A View of Arctic Ocean Observing Over the Last 30 Years

CLIVAR Summit

by

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The Classic Anticyclonic View of Arctic Ocean Circulation

- Many believe that anticyclonic circulation characterized by the intensity of the Beaufort Gyre has dominated Arctic Ocean circulation in recent years.
- e.g., Hoffman et al. [2015] claim, " An anticyclonic circulation regime has dominated in this region for the past ~16 years, intensifying the buildup of fresh water in the gyre,…"

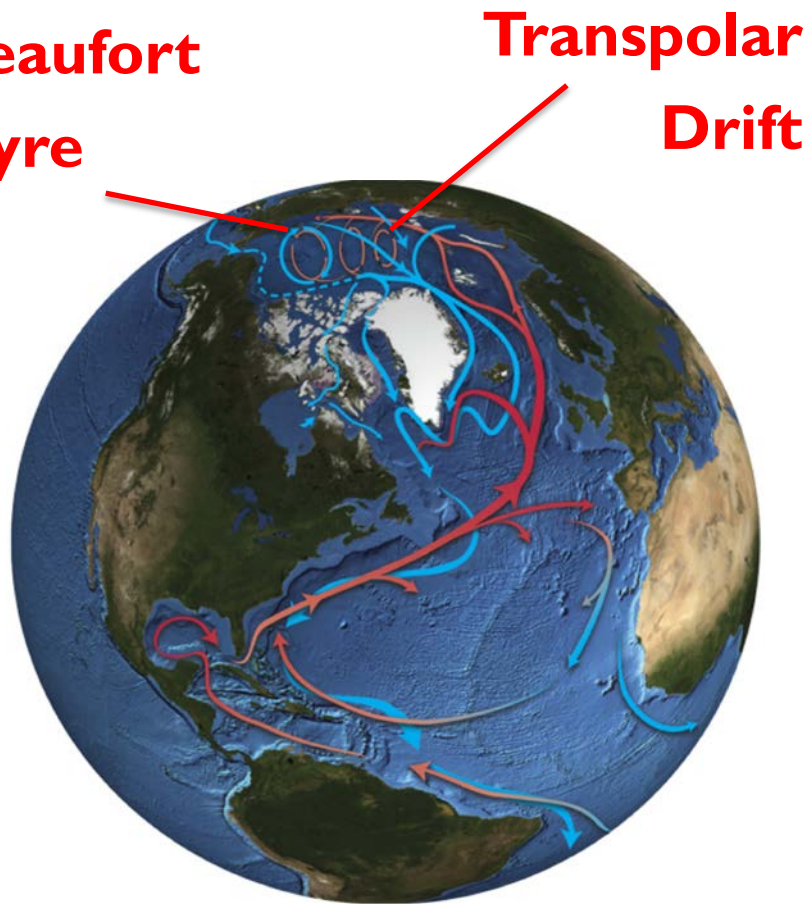
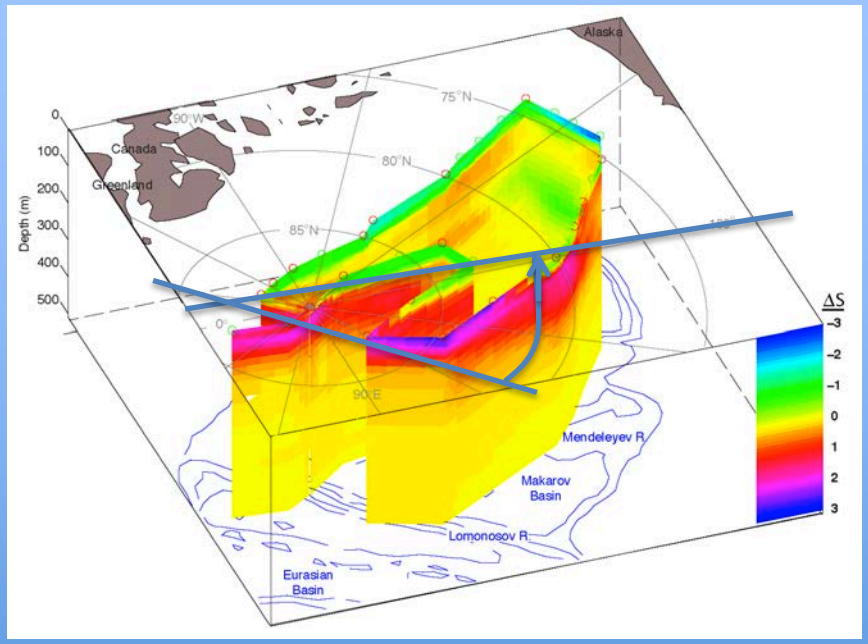


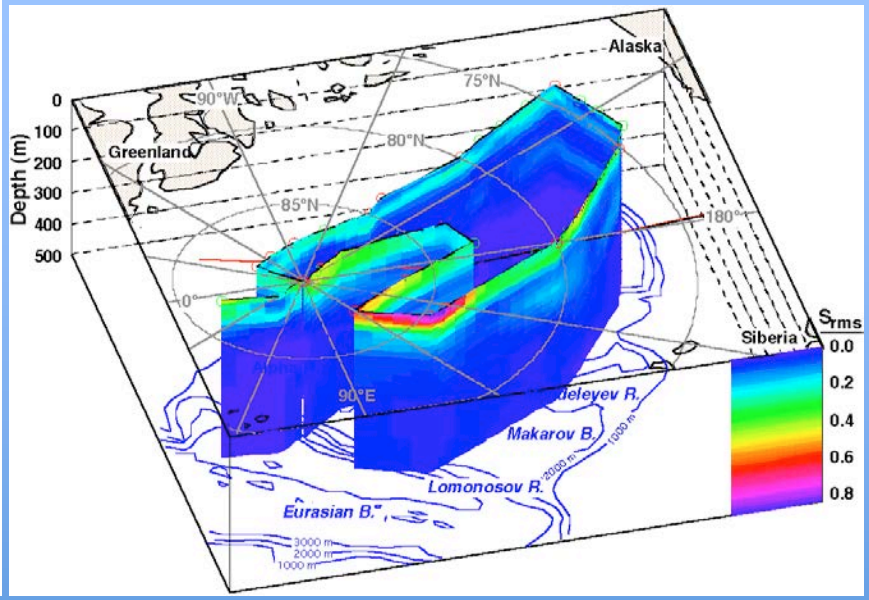
Figure 1 from Hoffman et al. (2015)

A simplistic view based on spatially biased observations and a narrow regional index.

cience plan for a collaborative
ntic-Arctic system, a report of a
Planning Workshop for an International Research Program on the Coupled North Atlantic-Arctic System (14-16 April 2014, Arlington, VA), 37 pp. http://www.whoi.edu/website/NAtl_Arctic/

Alternate view shown by 1993 cyclonic shift in the front between Atlantic and Pacific-derived upper ocean waters seen as *Pargo* '93 Salinity – U.S.- Russian 1950-89 Climatology.





1993 Salinity – Summer Climatology shows cyclonic shift in the Transpolar front, increased salinity in the Makarov, decreased salinity in the Beaufort Sea.

1970s RMS Salinity Variation from US-Russian climatology shows the same pattern of variability though a factor of 5 less.

