Climate of the Present, Past, and Future

What we know, and how we know it

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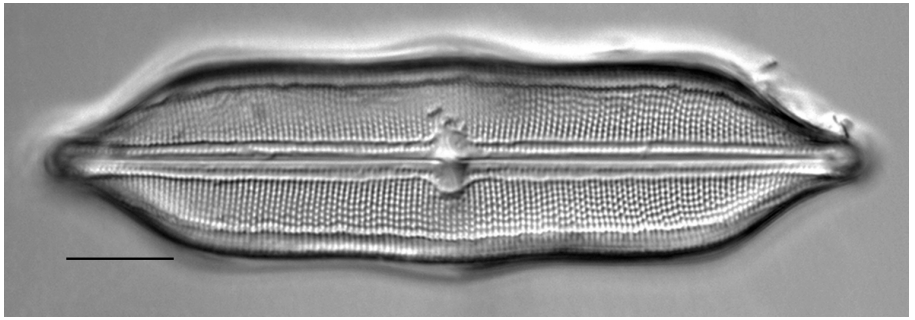
About me



Today's topics

1: Intro to the climate system

2: Global warming and the greenhouse effect

3: Past climate and climate proxies

4: Future climate models and scenarios

5: Climate data

Part 1

What exactly *is* “climate” anyway?

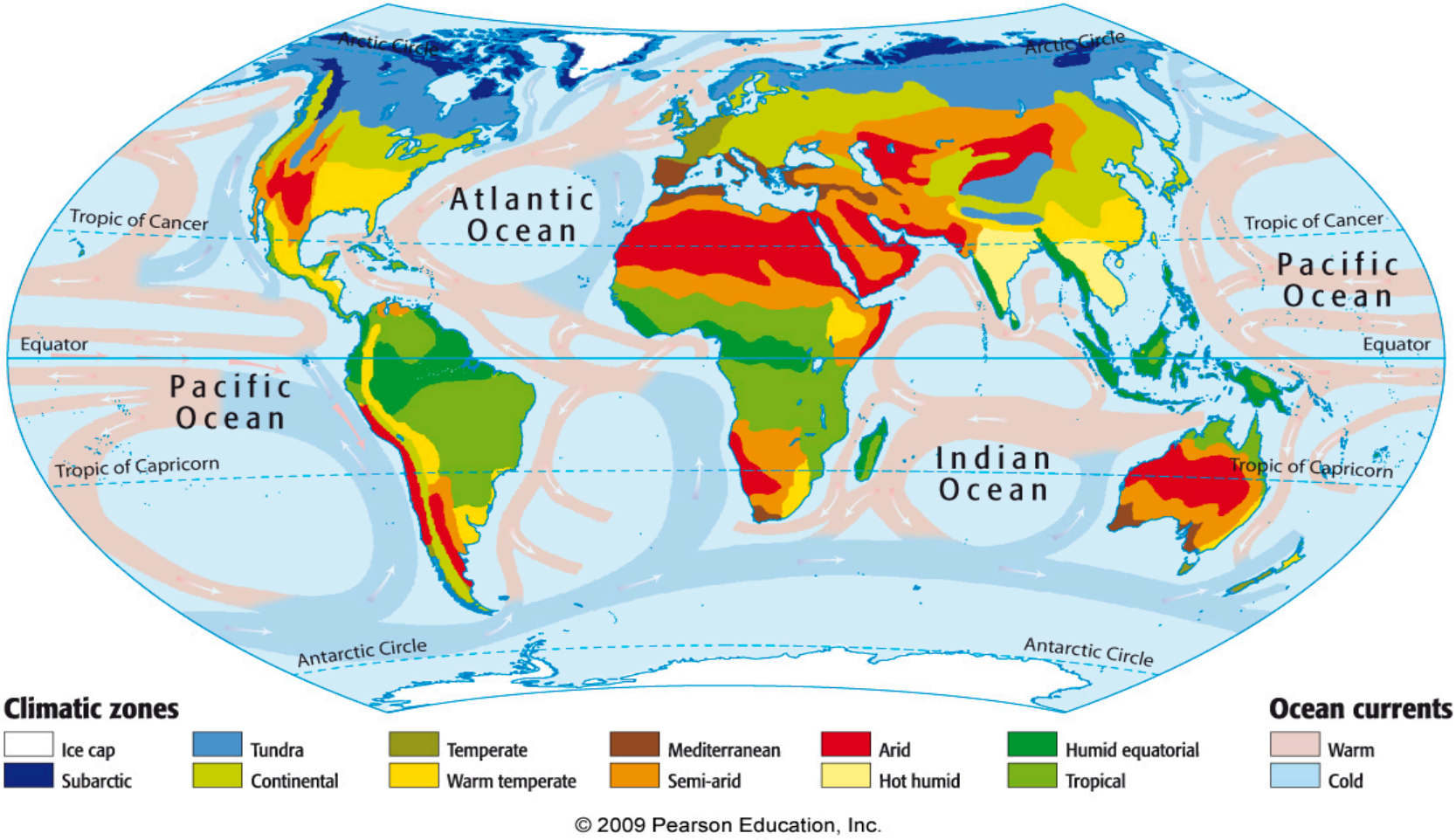
Climate

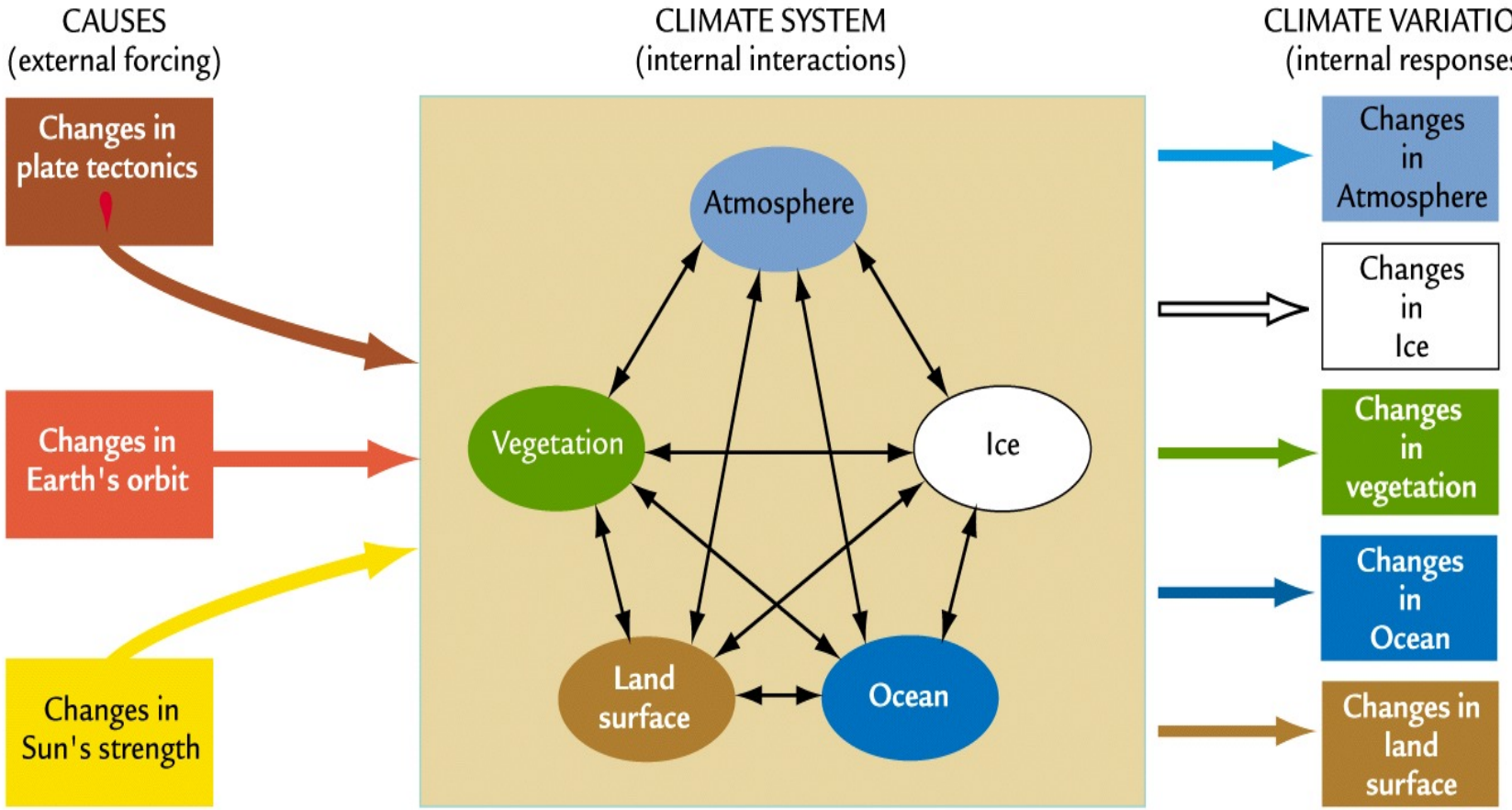
Not weather!

Defined as weather averaged over a long period of time (often 30 yrs)

Weather: Day-to-day changes in temperature, precipitation, snow cover, and wind; highly variable

Climate zones



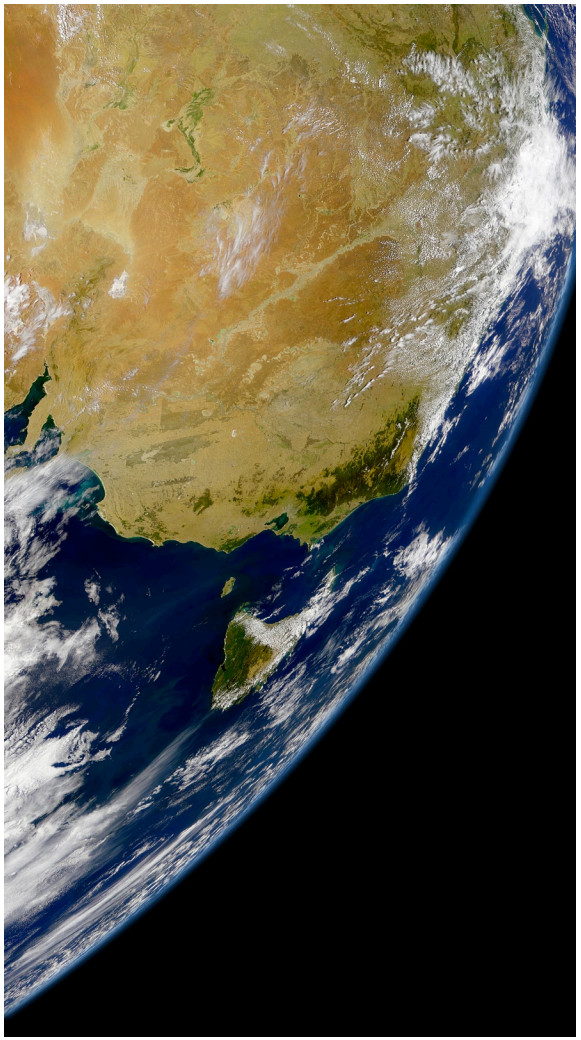


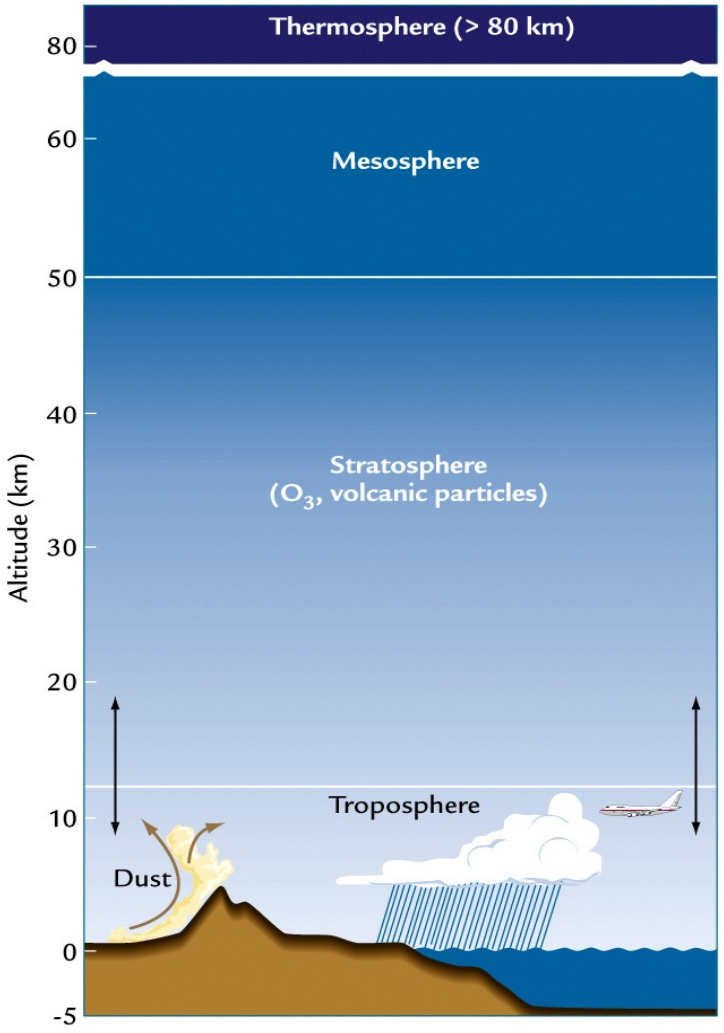
Changes in atmospheric composition (greenhouse gases)

- External factors *force* or *drive* changes in the climate system
- Internal components of the climate system *respond* by changing and interacting in many ways

Atmosphere

- Thin!
- 10 km contains 90% of mass
- Troposphere = where weather/ climate happens

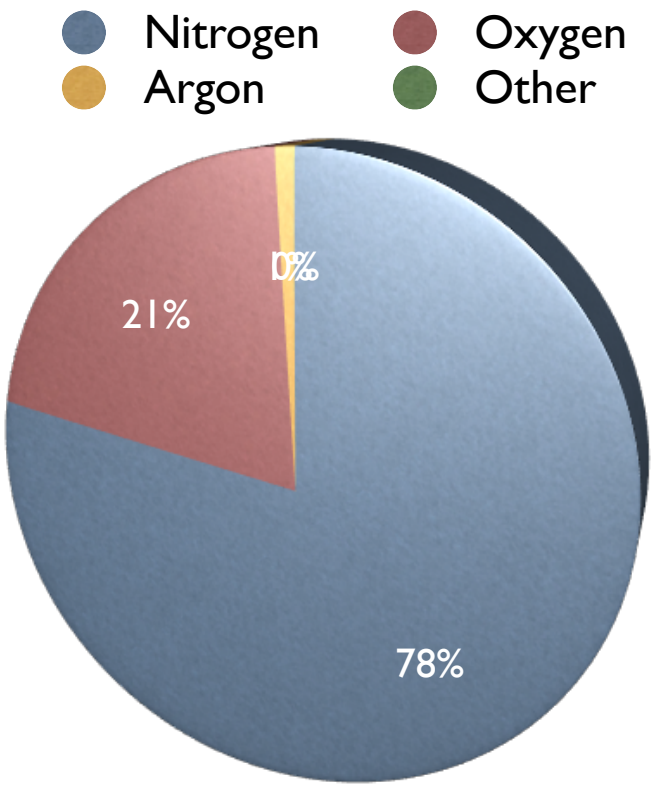




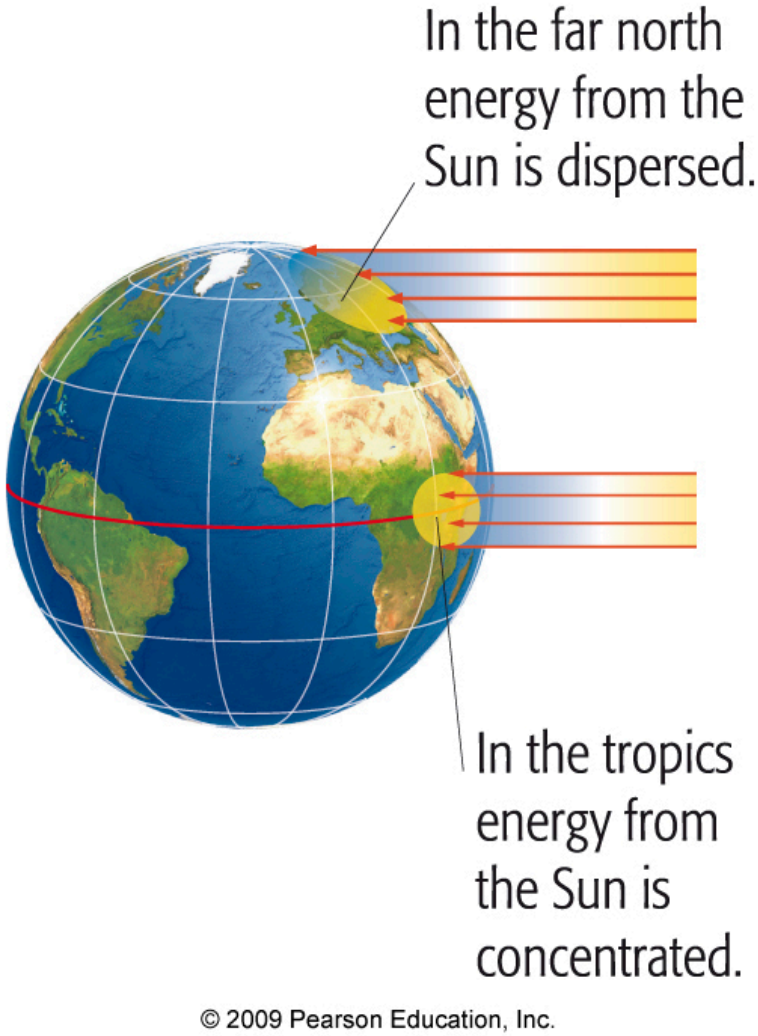
Atmospheric Composition: Permanent Gases

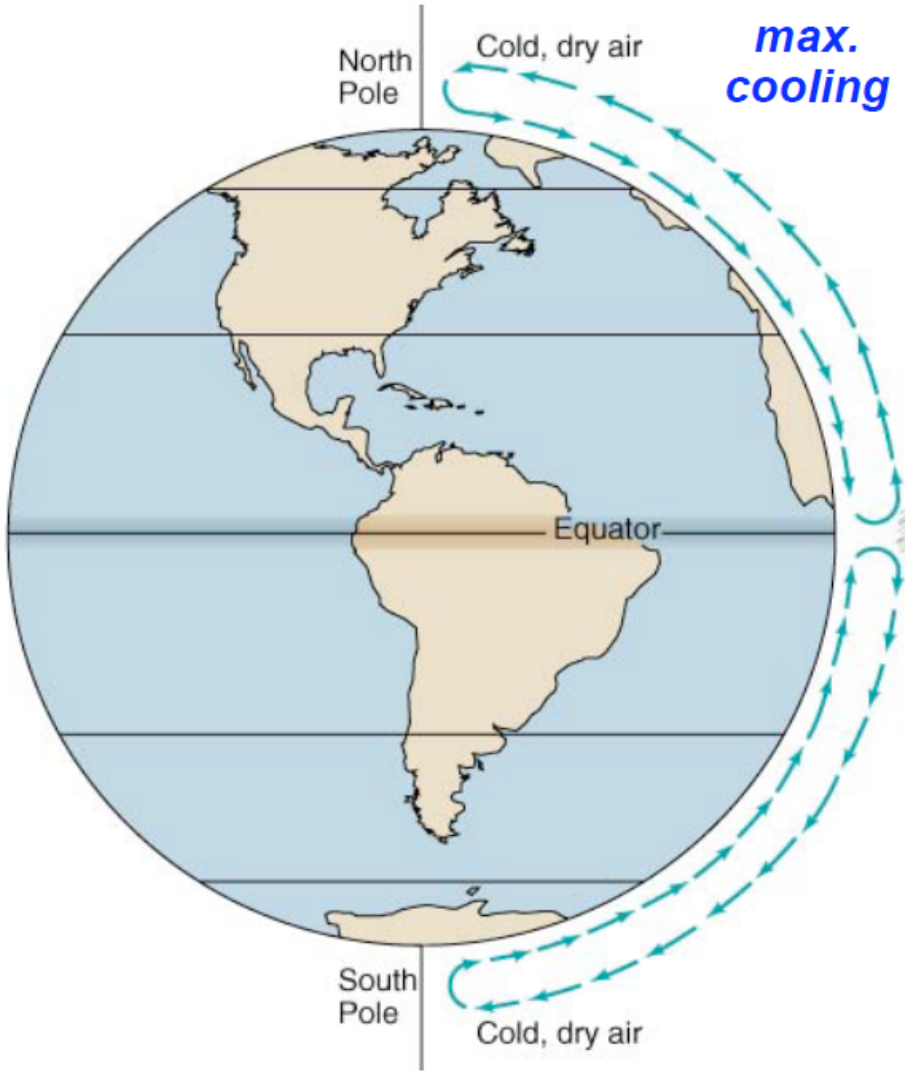
TABLE 1–2 Permanent Gases of the Atmosphere

Constituent	Formula	Percent by Volume	Molecular Weight
Nitrogen	N_2	78.08	28.01
Oxygen	O_2	20.95	32.00
Argon	Ar	0.93	39.95
Neon	Ne	0.002	20.18
Helium	He	0.0005	4.00
Krypton	Kr	0.0001	83.8
Xenon	Xe	0.00009	131.3
Hydrogen	H_2	0.00005	2.02

