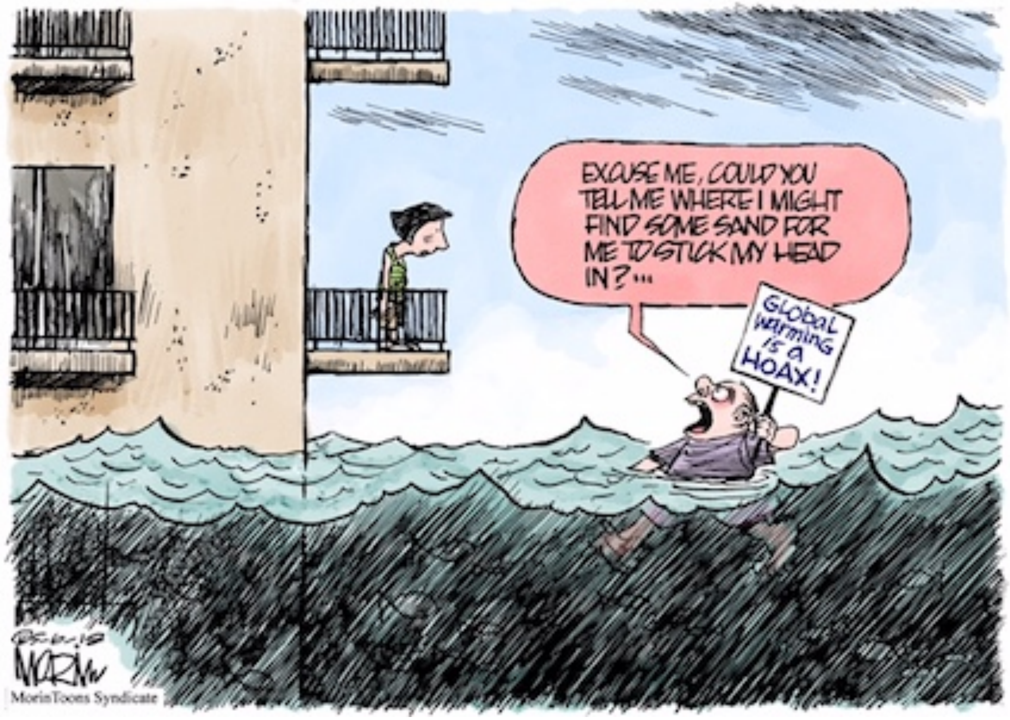


Class 6: (Climate Forcings and Feedbacks)

- What controls climate on Earth over varying timescales (the forcings)?
- What are some important climate feedback systems and how do they work?

Learning Objectives

- **Describe Earth's orbital cycles and explain how they influence climate**
- **Understand and be able to provide specific examples of how feedback systems can amplify or diminish a climate system forcing**
- **Understand how the three "knobs" of global climate (incoming solar radiation, albedo, the greenhouse effect) change over time**
- **Explain why a large, short-term perturbation to the climate system could create long-lasting effects**

Heads up on planning - Exams

THURSDAY September 26

THURSDAY October 24

THURSDAY November 21

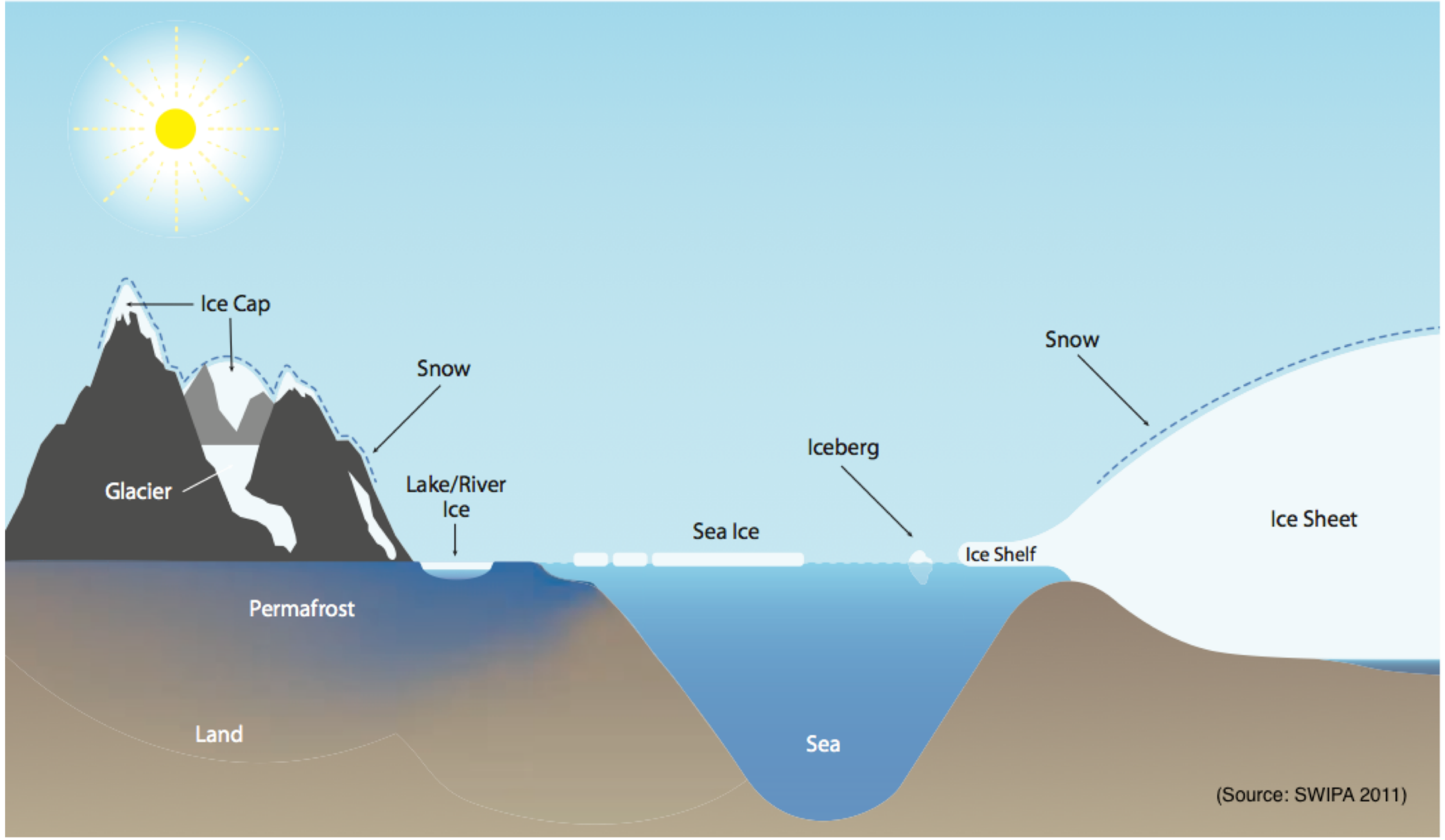
- Are during class time (75 min) – no exceptions – per syllabus (except for ACCESS)
- Can be taken anywhere with good internet connection – on blackboard
- Are on your honor
- Will be based on information provided in class
- We will do our best to have review sessions – may be on-line
- Short answer and essay format
- No final exam; there will be final paper (due date TBD)

Today’s Class

1. **Looking back at last lecture (and finishing it!) including sea level**
2. **Earth’s orbital cycles**
3. **Feedback systems**
4. **Climate in the news**
5. **How the three “knobs” of global climate change over time**
6. **How a large, short-term perturbation to the climate system create long-lasting effects**
7. **Quiz 1, take 2!**

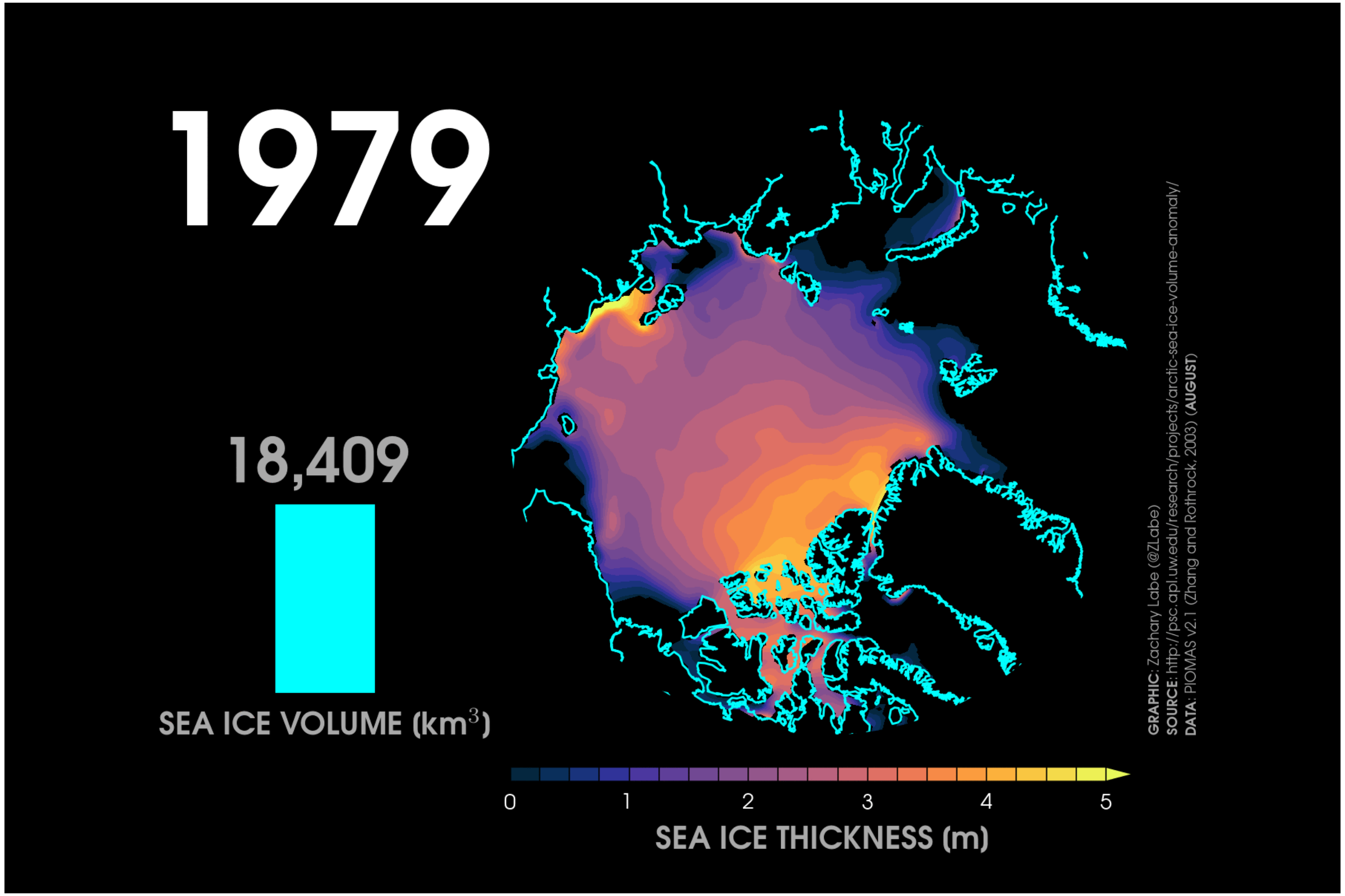
1. Looking back. Cryosphere (frozen places) Components (description and process)

- Sea ice
- Glaciers
  - Ice sheets and ice caps
  - Alpine glaciers
- Ice Shelves
- Icebergs
- Permafrost
- Seasonal snow cover



https://globalcryospherewatch.org/about/cryosphere.html

Sea Ice – it's diminishing in coverage, volume, and age and that's important for climate (and shipping!)

