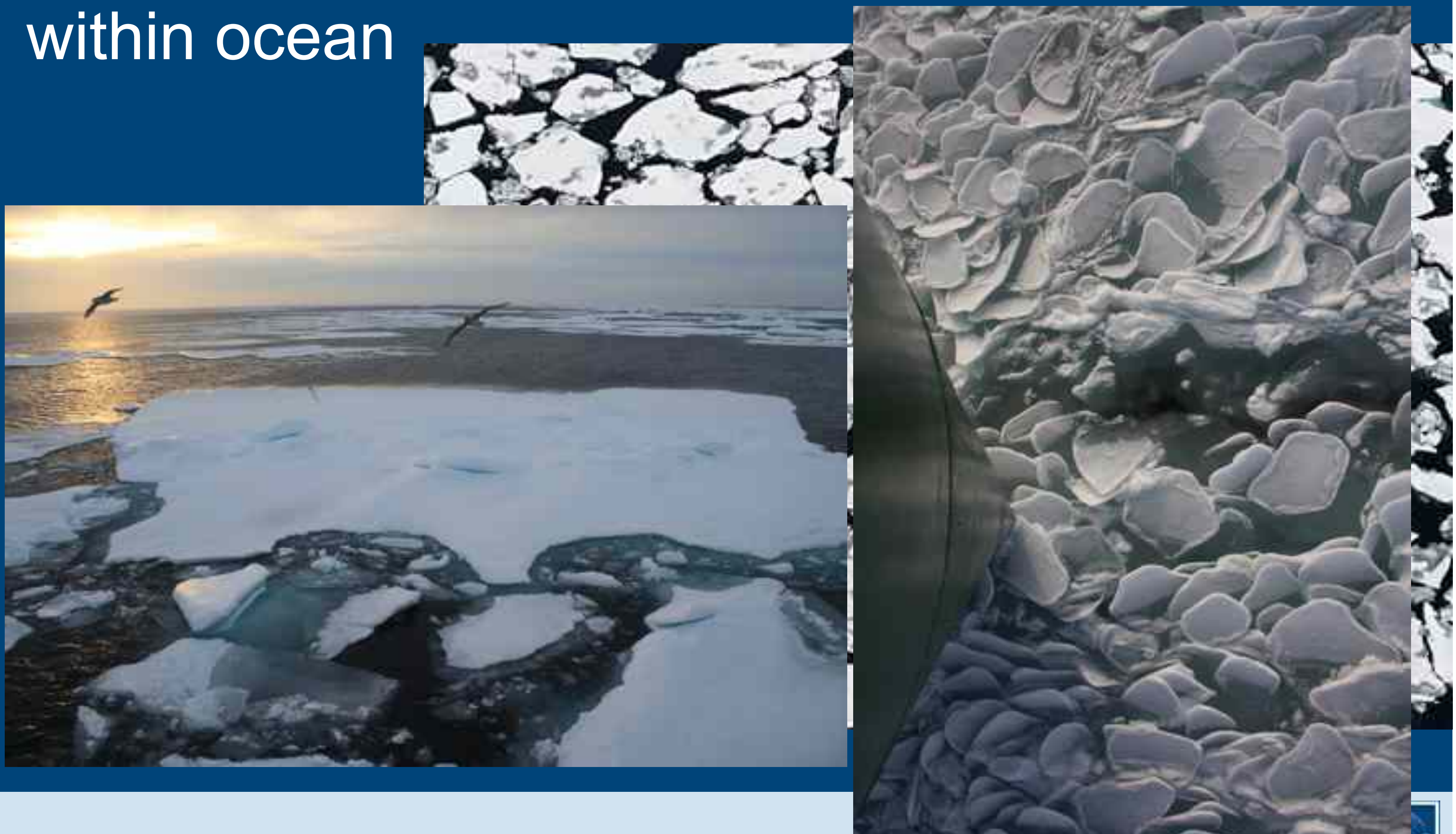
Causes and Implications of Reduced Arctic Sea Ice Loss

Julienne Stroeve
National Snow and Ice Data Center, Cooperative Institute for Research in Environmental Sciences at the University of Colorado Boulder

What is sea ice?

- Frozen surface of the ocean – originates within ocean



What is sea ice

- Sea ice does not include land ice (glaciers, ice sheets)

- Does not include other floating ice (ice shelves, icebergs)
- If sea ice melts, sea level will not rise

