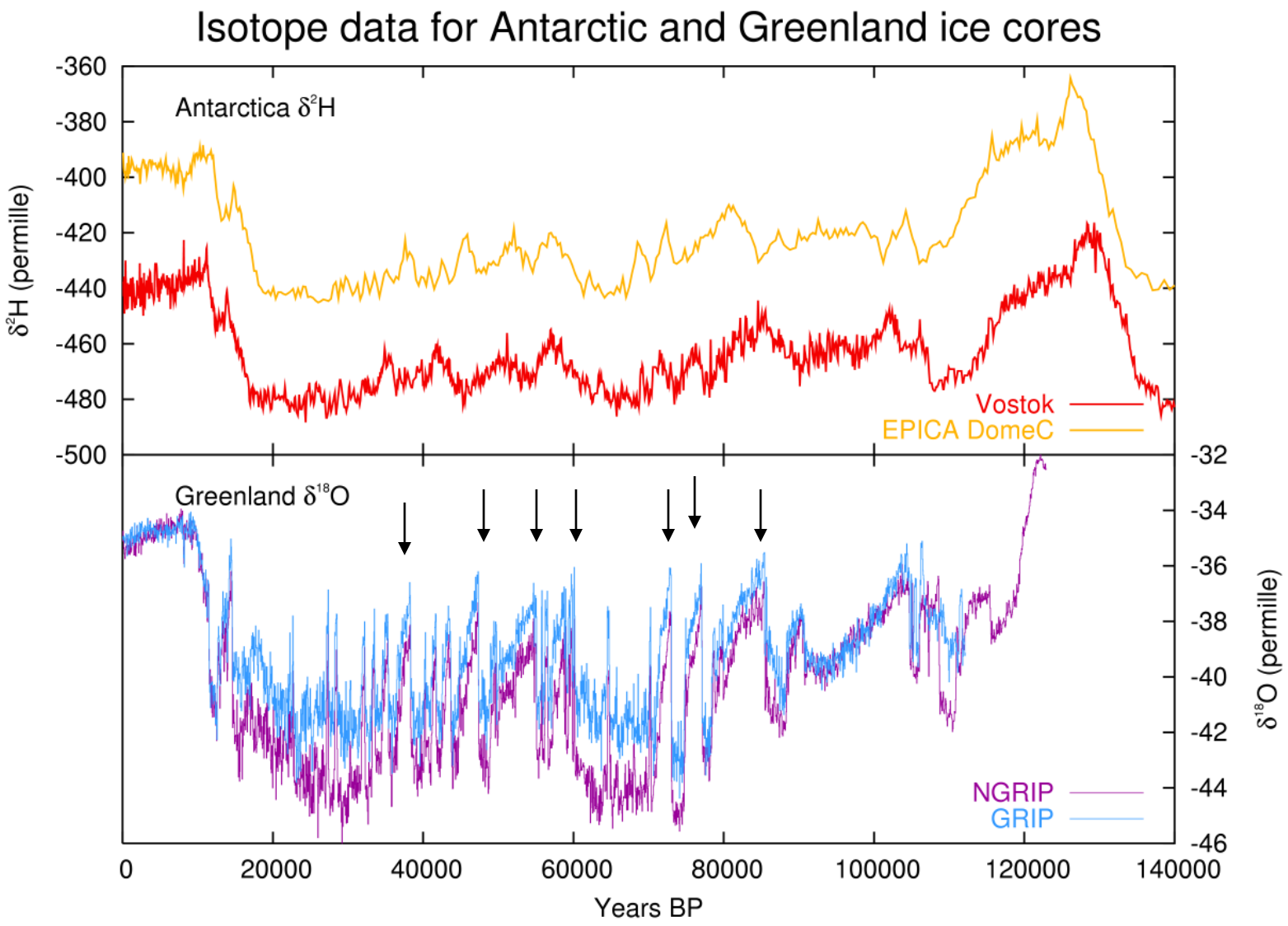
Sea ice (see ice?)

(and abrupt climate change)



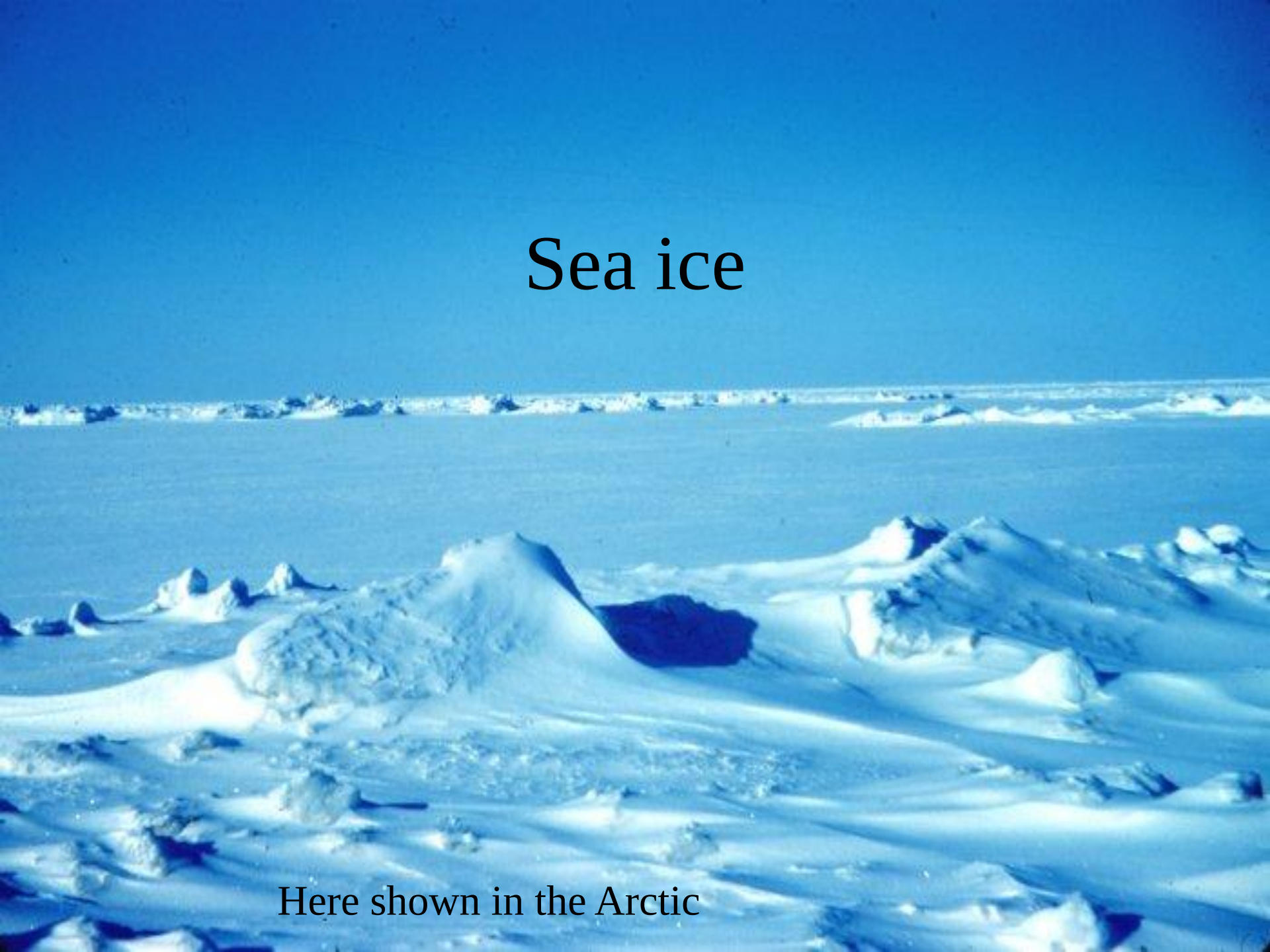
Dansgaard-Oeschger events

What is the difference between the climate near Greenland versus Antarctica?

