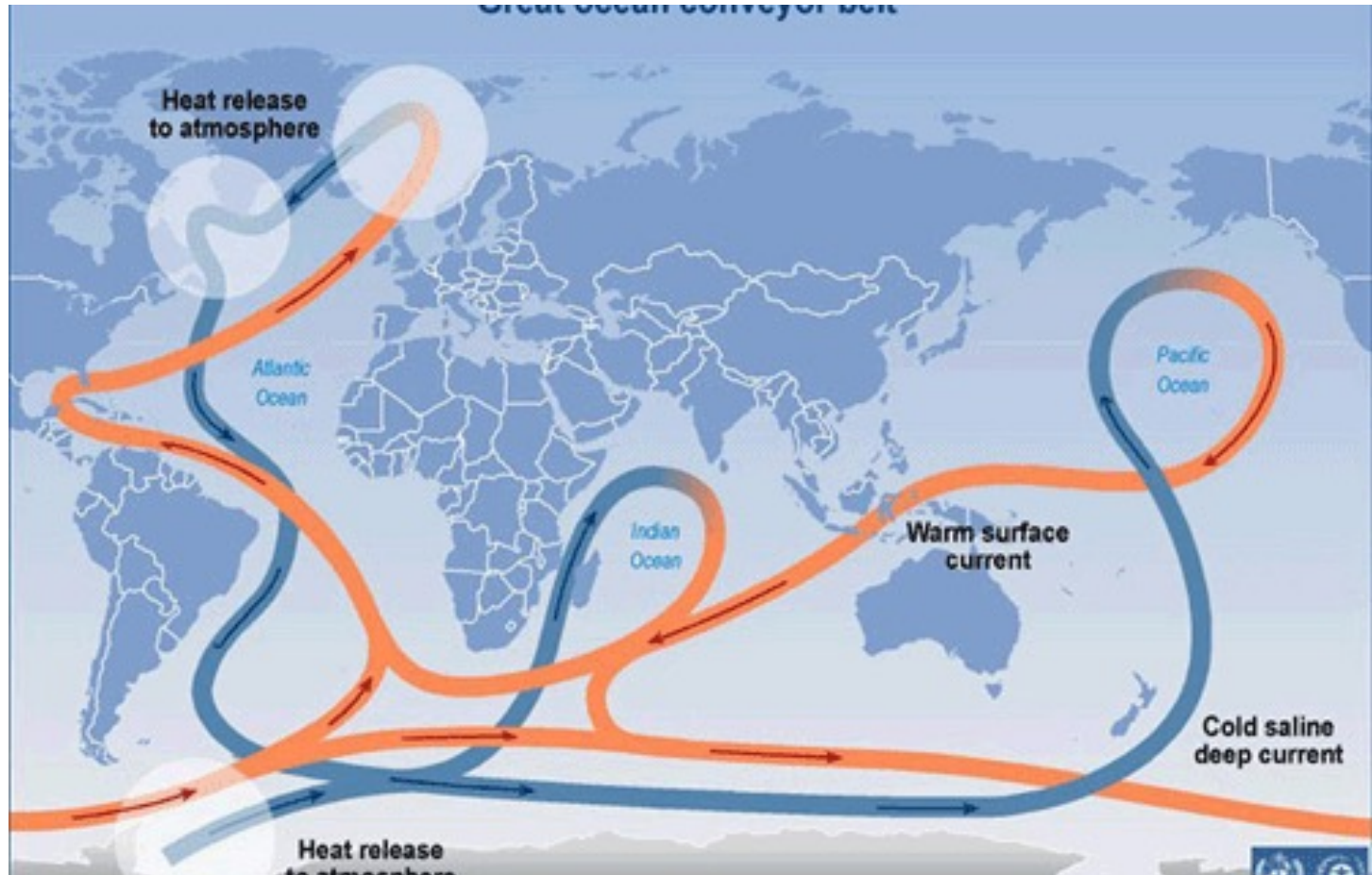
Sep 2015

Terrestrial Water Storage Anomaly (cm.)



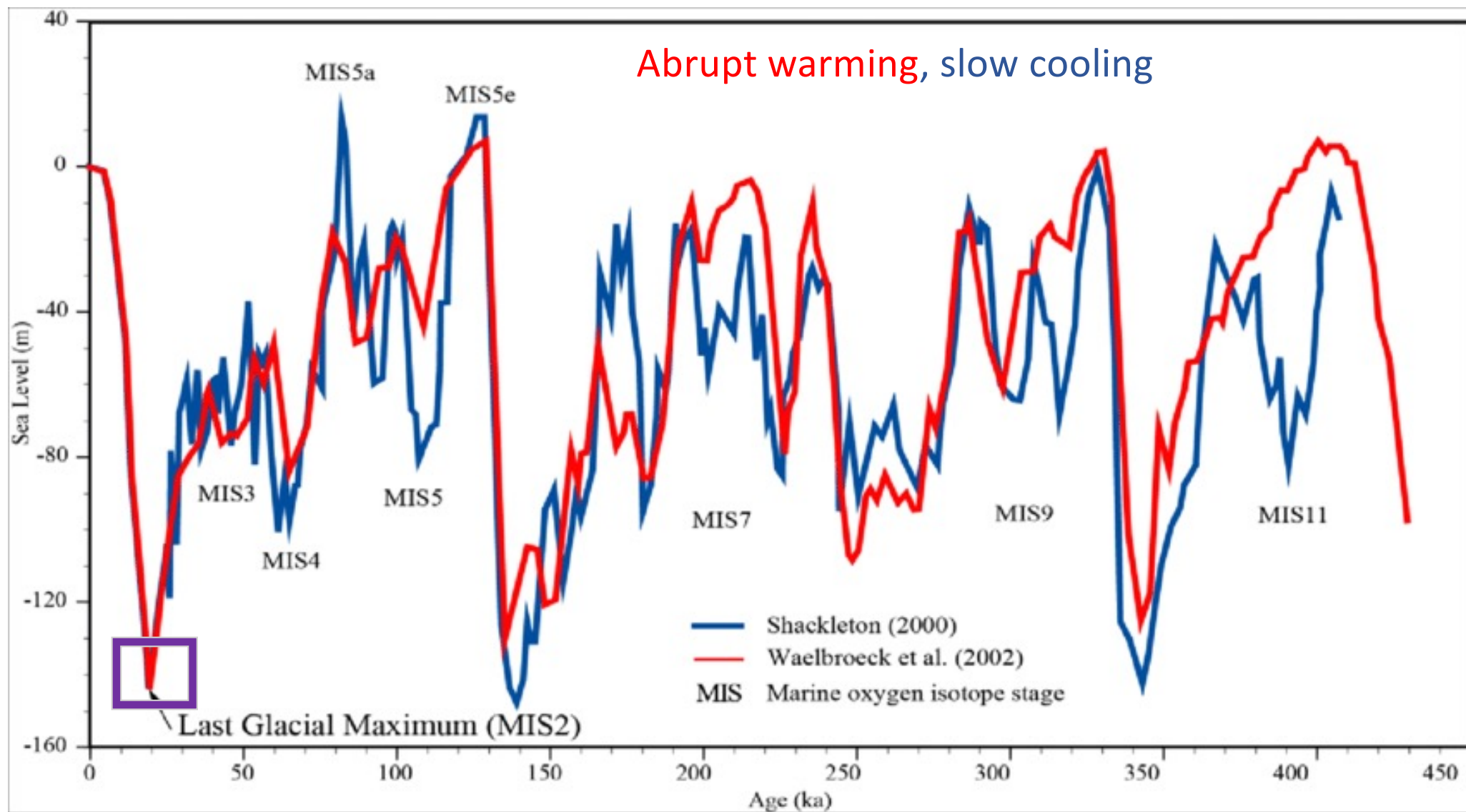
circles = deep water formation (aka drivers of ocean circulation)

Can ocean
circulation
turn off?





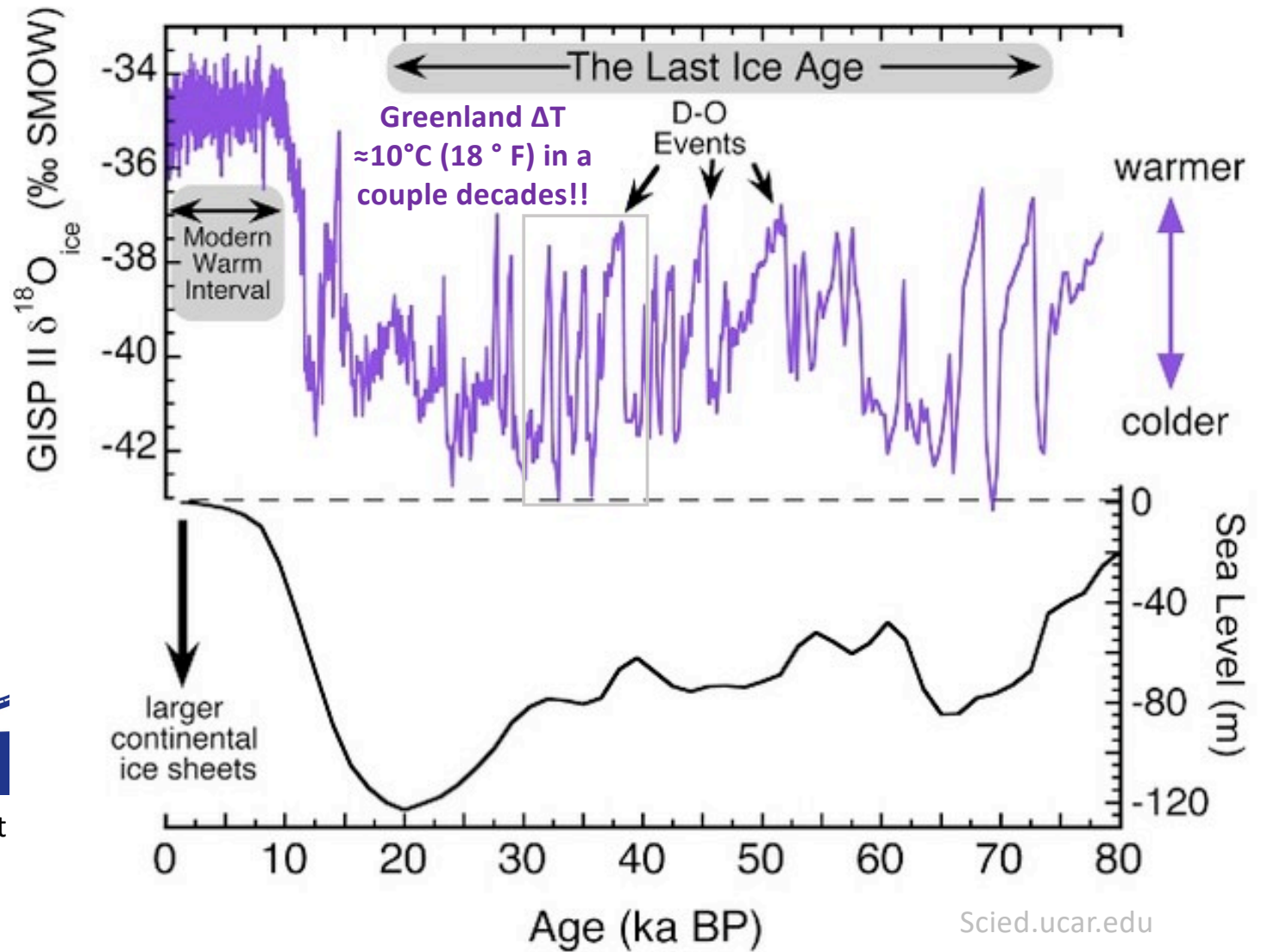
What is possible?
A look to Earth's
past.



