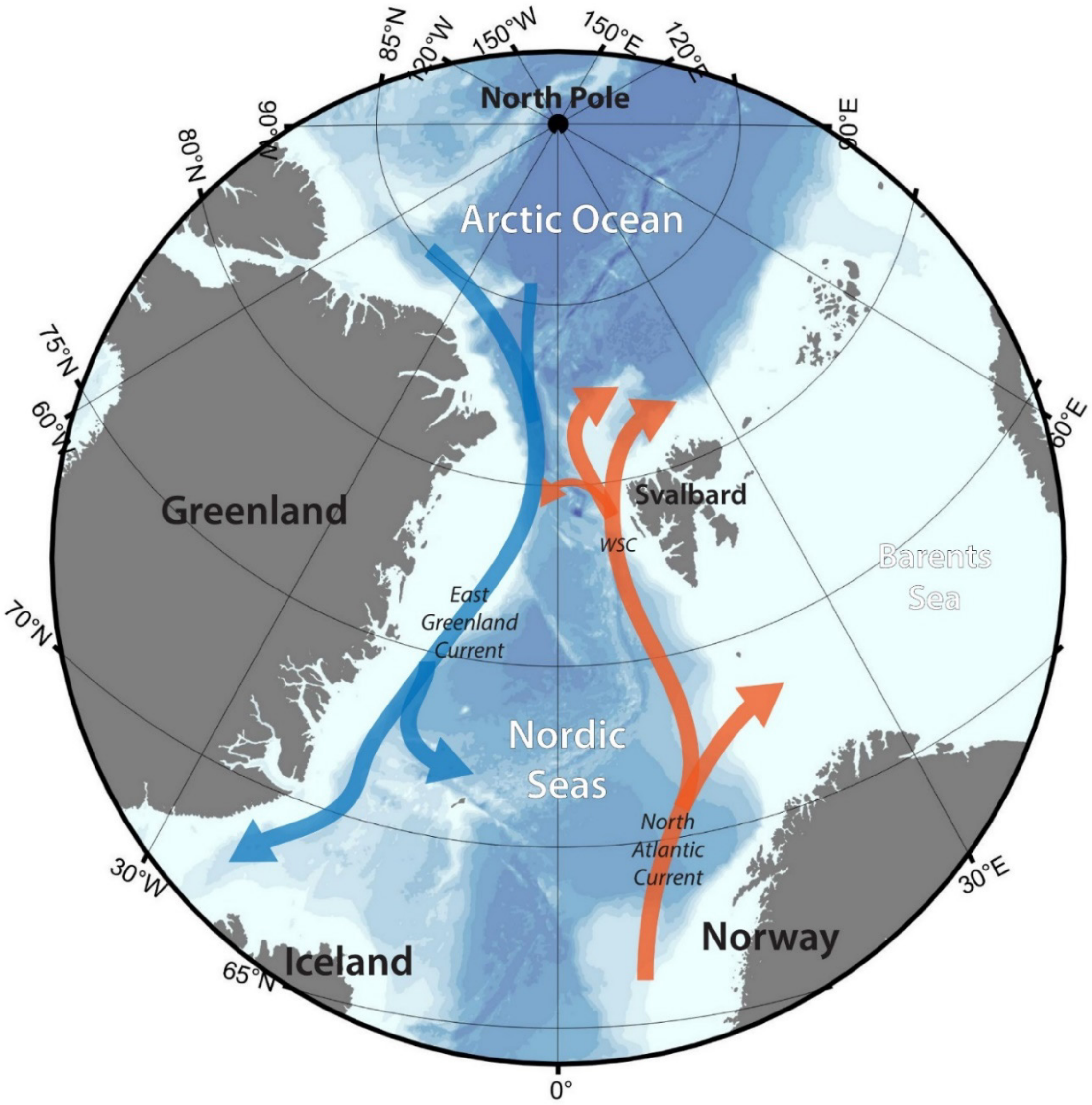
Circulation interactions between Arctic Ocean and sub-Arctic seas



Cecilia Peralta-Ferriz, ferriz@uw.edu,
Polar Science Center, Applied Physics Laboratory,
University of Washington

With special contributions from:

Laura de Steur, Norwegian Polar Institute

Acknowledgements:

Jamie Morison, Jinlun Zhang, John M. Wallace (UW)

US CLIVAR Workshop, Seattle, WA, USA, June 27th, 2022

Circulation interactions between Arctic Ocean and sub-Arctic seas

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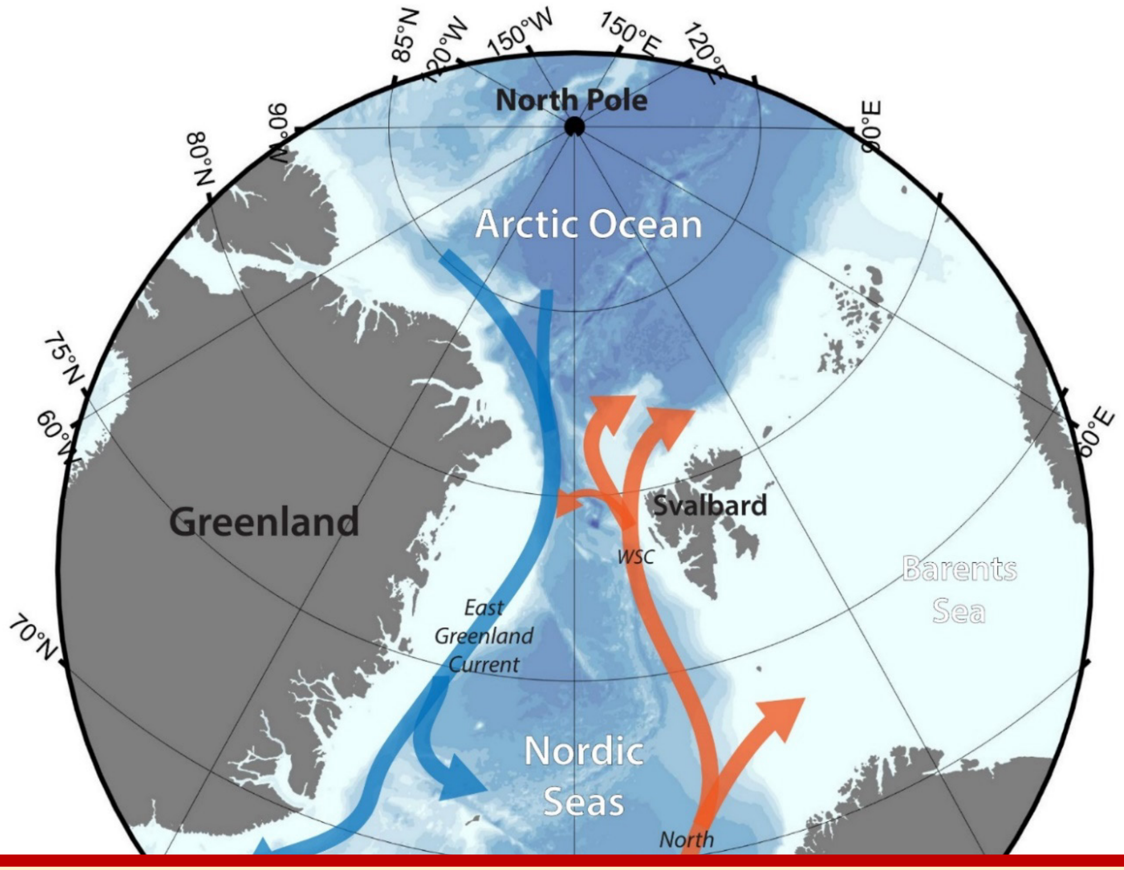


With special contributions from:
Laura de Steur, Norwegian Polar Institute
Acknowledgements:
Jamie Morison, Jinlun Zhang, John M. Wallo

MESSAGES:
- **Recent observations in FWT (liquid & ice) through Fram Strait**
- **Similar atmospheric forcing is linked to Arctic/Nordic Seas circulation variability**
- **Need for sustained in situ observations in the region**

US CLIVAR Workshop, Seattle, WA, USA, June

Arctic Ocean & Nordic Seas

- **Region of significant water mass transformations: ocean/ice properties entering and exiting the Arctic**

  Smedsrud et al. (2021), Reviews of Geophysics

- **Water mass transformations in the Nordic Seas warm and moisturize the air-sea boundary layer, impacting atmosphere and ecosystems**

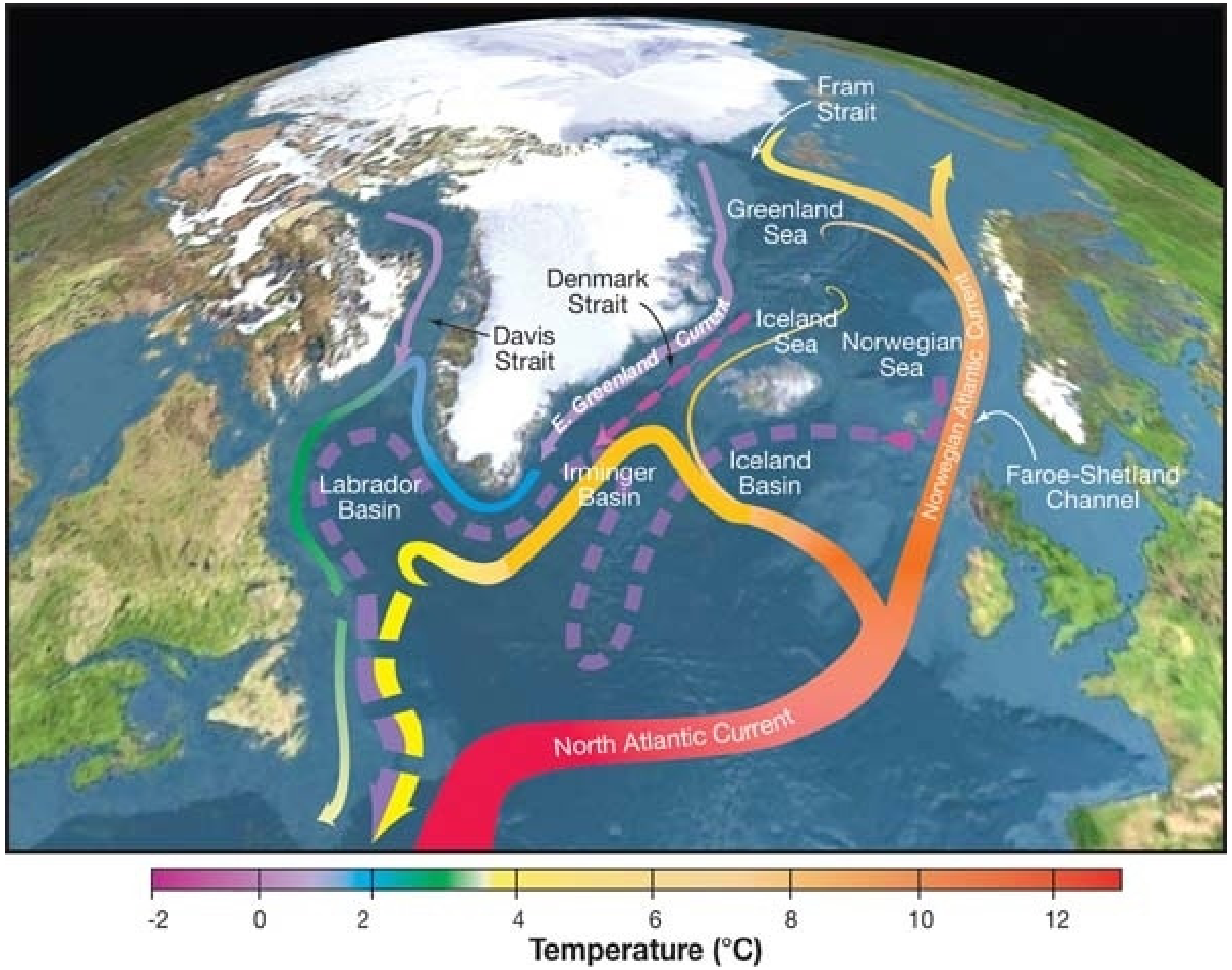
  Moore et al., 2022, Nature Communications

  Emblemsvåg et al., 2022, Global Change Biol.

- **Increase in Arctic freshwater and sea ice export can reduce/suppress deep winter convection, impacting AMOC**

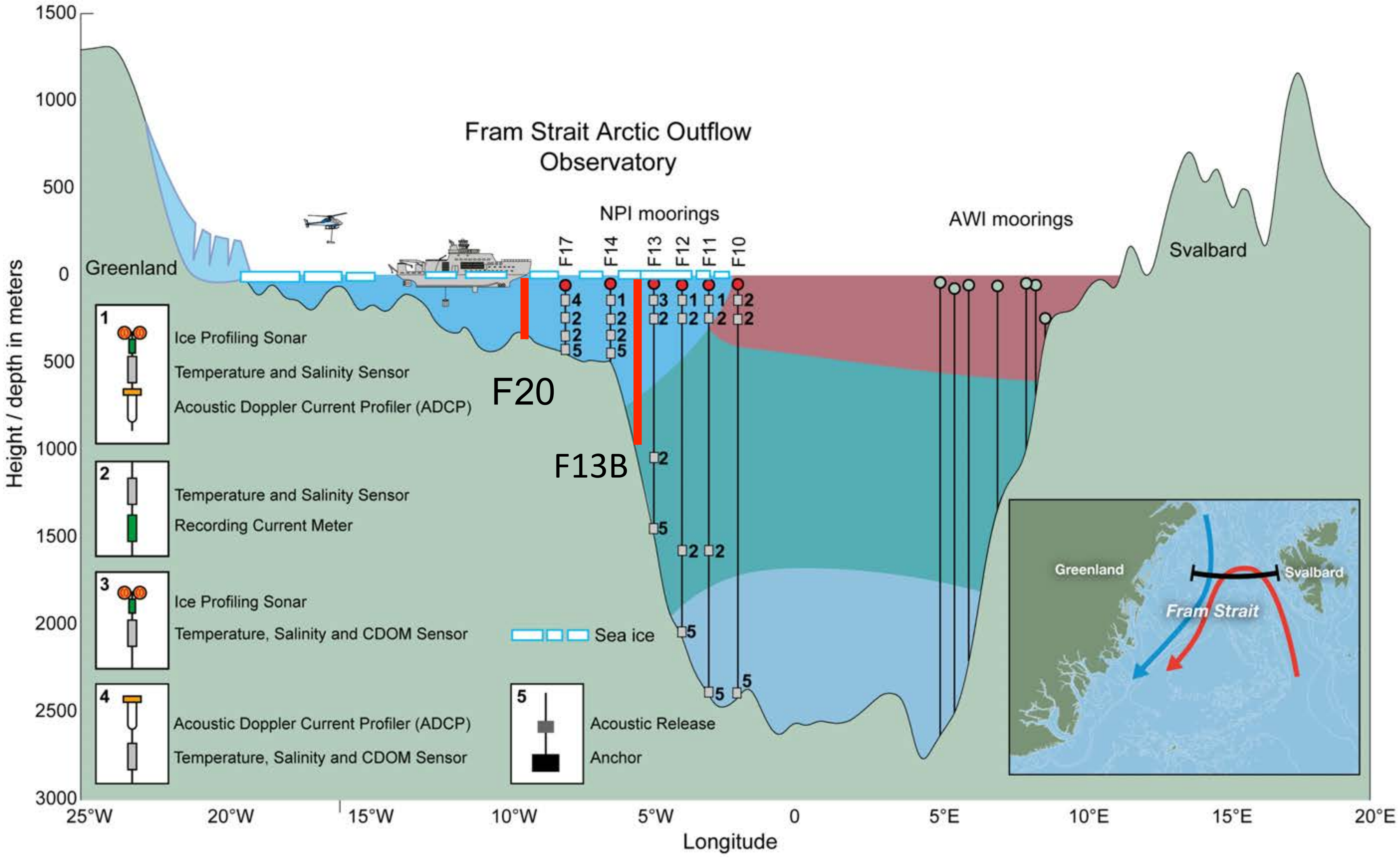
  Dickson et al. (1988), Progress in Oceanography

