Arctic Ocean Change and Effects on Global Climate

by
Jamie Morison
for
CLIVAR Summit
POS-PSMI Breakout Session
10:30 AM, Wed , August 9, 2017
at
Royal Sonesta Harbor Court Hotel
Baltimore, MD

Acknowledgements: Ron Kwok, Ignatius Rigor, Matt Alkire, Cecilia Peralta-Ferriz, Roger Andersen, Sarah Dewey , Suzanne Dickinson, David Morison, and many more

Polar Science Center

Background
Arctic Ocean: Inflow, Outflow, and Circulation

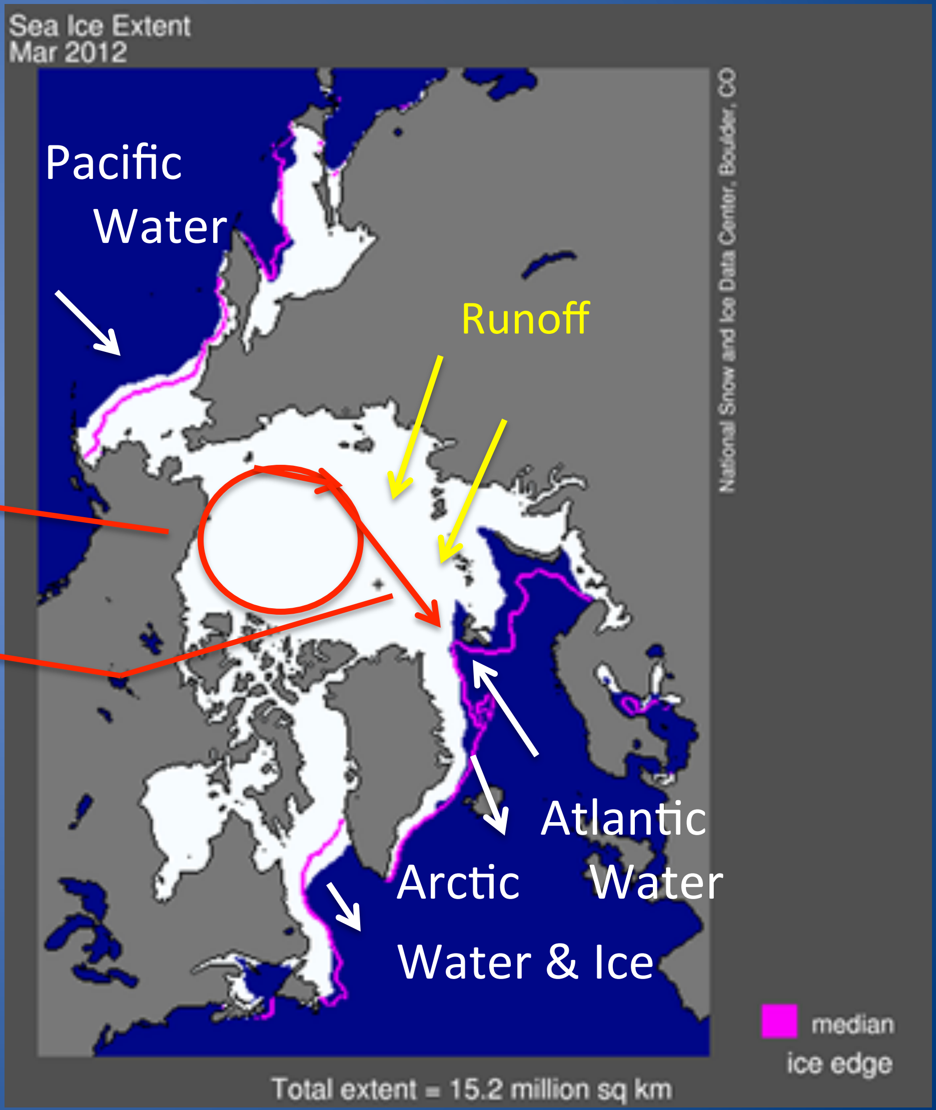
The Arctic Ocean is an ice factory and mixing bowl for Atlantic Water (S~35), Pac. Water (S~31-32), & runoff (S=0) .

Average circulation has commonly been characterizedy by:

Beaufort Gyre

Transpolar Drift

Winter ice extent been relatively stable, witness March 2012
But average thickness as changed from about 3m to about 2m in recent decades



Background
Arctic Ocean: Inflow, Outflow, and Circulation

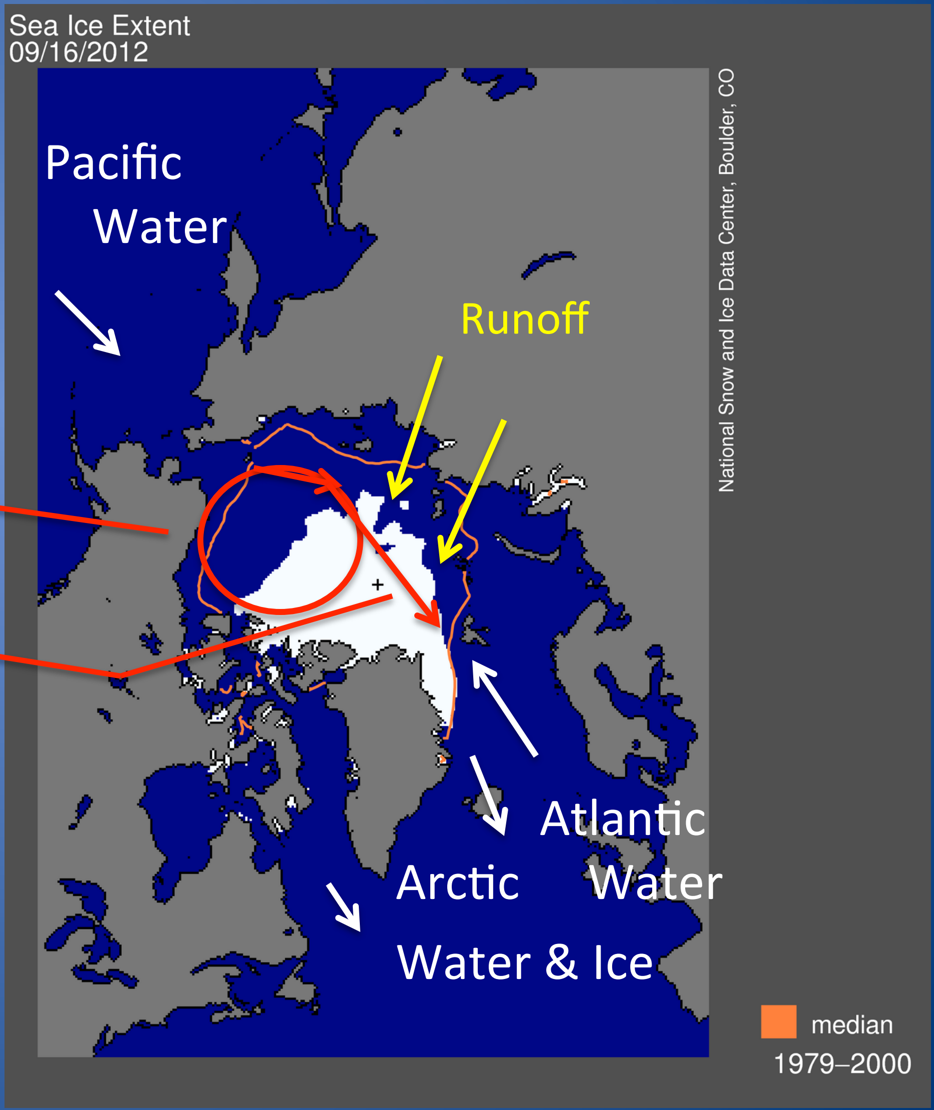
The Arctic Ocean is an ice factory and mixing bowl for Atlantic Water (S~35), Pac. Water (S~31-32), & runoff (S=0) .