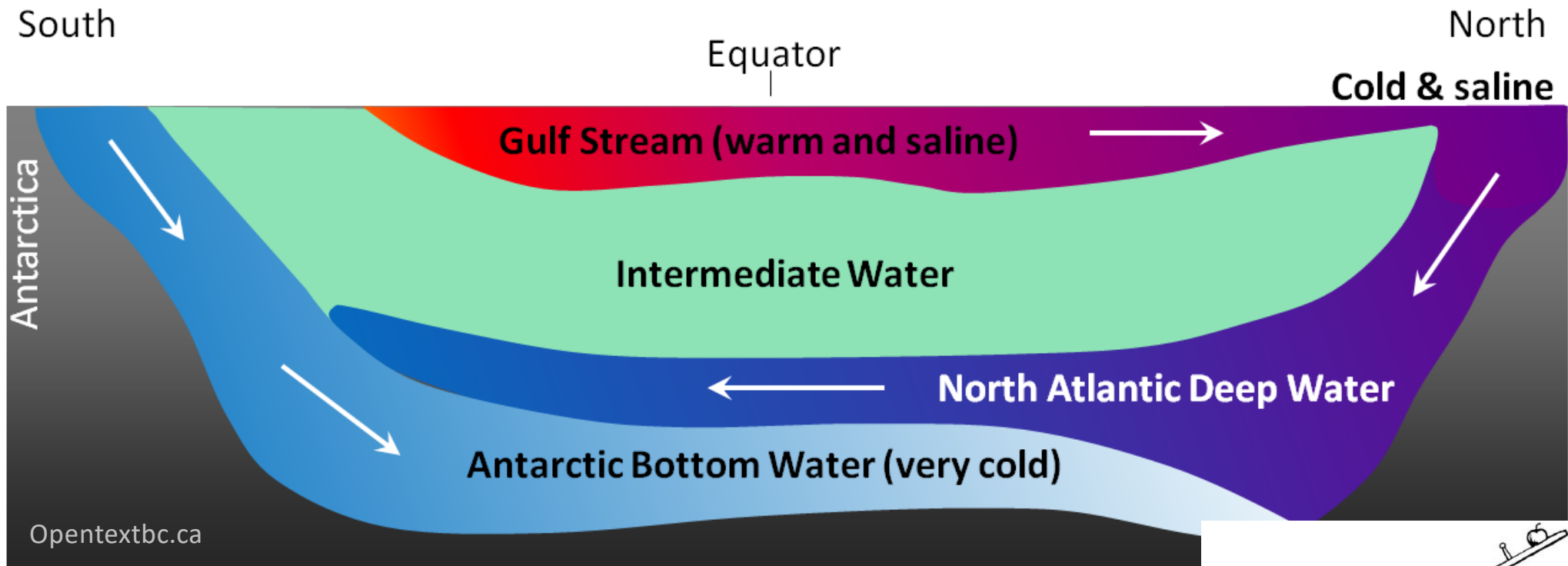
During the last ice age, temperatures in the Northern Hemisphere went on a roller coaster ride, every 1500 years or so...



D-O = Dansgaard-Oeschger Event

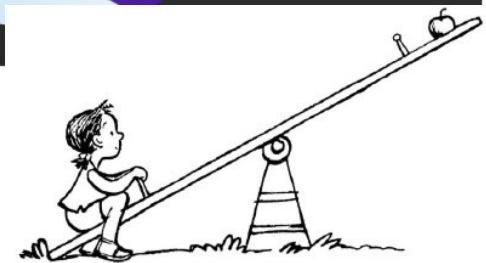


Each plummet in the temperature record corresponds to slower overturning circulation...

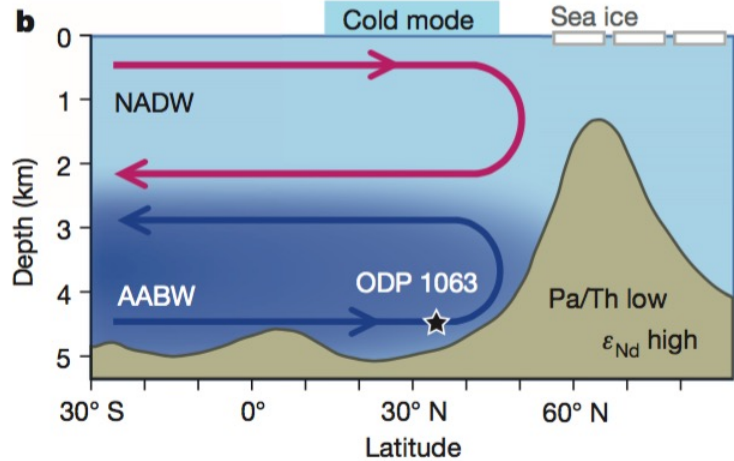
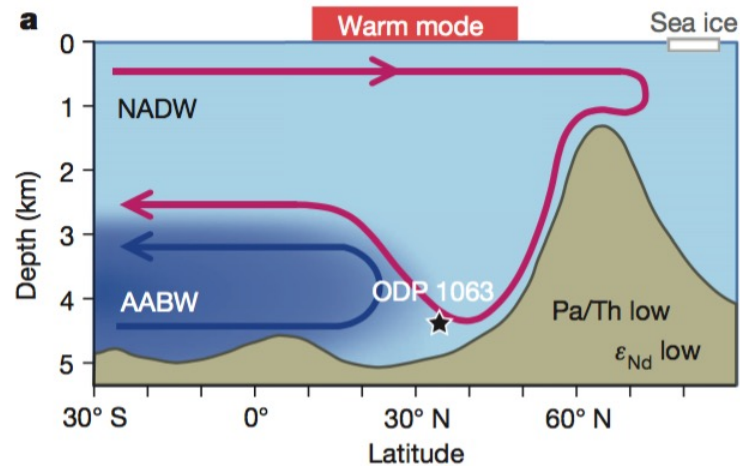


Warming in North Atlantic → Cooling in Antarctica

North Atlantic ocean circulation and abrupt climate change during the last glaciation-L.G. Henry et al. 2016, DOI: 10.1126/science.aaf5529



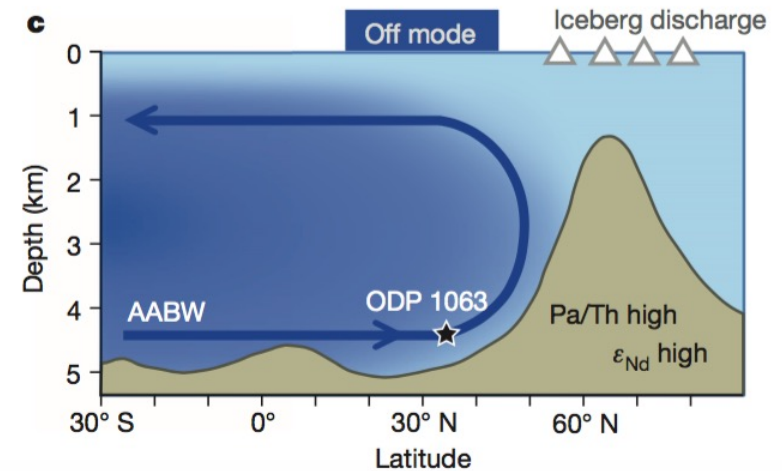
Changes to Circulation in the Atlantic Ocean

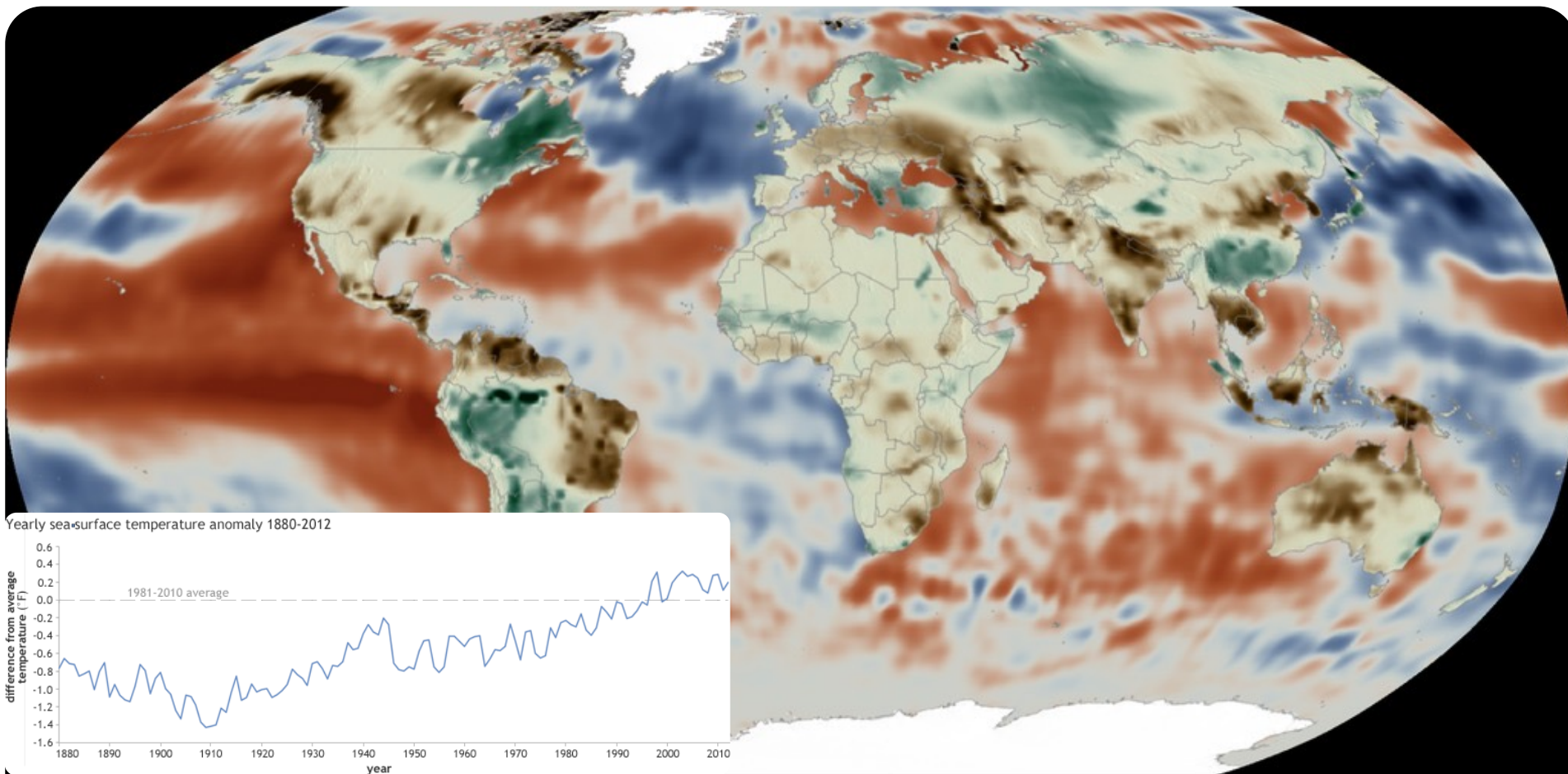


Last Glacial Maximum

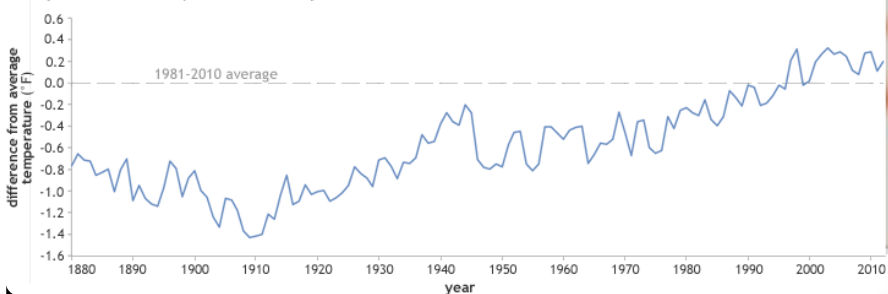
Böhm et al. 2015

Heinrich Events

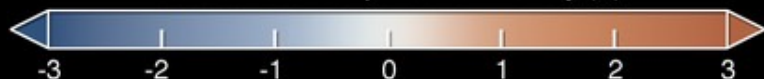




Yearly sea surface temperature anomaly 1880-2012



Sea Surface Temperature Anomaly (K)

