ATM S 111: Global Warming

Ice: The Big Melt

Jennifer Fletcher

Day 15: July 12 2010

Today: Melting Ice

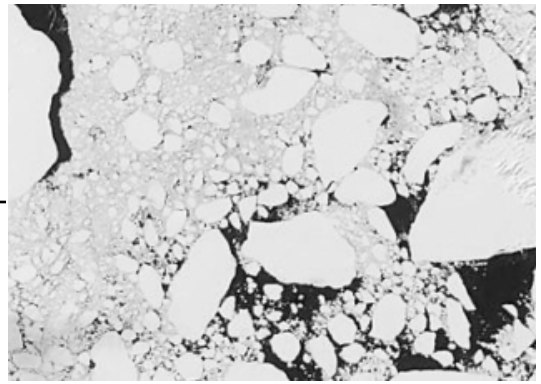
- Changes in both extreme heat & precipitation patterns have been seen already
  - But the changes have been *somewhat small*
  - Predicted to be much larger in the future
- Climate change in the Arctic is part of **everyday life**
  - Changes have been **huge** already

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

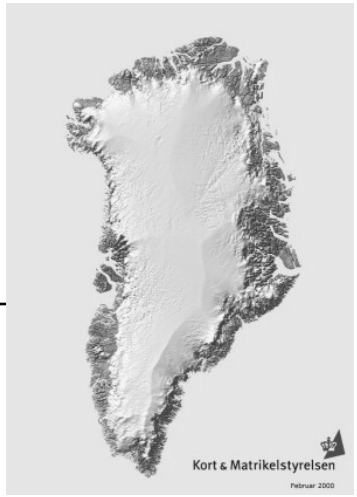
The ***cryosphere***

sea ice



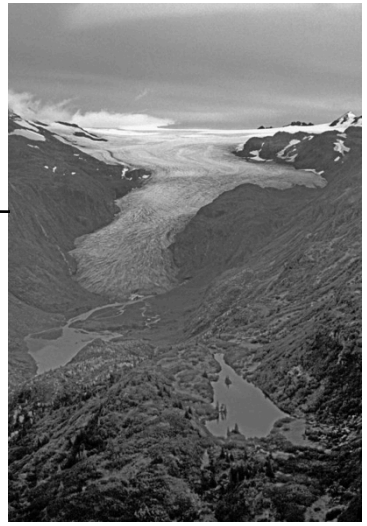
continental ice sheets

ice caps

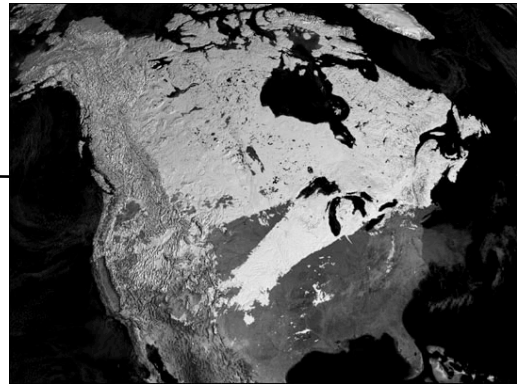


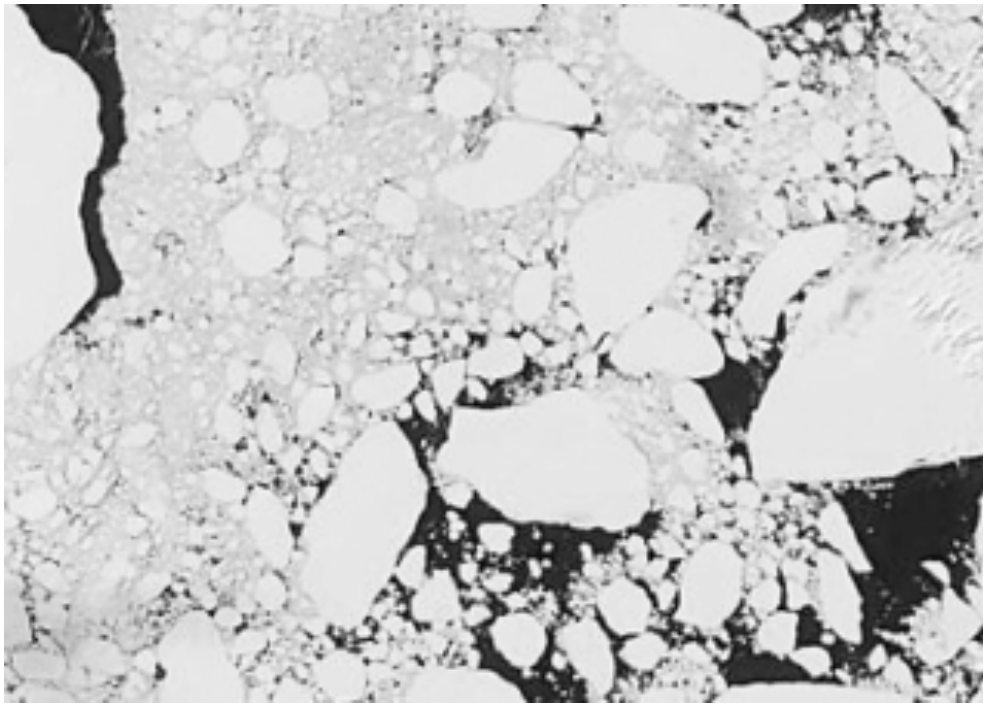
permafrost

mountain glaciers



snow cover

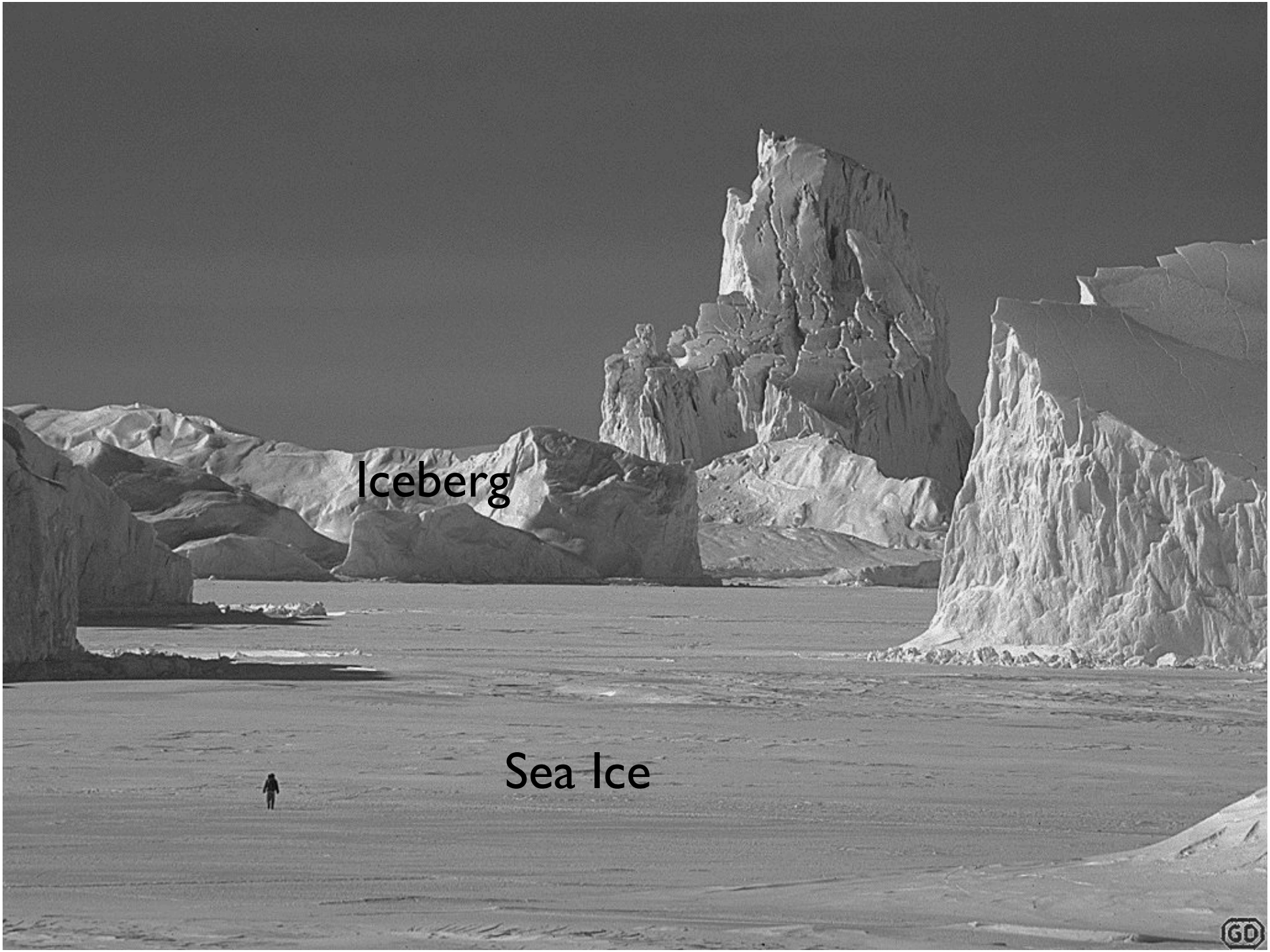





Sea ice

Sea Ice

- Forms from **frozen ocean water**
  - *Not* the same as icebergs, which break off of land ice
  - Generally much thinner
- Floats on the ocean surface
- Grows over the winter, melts in the summer – though much of it will last for several years.


Iceberg
Sea Ice

How thick is sea ice?

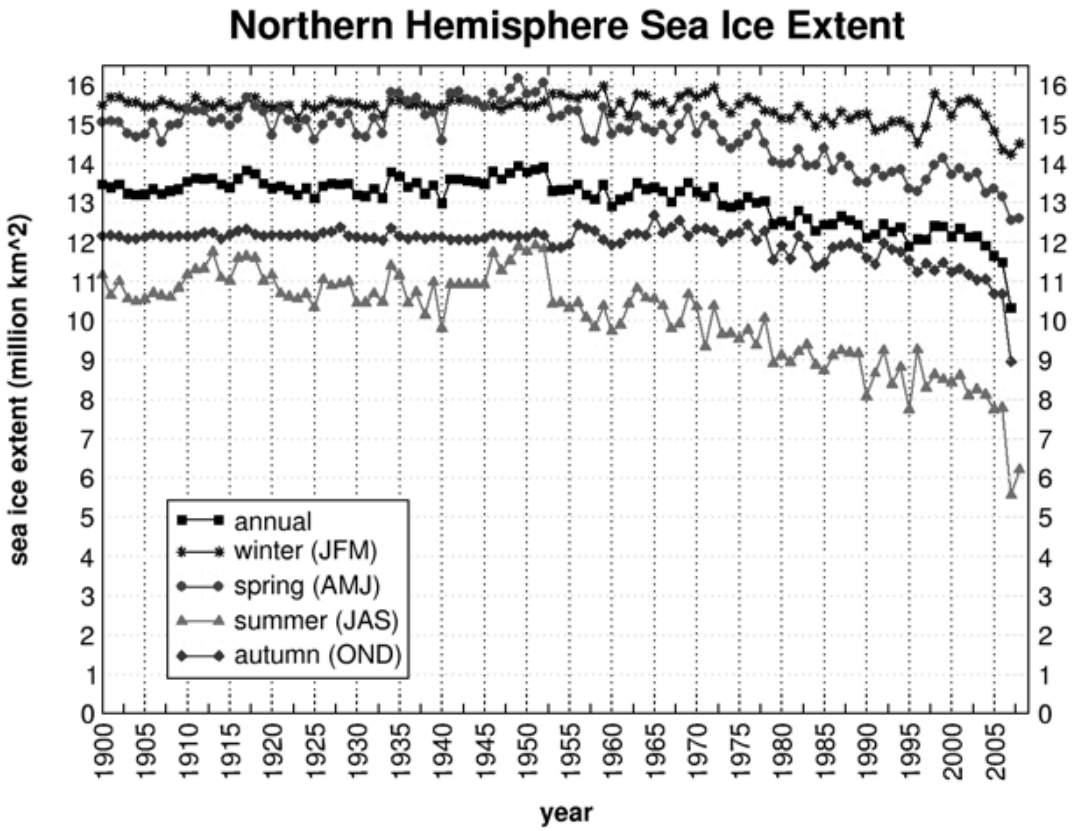
Arctic Sea Ice is typically 0.5 to 3 m thick

