Drivers of the increasing Pacific inflow to the Arctic through the Bering Strait: Insights from gravity and altimetry data, and possible reasons why models fail to simulate the increasing flow

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A. Nguyen (U Texas), D. Wiese (JPL), J. Morison (APL-UW), R. Kwok (APL-UW), and J. Bonin (USF)

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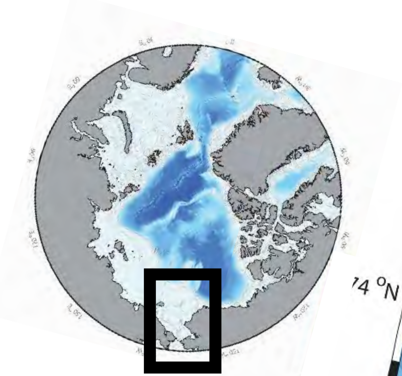
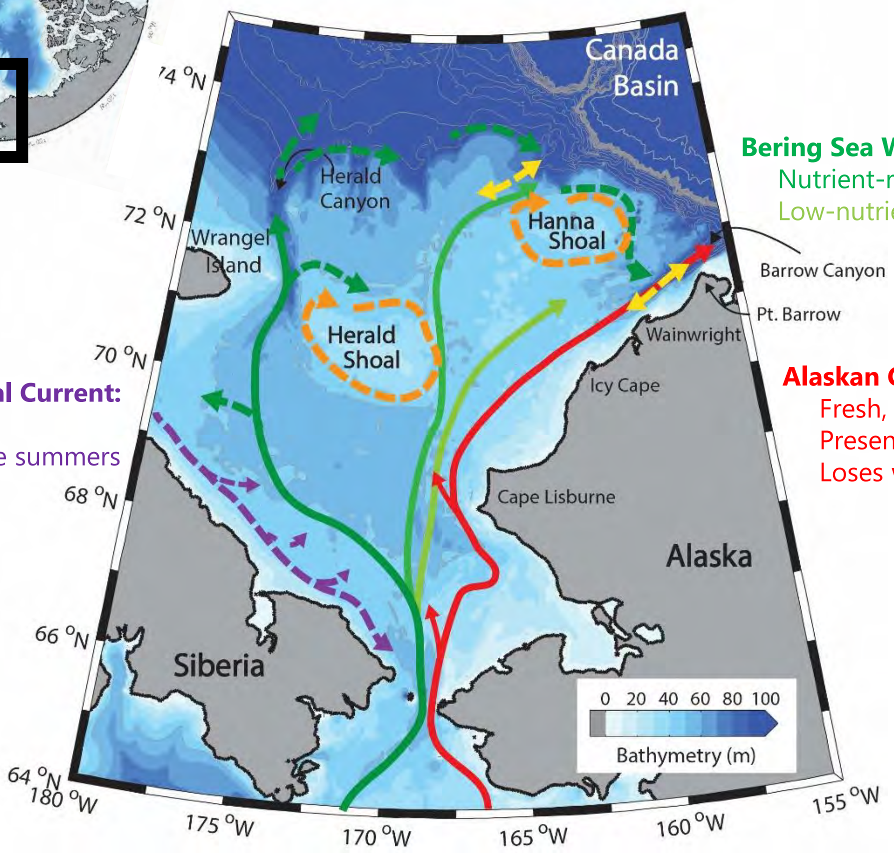
NSF AON grants PLR-1758565 and PLR-2153942
NASA grant 80NSSC20K0763

Bering Strait: the only Arctic-Pacific oceanic gataway



- ~1/3th of the freshwater content in the Arctic
- Its heat onsets seasonal Western Arctic sea-ice melt
- Major source of nutrients to the Arctic.

Siberian Coastal Current:
Fresh, cold
Present some summers



Bering Sea Water:
Nutrient-rich Anadyr Water
Low-nutrient Bering Shelf water

Alaskan Coastal Current:
Fresh, warm
Present summer to late fall
Loses water to central Chukchi

Adapted from *Woodgate* (2004) and *Danielson et al.* (2015)

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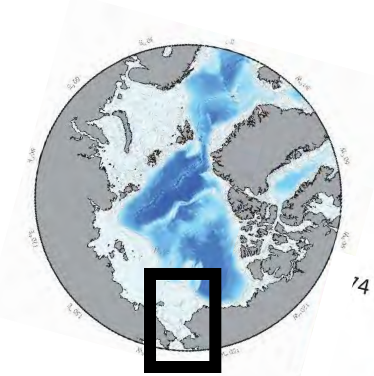

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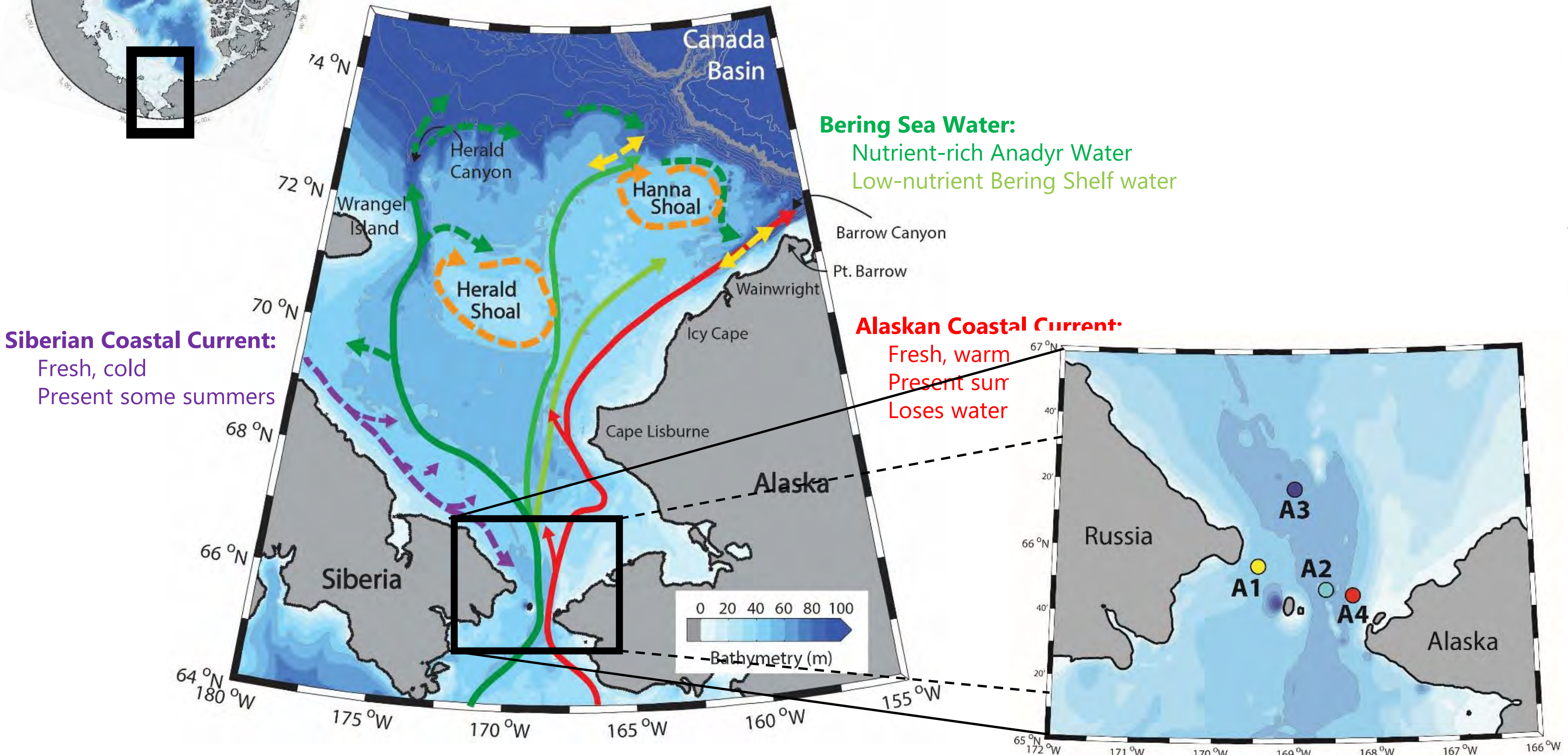
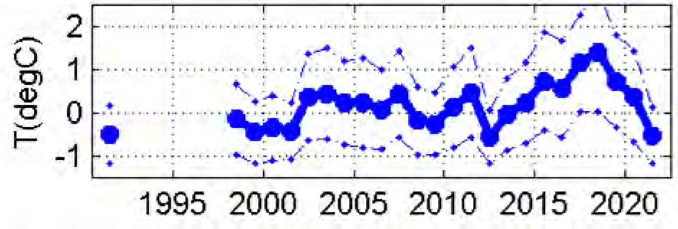