Average circulation has commonly been characterized solely by:

Beaufort Gyre

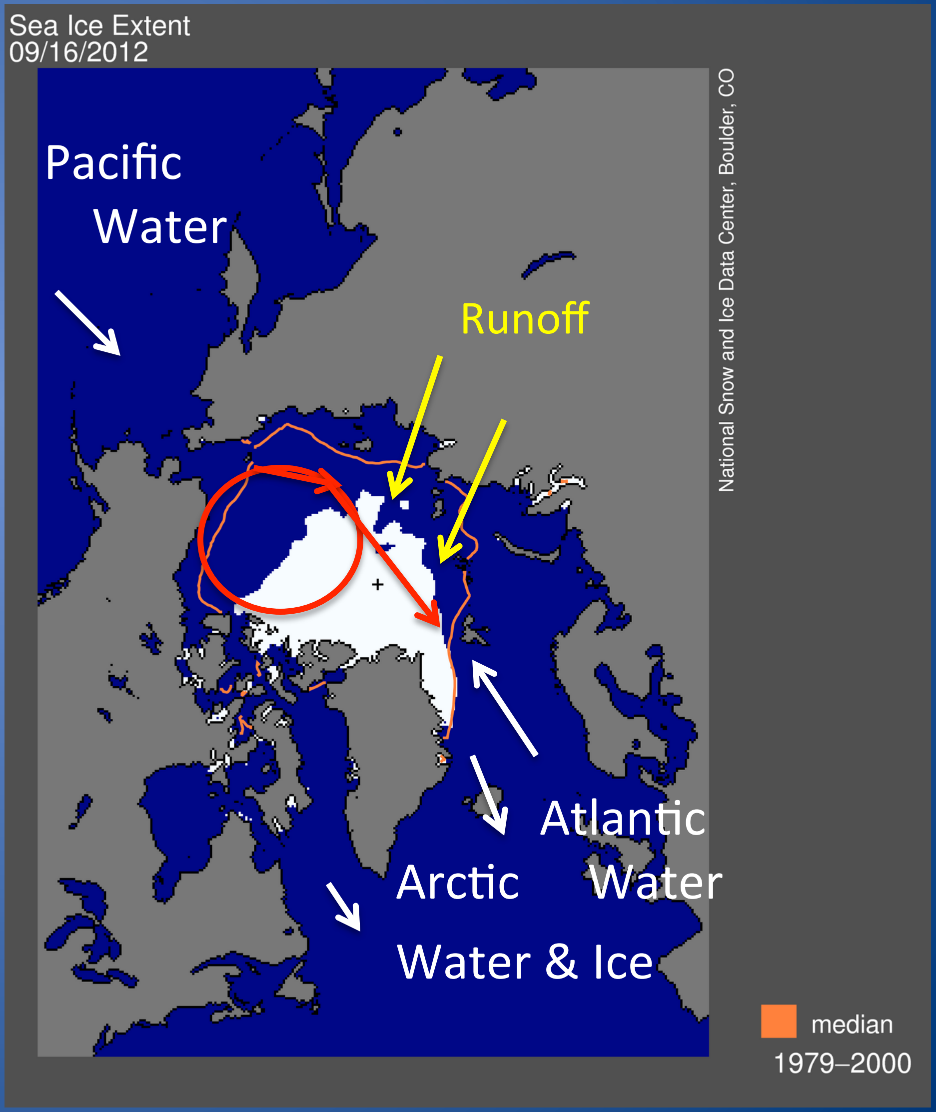
Transpolar Drift

Minimum ice extent has decreased dramatically, witness record minimum in Sept 2012
 Consequently the average ice volume has dropped over 50%.



Background
Arctic Ocean: Important tidbits

- Arctic Ocean is salt stratified (salinities differences large & thermal expansion coefficient small)
- Deep mixing is weak
- Pacific Water circulates anticyclonically in the wind-driven Beaufort Gyre
- Atlantic Water circulates cyclonically descending below Pacific Water
- Average ice drift: 1-3 cm/s approx with surface geostrophic current & parallel to atmos isobars, but tends to converge under anticyclone, diverge under cyclone
- RMS ice drift: 7-10 cm/s corresponding to 2-3% RMS wind speed