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


A scientific research team on sea ice

Melting Sea Ice

- Recent autumn Arctic sea ice coverage is 30% lower than 30 years ago

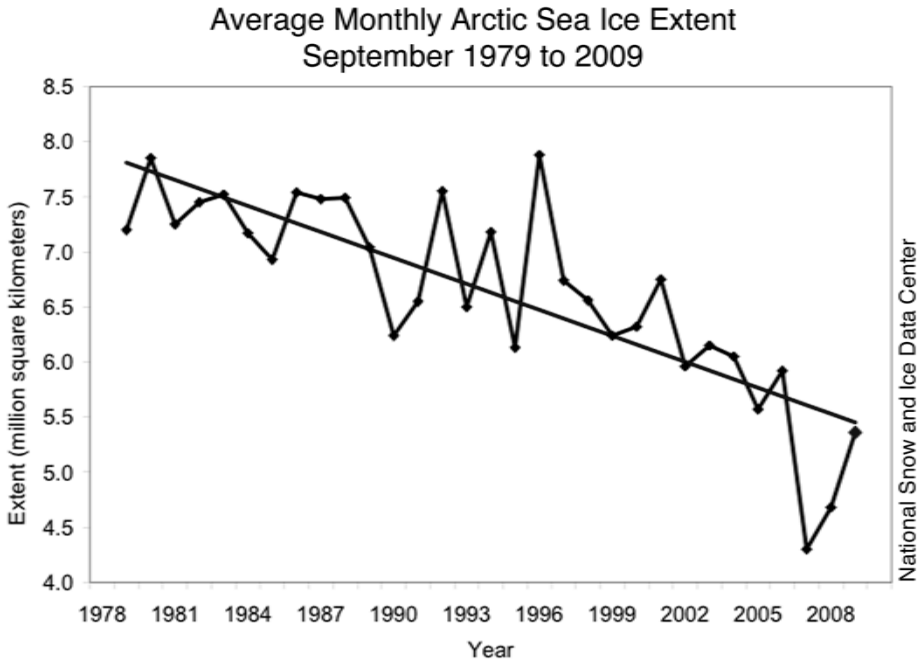


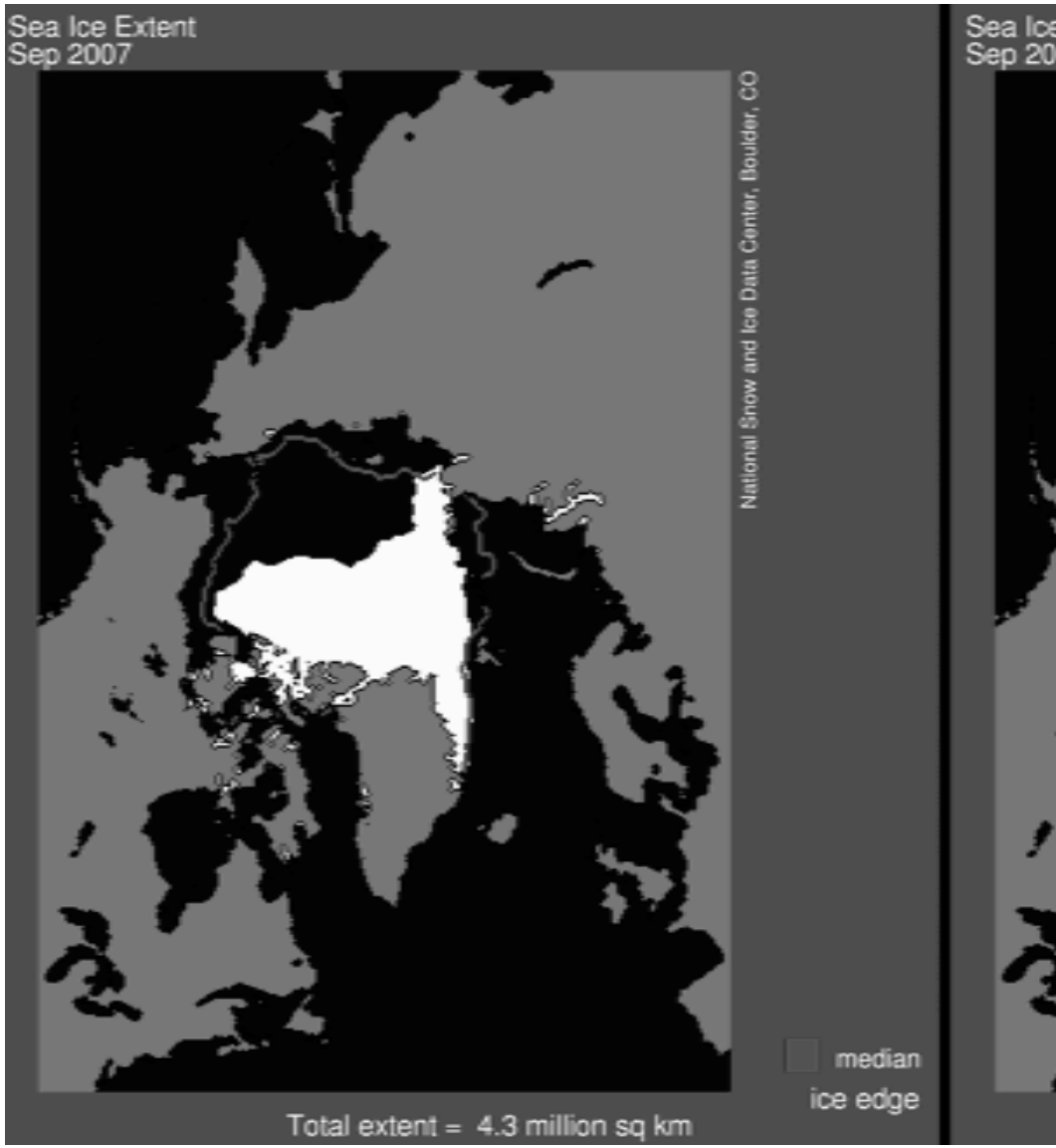
Especially **2007** was an extremely anomalous year

Last 3 autumns have been the three lowest years in Arctic sea ice extent on record.

September Minimum Ice Extent

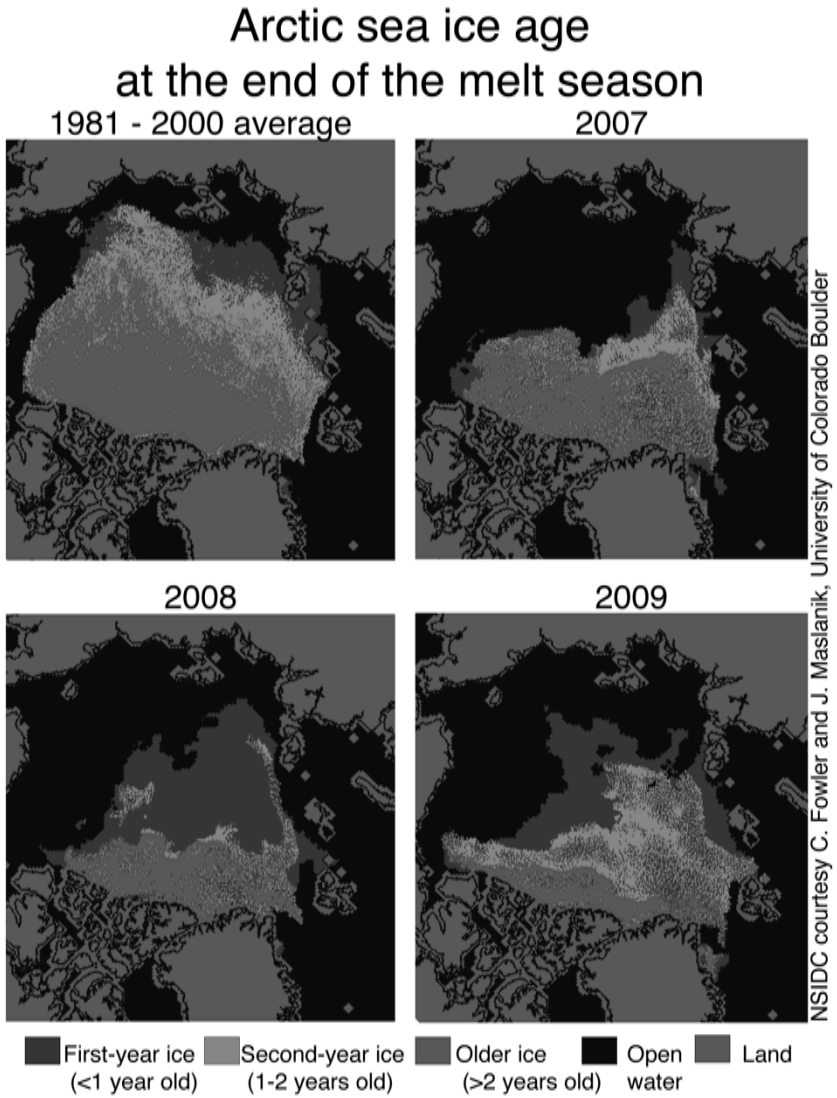
- September 2007 → shattered all previous records



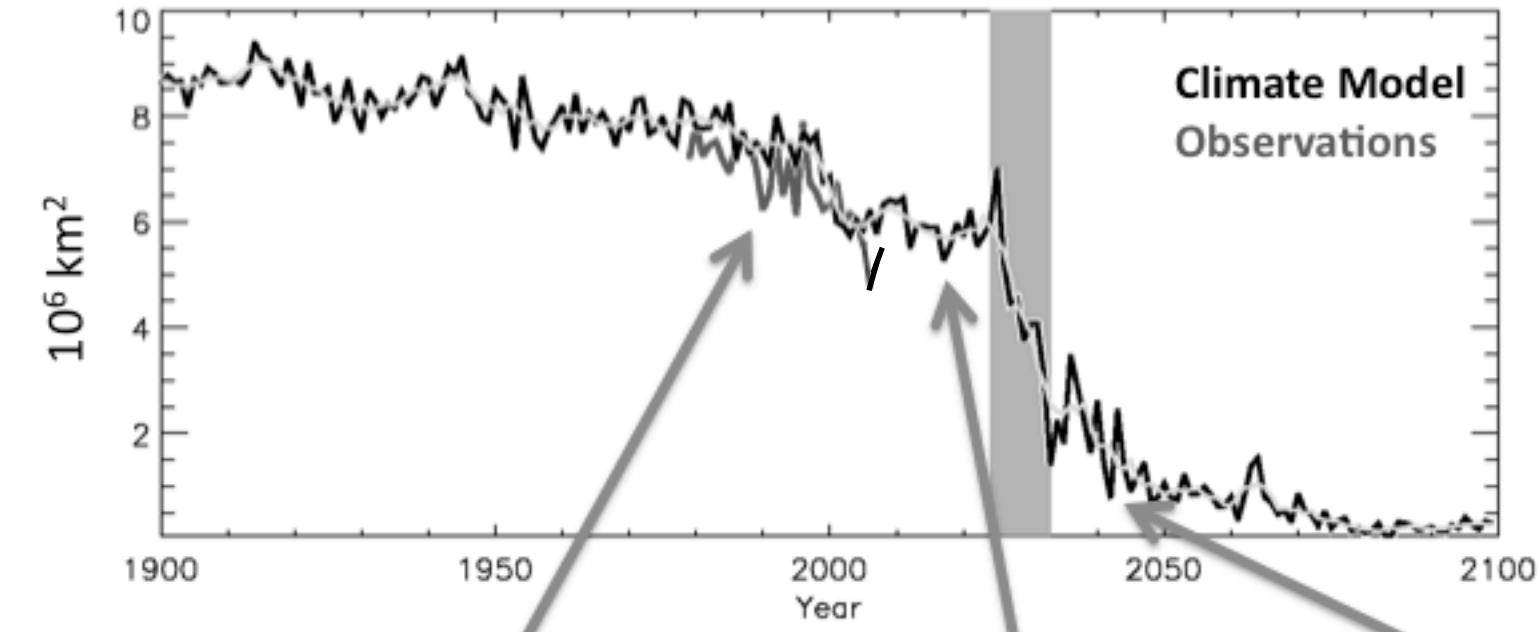


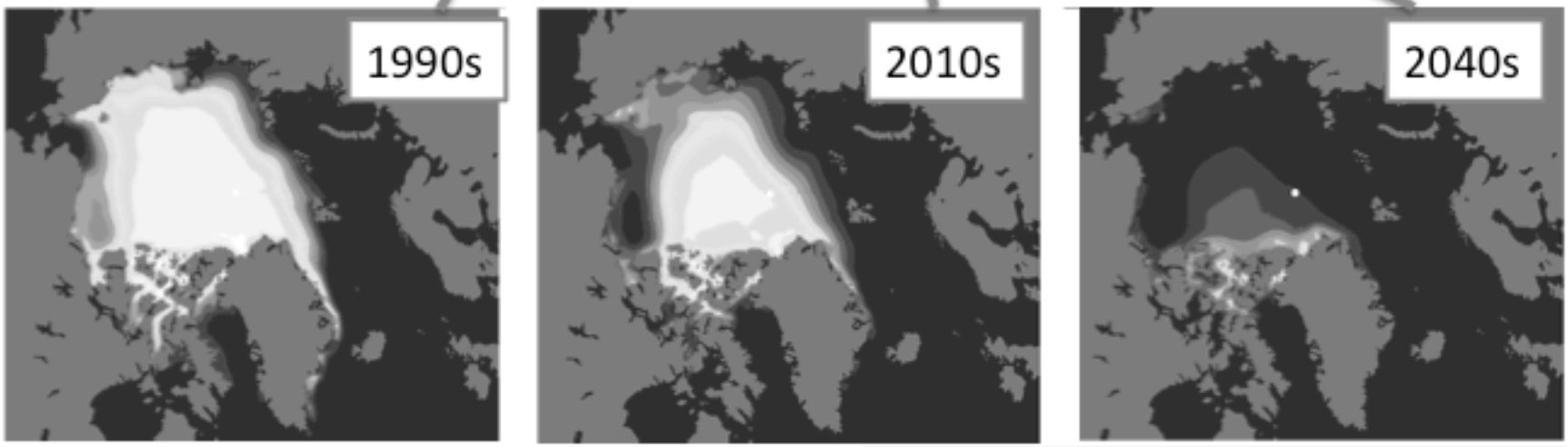
September Sea Ice

- Sea ice always grows back in the winter
  - When there's no sunlight and it's extremely cold, the seawater freezes
- Ice is getting **younger** → and **thinner** because more of the winter ice is melting in the summer.
- What are the predictions of future ice loss?



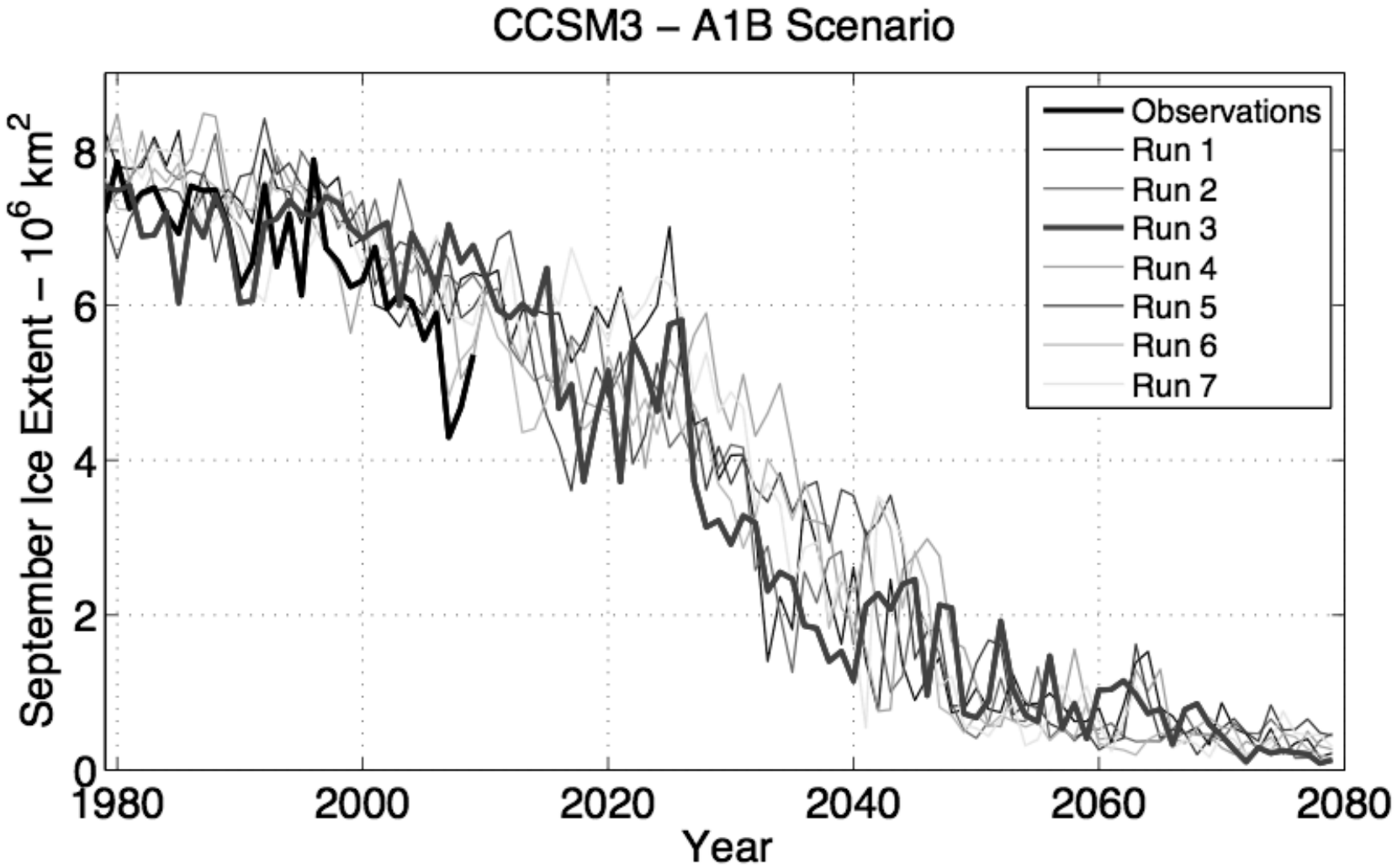
September Sea Ice Extent





UW Research (Cecilia Bitz)

Holland, Bitz, and Tremblay, 2006



Trend and year-to-year variability is well represented in some models
note occasional decade of little change

Holland et al 2006, 2008

Projected summer shipping routes

THE HOT ZONE

The oil-rich waters around the Arctic Circle are heating up — and are up for grabs. A look at some of the territorial battles ahead.

1 U.S. CONTINENTAL SHELF

If the U.S. ratified the **Law of the Sea** treaty, it could claim territory here roughly half the size of Alaska.

2 CHUKCHI SEA

Shell has plans to explore here. But since Russia is claiming nearly half the Arctic Ocean, it may run into trouble.

3 BEAUFORT SEA

A 100-square-mile area in this body of water is said to be rich with oil and gas, but it's in dispute — so no one has bid on a drilling lease offered by both Canada and the U.S.

