Arctic Ocean circulation patterns using GRACE

A. Cecilia Peralta Ferriz
Polar Science Center, Applied Physics Lab.,
University of Washington

In collaboration with:
UW: James H. Morison, Jinlun Zhang, John M. Wallace
USF: Don Chambers and Jennifer Bonin

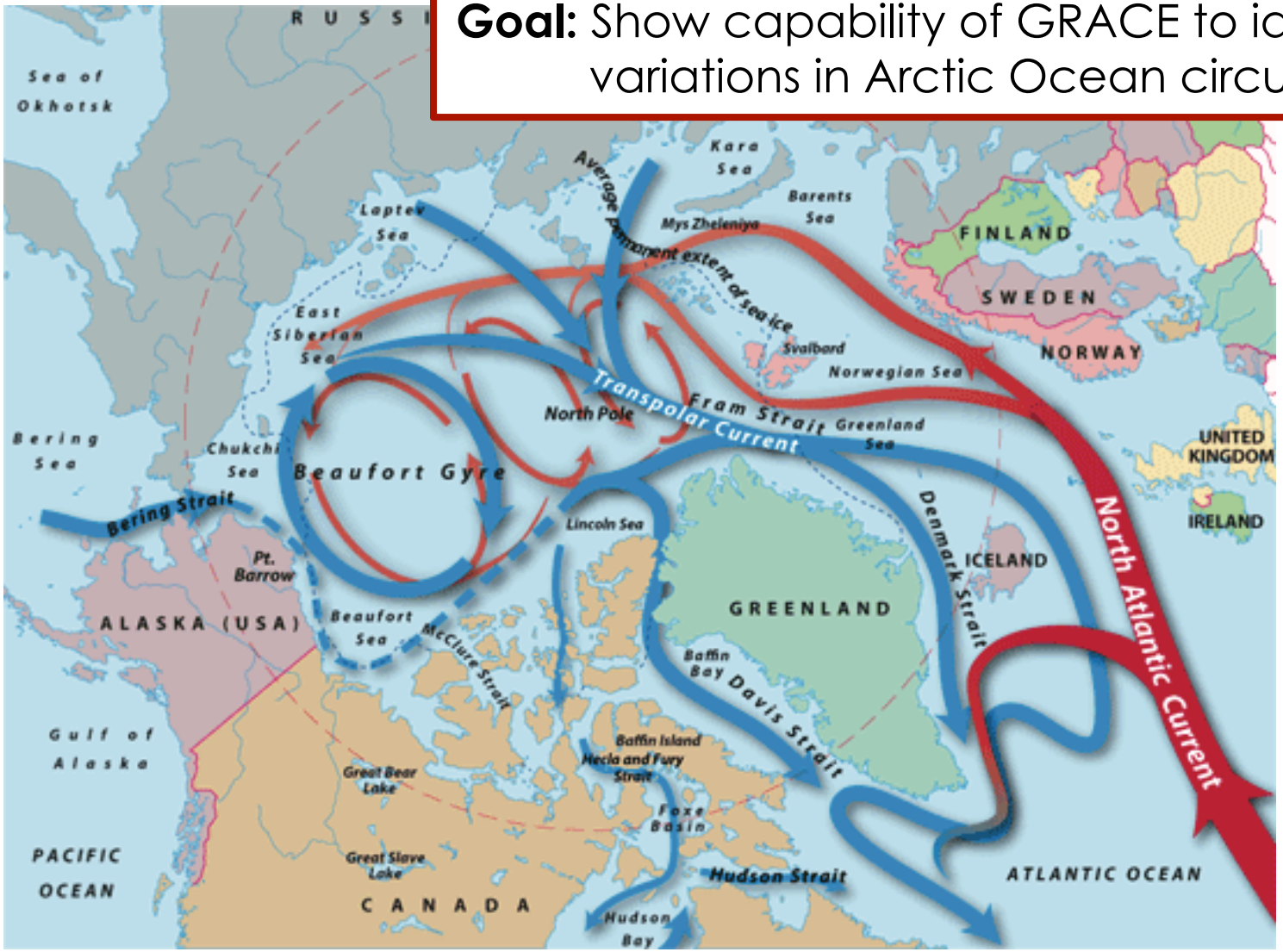
AOMIP/FAMOS, WHOI, October 22-26, 2012

mean Arctic Ocean circulation

http://www.whoi.edu/

mean Arctic Ocean circulation

Goal: Show capability of GRACE to identify variations in Arctic Ocean circulation



http://www.whoi.edu/

ocean bottom pressure (OBP)

OBP

$$P_b'(t) = g\int_{-H}^{\eta'(t)} \rho'(z,t)dz + P_a'(t) = g\int_{-H}^{0} \rho'(z,t)dz + \rho_o g\eta'(t) + \overline{P_a}'(t)$$

[*Ponte, 1999*]

oceanic mass

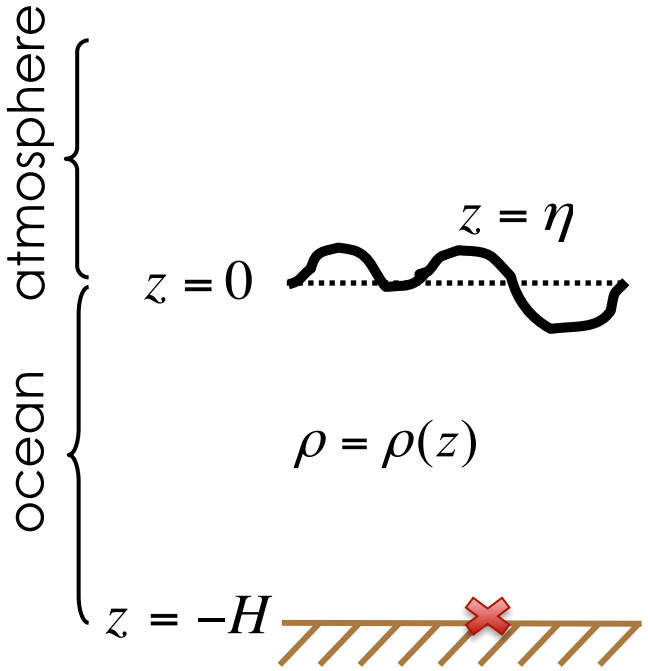
atmospheric mass

Density, Steric pressure,
P'_{steric} = - steric height

Sea surface height, SSH,
inverted-barometer adjusted

Atmos averaged over oceans

No ocean dynamics



$$\eta'_{steric}(t) = -\frac{1}{\rho_o}\int_{-H}^{0} \rho'(z,t)dz = -\frac{P'_{steric}(t)}{\rho_o g}$$

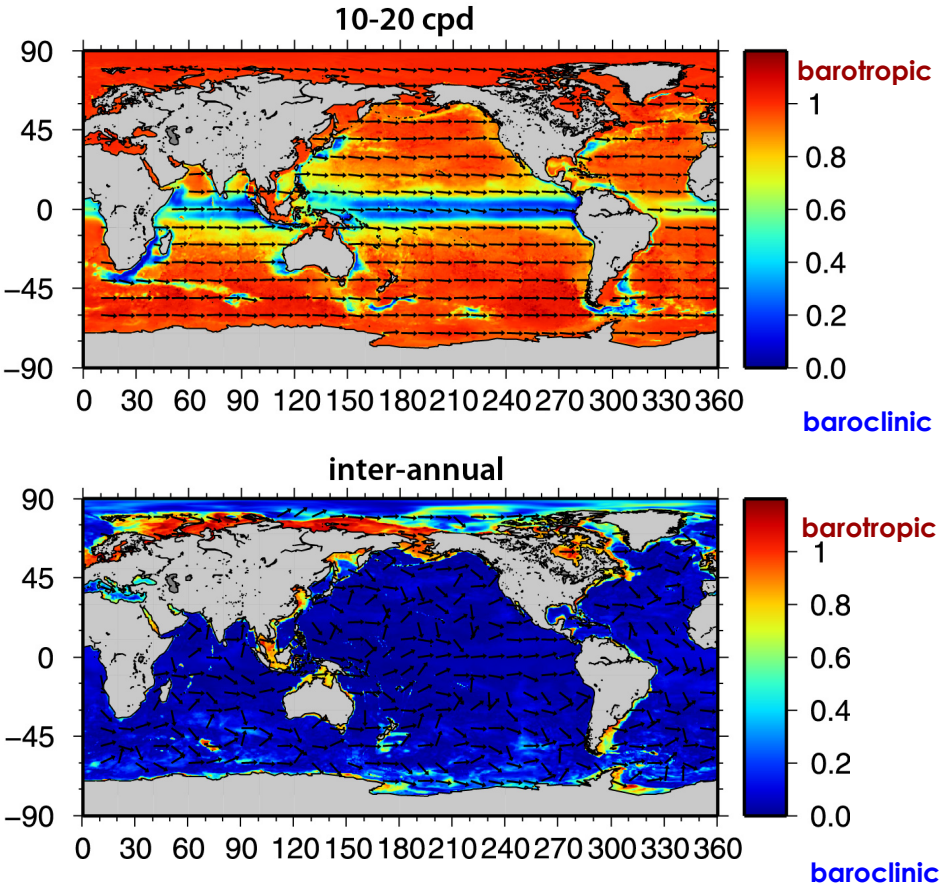
[*Gill and Niiler, 1973; Landerer et al., 2007*]

OBP units:

1 mbar or 1 hPa → 1 cm

timescale dependence (previous work)

Model-based



Admittance amplitude and phase between sea level (SSH) and bottom pressure (OBP) anomalies.

[*Bingham and Hughes*, 2008]

At hourly timescales, Arctic Ocean is barotropic

At inter-annual scales, Arctic is barotropic only on the shelves

Observation-based

At inter-annual scales, Arctic basin (deep) tends to adjust baroclinically

[*Morison et al.*, 2012]

objective

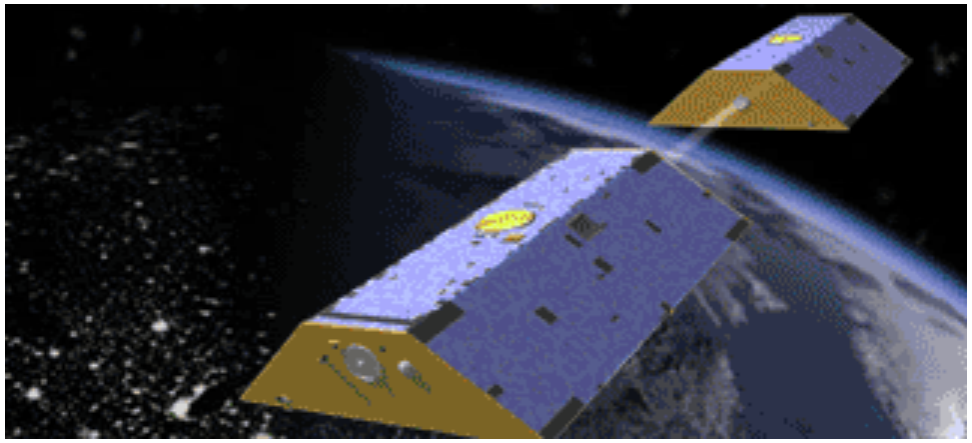
Identify temporal and spatial patterns of Arctic Ocean circulation at monthly to longer timescales

1. What processes control OBP variations in the Arctic?

2. Where/when are OBP variations dominated by changes in SSH?

data and model output

GRACE: Gravity Recovery and Climate Experiment



http://grace.jpl.nasa.gov/

- U. of Texas, CSR, Release 4
- Processed by J. Bonin and D. Chambers [2012, submitted to *Geophys. J. Intl.*]
- Monthly OBP observations

Ocean models

PIOMAS (UW)

Pan-Arctic Ice Ocean Modeling Assimilation System

[*Zhang and Rothrock*, 2003]

- 30 vertical levels
- Horizontal resolution ~22 km
- Forced with NCEP/NCAR

ECCO2 (JPL)

