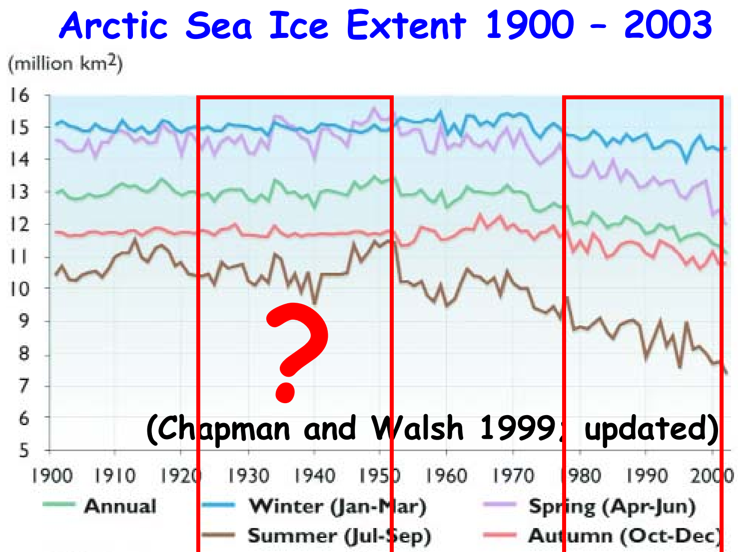
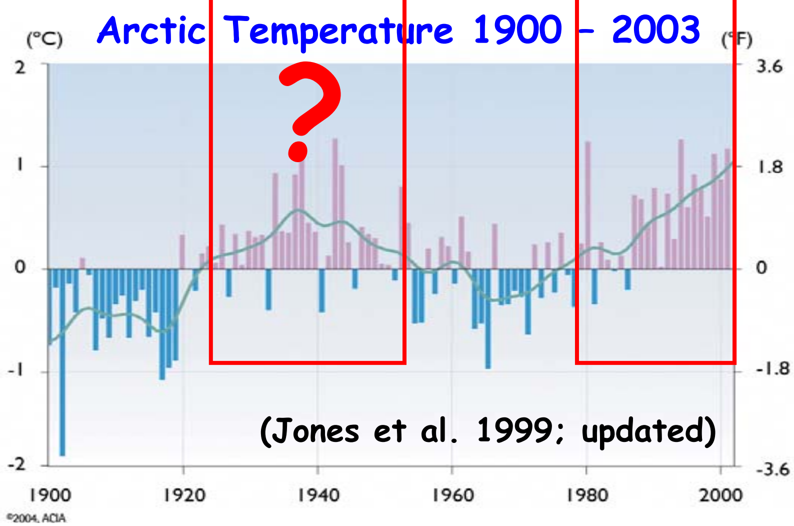
Preconditioning of Arctic Sea Ice on Decadal Time Scales

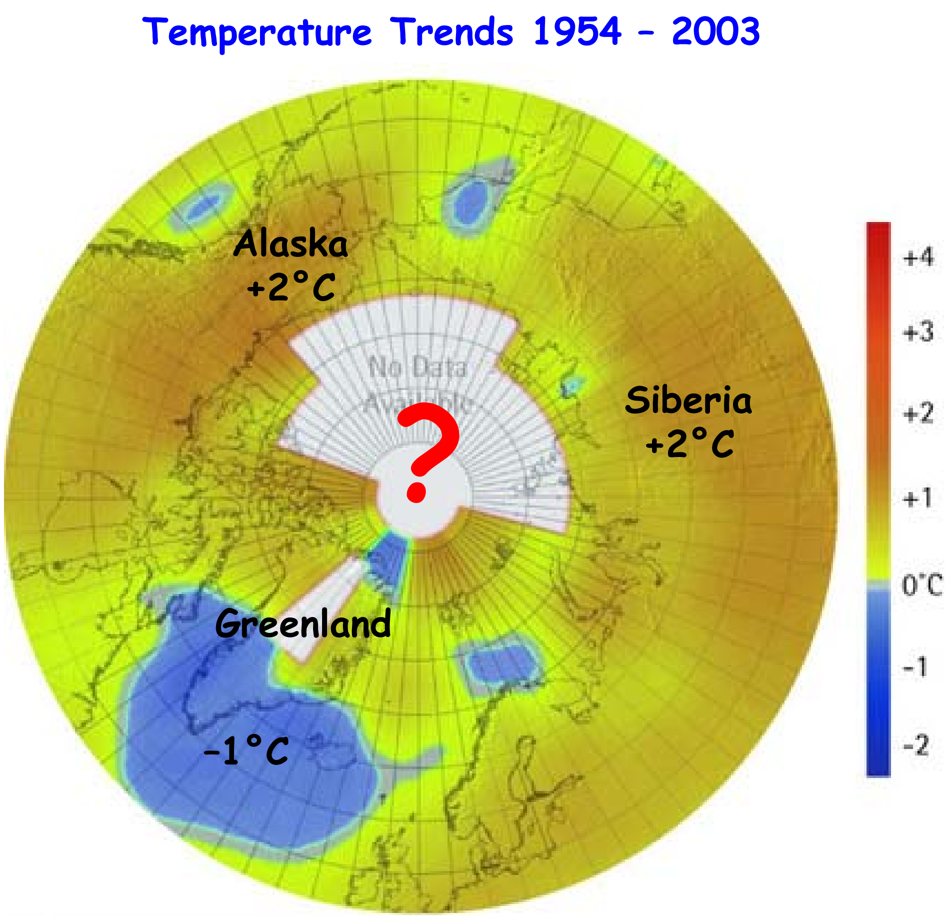
Ignatius G. Rigor and many others
Polar Science Center, Applied Physics Lab
University of Washington

Resolving some Uncertainty in our Climate Records

Decreases in Sea Ice are Attributed to Increases in Temperature

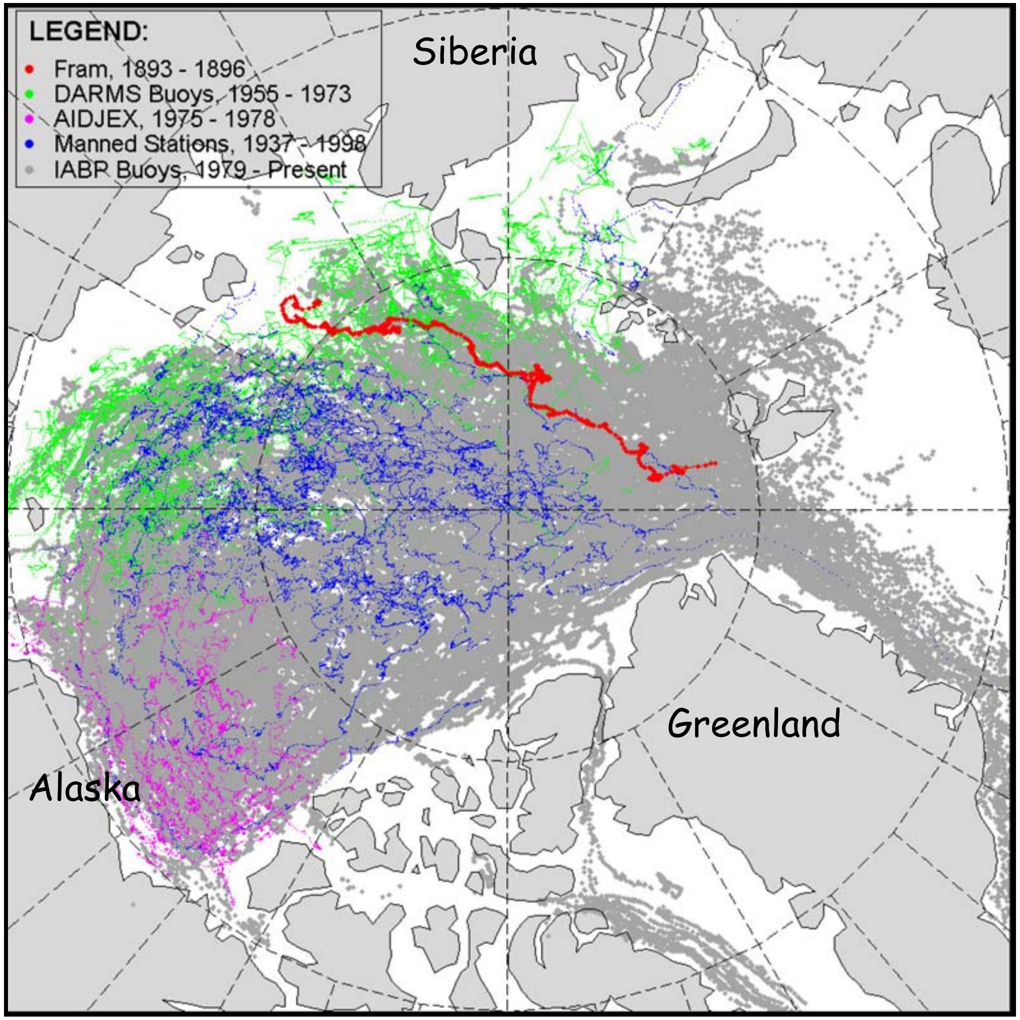


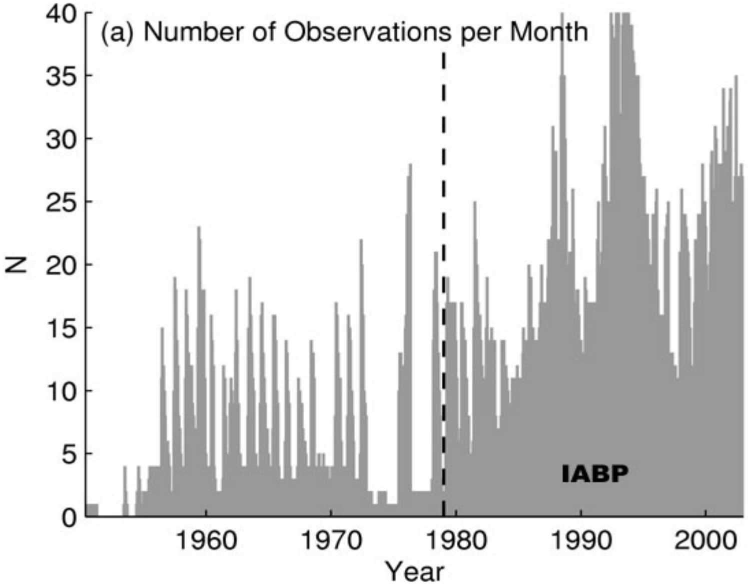




Arctic Climate Impacts Assessment (ACIA) Report 2004

Observations on the Arctic Ocean 1893 - present



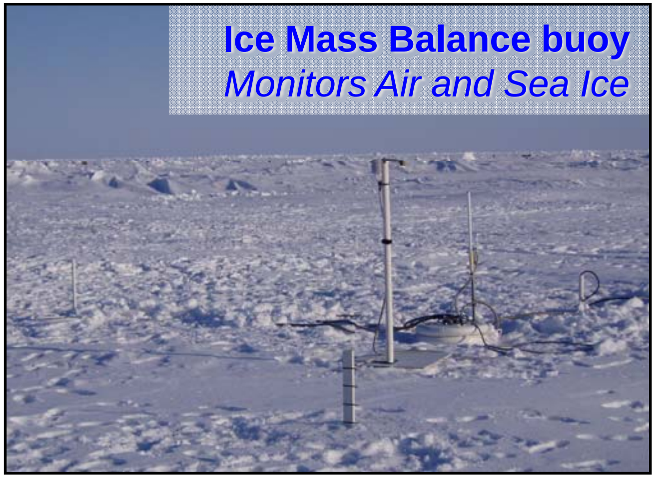


- APL/UW Arctic Buoy Program established in 1979
- Evolves into International Arctic Buoy Programme (IABP) in 1991.
- Monitors pressure, temperature, ice motion, etc.

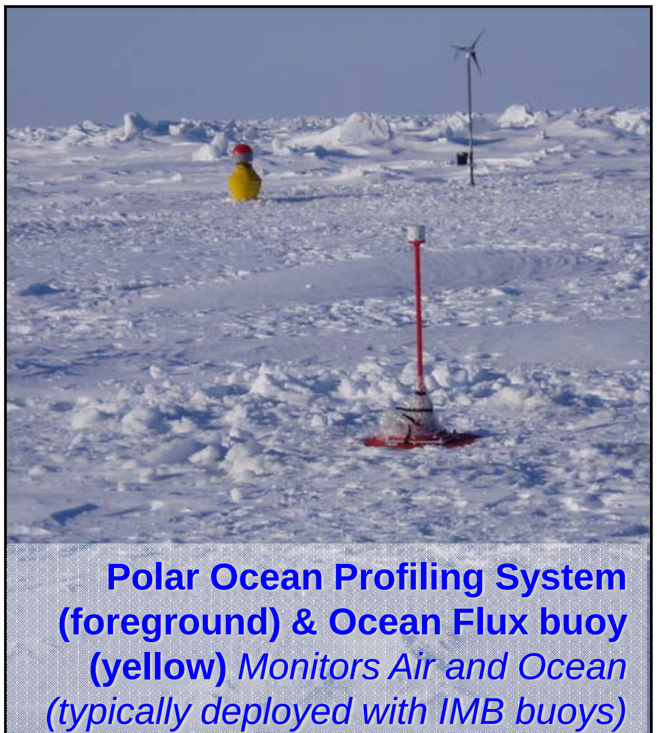
(From http://IABP.apl.washington.edu)

