

Today: Melting Ice

- Changes in both extreme heat & precipitation patterns have been seen already
 - But the changes have been *somewhat small* compared to natural variations in climate
 - Predicted to be much larger in the future
- Climate change in the Arctic is part of **everyday life**
 - Changes have been **very significant** already

Questions to Think About

- What types of ice are melting most rapidly?
- Which types of melting ice cause sea level rise?
 - And what have been the main contributors to sea level rise so far?
- What are the impacts of melting ice?
 - On nature
 - On humans

News This Fall

- **Warming Revives Dream of Sea Route in Russian Arctic – New York Times**



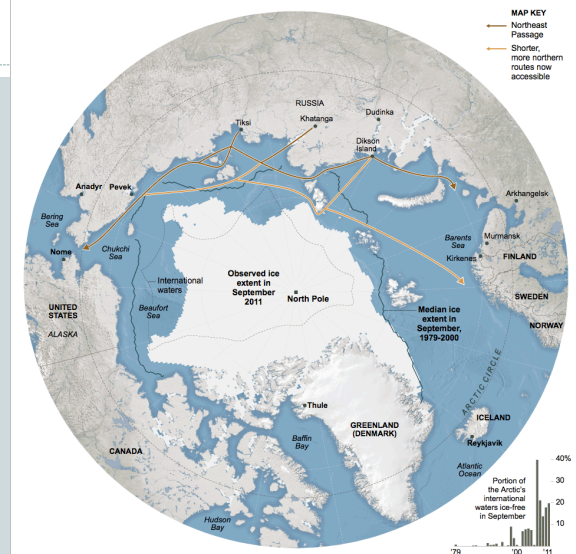
The tanker Vladimir Tikhonov in the Bering Strait.

New York Times,
Oct 2011.

In 2009, the [first two international commercial cargo vessels](#) traveled north of Russia between Europe and Asia. This year, 18 ships made the crossing.

The Northeast Passage Opens Up

The Arctic ice cap has been shrinking, opening up new shipping lanes. This has given access to oil and gas fields, as well as fishing in international waters that were not accessible before. *Reuters Arctic*

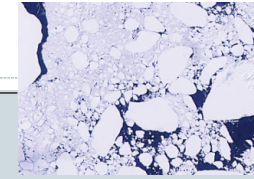


In the news

- Exxon signs deal to drill in Russian Sector of Arctic Ocean
- “It is paradoxical that new opportunities are opening for our nations at the same time we understand that the threat of carbon emissions have become imminent,” Iceland’s president, Olafur Ragnar Grimsson
- “The Arctic is the shortcut between the largest markets of Europe and the Asia-Pacific region,” he said. “It is an excellent opportunity to optimize costs.” -Vladimir Putin Russian PM

The **cryosphere**

sea ice



continental ice sheets

ice caps



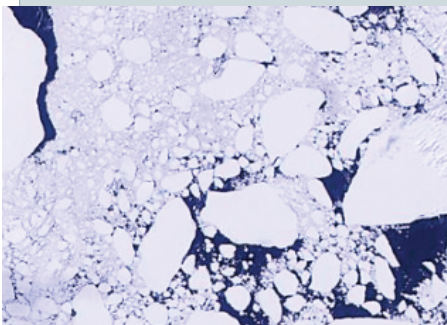
permafrost



mountain glaciers



snow cover



Sea ice

Sea Ice

- Forms from **frozen ocean water**
 - *Not the same as icebergs, which break off of land ice*
- Floats on the ocean surface
- Grows over the winter, melts in the summer



