Understanding Recent Change in the Bering Strait

Rebecca Woodgate
University of Washington

NSF-AON project, with
co-PIs: **An Nguyen and Patrick Heimbach** ***MIT/Univ of Texas Austin***
Collaborators: **Julie Raymond-Yakoubian,** ***Kawerak, Inc***
Cecilia Peralta-Ferriz, ***University of Washington***

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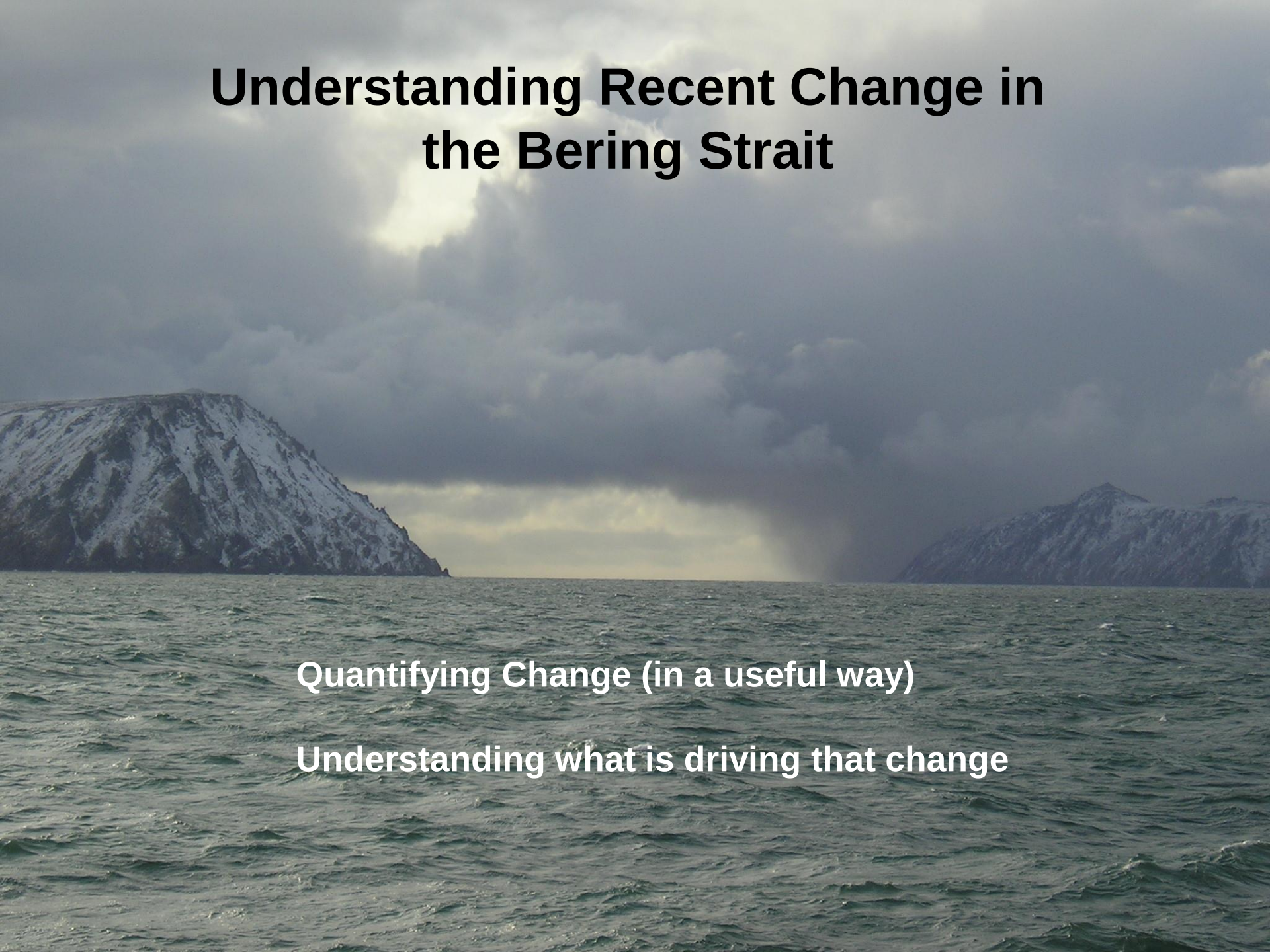
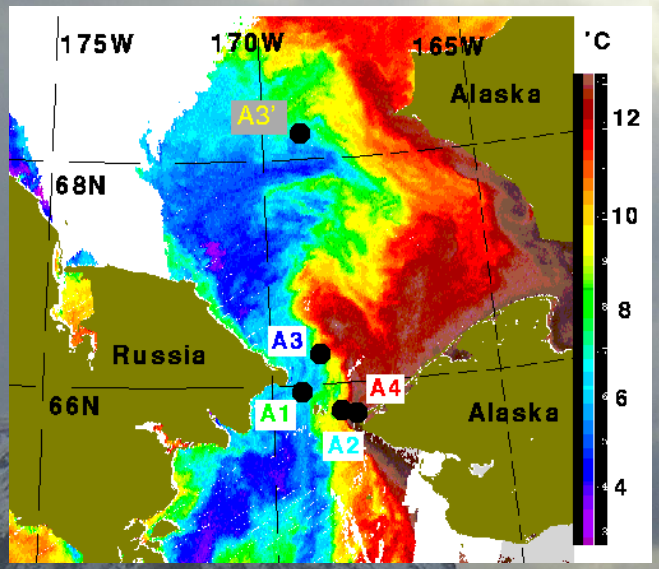
Understanding Recent Change in the Bering Strait



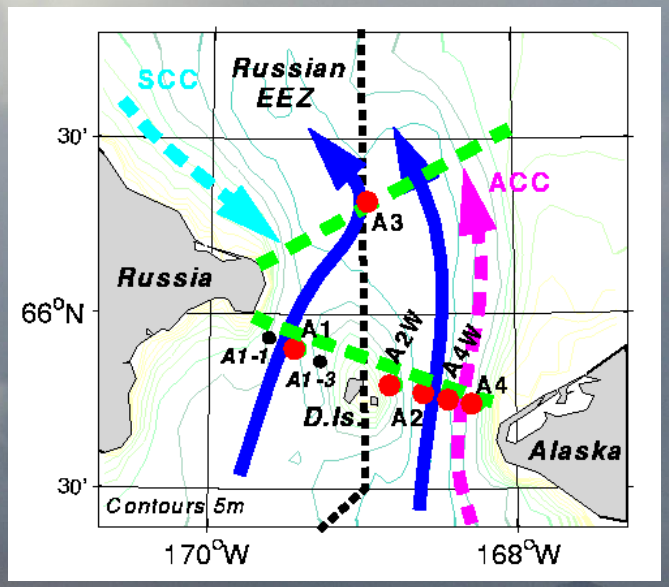
Quantifying Change (in a useful way)

Understanding what is driving that change

Overview of Bering Strait measurements



MODIS SST 26th Aug 2004



Early 1990s, 2004-2006

== 1+ moorings also in Russian waters.

2007-2011/2012

== ~ 8 moorings (including upper layer) in "high-resolution" US-Russian array

2012-present

== 3 moorings ("monitoring array") all in US waters (A2, A4, and A3 "climate)

1990 - present

== year-round moorings in US mid-channel (A1, A2, A3, A3')

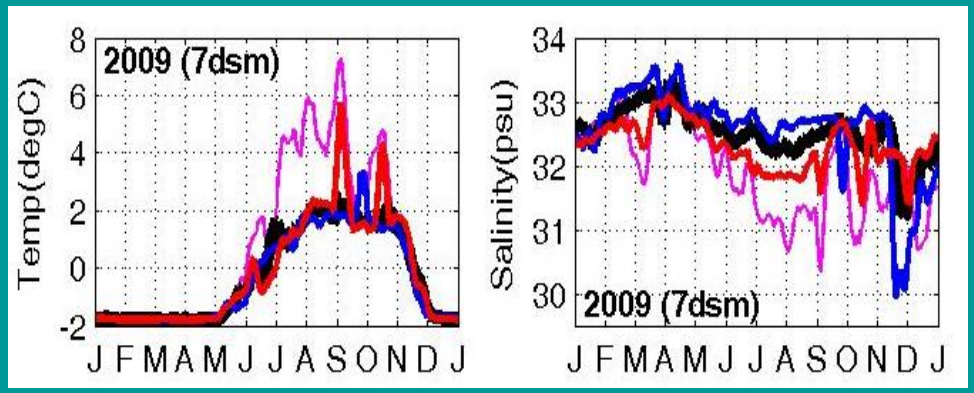
== mostly near bottom

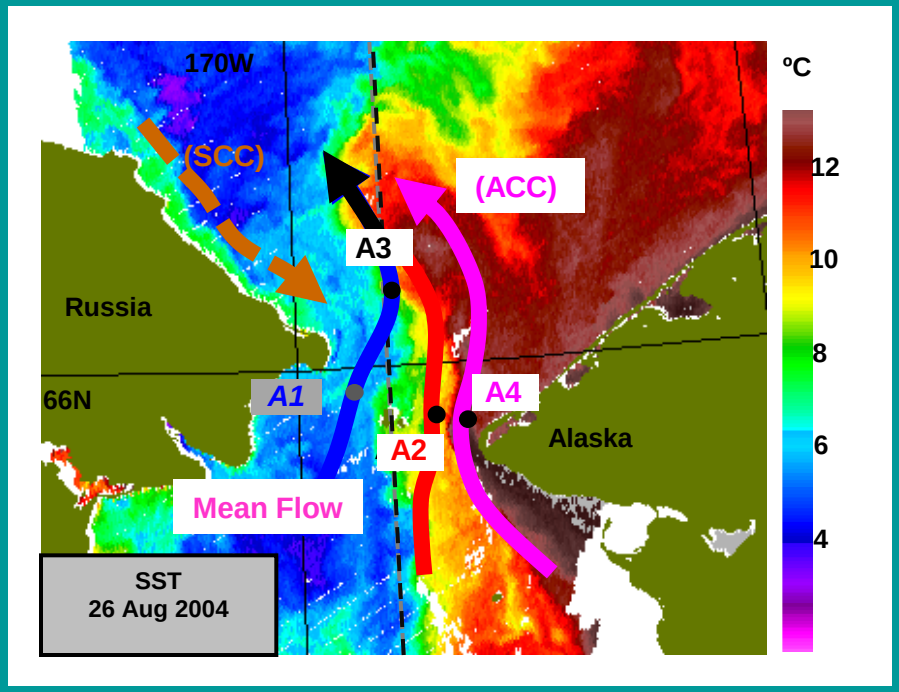
== 2001 started measuring the Alaskan Coastal Current with A4.

Woodgate et al, 2015, Bering Strait Synthesis, RUSALCA special issue of Oceanography, doi:10.5670/oceanog.2015.57

The 3-mooring scheme for the Bering Strait throughflow

Prior data show can quantify **physical** fluxes, using only 3 US moorings A2,A3,A4





Velocity

- well correlated at all sites

Temperature & salinity

- A3 (climate site, black) is a useful average of channel flows, i.e., A1 (blue) & A2 (red)

(Can infer A1 properties to ~ 0.1ºC and 0.2psu from A3 & A2)

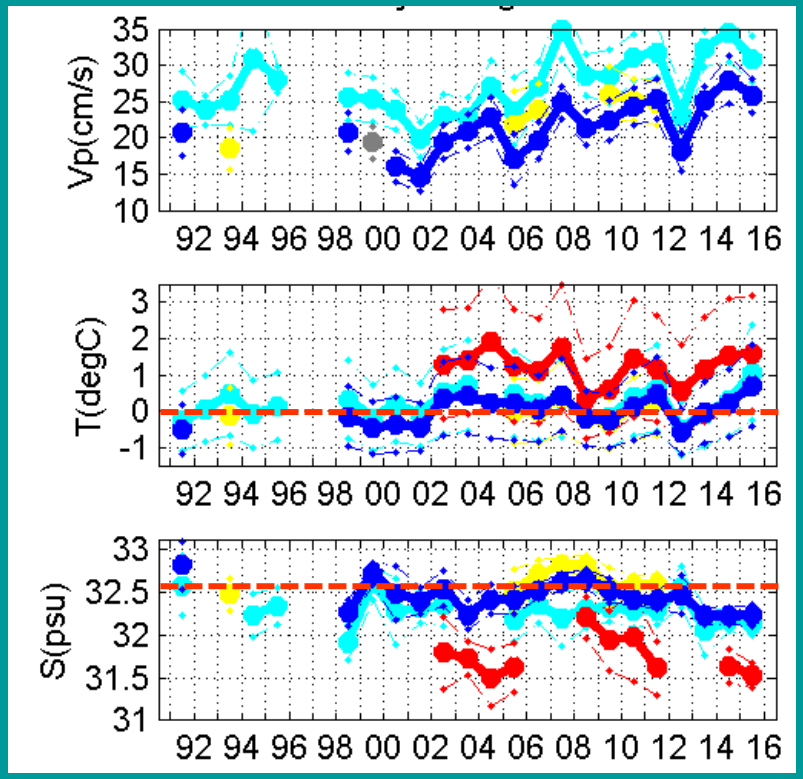
Must also measure A4, Alaskan Coastal Current (ACC)