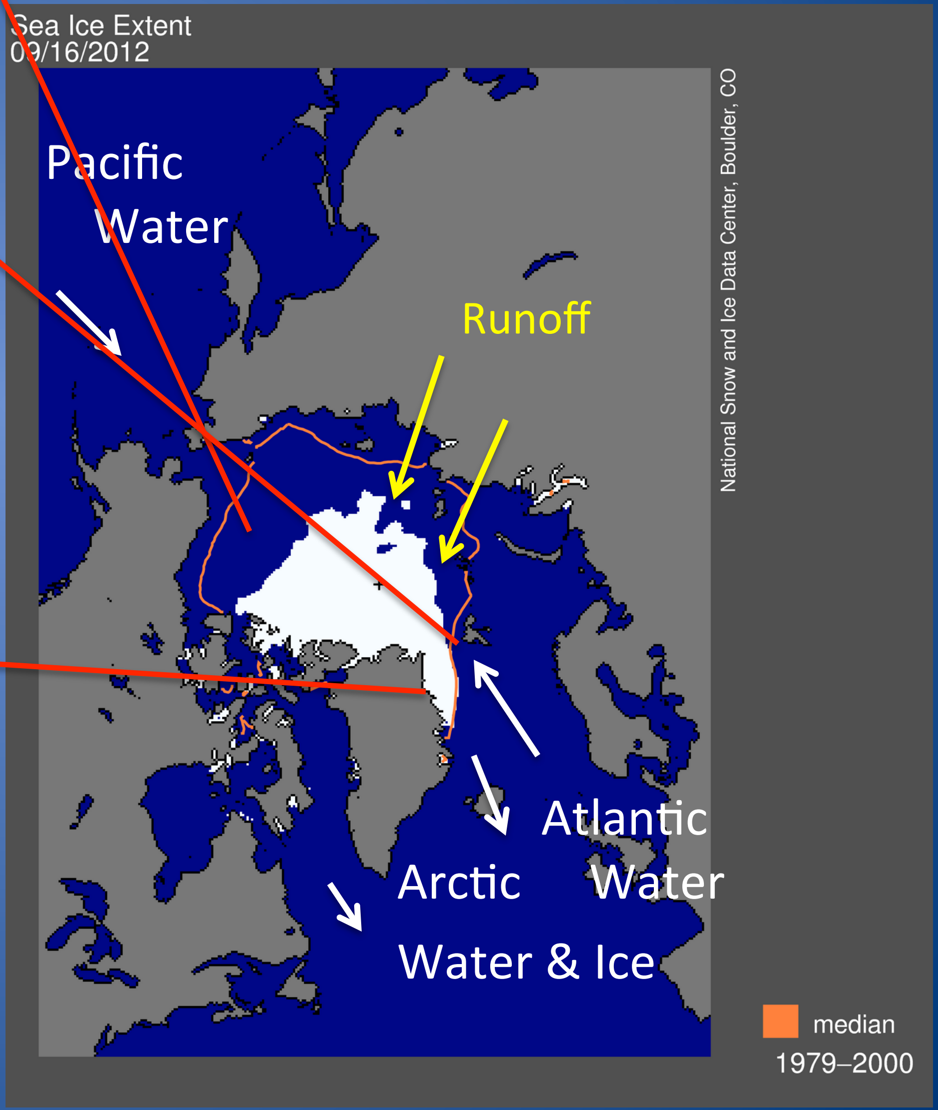
Polar Science Center

Background
Arctic Ocean: Potential Climate Feedbacks

Ice-Albedo Feedback:
Reduction in ice area allows more radiative heating of the ocean which reduces ice area further

Freshwater Effect on Global Thermohaline Circulation:
Ice and freshwater export increases stratification and reduces potential for convection in the sub-Arctic seas*

Flushing of Glacier Termini:
Export of freezing point water along N.E. Greenland shelf protects glacier termini. Increased current flushes away protection



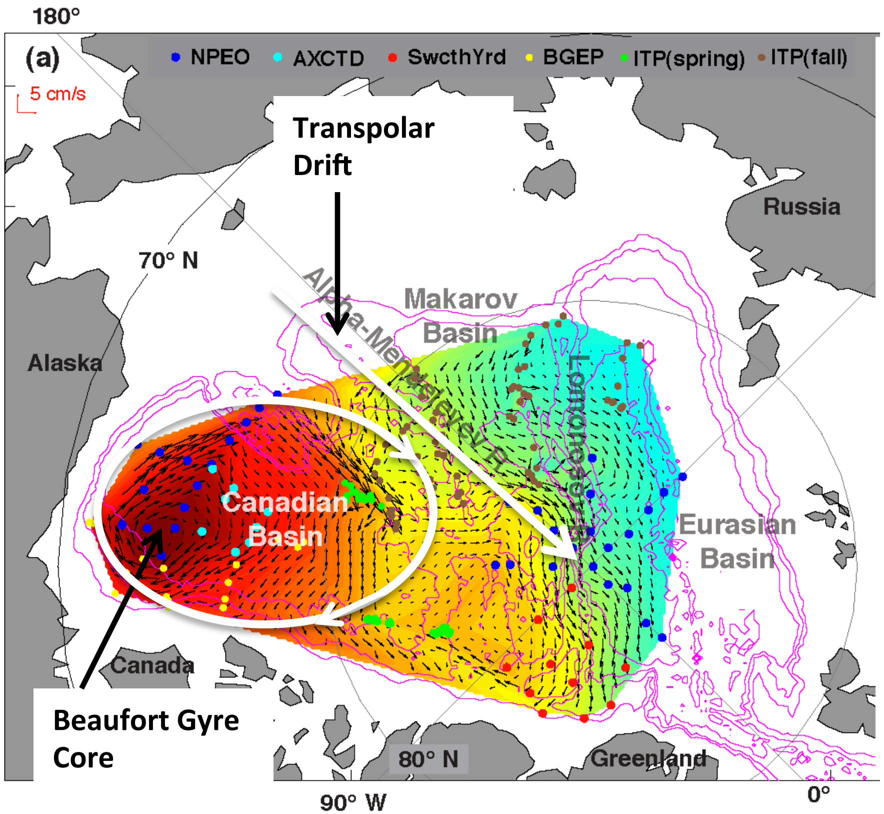
* R.R. Dickson, J. Meincke, S.-A. Malmberg, A.J. Lee,The "Great Salinity Anomaly" in the northern North Atlantic, 1968-1982, Progress in Oceanography, 20 (2) (1988), pp. 103–151