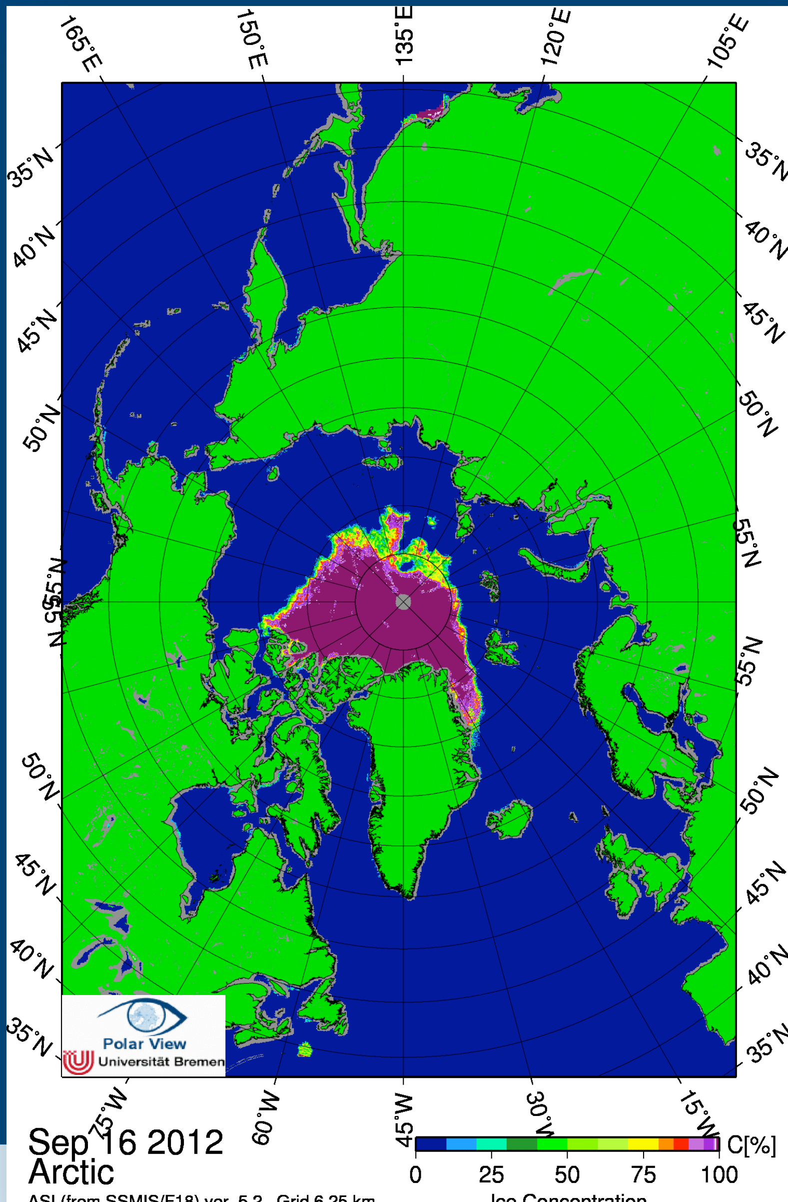
Image Courtesy Sebastian Copeland

Annual sea ice variability

Maximum extent occurs in February/March (14-16 million km^2

The shrinking summer ice cover

September 2012: A new record low



Sept 16, 2007: 4.17 million sq. km

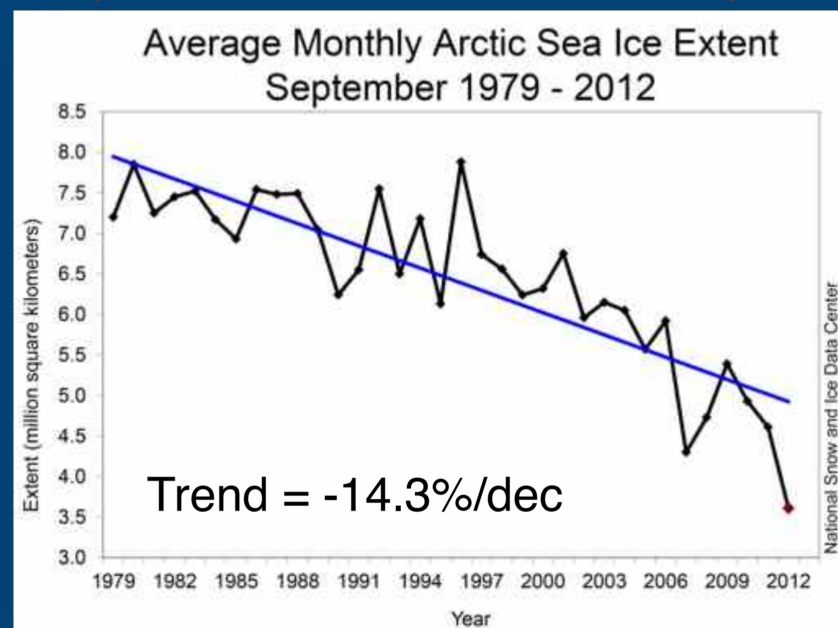
Sept 14, 2008: 4.51 million sq. km

Sept 12, 2009: 5.10 million sq. km

Sept 19, 2010: 4.60 million sq. km

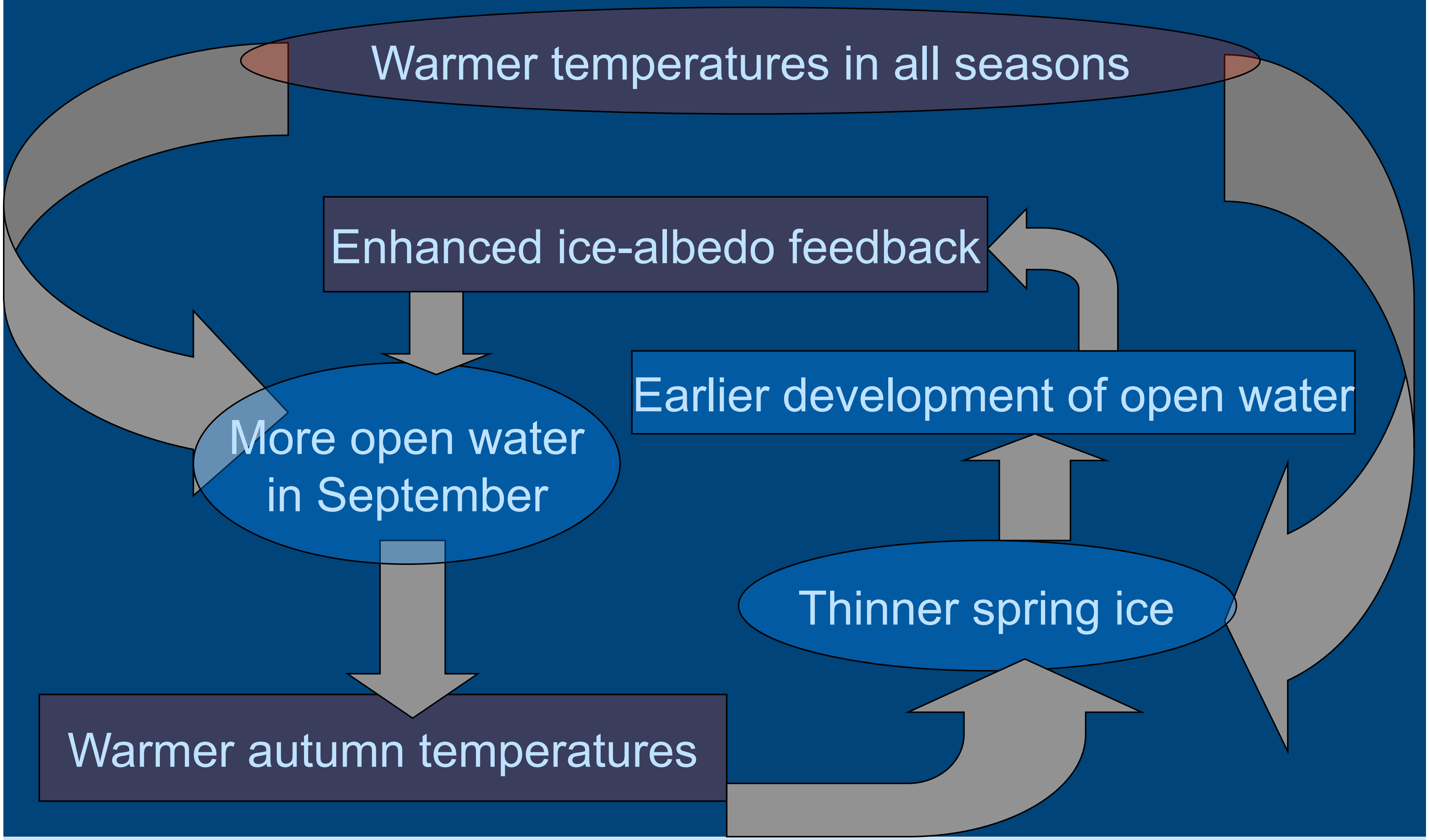
Sept 9, 2011: 4.33 million sq. km

Sept 16, 2012: 3.41 million sq. km

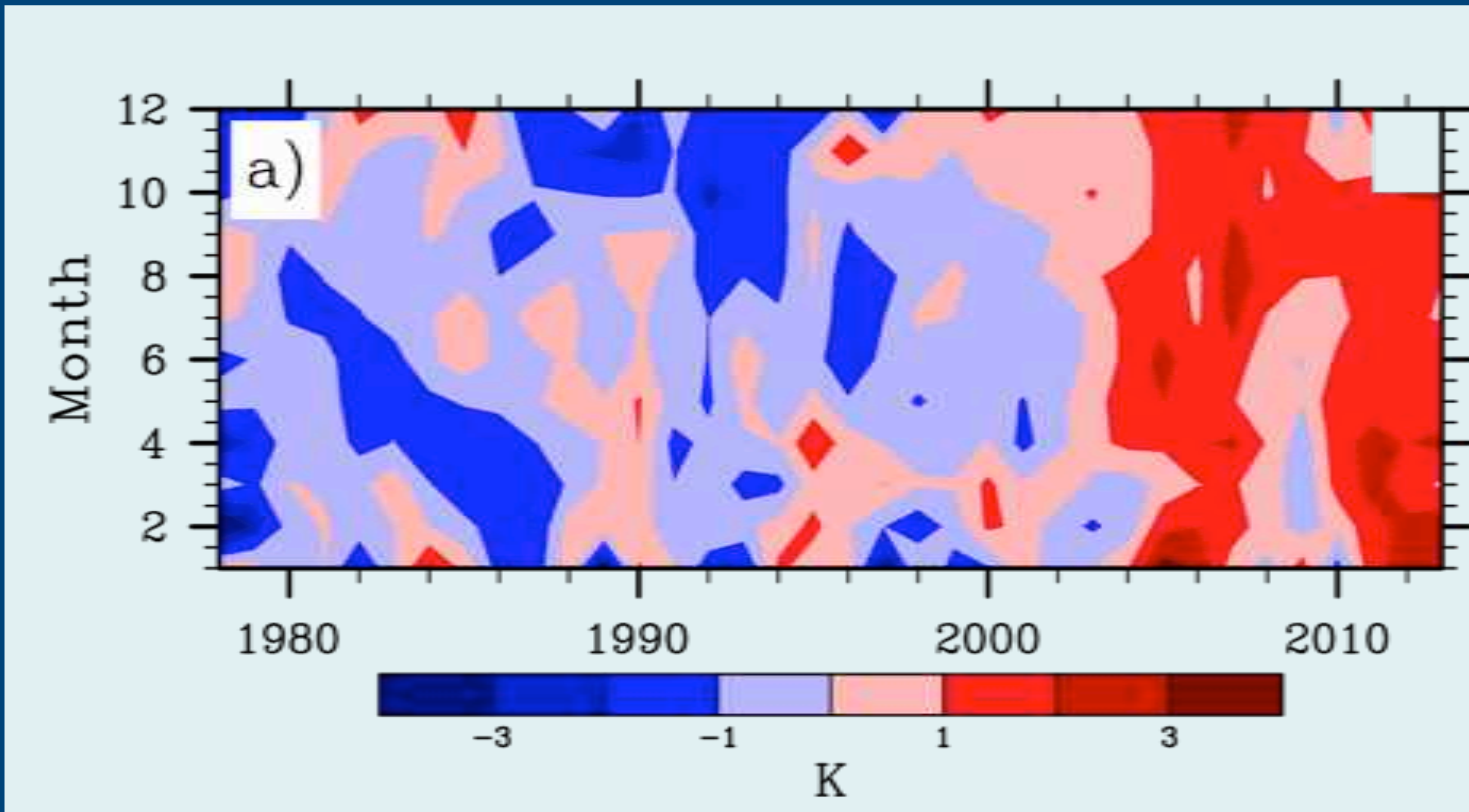


Left: Univ. Bremen; right: NSIDC

What is causing the sea ice to retreat?



Warmer in all seasons

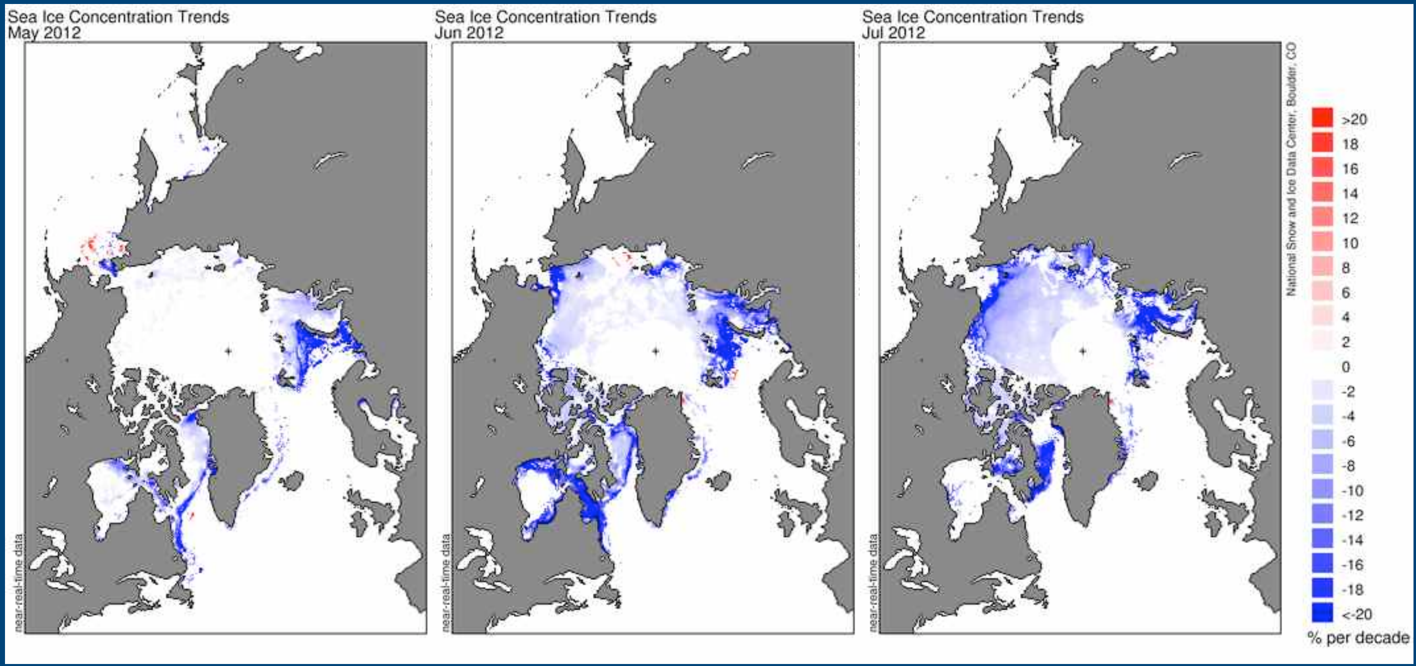


925 hPa air temperature anomalies from ERA-Interim averaged from 60-90N

Earlier formation of open water

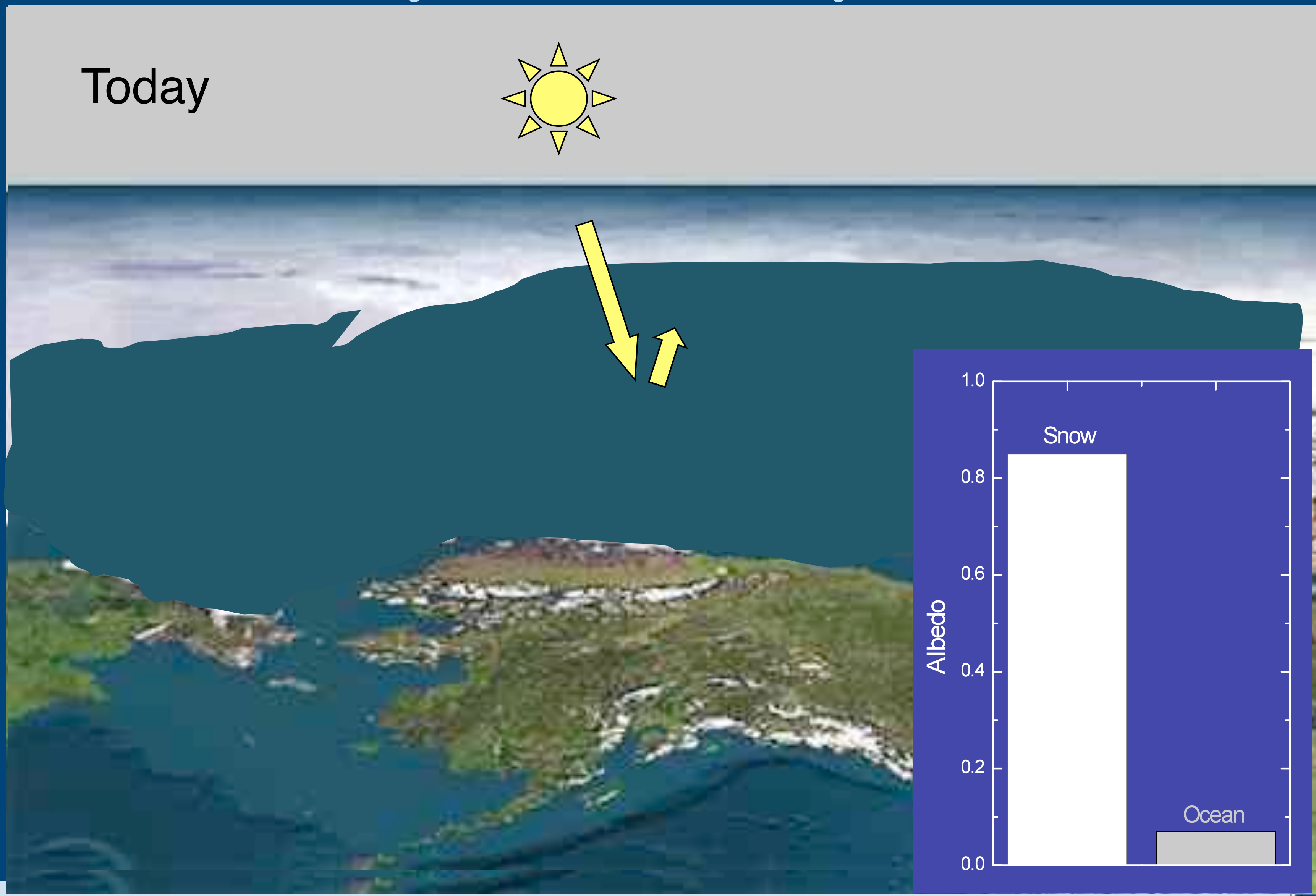
Negative trends in summer ice concentration imply a corresponding reduction in albedo