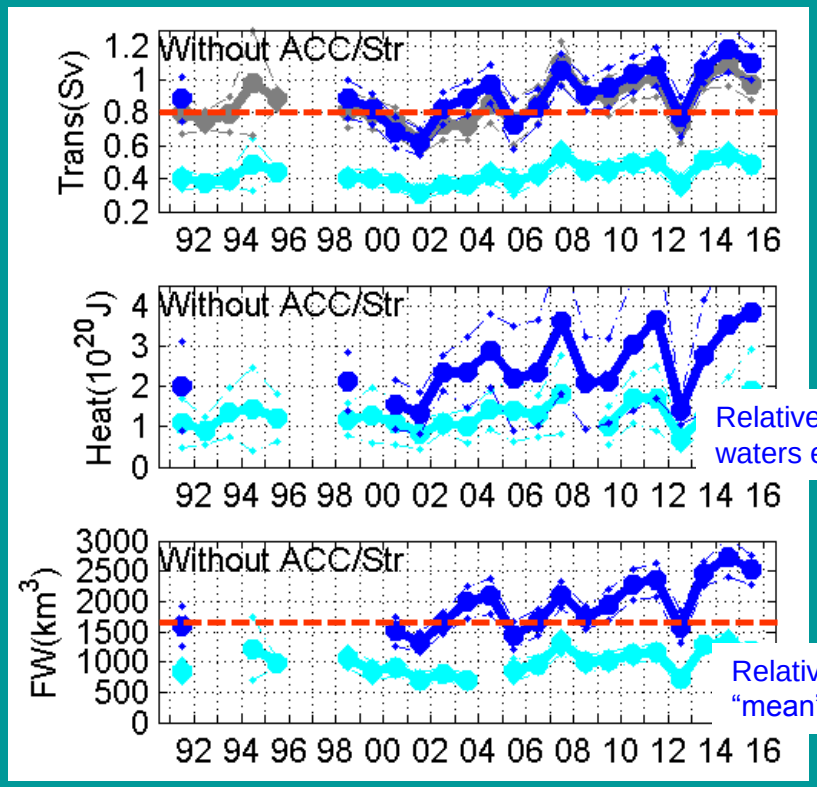
~ 1/3rd of total heat flux

~ 1/4 of total freshwater flux

Continuing Increases in Bering Strait fluxes

Focus on A3 (blue)
A4 (ACC) (red)





Relative to T Bering Strait waters exit Arctic(freezing)

Relative to 34.8psu, "mean" salinity of Arctic

Apart from 2012, volume transport increasing (now > 1Sv)

Modest warming (step change 2001-2002), possible freshening (if include 1991)
- with increased volume yields significant increases in Heat & Fresh

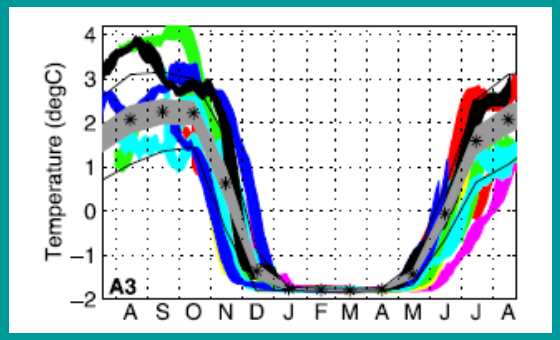
Record freshwater fluxes (> 3500km^3/yr)

No significant trends in the (shorter) A4 (ACC) timeseries

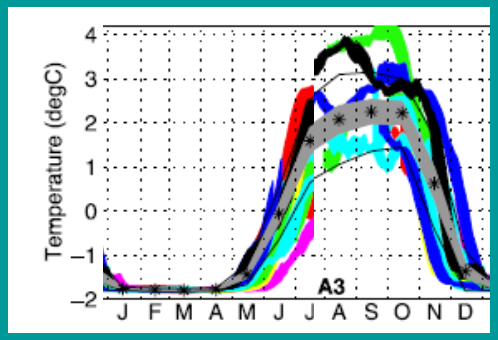
strangely unsatisfying without some understanding

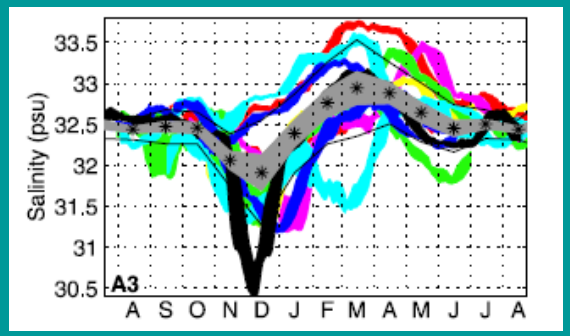
Seasonality of the Bering Strait

Grey=climatology
Colors = individual years

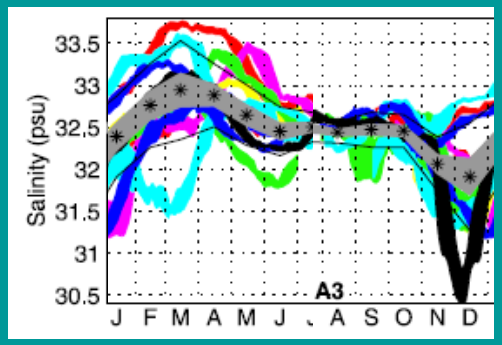


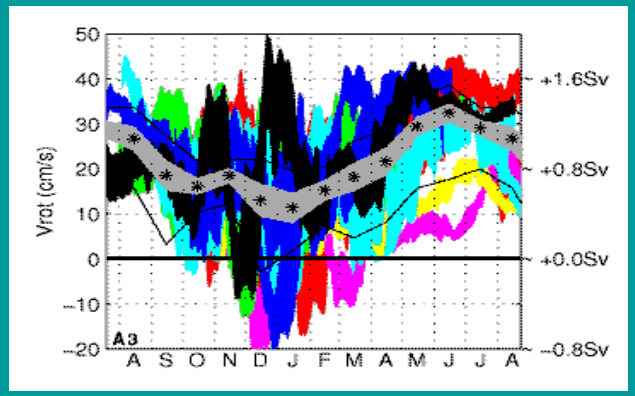
Temperature Seasonality
- warm in summer
- freezing temp in winter



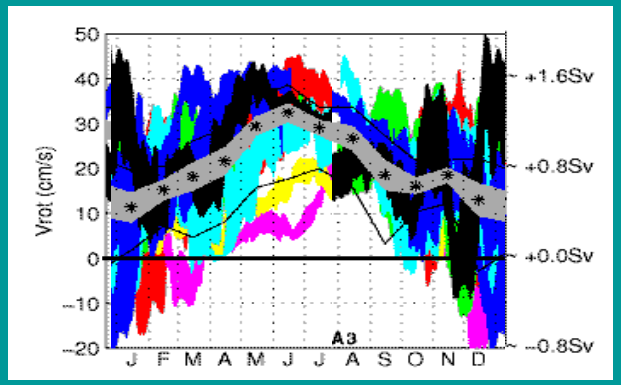


Salinity Seasonality
- high in winter (ice formation)
- freshening (ice melt, rivers, ACC)
- fall mixing of surface freshwaters





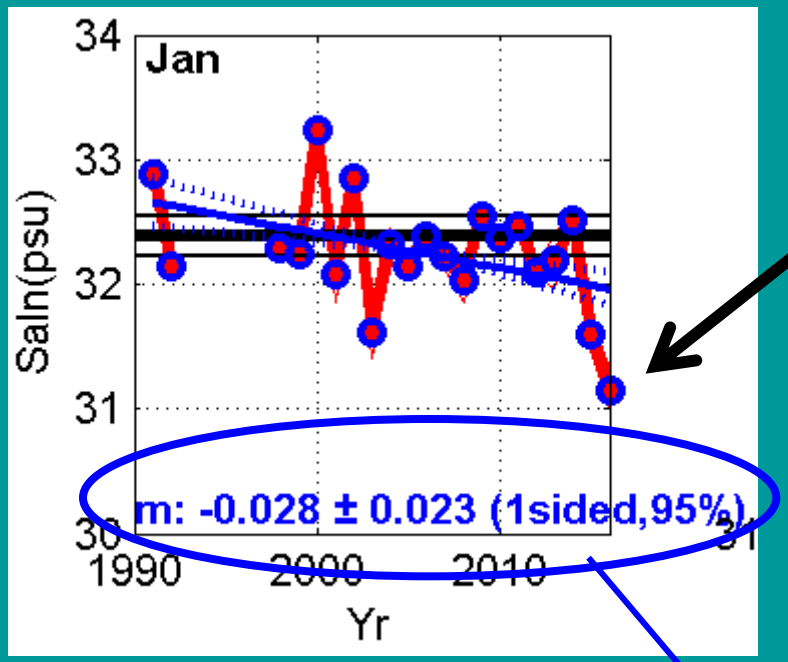
Transport Seasonality
- high in summer
- weak in winter
(stronger southward winds)