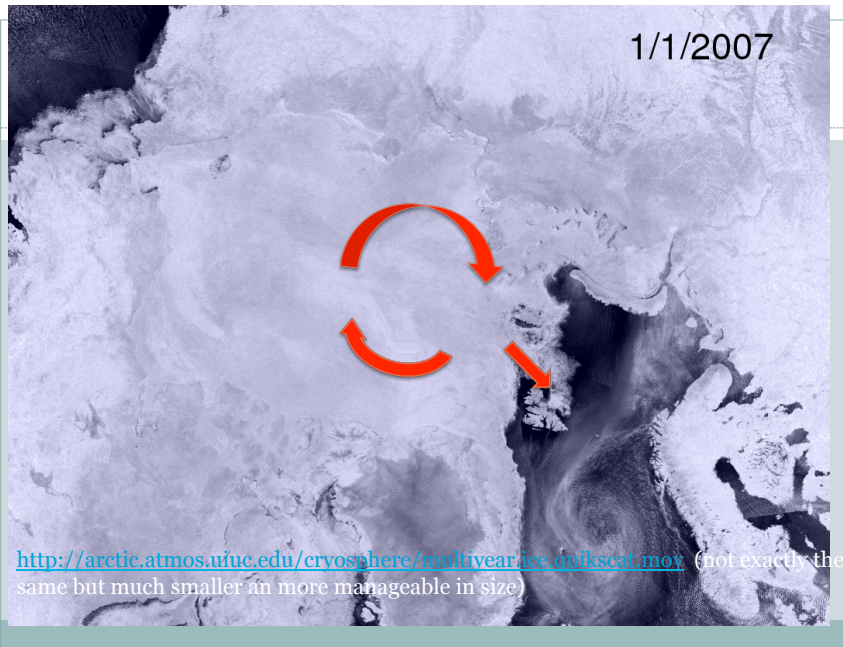
How thick is sea ice?

Arctic Sea Ice is typically 0.5 to 3 m thick

An exception is in *pressure ridges* which form when sea ice bumps into other sea ice. These can be 10-30 m thick

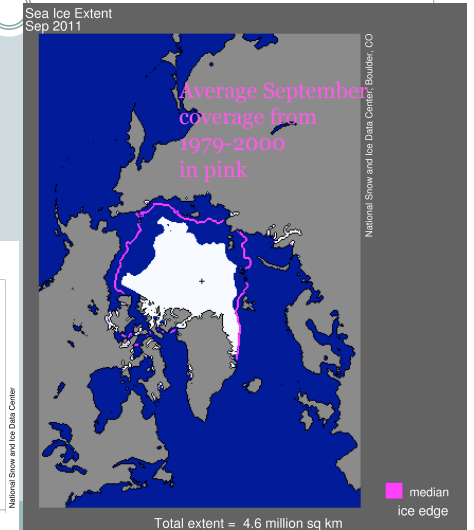
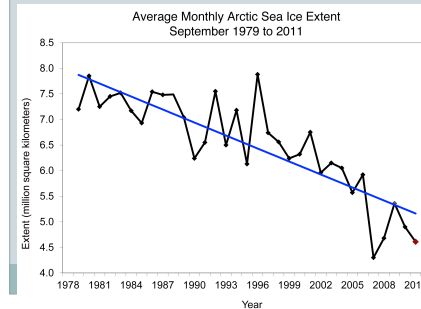


<http://svs.gsfc.nasa.gov/vis/a000000/a003500/a003547/index.html>



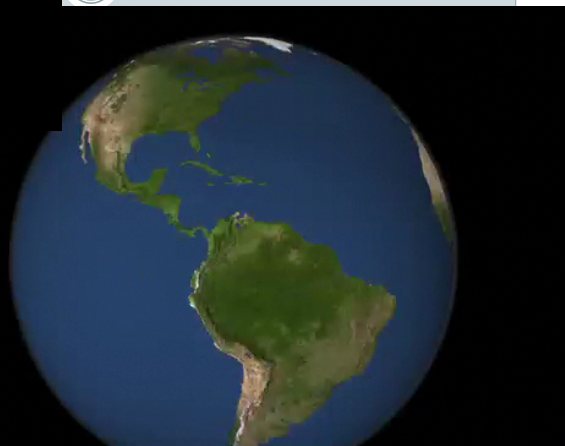
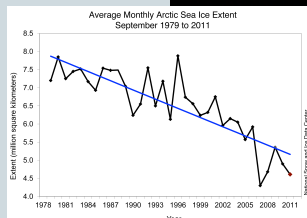
September Minimum Ice Extent

- Last 5 yrs: five lowest years in Arctic sea ice extent
- Recent summer Arctic sea ice coverage is **30% lower** than 30 years ago



