Freshening (and other change) in the Bering Strait

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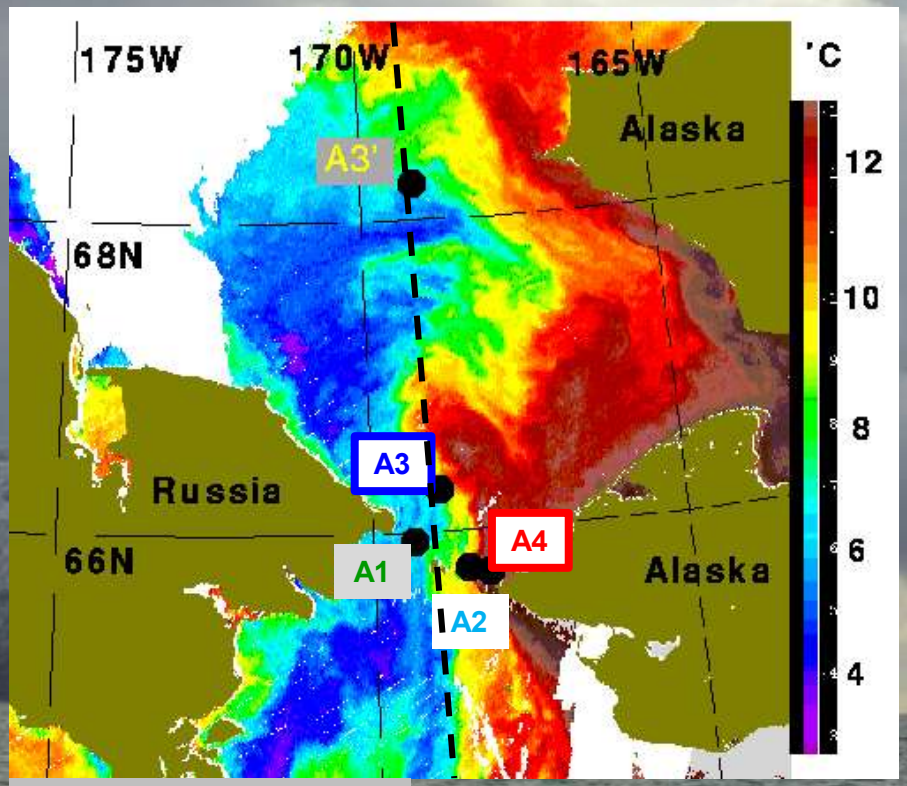
= Recent change in the Bering Strait
= How the **Arctic** drives the Bering Strait throughflow
= Freshening of the throughflow, … and Arctic **implications**

Funded by US National Science Foundation
Office of Polar Programs, Arctic Observing Network

Diomede Islands, mid Bering Strait,
Photo: R Woodgate

Bering Strait Moorings



MODIS SST 26th Aug 2004

1990 – present (29+ years)
== year-round moorings
mid channel (e.g.,A1, A2, A3, A3')
== mostly near bottom
== 2001 started measuring the Alaskan Coastal Current with A4

Climate site (A3)
~ ***Russian Channel (A1)*** **+** ***US Channel (A2)***

Total Flow is ~

Climate site (A3)

+

Alaskan Coastal Current (A4)

== Woodgate et al, 2015, Bering Strait Synthesis,
RUSALCA special issue of ***Oceanography***, doi:10.5670/oceanog.2015.57
== Woodgate, 2018, ***Progress in Oceanography*****,** doi: 10.1016/j.pocean.2017.12.007

Trends in Annual Means to 2018

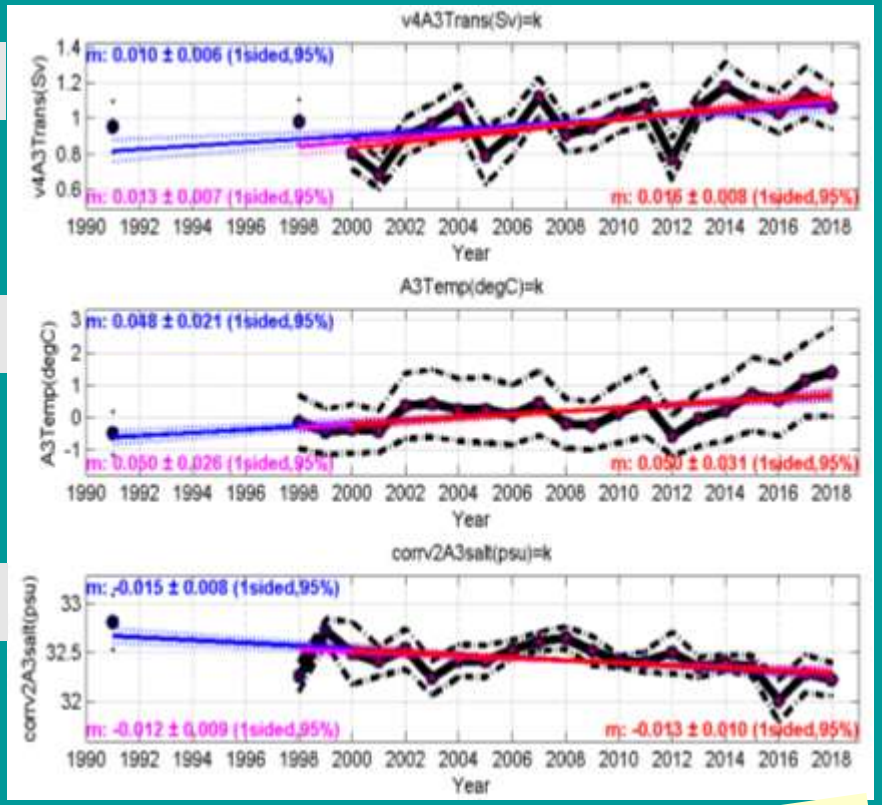
From Climate Site, A3:
Significant trends in
- transport *(increasing)*
- temperature *(warming)*
- salinity *(freshening)*

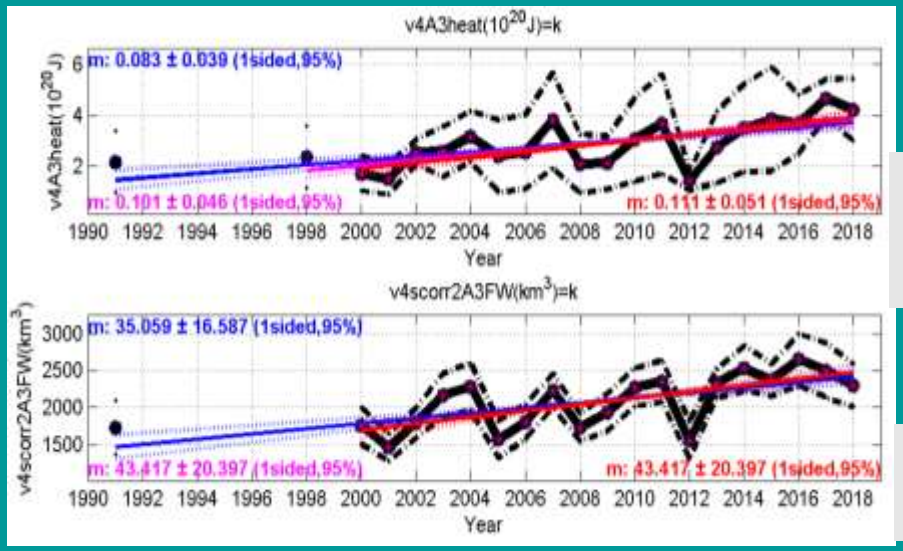
.. and increasing heat and freshwater fluxes