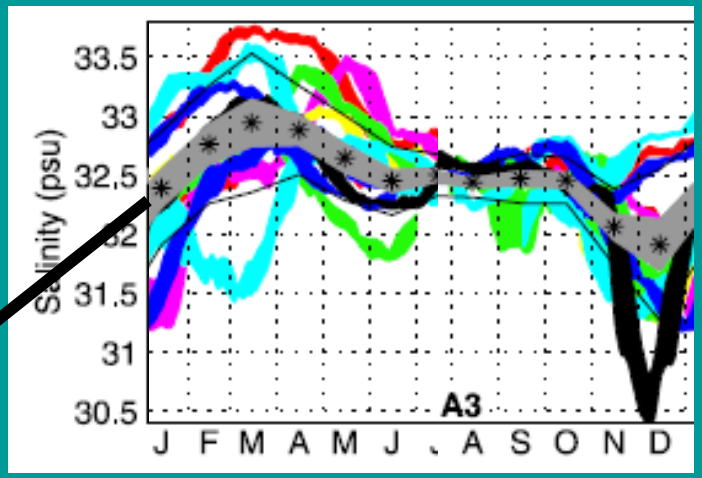


Woodgate et al, 2005, GRL

First – seasonal change in salinity

For each month …

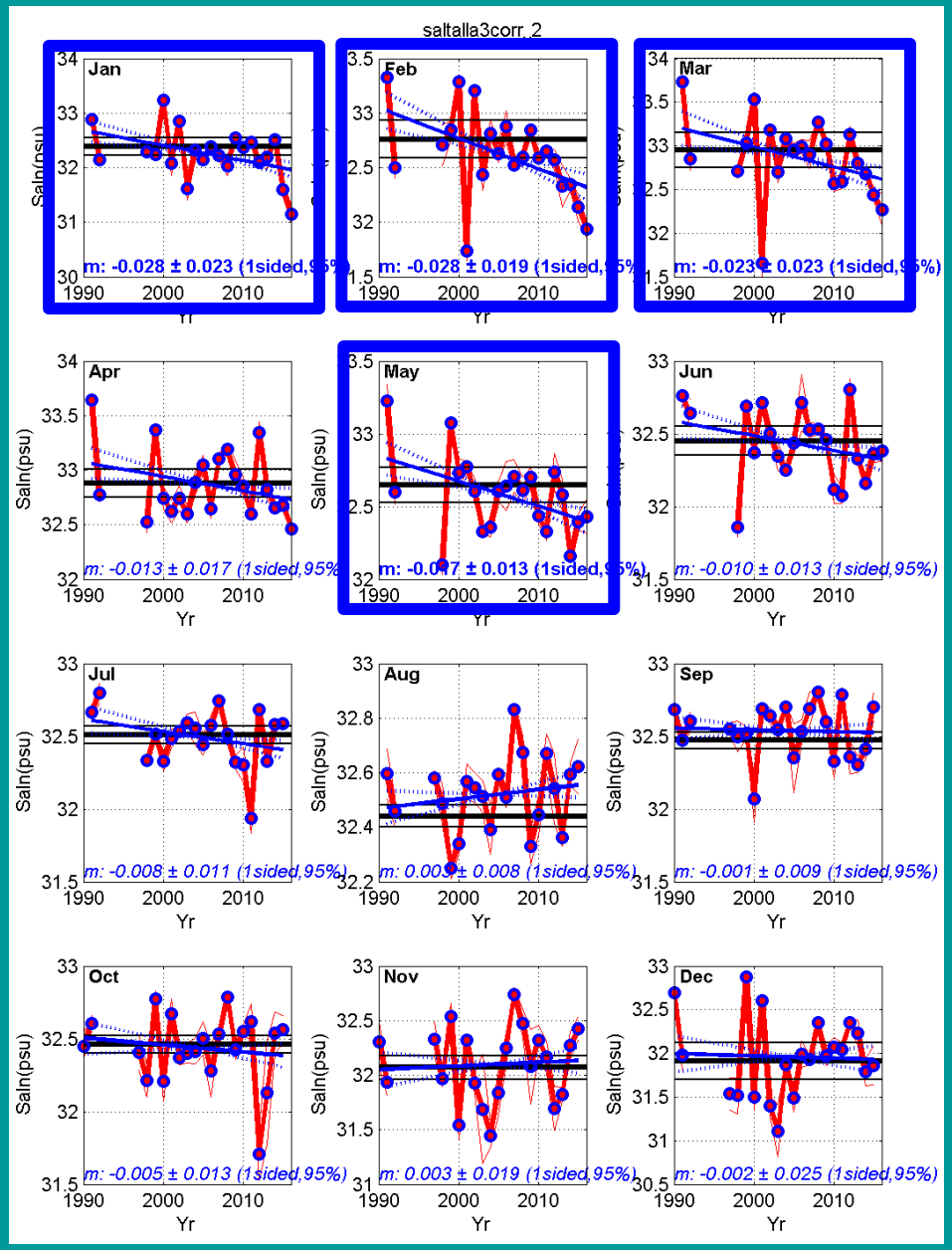




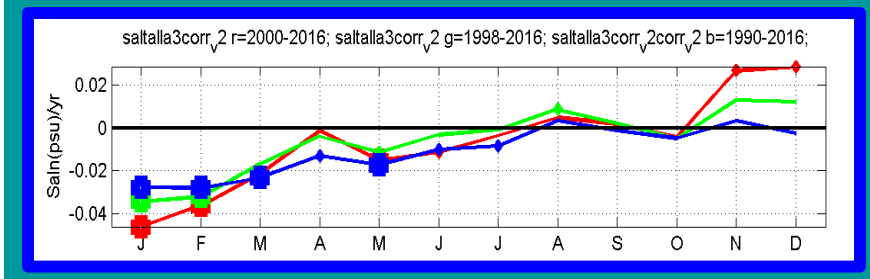
Woodgate et al, 2005, GRL

Linear trend of Monthly mean over years *(Italic = not significant at 95%)*

Trends in Salinity in different seasons



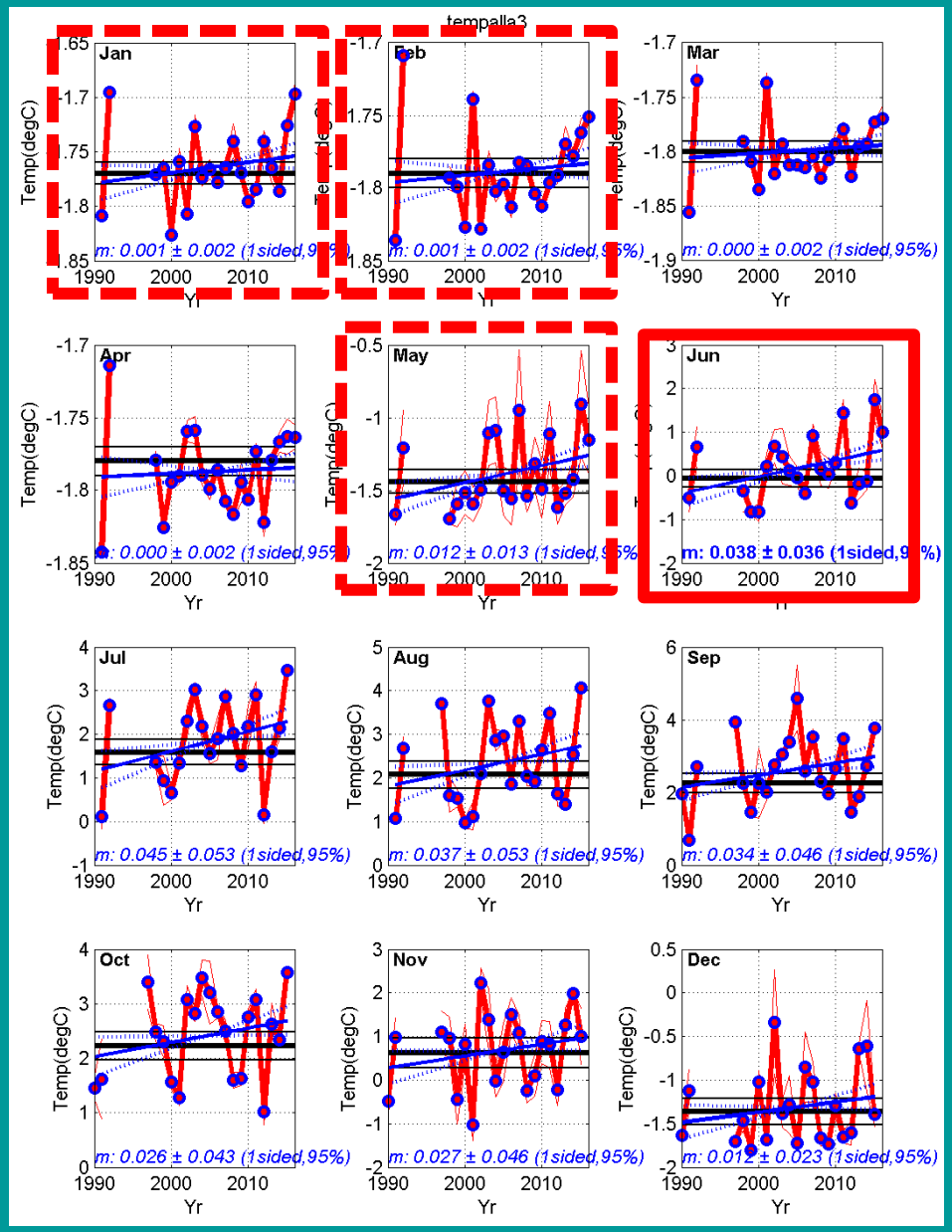
Statistical significant freshening in winter/spring



Only SOME months have significant trend

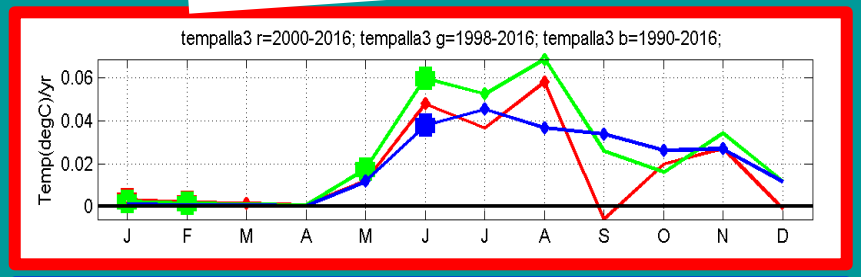
Summarize those trends by month for different periods
- blue 1990-2016
- green 1998-2016
- red 2000-2016

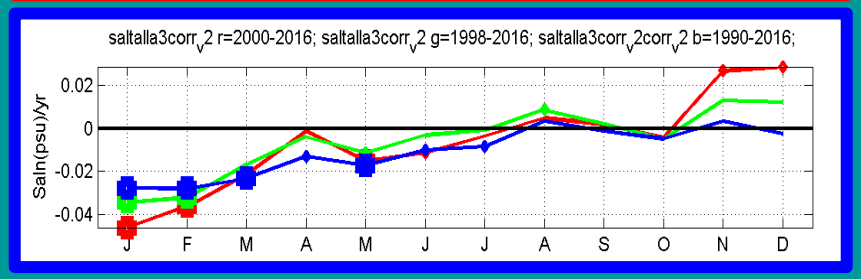
Trends in Temperature in different seasons



Statistical significant (just)
- warming in June
- freezing pt warming in winter

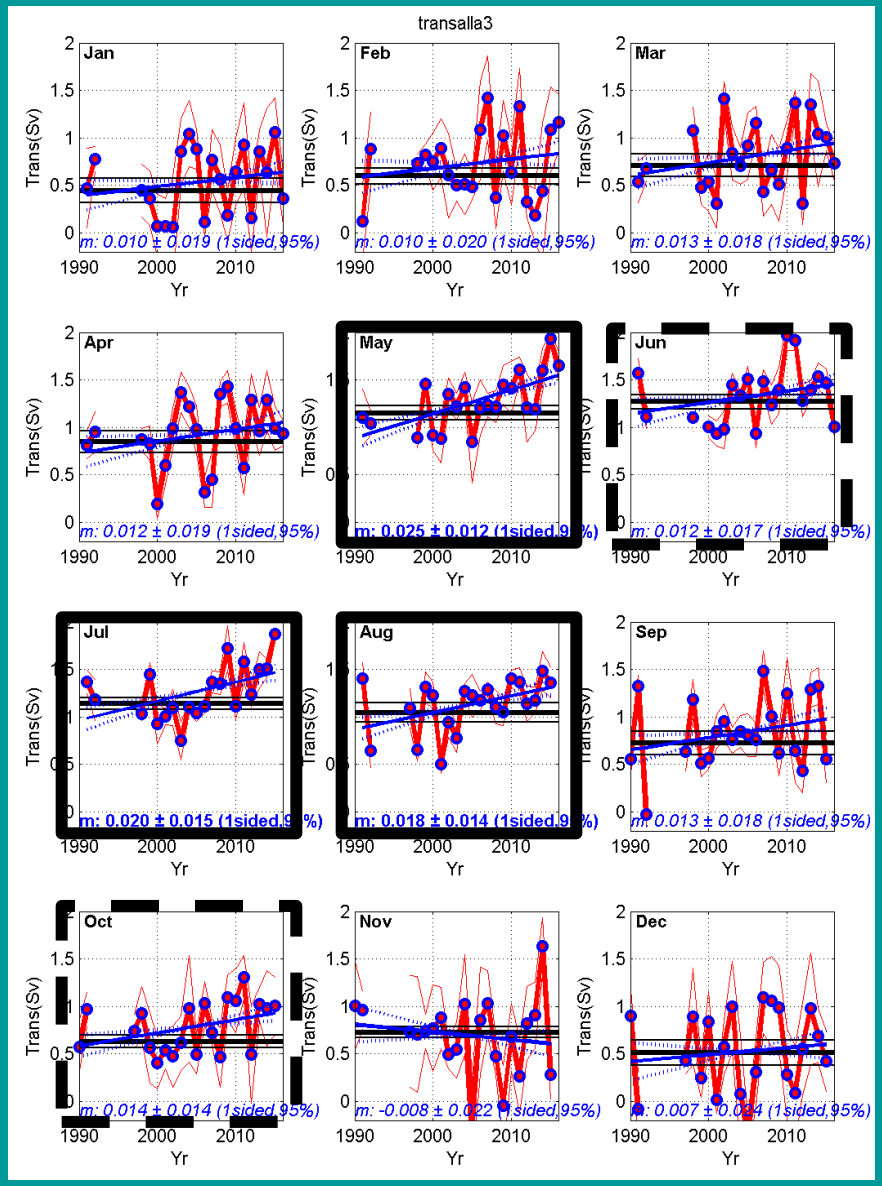
Also, trend to earlier arrival of warm waters





Summarize those trends
by month for different periods
- blue 1990-2016
- green 1998-2016
- red 2000-2016

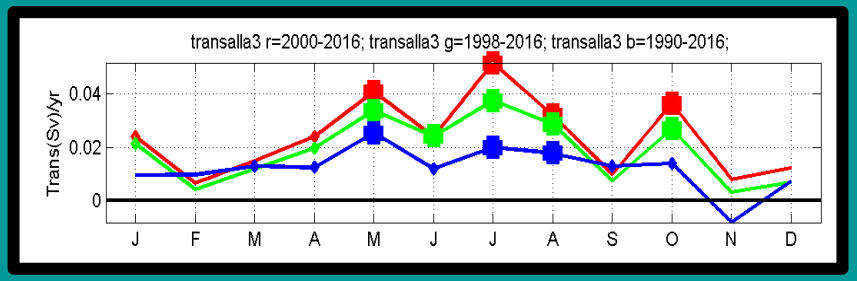
Trends in Velocity in different seasons



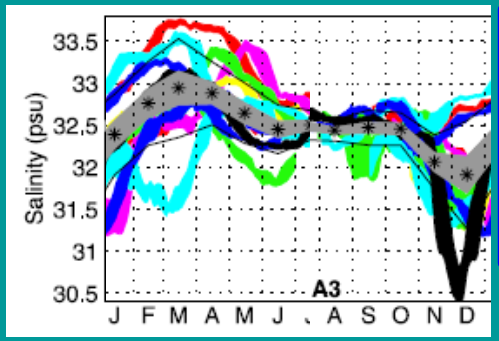
Statistical significant flow increase in summer

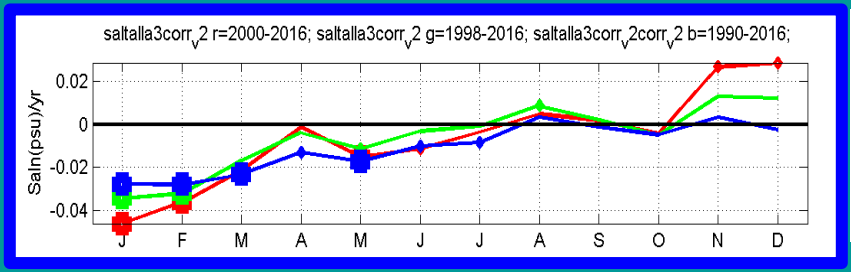
Summarize those trends by month for different periods