Estimating the Circulation and Climate of the Ocean, Phase II Project

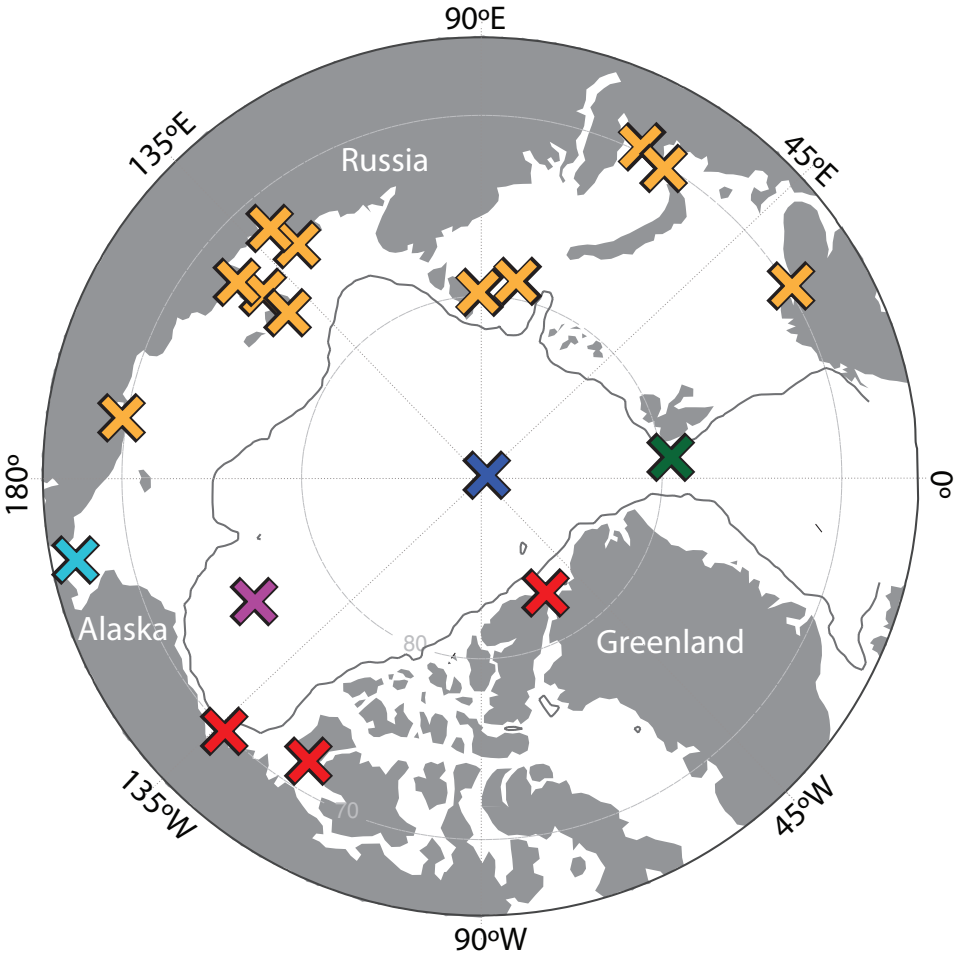
[*Nguyen, et al.*, 2011]

- 50 vertical levels
- Horizontal resolution ~18 km
- Forced with JRA-25

in situ data

18 tide and pressure gauges

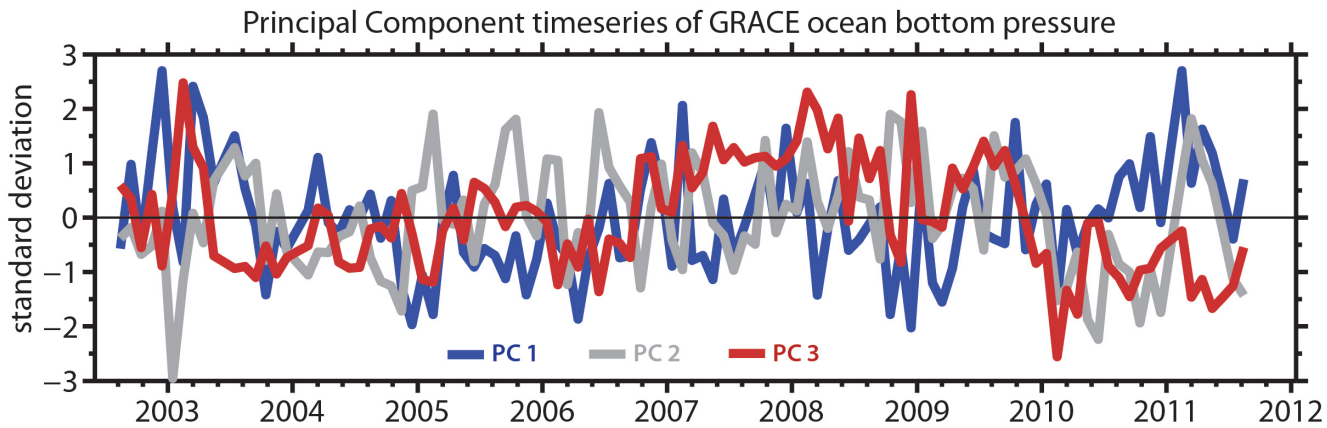
- ABPR, North Pole (NPEO)
- BPR, Beaufort Sea (BGEP)
- BPR, Bering Strait (RUSALCA)
- TG, Fisheries and Oceans, Canada
- PIES, Fram Strait (AWI)
- TG, Russian (AARI), through PSMSL at Nat. Oceanography Centre, UK

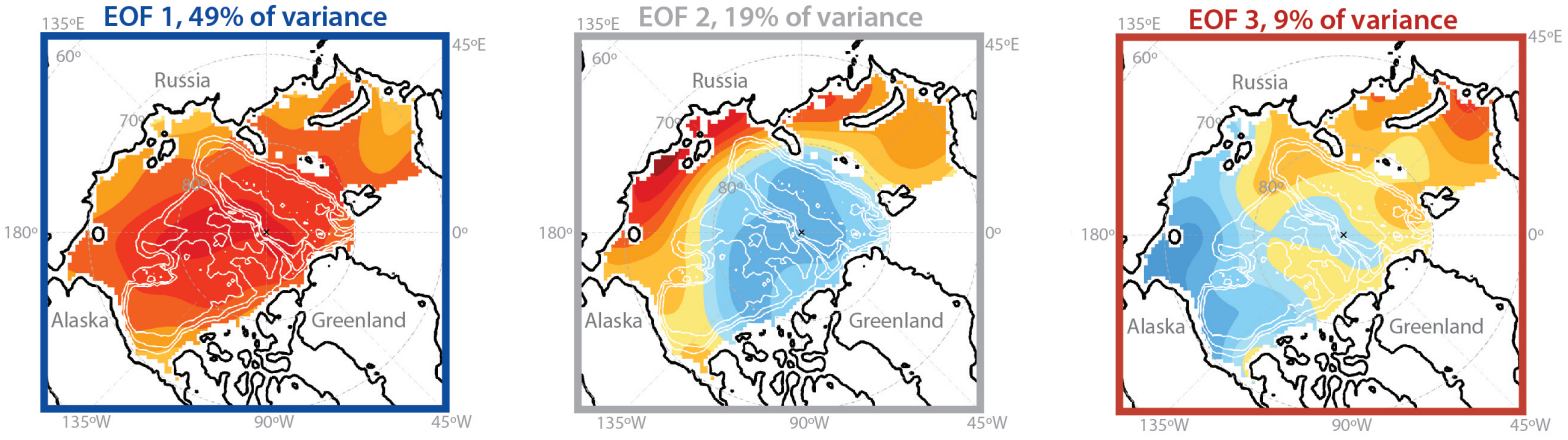


Thank you so much!!

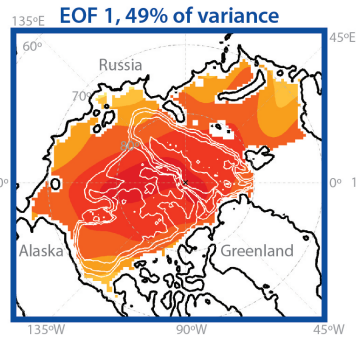
temporal-spatial modes of variability

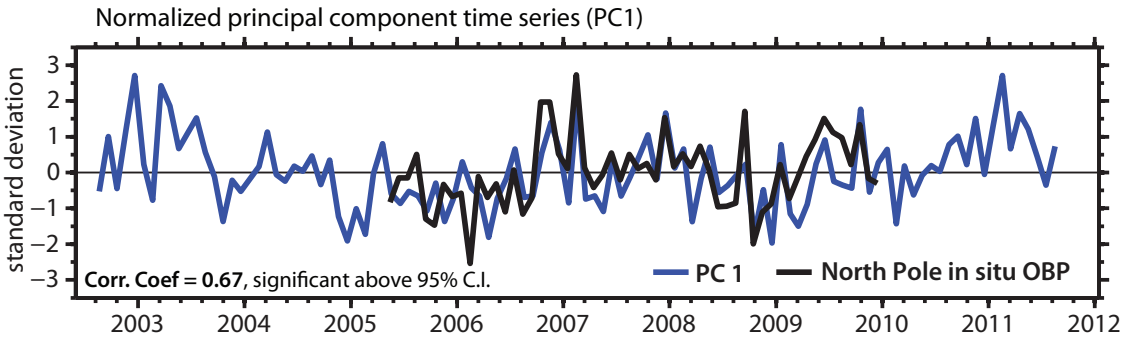
- **EOFs of GRACE OBP. Mean seasonal variation and long term trend removed. There are 3 significant, independent modes.**



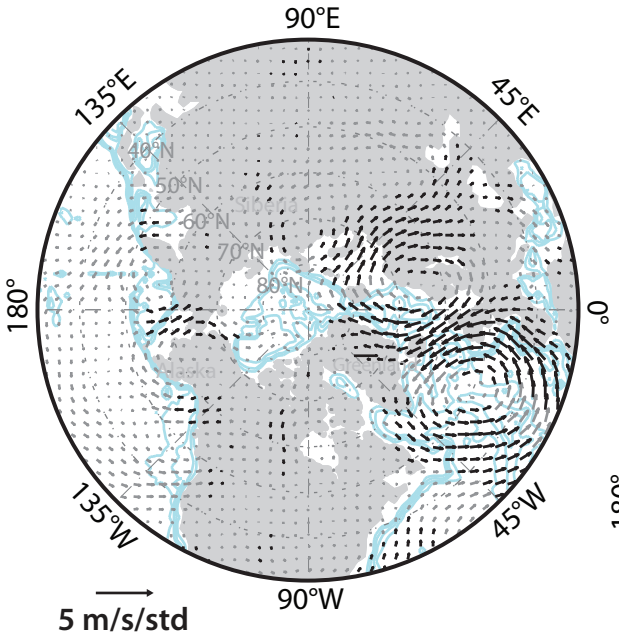


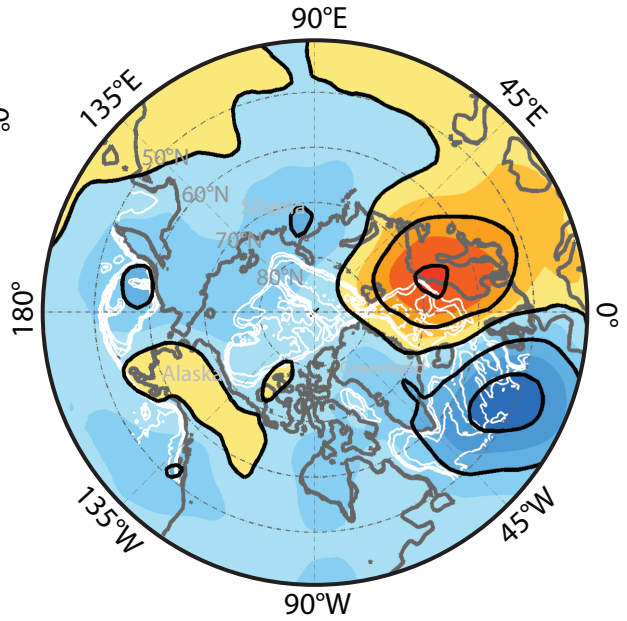
Mode 1: basin-wide OBP change

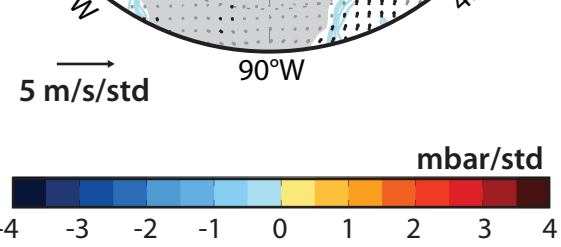




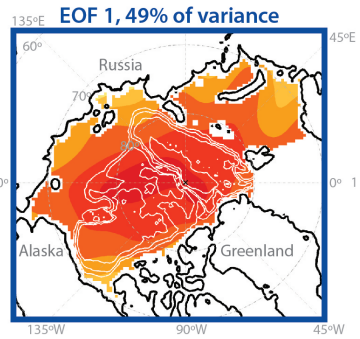
NCEP/NCAR winds (925 hPa) and SLP projected on PC1.