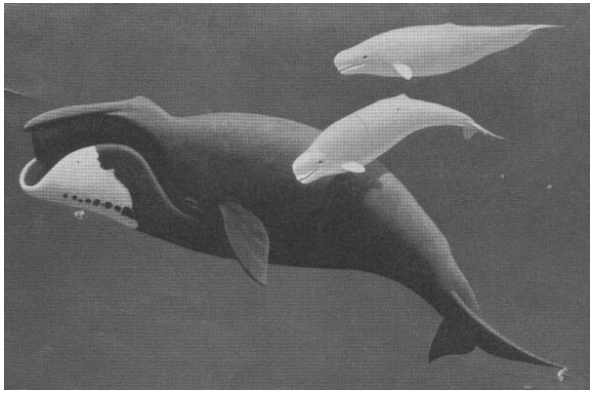
4 LOMONOSOV RIDGE

This giant undersea landmass extends from Russia to Greenland — and the two countries are fighting over it. In June, Russia said its scientists found evidence of a **70-billion-barrel deposit** and claimed rights to the whole ridge.

INTERNATIONAL MAPPING

What's so special about Arctic climate **impacts**?

- Fragile and specialized **ecosystems**
- Rising **sea level** problem?
- **Erosion of land** if sea ice disappears (it buffers land against harsh waves)
- Thawing **permafrost** causes surfaces to soften



Bowhead and Beluga whales

Walrus

Harp seal

Northern fur seals

Polar bear

Arctic 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 Laverty, 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.

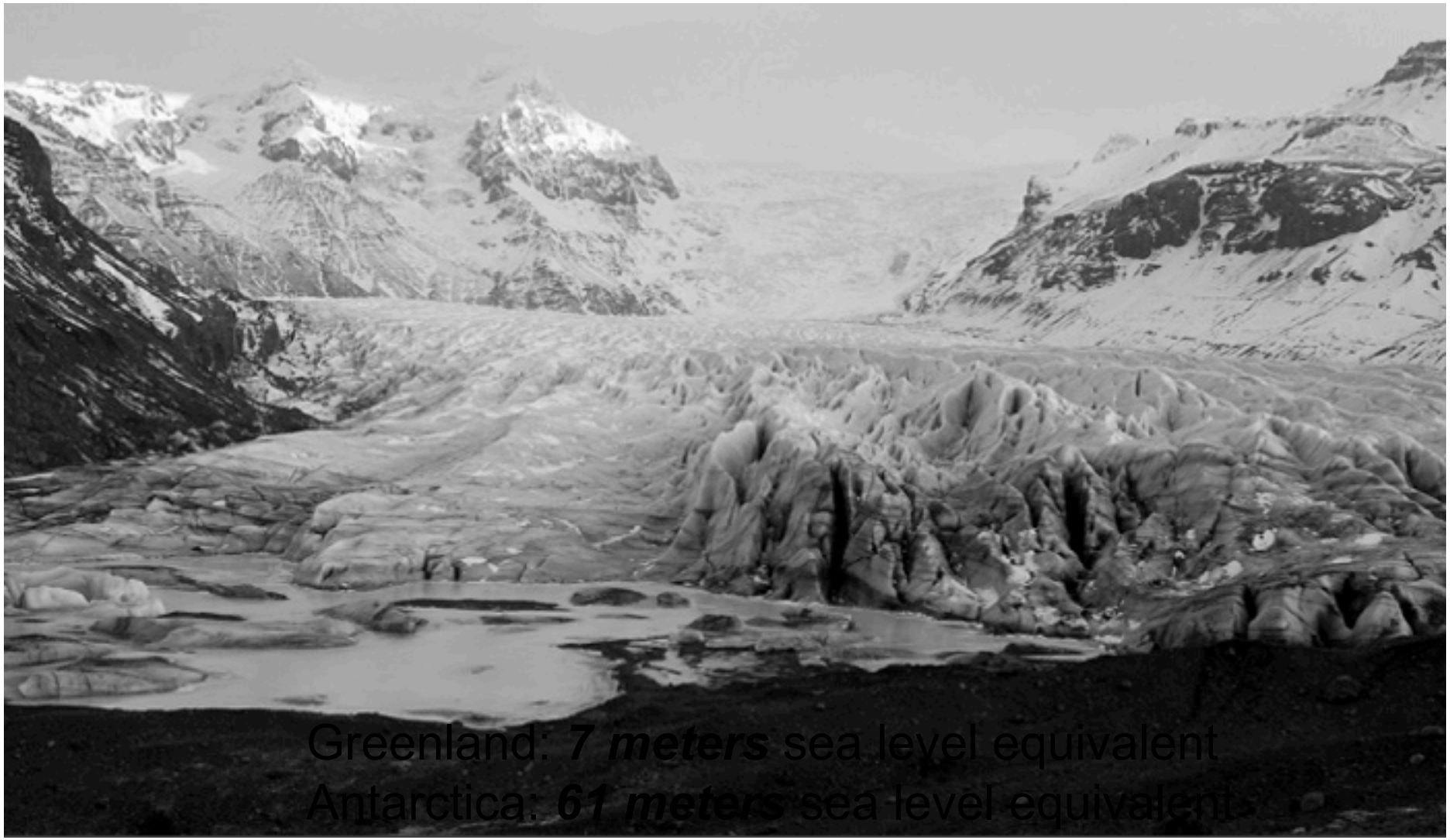
Does the water level change when the ice melts?

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

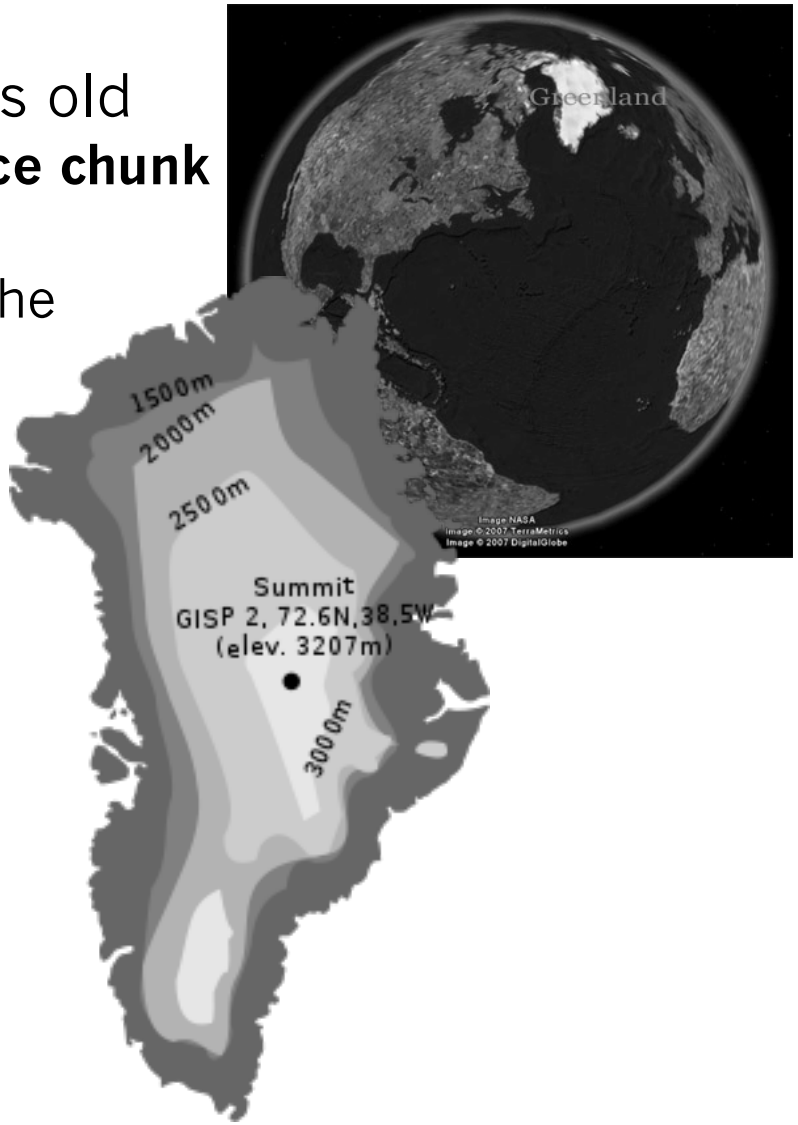
What about land ice?



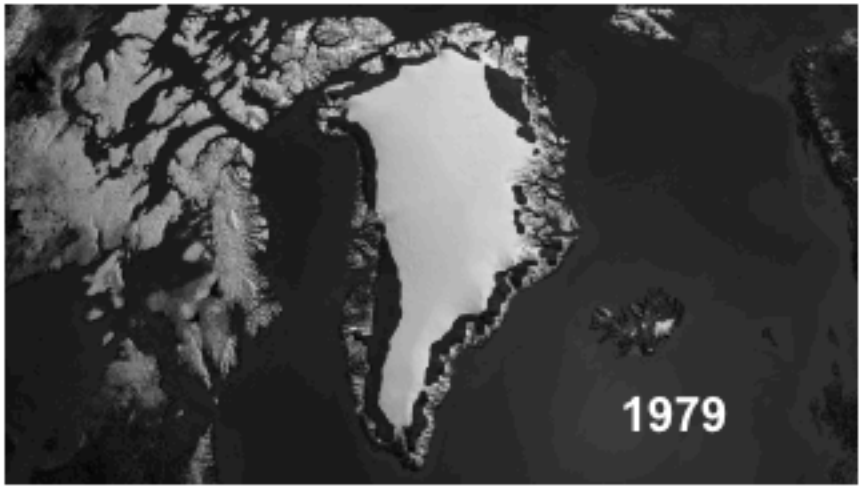
The Arctic is changing most rapidly, so let's start with Greenland...

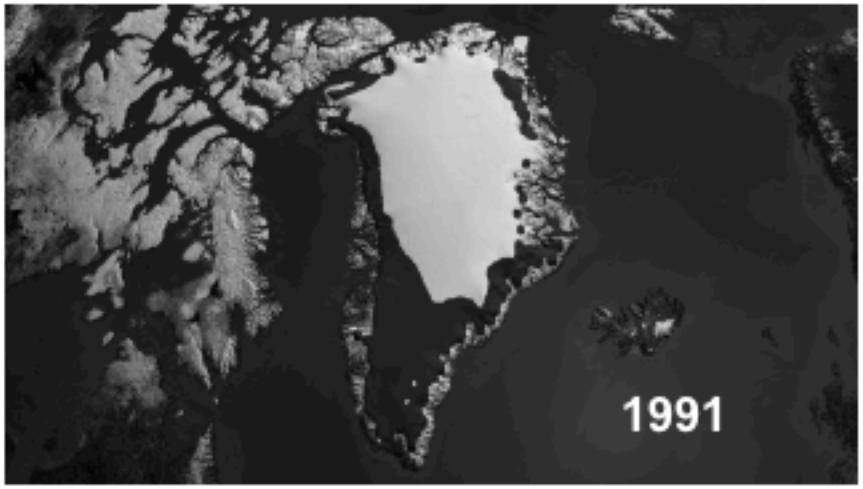
Greenland Ice Sheet

- 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 melted, sea levels would go up by over 7 meters (22 feet)
- Is it melting?