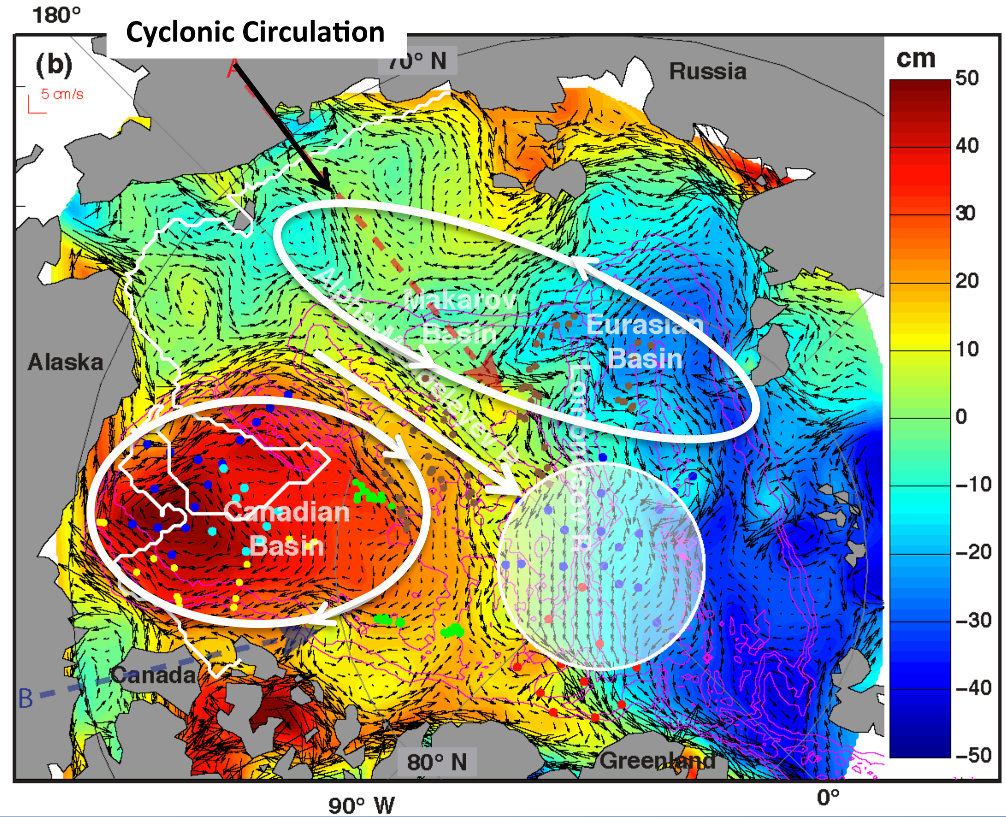
Polar Science Center

To in Situ Observations, the Arctic Ocean is the Beaufort Gyre

Spring 2008 dynamic height and surface geostrophic current relative to 500 dbar from available hydrographic profiles only show the Beaufort Gyre and Transpolar Drift

ICESat dynamic ocean topography (DOT) and surface geostrophic current reveal DOT trough and cyclonic circulation on the Russian side of the Arctic Ocean





- **Agreement between dynamic height and DOT (r = 0.92) => mostly baroclinic**

Kwok, R., and J. Morison (2011), Dynamic topography of the ice-covered Arctic Ocean from ICESat, *Geophysical Research Letters*, *38*(L02501), L02501.

This is important to climate because patterns of circulation are consistent with Anticyclonic (A) and Cyclonic (B) regimes of surface circulation of the Arctic Ocean from *Sokolov* [1962] & *Proshutinsky and Johnson* [1997]

Anticyclonic Mode **Cyclonic Mode**

PROSHUTINSKY AND JOHNSON: ARCTIC OCEAN CIRCULATION REGIMES

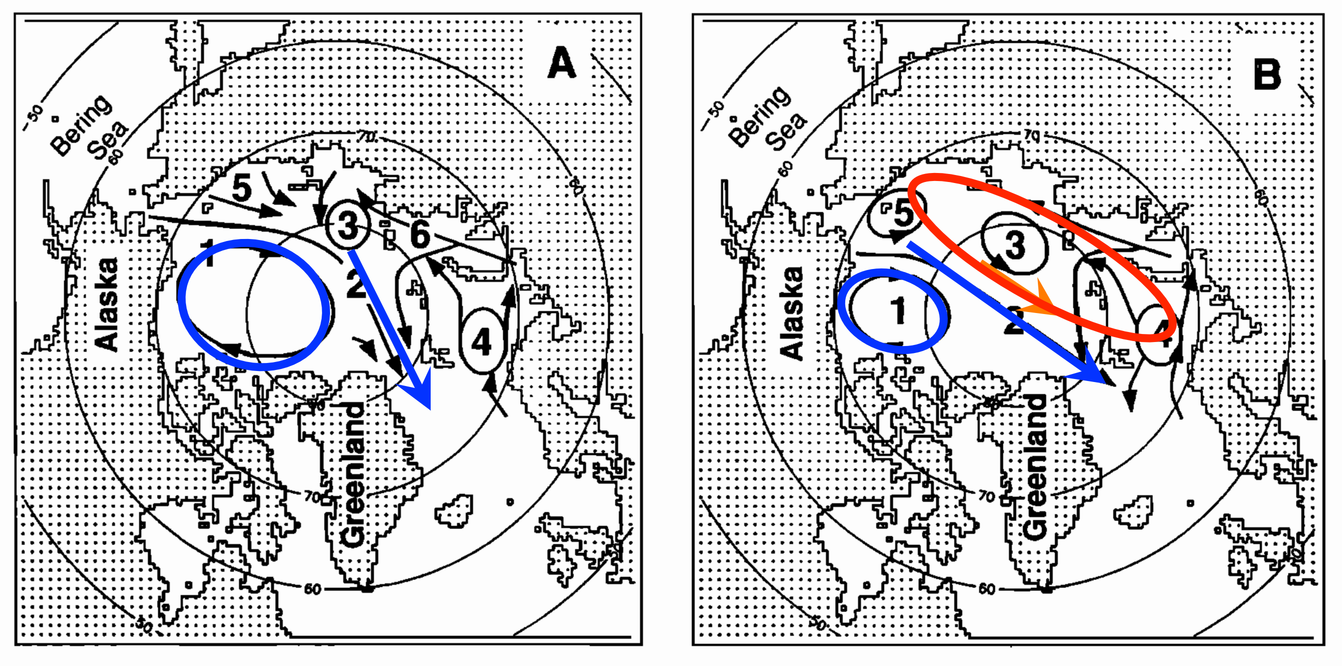


Figure 4. Regimes of surface currents and ice drift in the Arctic Ocean redrawn from *Sokolov* [1962]. (a) Type A circulation, corresponding to prevailing Arctic High atmospheric pressure; (b) Type B circulation, corresponding to prevailing Icelandic Low atmospheric pressure. Numbered features are 1, Beaufort Gyre; 2, Transarctic Drift Current; 3, Laptev Sea cyclonic circulation; 4, Barents Sea currents; 5, East Siberian Sea circulation; and 6, Kara Sea coastal flow.

