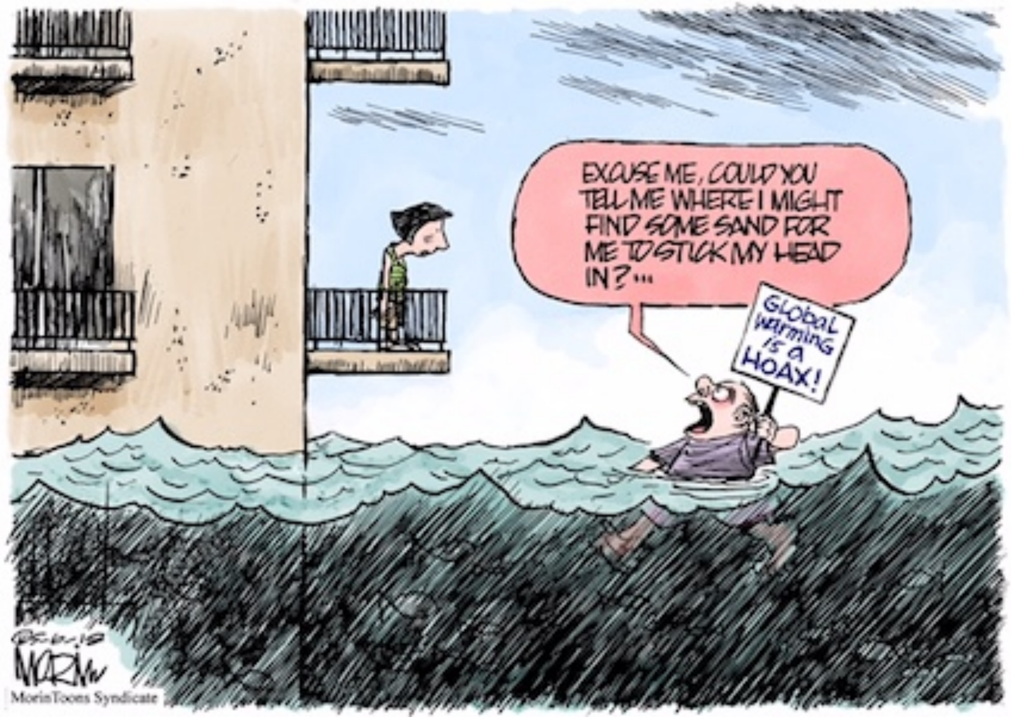


Class 5: Cryosphere and Sea Level

- What makes up the cryosphere and why is it so important for climate change?
- What controls and does not control sea level?

Learning Objectives

1. Understand ice physics sufficiently to explain why ice sheets are not simply static bodies of ice, but are complex and dynamic
2. Describe the processes that will lead to melting, others forms of mass loss, and/or destabilization of Earth's two large ice sheets
3. Explain why predictions of sea level rise contain so much uncertainty
4. Understand why rising sea level is not a slowly building threat, but could create large impacts in the near future

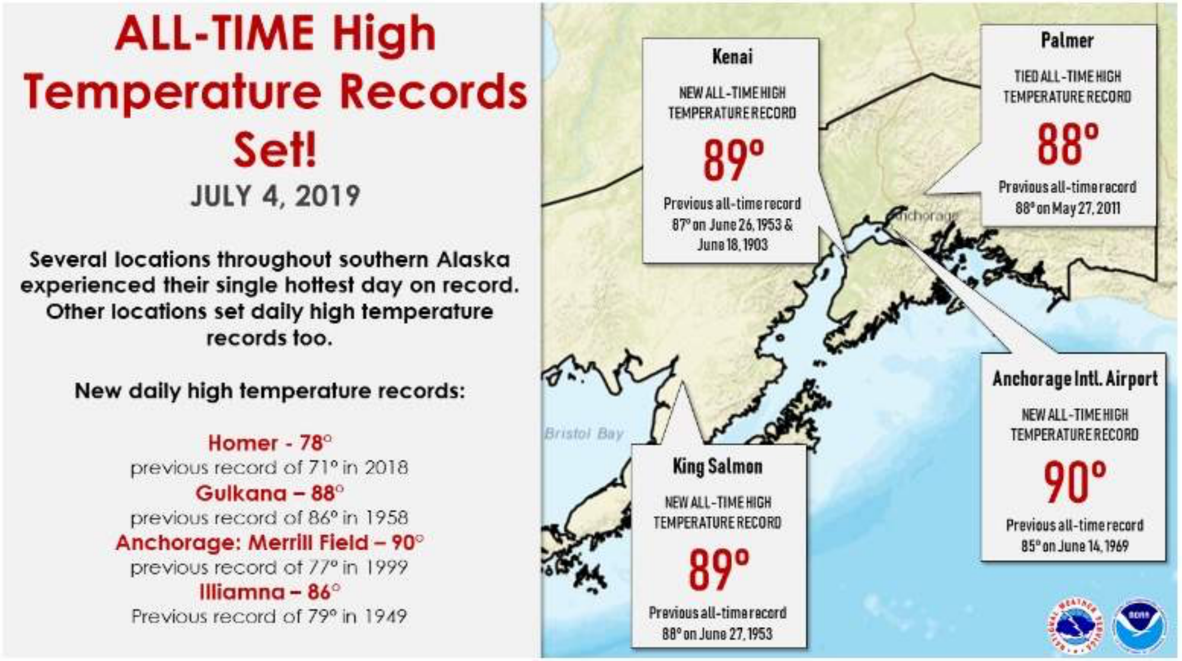
Climate in the news

Alaska's Hottest Month on Record: Melting Sea Ice, Wildfires and Unexpected Die-Offs

Arctic sea ice is at a record low for this time of year, and the usual buffer that helps keep Alaska cool is gone.

BY SABRINA SHANKMAN Follow @shankman

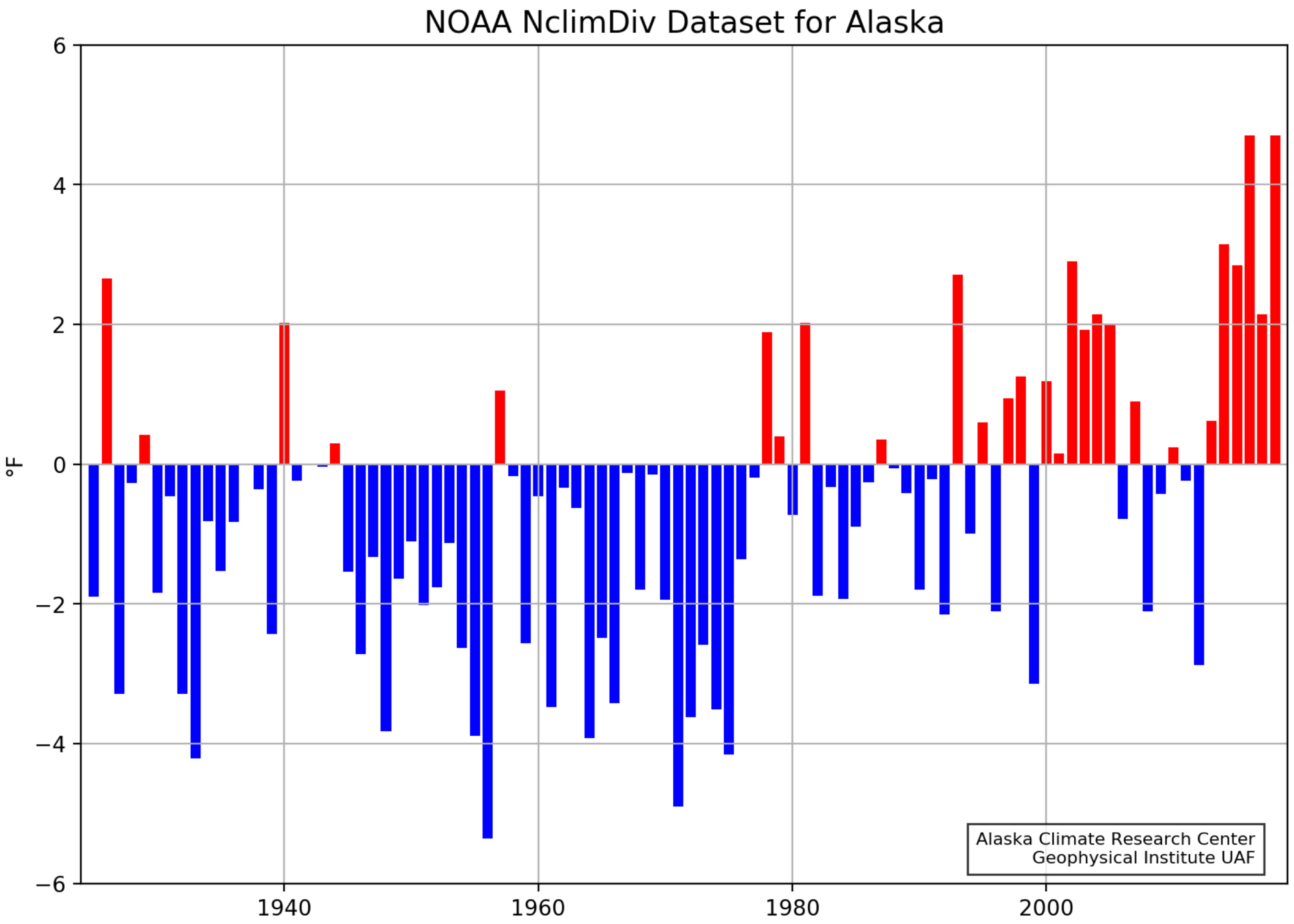
Alaska just recorded its warmest July—and warmest month—on record, the National Oceanic and Atmospheric Administration (NOAA) announced Wednesday.

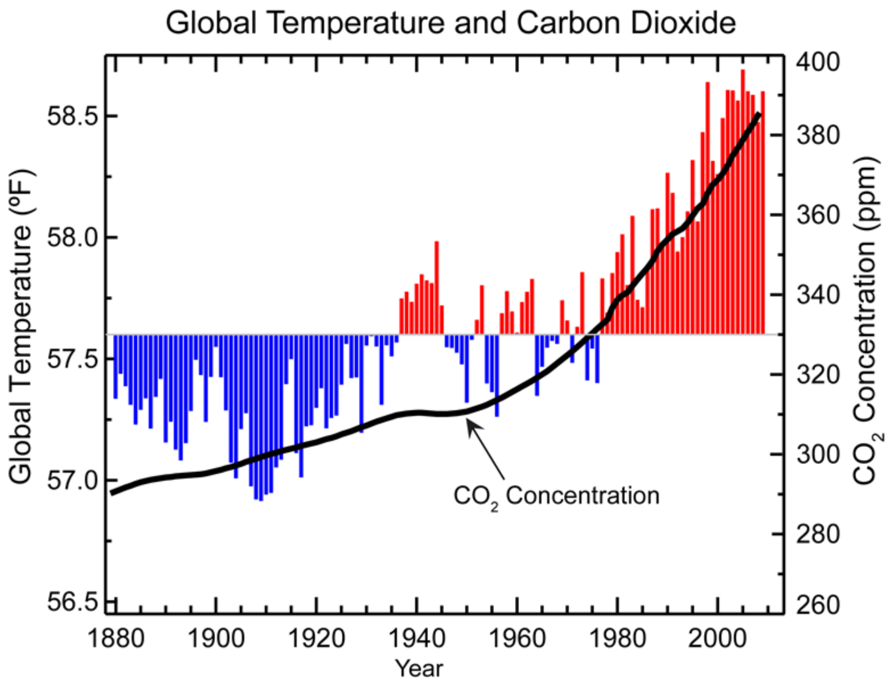


Arctic amplification

Alaska and the world are getting warmer BUT…how much warmer?

Mean annual air temperature, departure from normal (base: 1981-2010)

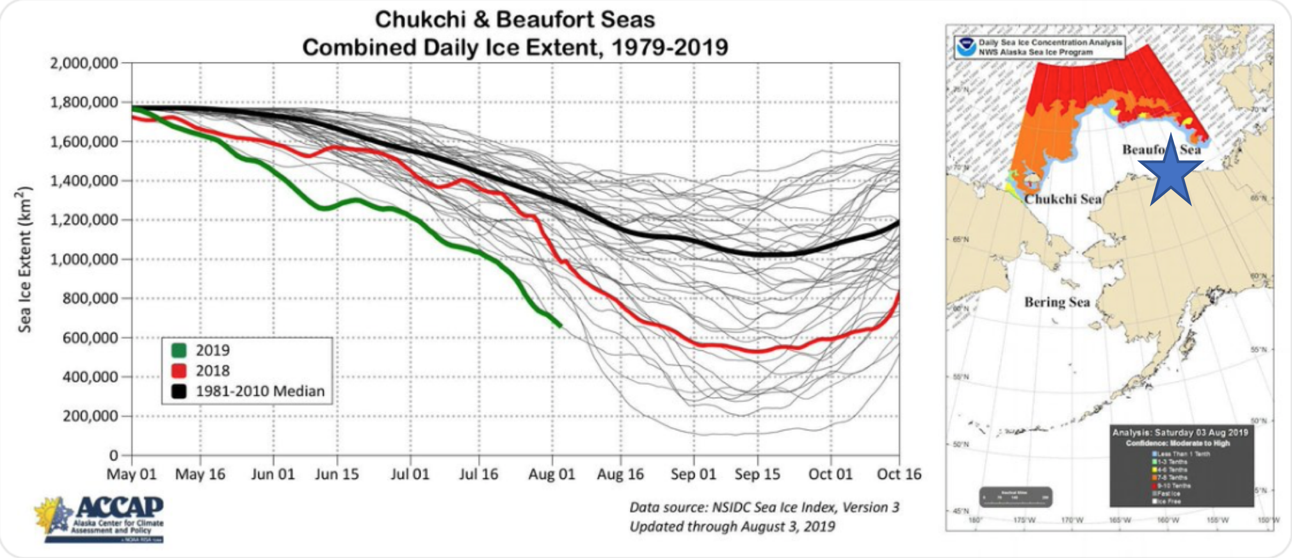




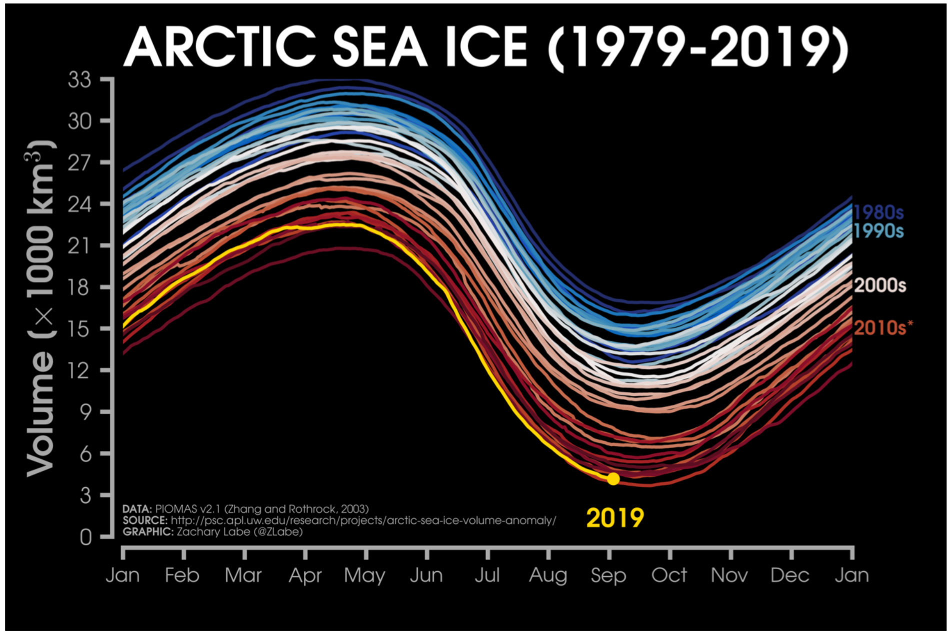
Rick Thoman
@AlaskaWx

Follow

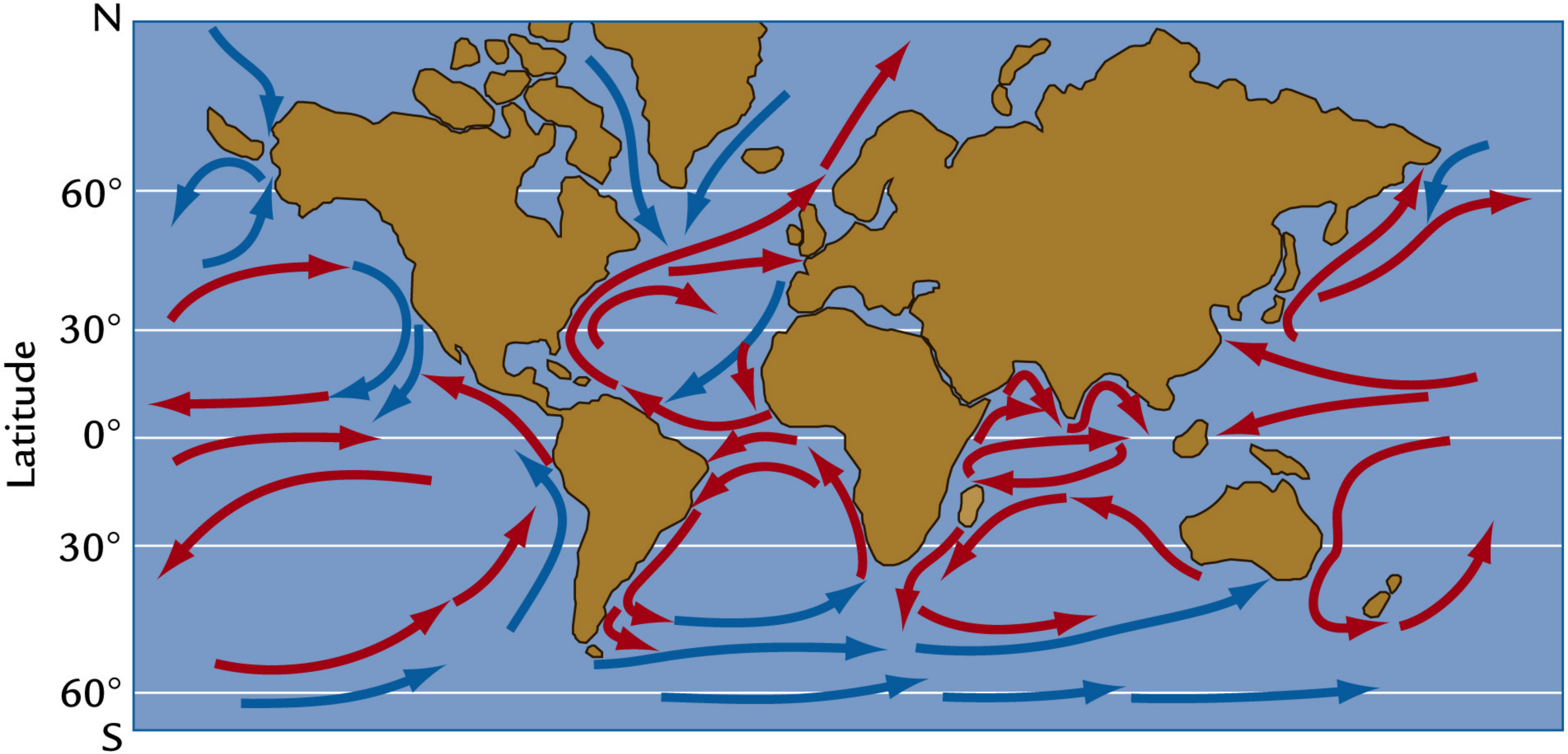
Alaska waters now completely clear of #seaice as last ice in the Beaufort Sea offshore Prudhoe Bay melted away. The closest ice to Alaska is now about 150 miles (240km) northeast of Kaktovik. Chukchi Sea maintaining lowest ice extent in @NSIDC data. #akwx #Arctic @Climatologist49