- blue 1990-2016
- green 1998-2016
- red 2000-2016

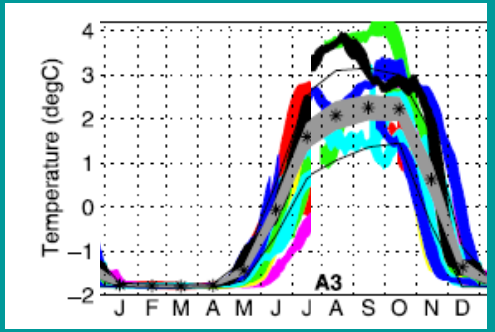


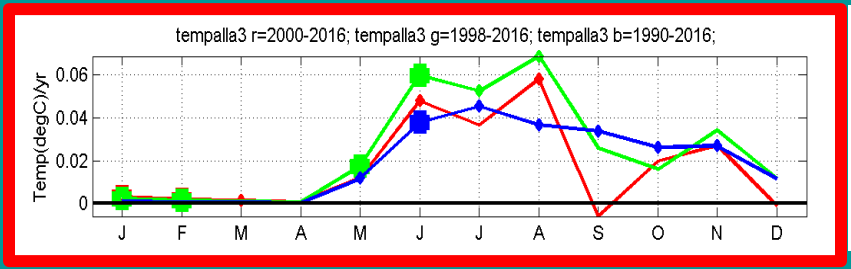
Trends in different seasons



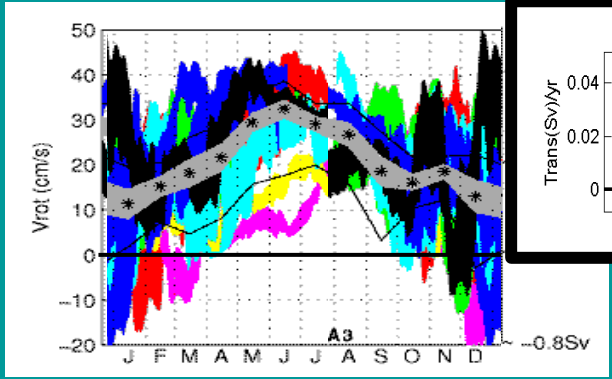


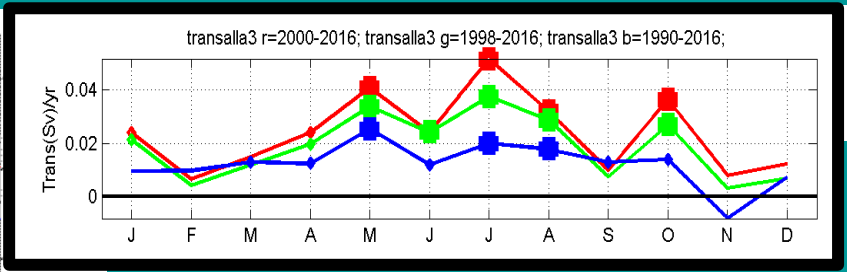
Change in S cycle
Less ice formation?
Earlier ice melt?
More river water?





Warming, esp in early summer
Earlier arrival of warm waters

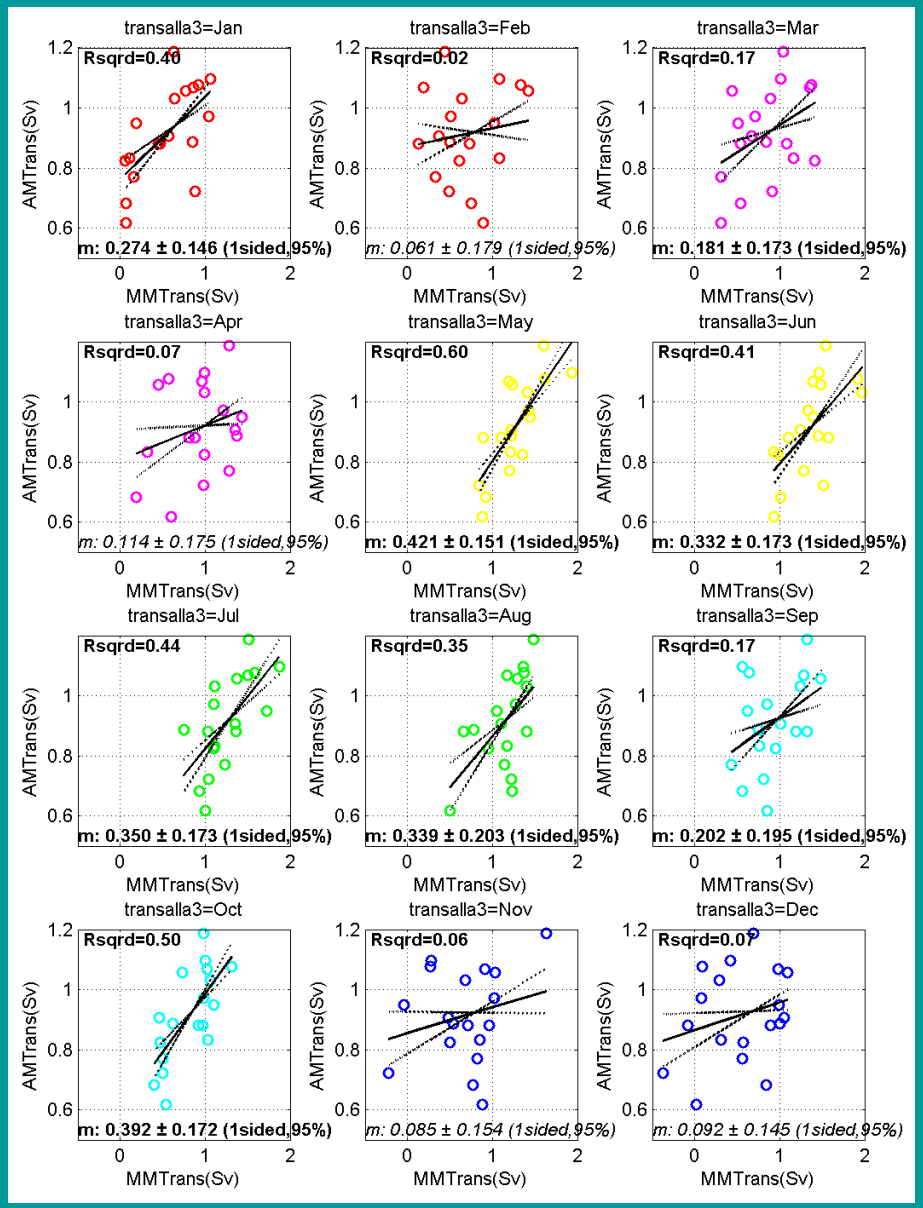




Increasing flow in summer

Grey=climatology
Colors = individual years

Summer (May and Oct) transports significantly correlated with annual mean transports



Monthly mean explains ?? of annual mean variance

Jan	~ 40%
Feb	*~ 2%*
Mar	*~ 17%*
Apr	*~ 7%*
May	**~ 60%**
Jun	~ 41%
Jul	~ 44%
Aug	~ 35%
Sep	*~ 17%*
Oct	**~ 50%**
Nov	*~ 6%*
Dec	*~ 7%*

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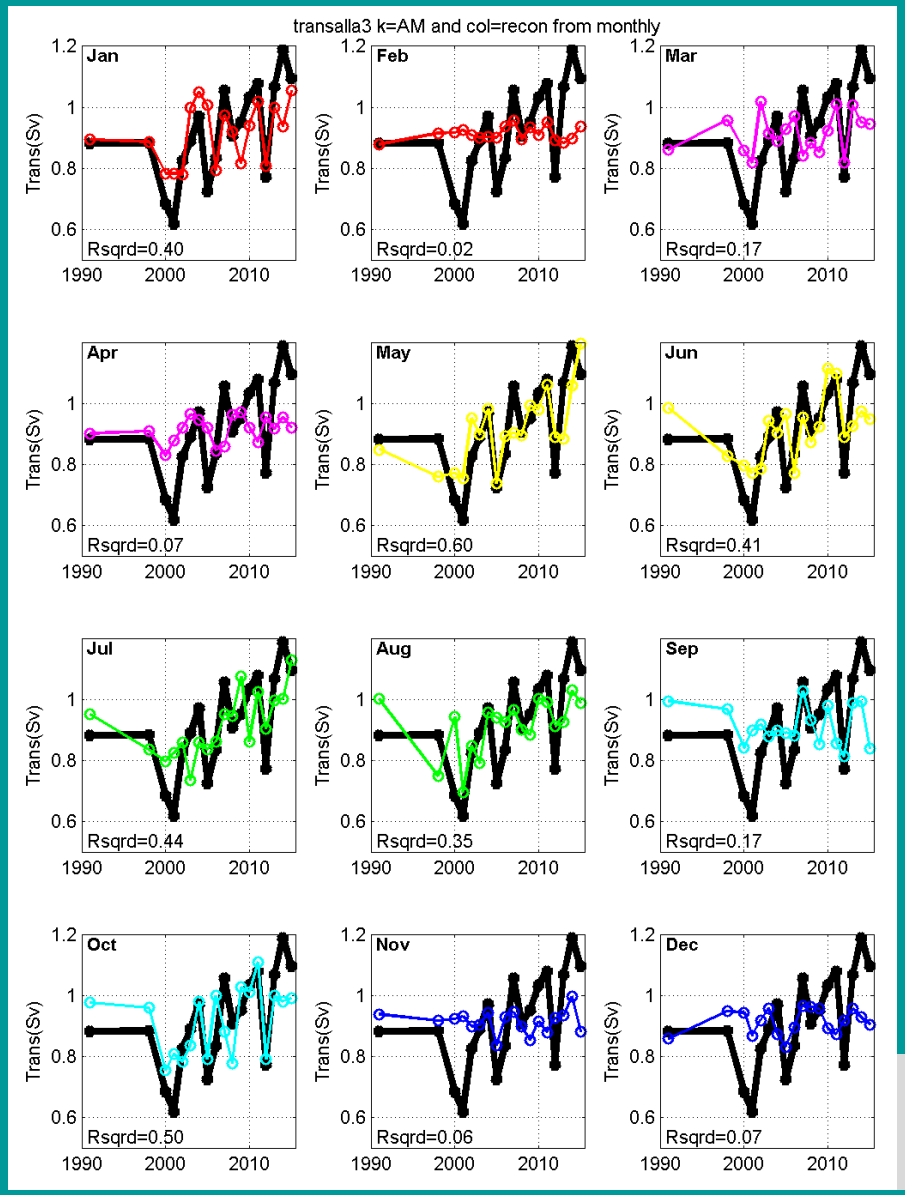

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Reconstruction (color) of annual mean (black)

Variability, trends, and predictability of seasonal sea ice retreat and advance in the Chukchi Sea

JGR 2015

Mark C. Serreze[1], Alex D. Crawford[1], Julienne C. Stroeve[1], Andrew P. Barrett[1], and Rebecca A. Woodgate[2]

Date of sea-ice retreat in the Chukchi

- strongly (r~0.8) with April-June Bering Strait Heat Flux

- better correlated with Bering Strait than with other temp/radiation terms

Table 1. Pearson Correlations Between Detrended Time Series of Retreat Day and Seasonal Oceanic, Surface Radiation, and Atmospheric Variables Averaged for April Through June[a]

Variable	Full Record (1979–2014)		1991–1992, 1998, 2000–2013	
Bering Strait heat inflow	N/A		**−0.81** (0.000)	
	MERRA	ERA-Interim	MERRA	ERA-Interim
10 m meridional wind	−0.29 (0.08)	−0.29 (0.09)	−0.11 (0.66)	−0.12 (0.64)
2 m temperature	**−0.43** (0.01)	**−0.42** (0.01)	**−0.60** (0.01)	**−0.59** (0.01)
Net allwave radiation	**−0.66** (0.00)	**−0.74** (0.00)	**−0.59** (0.01)	**−0.66** (0.00)
Net shortwave radiation	**−0.39** (0.02)	**−0.56** (0.00)	−0.47 (0.06)	**−0.52** (0.03)
Downwelling shortwave radiation	**+0.39** (0.02)	+0.24 (0.16)	+0.16 (0.53)	+0.14 (0.59)
Upwelling shortwave radiation	**−0.73** (0.00)	**−0.65** (0.00)	**−0.68** (0.00)	**−0.67** (0.00)
Net longwave radiation	**−0.34** (0.04)	−0.22 (0.21)	−0.10 (0.69)	−0.09 (0.72)
Downwelling longwave Radiation	**−0.50** (0.00)	**−0.37** (0.02)	−0.47 (0.06)	−0.39 (0.12)
Upwelling longwave radiation	**+0.45** (0.01)	**+0.42** (0.01)	**+0.65** (0.00)	**+0.55** (0.02)

[a]When applicable, correlations are calculated using two atmospheric reanalyses and time periods. Bold values are significant at $p < 0.05$ (p values are in parentheses and assume independent observations). Radiation fluxes are defined as positive downward.