International Arctic Buoy Programme

NIC and APL/UW Co-Manage the US Interagency Arctic Buoy Program

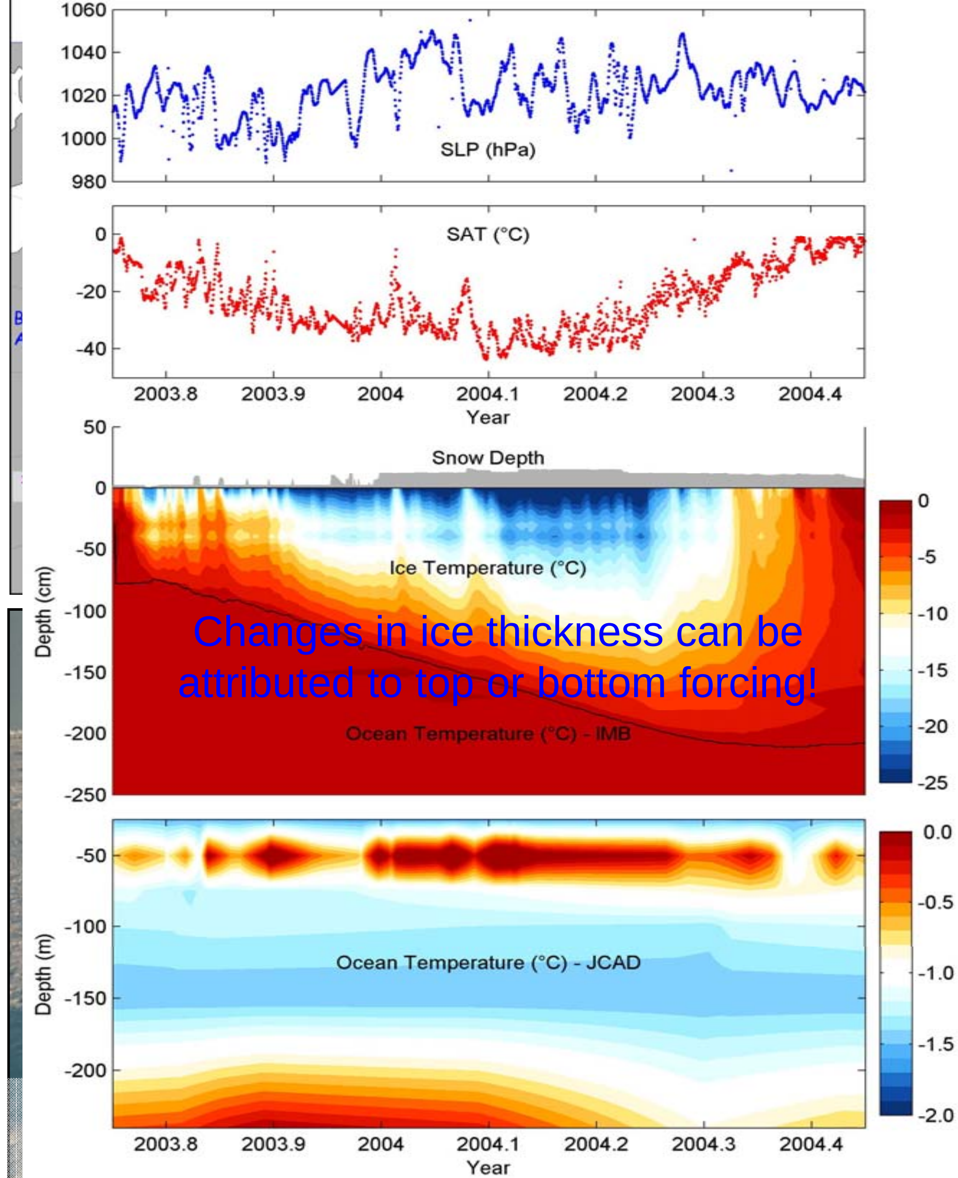


Ice Mass Balance buoy
Monitors Air and Sea Ice



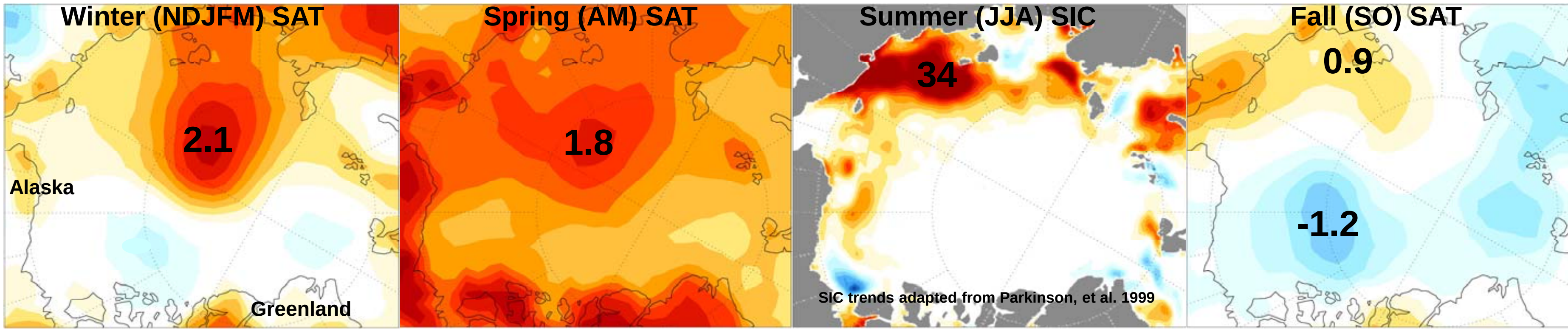
Polar Ocean Profiling System (foreground) & Ocean Flux buoy (yellow) *Monitors Air and Ocean (typically deployed with IMB buoys)*

IMB and Ocean Observations

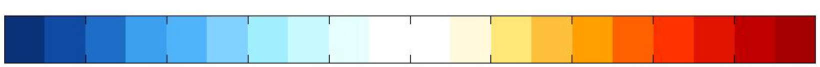


Surface Air Temperature (SAT) Trends Over the Arctic Ocean

Seasonal Trends 1979 - 1998



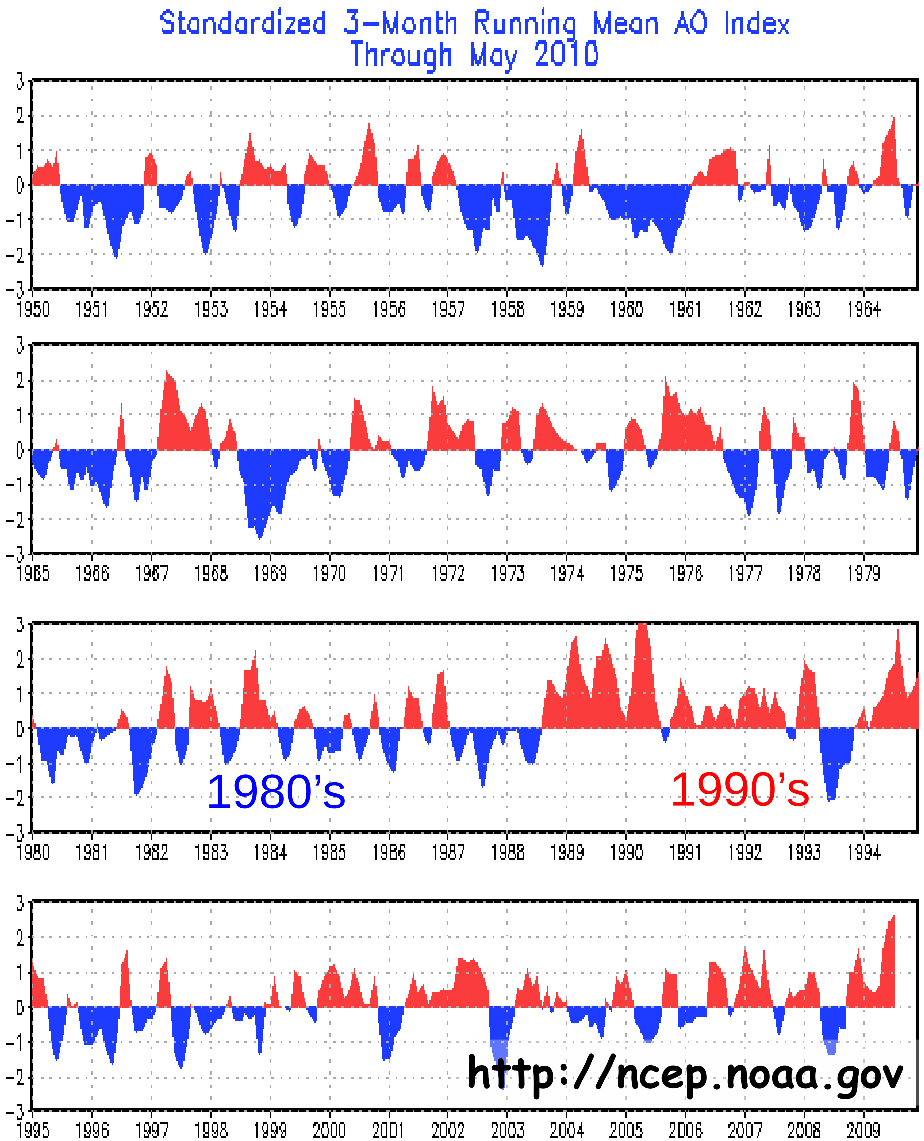
- Trends noted over land extend over the Arctic Ocean.
- Warmed during winter, spring, and fall.
- Sea Ice Concentrations decreased during summer.



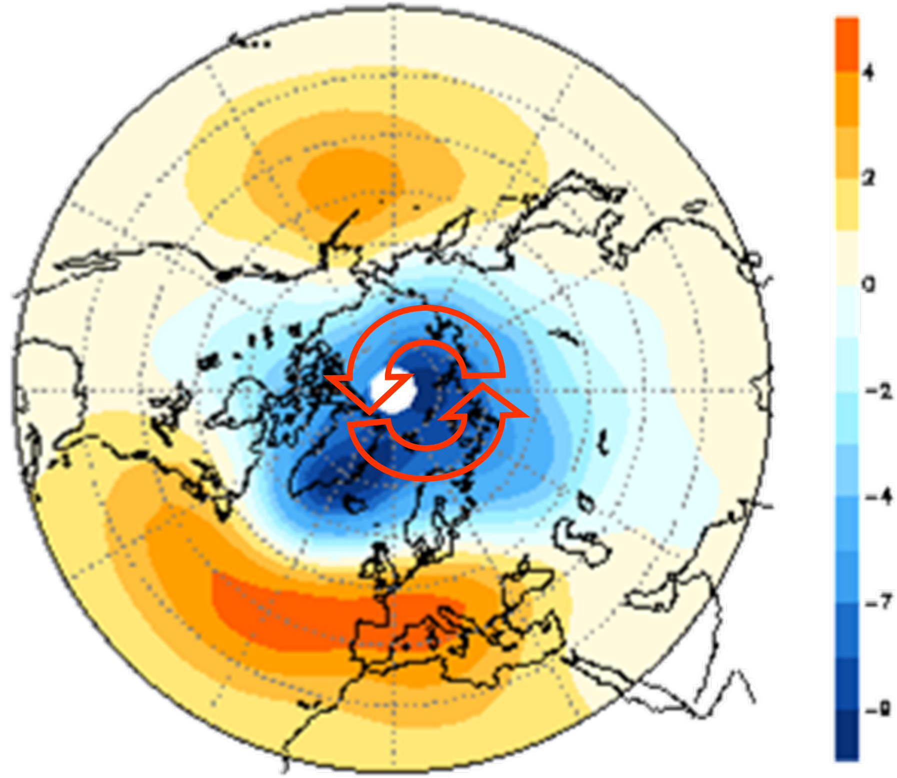
(Adapted from Rigor et al., 2000)

Arctic Oscillation (AO)

Increased occurrence of high AO conditions may be related to increases in Green House Gases

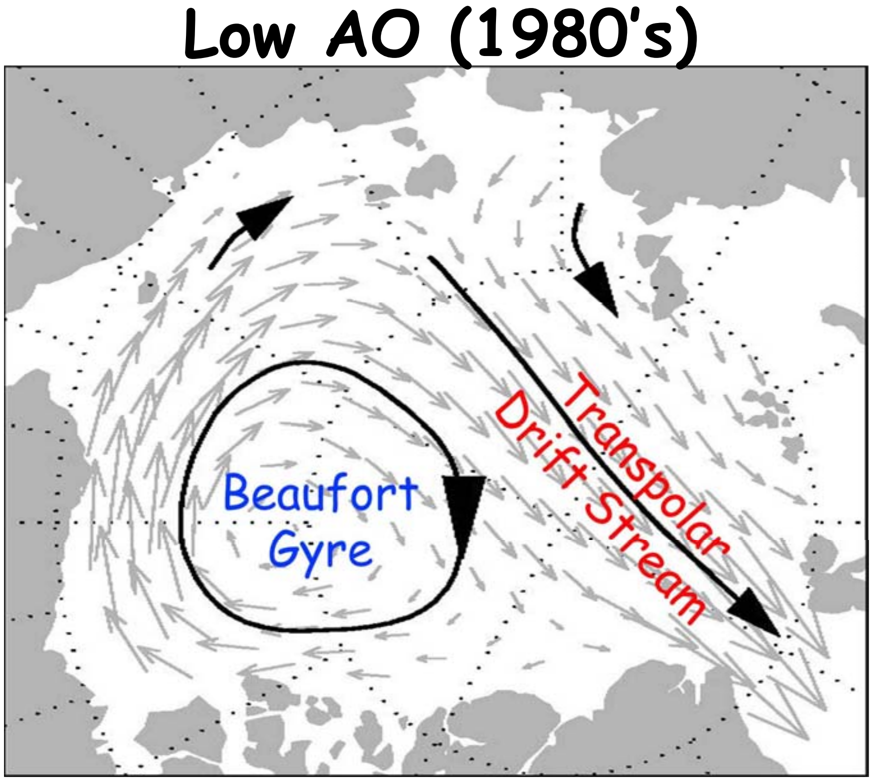


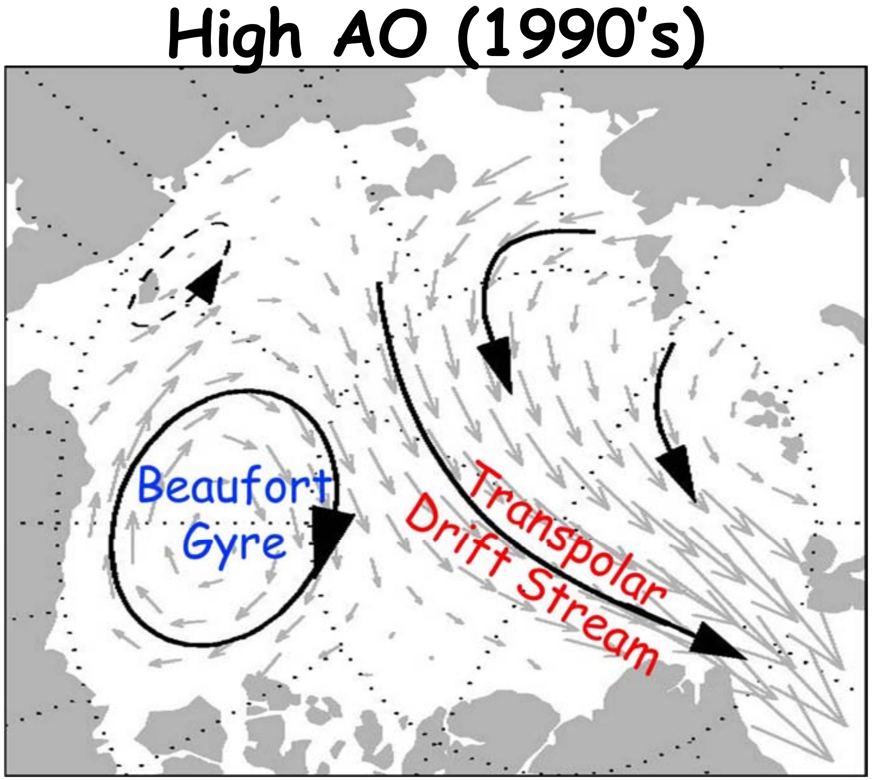
Covariance of Sea Level Pressure with AO index (hPa/30 years)