Transport

Temperature

Salinity





Heat relative to-1.9ºC
before ACC/stratification contribution (~ 2x10^{20}J)

... large (>50%) increases since 1990s

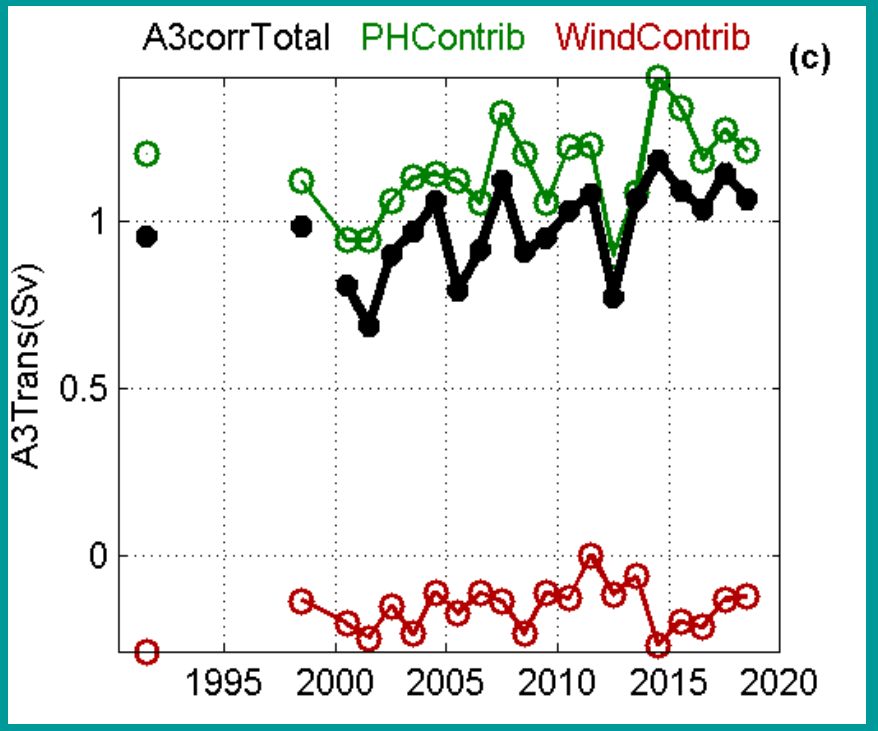
... strongly driven by transport

Freshwater relative to 34.8psu
before ACC/stratification contribution (~1000km^3)

Transport Variability

Transport ~ FAR FIELD + LOCAL forcings
Fit for:
Transport = A + B x Northward Wind

A = Pressure Head (PH) (FAR FIELD)
B x N Wind = Wind Forcing (LOCAL)
Updated from Woodgate, 2018

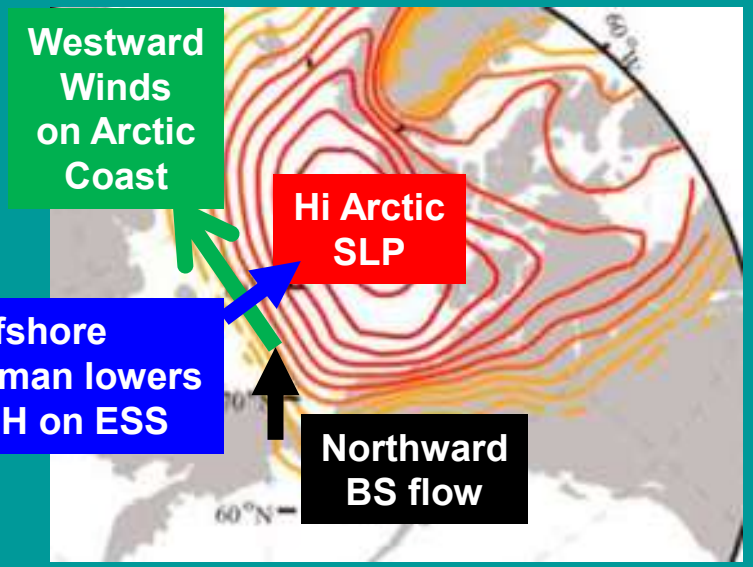


= Trends in PH are significant, and are in almost all months.

= No significant trend in wind

What causes change in Pressure Head?
- Peralta-Ferriz & Woodgate, 2017, find relationships to ARCTIC (**East Siberian Sea**) ocean mass change (GRACE).

ARCTIC variability is the dominant driver of the flow variability, (Pacific important in winter too.)



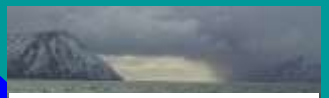
Bering Strait Drivers from an ECCO Adjoint Model

ECCO Model

Ice-Ocean

Forward Run

Arctic/ Global

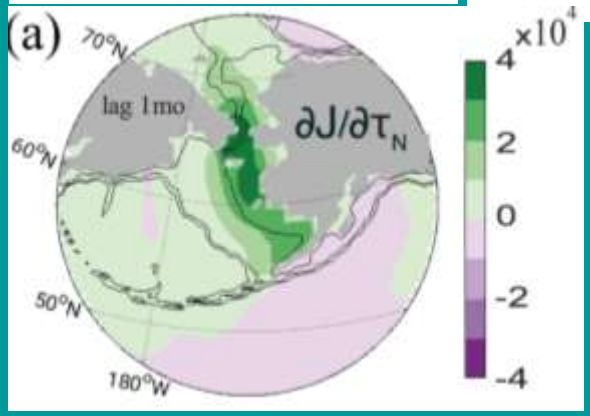


Bering Strait Flow = J

Adjoint Run

How any forcing (Ω_i) at all places affects J, i.e., $\frac{\partial J}{\partial \Omega_i}$