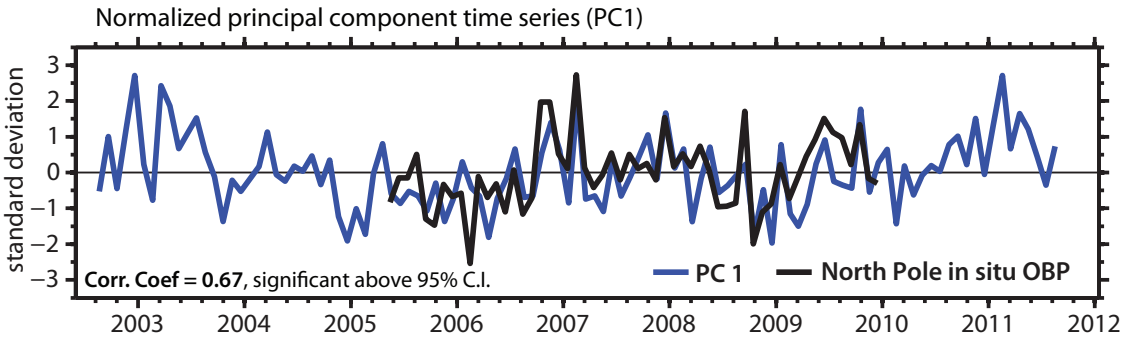


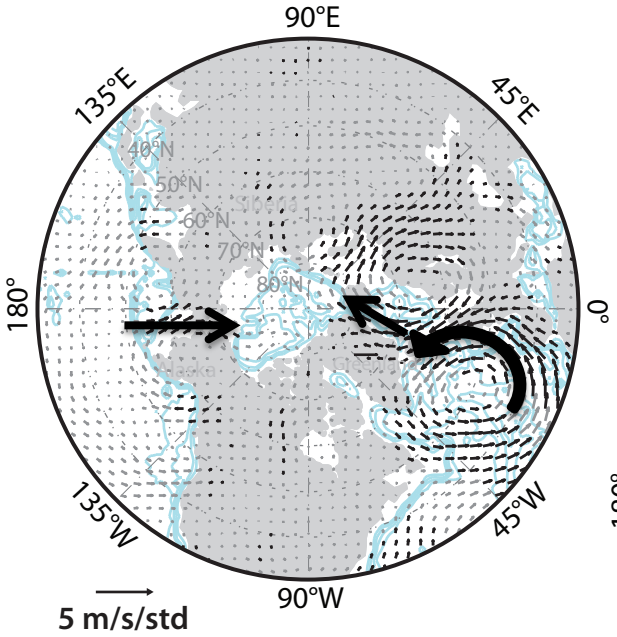




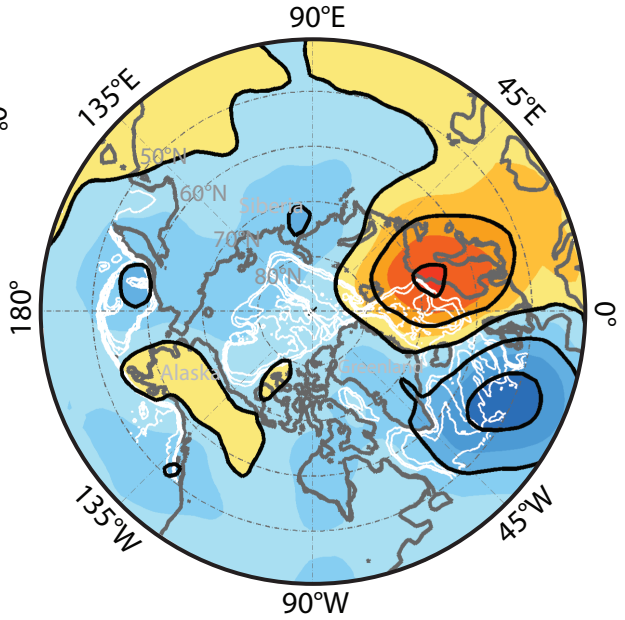
Mode 1: basin-wide OBP change







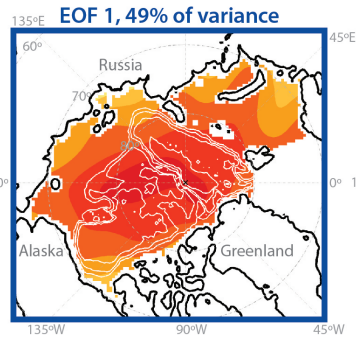
NCEP/NCAR winds (925 hPa) and SLP projected on PC1.

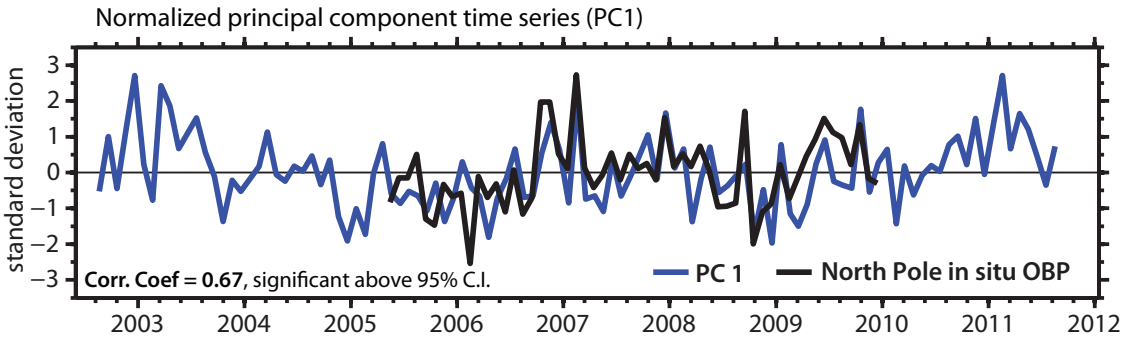


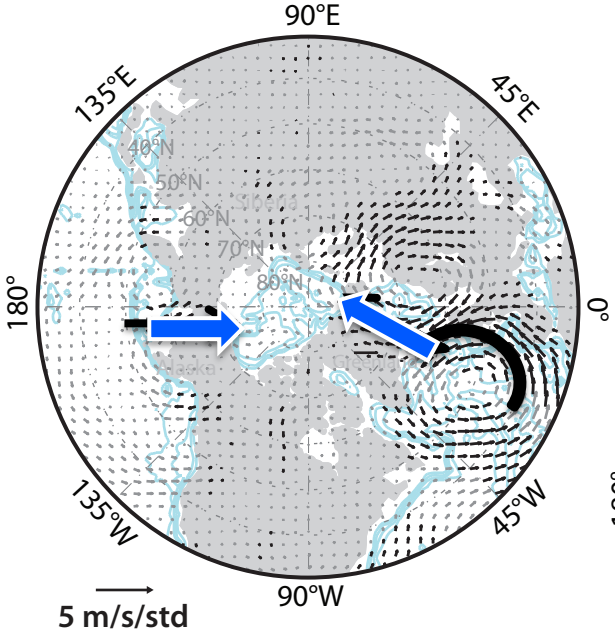
FORCING:

Northward component of the winds over the Arctic gateways.

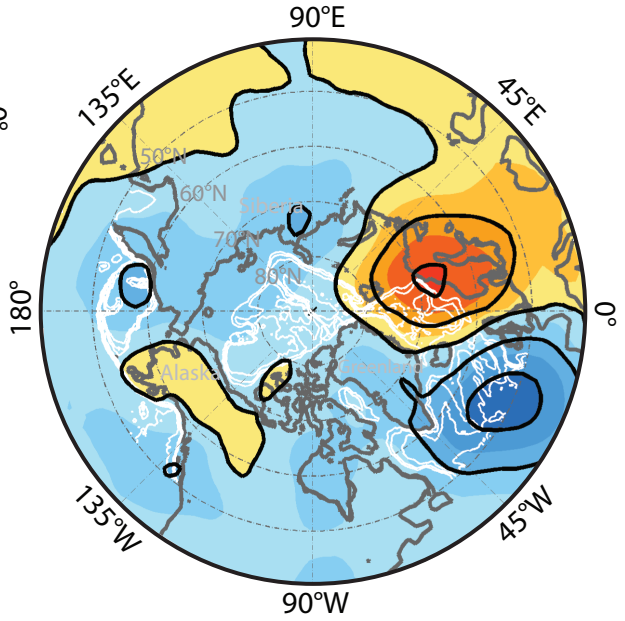
Mode 1: basin-wide OBP change







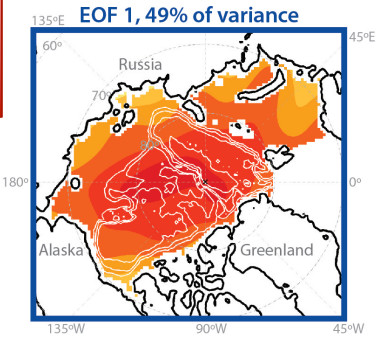
NCEP/NCAR winds (925 hPa) and SLP projected on PC1.

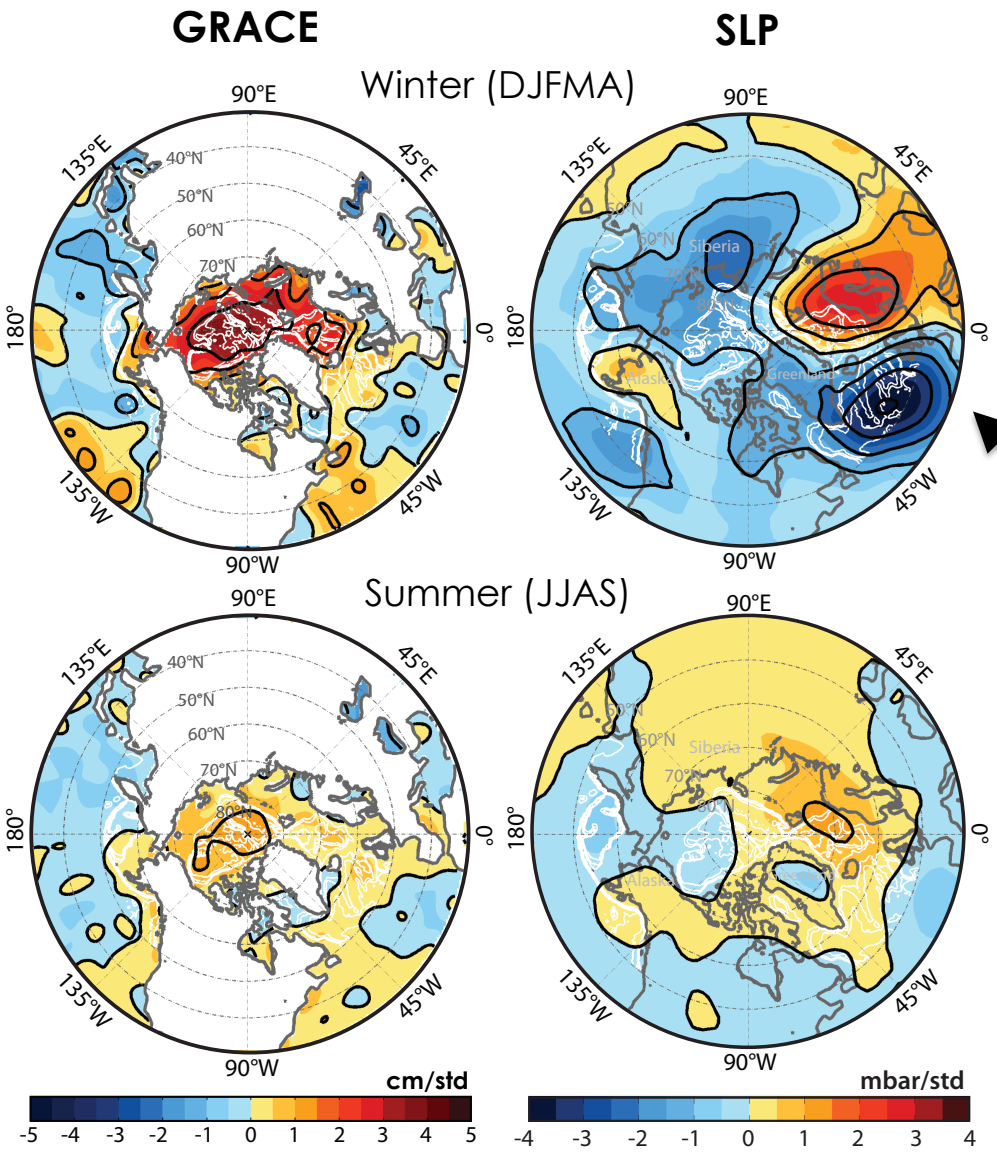


FORCING:
Northward component of the winds over the Arctic gateways.

PROCESS:
Geostrophic slope current through the straits.

Mode 1: seasonal forcing

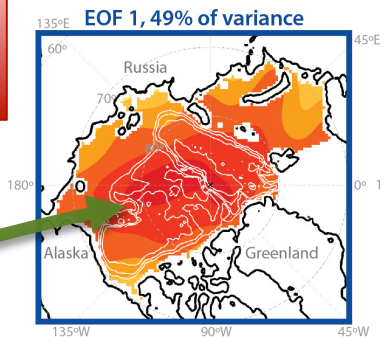




Regression maps of GRACE OBP and SLP on PC1.