Changes in the early 1990s suggested shift to the cyclonic mode with tighter Beaufort Gyre, counterclockwise shift in Transpolar Drift, and cyclonic circulation (ccw) on Russian side

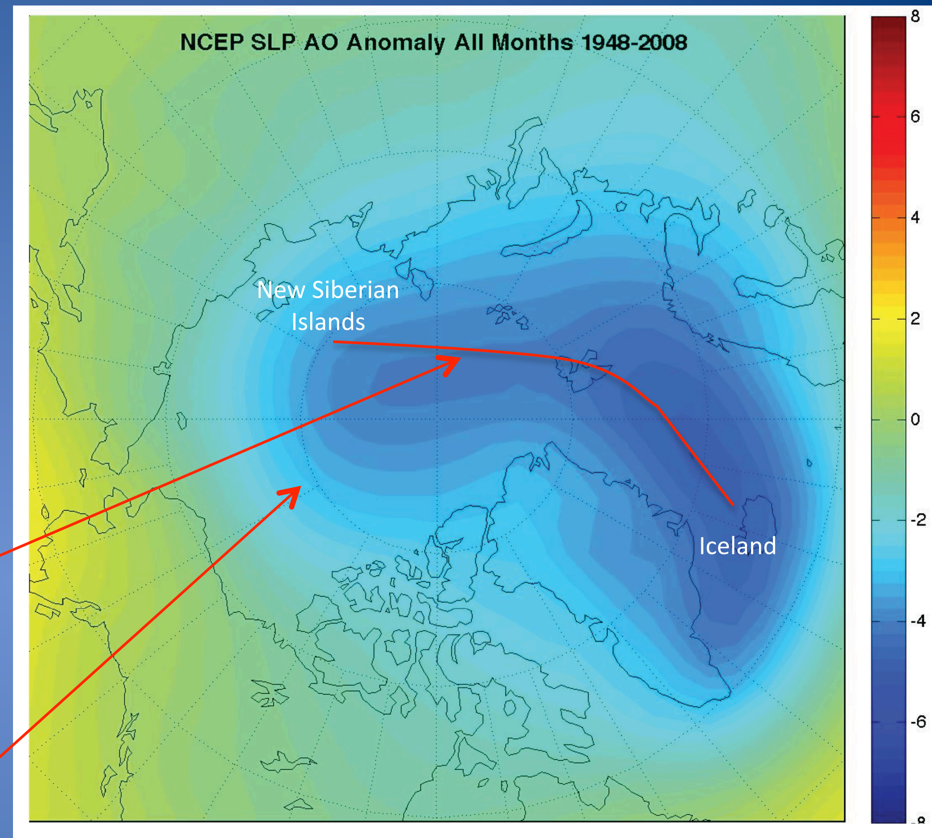
Sokolov, A. L. (1962), Drift of ice in the Arctic Basin and changes in ice conditions over the northern sea route, *Probl. Arct. Antarct., Engl. Transl., 11*, j1-j20.

Can we relate the cyclonic mode of circulation to global climate?

Sokolov [1962] => cyclonic mode prevails when the Icelandic Low is strong relative to the Polar High.

= pattern of SLP under a positive phase of the Arctic Oscillation

According to Z. M. Gudkovich the following factors determine the observed pattern of circulations: The prevailing wind conditions over the basin play the major role in its formation. Wind conditions are determined mainly by the presence and position of the trough of the Iceland low pressure area and of the polar high. It is known that the Iceland low usually influences a vast territory of the ocean from Iceland to the New Siberian Islands. The wind conditions caused by it induce a cyclonic-type circulation of surface waters in the Greenland, Norwegian, Barents, Kara, and Laptev Seas. The winds at the northern periphery of the Iceland low create a surface current directed toward the strait between Greenland and Spitsbergen. The polar high, conversely, causes anticyclonic circulation of waters in the Canadian region of the Arctic Basin. In general the conditions described prevail for long periods, on the order of a season. The specific synoptic situation can, however, change quite substantially.

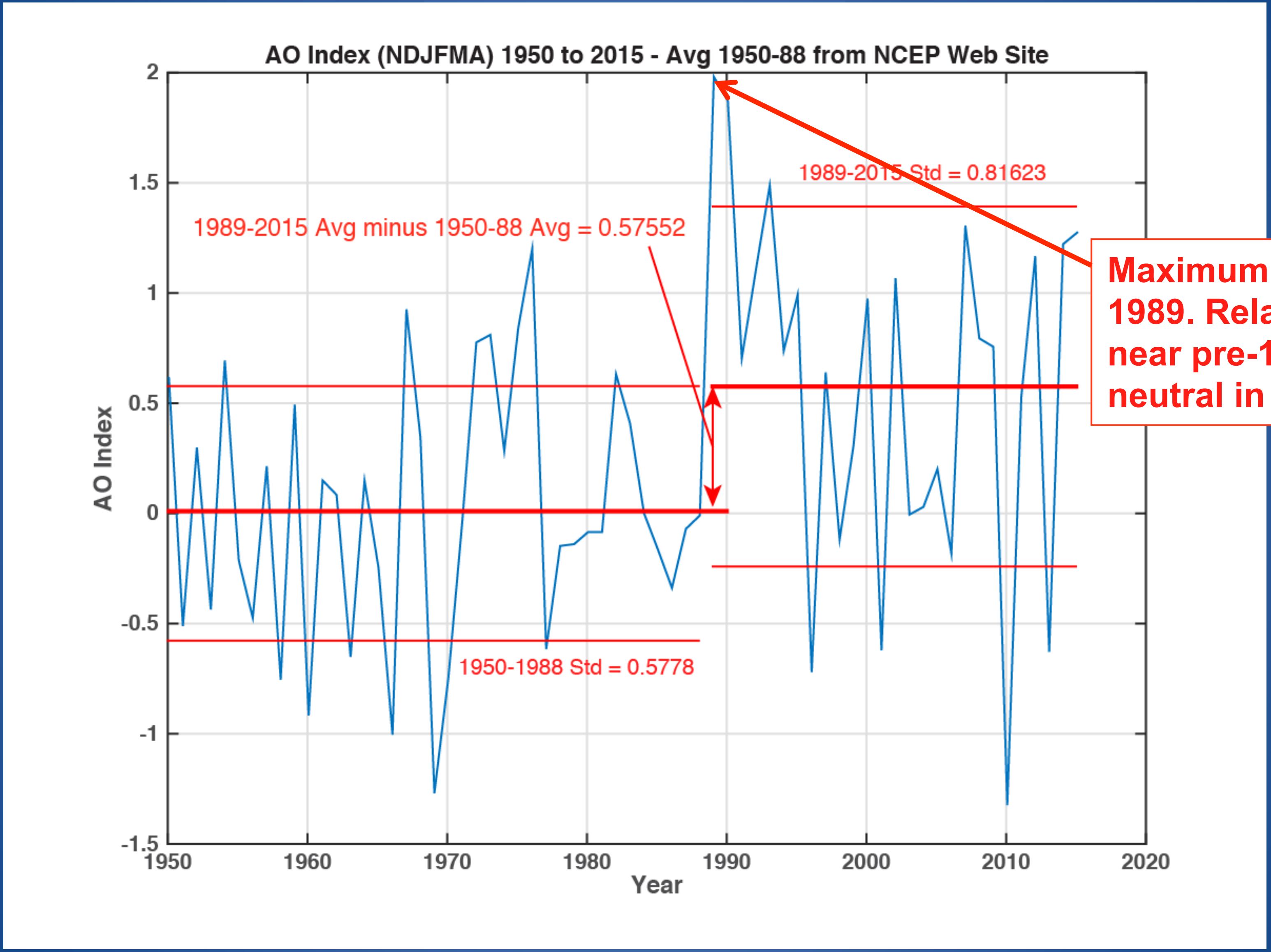


[Morison, J., R. Kwok, C. Peralta-Ferriz, M. Alkire, I. Rigor, R. Andersen, and M. Steele (2012), Changing Arctic Ocean freshwater pathways, *Nature*, *481*(7379), 66-70.]