9:06 AM - 4 Aug 2019

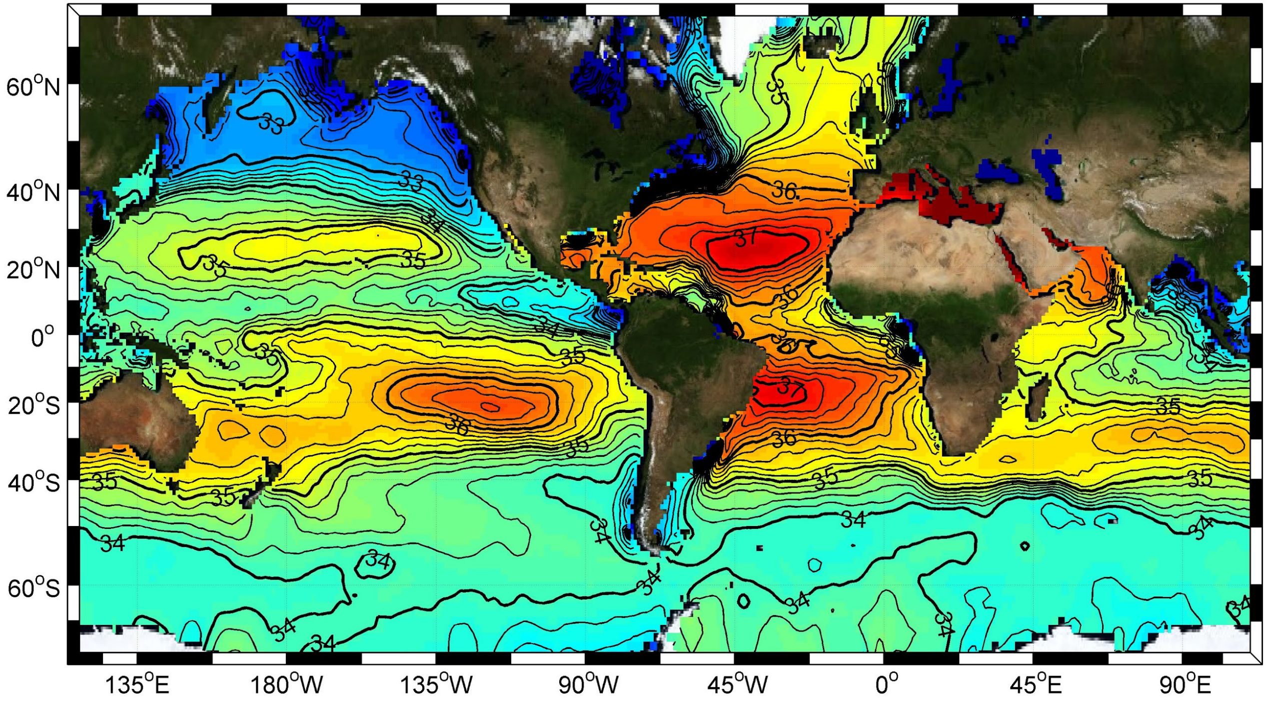


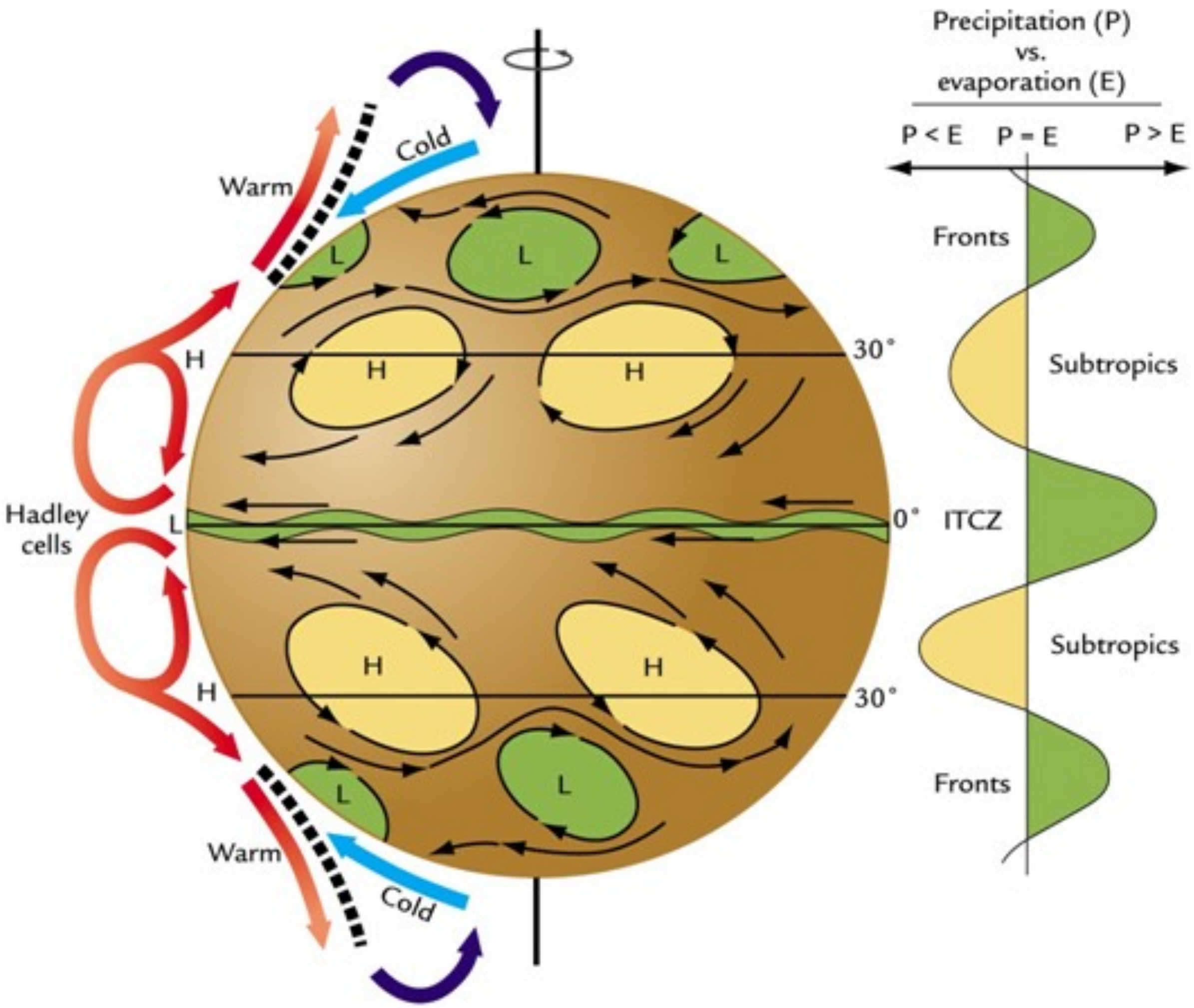
Recap from last lecture – Oceans and heat transport



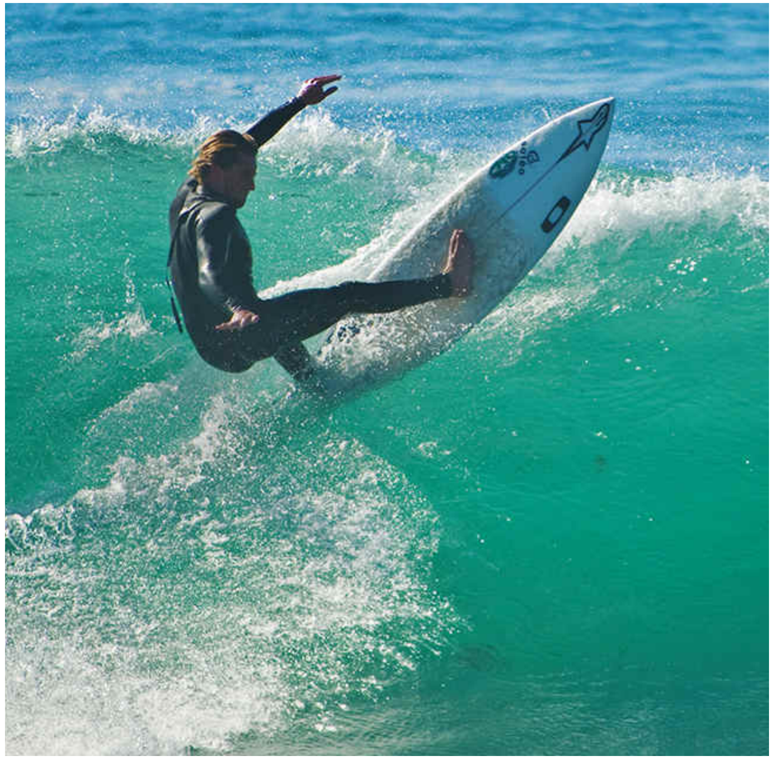
Ocean Water Contains Salt – density is key to circulation and directly tied to climate (evaporation!) and then heat transport

Salinity map (ppt, parts per thousand)





Ocean Heat Transport

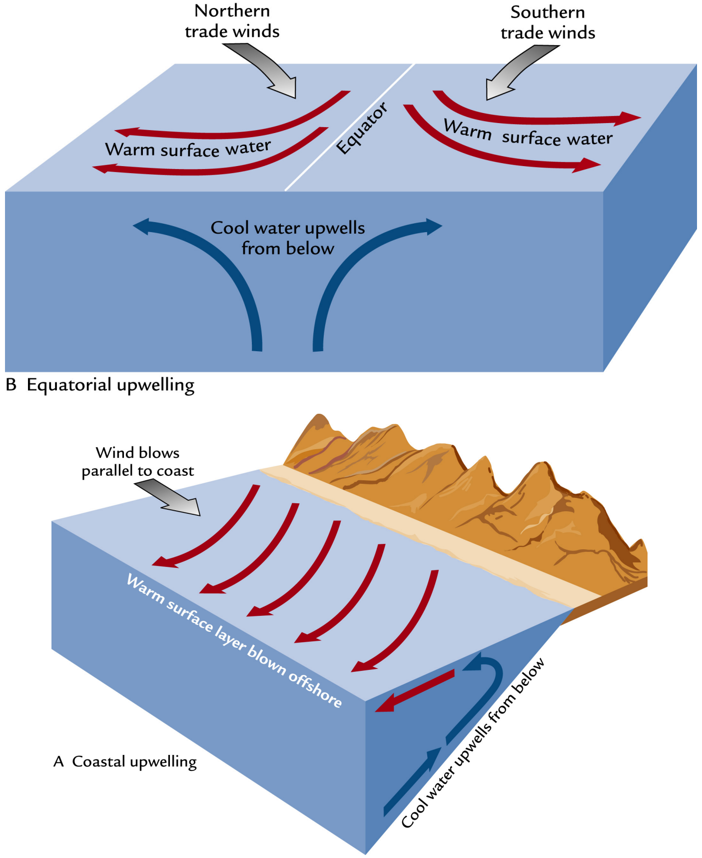


California: ~35°N
60°F Water Temp

Cold Eastern Boundary Currents

Warm Western Boundary Currents

Equatorial & Coastal Upwelling



North Carolina: ~35°N
75°F Water Temp

Atlantic Meridional Overturning Circulation (AMOC)

Critical to heat transport from equator to polar regions

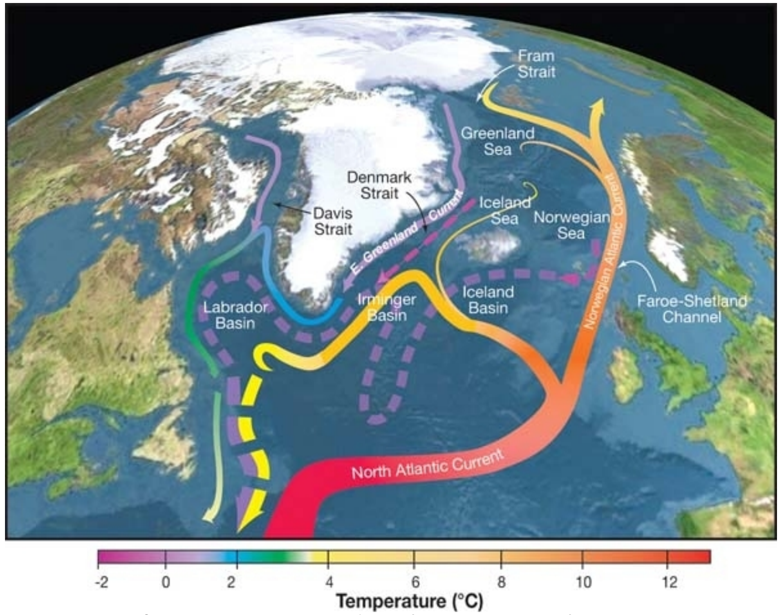
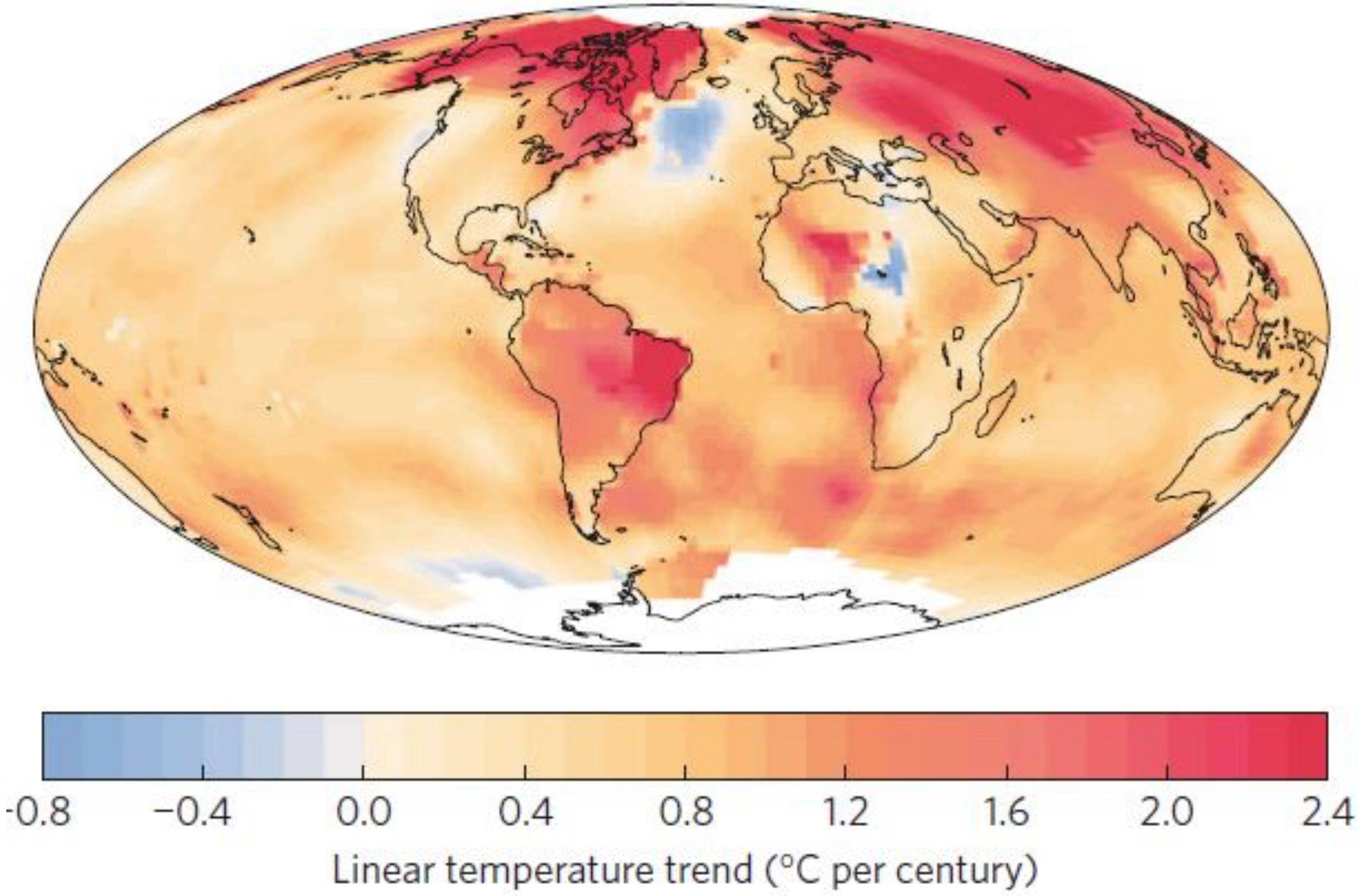


Figure from R. Curry, Woods Hole Oceanographic Institute

https://pmm.nasa.gov/education/sites/default/files/videos/thermohaline_conveyor_30fps.mp4

Is the AMOC slowing (think Day after Tomorrow?)