What is driving the interannual change?

As many have done, from DATA we seek a fit of the form:

Water Velocity = mmm x Local Wind + Offset

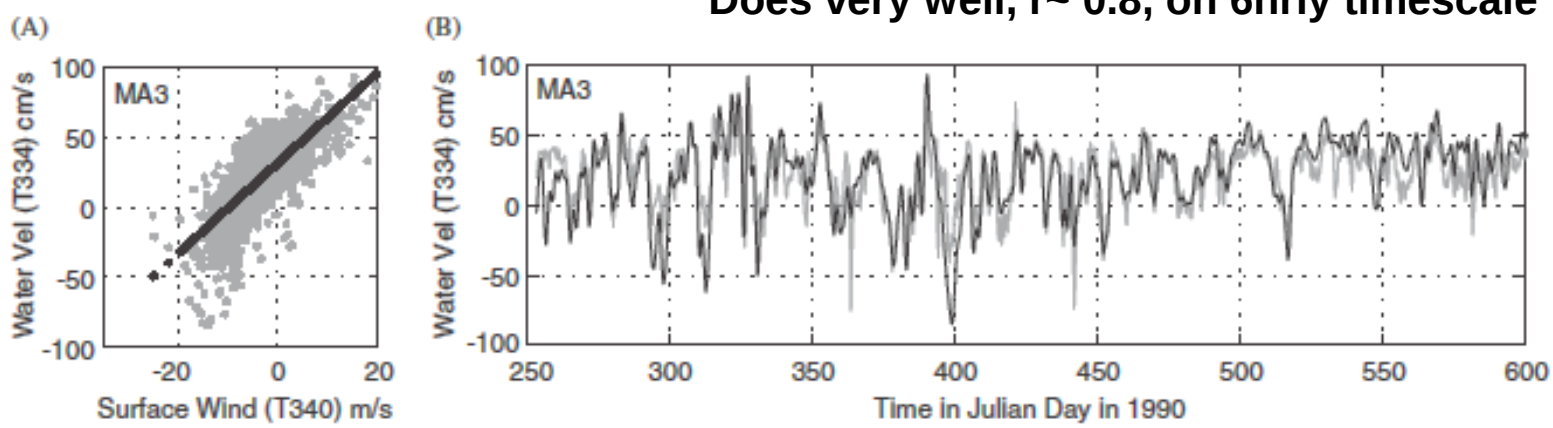
Coachman & Aagaard, 1981,
Aagaard et al, 1985,
Woodgate et al, 2012

Far-Field Forcing i.e., the "Pressure Head"
(Bit we can't explain with local wind)

Pick the wind direction which best correlates with the flow
~ 330°, i.e., ALONG strait
best with velocity, not (velocity)^2

Can prove both of these (Woodgate et al, in prep)

Does very well, r~ 0.8, on 6hrly timescale



Woodgate, et al, 2005, DSR

What is driving the interannual change?

As many have done, from DATA, seek a fit of the form:

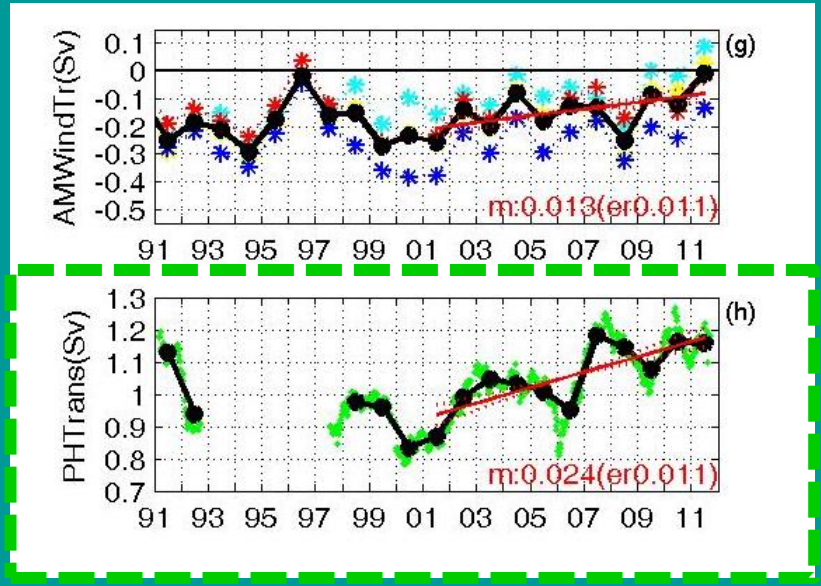
Water Velocity = mmm x Local Wind + Offset

Pick the wind direction which best correlates with the flow
~ 330°, i.e., ALONG strait
Best with W, not W^2

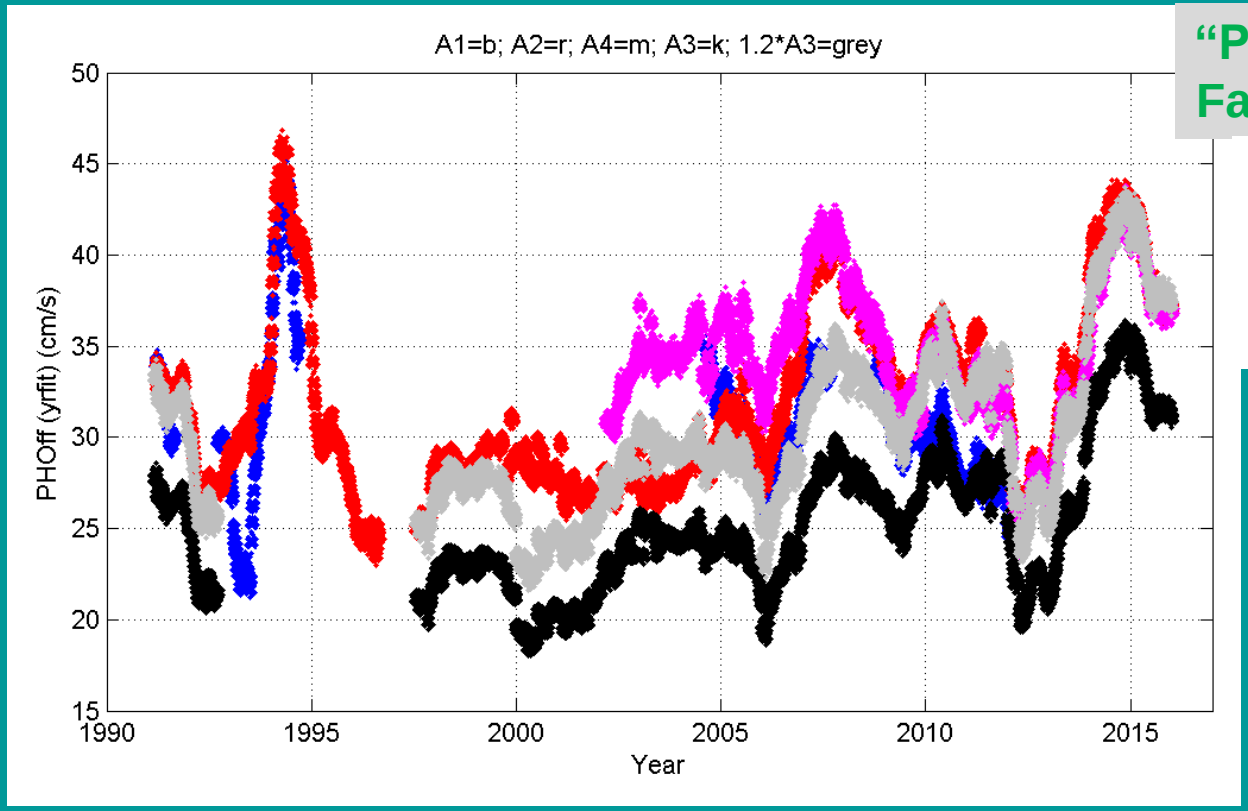
Far-Field Forcing i.e., the "Pressure Head"
(Bit we can't explain with local wind)

<u>But what drives change in annual mean?</u>
~ 1/3rd due to changes in wind
~ 2/3rds due to Pressure Head
(i.e., can't infer from the wind)

Woodgate et al, 2012, GRL



More years, more moorings …



"Pressure Head"
Far Field Forcing

A3=black
A3 scaled = grey
A1=blue
A2=red
A4=magenta

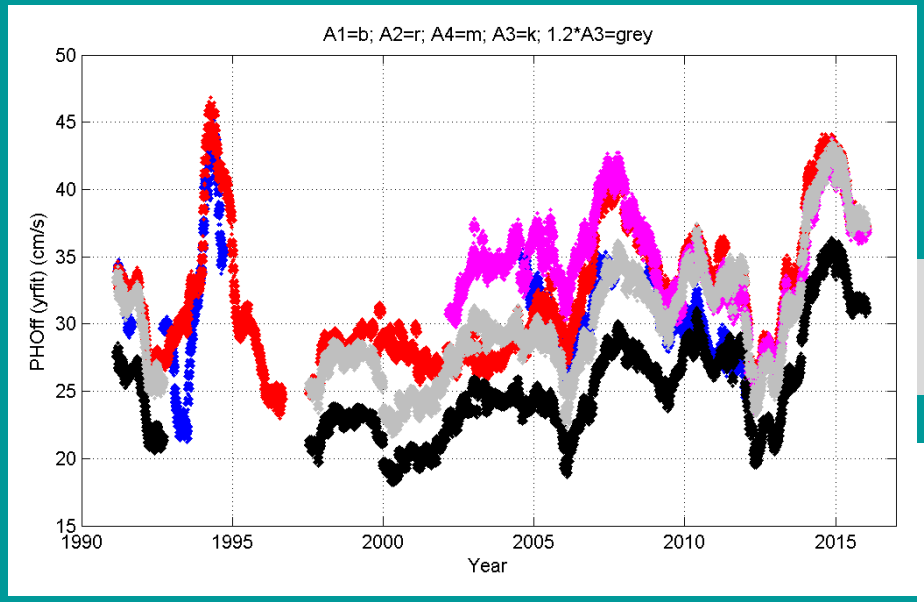
Based on fit within 1year long moving window

Satisfying (if perhaps not unexpected) agreement between moorings

Sizeable interannual variabiity

Is that the whole story?
Check the other terms

More years, more moorings



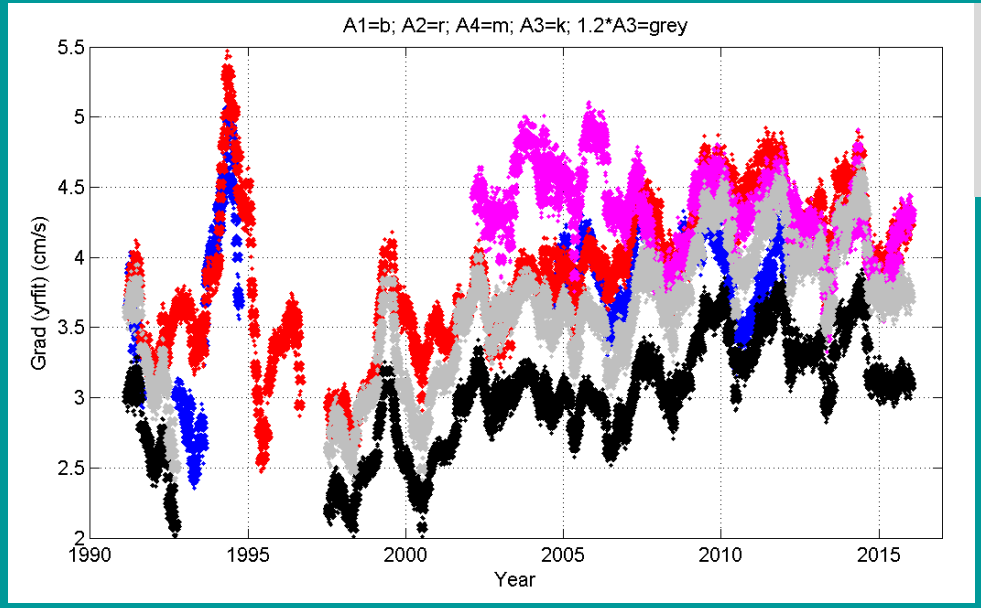
Based on fit within 1year long moving window

Water Velocity
=
mmm x Local Wind
+
Offset (PH)