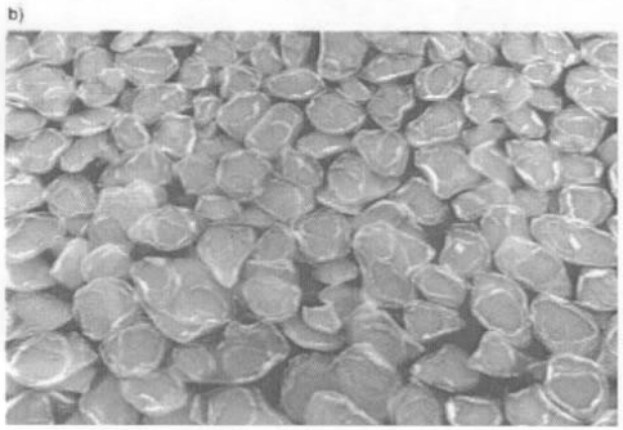
Region of deep water formation?

(recall we've already noted the importance of fresh water melt from ice sheets in stabilizing the ocean, and causing local cooling….)

Sea ice



Here shown in the Arctic



b)

©Wadhams

Pancake ice

Forms in small splinters which collect at the surface.

Pack together into small “pancakes”

Pack together to form consolidated sheets

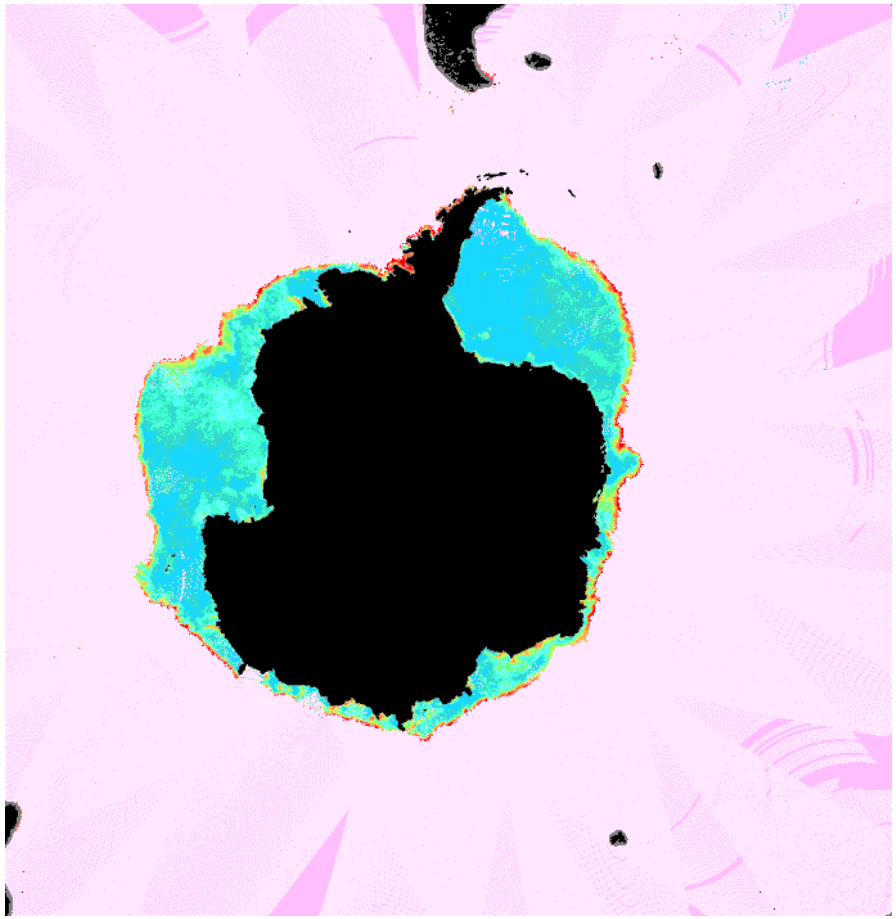
©Wadhams

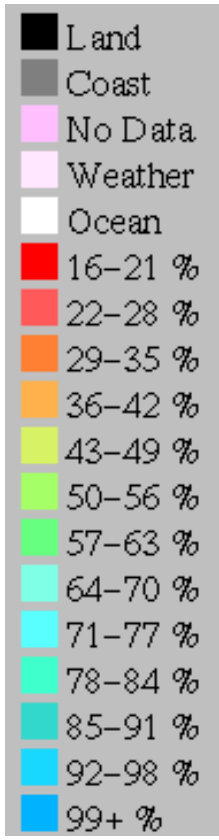
Consolidated pancake ice in the Antarctic (continuous sheet)

Ice is solid… but moves!