May June July



Trends from 1979 to 2012 in %/decade

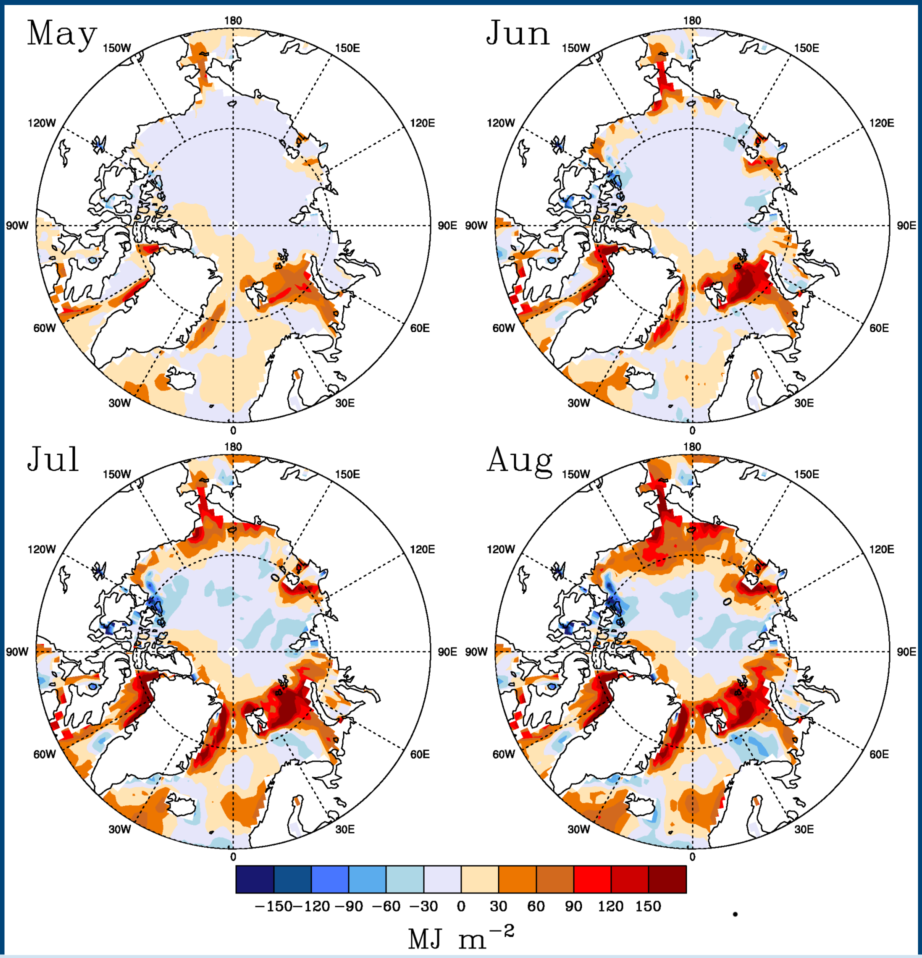
Enhancement of the ice-albedo feedback



Leads to increased absorbed solar energy

2002-2008 anomalies in cumulative absorbed SW relative to 1979-2008 mean

Cumulative anomalies for August locally exceed 150 MJm^{-2}, representing an equivalent melt of ice thickness of 49 cm



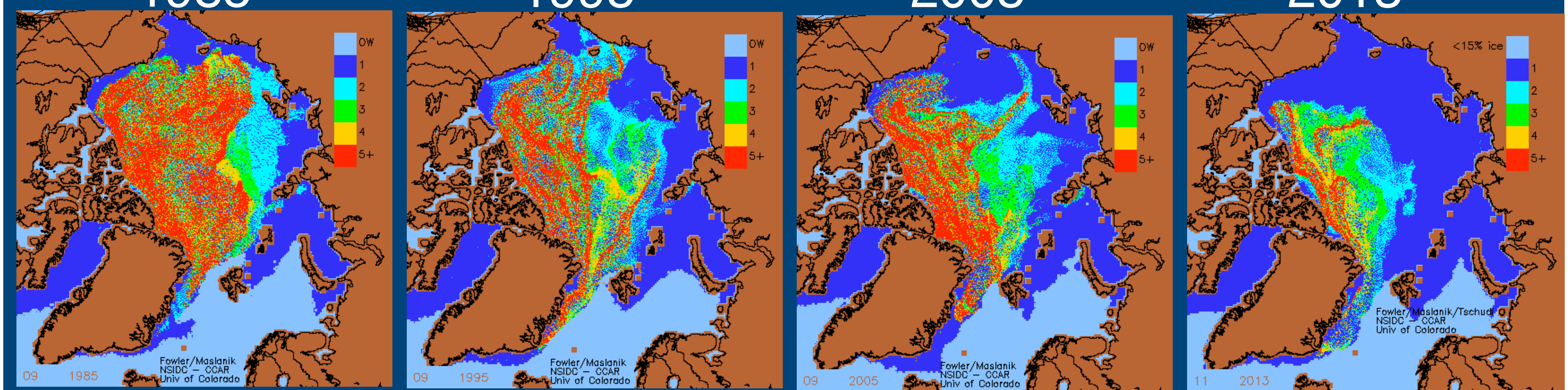
Data from JRA-25 Reanalysis

Figure from Stroeve et al., 2012

Ice is becoming younger and thinner

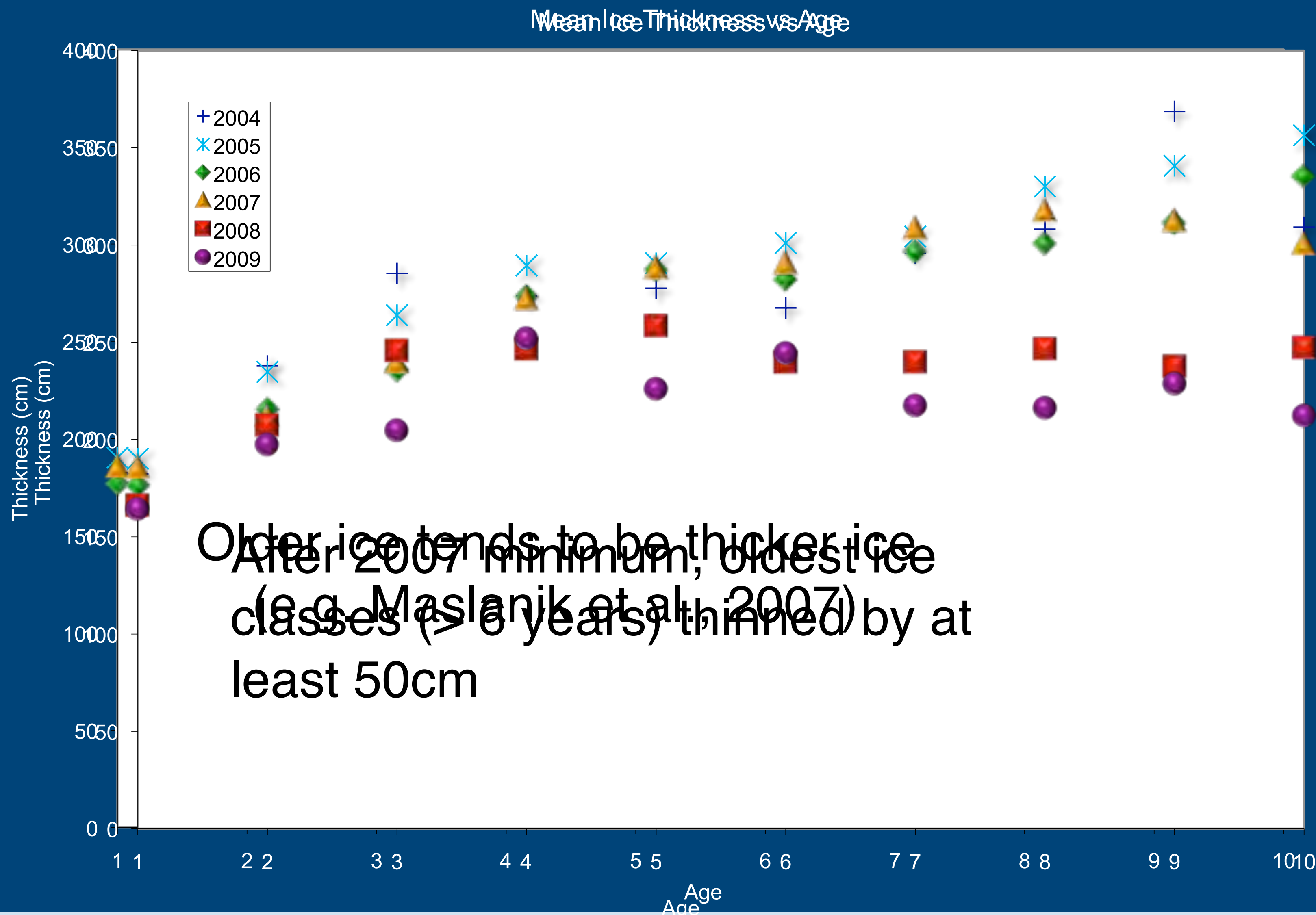
- At the same time the extent has decreased, the ice has become younger and thinner.