Animation of September Sea Ice Coverage

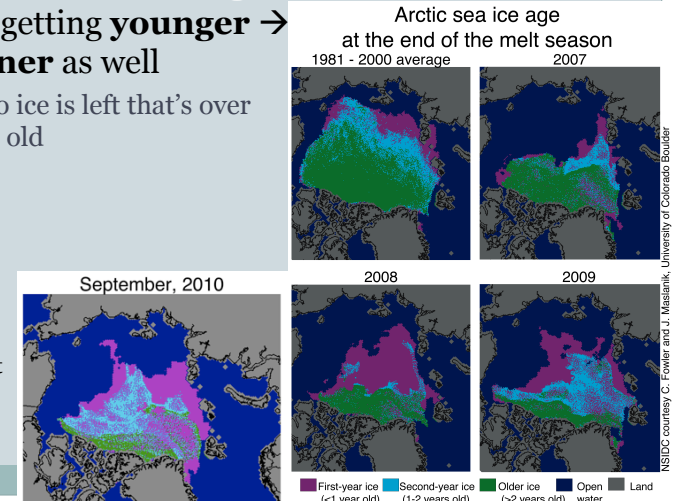
- Each year's Sep sea ice extent since 1979-2010



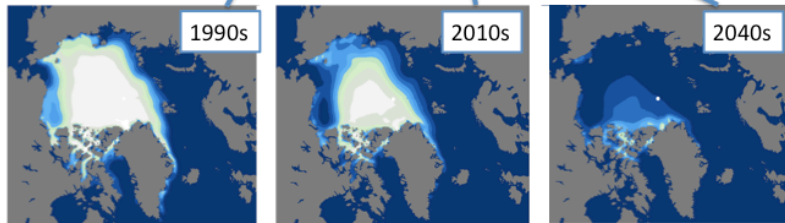
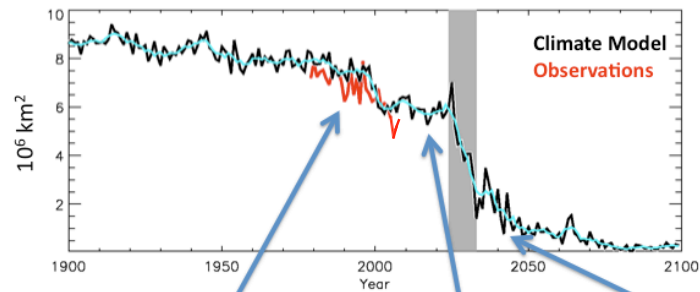
Winter Sea Ice

- Sea ice is getting **younger** → and **thinner** as well
 - Almost no ice is left that's over two years old

What do climate models say about the future of sea ice?

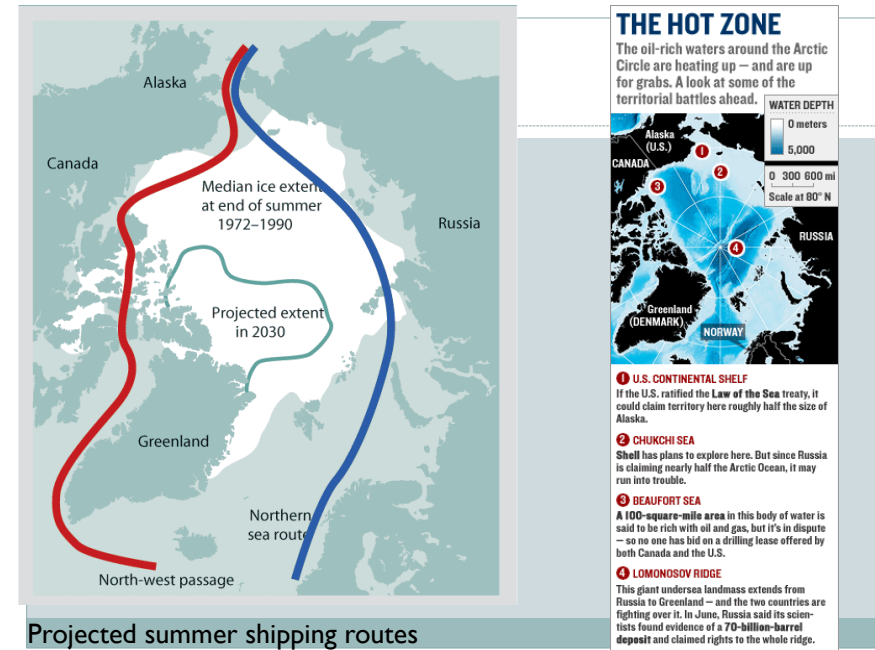


September Sea Ice Extent



UW Research (Prof. Cecilia Bitz)