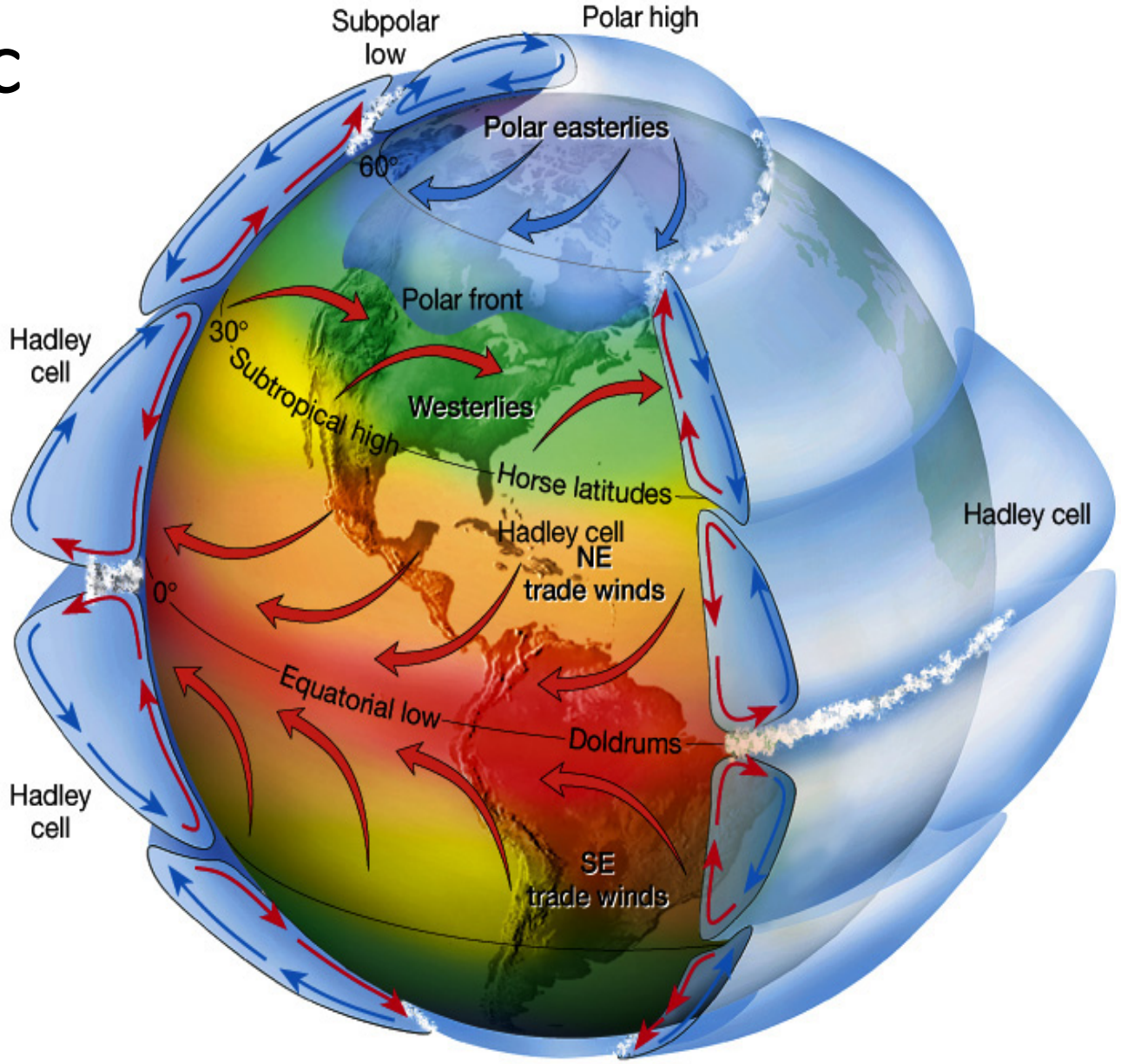


Transfer of heat energy

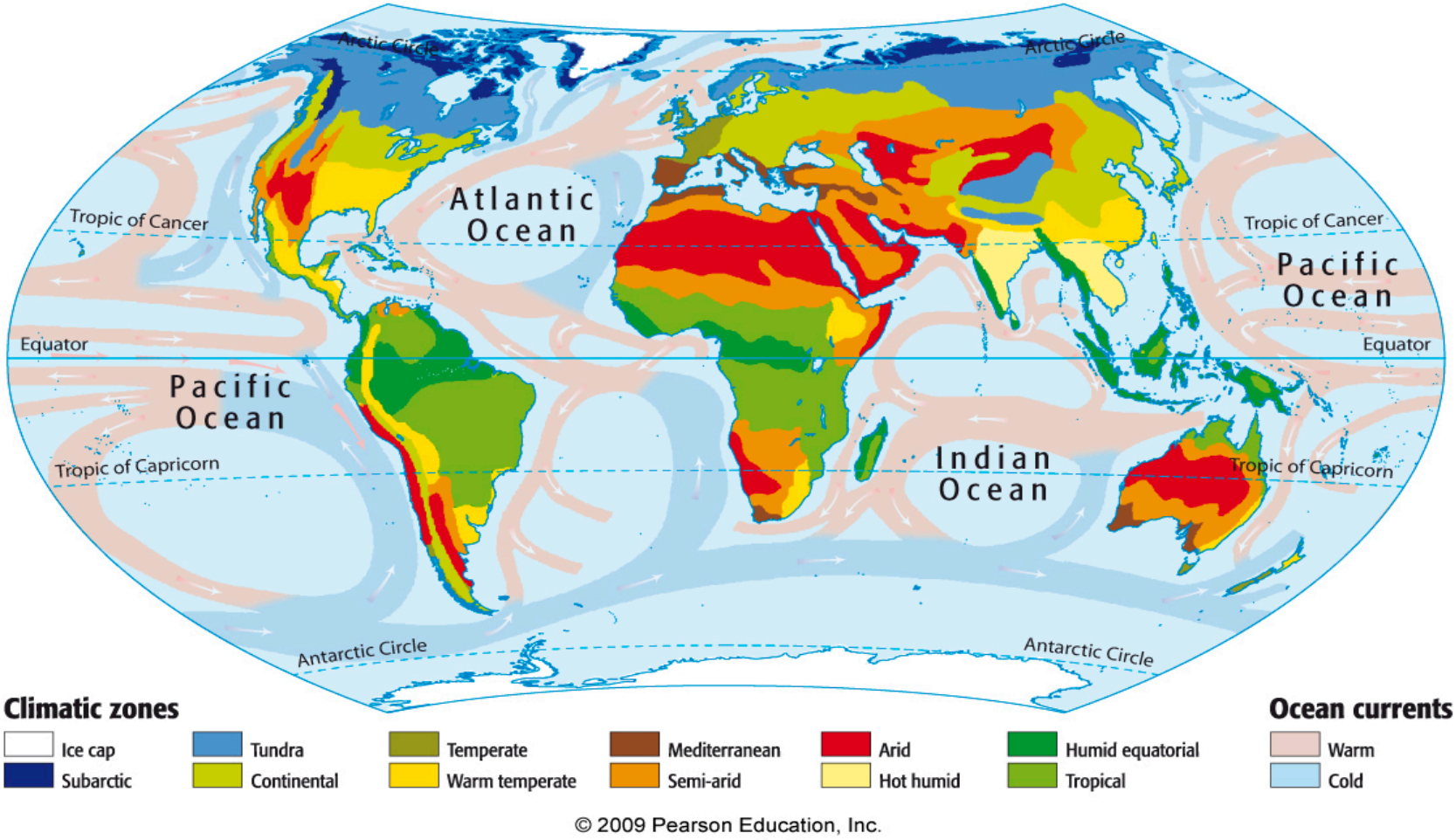




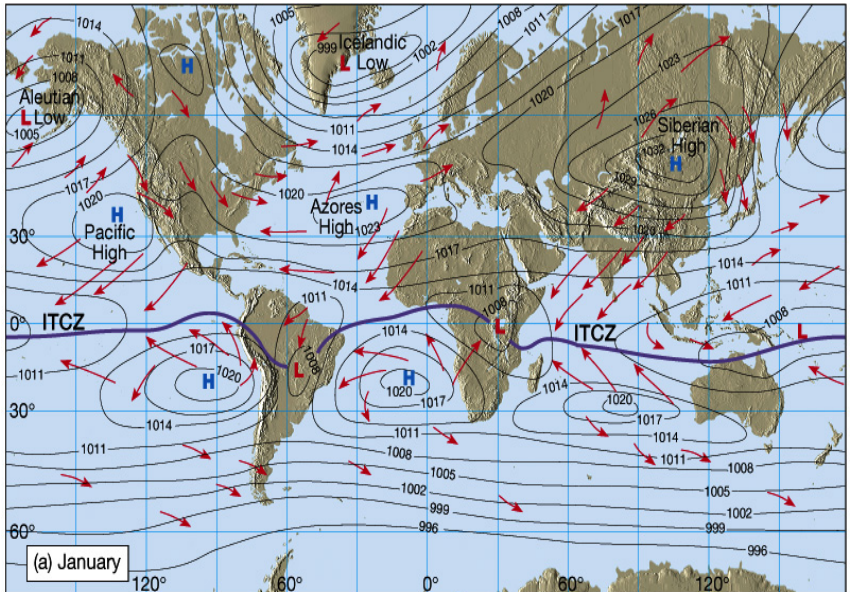
General atmospheric circulation



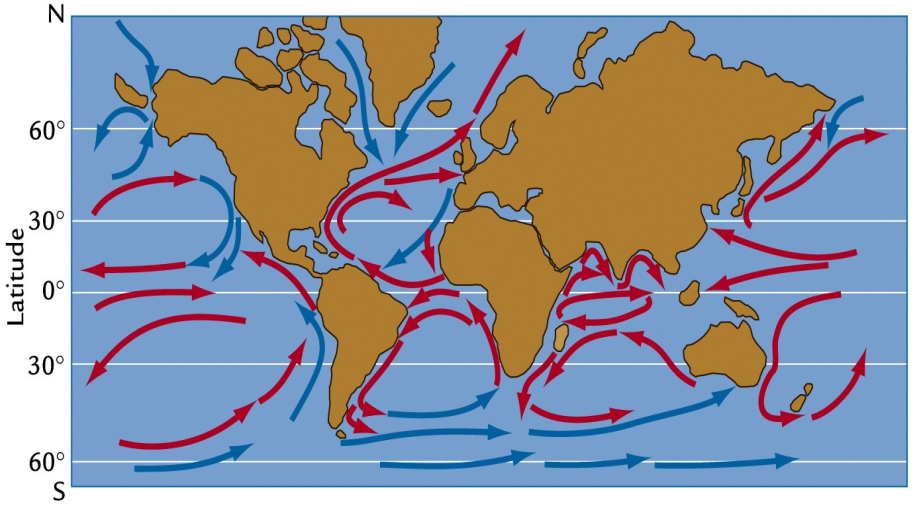
Climate zones

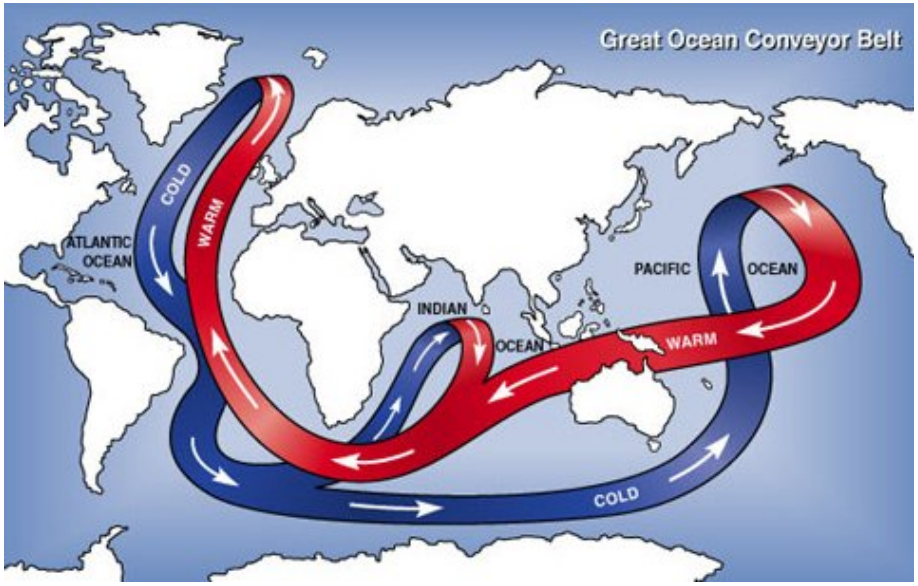


Hydrosphere



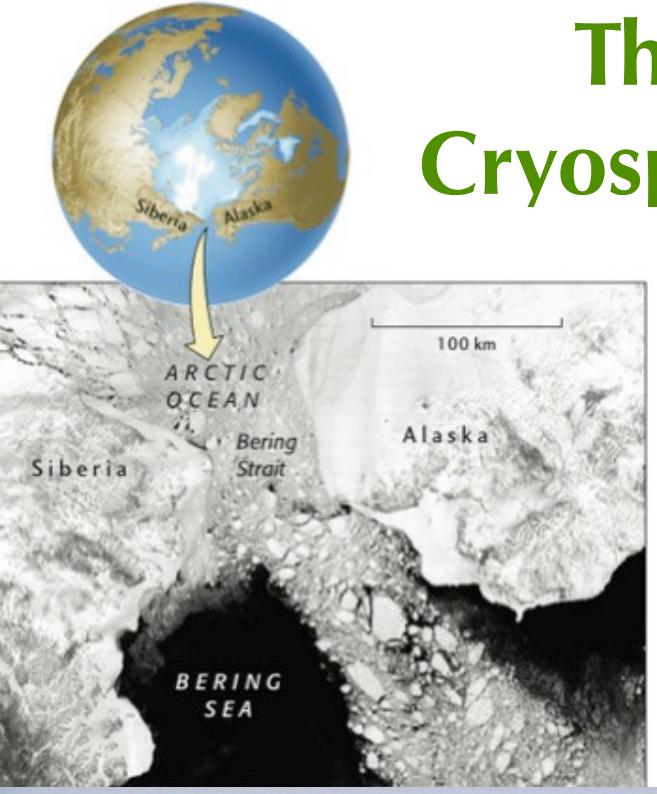
← Surface currents (wind driven)





Deep currents (density driven)

The Cryosphere

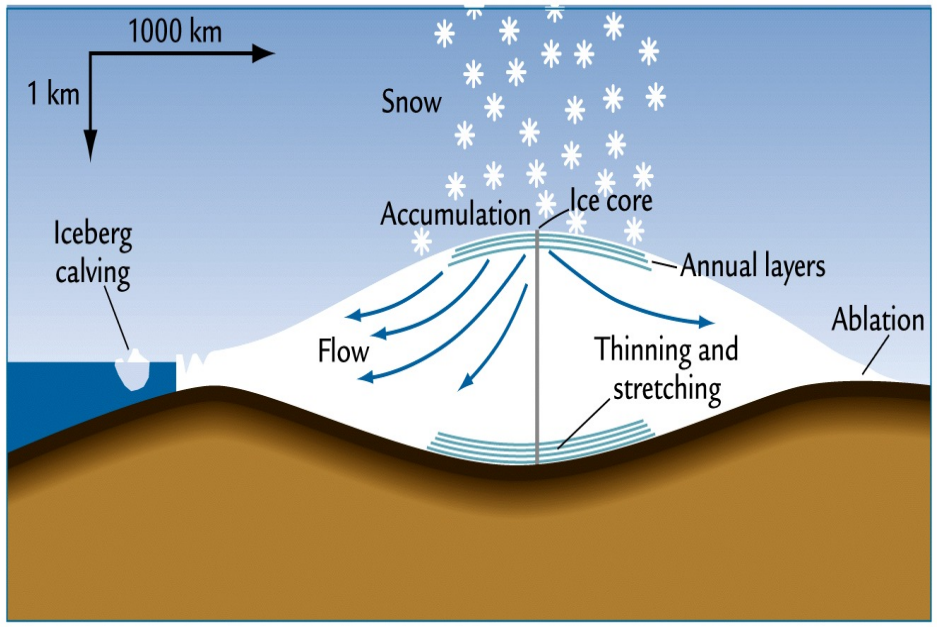


Sea Ice

Glaciers (Land Ice)

Ice Shelves (margin)

"places where water is in its solid form, frozen into ice or snow."



B Continental ice sheets

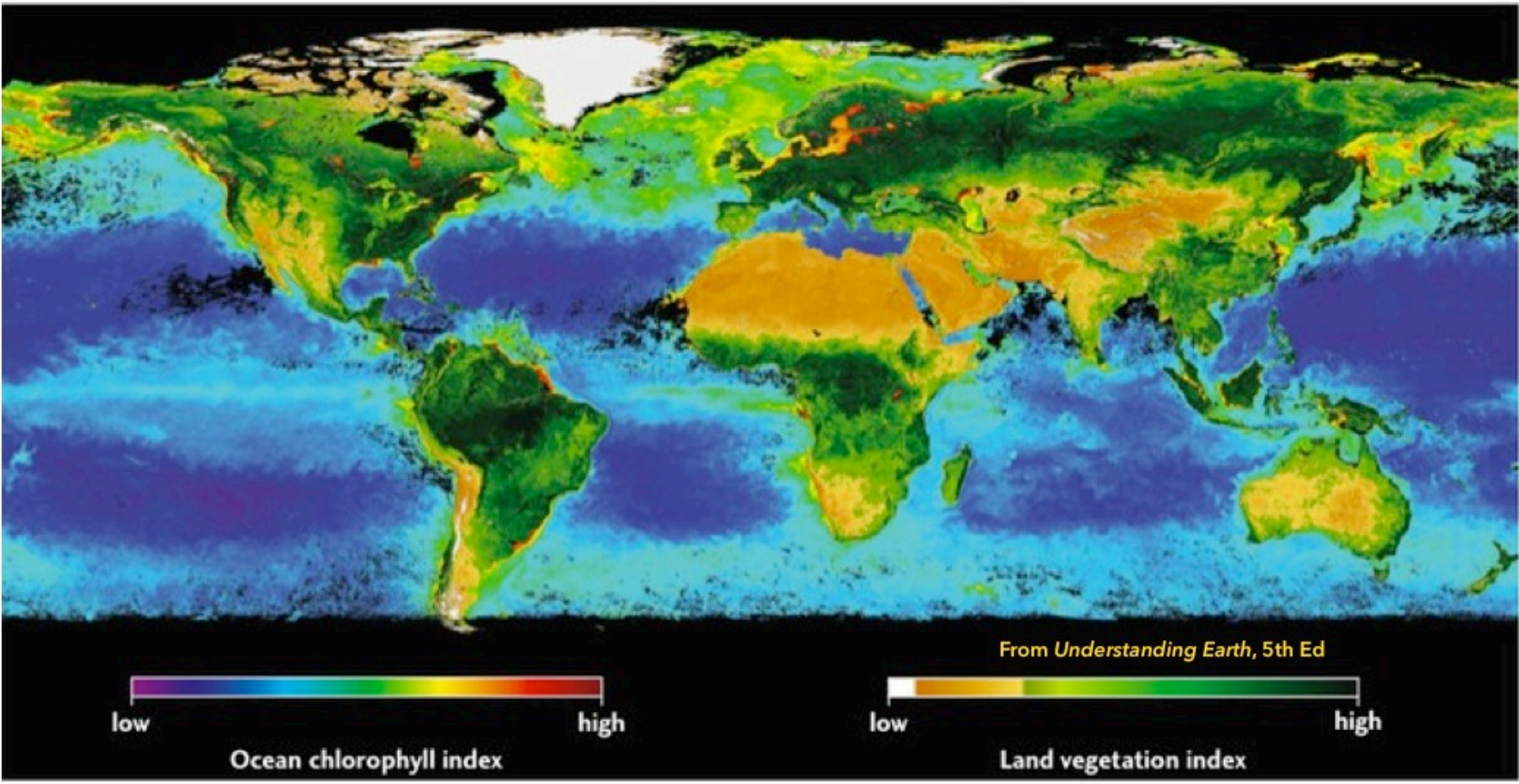
Link to NASA tour of cryosphere

http://www.youtube.com/watch?v=PjAXoETeVIc

Continental-scale ice sheets (Greenland and Antarctica)

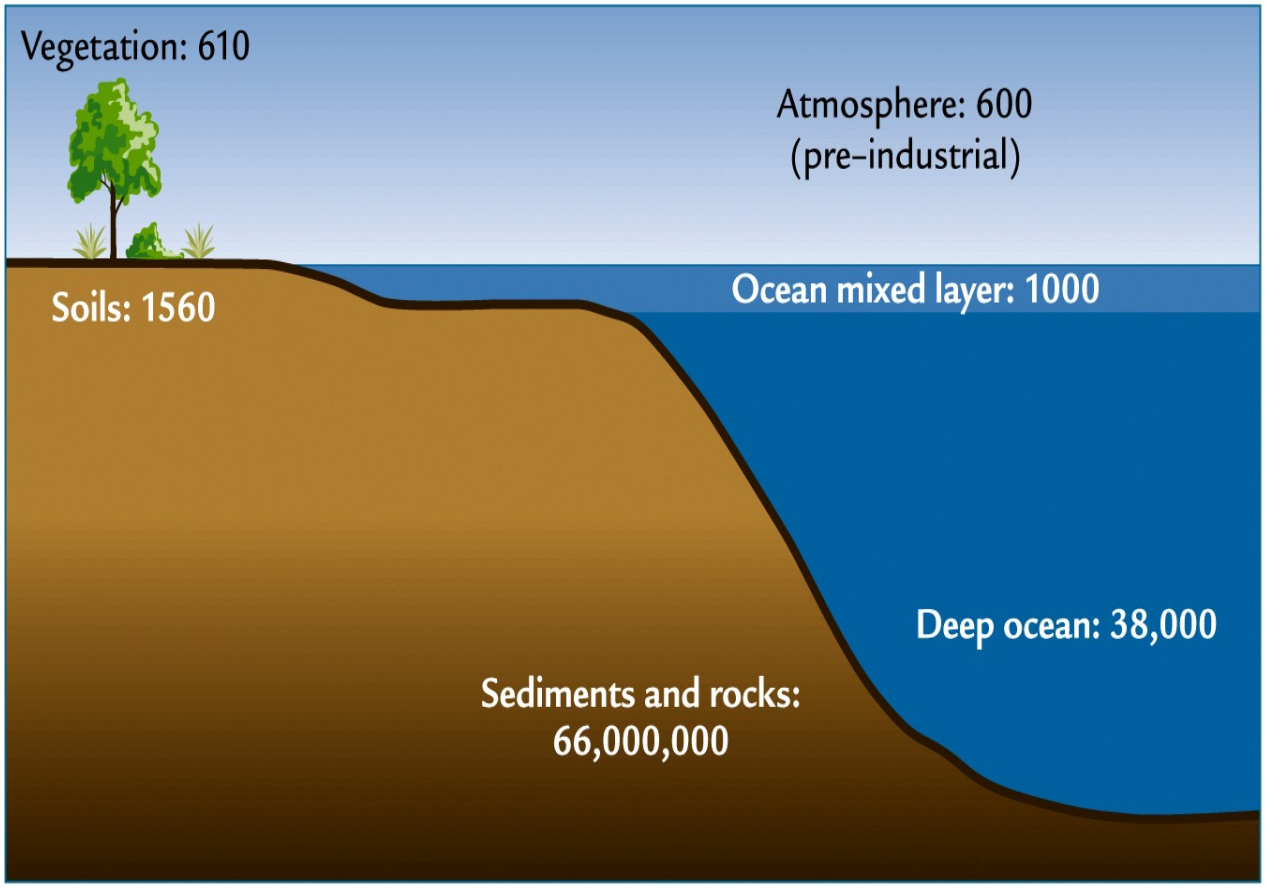
- Cover 11% of Earth's land surface
- If all ice melted, sea level would be 70 m higher
- Thousands of kilometers wide; 1-4 km thick

Biosphere



"Biosphere = global sum of all ecosystems
= the zone of life on Earth"

Carbon



A Major carbon reservoirs (gigatons)

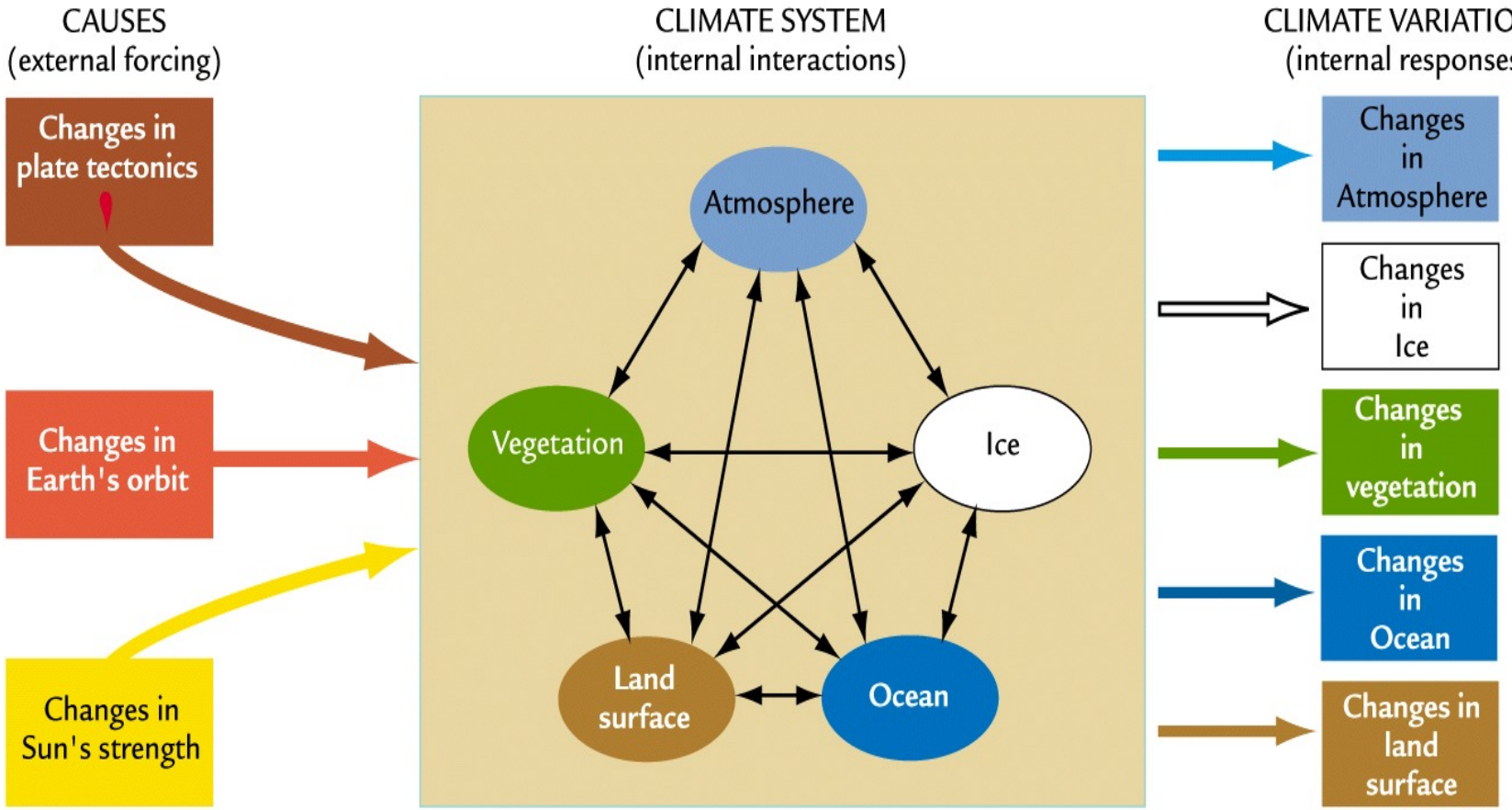
Lithosphere

- Land! 30% of earth

- Dark areas are forests and large lakes
- Lightest areas are deserts and ice

Albedo = Surface reflectivity

Snow & ice = 70-90%
Forest = 5-20%
Water = 5-10%



Changes in atmospheric composition (greenhouse gases)