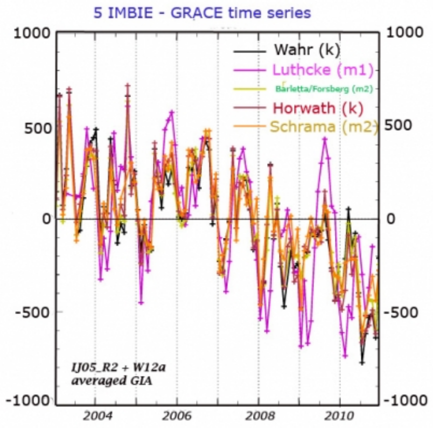


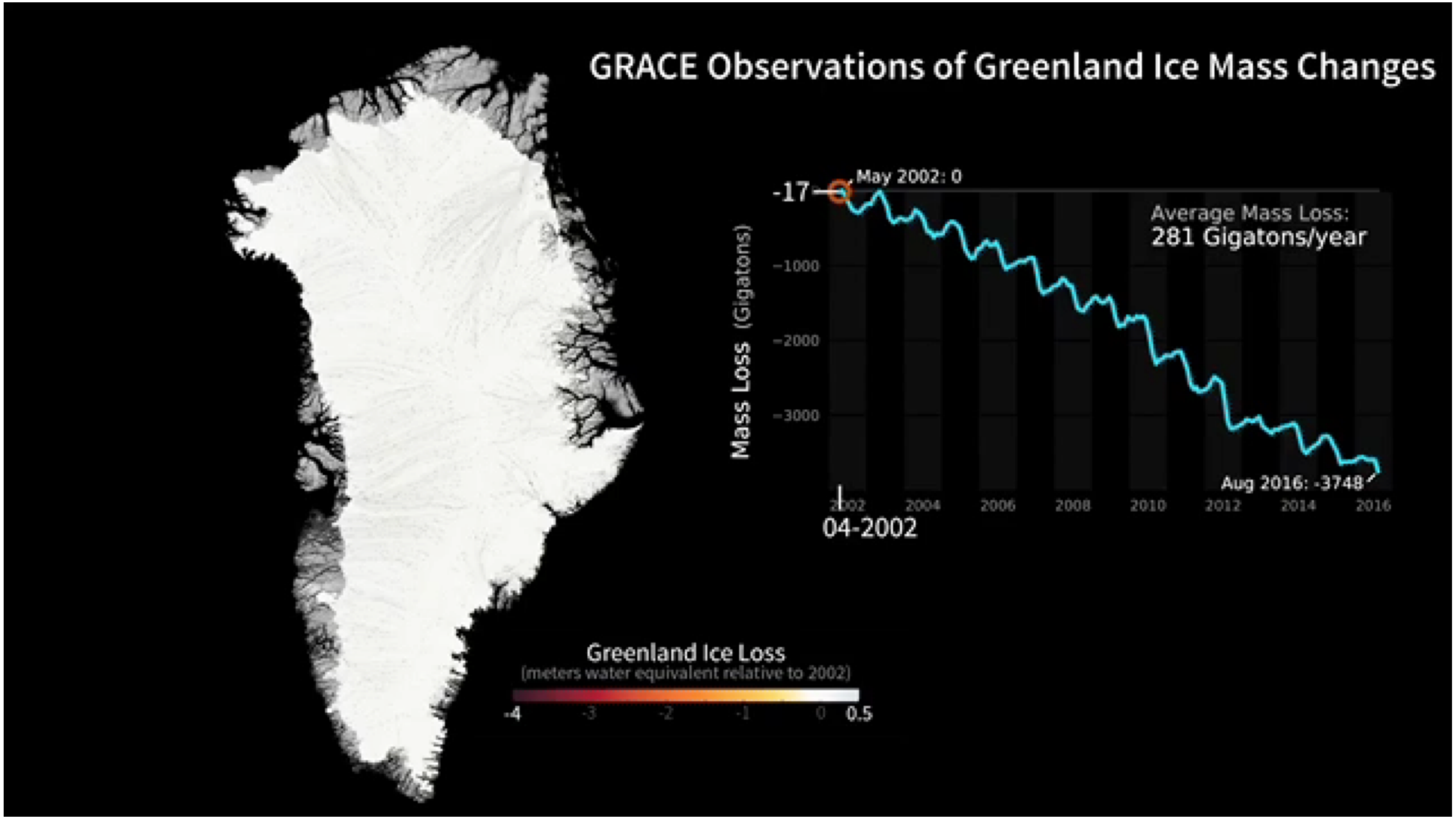
https://sites.uci.edu/zlabe/

Both large **Ice Sheets** are melting and losing mass

NASA's Gravity Recovery and Climate Experiment

Antarctic = similar



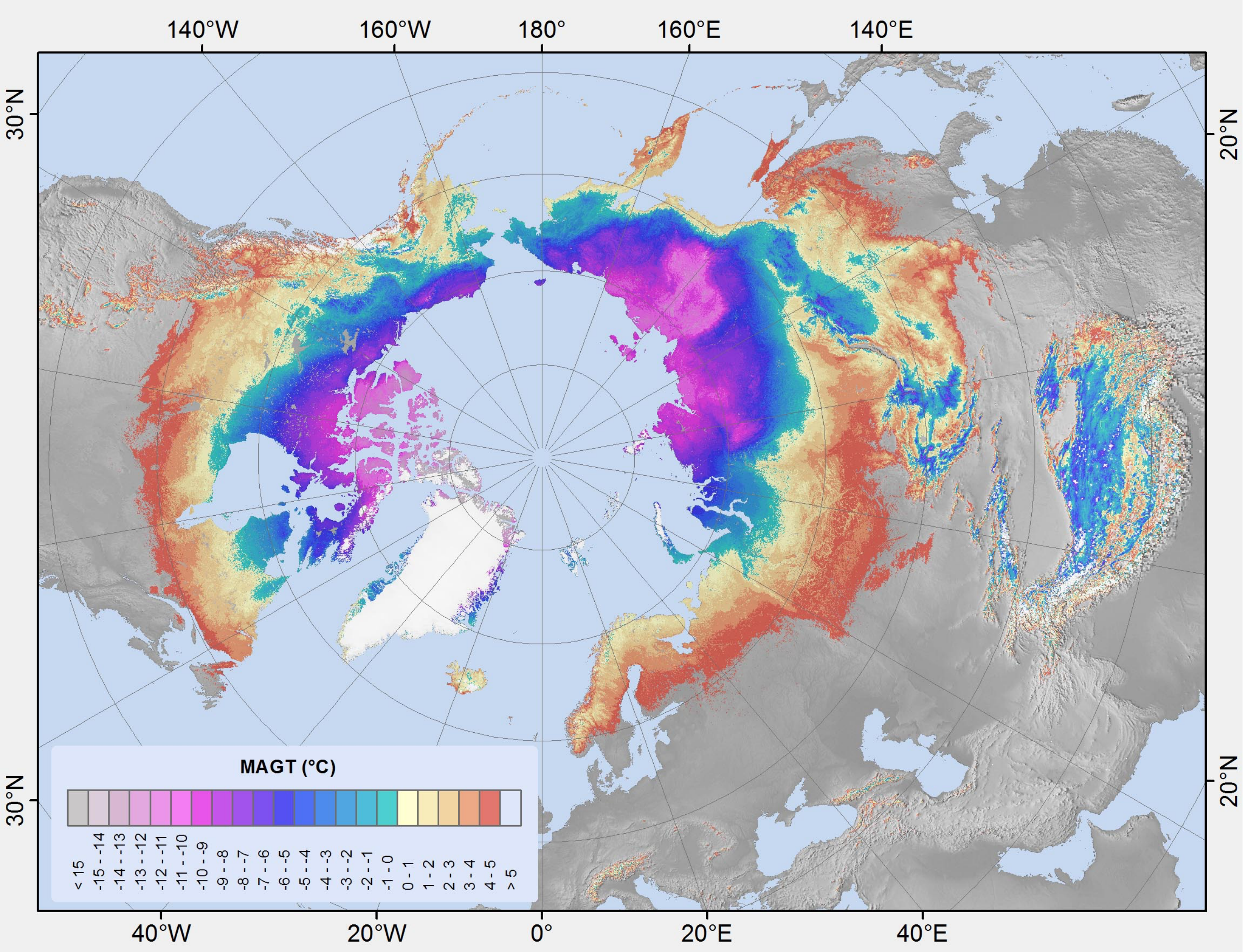


Ice Shelves – are floating ice but matter to ice sheets

- Some glaciers extend to the ocean and **transition to ice shelves**
- Ice shelves **buttress glaciers and slow flow**
- **When ice shelves calve**, glacier flow rates increase, glaciers lose mass, and their surface lowers

https://www.nationalgeographic.com/environment/2018/11/exclusive-first-pictures-of-iceberg-three-times-the-size-of-manhattan/

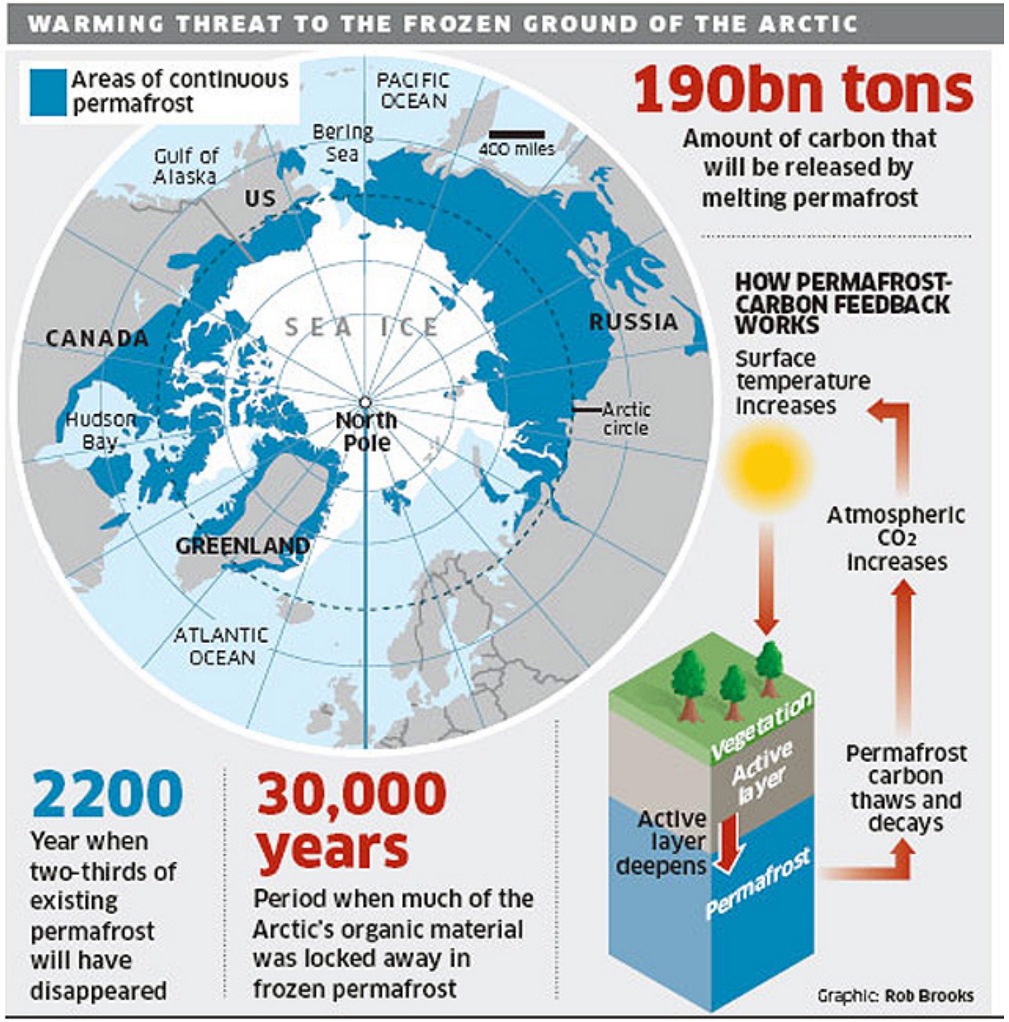
Permafrost – ground ice, mean annual ground T < 0C



Permafrost – tricky stuff – requires good engineering to prevent melting EVEN when climate is stable