(Provided by D. Thompson)

Impact of Arctic Oscillation (AO) on Sea Ice Motion

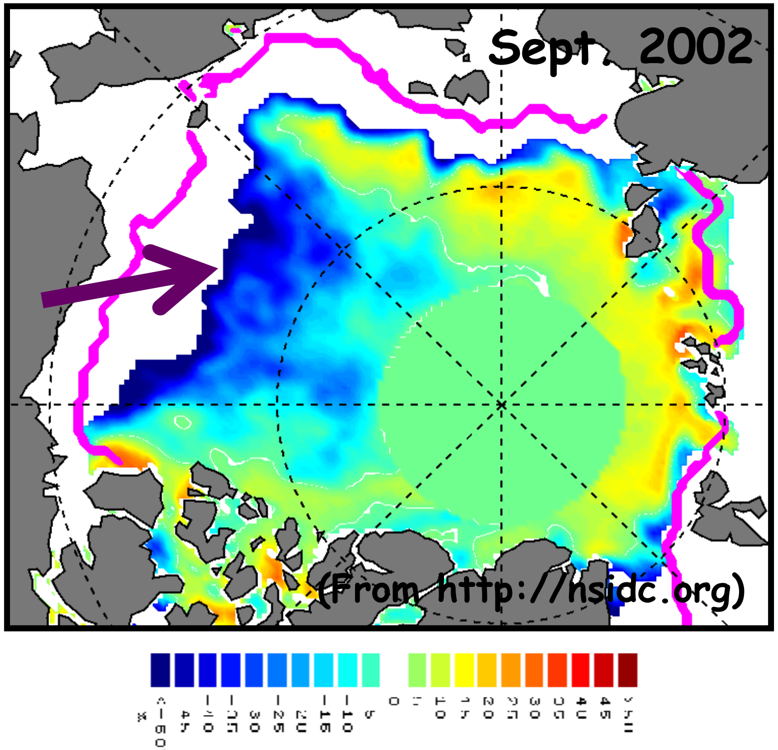


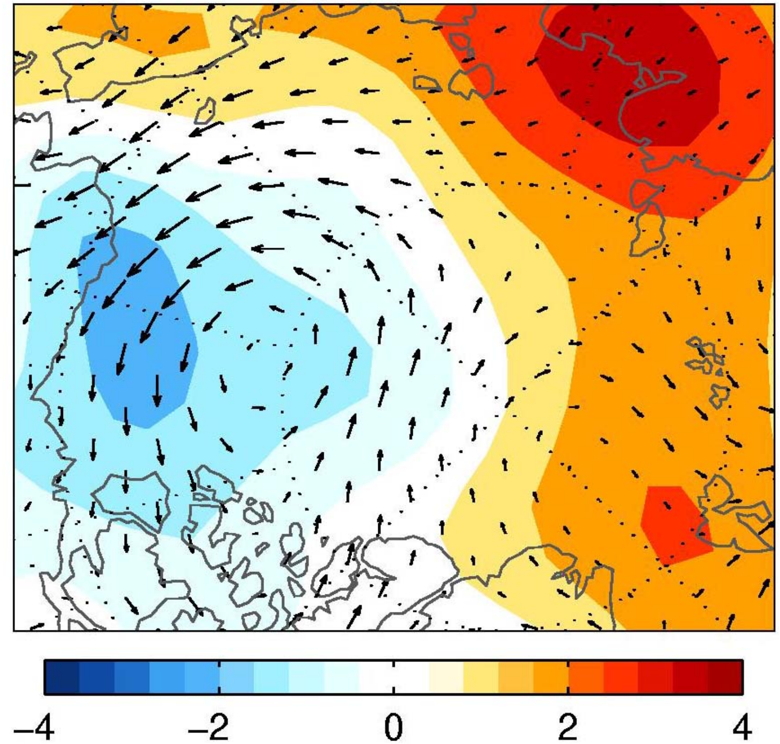


- Sea ice may reside in the Arctic for over 5 years.
- Increased ice advection away from the Russian coast during high AO.
- Faster export of sea ice from the pole to Fram Strait.

(Rigor et al. 2002)

Wind Forcing of 2002 and 2003 Minima



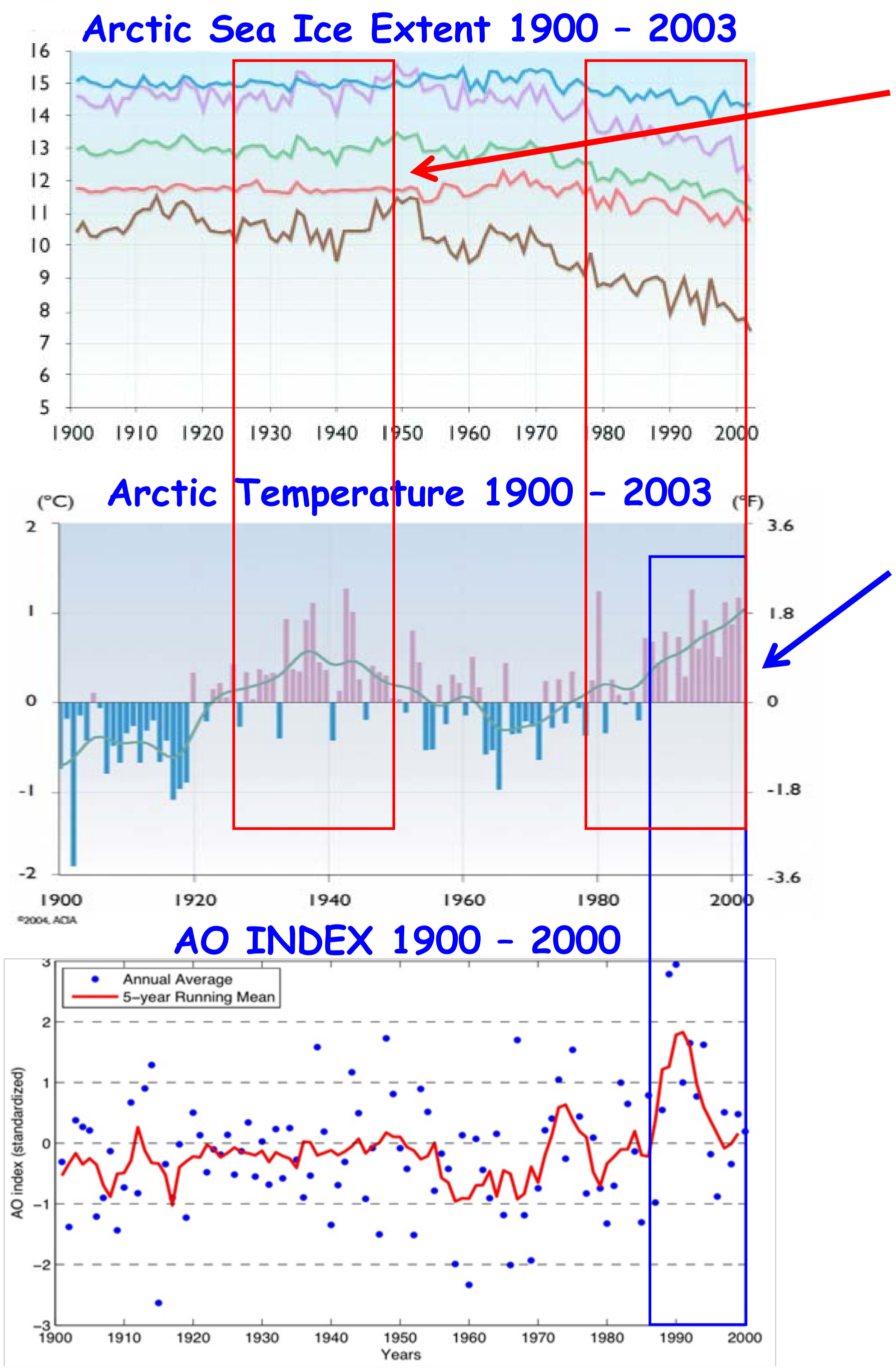


- **Typically associated with low AO conditions** (i.e. winds from the SE blowing ice away from the coast and warmer air; e.g. Drobot & Maslanik 2003).
- **But the AO was in a high phase during the summer of 2002, and 2003** (i.e. colder and the winds blew the ice towards the coast).

Has the correlation between sea ice and the AO broken?

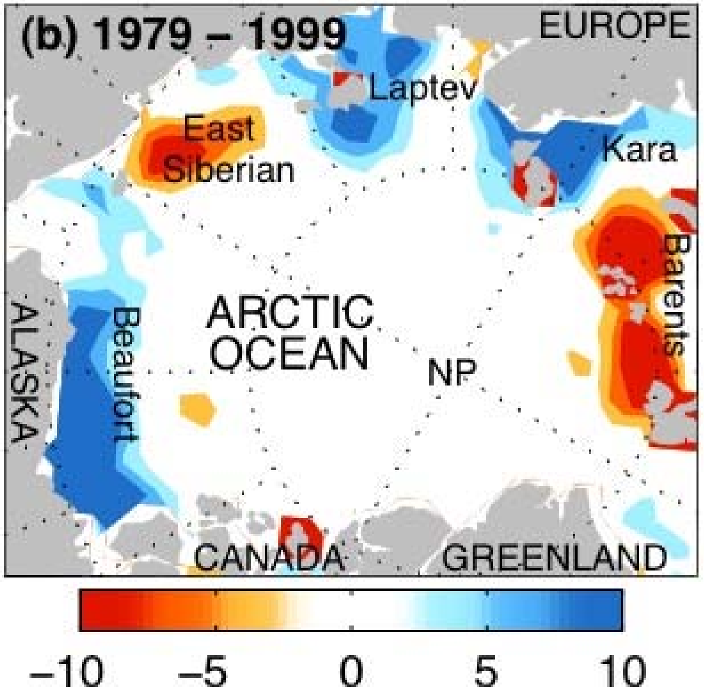
Some Discrepancies

- Warmer temperatures during the 1930's didn't decrease sea ice?
- The correlation between the AO and Arctic climate seems to be broken?

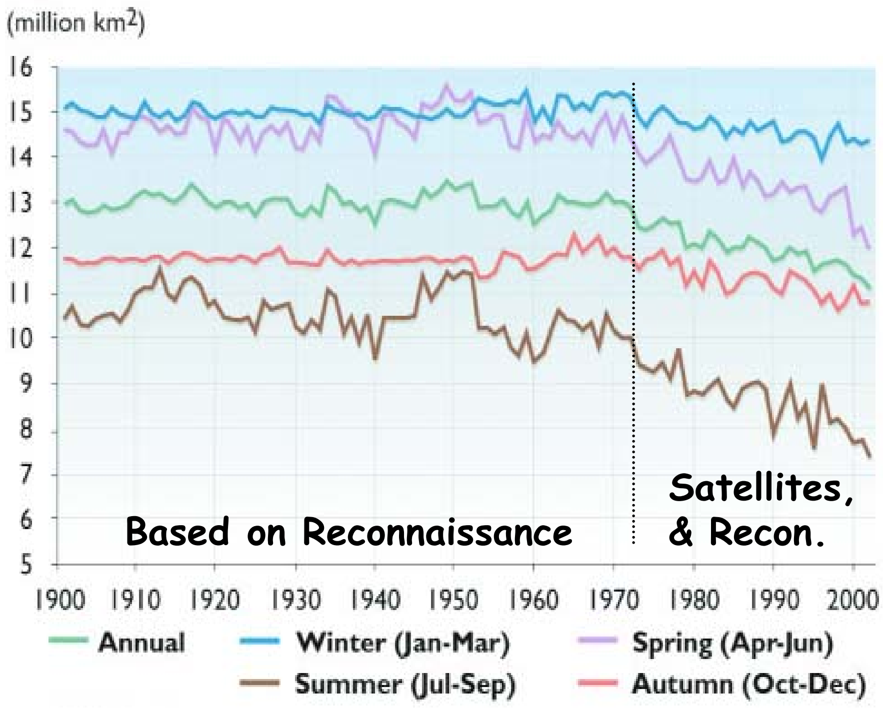


How good are our sea ice extent records?