Sensitivity to northward wind stress, $\boldsymbol{\tau_N}$



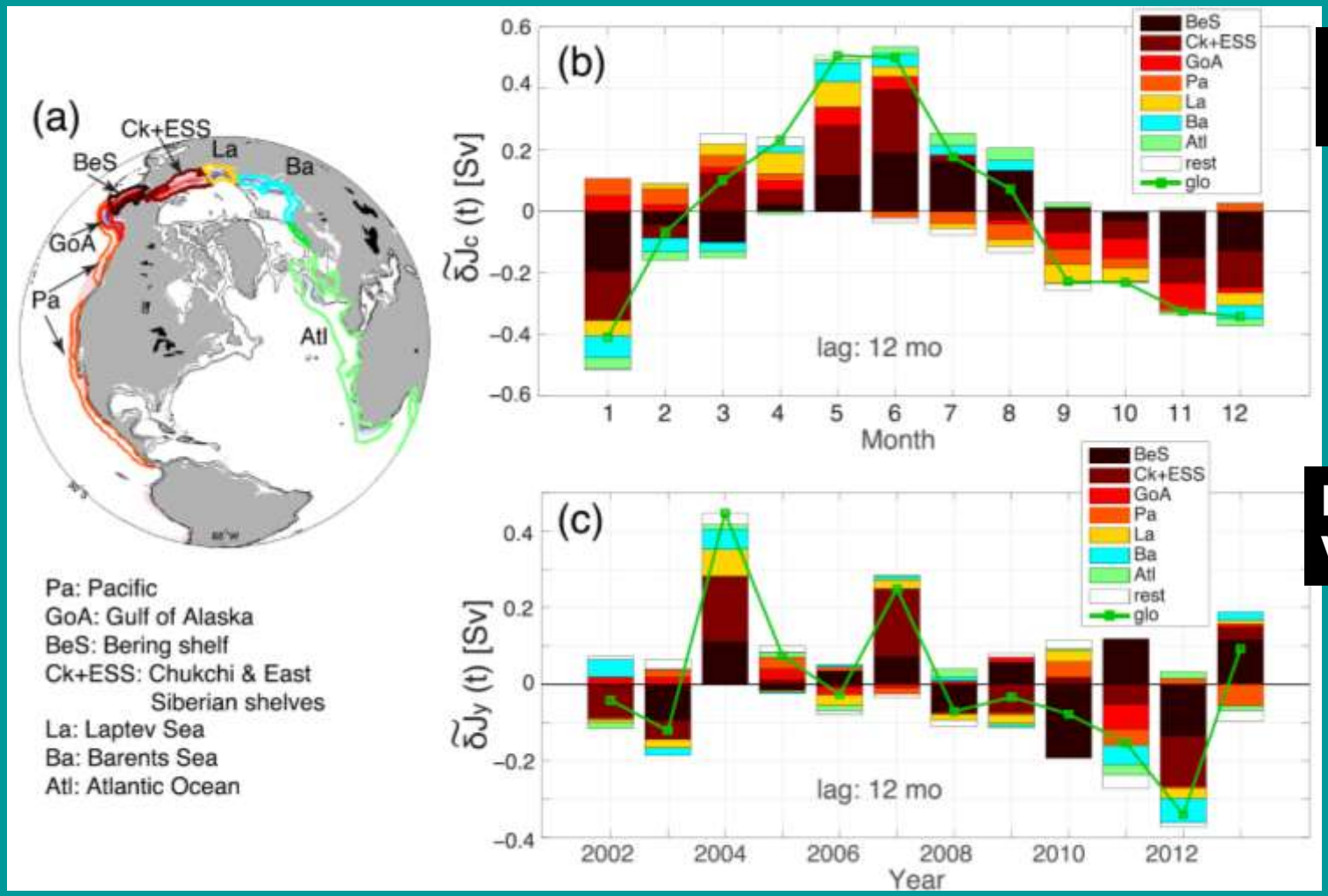
Reconstruction

Reproduce J from SUM of all forcings and "sensitivities"

Explain >90% of flow variance by winds over various regions ..

Nguyen et al, 2020, JGR

Bering Strait Drivers from an ECCO Adjoint Model



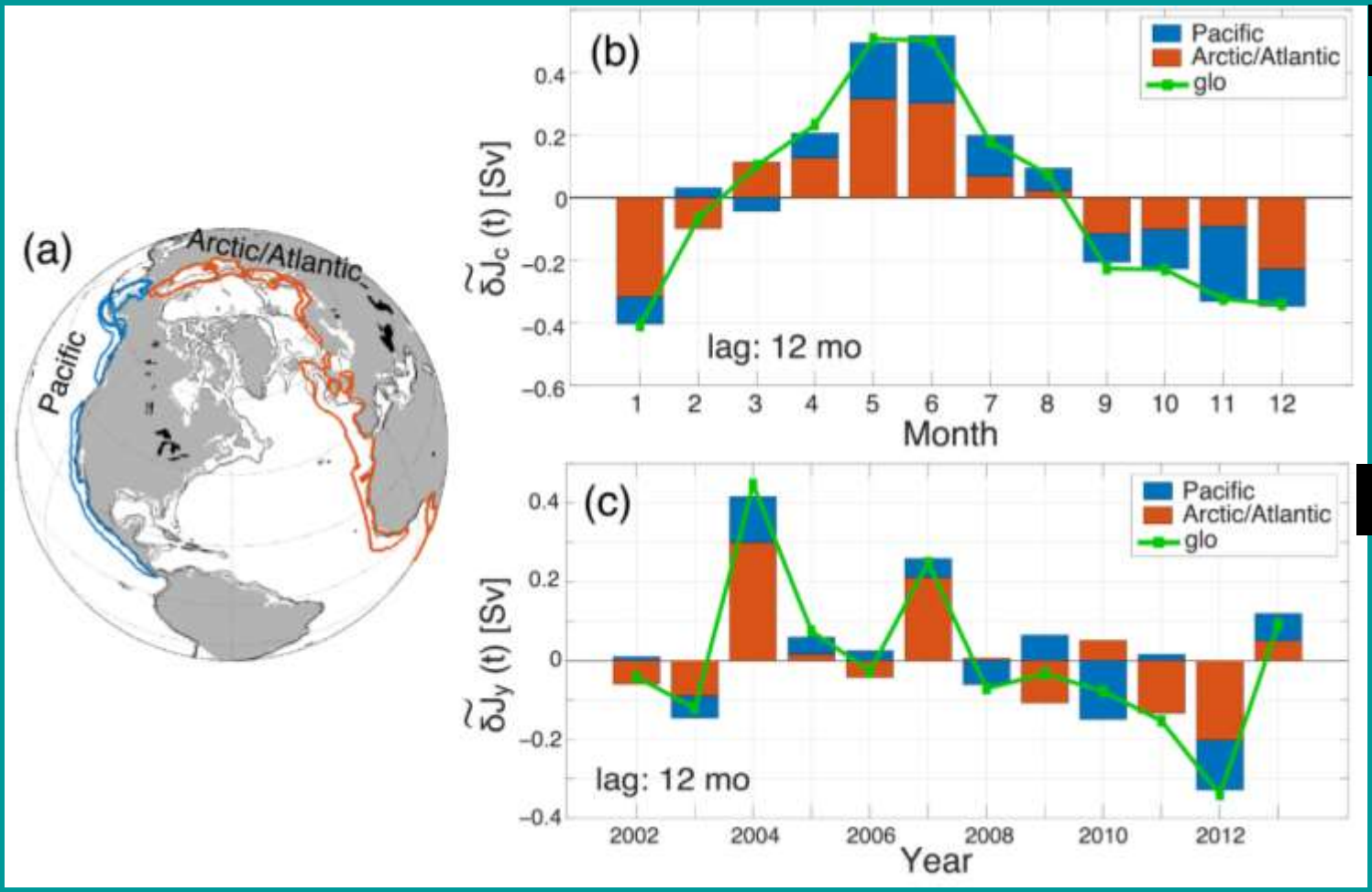
Seasonal Variability

Interannual Variability

Explain >90% of flow variance by winds over various regions ..

Nguyen et al, 2020, JGR

Bering Strait Drivers from an ECCO Adjoint Model



Seasonal

Interannual

ARCTIC drivers are most important, … though Pacific relevant too

Nguyen et al, 2020, JGR

Transport Variability

Transport ~ FAR FIELD + LOCAL forcings
Fit for:
Transport = A + B x Northward Wind

A = Pressure Head (PH) (FAR FIELD)
B x N Wind = Wind Forcing (LOCAL)
Updated from Woodgate, 2018

= Trends in PH are significant, and are in almost all months.