Climate change and a warming arctic will cause melting and damage

Permafrost – is loaded with carbon (methane) and it's melting

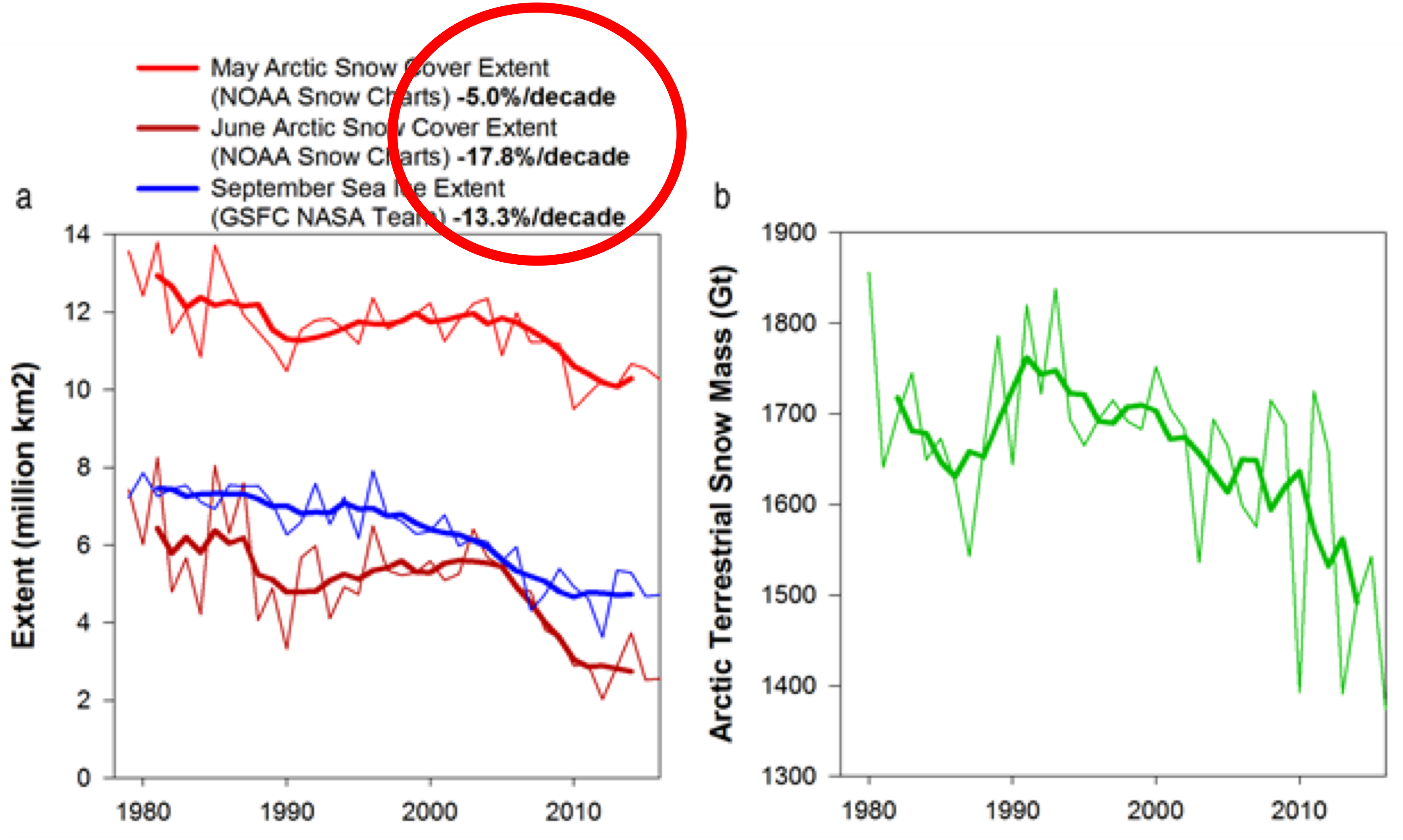


PS – that's not good for the climate system

http://www.scientistswarning.org/wiki/methane-emergency/

Seasonal Snowcover – matters for albedo!

Arctic **snow cover** (and mass) is decreasing over the last 40 years – just like sea ice



https://arctic.noaa.gov/Report-Card/Report-Card-2016/ArtMID/5022/ArticleID/276/Terrestrial-Snow-Cover

Sea level – what matters and what does not!

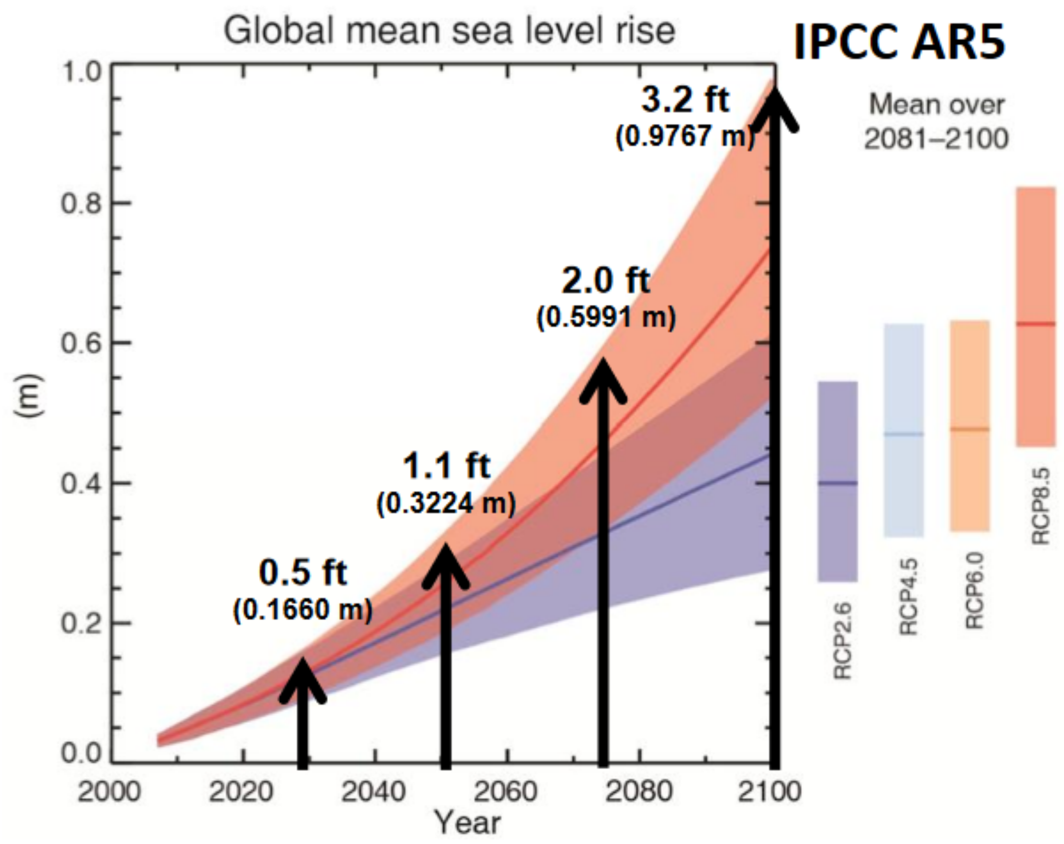
Sea level reflects the volume of ocean water and its temperature (since water expands when warm) with an adjustment for how the Earth deforms when loaded by water and ice.

if the ice is floating, it doesn't matter…

If the ice in on land, it matters!

Sea level – why the effect of climate change is tough to predict

- Sea-level rise is controlled by ocean temperature (water density) and by run-off as ice on land melts.
- Estimating ice sheet and glacier melt is difficult and complicated by estimation of temperature rise and seasonal precipitation change.
- There are many poorly constrained feedbacks!



THINK, PAIR, SHARE

Work with a partner and come up with THREE reasons why the Cryosphere and climate change are intimately linked and could affect sea level – consider feedbacks!

Sea level and climate effects of Cryospheric change

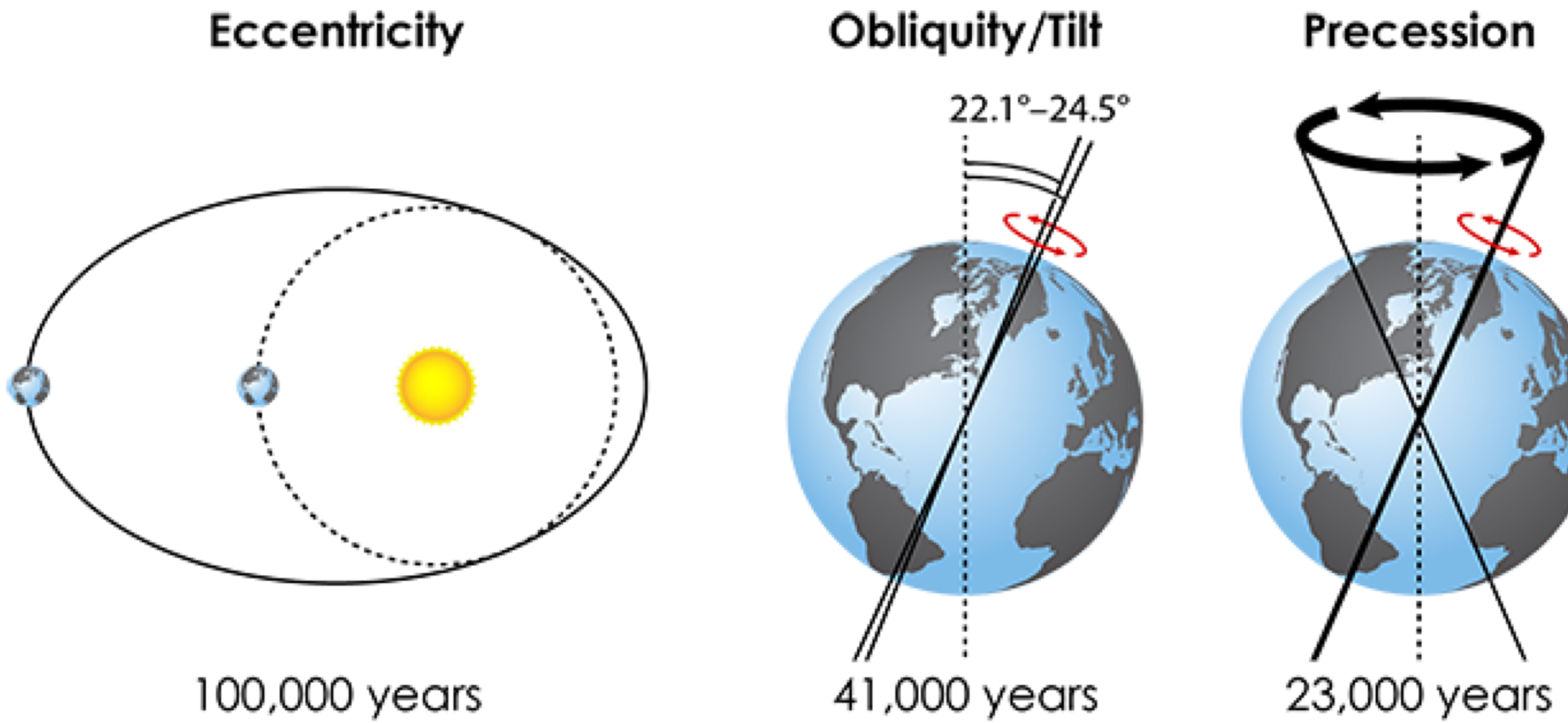
Water locked up in terrestrial ice ends up in the ocean changing volume and sea level

Loss of glacial ice equals reduced albedo, more solar energy absorbed; planet warms. Water expands.

Change of ice sheet size alters weather patterns and nutrient/sediment loads to ocean.

Loss of permafrost liberates fossil carbon and can destabilize landscapes

2. Orbital cycles and the seasonal distribution of radiation



Professor Milutin Milankovic – **Serbian mathematician and engineer**

The **Milankovitch cycles** are periodic or quasiperiodic changes in the parameters of the Earth's orbit and tilt

Collaborated with German meteorologist Vladimir **Köppen** (global climate classification) and German geophysicist Alfred **Wegener** (plate tectonics)

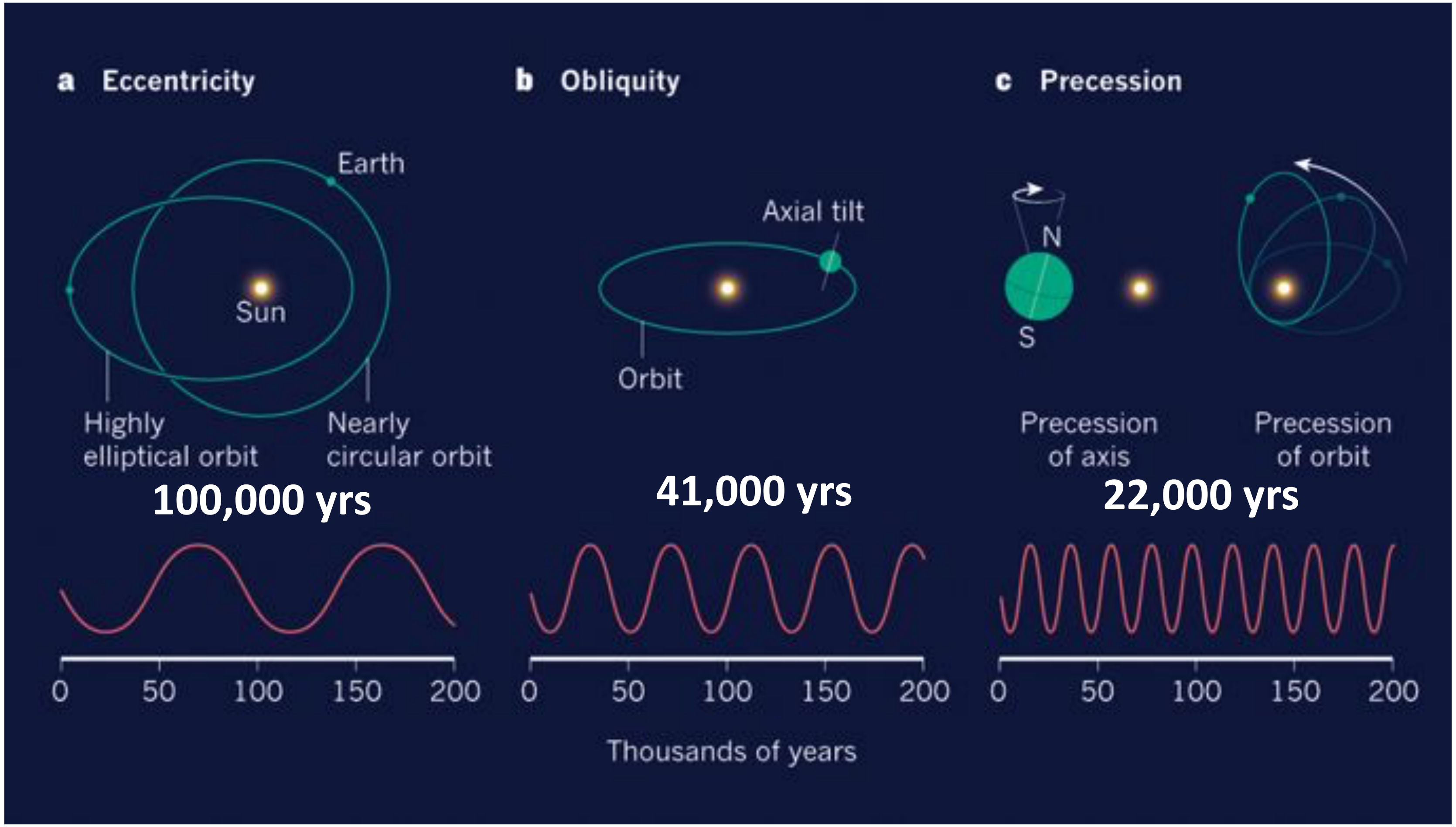
Ideas were **Accepted, rejected, accepted!**

"These changes do not effect the overall annual amount of solar radiation hitting the Earth, but they affect the strength of the seasons in different ways at different latitudes."