Summer Covariance (AO,SIC)



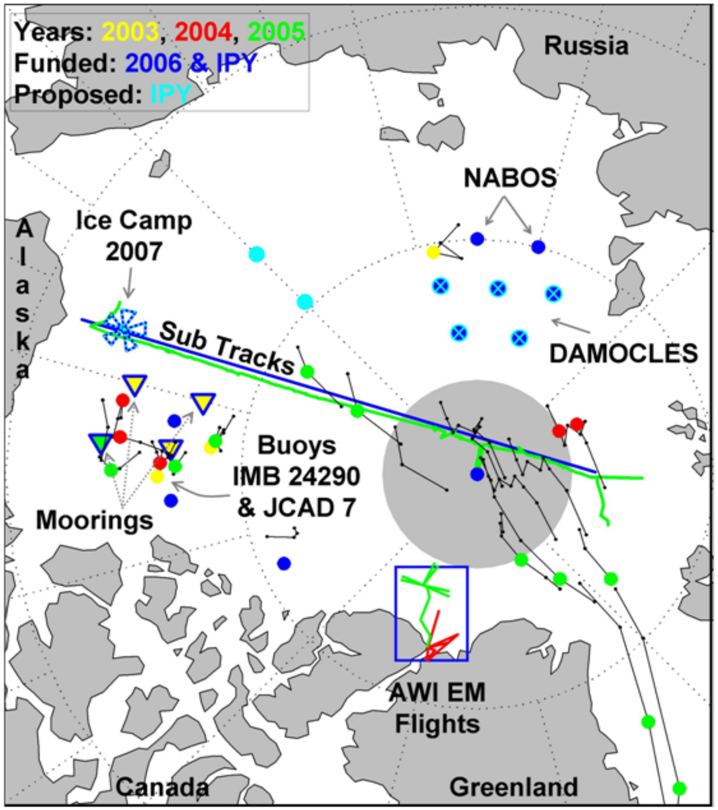
Arctic Sea Ice Extent 1900 – 2003



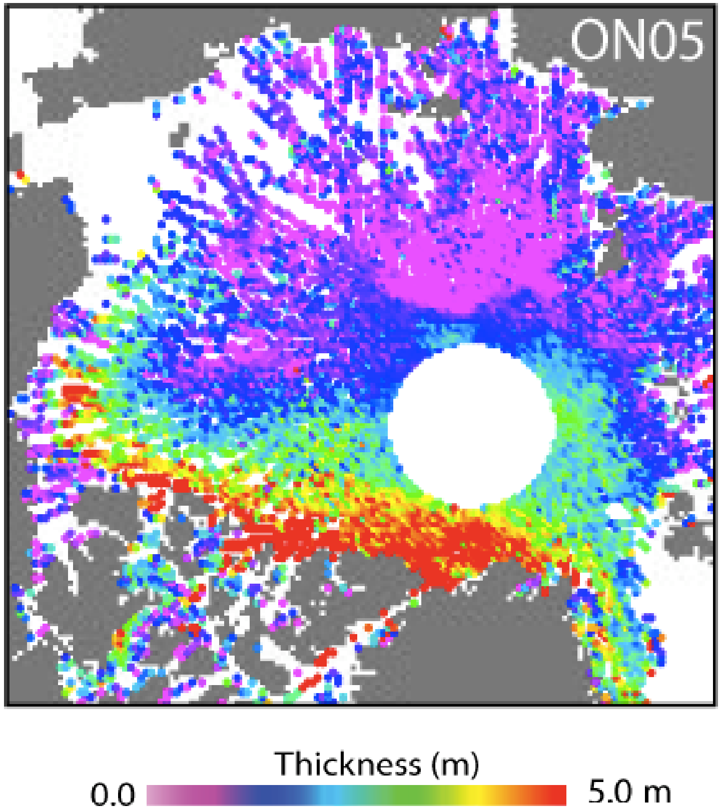
(ACIA, 2004; Chapman and Walsh 1999; updated)

Has sea ice thinned even more?

In Situ Thickness Measurements

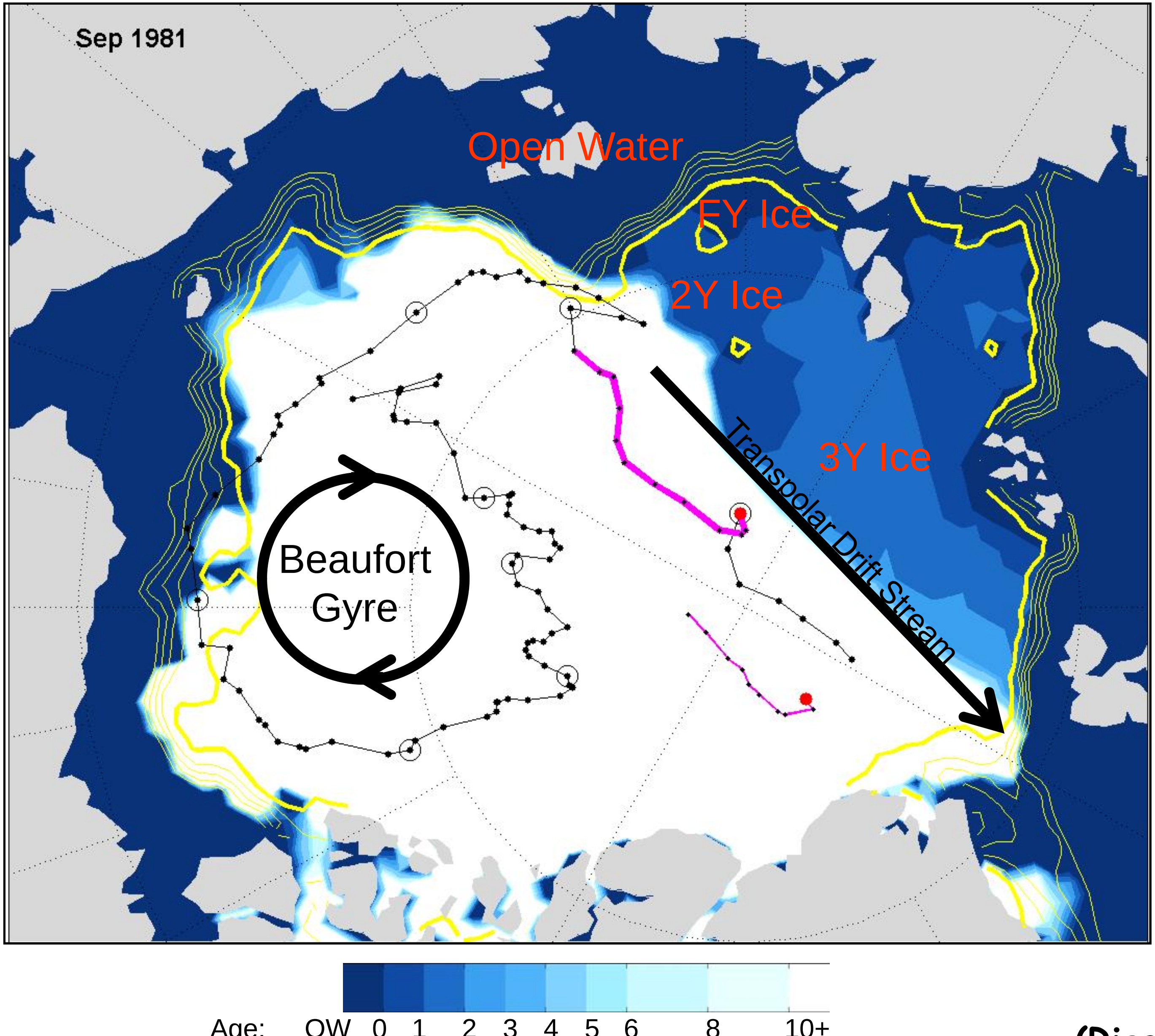


ICESat Laser Altimeter 2003-2008



Ice thickness data are sparse in space and time.

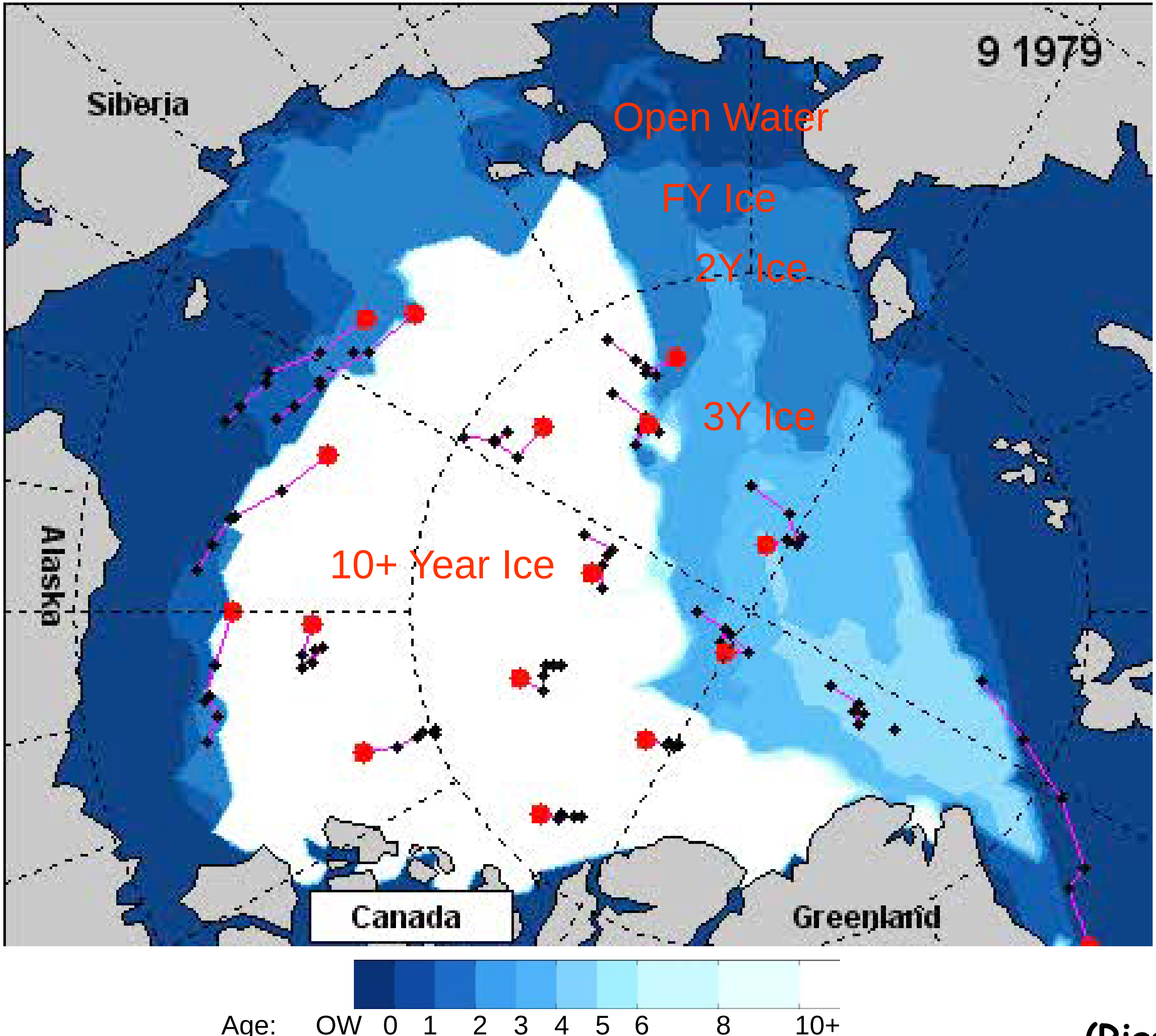
Estimating the Age of Sea Ice



- Age of Ice Model:
  1. We know how the ice moves.
  2. We know how much ice survives summer.
  3. We can tracks parcels of ice and age of ice that survives summer melt.
  4. Initialized in 1954 assuming all ice is new.
- Prior to 1989, ice over 80% of the Arctic Ocean is at least 10 years old.
- This is supported by the drift of the Russian manned drifting station, NP-22, which is shown as a black trajectory.

(Rigor and Wallace, 2004)