1993 Pattern of change was consistent with shift from Anticyclonic (A) to Cyclonic (B) regimes of circulation described by *Sokolov* [1962] & revealed by *Proshutinsky and Johnson* [1997]

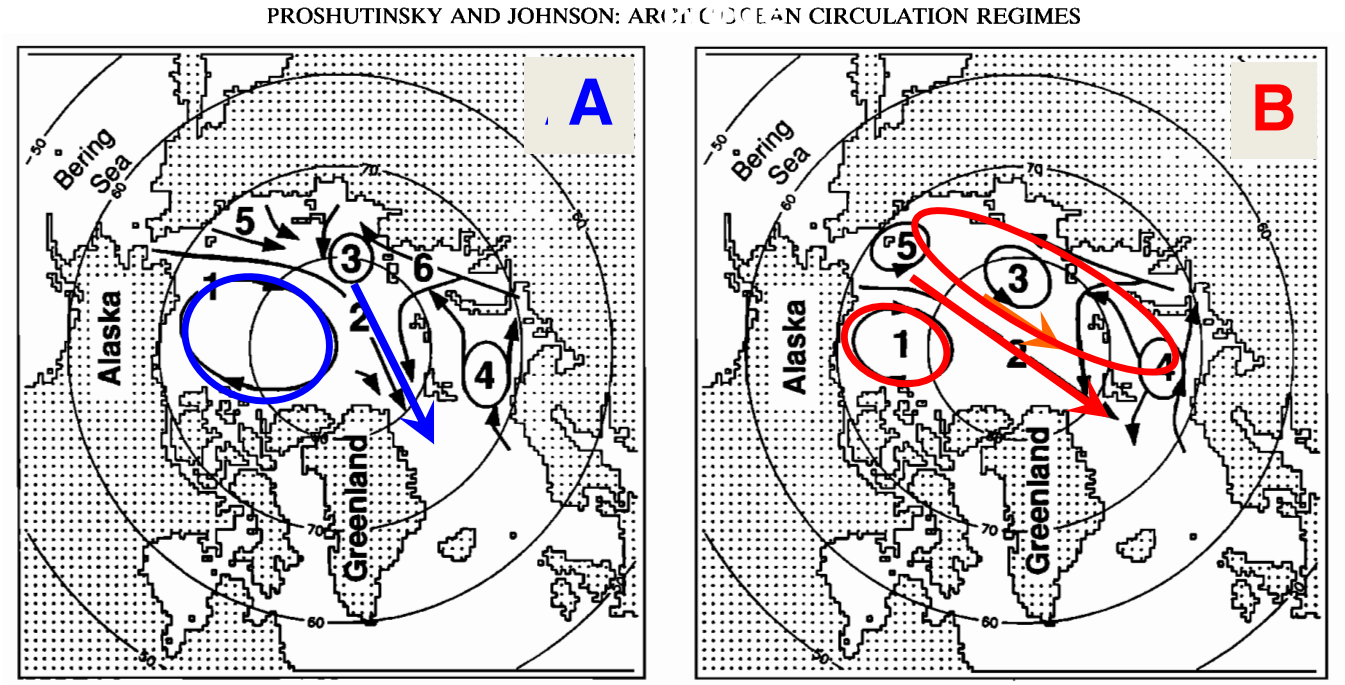


Figure 4. Regimes of surface currents and ice drift in the Arctic Ocean redrawn from *Sokolov* [1962]. (a) Type A circulation, corresponding to prevailing Arctic High atmospheric pressure; (b) Type B circulation, corresponding to prevailing Icelandic Low atmospheric pressure. Numbered features are 1, 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.

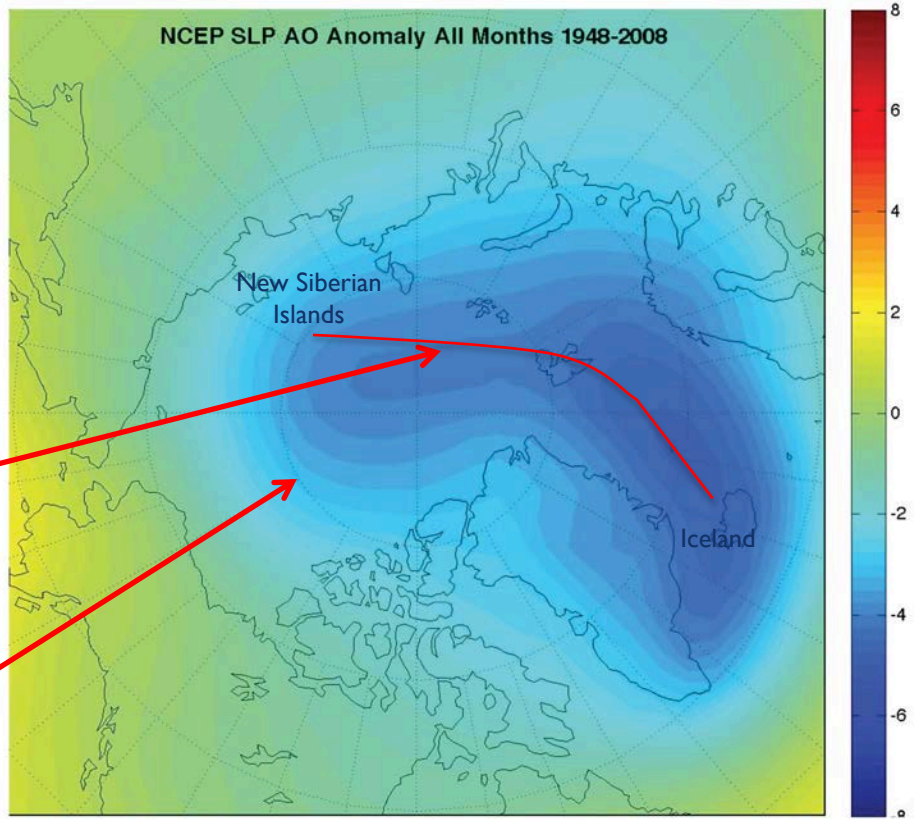
Changes in the early 1990s suggested shift to the the cyclonic mode with smaller Beaufort Gyre, counterclockwise shift in Transpolar Drift, and cyclonic circulation (ccw) on Russian side

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.

What's causes the cyclonic mode of circulation?

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

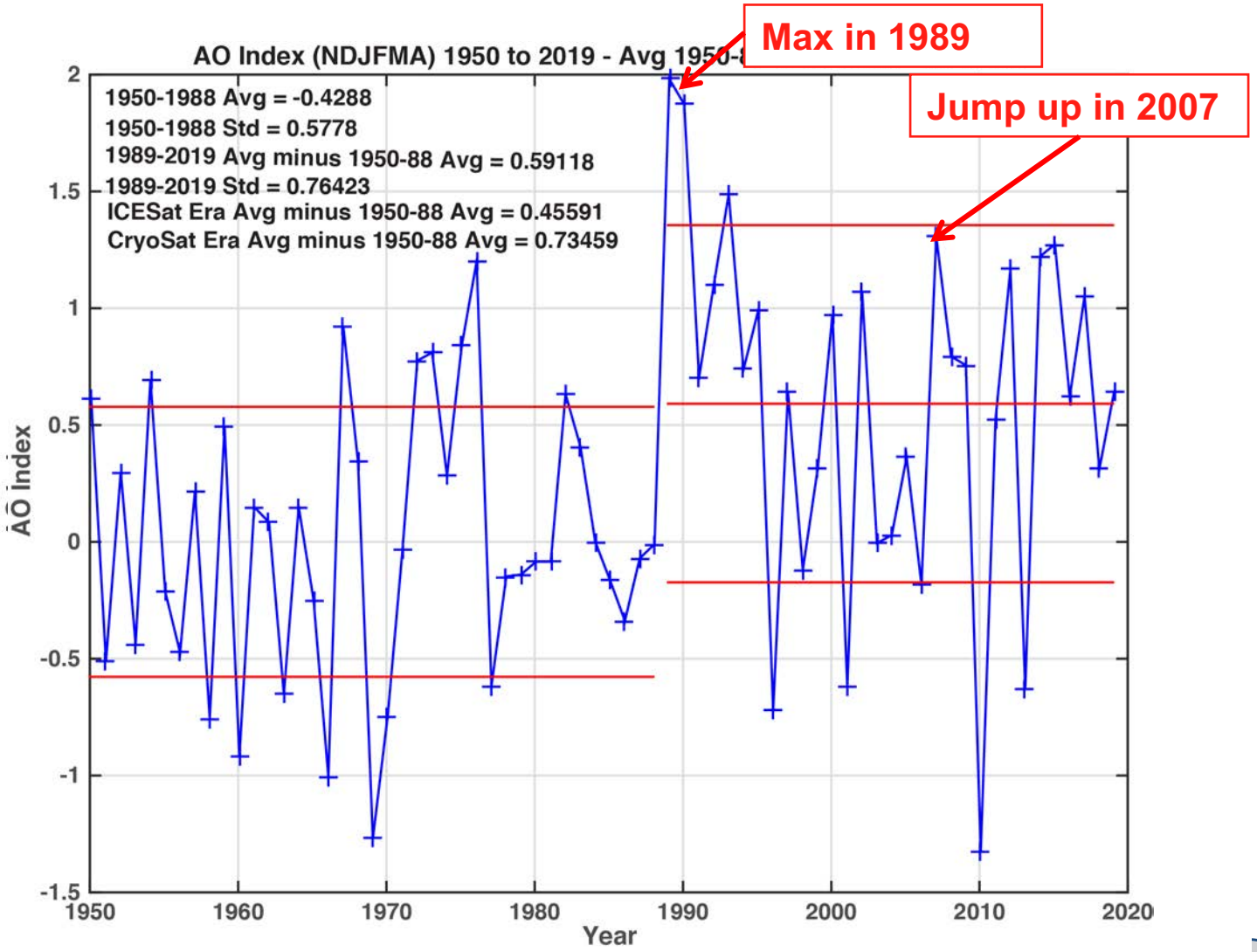
According to Z. M. Gudkovich the following factors determine the observed pattern of circulations: The prevailing wind conditions over the basin play the major role in its formation. Wind conditions are determined mainly by the presence and position of the trough of the Iceland low pressure area and 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.