1985 1995 2005 2013



In 2013, less than 5% of the ice cover is 5 years or older compared to > 20% in 1980s and early 1990s

Younger ice is thinner ice



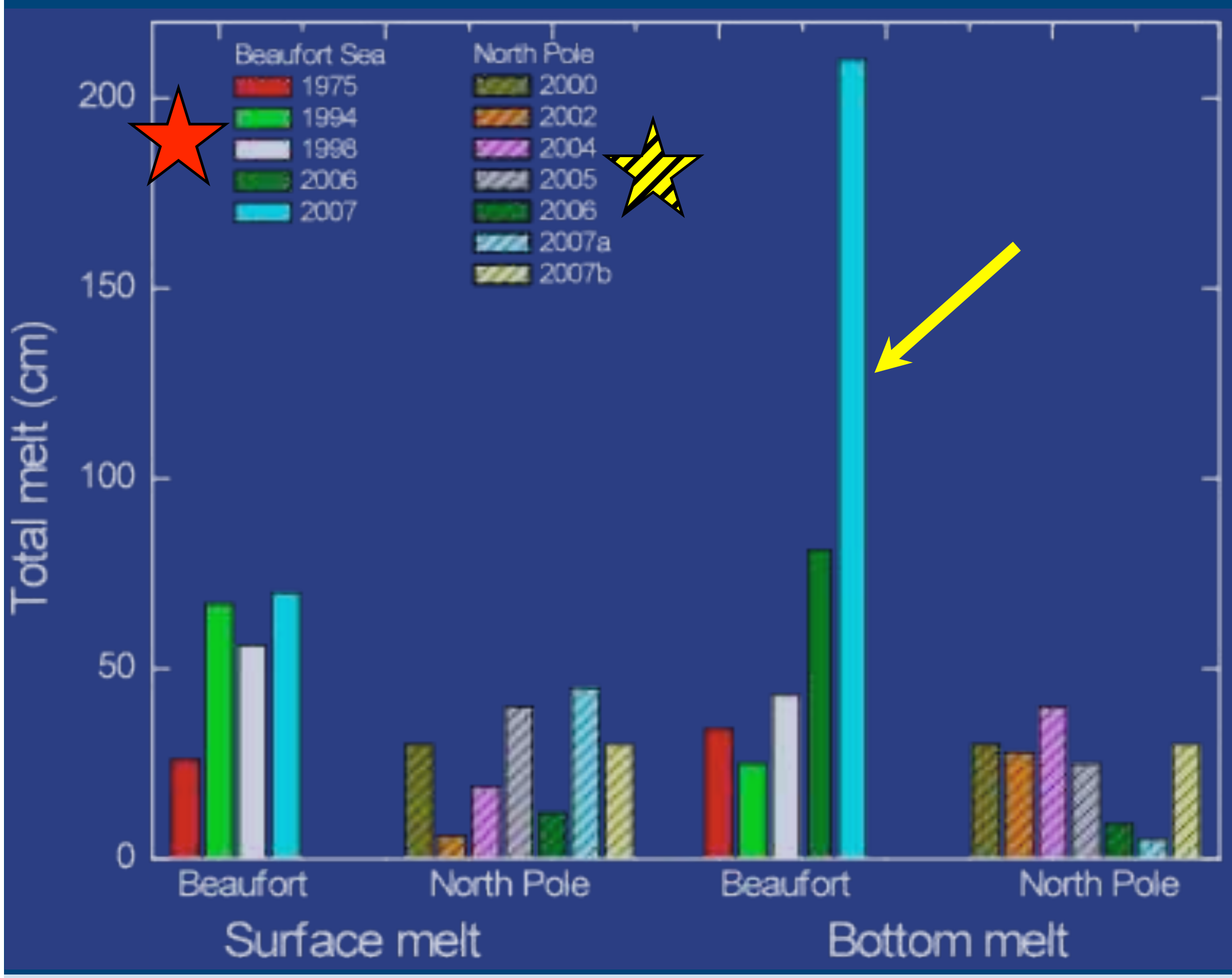
Older ice tends to be thicker ice (e.g. Maslanik et al., 2007)

After 2007 minimum, oldest ice classes (> 6 years) thinned by at least 50cm

Comparison of ice age with ice thickness from ICESat

Lots of basal melt in summer 2007

- Extremely large amount of ice bottom melting in Beaufort Sea in summer 2007!



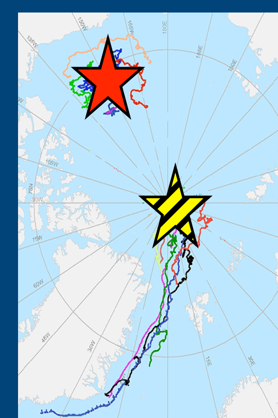
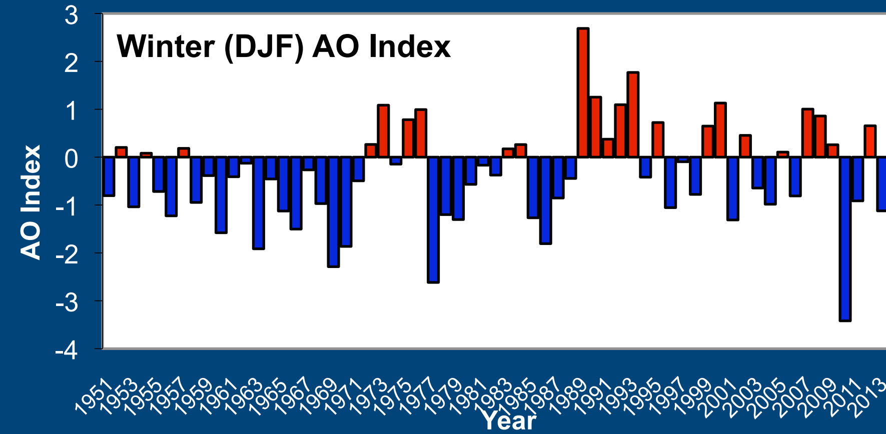


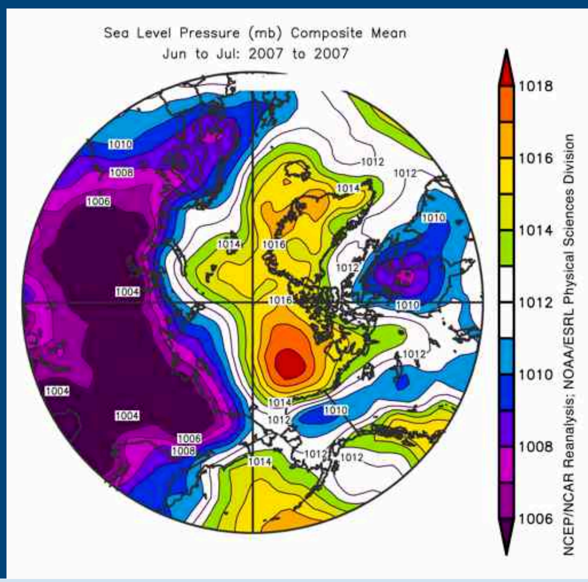
Figure from D. Perovich (GRL, 2008)

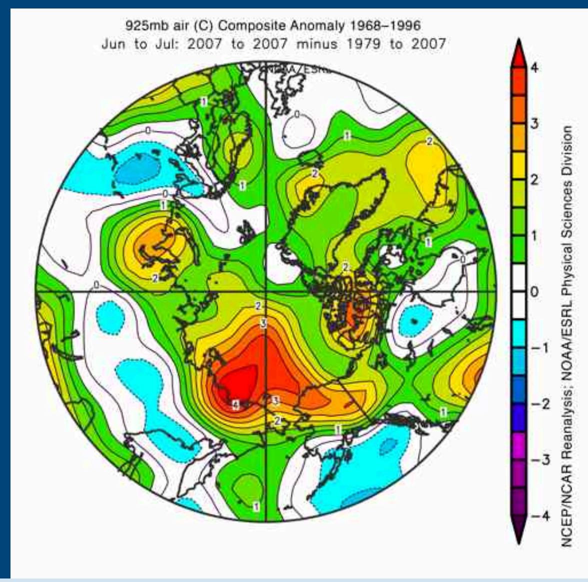
Other factors behind ice loss

- Changes in atmospheric circulation
  - Positive phase of the winter Arctic Oscillation in late 1980s/early 1990s



  - Dominance of summer Arctic Dipole Anomaly pattern (2007-2011)





JJA SLP Anomalies JJA 925 hPA Anomalies

Intrusion of warm water into Arctic

- Heat carried into the Arctic basin by the W. Spitsbergen current and the Bering Strait inflow has been documented
- But the mixing of those flows inside the Arctic basin remain a subject of research
- Certainty is that a small change in ocean heat flux can have a large effect on ice thickness.

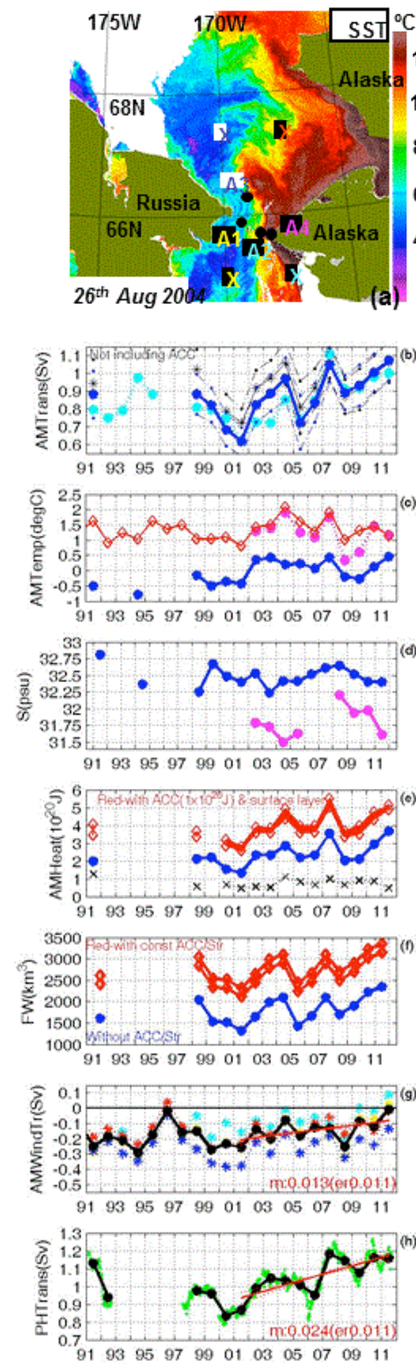


Figure from Woodgate et al., 2012 showing Bering Strait throughflow increases ~50% from 2001 to 2011.

Black carbon from incomplete combustion

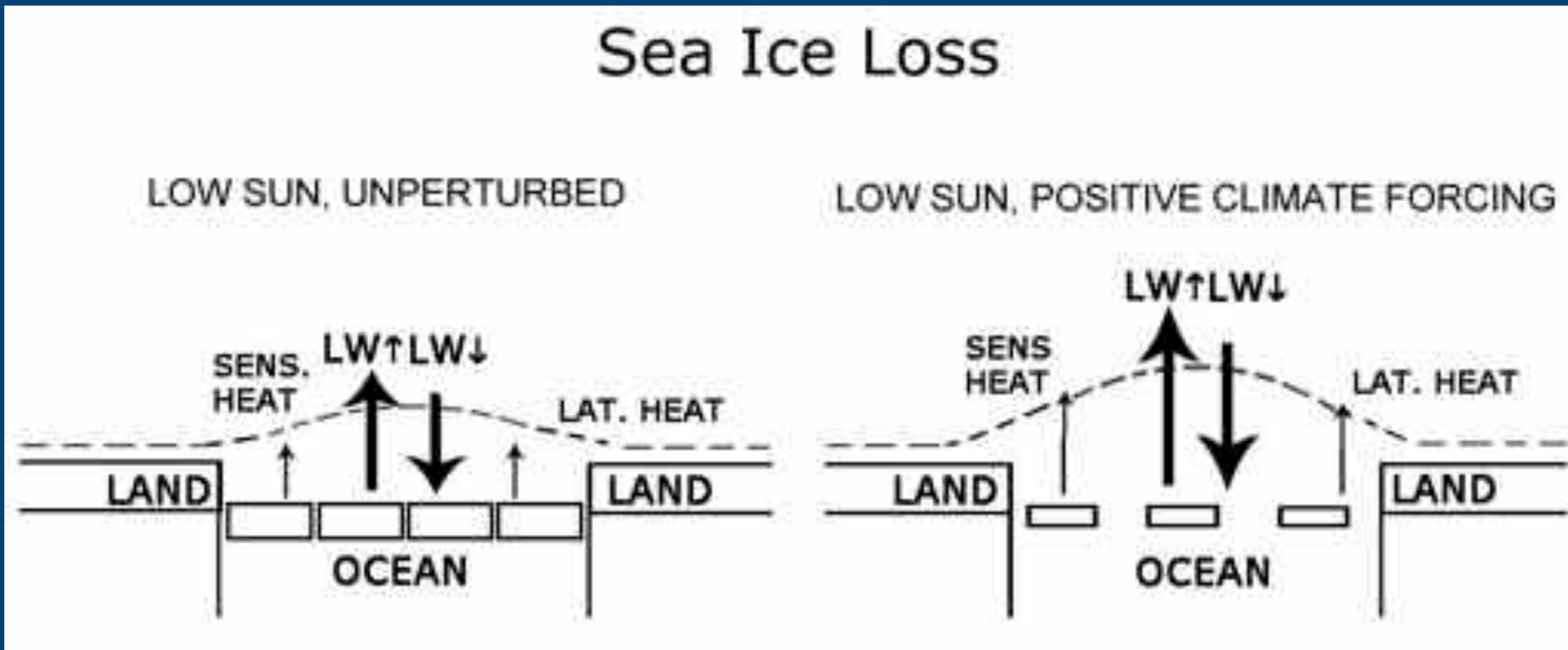
Atmospheric warming from black carbon aerosols

