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

Alaska just recorded its warmest July—and warmest month—on record, the National Oceanic and Atmospheric Administration (NOAA) announced Wednesday.
Alaska and the world are getting warmer BUT...how much warmer?

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

Arctic amplification

Global Temperature and Carbon Dioxide

CO₂ Concentration

Alaska Climate Research Center
Geophysical Institute UAF
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
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
Ocean Heat Transport

**Cold Eastern Boundary Currents**

**Warm Western Boundary Currents**

**Equatorial & Coastal Upwelling**

California: ~35°N 60°F Water Temp

North Carolina: ~35°N 75°F Water Temp
Atlantic Meridional Overturning Circulation (AMOC)

Critical to heat transport from equator to polar regions

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

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

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
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
Sea Ice – what is it?

https://nsidc.org/cryosphere/seaice/characteristics/formation.html;
Sea Ice – Why it matters, an important control on ocean heat flux and water vapor flux

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/
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/](https://www.harpersbazaar.com/culture/features/a23063189/women-in-science-glass-ceiling/)
Glaciers – What do they look like?

(a) Ice sheet

(b) Ice cap

(c) Cirque, Valley glacier

(d) Piedmont glacier
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.

What causes glacier movements
- precipitation
- melting/sublimation

Glacier movement
Glaciers – How does ice deform?

\[ \varepsilon = A \tau_b^n \]

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 \(-13^\circ\)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

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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
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.\n
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)

**Fraying edges**
Satellite altimeters show that the ice sheet’s margins are dropping as surface snow and ice melt and glaciers shed icebergs.

**Tallying the losses**
Because of increasing melt, surface mass gain from snowfall no longer offsets “dynamic” losses from iceberg calving, greatly increasing total mass loss.

Cumulative mass loss has risen in recent years, along with Greenland’s contribution to sea level rise.

*Global mean sea level*
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

Ice Shelves – These are not small!
Ice Shelves – and sometimes, they detach
Icebergs – sourced from marine terminating glaciers

Density contrast between water and ice: 0.9 vs 1.0 g/cm³

https://www.navcen.uscg.gov/?pageName=iipHowLargeWasTheIcebergThatSankTheTITANIC
Icebergs – sourced from marine terminating glaciers – best known for...disasters...

A stripe of paint on its side....

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 < 0°C
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 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