  Curry and Mauritzen (2005), Science Reports



Curry and Mauritzen (2005), Science Reports

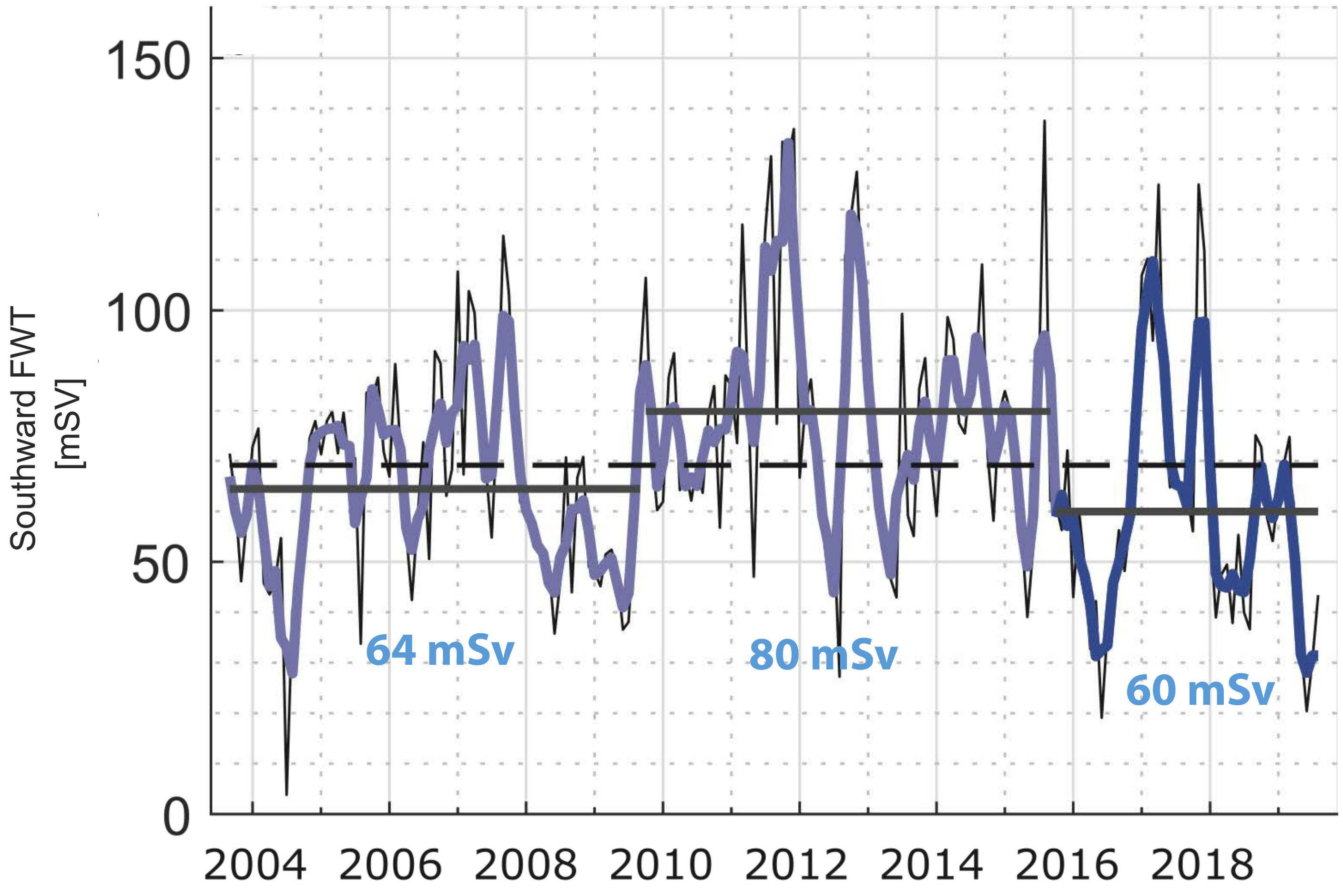
The Fram Strait Arctic Outflow Observatory



A long-term ocean & sea ice observing system (1990-present). Quantifying variations in Arctic freshwater and sea ice export, returning Atlantic Water, carbon and Ocean Acidification state.

https://www.npolar.no/en/projects/fram-strait-arctic-outflow-observatory/

Fram Strait liquid Freshwater Transport (FWT)



__During 2015-2019__:

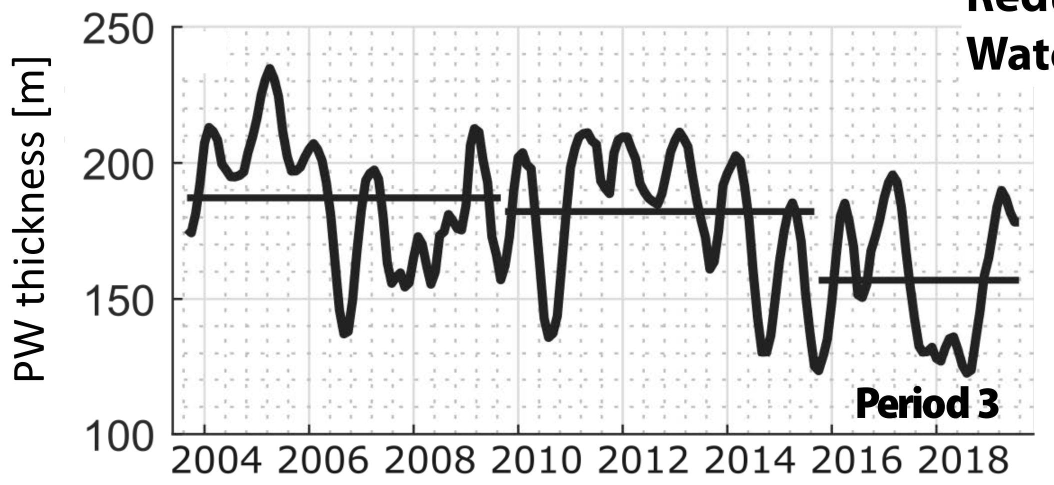
Reduction of FWT, due to both:

- **Reduced FWC and**
- **Weaker flow**
  (except in winter 2017)

FWT relative to 34.9

Karpouzoglou et al. (2022), JGR Oceans

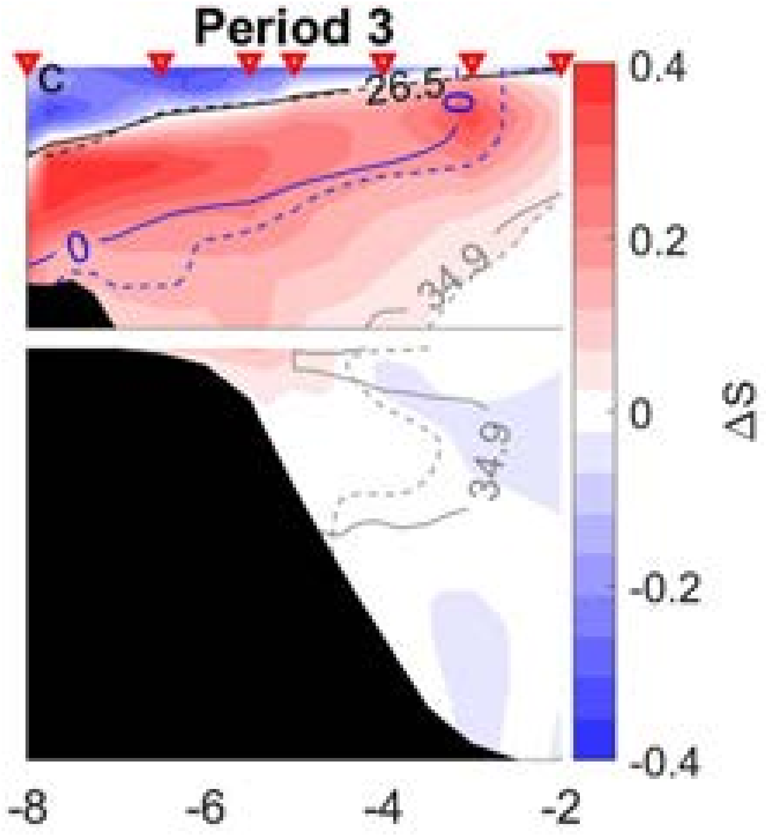
Fram Strait liquid Freshwater Transport (FWT)

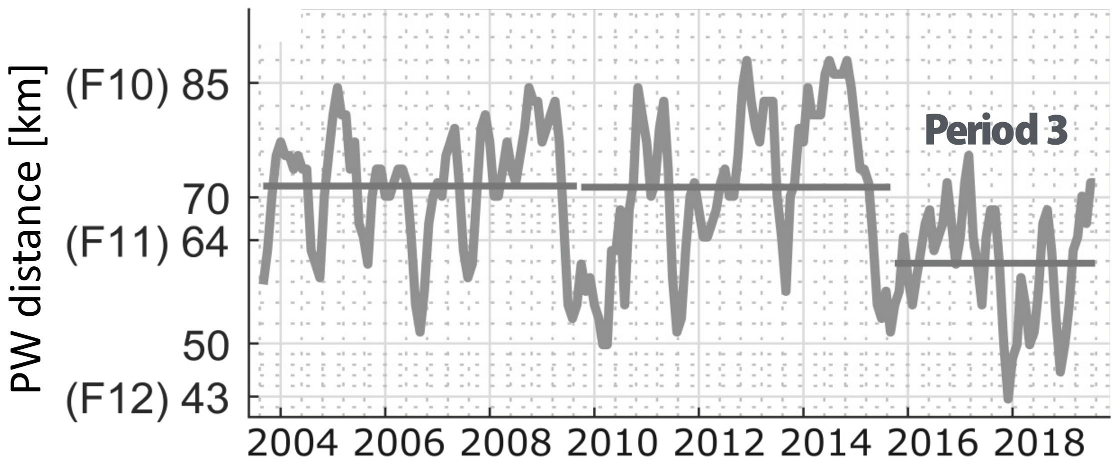


Reduction in Polar Water thickness

→ shoaling of AW

PW: $T < 0°C$
$\sigma_\theta < 27.7$ kg/m^3





Westward move of the PW/AW front

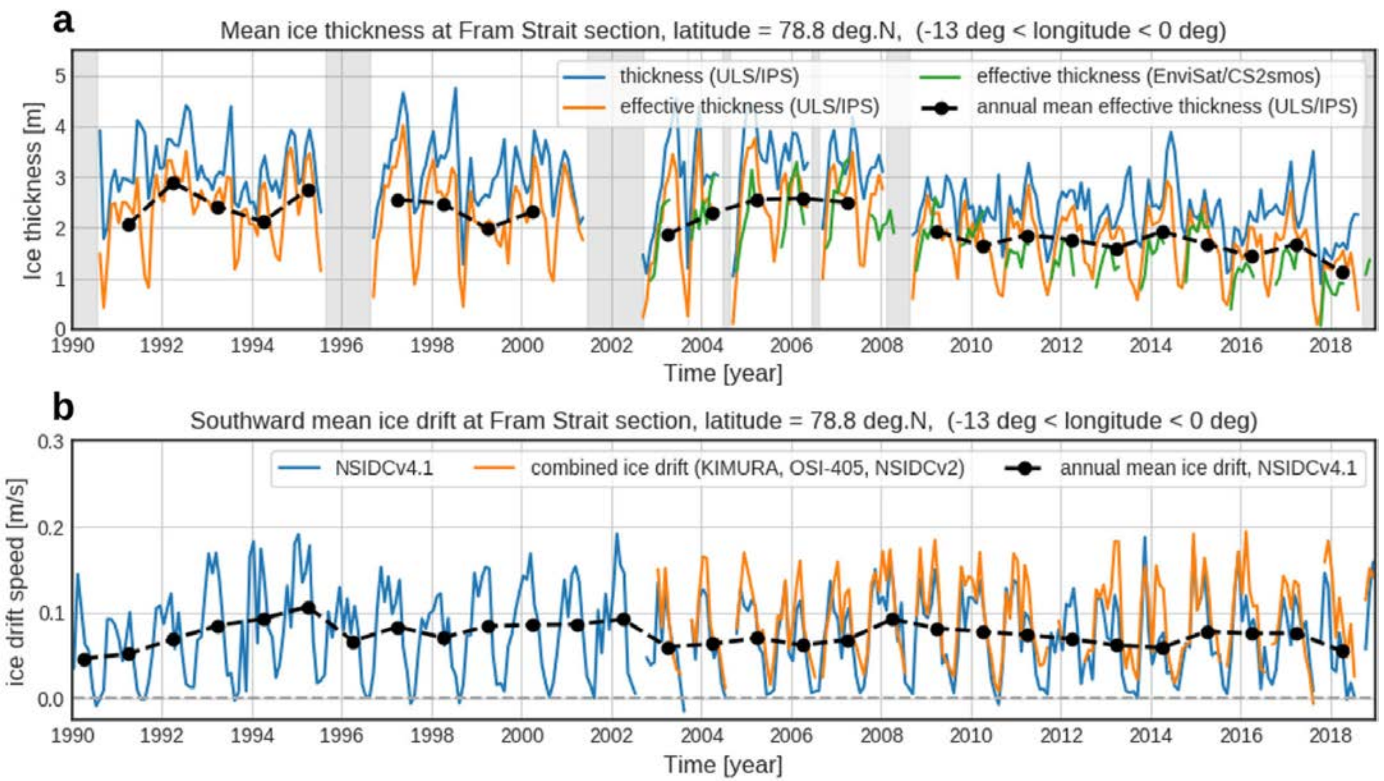
→ increased presence of AW

Karpouzoglou et al. (2022), JGR Oceans

Fram Strait sea-ice transport

Ice Thickness

Ice Drift

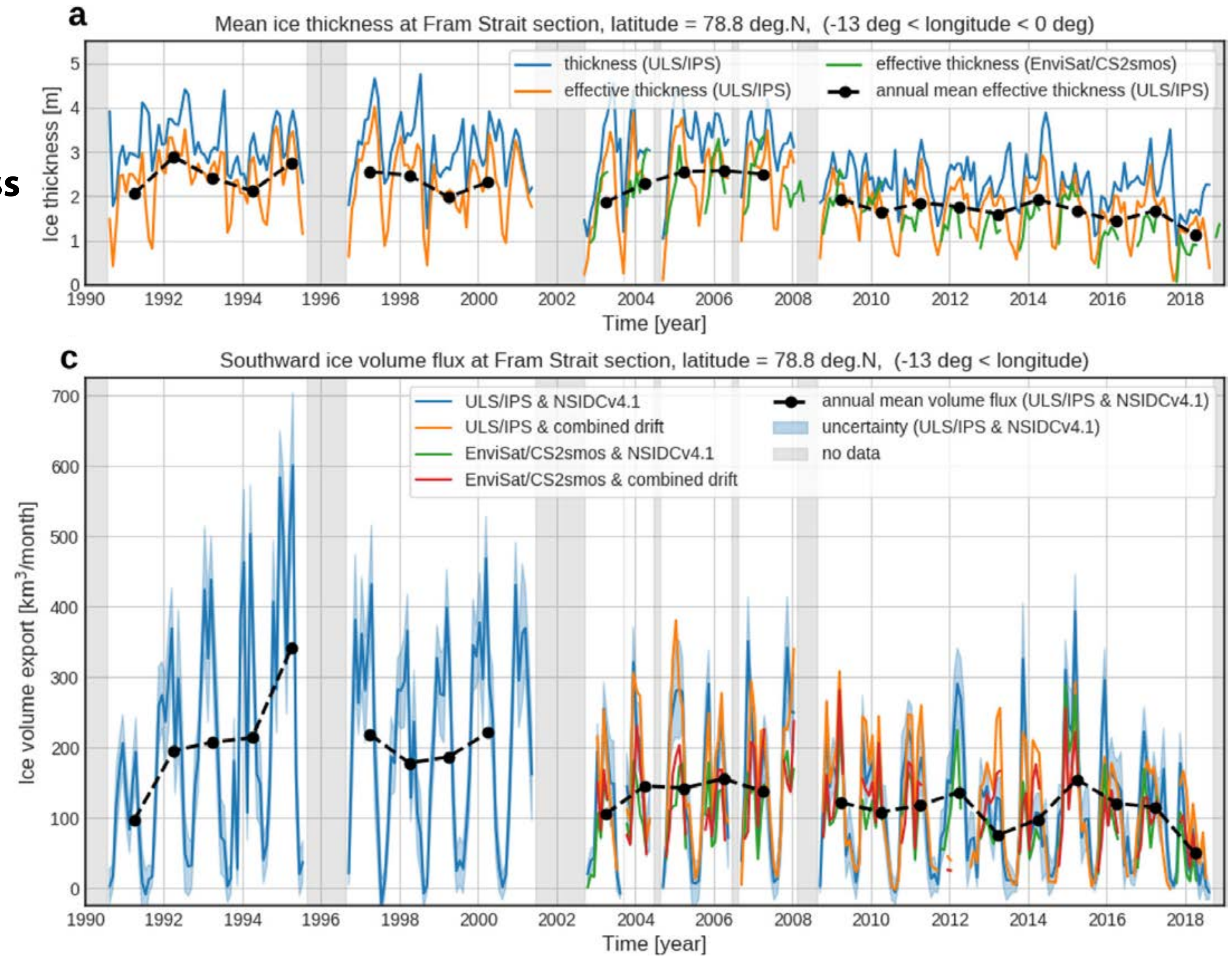


Sumata et al. (2022) Nature Comm.