The AO pattern in the Arctic strengthens the Icelandic Low and may weaken part of the Beaufort (Polar) High. In modern terms, cyclonic mode prevails when the AO is high.

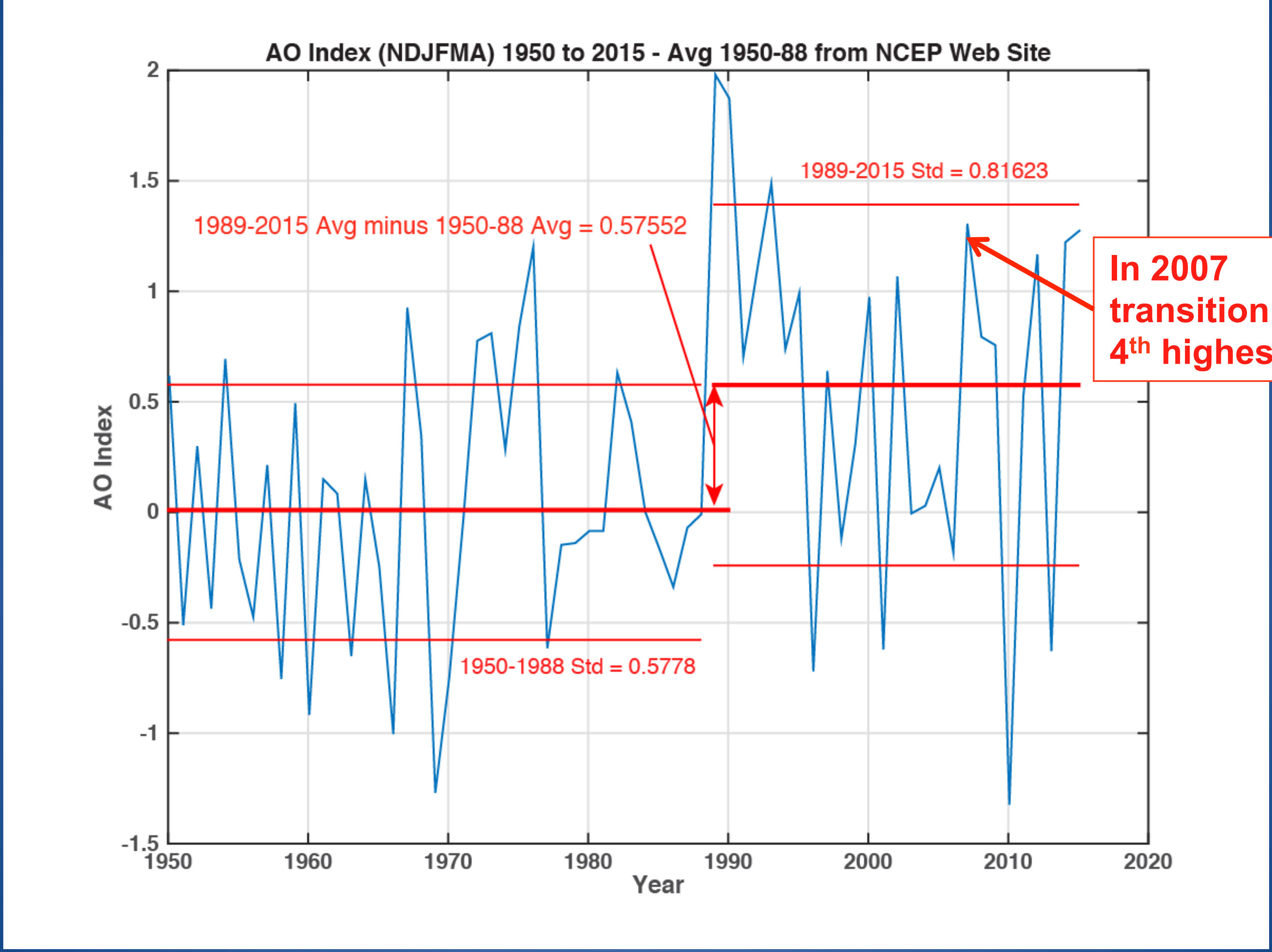
AIR · SEA · ICE
Polar Science Center
NSF
NASA

Regime of high winter AO starting in 1989



[Update of figure from Morison et al., 2012]