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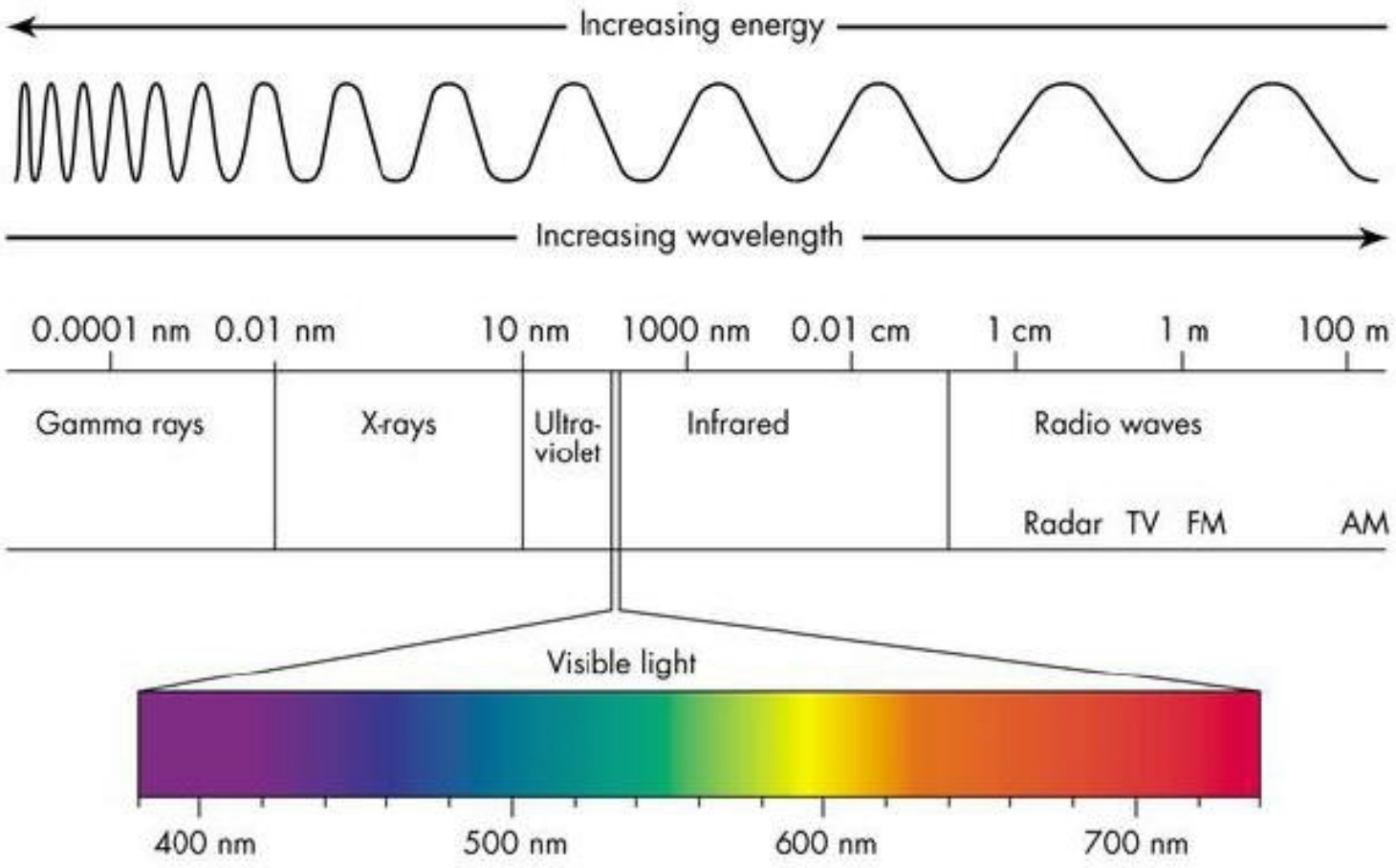
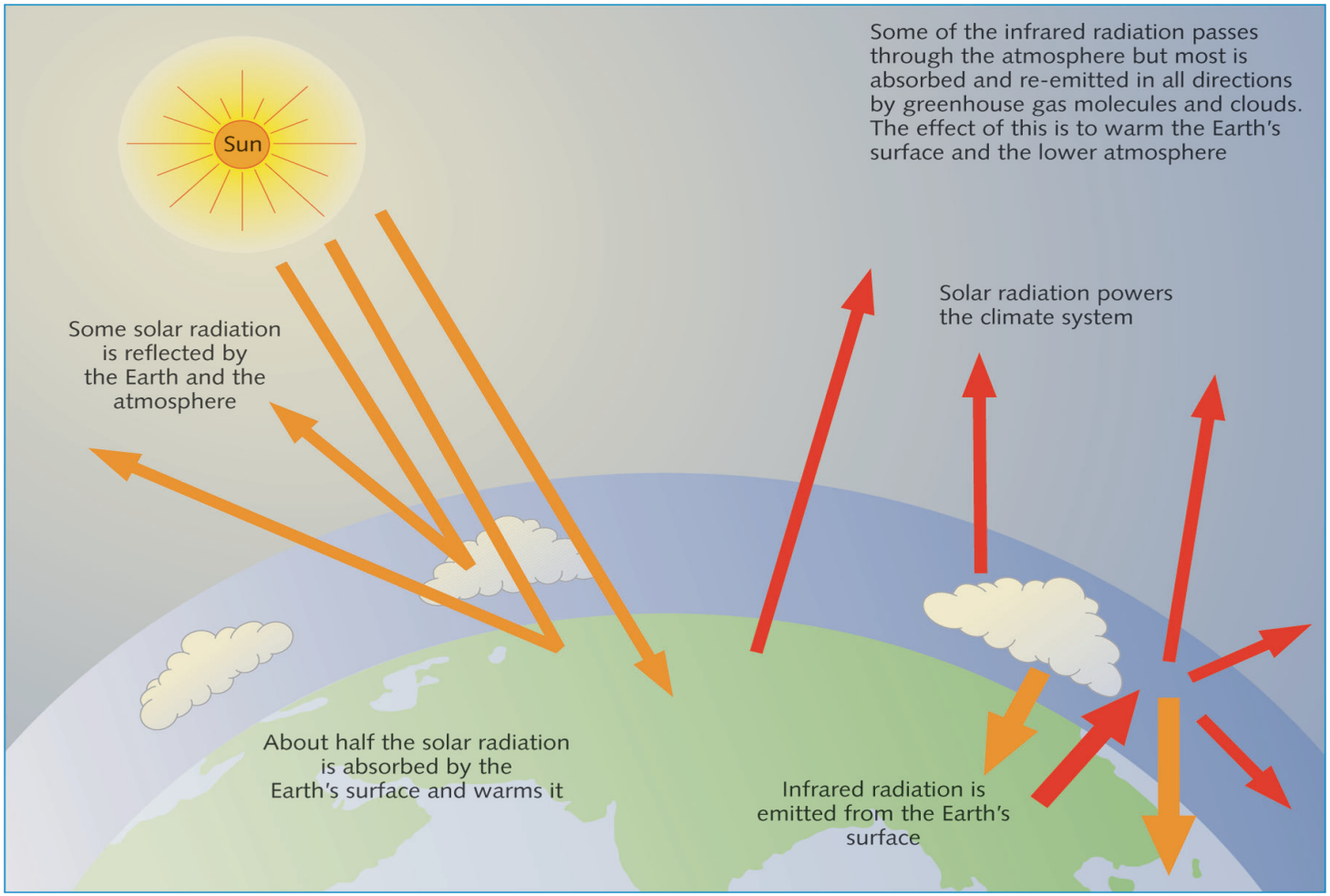
Part 2

What's the deal with global warming?

Electromagnetic radiation



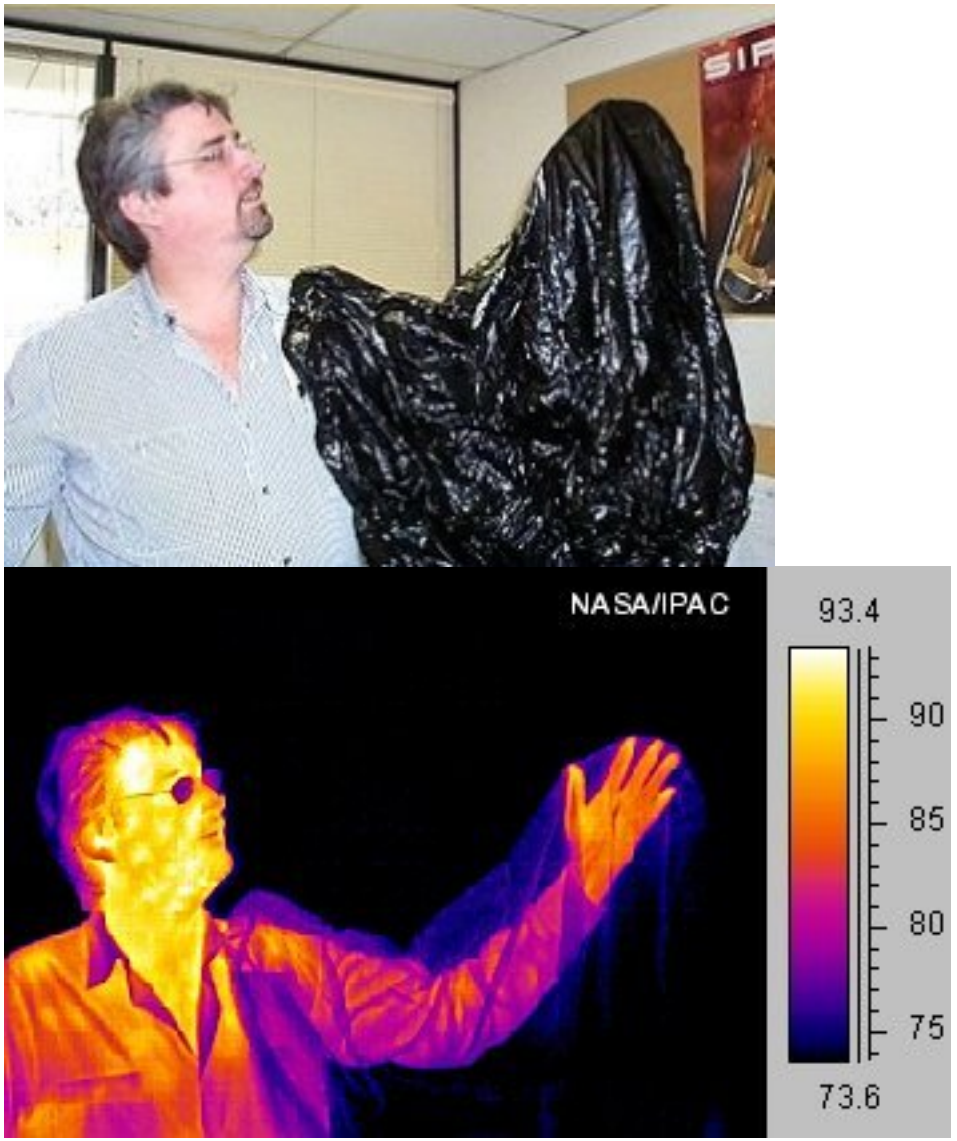
Greenhouse effect

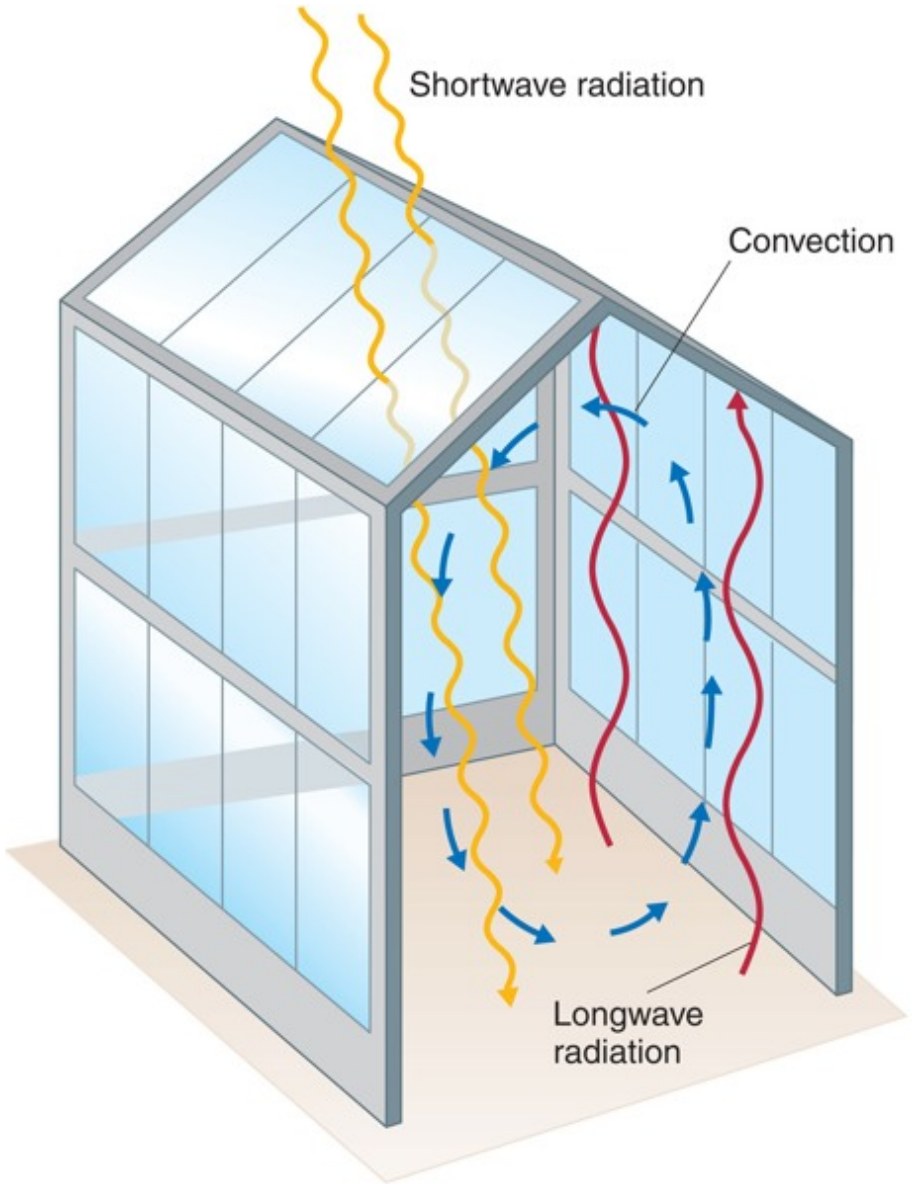


Visible vs. infrared

- *Visible* energy radiated by the sun
- *Infrared* energy re-radiated by the earth
- GHG's are transparent to different wavelengths…

https://www.youtube.com/watch?v=7perebgdXAQ

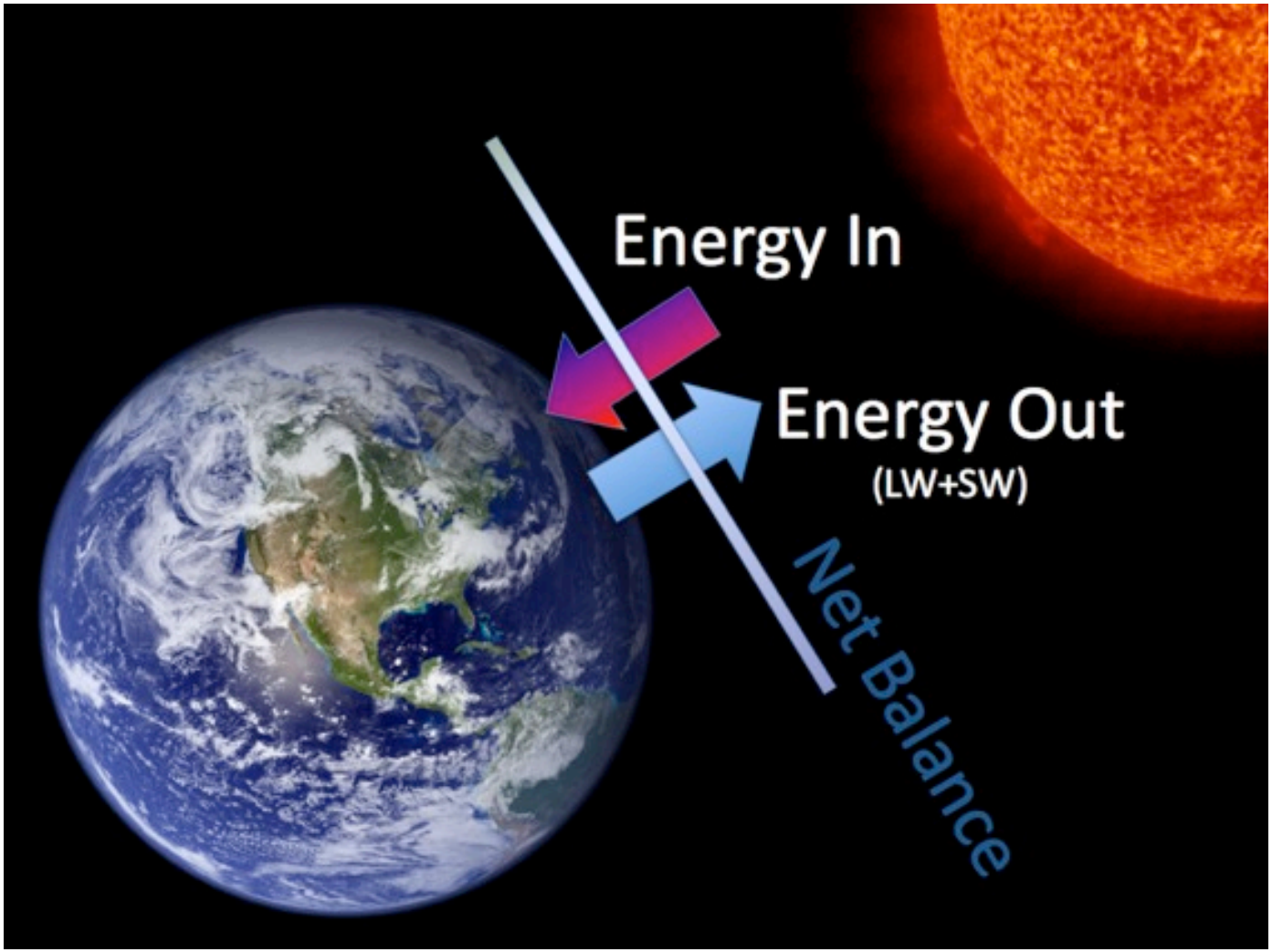




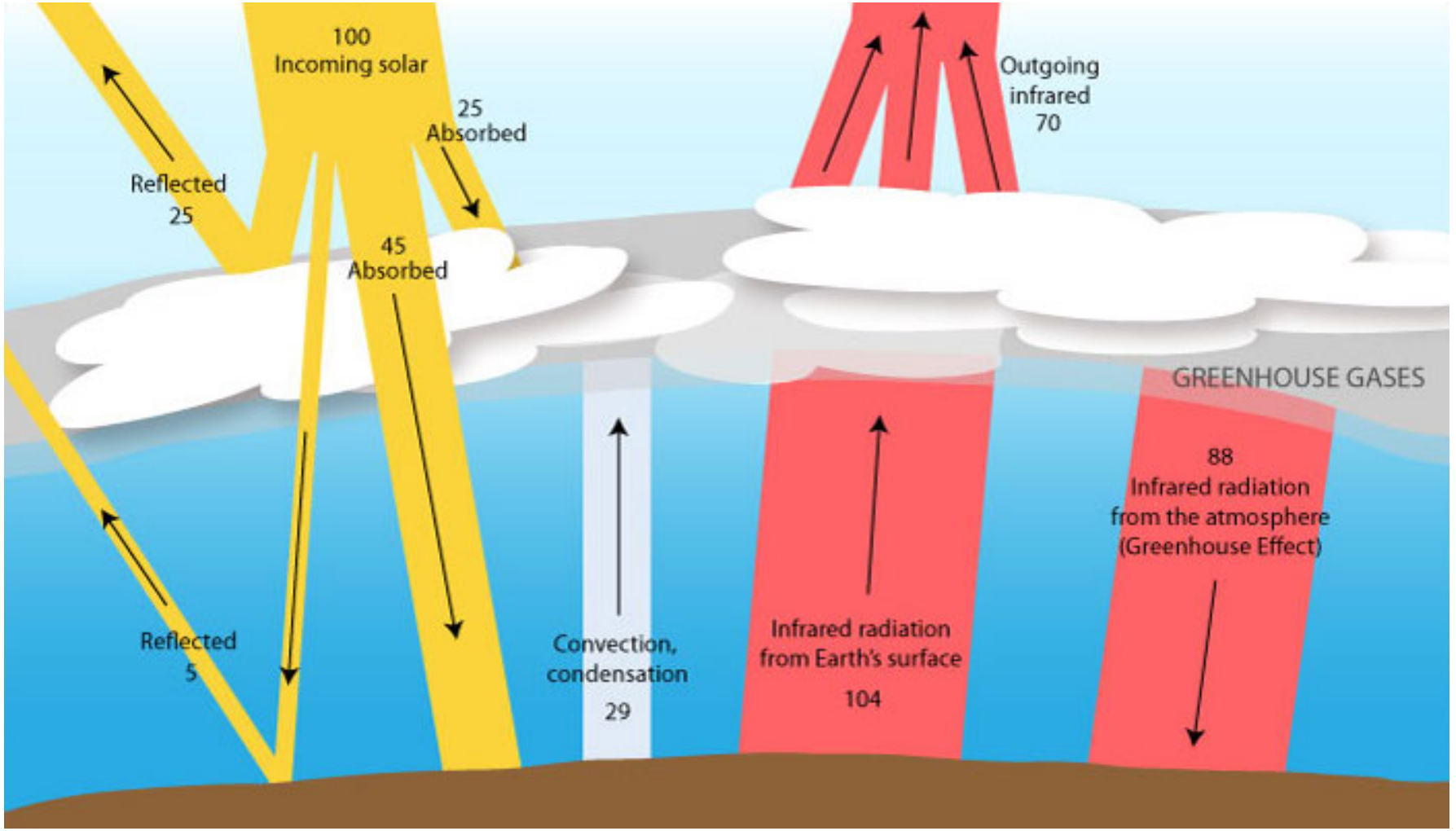
Heat **enters freely but cannot escape** : thermal energy builds up, temperature increases inside

Analogy for the trapping of outgoing longwave radiation by some gases, therefore dubbed **"greenhouse" gases.**

How do we end up with global warming?



Earth's energy balance



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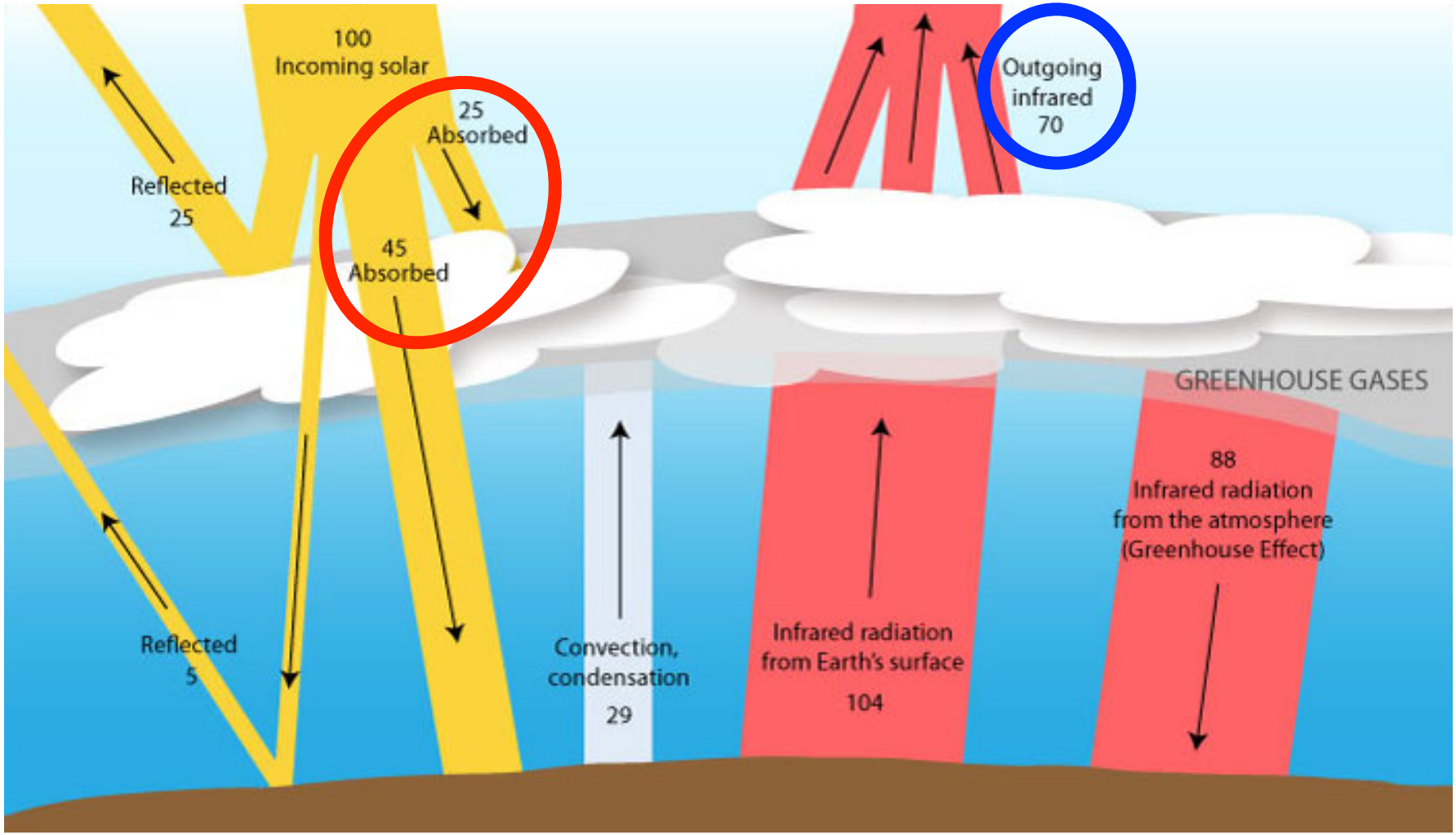