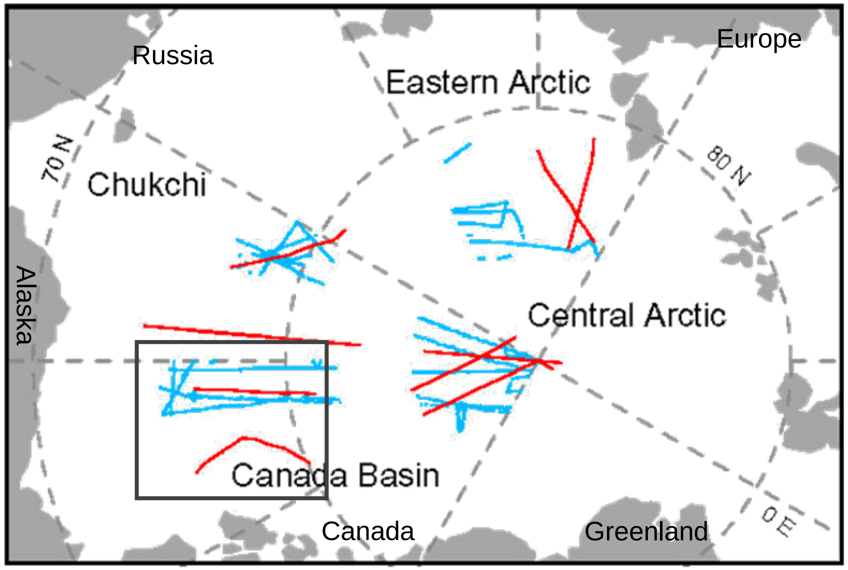
Changes in Wind, Ice Drift and Age

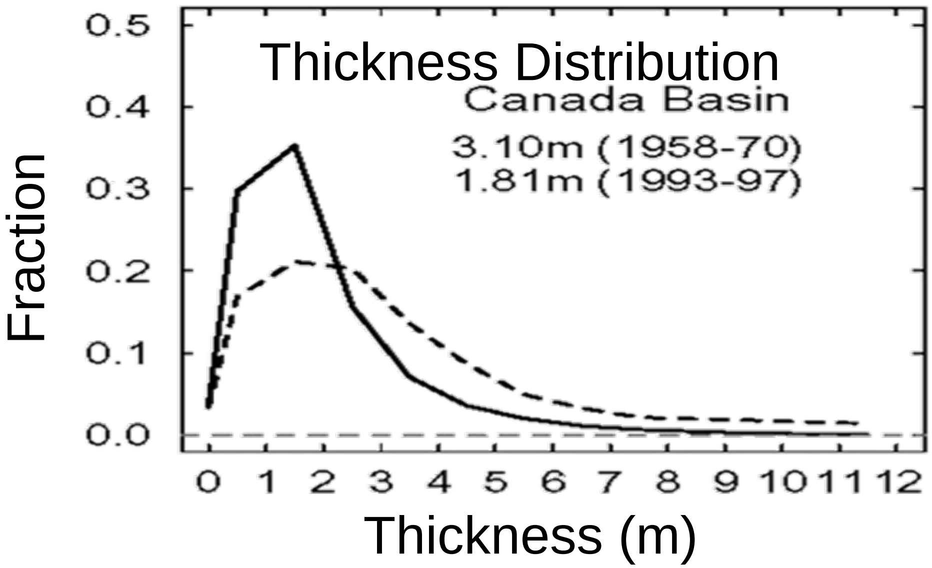


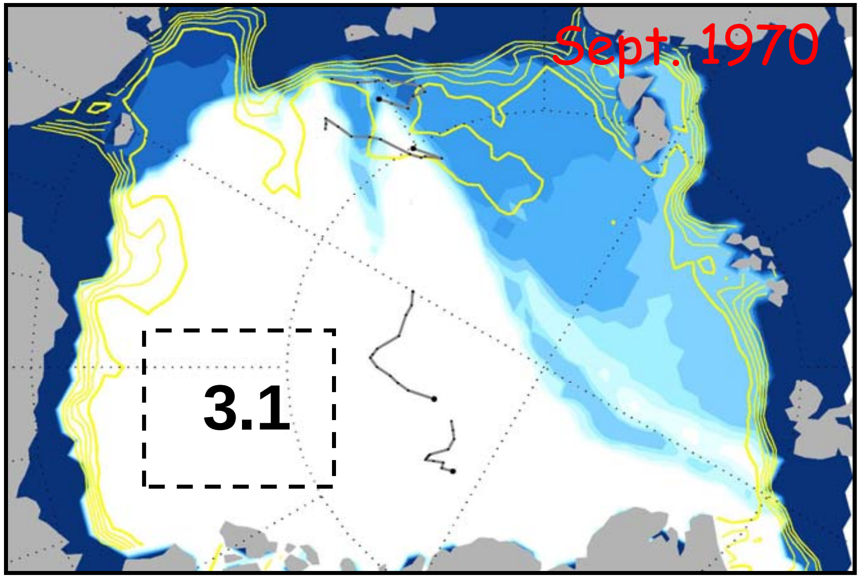
- Sea ice grows thicker with age.
- Prior to 1989, ice over 80% of the Arctic Ocean is at least 10 years old.
- High Arctic Oscillation (AO) conditions from 1989-1991 blew most of the older, thicker sea ice out of the Arctic Ocean.
- Younger (thinner) Ice persist through today despite "normal" AO conditions.
- The trend in the AO may be related to increases in Green House Gases.

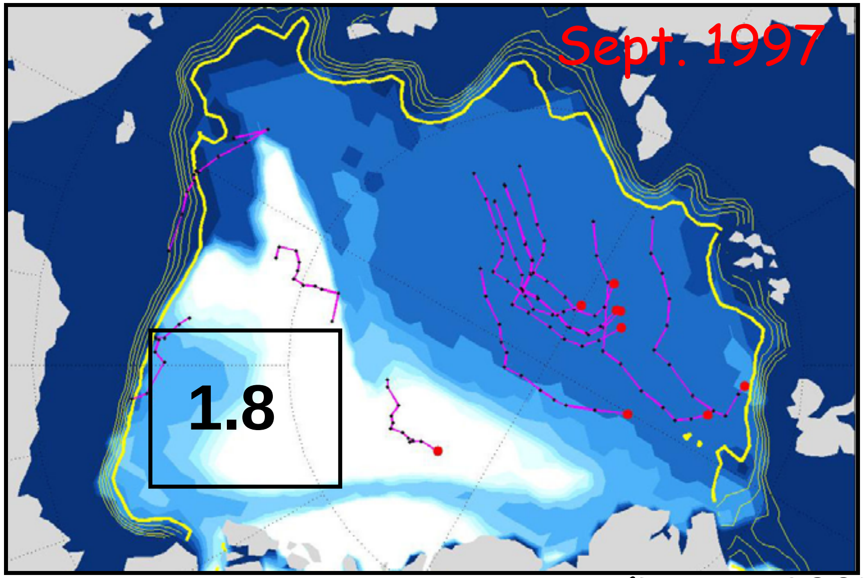
(Rigor and Wallace, 2004)

Differences in ice drafts between 1958 – 1970 and 1993 – 1997



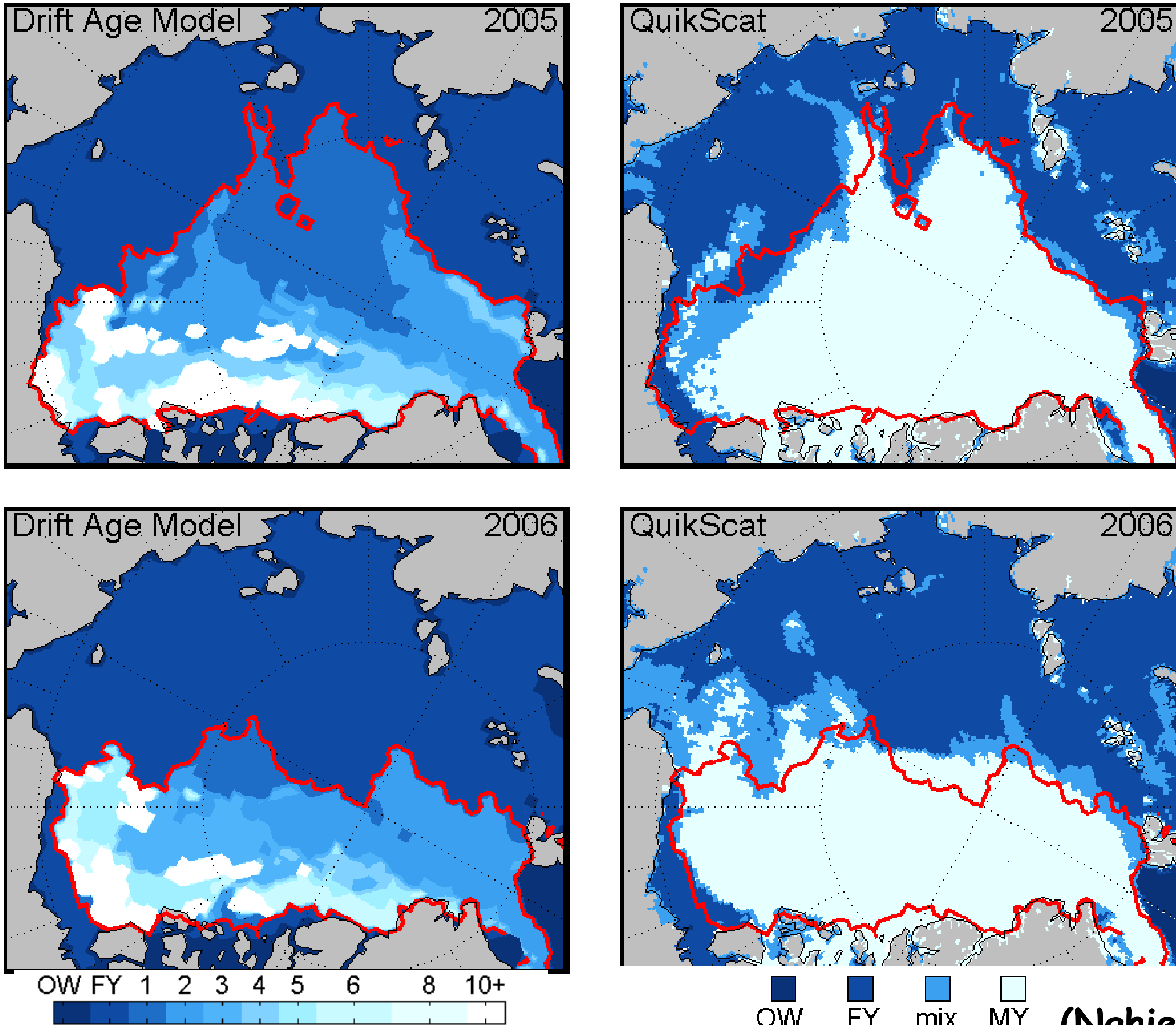






(Rigor, 2005)

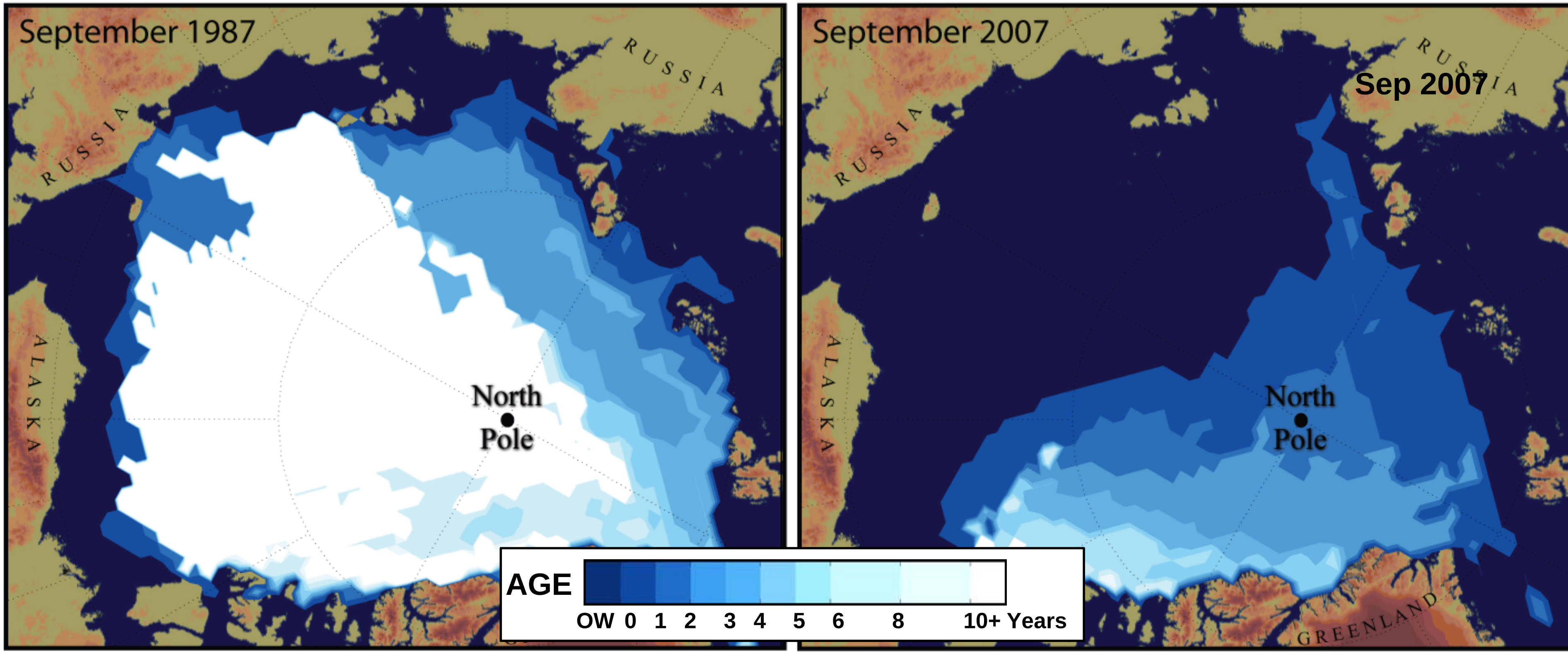
Validation: Ice Age vs. QSCAT



(Nghiem Etal 2007)

Positive Feedbacks

1980's (low AO, large gyre) | **Present (high AO, small gyre)**



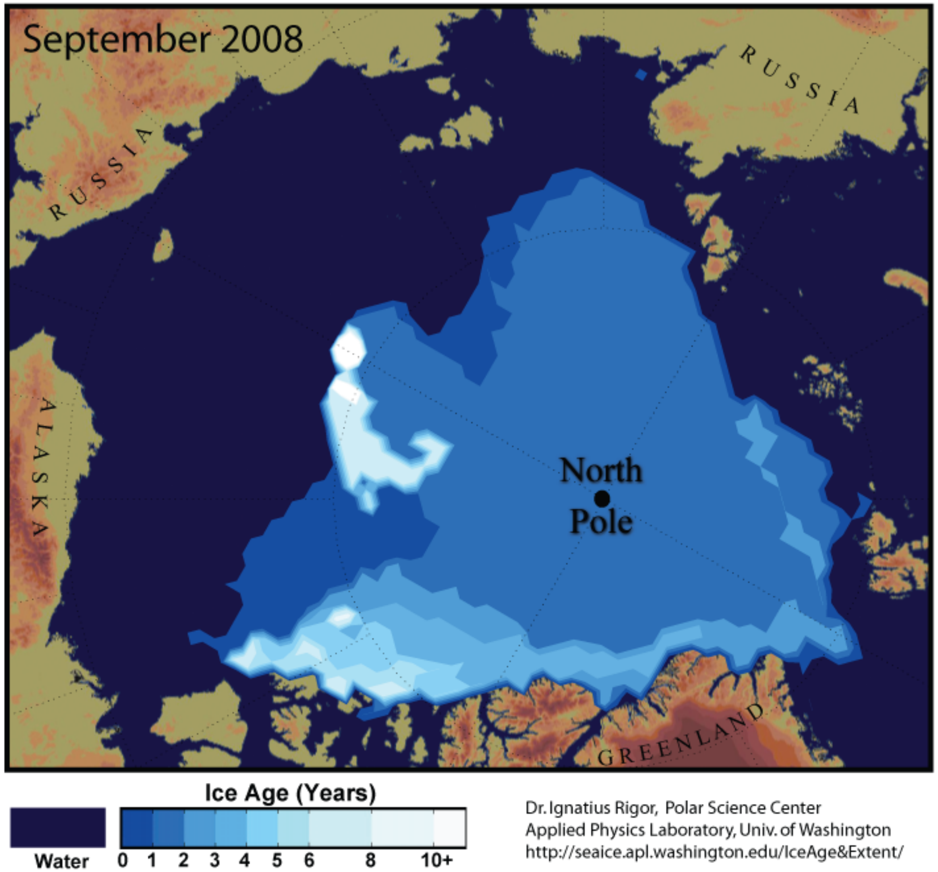
- More older, thicker ice.
- Later onset of melt, earlier onset of freeze.
- Winter and summer forcing is more important.