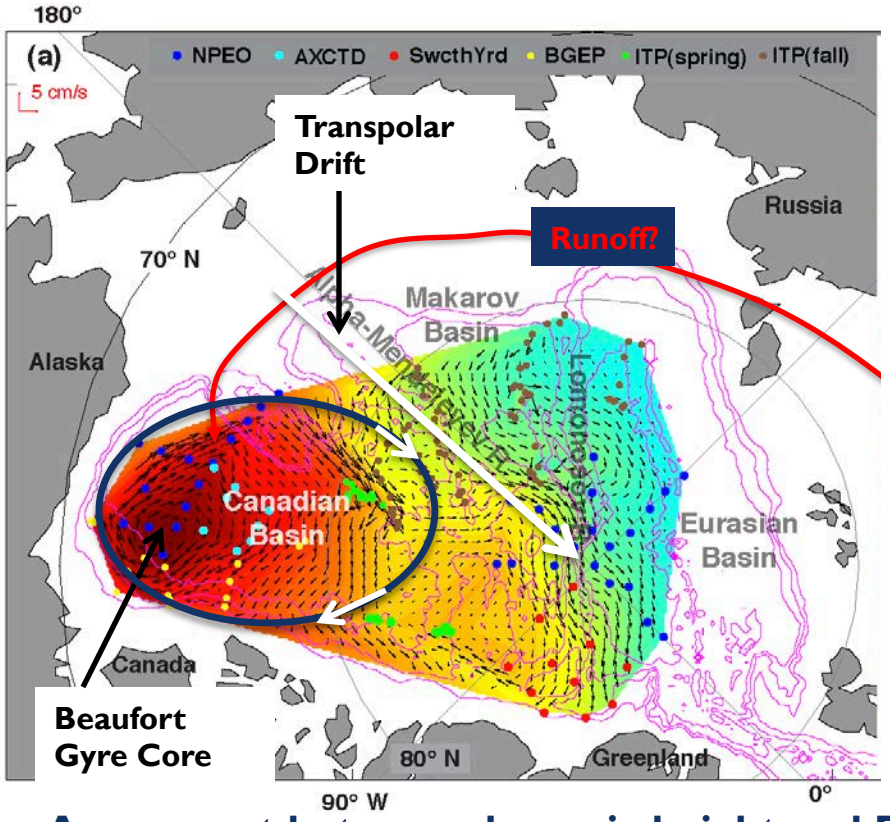
Cyclonic circulation in the early 1990s due to a positive shift in the AO.

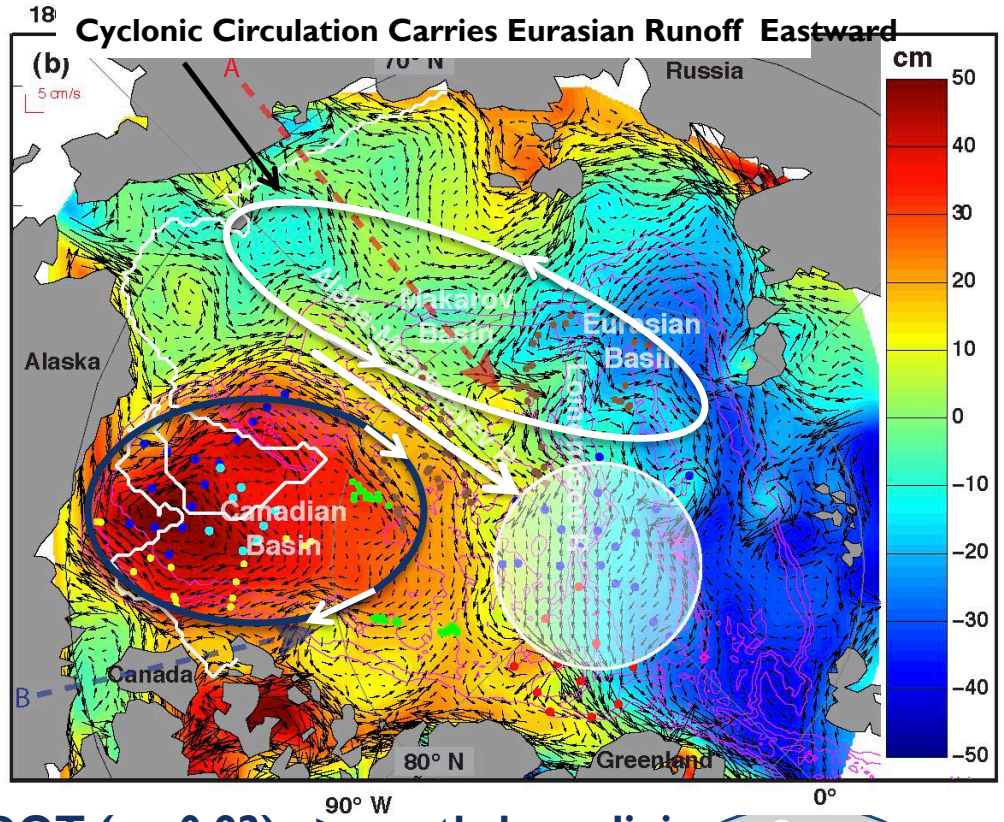


Expanding our View to See the Whole Arctic Ocean

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 invisible to surface obs.