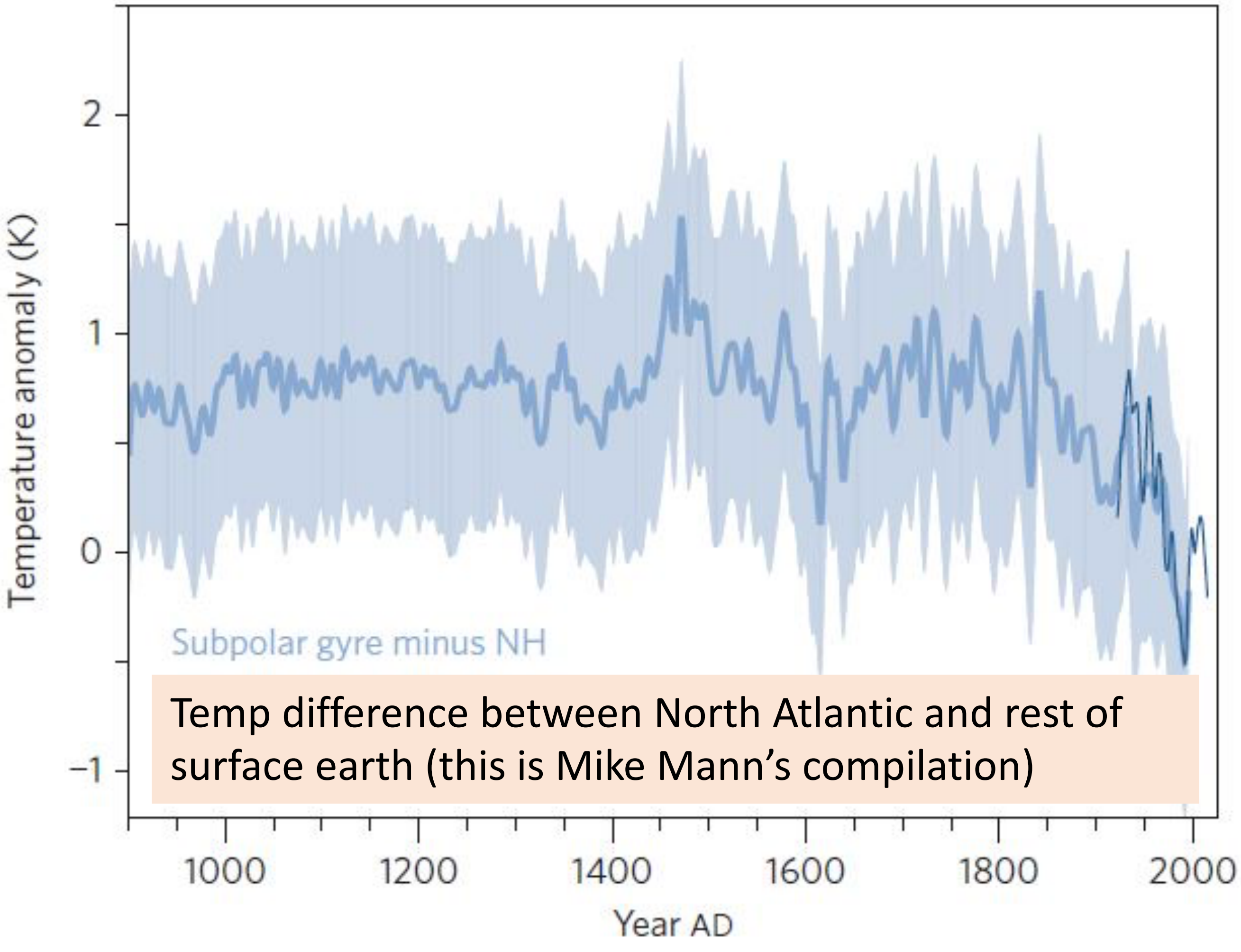


Linear temperature trend from 1900 to 2013. The cooling in the subpolar North Atlantic is remarkable and well documented by numerous measurements. **(Rahmstorf et al. 2015)**

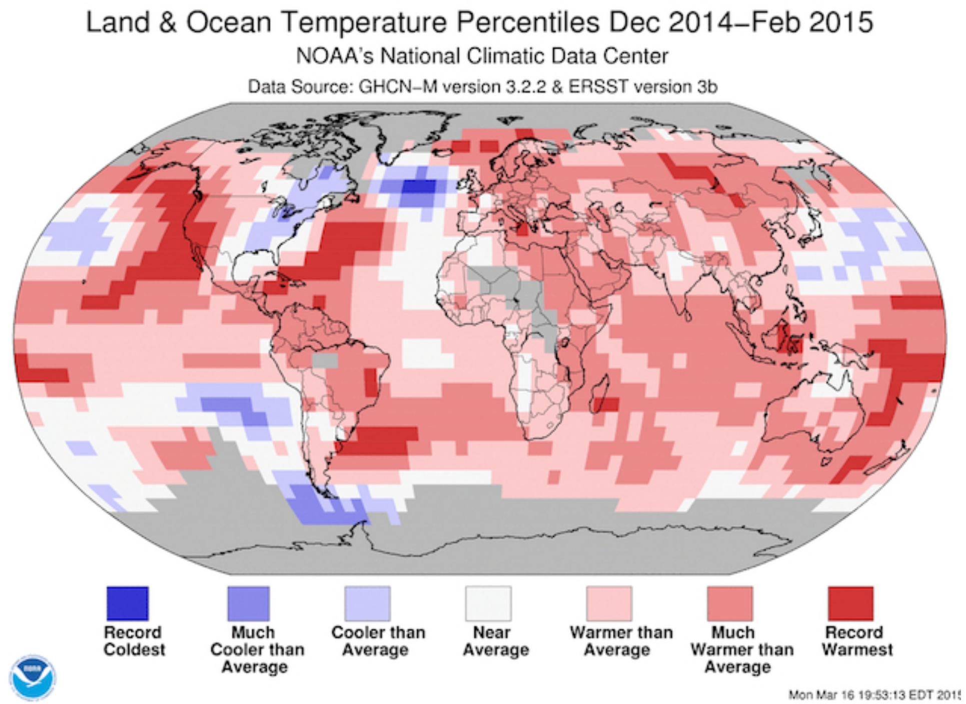
THINK PAIR SHARE

If the AMOC slows….what do you think will happen to temperatures in the arctic and near the equator?

Data suggest AMOC slow down (inferred from cool North Atlantic) – **less heat is coming northward**



Temp difference between North Atlantic and rest of surface earth (this is Mike Mann's compilation)



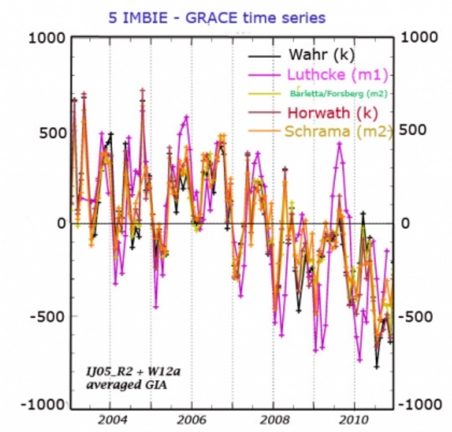
2015 was globally the warmest since records began in 1880. But in the subpolar North Atlantic, it was the coldest on record!

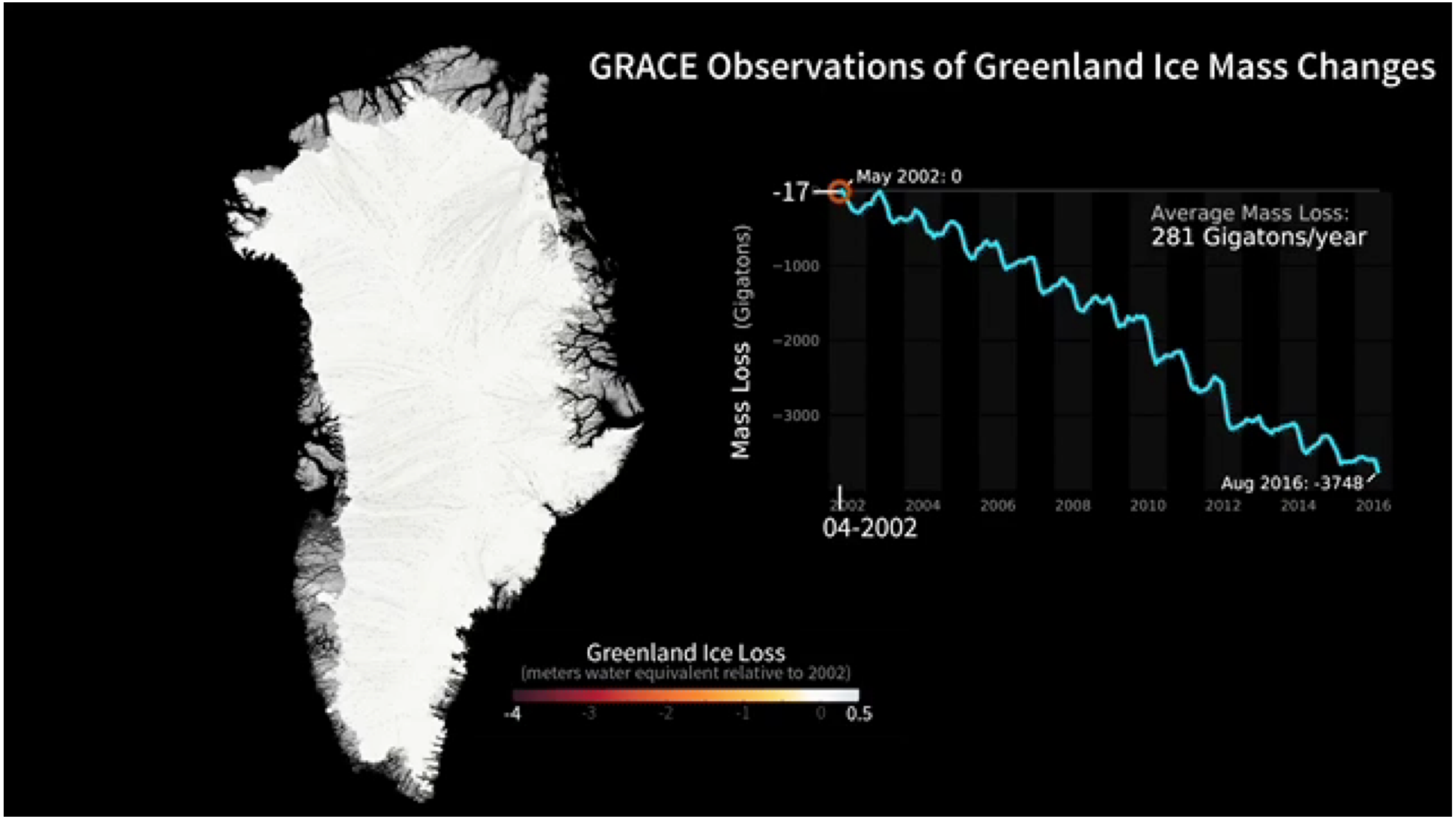
http://www.realclimate.org/index.php/archives/2015/03/whats-going-on-in-the-north-atlantic/

What’s driving this slow down? Greenland?

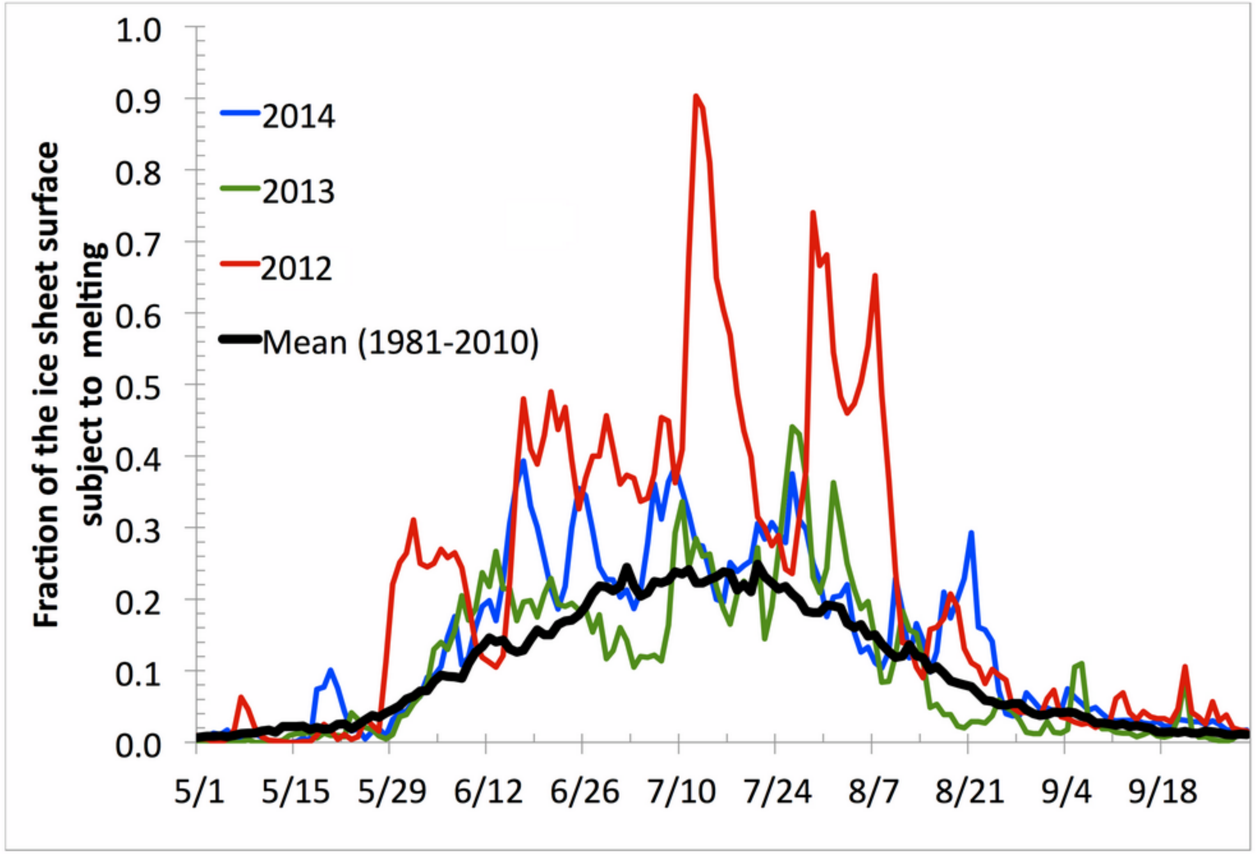
NASA's Gravity Recovery and Climate Experiment

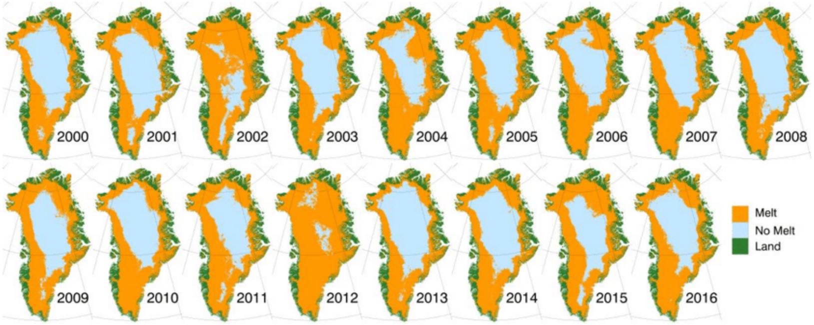
Antarctic = similar

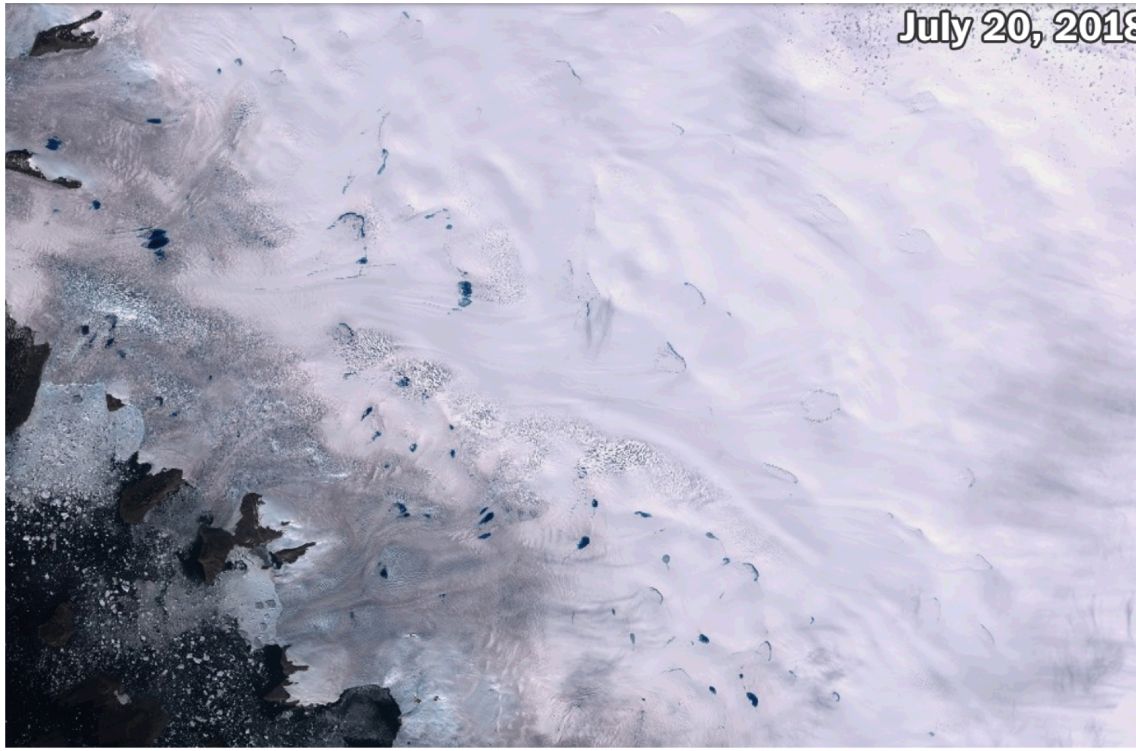




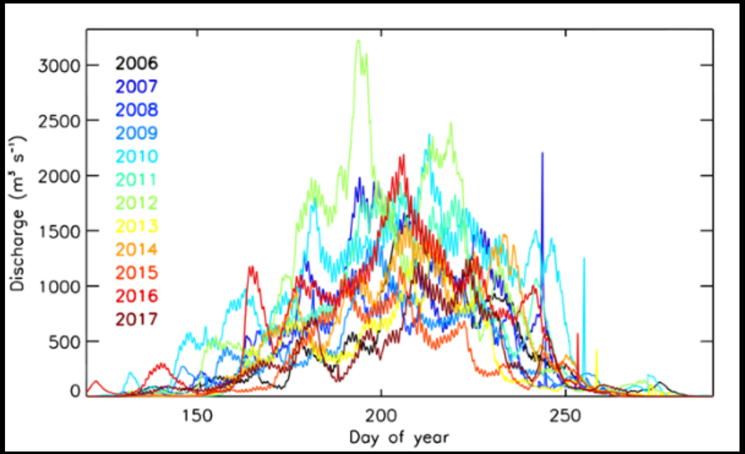
For Greenland, 2012 was record melt year, 2019 came close!