What matters is summer radiation in high latitudes…the birthplace of glaciers (65 N, Why?)

Over time

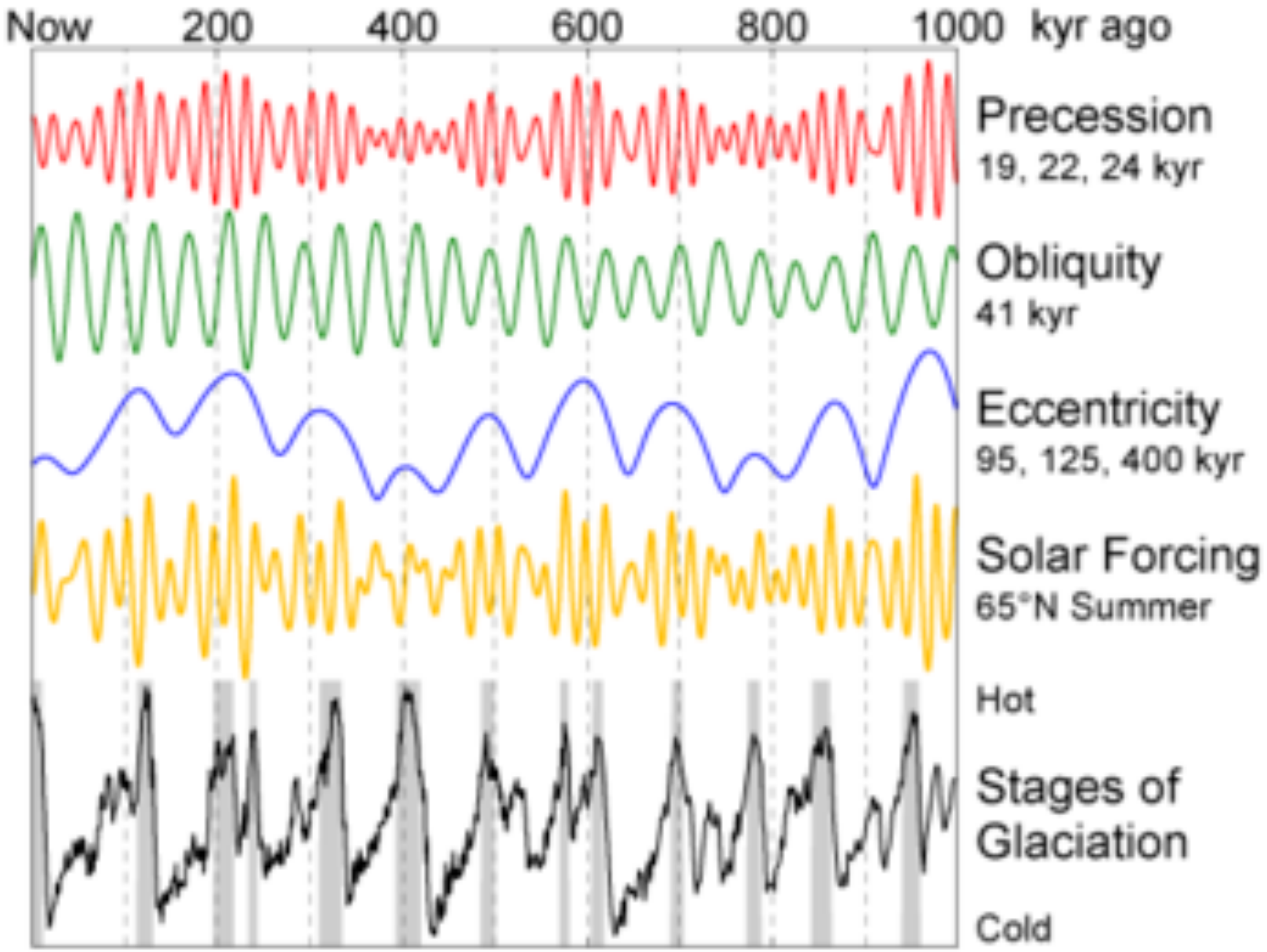
- The Total radiation supplied to Earth DOES NOT CHANGE
- The seasonal and latitudinal distribution of radiation CHANGES



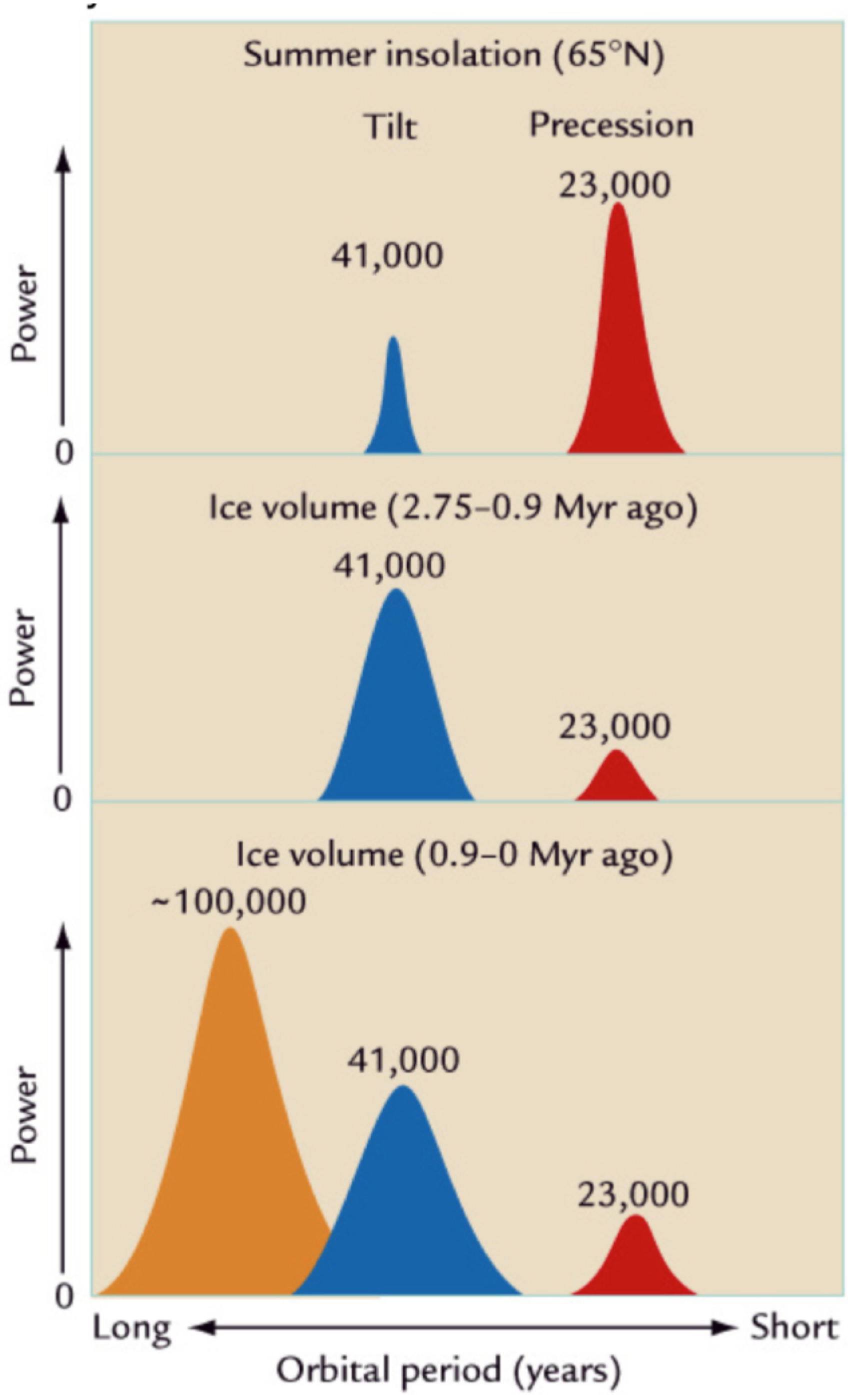
Do orbital cycles explain climate change directly?

- No – their pacing matches the pace of geologic climate change but the amplitude is wrong

FEEDBACKS are key



Climate signals have the same periods as the orbital forcings but NOT magnitude.



Richard Alley (you'll hear more about him), Penn State and Obliquity (the 41,000 year cycle)

This is 2010.

Rohrabacher doubts that global warming is caused by humans. During a congressional hearing on climate change on February 8, 2007, Rohrabacher mused that previous warming cycles may have been caused by carbon dioxide released into the atmosphere by "dinosaur flatulence".

Ok, Wikipedia…lost in 2018…

Comprehension Check

Orbital mechanics, as analyzed by Milankovic, describe how:

A. the total energy received over a year by Earth from the sun changes over time.

B. the seasonal distribution of energy arriving at Earth from the sun over a year changes over time at high latitudes.

C. the Earth changes from glacial to non-glacial climates.

D. climate zones around the Earth are distribute by latitude

E. the seasonal distribution of energy arriving at Earth from the sun over a year changes over time at low latitudes.

3. Feedback systems

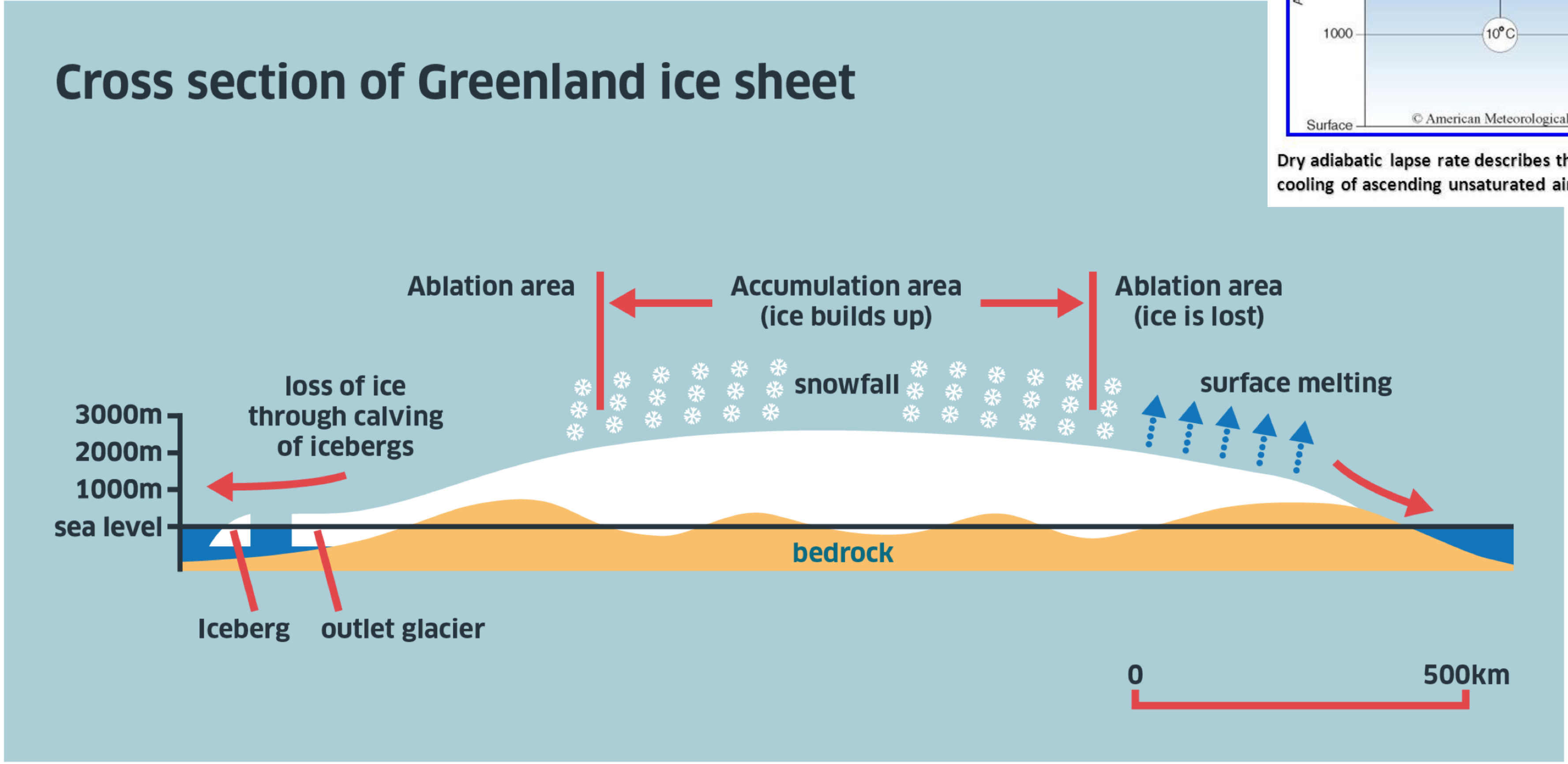
Example 1. (+) Ice sheet melt then surface lowering (lapse rate)