Fram Strait sea-ice transport

Ice Thickness

Ice Volume Export

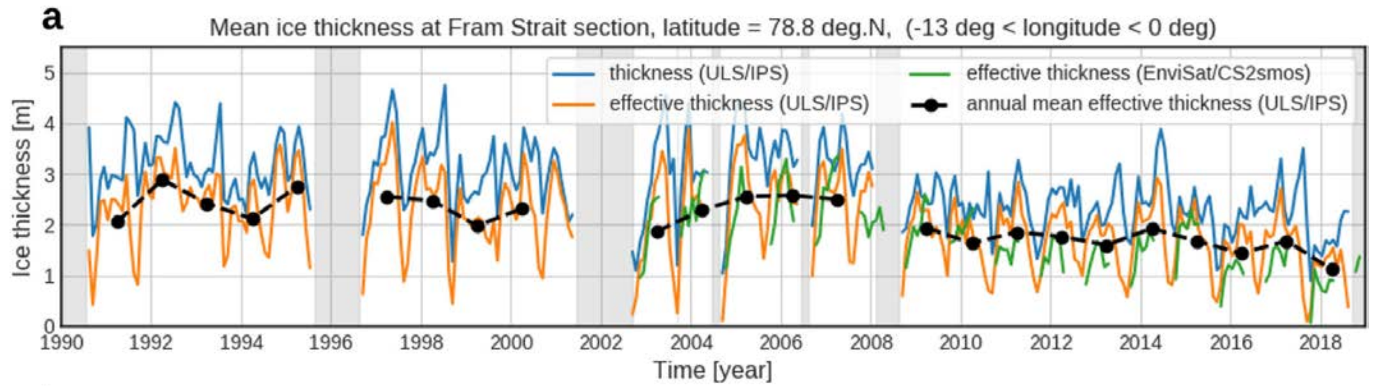


Ice volume export:
Record low in 2018
~25% of the 1990s

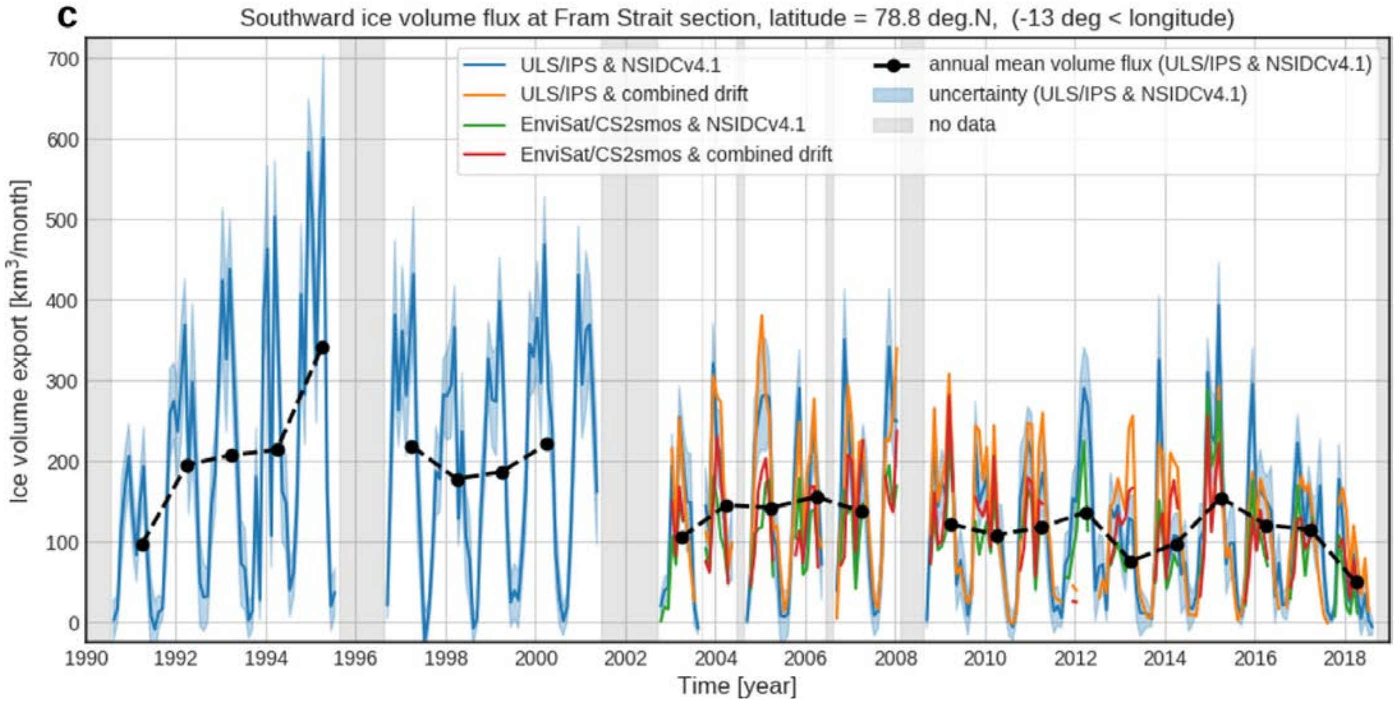
Sumata et al. (2022) Nature Comm.

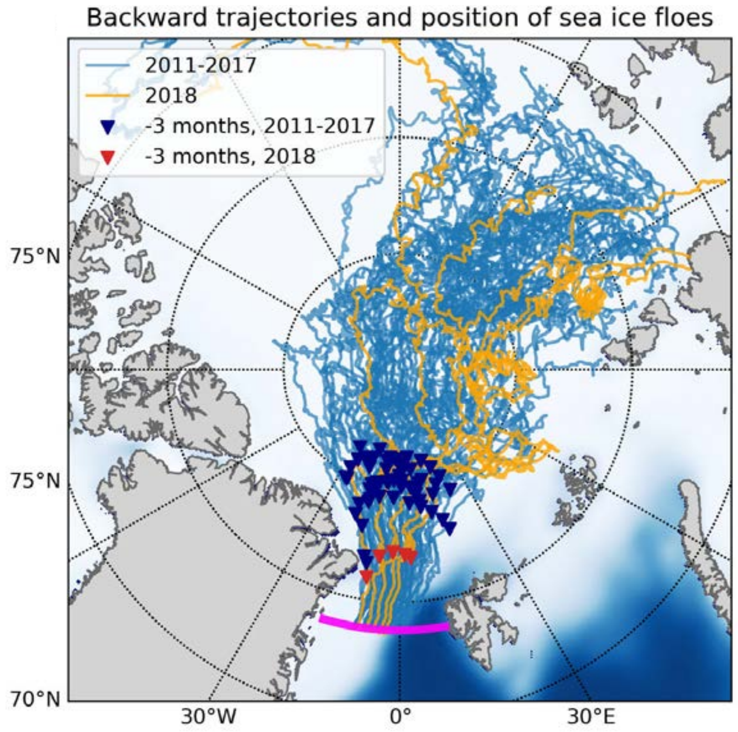
Fram Strait sea-ice transport

Ice Thickness



Ice Volume Export



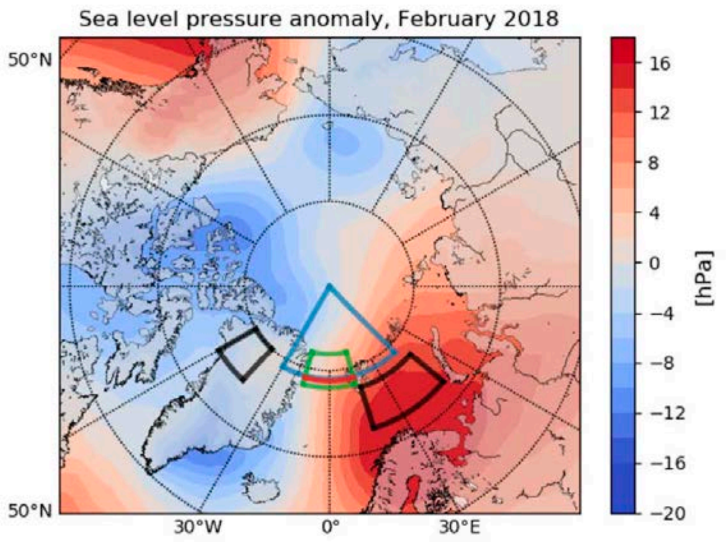


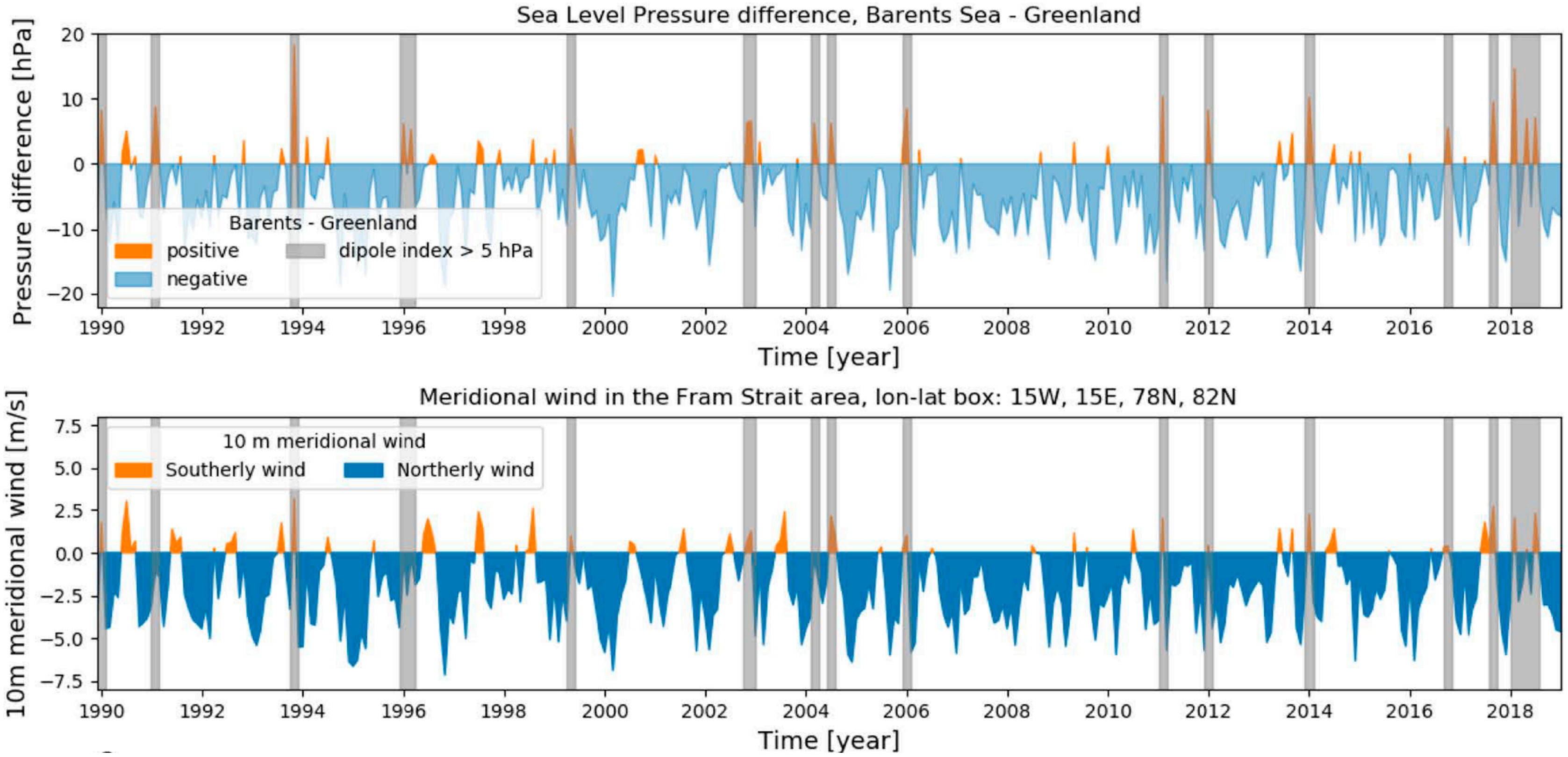
Ice volume export: Record low in 2018 ~25% of the 1990s

Sumata et al. (2022) Nature Comm.

Fram Strait sea-ice transport

Prevailing winds from the south in 2018 forced ice floes to remain north of Fram Strait for several months → thinning the sea ice in that region

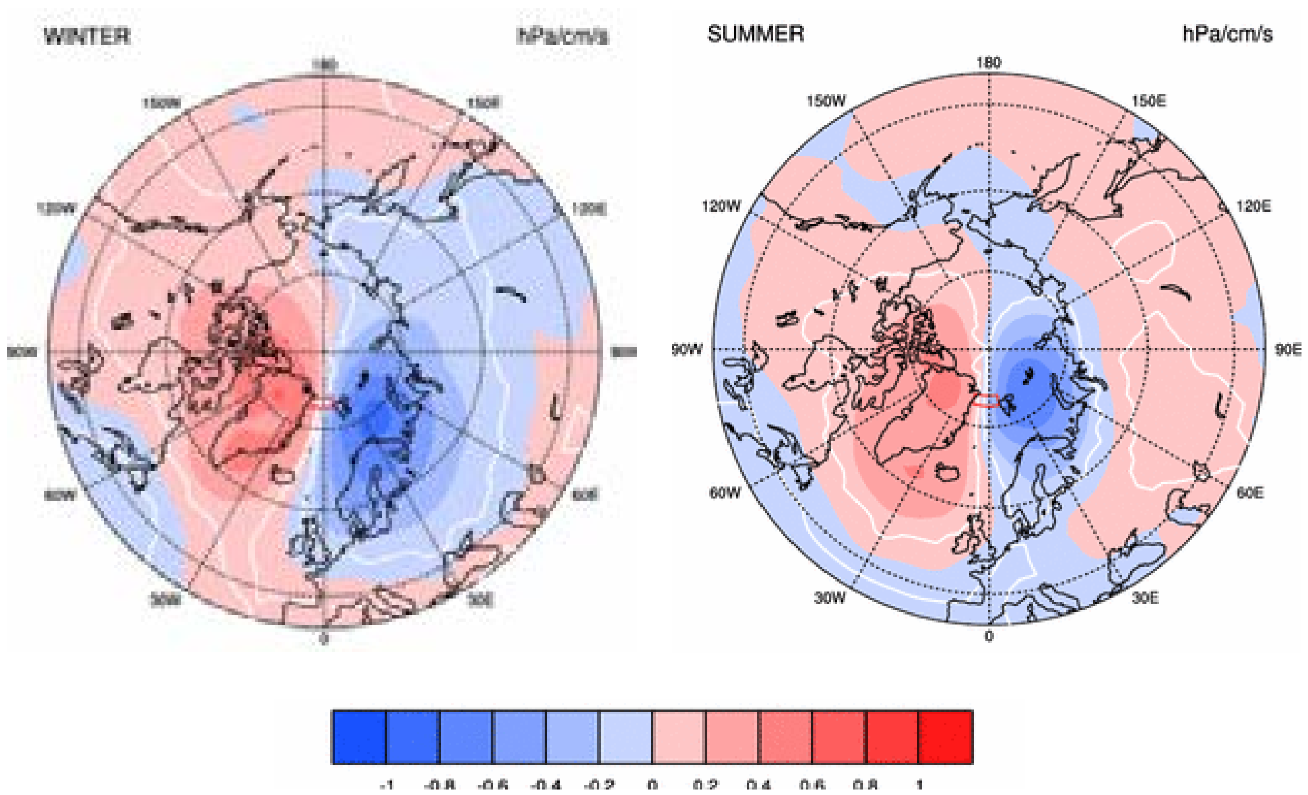




Sumata et al. (2022) Nature Comm.

Atmospheric Blocking Events

Regression coefficients between SLP and southward sea ice velocity through Fram Strait.



Tsukernik et al. (2010), Clim. Dynamics

High-frequency (periods ~5-60 days) variability of sea ice export through Fram Strait are driven by the SLP pressure gradient (Greenland – Barents Sea).

Episodic Blocking Events

Rennert and Wallace (2009), J. of Climate

Greenland Blocking Index (GBI)

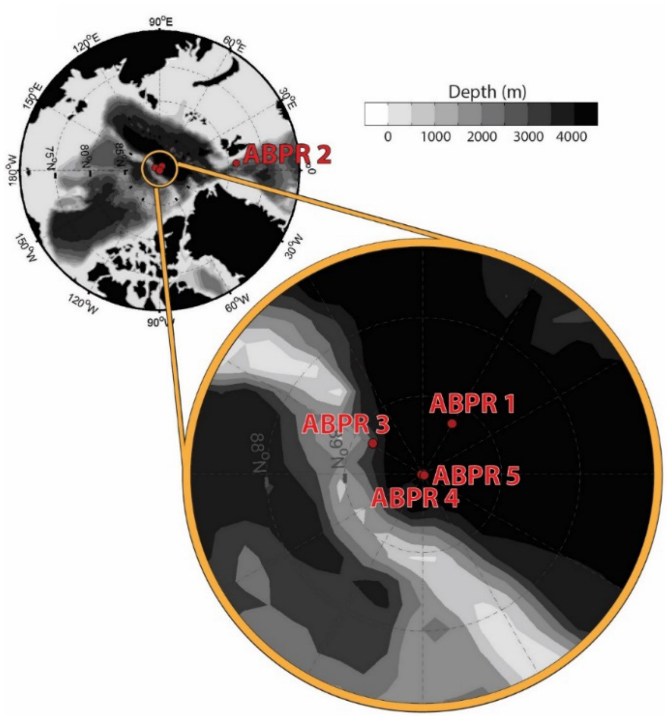
Hanna et al. (2016), Int. J. Climatology

Linkage between atmospheric blocking, sea ice export and AMOC

Ionita et al. (2016), Scientific Reports

Variability in the (liquid) ocean (Arctic and Nordic Seas) is also linked to these atmospheric blocking events.