OBP mode 1: forced by winter dynamics

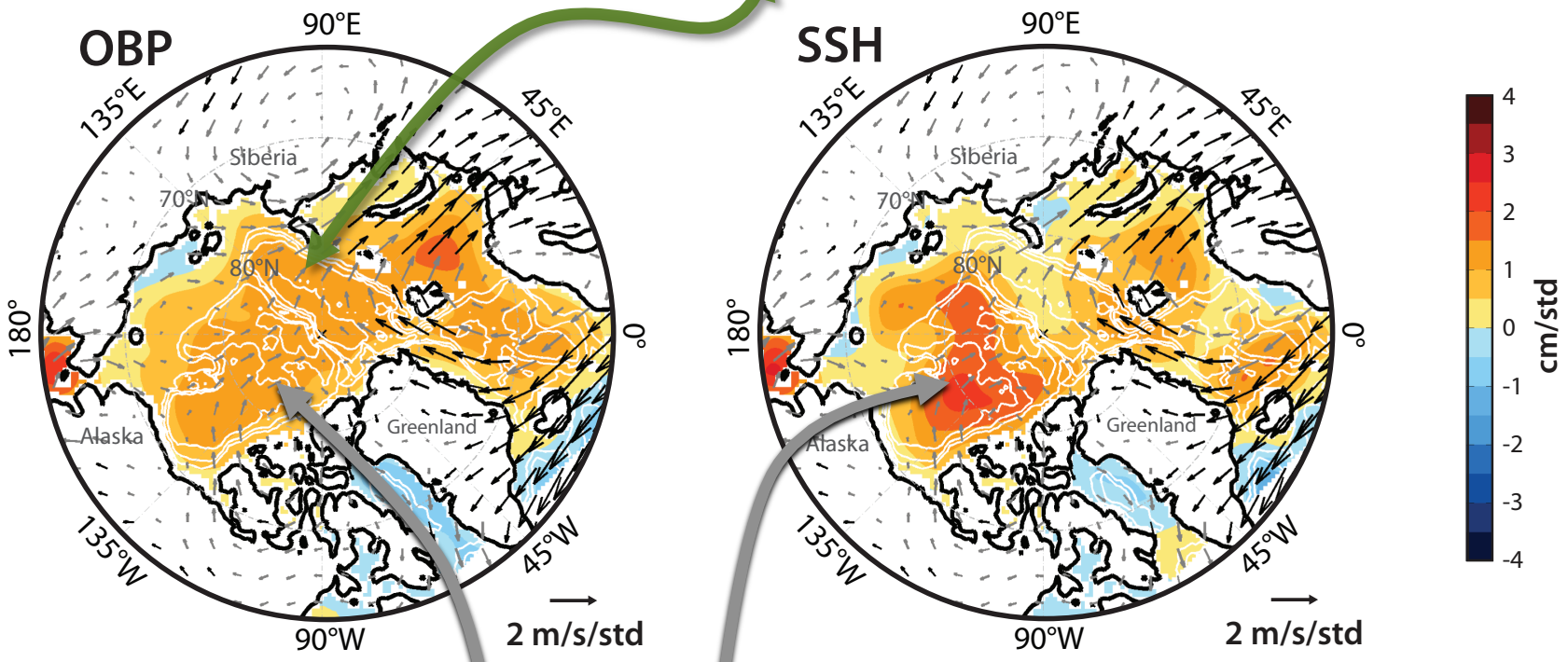
Mode 1: modeled OBP and SSH



Modeled OBP and SSH regressed on **winter** GRACE PC1

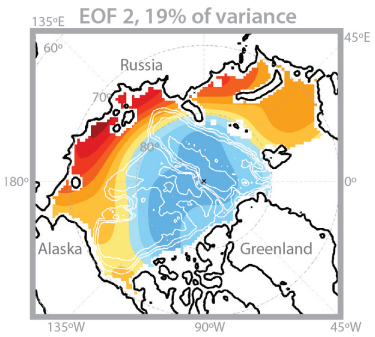
Model captures observed basin-coherent OBP change

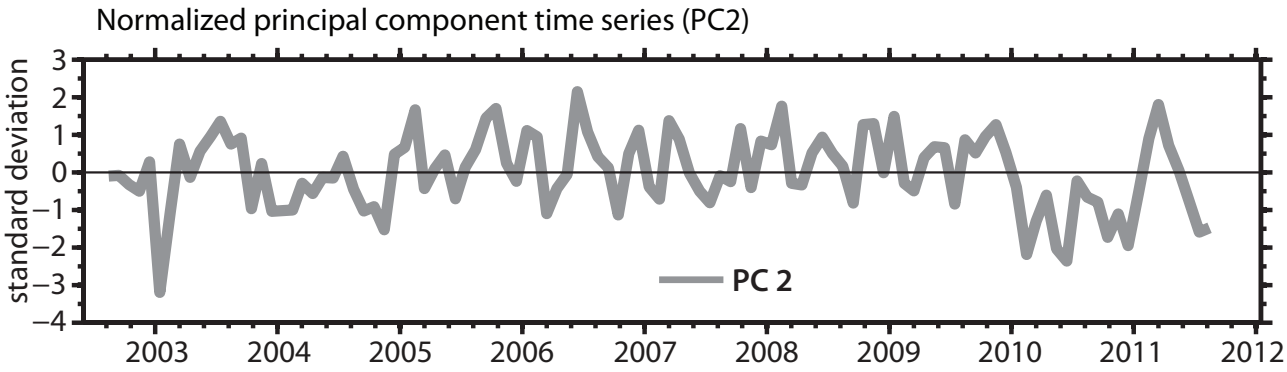
Modeled OBP underestimates observed OBP.



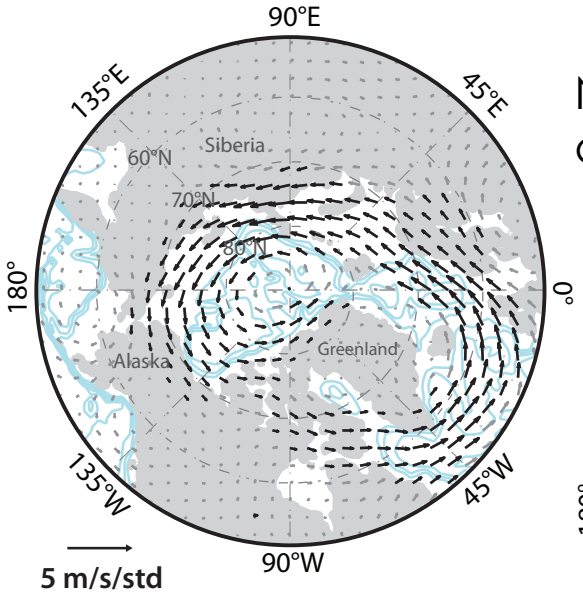
OBP ≠ SSH → Modeled SSH is partially compensated by steric pressure change.

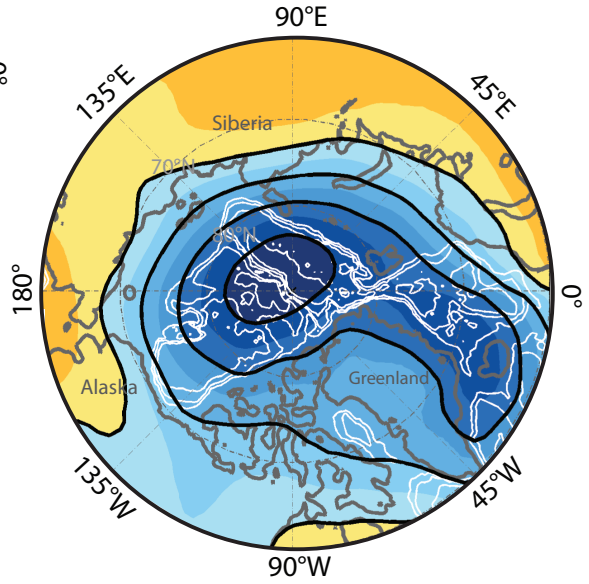
Mode 2: Siberian shelves

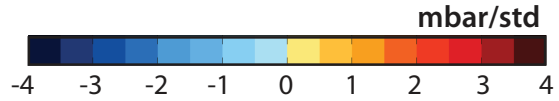




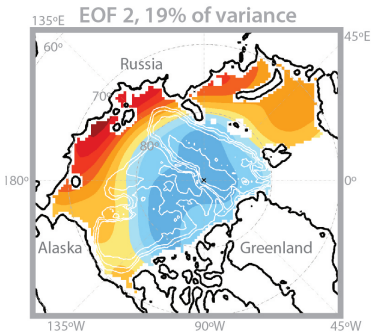
NCEP/NCAR winds (925hPa) and SLP regressed on PC2.

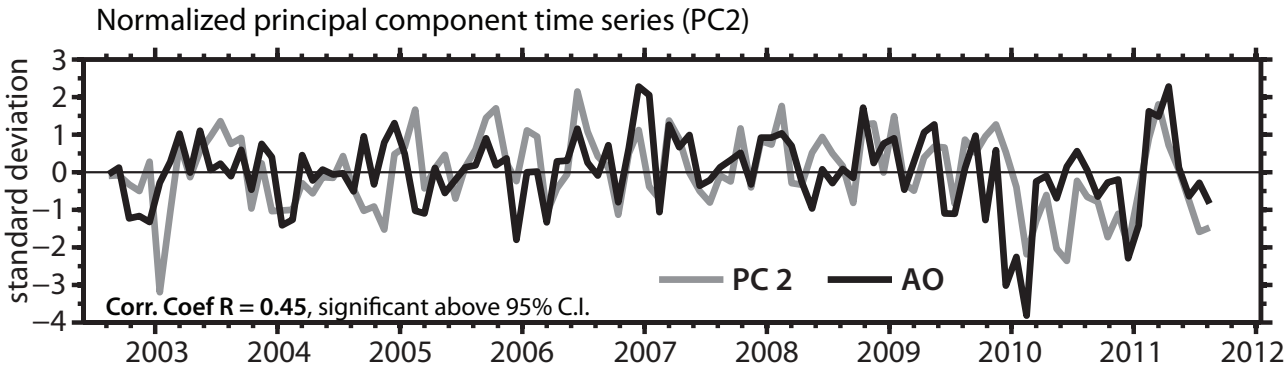




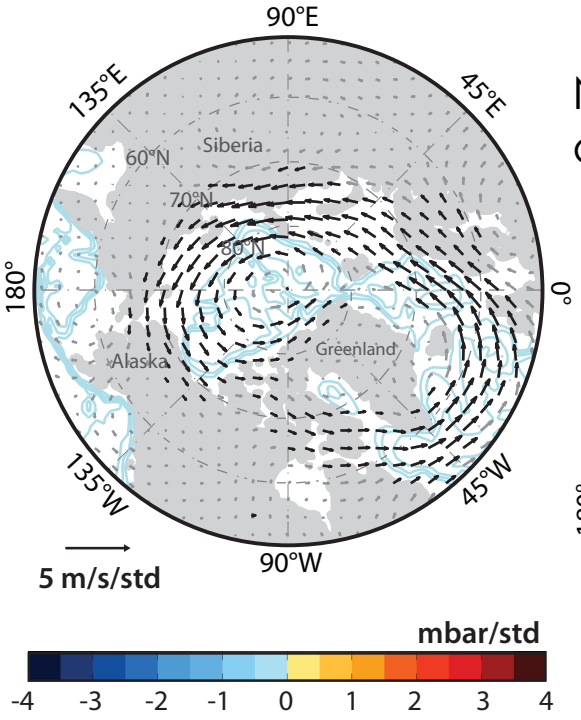


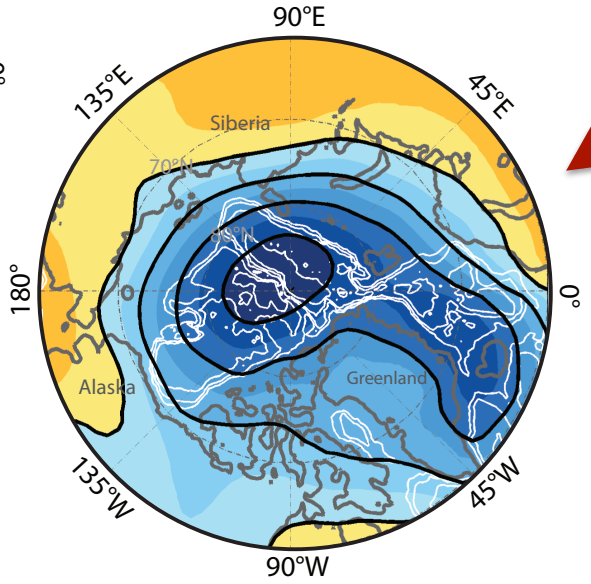
Mode 2: Siberian shelves





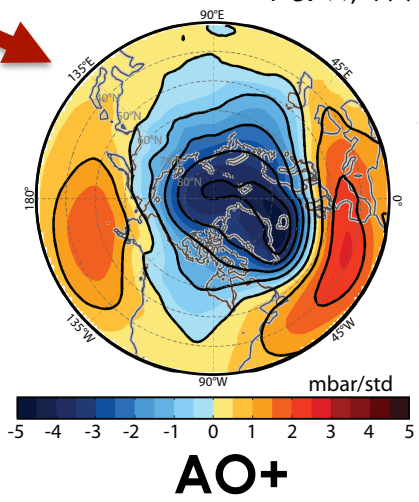
NCEP/NCAR winds (925 hPa) and SLP regressed on PC2.





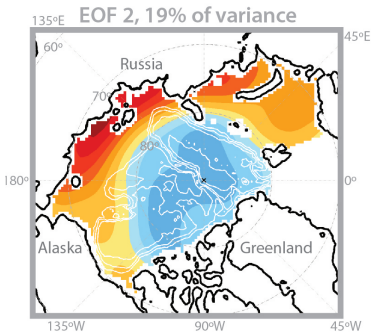
Forcing resembles the Arctic Oscillation!!