Holland, Bitz, and Tremblay, 2006



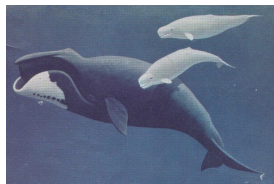
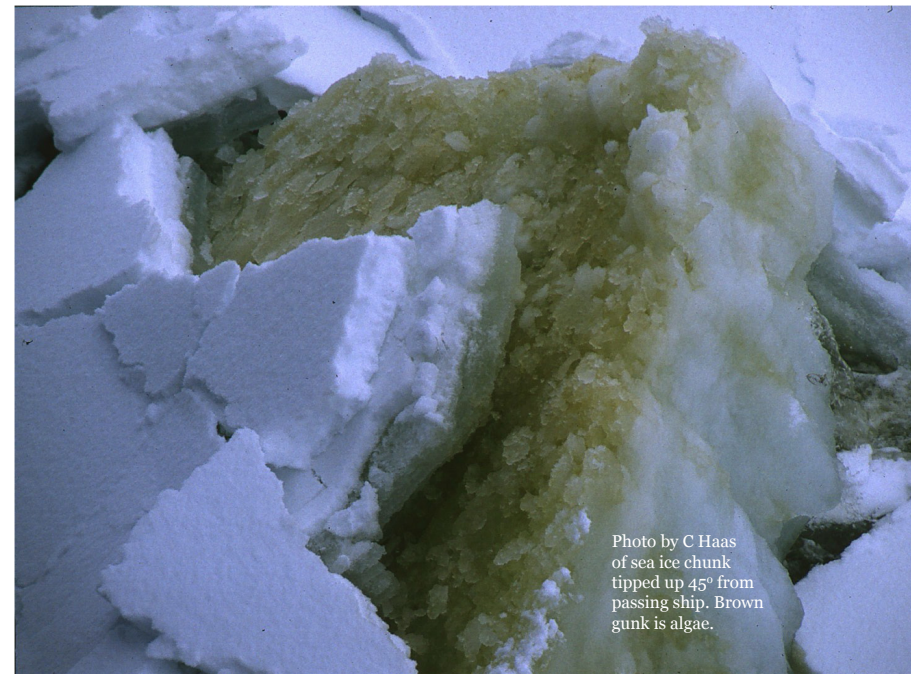
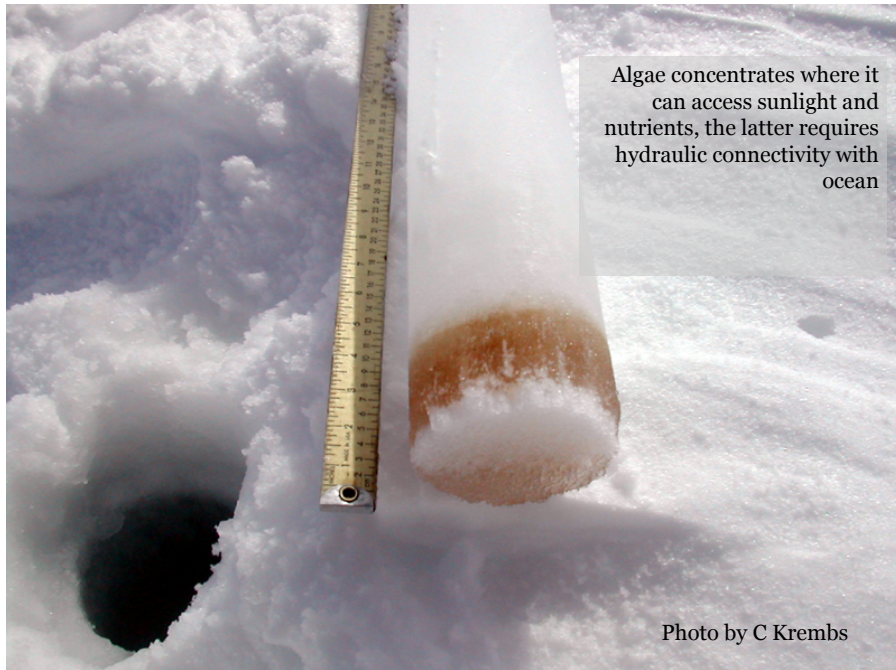
Projected summer shipping routes

How does sea ice loss affect **climate**?