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

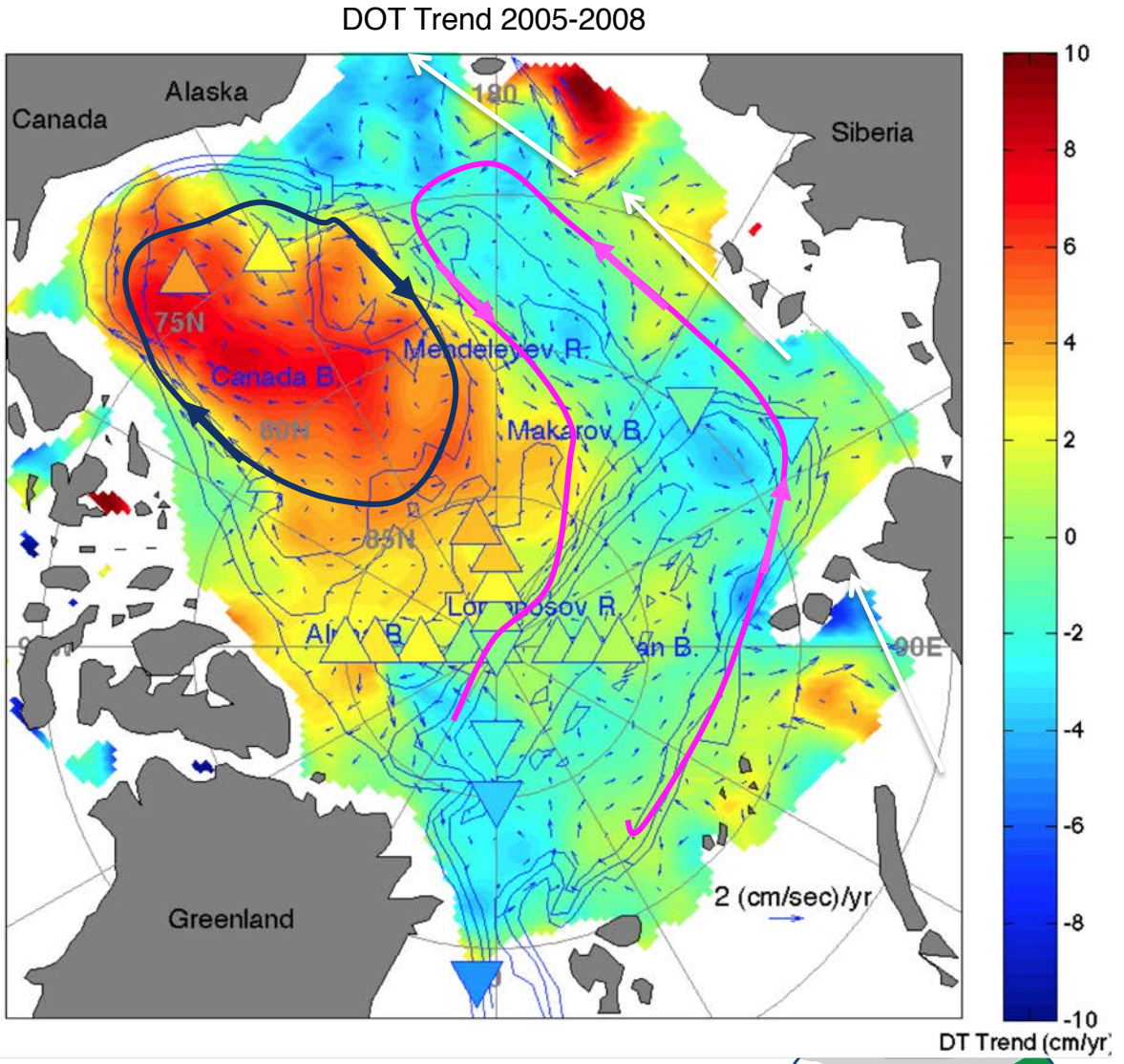
Kwok, R., and J. Morison (2011), Dynamic topography of the ice-covered Arctic Ocean from ICESat, *Geophysical Research Letters*, *38*(L02501), L02501.

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

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

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

Which carries more Eurasian runoff eastward to enter Beaufort Gyre.



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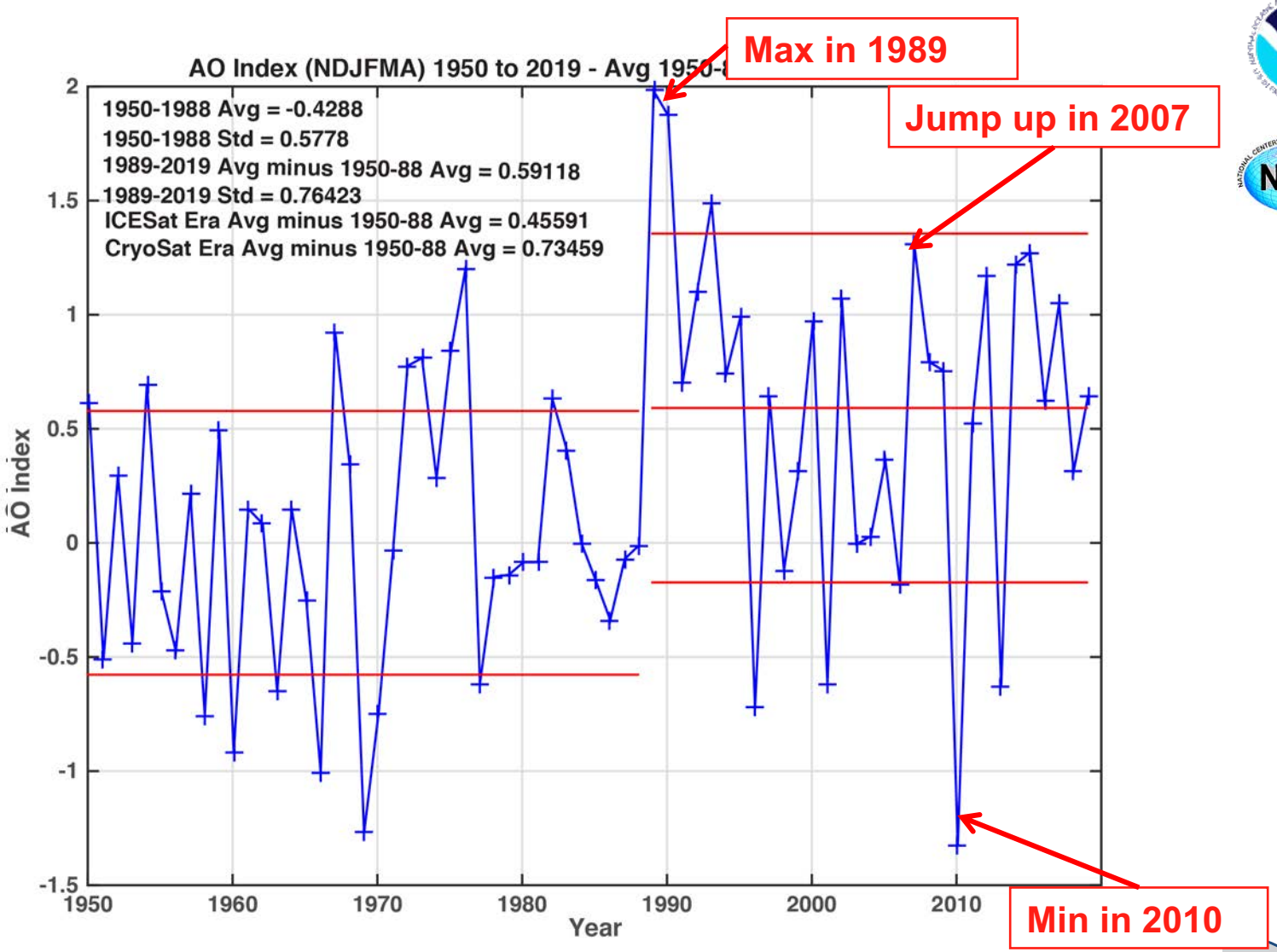
Persistence of Cyclonic Circulation Pattern due to Persistently Positive Winter AO