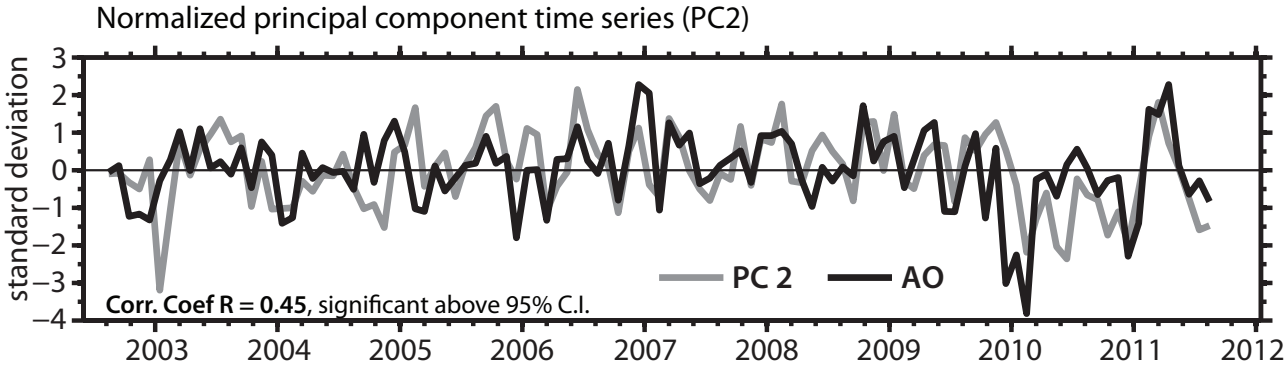
T & W, 1998

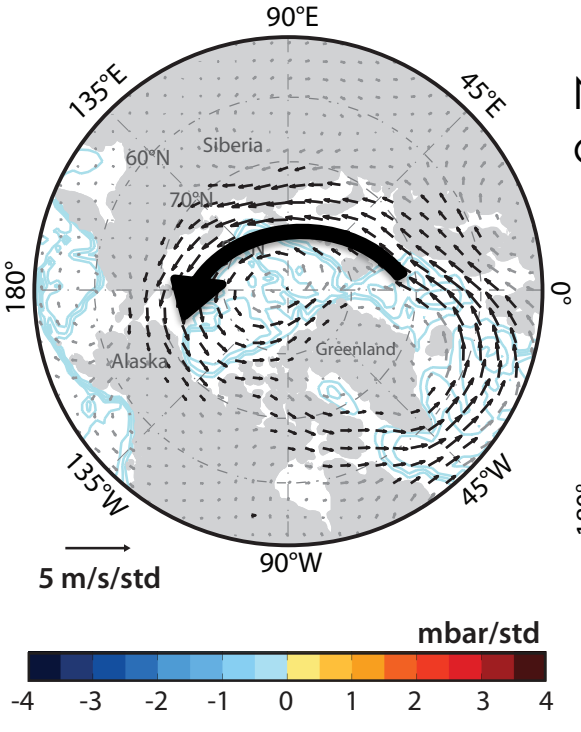


AO+

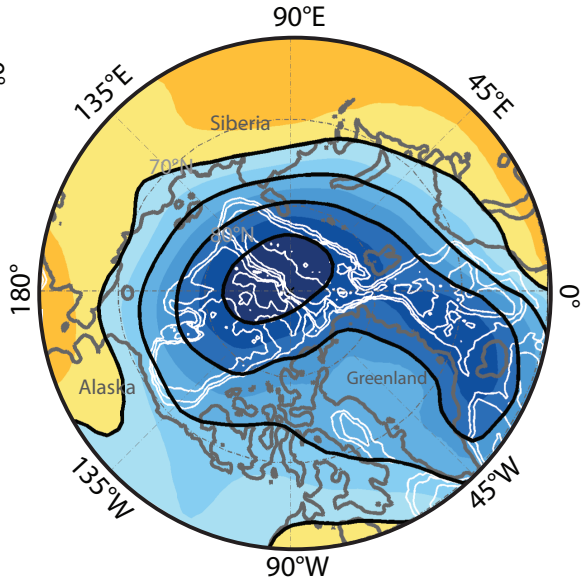
Mode 2: Siberian shelves







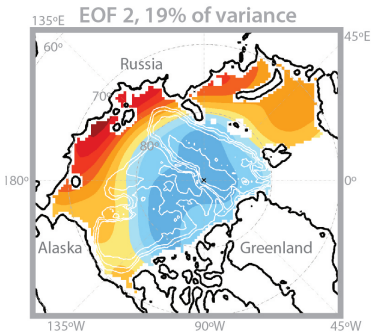
NCEP/NCAR winds (925 hPa) and SLP regressed on PC2.

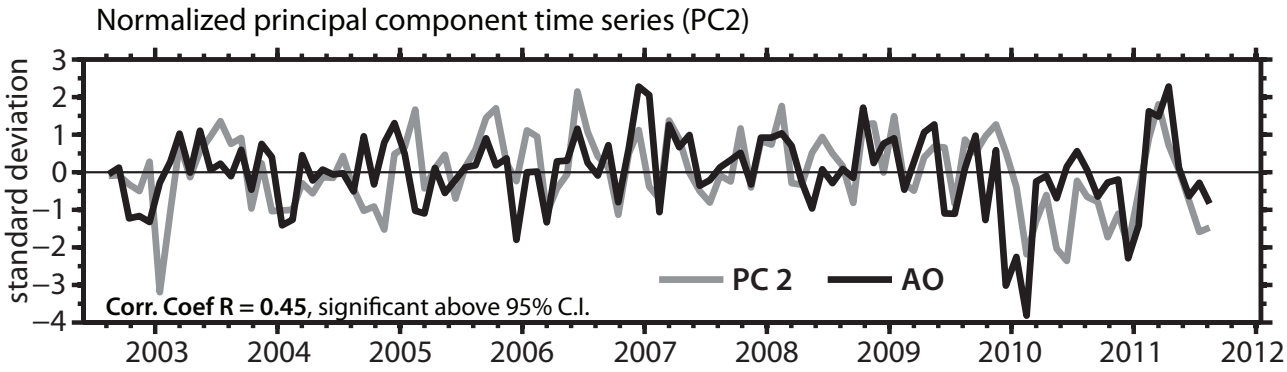


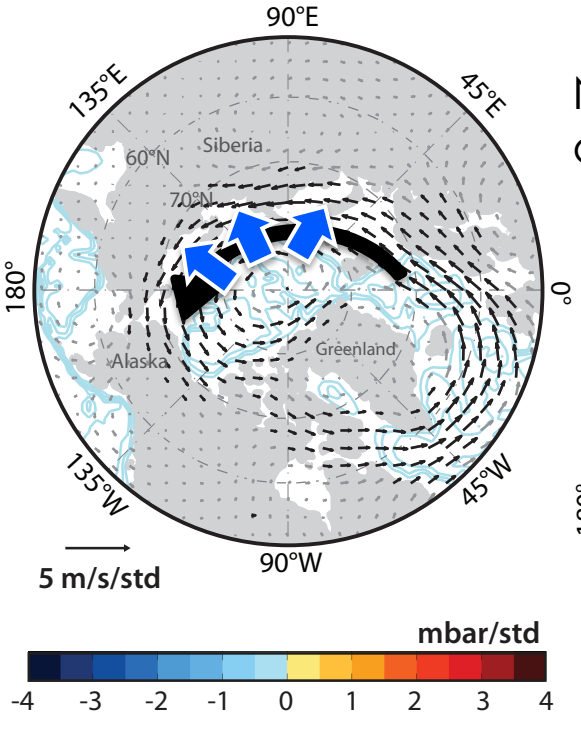
FORCING:

Positive phase of AO generates eastward alongshore winds

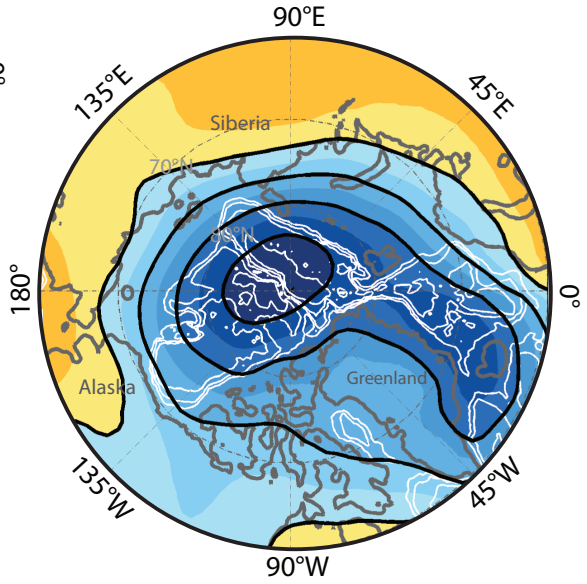
Mode 2: Siberian shelves







NCEP/NCAR winds (925 hPa) and SLP regressed on PC2.



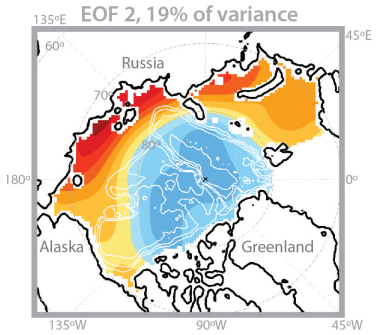
FORCING:

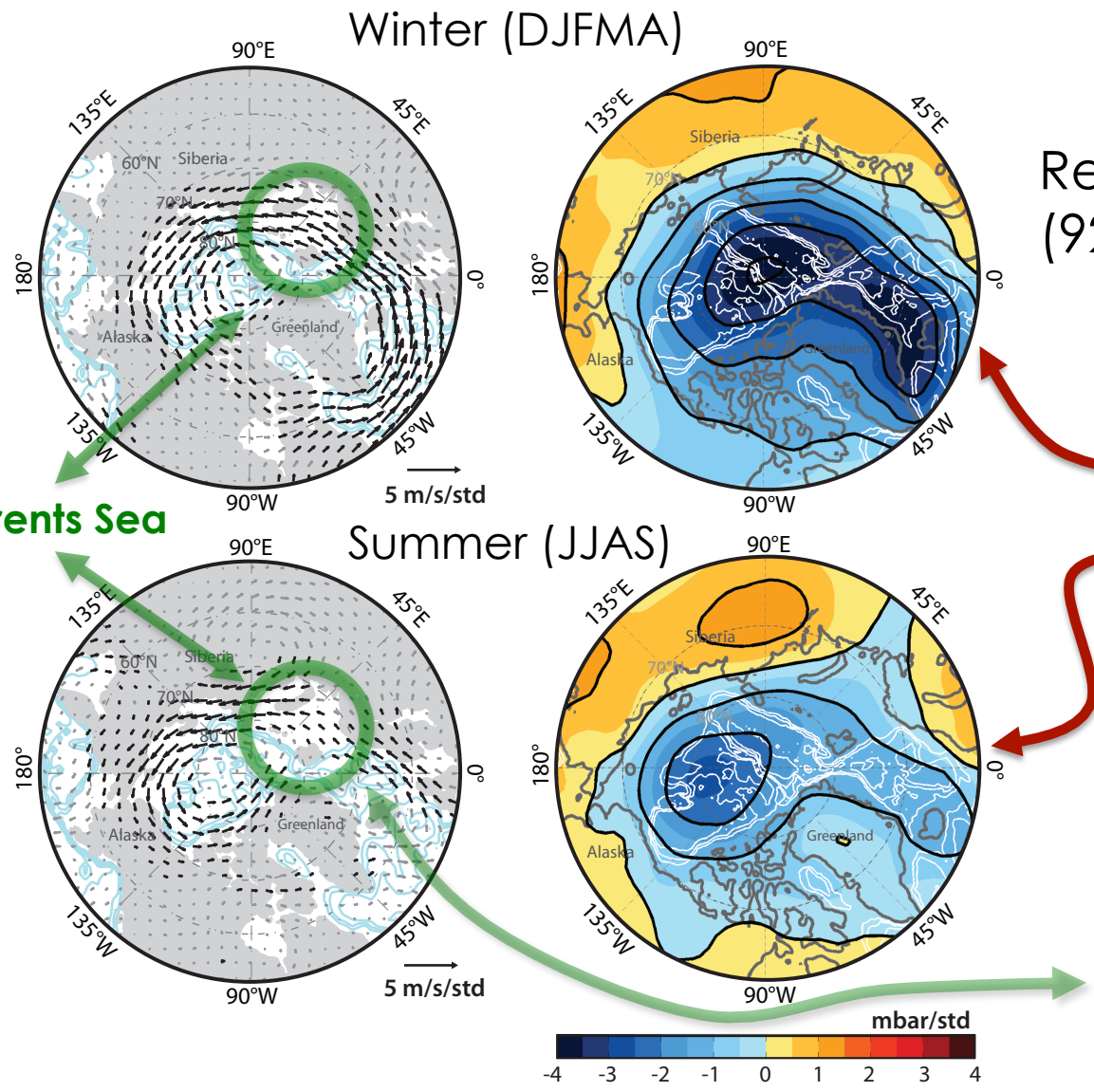
Positive phase of AO generates eastward alongshore winds

PROCESS:

Surface Ekman transport drives the OBP increase on the Siberian shelves.