Sea ice today

Valid Time 10 April 2009 00 UTC

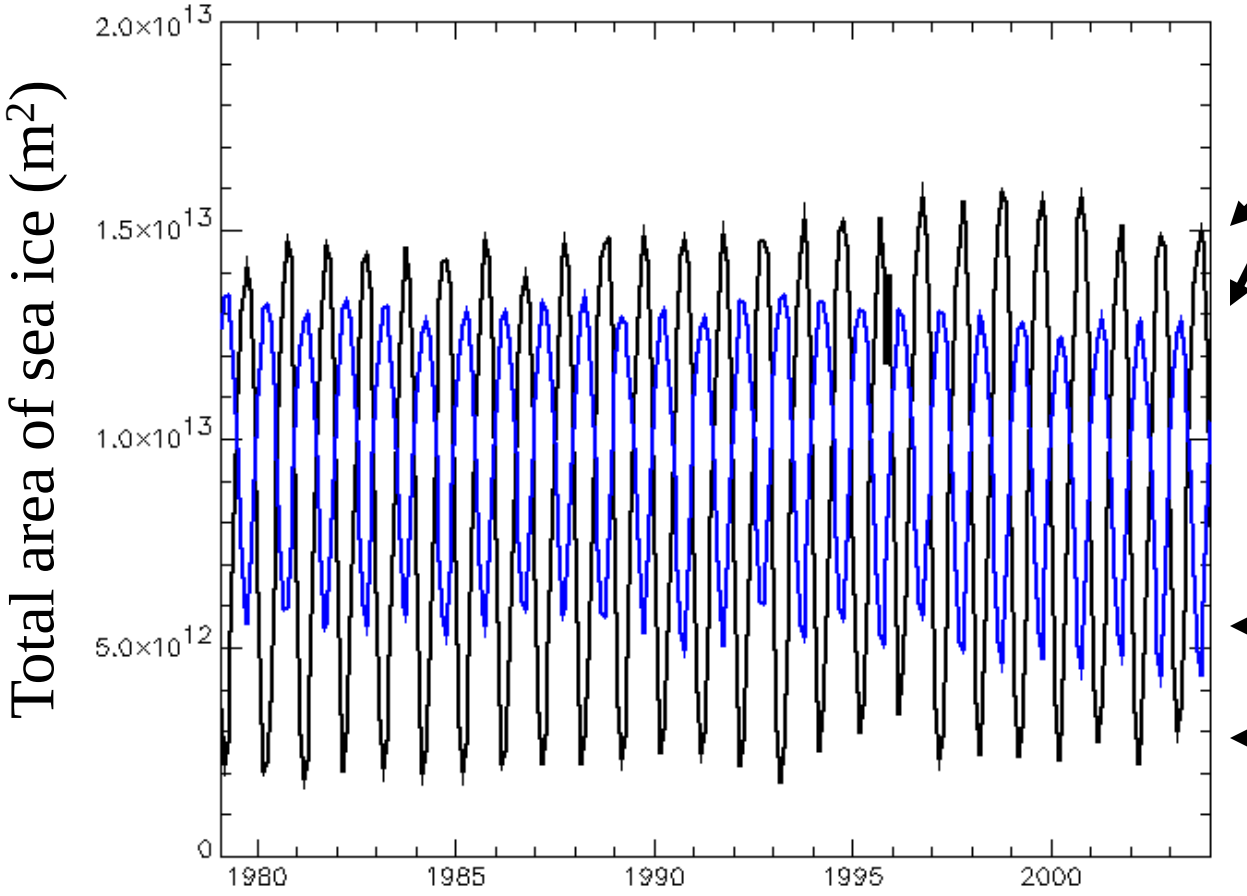




http://polar.ncep.noaa.gov/seaice/Analyses.html

Seasonal variation in sea ice

Northern Hemisphere (blue) Southern Hemisphere (black)

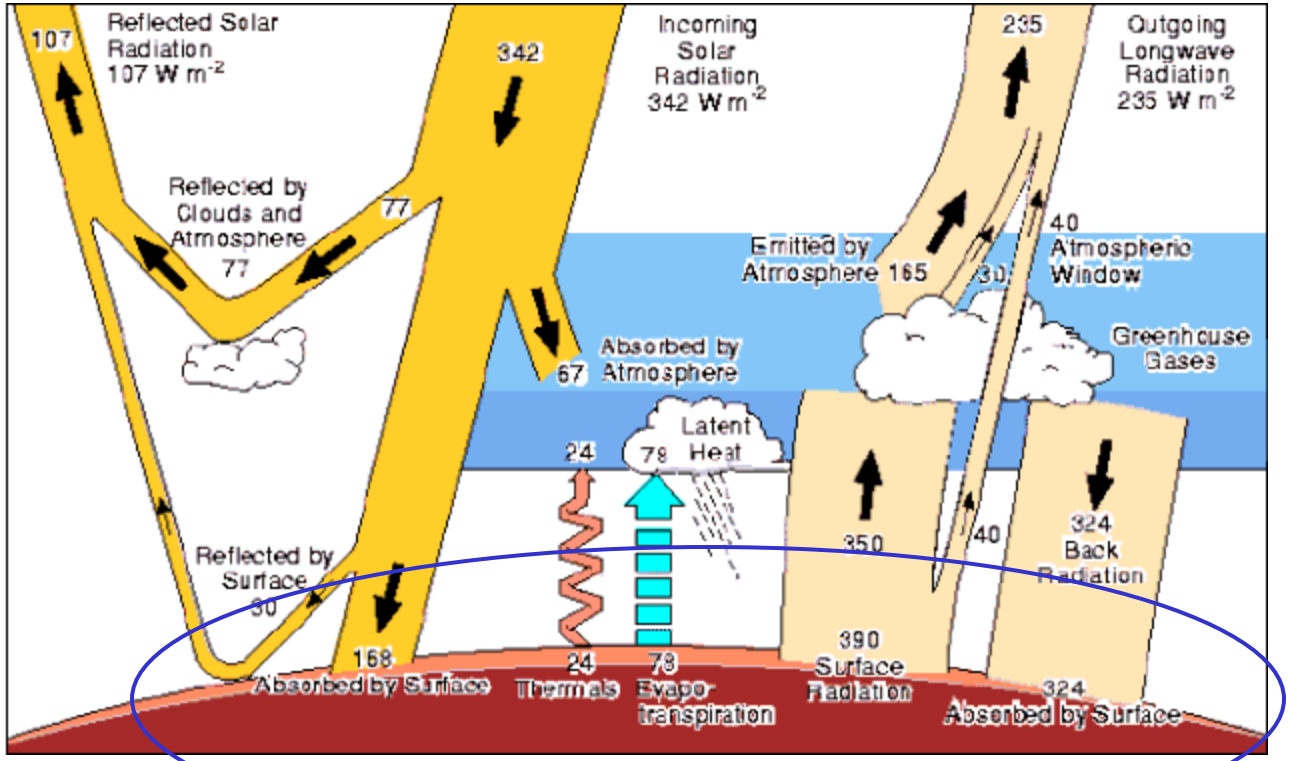


Huge amounts of ice around Antarctica, but limited by continents in the Arctic

Lots of ice remains in northern summer

Almost all gone in southern summer

Sea ice and energy budget



Solar radiation

Longwave radiation
(up emitted and absorbed)