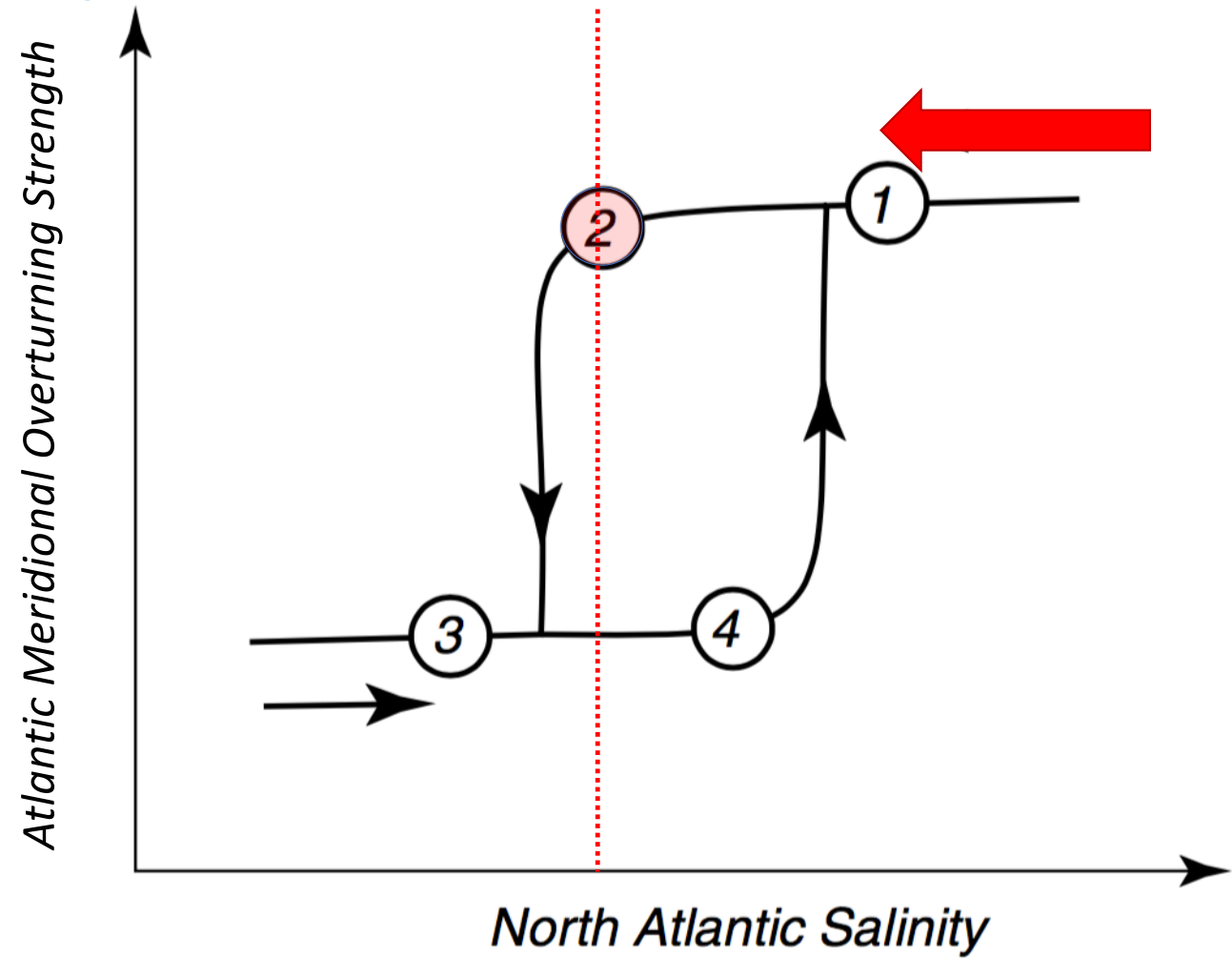


Sep 2015

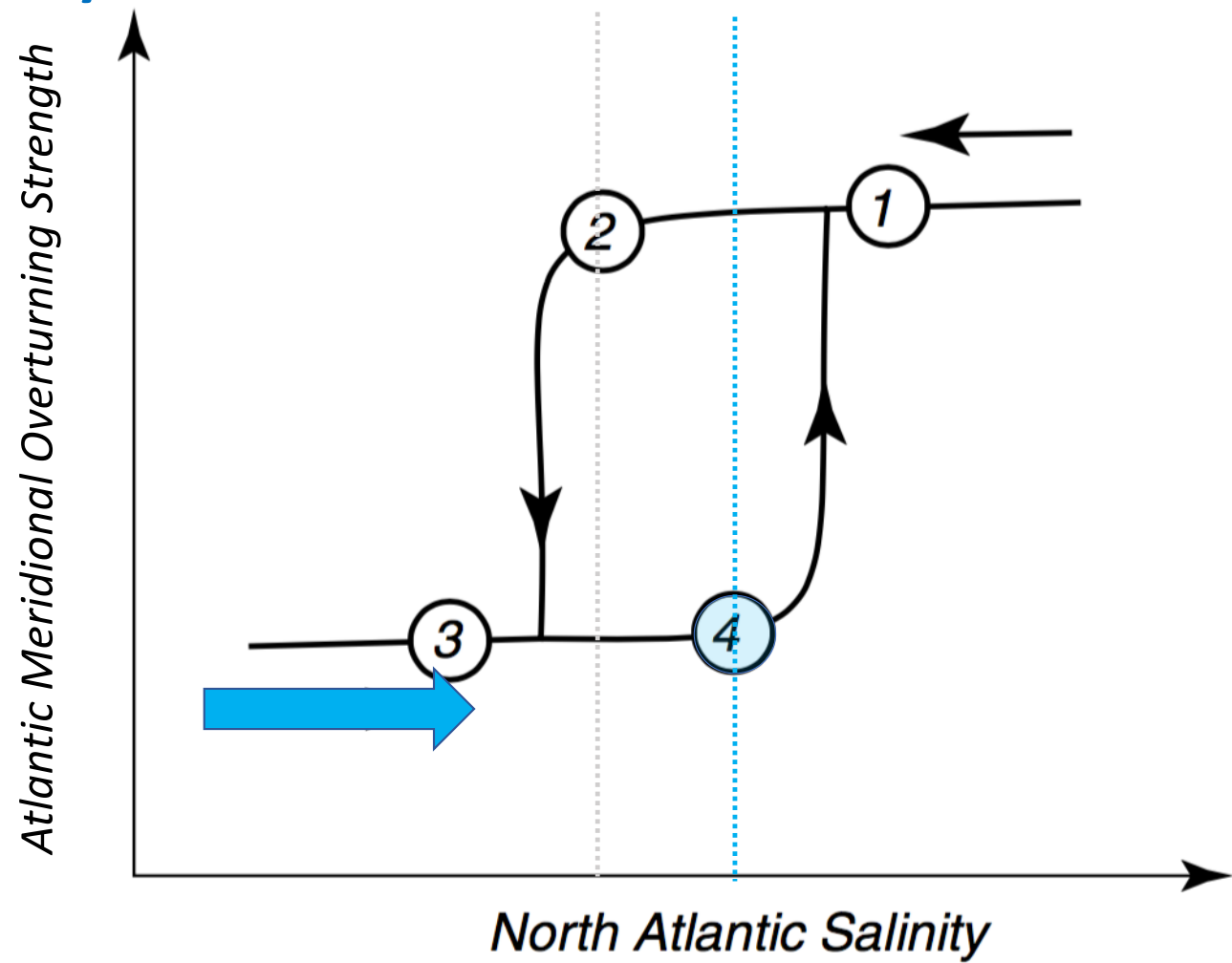
Terrestrial Water Storage Anomaly (cm.)