- **Ice-albedo feedback** amplifies warming
- Although this albedo feedback takes place in high latitudes, energy is mixed north and south by the atmosphere (mostly transported poleward) and so **lower latitudes warm more too**

What are other **impacts** of sea ice loss?

- **Erosion** if sea ice disappears (it damps waves)
 - Thawing **permafrost** also causes surfaces to soften
- Fragile and specialized **ecosystems**



Bowhead and Beluga whales



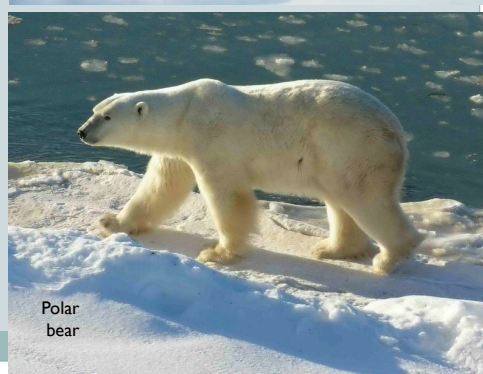
Harp seal



Northern fur seals



Walrus



Polar bear

Arctic wildlife



Emperor penguins (a)



Albatross



Krill



(c)



Leopard seal

Antarctic wildlife

Polar Bears

- Sea ice is key for polar bears to find food
 - They hunt for seals on the ice
 - Shorter season with ice connected to land means less time for feeding



http://www.interior.gov/secretary/speeches/081405_speech.html

U.S. Department of the Interior

Remarks By Secretary Kempthorne Press Conference On Polar Bear Listing May 14, 2008

Today I am listing the polar bear as a "threatened" species under the Endangered Species Act.

I believe this decision is most consistent with the record and legal standards of the Endangered Species Act – perhaps the least flexible law Congress has ever enacted.

I am also announcing that this listing decision will be accompanied by administrative guidance and a rule that defines the scope of impact my decision will have, in order to protect the polar bear while preventing unintended harm to the society and economy of the United States.

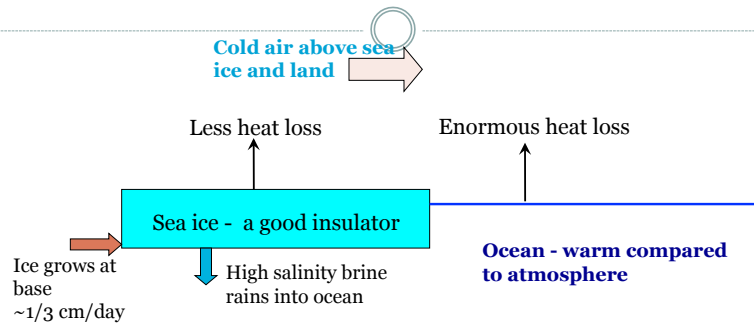
In taking these actions, I accept the recommendations of the Assistant Secretary for Fish and Wildlife and Parks, Lyle Lavery, and the Director of the U.S. Fish and Wildlife Service, Dale Hall. I also relied upon scientific analysis from the Director of the U.S. Geological Survey, Dr. Mark Myers, and his team of scientists.

The ESA protects vulnerable animals with two classifications:

- An "endangered" species is in danger of extinction
- A "threatened" species is likely to become an endangered species in the foreseeable future.

Today's decision is based on three findings. First, sea ice is vital to polar bear survival. Second, the polar bear's sea-ice habitat has dramatically melted in recent decades. Third, computer models suggest sea ice is likely to further recede in the future.

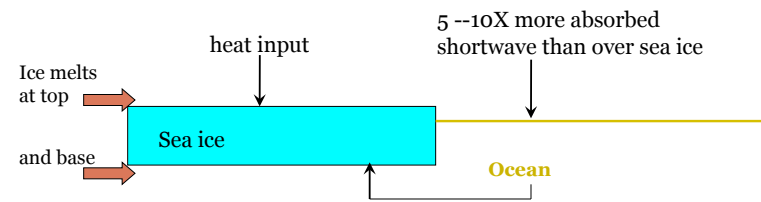
Arctic in winter (about 9 months)



Sea ice grows when the ocean cools to the freezing point. This happens very quickly in the absence of sunlight, wherever the ocean heat transport cannot keep pace.

Growth is inversely proportionate to thickness, so thin ice grows very fast

Arctic in summer (about 3 months)



Ice melts at top and bottom total rate of ~2 cm/day

Positive ice-albedo feedback as the ice retreats



Does the water level change when the ice melts?