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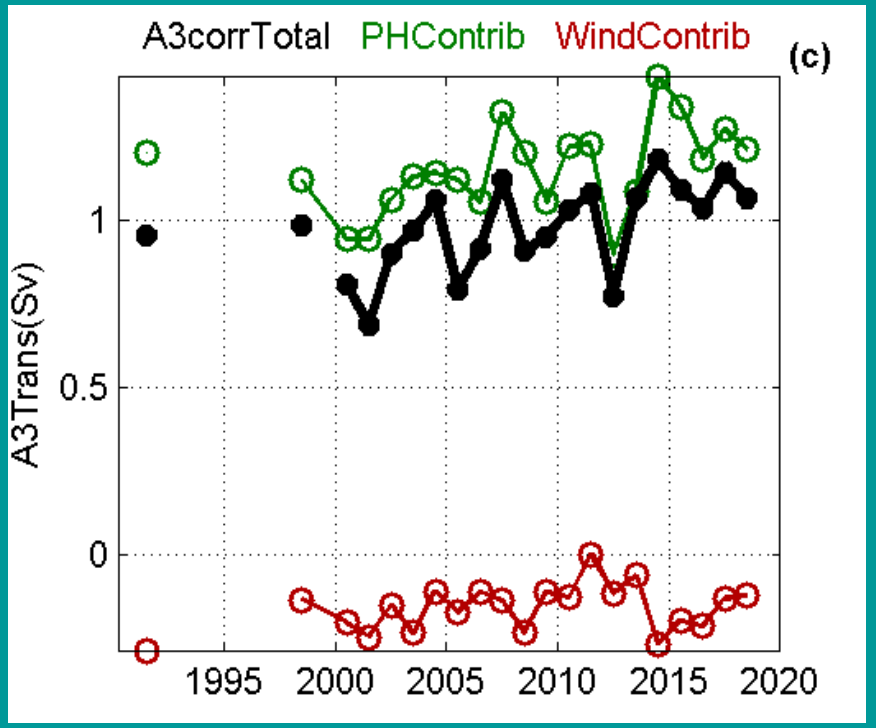
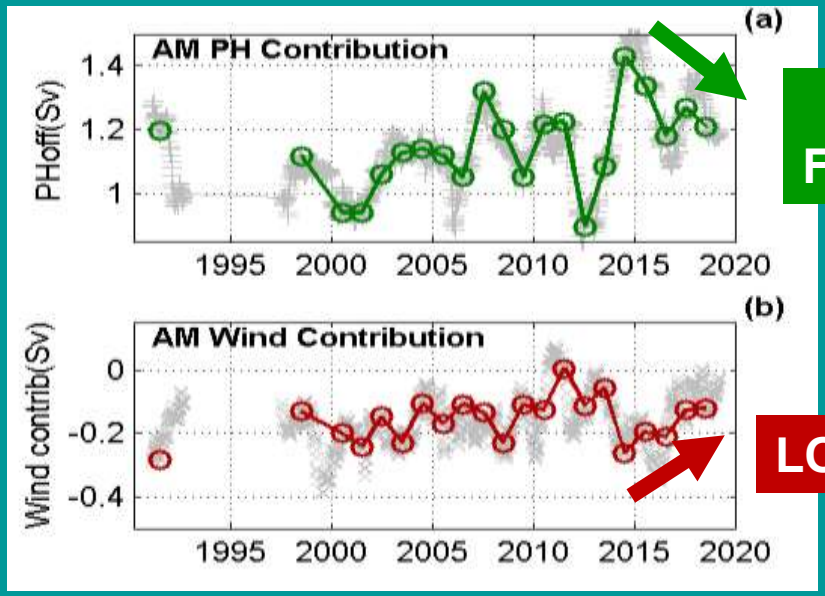




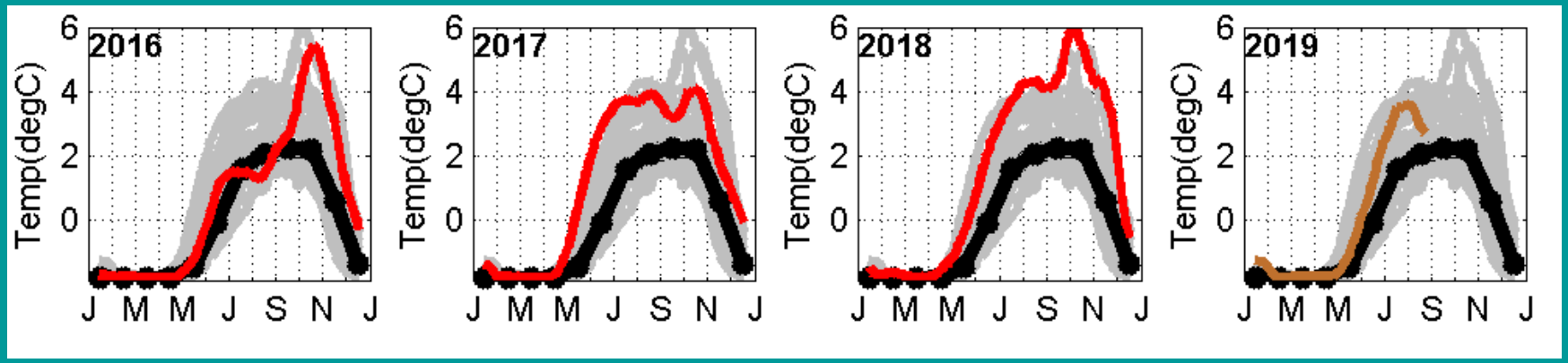
FAR FIELD

LOCAL

Recent change due to <u>both</u>
- FAR-FIELD Pressure Head (PH)
- LOCAL wind change

How strange were recent years?

30day smoothed
TEMPERATURE (ºC)



Grey = all prior years
Color = year in question (red="above average")
Black = Woodgate, 2005, climatology

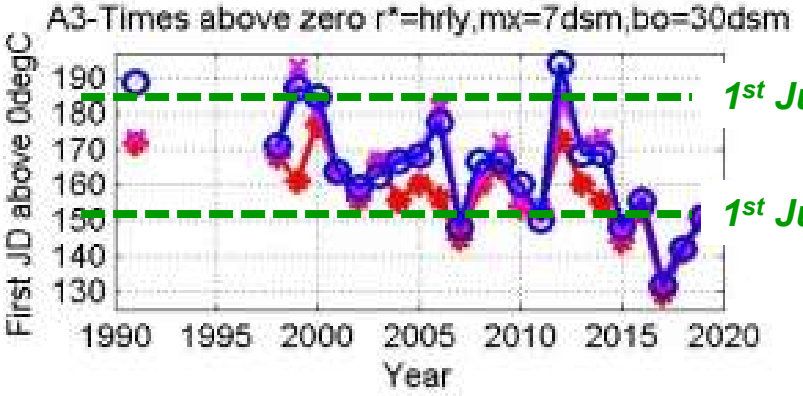
Warming earlier
Cooling later
Several degrees above "normal"

