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# Ekman Ocean Surface Dynamics in the Arctic Seas

Michael Steele, Suzanne Dickinson, Axel Schweiger, & Jinlun Zhang

*Applied Physics Lab, University of Washington, Seattle, WA USA*

**Mike**
*Lead PI, MISO*

**Suzanne**
*Analysis*

**Axel & Jinlun**
*PIOMAS model*

*…in preparation for submission to JGR*

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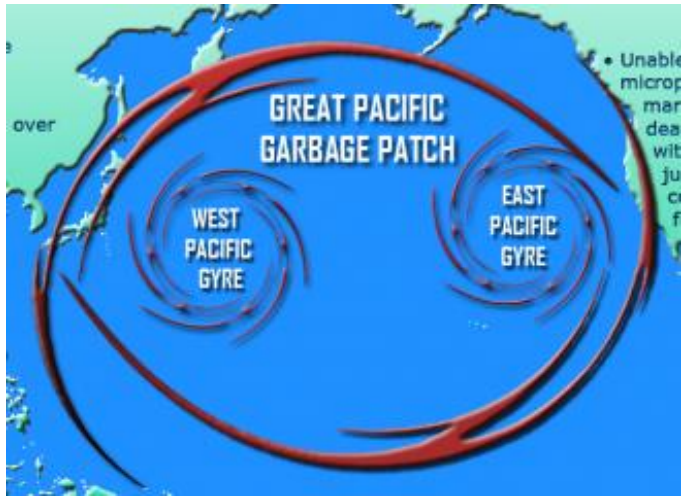
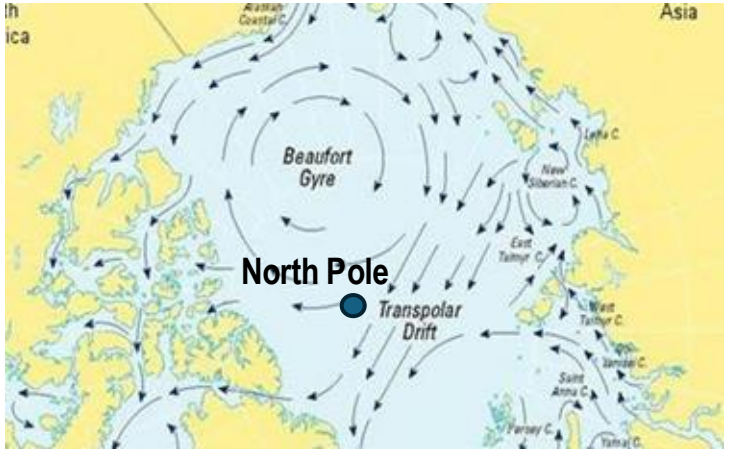
U.S. National Science Foundation
2022-2027




surface-convergent gyres




What about the Arctic Ocean?

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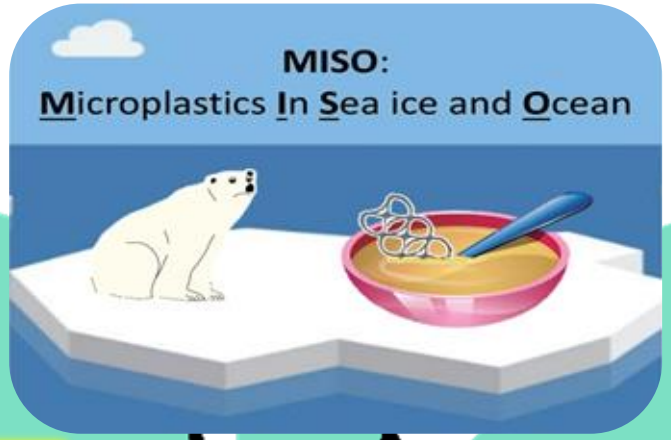
**Bonnie** *(UW)*

**Monica** *(ISB/UW)*

**Claudia** *(ISB)*

**John** *(ISB)* *outreach intern*




**Woods Hole**

**Mike** *(UW)*

**Suzanne** *(UW)*

**Erin** *(UW)*

**Sophia** *(UW)* *lab tech*

**Boulder**

**Alex & Lingwei** *(**U of CO**, Dept of Atmos & Ocean Sci.)*



**Dave** *(**NCAR**: National Center for Atmospheric Research)*

**Seattle**

**Luke** *(UW)* *lab tech*

**Barb** *(ISB/UW)*

**Maddie** *(**WHOI**: Woods Hole Oceanographic Institute)*

**UW**:
*Polar Science Center*
*Applied Physics Lab*
*U of WA*

**ISB**:
*Institute for Systems Biology*

**Summer Teachers:**
Christina Scott, Beth Uhrich, Eric Muhs, Melissa Gioini, Matt Gallagher, India Carlson, Wendy Lane, Mari Herbert, Ji Hea Shin