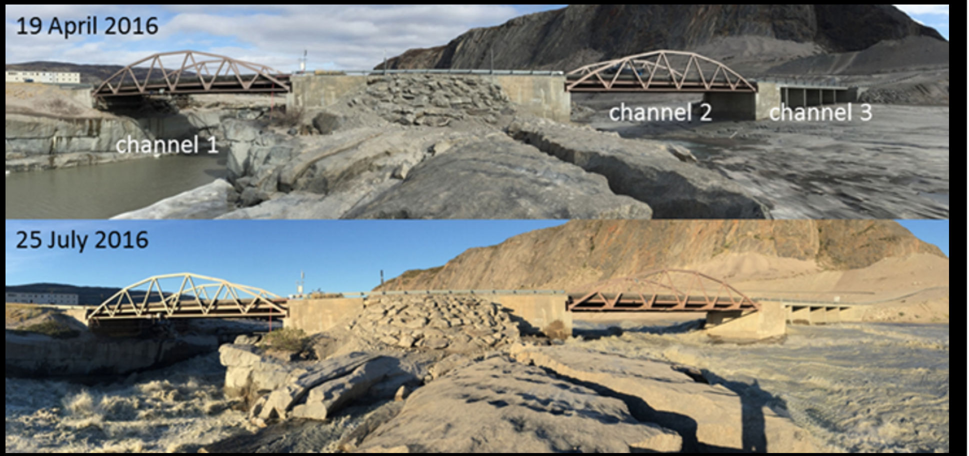




https://www.researchgate.net/figure/Maps-of-maximum-annual-surface-melt-on-the-Greenland-Ice-Sheet-derived-from-the-MOD29_fig3_324238865



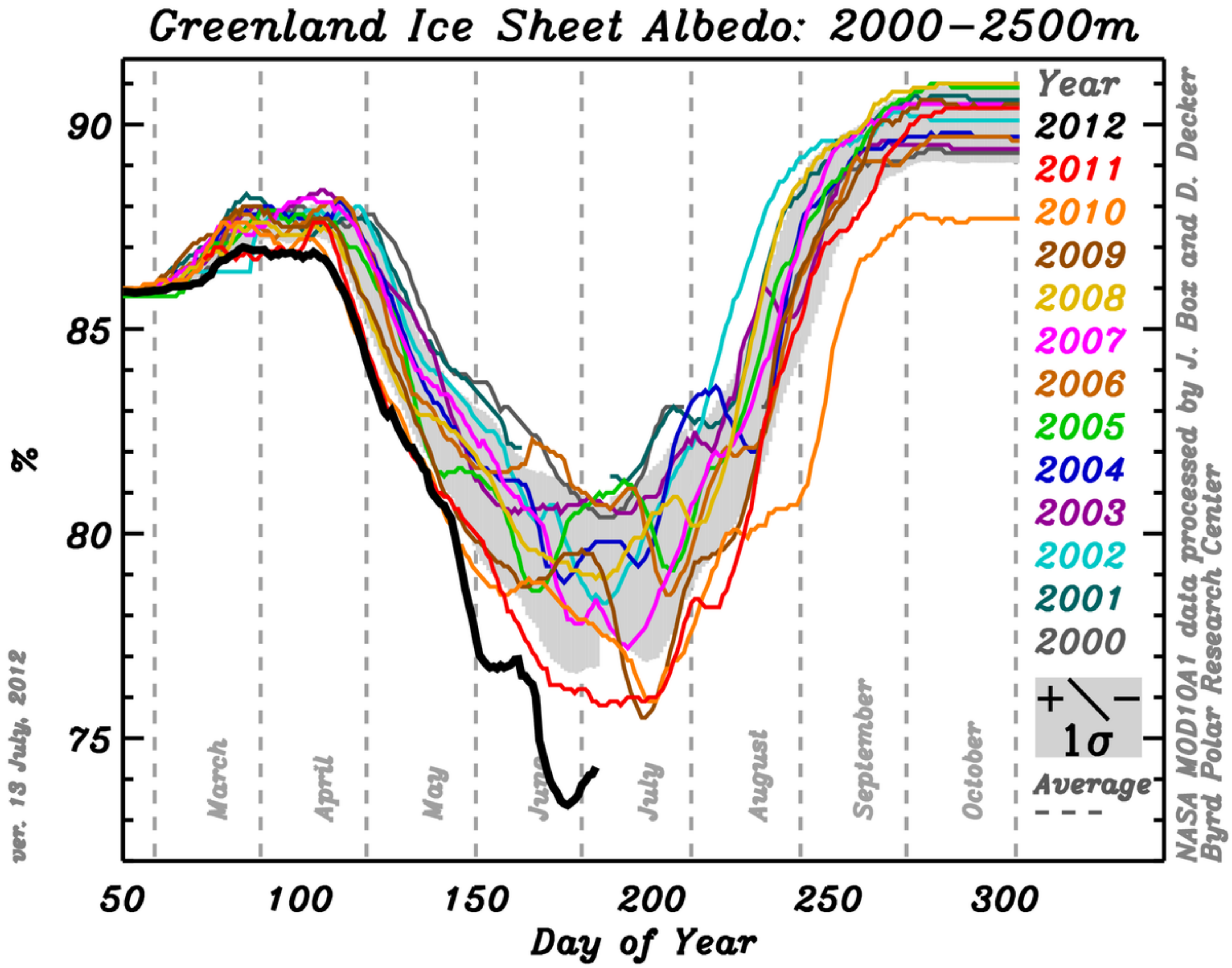
Discharge (m³ s⁻¹)
Day of year
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017



19 April 2016
channel 1
channel 2
channel 3
25 July 2016

There are feedbacks! Albedo...

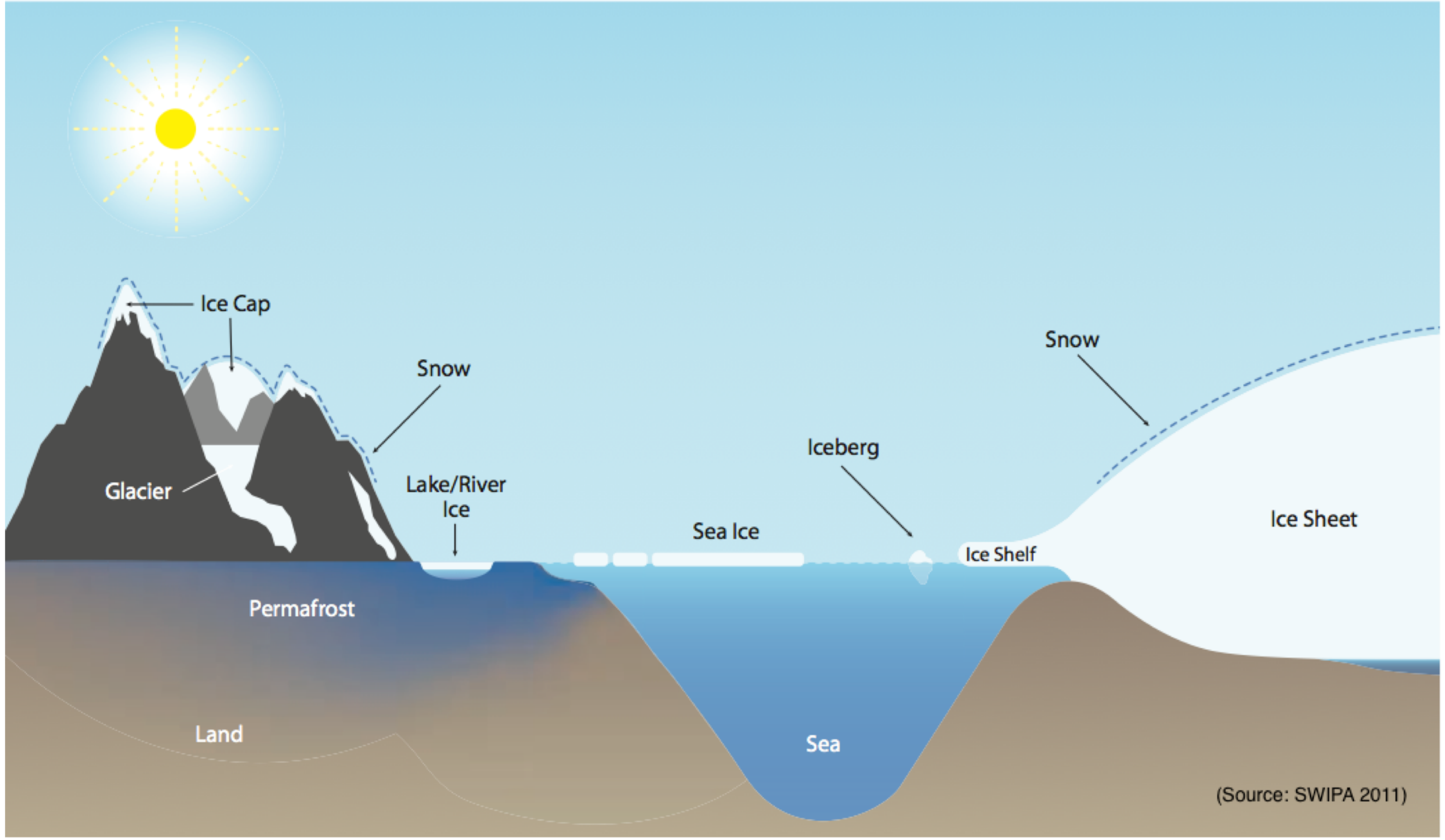
WHY the seasonal cycle?



https://serc.carleton.edu/details/images/42547.html

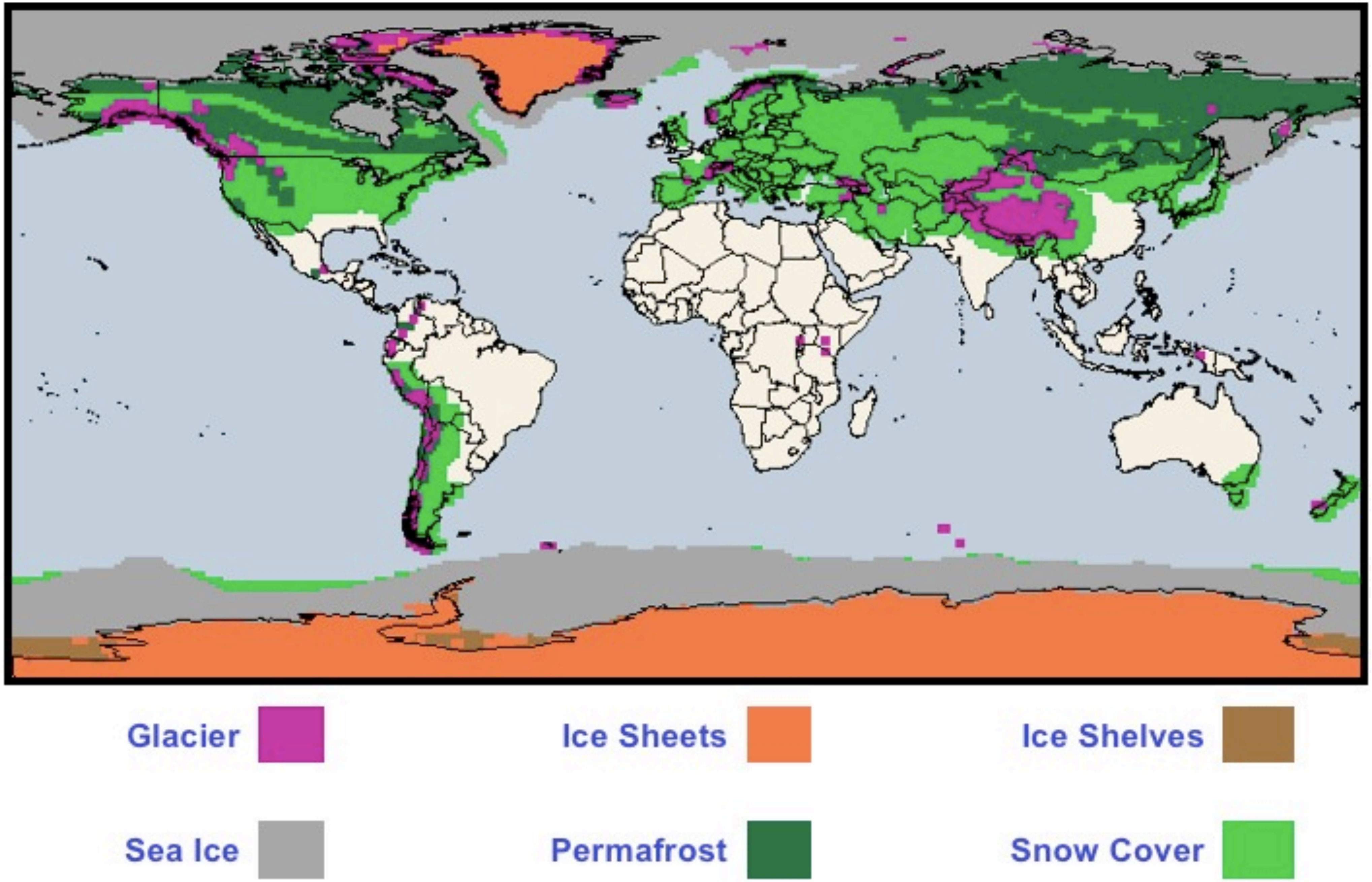
Cryosphere (frozen places) Components (we will consider description and process)

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

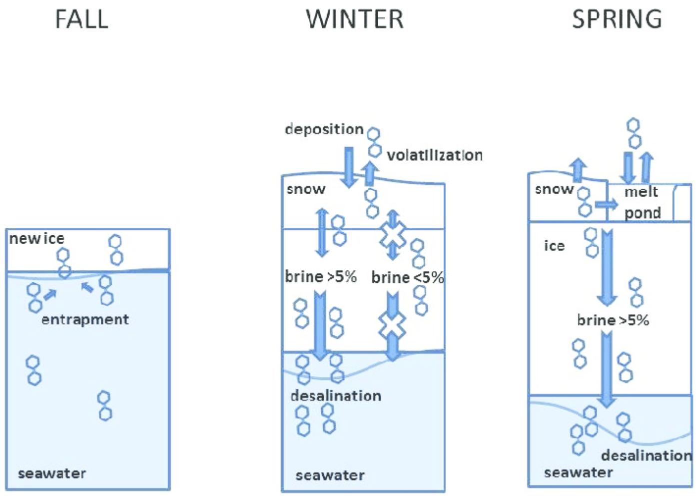


https://globalcryospherewatch.org/about/cryosphere.html

Global Cryosphere by Type

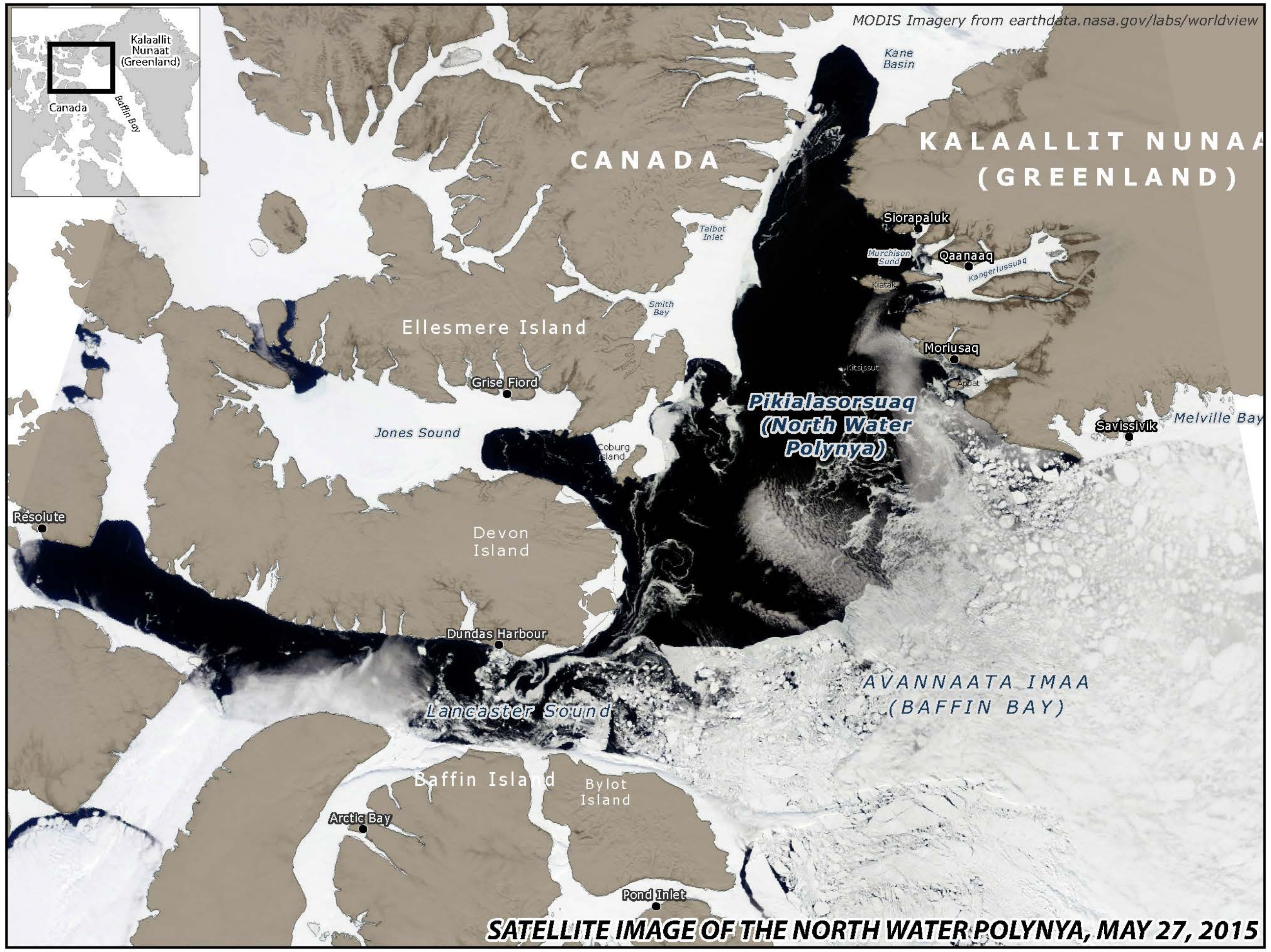


Sea Ice – what is it?