Sensible heat flux Latent heat flux

Energy fluxes

Consider surface with ice compared to open ocean…

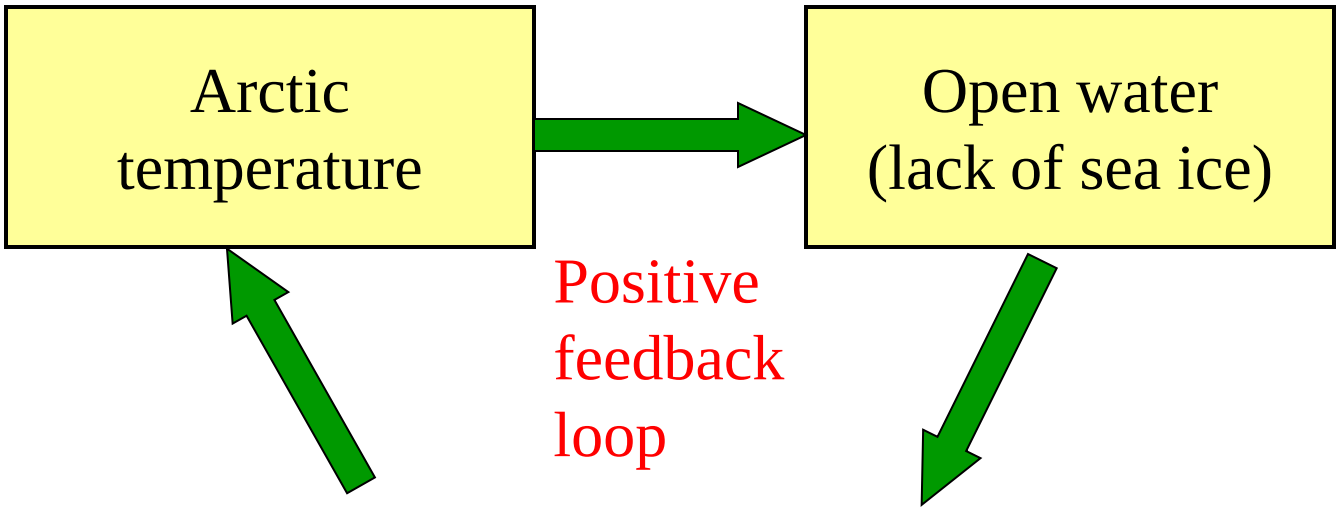
- Albedo of ice higher
  => less shortwave energy
- Temperature of ice lower than liquid ocean
  => less energy going up
- Latent heat needs to convert solid water to vapor,
  (rather than just liquid to vapor)
  => less latent heat flux
- Temperature of ice lower than liquid ocean
  => Less sensible heat flux (conduction)

Conclude sea ice acts to ***insulate*** the atmosphere from the ocean

Recall both the atmosphere and ocean transport heat poleward.
Sea ice thus stops the ocean from exchanging that heat

So when there is sea ice, the Arctic stays cold,
where there is no sea ice the Arctic can stay warmer.
This is the sign of a positive feedback!

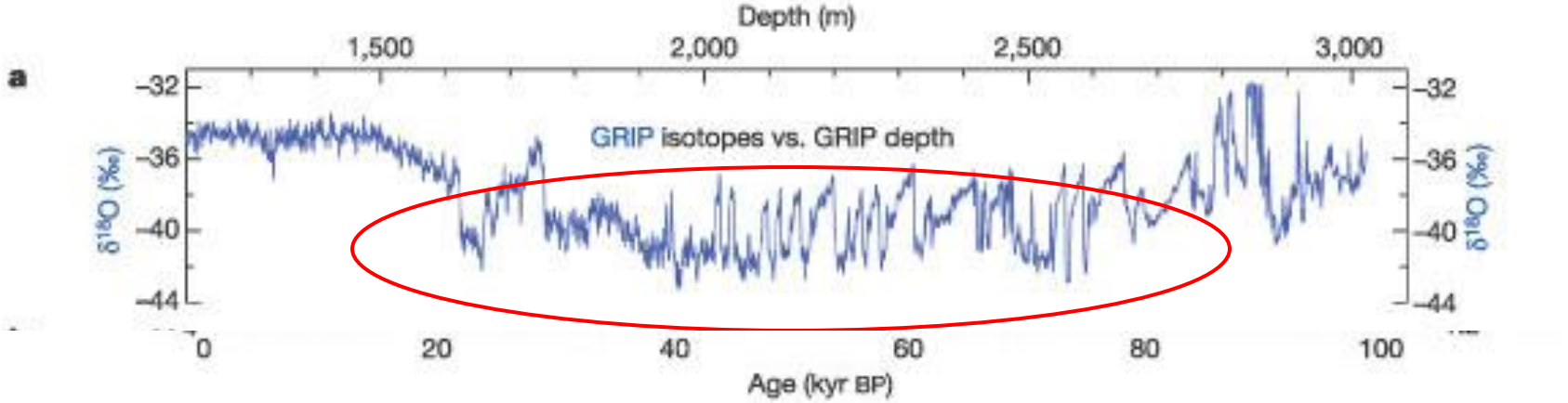
Sea ice feedback



- Cooler temperatures
- More sea ice
- Less heat flux to atmosphere from ocean to keel the Arctic warm
- Gives colder temperature

- Warmer temperatures
- Less sea ice
- More heat flux to atmosphere from ocean
- Gives warmer temperature

Ice cores from Greenland



Rapid transition from one climate to another symptomatic of positive feedbacks

Climate change near Greenland is closely linked to Arctic sea ice

Arctic sea ice likely to provide the positive feedback

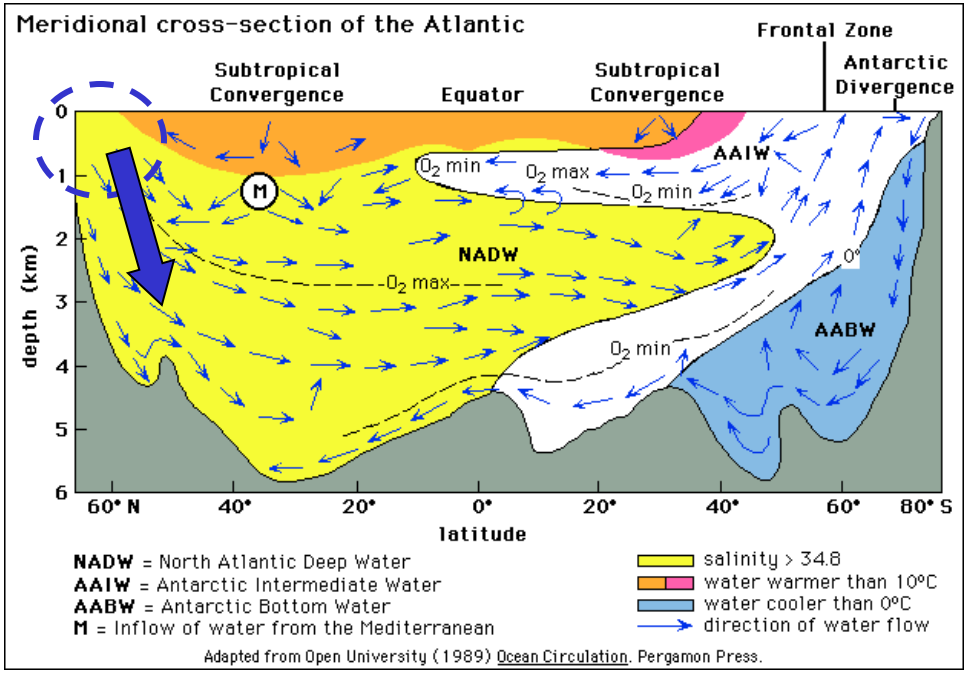
(*i.e., need a positive feedback to allow transitions….)*

Why would sea ice influence climate?