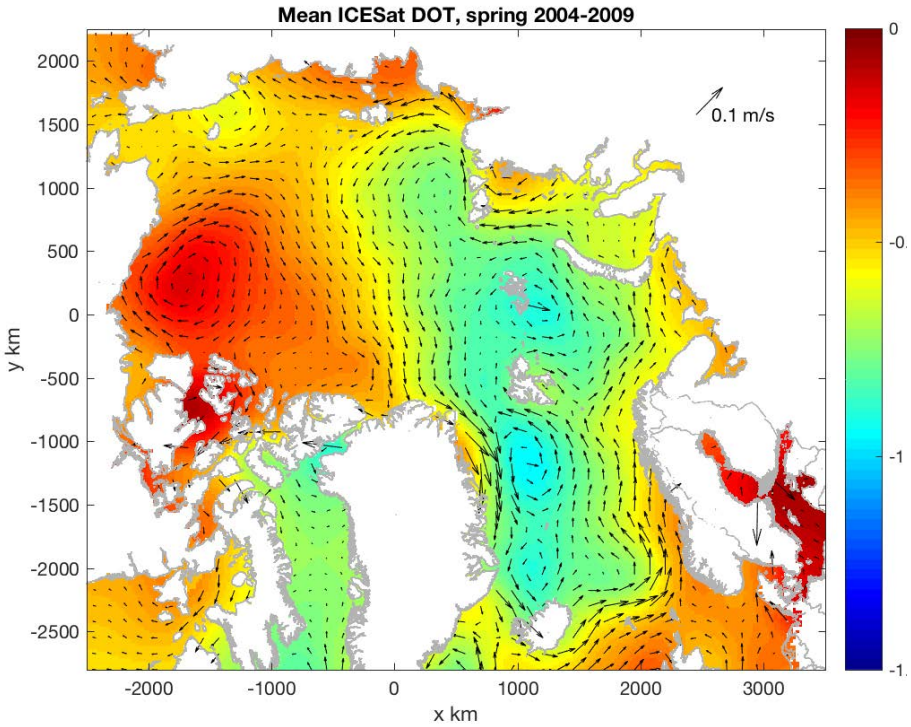


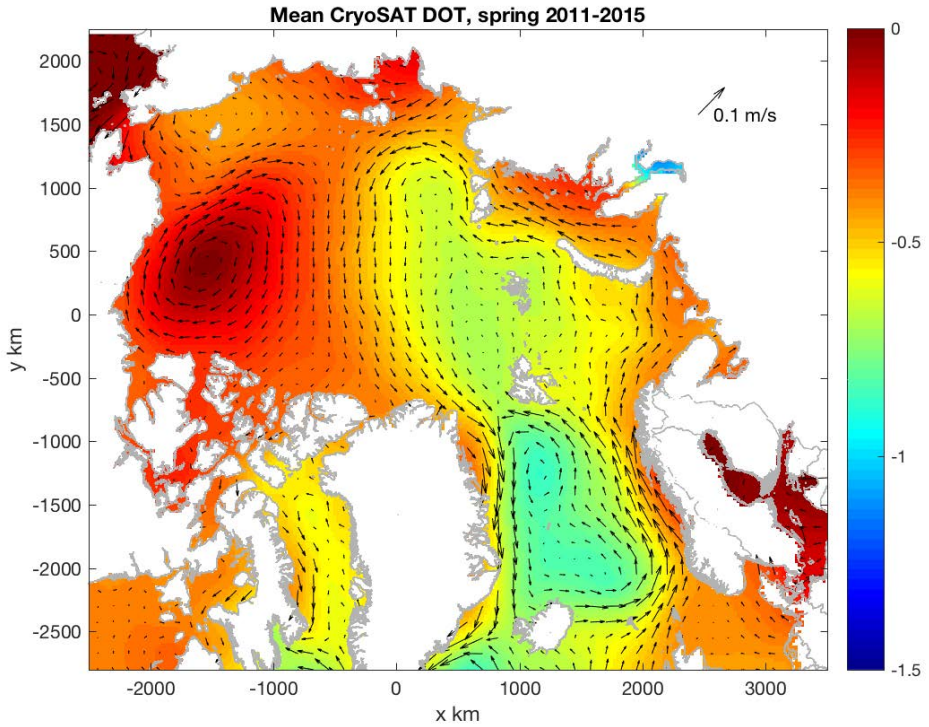
Ocean Conditions Bracketing the Record Minimum AO in 2010

2009
AO (= 0.7557)
Average ICESat DOT 2004-09 shows a strong cyclonic pattern with trough on Russian side of Canadian Basin

2010
AO = -1.3233

2011
AO (0.5262)
Average CryoSat DOT 2011-15 shows a strong anticyclonic pattern with no trough in the Canadian





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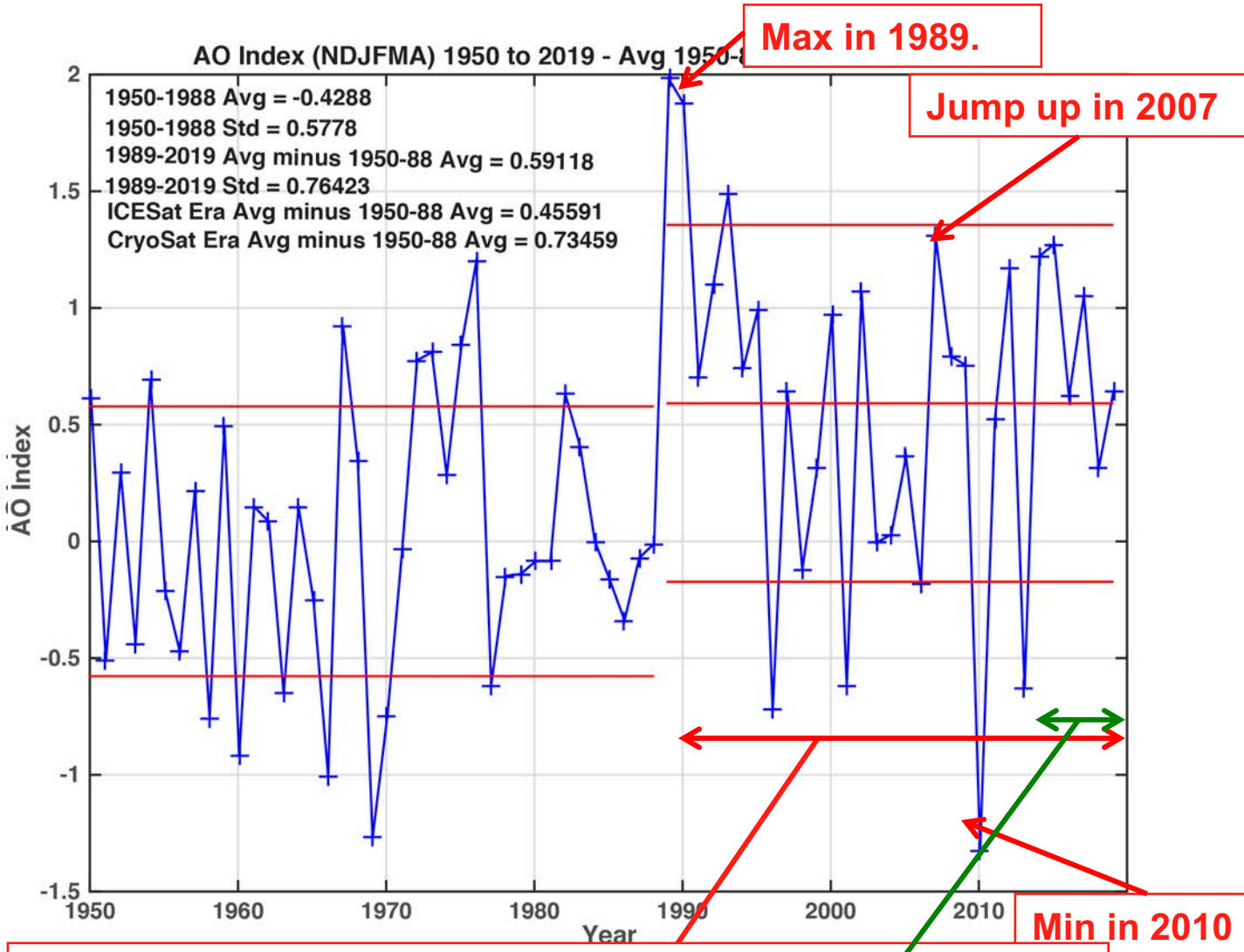