Regime of high winter AO starting in 1989



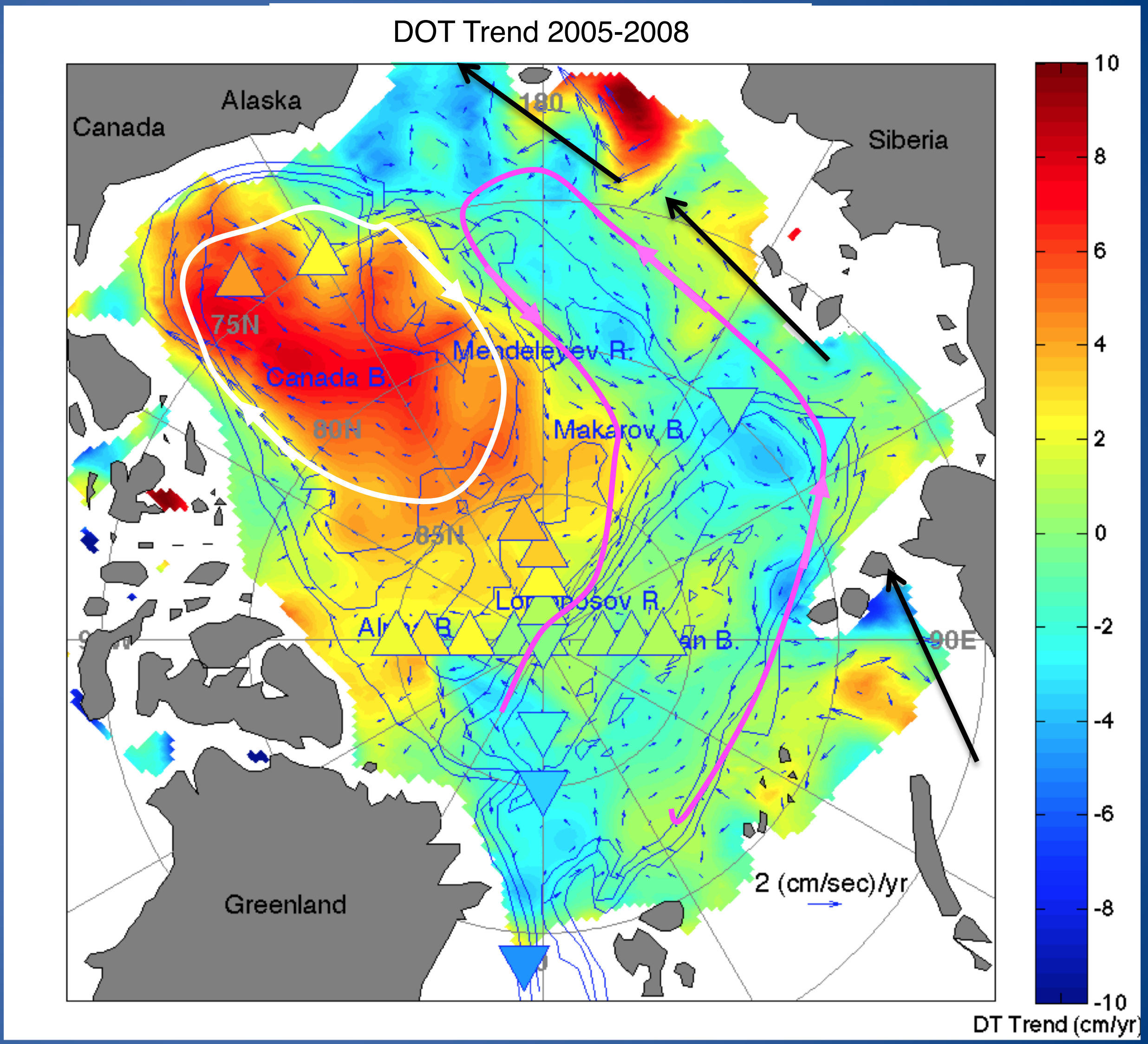
[Update of figure from Morison et al., 2012]

SSH Trend 2005-08 From ICESat Altimetry And From GRACE Bottom Pressure - CTD Steric Pressure (triangles)

Color contours of SSH change and velocity trends 2005-2008 also => shift to cyclonic mode. Beaufort Gyre tightens becomes more intense with increase in freshwater.

Developing SSH trough aligned with the Russian shelf break produces cyclonic circulation.

Which carries Eurasian runoff (plus Russian pollutants) eastward to enter Beaufort Gyre.

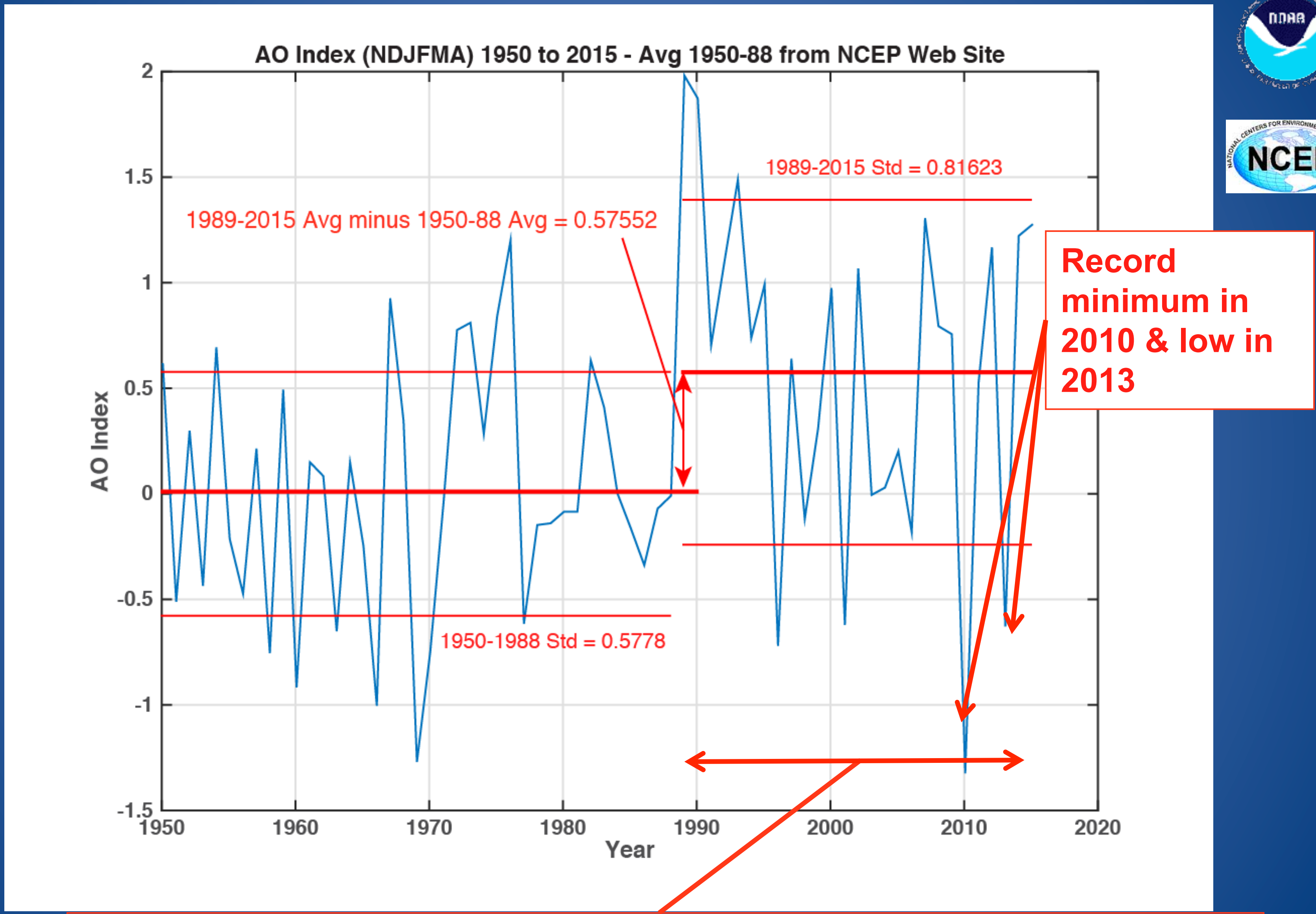


ICESat & GRACE

In Situ Hydro

*[*Morison, J., R. Kwok, C. Peralta-Ferriz, M. Alkire, I. Rigor, R. Andersen, and M. Steele (2012), Changing Arctic Ocean freshwater pathways, *Nature*, *481*(7379), 66-70.