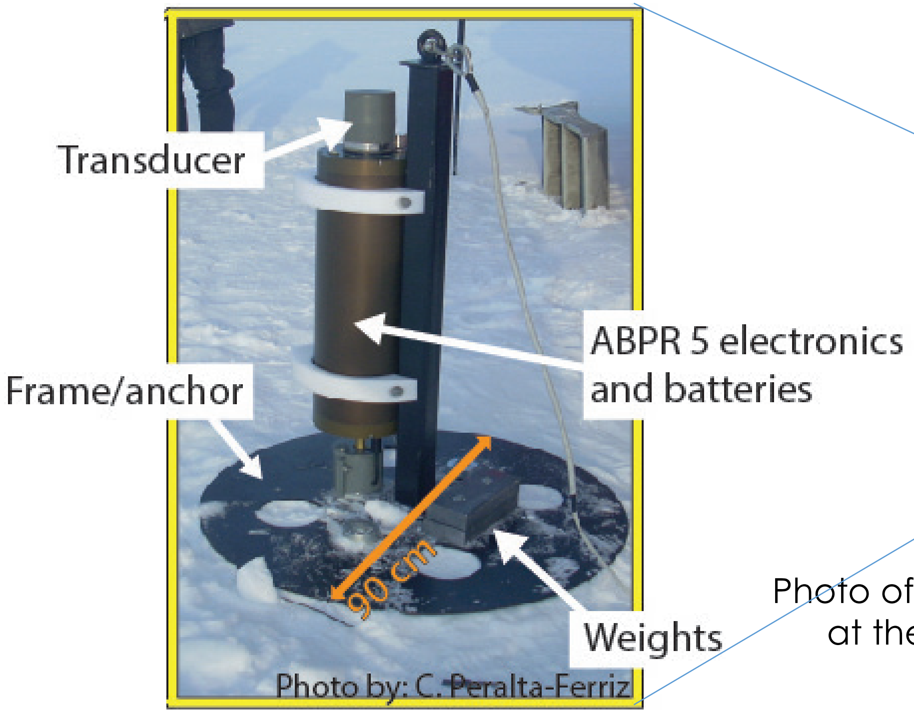
North Pole ocean bottom pressure (OBP)



ABPR (hourly data, 2005-2015)

North Pole OBP data available at:
http://psc.apl.washington.edu/northpole/

Ocean bottom pressure anomalies were measured at the North Pole from 2005 to 2015, using Arctic Bottom Pressure Recorders (ABPRs), as part of UW's North Pole Environmental Observatory (NPEO).



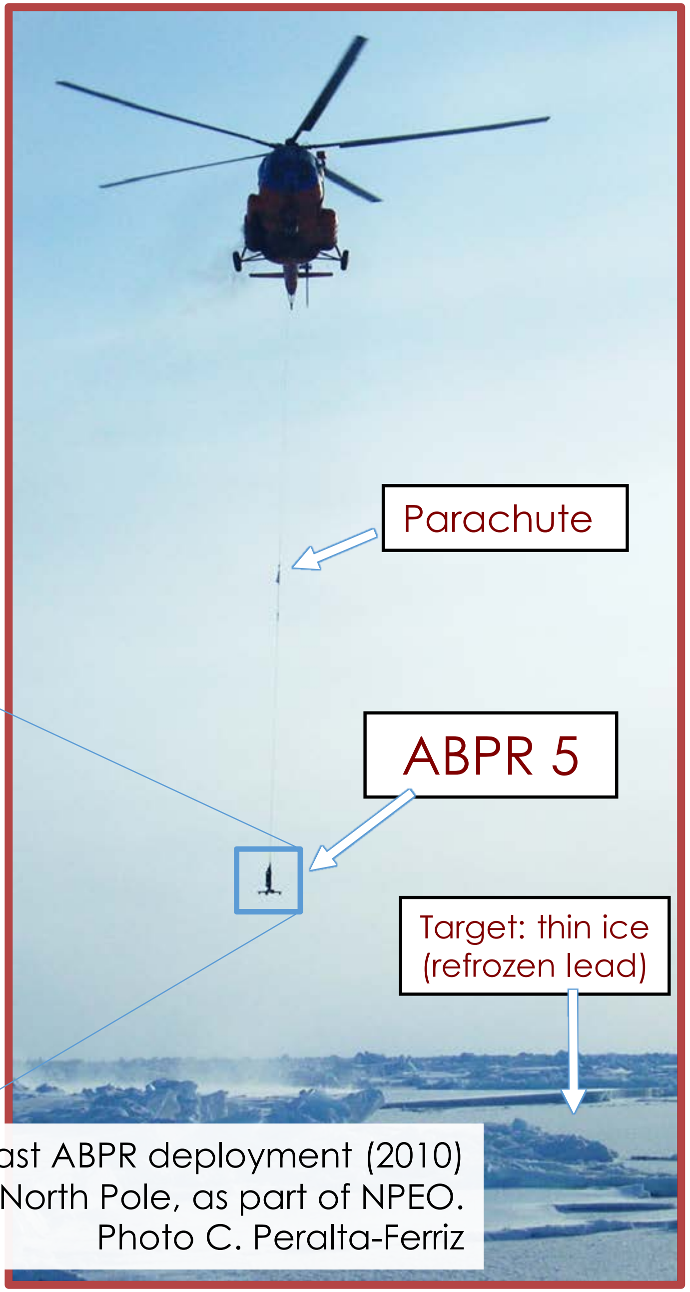


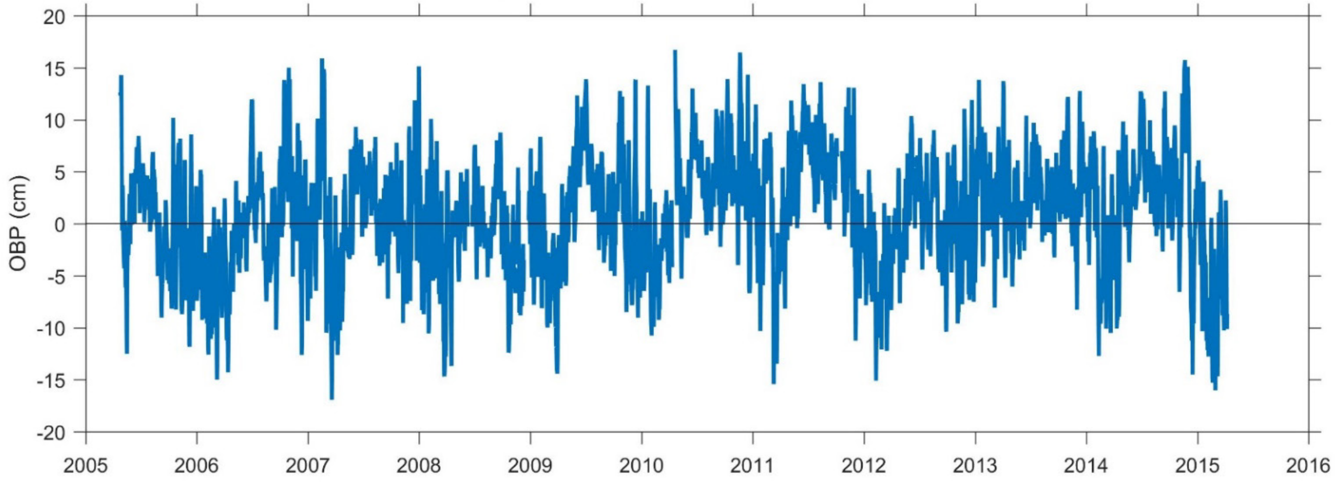
Photo of last ABPR deployment (2010)
at the North Pole, as part of NPEO.
Photo C. Peralta-Ferriz

N 89° 58.7', W 32° 55.4'
ABPR-5 deployment, April 2010

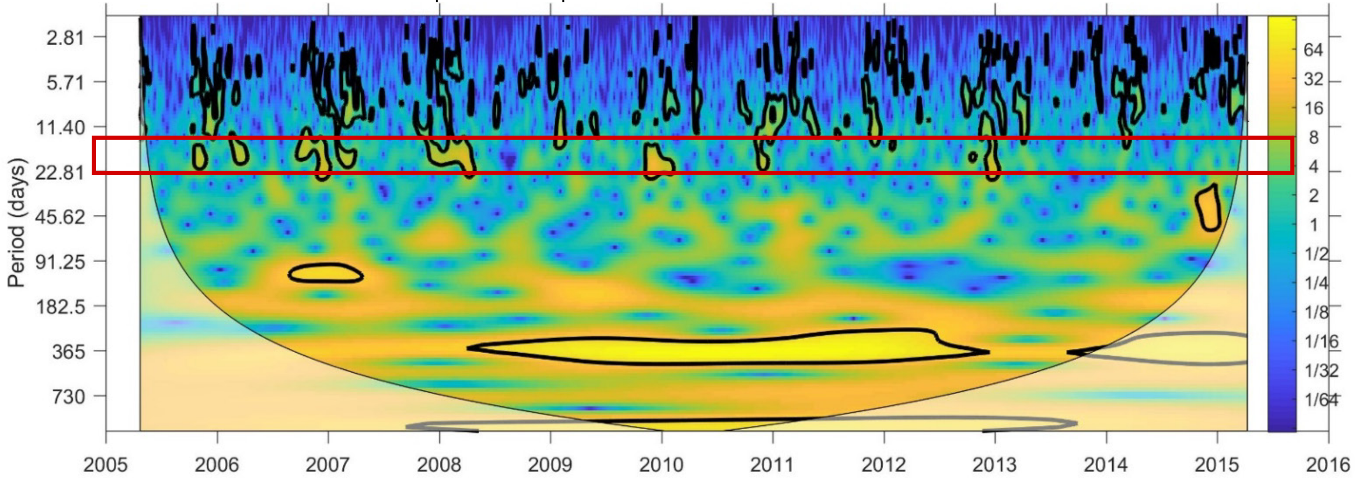
Peralta-Ferriz et al. (2014), Marine Tech. Soc.

Sub-monthly energy of North Pole OBP

Daily, de-tided ocean bottom pressure (OBP)

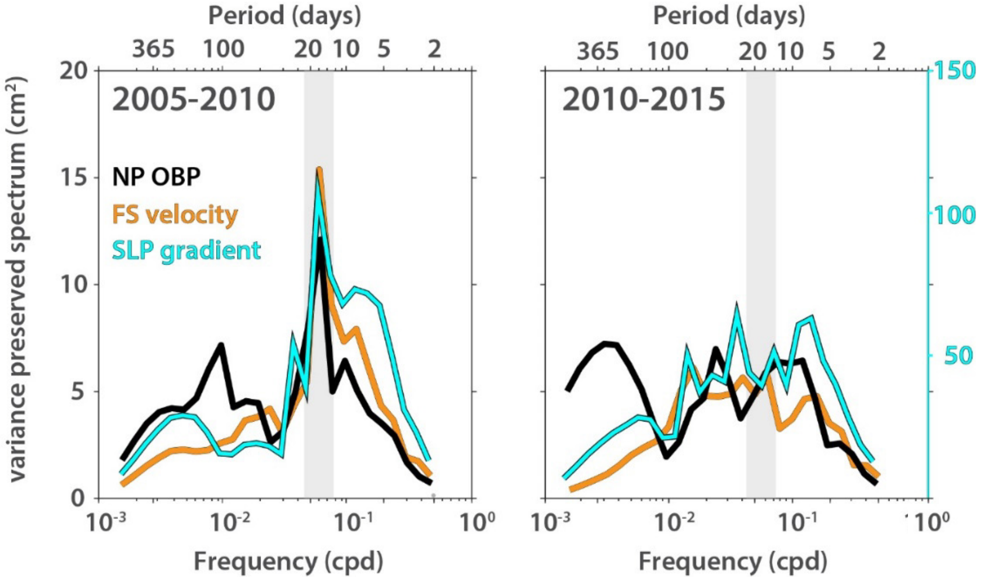


Normalized wavelet power spectrum of OBP



The first 5 years revealed a sub-monthly (~20day period), wintertime (NDJFM) mode of variability.

Last 5 years of the record shows the winter variability in OBP, but the semi-periodic nature erodes.

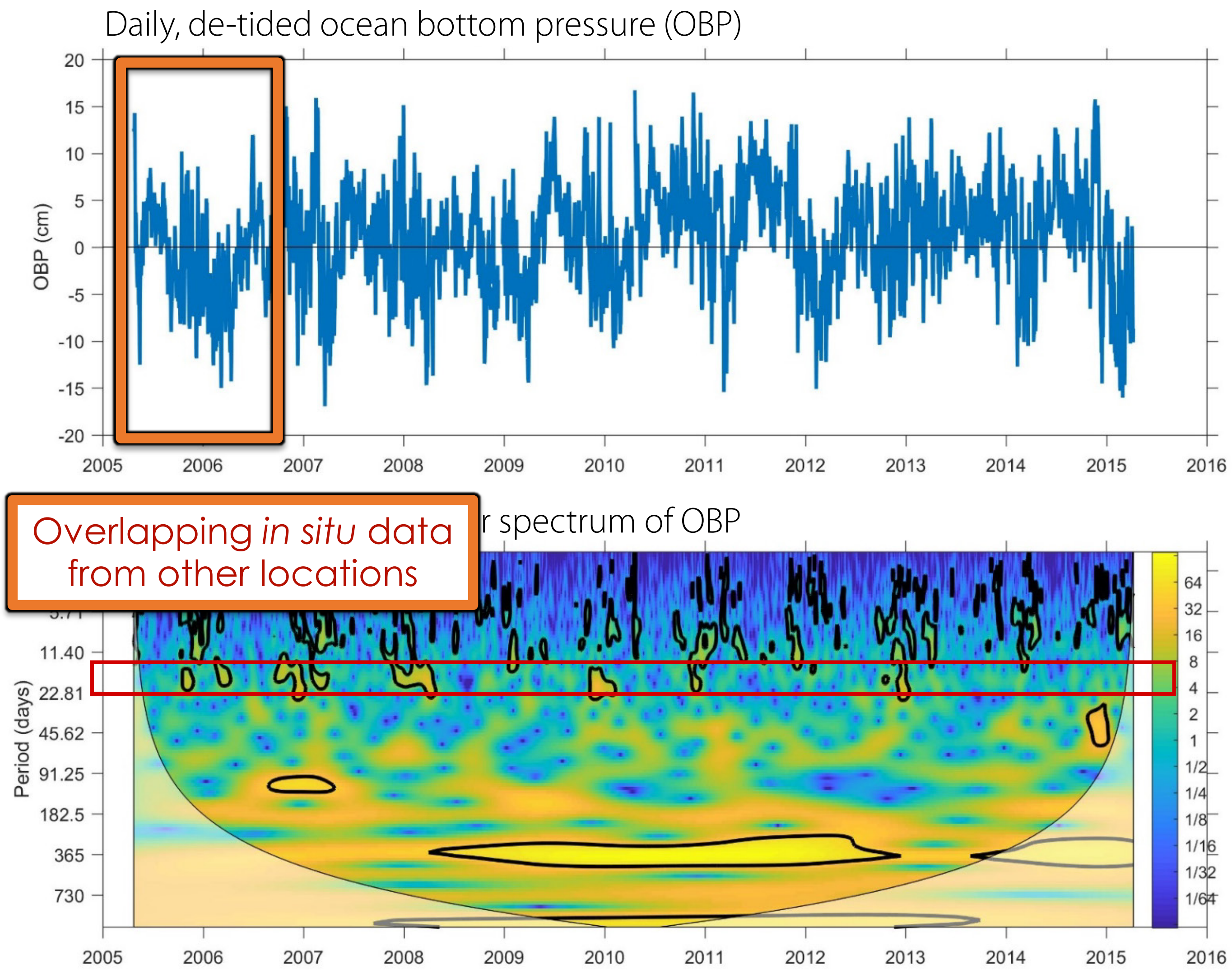


The near-20-day period is present in:

- **4 out of 5 winters of 2005-2010**
- **2 out of 5 winters in 2010-2015**

Updated from Peralta-Ferriz et al. [2014], Marine Tech. Soc.; Peralta-Ferriz et al. (2011), GRL

Sub-monthly energy of North Pole OBP



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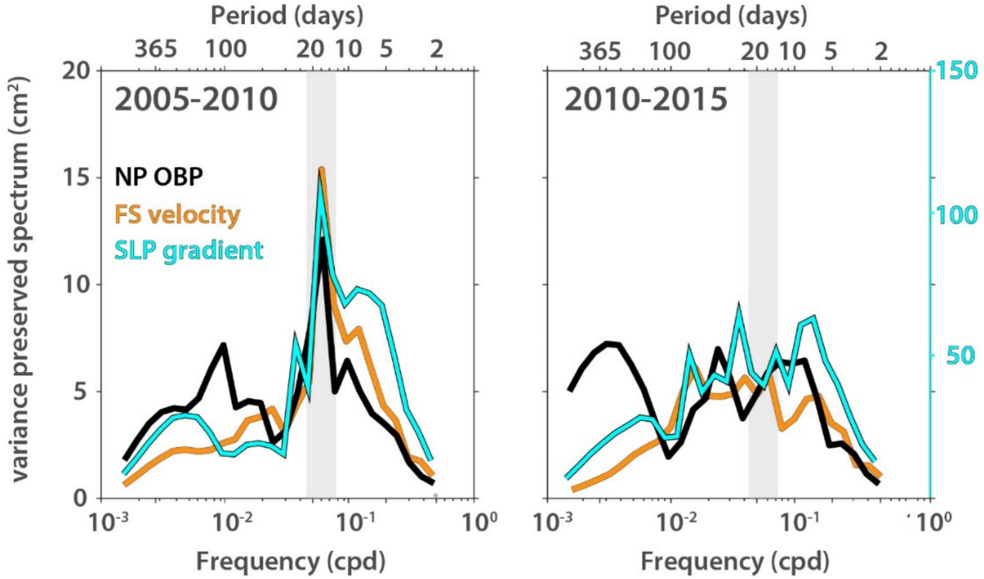