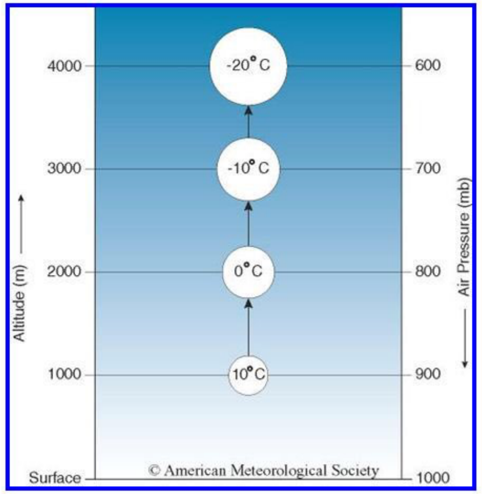
Example 2. (-) Mountain glacier retreat

Example 3. (+) Loss of glacier grounding, floating ice

Feedback Example 1. (+)
Ice sheet melt then lowering (lapse rate)

Adiabatic Processes





Dry adiabatic lapse rate describes the expansional cooling of ascending unsaturated air parcels

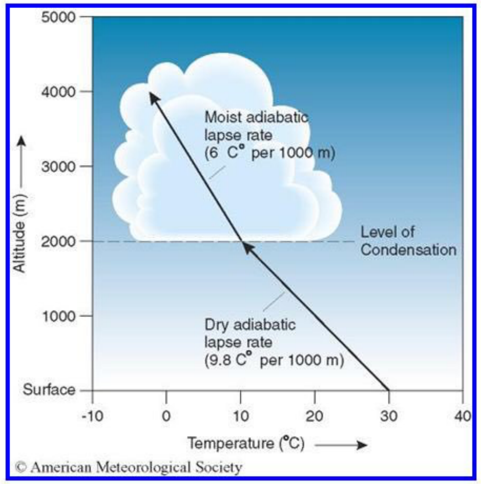
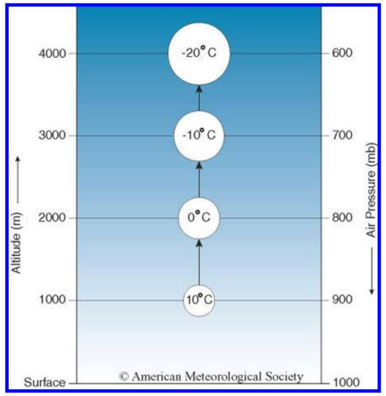


Illustration of dry and moist adiabatic lapse rates

6

Feedback Example 2. (-) Mountain glacier retreat

Adiabatic Processes



Dry adiabatic lapse rate describes the expansional cooling of ascending unsaturated air parcels

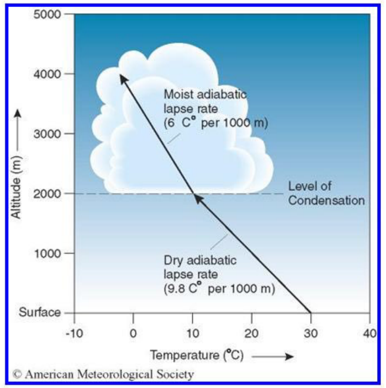
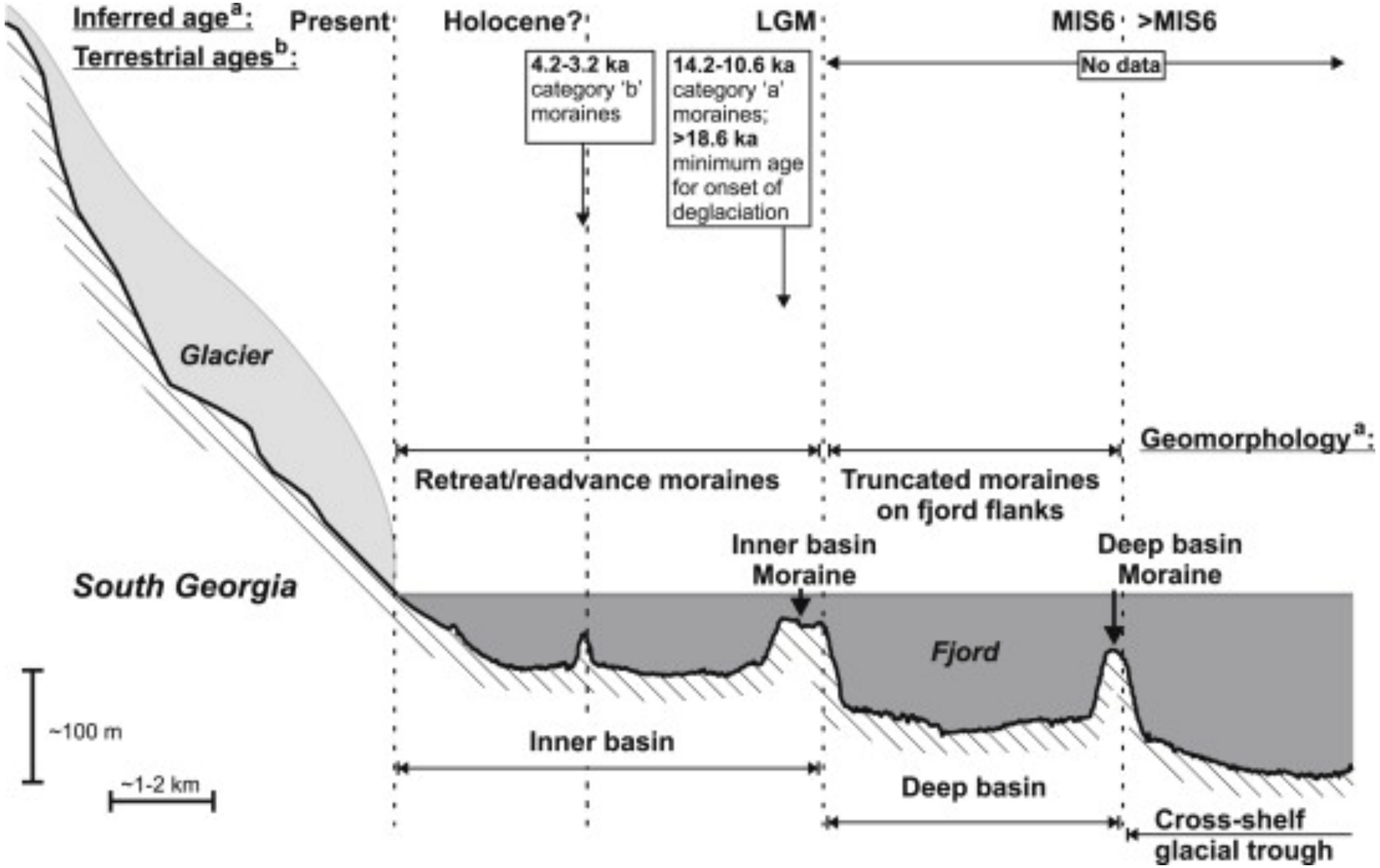
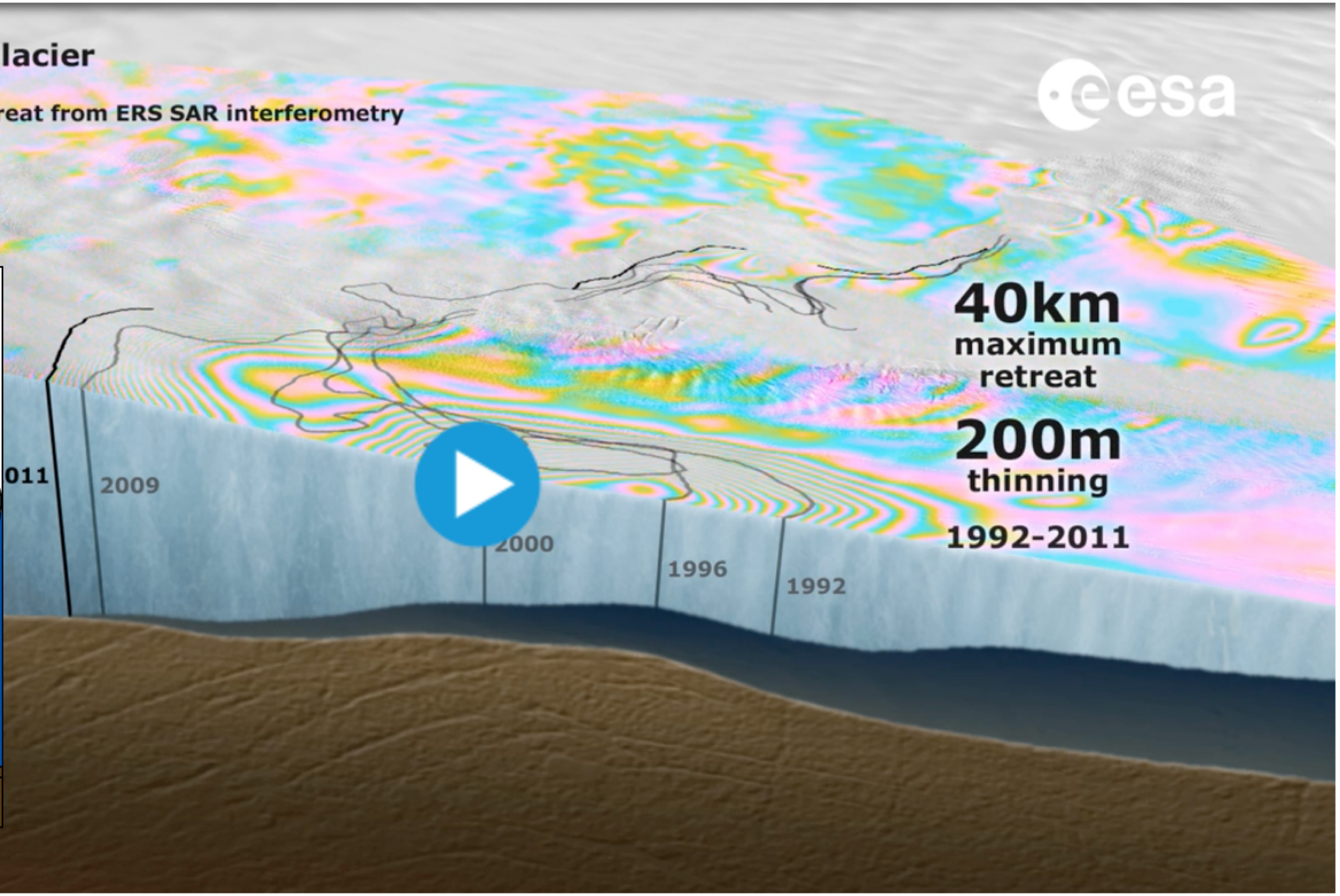