Warming, Cooling, Open Water times

MELT
First above 0ºC

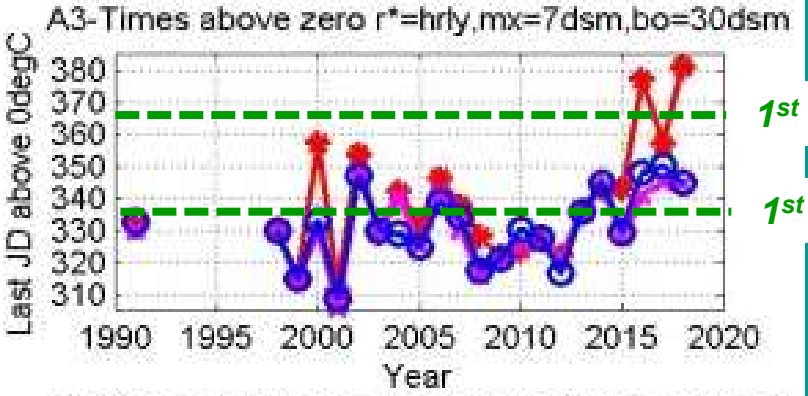
FREEZE
Last above 0ºC

OPEN WATER TIME
Days above 0ºC



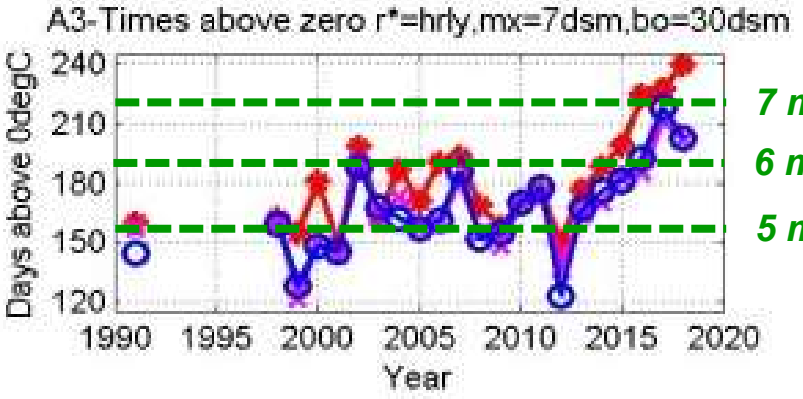
1st July

1st June



1st Jan

1st Dec



7 months

6 months

5 months

Warming earlier
(1.3 days/yr)
Freezing later
(0.6 days/yr)
Longer open water
(2 days/yr)

Melt was mid June, now May

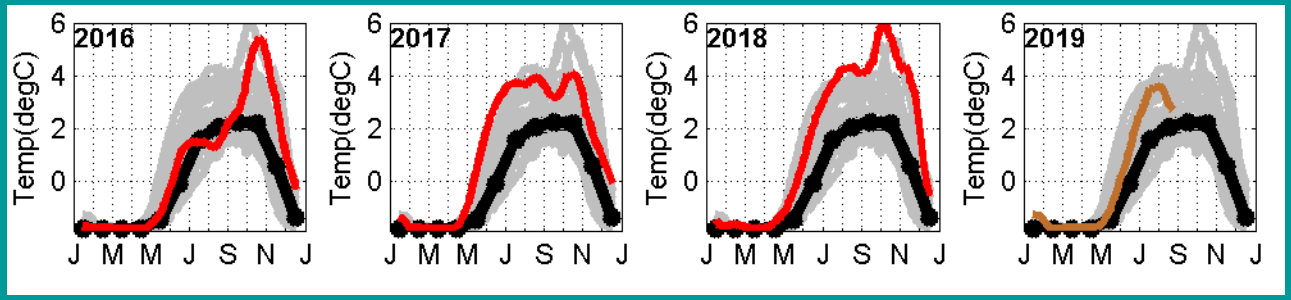
Waters above 0ºC was mid Nov, now Dec+

Now more than 6 months above 0ºC

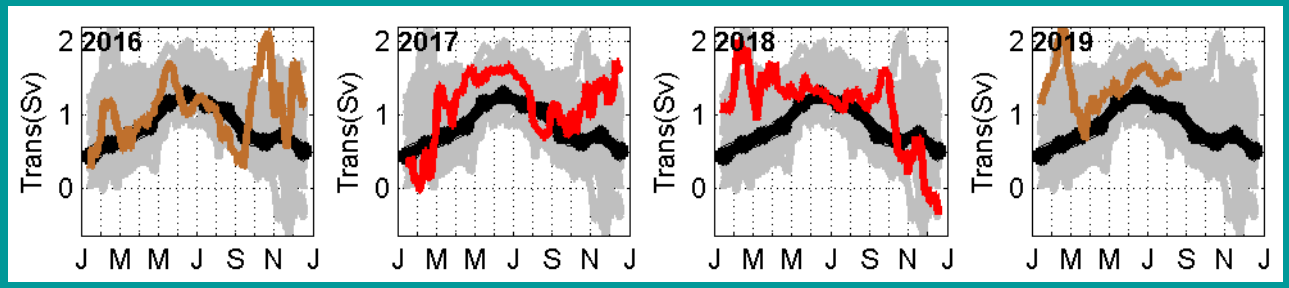
BUT *(not shown)*
no significant trends in Alaskan Coastal Current

How strange were recent years? – heat …

30day smoothed
TEMPERATURE (ºC)

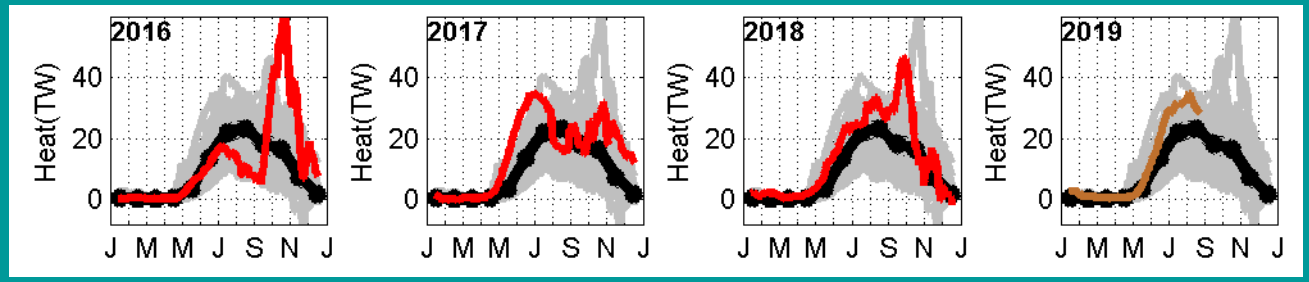


30day smoothed
TRANSPORT (Sv)



~ 1.0Sv **~ 1.1Sv** **~ 1.1Sv**

30day smoothed
HEAT TRANSPORT (TW)
relative to -1.9ºC

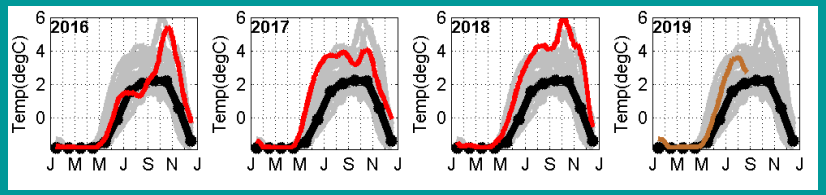


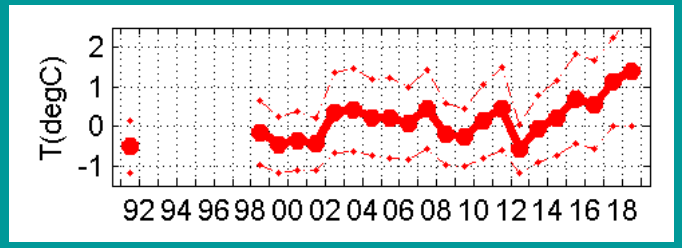
ADD 1-2 x10²⁰J for ACC/ stratification

~ 3.6 x10²⁰J **~ 4.6 x10²⁰J** **~ 4.2 x10²⁰J**

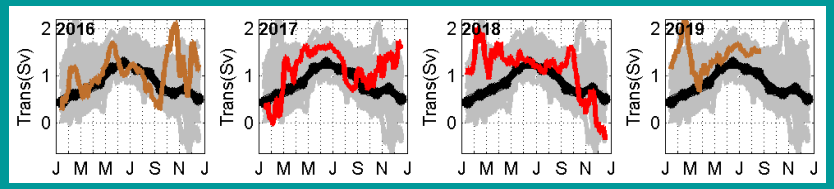
How strange were recent years? – heat …

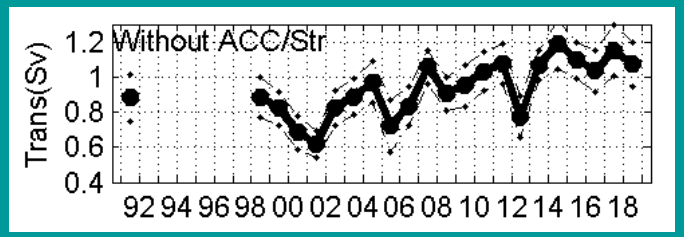
30day smoothed
TEMPERATURE (ºC)