"Pressure Head" (PH)
Far Field Forcing

A3=black
A3 scaled = grey
A1=blue
A2=red
A4=magenta

Ice?
Problems?
Let's look seasonally



mmm
Wind-Water
Coupling

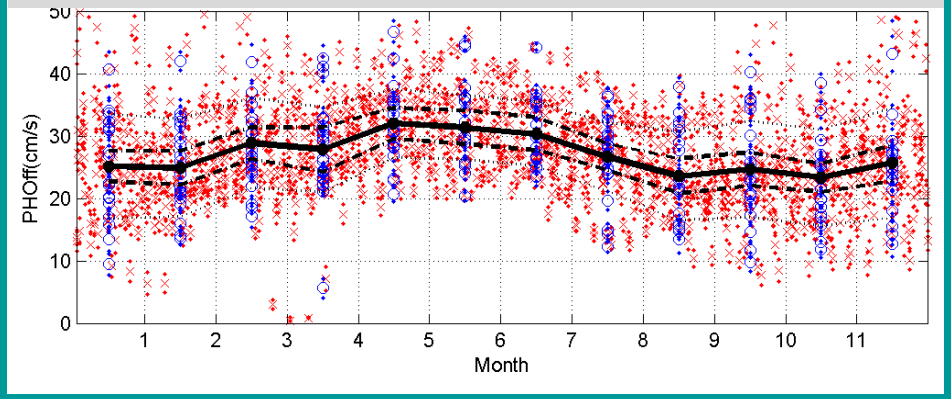
Significant variability in mmm
(Smaller than PH change, but still substantial)

Interannual and Seasonal

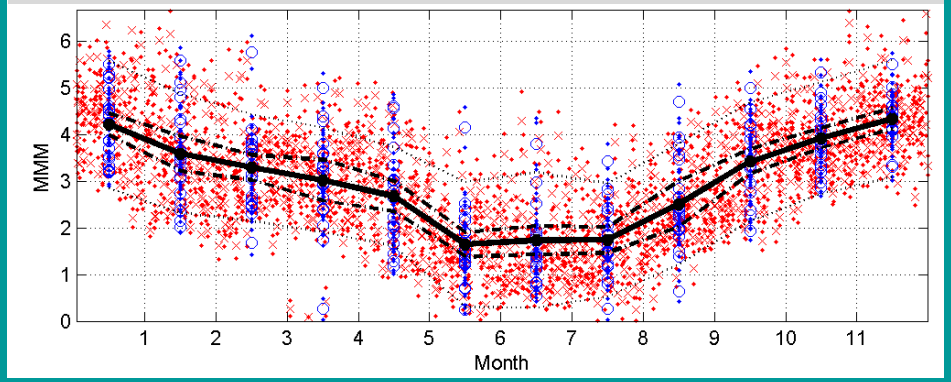
Return to Seasonality of Fit

For each month, fit for
Water Velocity
=
mmm x Local Wind
+
Offset

offset, PH



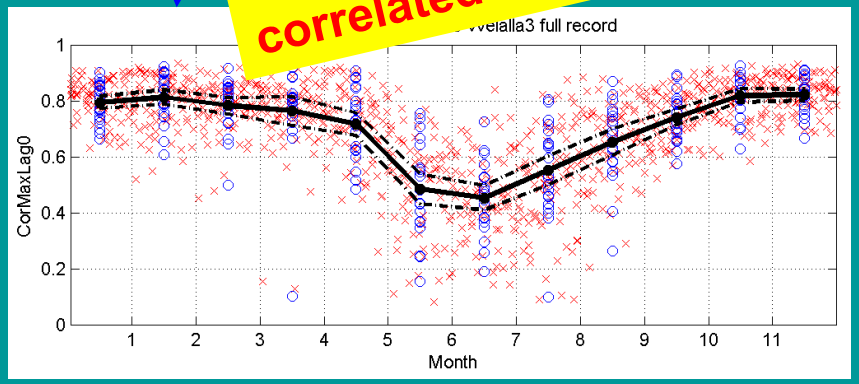
mmm, Wind coupling



Not much seasonality in PH,

but STRONG seasonality in strength of wind coupling (and in correlation of wind with water velocity)

Summer flows much less correlated with winds



Is this:
- ice-ocean coupling
- pressure head dominance
… or .. unreliable winds?

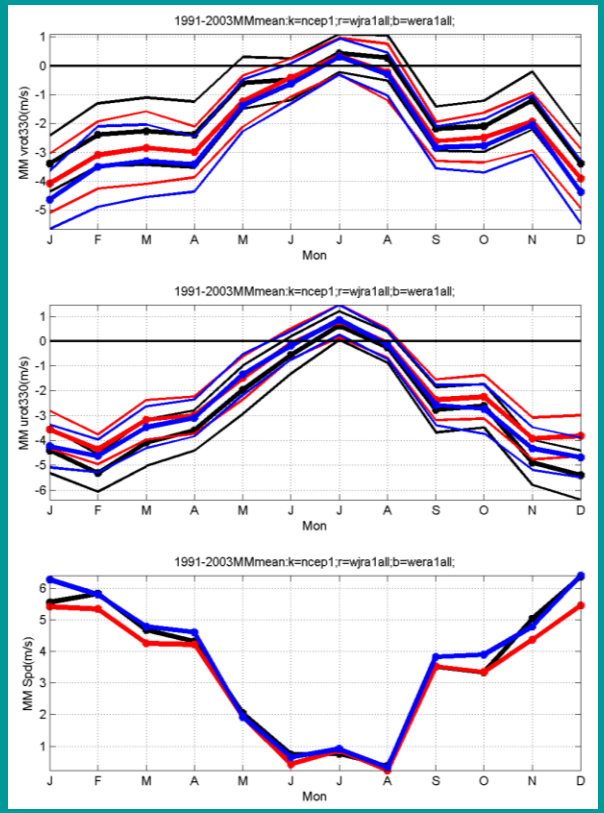
“Atmospheric Depression”

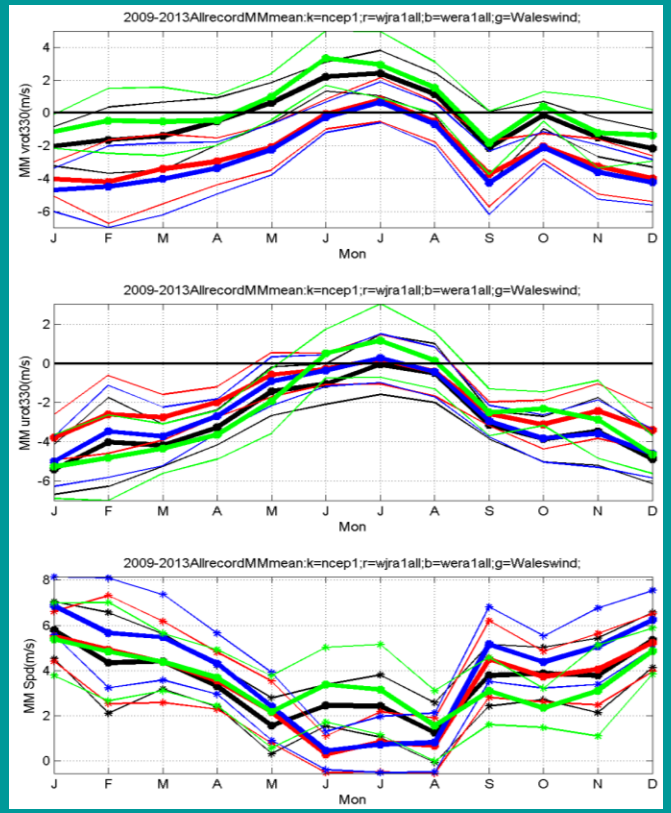
Compare: NCEP, JRA, ERA1 and observed winds at Bering Strait (Wales)

Along Strait Wind

Cross Strait Wind

Wind Speed





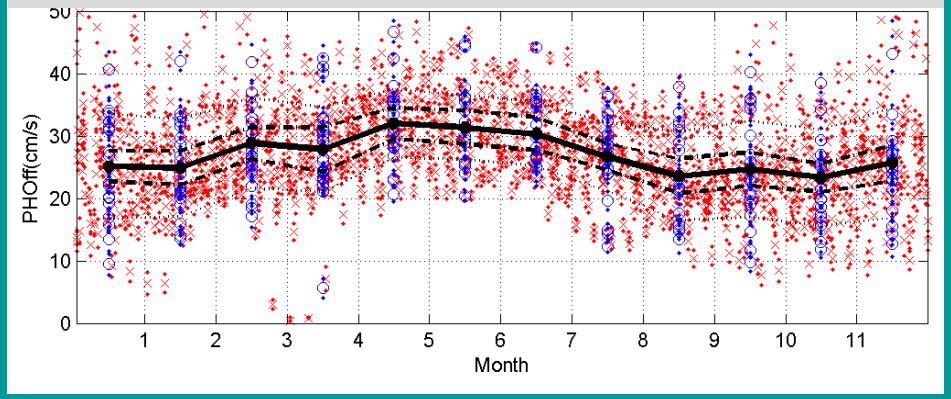
Hmm
- **all have a seasonal cycle**
- **all weak in summer, … but large discrepancies in details.**

All agree winds weak in summer, when we see the trends in transport

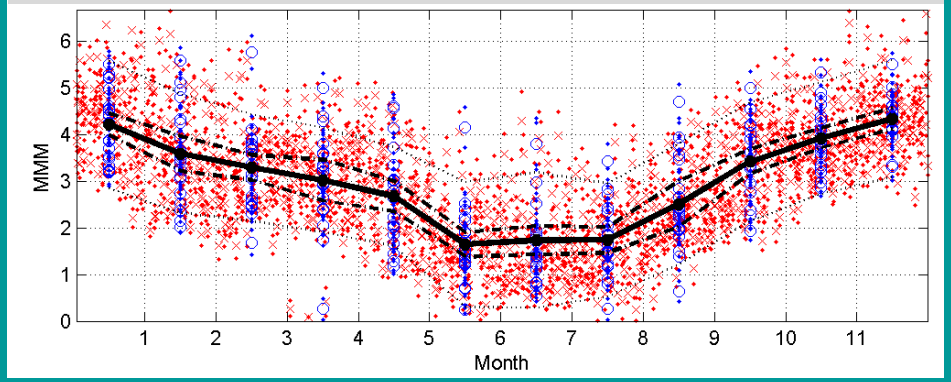
Return to Seasonality of Fit

For each month, fit for
Water Velocity
=
mmm x Local Wind
+
Offset

offset, PH



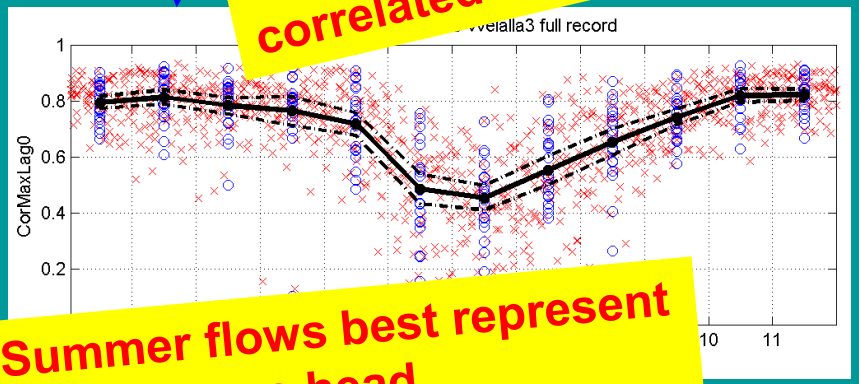
mmm, Wind coupling



Not much seasonality in PH,

but STRONG seasonality in strength of wind coupling (and in correlation of wind with water velocity)

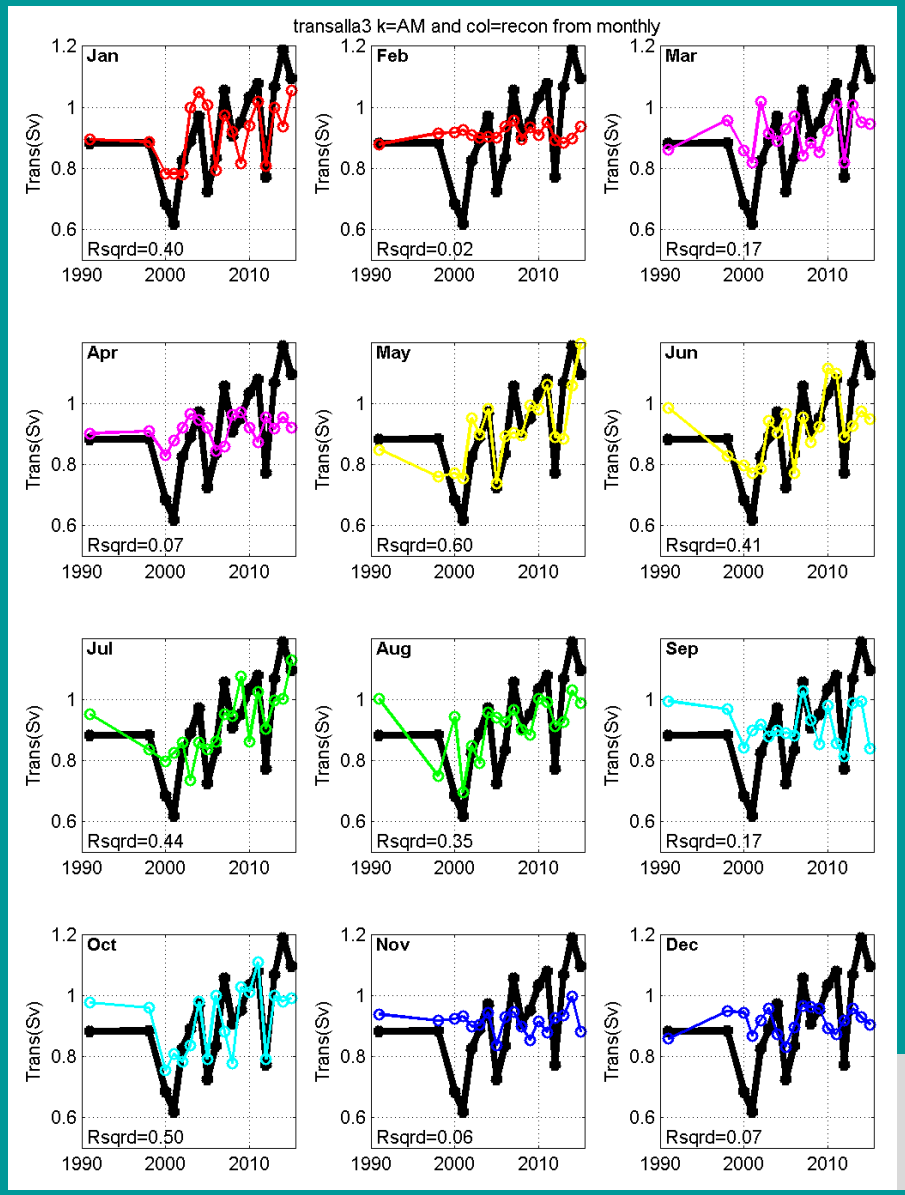
Summer flows much less correlated with winds



Summer flows best represent the pressure head

Is this:
- ice-ocean coupling
- pressure head dominance
… or .. unreliable winds?