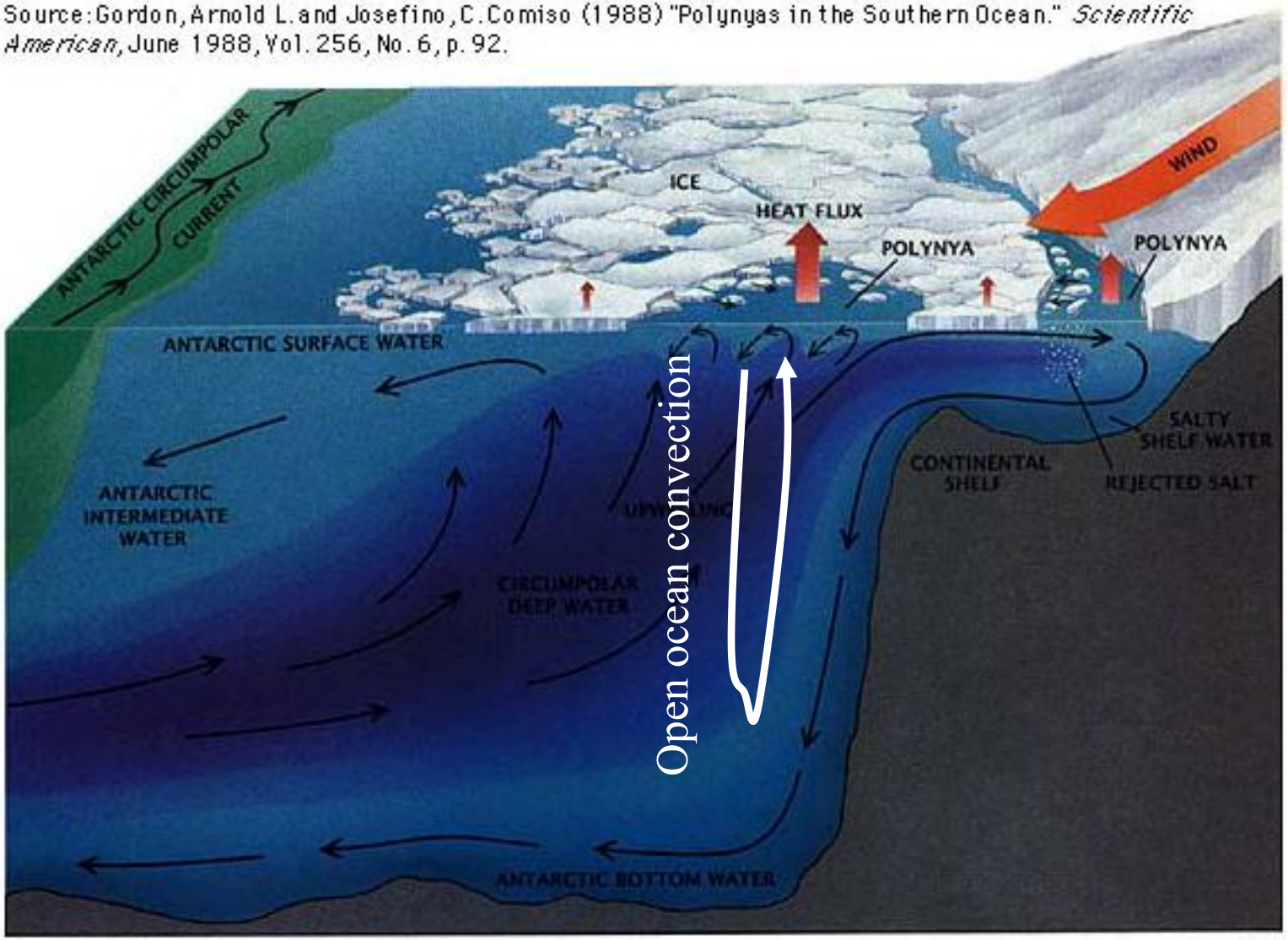
- Surface energy balance
- Albedo
- Evaporation
- Changes in surface temperature
  - Sea ice is about -15C!
  - Compared to ocean water at 0C)
- Can chance atmospheric circulation patterns

Brine rejection

- Open water freezes
- Only the fresh water turns to ice, leaving the salt behind
- Cold Arctic ocean becomes more saline
- More saline water sinks
- This drives the deep ocean circulation.
  Important linkage between sea ice and ocean circulation

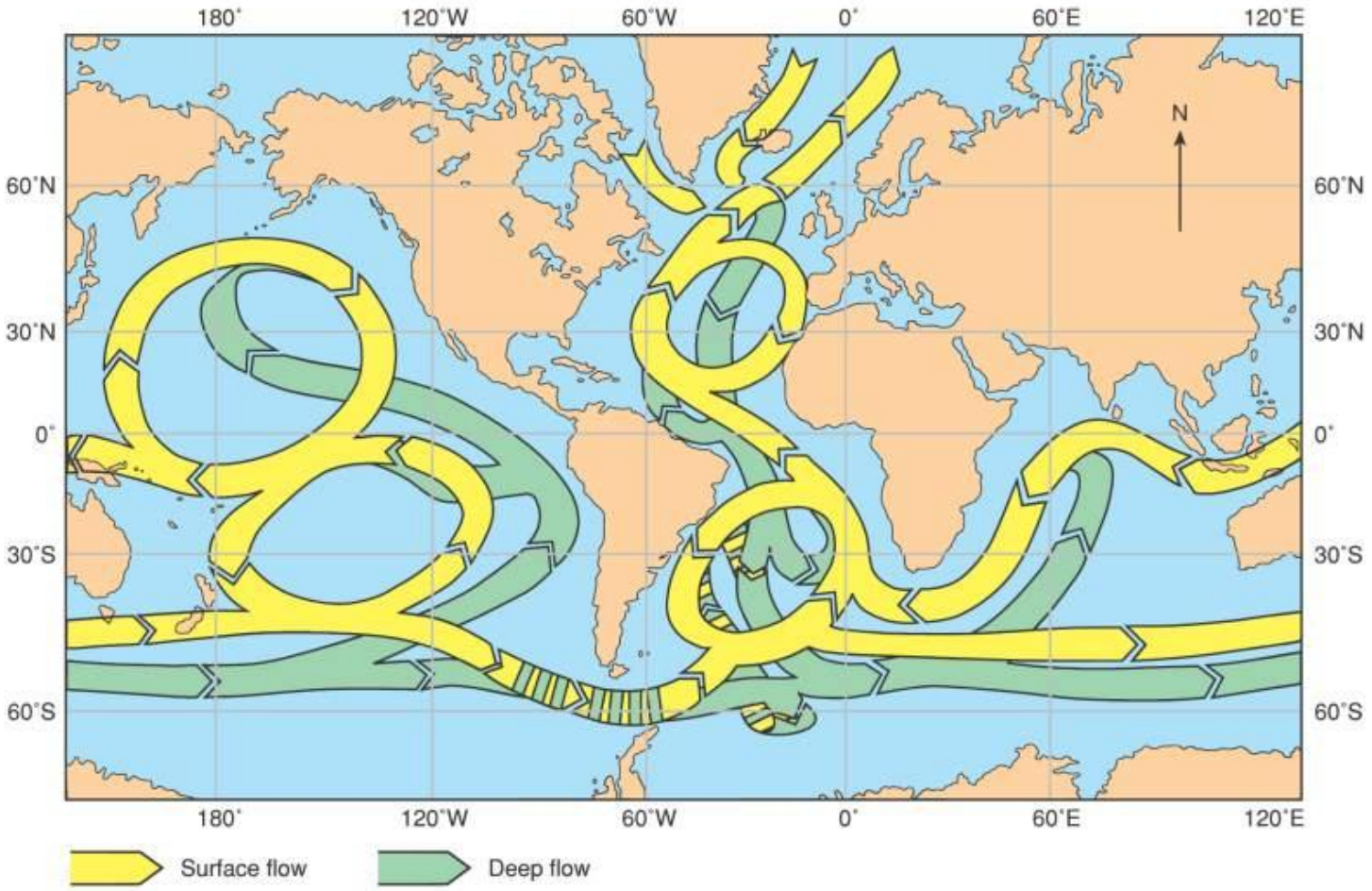


Source: Gordon, Arnold L. and Josefino, C. Comiso (1988) "Polynyas in the Southern Ocean." *Scientific American*, June 1988, Vol. 256, No. 6, p. 92.