Mode 2: seasonal forcing



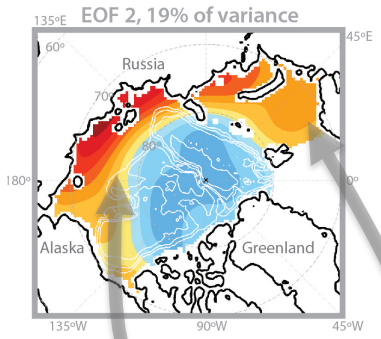


Regression maps of winds (925 hPa) and SLP on PC2.

Mode 2 is **forced similarly in winter and summer…**

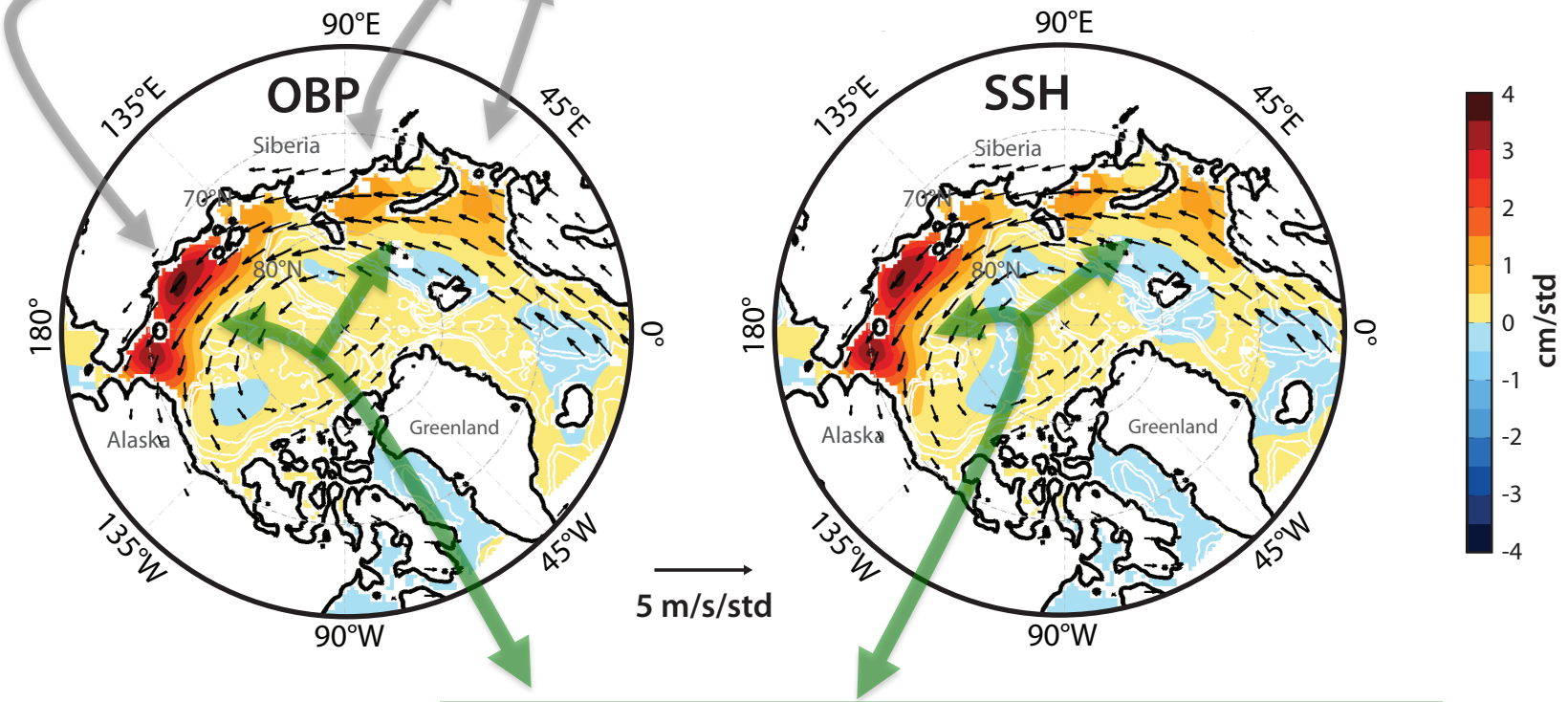
… except in the Barents Sea: weaker during summer

Mode 2: modeled OBP and SSH



Modeled OBP and SSH regressed on **all months** GRACE PC2

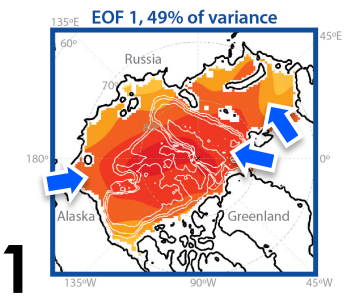
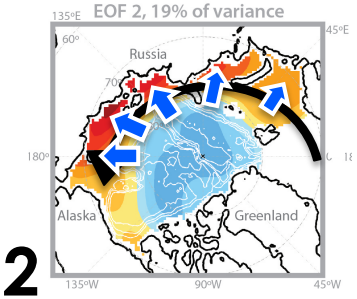
Models show Siberian shelves OBP increase



OBP = SSH → OBP change on the Siberian shelves is of barotropic character.

summary

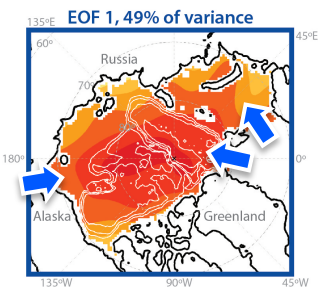
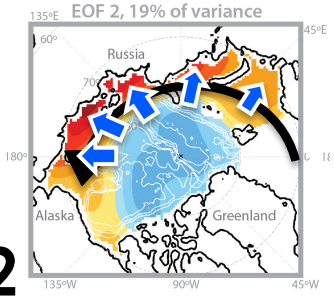
- Using **GRACE**, 2 modes of circulation and forcing were identified:

MODE	FORCING	PROCESS	SSH-OBP RELATION
1 	Wintertime southerly winds at straits	Northward slope current	Partially baroclinic (basins)
2 	Arctic Oscillation (+)	Surface Ekman transport	Barotropic (shelves)

- Ocean models capture the large-scale patterns of variability in ocean circulation at these time scales.

summary

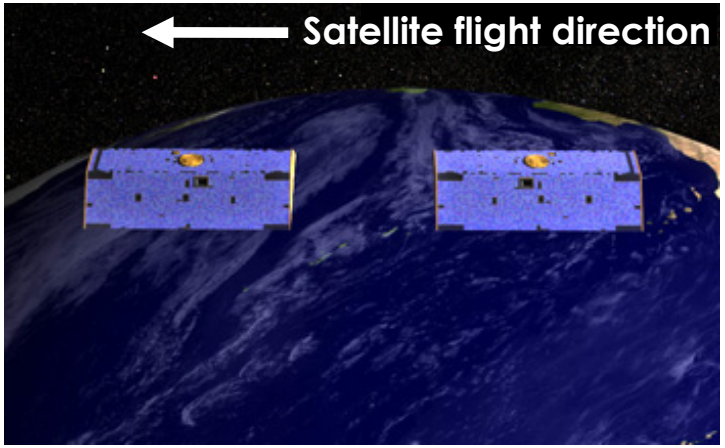
- Using **GRACE**, 2 modes of circulation and forcing were identified:

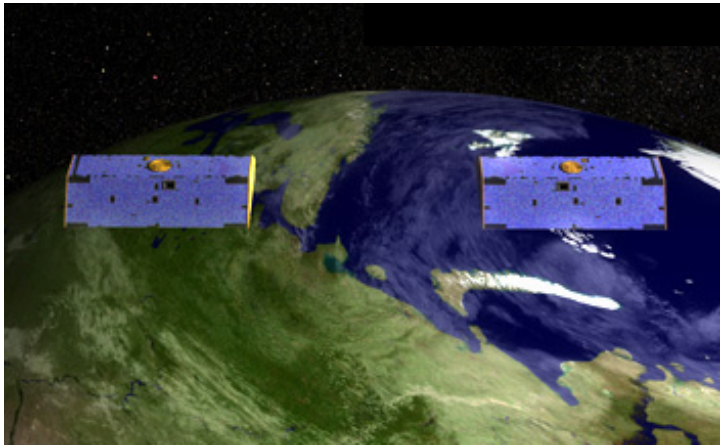
MODE	FORCING	PROCESS	SSH-OBP RELATION
1 	Wintertime southerly winds at straits	Northward slope current	Partially baroclinic (basins)
2 	Arctic Oscillation (+)	Surface Ekman transport	Barotropic (shelves)

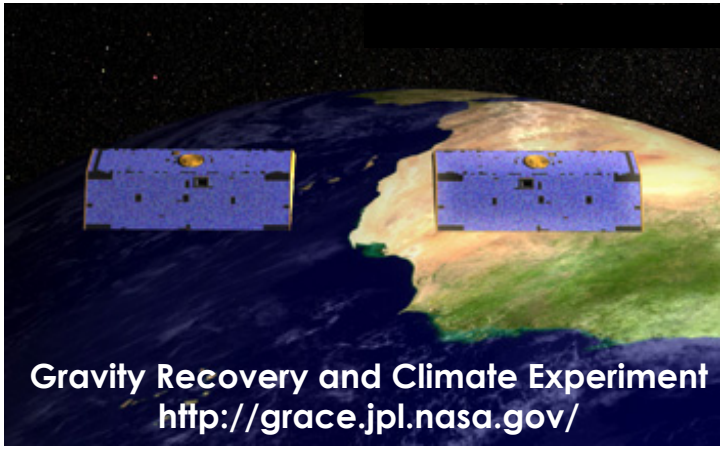
- Ocean models capture the large-scale patterns of variability in ocean circulation at these time scales.

Thank you!

GRACE


Satellite flight direction




Gravity Recovery and Climate Experiment
http://grace.jpl.nasa.gov/

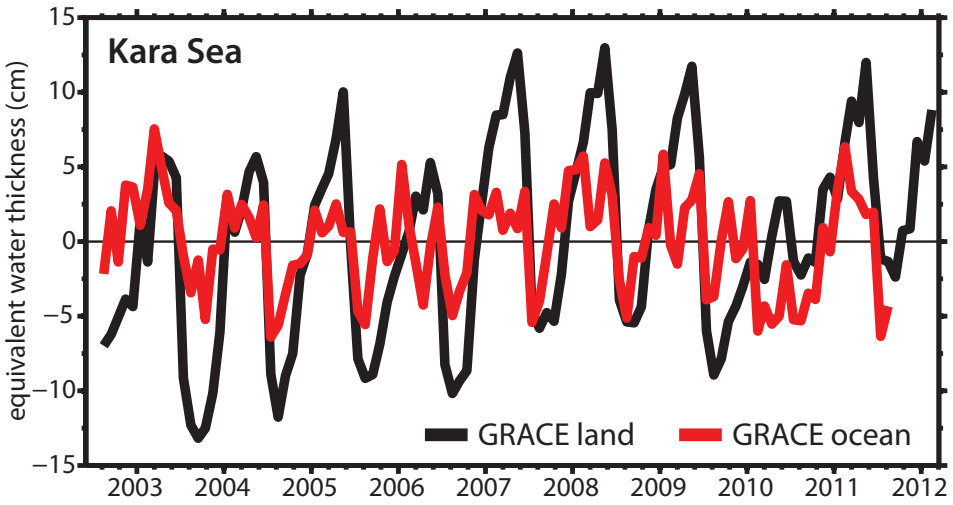
GRACE – *in situ* mismatch in Kara & Barents seas

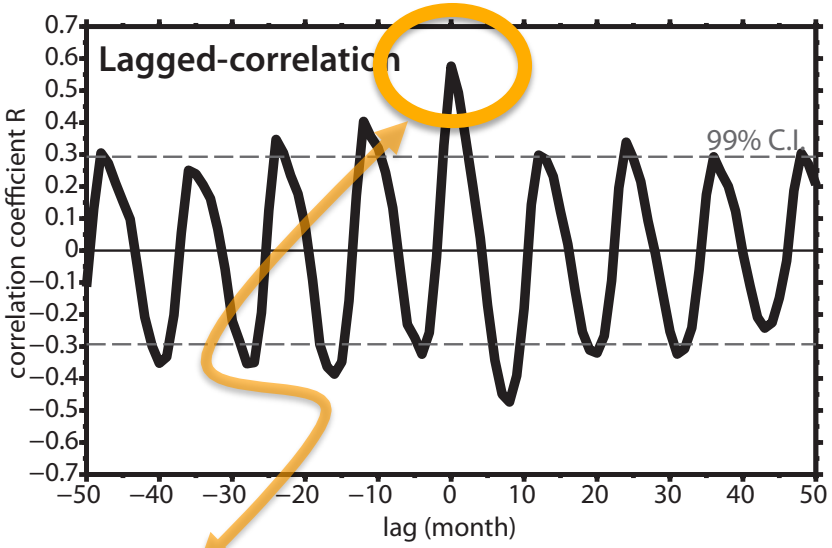
Why tide gauge – GRACE mismatch in Kara and Barents Sea?

a) GRACE may have seasonal leakage from land-hydrology

b) Contrary to *B&H* [2008], Kara and Barents Seas might have strong steric pressure signal, likely due to runoff influence.

GRACE land mass change of Kara watersheds.