Regime of high winter AO starting in 1989



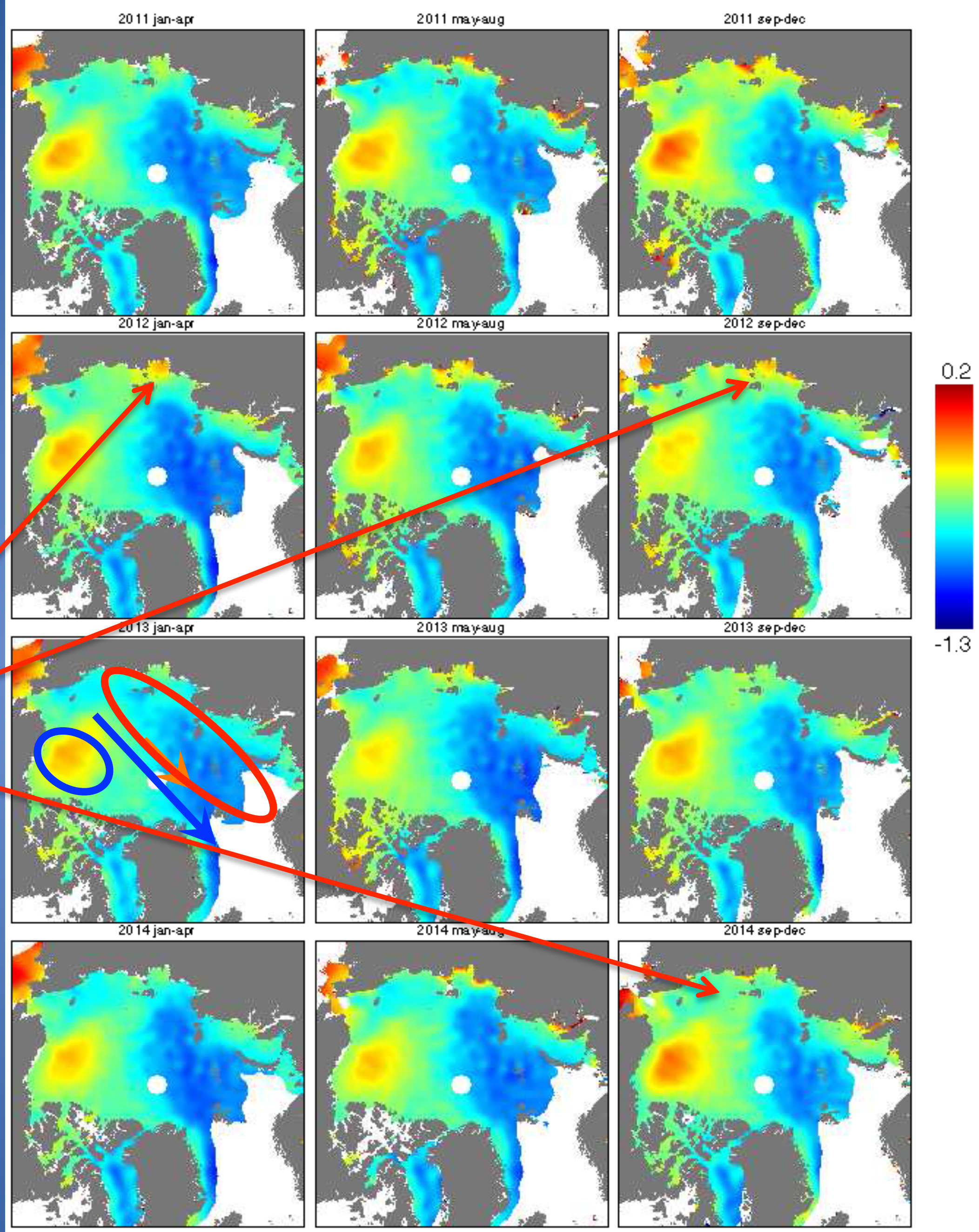
But on average, 25 years of elevated winter AO

[Update of figure from Morison et al., 2012]

DOT 2011-14 From CryoSat-2 Altimetry =>

There is variability but for all periods, the core of Beaufort Gyre is southeast in the Beaufort Sea and a trough of low DOT extends along the Russian side of the Arctic Ocean producing cyclonic circulation there, hallmarks of the cyclonic mode.

Key element not observed with *in situ* observations alone is rising DOT towards Russian Coast, a downwelling pattern that creates an eastward alongshore flow.



Kwok, R. and J. Morison (2015), Sea surface height and dynamic topography of the ice-covered oceans from CryoSat-2: 2011-2014, submitted to JGR Sept. 2015.

Possible Influences of High AO / Cyclonic Regime on Climate

Consistent with these circulation changes, high winter AO results in:

- **Increased air temperature over the Russian Arctic [*Thompson and Wallace, 1998*] decreasing winter ice growth**
- **Sea ice divergence and enhanced transpolar drift and ice export (*Kwok et al.* 2013) leading to reduced ice age, thickness and extent (*Rigor et al.,* 2002, 2004; *Lindsay and Zhang*, 2005) thereby triggering/enhancing ice albedo feedback.**
- **Enhanced freshwater and ice export export (*Kwok et al.* 2013) tends to stratify the sub-arctic seas weakening convection there**
- **Cyclonic circulation sends Eurasian runoff to freshen the Canada Basin at the expense of the Eurasian Basin (*Morison et al.*, 2012)**
- **Diversion of Eurasian runoff to the Canada Basin also shrinks the cold-halocline of the Eurasian Basin that isolates the sea ice from the heat in the deeper Atlantic water (*Steele and Boyd*, 1998)**
- **Increased strength of the outflow of ice and cold low-salinity Arctic water along the East Greenland continental shelf may also impact ocean temperatures affecting the marine terminating glaciers of the Greenland ice sheet. There is also evidence that recent freshening of the whole water column of the Nordic sub-Arctic seas has freshened the entire North Atlantic (*Curry et al.* 2003).**
- **Some early studies suggest increased AO with global warming (*Fyfe et al.*, 1999; *Shindell et al.*, 1999; *Randel and Wu*, 1999)**

AIR · SEA · ICE
Polar Science Center

Thank You