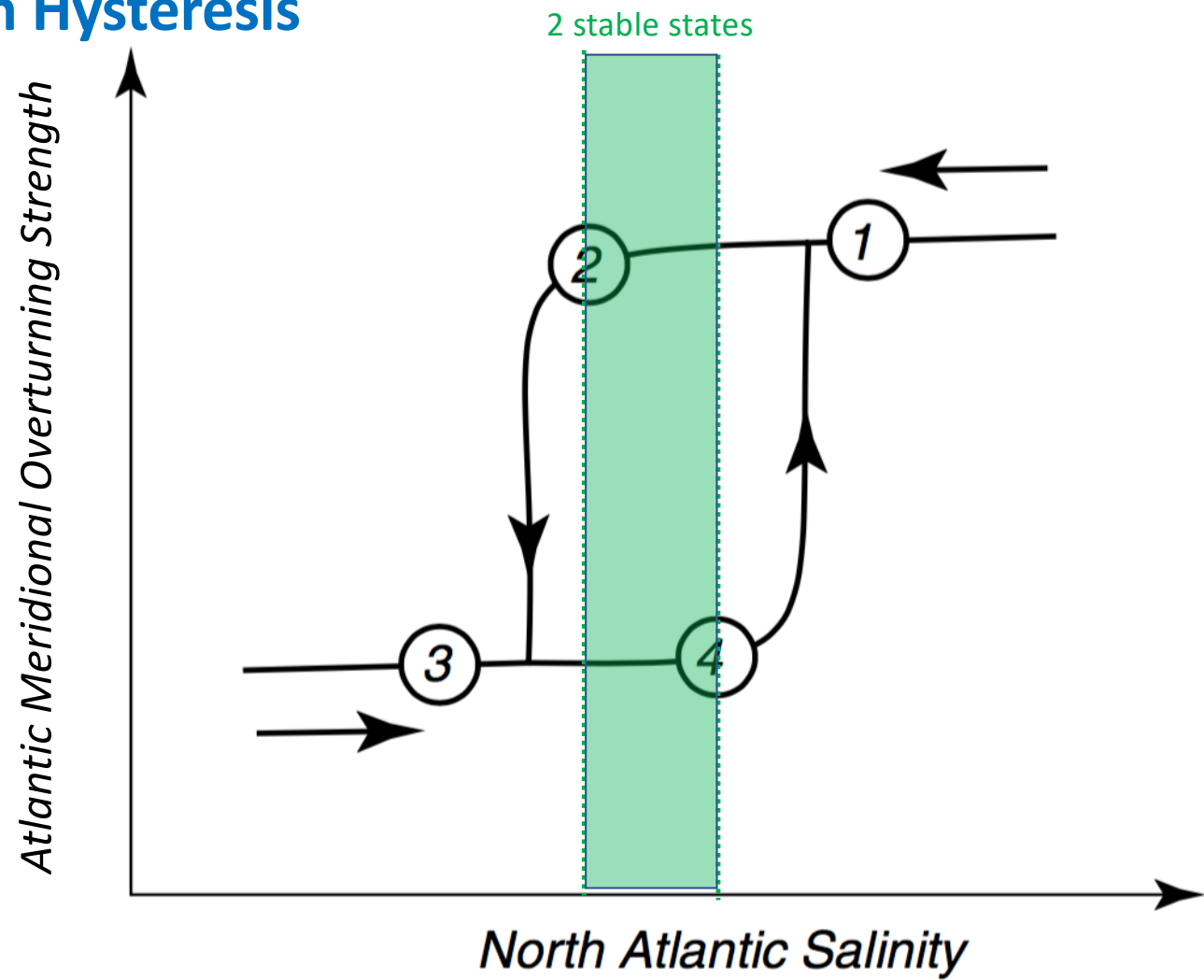
Ocean Circulation Hysteresis



Ocean Circulation Hysteresis



Ocean Circulation Hysteresis



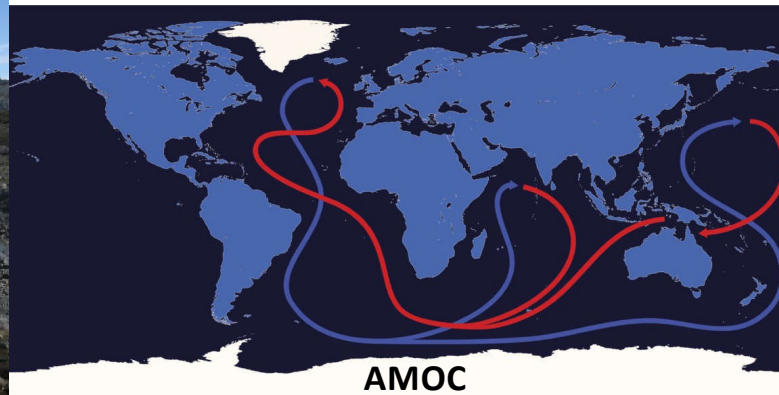
Why do we care? (Can it happen again?)



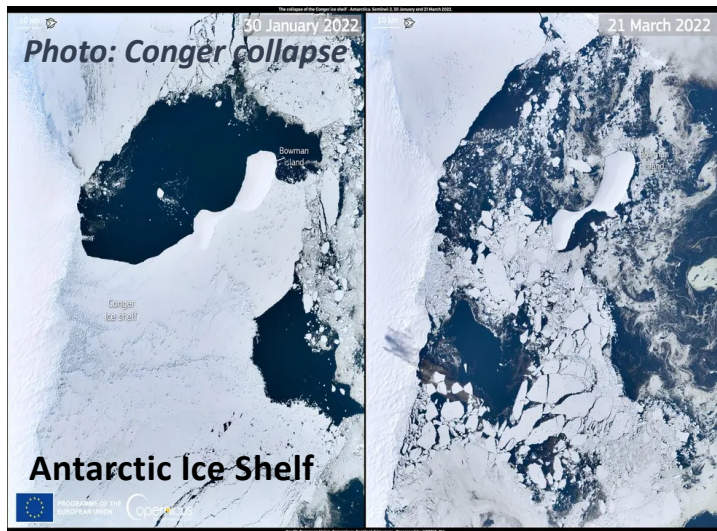
Hothouse Earth



Europe Freeze



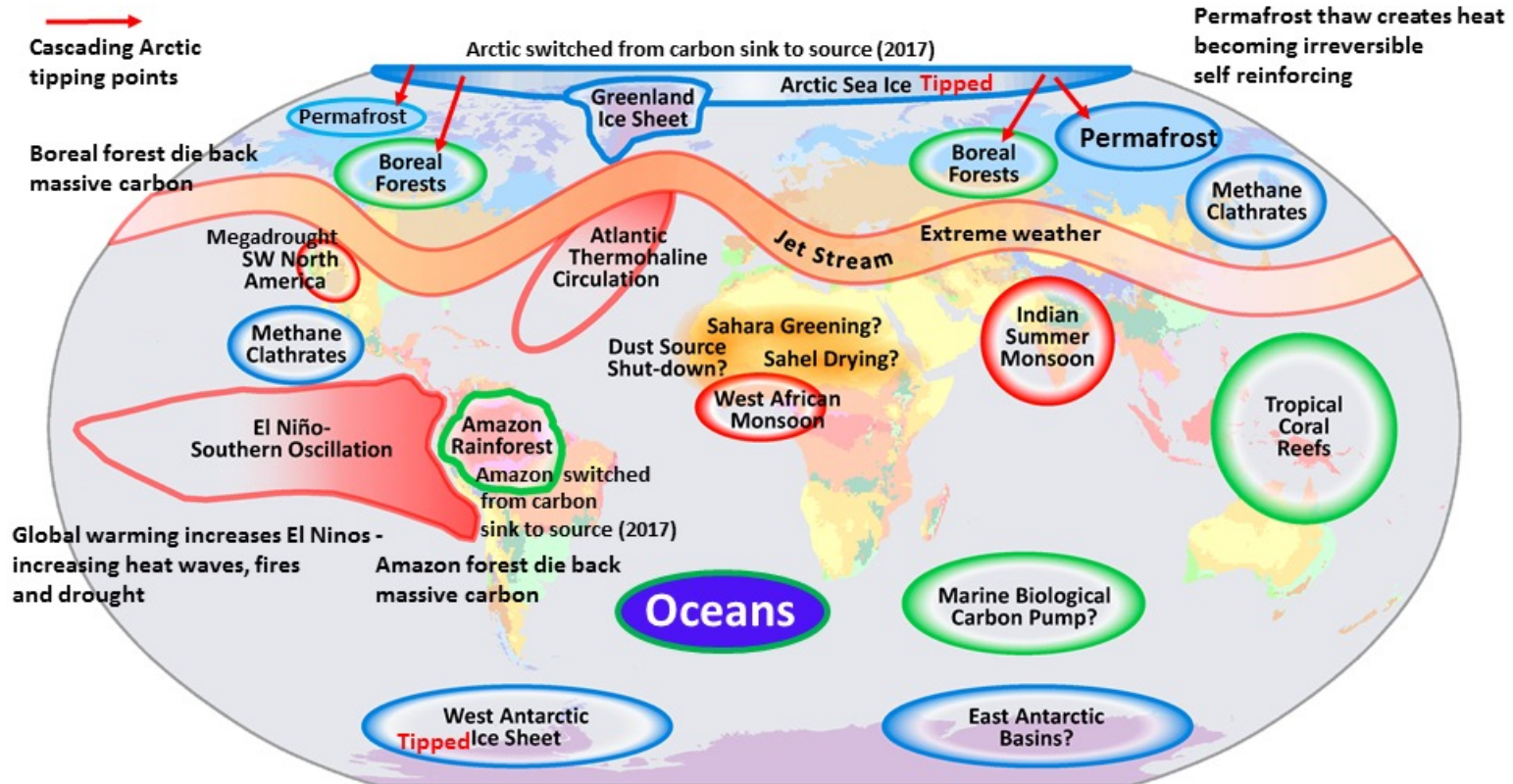
We *think* we know  what they are... but where?



Global Warming Vulnerable Tipping Points

Committed global warming ($>2^{\circ}\text{C}$) commits most, most likely past tipping
Thawing permafrost is emitting CO_2 , methane & nitrous oxide

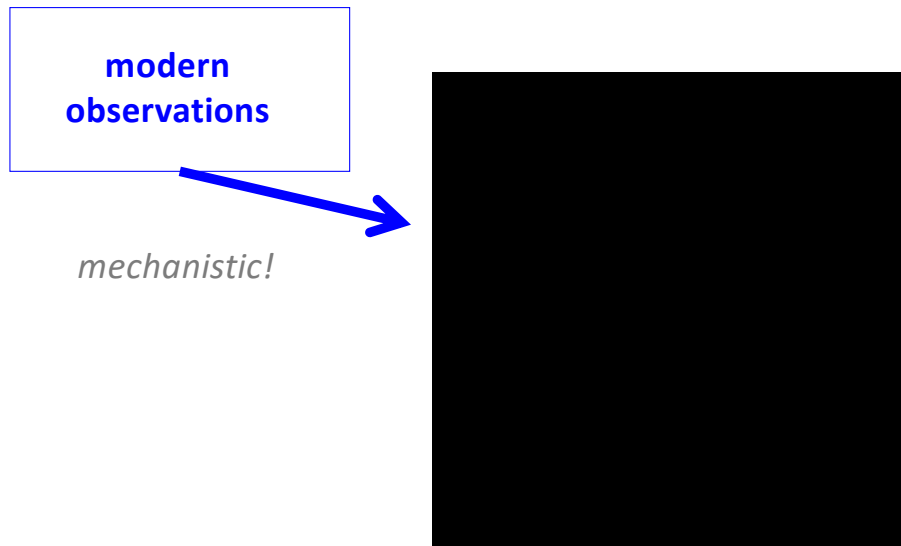
- Cryosphere Entities
- Circulation Patterns
- Biosphere Components

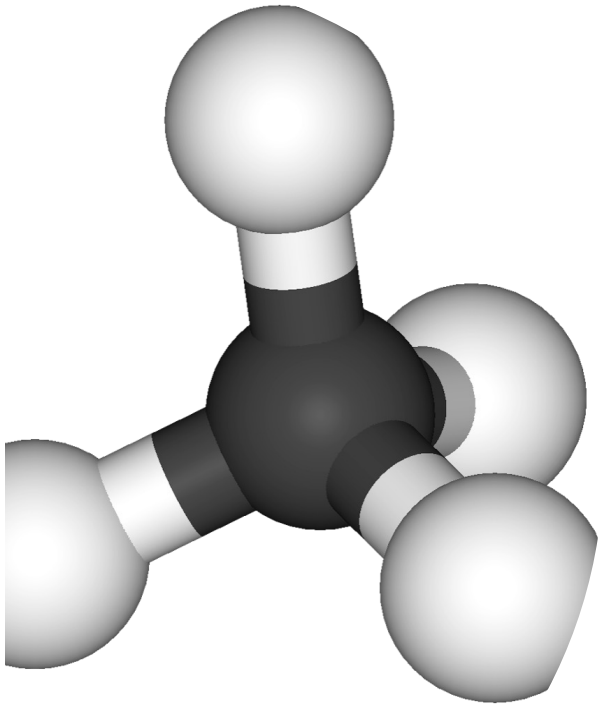
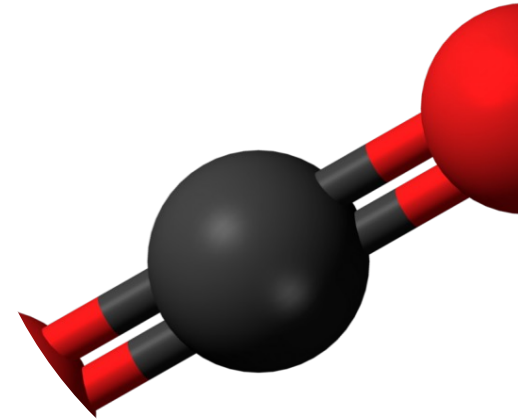
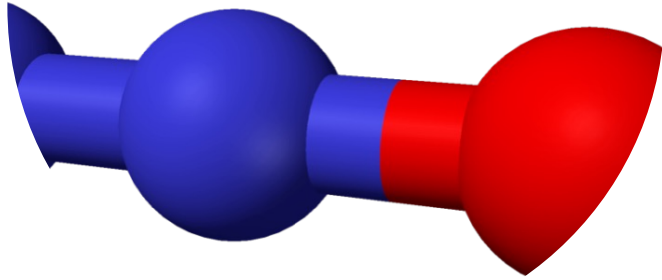


Oceans: Heating, Acidification & Deoxygenation

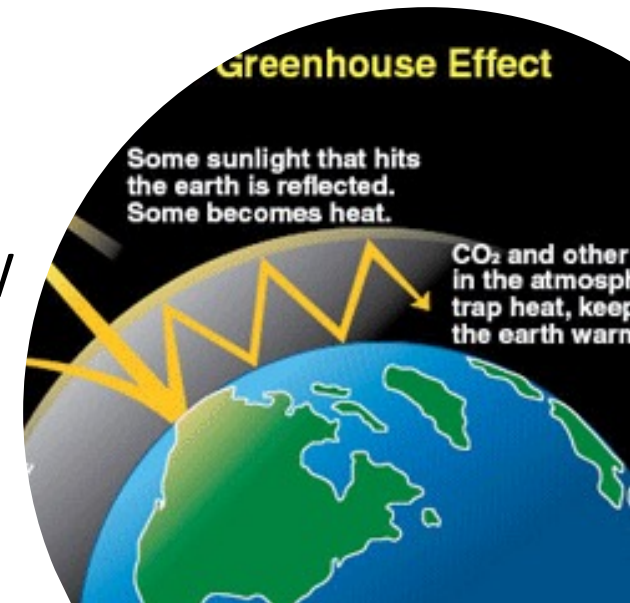
Adapted from Potsdam Climate Institute
Tipping Elements the Achilles Heels
of the Earth System

How do climate models work?