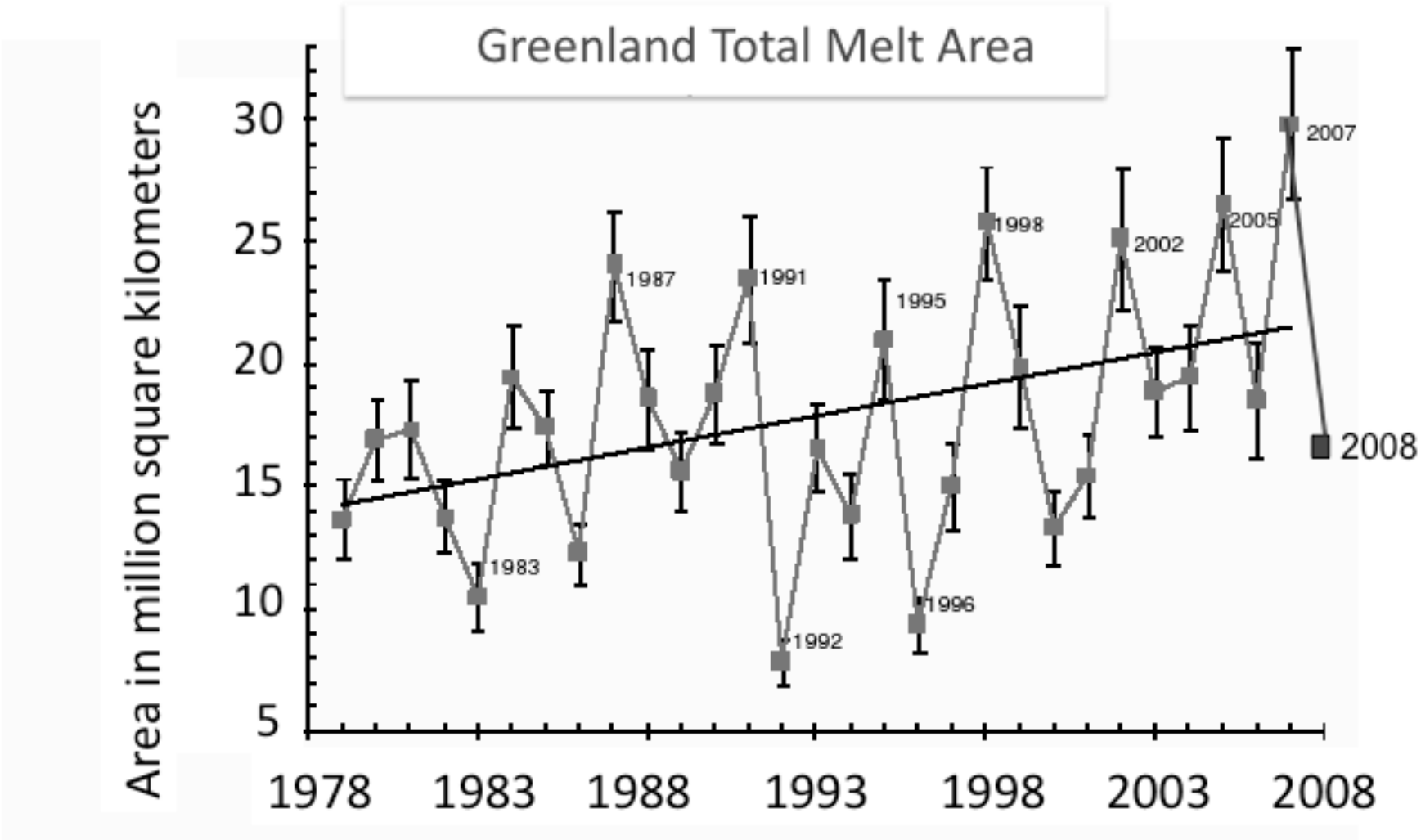


Area of Greenland Experiencing Melt



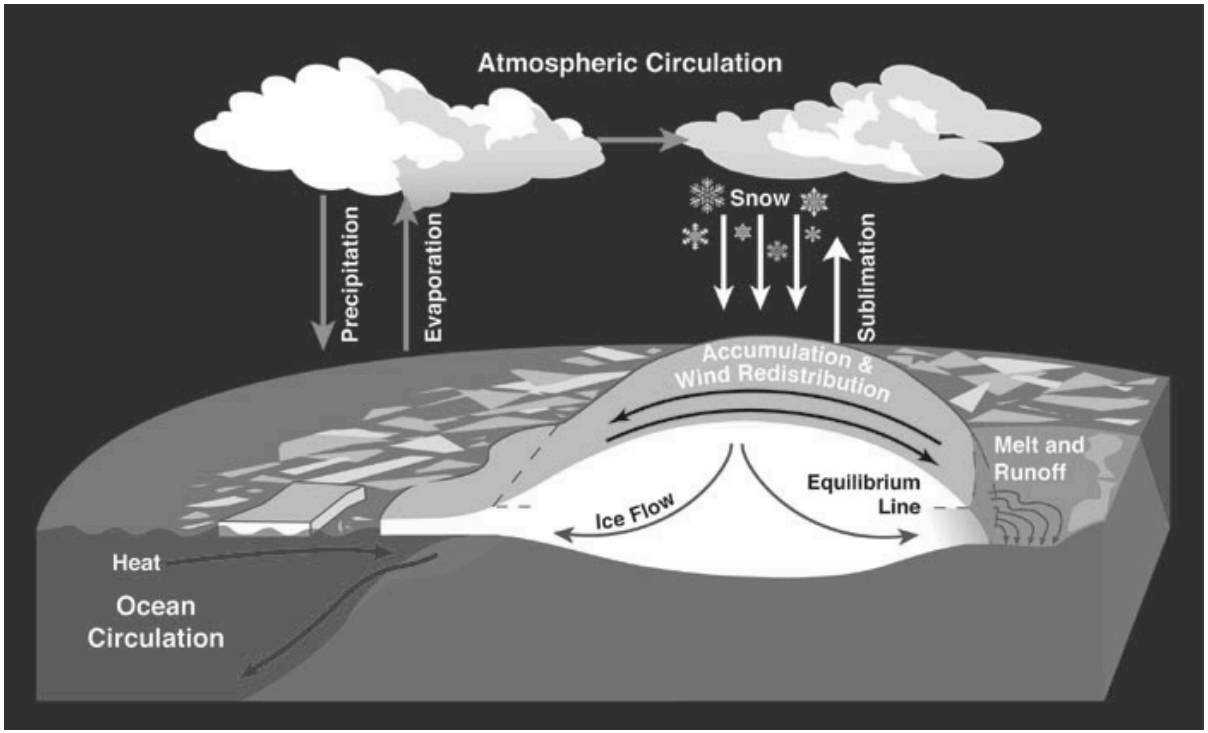


Melt area: the region of the glacier that is actively melting



Melting so far has amounted to a tiny fraction of total volume

Steffan and Huff, CU

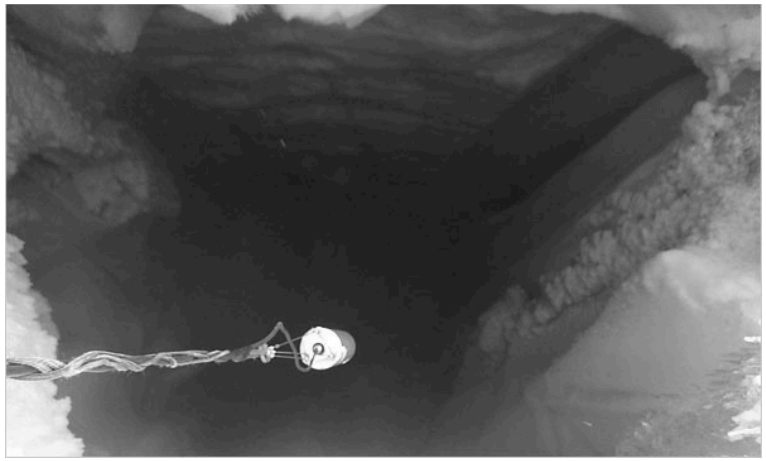


Mass balance of an ice sheet

Gains mass from **snow** on top
Loses mass from **melting** and **icebergs** breaking off the side (called calving)

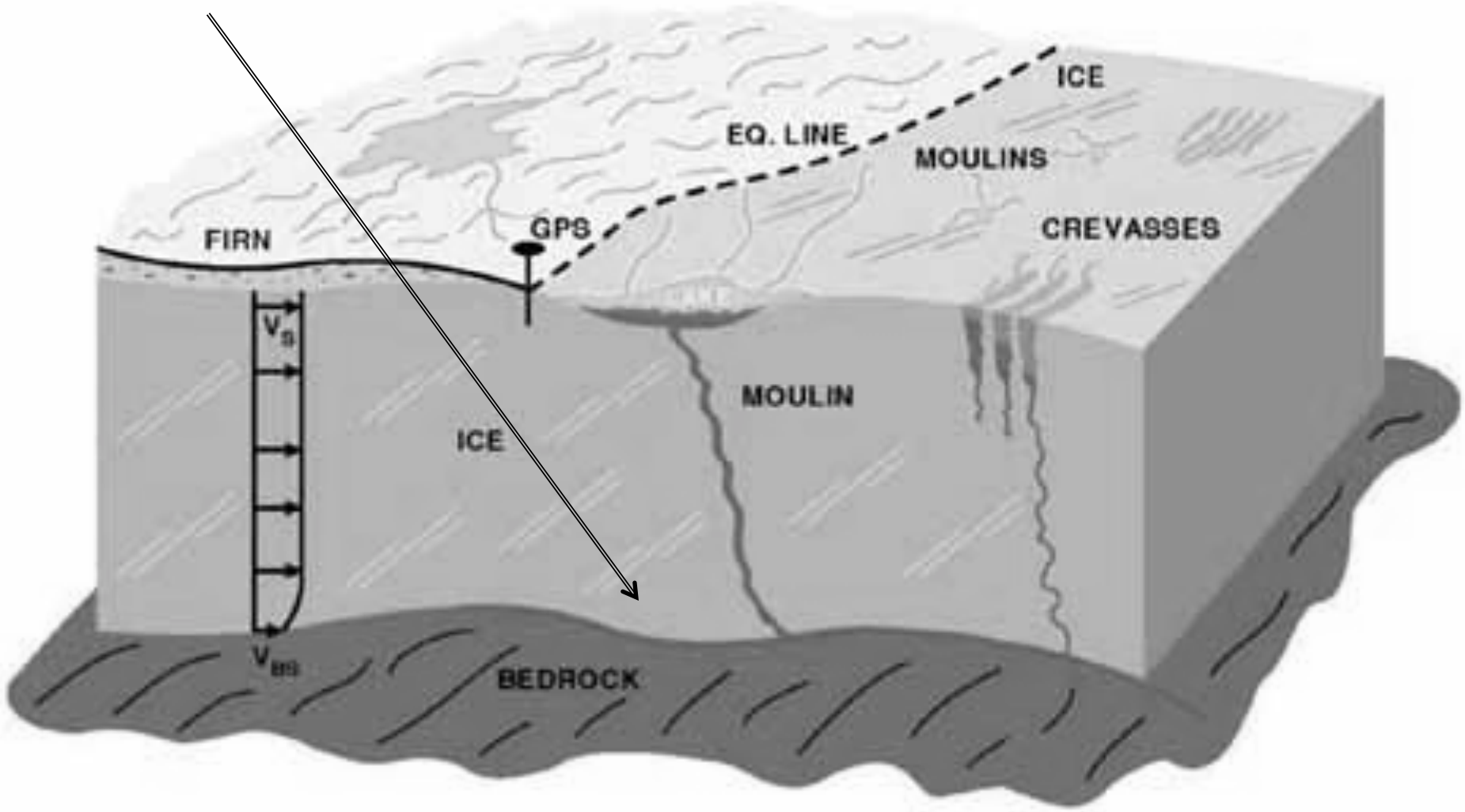
Postive mass balance: net growth (gains > losses)
Negative mass balance: net shrink (gains < losses)

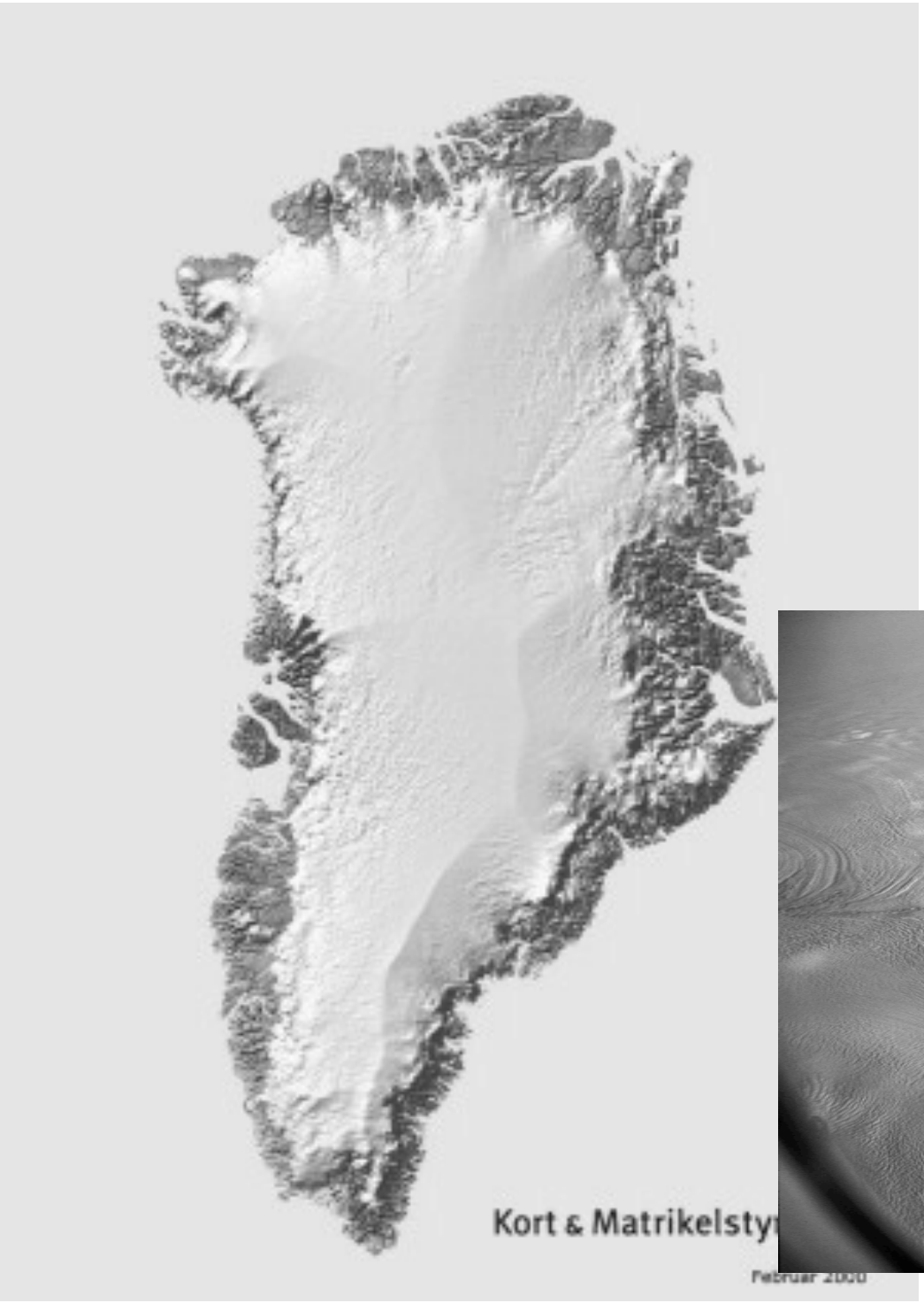
More melting may cause more icebergs to break off



The melt water can fall through cracks that reach the bedrock below

Water dripping through could cause it not to stick to the bottom as much & flow faster

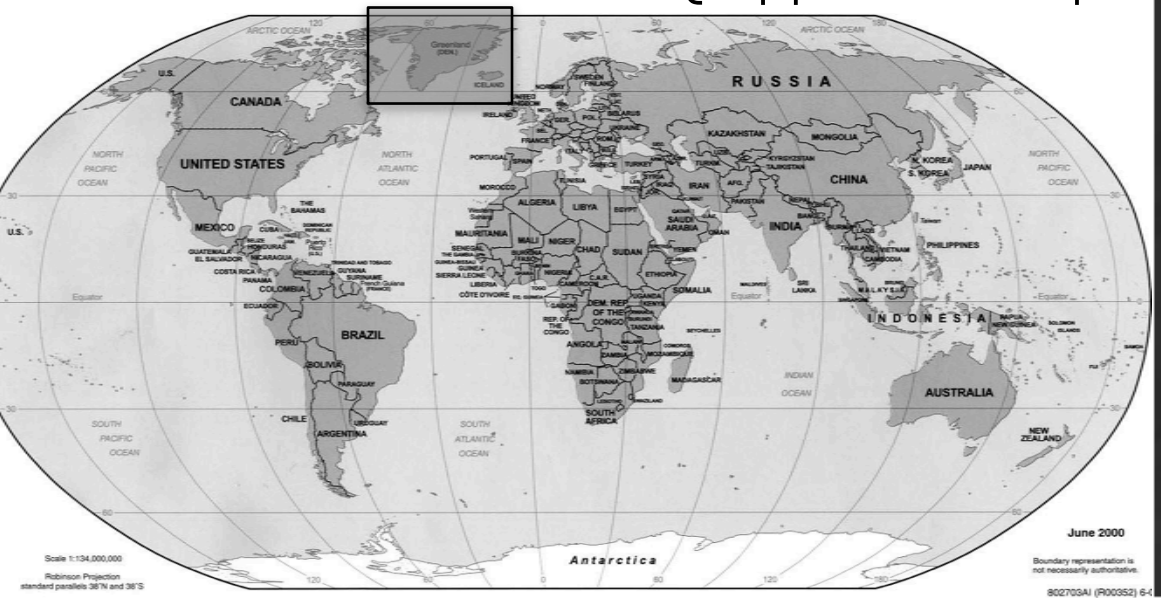


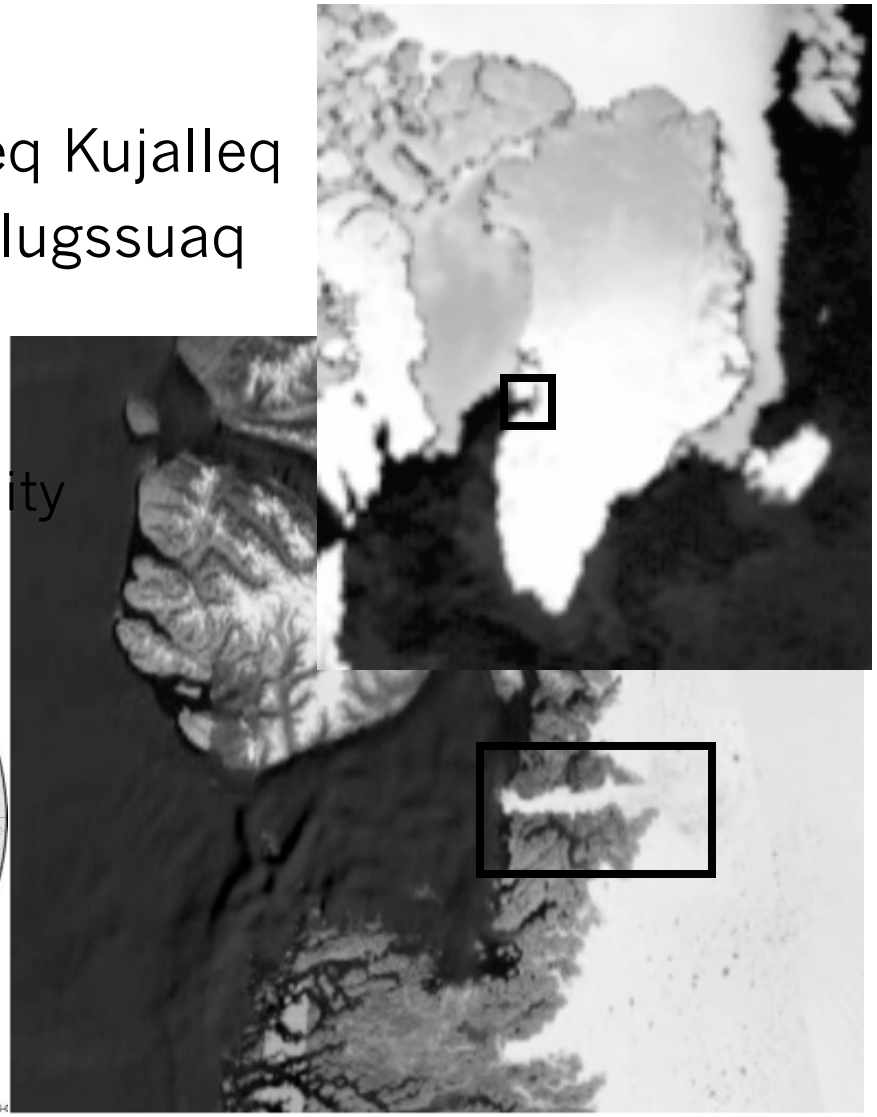


Greenland is surrounded by fjords filled with ice streams

Greenland Ice Loss

- Next: Jakobshavn Isbrae
  - You might know it as Sermeq Kujalleq
  - Don’t confuse with Kangerdlugssuaq
  - Near town of Ilulissat
  - In Qaasuitsup municipality
    - North of Qeqqata municipality





Jakobshavn drains 6.5% of Greenland ice and makes the most icebergs in the N. Atlantic.