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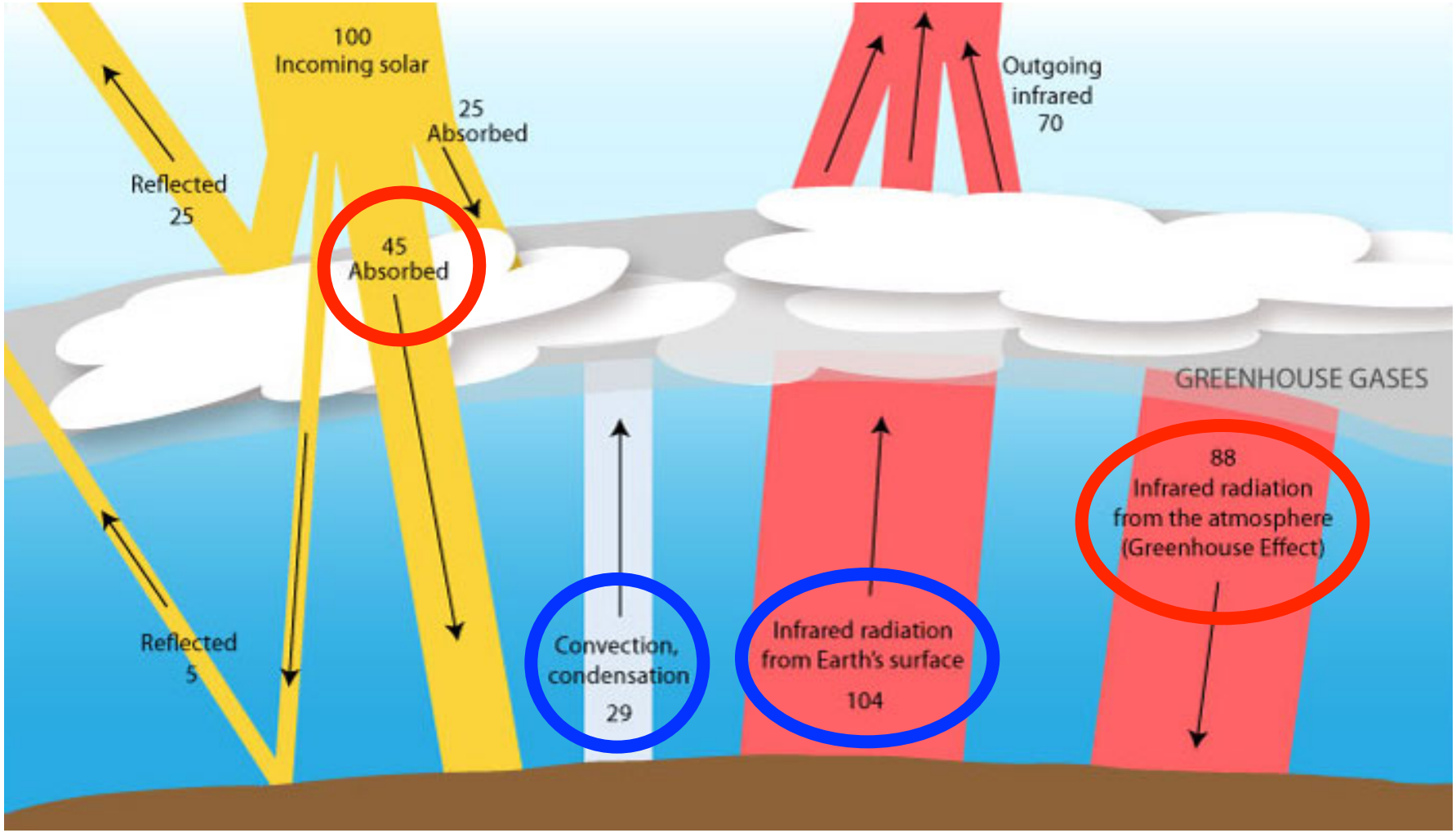
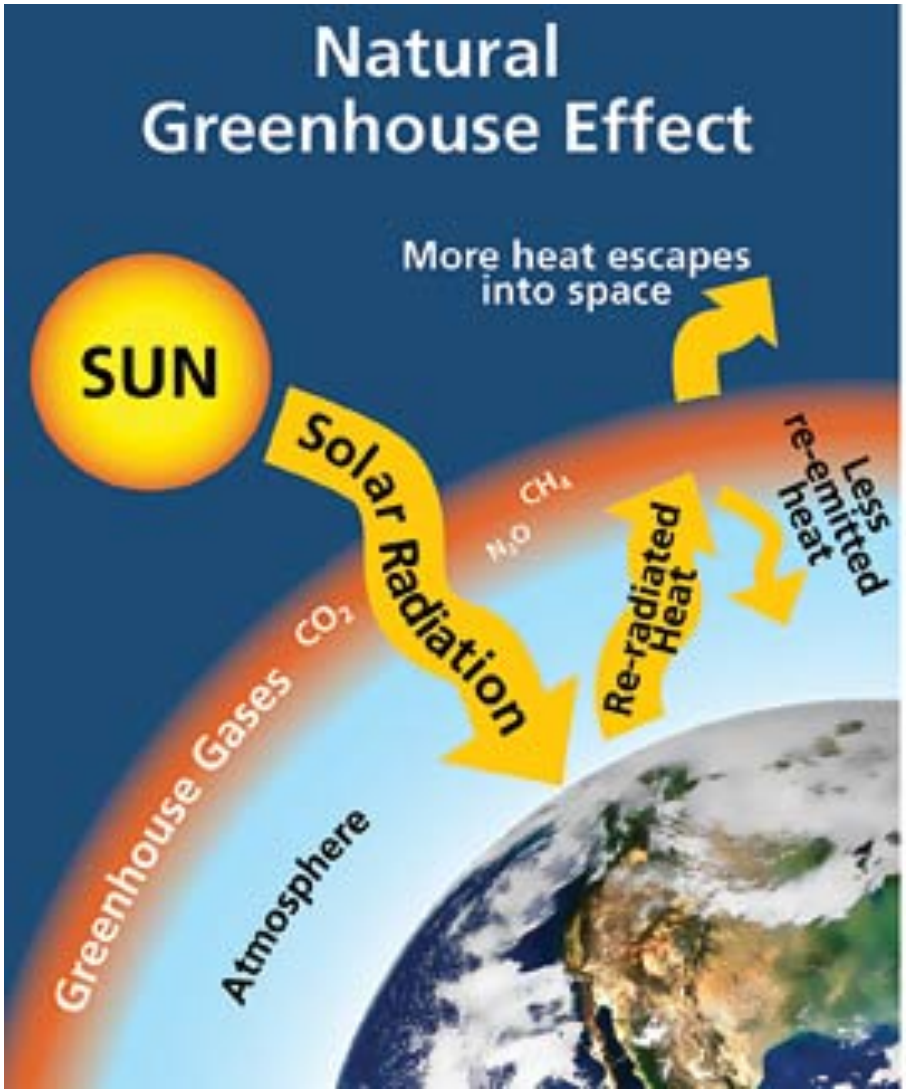
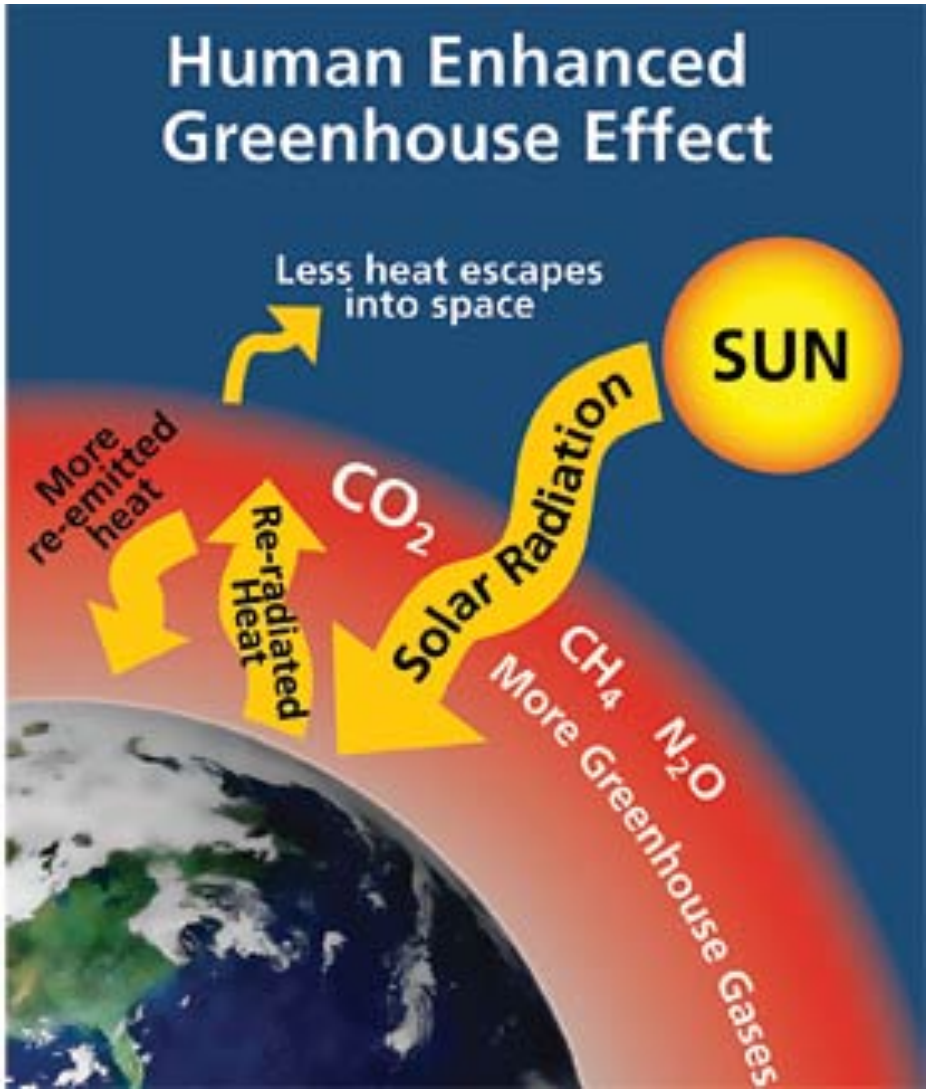
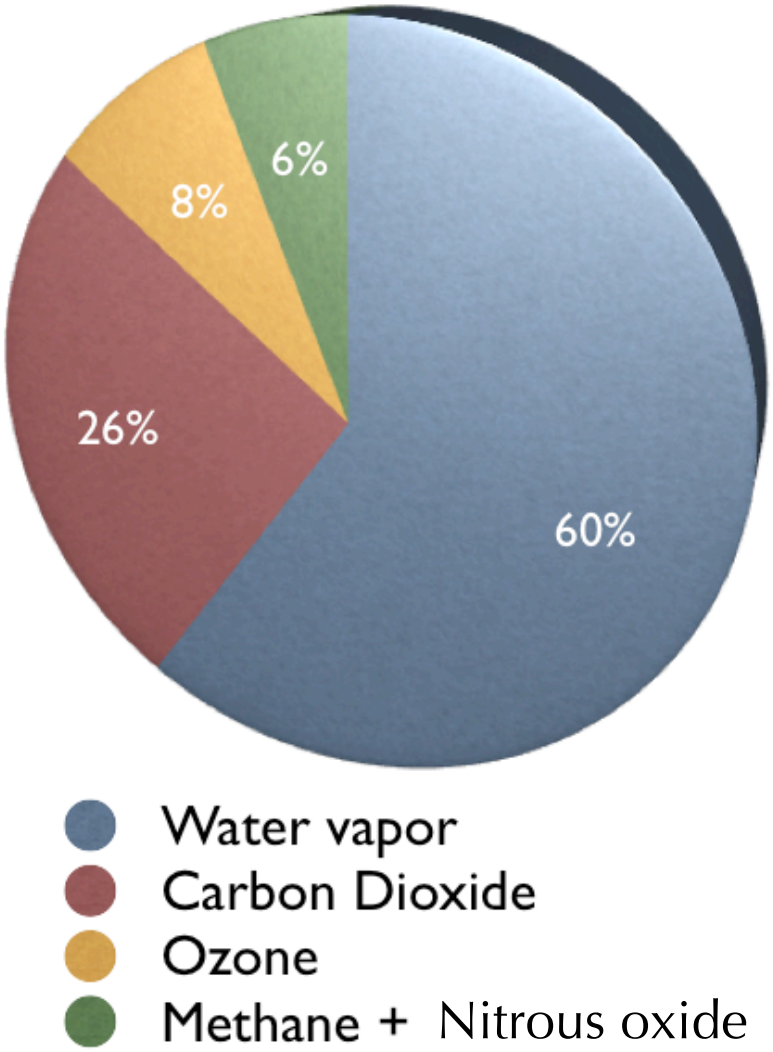


Natural vs. Anthropogenic





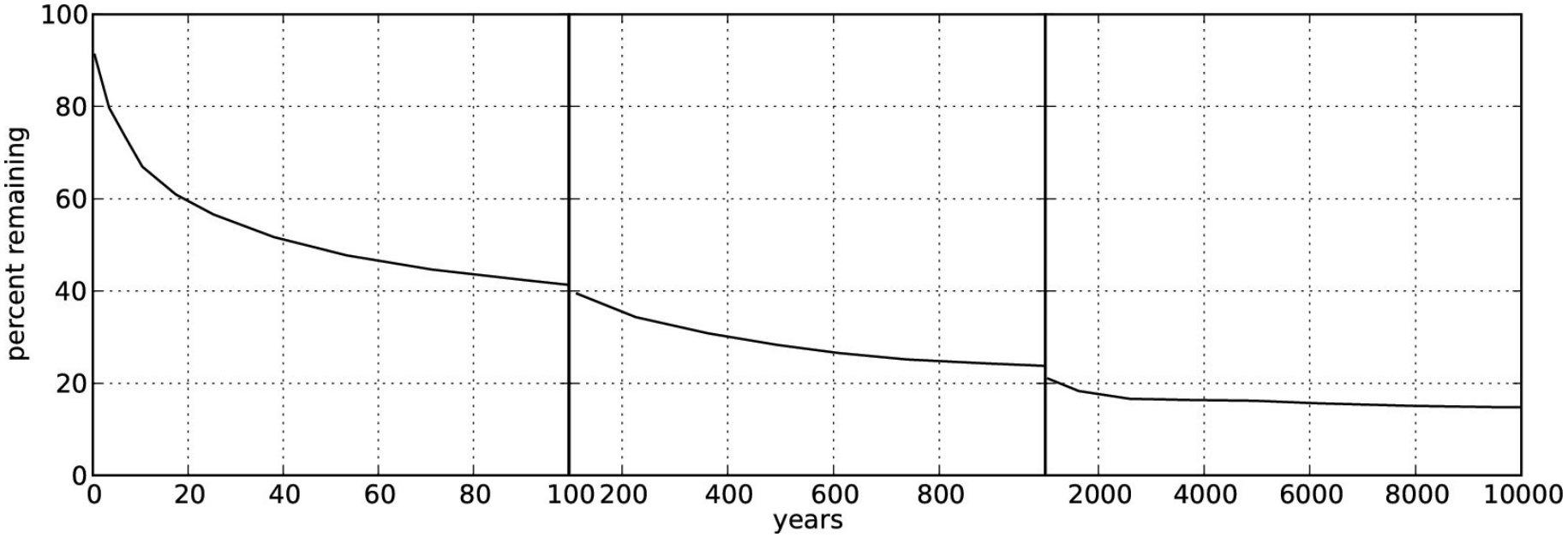


Water vapor is (currently) the largest contributor to the greenhouse effect

~ therefore, why are we even worrying about CO_2 ?

Why don't we care about water vapor?

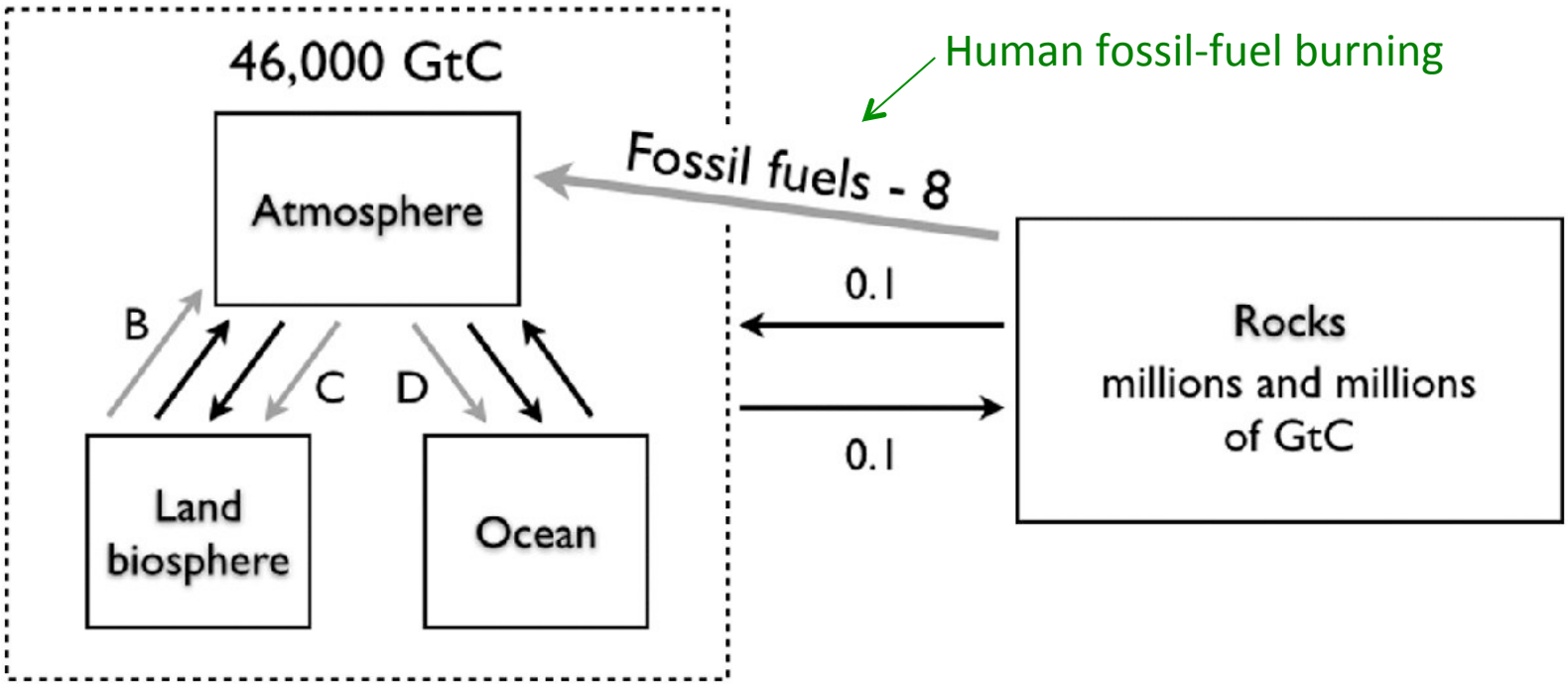
Why CO_2?



The long ***residence time*** of CO_2 coupled with its ***anthropogenic sources*** makes it the most important greenhouse gas

Where does the CO_2 come from?

Human influence on the carbon cycle



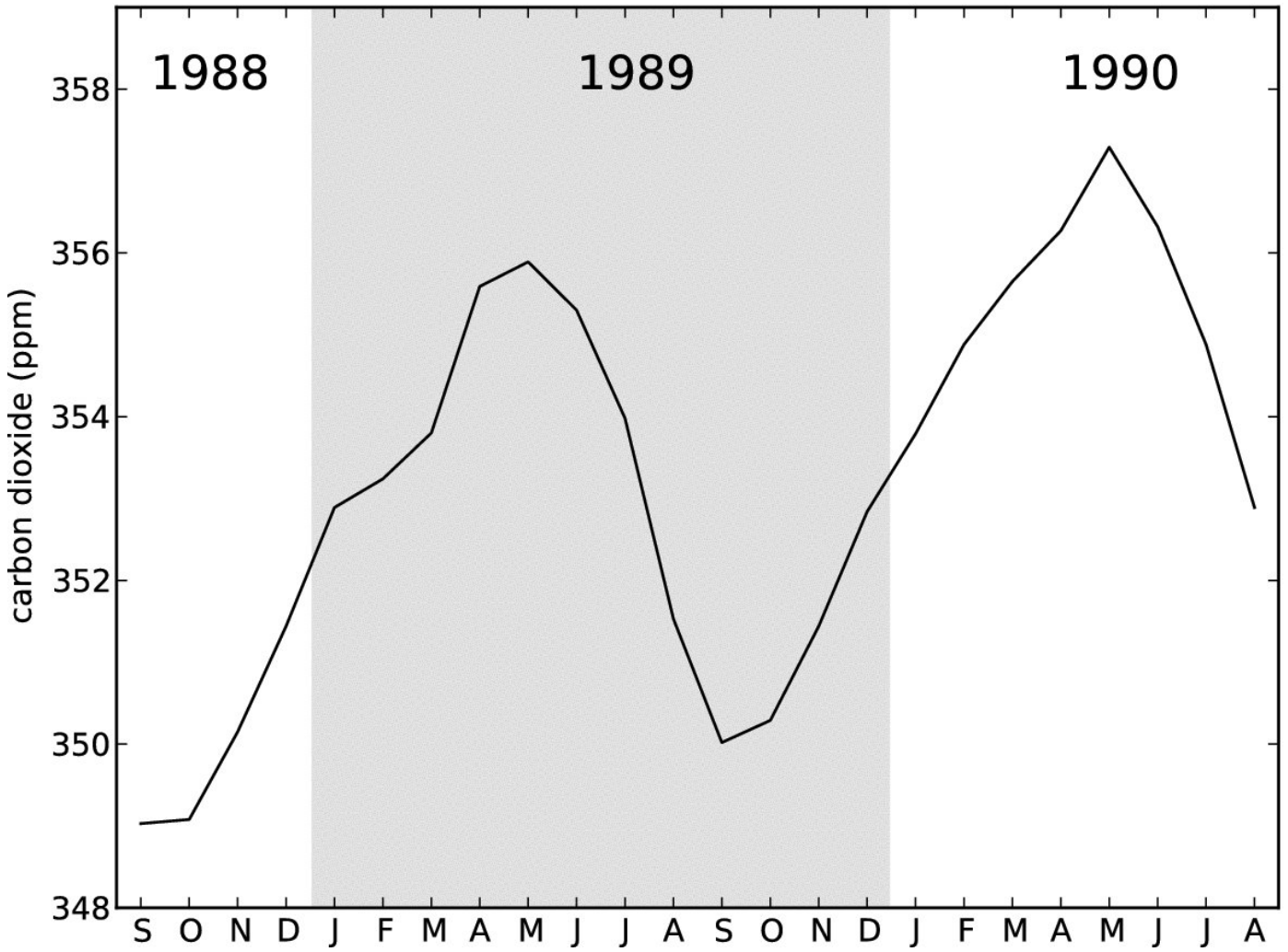
Gray arrows show flow of carbon caused by humans

B = Deforestation

C = CO_2 "fertilization"

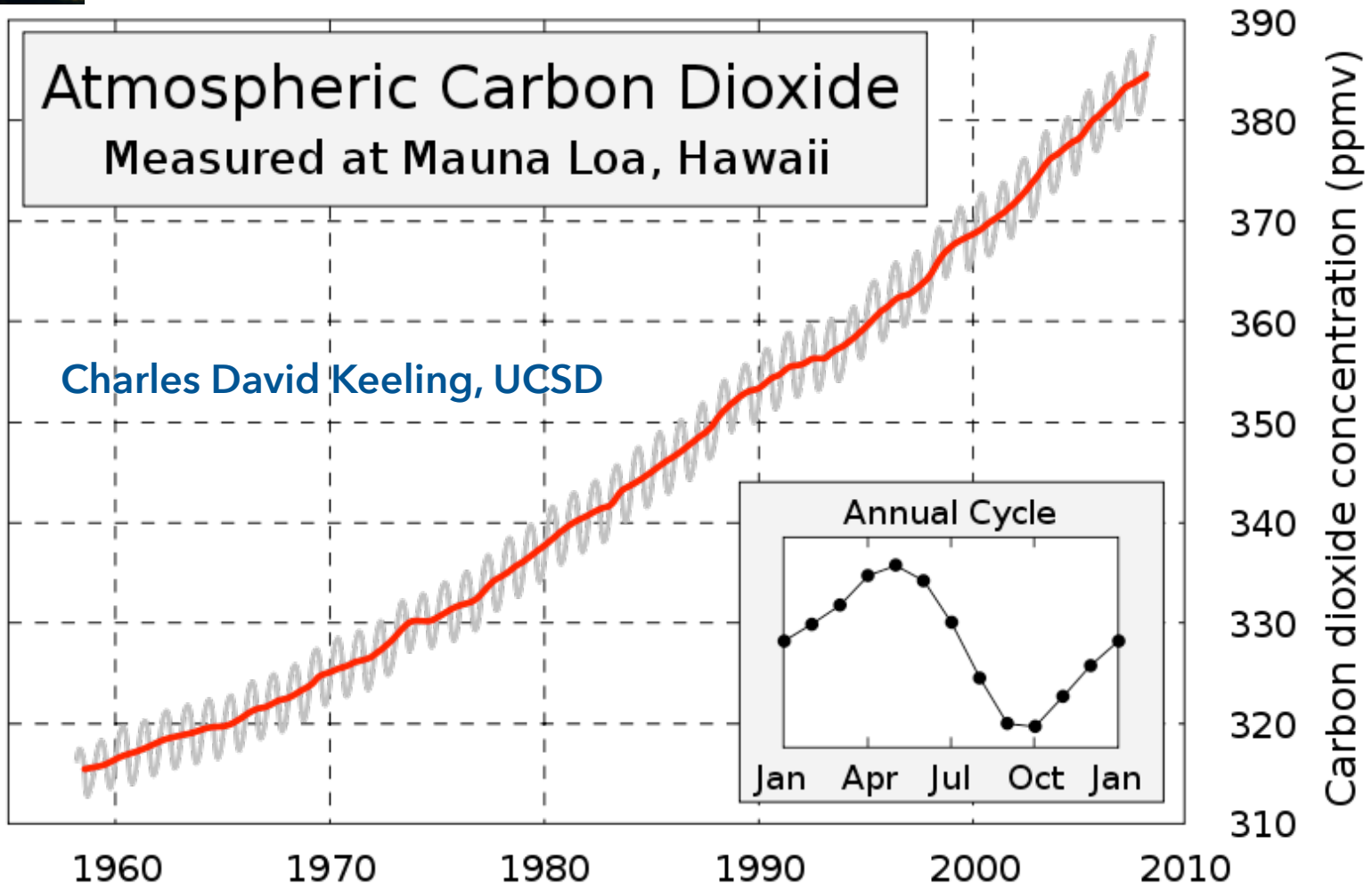
D = Ocean uptake

Annual cycle of atmospheric CO_2



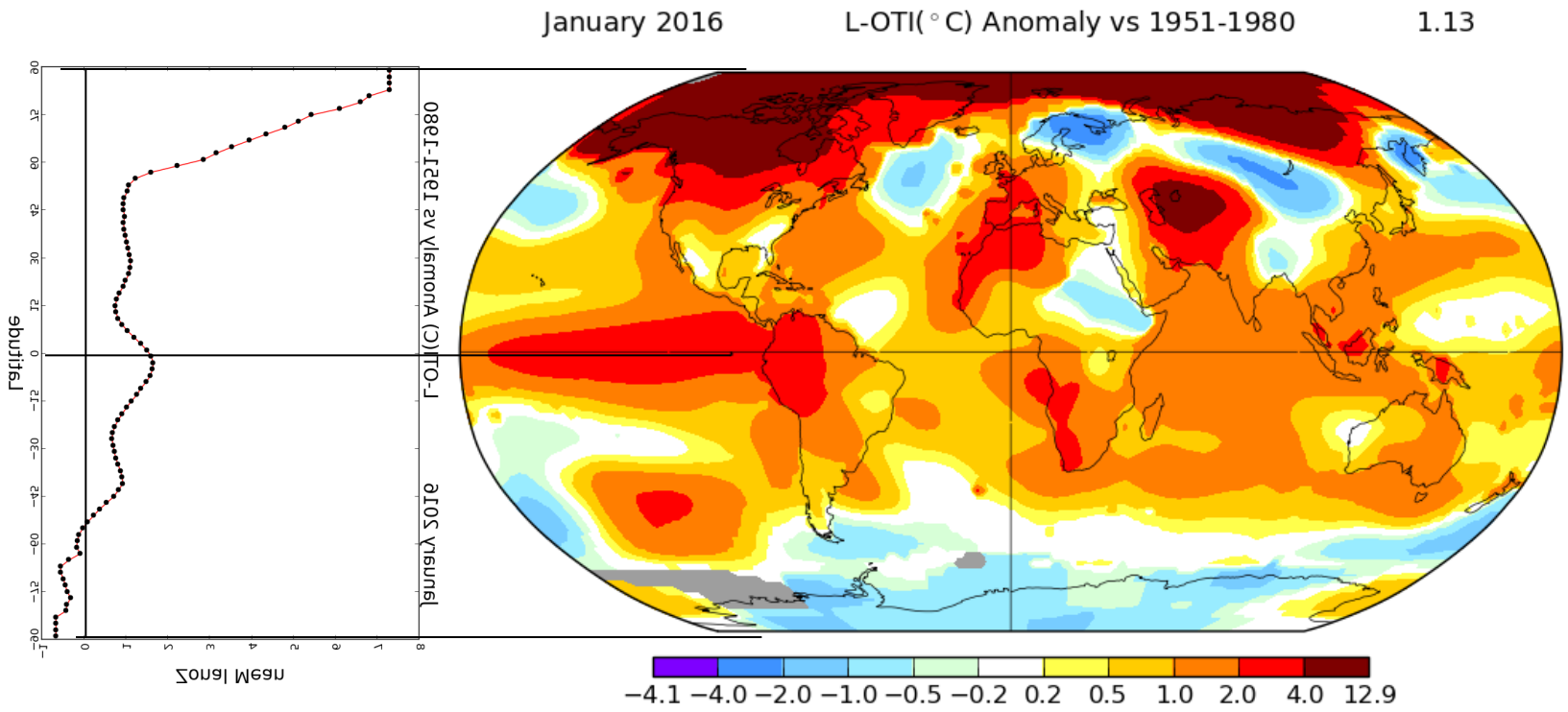
http://svs.gsfc.nasa.gov/vis/a000000/a002000/a002085/a002085.mpg