- Less older, thicker ice.
- Earlier onset of melt, more absorbed sunlight, later onset of freeze, longer melt season.
- Warmer temperatures.

- Positive Feedbacks maintain either state.

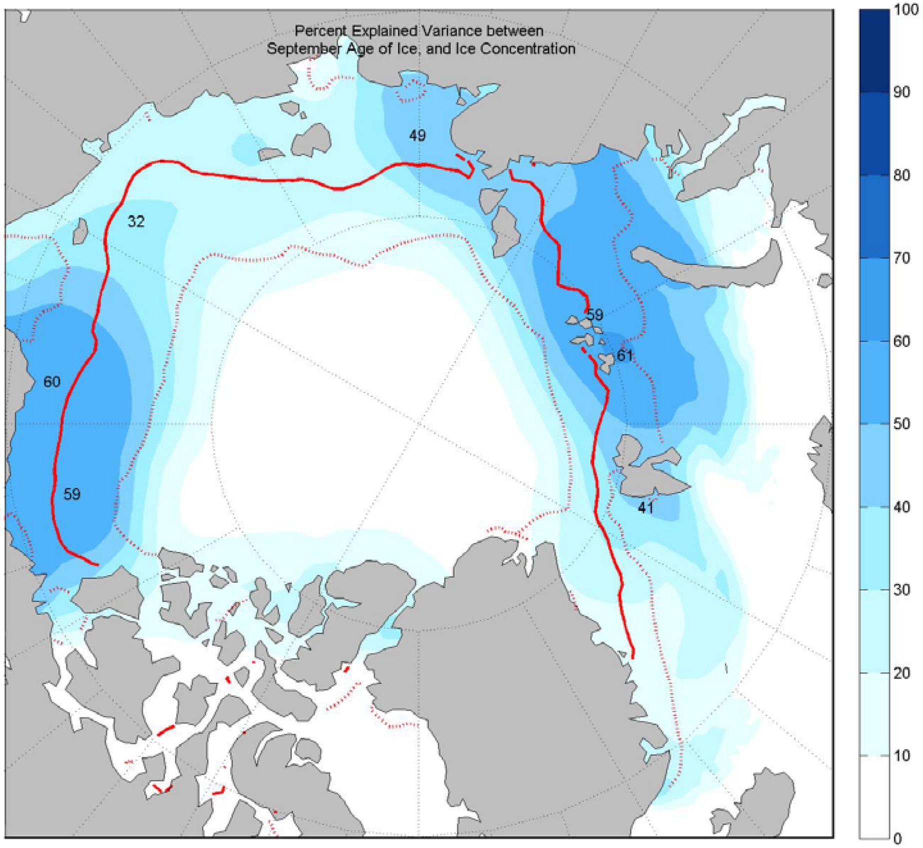
Percent of Variance of SIC Explained by the Age of Sea Ice

Age of Ice

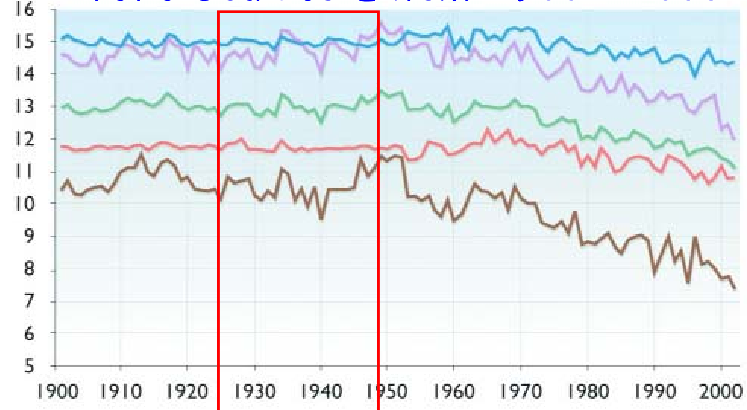


Dr. Ignatius Rigor, Polar Science Center
Applied Physics Laboratory, Univ. of Washington
http://seaice.apl.washington.edu/IceAge&Extent/

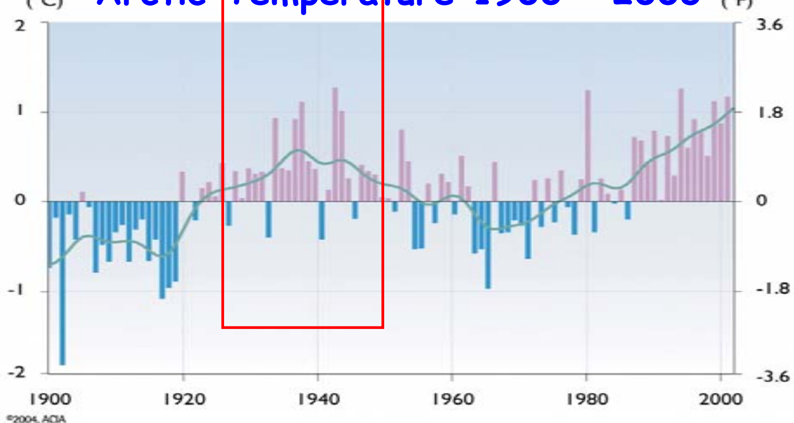
Variance Explained



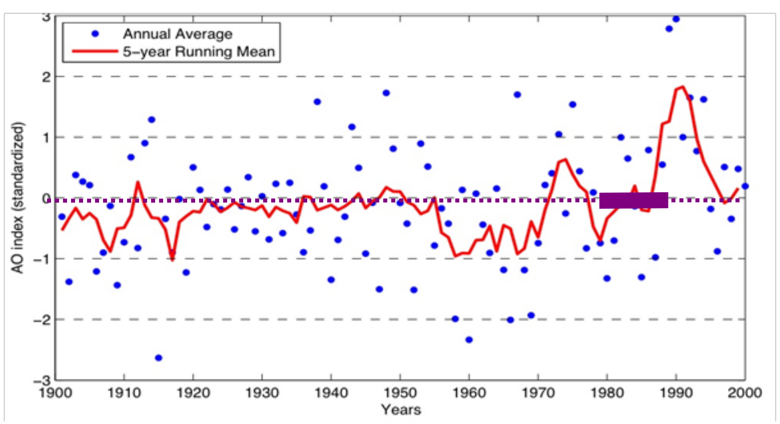
Arctic Sea Ice Extent 1900 – 2000



Arctic Temperature 1900 – 2003

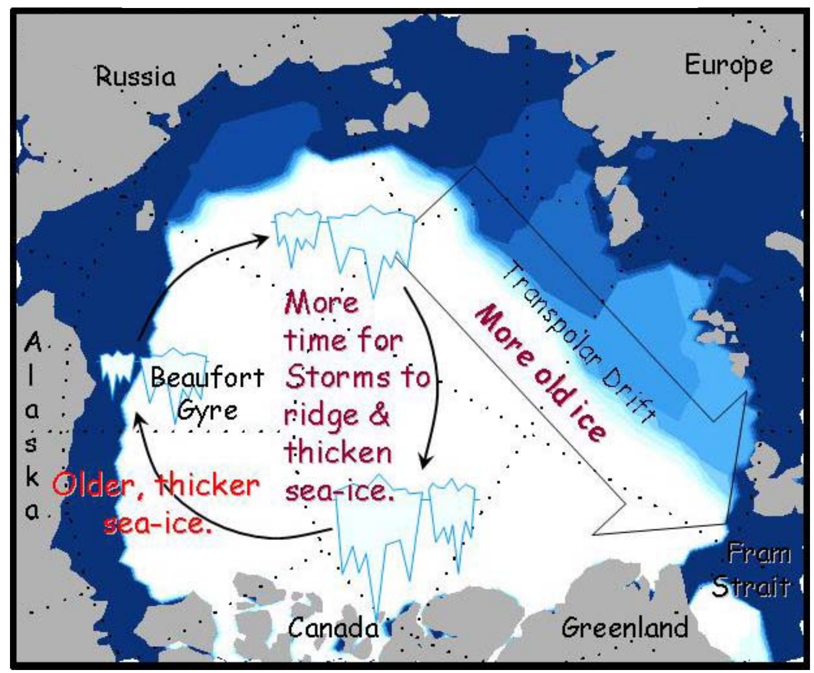


AO INDEX 1900 – 2000



How can we explain the discrepancy in the temperature and sea ice extent records?

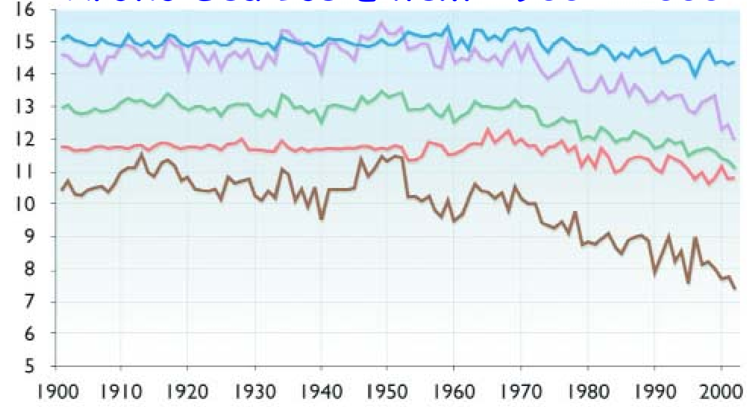
1980's Type of Ice Motion



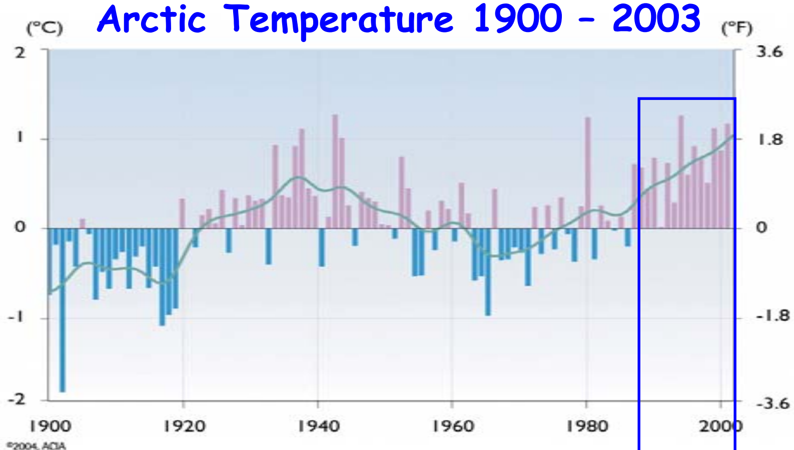
No big "flushing" of sea ice from the Arctic as we saw in the early 1990's?