Meridional circulation pattern of the Southern Ocean (the ocean surrounding Antarctica) is dominated by the upwelling of a warm, salty water mass called the Circumpolar Deep Water and its transformation into Antarctic Surface Water, which ultimately sinks to become Antarctic Intermediate Water and Antarctic Bottom Water. The circulation is driven by wind and the exchange of heat and fresh water between the ocean and the atmosphere.

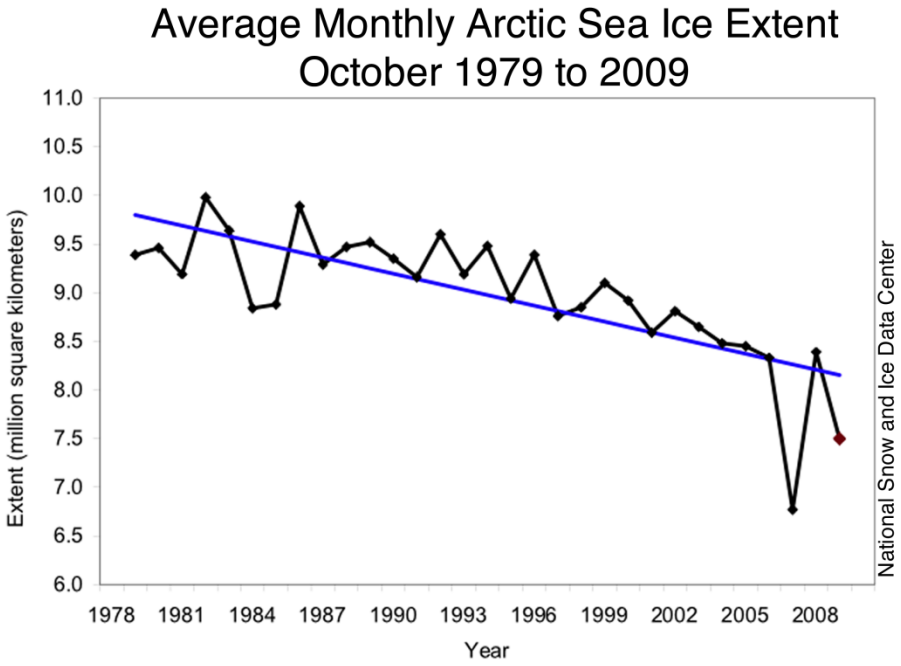
Recall the ocean deep ocean thermohaline circulation

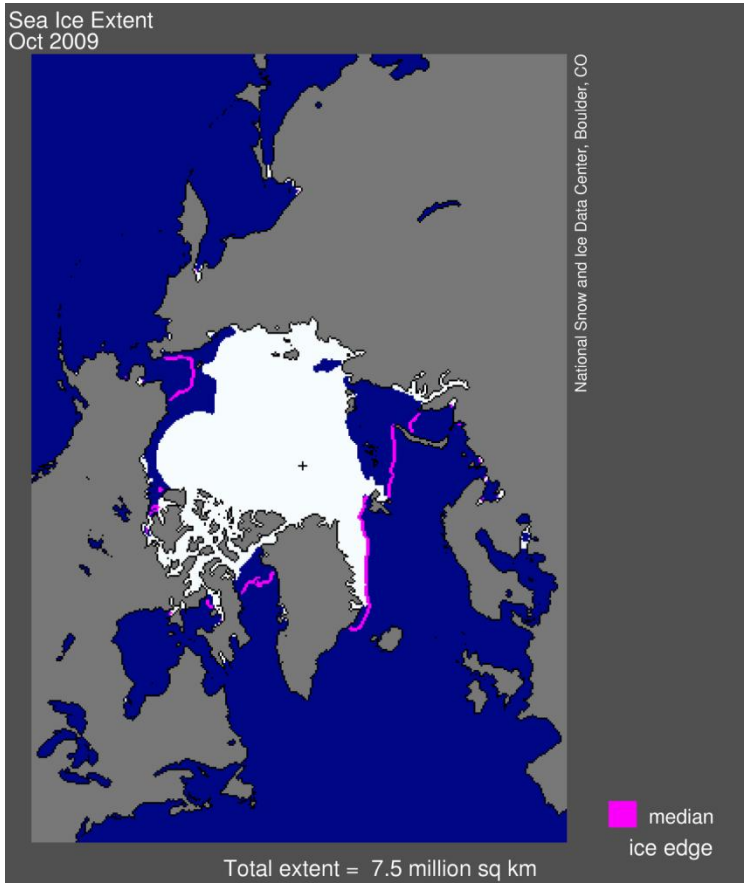


Trends in sea ice

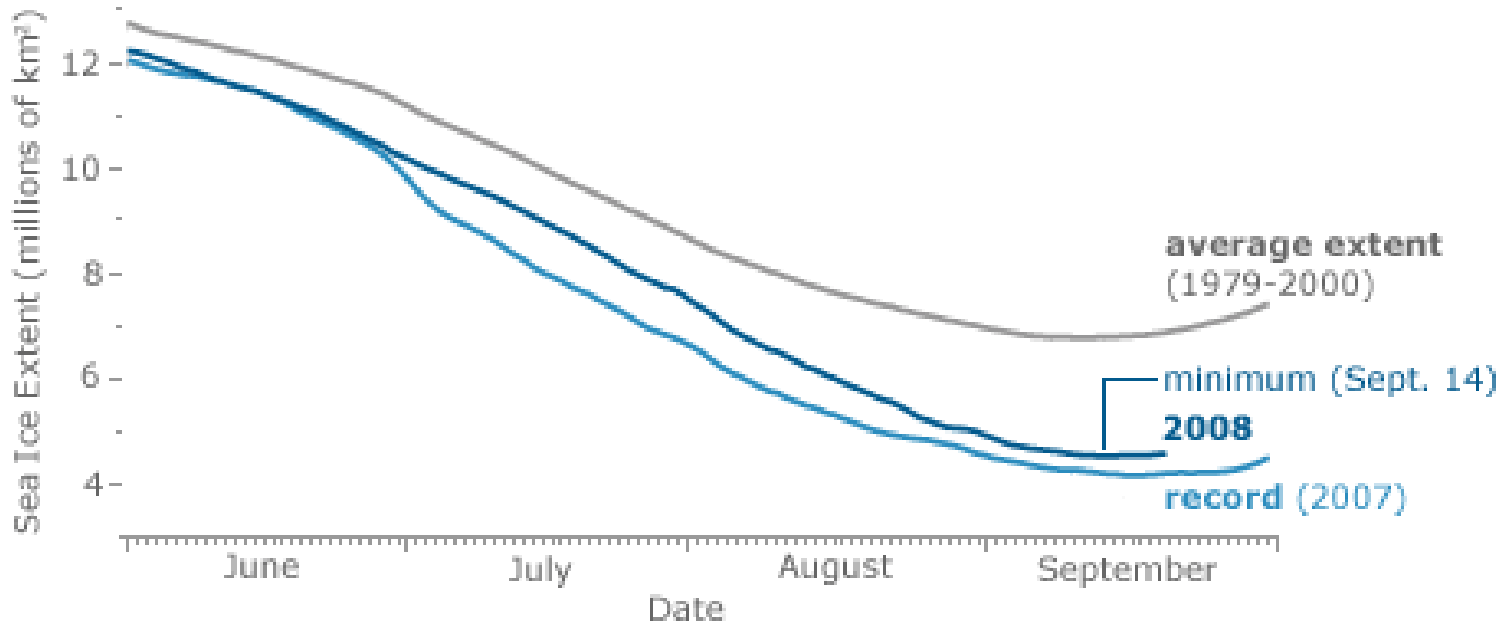
Very accurate data since about 1979 from satellites