The Keeling Curve



https://www.youtube.com/watch?v=t0dXjmoA0dw

Temperatures through time and space

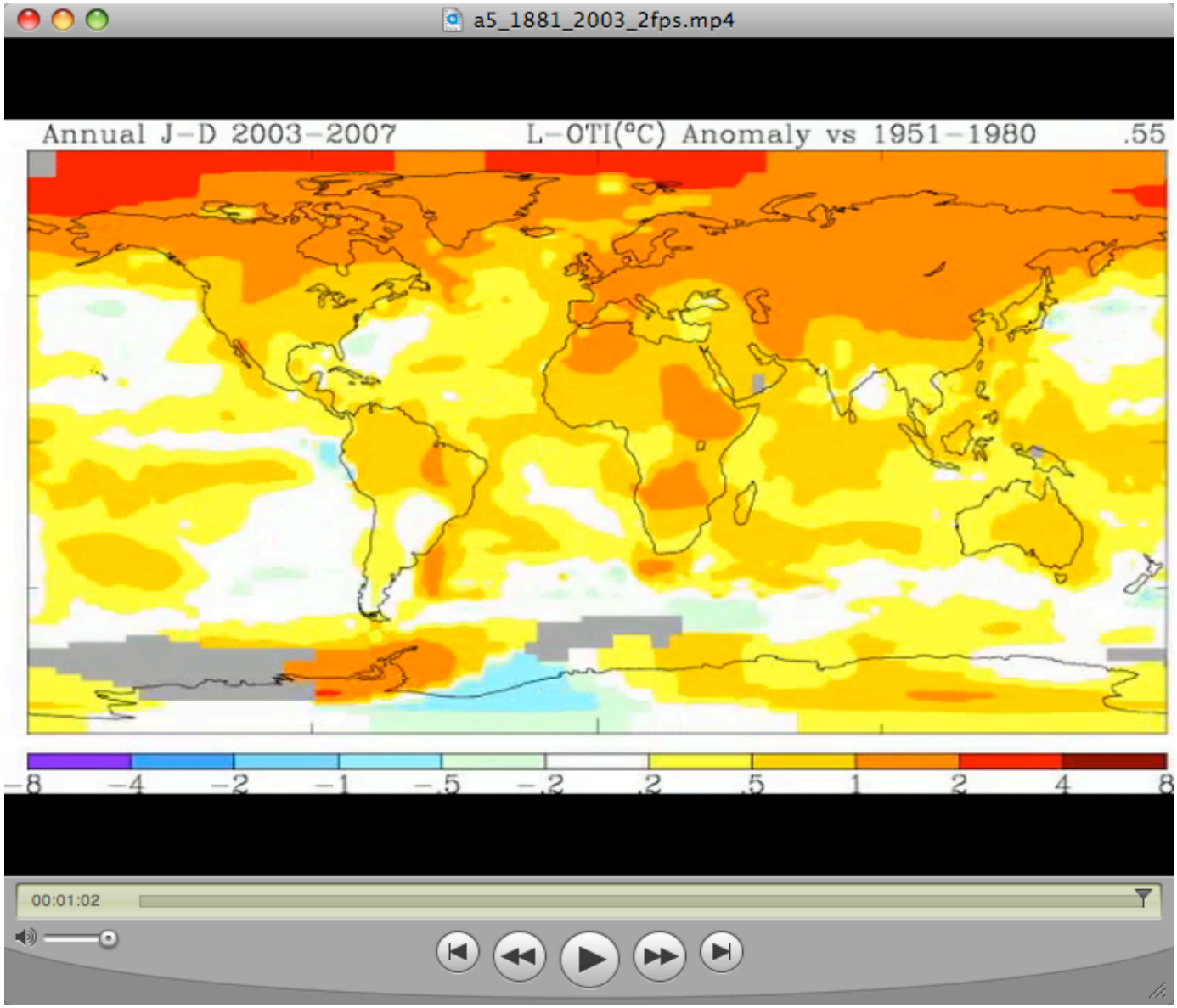


January 2016 temperature compared with normal

From: http://data.giss.nasa.gov/gistemp/maps/

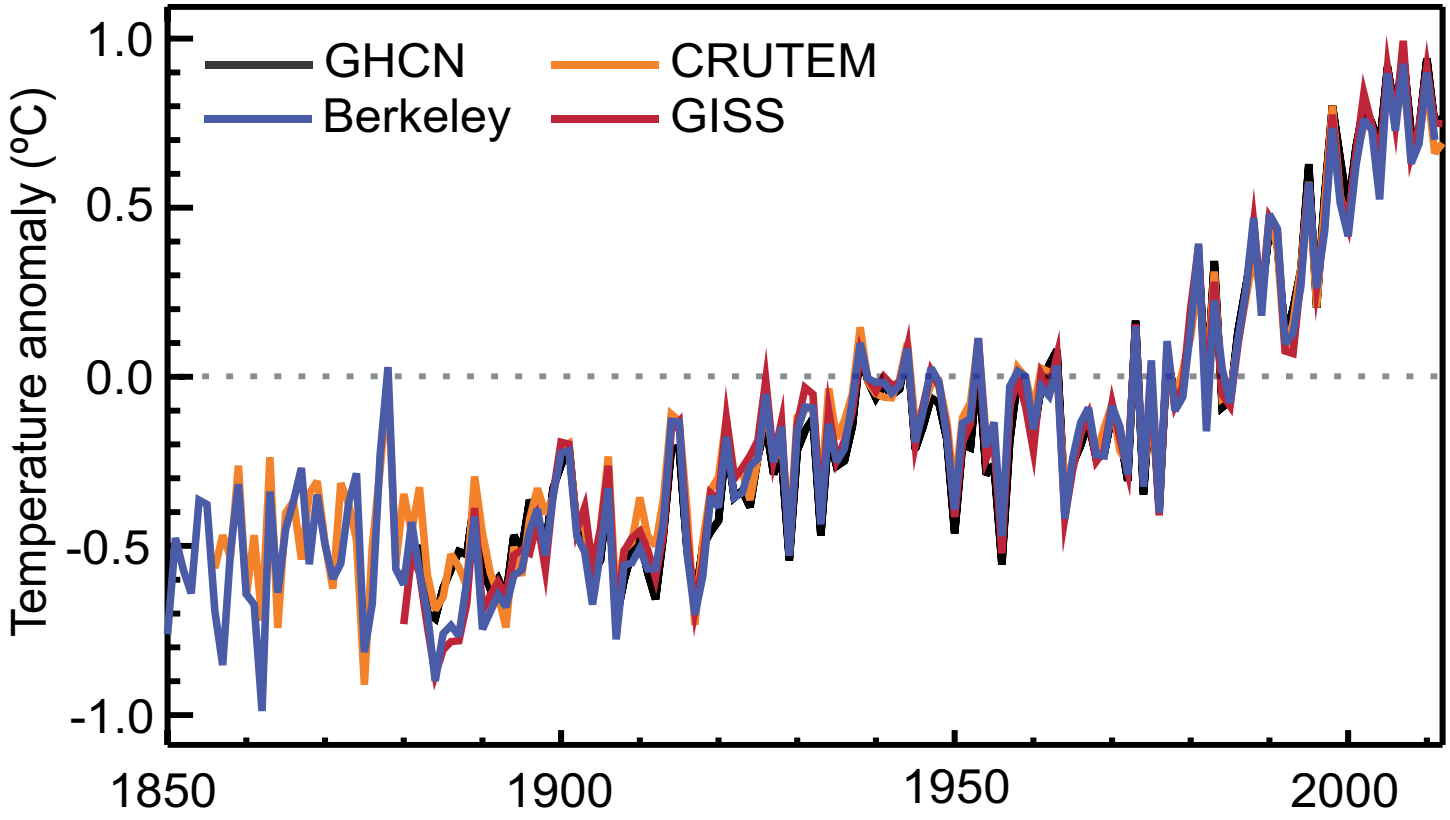
http://cci-reanalyzer.org/animations/scycle/World_ERAI_T2_scycle.gif

An *anomaly* is a departure from a reference value or long-term average



http://svs.gsfc.nasa.gov/vis/a000000/a003900/a003901/

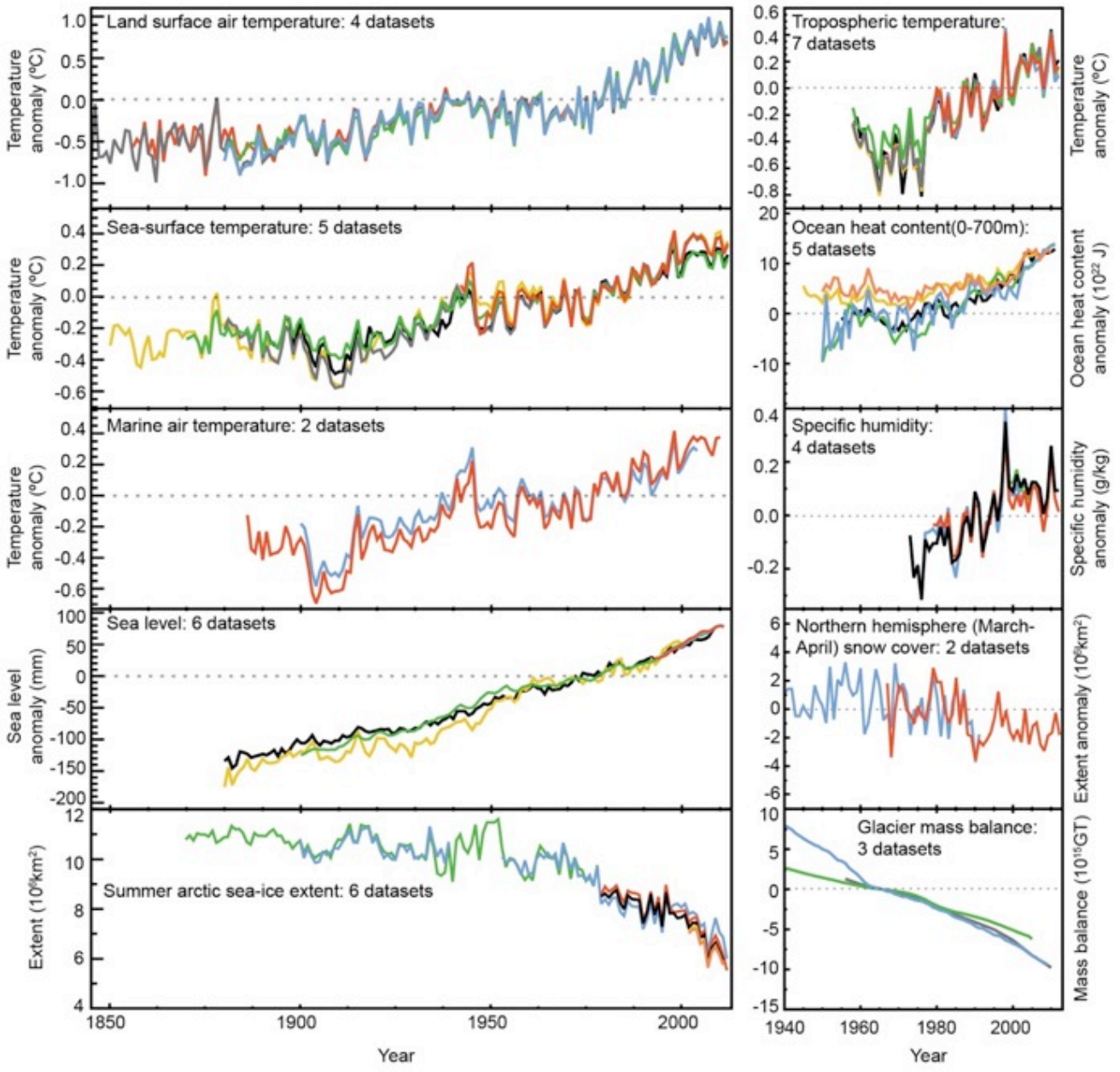
Globally averaged surface temperature



Records from four different sources all agree:

- temperature rose rapidly from 1910s to early 1940s
- stabilized (possibly cooled) from late 1940s to late 1970s
- rose abruptly since late 1970's

Independent Signs of Warming



Land Sfc Temp

Tropospheric Temp

Sea-surface temp

Ocean Heat Content

Marine Air Temp

Specific Humidity

Sea Level

Snow Cover

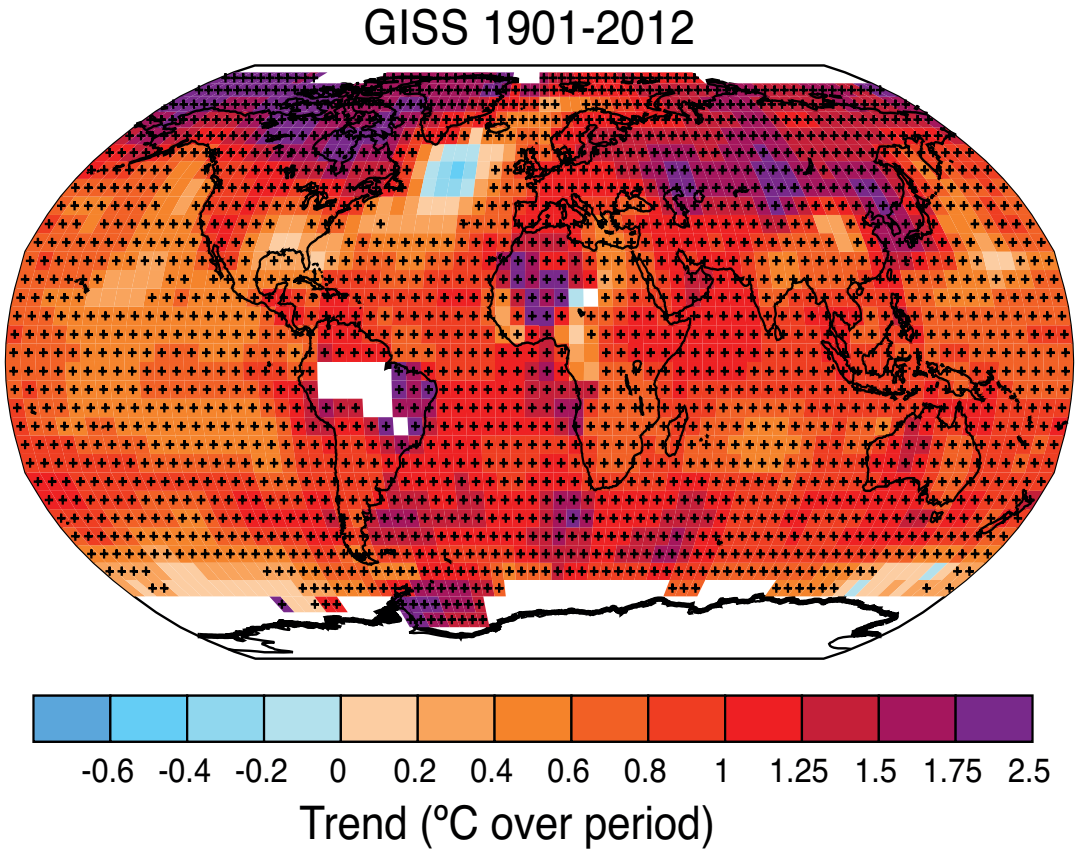
Arctic Sea Ice

Glacier Mass Balance

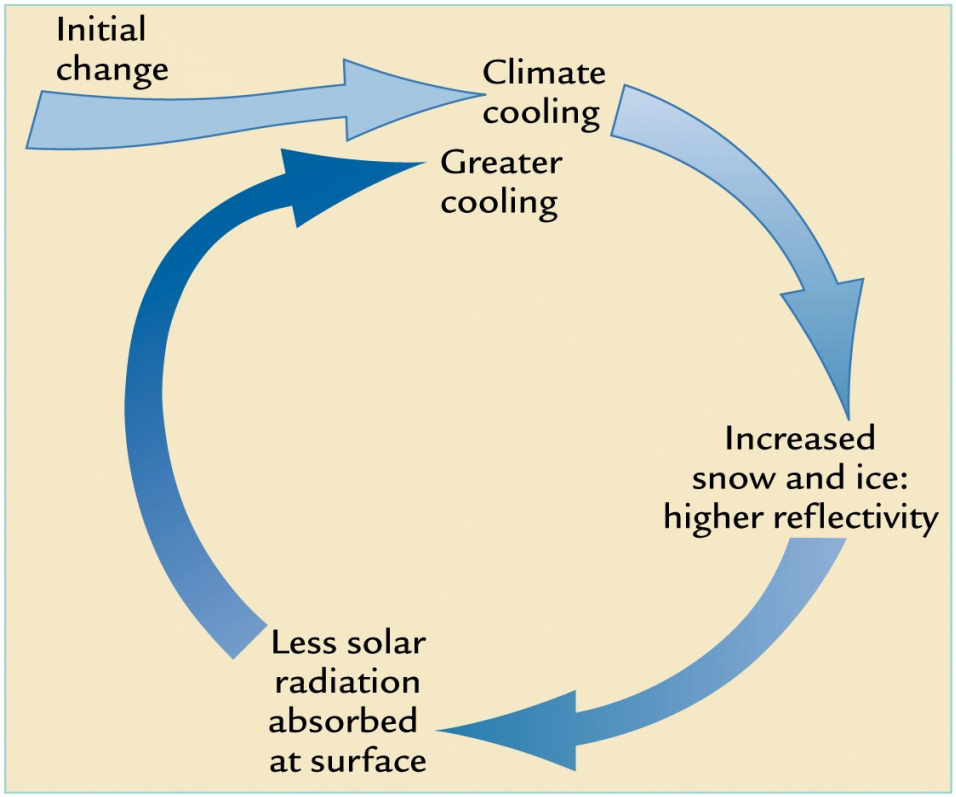
IPCC AR5 TS

“Global warming” is uneven

- Some areas are cooling
- More warming in the Arctic
- More warming over land



The Albedo feedback



Ice albedo: Positive feedback on climate

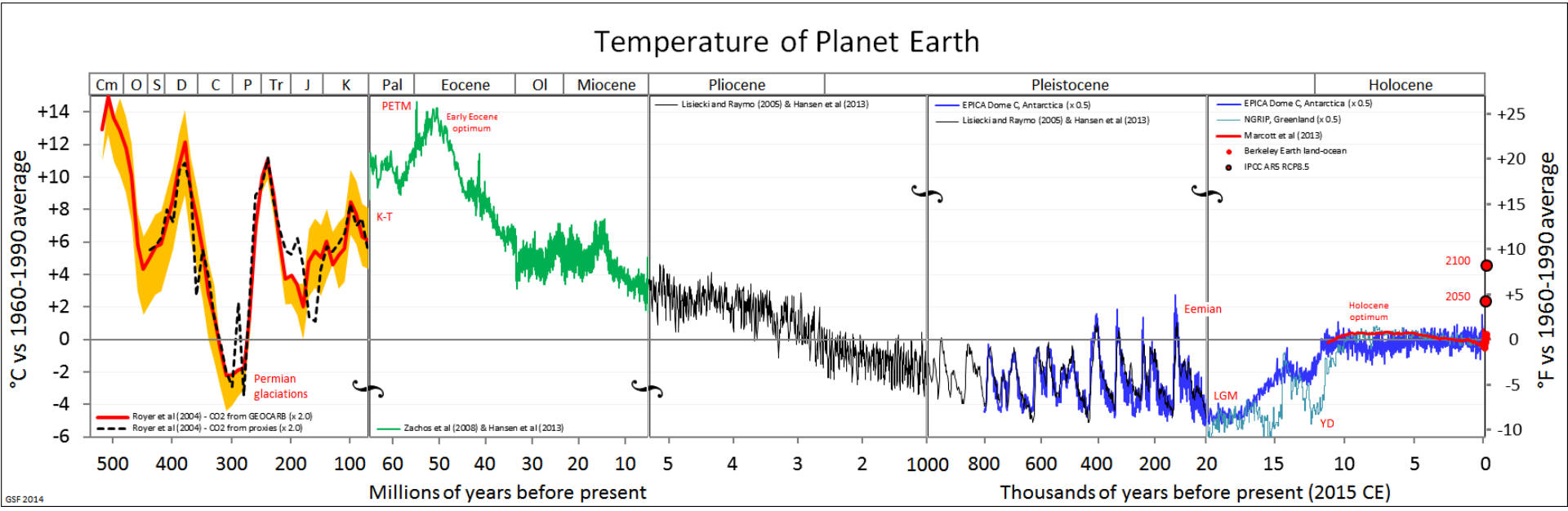
- Cooler climate = ↑ ice = ↑ albedo
- Higher albedo = ↑ cooling
- Initial change is reinforced, leading to great change

Part 3

What do we know about long-term, "natural" climate variability?

Paleoclimate: the long view

- What's "normal"?
- Are there natural long-term cycles?
- How does recent climate change compare with natural variability?
- What's the world like when it's warmer (analogs)?
- And: how do we know all of this?

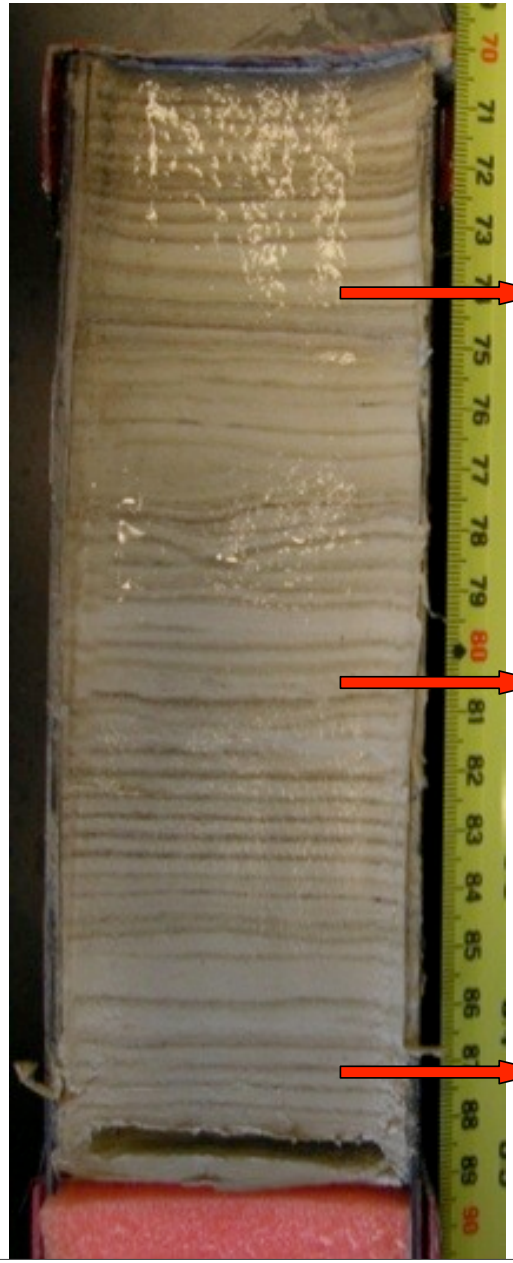


How do we study paleoclimate?