How can we explain the discrepancy in the AO and sea ice extent

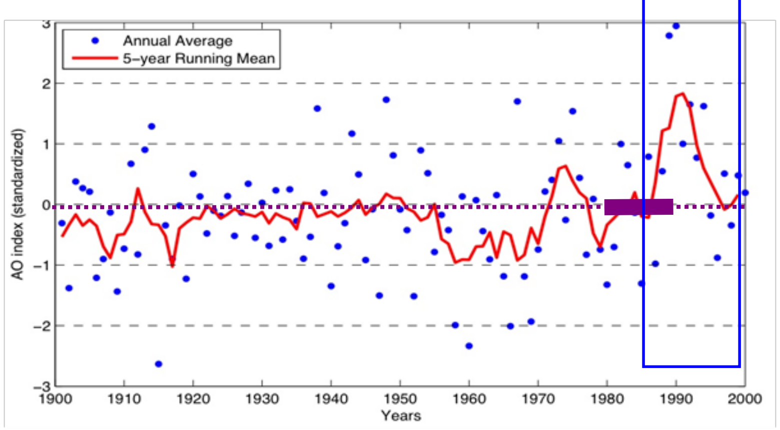
Arctic Sea Ice Extent 1900 – 2000

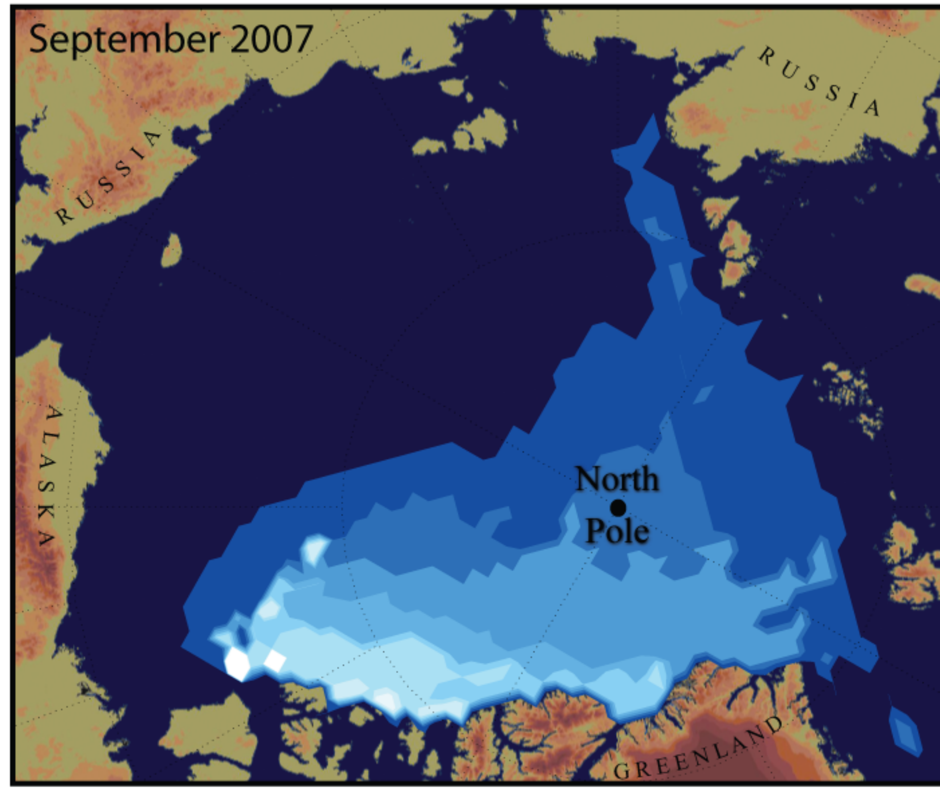


Arctic Temperature 1900 – 2003



AO INDEX 1900 – 2000

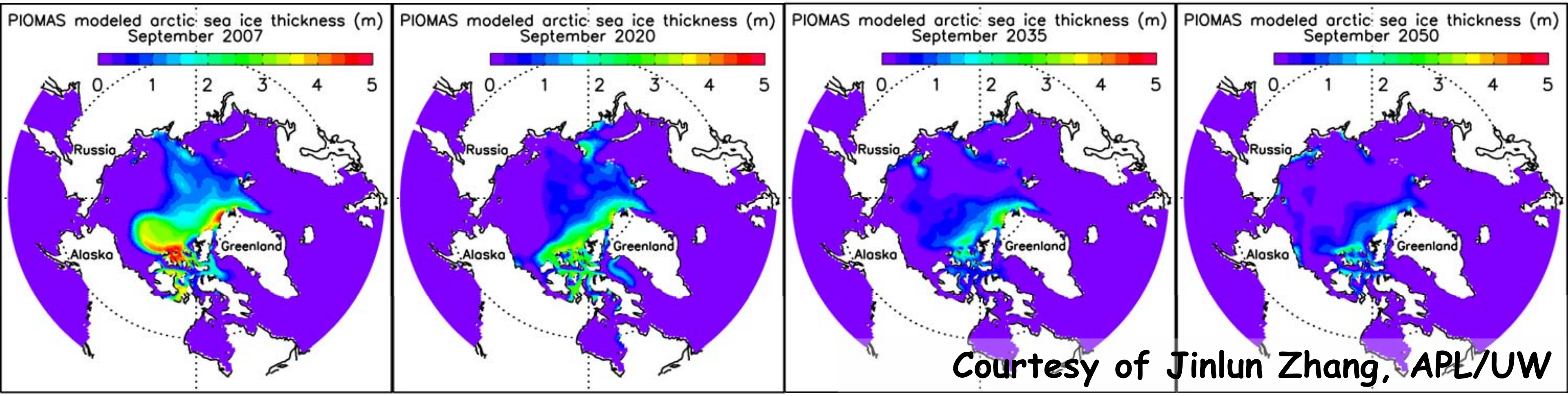




Not enough thickness (mass) to survive even a cold summer.

Summary

Projections for Arctic Summer Sea Ice Thickness



Courtesy of Jinlun Zhang, APL/UW

- Drivers of the Decline of Sea Ice: Warmer Temperatures, Changes in wind and ice motion, Ice-Albedo and other Positive Feedbacks
- Inter-decadal variation in sea ice are consistent with natural modes of variability (e.g. the AO), and increasing green house gases.
- My certainty for the long-term outlooks is also 3-4.

END

Extra Slides

US Interagency Arctic Buoy Program (USIABP)

Ignatius Rigor (PSC/APL/UW),
Pablo Clemente-Colon & LTJG Kyle Obrock (Naval Ice Center)

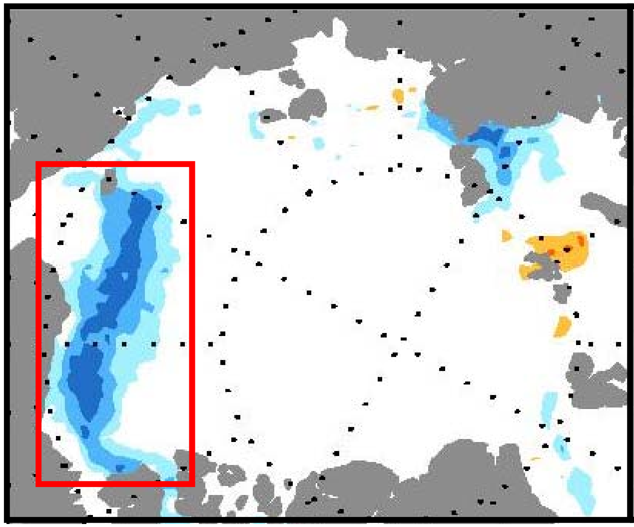
- **USIABP coordinates US contributions to the International Arctic Buoy Programme (IABP),** which has 28 Participants from 8 different countries, including the WCRP and EUMETNET; and others, e.g. DAMOCLES.

- **Goal:** IABP monitors air, sea and ice using drifting buoys.
- **Observations are used for both operations and research.**
  - forecasting weather and ice conditions,
  - validation and forcing of climate models,
  - validation of satellite data,
  - assimilated into reanalysis fields (e.g. NCEP/NCAR), and
  - for studies of climate change.

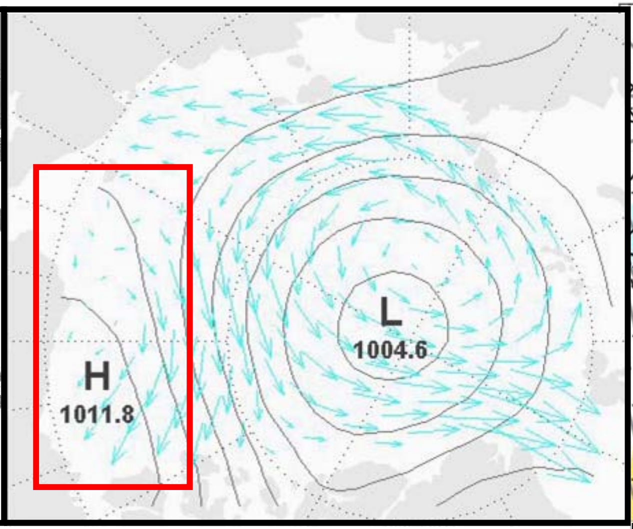
- **Contributors to USIABP:** IARC, NASA, NIC, NOAA (ARO, NESDIS, OCO), NSF, Navy (NAVO, NRL, ONR), USCG

Impact of Summer AO on Summer Sea Ice Extent (SIE)

Covariance(AO_{JJA}, SIC)

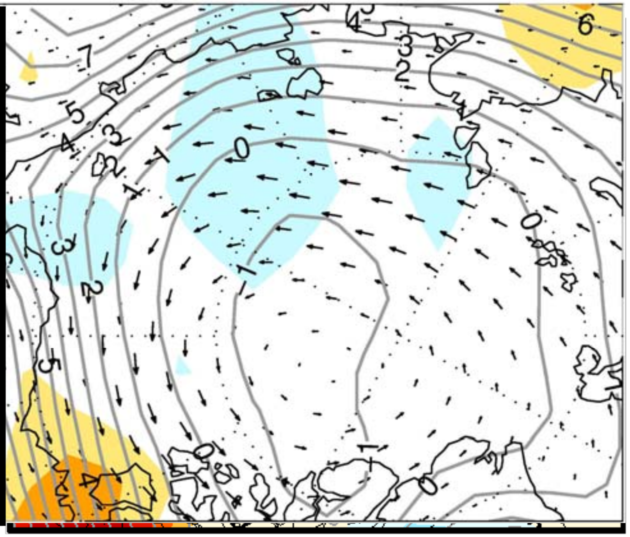


SLP and Ice Motion



Ice stays or is blown towards Alaskan coast!

Temperature Advection



Cold Adv. in Chukchi Sea, Warm Adv. in Canadian Beaufort Sea (less than 0.2°C/day)?

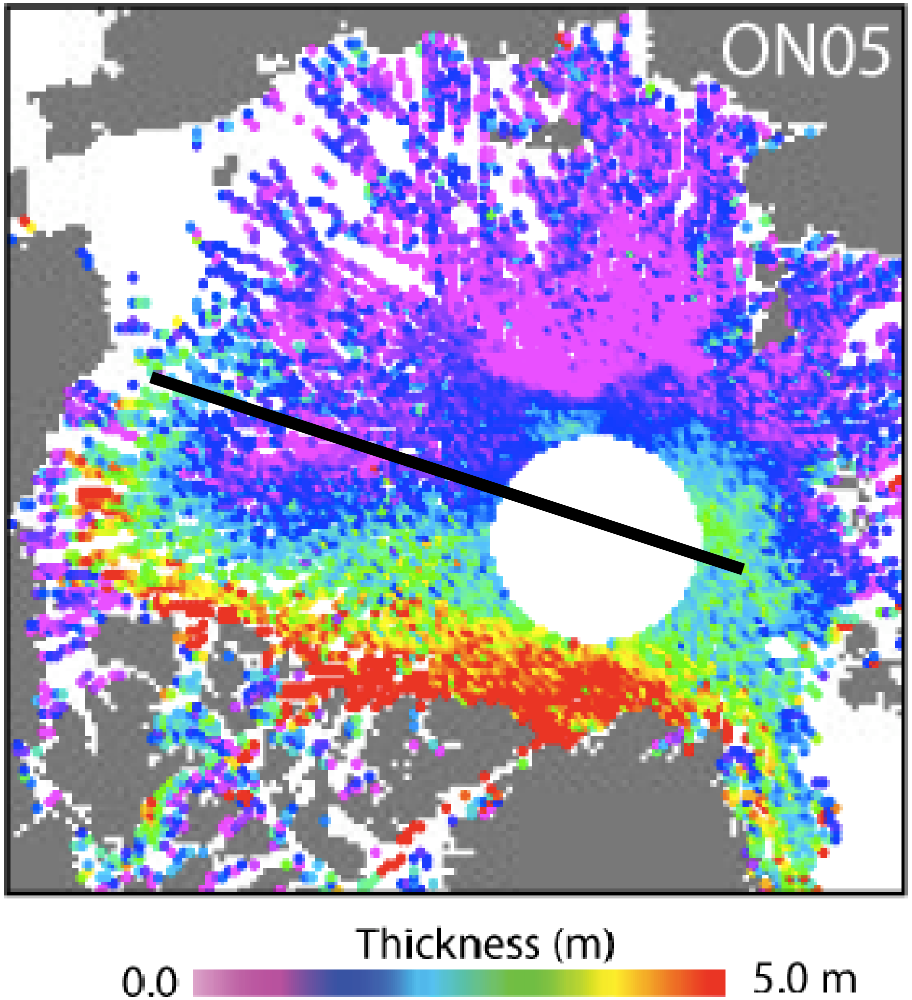
During high AO summers (JJA):

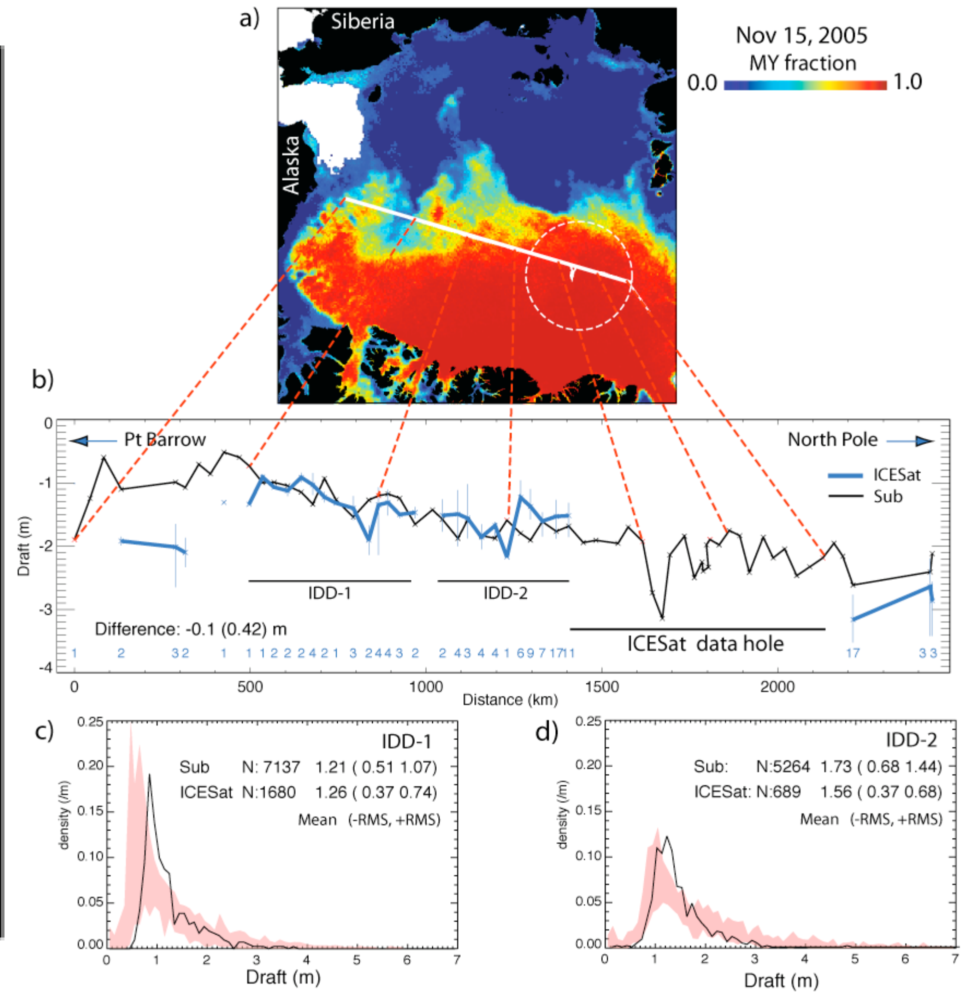
- Ice motion increases concentration of sea ice
- Weak Temperature advection increase ice concentration in Chukchi Sea, but decreases ice concentration in Canadian Beaufort Sea.