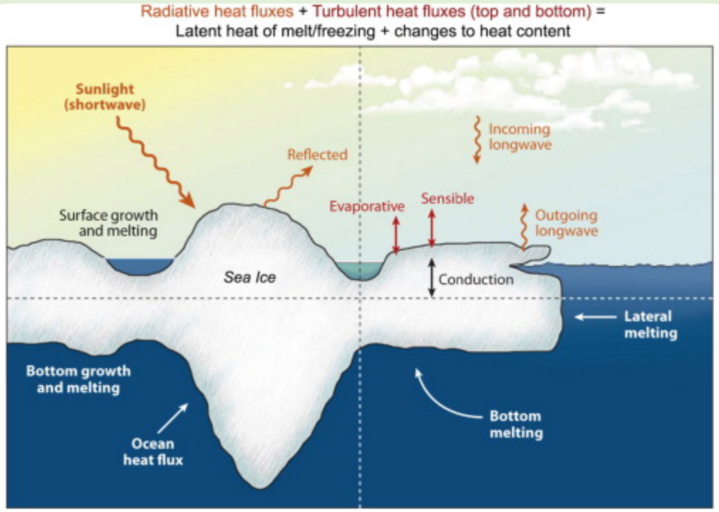


https://nsidc.org/cryosphere/seaice/characteristics/formation.html; https://www.researchgate.net/figure/Sea-ice-formation-and-growth-during-the-winter-season-and-associated-behavior-of-POPs_fig4_307653810

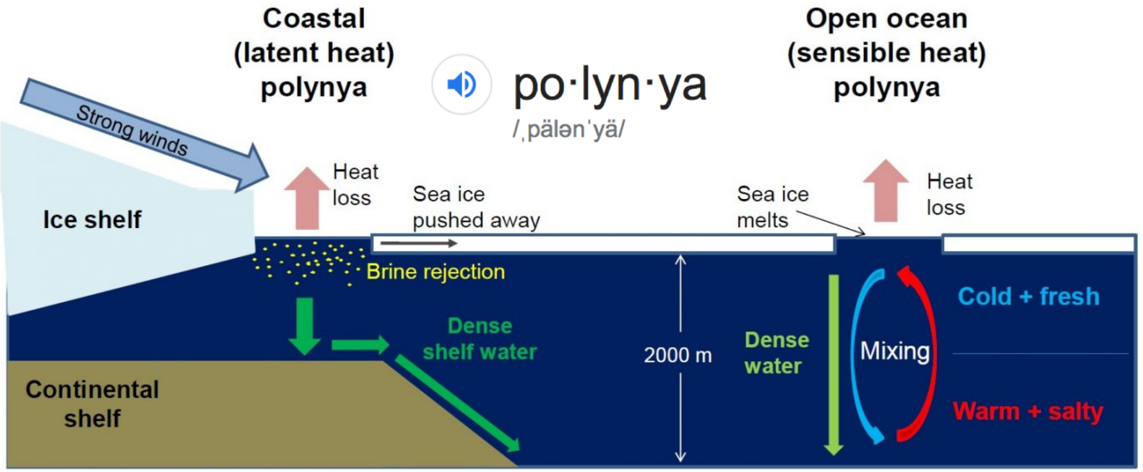
Sea Ice – Why it matters, an important control on ocean heat flux and water vapor flux



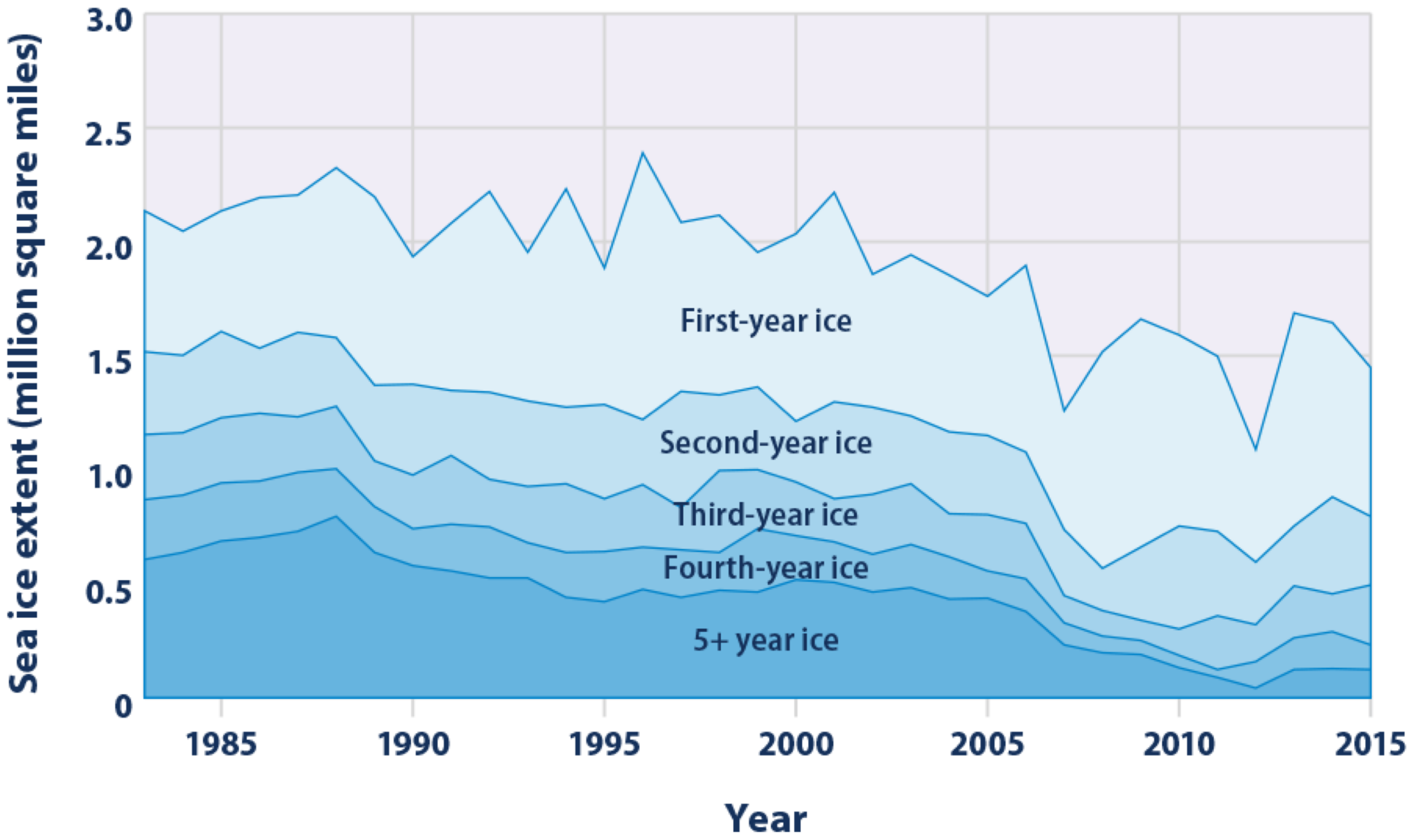
https://blogs.egu.eu/divisions/cr/2016/11/25/image-of-the-week-what-an-ice-hole/



https://ars.els-cdn.com/content/image/1-s2.0-S1873965210000411-gr4.jpg



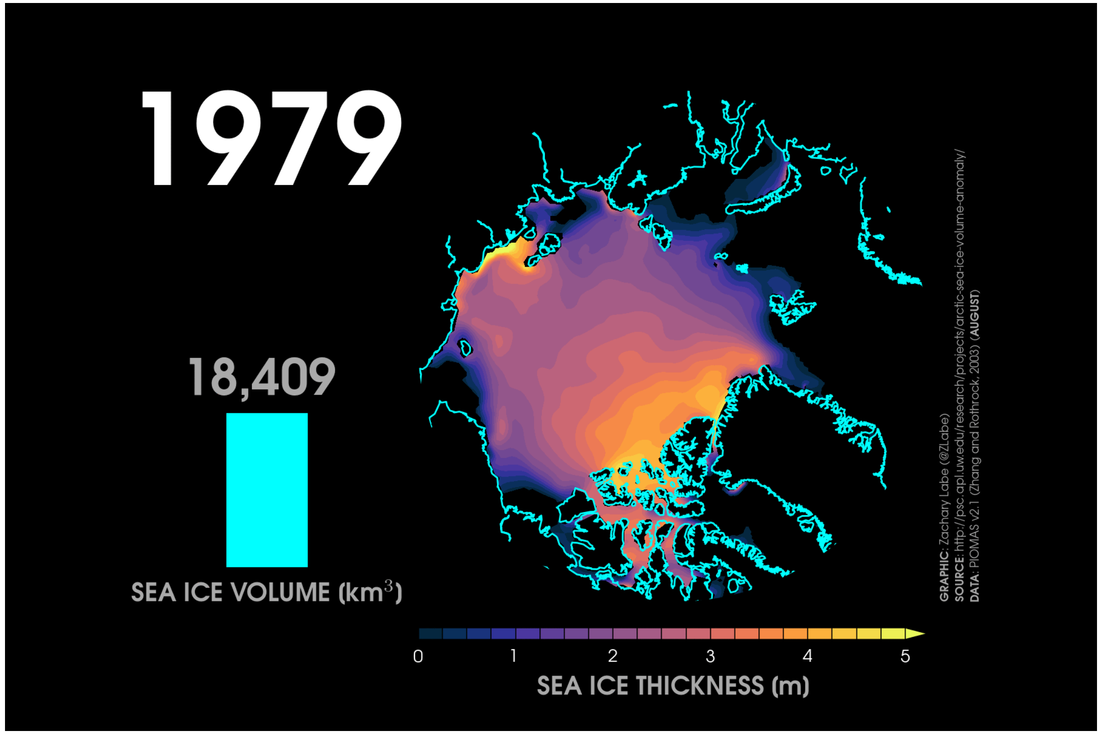
Sea Ice – what's happening to it?

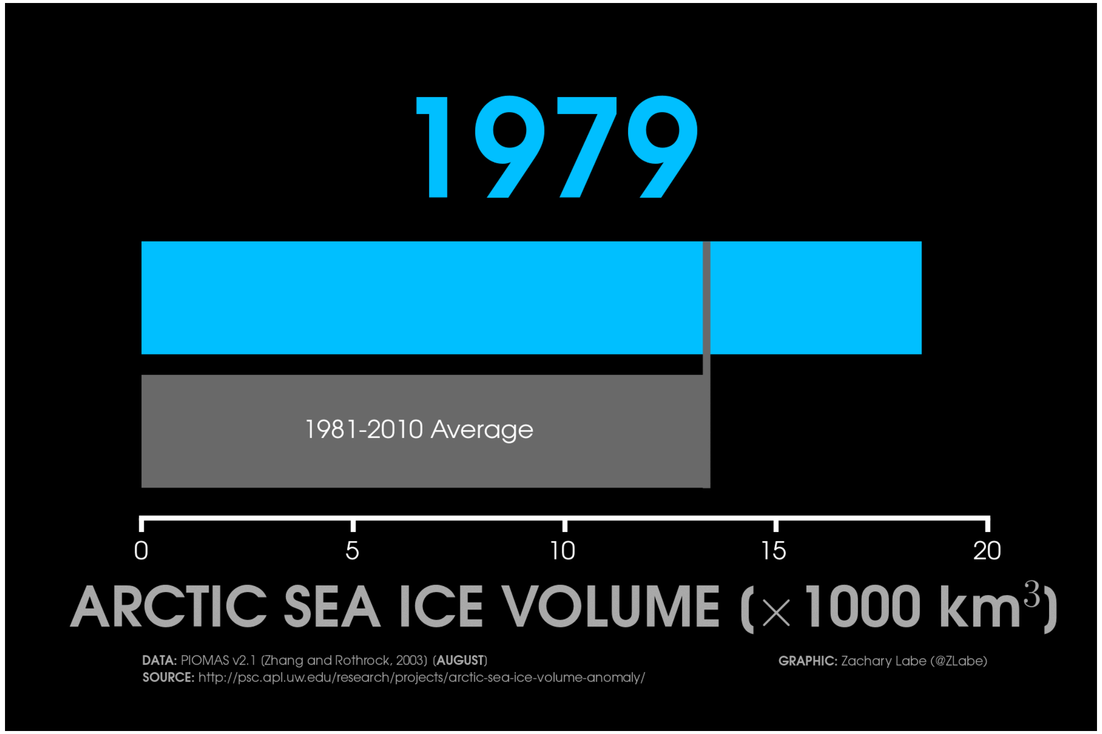


https://www.epa.gov/climate-indicators/climate-change-indicators-arctic-sea-ice

Think, pair, share

Work with your neighbor to understand what is happening over time to the area, thickness, and volume of sea ice



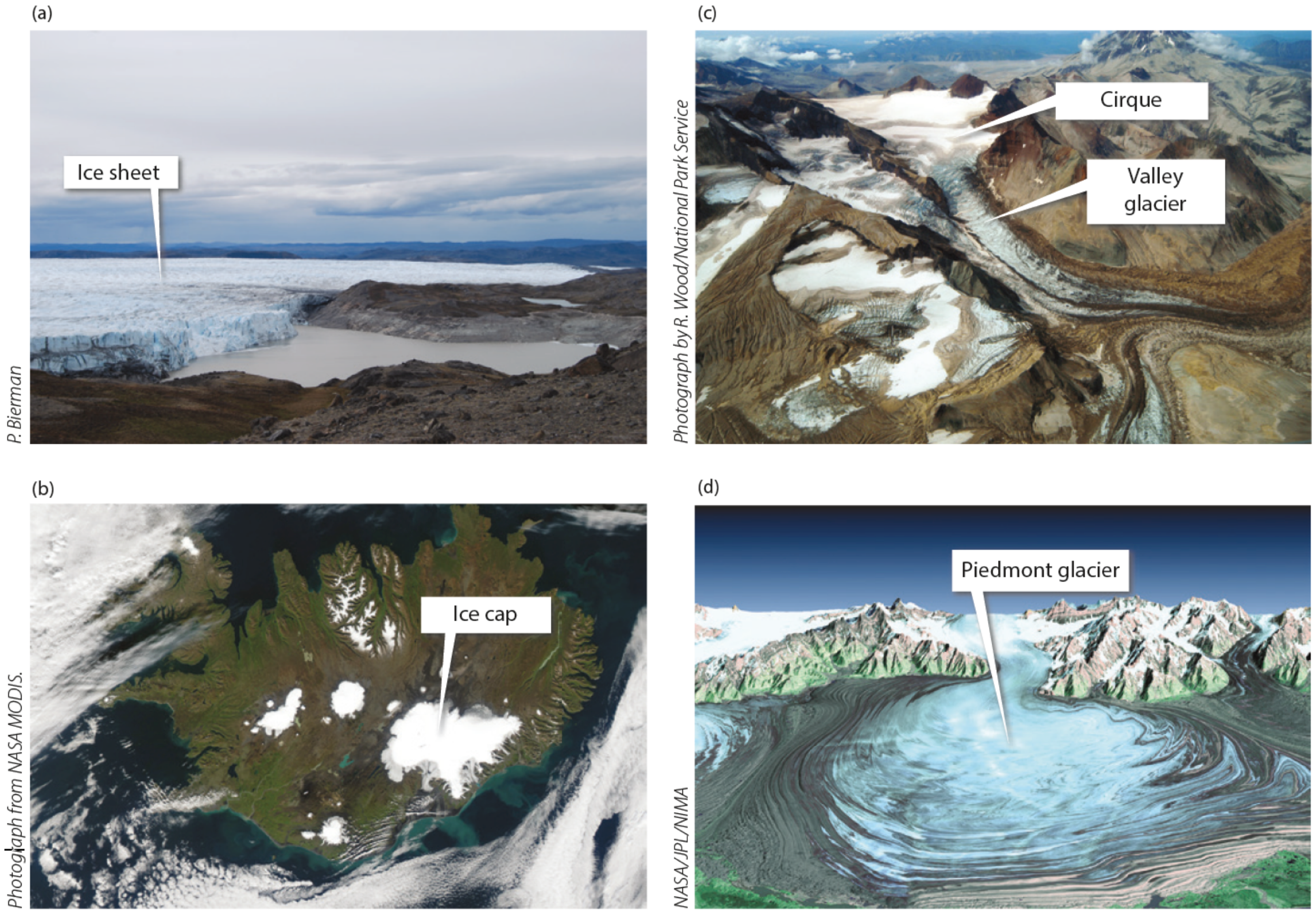


https://sites.uci.edu/zlabe/

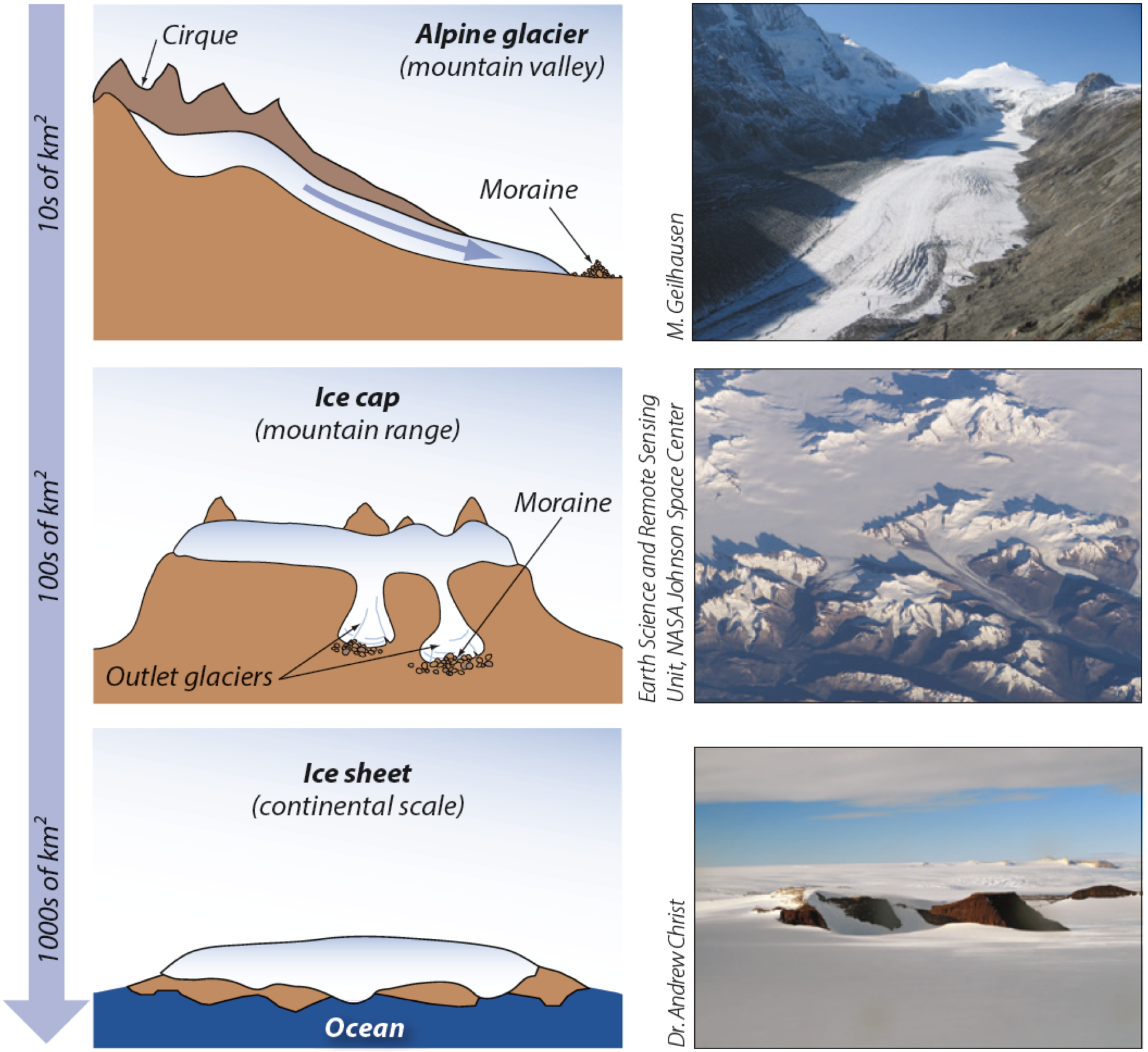
Professor Julienne Stroeve – Sea Ice Scientist

Everything in our physical environment is interconnected," Stroeve says. The polar regions are normally covered by snow and ice, which help to keep our planet relatively cool. One of the effects of climate change is a decrease in the mass of ice sheets in polar regions. As polar ice caps disappear, the rate at which the entire planet warms increases. "This will have worldwide consequences, both in terms of raising global sea levels and also changing all of our weather patterns that govern our water and food supplies," https://www.harpersbazaar.com/culture/features/a23063189/women-in-science-glass-ceiling/

Glaciers – What do they look like?