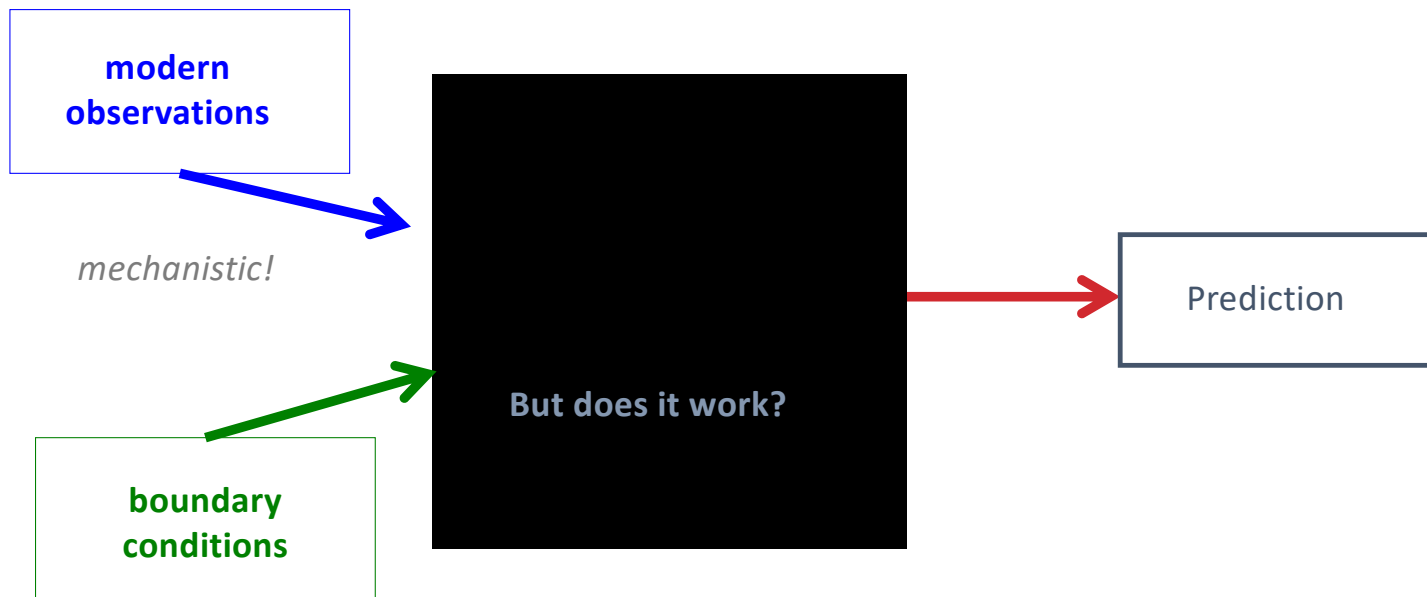




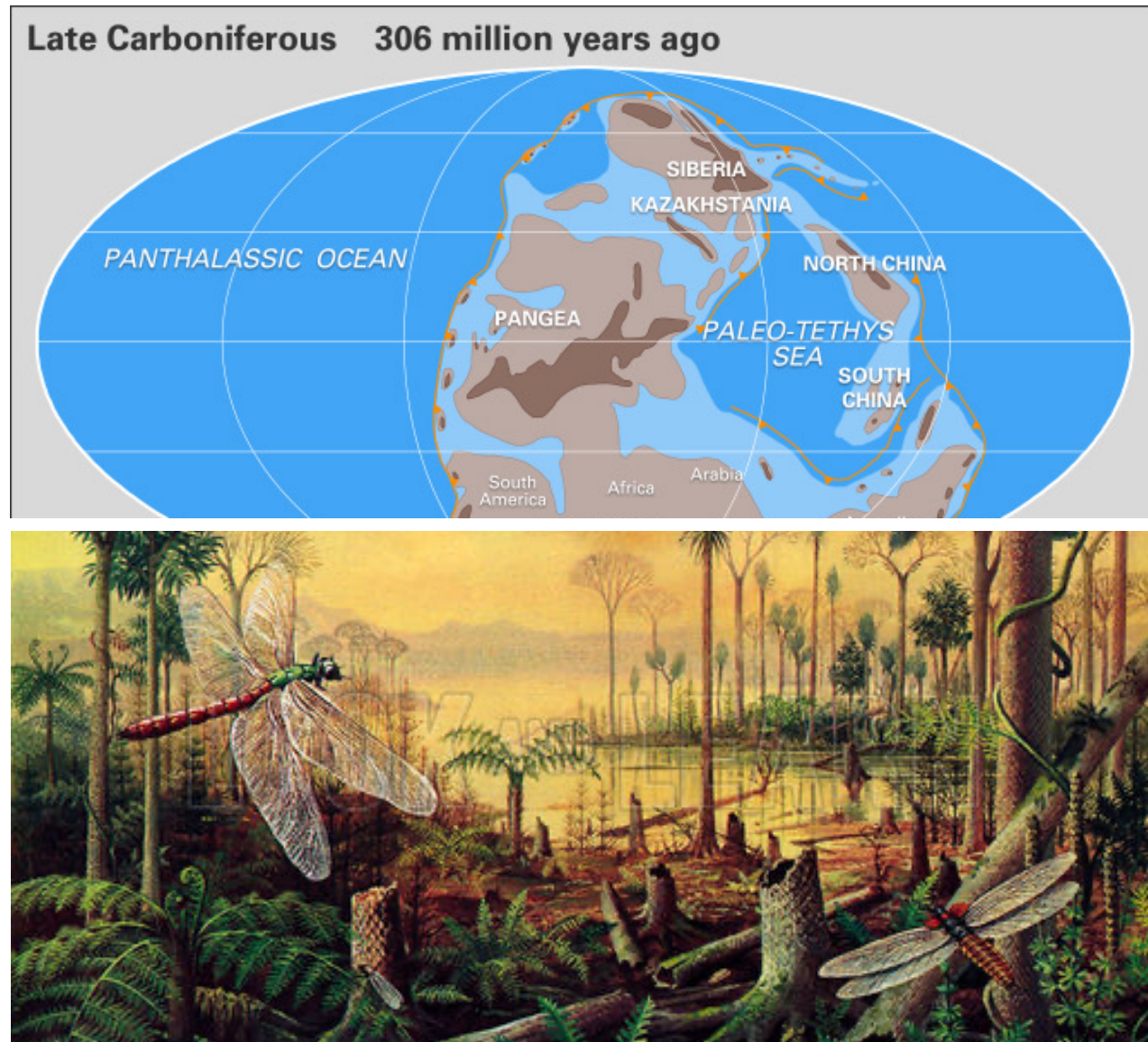
Processes we know

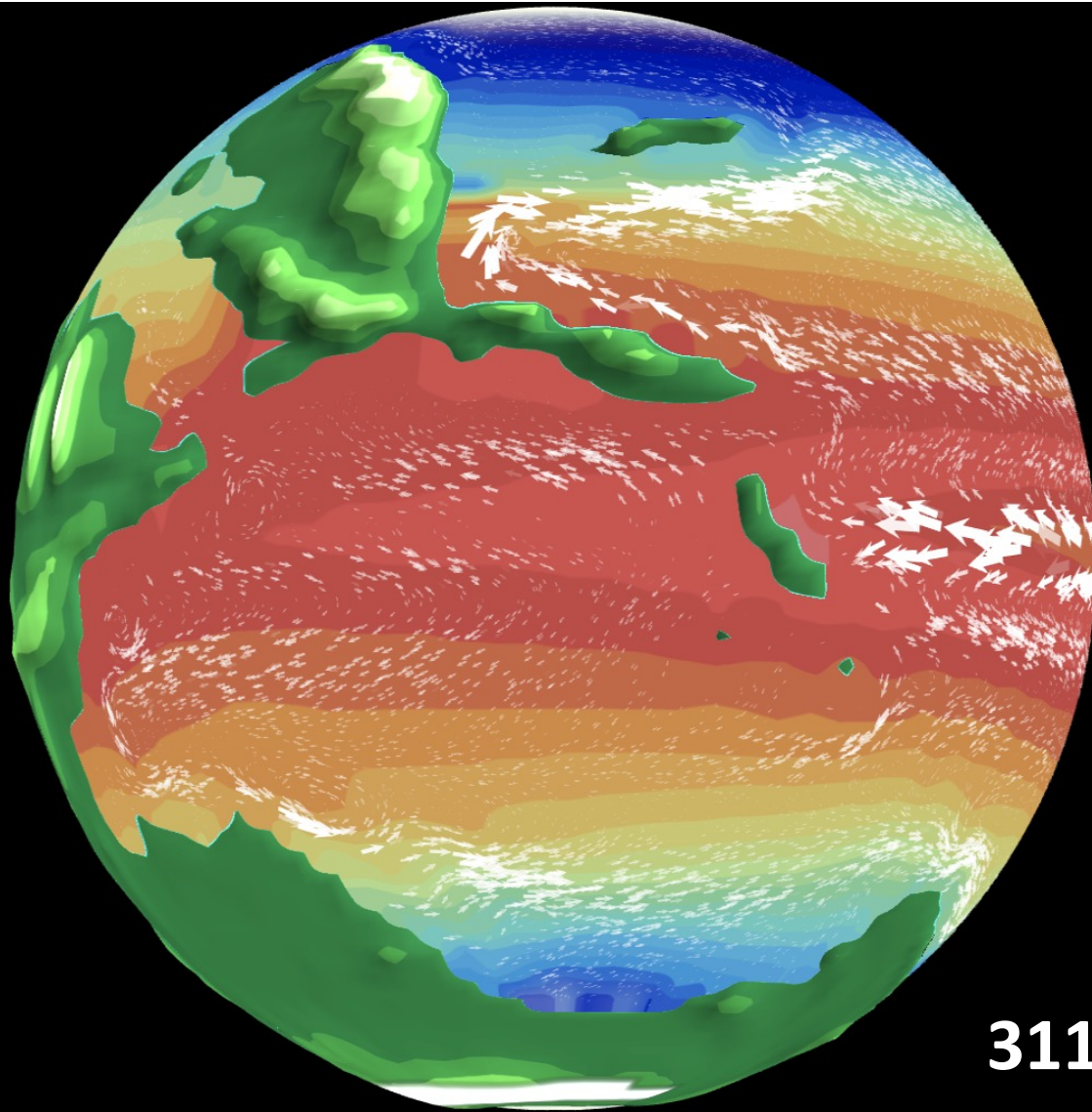


How do climate models work?