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# Lab (*cold room*)

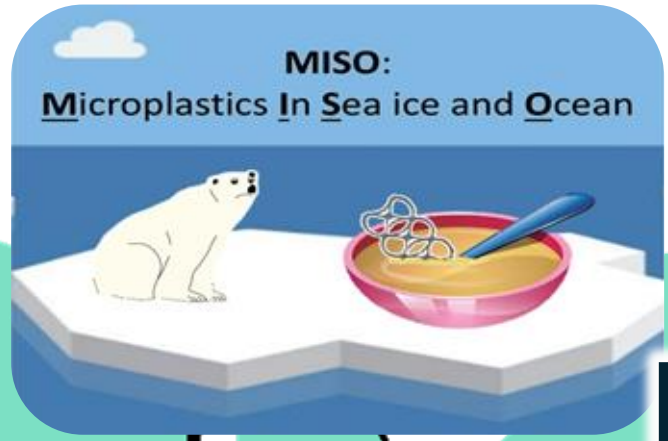
**Bonnie Light**
*(ice/ocean)*

**Monica Orellana**
*(micropolymer gels)*

Mike *(UW)*

Suzanne *(UW)*

**Seattle**




**Boulder**

Alex & Lingwei
*(U of CO)*

Dave
*(NCAR)*

**Woods Hole**

Lab

***Maddie Smith***
*(ice/ocean)*

How do microplastics get **into sea ice** *(during freezing)* and **out again** *(during melt)*?

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Bonnie

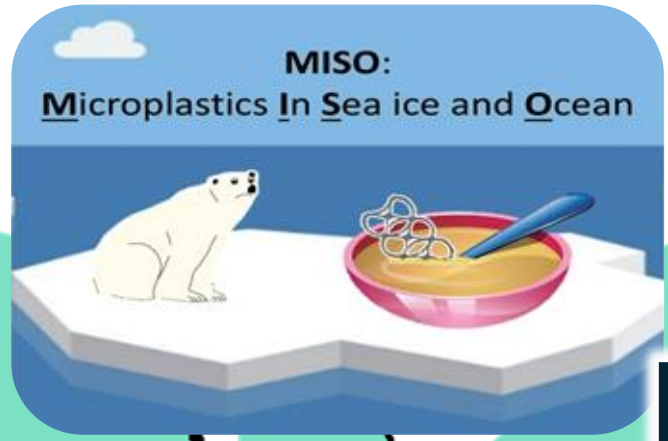
Monica

## Seattle

**Mike Steele**
*(APL/UW)*

**Suzanne Dickinson**
*(APL/UW)*

**Model**
*(PIOMAS, CESM)*




## Boulder

**Alex Jahn &**
**Lingwei Li**
*(U of CO)*

**Dave Bailey**
*(NCAR)*

**Model**
*(CESM, ICEPACK)*

## Woods Hole

***Maddie Smith***
*(WHOI)*

**Model**
*(ICEPACK)*

ICEPACK (1D): Parameterize microplastic sea ice uptake & release

PIOMAS, CESM (3D): Where are microplastics (*ocean & sea ice*)?

Model insights into the ice-ocean exchange and variability of microplastics in the Arctic Ocean (*Li et al., JGR submitted*)

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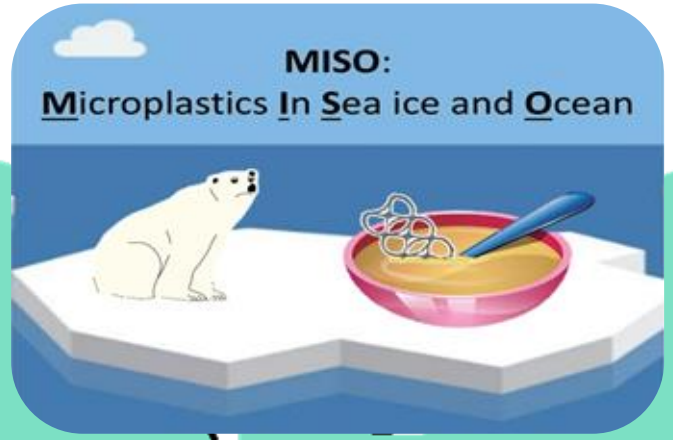
CAMAS Monterey
*April 2026*