Retreated significantly since 1990 and is speeding up

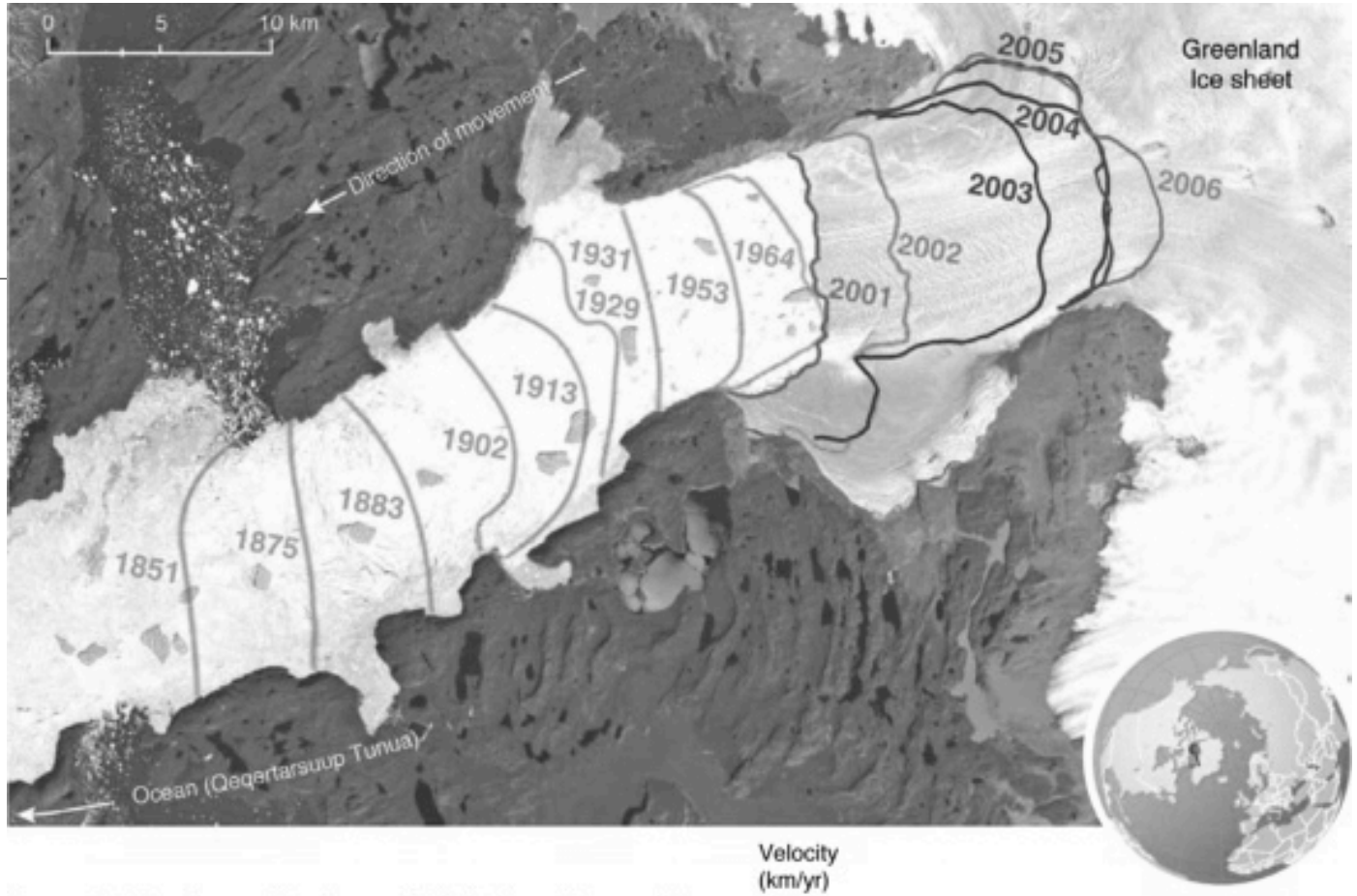
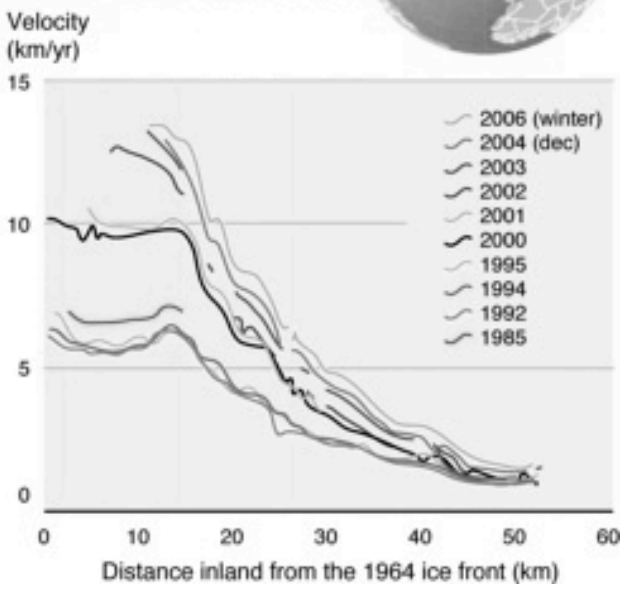
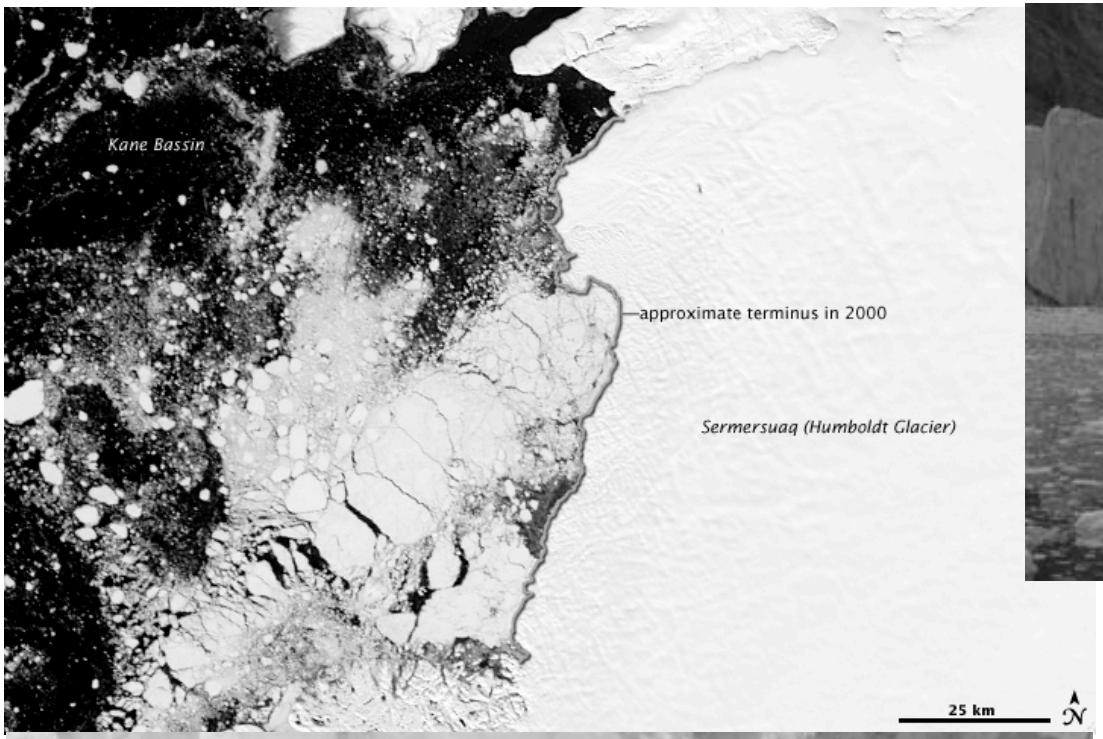


Figure 6A.6: Landsat satellite image of Jakobshavn Isbrae and its fjord, showing locations of the calving ice front in years from 1851 to 2006. The glacier extends through the Illulisat Icefjord, surrounded by mountains. Icebergs calve off from the main glacier, pile up and block the fjord before being released into Qeqertarsuup Tunua (Disko) Bay and Davis Strait. The whiter areas in the fjord are piled-up icebergs and the "real" glacier ends where the greyish striped section ends – showing that this image is from 2001.
The graph shows glacier-velocity profiles for 1985 to 2006. During this period Jakobshavn Isbrae, already the world's fastest glacier, doubled its speed to almost 14 km per year[28,29] after rapid thinning and break up of its floating ice tongue[31].

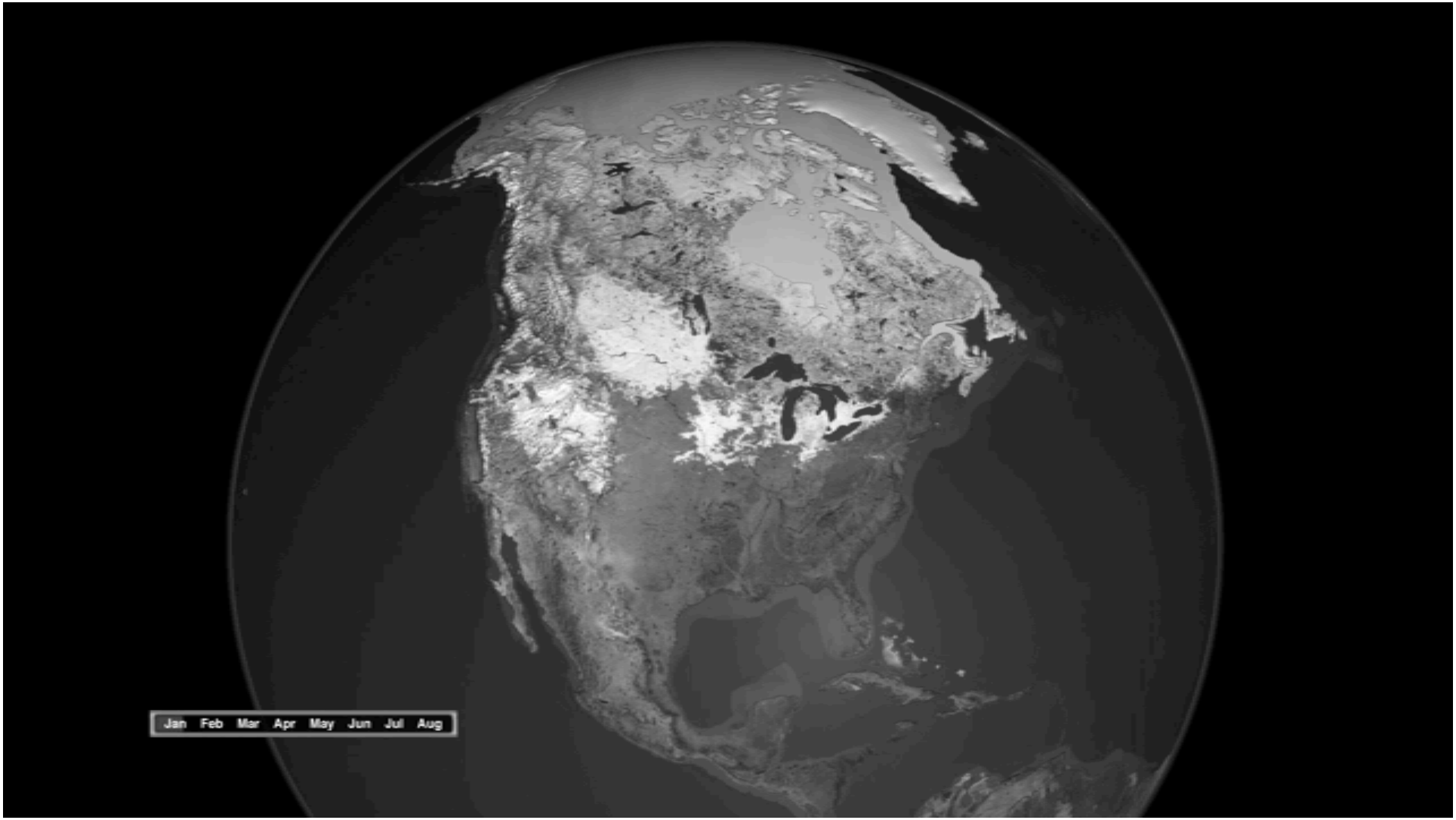
Sources: NASA/Goddard Space Flight Center Scientific Visualization Studio. Historic calving front locations courtesy of Anker Weidick and Ole Bennike
Source: based on Howatt and others 2007





Glacier calving

A natural process.
But the terminus of many glaciers is retreating



Ayles ice shelf movie

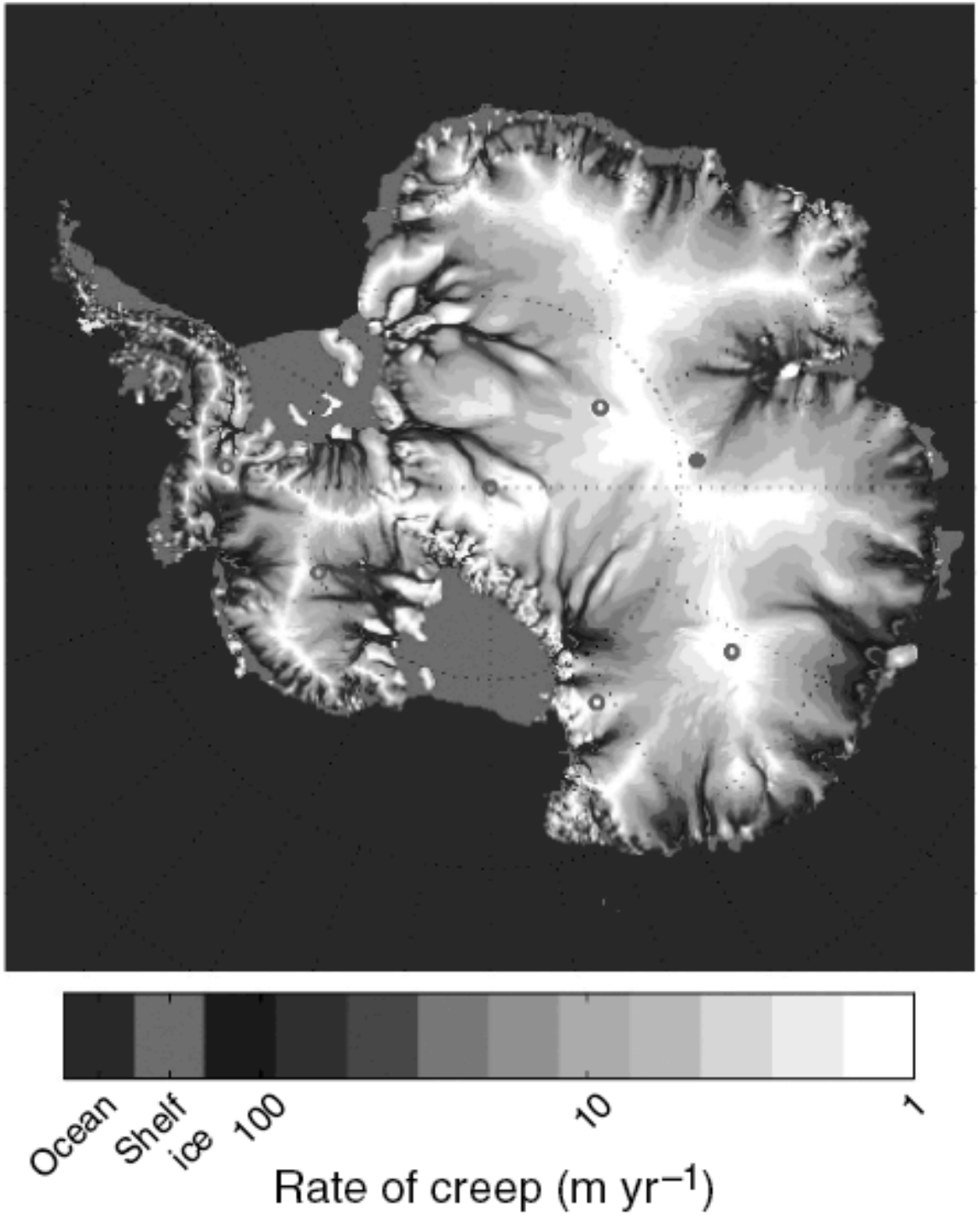
Ice shelf = connected to the ice sheet but also floating in the ocean
This one broke off due to warmer ocean temperatures

http://svs.gsfc.nasa.gov/vis/a000000/a003400/a003430/

Future of Greenland

- A 2^{o} C temperature rise would almost certainly melt Greenland (eventually)
  - This would likely take centuries
- Currently, Greenland melting is a small (less than 10%) contribution to sea level rise
  - This is likely to become a larger percentage in the future

What about Antarctica's ice sheet?