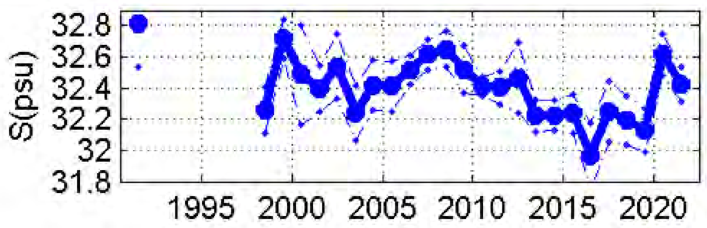
Adapted from *Woodgate* (2004) and *Danielson et al.* (2015)

Mooring A3 (climate site) shows (1991-2021):

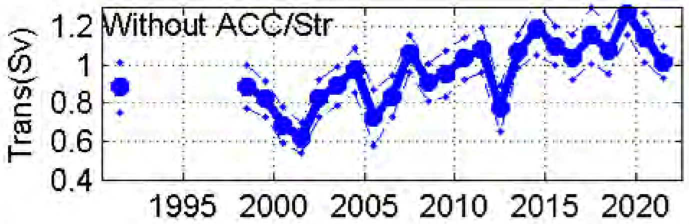
Warming: 0.03±0.02°C/yr



Freshening: 0.013±0.007psu/yr



Flow increasing: 0.01±0.005Sv/yr, 0.23±0.12cm/s/yr



Forcings of the flow: Local (wind) & far-field (PH term)

Local wind forcing:

- Nearly northward (330^{o}N) winds
- Geostrophic flow northward
- Dominant during the winter.
- Does not show long-term (1991-2021) trend.

Far-field (pressure-head, PH) forcing:

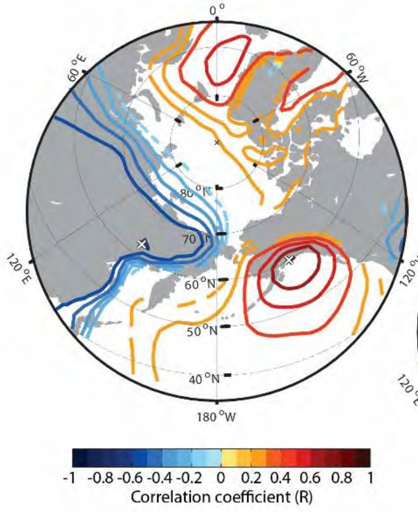
Vvel = *m* x wind*NCEP* + PH term

Woodgate et al., (2005; 2006)

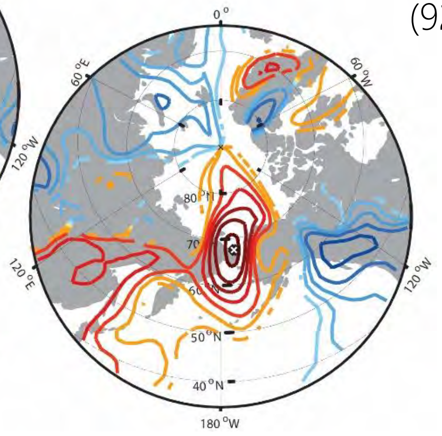
- Low Ocean Bottom Pressure (OBP) in the East Siberian Sea (ESS)
- PH term dominant during the summer.
- Shows long-term (1991-2021) trend.

Peralta-Ferriz & Woodgate (2017)

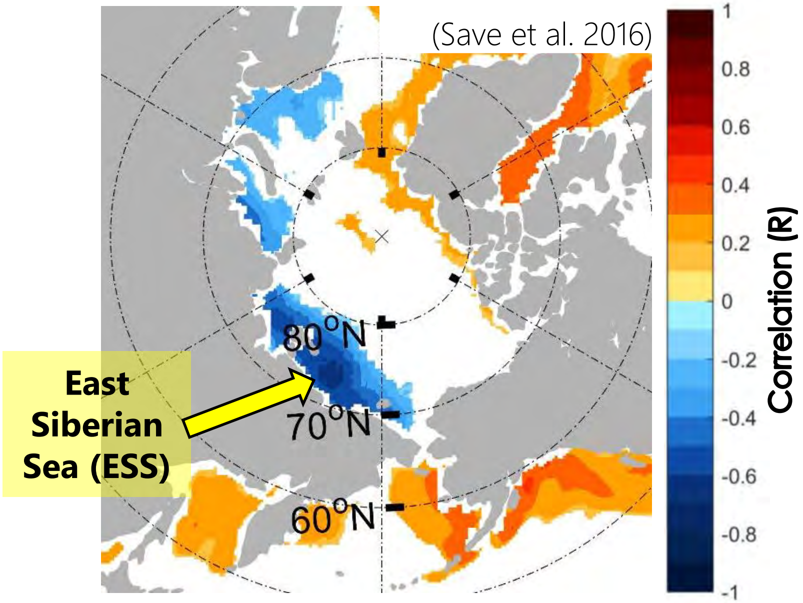
NCEP Sea Level Pressure (SLP)



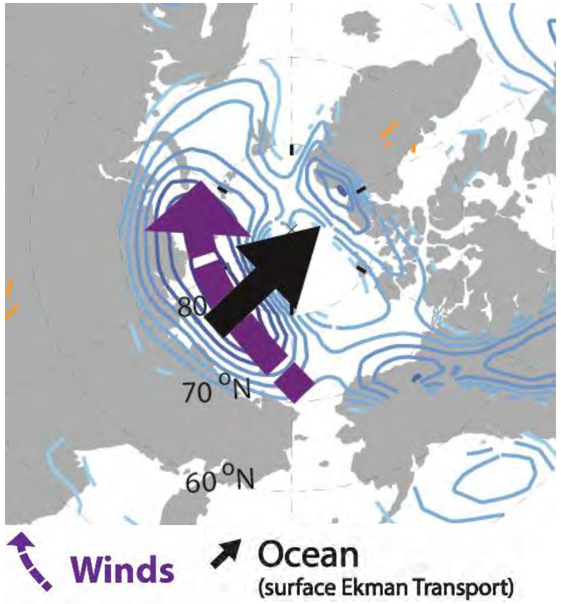
Meridional NCEP (V) winds (925hPa)