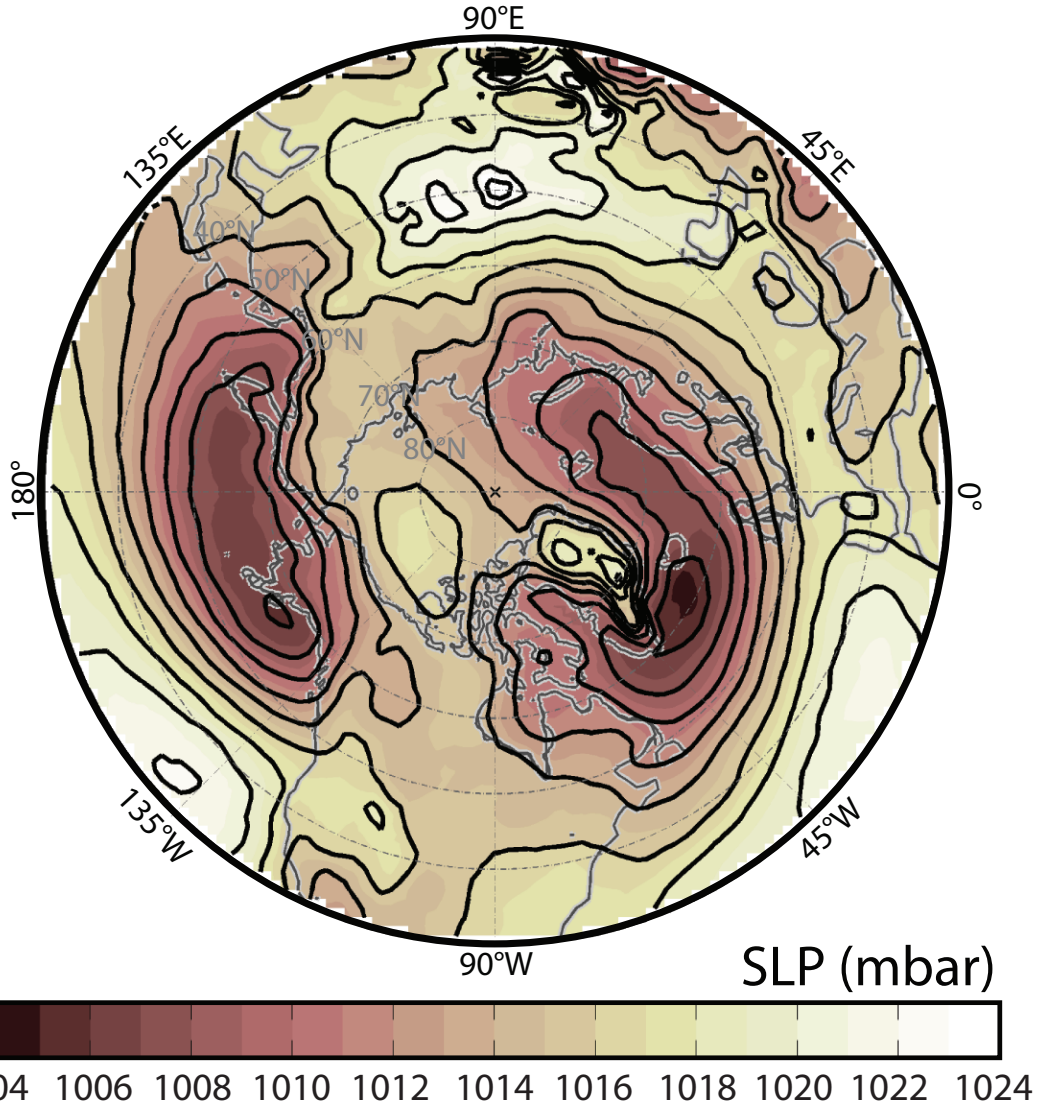




Good correlation at no lag → land mass change may leak into ocean OBP estimate… but mainly at seasonal timescales!

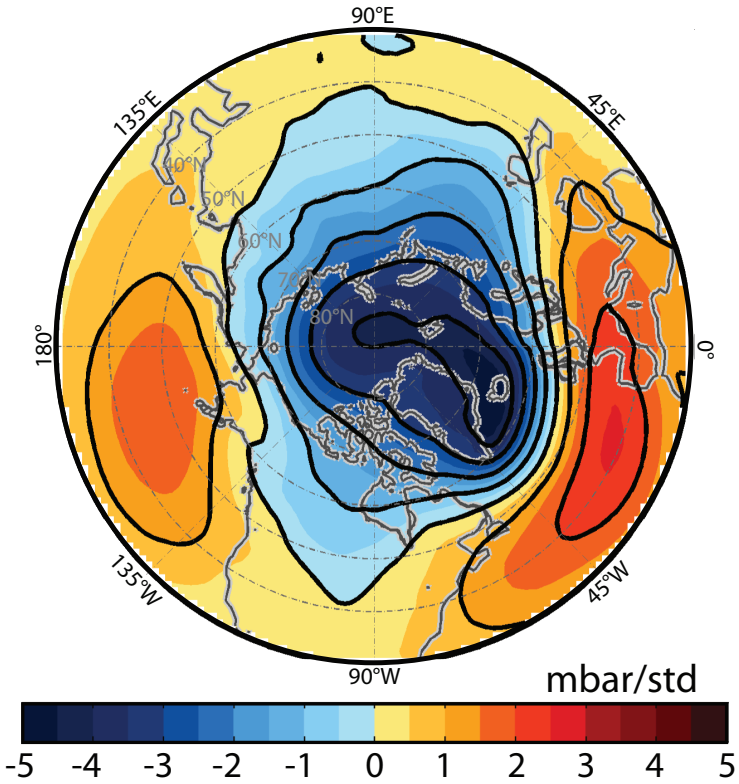
GRACE-land data from *Landerer and Swenson* [2012]

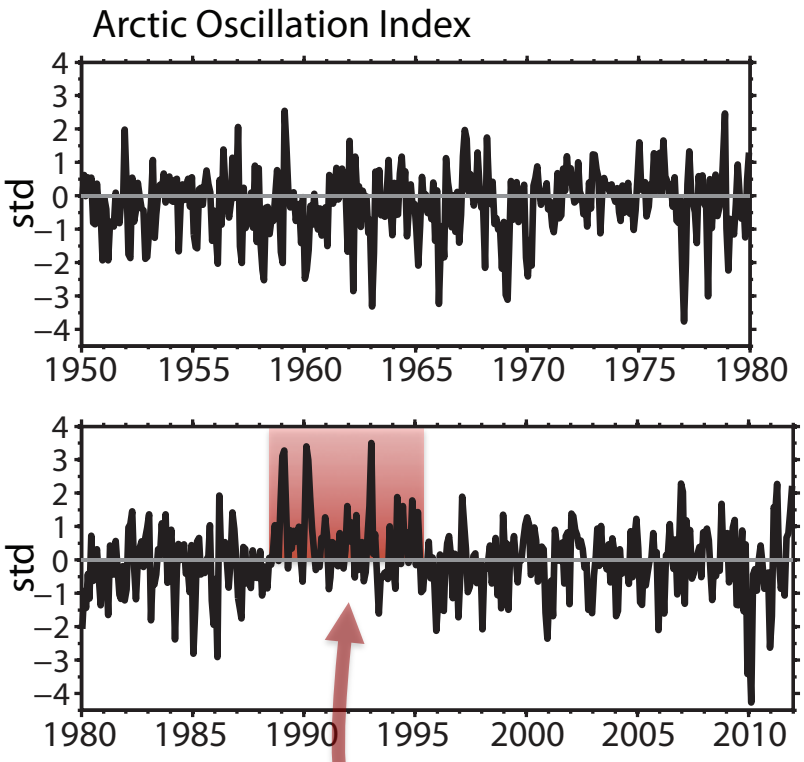
mean sea level pressure



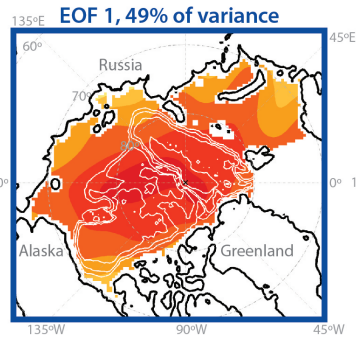
Arctic Oscillation (AO)

The AO is the leading EOF mode of the sea level pressure in the northern hemisphere (>30°N) [*Thompson and Wallace*, 1998].





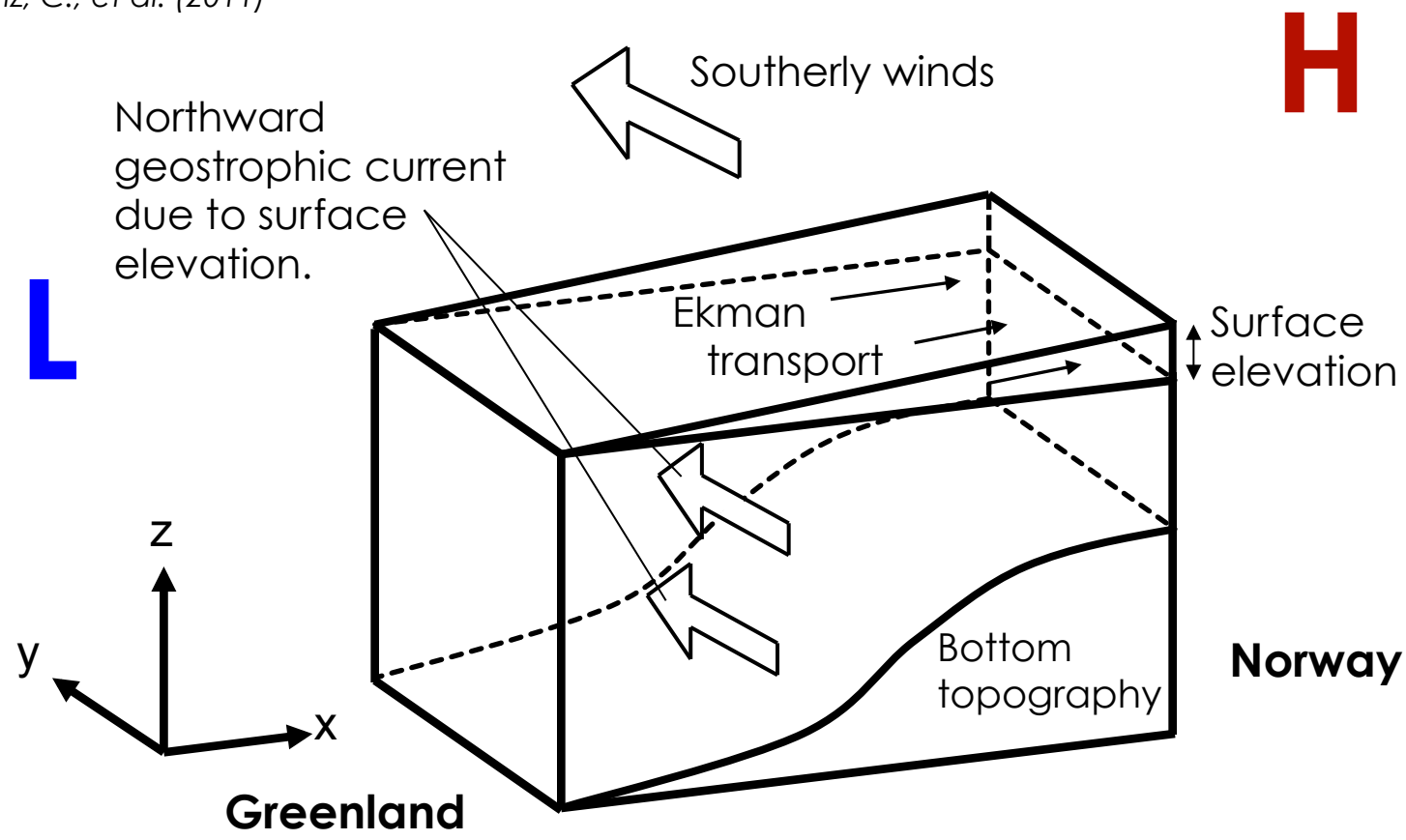
NCEP/NCAR SLP projected on AO index values from NOAA's Climate Prediction Center



atmosphere – ocean dynamics

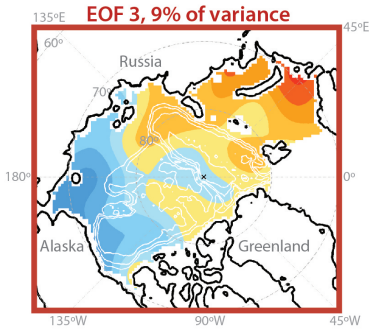
A geostrophic slope current due to southerly winds along the Norwegian Sea generates flow into the basin, increasing Arctic OBP.