We know quite a bit about some interesting times in Earth's history... many quite different from the Earth we know today...



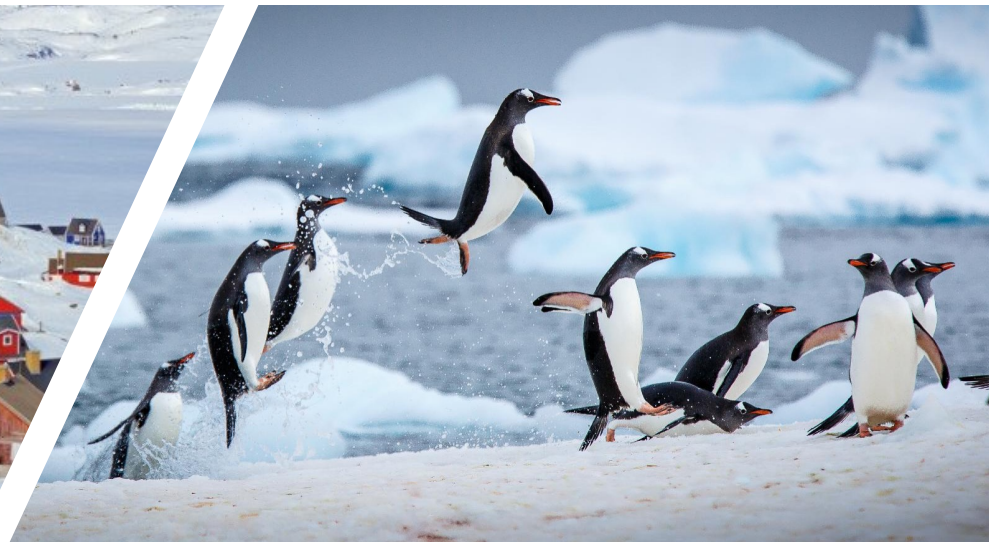


[Climatearchive.org/#](https://climatearchive.org/#)

311 Ma

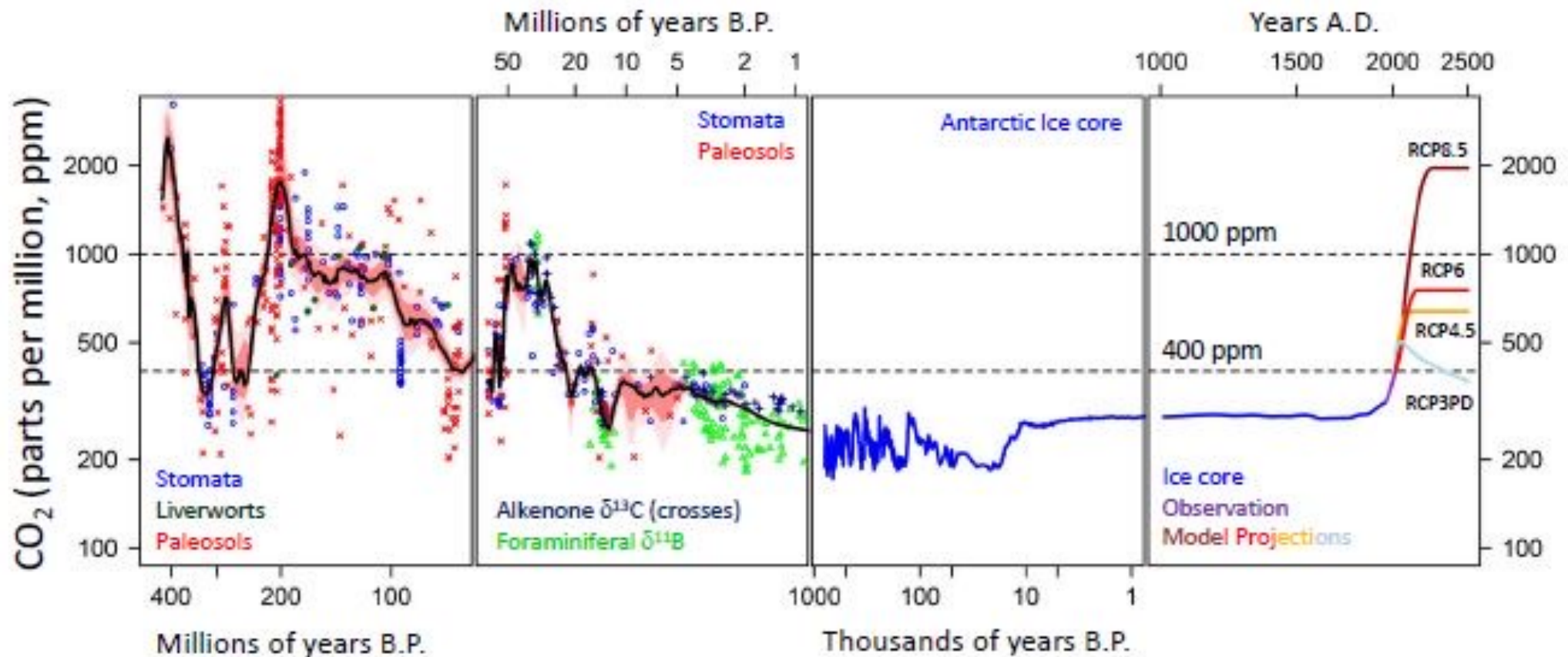


Fossils tell us about palm trees in places like Antarctica & Greenland during the Eocene

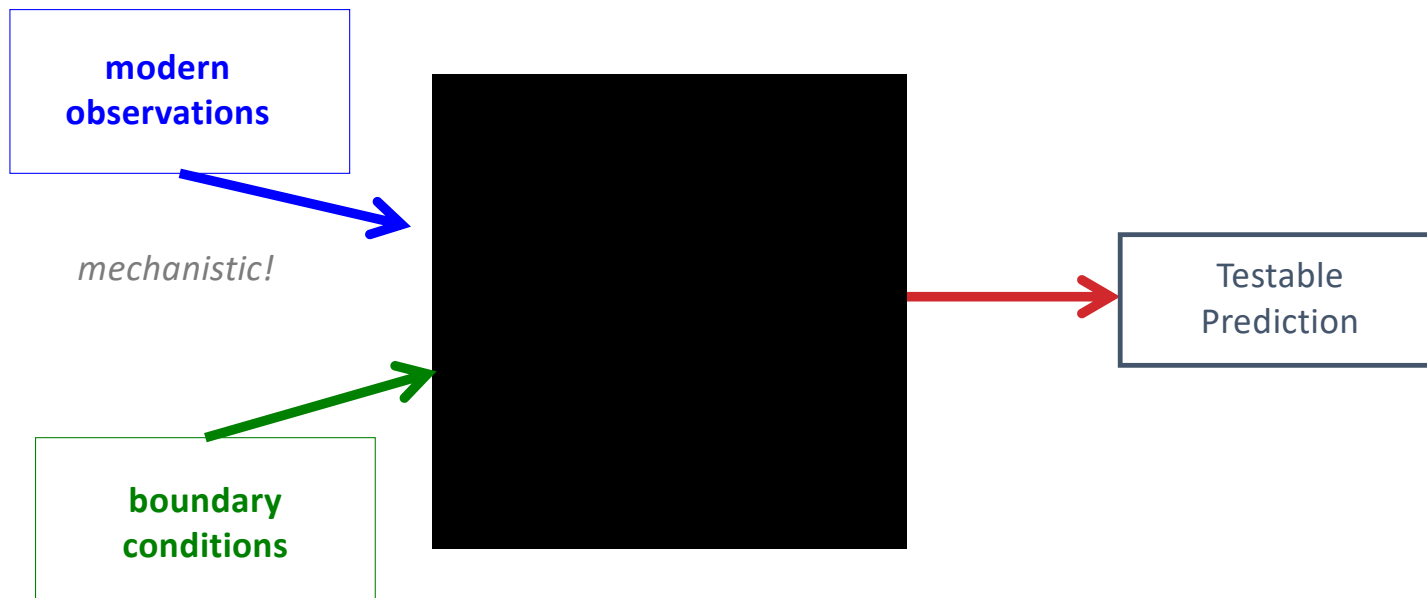


We can even reconstruct atmospheric composition!

<http://descentintotheicehouse.org.uk/past-and-future-co2/>

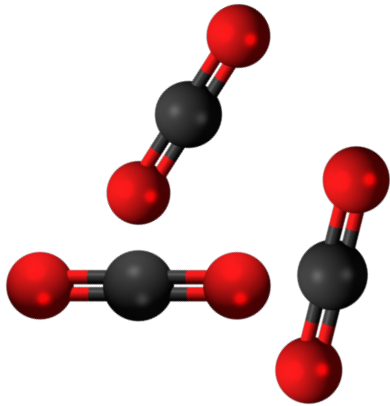


How do climate models work?

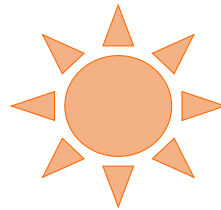


How do we make a testable prediction?

We predict the past!