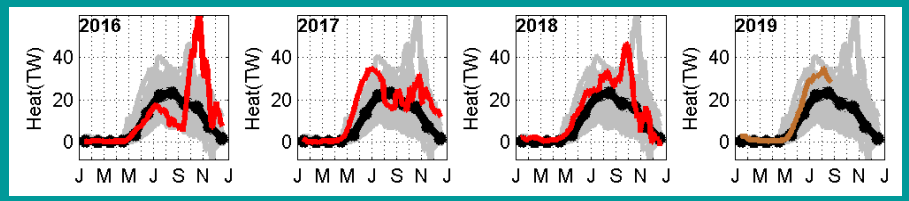


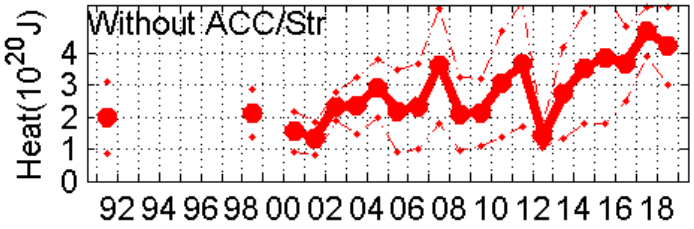
30day smoothed
TRANSPORT (Sv)





30day smoothed
HEAT TRANSPORT (TW)
relative to -1.9ºC





ADD 1-2 x10²⁰J for ACC/ Stratification

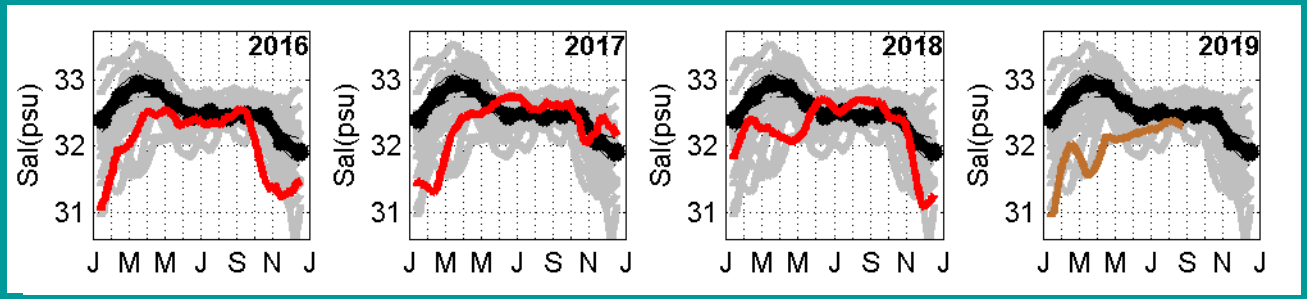
Bering Strait heat flux from 3 to 6x10²⁰J/yr -- melt 1-2 x 10⁶ km²/yr of 1m thick ice

Comparable to Solar heat into Chukchi

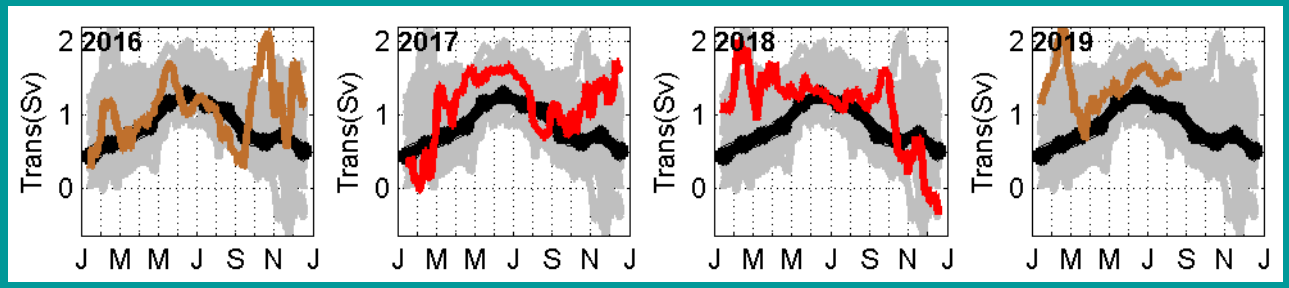
Roughly doubled since 2000, due to warming and flow increase

How strange were recent years? - salinity

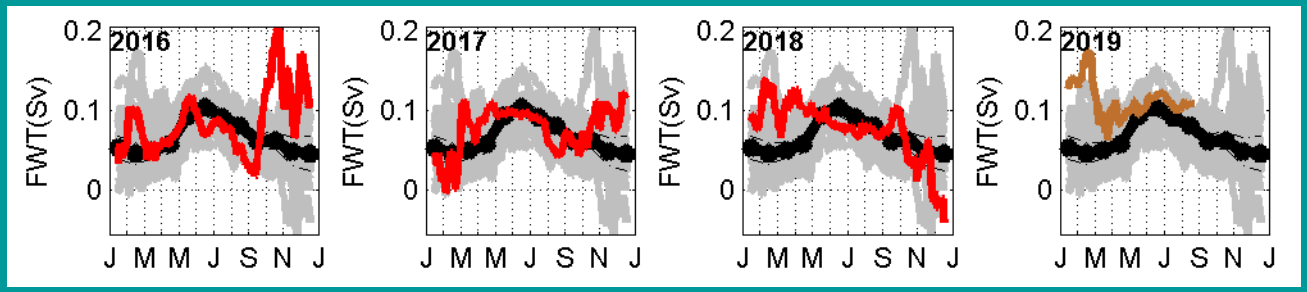
30day smoothed
SALINITY
(psu)



30day smoothed
TRANSPORT
(Sv)