**Seattle**

**Claudia Ludwig** *(ISB)*
*Curriculum development*



**Barb Steffens** *(ISB/UW)*
*Curriculum development*

By the end of 2026:

A 2-week curriculum on
**Arctic Microplastics**
for high school Earth Science classrooms

**UW**:
*U of Washington*

**ISB**:
*Institute for Systems Biology*

**Summer Teachers:**
Christina Scott, Beth Uhrich, Eric Muhs, Melissa Gioini, Matt Gallagher, India Carlson, Wendy Lane, Mari Herbert, Ji Hea Shin

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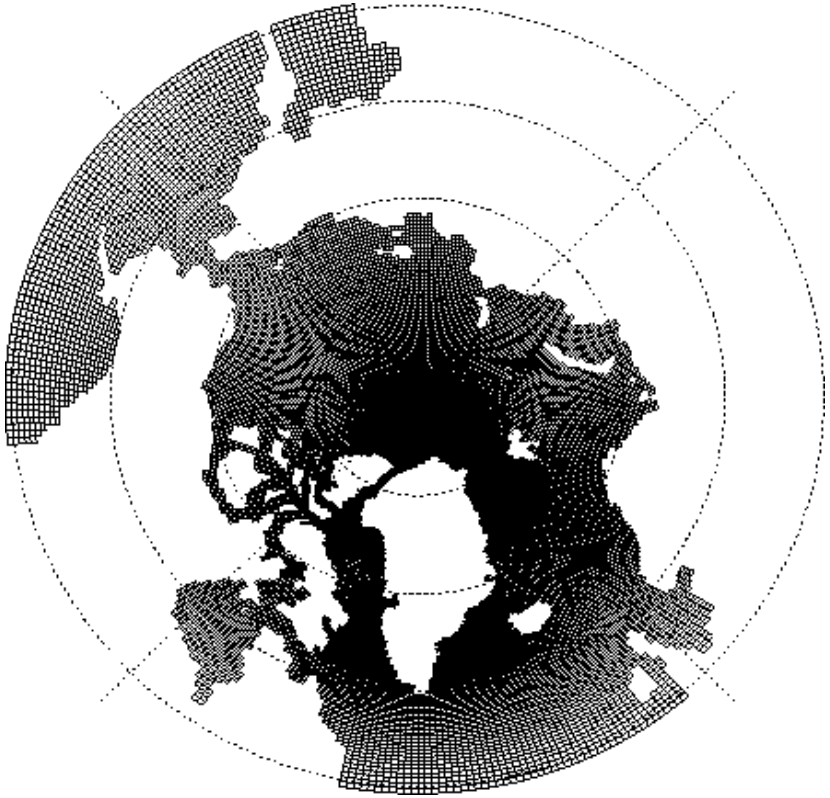
# **PIOMAS**:
## **P**an-arctic **I**ce-**O**cean **M**odeling & **A**ssimilation **S**ystem

Schweiger, Zhang et al. (*JGR, 2011*)



- Sea ice (multicategory snow & ice thickness) – ocean (POP) model
- NCEP/NCAR forcing
- Average 30 km resolution (65-90ºN)
- 40 vertical ocean levels, 5 m thickness in upper 50 m
- North Pole in Greenland
- 1979-present
- Lateral b.c.'s (49ºN) from a global version of the model
- No assimilation of obs (SST, SIC, SIT)

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# So, what about Ocean Dynamics & Microplastics?

Most of it is **at/near the surface**

Especially in the Arctic:

- *Not many local sources*
- *heavy stuff falls out earlier*

∴ We just consider
**ocean surface dynamics (conv/divergence)**

*(setting the microplastics issue aside)*

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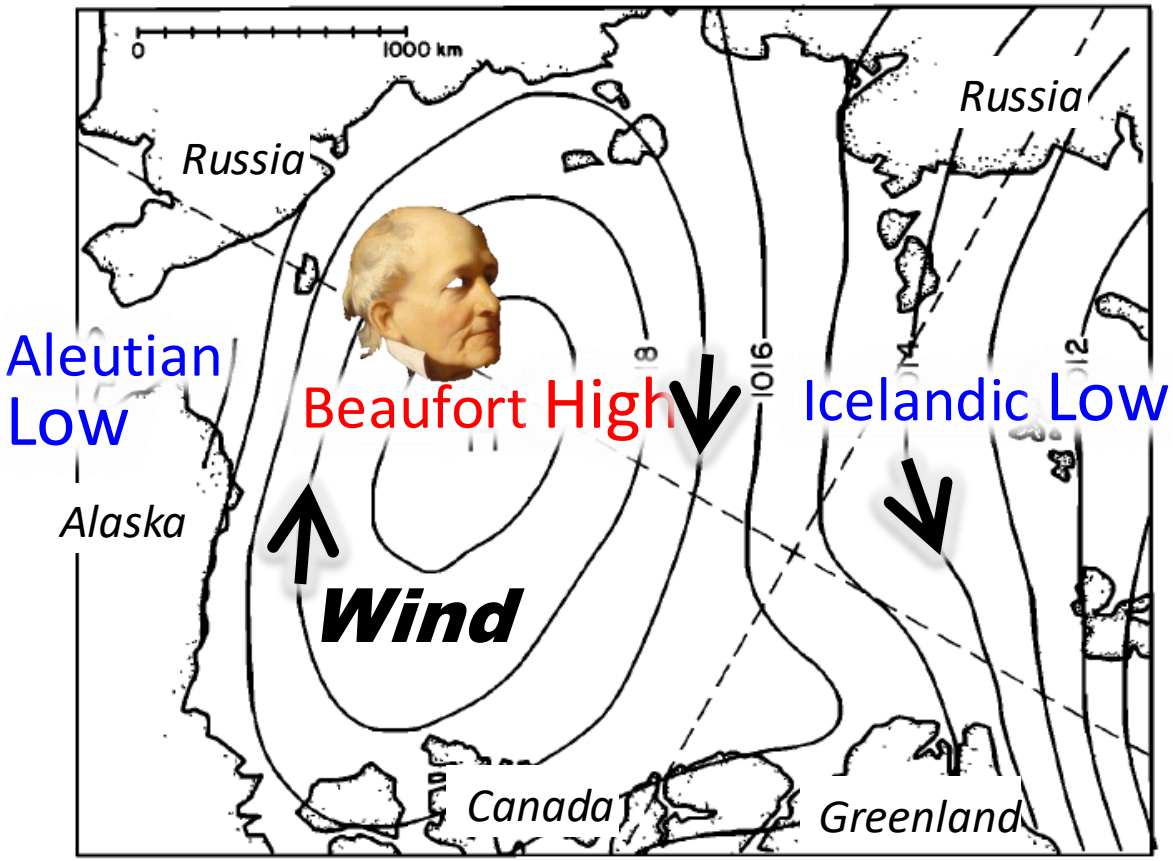
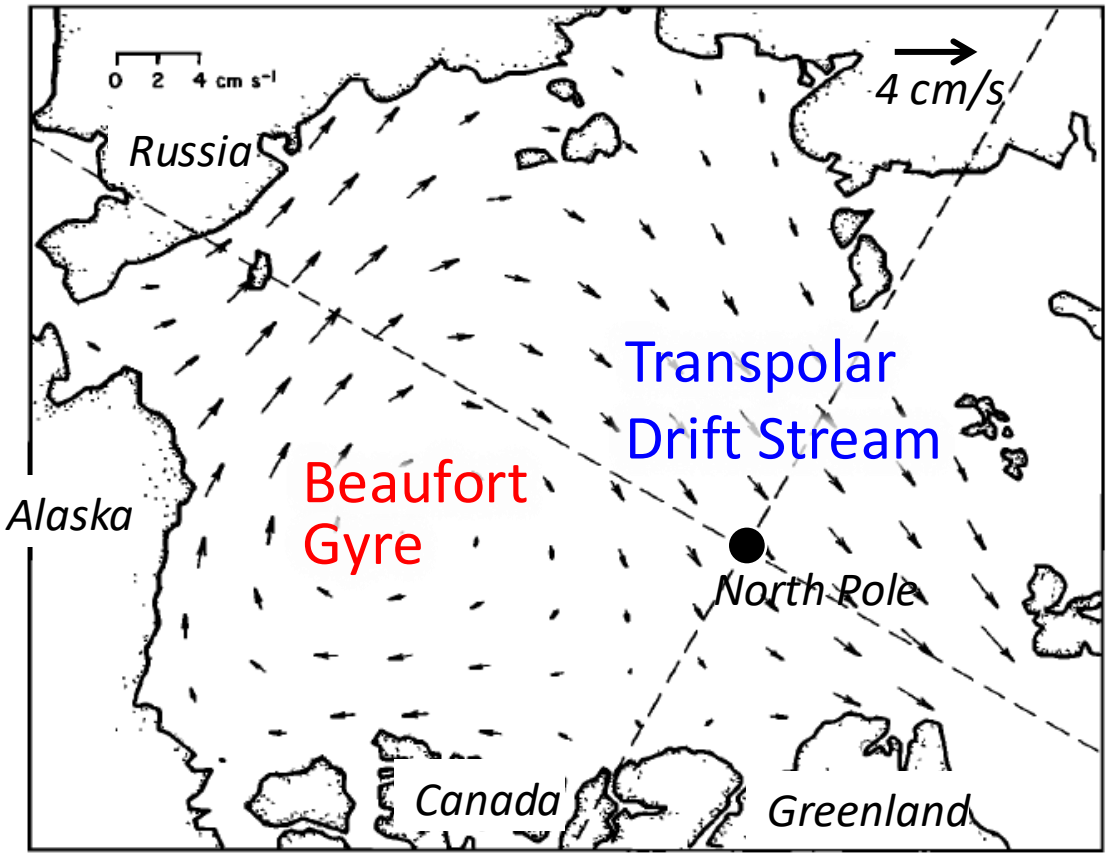
# SLP/winds