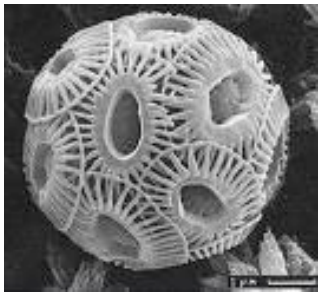
- *Proxy data* from *natural archives*
  - Marine sediment cores
  - Lake sediment cores
  - Ice cores
  - Tree rings
  - Corals
  - Speleothems (stalagmites)
  - Evidence of glaciers/water level changes

Paleoceanography

the science of past oceans



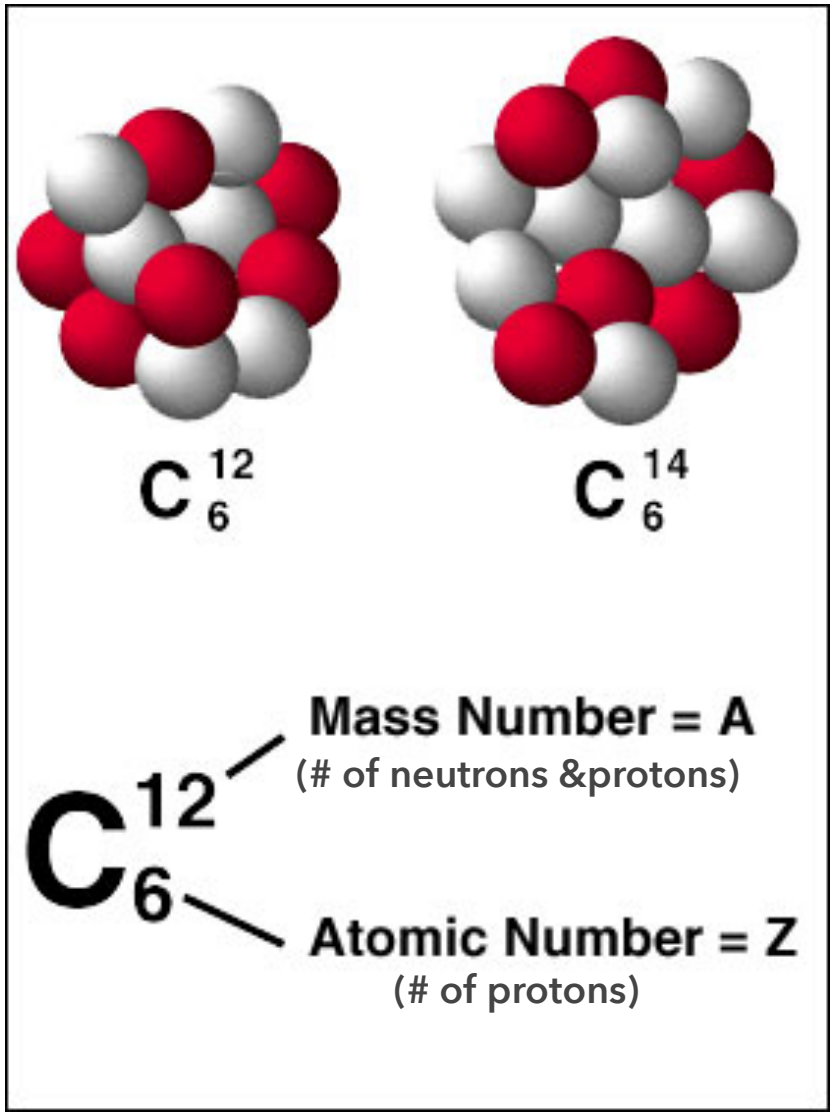
youngest



oldest

living micro-organisms record information about seawater composition when they form their shells

Isotopes



Definition:

- avatars of one **element** that contain the same number of protons but a different number of neutrons

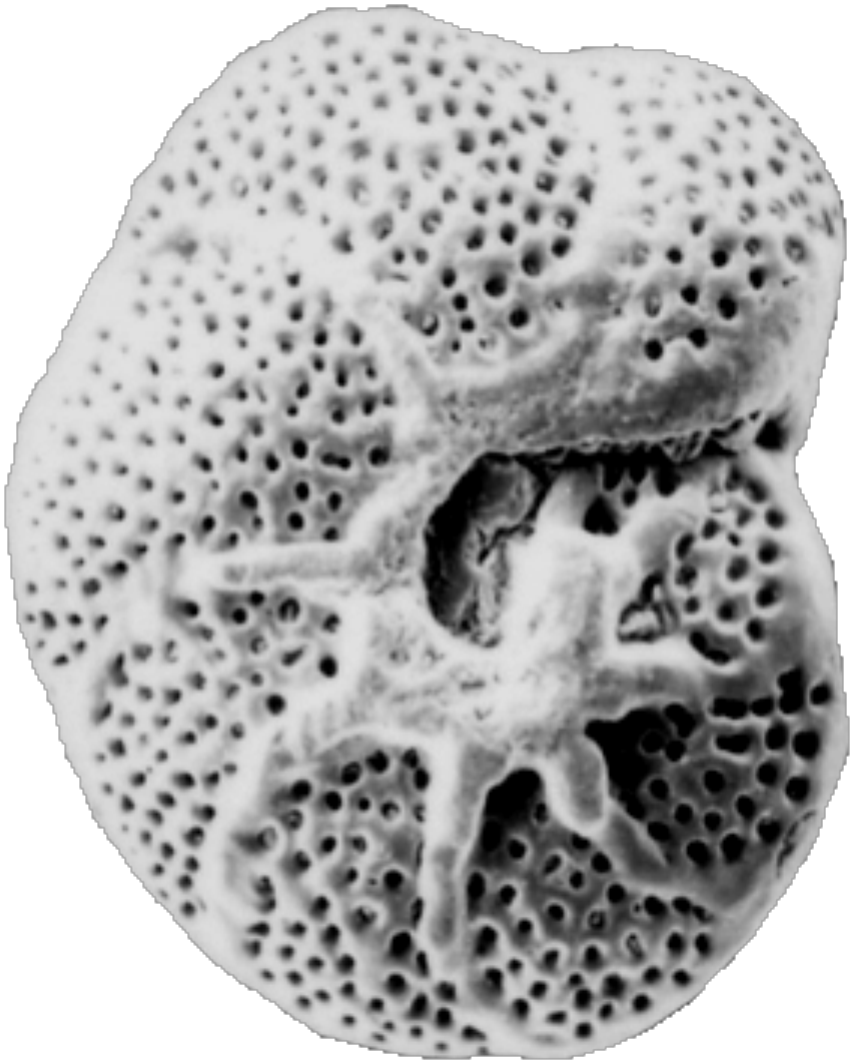
Two kinds:

- Stable isotopes (stick around)
  - e.g. ^{13}C, ^{18}O, ^{2}H
- Radiogenic isotopes (decay)
  - e.g. ^{14}C, ^{87}Rb, ^{238}U

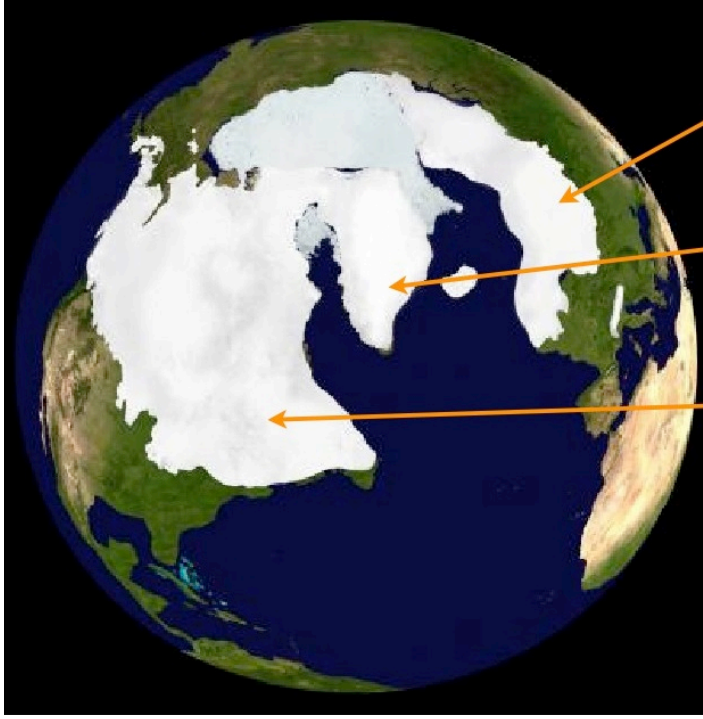
Both are extremely useful in geology

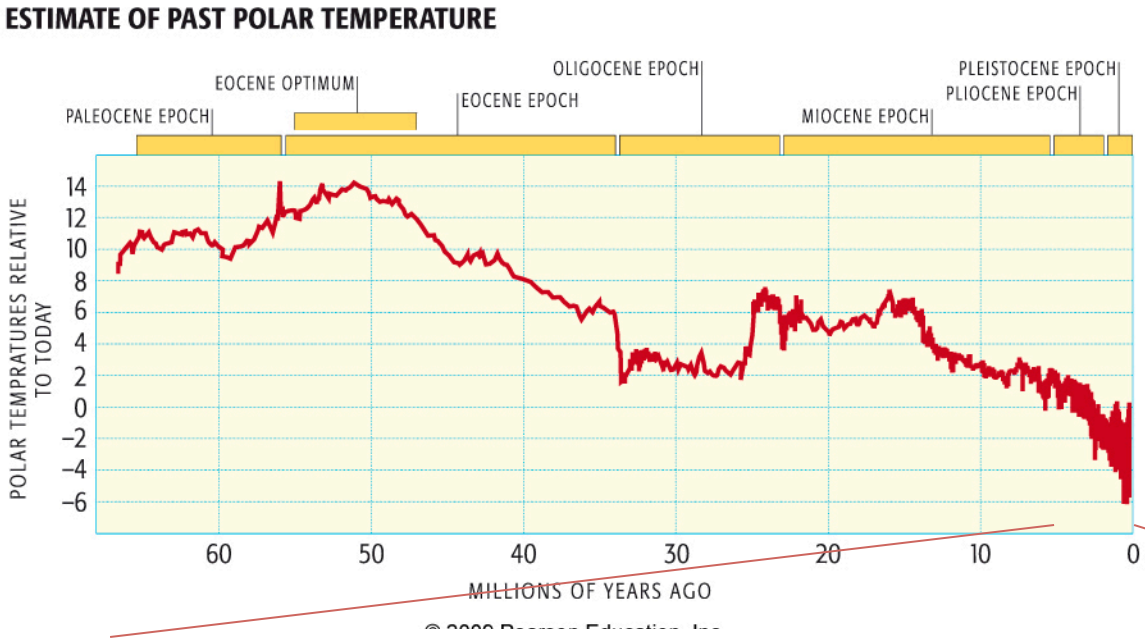
Foraminifera

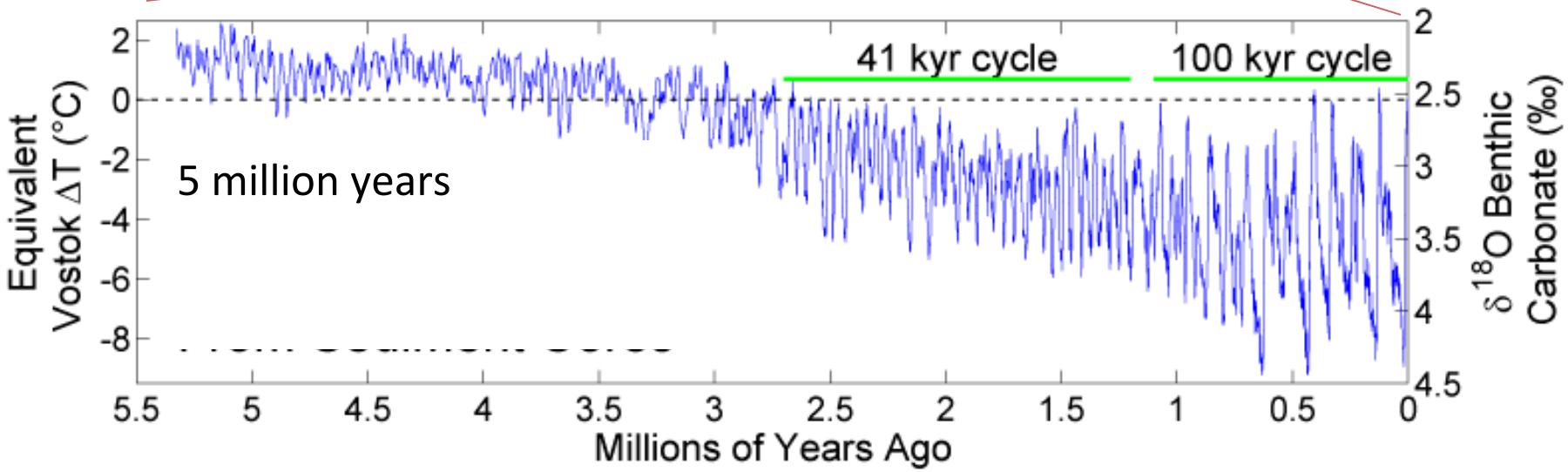
- Marine critters made of calcium carbonate ($CaCO_3$)
- Tell us most of what we know about past temperatures



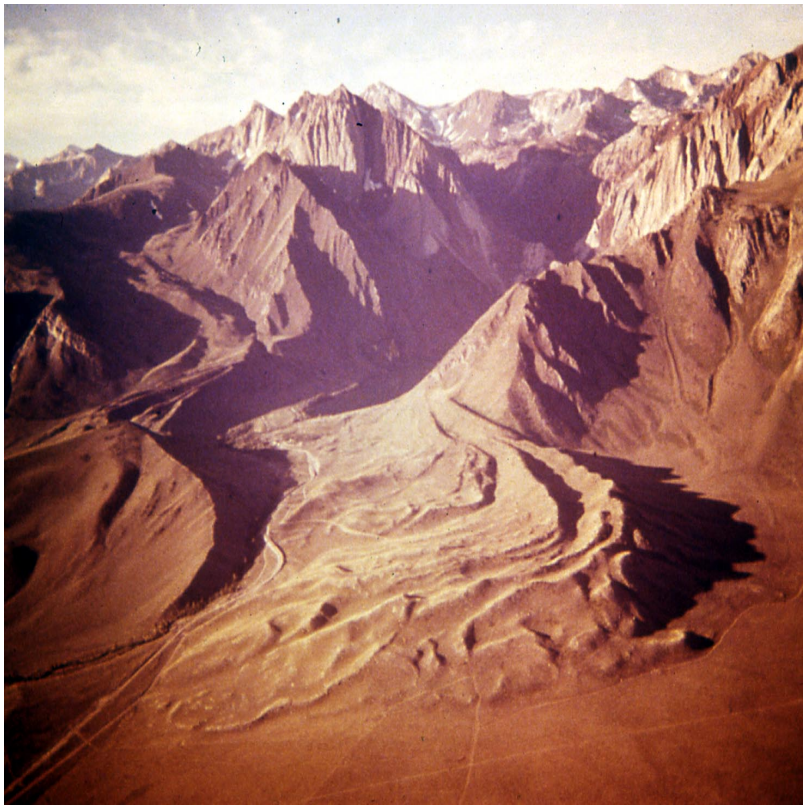
Glacial periods



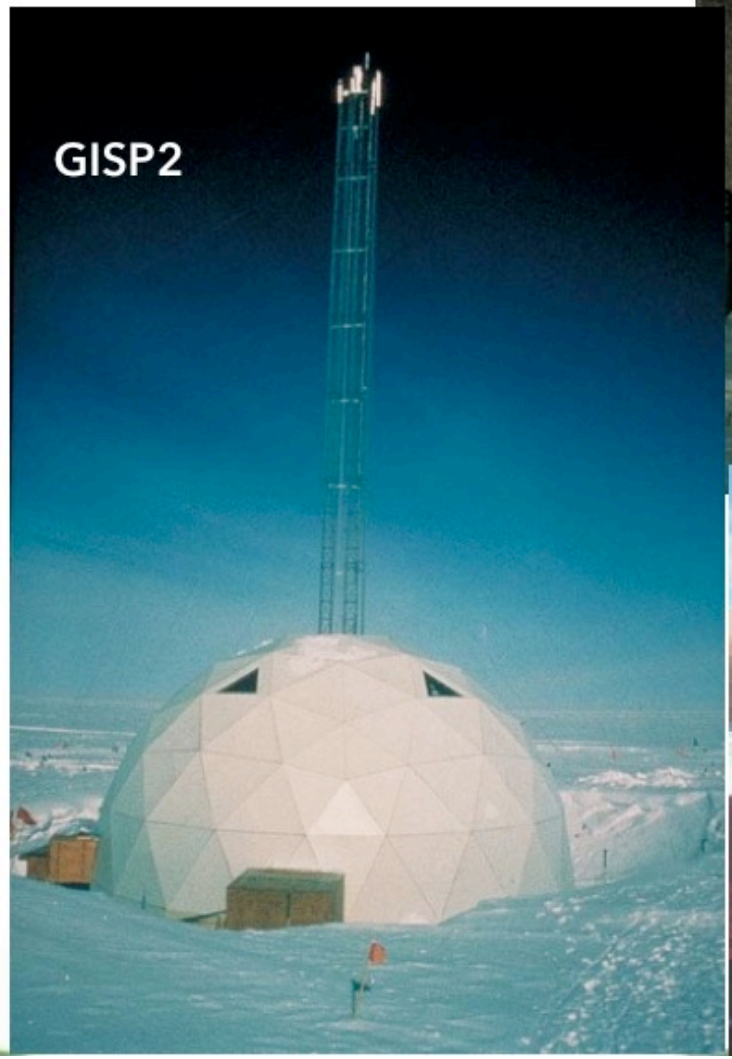




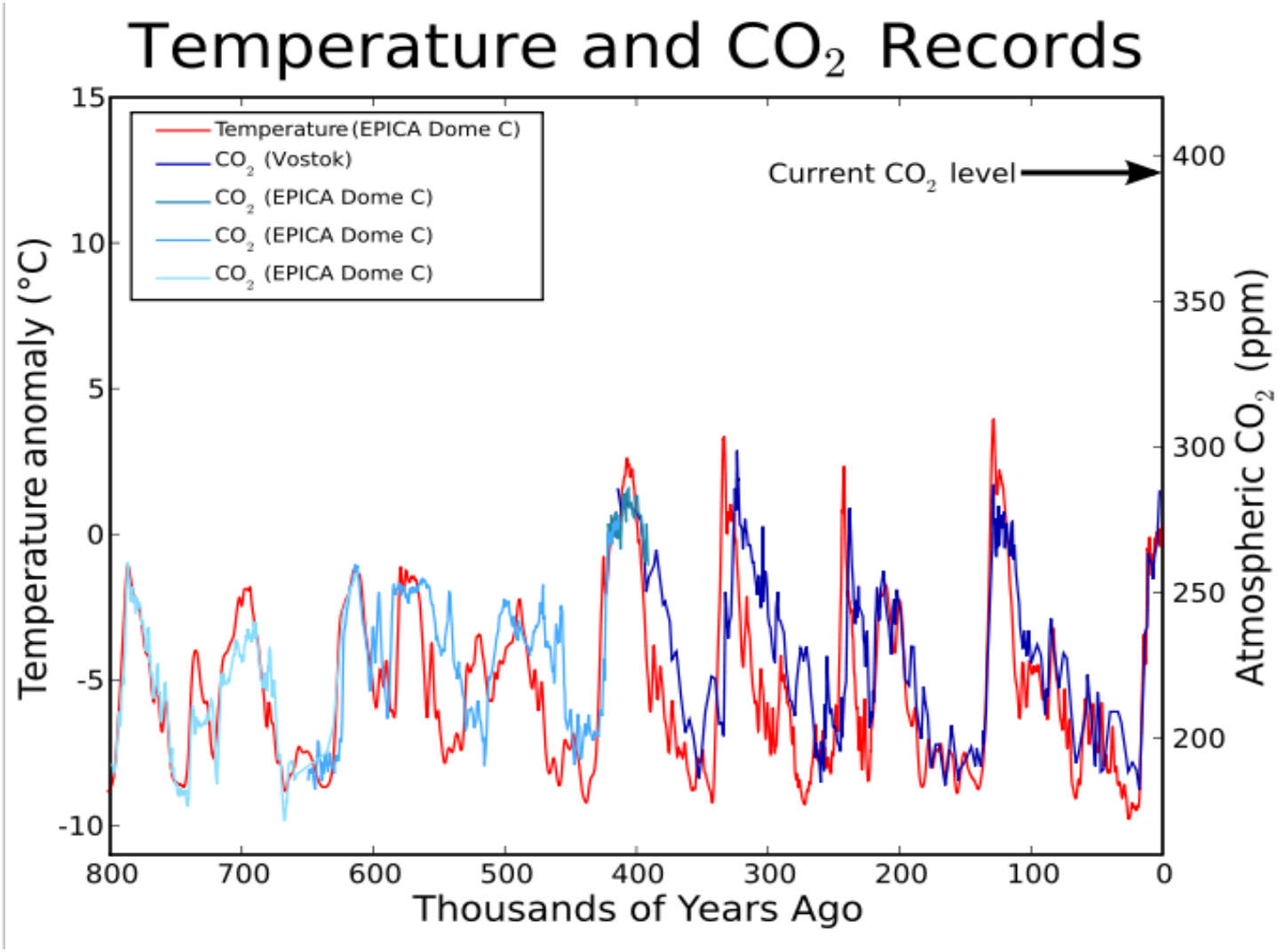
Evidence of larger glaciers

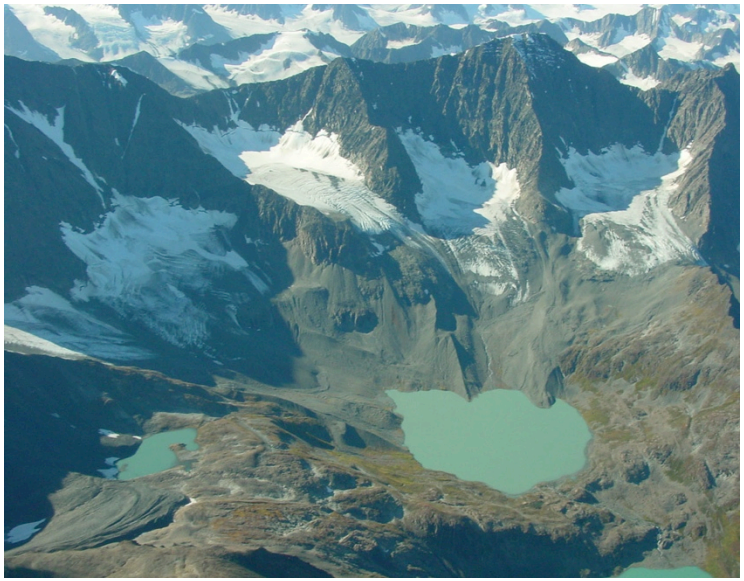


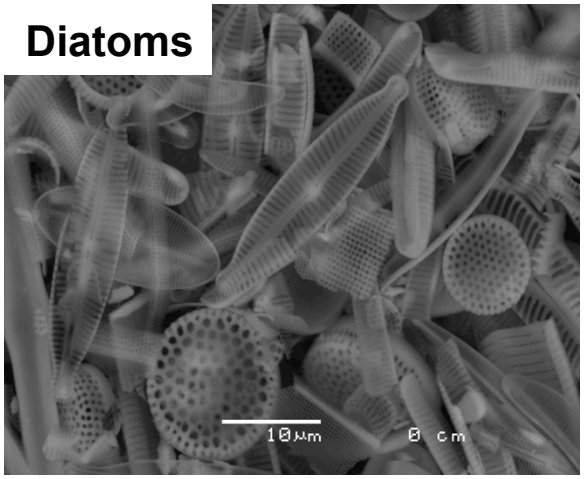
Indicators of Past Climate: Ice Cores
(Greenland and Antarctica)

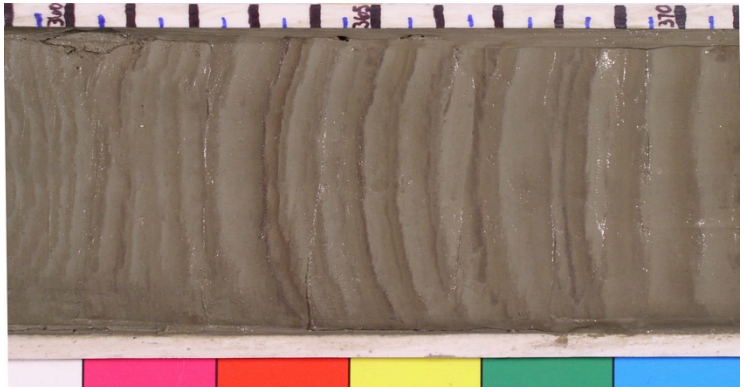


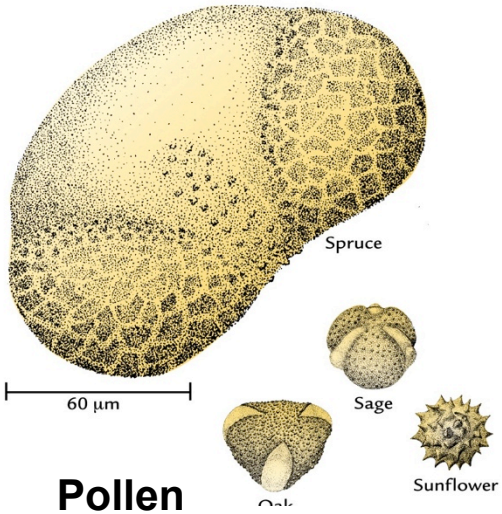
Ice core operations in Greenland


Temperature and CO_2 Records
Temperature (EPICA Dome C)
CO_2 (Vostok)
CO_2 (EPICA Dome C)
CO_2 (EPICA Dome C)
CO_2 (EPICA Dome C)
Current CO_2 level
Temperature anomaly (°C)
Atmospheric CO_2 (ppm)
Thousands of Years Ago
15
10
5
0
-5
-10
400
350
300
250
200
800
700
600
500
400
300
200
100
0