30day smoothed
FRESHWATER
TRANSPORT
(Sv)
relative to 34.8psu



~ 2600km^3

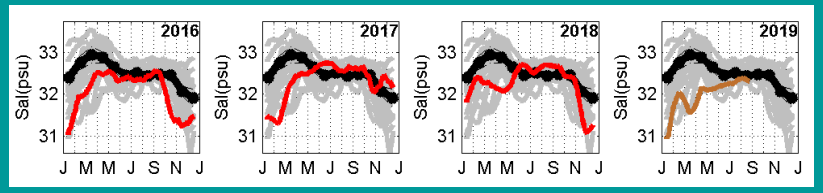
~ 2500km^3

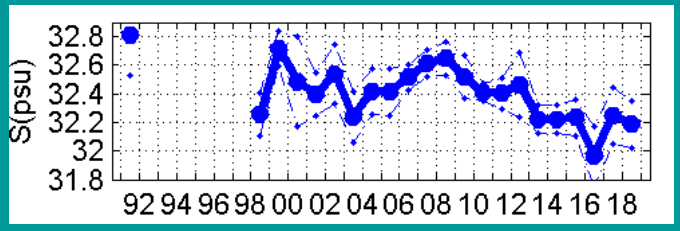
~ 2300km^3

ADD 800-1000km^3/yr for ACC/ stratification

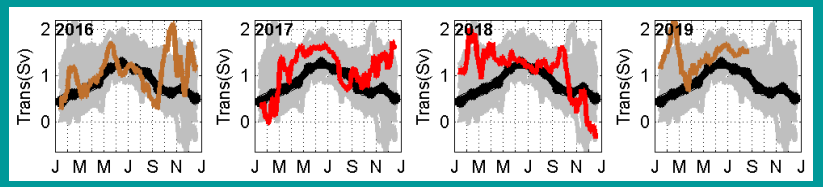
How strange were recent years? - salinity

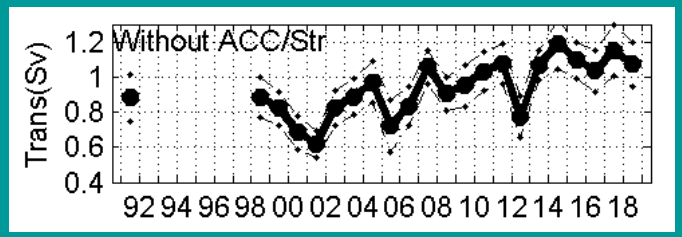
30day smoothed
SALINITY
(psu)



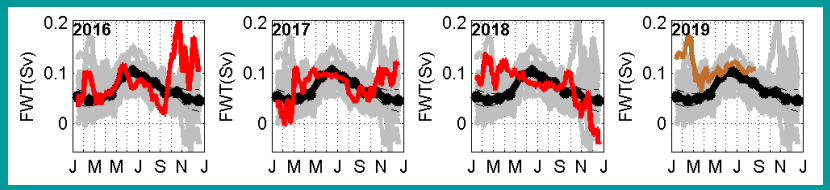


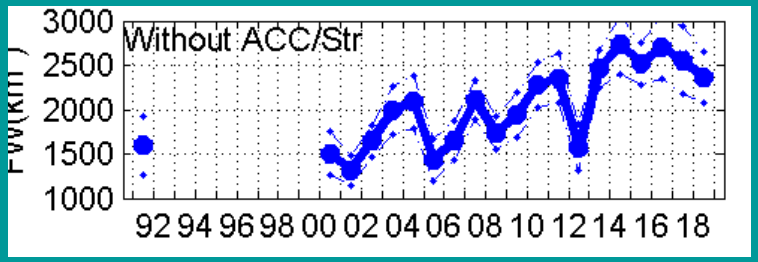
30day smoothed
TRANSPORT
(Sv)





30day smoothed
FRESHWATER
TRANSPORT
(Sv)
relative to 34.8psu





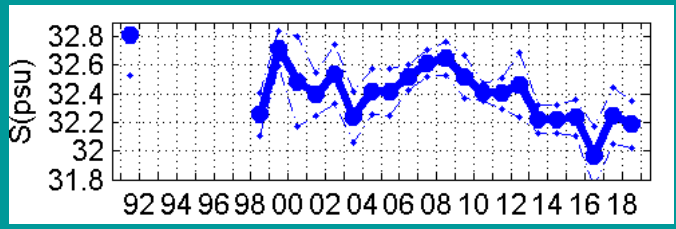
ADD 800-1000km³/yr for ACC/ stratification

Change since 2000 ~ 1,000km³/yr

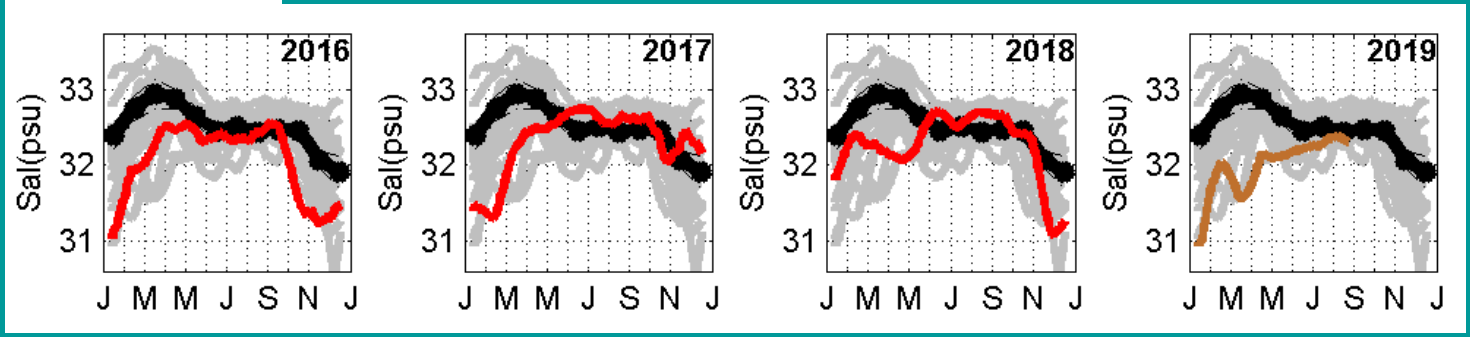
(Total river input to Arctic ~ 3,200km³/yr)

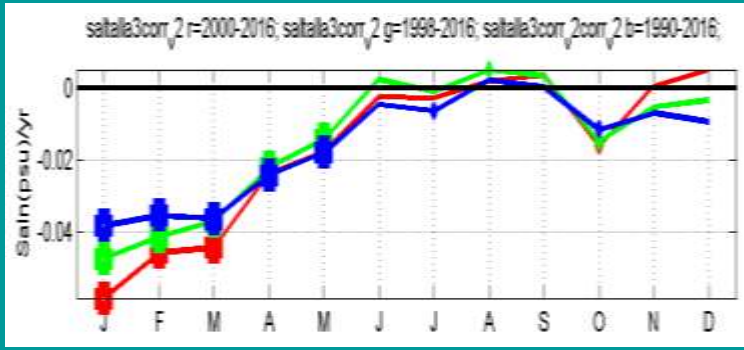
Annual mean salinity down ~ 0.5psu from 1990s to 2010s

Dig into this salinity change



30day smoothed
SALINITY (psu)