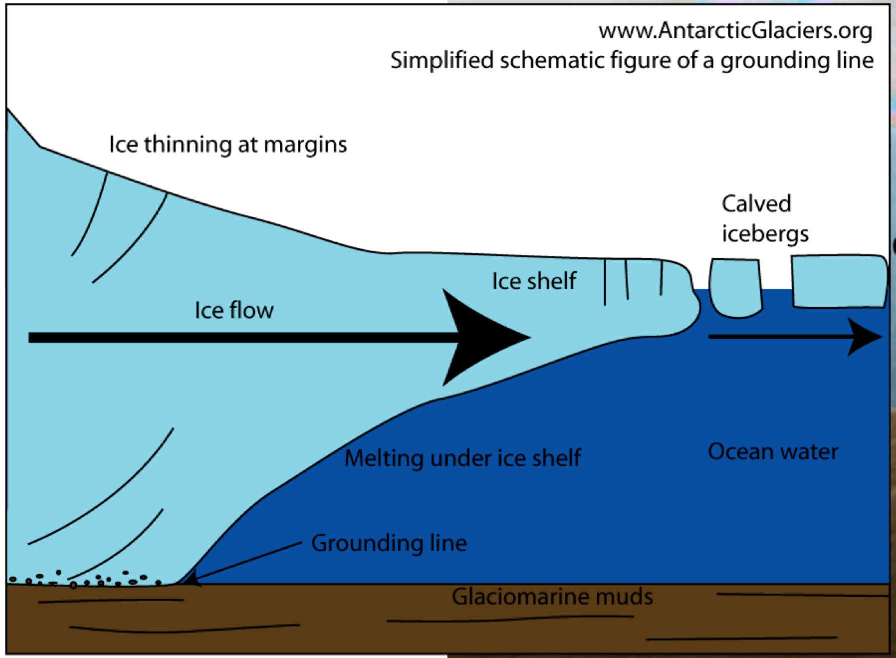
Illustration of dry and moist adiabatic lapse rates



https://www.researchgate.net/figure/Cross-section-schematic-of-a-typical-South-Georgia-glaciated-fjord-showing-main_fig3_260806212

Feedback Example 3. (+) Loss of glacier grounding, floating ice followed ice shelf thinning





4. Climate in the news

Newsweek

The Amazon Rainforest Fires Are Pumping the CO2 Trees Normally Absorb Out Into the Atmosphere

The European Space Agency (ESA) has said that forest fires in the Amazon could be having an impact on global climate change as they ...

20 hours ago

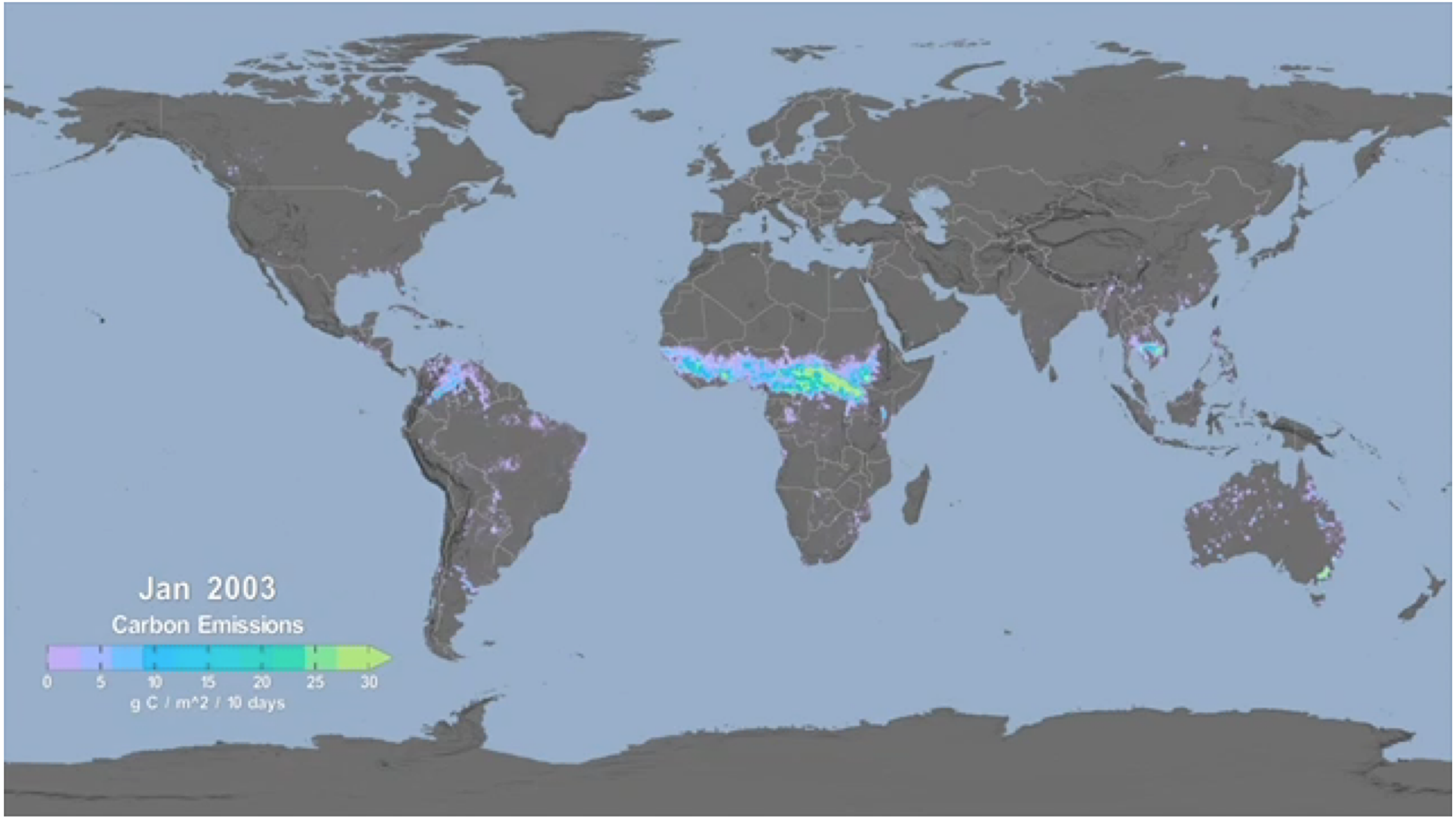
Los Angeles Times

The Amazon rainforest is on fire. Climate scientists fear a tipping point is near

Land-grabbers in Brazil are slashing and burning the Amazon rainforest. If too many trees are removed, Earth's climate could lose a critical ...

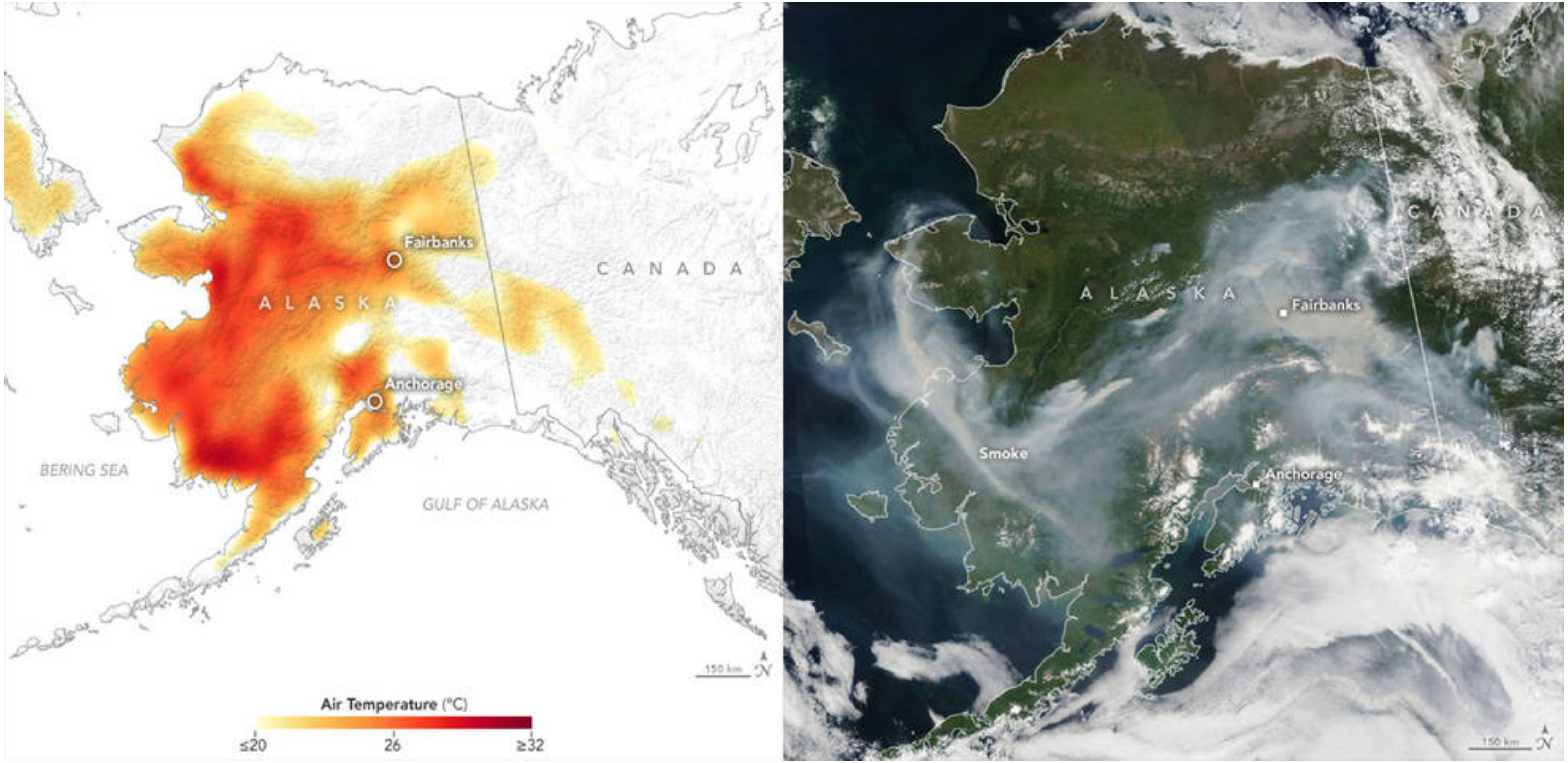
2 weeks ago

Where are most fire emissions of carbon? Are they seasonal? Do they reoccur yearly?



https://www.nasa.gov/feature/goddard/2019/satellite-data-record-shows-climate-changes-impact-on-fires