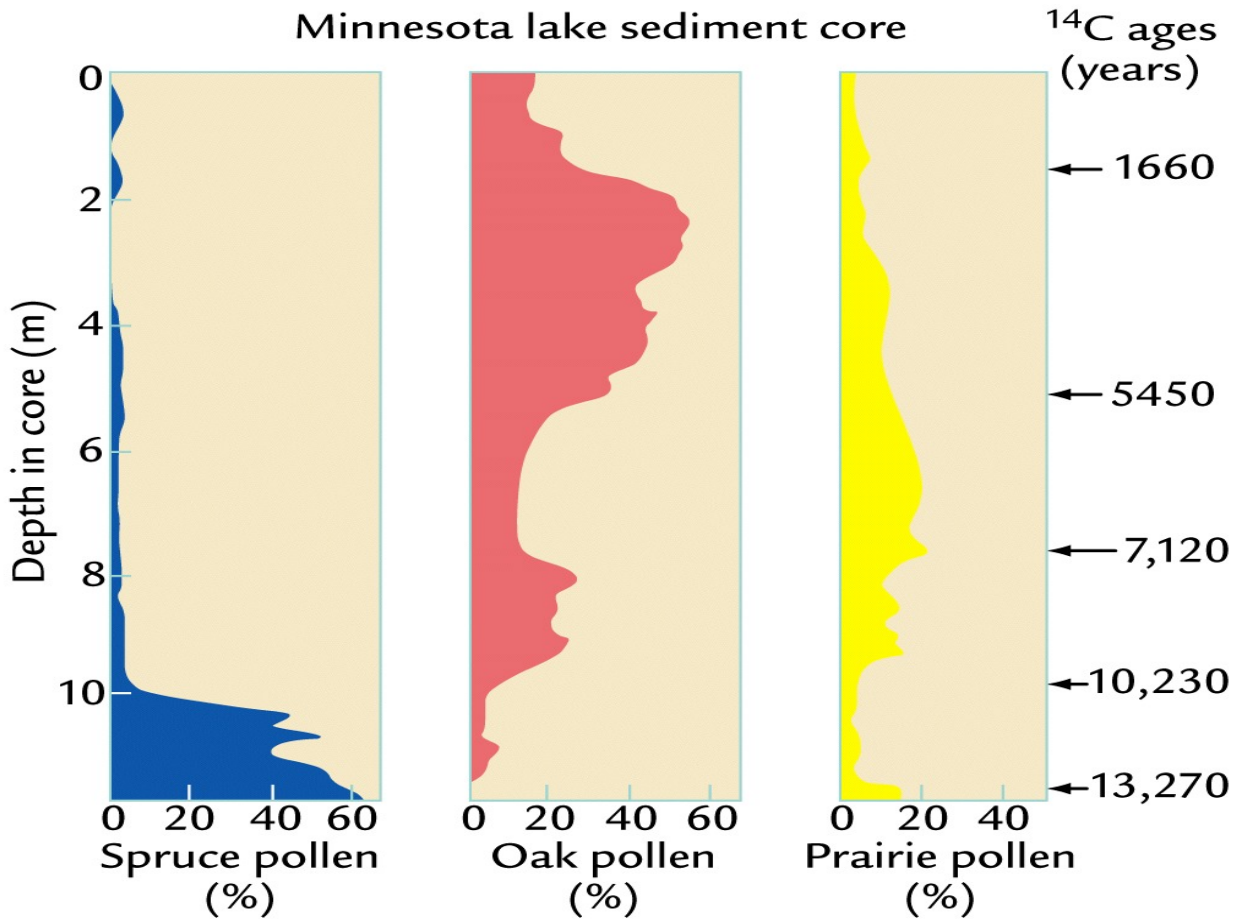


Lakes

Evidence of *regional* climatic changes

Go back ~10,000 years

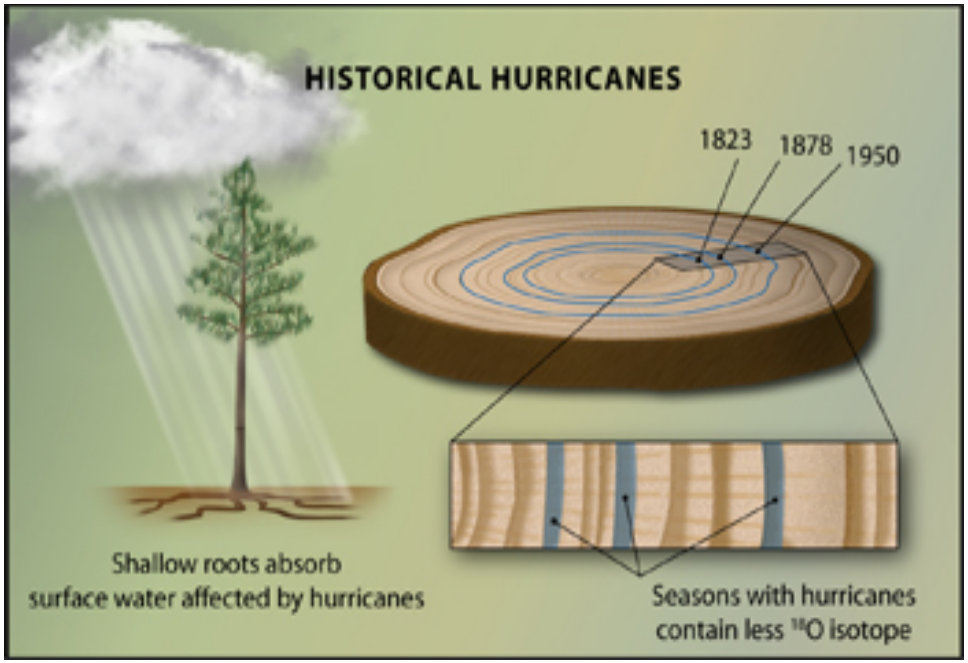
Various biological and physical indicators of climate are preserved



- *Pollen* produced by vegetation is preserved in lake sediments that can be dated by *radiocarbon (^{14}C)*

Trees

- Annual layers are best developed in mid-latitude and high-latitude regions that experience large seasonal changes
- Thickness of layers indicates growth conditions over decades to centuries
- Hurricanes, fires, and other events can be inferred from tree rings



Part 4

What about climate of the future?

So… what's going to happen?

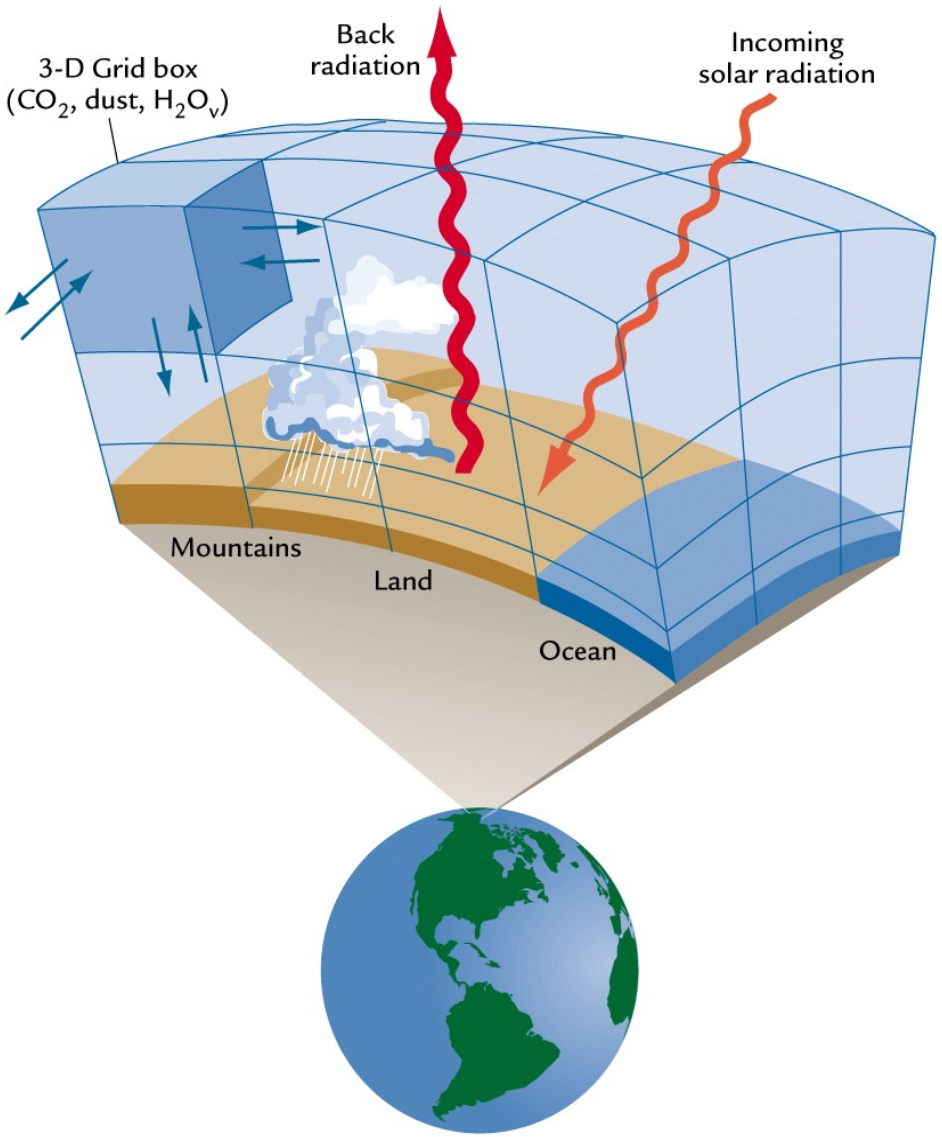
To address this, we need to know about *climate models*

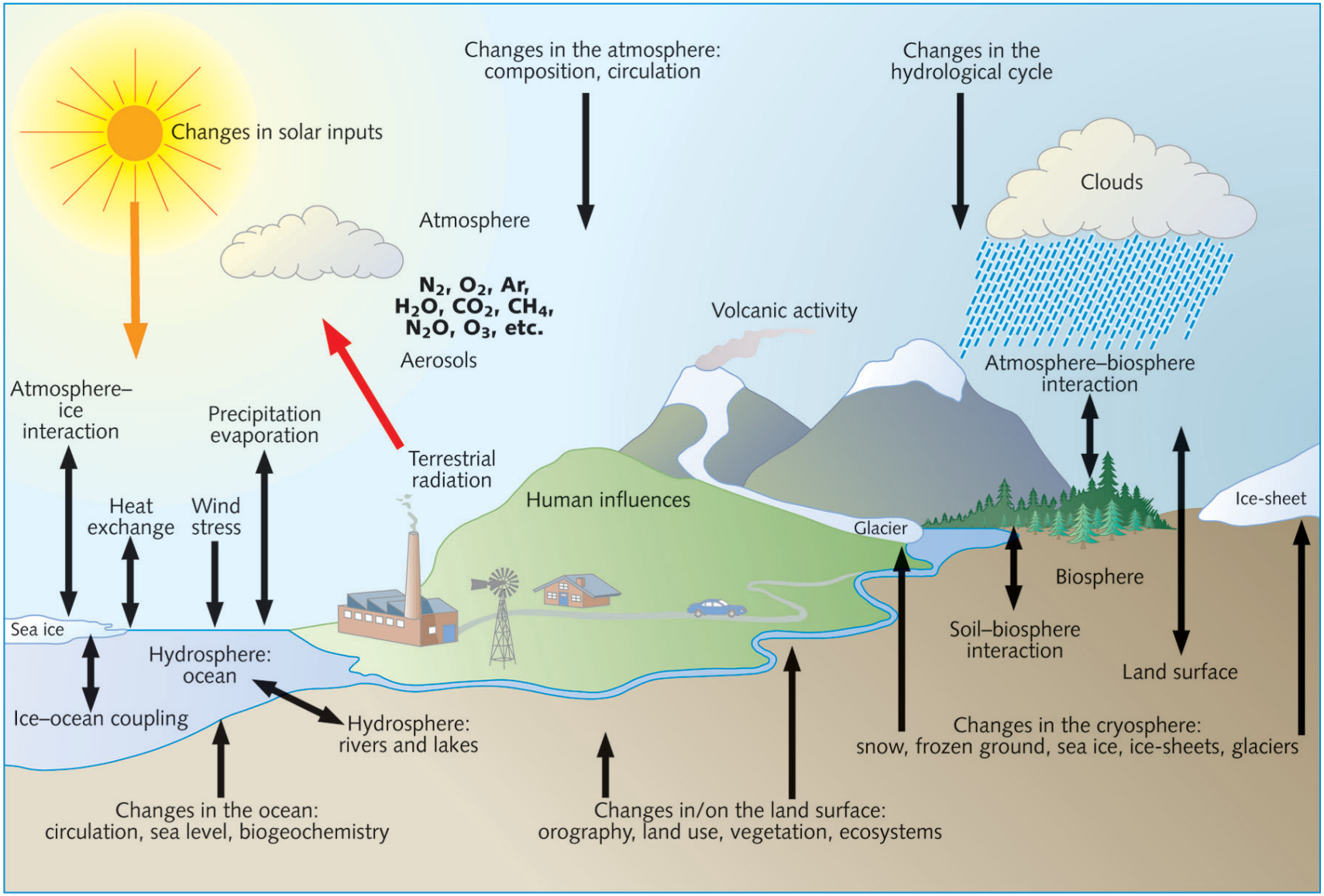
What is a climate model?

a mathematical representation of the climate system based on physical, biological and chemical principles

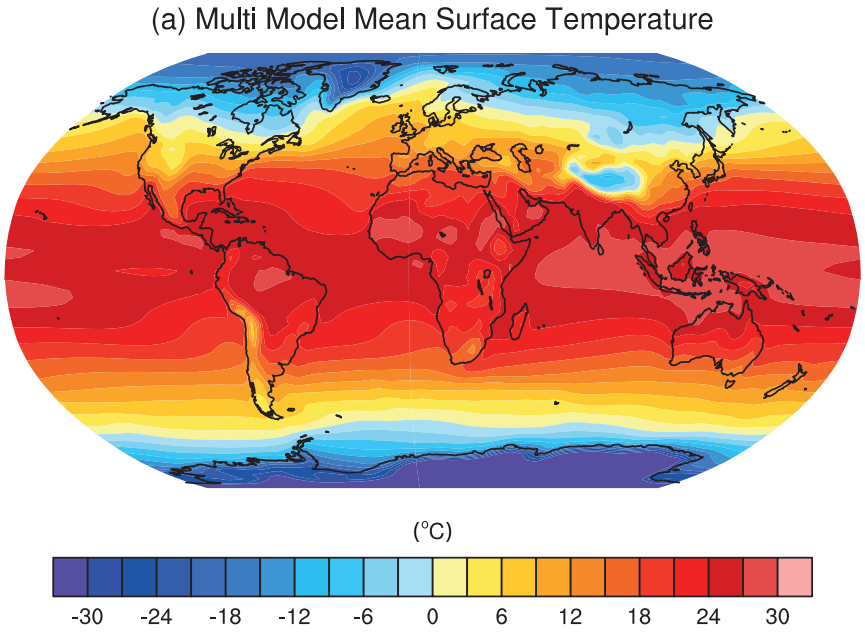
General circulation models

- Mathematical representations of main features of land, water, ice, atmosphere
- Models use equations for physical laws to control the circulation of the atmosphere
- For example: convection, conservation of mass and energy

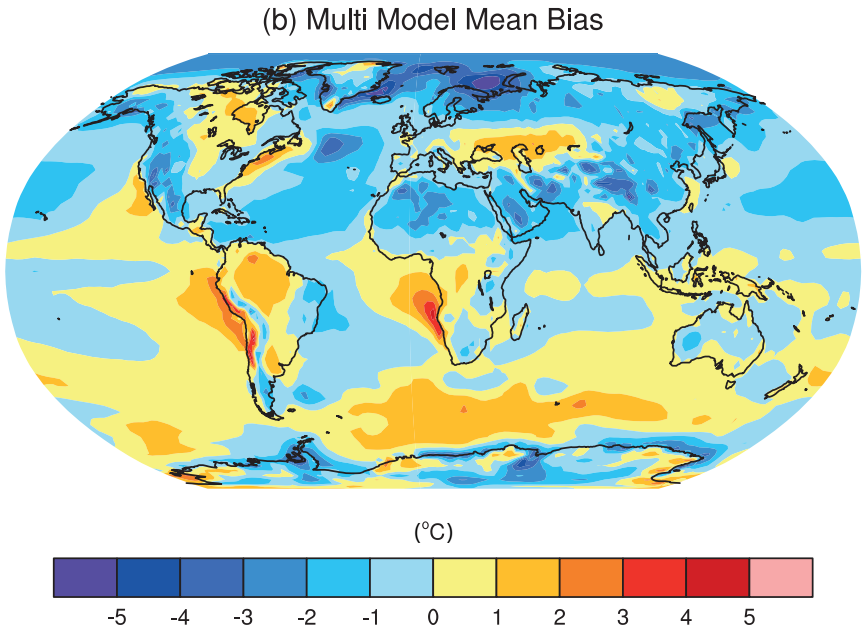



Changes in the atmosphere: composition, circulation
Changes in the hydrological cycle
Changes in solar inputs
Clouds
Atmosphere
N_2, O_2, Ar,
H_2O, CO_2, CH_4,
N_2O, O_3, etc.
Aerosols
Volcanic activity
Atmosphere–biosphere interaction
Atmosphere–ice interaction
Precipitation evaporation
Terrestrial radiation
Heat exchange
Wind stress
Human influences
Glacier
Ice-sheet
Biosphere
Sea ice
Hydrosphere: ocean
Soil–biosphere interaction
Land surface
Ice–ocean coupling
Hydrosphere: rivers and lakes
Changes in the cryosphere: snow, frozen ground, sea ice, ice-sheets, glaciers
Changes in the ocean: circulation, sea level, biogeochemistry
Changes in/on the land surface: orography, land use, vegetation, ecosystems

Why do we trust climate models?

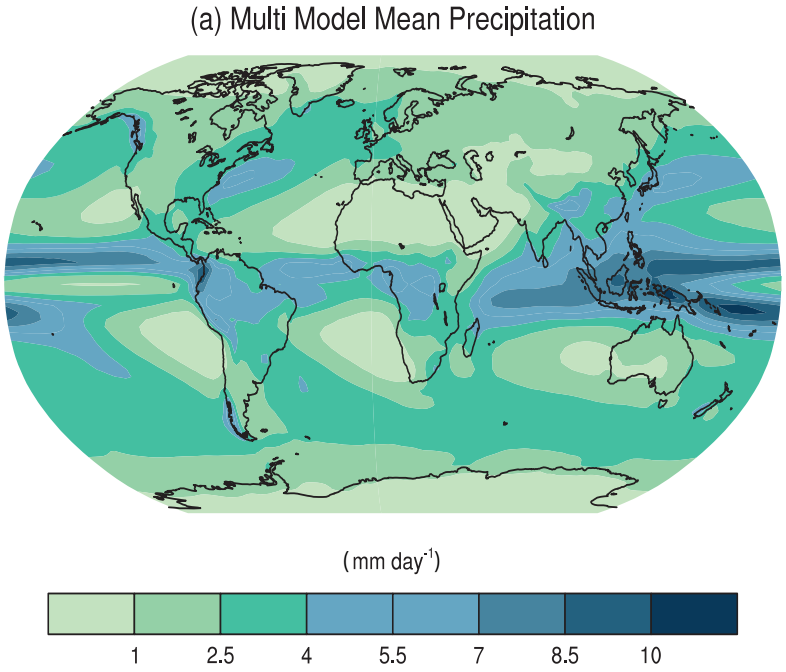


Model simulated temperature (1980-2005)

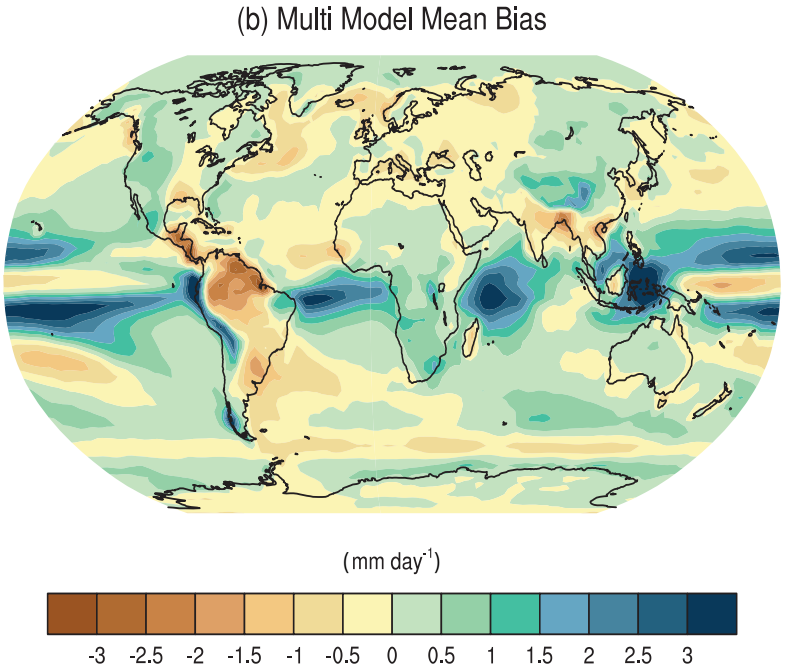


Difference between simulated and observed temperature (1980-2005)

Why do we trust climate models?



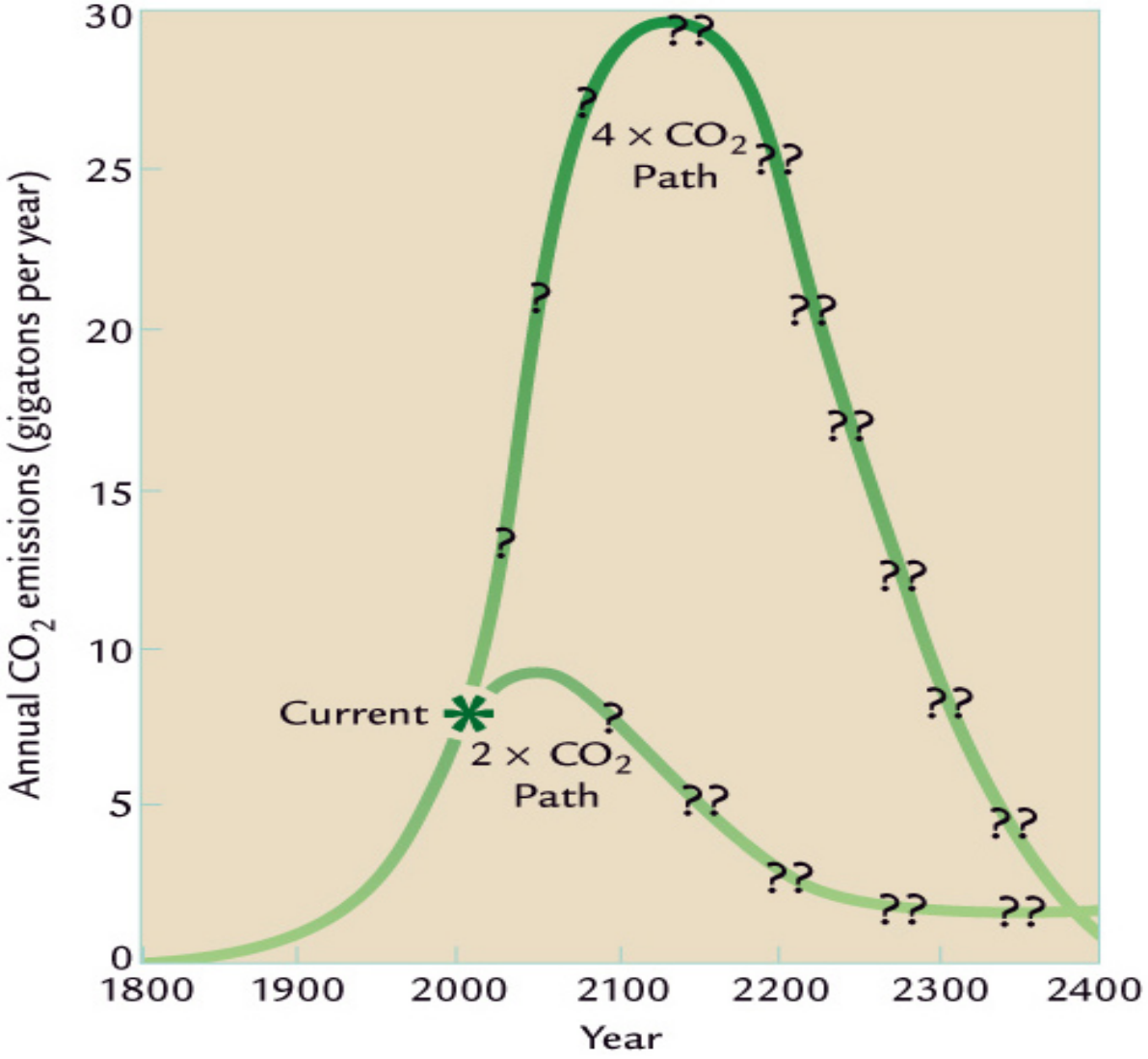
Model simulated precipitation (1980-2005)



Difference between simulated and observed precipitation (1980-2005)

Emissions scenarios

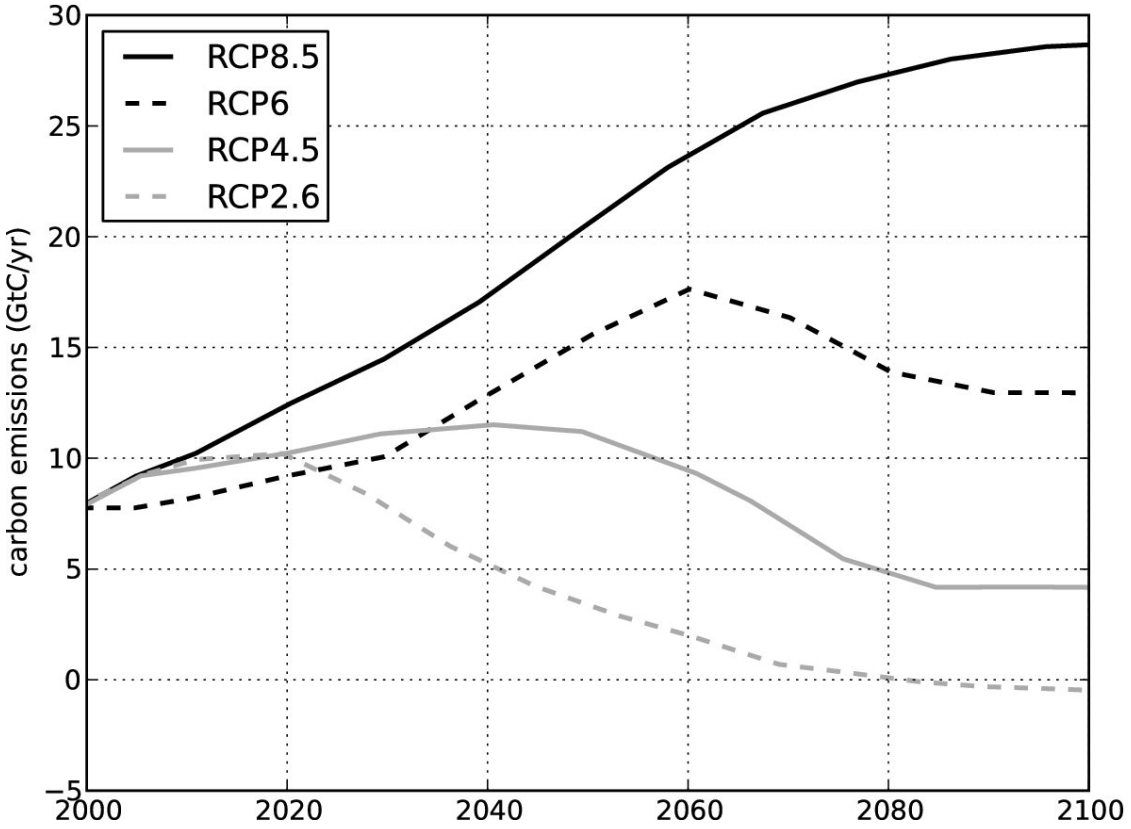
- Projections of CO_2 emissions range from fossil-fuel intensive (business as usual) to drastic reductions
- Emissions will eventually decrease as fossil fuel reserves are consumed
- Sufficient reserves for continued growth well into the 22nd century