Colony & Thorndike (1984)

# Sea Ice Motion



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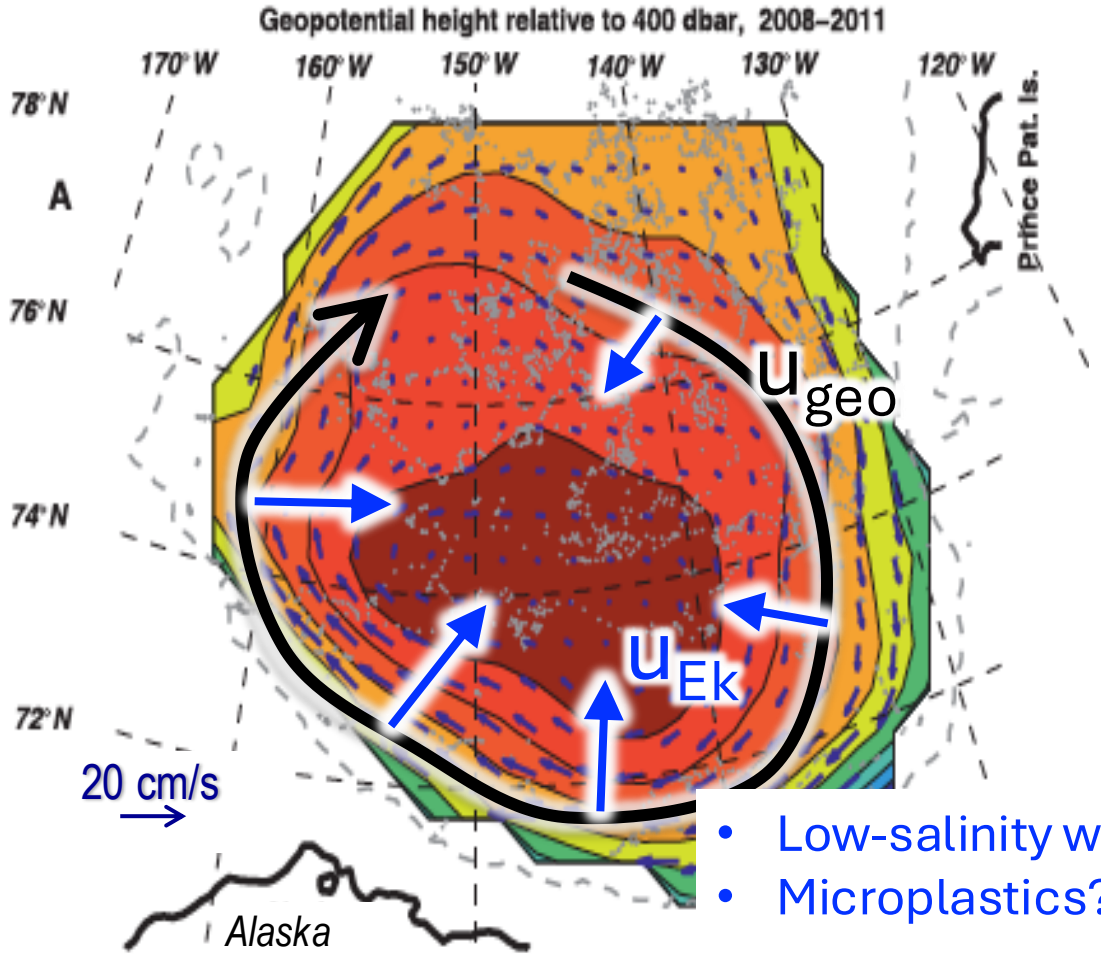
# Beaufort Gyre




- Low-salinity water
- Microplastics?