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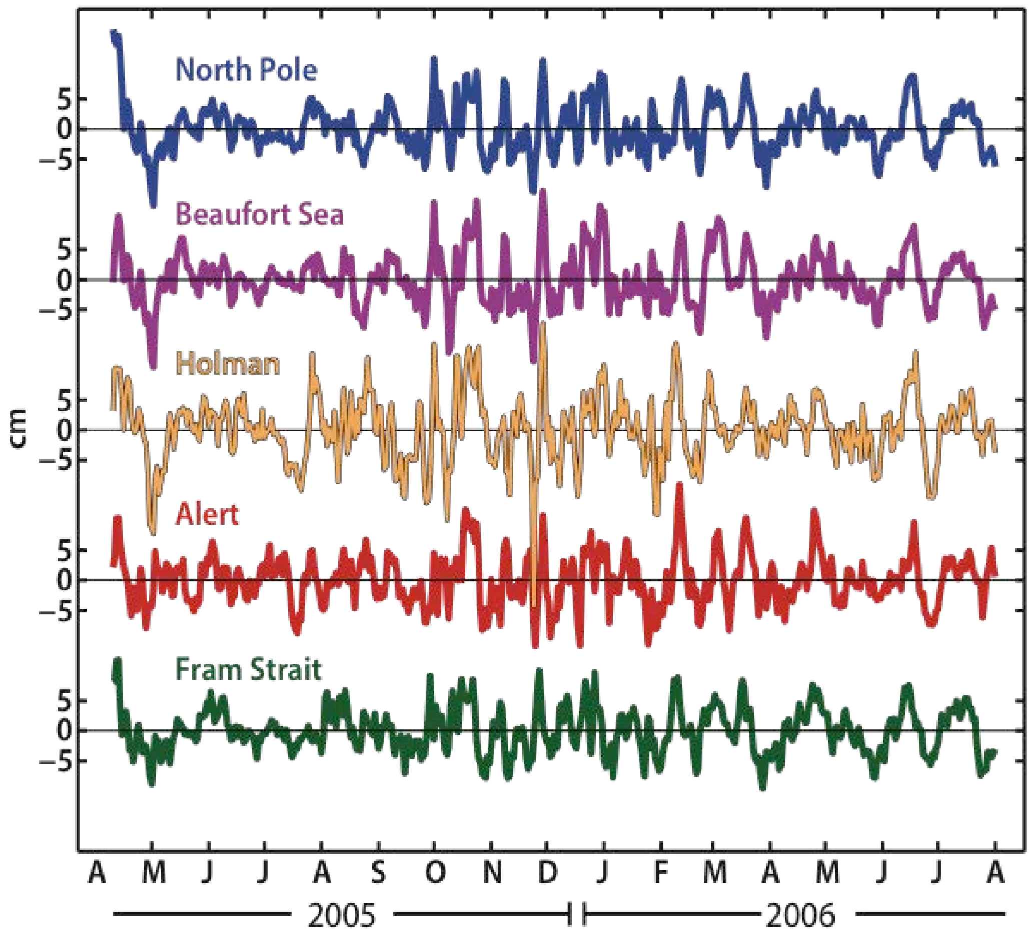
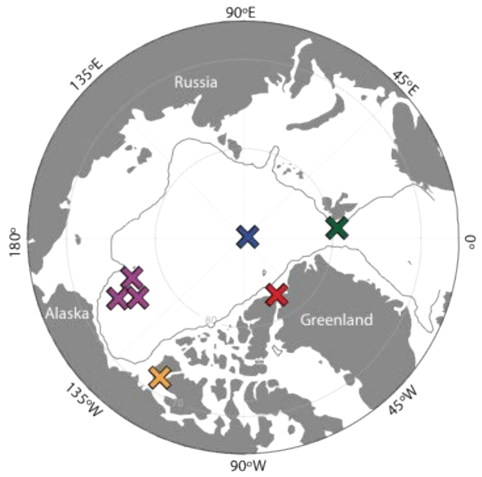
Updated from Peralta-Ferriz et al. [2014], Marine Tech. Soc.; Peralta-Ferriz et al. (2011), GRL

Basin-coherent in situ variability

In situ OBP data from other locations in the Arctic suggest this wintertime, sub-monthly mode of variability is basin-coherent.



Peralta-Ferriz *et al.* [2011], GRL

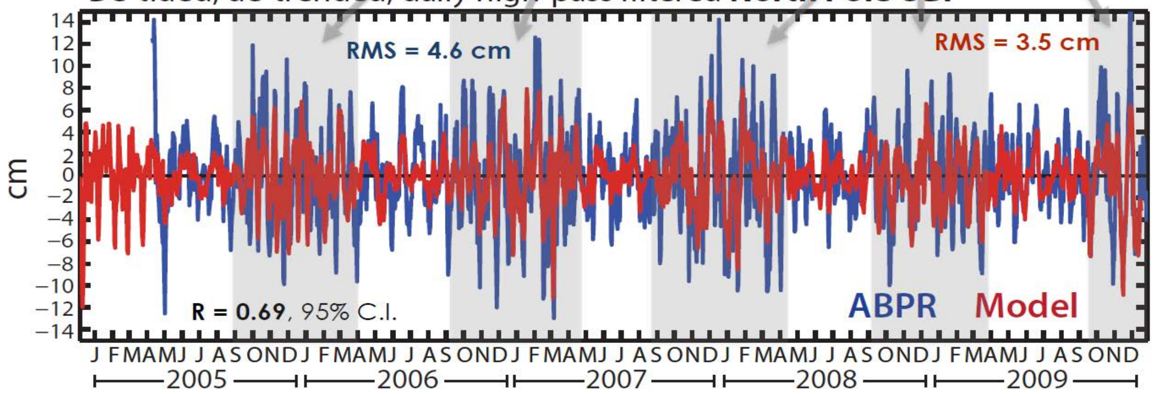


- ABPR from North Pole Environmental Observatory (NPEO)
- Bottom Pressure Recorders, from Beaufort Gyre Exploration Project (BGEP-WHOI)
- Tide gauges (TG) at Holman and Alert Stations, Fisheries and Oceans, Canada
- Pressure Inverted Echo-Sounders (PIES), from the Alfred Wegener Institute (AWI)

UW's PIOMAS model (Zhang and Rothrock, 2003) captures the sub-monthly, wintertime mode of variability

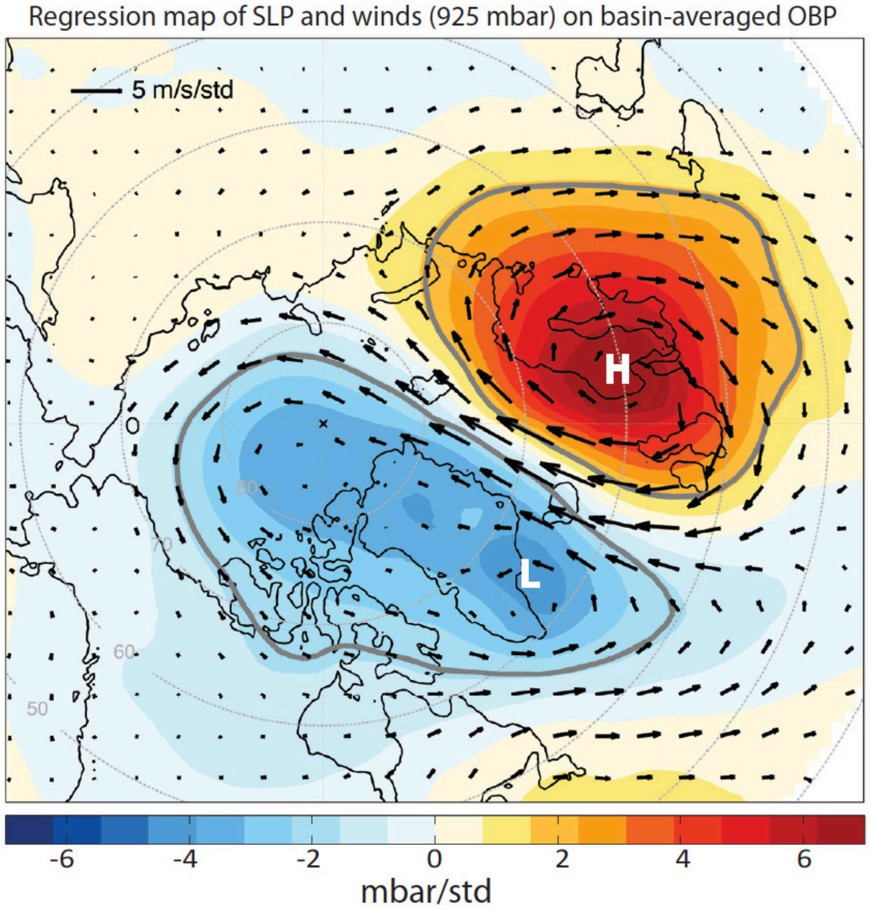
LARGEST variability during winter

De-tided, de-trended, daily high-pass filtered **North Pole OBP**



Atmospheric forcing of the sub-monthly OBP variability

Regression map of NCEP winds (925 hPa) and sea level pressure (SLP) on modeled basin-averaged OBP (2000-2010).



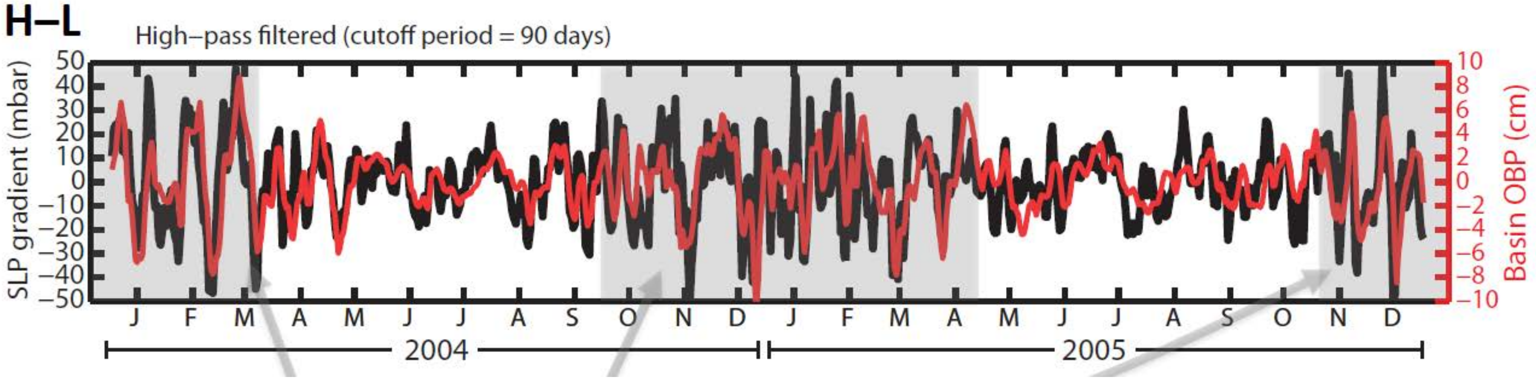
Pattern resembles **episodic blocking events,**

[*Rennert and Wallace*, 2009; *Tsukernik et al.*, 2010]

H–L → SLP gradient

— 95% C. I.

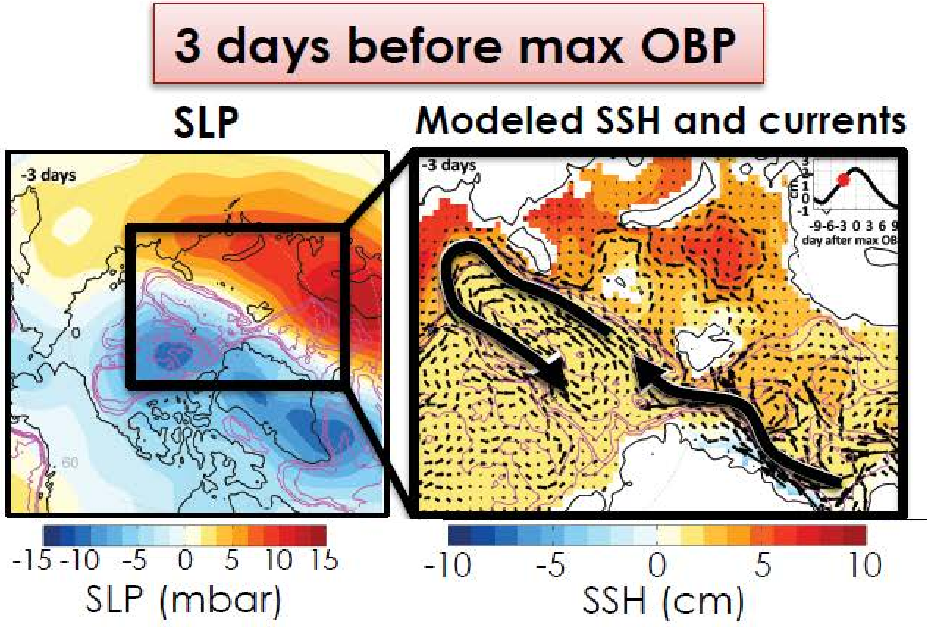
Winds from the south generate a geostrophic slope current that leads to ocean mass increase in the Arctic.



Peralta-Ferriz et al. [2011], GRL

Modeled ocean circulation anomaly

2000-2010 composites of NCEP SLP, modeled SSH and depth-averaged ocean currents relative to maximum and minimum OBP.



Peralta-Ferriz et al. (2011), GRL

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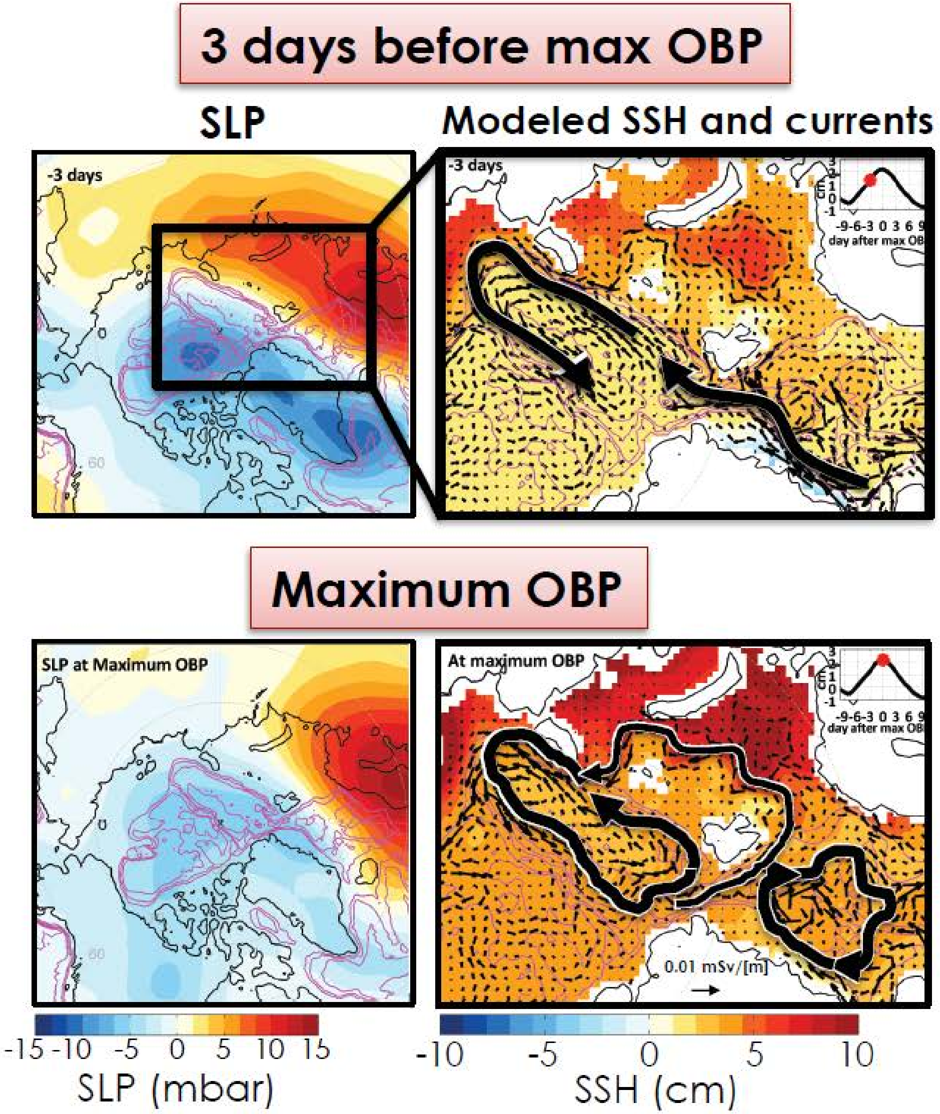