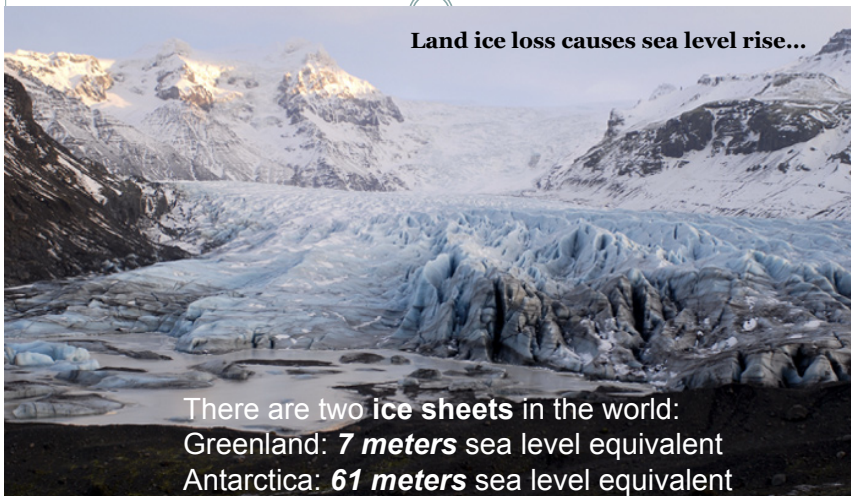
Does sea ice melting cause sea level rise?

Summary of Sea Ice

- Sea ice is melting rapidly in the Arctic
- Dangerous for animal habitats there
 - Polar bears
 - Ringed seals
- Coastal erosion enhanced nearby
- Sea ice melting **doesn't** lead to sea level rise though
 - **Land ice** melting does affect sea level – let's discuss that next

What about land ice?

Land ice loss causes sea level rise...

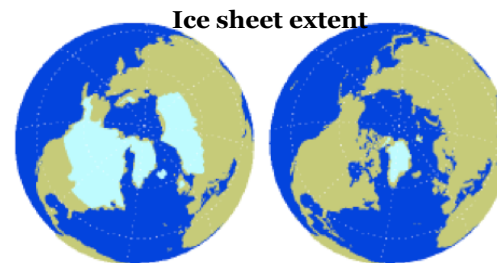


There are two **ice sheets** in the world:
 Greenland: **7 meters** sea level equivalent
 Antarctica: **61 meters** sea level equivalent

The Arctic is changing most rapidly, so let's start with Greenland...

Sea Level of the Past

- **Last Glacial Maximum** (15,000 yrs ago): **120 meters** lower sea level!
- **Cretaceous** (100 mil yrs ago): **>100 meters** higher!



Last Glacial Maximum

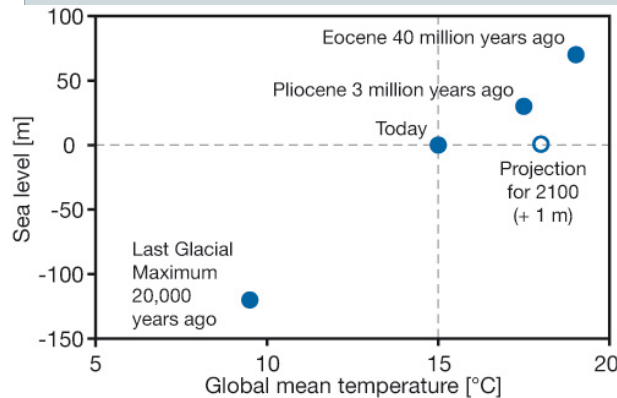
Present



The Cretaceous Seaway

Predictions of Sea Level Rise vs Past Changes

- Last time the temperature was 3° C warmer, sea level was **30 meters** higher...