Glaciers – How do you classify them?



Alpine glaciers are topographically constrained by the cirques in which they originate and the valley walls that confine them. Lower reaches of alpine glaciers are often bordered by moraines.

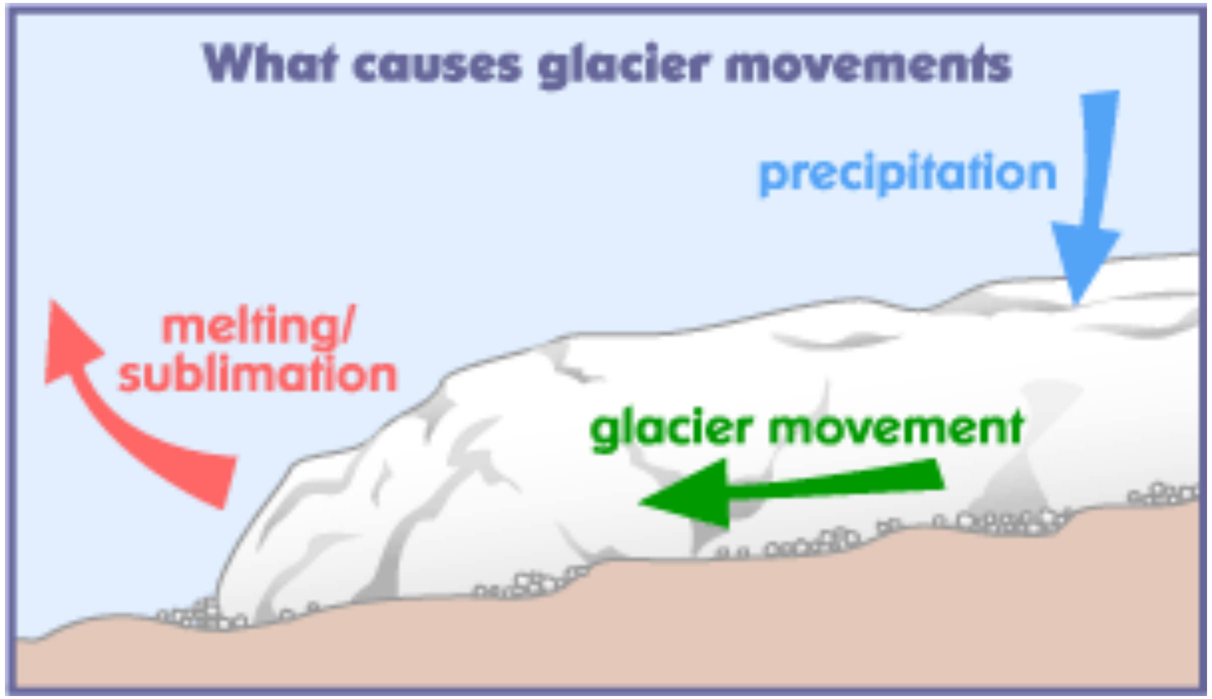
Ice caps occupy highlands and in many places bury existing topography. They are drained by outlet glaciers that transport ice to lower elevations where it melts and deposits moraines.

Ice sheets largely overwhelm topography, ice buries peaks, and the surface slope of the ice sheet controls ice flow direction. Ice sheets deposit moraines and other glacial sediments.

Glaciers – How do they move?

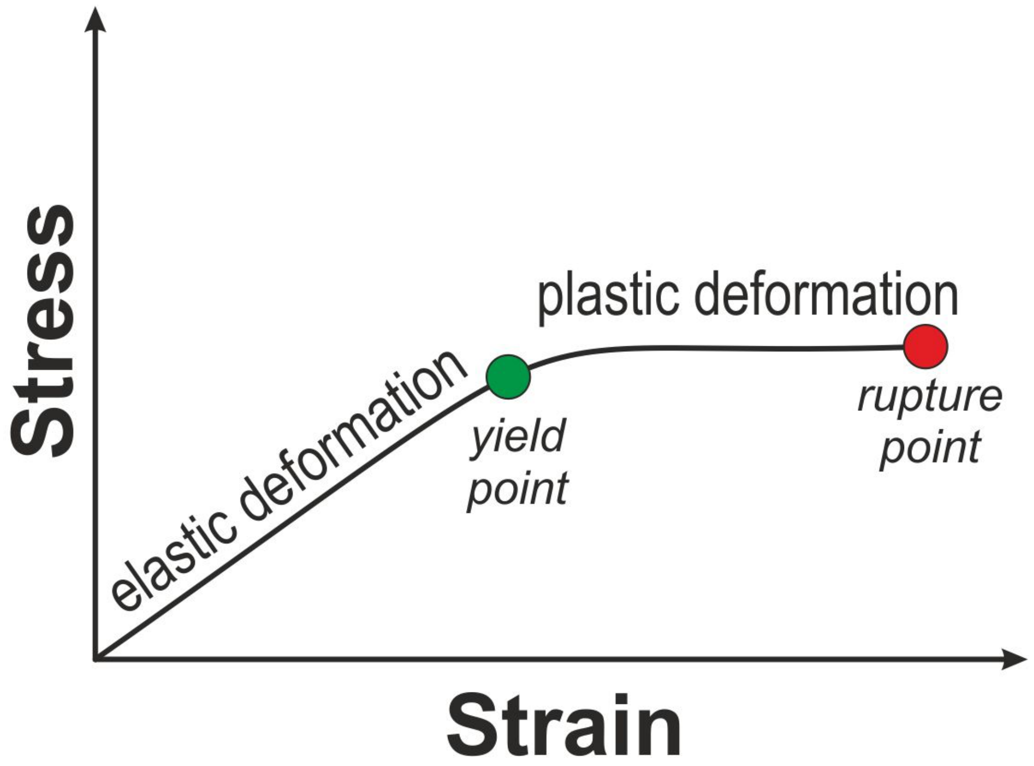
https://www.youtube.com/watch?v=RnlPrdMoQ1Y

Glaciers are flowing bodies of ice that deform under their own weight and slide under the force of gravity



Glaciers – How does ice deform?

$$\epsilon = A{\tau_b}^n$$



The creep of polycrystalline ice

By J. W. Glen

Cavendish Laboratory, University of Cambridge

(*Communicated by M. F. Perutz, F.R.S.—Received* 1 *November* 1954)

Polycrystalline blocks of ice have been tested under compressive stresses in the range from 1 to 10 bars at temperatures from −13°C to the melting-point. Under these conditions ice creeps in a manner similar to that shown by metals at high temperatures; there is a transient

THE FLOW LAW OF ICE

A discussion of the assumptions made in glacier theory, their experimental foundations and consequences

J. W. GLEN

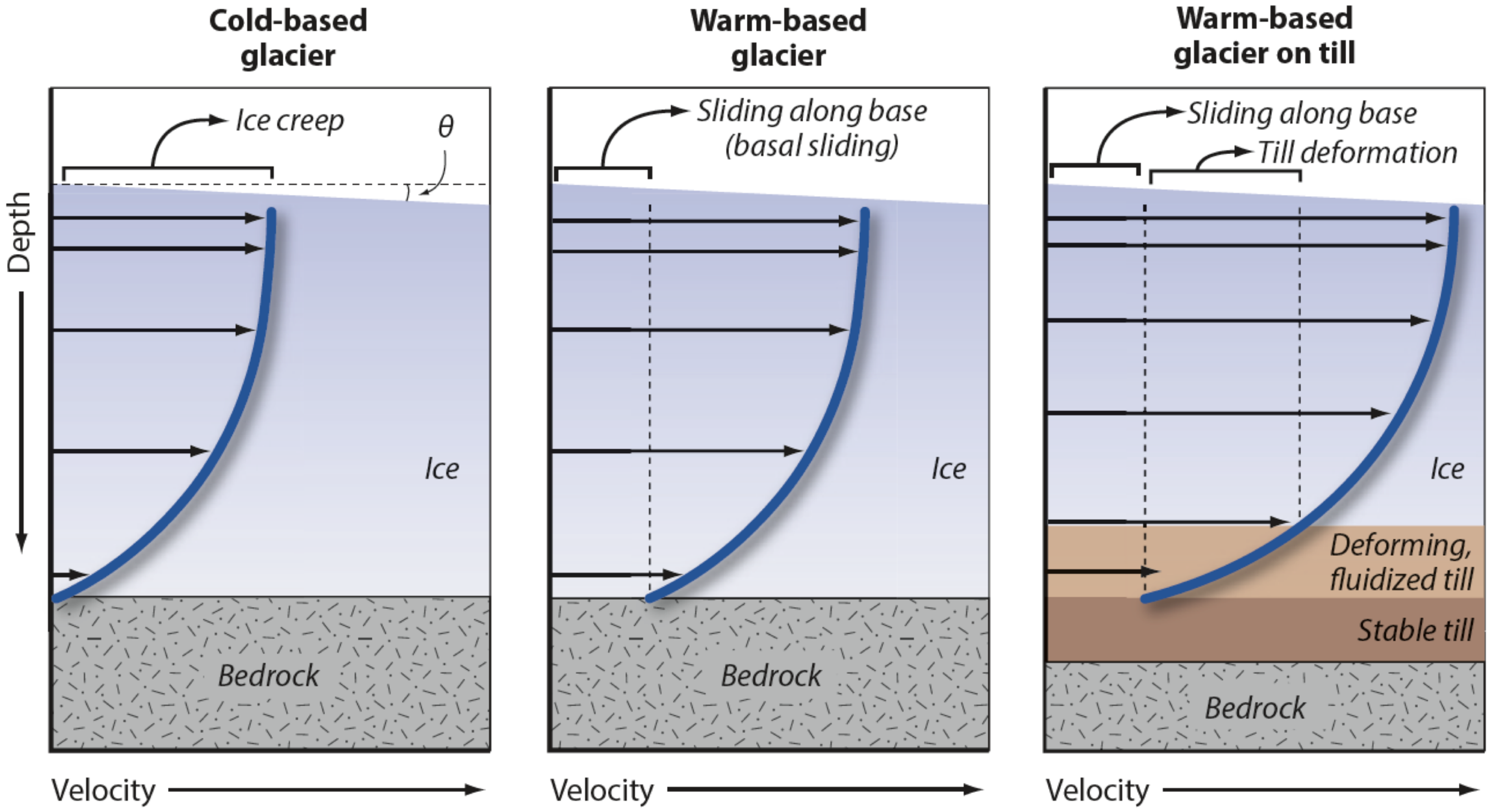
Physics Department, Birmingham University, England

Summary

Experimental evidence on the flow law of ice is reviewed, and the justification for various assumptions commonly made in theoretical studies of ice movement is discussed. This enables the reliability of results obtained using the assumptions to be assessed.

The general theory developed allows certain predictions to be made concerning the effects of complicated stressing systems, and in particular the theory is applied qualitatively to explain the anomalous behaviour of glaciers below ice falls and in other places where large stresses are acting in the ice due to its flow.

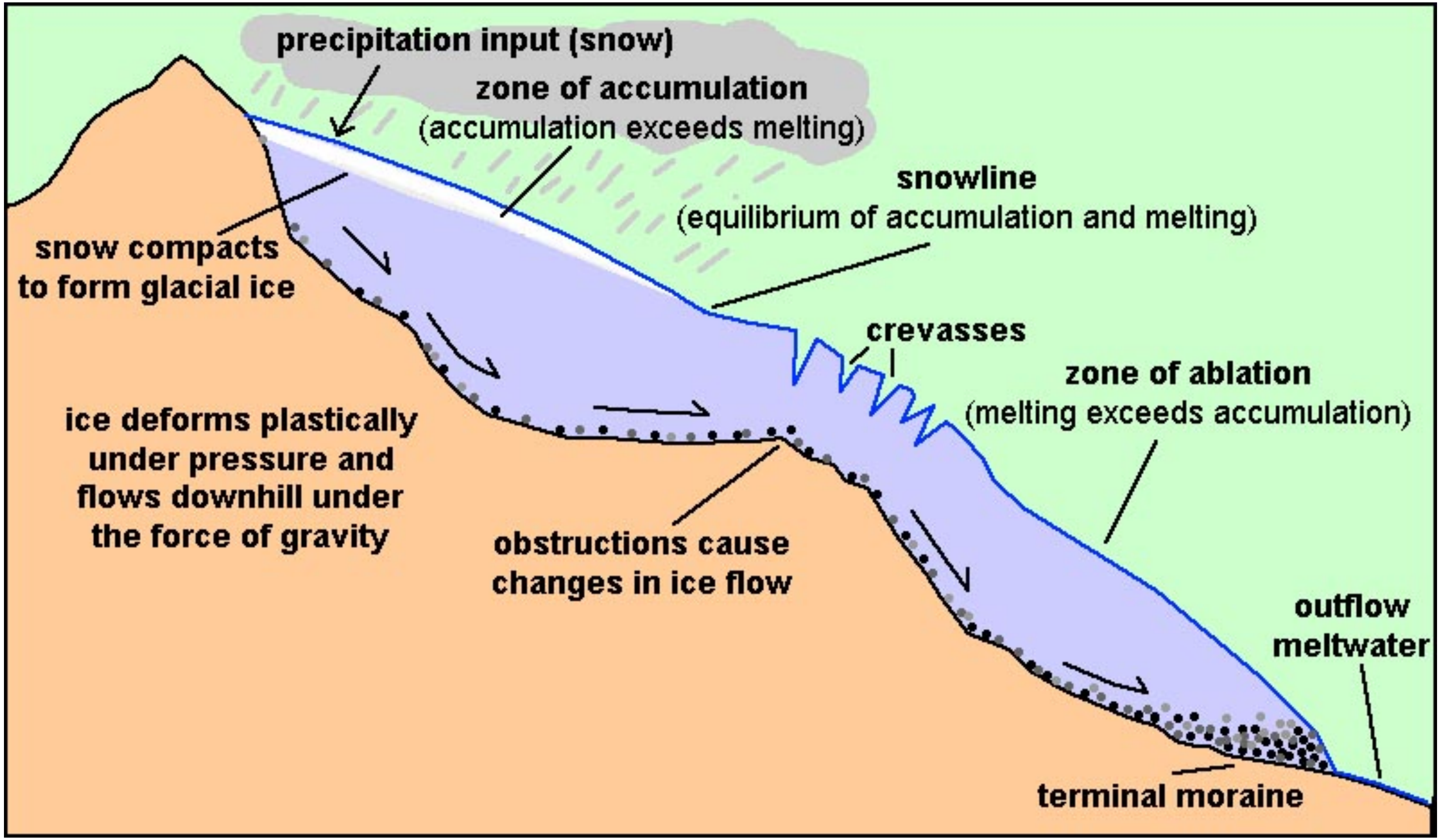
Glaciers – Ice also slides



Sliding

Deformation

Glaciers – How do they come and go?