Black carbon on snow and ice enhances melt

newsbusters.org (left), blogs.tnr.com (right)

Implications of summer ice loss

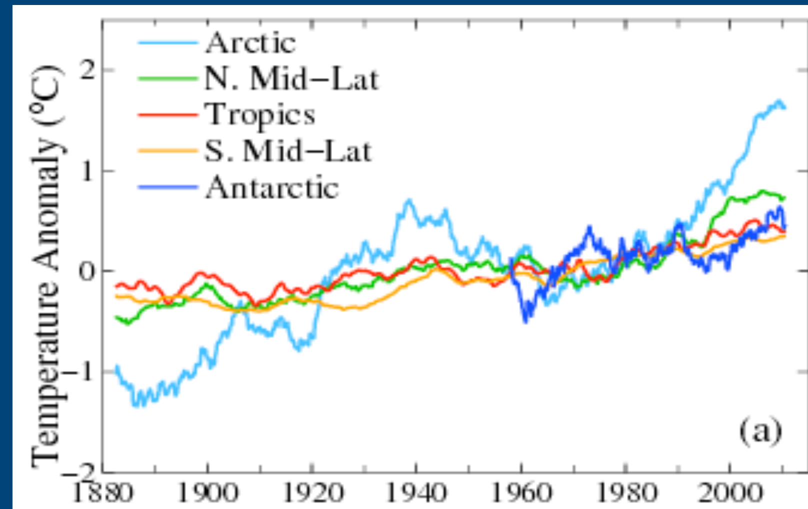
Arctic Amplification



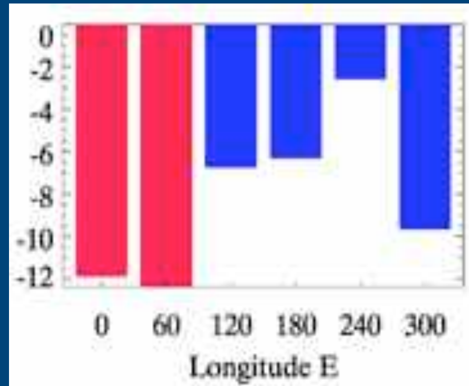
- Ocean picks up more heat in summer
- Releases more heat back to the atmosphere in autumn and winter

Arctic Amplification

- Widespread warming of the Arctic troposphere acts to weaken the north-south temperature gradient at high latitudes.
- Observations show that the poleward thickness gradient has decreased over the past several decades.
- Changes in meridional temperature and thickness gradients influence the structure of atmospheric zonal flow (through thermal wind)



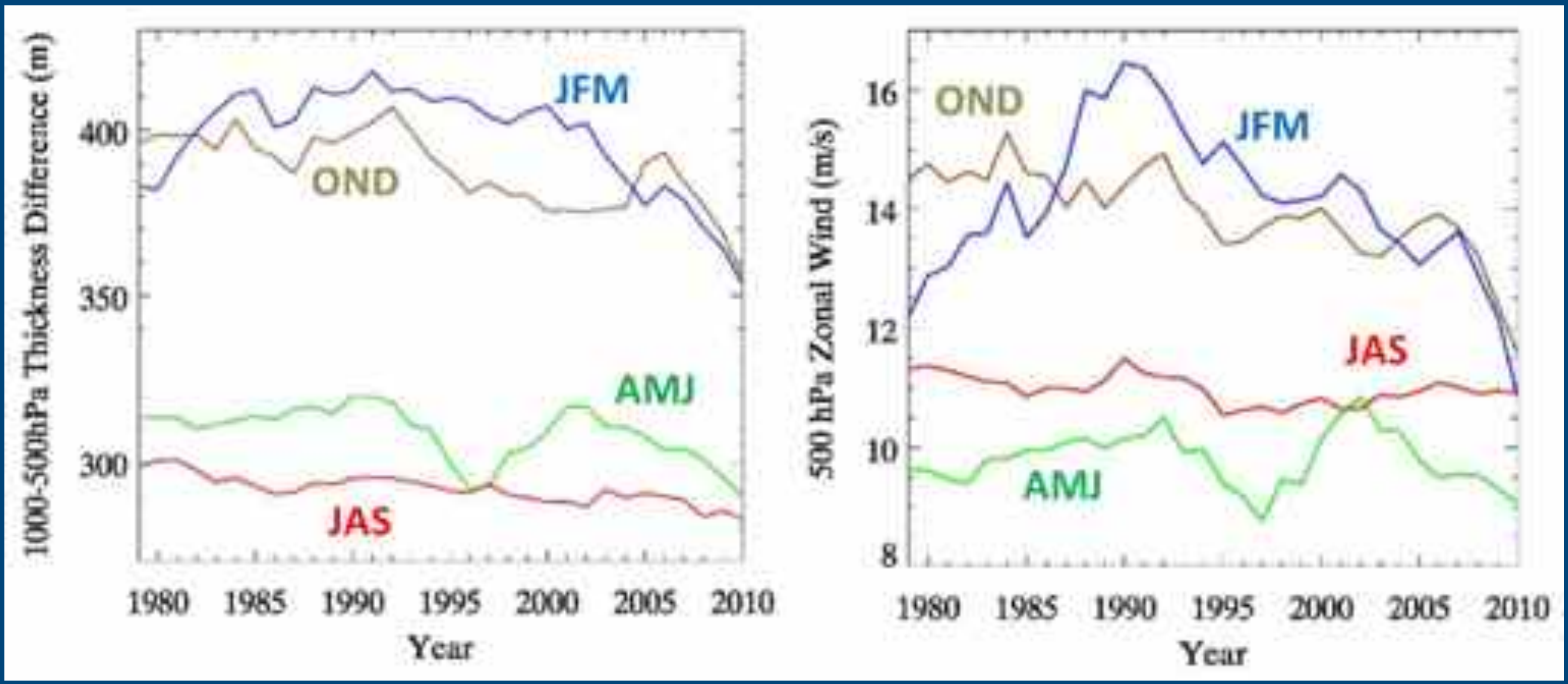
Time-series of zonal-averaged temperature anomalies from NASA GISS



Trend in m/dec in poleward 1000-500 hPa thickness difference [40-30^{o}N to 80-70^{o}N] from 1979 to 2012 during fall (Oct-Nov) along various longitudes. Red is significant at 90%.