Antarctica Facts

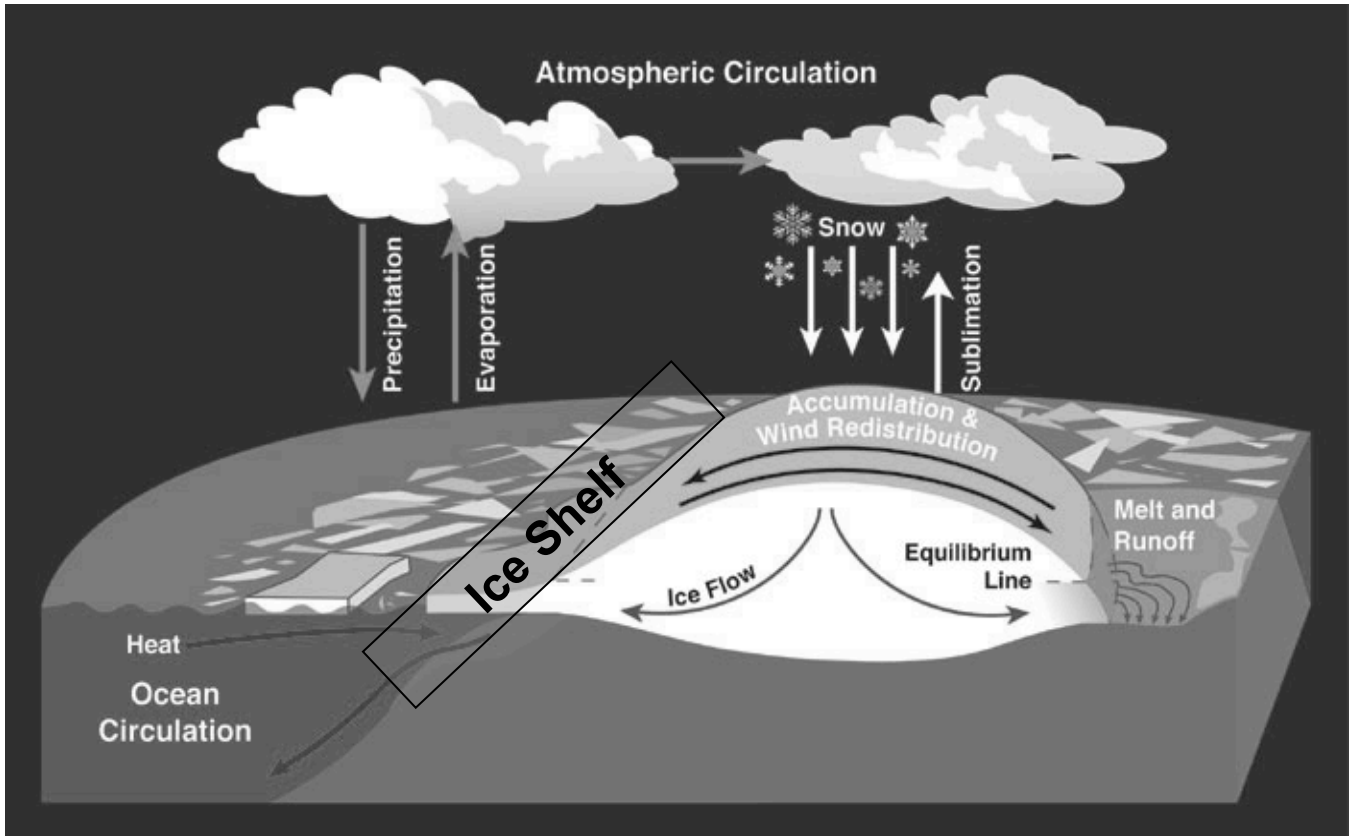
Has two giant **ice shelves** and many more smaller ones.

Drained by about a dozen ice streams (white features at left). It is unknown if recent acceleration is normal or a symptom of instability.

Antarctica Facts

The shelves reduce dynamic ice loss

Antarctica's icy surfaces are very cold, but warming in the surrounding ocean is a problem for the shelf base




Ice shelf
© www.virtualantarc

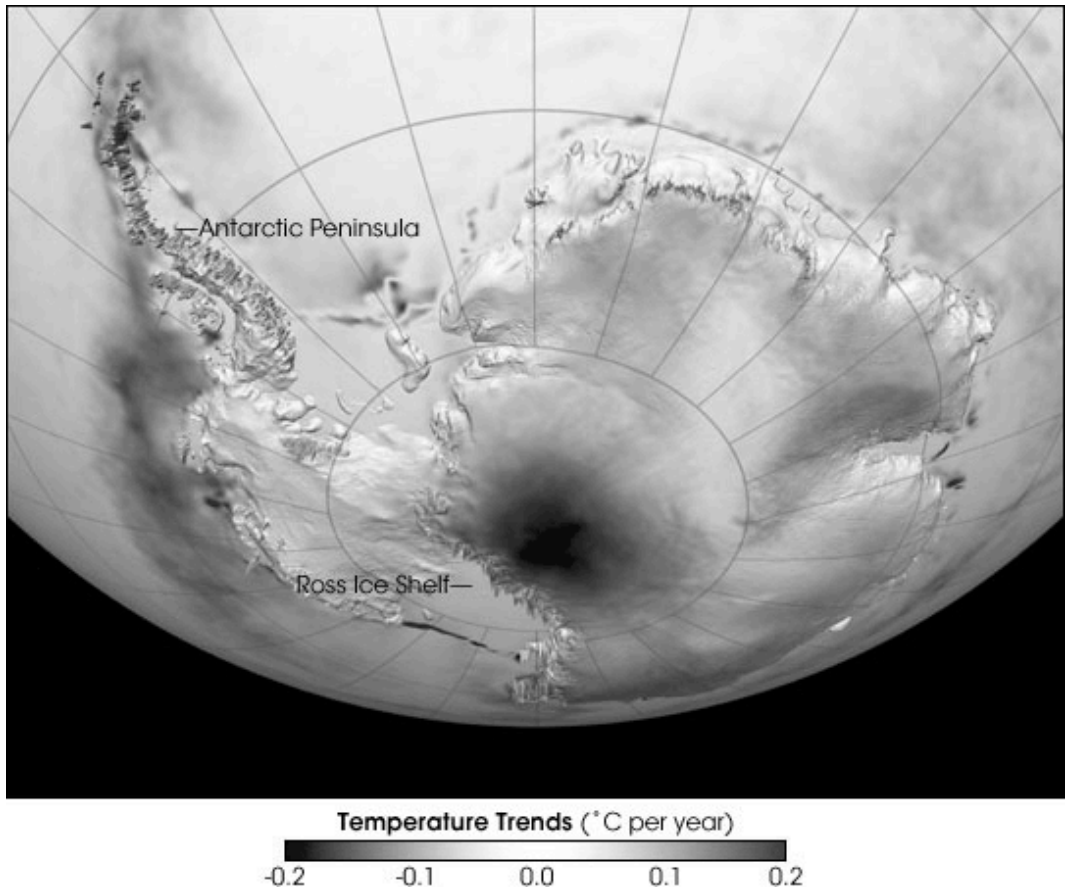

Icebergs

Antarctic Melting

- Antarctica has experienced relatively small warming to this point
  - Strong jet stream has kept warmer air out of high latitudes
  - Also ocean nearby has taken up heat
  - No sea ice decrease has happened in Antarctica either. (Although nearly all Antarctic sea ice melts each summer anyway)

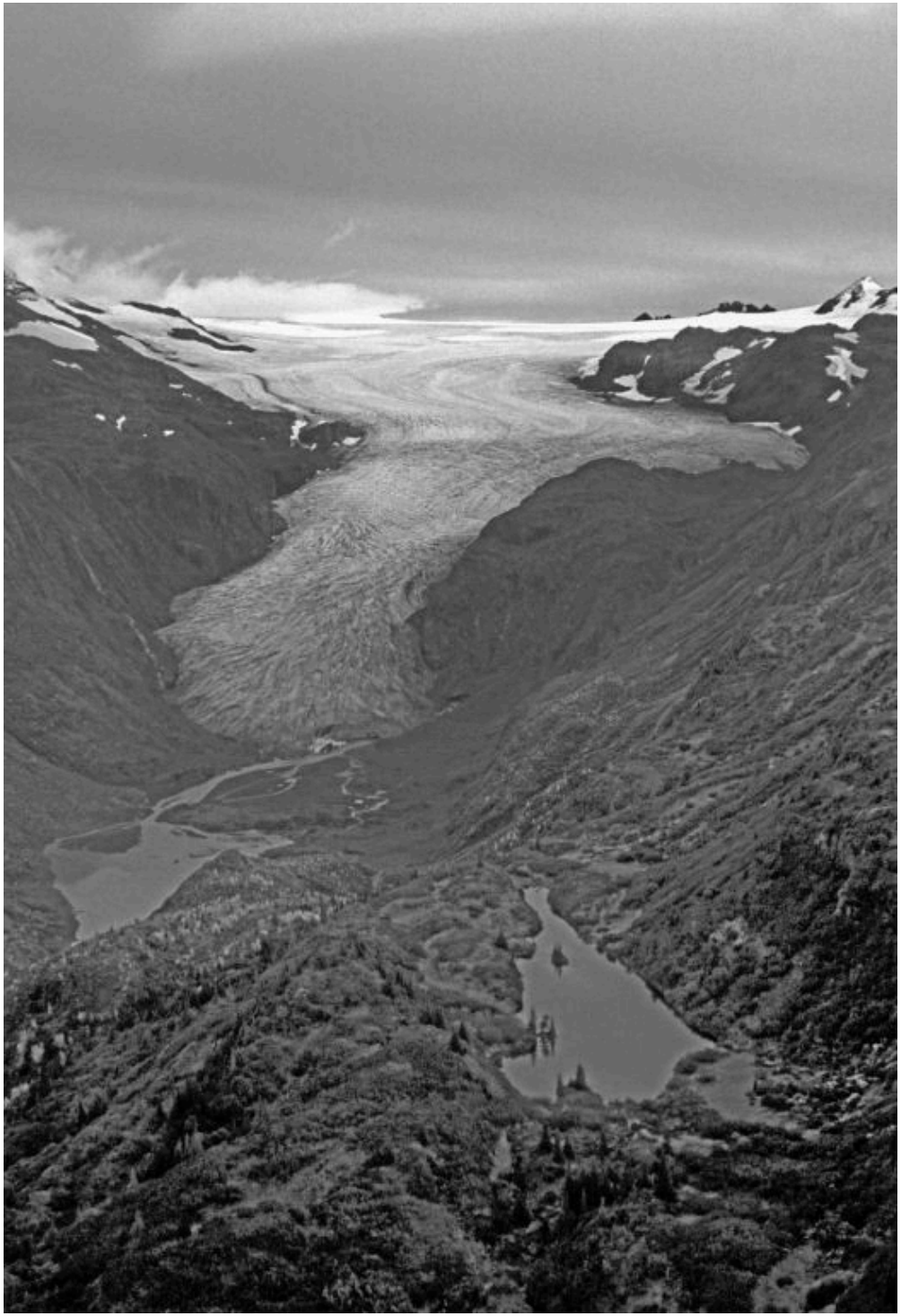
Antarctic Melting

- East Antarctica is cooling, West Antarctica is warming slightly.
- Antarctic melting contributes less than 5% to current sea level rise.
- Average temperature changes 1982-2004



Future of Antarctic Melting

- Antarctica has the most land ice (61 meters of potential sea level rise)
  - But East Antarctica (the big part) is thought to be safe
    - It's really cold there...
  - West Antarctica is potentially dangerous: 5 m of sea level rise
    - Much of the West Antarctic Ice Sheet is *under sea level* so warmer ocean water could get in and melt much more after melting starts
    - Small probability of happening but high impact

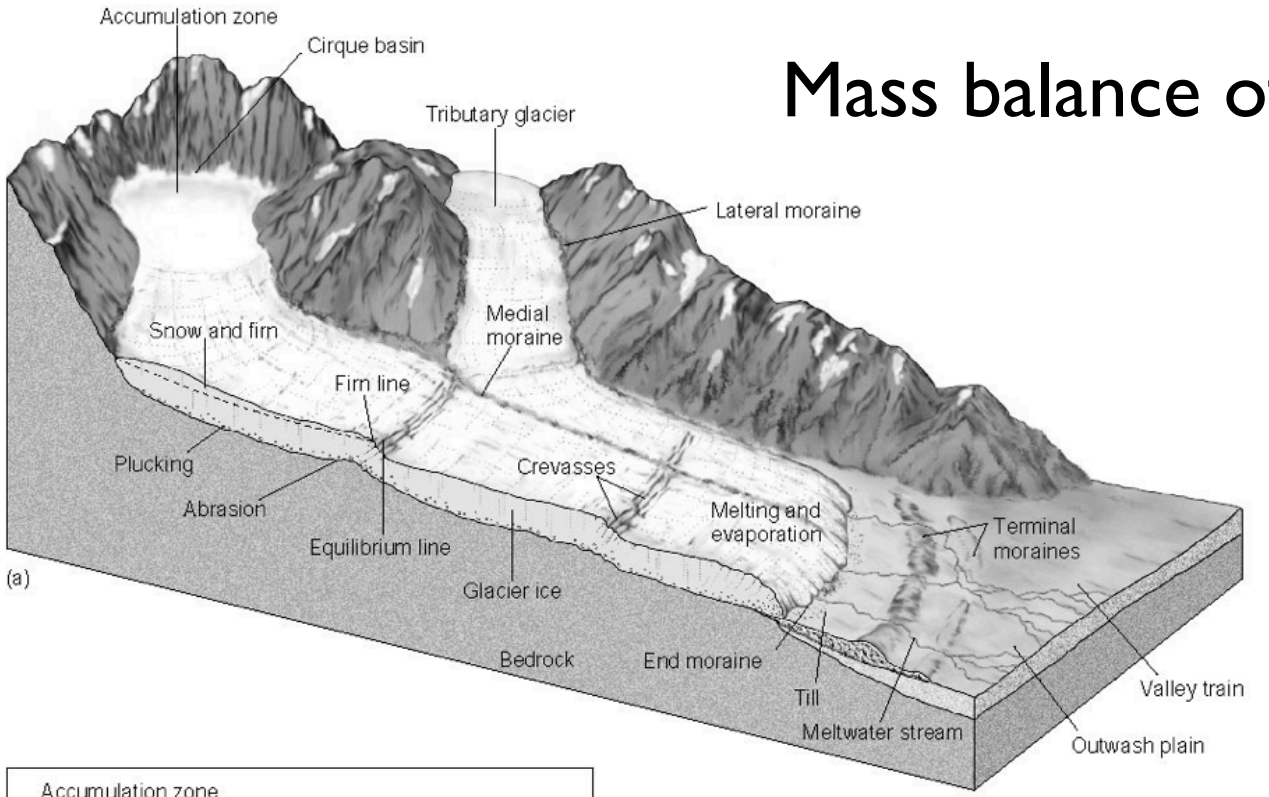


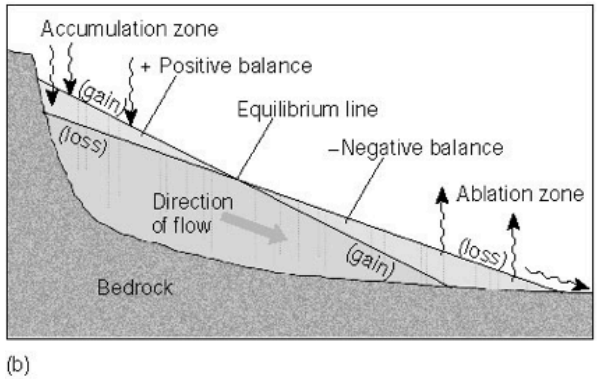
Mountain Glaciers

Presently **melting mountain glaciers** are contributing more to sea level rise (almost 20%) than Greenland and Antarctica **combined**.