Alaska 2019 – Heat wave and fire appear related

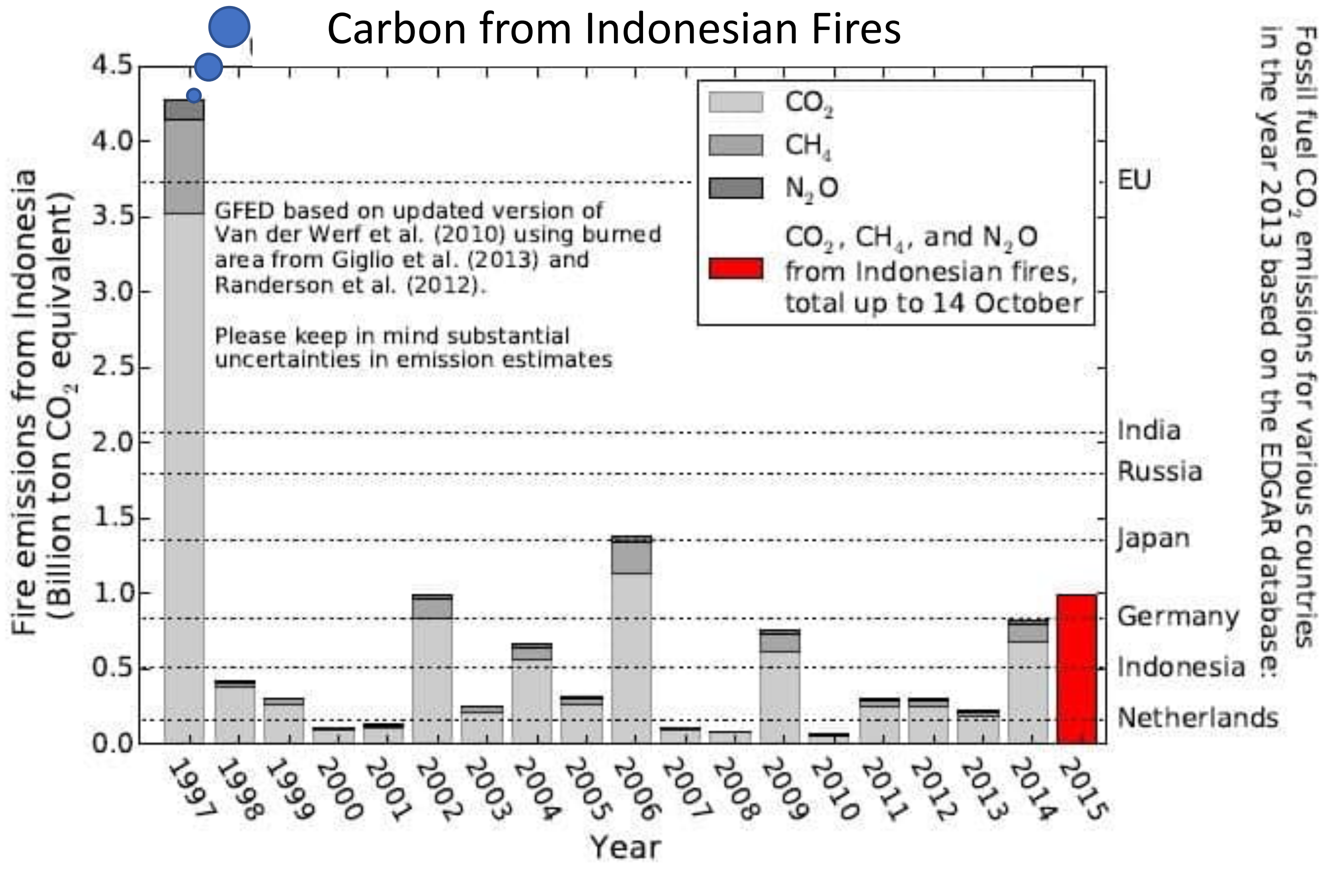


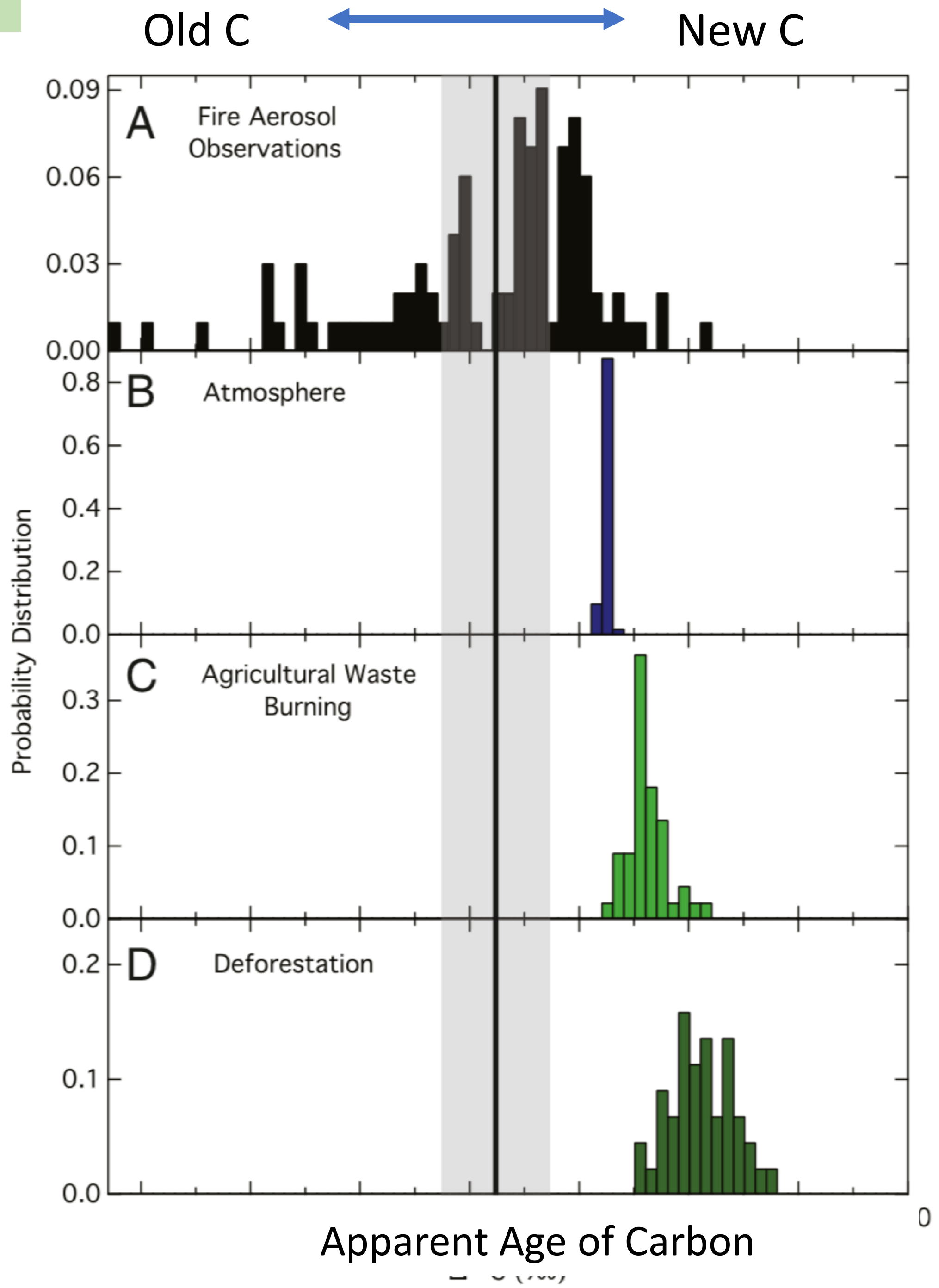
Fire/climate feedbacks are numerous and varied

- **Fires damage forests,** temporarily lowering carbon uptake
- **Fires release stored carbon**, radiocarbon age of carbon emissions from Indonesian peat fires is about 800 years!
- **Fires release black carbon (soot)** which absorbs solar radiation and darkens snow
- **Aerosols from fires reduce rainfall** by making it harder for water droplets to form in the tropics, and thus

Carbon from Indonesian fires matter at a global level

"equivalent to 13–40% of the mean annual global carbon emissions from fossil fuels."





Comprehension Check

Which of the statements below is true.

A. We can estimate with certainty future carbon emissions.

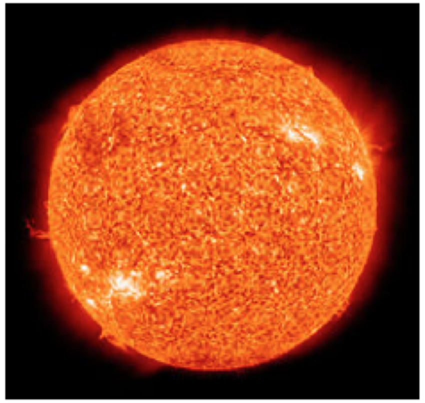
B. We can use estimates of ice sheet melt to estimate sea level rise.

C. We understand all the feedbacks (and their magnitude) that control the melting of ice sheets.

D. We know exactly how climate change will affect the global distribution of precipitation

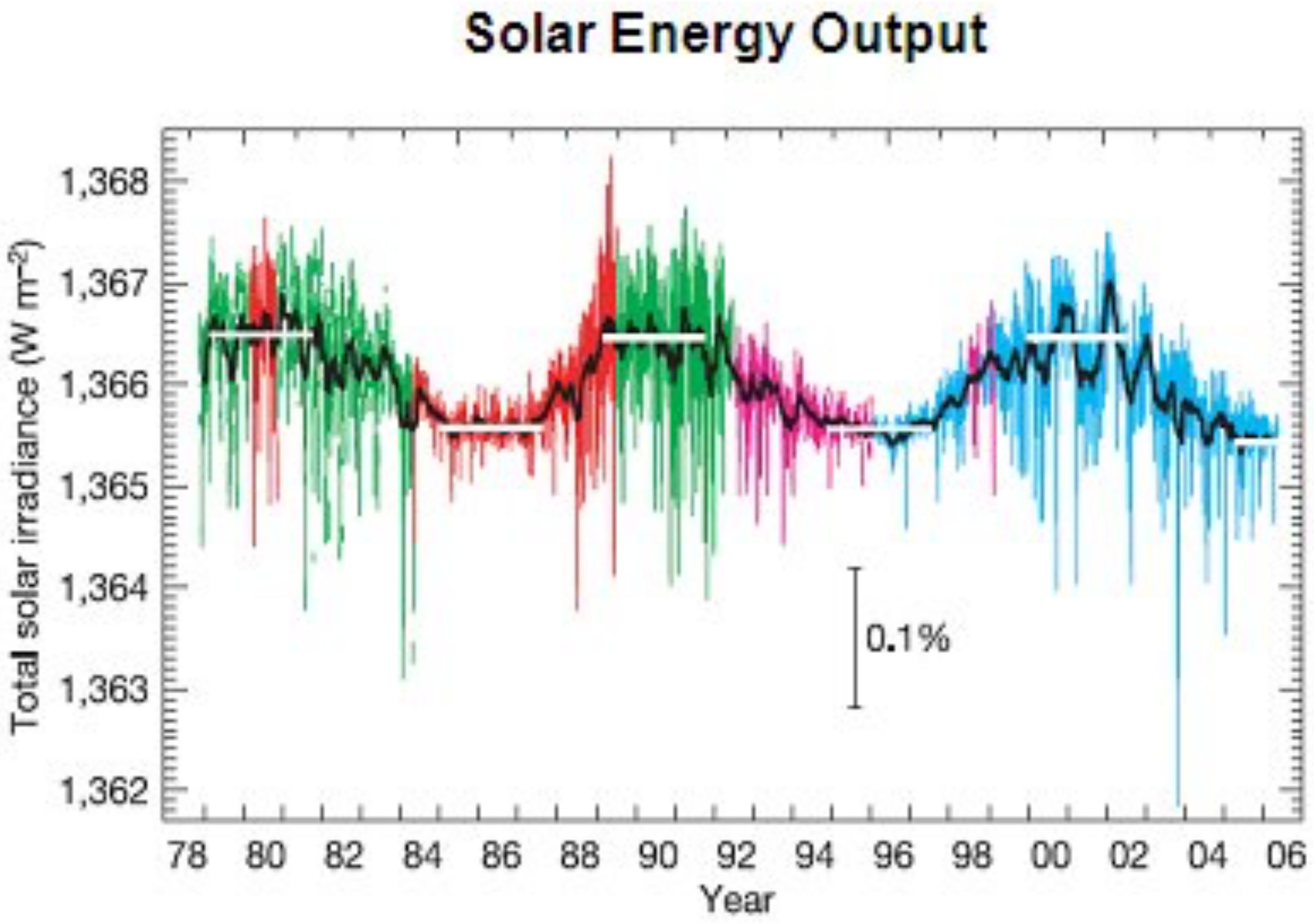
E. We know exactly how climate change will affect the global distribution of temperature.

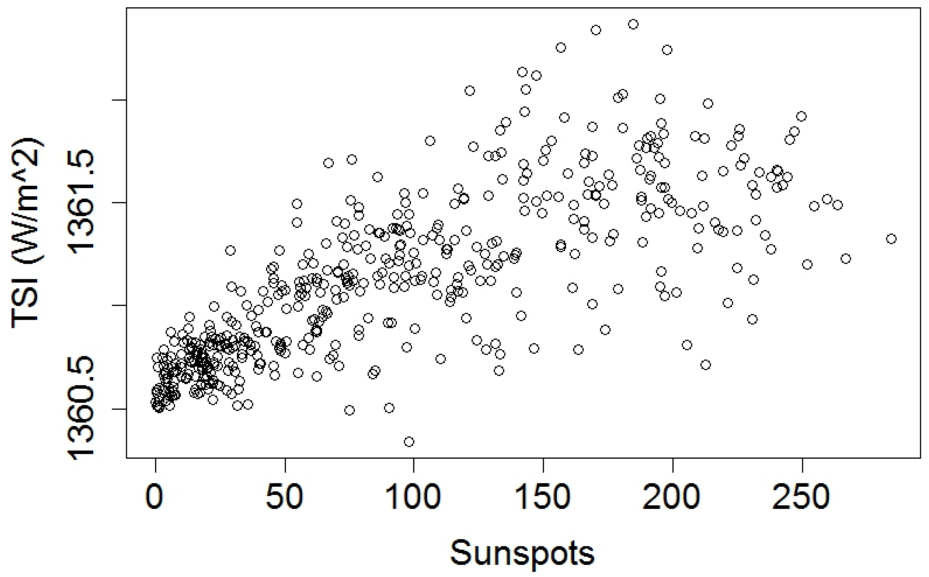
5. How the climate knobs get tweaked (examples)

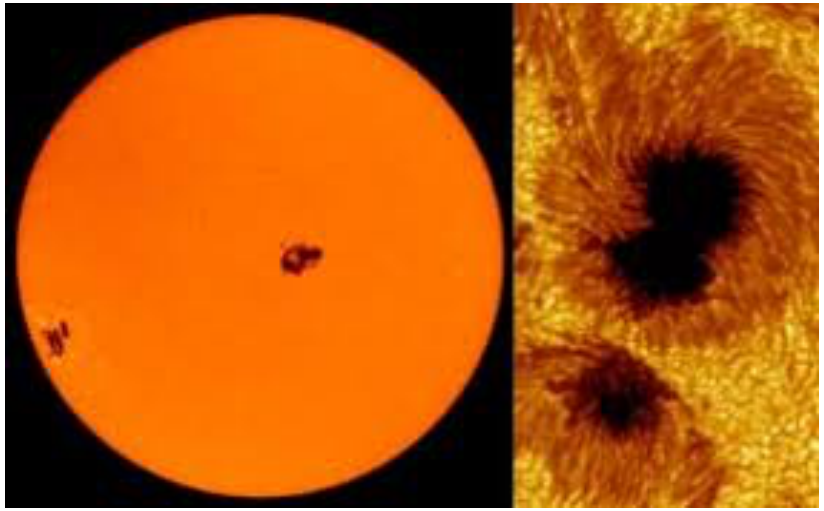


- **Incoming solar radiation** – stable sun but reduced by large volcanic eruptions
- **Albedo –** change largely driven by cryosphere
- **Greenhouse effect –** we've talked about this…