PH term & GRACE CSR masc Rel05



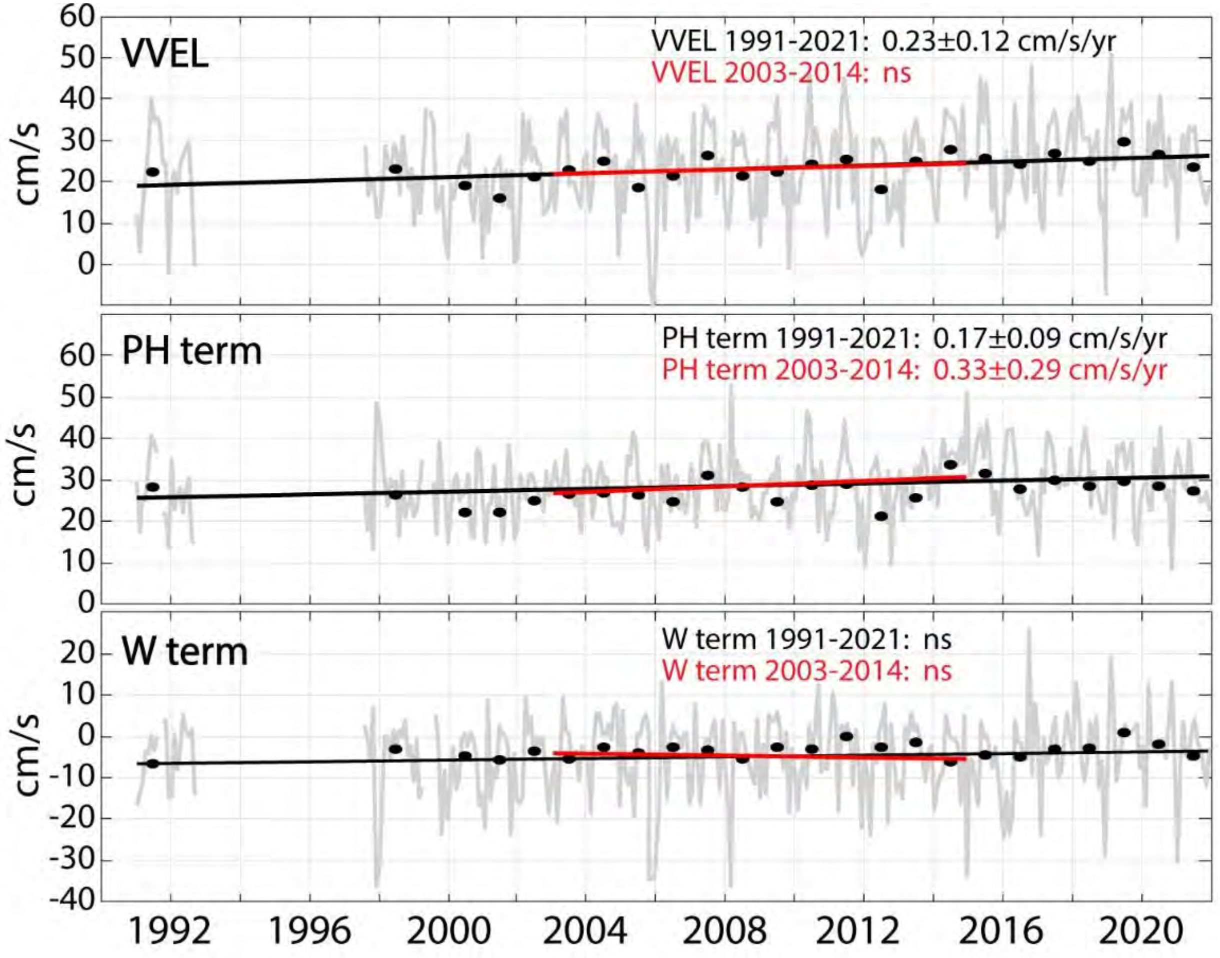
Zonal NCEP (U) winds and PHterm

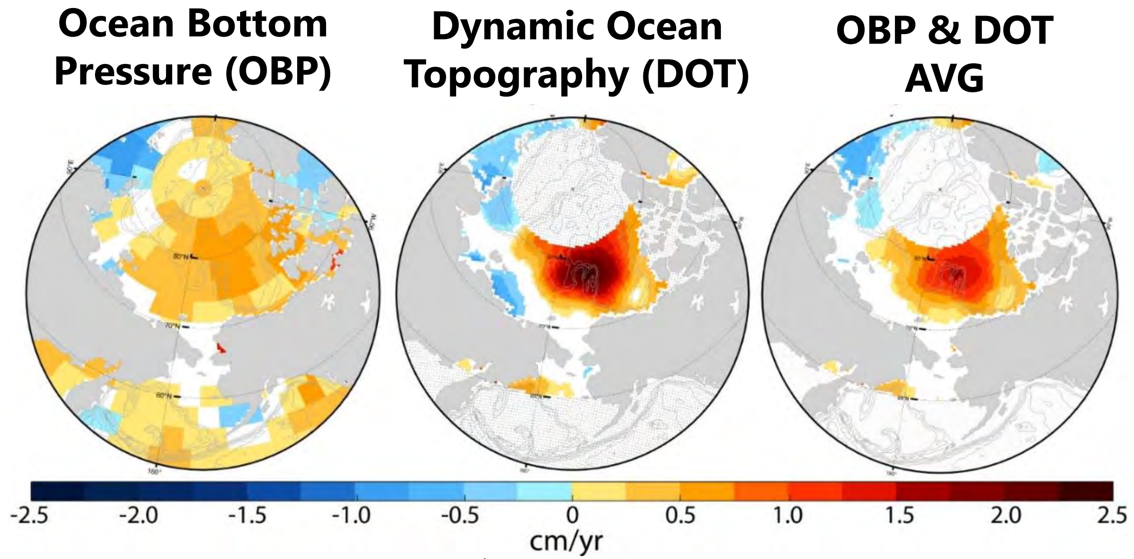


Peralta-Ferriz & Woodgate (2017)

Year-round trends

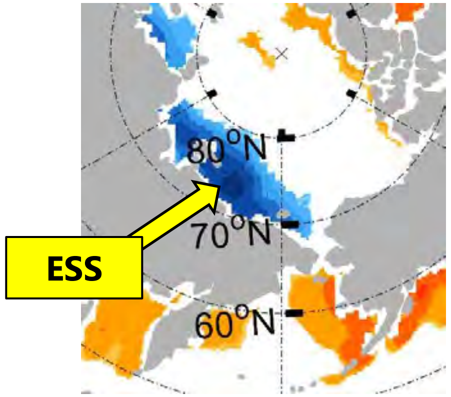
Focus on 2003-2014: annual trends show no significant features





GRACE JPLmasc Rel06 ver2 (Wiese et al., 2018)

EnviSat+CryoSat DOT (Armitage et al. 2016)



AVG between OBP & DOT is the direct driver of the flow:

$$\Delta T = \frac{-gH}{f} \Delta \left(\frac{DOT+OBP}{2} \right)$$

Peralta-Ferriz & Woodgate (2023), GRL

Year-round trends

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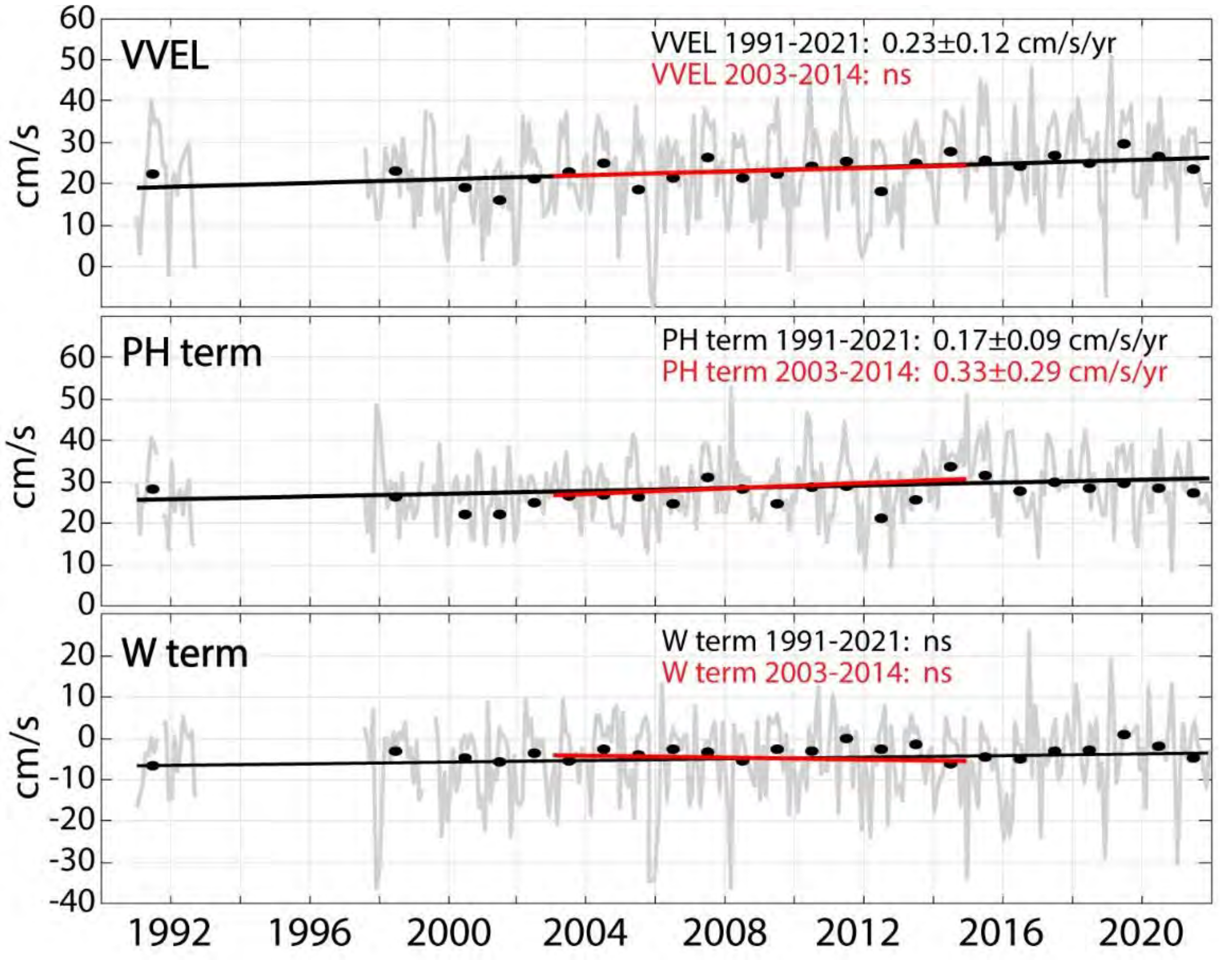
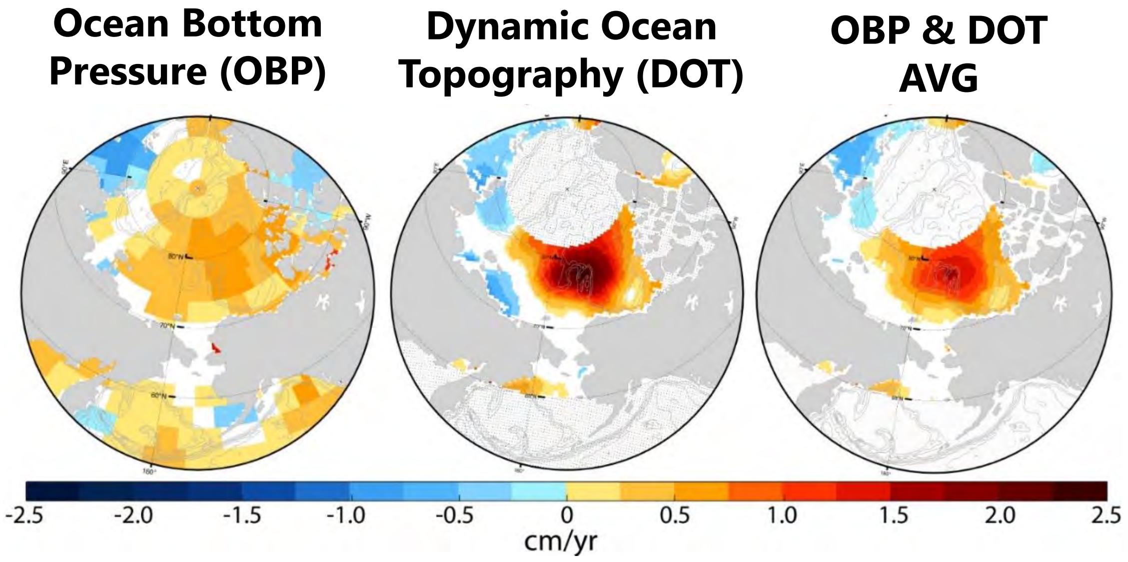
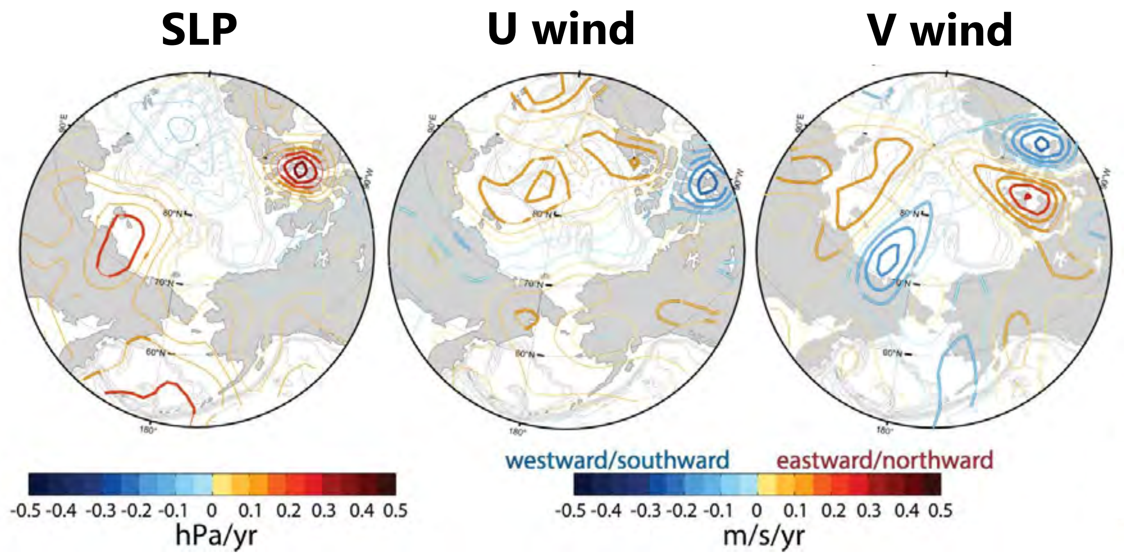
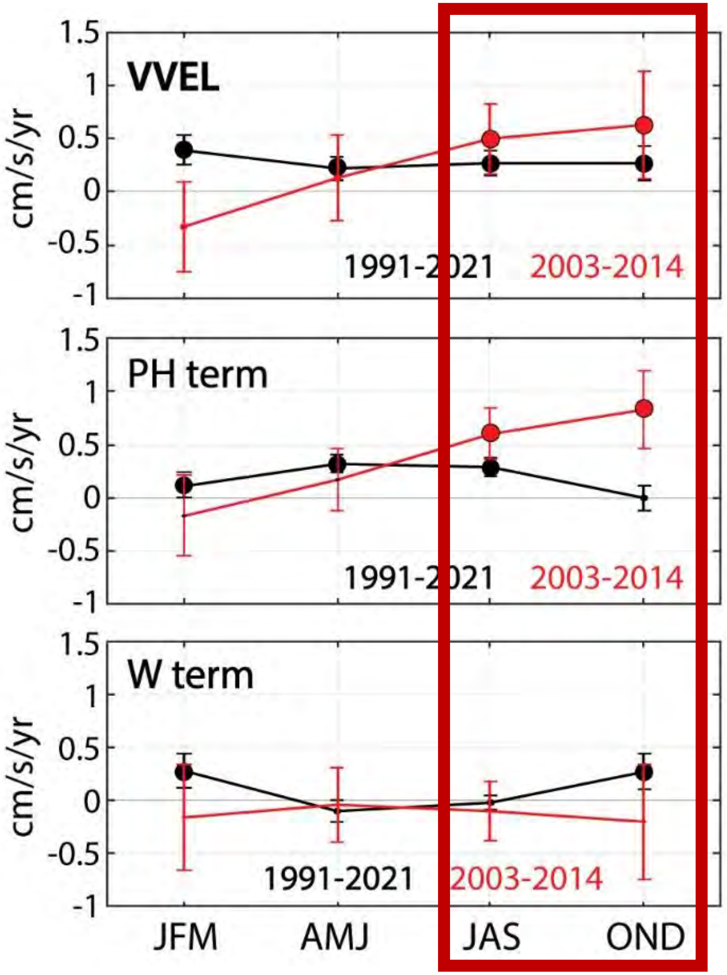


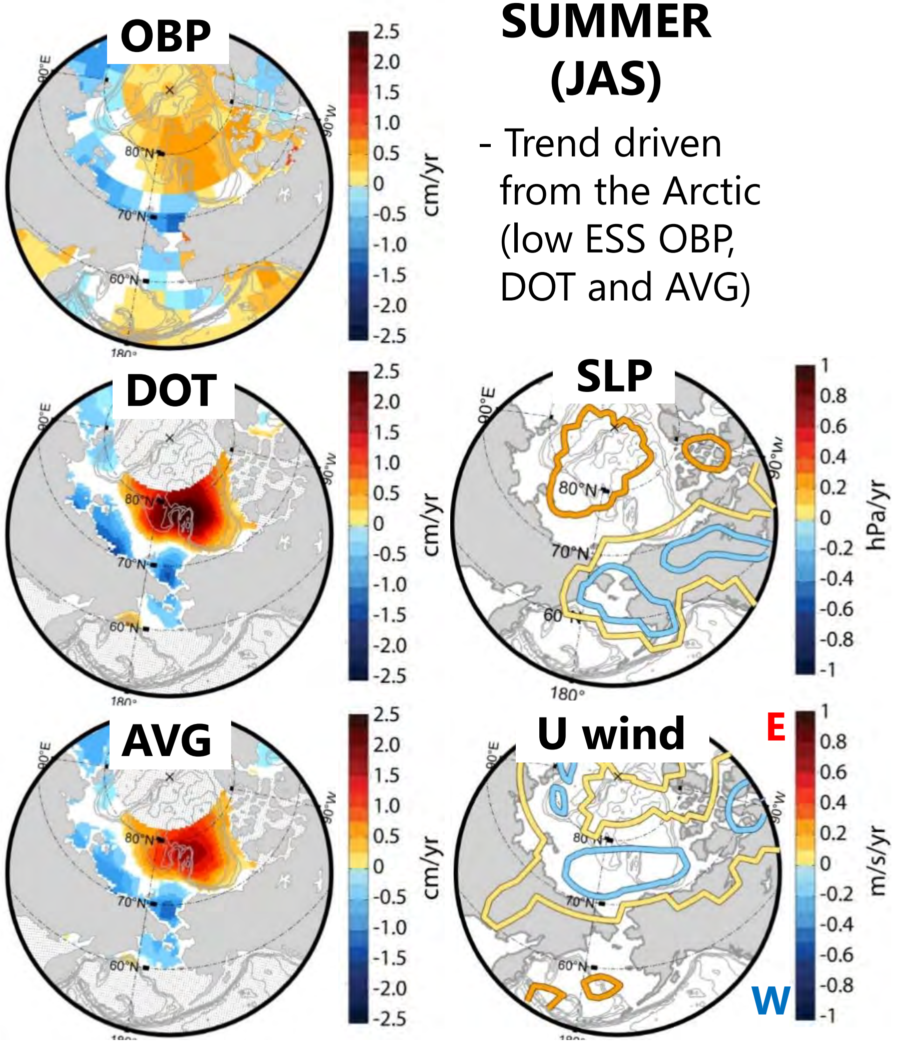
Peralta-Ferriz & Woodgate, 2023, GRL





Seasonal trends (2003-14): summer and fall features





SUMMER (JAS)