Summer (May and Oct) transports significantly correlated with annual mean transports



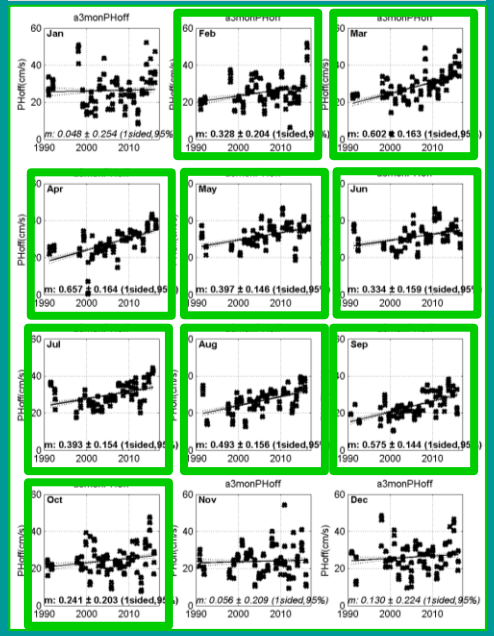
Monthly mean explains ?? of annual mean variance

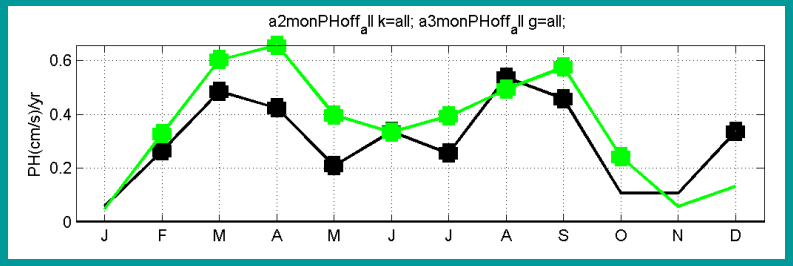
Jan	~ 40%
Feb	*~ 2%*
Mar	*~ 17%*
Apr	*~ 7%*
May	**~ 60%**
Jun	~ 41%
Jul	~ 44%
Aug	~ 35%
Sep	*~ 17%*
Oct	**~ 50%**
Nov	*~ 6%*
Dec	*~ 7%*

Reconstruction (color) of annual mean (black)

And if seek wind coupling and PH terms by month .. and look for significant interannual trends

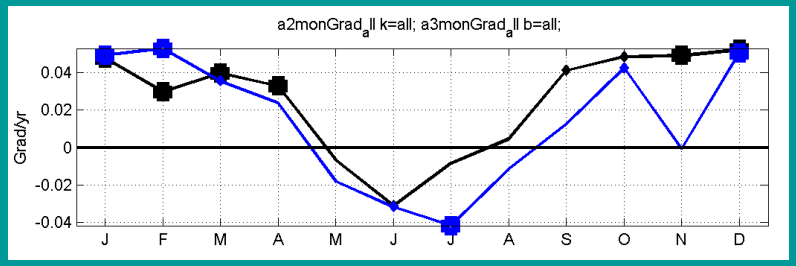
offset, PH





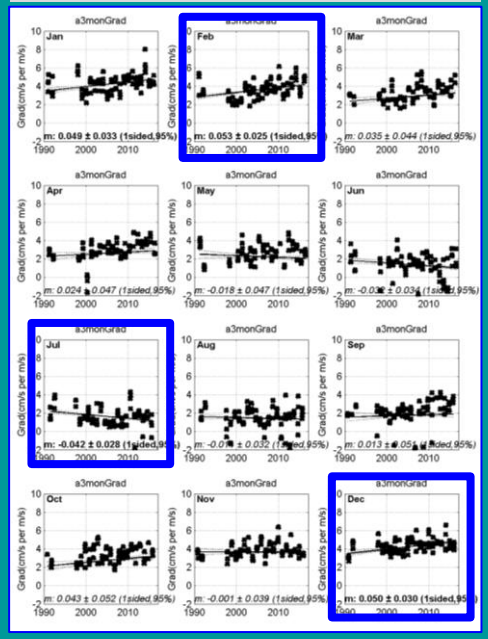
Increasing trend in PH over almost all months

Several indications that PH is driving Bering Strait increase



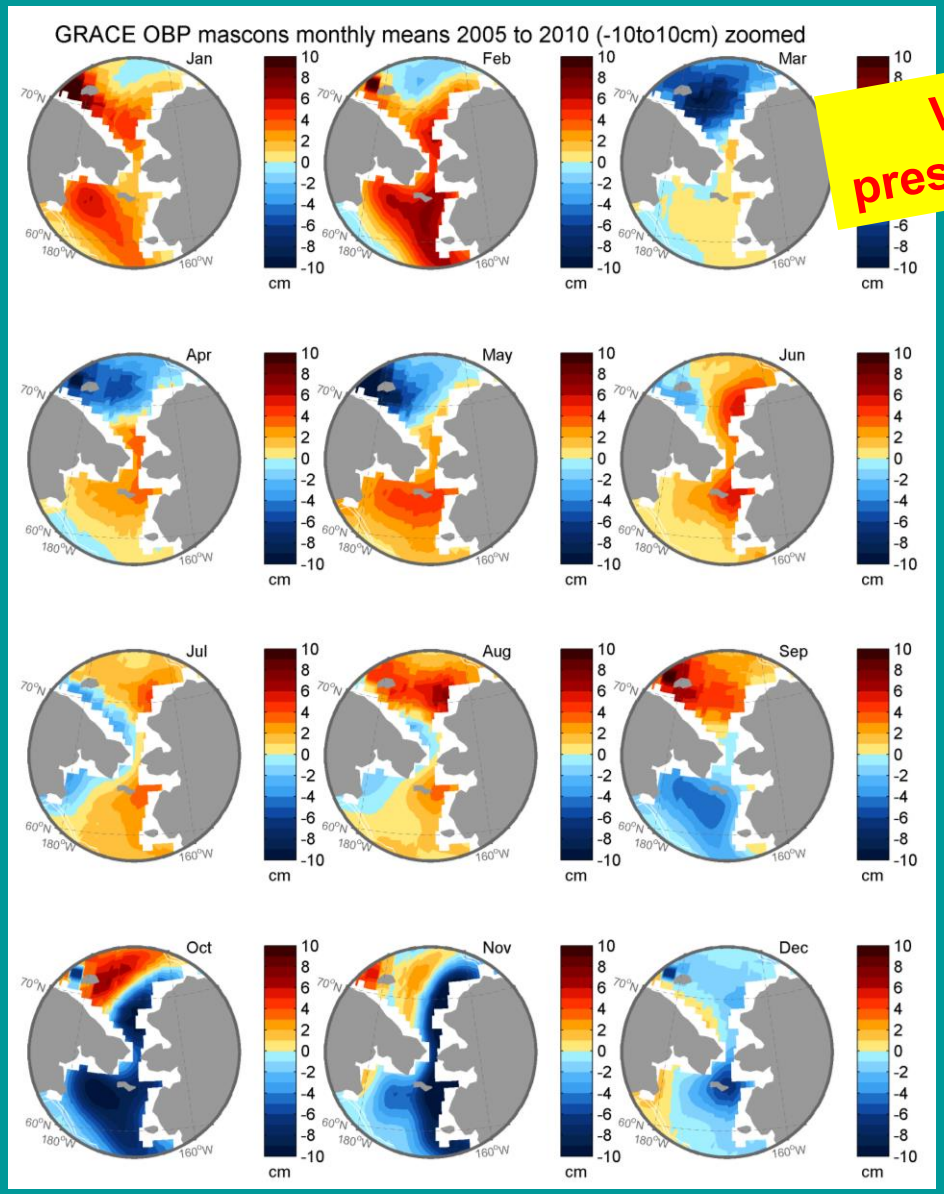
Increased coupling in winter (more mobile ice??)

mmm, Wind coupling

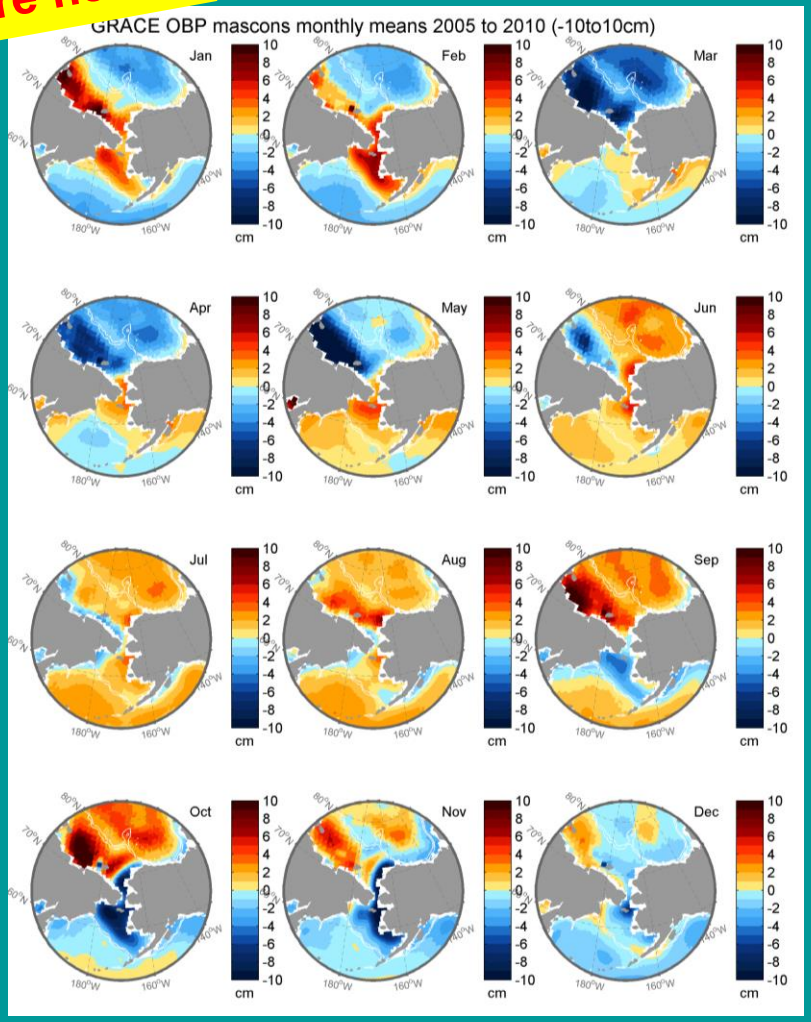


What IS this pressure head forcing?