McPhee et al. (*GRL, 2009*)

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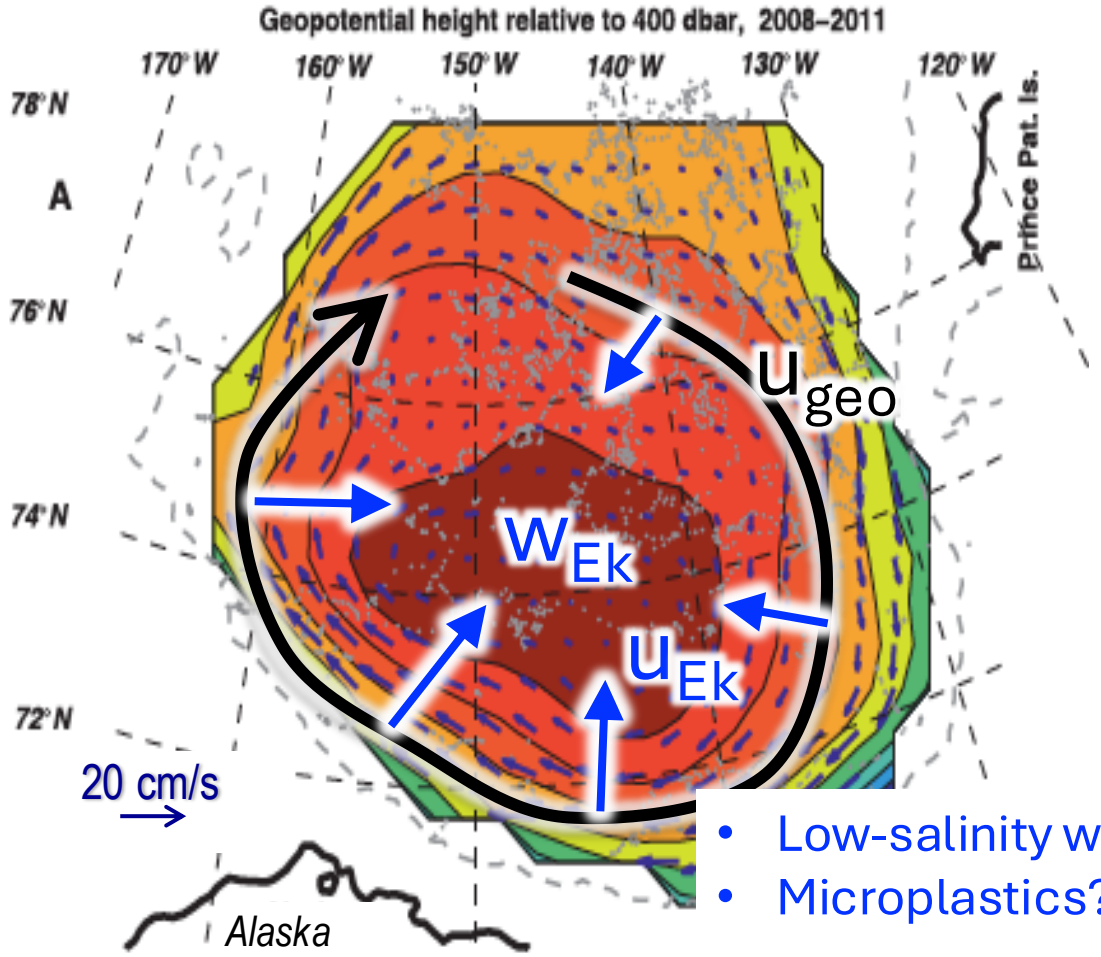
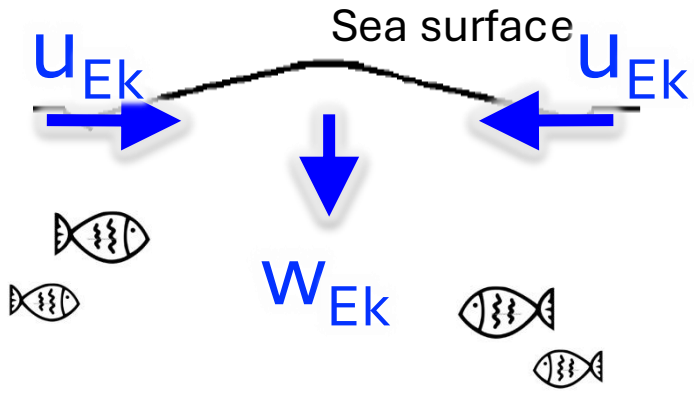
# Beaufort Gyre