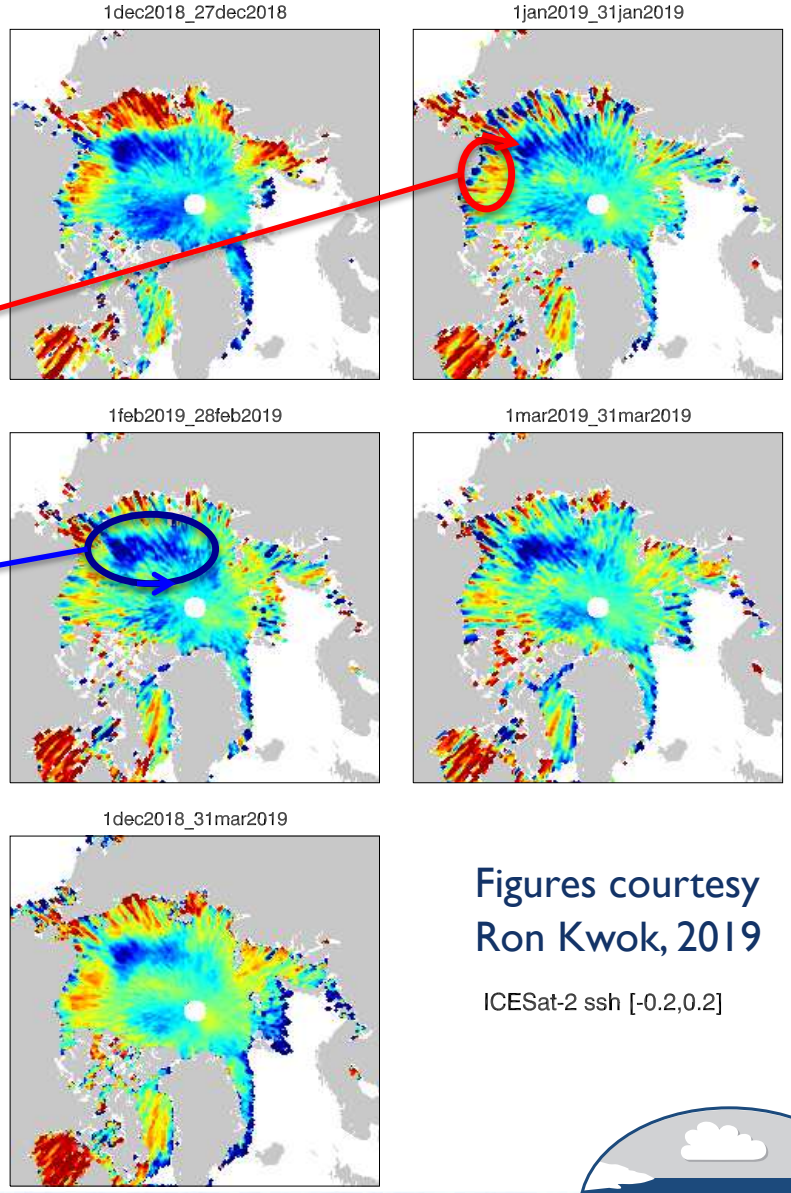
So after elevated winter AO for 30 years and particularly since 2014

What did DOT Look Like Dec 2018 – April 2019?

ICESat-2 SSH anomaly relative to the CyroSat-2 2011-2018 MSS

Shows +10 to 20 cm in the Southern Beaufort

but -20 cm on the Russian side of the Basin and Northern Beaufort is dominant
=>
Cyclonic Mode.



Figures courtesy
Ron Kwok, 2019

ICESat-2 ssh [-0.2,0.2]

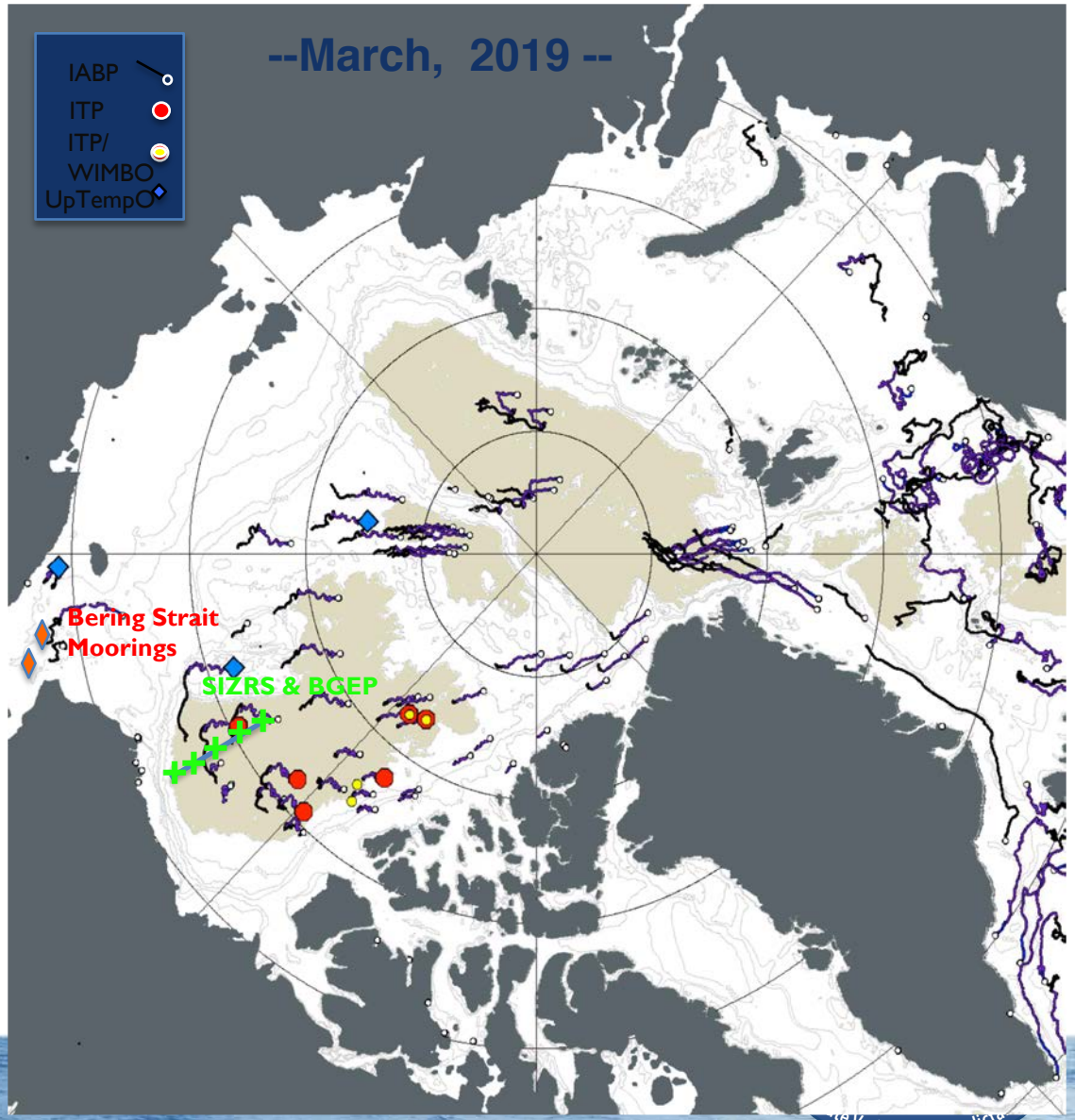
And after 3 decades of elevated AO, how is our *in situ* observing system set to observe the cyclonic mode of circulation?

Not well at all.

IABP surface drifters measuring atmos. P&T are in Beaufort and Transpolar Drift

Six ITP – CTDs capable of dynamic height measurement are all in the eastern Beaufort Sea

In 2018-2019 the cyclonic mode has been unobservable with these *in situ* observations



Why Does the Cyclonic Mode Matter?

Among other reasons:

Rising AO has been argued to be a characteristic of global warming. (This has seemed to hold with respect to winter AO since 1989).

Cyclonic mode arguably leads to more ice export from the Siberian shelf causing a negative correlation between summer ice extent and the previous winter AO [Rigor et al., 2002]

The cyclonic mode sends Eurasian runoff to the east, starving the cold halocline layer of fresh water and allowing Atlantic Water heat to reach the surface and melt the ice cover [Steele and Boyd, 1998]

In anticyclonic circulation Russian radioactive waste in the Barents and Kara seas and watersheds goes to Fram Strait and the Atlantic, but in cyclonic circulation such contaminants will go to the Beaufort Sea.