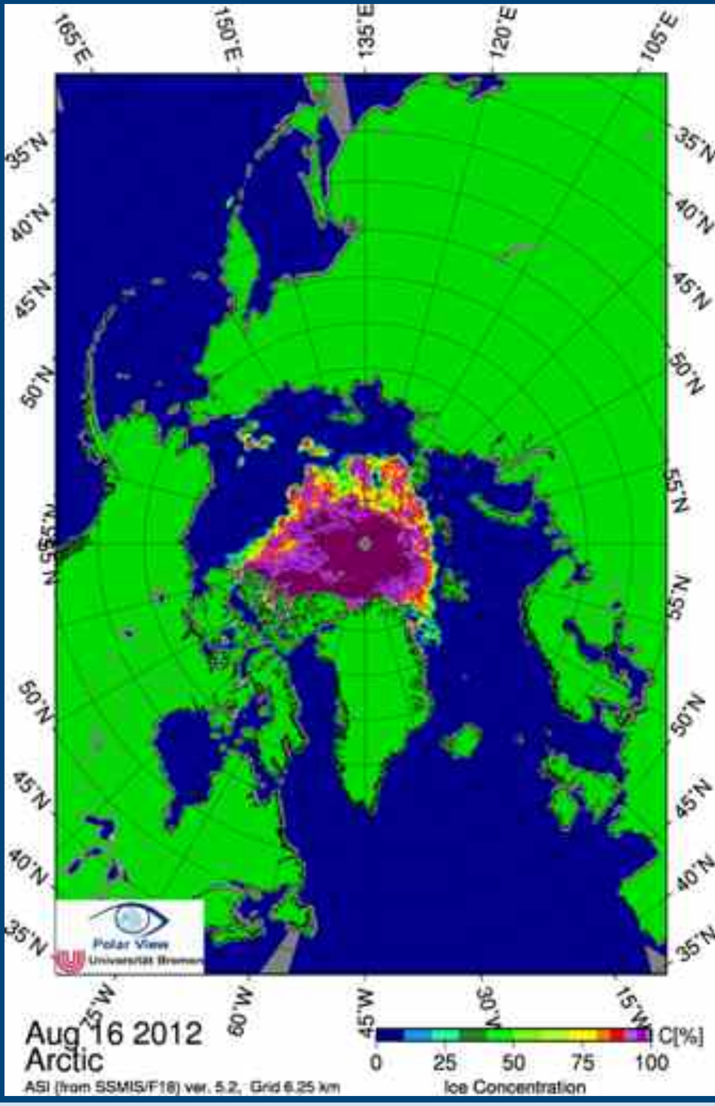
Impacts of Arctic Amplification

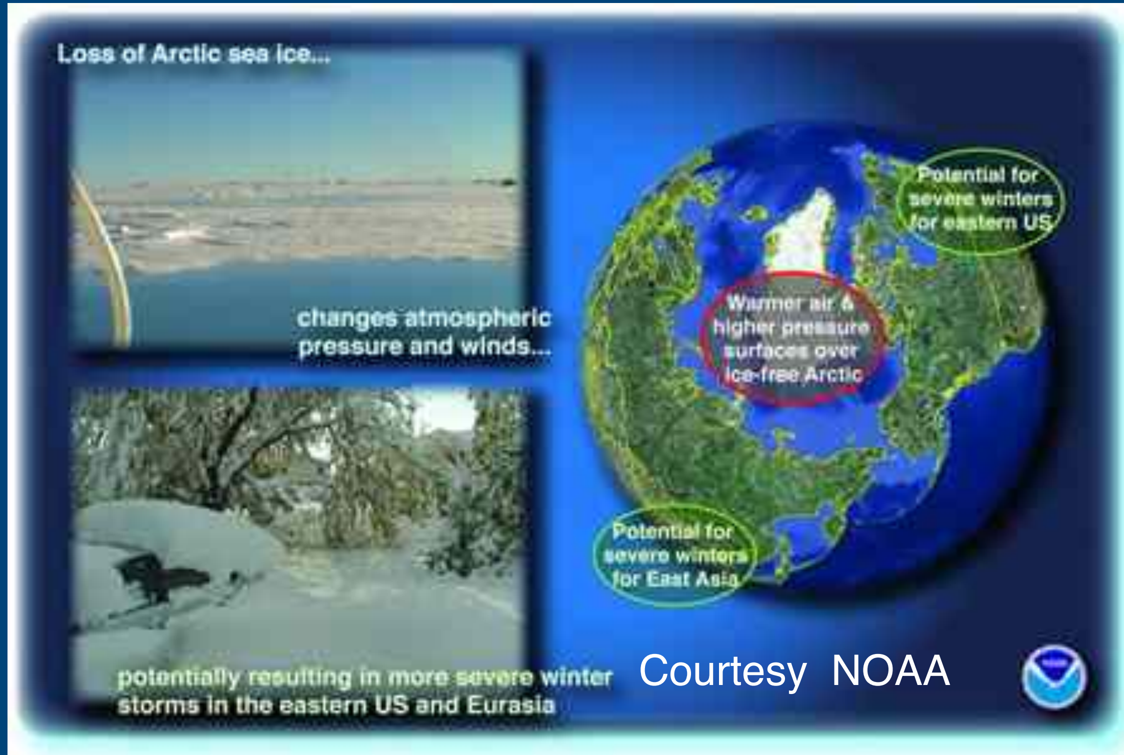
Thickness and Zonal Wind Speed Differences between 60-80ºN and 50-30ºN



- Changes in zonal flow alter both vertical Rossby wave propagation and wave breaking by merdionally propagating waves
- Weakening of extratropical zonal flow is connected to increases in the incident of blocking and could cause air outbreaks during winter with pronounced sea ice loss (Francis and Vavrus, 2012).

Impacts on atmospheric circulation





Numerical experiments forced with sea ice reductions reveal changes in the large-scale atmospheric flow consistent with the negative phase of the Arctic Oscillation [e.g. Deser et al., 2010, Porter et al., 2012].

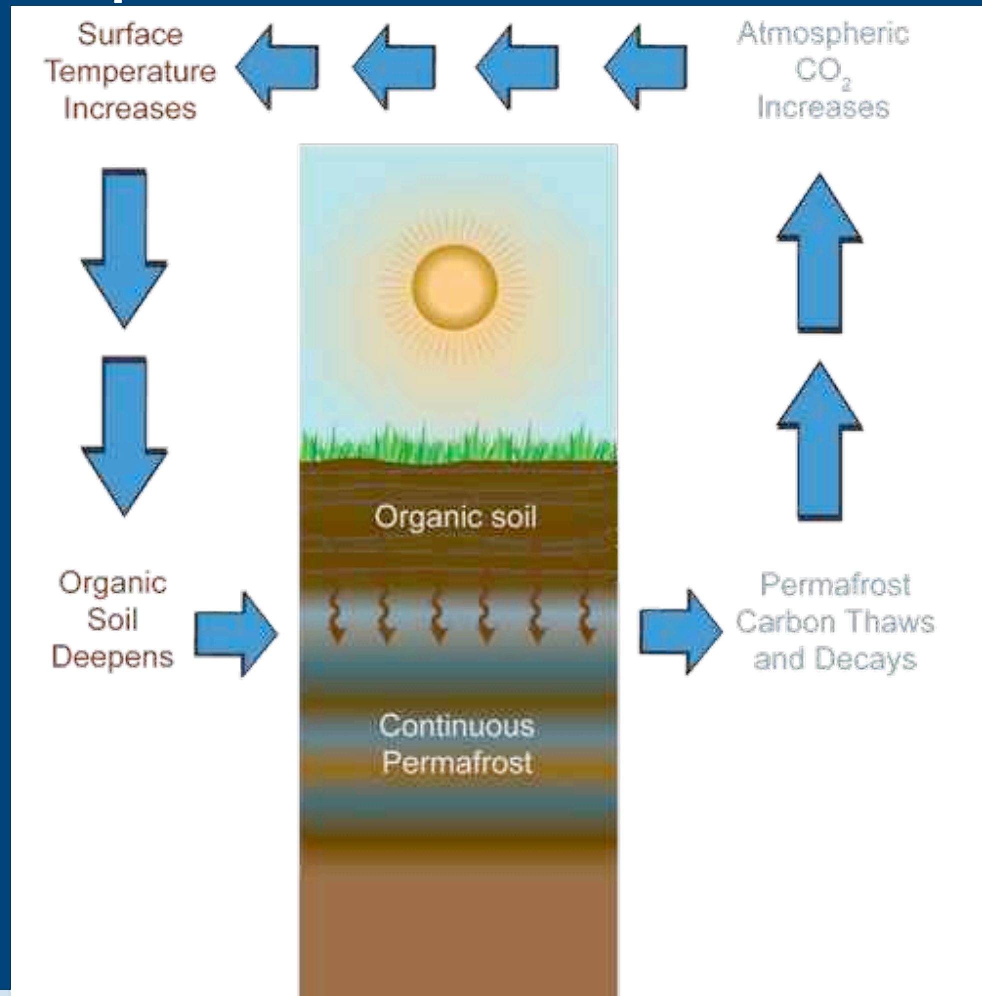
Implications of summer ice loss

Coastal Erosion




Permafrost carbon cycle

Permafrost contains about 1600 Gt of carbon. For comparison, carbon content of Earth's atmosphere is about 730 Gt.

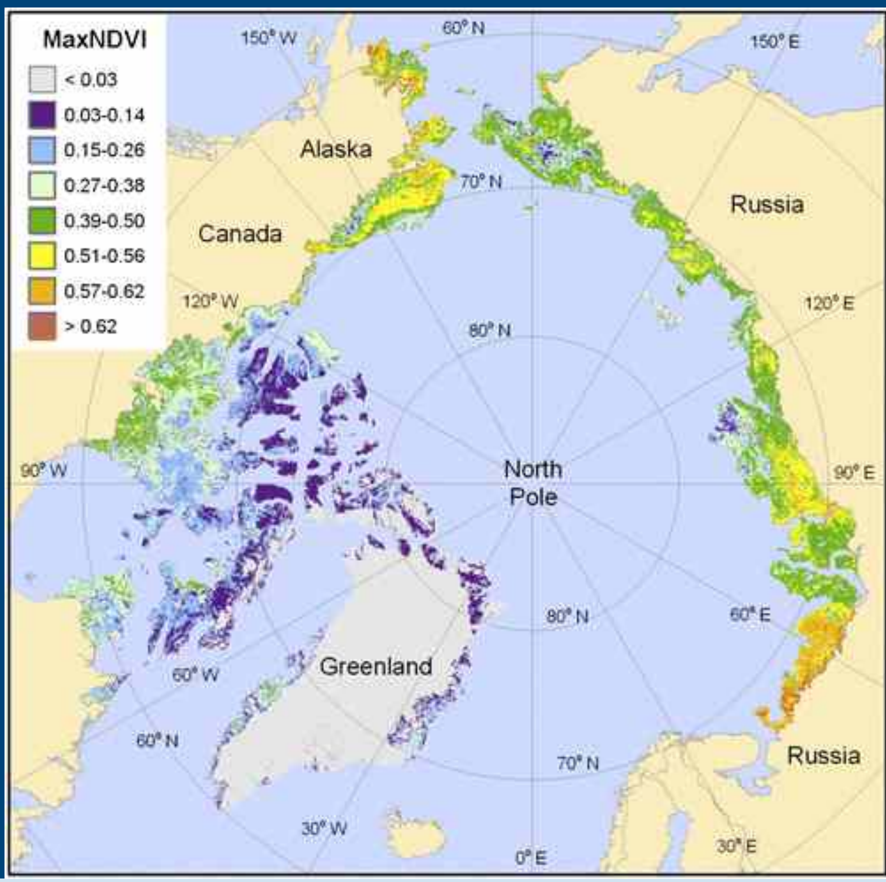


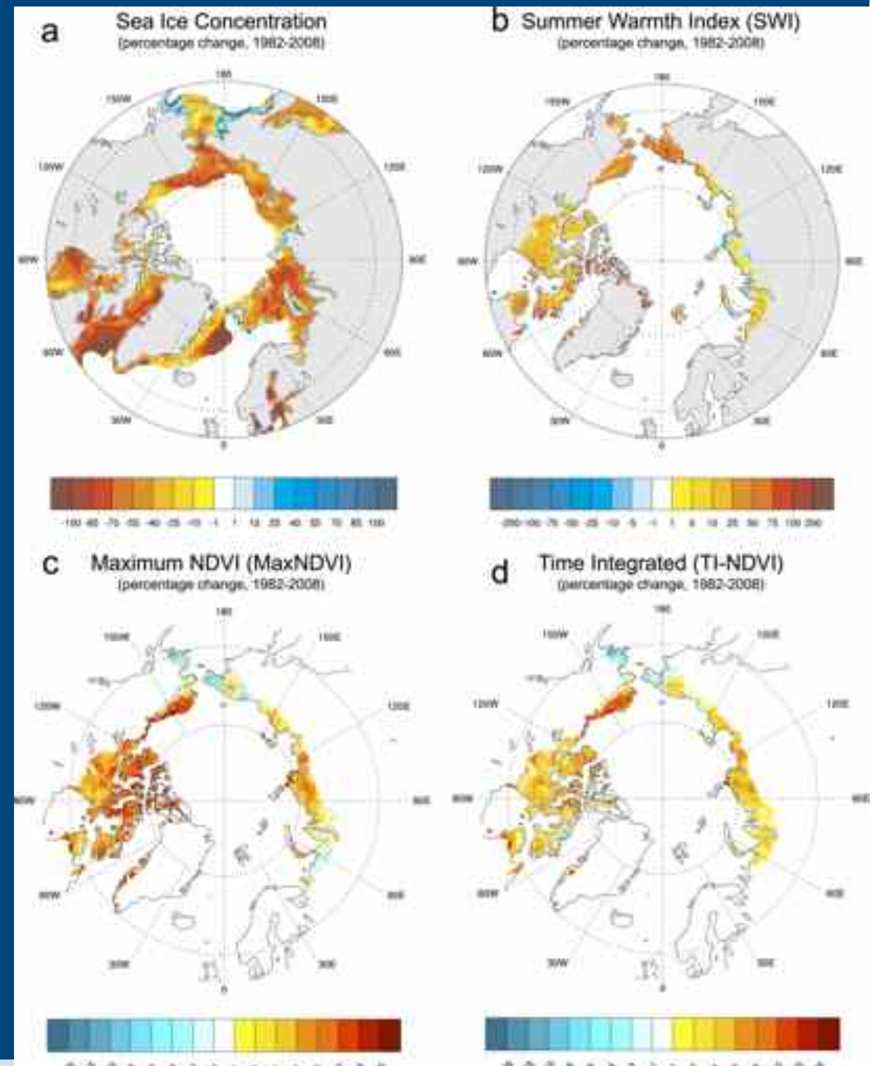
http://na.unep.net/geas/newsletter/Mar_11.html