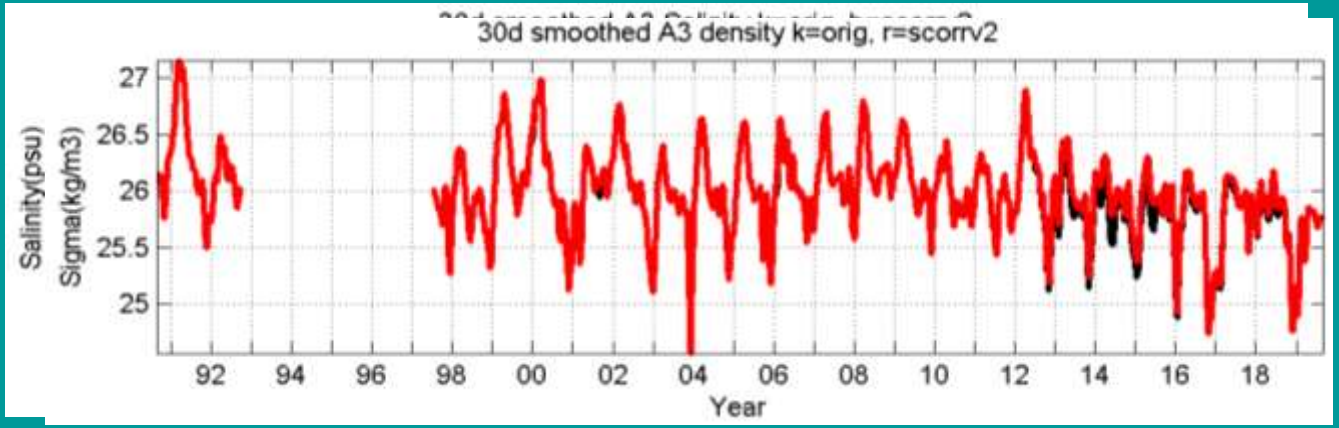
- Freshening in WINTER
2007-2018 trends
- 0.08psu/yr all water column

- Prior Seasonal Cycle lost

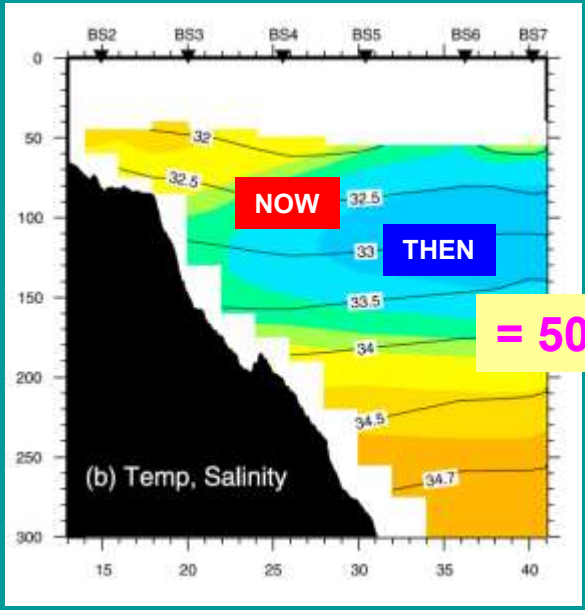
Salinity Trend by Month
- colors different time periods
- dots if significant at 95%

Driver of freshening?
- Bering Sea rivers (Yukon, etc.)? .. *likely too small*
- Sea ice? Is thinning, …. *but can't explain annual mean change..*
- Gulf of Alaska input to the Bering Sea?

Implications of winter freshening ….



Large fresh events in winter, traditional seasonal cycle missing
Maximum salinities: from ~ 33psu in 1990s (winter), 32.5psu now (summer)

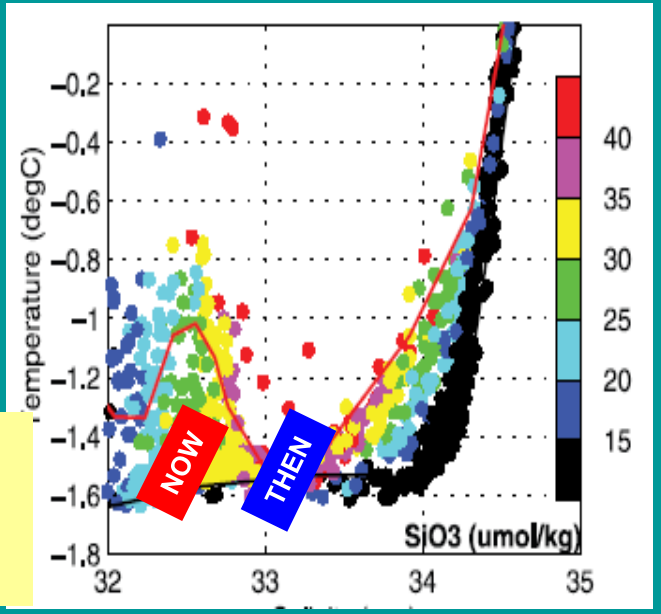


2002-2003 data, Pickart et al., 2009

Winter water less dense (~ 0.5 kg/m^3)

= 50m shallower?

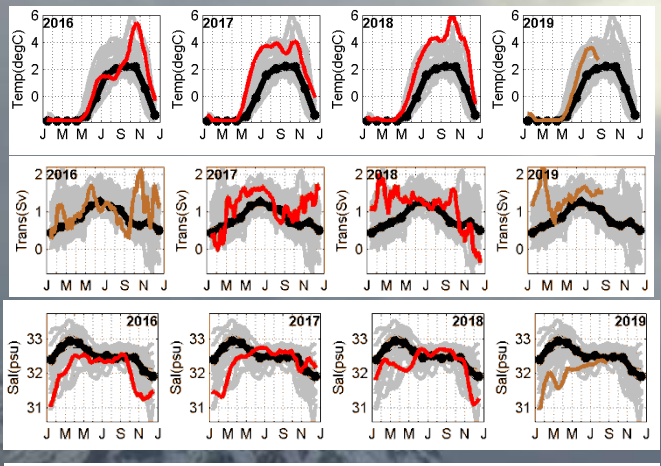
= No longer supplying cold halocline in winter?



2002 data, Woodgate et al., 2005

What's new in the Bering Strait

Change in recent years

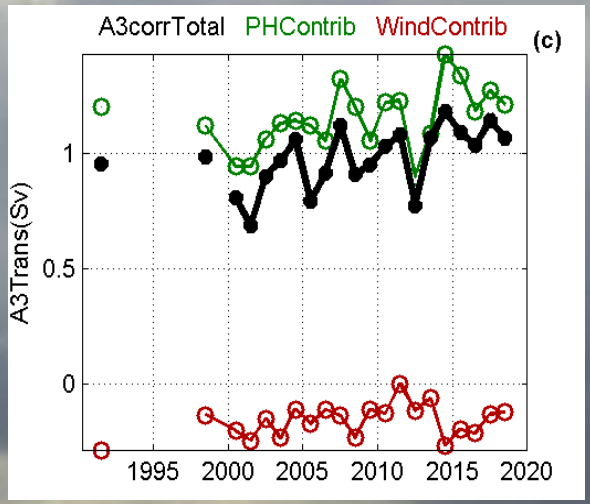


Earlier warming, later cooling, longer open water season.

Significant trends in
- temperature (warming)
- transport (increasing)
- salinity (freshening)
Almost doubling heat and freshwater fluxes

No Trend in the Alaskan Coastal Current

Transport increase

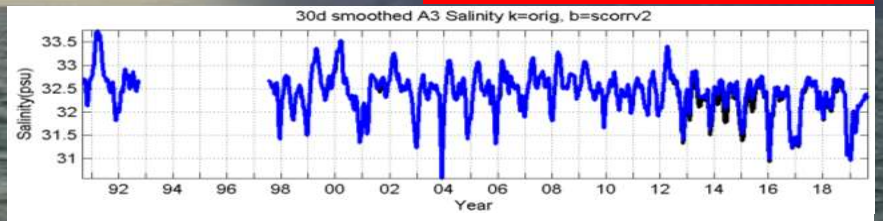


Both wind and pressure head changes important.

Long term trend only in pressure head, not wind

Recent (2015 ..) increase WIND not pressure head

Winter freshening



Pacific Winter Waters less dense than in 1990s

~ 50m shallower?
- not ventilating cold halocline?

psc.apl.washington.edu/BeringStrait.html