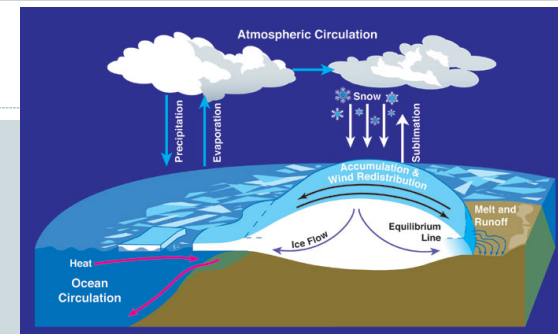
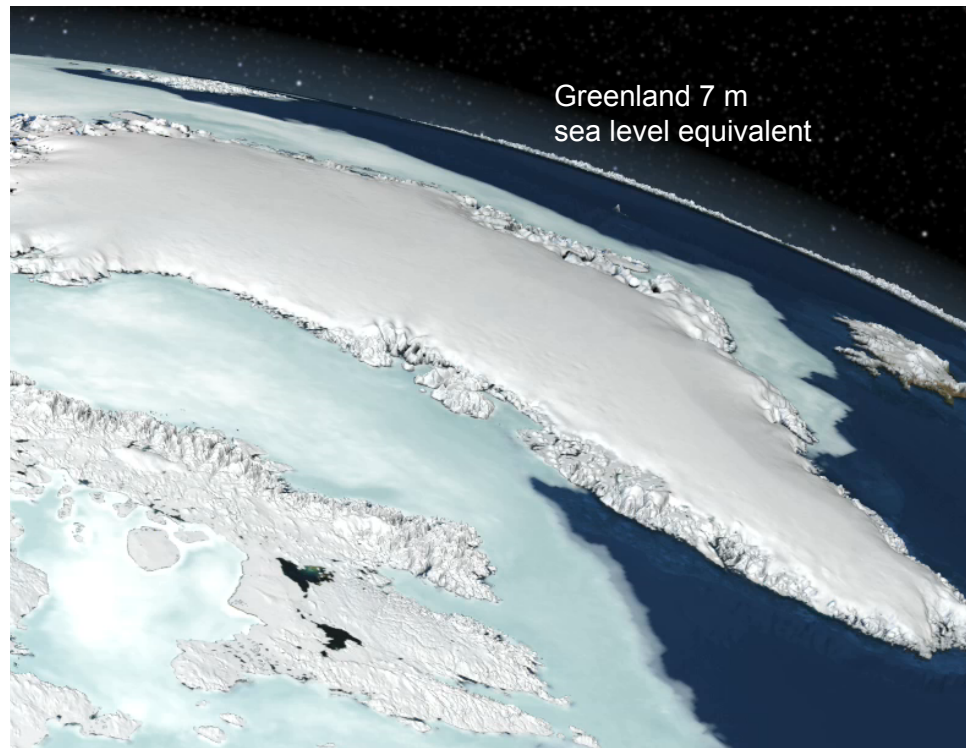
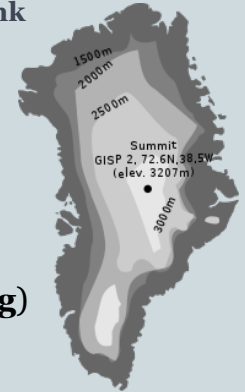
Sea levels have varied a huge amount in the past!

This is **not even close** to what's predicted though

We'll talk about why, and whether more extreme changes are possible

Greenland Ice Sheet

- Greenland ice sheet is ~100,000 yrs old
 - Ice sheet is a misnomer: more like **ice chunk**
 - ✦ Almost all over a mile high
 - Top of Greenland is approximately the height of **Mount Baker**
 - If it all went into the ocean, sea levels would go up by over 7 meters (22 feet)
- Mass loss can come from **melting** or **icebergs** breaking off (called **calving**)
 - Is Greenland losing mass?

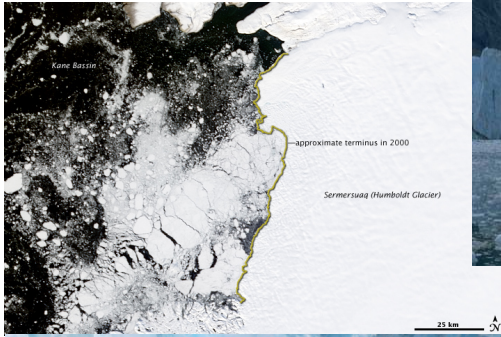


Mass balance of an ice sheet

Gains mass from **snow** on top

Loses mass from **melting** and **calving** of **icebergs**

Both **loss** and **gain** are **increasing** (increased precipitation at high latitudes)
Greenland is losing mass though (losses are bigger than gains)...



Glacier **calving**:
breaking of ice to form
icebergs

A natural process
but terminus of many
glaciers is retreating