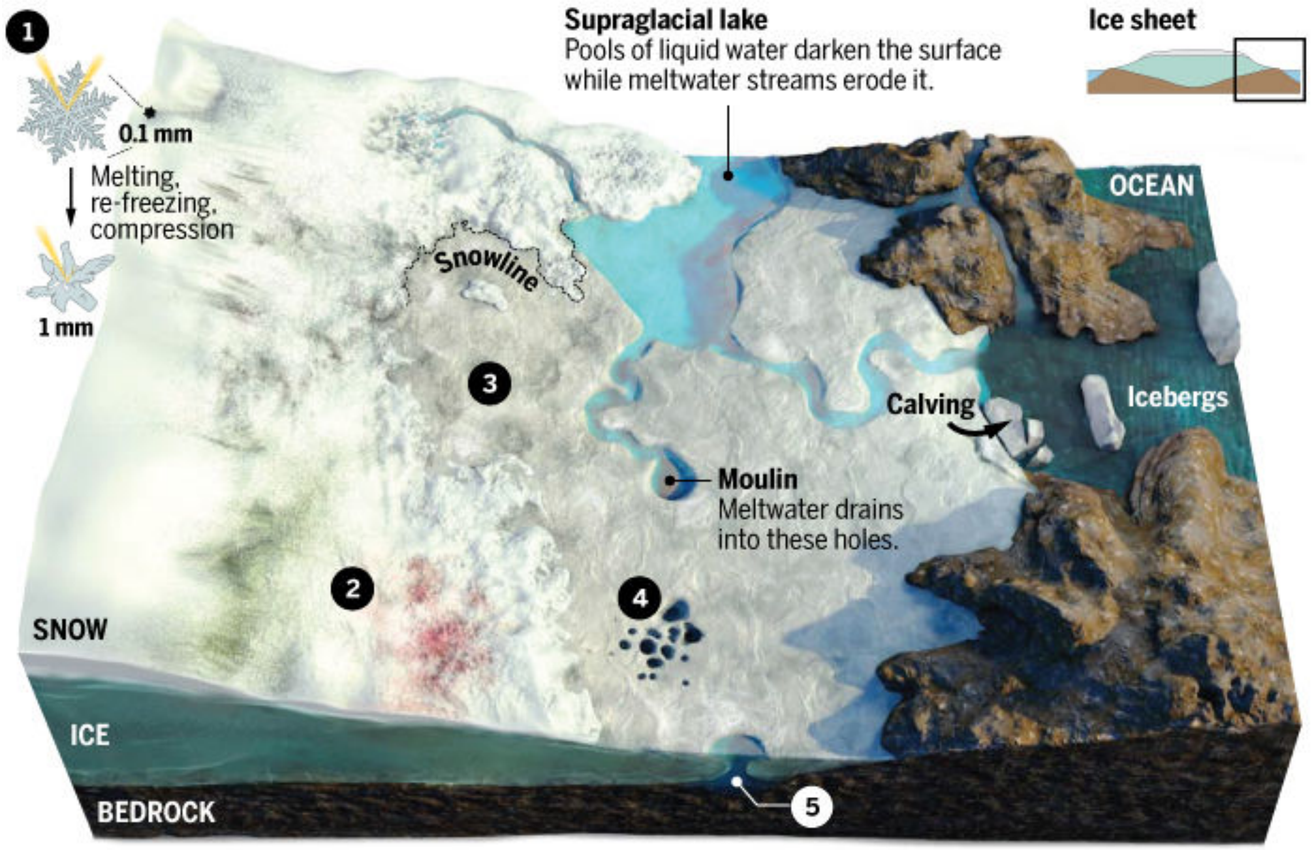
Mass and energy balance

- Ice in
- Ice out

Glaciers (Demise of the Greenland Ice sheet)

The melt zone

Physical and biological factors are driving the Greenland Ice Sheet's melt, which since 2005 has contributed more to ice loss than calving of icebergs at sea.v



1 Rounded crystals Freeze-thaw cycles create rounded ice particles that absorb more heat than fresh snow.

2 Colored snow Algae and microbes are proliferating as the amount of liquid increases and temperatures warm.

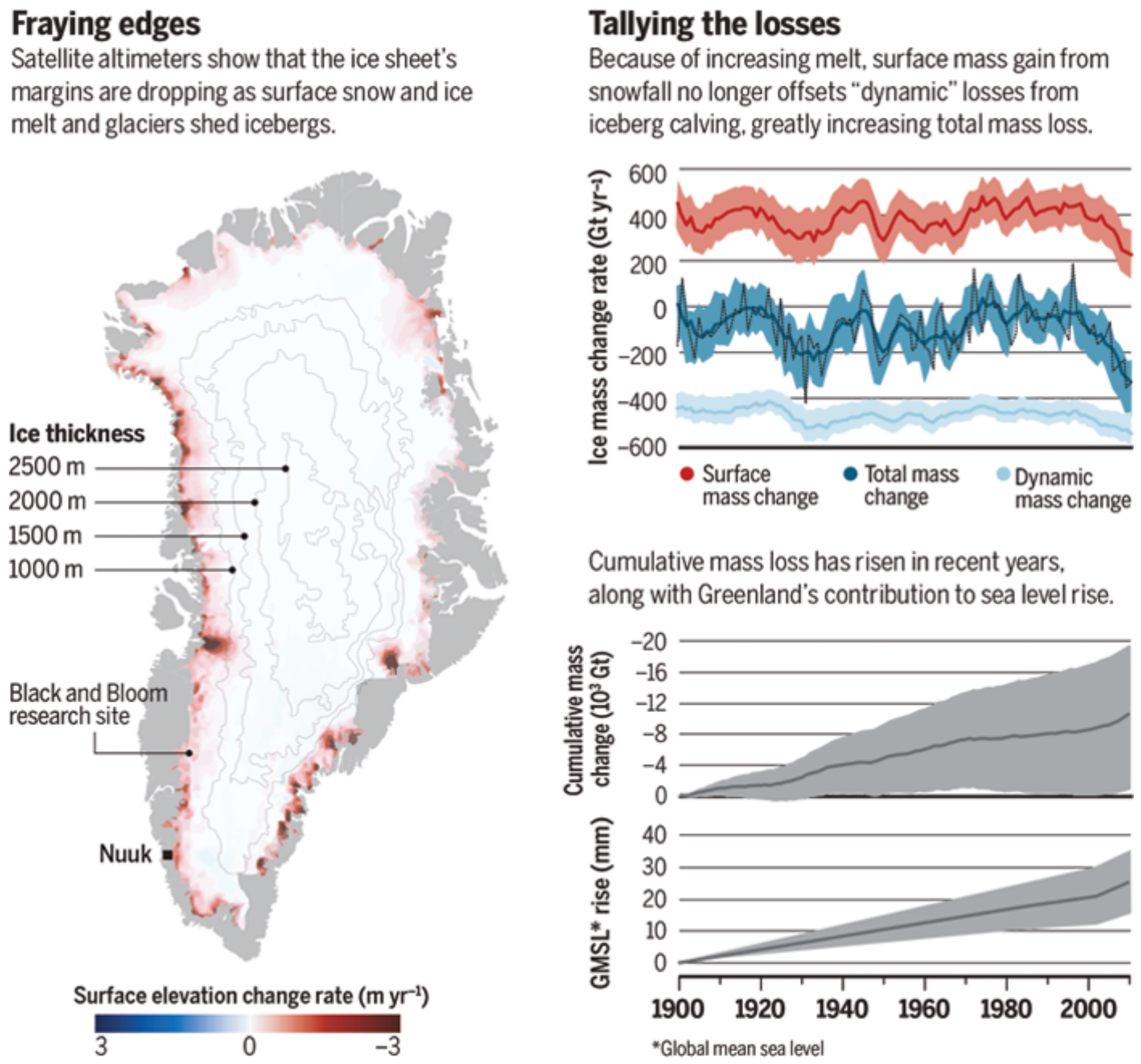
3 Dirty ice Soot, aerosol particles, and dust create dark spots and may feed microbial growth.

4 Cryoconite holes Dust, soot, and microbes form black gunk that coagulates in pits.

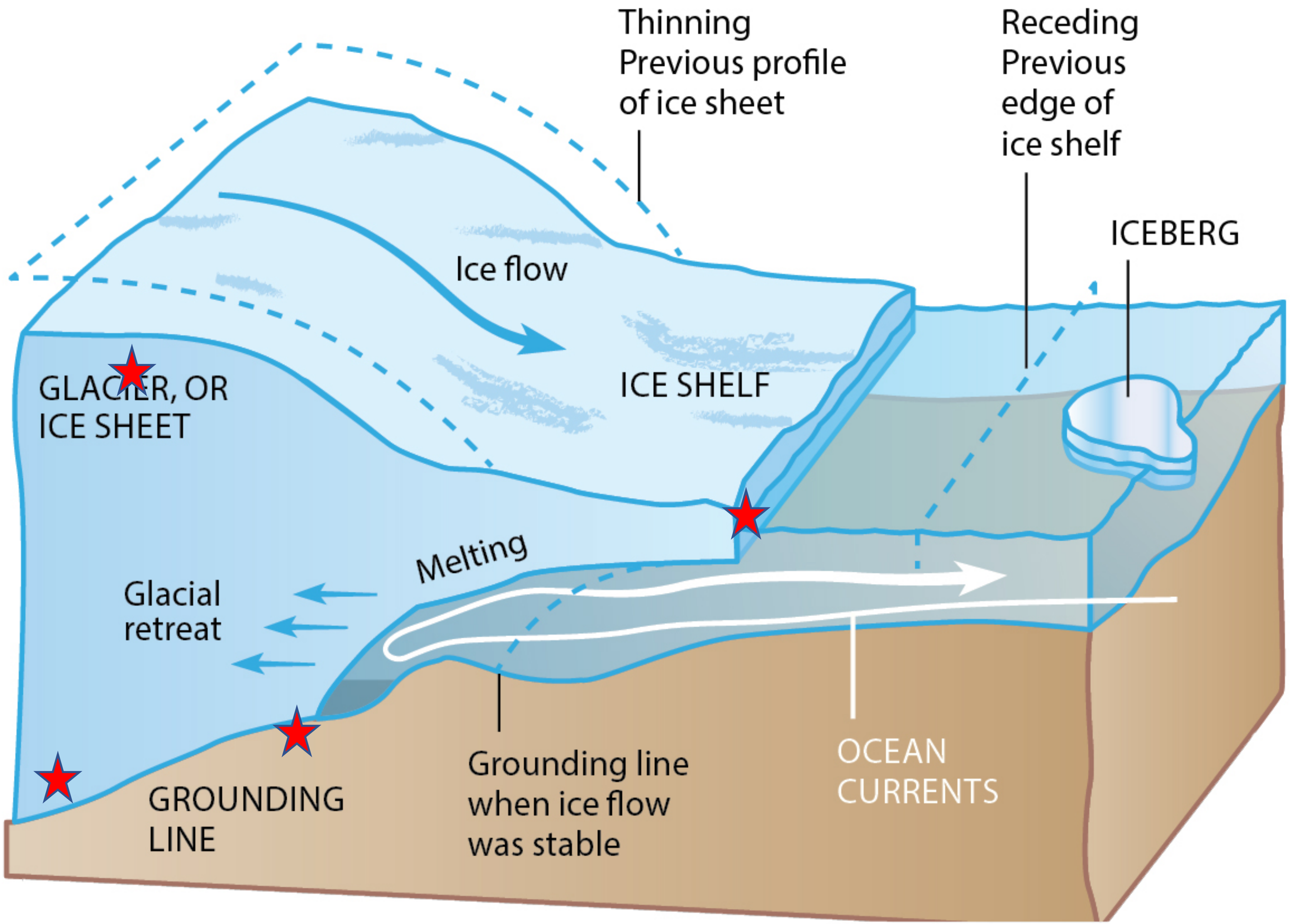
5 Subglacial water Gushing meltwater may speed the movement of glaciers by lubricating the bedrock below the massive ice.

https://www.sciencemag.org/news/2017/02/great-greenland-meltdown

Glaciers (Demise of the Greenland Ice sheet)



Glaciers (Demise of the West Antarctic Ice sheet)



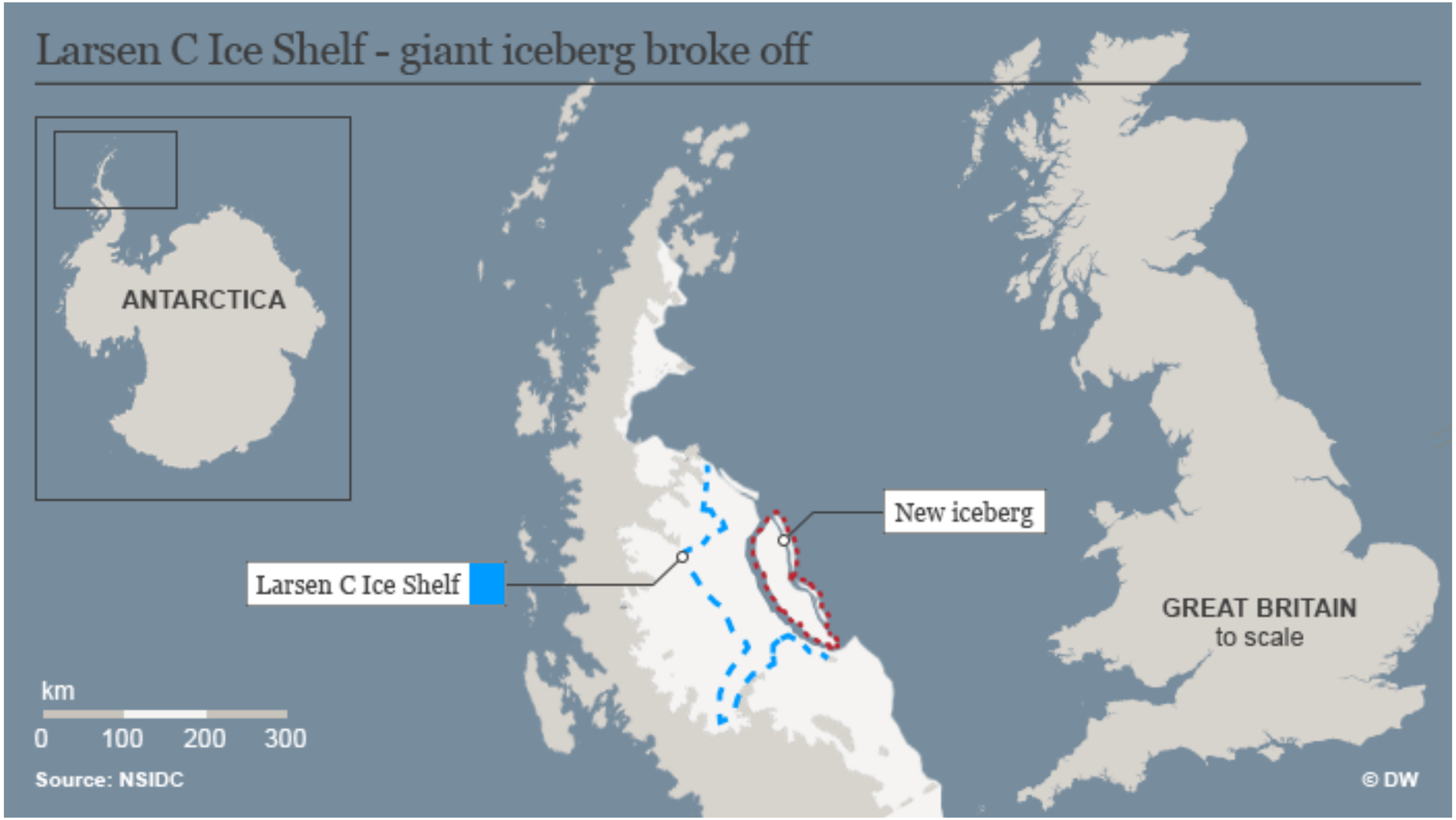
http://discovermagazine.com/2017/june/meltdown

Ice Shelves – What are they? Why care?

- Some glaciers extend to the ocean and **transition to ice shelves**
- Ice shelves **buttress glaciers and slow flow**
- **When ice shelves calve**, 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/

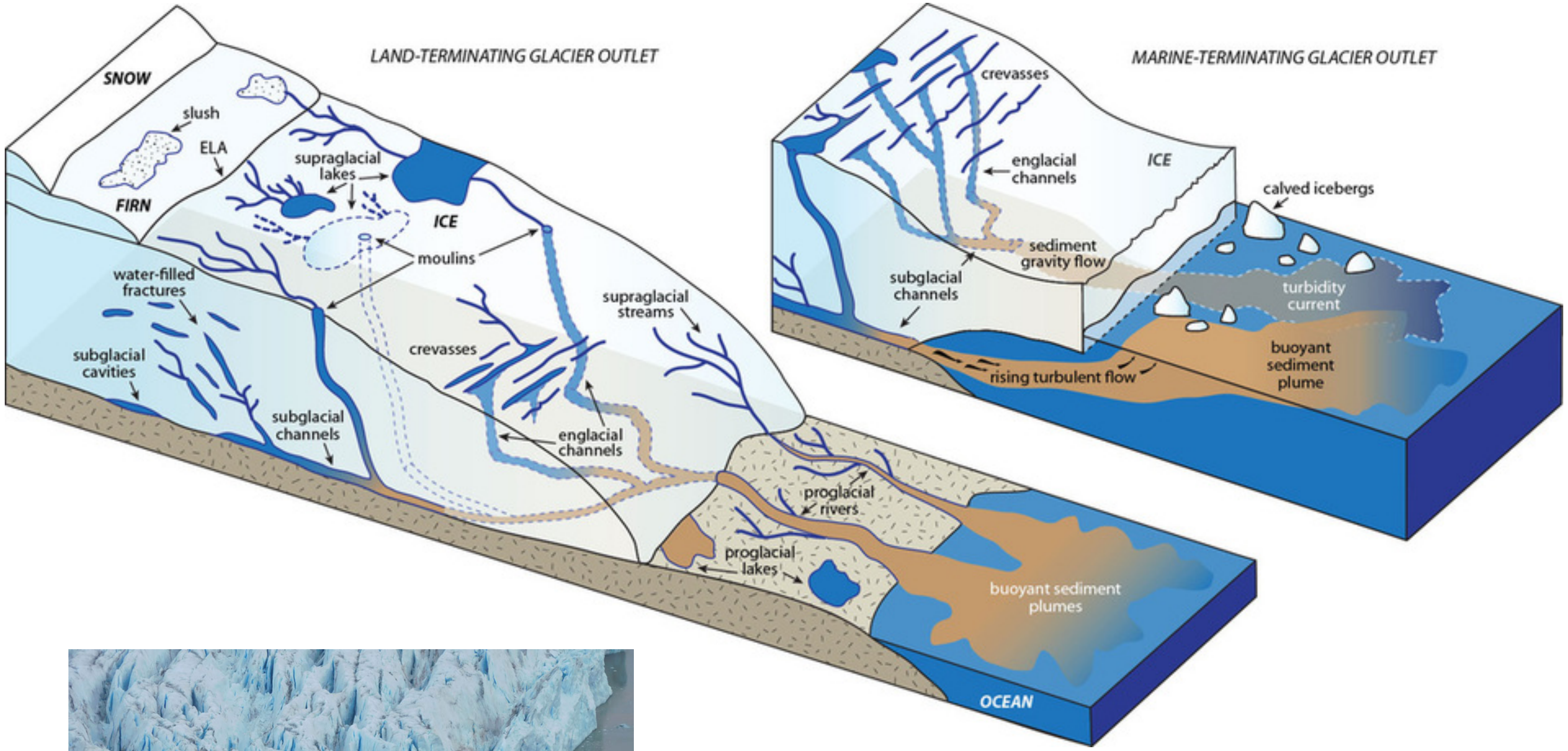
Ice Shelves – These are not small!