Challenges to Observing Circulation *In Situ*

Thwarting old-fashioned hydrography by over reliance on automated semi-Lagrangian drifting platforms that

- **Do not cross fronts**
- **Converge in anticyclonic circulation and diverge from cyclonic circulation, thereby spatially biasing sampling**

Difficulty accessing the Russian side of the Basin

Degradation of the ice cover making many kinds of traditional Sever-type air operations harder.

Answers

National/International/Agency commitment to repeat hydrographic observations and ideally sections as in Sever

Embrace of new techniques, e.g.,remote sensing, air-drop probes, autonomous vehicles

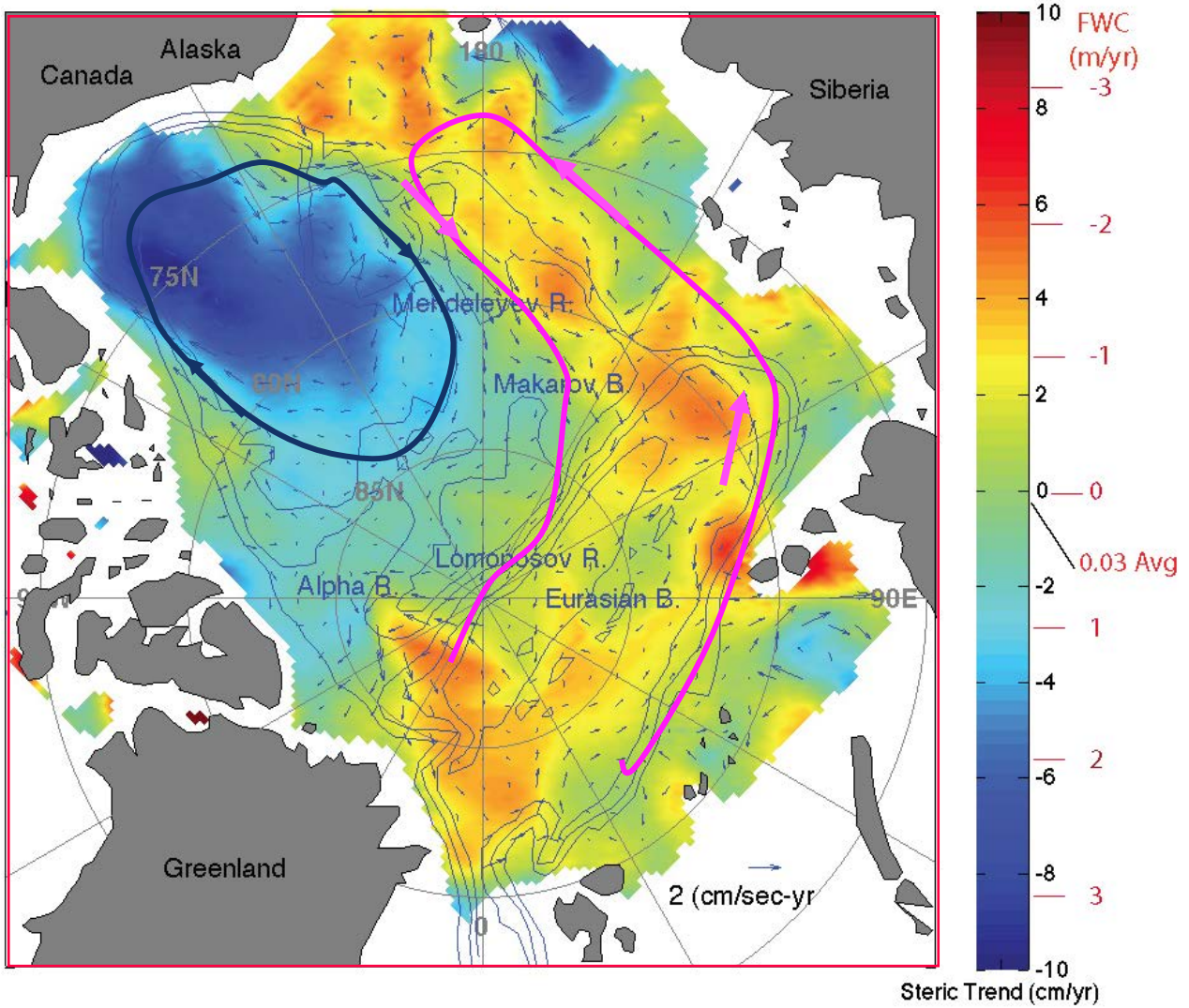
Thank You

2005-08 Steric Pressure Trend (GRACE OBP - ICESat DOT) & Freshwater Trend ~ -36 x Steric Pressure Trend

FWC increase in the Beaufort Sea is balanced by decreases almost everywhere else.

Average change in FWC in deep basin (> 500m) inferred from GRACE OBP and ICESat DOT is small, (0.18 m yr^{-1}) compared to the inter-basin changes due to a shift in freshwater trajectory but similar to *Rabe et al.* [2011] (0.18 m yr^{-1}) and to reduction in average resident sea ice mass (0.17 m yr^{-1}).

Steric Pressure and FWC Trend 2005-2008



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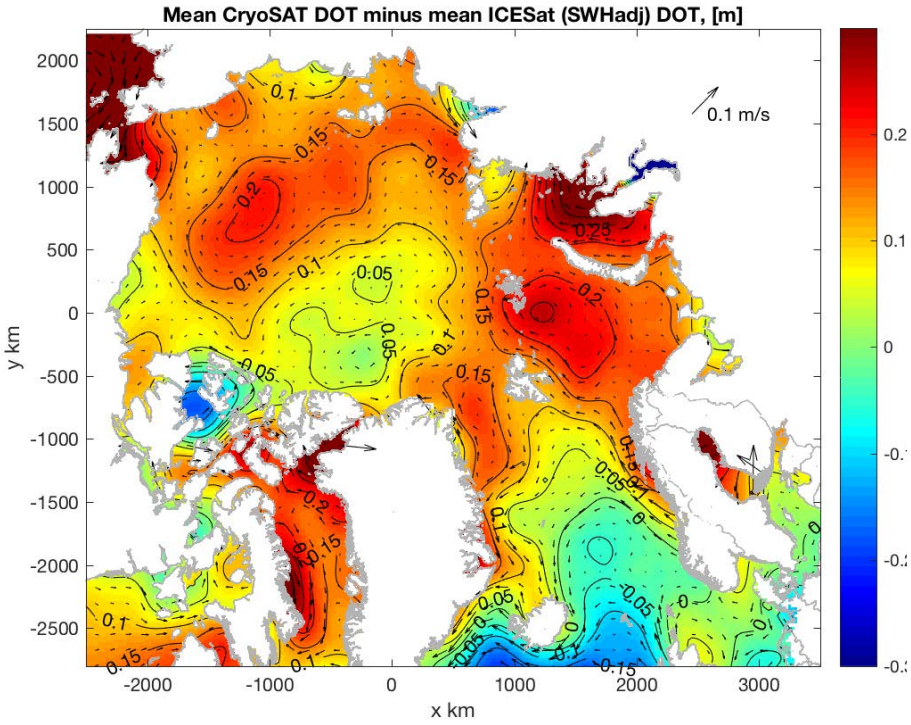
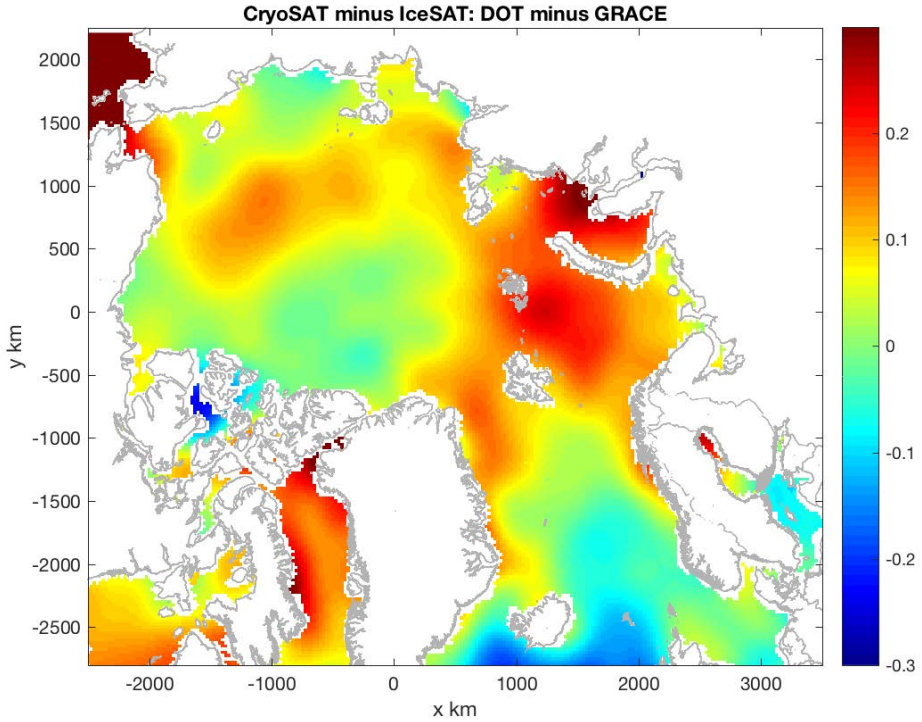
Changes in DOT and DH+OBP Between the ICESat and CryoSat2 Periods