Implications of summer ice loss

"Greening" of the Arctic tundra

Maximum NDVI over tundra (below) and trends (right)



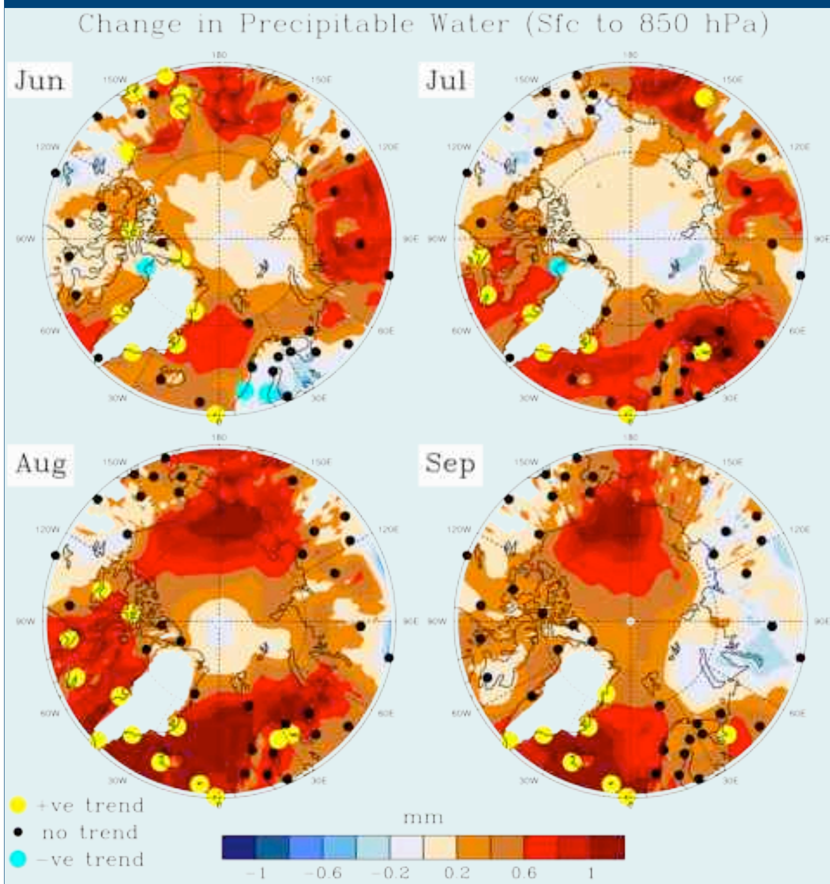


From Bhatt et al., 2010

NSIDC

Implications of summer ice loss

Increases in humidity and cloud cover



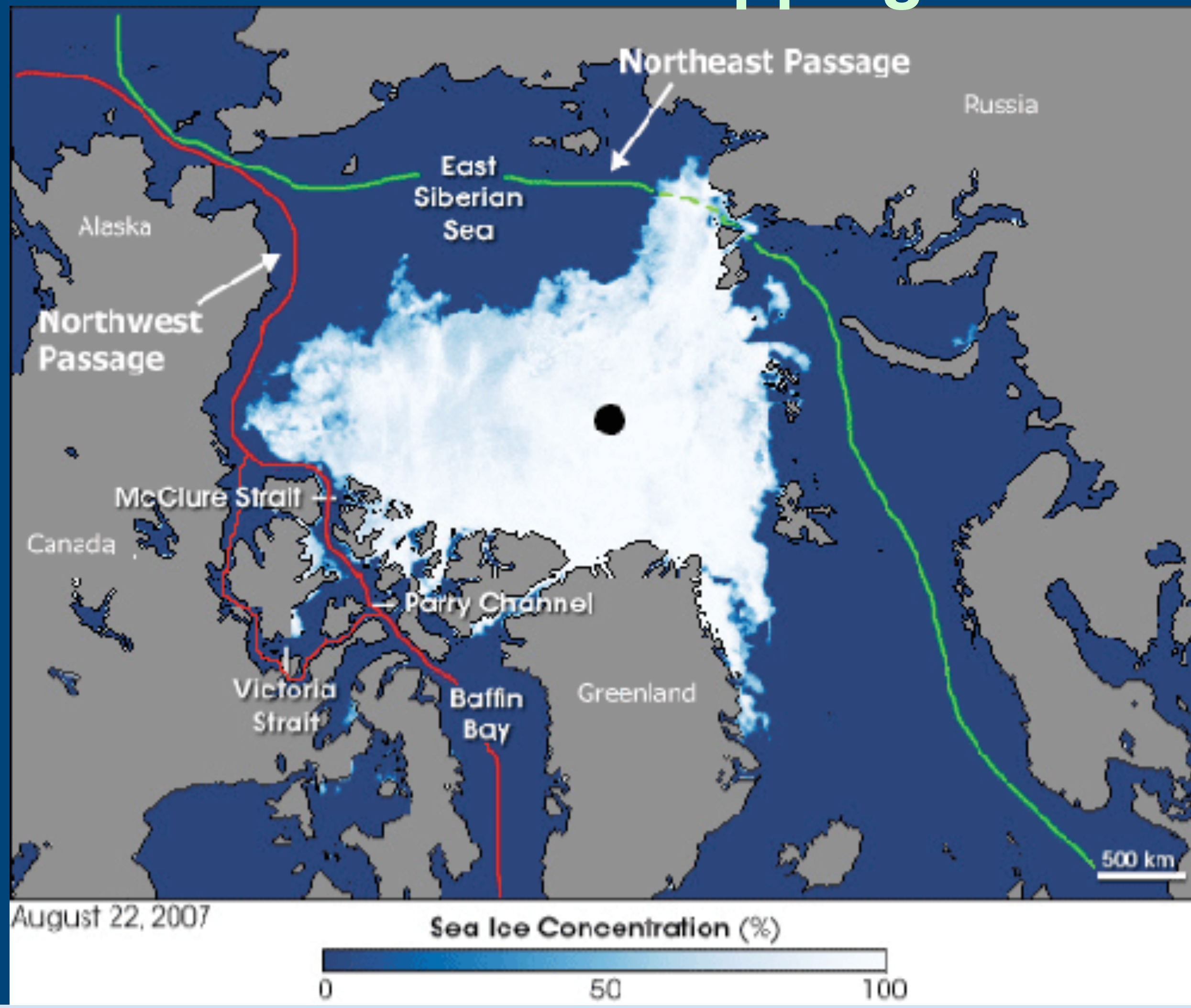
MERRA Reanalysis

http://rapidfire.sci.gsfc.nasa.gov/subsets/?mosaic=Arctic

Implications of summer ice loss

Commercial shipping

In 2012, 48 vessels traveled through the NSR carrying more than 1.2 million tons of cargo, compared to 34 in 2011 and 4 in 2010.

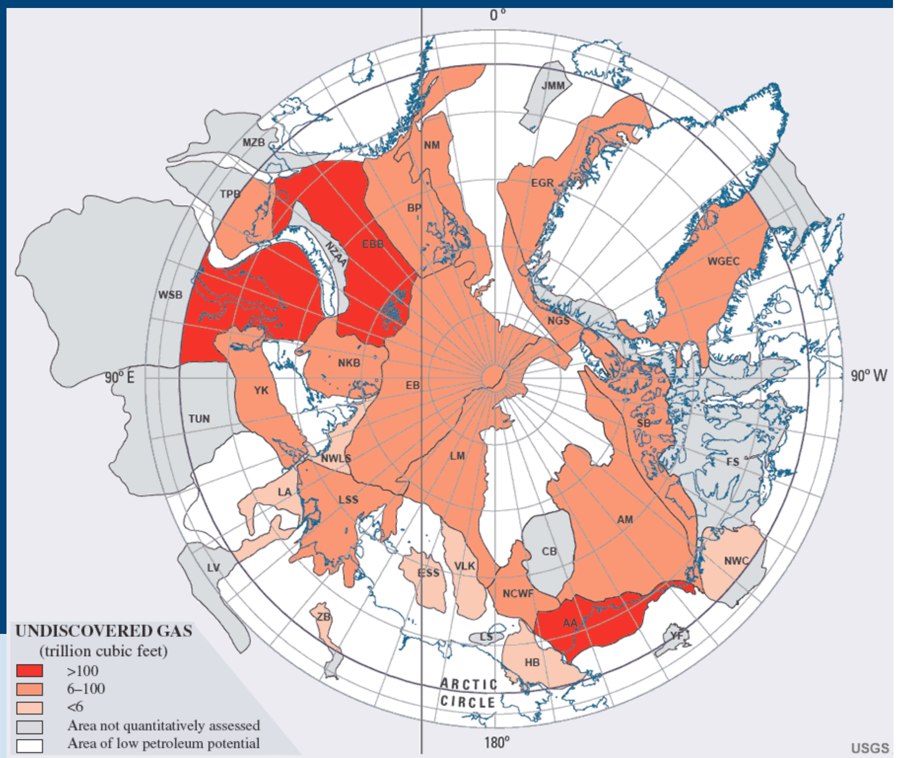


http://www.wunderground.com/climate/NorthernPassages.asp

Implications of summer ice loss

Access to Natural Resources

USGS estimated in 2008 that 90 billion barrels of oil, 1,700 trillion cubic feet of natural gas and 44 billion barrels of natural gas liquids may be found in the Arctic, of which ~84% occurs offshore.