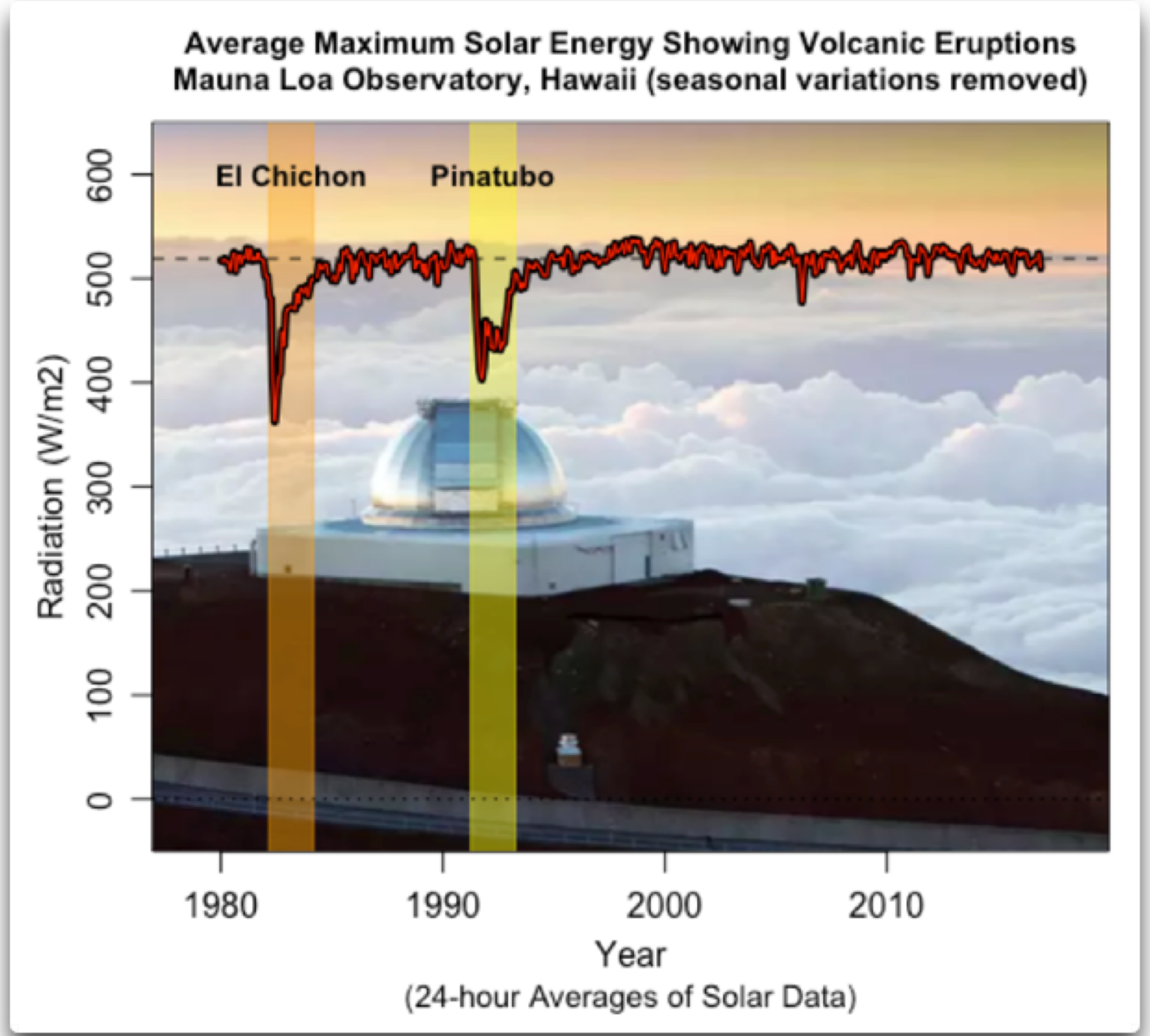
Solar output is VERY stable (< 1%)



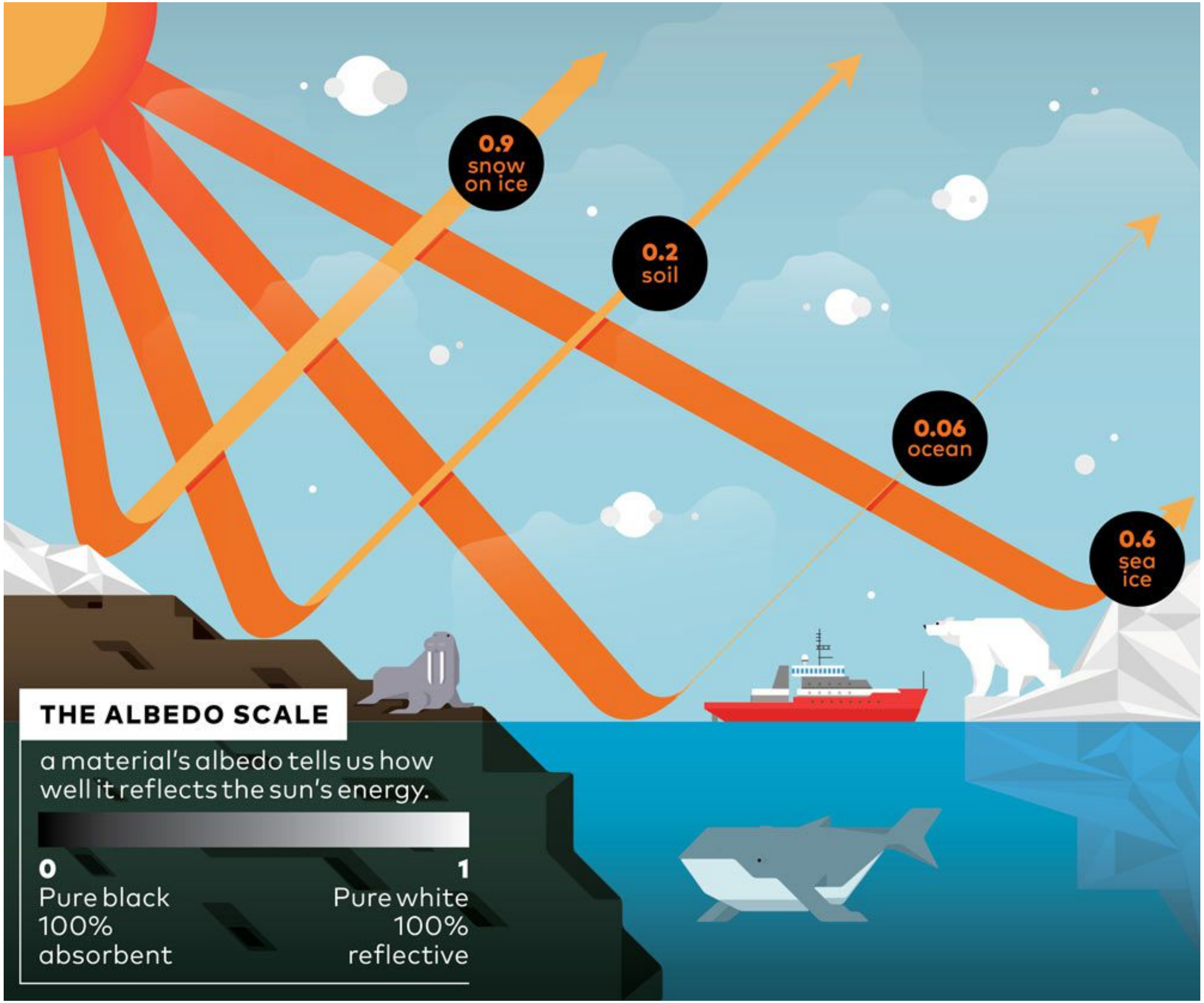




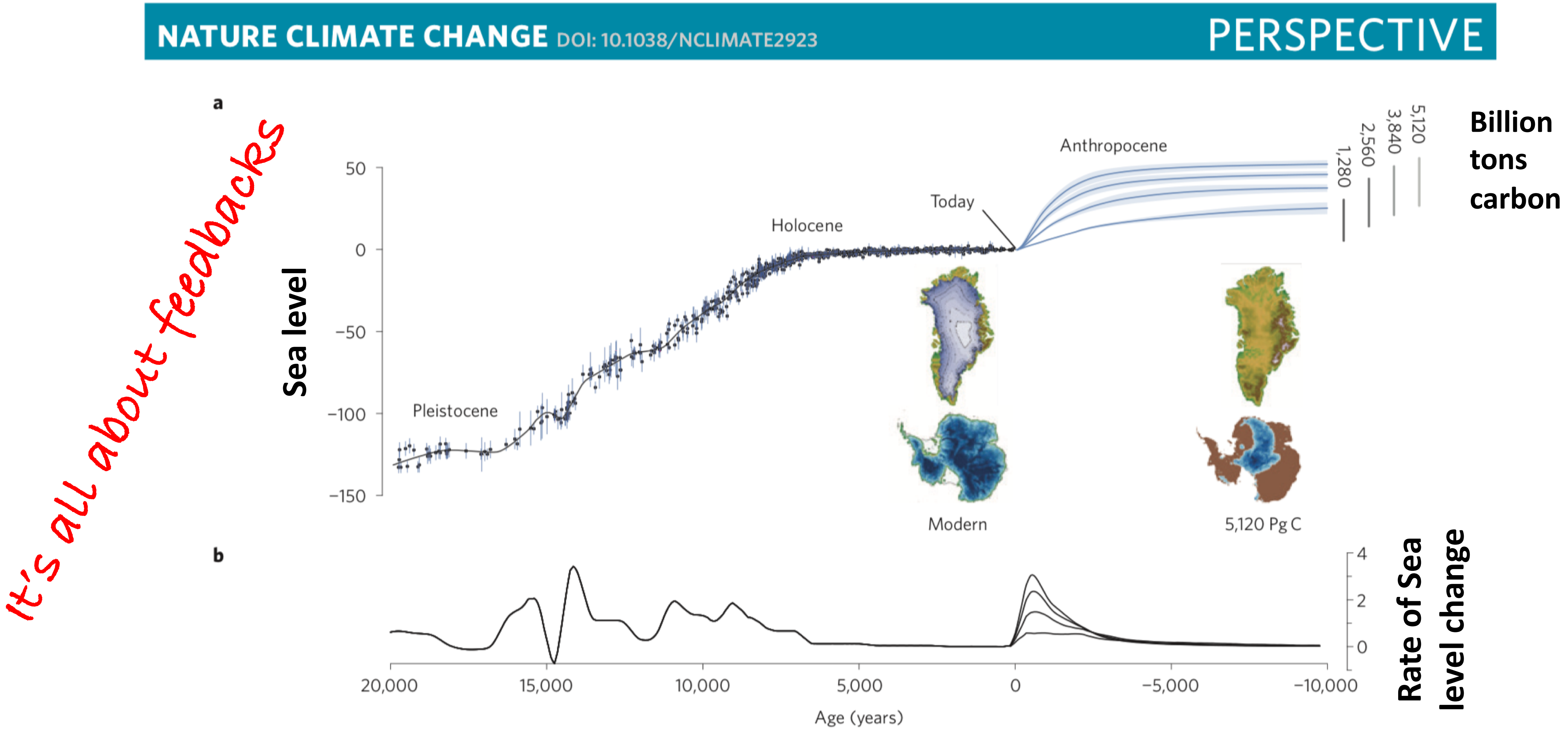
But… **Incoming solar radiation is** reduced by large volcanic ash eruptions – short lived effect.



Albedo – change largely driven by cryosphere



6. How a small change now can make a big difference for a long time



Next time - The Carbon Cycle

READ: Carbon Cycle Primer Website and Ruddiman Ch. 19

- Identify carbon sinks, sources, and reservoirs and predict how they will change if people keep doing what they have been doing since the dawn of the industrial revolution
- Explain the difference in processes between the ‘surficial’ carbon cycle and the ‘deep’ carbon cycle.
- Explain why atmospheric carbon dioxide concentrations fluctuate in a consistent manner throughout the year
- Diagram the interactions over time between various stocks and flows of the carbon cycle