2011 DOT from CryoSat minus 2009 DOT from ICESat shows increase along Russian side, opposite of 2007 change

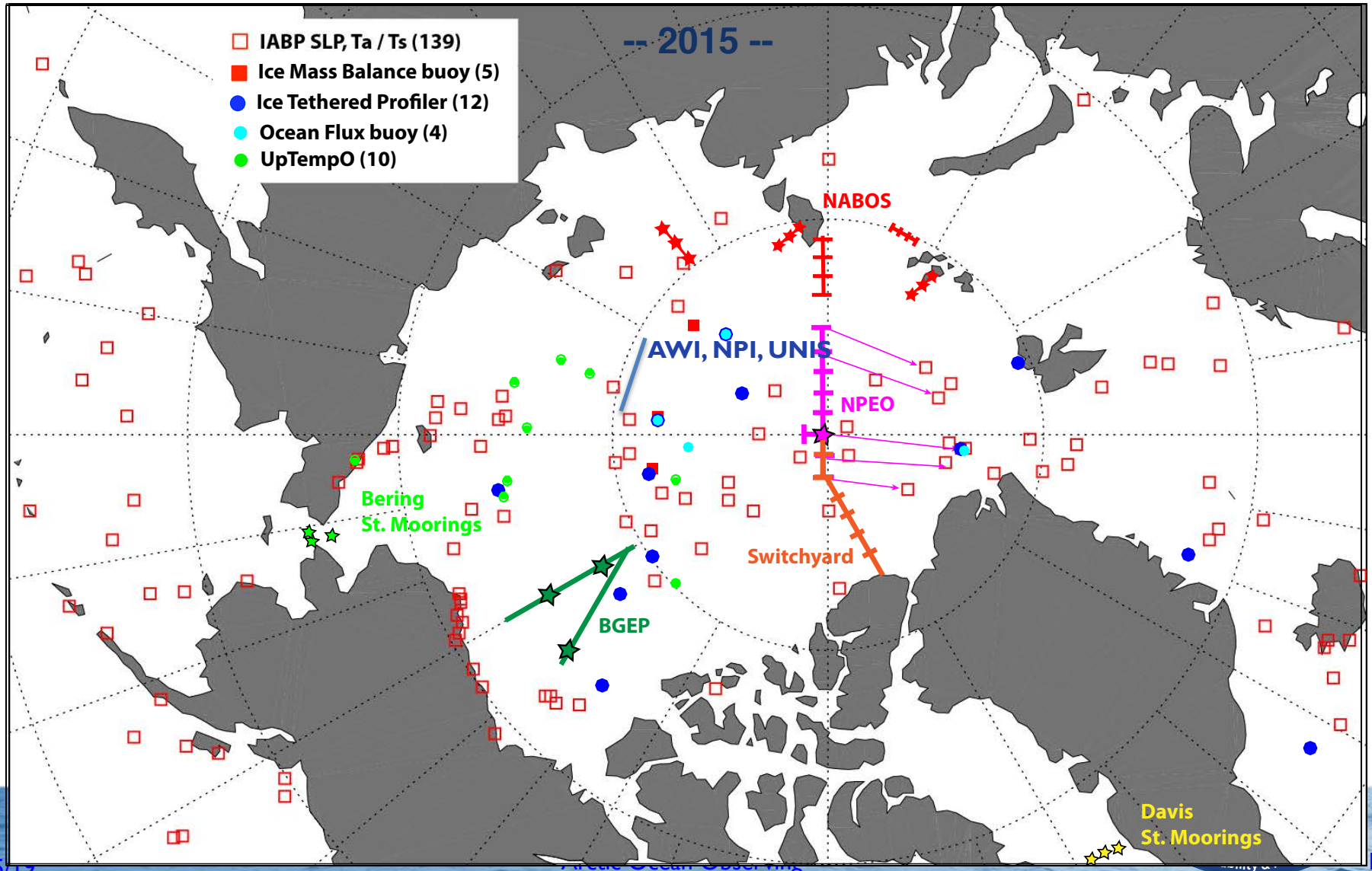
(The difference of DH+OBP from the same EWCT between 2009 and 2011 also shows increase along Russian coast, opposite the 2007 change)





So after 3 decades of elevated AO, how is our in situ observing system set to observe the cyclonic mode of circulation?

In 2015 at least NABOS and NPEO made some repeat hydrography and chemistry measurements in east longitudes.

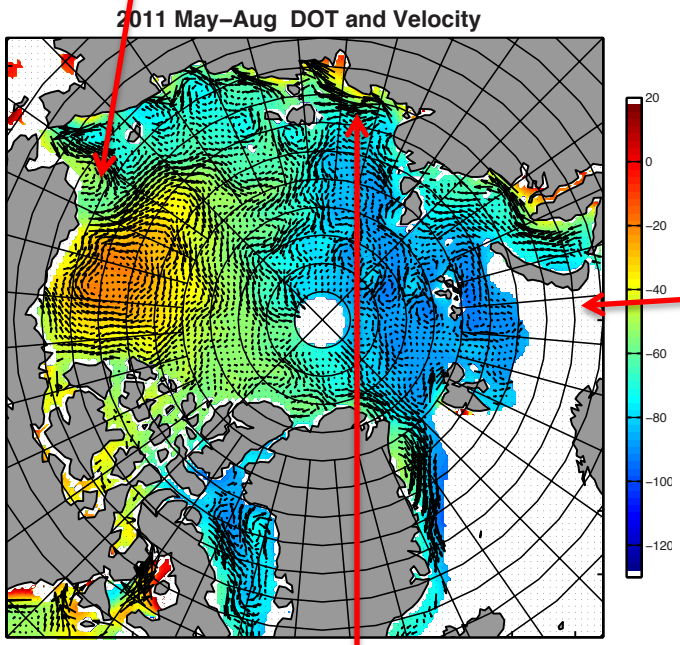


High AO, Cyclonic Circulation, and Russian Radionuclides

In the early '90s ONR's ANWAP explored the fate of Russian radioactive waste in the Barents and Kara seas and watersheds. In anticyclonic circulation, these would go to the North Atlantic.

To end up in Alaskan waters here

Which leads to more of what leaks out of wrecks like this



K-159 which sunk in the eastern Barents with 800 kilograms of spent uranium fuel aboard

But arguably, global warming leads to increased AO, which leads to a cyclonic pattern and more flow along the Russian coast.