- Low-salinity water
- Microplastics?

convergence




McPhee et al. (*GRL, 2009*)

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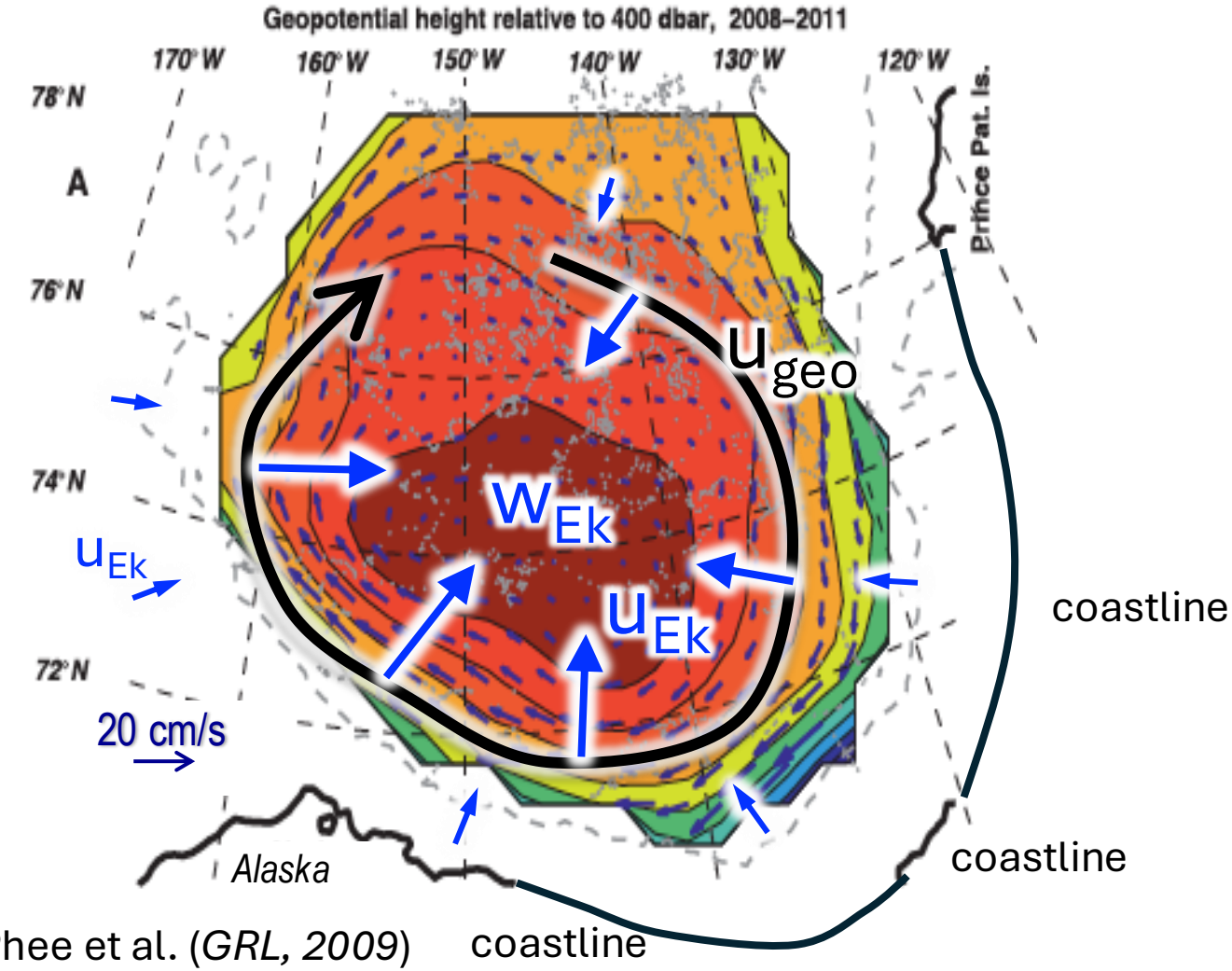


McPhee et al. (*GRL, 2009*)