Emissions scenarios: RCP's

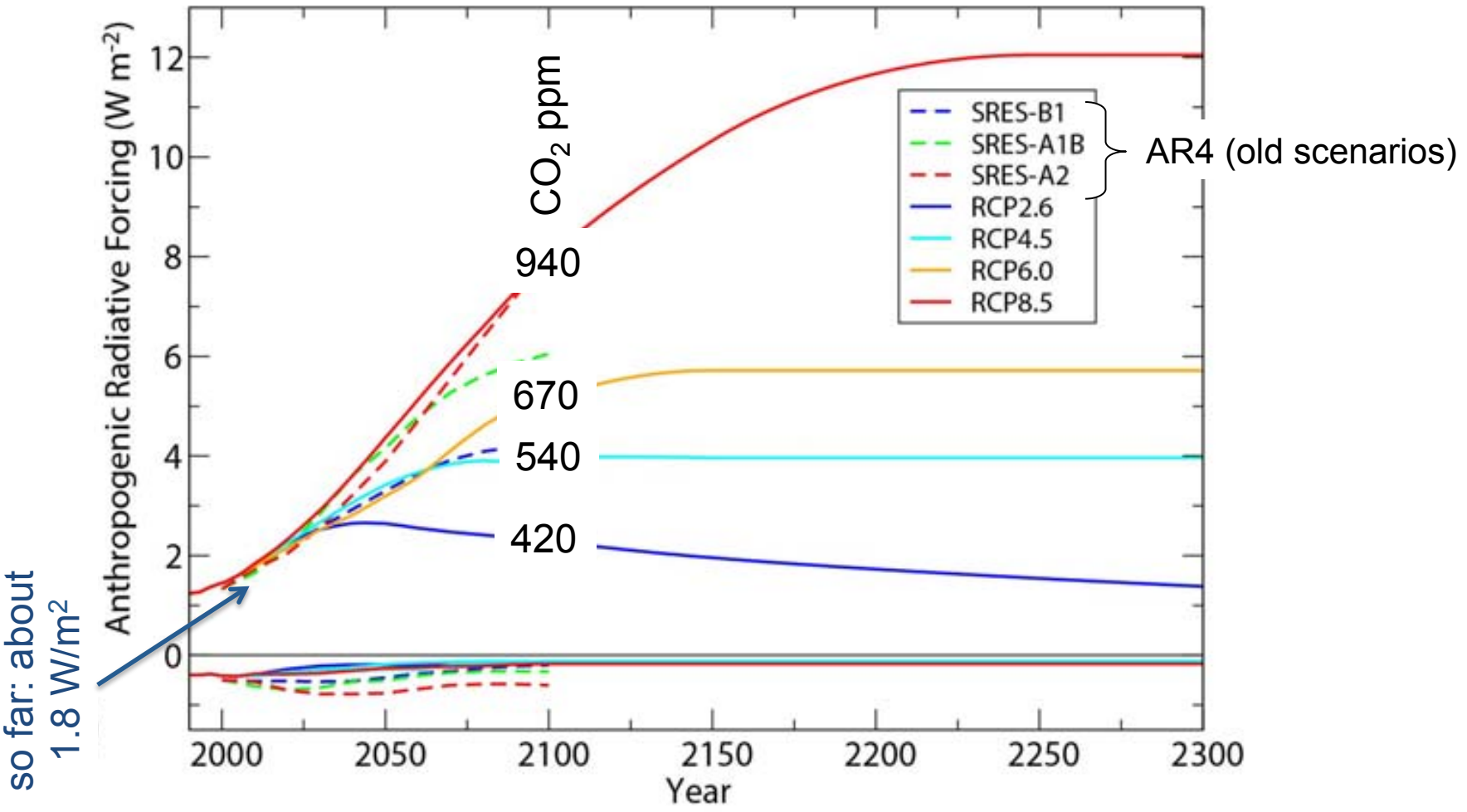
RCP = representative concentration pathways
= plausible emissions trajectories based on different assumptions about society and technology

= approximate total radiative forcing by 2100 (Wm^{-2})

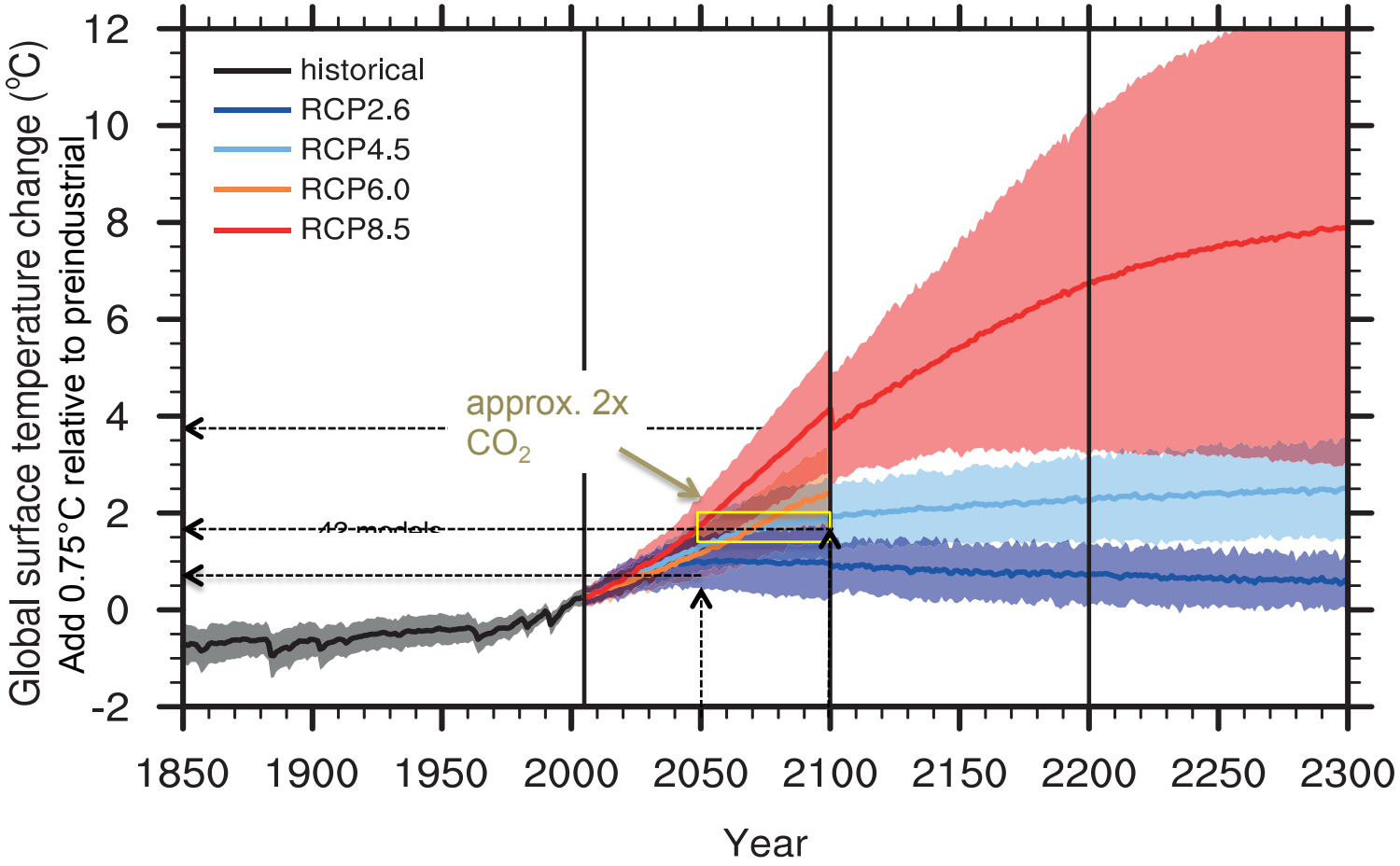


- PCP 8.5 = business as usual; nationalism; slow technological advancement
- RCP 6 = middle of the road; some effort to reduce emissions
- RCP 4.5 = emphasis on global solutions to sustainability
- RCP 2.6 = drastic reductions; peaking 2020 and negative after 2080

CO_2 concentration ➔ radiative forcing

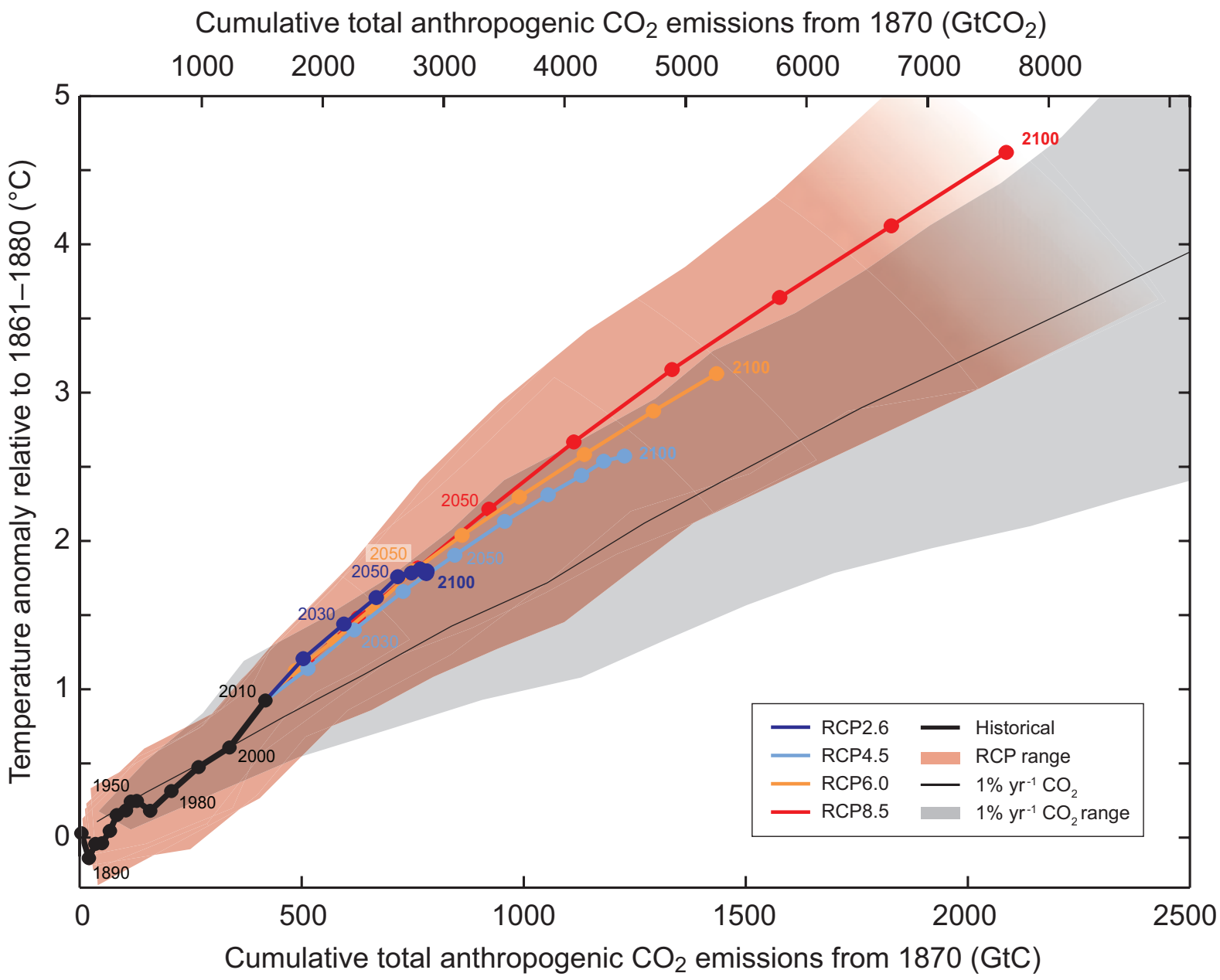


radiative forcing ➔ temperature



- Uncertainty among climate models (light-colored areas) is less than the differences among scenarios (curves)

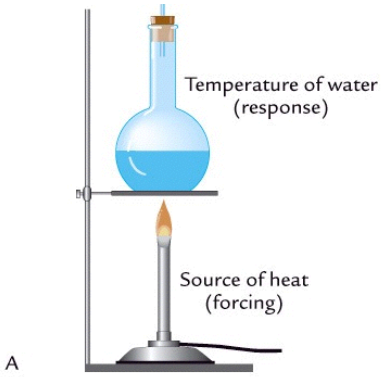
- Global average temperature is likely to rise by 1-2°C by the middle of this century; by 2-4 °C by the end of the century (relative to 1986-2005)

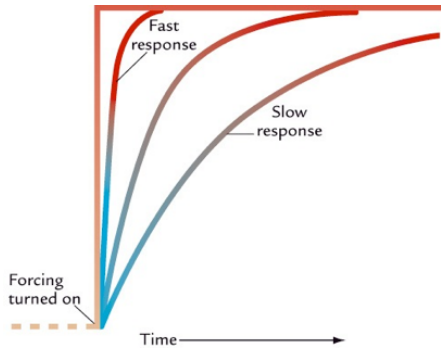

Cumulative total anthropogenic CO_2 emissions from 1870 ($GtCO_2$)
1000
2000
3000
4000
5000
6000
7000
8000
Temperature anomaly relative to 1861–1880 (°C)
0
1
2
3
4
5
2100
2100
2100
2050
2050
2050
2050
2030
2030
2010
2000
1980
1950
1890
RCP2.6
RCP4.5
RCP6.0
RCP8.5
Historical
RCP range
1% yr^{-1} CO_2
1% yr^{-1} CO_2 range
0
500
1000
1500
2000
2500
Cumulative total anthropogenic CO_2 emissions from 1870 (GtC)

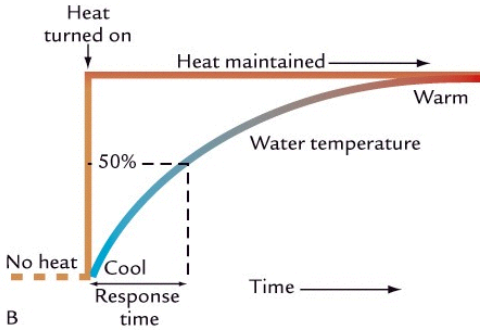
Committed Warming

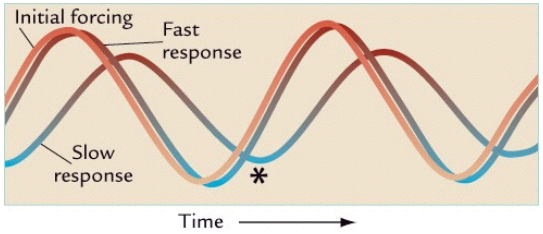
- The climate system does not equilibrate immediately after a climate forcing
- The large heat capacity of oceans causes a delay
- Even if GHG concentration stabilized, warming will continue
- Best estimates are another 0.5°C mean global temperature rise

Forcings and Response

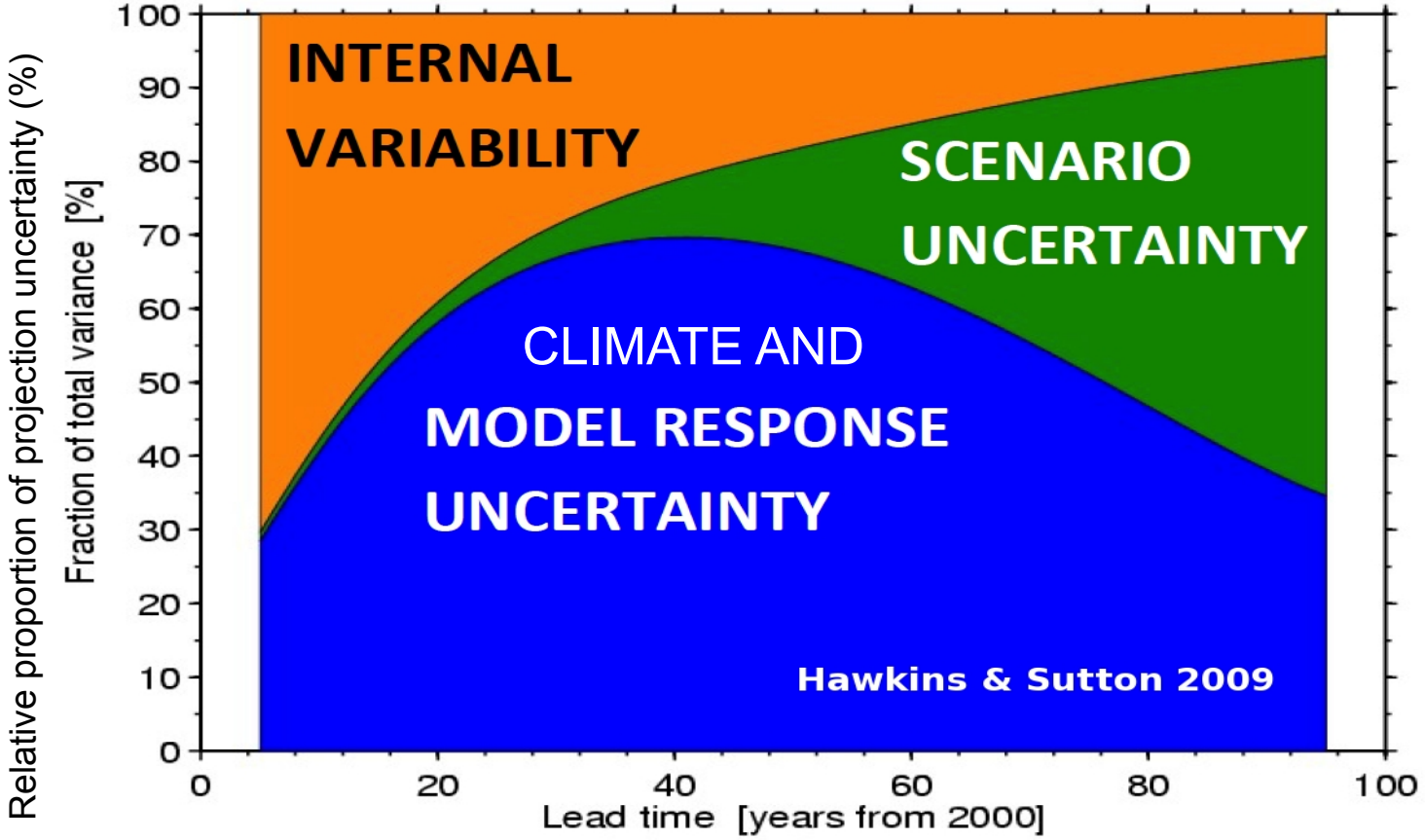








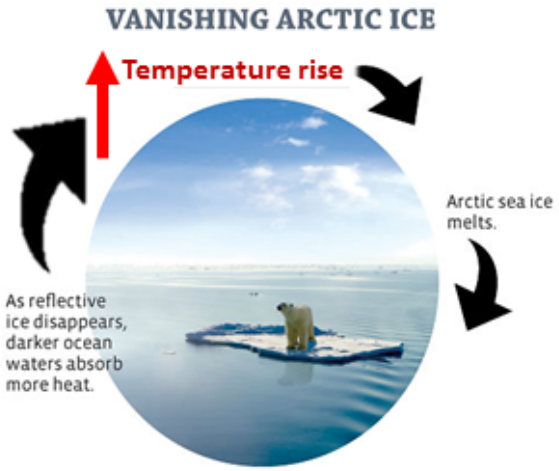
Committed warming: Climate change that will happen in the future because of past emissions, regardless of changes in future emissions

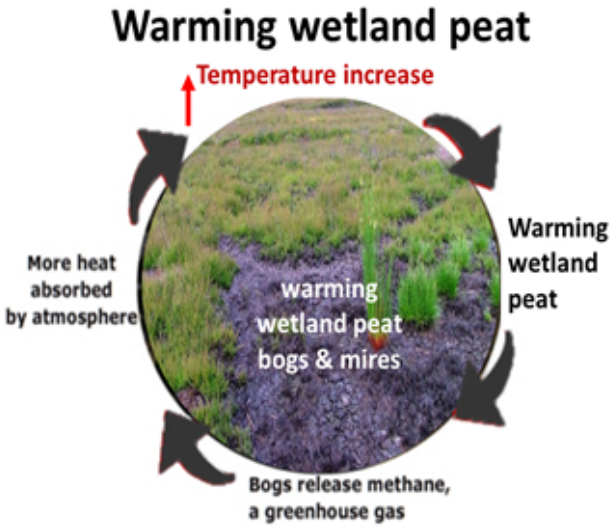


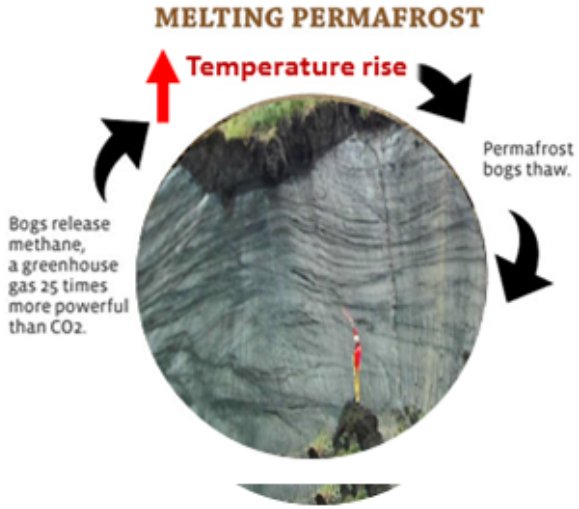
Biggest uncertainties are different into the future:

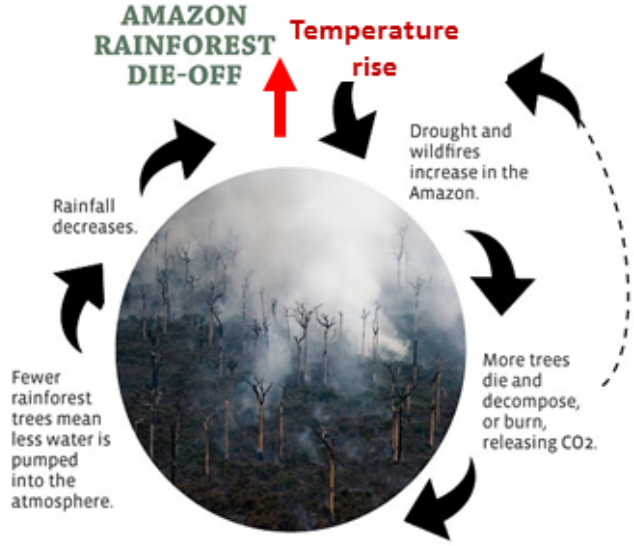
- Less than 20 years: internal climate variability (e.g., El Niño)
- Multiple decades: confidence in climate projections (e.g., clouds and other feedbacks)
- End of century and beyond: what people will do (emissions scenarios)

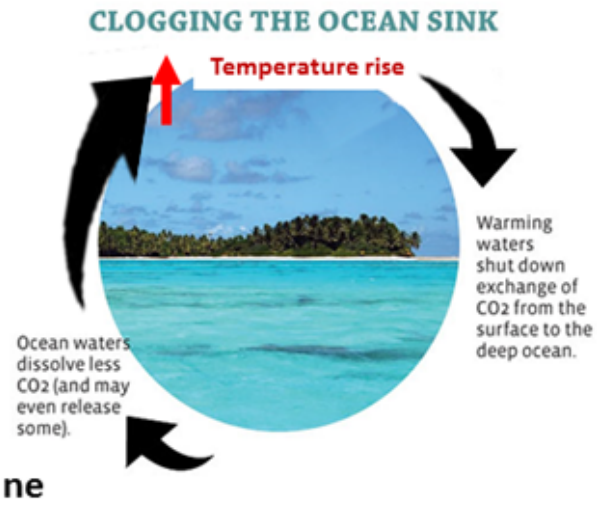
Climate Feedbacks

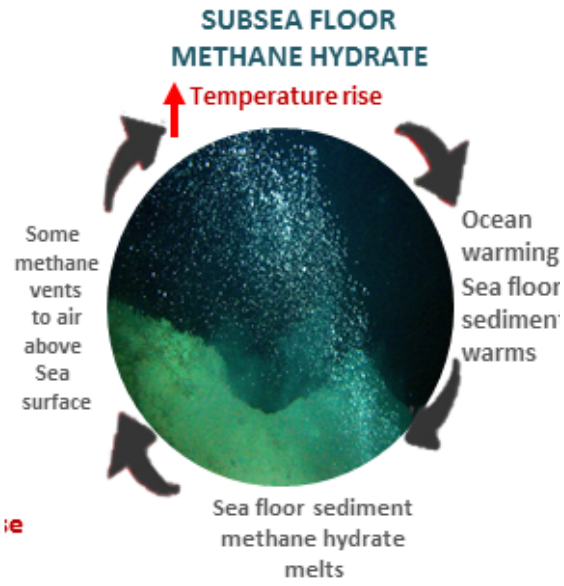












Part 5

Where can we find climate data?

Weather and climate data

1) earth

https://earth.nullschool.net/

2) NASA Climate

https://climate.nasa.gov/

3) Erb Weather

http://erbweather.com/

4) MesoWest

https://mesowest.utah.edu/

Paleoclimate data

5) NOAA Paleoclimate

https://www.ncdc.noaa.gov/data-access/paleoclimatology-data

6) Neotoma Paleoecology Database

https://www.neotomadb.org/

7) LiPDVerse

https://www.lipdverse.org/

Diatom data

Diatoms of North America

https://diatoms.org/

… and counts!

Diatom data

Diatoms of North America

https://diatoms.org/

… and counts!

Ways to use data:

-species diversity

-planktic/benthic (higher lake level = more planktic)

-morphologies

-and more!