- Trend driven from the Arctic (low ESS OBP, DOT and AVG)

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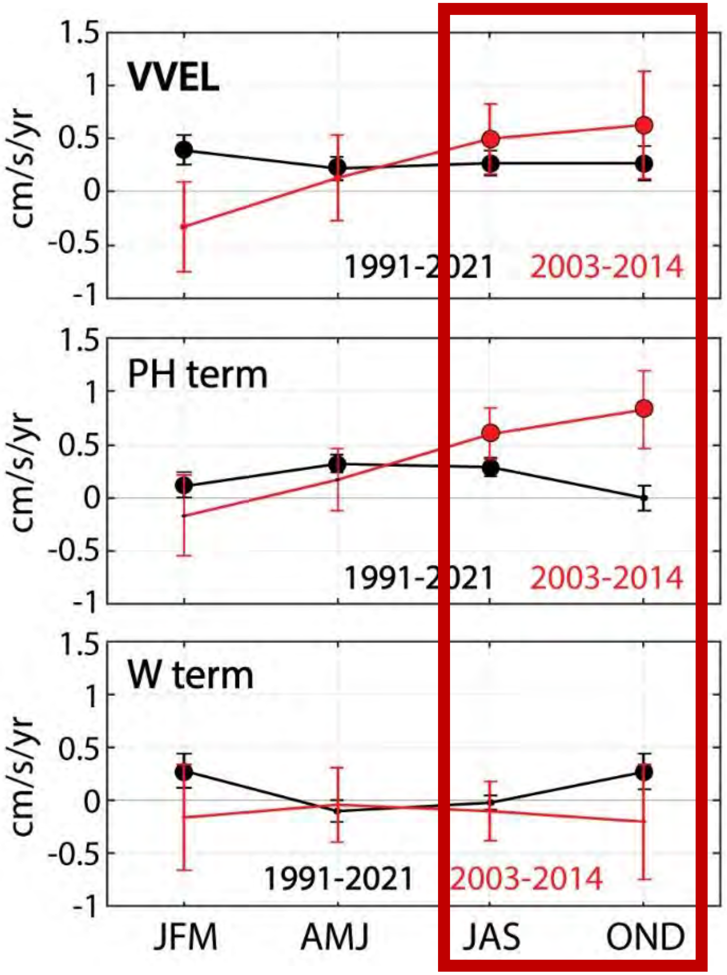
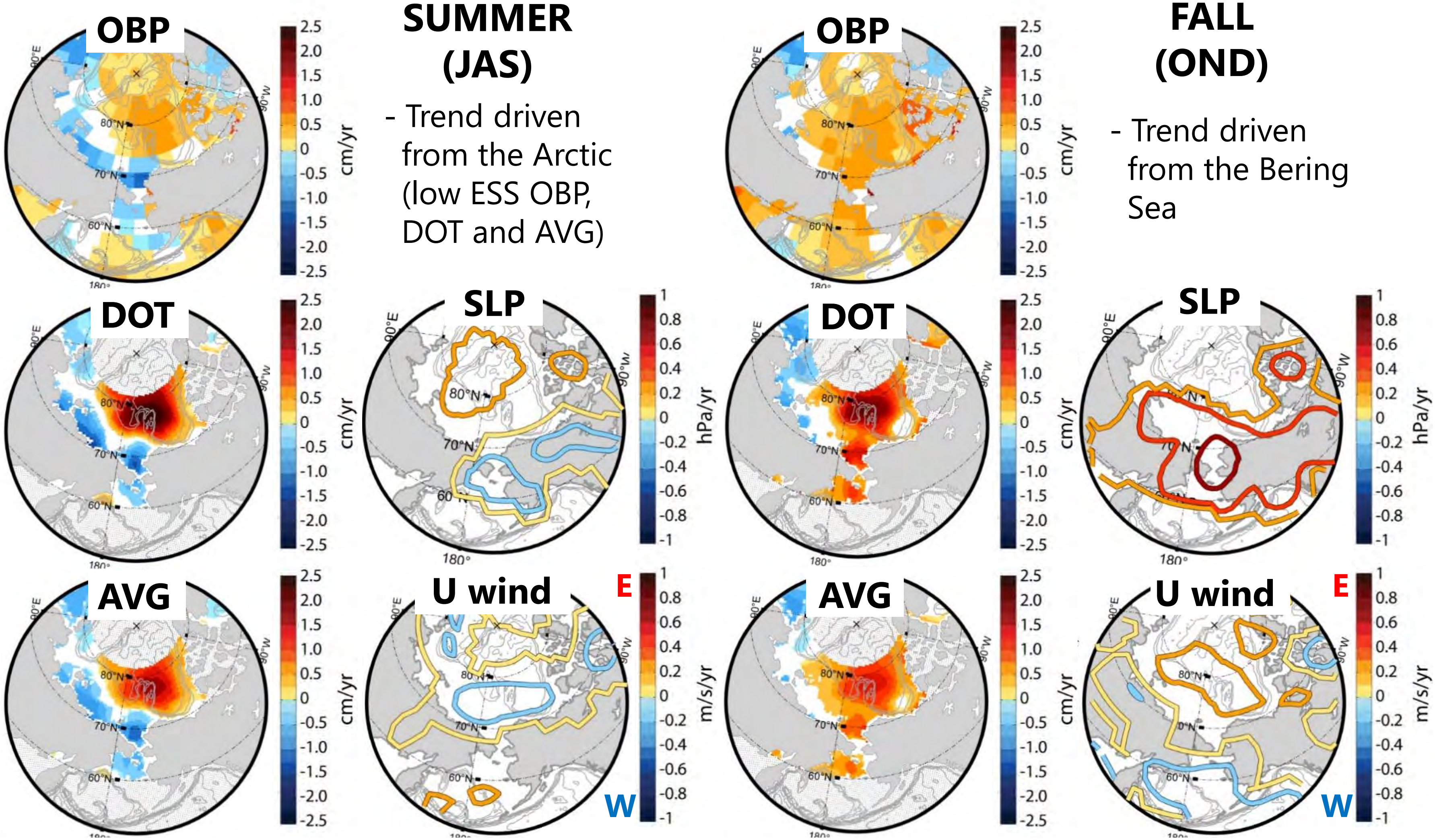




SUMMER (JAS)

- Trend driven from the Arctic (low ESS OBP, DOT and AVG)

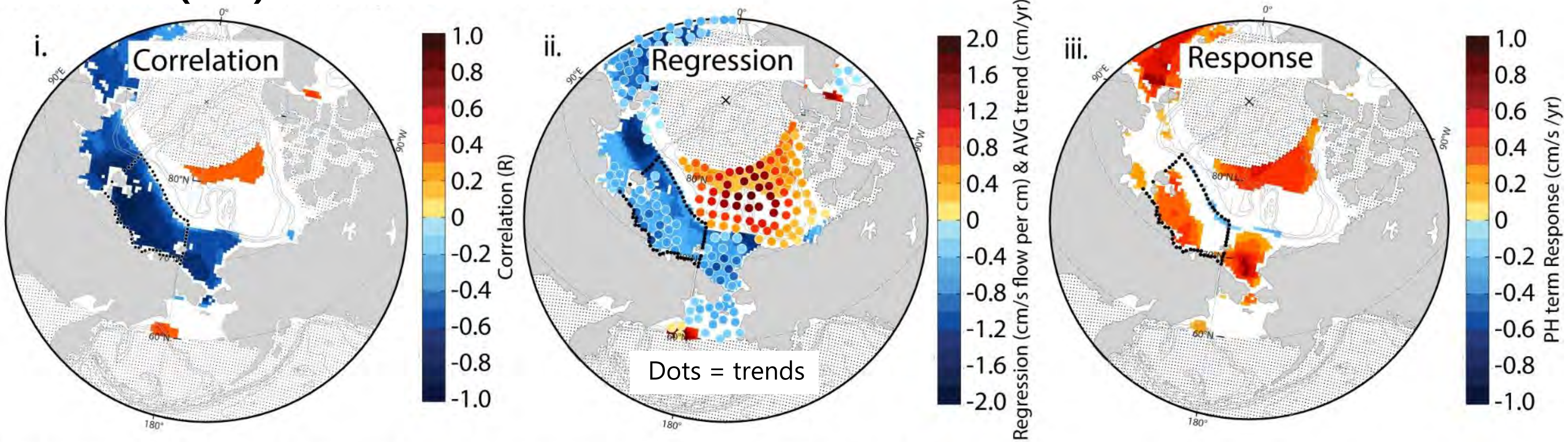
FALL (OND)