→ *Hughes C. W. and V. N. Stepanov (2004)*
→ *Peralta-Ferriz, C., et al. (2011)*

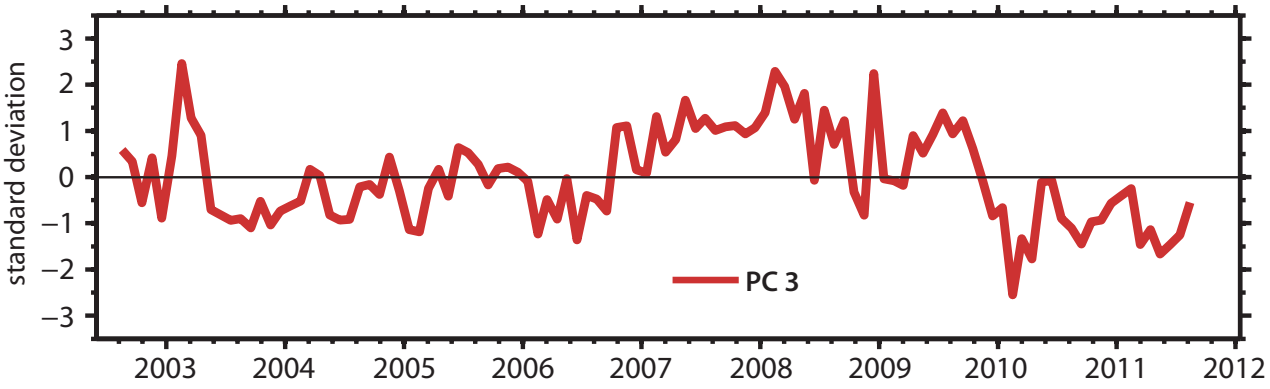


Peralta-Ferriz, C., et al. (2011)

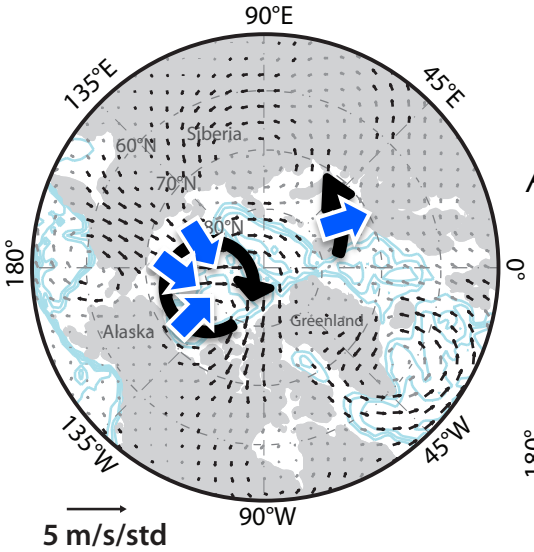
Mode 3: Shelves dipole

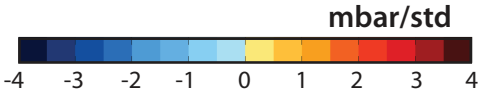


Normalized principal component time series (PC3)

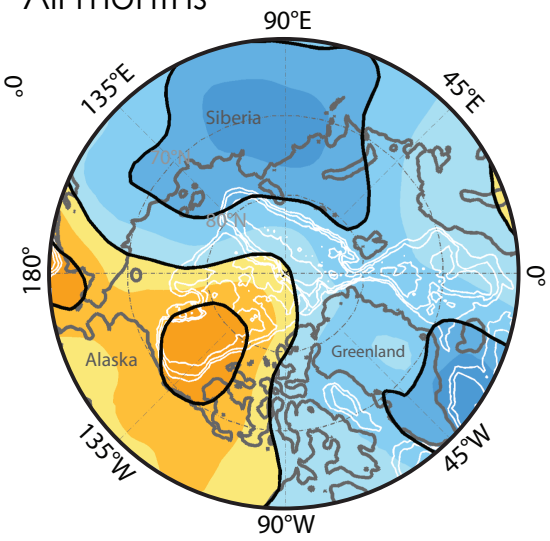


NCEP/NCAR winds (925 hPa) and SLP regressed on PC3.





All months



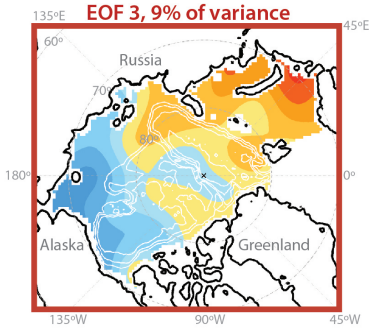
FORCING:

- Beaufort Gyre spin-up
- Alongshore westerly winds in the Barents Sea.

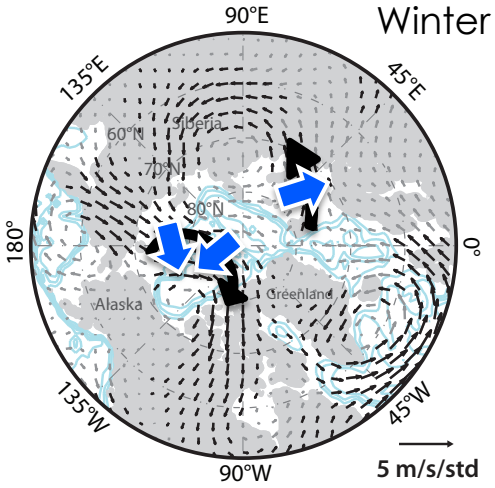
PROCESS:

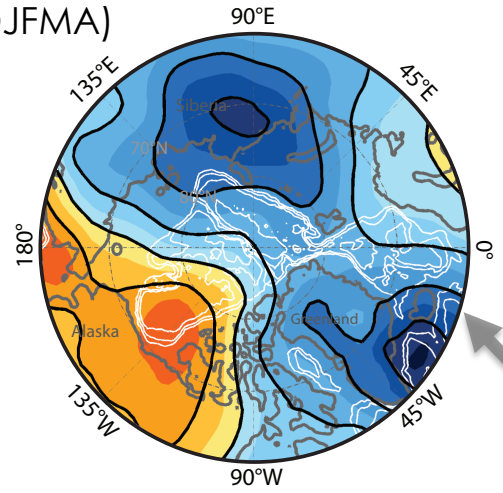
- Ekman convergence pulls mass away from 'Western' shelves.
- Ekman transport

Mode 3: seasonal forcing



Winter (DJFMA)

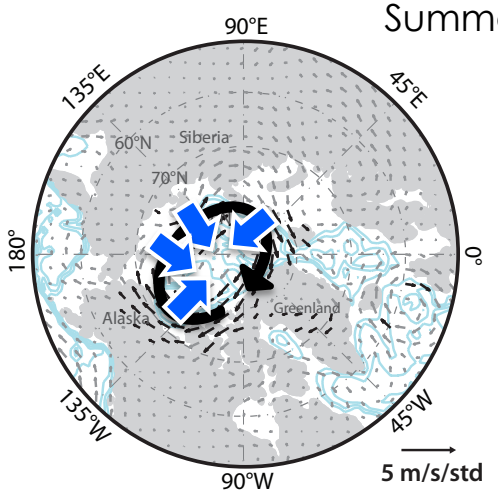


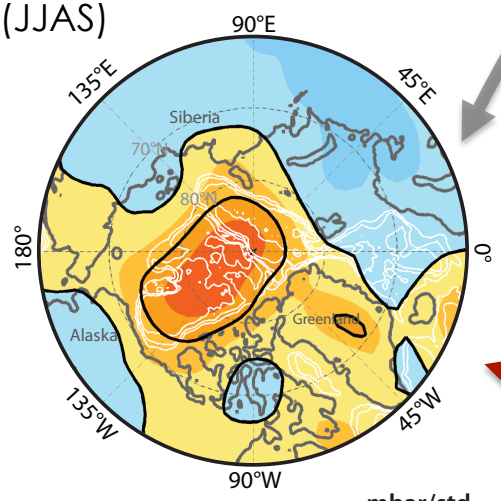


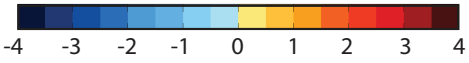
Regression maps of winds (925 hPa) and SLP on PC3.

OBP change from mode 3 is **forced differently** in winter and summer

Summer (JJAS)

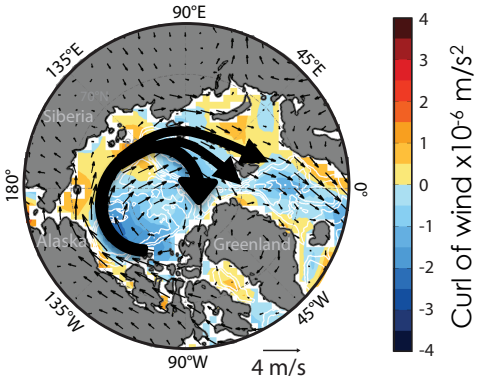




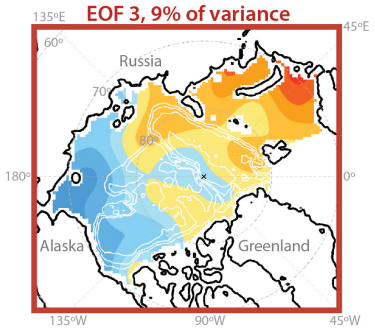


Reflects multi-year variations

<2007-2009> - <2002-2006>



Tendency of summer atmospheric circulation toward anticyclonic winds [*Ogi and Wallace*, 2012]



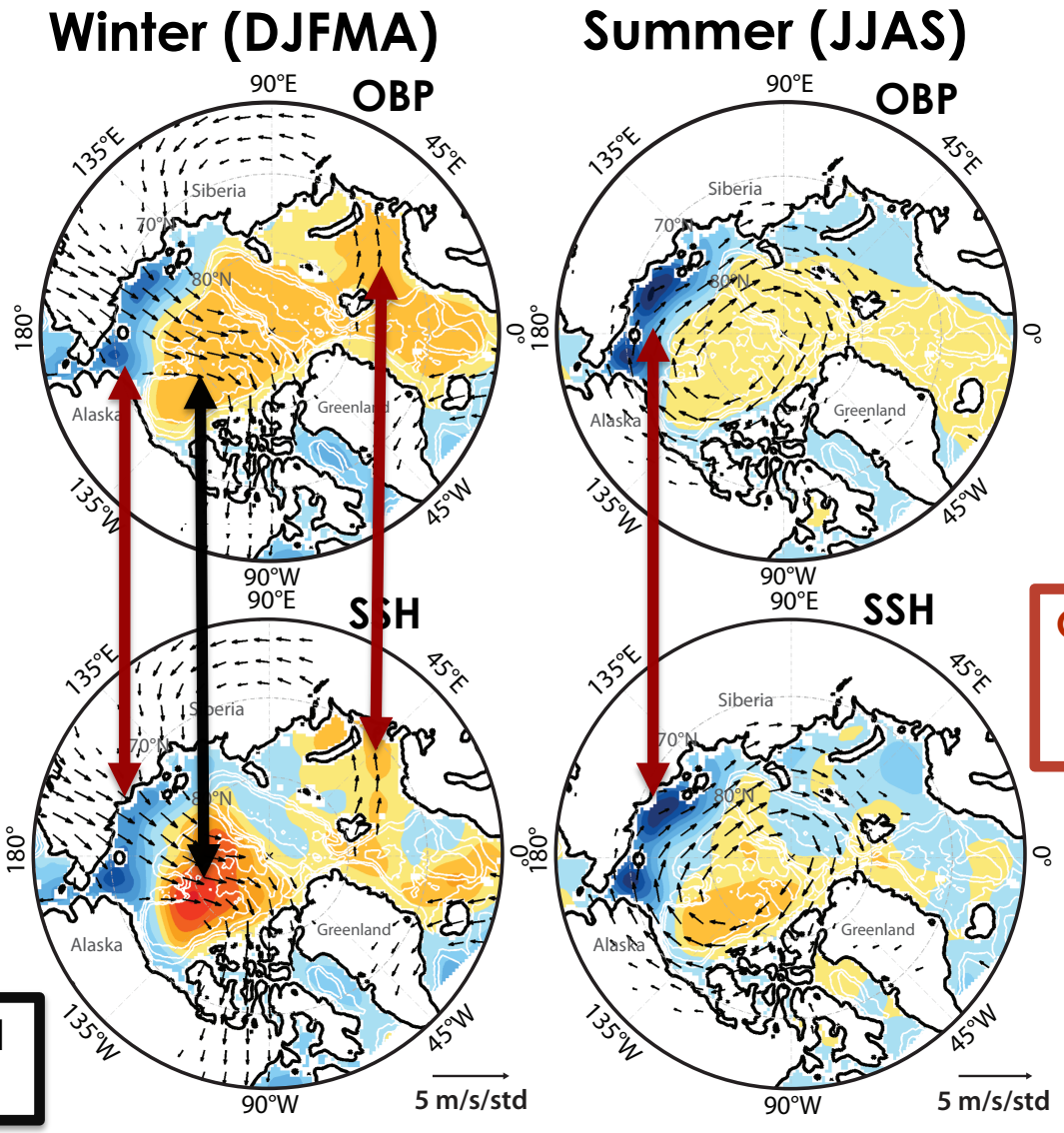
Mode 3: modeled OBP and SSH

Modeled OBP and SSH regressed on GRACE PC3

Model detects increased OBP in Barents Sea in winter.

Model suggests OBP low on 'Western' shelves occurs in winter and summer.

In the basin, OBP ≠ SSH → baroclinic



On the shelves, OBP = SSH → barotropic