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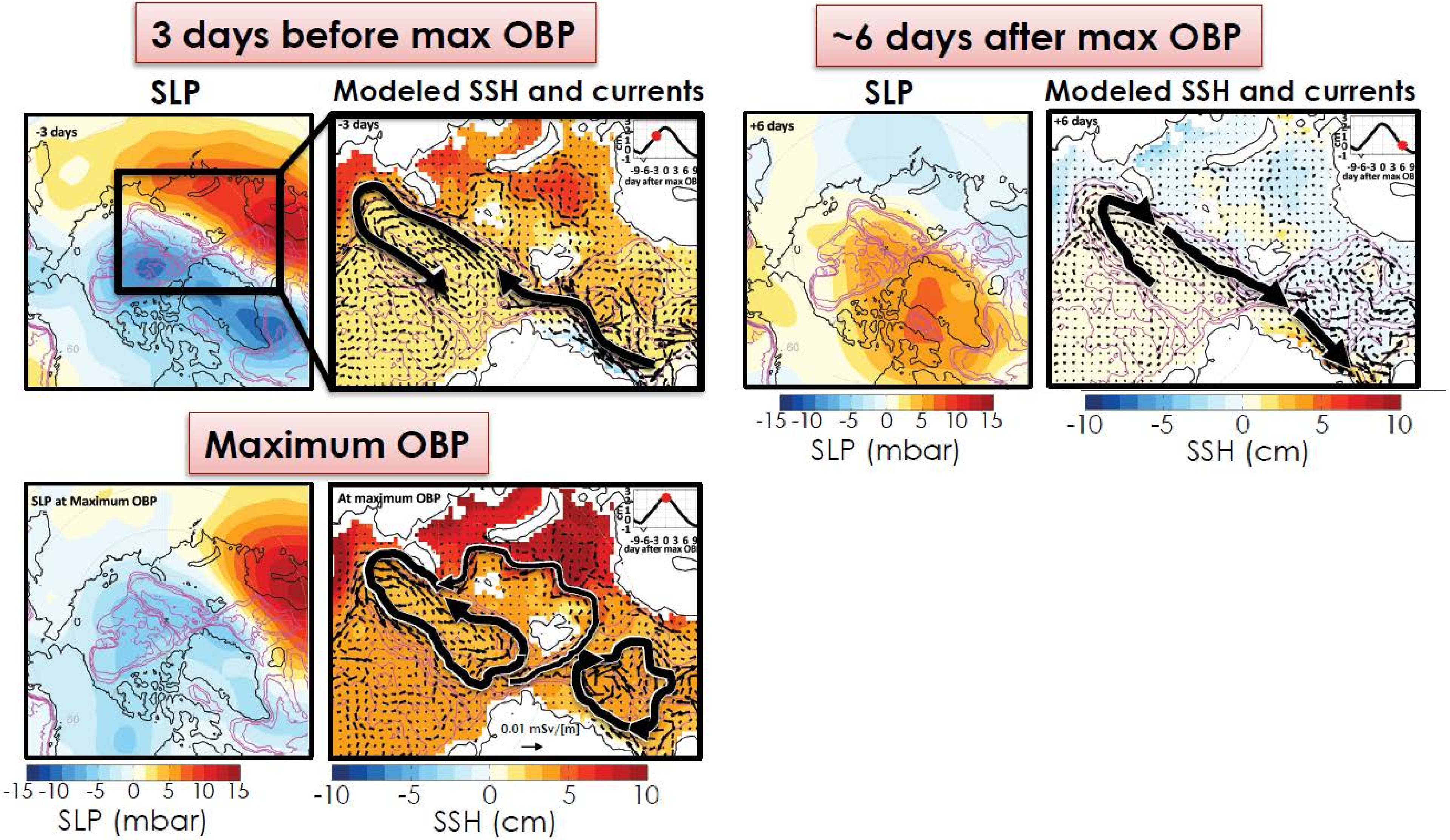

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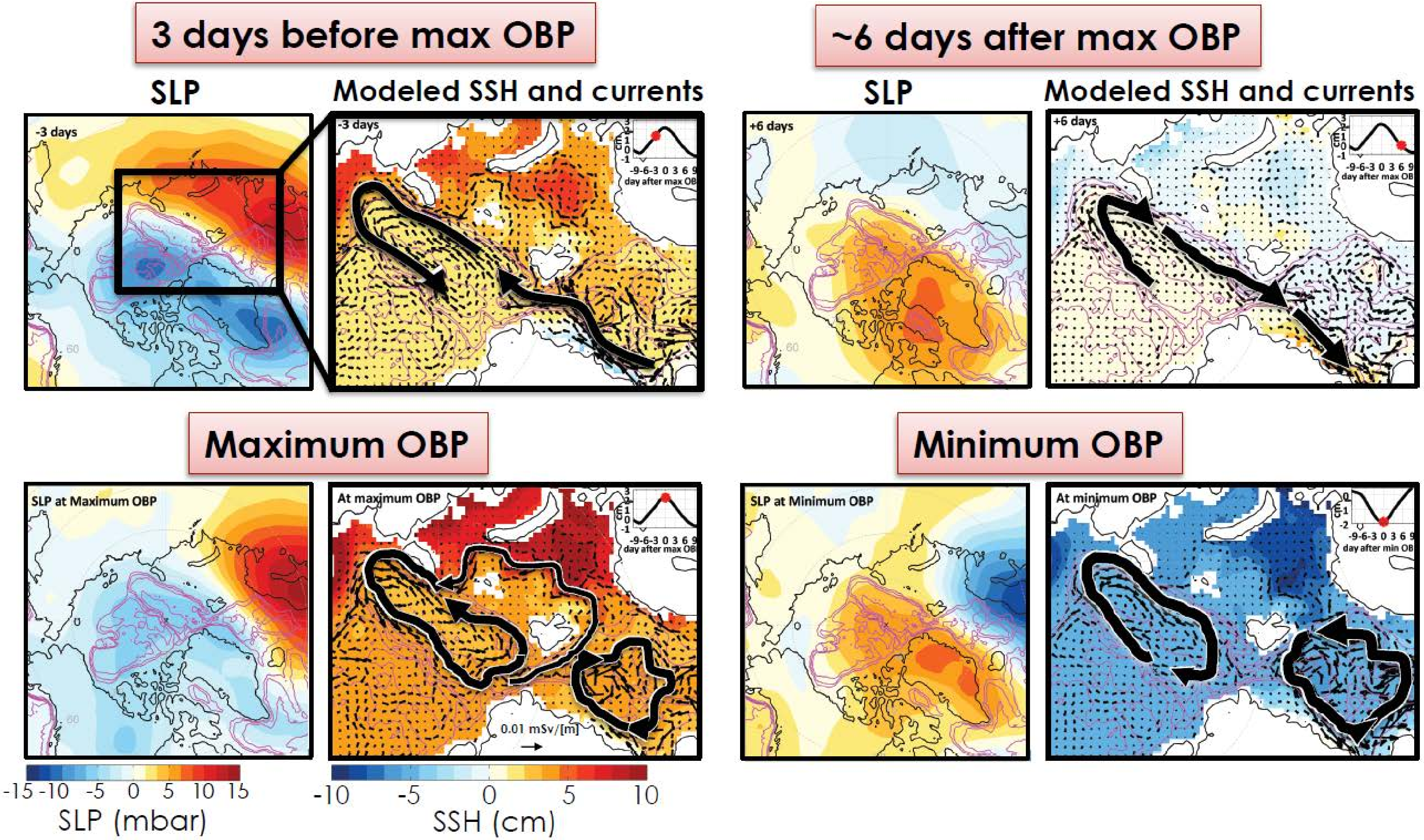

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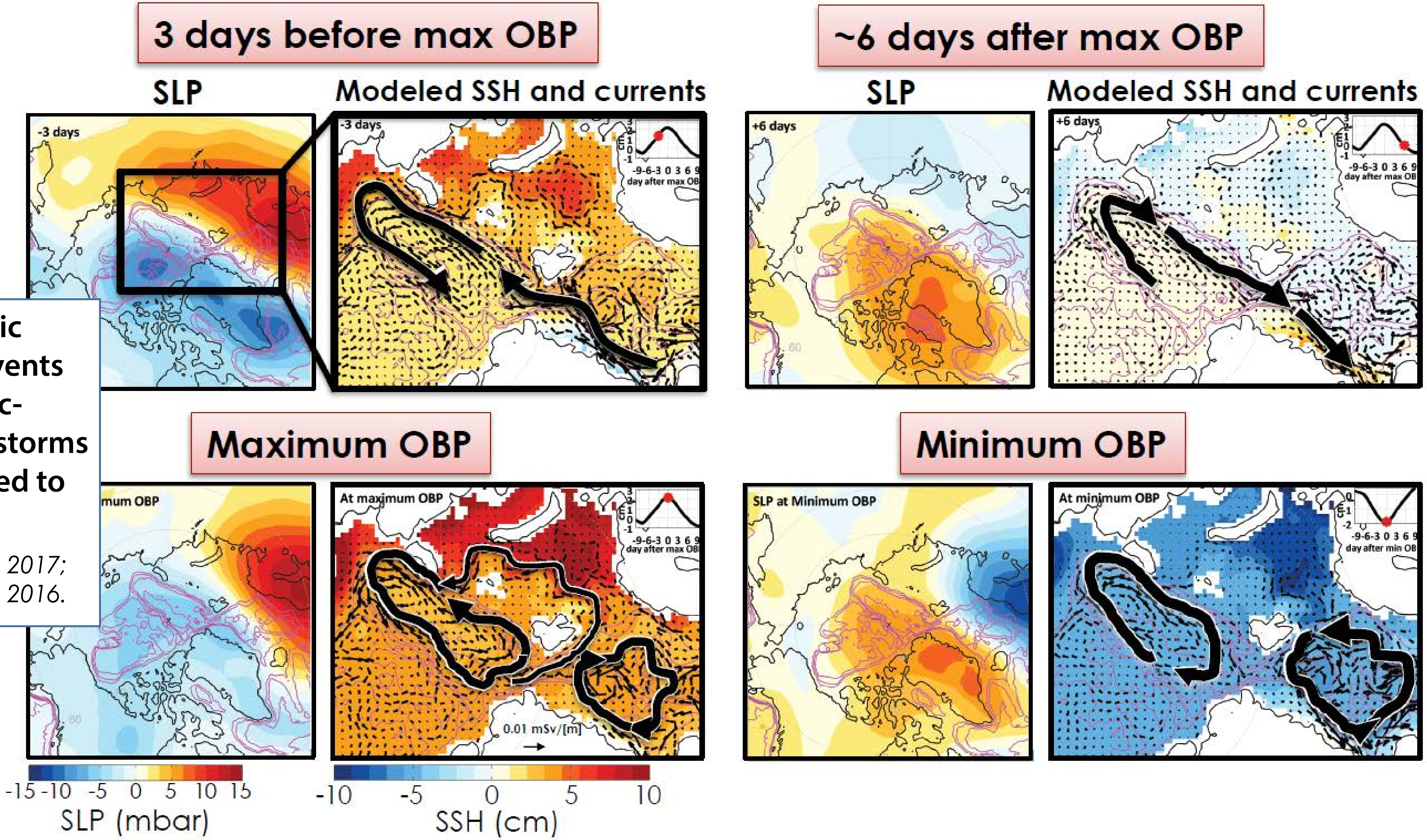

Atmospheric Blocking events and Atlantic-generated storms are projected to increase

Graham et al 2017; Ionita et al., 2016.

Peralta-Ferriz et al. (2011), GRL

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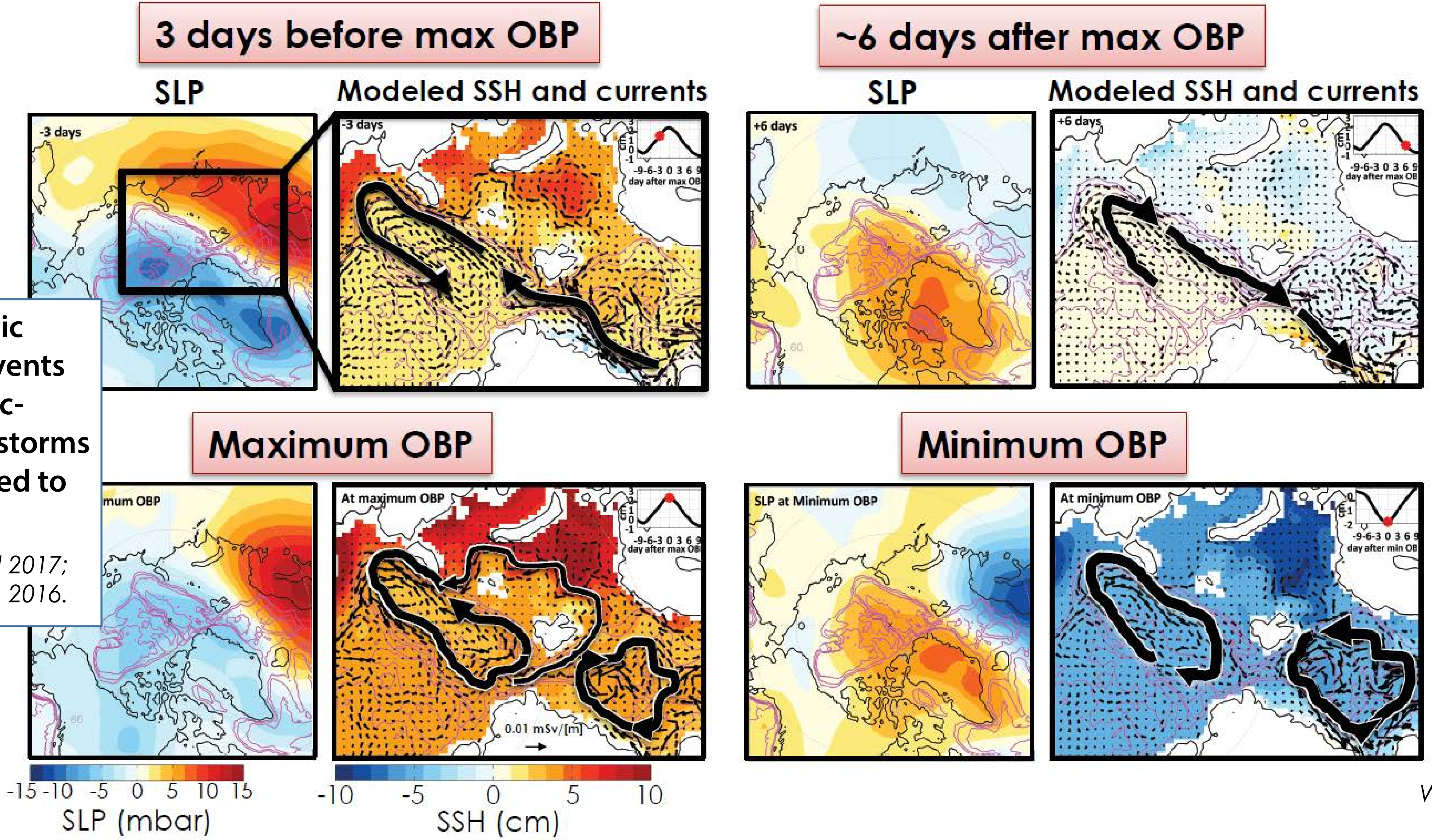

Atmospheric Blocking events and Atlantic-generated storms are projected to increase

Graham et al 2017; Ionita et al., 2016.

Spin-up of the Nordic Seas gyre may also increase fluxes (volume, heat, salt) into the Arctic

Wang et al. (2020), GRL

Peralta-Ferriz et al. (2011), GRL

North Pole ABPR-FO → Aug 2022

ABPR-FO system during free-fall test in Lake Washington aboard R/V Robertson in 2021.

NASA-funded North Pole ABPR-Follow-On (ABPR-FO) will be deployed in August 2022.

The deployment and data-collection in the subsequent five years, will be supported by Le Ponant's icebreaker Le Commandant Charcot and its crew members during one of its new summer tourist cruises to the North Pole.