- Trend driven from the Bering Sea

Peralta-Ferriz & Woodgate, 2023, GRL

Summer PH term response to AVG and surface stress (τ^x) trends

Summer (JAS) AVG and PH term



SUMMER (JAS)

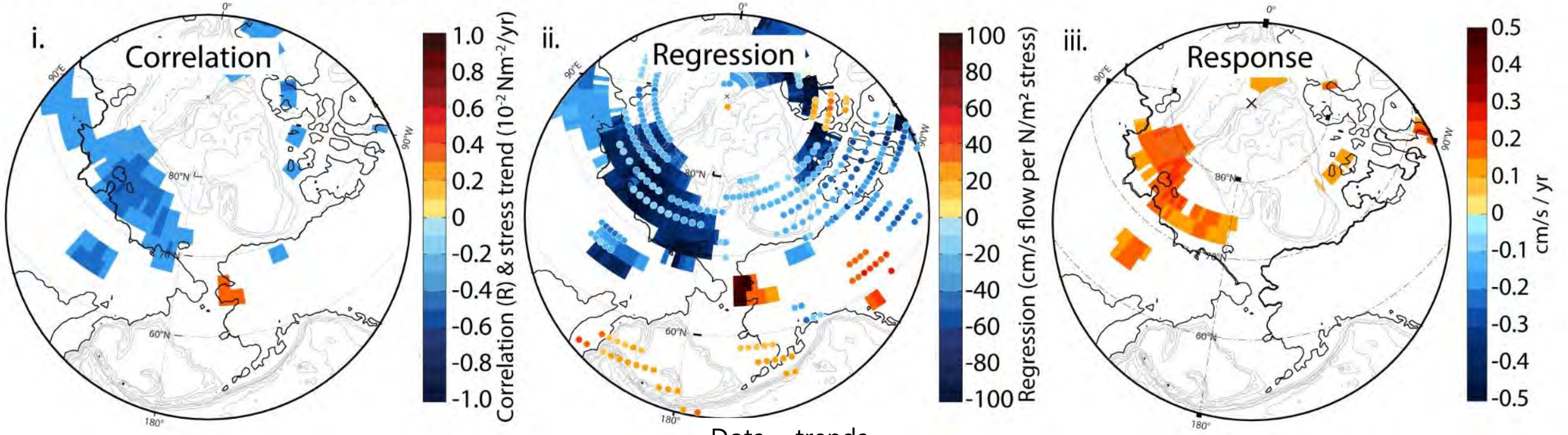
Observed PH term trend:

~0.6±0.3 cm/s/yr

Change in ESS AVG $_{(OBP\&DOT)}$:

~0.4±0.3 cm/s/yr

Summer (JAS) τ^x and PH term



SUMMER (JAS)

Observed PH term trend:

~0.6±0.3 cm/s/yr

Change in ESS τ^x:

~0.2±0.15 cm/s/yr

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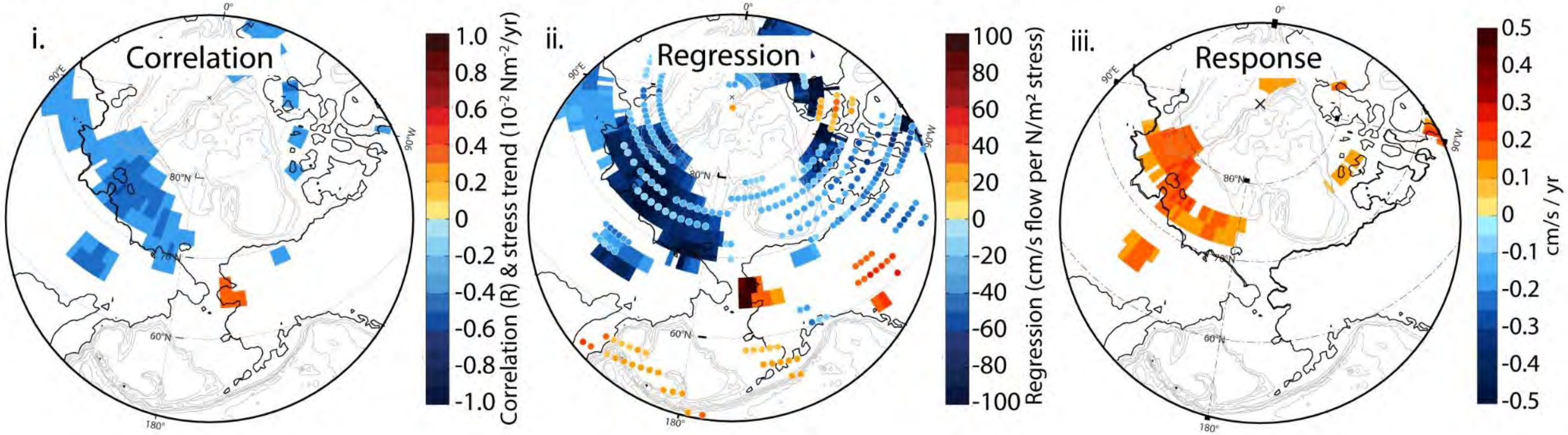
Summer and Fall PH term response to τ^x trends

Summer (JAS) τ^x and PH term



SUMMER (JAS)

Observed PH term trend:

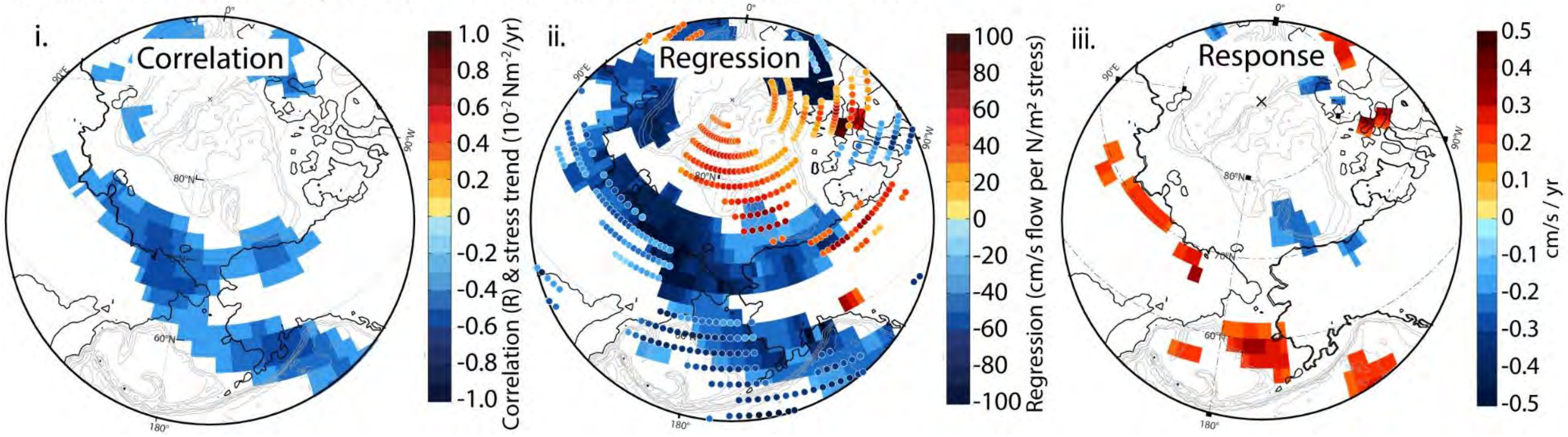
~0.6±0.3 cm/s/yr

Change in ESS τ^x:

~0.2±0.15 cm/s/yr

Fall (OND) τ^x and PHterm

Dots = trends



FALL (OND)

Observed PH term trend:

~0.8±0.5 cm/s/yr

Change in Bering Sea τ^x:

~0.3±0.2 cm/s/yr

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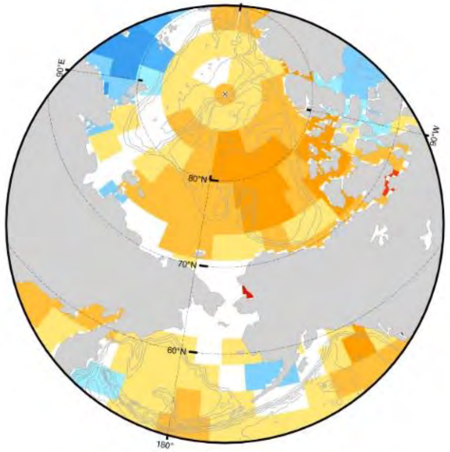
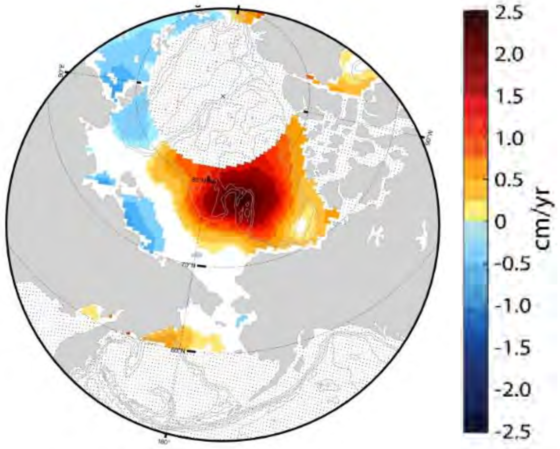
OBP and DOT differences imply ESS salinization

GRACE OBP



Altimetry DOT



Potential sources of ESS salinization:

a) **Sea ice formation:** needs ~2m sea ice growth in 2014 than 2003, or~50% of existing seasonal sea ice change → **too small**

b) **P – E** : ~200km^3/yr (Alkire et al., 2017), removed from ESS, would yield ~0.1psu salinization or ~5% of our → **too small**

c) **Upwelling** of deep/salty water into ESS: would need to fill ~10% of the ESS with 34psu water from 100m deep → **unlikely**

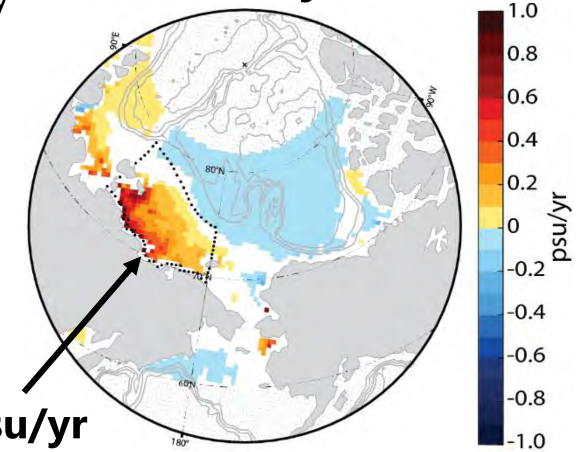
d) **Advection of Pacific Water** into ESS would only require a 5% increase ~0.02 Sv along Long Strait → **MOST LIKELY!**

Assuming steric (density) change is dominated by salinity change, we can estimate Salinity anomaly from Steric height following:

$$dS = -\frac{1}{\beta D} d\eta_{steric} \qquad \beta = (1/\rho)(d\rho/dS)$$

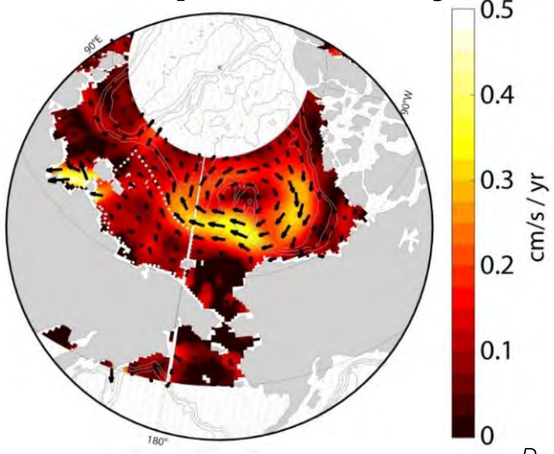
Armitage et al. [2016], JGR

Salinity



ESS: 0.17±0.06psu/yr

Geostrophic velocity



SMAP (2015-20) data suggests ESS salinization

Zhuk and Kuryalov, 2021

There is no in situ salinity data over 2003-14 period.

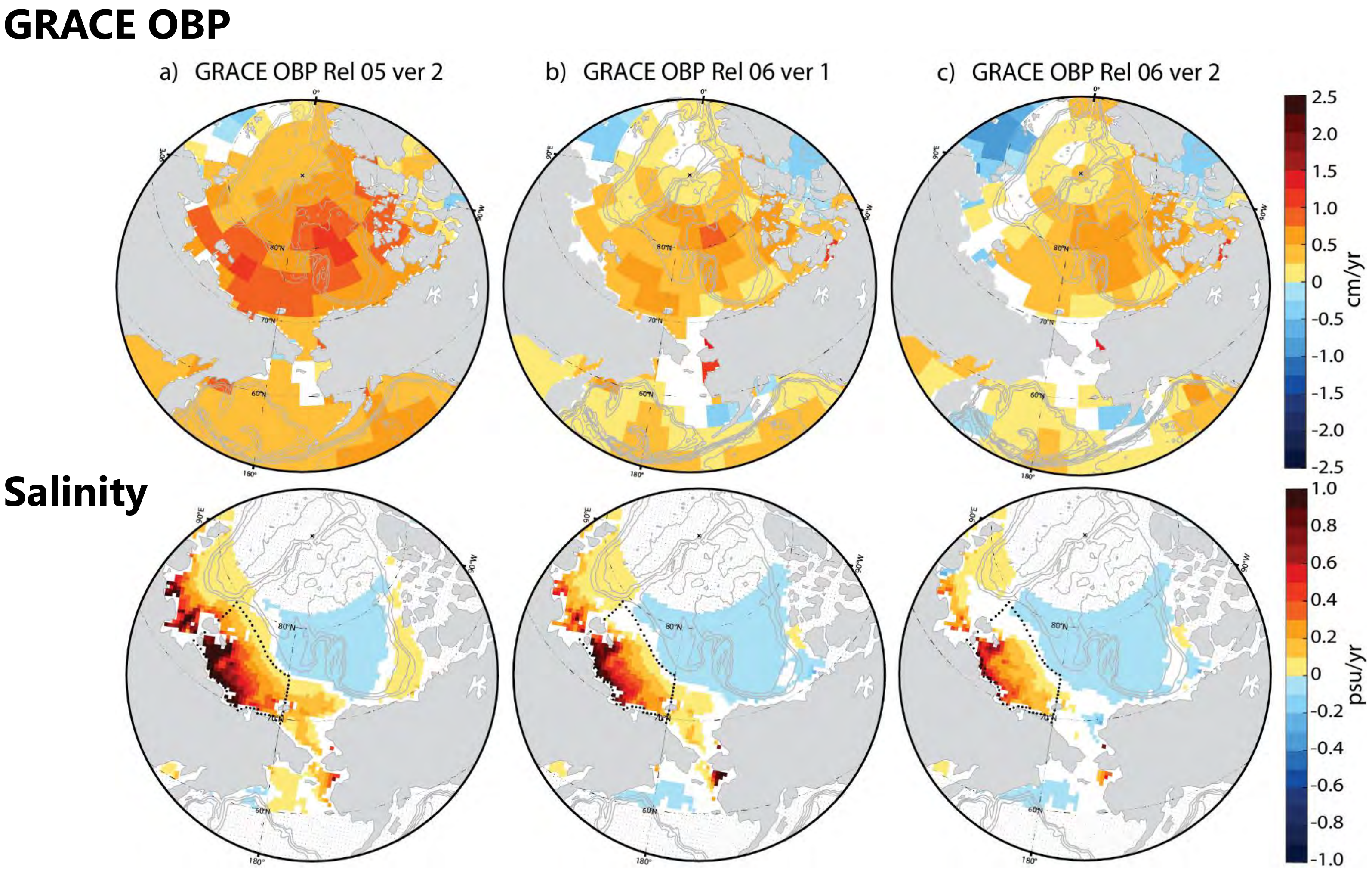
Peralta-Ferriz & Woodgate, 2023, GRL

Salinization from older GRACE JPL OBP versions

ESS Salinity trends are very sensitive to the GRACE data version used.