Satellite measured (GRACE) Ocean Bottom Pressure anomalies
- monthly means (2005-2010)
(Peralta-Ferriz et al, in prep)

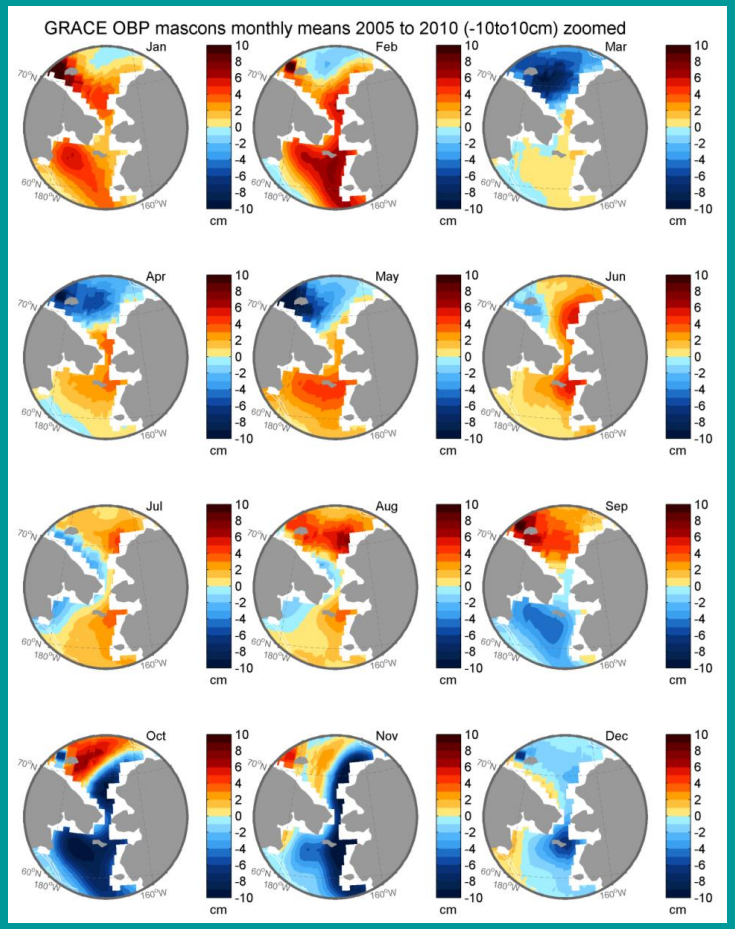


WHICH pressure head?



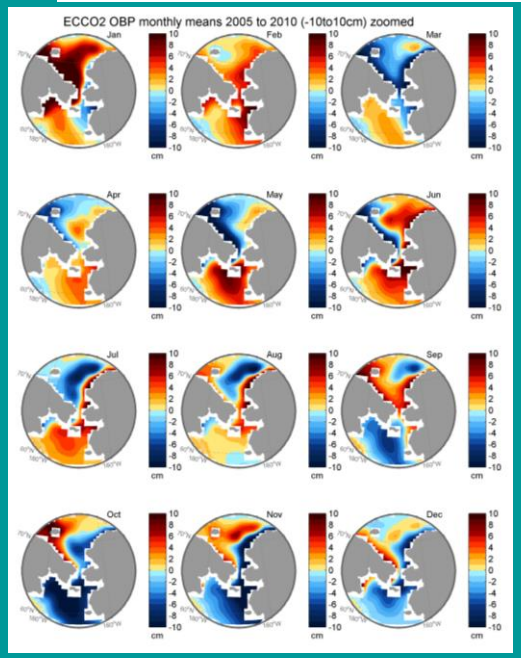
zoomed out to Pacific-Arctic

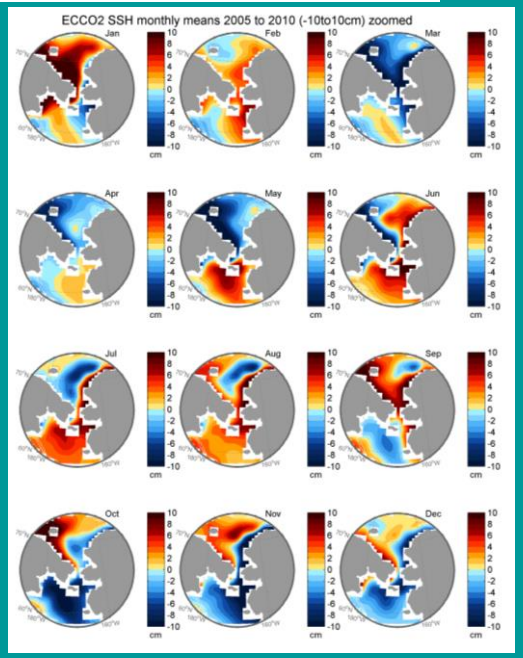
Look to model for guidance



Satellite measured (GRACE) Ocean Bottom Pressure anomalies – monthly means (2005-2012)
(Peralta-Ferriz et al, in prep)

ECCO2 Ocean Bottom Pressure and SSH anomalies – monthly means (2005-2012)
(Peralta-Ferriz et al, in prep – model results from An Nguyen)



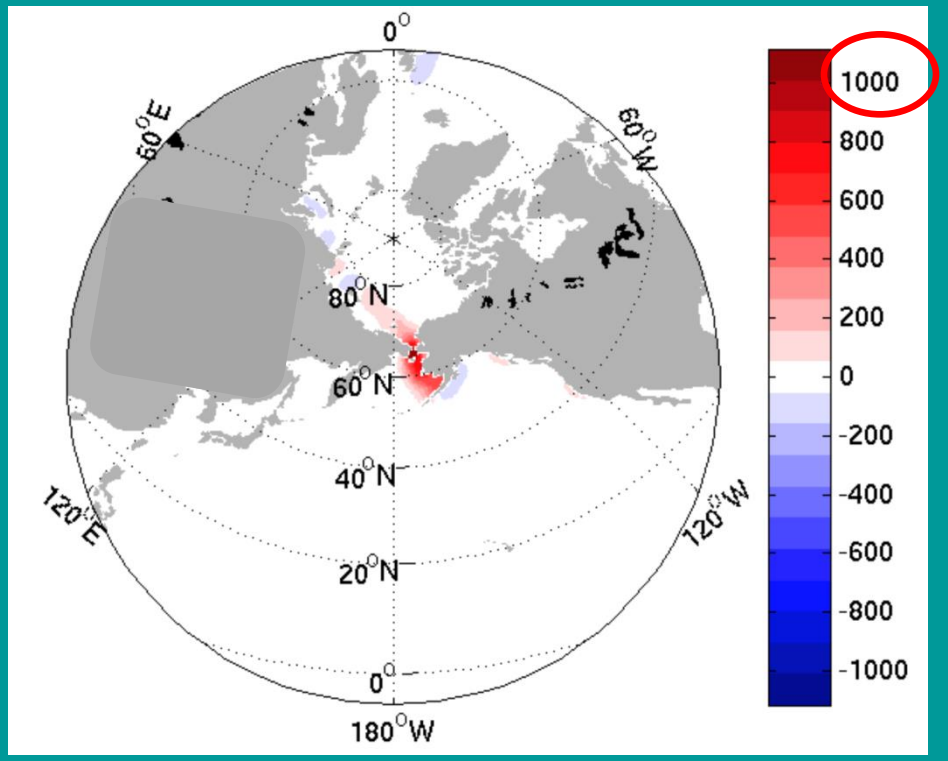


Model (Adjoint) studies to test driving mechanisms

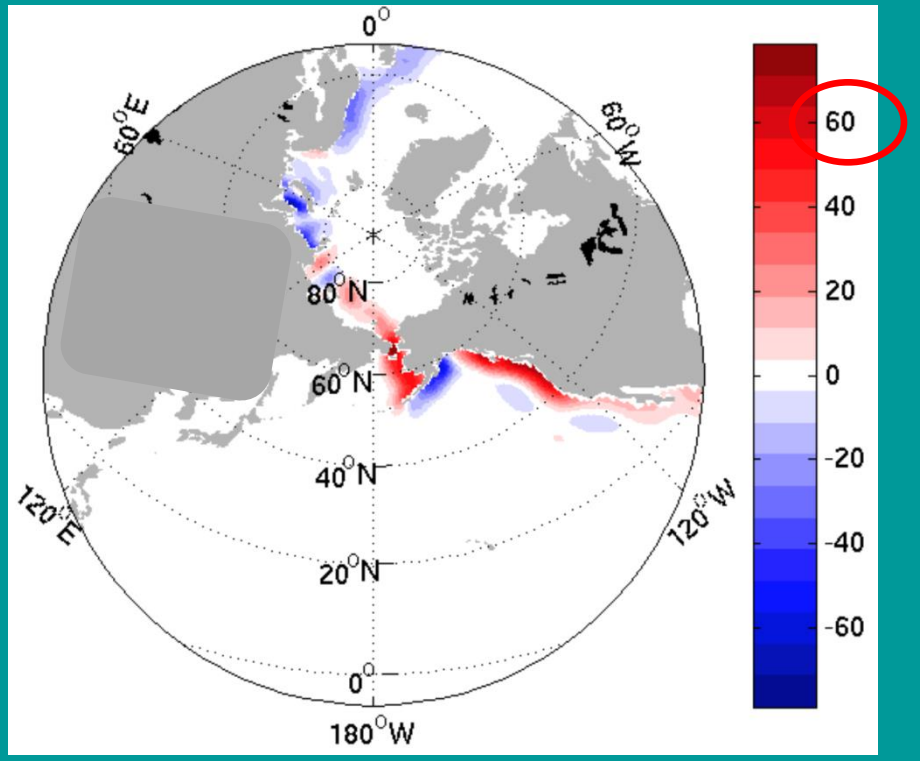
An Nguyen, Rebecca Woodgate, Patrick Heimbach

$$\frac{\partial F_{BE}}{\partial v_{\mathcal{N}}(x,y,-t)} = \text{Sensitivity of northward transport } F_{BE} \text{ to northward wind } v_{\mathcal{N}}$$

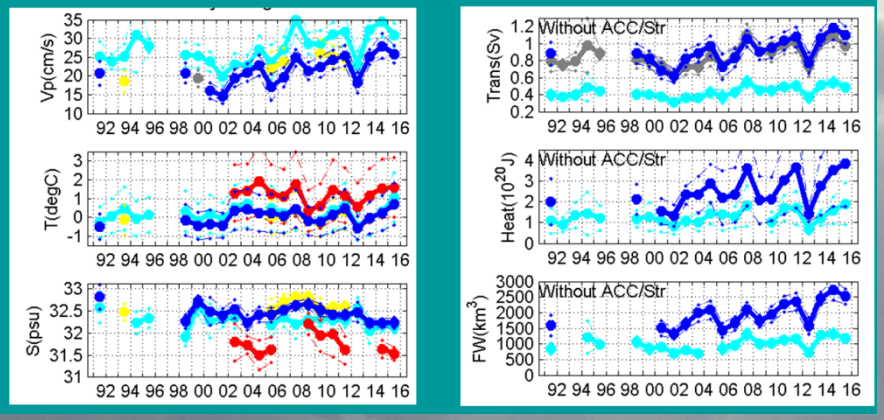
–1 months m^3s^{-1} / ms^{-1}



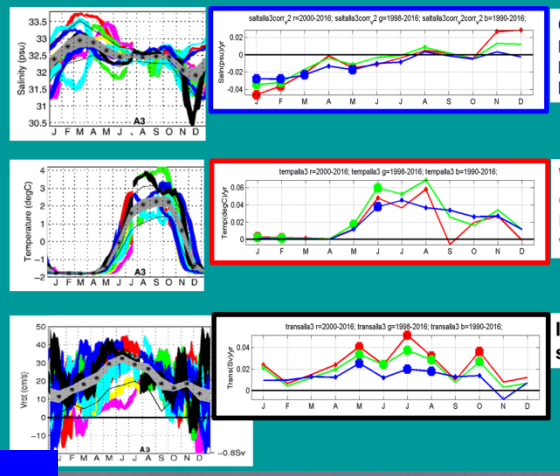
–2 months m^3s^{-1} / ms^{-1}



Continuing Increases in Bering Strait fluxes



Trends in different seasons



Change in S cycle
Less ice formation?
Earlier ice melt?
More river water?

Warming, esp in early summer
Earlier arrival of warm waters

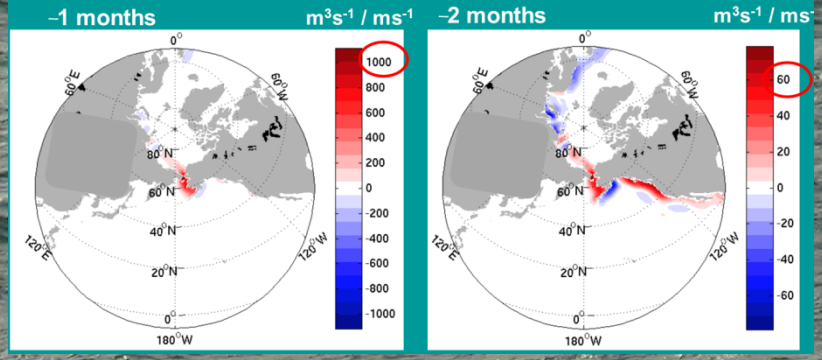
Increasing flow in summer

Some warming in early summer
Some freshening in midwinter
Velocity increases in most non-winter months
= Transports (vol, heat, freshwater) all increasing

Model (Adjoint) studies to test driving mechanisms

An Nguyen, Rebecca Woodgate, Patrick Heimbach

$$\frac{\partial F_{BE}}{\partial v_{\mathcal{N}}(x,y,-t)} = \text{Sensitivity of northward transport } F_{BE} \text{ to northward wind } v_{\mathcal{N}}$$



= Mostly driven by SUMMER transport changes
= Summer best measure of far field (60% annual mean variance)
= Increases due to Pressure Head/Far Field, not wind

= Adjoint and OBP to study far field
= A new seasonal climatology?