Ice Shelves – and sometimes, they detach

Icebergs – sourced from marine terminating glaciers

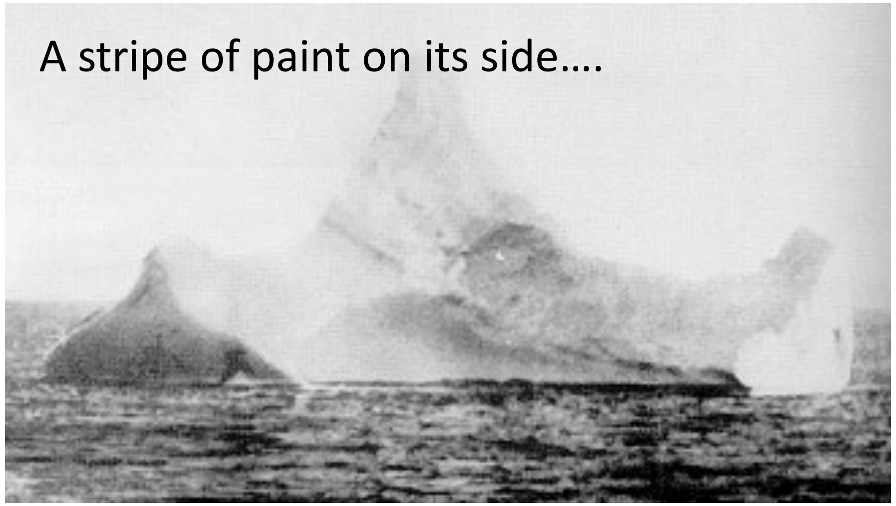
fa10239865 FreeArt



Density contrast between water and ice 0.9 vs 1.0 g/cm^3

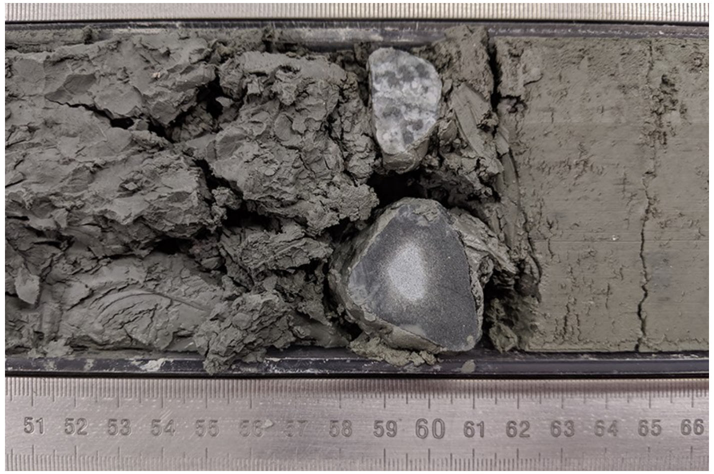
https://www.navcen.uscg.gov/?pageName=iipHowLargeWasTheIcebergThatSankTheTITANIC

Icebergs – sourced from marine terminating glaciers – best known for…disasters…



https://www.navcen.uscg.gov/?pageName=iipHowLargeWasTheIcebergThatSankTheTITANIC

Icebergs – source of debris used to know when glaciers were calving in the past…



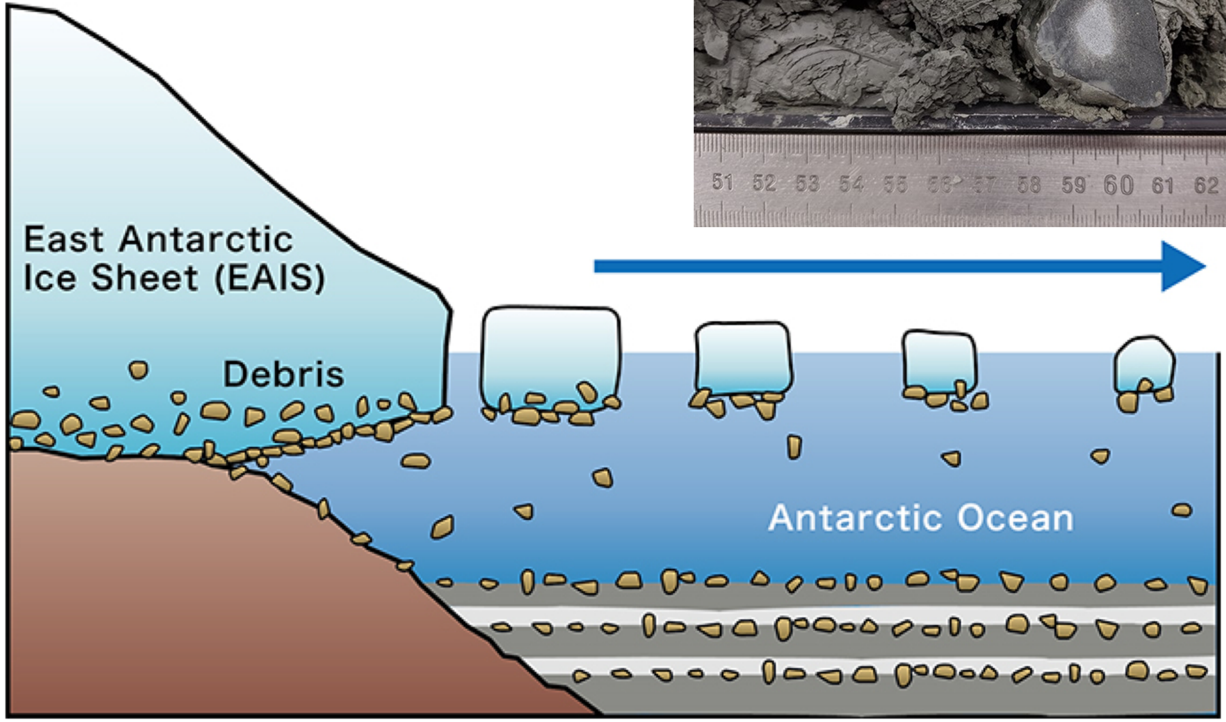


Fig.4. A diagram showing ice-berg rafted debris accumulating on the seafloor.

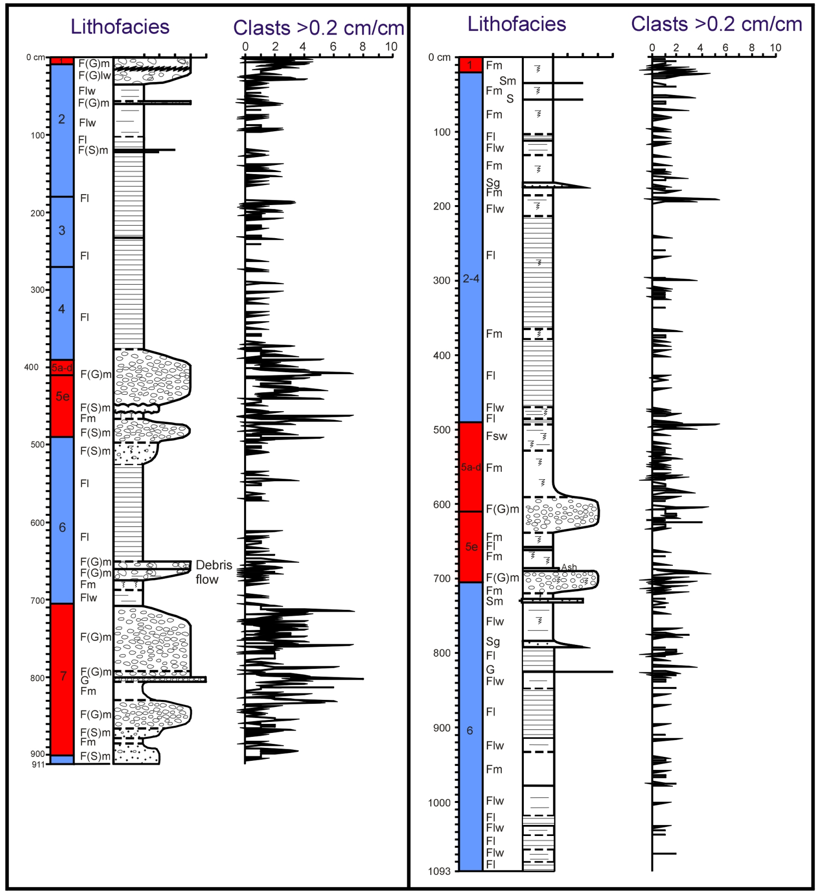
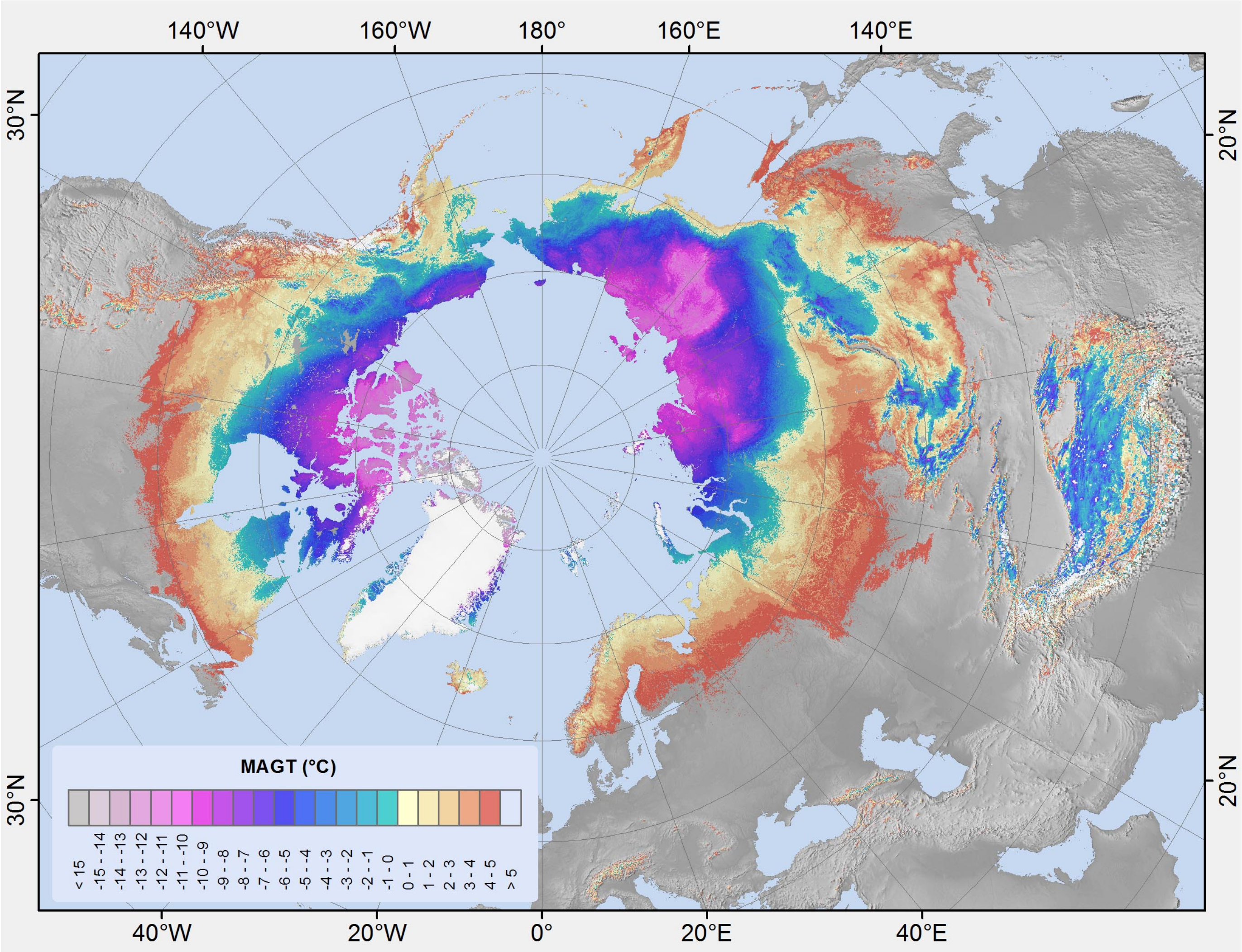


Fig. 2. Sediment cores from the Antarctic Peninsula continental margin.
(Source: modified from Ó Cofaigh et al., 2001; Quaternary Research).

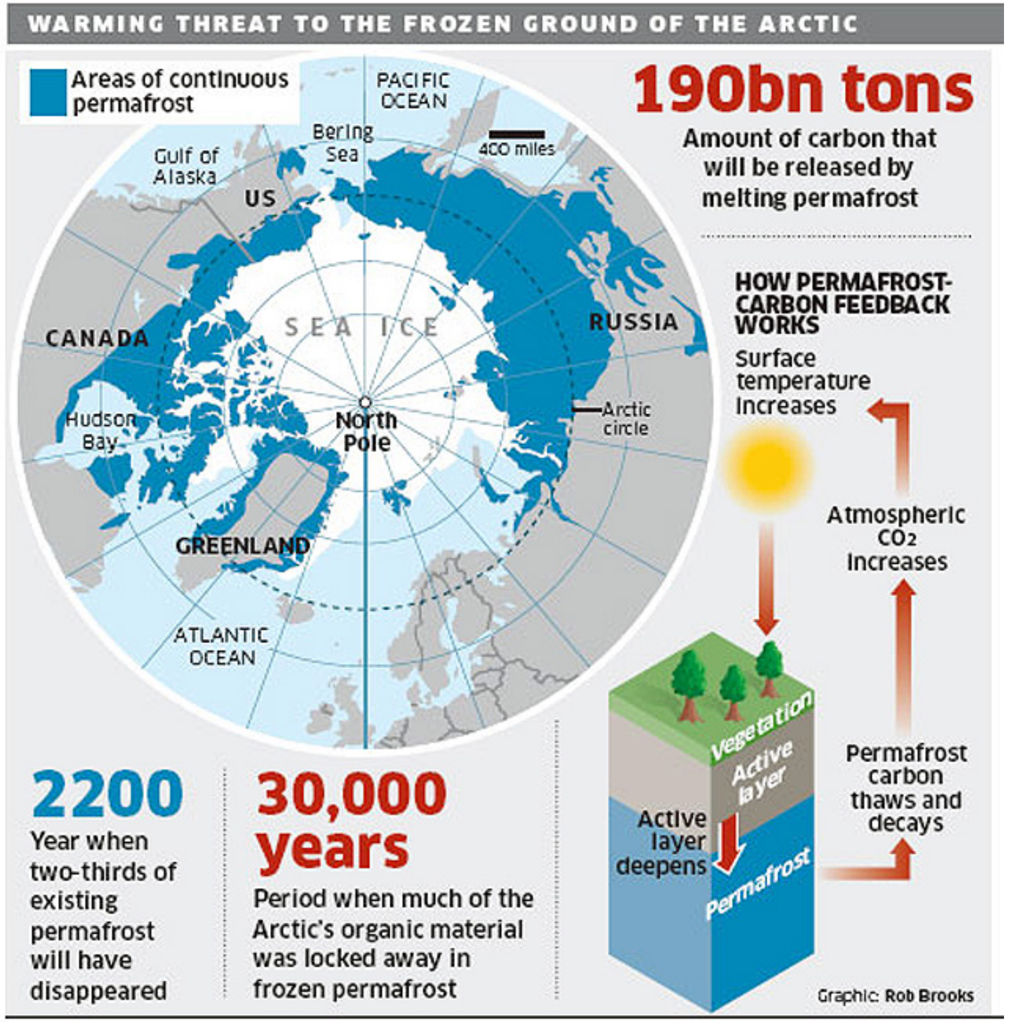
Permafrost – ground ice, mean annual ground T < 0C



Permafrost – tricky stuff – requires good engineering to prevent melting 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



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

Sea level – what matters and what does not!

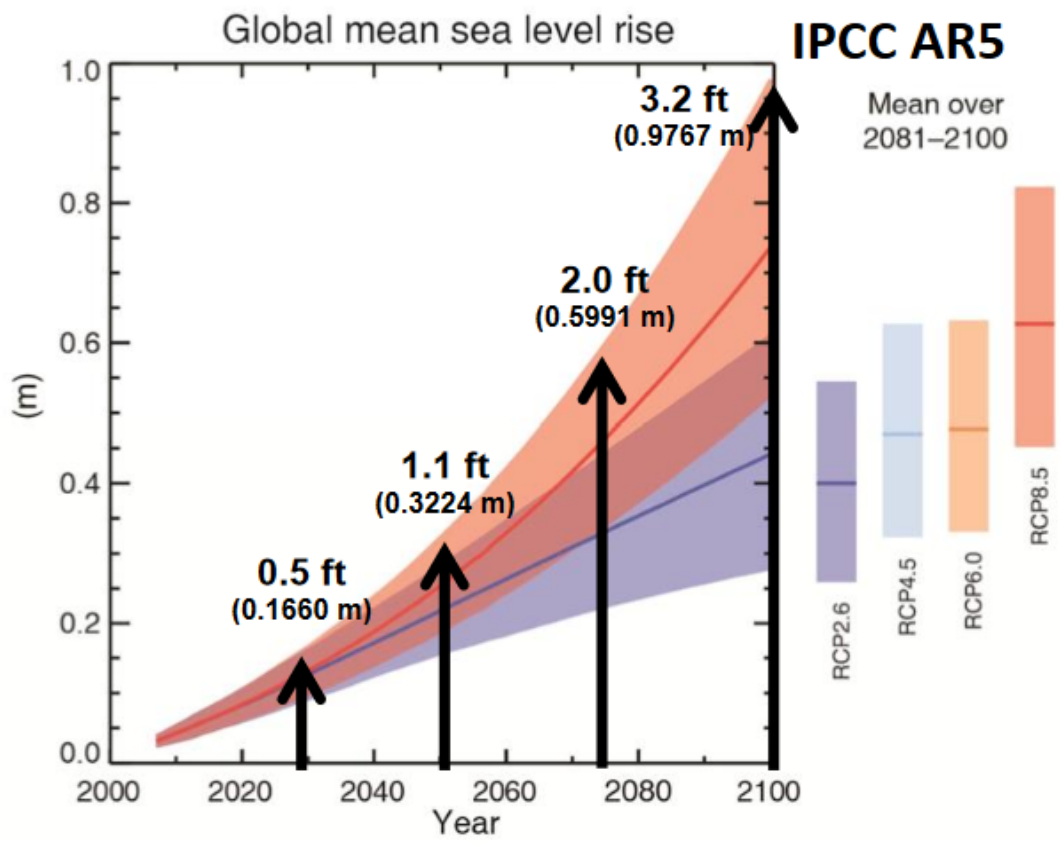
Sea level reflects the volume of ocean water and its temperature (since water expands when warm) with an adjustment for how the Earth deforms when loaded by water and ice.

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?

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 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

Next time - Climate Forcings and Feedbacks

- **We’ll do those complex orbital changes in Ruddiman Chapter 8**

AND

- **Understand how the three “knobs” of global climate (incoming solar radiation, albedo, the greenhouse effect) change over time and with human influence**
- **Understand and be able to provide specific examples of how feedback systems can amplify or diminish a climate system forcing**
- **Explain why a large, short-term perturbation to the climate system could create long-lasting effect**