Models assimilating/tuned to older GRACE data will be missing a vital forcing of the flow. E.g., ASTE (Nguyen et al, 2021), using JPL masc Rel05 v2.

Pacific Water enters ESS region, thus accurate representation of salinity of Bering Strait waters is vital to getting trend in the flow correct.

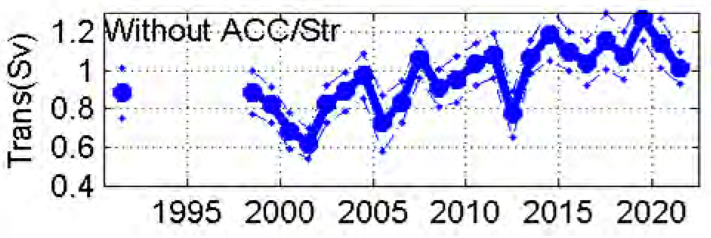


ESS trend: 0.4±0.06psu/yr **0.27±0.05psu/yr** **0.17±0.06psu/yr**

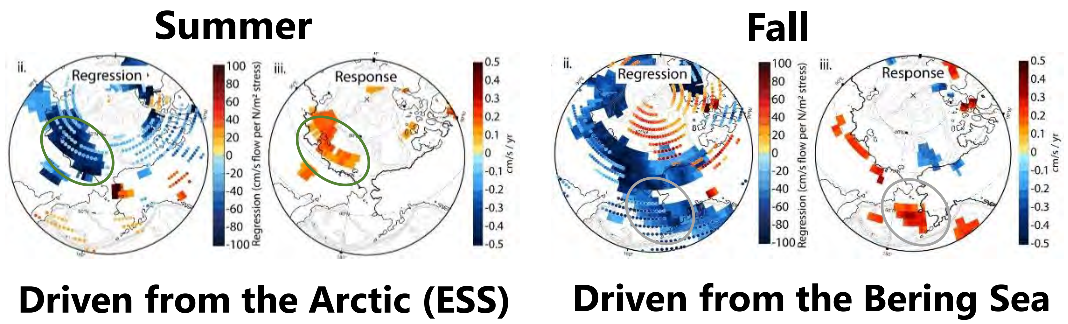
Peralta-Ferriz & Woodgate, 2023, GRL

Summary

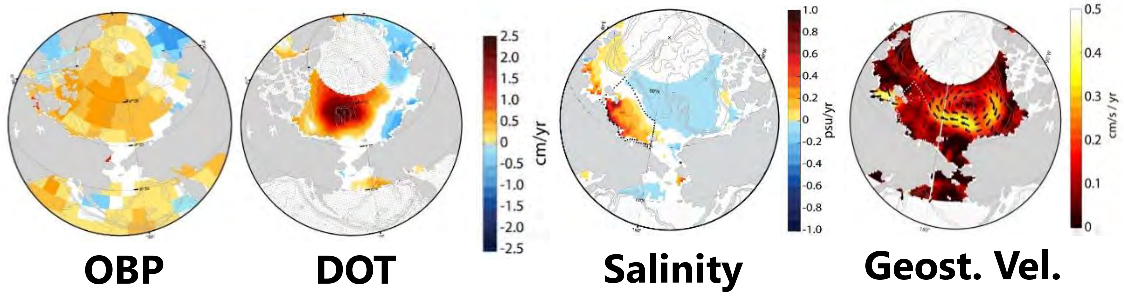
1. Since the 1990s, Bering Strait oceanic inflow has been increasing (**0.01±0.005Sv/yr ~ 0.23±0.12cm/s/yr**), warming (**0.03±0.02°C/yr**), freshening (**0.013±0.007psu/yr**).



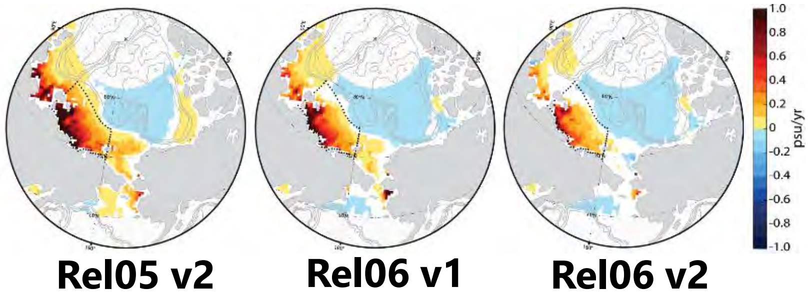
2. Increasing flow is due to increased PH forcing. Satellite data (2003-14) shows that the drivers of the increasing flow are from the Arctic's East Siberian Sea during the summer, and from the Bering Sea during the fall.



3. Difference in OBP and DOT trend imply **salinization in the ESS (~0.17psu/yr)**, **likely due to inflow of Pacific Waters** into the ESS region.



4. ESS salinization is very sensitive to the GRACE version. **Models assimilating older GRACE data, and/or getting the salinity of the strait flow wrong, will be missing forcing of the flow.**



Peralta-Ferriz & Woodgate, 2023, GRL

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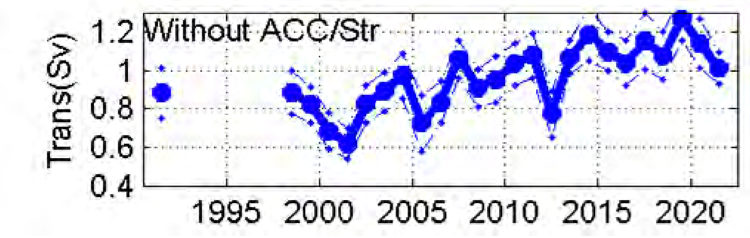

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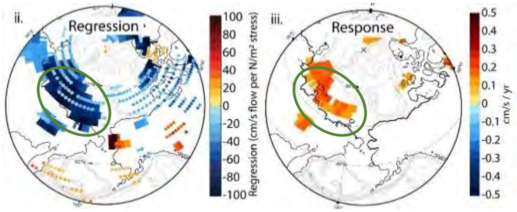
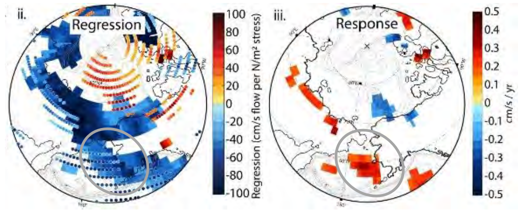
Summer



Driven from the Arctic (ESS)

Fall



Driven from the Bering Sea

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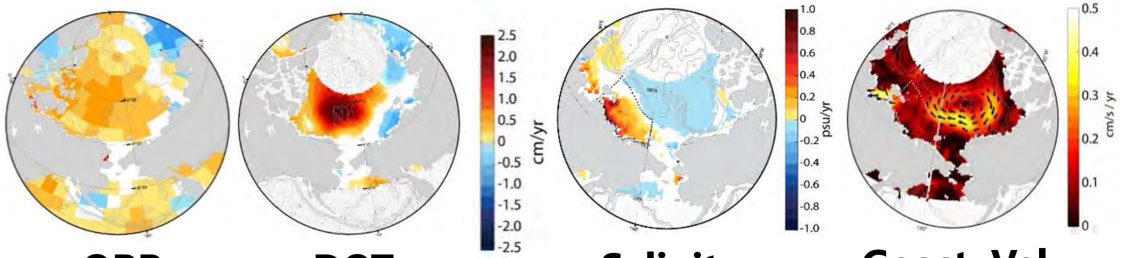

OBP **DOT** **Salinity** **Geost. Vel.**

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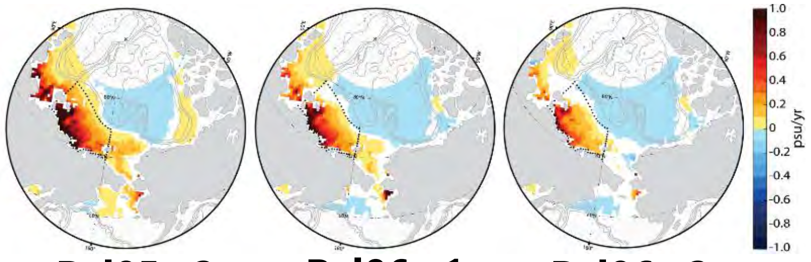

Rel05 v2 **Rel06 v1** **Rel06 v2**

Peralta-Ferriz & Woodgate, 2023, GRL

Thank you!