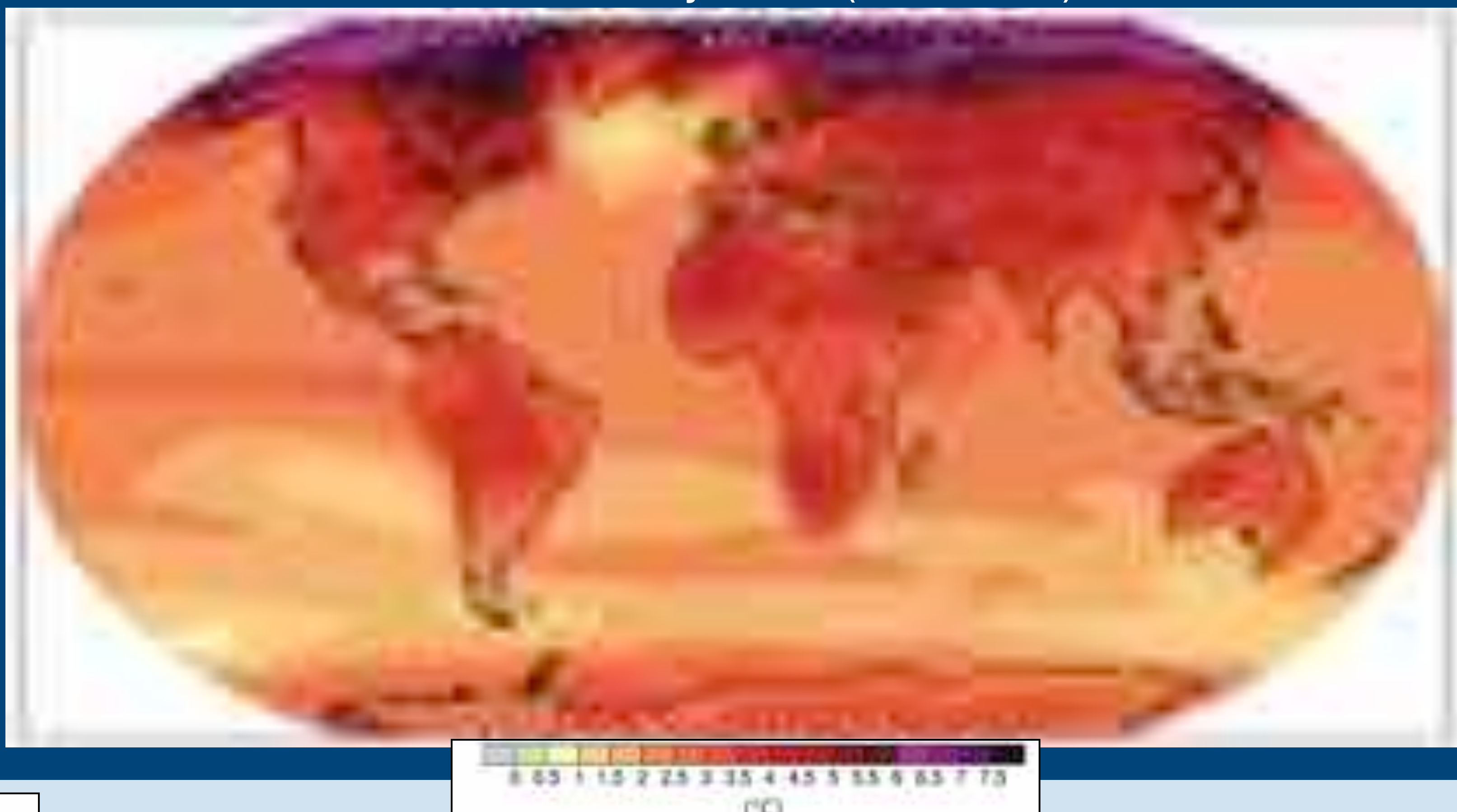
Implications of summer ice loss

Polar bears and other charismatic megafauna

Future warming projections

Air temperature: A1B scenario by 2100

Global mean warming of ~2.8^{o}C (or ~5F);
Much of land area warms by ~3.5^{o}C (or ~6.3F)
Arctic warms by ~7^{o}C (or ~12.6F)

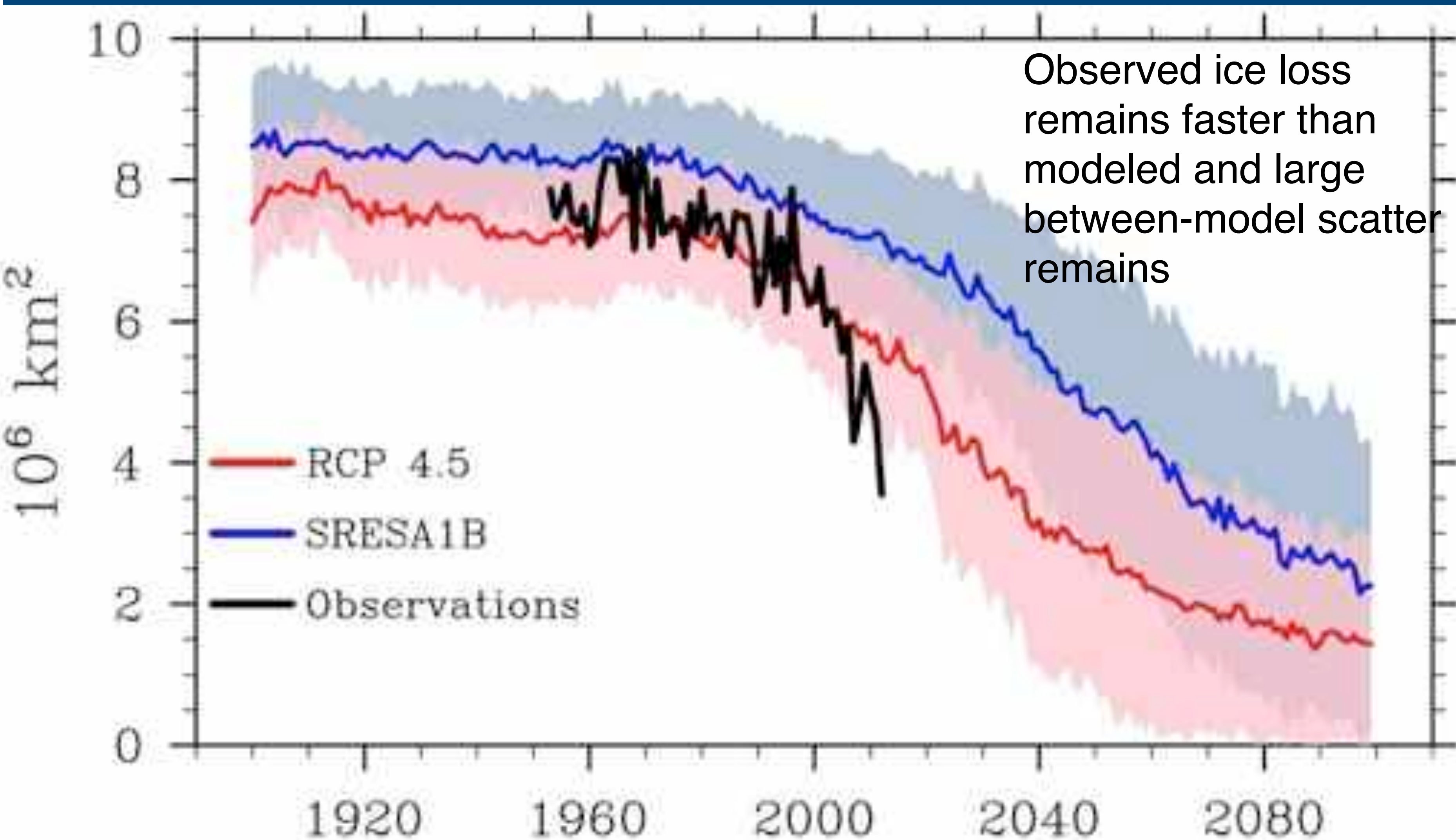


NCAR

IPCC-AR4 ensemble mean, A1B Scenario, courtesy M. Holland

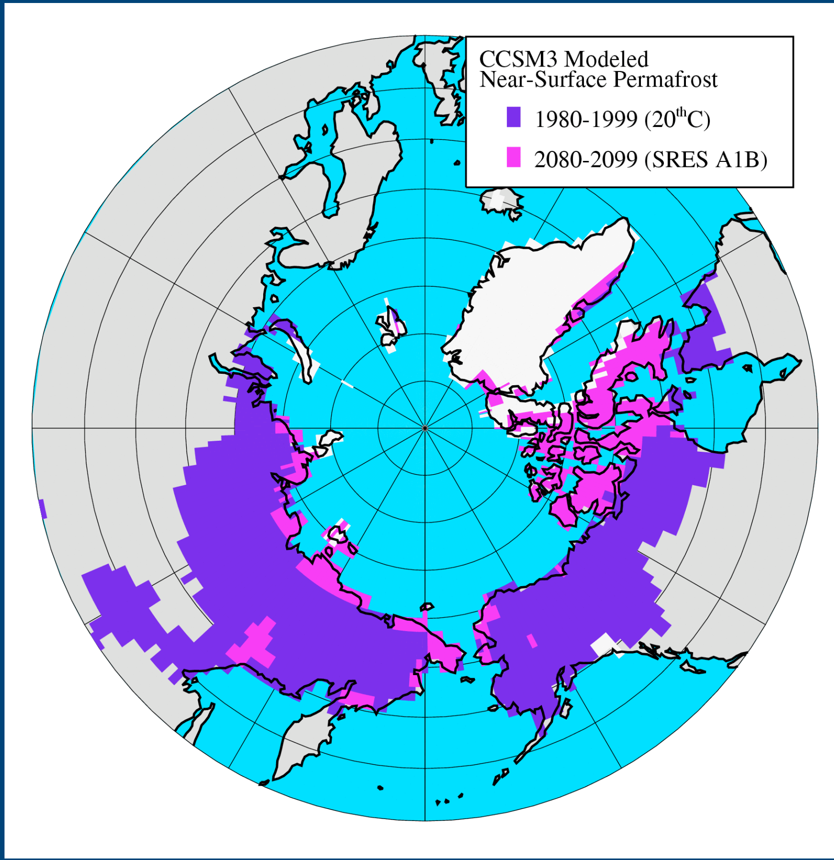
NSIDC

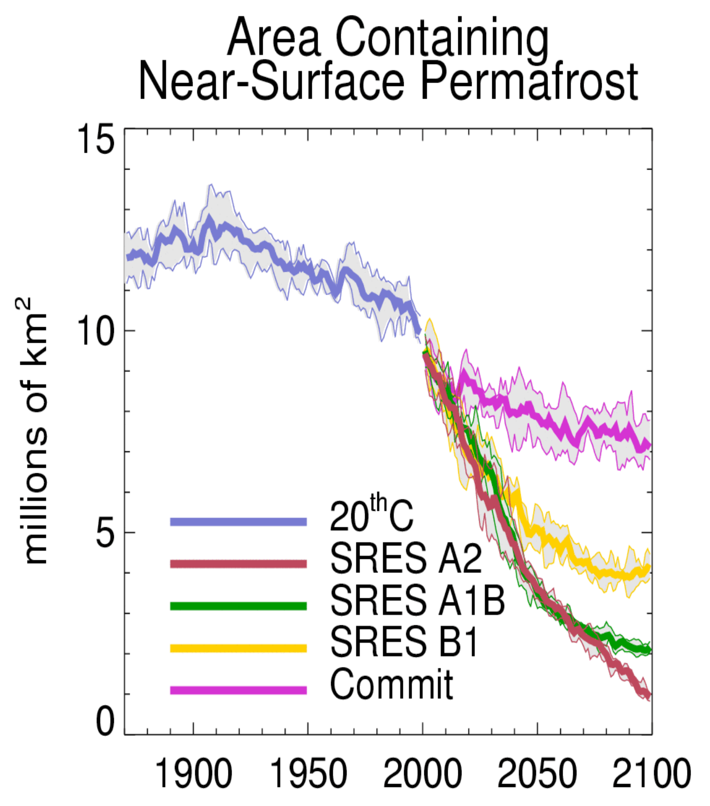
Future sea ice projections



From Stroeve et al. (2012)

Accelerated thawing of permafrost





Large reductions in permafrost area expected as Arctic continues to warm

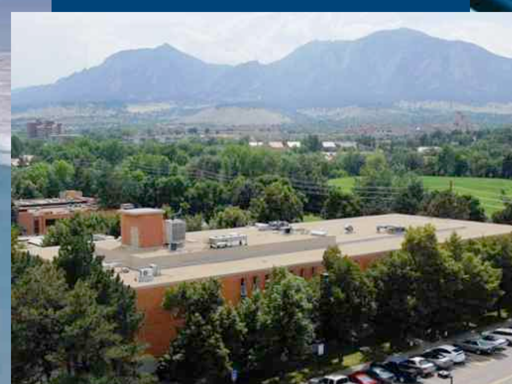
Lawrence and Slater, 2005

Conclusions

- We are quickly losing the ice cover
  - Impacts are already being felt
  - Essentially ice-free summers by 2030?
- Arctic amplification will be a big issue
  - Impacts on atmospheric circulation
  - Since AA has emerged only recently in the real world, the robustness of linkages between sea ice loss and mid-latitude weather remains unclear
  - Impacts on terrestrial warming and carbon cycle
- The geopolitics of Arctic change – many wild cards

The National Snow and Ice Data Center (NSIDC)

Studying the Earth's frozen realms



Courtesy NSIDC and NASA

Thank You