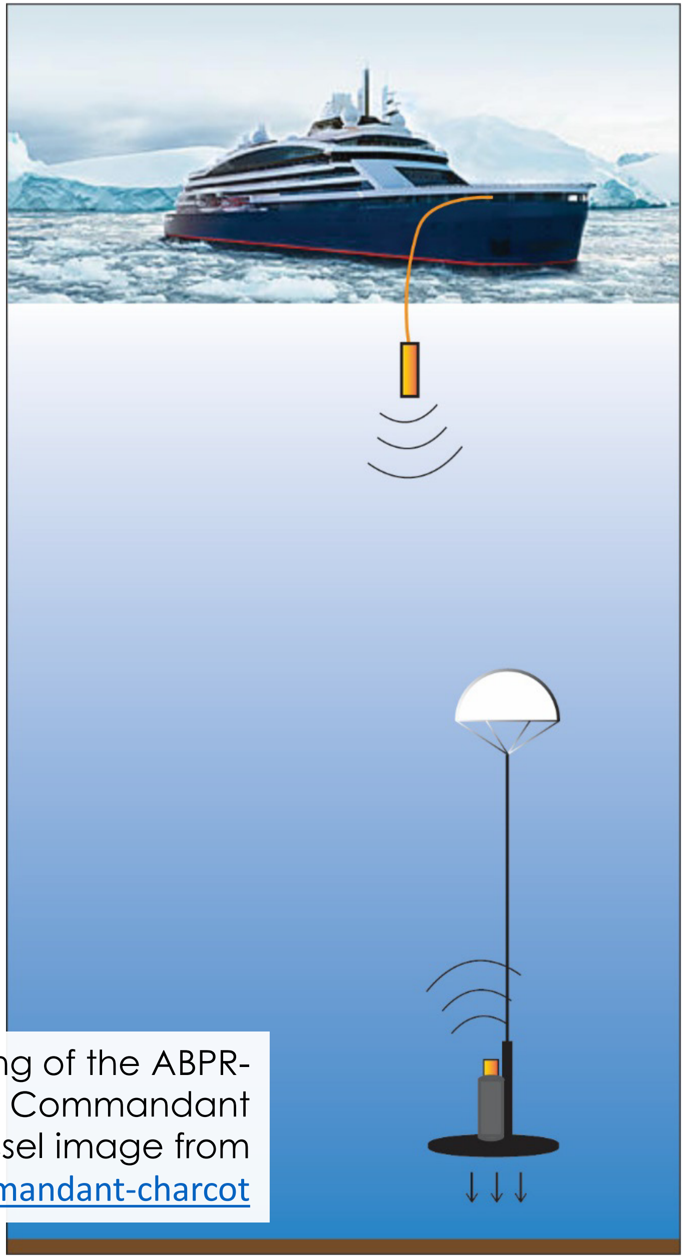

Illustration of acoustic monitoring of the ABPR-FO's deployment from Le Commandant Charcot's lab/deck. Vessel image from https://us.ponant.com/le-commandant-charcot

Summary

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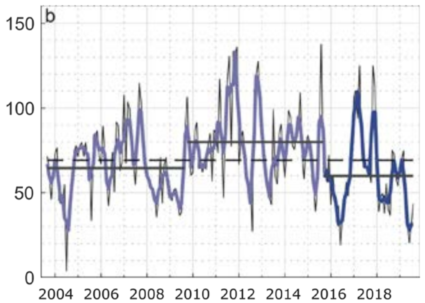

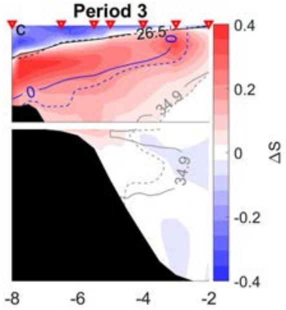

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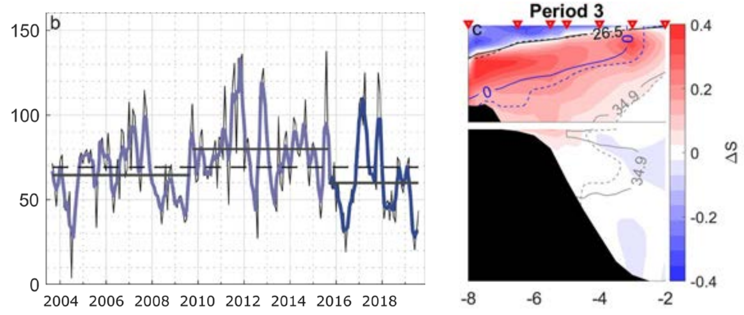
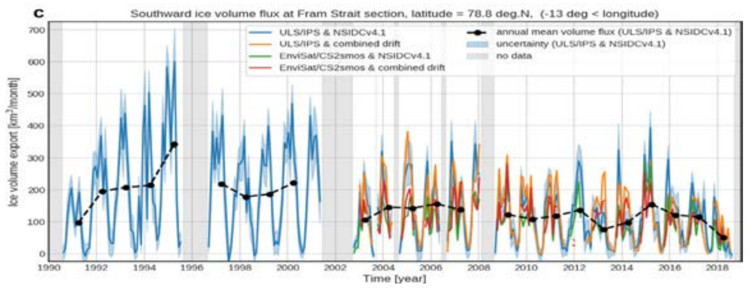
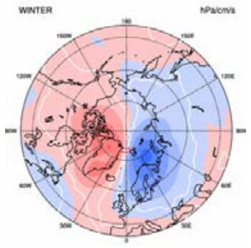


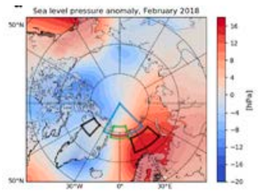
2. Record low sea ice export and **total FWT** through Fram Strait **in 2018**



Summary

3. These recent reduced ice export and FWT are driven by atmospheric circulation changes, related to atmospheric blocking events.





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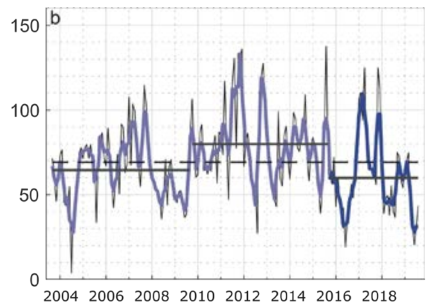

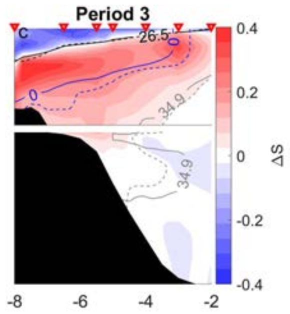

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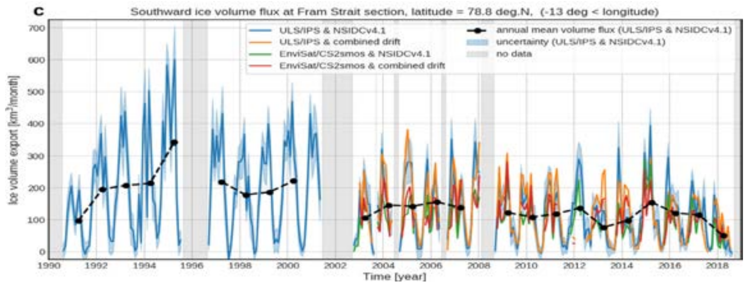

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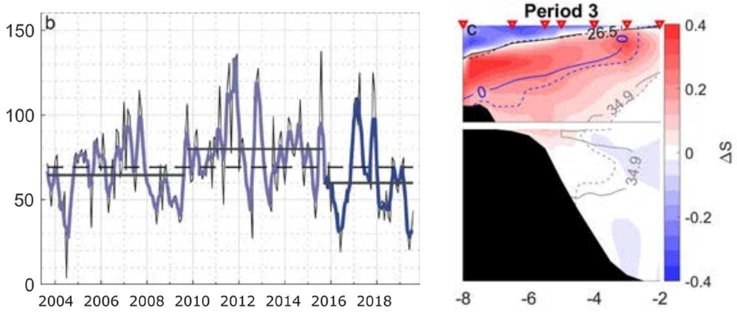

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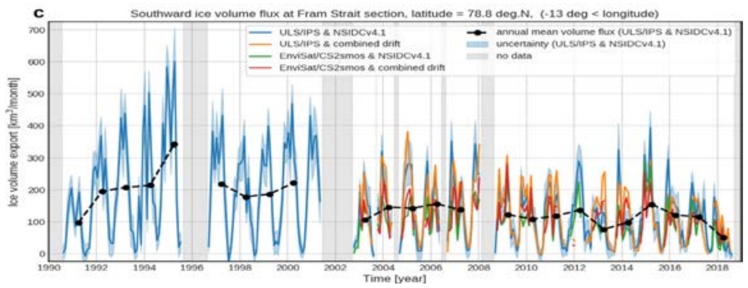

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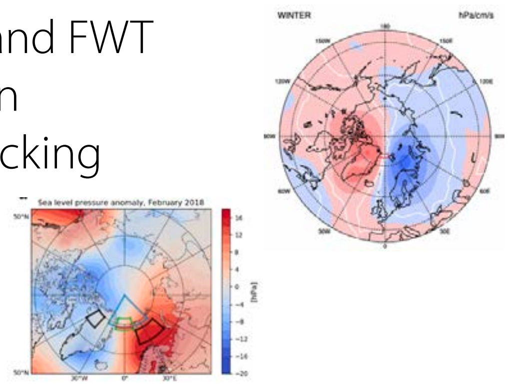
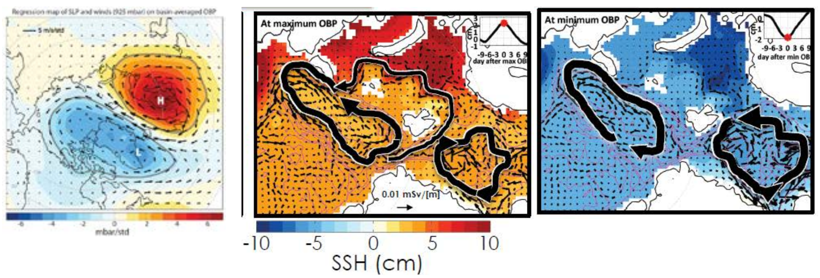


4. Atmospheric blocking drives variability in sea ice export through Fram Strait, and sub-monthly variability in Arctic OBP, and are linked to spin up/down of the Nordic Seas & Eurasian Basin gyres.



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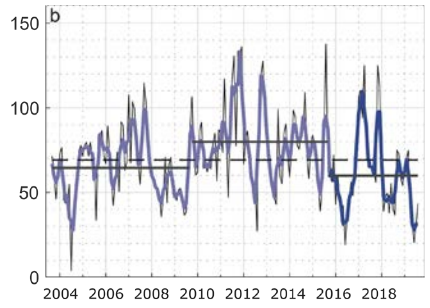
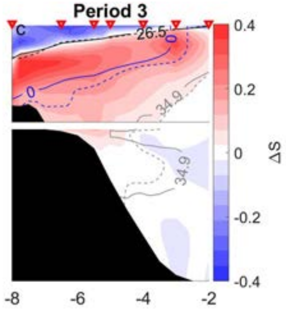
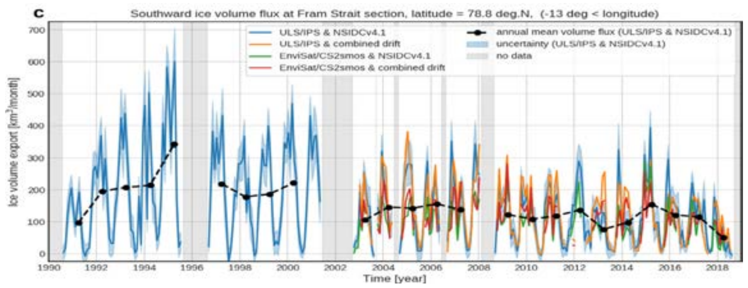
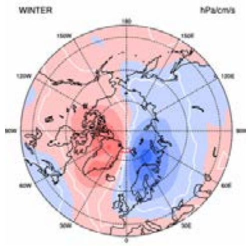


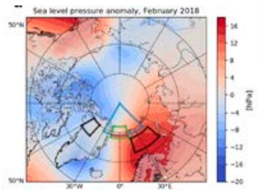


2. Record low sea ice export and **total FWT** through Fram Strait **in 2018**



3. These recent reduced ice export and FWT are driven by atmospheric circulation changes, related to atmospheric blocking events.





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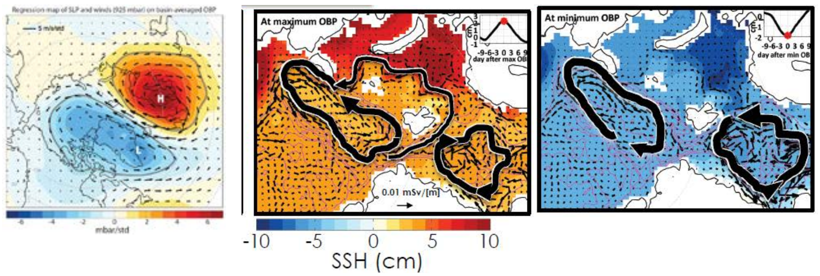

5. Atmos. blocking events and cyclones/storms have been proposed to increase under ongoing warming climate. Bottom pressure recorders: excellent tool to identify and quantify high-frequency atmos-ocean interactions and their associated effects in circulation at various timescales.

Summary

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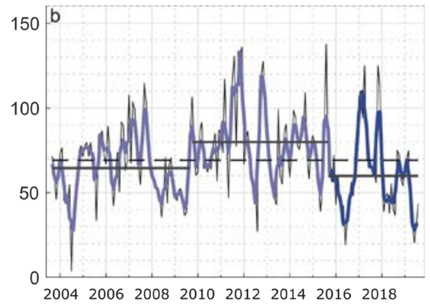

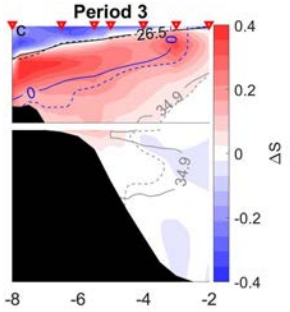

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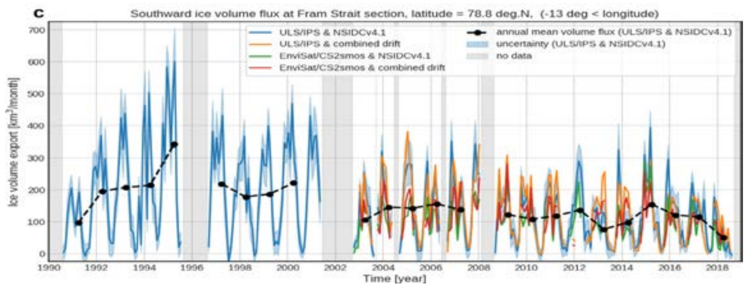

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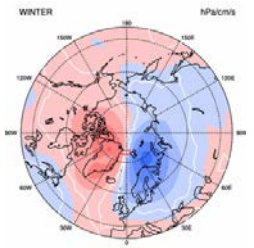

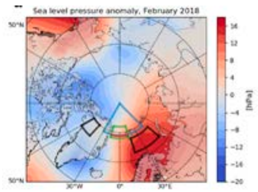

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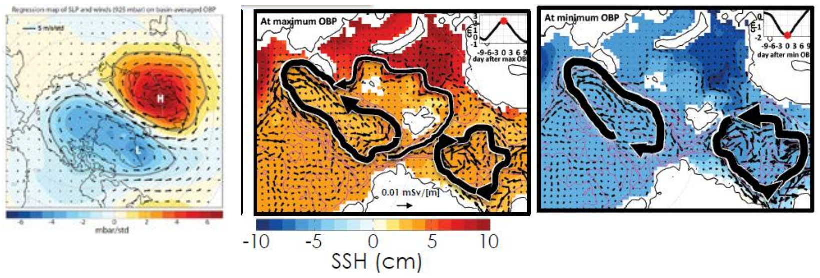

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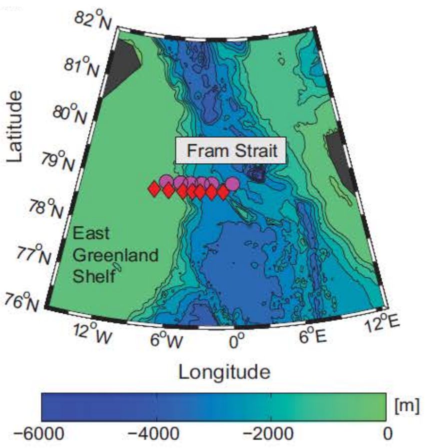
Thank you

Fram Strait *in situ* v-velocity and temperature

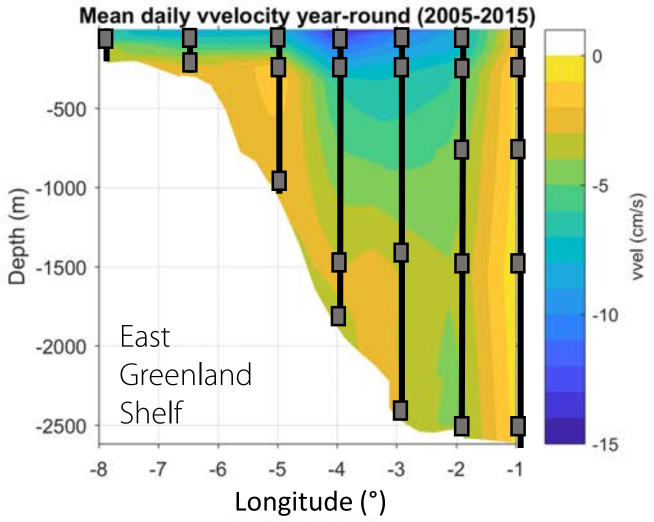
Daily de-tided, v-velocity (vvel) and temp. averaged over 2005-2015, consistent with 2002-2009 avg.