This probably won't be the case in 50 years (the ice sheets are so much bigger...)

Mass balance of a glacier





(b)

Gain due to snowfall

Loss due to melting, sublimation

Mountain glaciers don't lose mass due to breaking off chunks into the sea

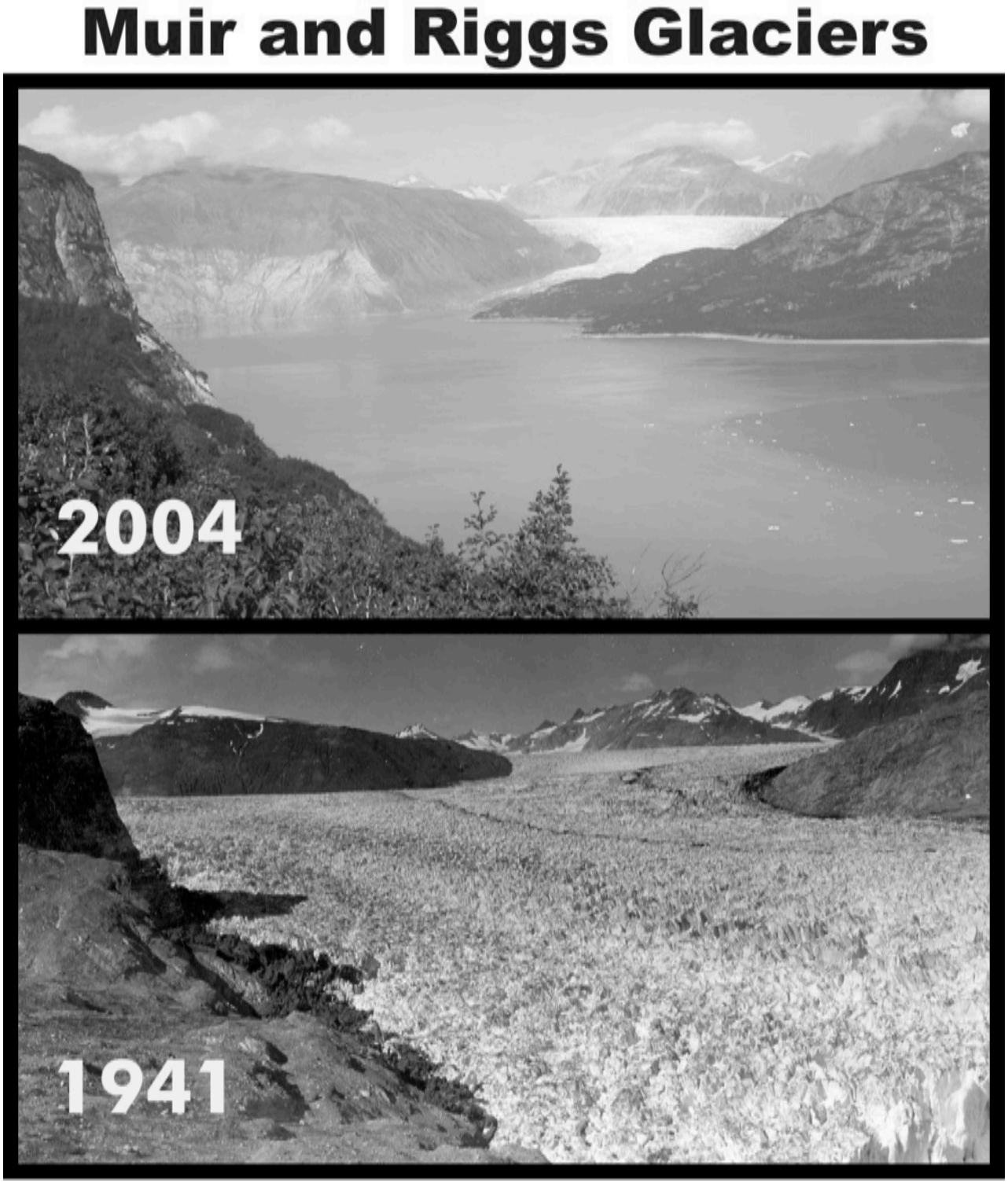
Mountain glaciers

White Chuck glacier
North Cascades

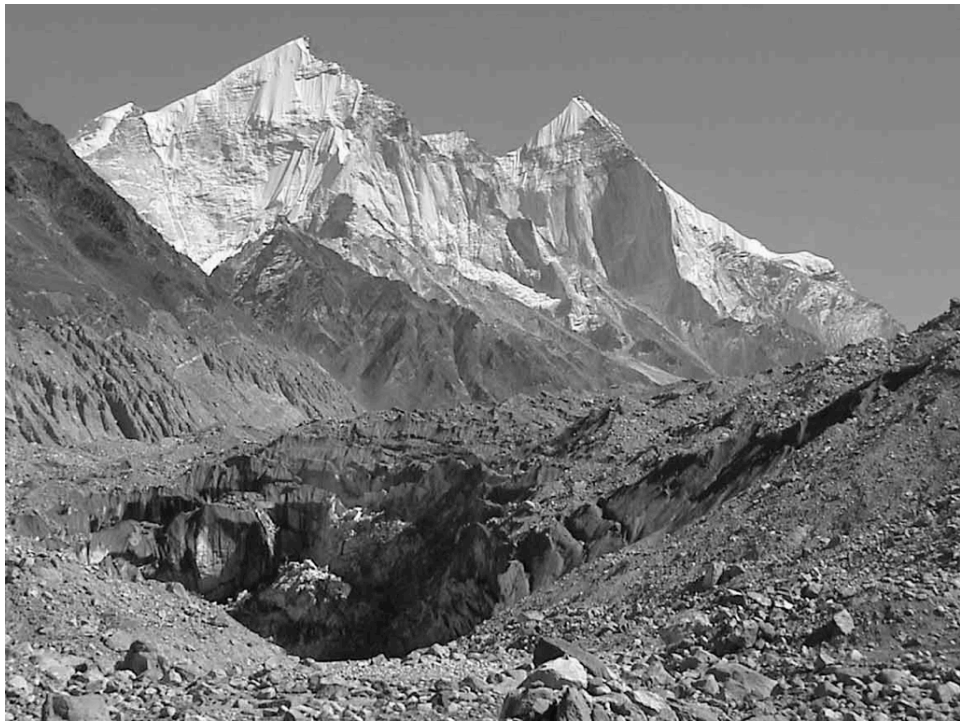
Moraine

Glacier Park, Montana

Austria



Glacier Bay
Alaska



Himalayan glaciers may be melting from black carbon deposition too

Andes

Quelccaya Icecap, Ecuador

Photo courtesy of Lonnie Thompson

Tropical glaciers

Ruwenzori
Uganda

1906

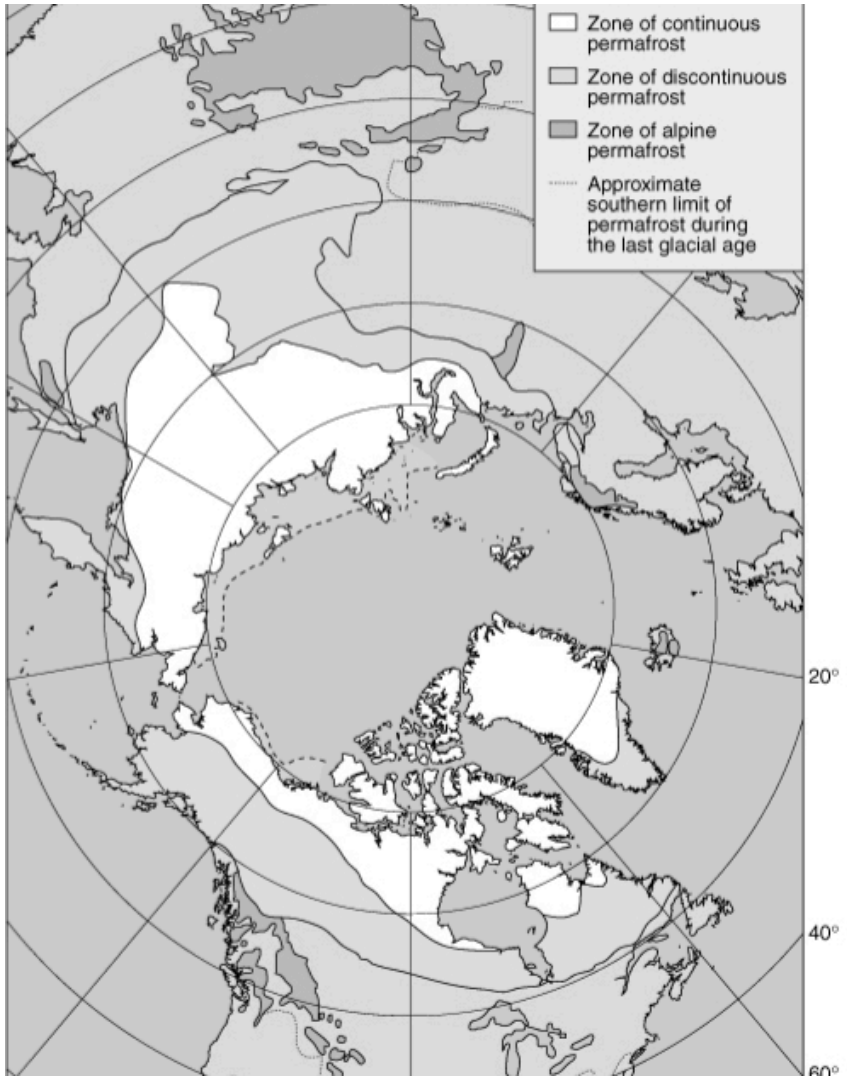
present day

Kilimanjaro

Kilimanjaro snow is disappearing from sublimation because the atmosphere there is drier now. May still be anthropogenic, but not directly by warming.

Permafrost

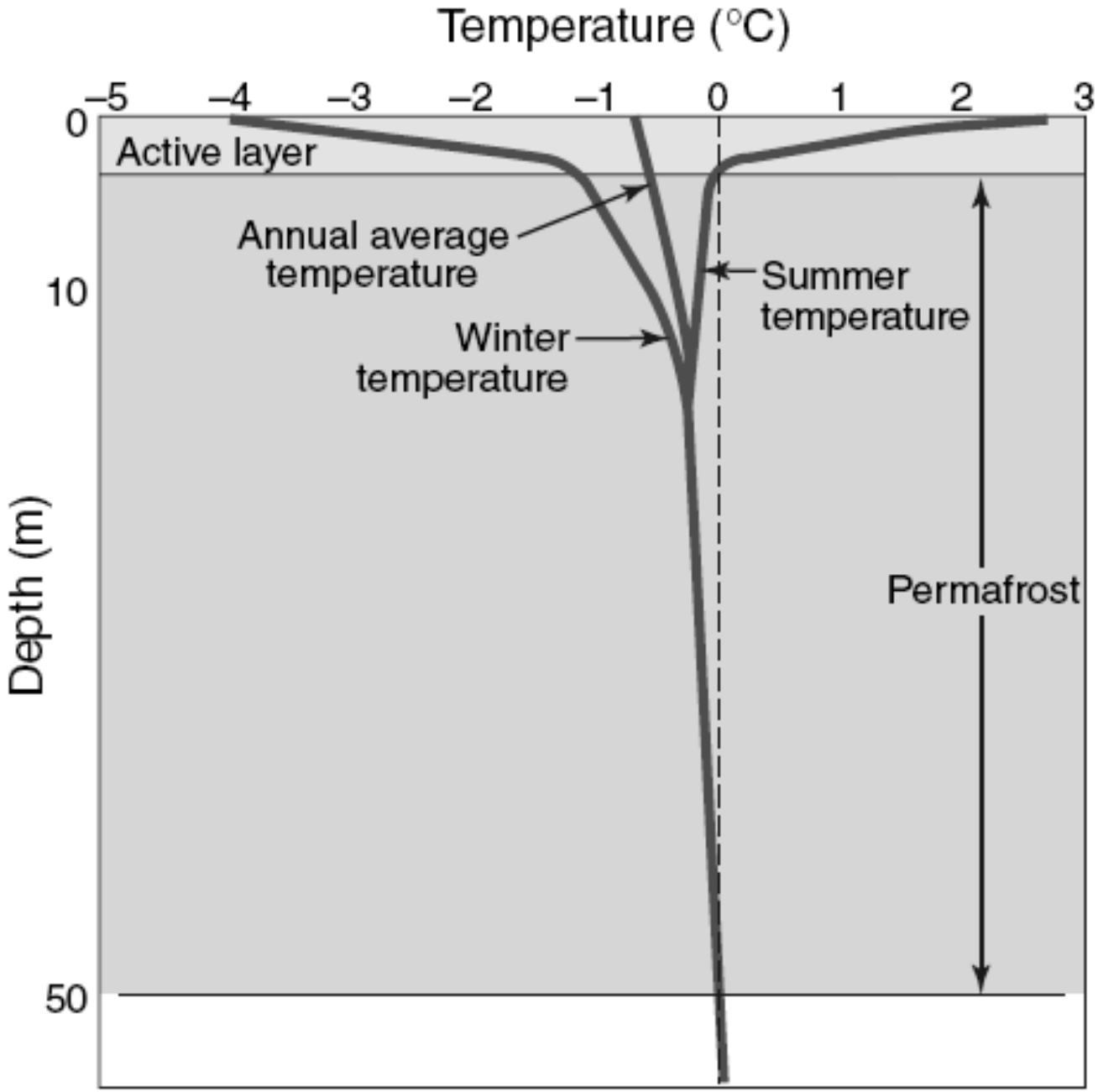
- **Permafrost**: ground that's frozen year-round
  - Extent at present →



- Typically has a thin layer on top that melts in the summer: the "**active layer**"

Ice is usually underground. Can be visible at river channel. This picture shows ice massive (the blue stuff) and active layer (grey above).

http://gsc.nrcan.gc.ca/permafrost/suppdoc_e.php


Temperature (°C)
–5
–4
–3
–2
–1
0
1
2
3
0
10
50
Depth (m)
Active layer
Annual average temperature
Winter temperature
Summer temperature
Permafrost

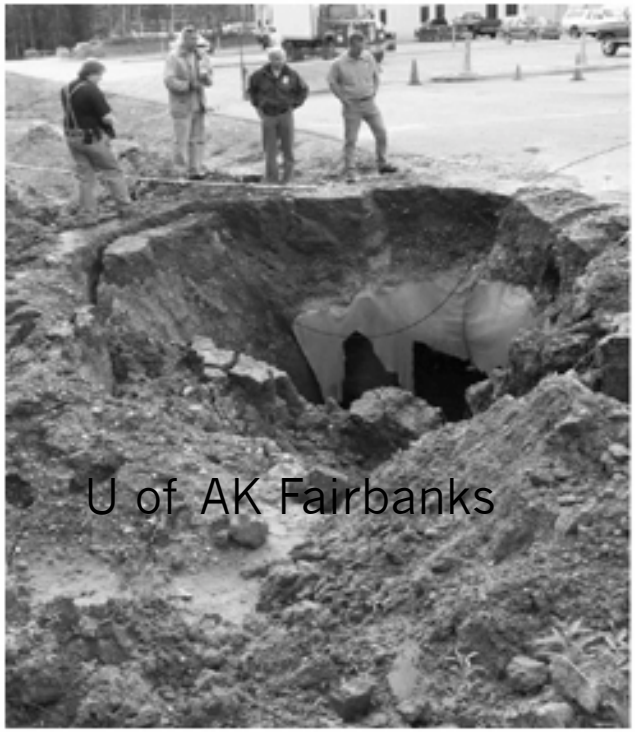
“Drunken Forest”

- Ice expands upon freezing
  - This causes potholes in roads in winter, etc
- Frozen ground causes weird formations

- When permafrost thaws, trees point in all directions!