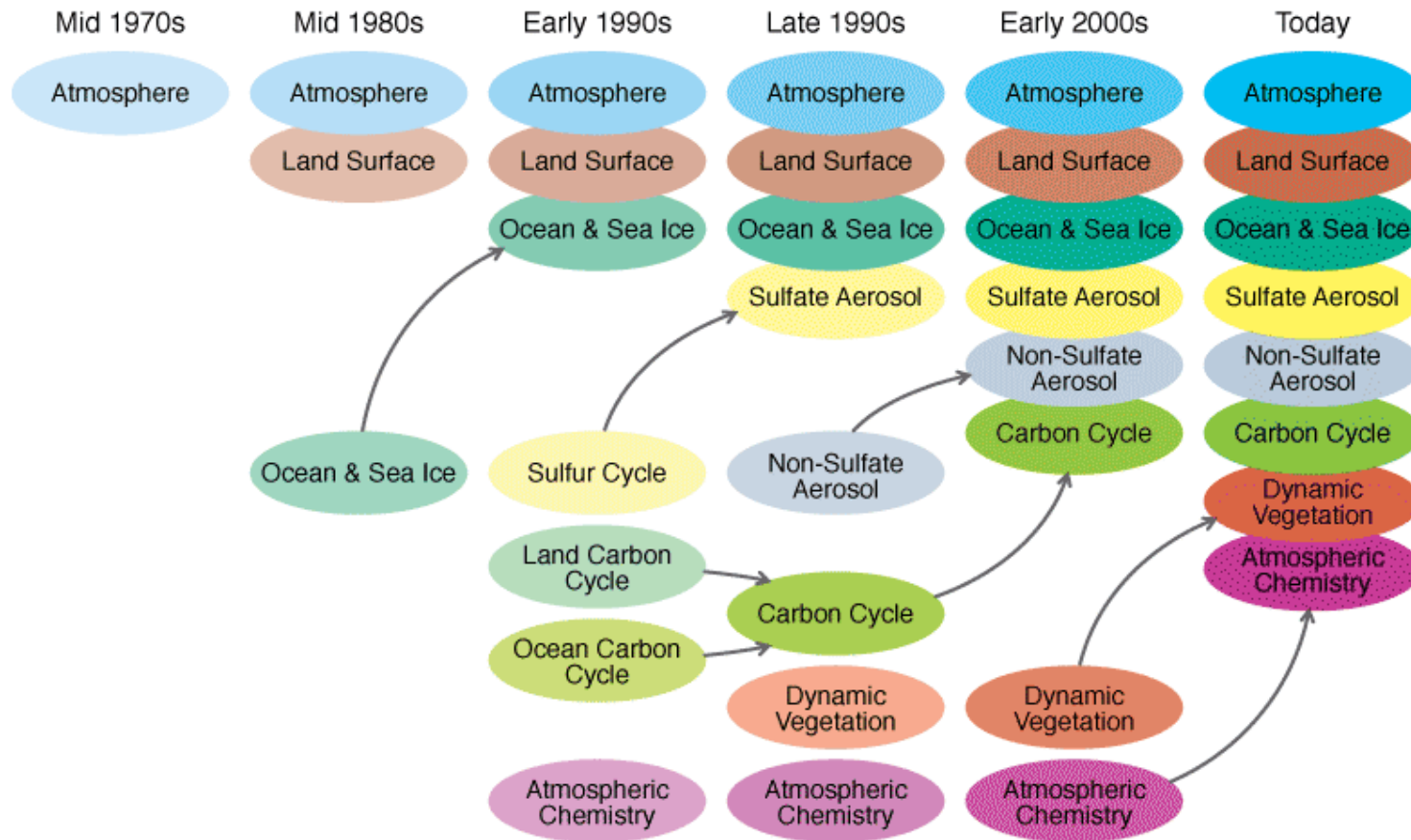
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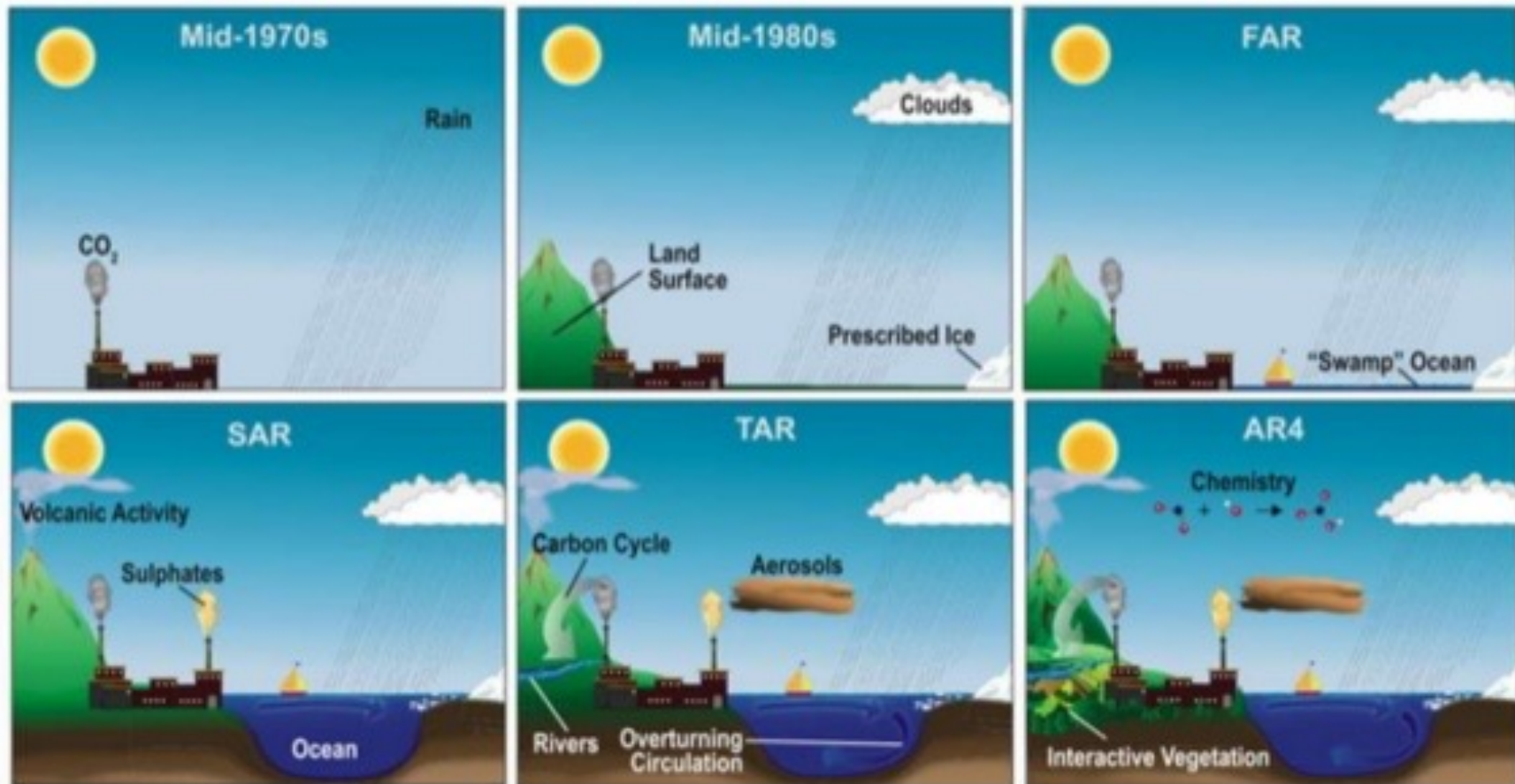
=

observed
paleo-proxy
records?