(Rigor et al. 2005)

Assessment of Ice Thickness Estimates ICESat compared Submarine ULS

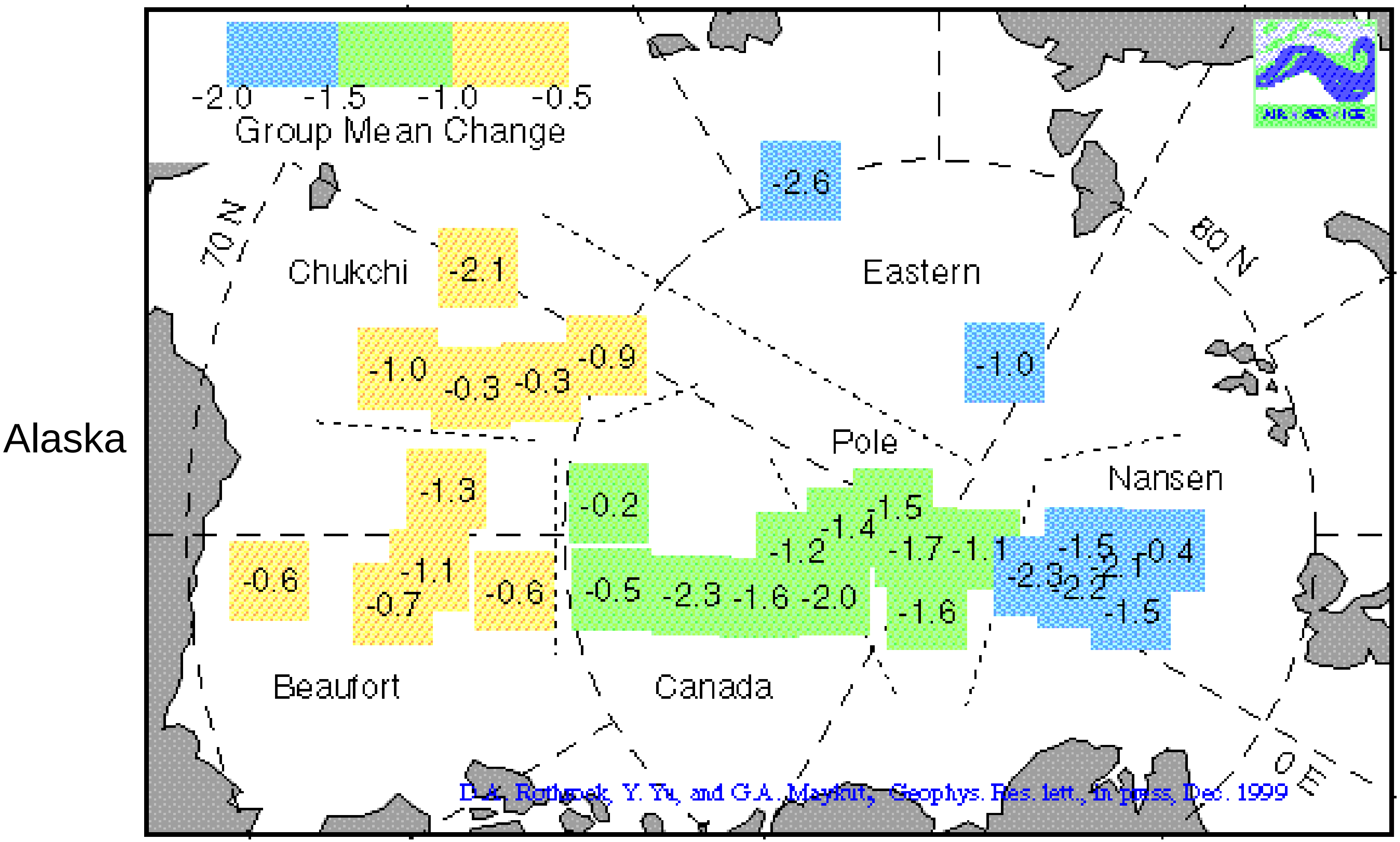
ICESat Laser Altimeter ON 2005





Arctic Sea Ice Thinned

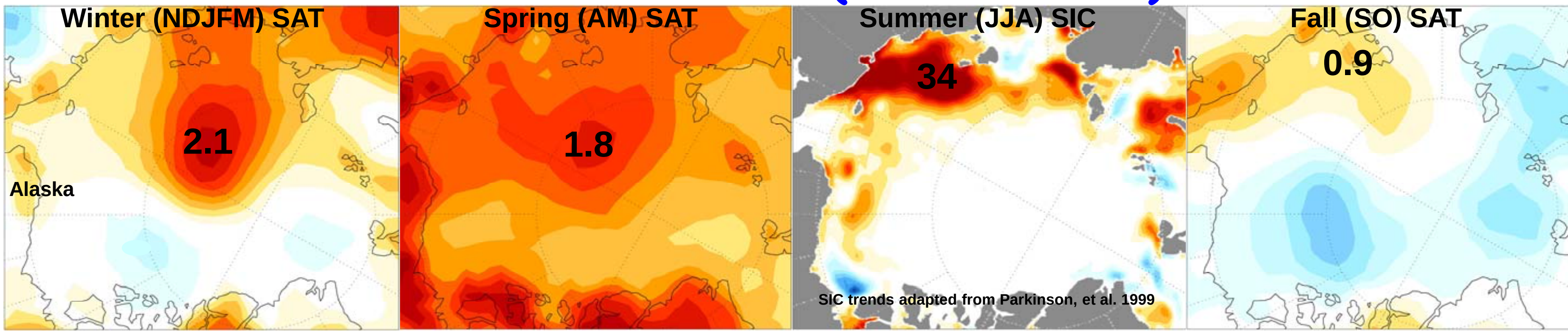
Submarine Ice Draft Data: 1993-1997 minus 1958-1976



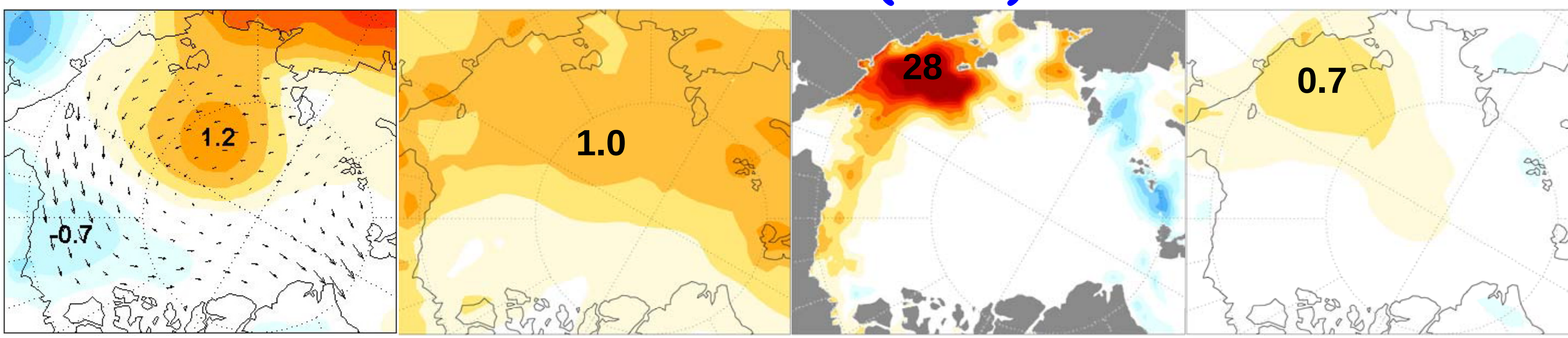
Rothrock et. Al, 1999

Seasonal Memory of Prior Winter AO

Seasonal Trends (1979 – 1998)



Seasonal Covariance with (Prior) Winter AO

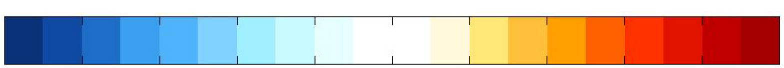


Anomalies act to thin sea ice.

Heat flux increases.

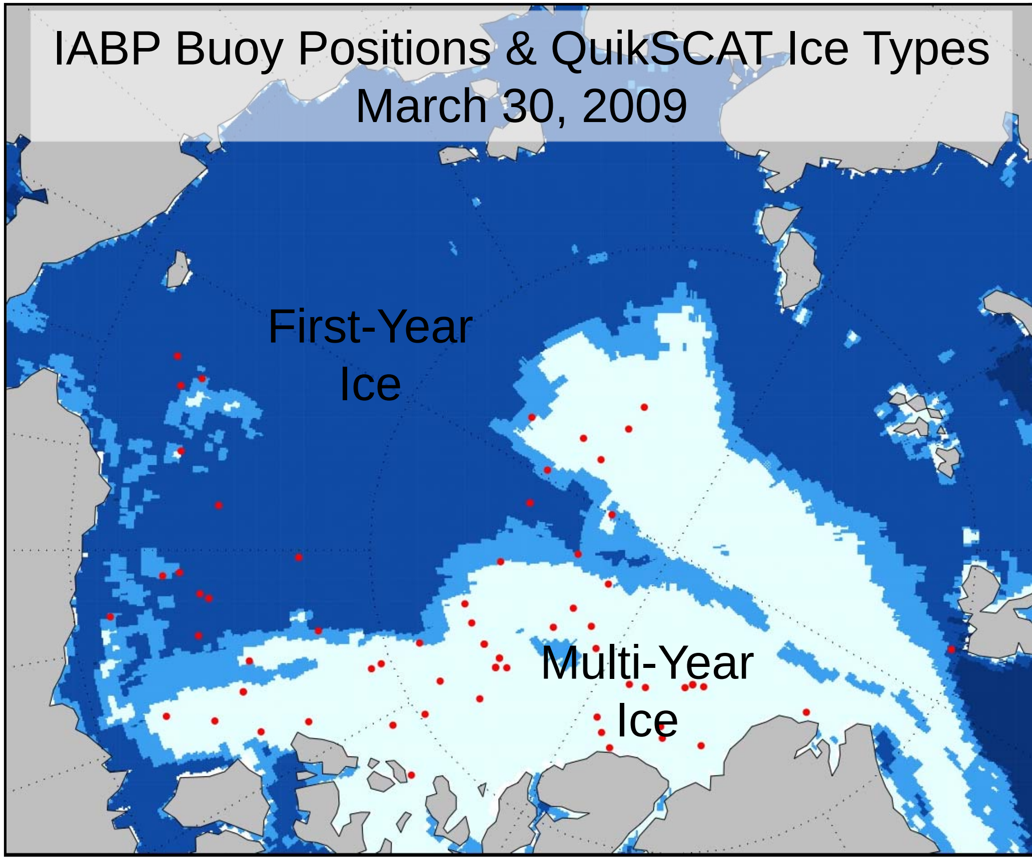
Ice decreases, more absorbed insolation (+ feedback)

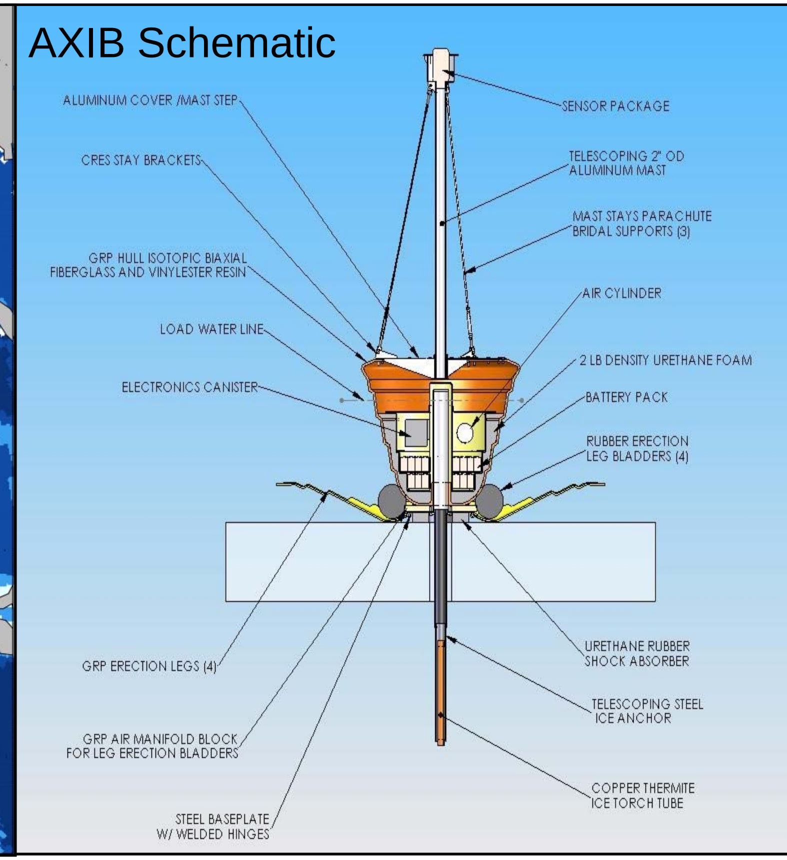
More heat is liberated.



(Rigor et al. 2002)

Airborne eXpendable Ice Buoys (AXIB)





- Low cost aircraft dropable buoy (with surface deployment capability)
- Sensors /measurements include surface air temperature, surface pressure, GPS location, and Argos transmitter.
- Capable of operation in ice and open water through freeze/thaw cycles.
- Prototypes were deployed from the USCG Healy last summer.