Thawing permafrost

- widespread evidence of thaw
- causing:
  - damage to roads and buildings
  - methane to be liberated
  - vegetation to increase
- to melt all the permafrost would take centuries
- permafrost thawing will be accelerated if summer sea ice continues to retreat



Will thawing permafrost release or take up greenhouse gases?

Snow-free season is short so plant growth rates are low. Plants are cold adapted, which is their strategy for survival. **Not** adapted for much competition. Likely more vegetation will come in after thaw.

Soils are very carbon rich (decaying plants & animals frozen into permafrost). Some fear **methane release** from thaw. Others say greater vegetation will draw down CO2.

Methane or Clathrate Hydrates

are water ice cages enclosing methane

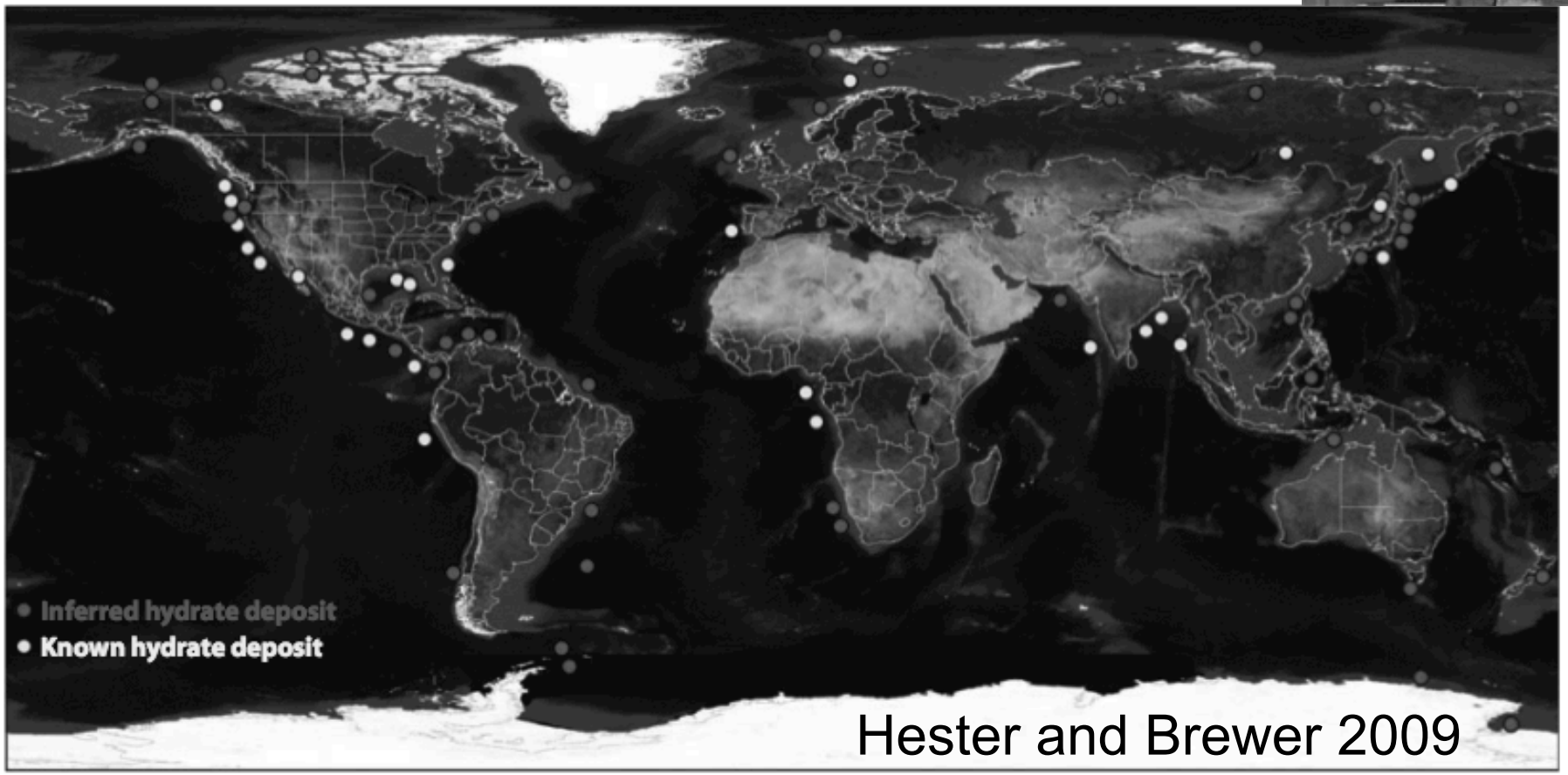


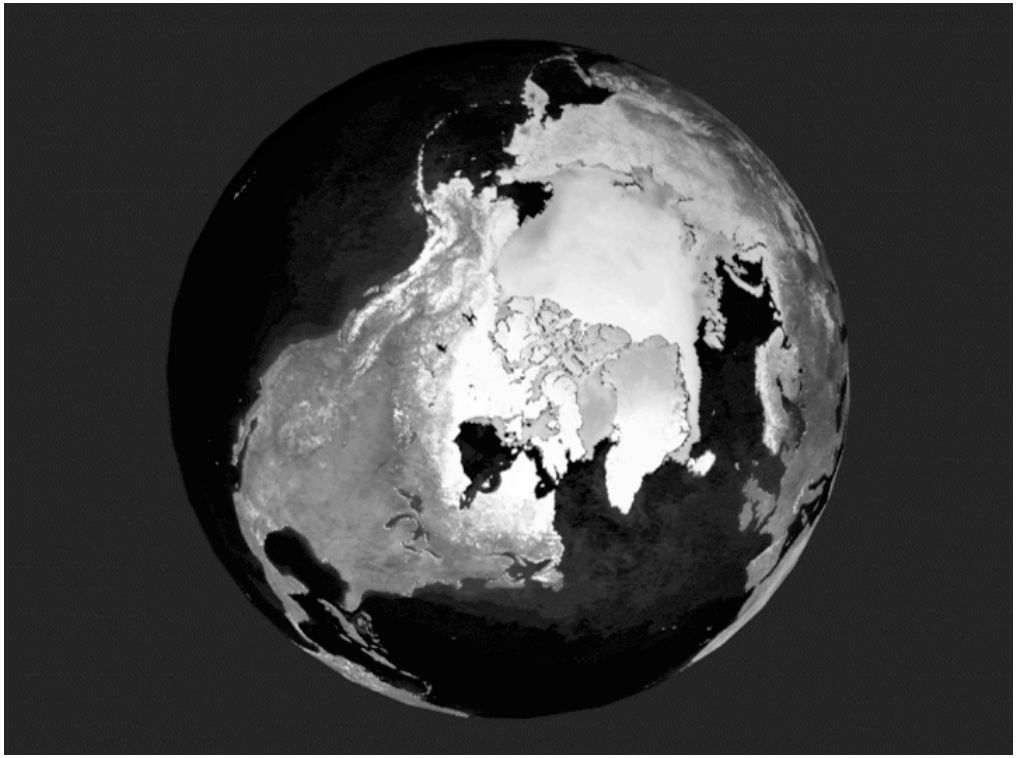
Figure 1

Worldwide map of more than 90 documented hydrate occurrences. Data from Kvenvolden & Lorenson (2001) and Milkov (2005). Inferred hydrate deposits were identified with indirect hydrate markers, mainly from seismic reflectors and pore-water freshening in core samples. Known hydrate deposits are areas where hydrates have been directly sampled from ocean drilling and remote-operated

55 million years ago methane hydrates appear to have been released to the atmosphere at a time when the earth also warmed 2-3 C

There are pockmarks in ocean sediments as indication of past catastrophic release.

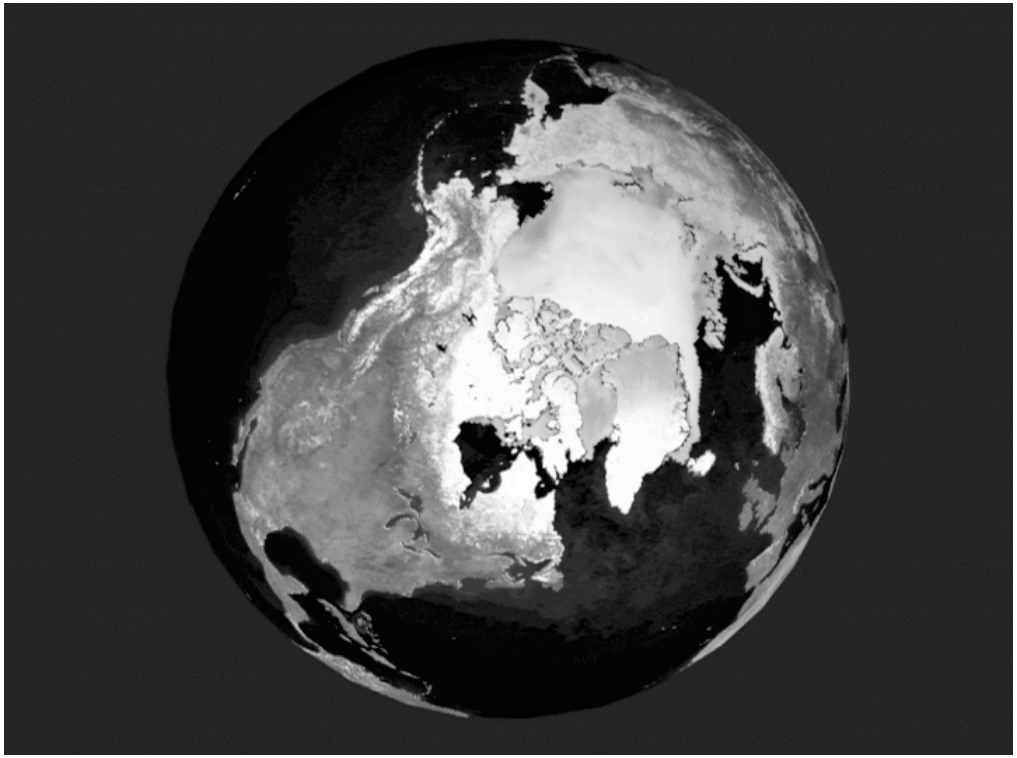
"Pockmarked" ocean floor suggesting shallow gas deposits; Canada's Beaufort Sea Geohazards Project.
Source: http://gom.nrcan.gc.ca/beaufort/images/pockmarksdem.jpg; accessed November 27, 2005.



Snow covered land is by far the largest **area** component of the cryosphere.

Snow is part of the positive ice-albedo feedback cycle, such that if snow melts earlier in spring, it causes spring warming and soil drying.

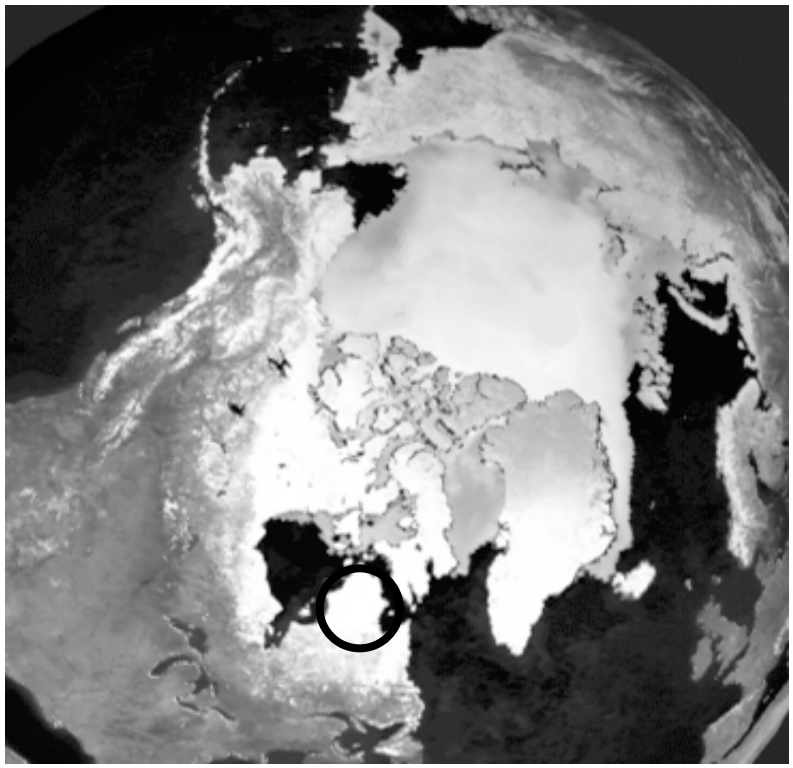
Snow is an important reservoir for water in some communities.



Precipitation is increasing in high latitudes with global warming

Snow covered season is shorter but depth may be greater

20,000 musk oxen die from Banks Island rain on snow



Rain falls onto snow, refreezes later & animals cannot graze

UW research: Rennert et al 2009 and many other studies

Summary

Sea ice: relatively thin frozen sea water. Summertime extent decreasing ~10%/decade in Arctic. Antarctic sea ice isn't changing.

Climate models project a sea ice free Arctic in the month of September between 2050 & 2100.

What is so special about climate in the polar regions? Ice-albedo positive feedback (sea ice and snow on land) amplifies warming.

Sea ice erosion seriously impacts polar bears, seals, and leaves coastal areas vulnerable to erosion by waves.

Summary of the Big Melt

Greenland ice sheet's melt zone is expanding, and the rate of melting could be increasing.

A 2 °C warming could melt all of Greenland, but it would take centuries to happen. This would raise global sea level by about 7 m. Greenland melt thus far has contributed to less than 10% of sea level rise.

Much of Antarctica is cooling due to a stronger polar vortex, caused by the ozone hole. The West Antarctica could be unstable and would contribute to 5 m sea level rise if it melted. Current Antarctic melt contributes less than 5% to sea level rise.

Almost all mid-latitude and tropical mountain glaciers are retreating, contributing to almost 20% of sea level rise. Many are retreating due to temperature rise. Kilimanjaro is retreating due to atmospheric drying in that region.

Summary of the Big Melt

Permafrost becomes spongy when it thaws, making the ground unstable.

As the far north warms, low latitude plants that invade tend to be aggressive competitors. Some fear methane release from permafrost thaw, while others expect CO2 drawdown from plant growth.

Snow covered land is by far the largest area component of the cryosphere. Snow is part of the positive ice-albedo feedback cycle, such that snow melt earlier in spring causes spring warming and soil drying. Snow is an important reservoir for water in some communities.