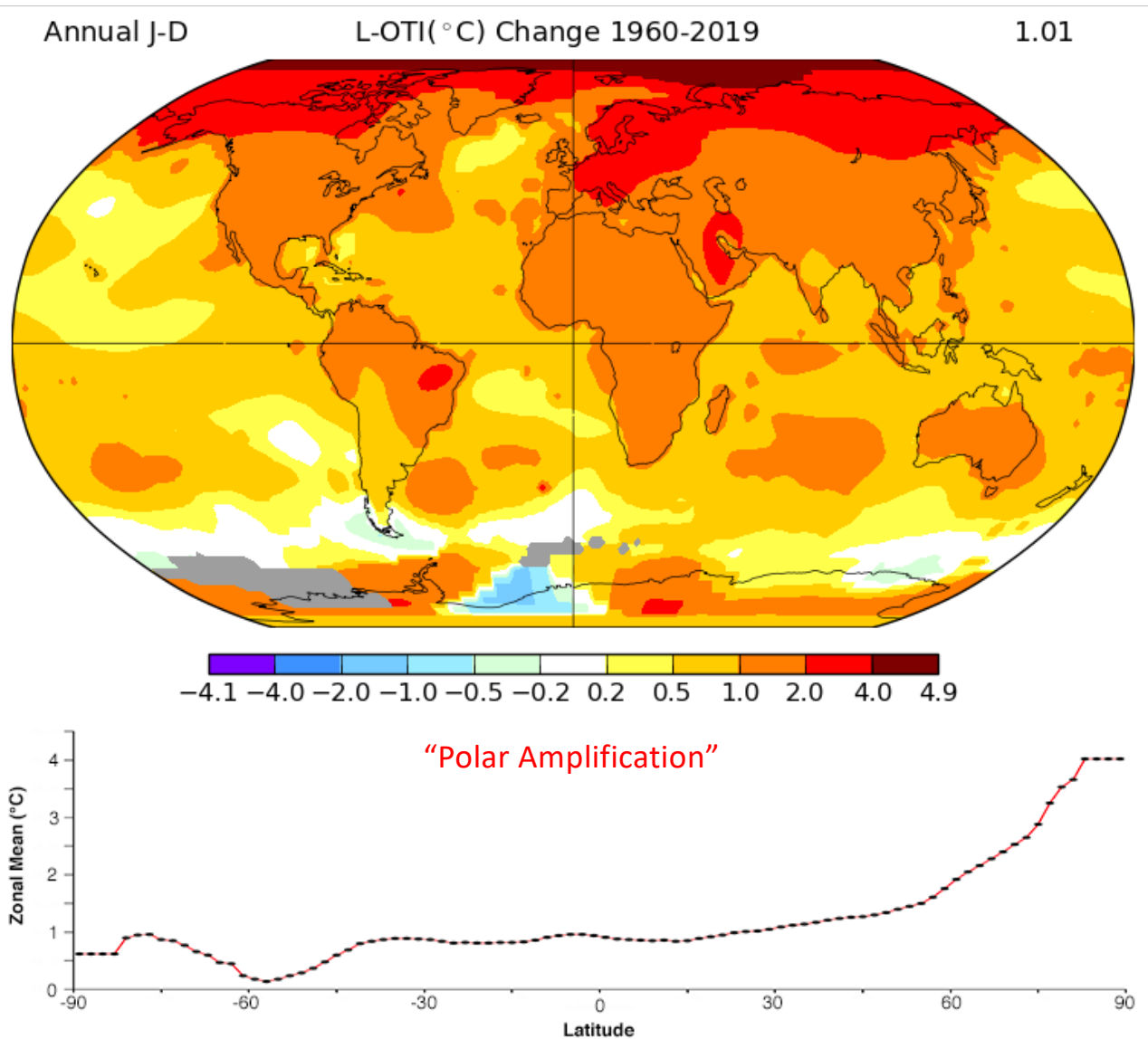
Development of Climate Models



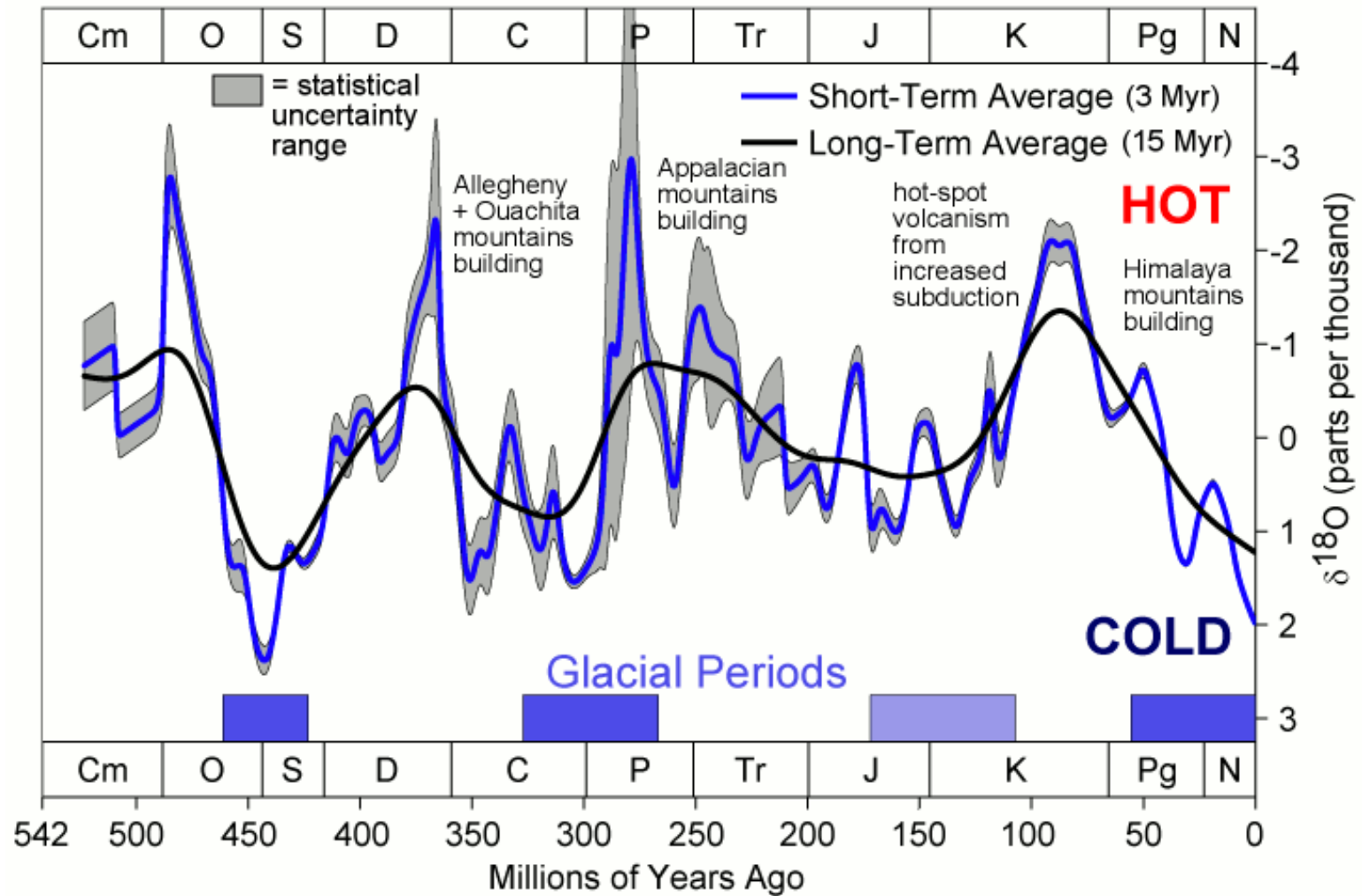
Increasing Model Complexity

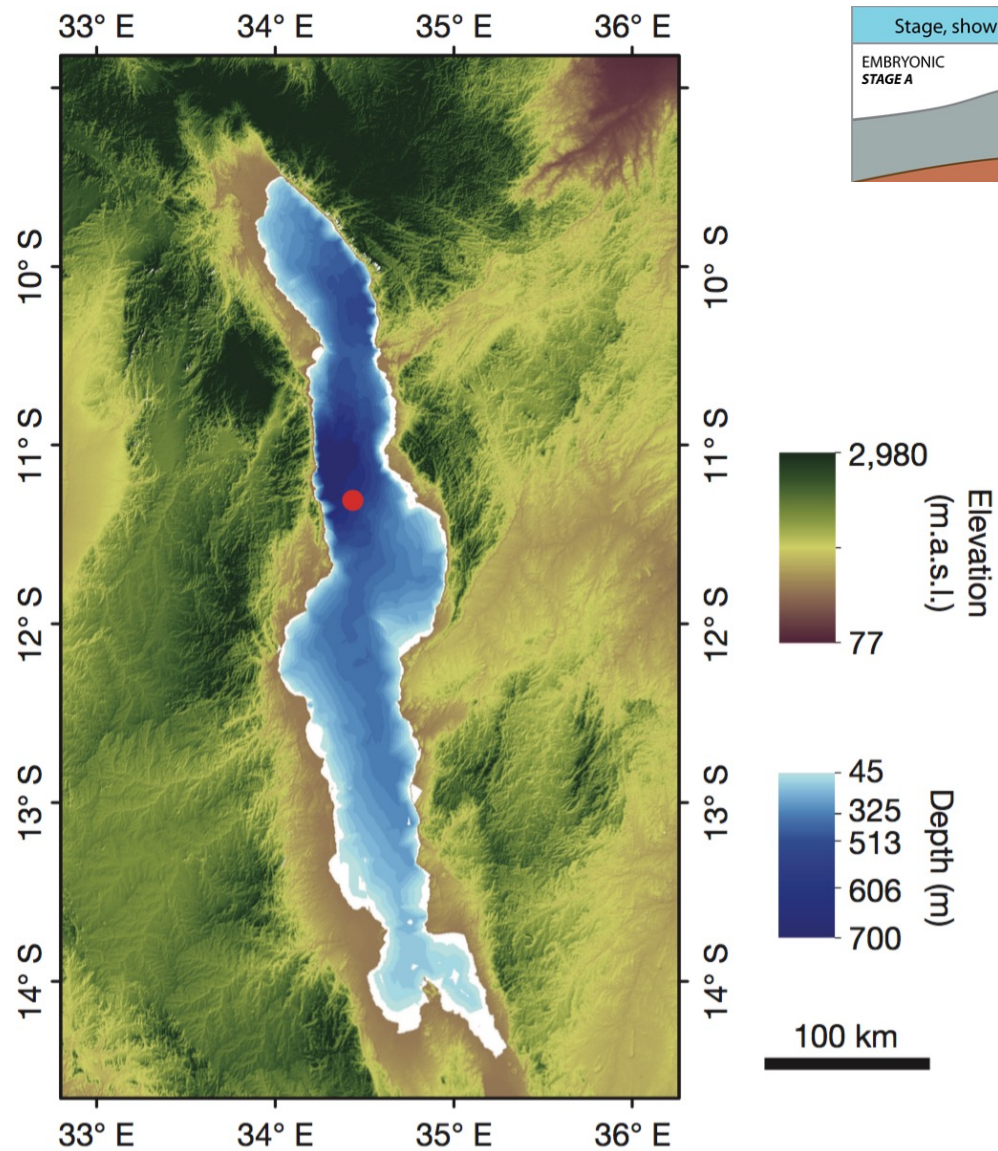


*Compare to proxy
records
(sediments!) to
see how well they
do w/ past
features*

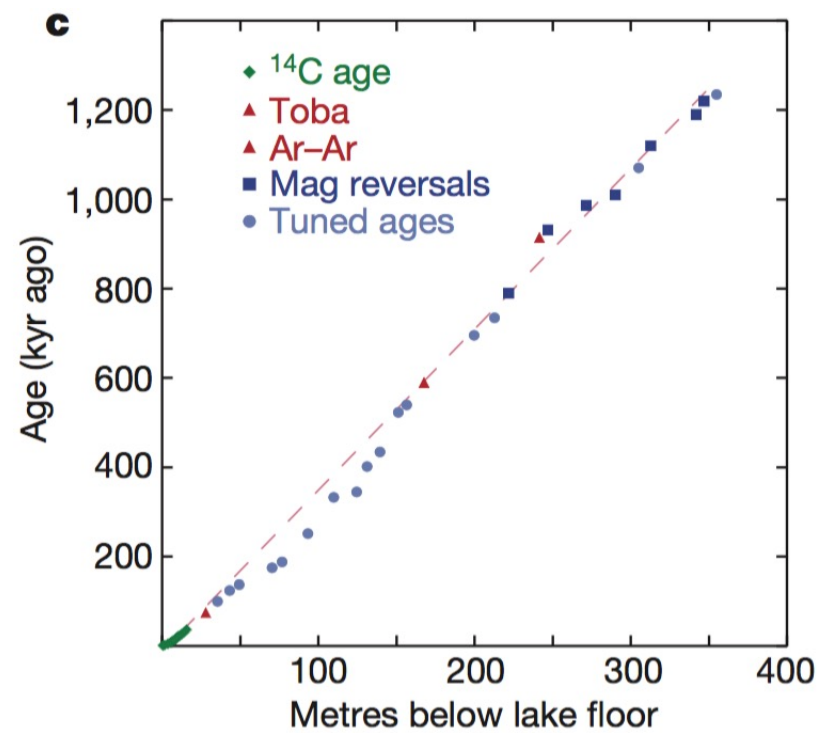


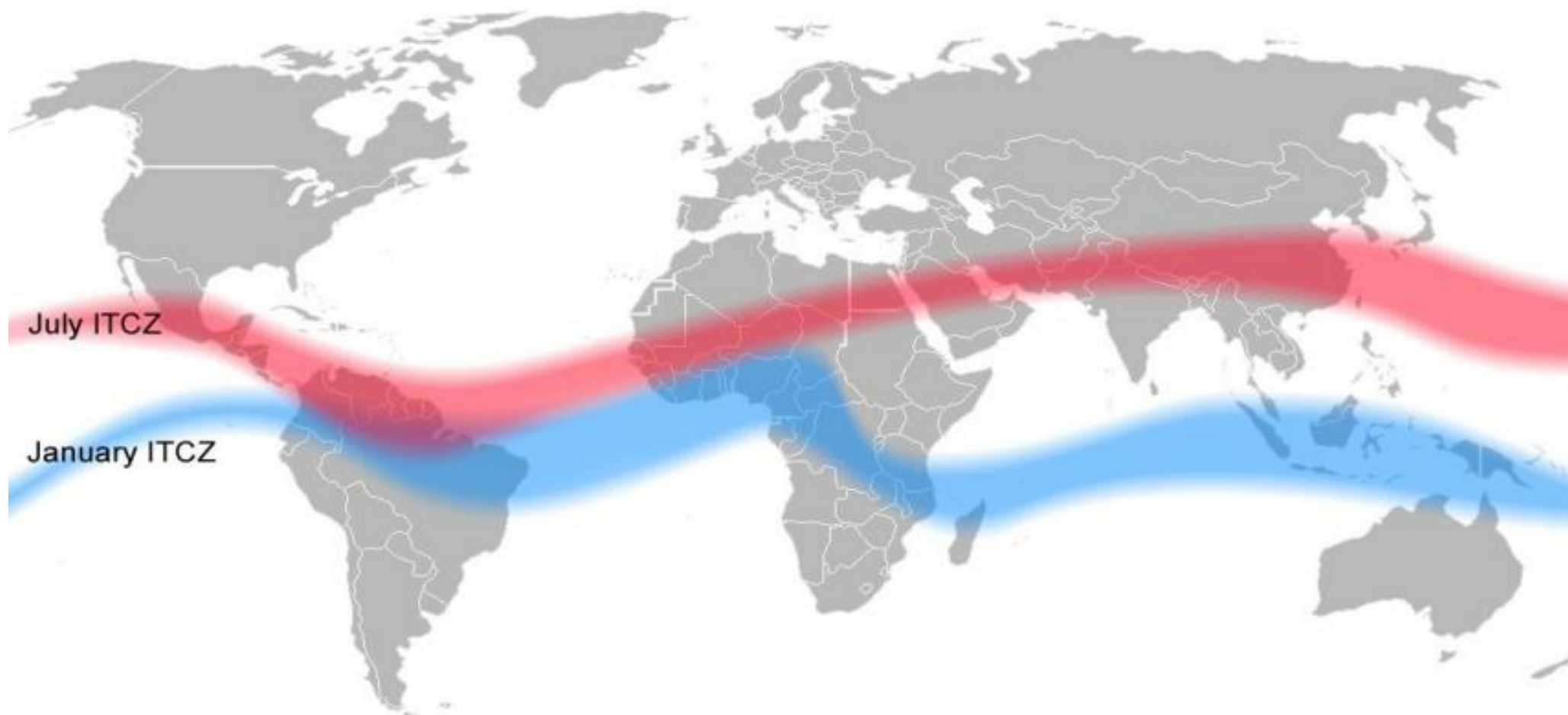
Phanerozoic Climate Change





Stage, showing cross-sectional view	Motion	Physiography	Example
EMBRYONIC STAGE A	Uplift	Complex system of linear rift valleys on continent	East African rift valleys





Location = difference between 1 wet season and 2

What type of changes?

- Rising Sea Levels
- Rising Global Temperatures
- Warming Oceans
- Changing Precipitation
- Shrinking Ice Sheets
- Increasing Extreme Events
- Ocean Acidification
- Ocean Deoxygenation