Some other data from ships
(and submarines!) give longer records.





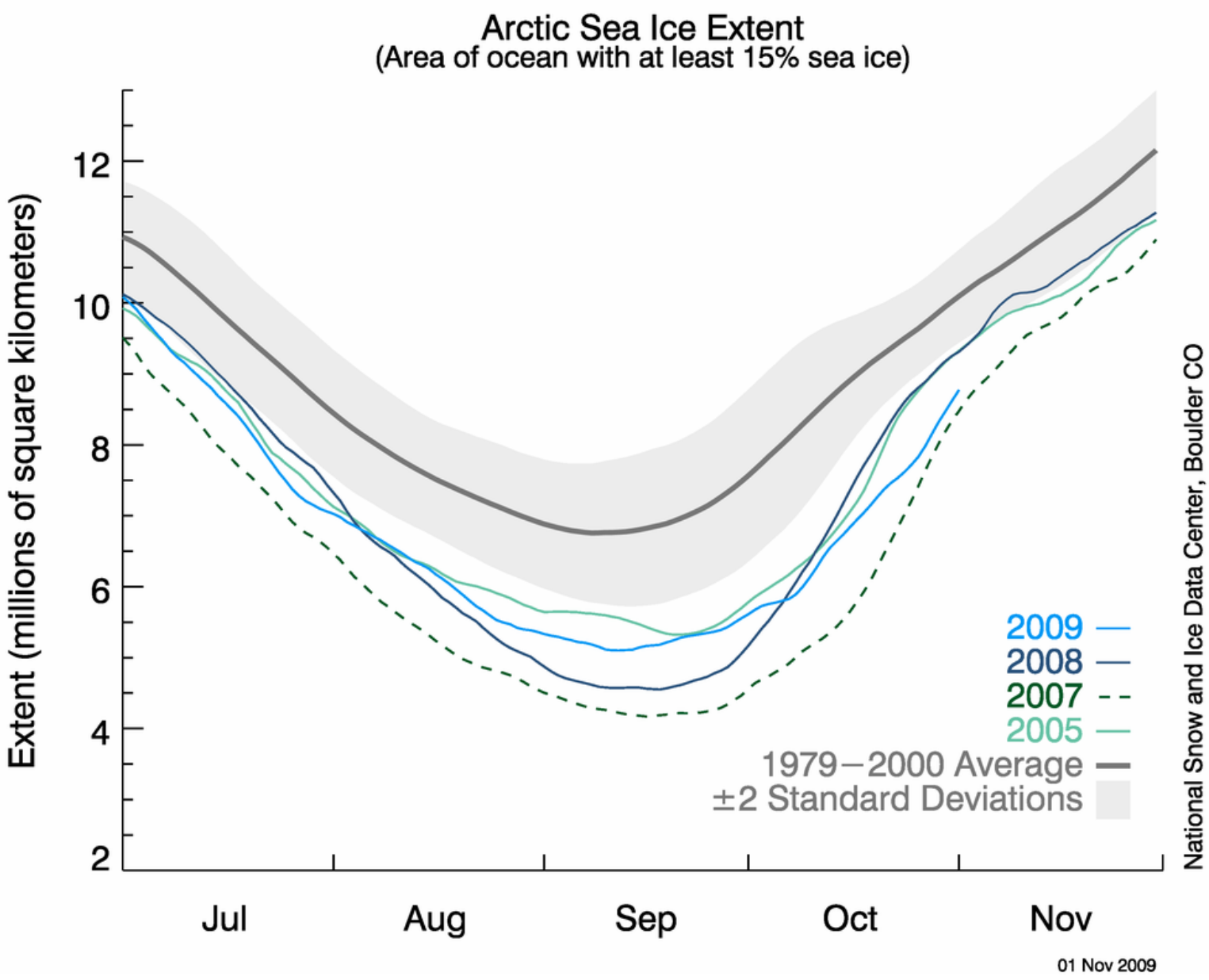
Recent changes in the melt season



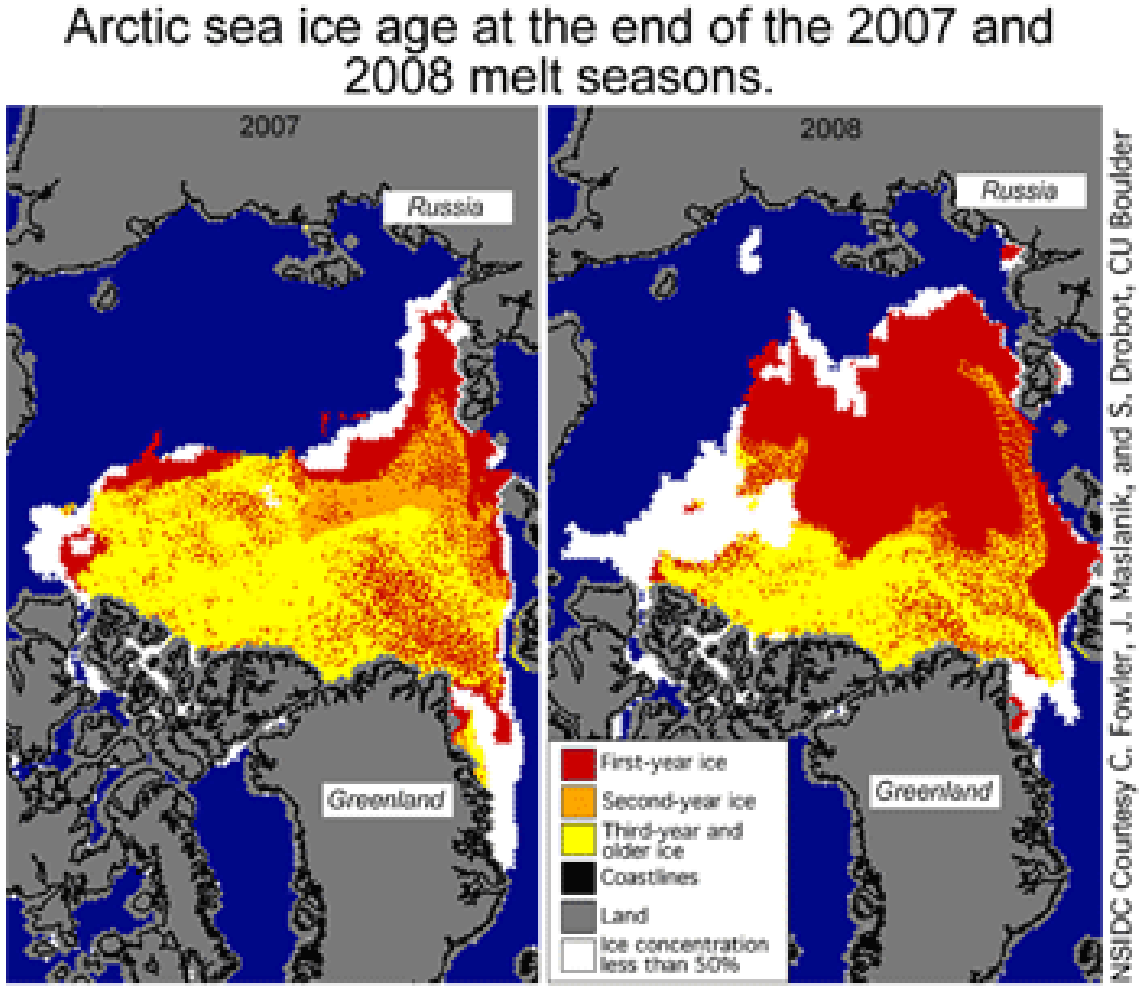
Melting occurring earlier and earlier.

2007 was the record least summer ice

… and was an extremely early melt year!

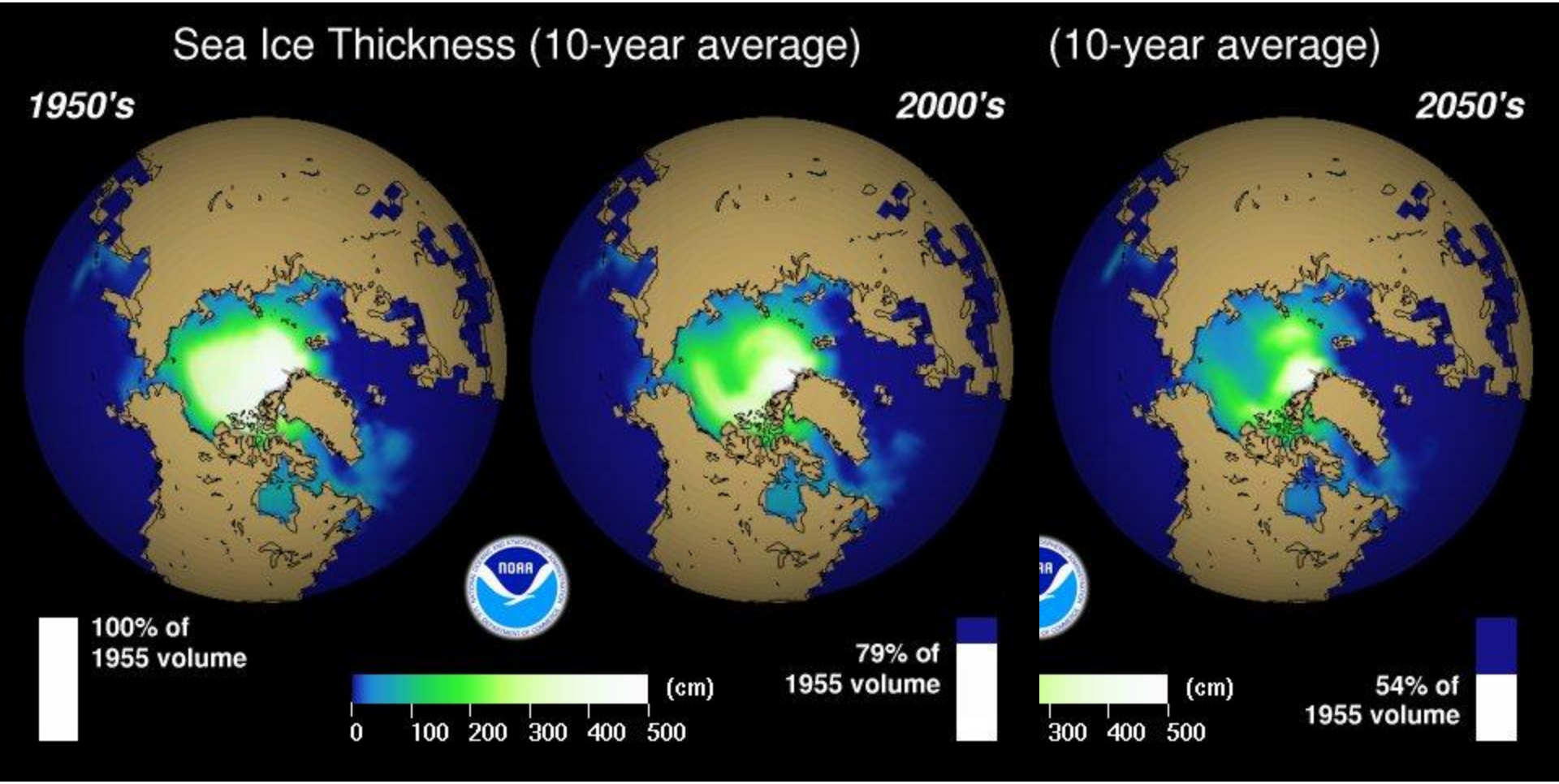

Arctic Sea Ice Extent
(Area of ocean with at least 15% sea ice)
Extent (millions of square kilometers)
12
10
8
6
4
2
Jul
Aug
Sep
Oct
Nov
2009
2008
2007
2005
1979–2000 Average
±2 Standard Deviations
National Snow and Ice Data Center, Boulder CO
01 Nov 2009

Not just less, but thinner, and recently formed!



National Snow and Ice Data Center, CIRES/CU

The future of sea ice



Climate model projections

Key points

- Sea ice has very large seasonal variations
- In the Arctic some fraction of the sea ice typically does not stay from year to year
- In Antarctica nearly all the ice grows and melts each year
- Sea ice regulates the exchange of energy/heat between the atmosphere and ocean
- That is, sea ice acts as an ***insulator***

- Sea ice can play a very important role in positive feedbacks that amplify climate changes at high latitudes (energy, and salinity)

- Observations show a dramatic decline (especially 2007 and 2008!)
- Projections of climate suggest the Arctic may be free of ice in the summer by 2050!

  (This is not good news for polar bears)