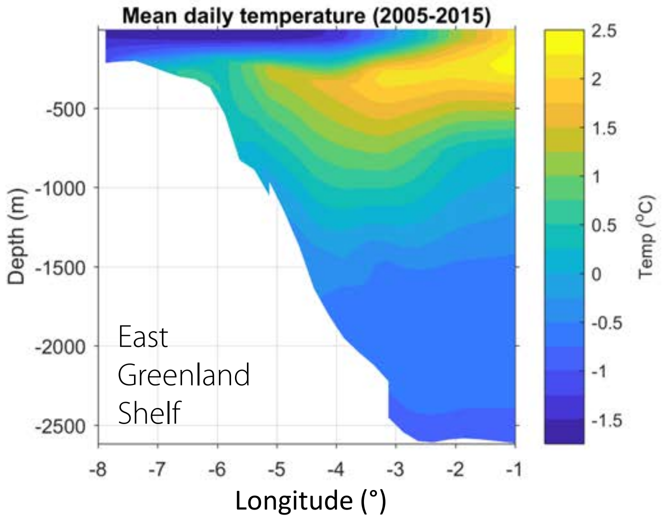
vvel

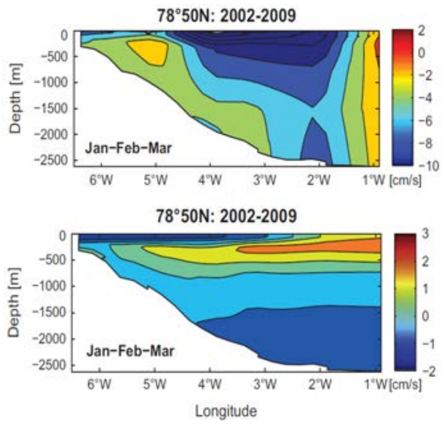
temperature



deSteur et al. [2014]







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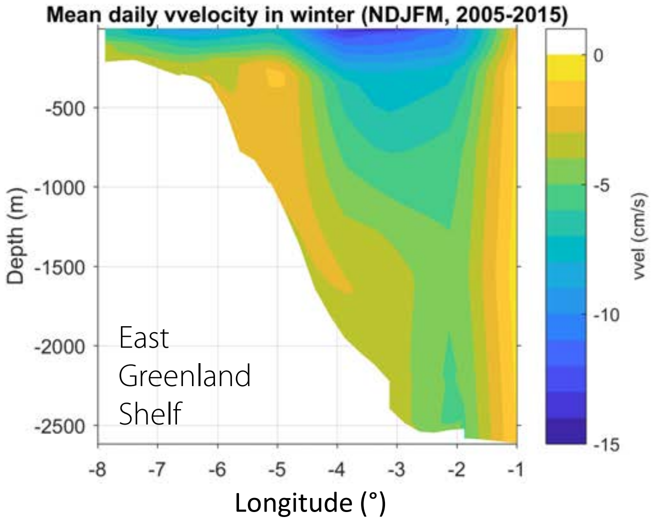
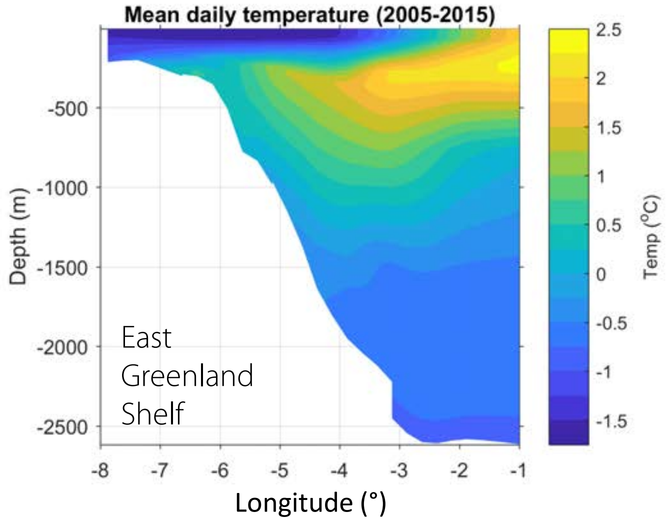
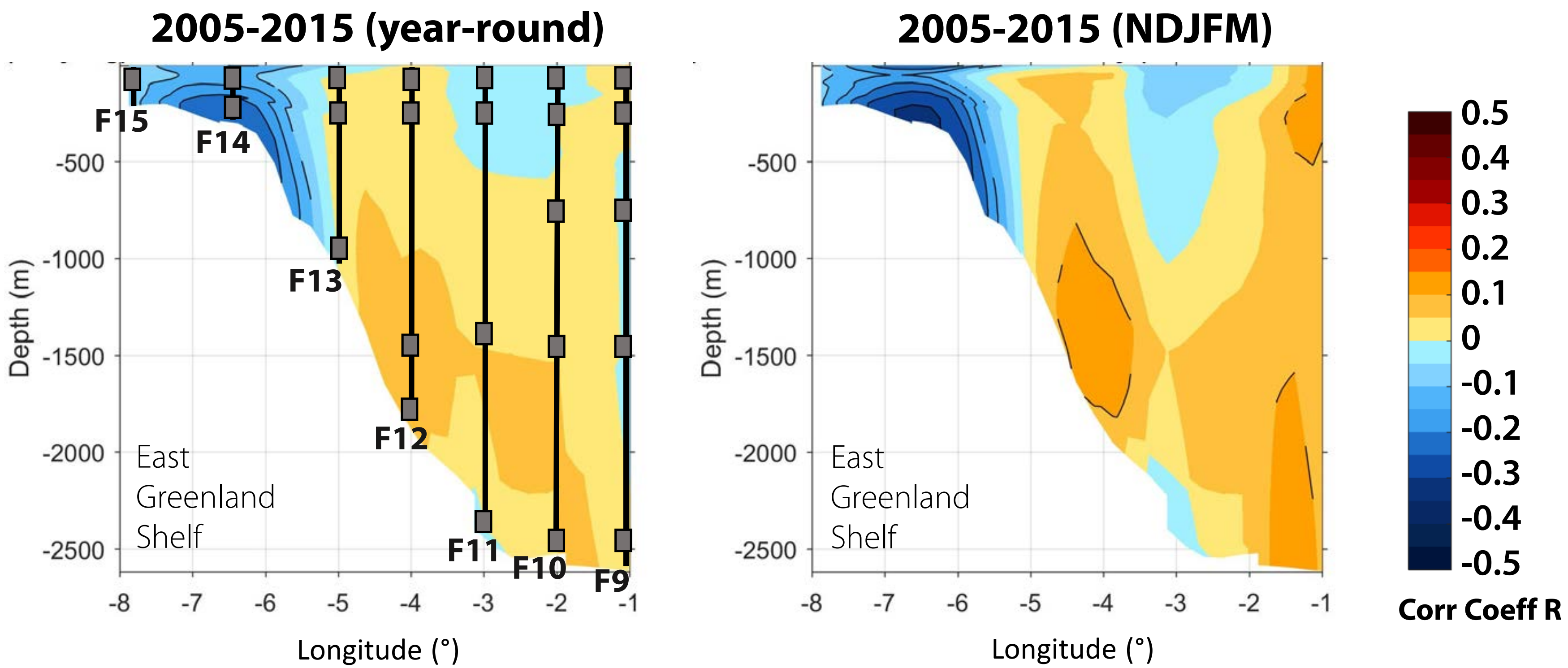




Fram Strait vvel and North Pole OBP

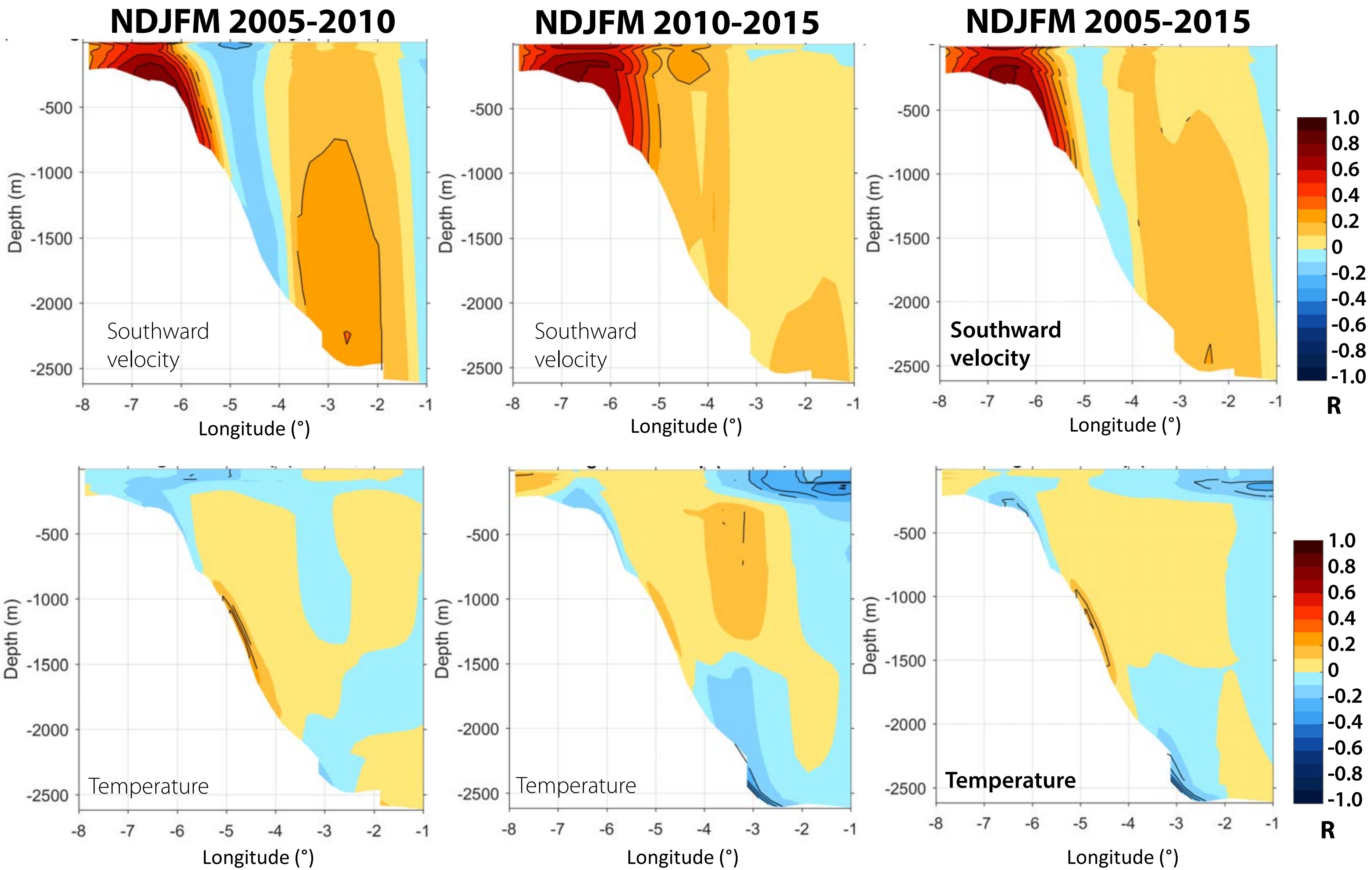
Correlation coefficient (R) at 0-day lag between daily, high-pass filtered (cutoff=90days) Fram Strait southward velocity and North Pole OBP.



North Pole OBP is significantly correlated with vvel on the East Greenland shelf. Higher OBP = weaker southward flow, and more strongly during the winter.

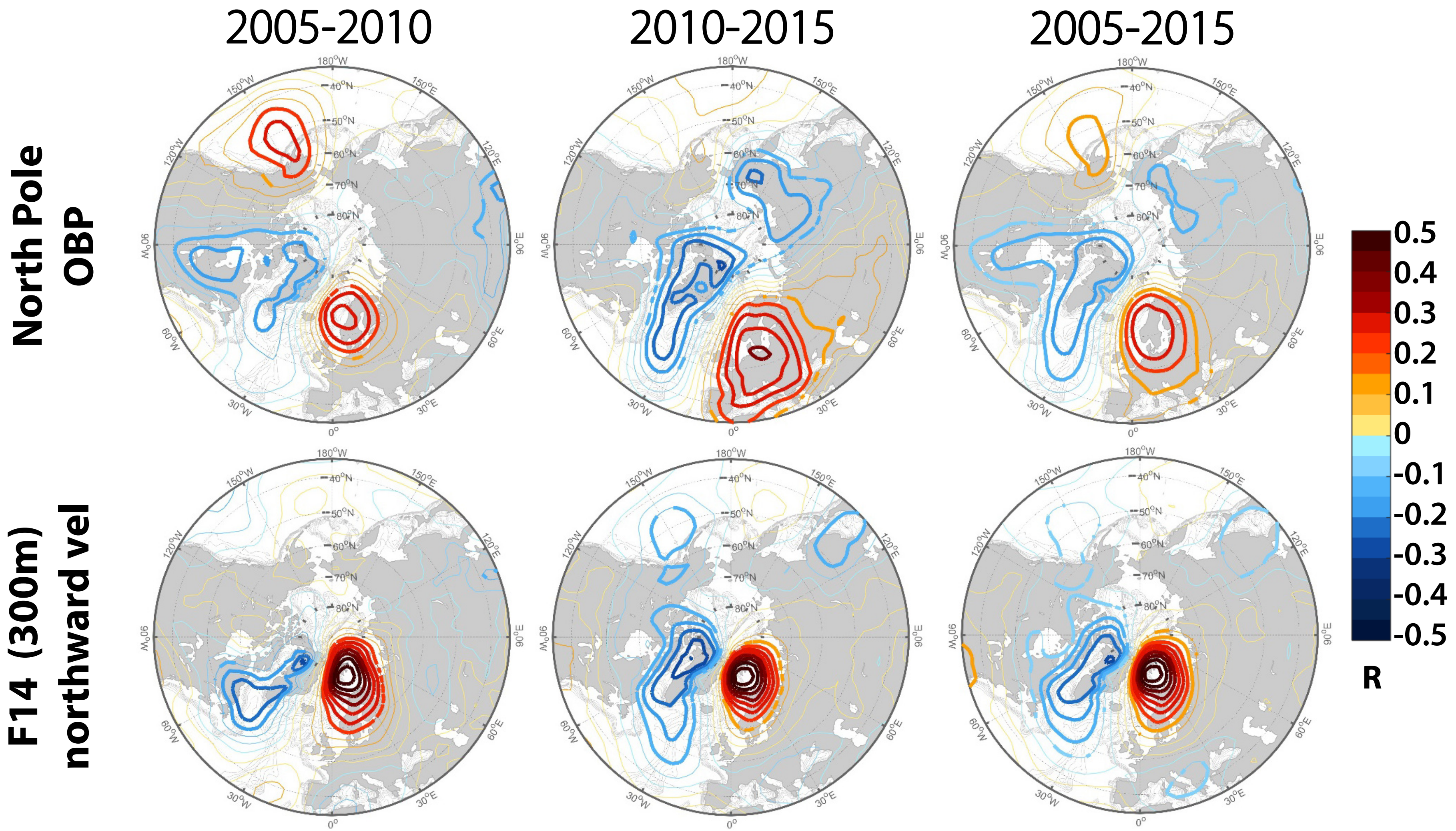
SLP gradient vs Southward vvel and temp (1d lag)

Maps of correlation between SLP gradient (Greenland minus Barents) and southward velocity and Temp.



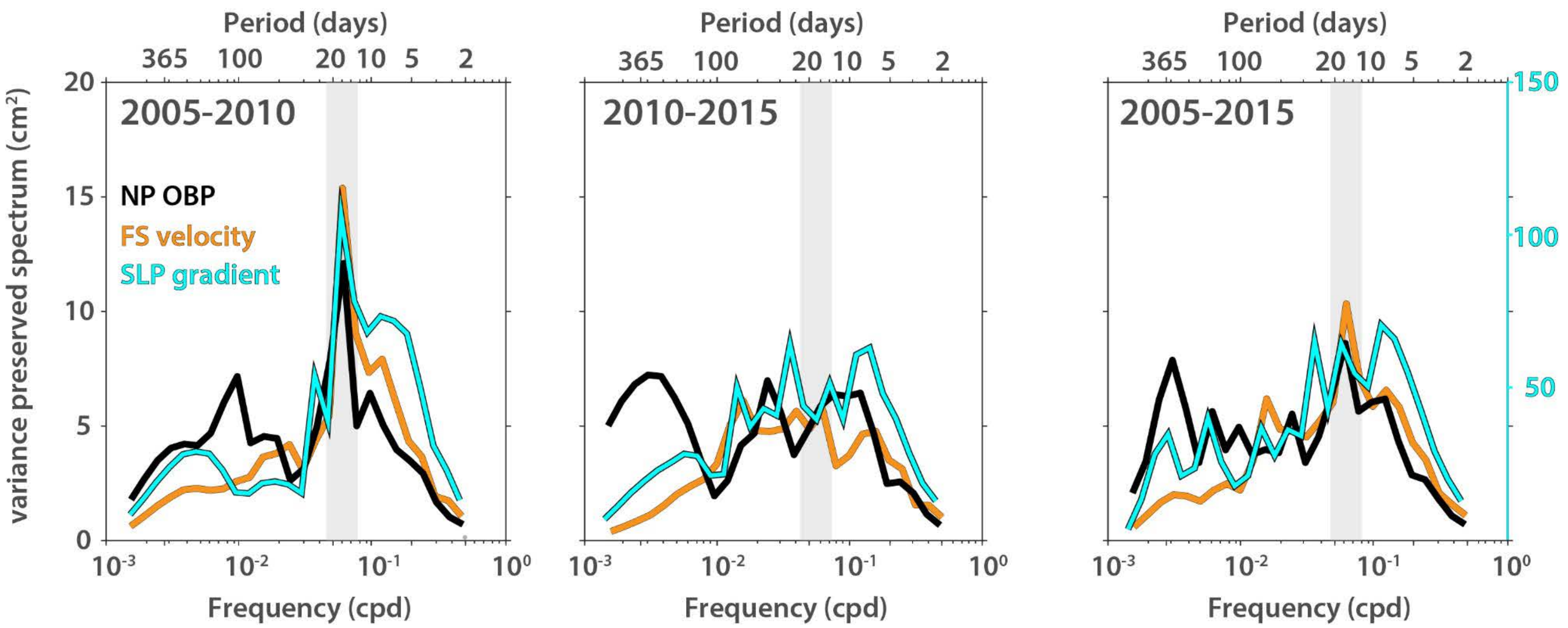
Link to winter (NDJFM) SLP variability

Maps of correlation between daily, high-pass filtered (cutoff=90days) SLP (NCEP) and North Pole OBP (top) and Fram Strait northward velocity of mooring F14 (~300m) at 2-day lag.



SLP gradient (Greenland SLP minus Barents Sea SLP)

Power spectrum of daily SLP (NCEP), North Pole OBP and Fram Strait northward velocity of mooring F14 (300m)



WINTER SLP variability explains the presence (2005-10) and absence (2010-15) of the ~20day mode in the North Pole OBP and the EGC v-velocity, perhaps due to an increase in Atlantic-originated storms in the region from 2010-onward? [*Graham et al.*, 2017].