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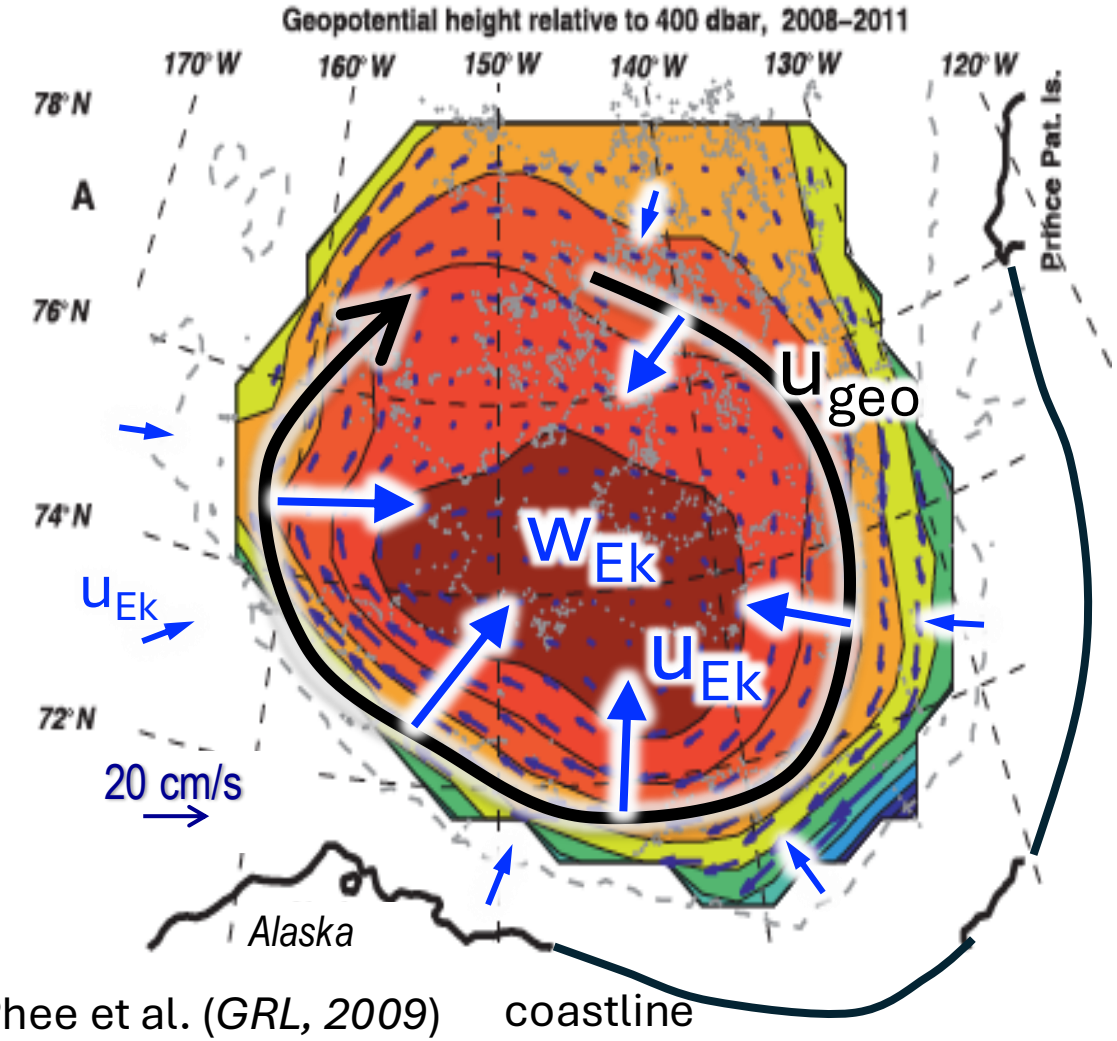
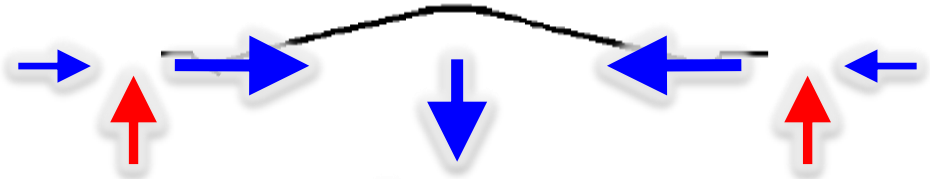



McPhee et al. (*GRL, 2009*)

coastline

divergence & convergence



| up | down | up |
|---|---|---|
| "Ekman suction" | "Ekman pumping" | "Ekman suction" |
| *BG **rim*** | *BG **interior*** | *BG **rim*** |

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# How to compute **ocean surface convergence/divergence**?

☞ *compute Ekman pumping/suction* $W_{ek}$

Observations method:

$W_{ek} = \nabla \times \tau$; $\tau$ = *surface stress from obs. SLP/wind & ice motion*

Model short-cut:

$W_{ek} = (\nabla \bullet u_{surf}) \, dz$; $u_{surf}$ *from model,* $dz = 5$ *m*

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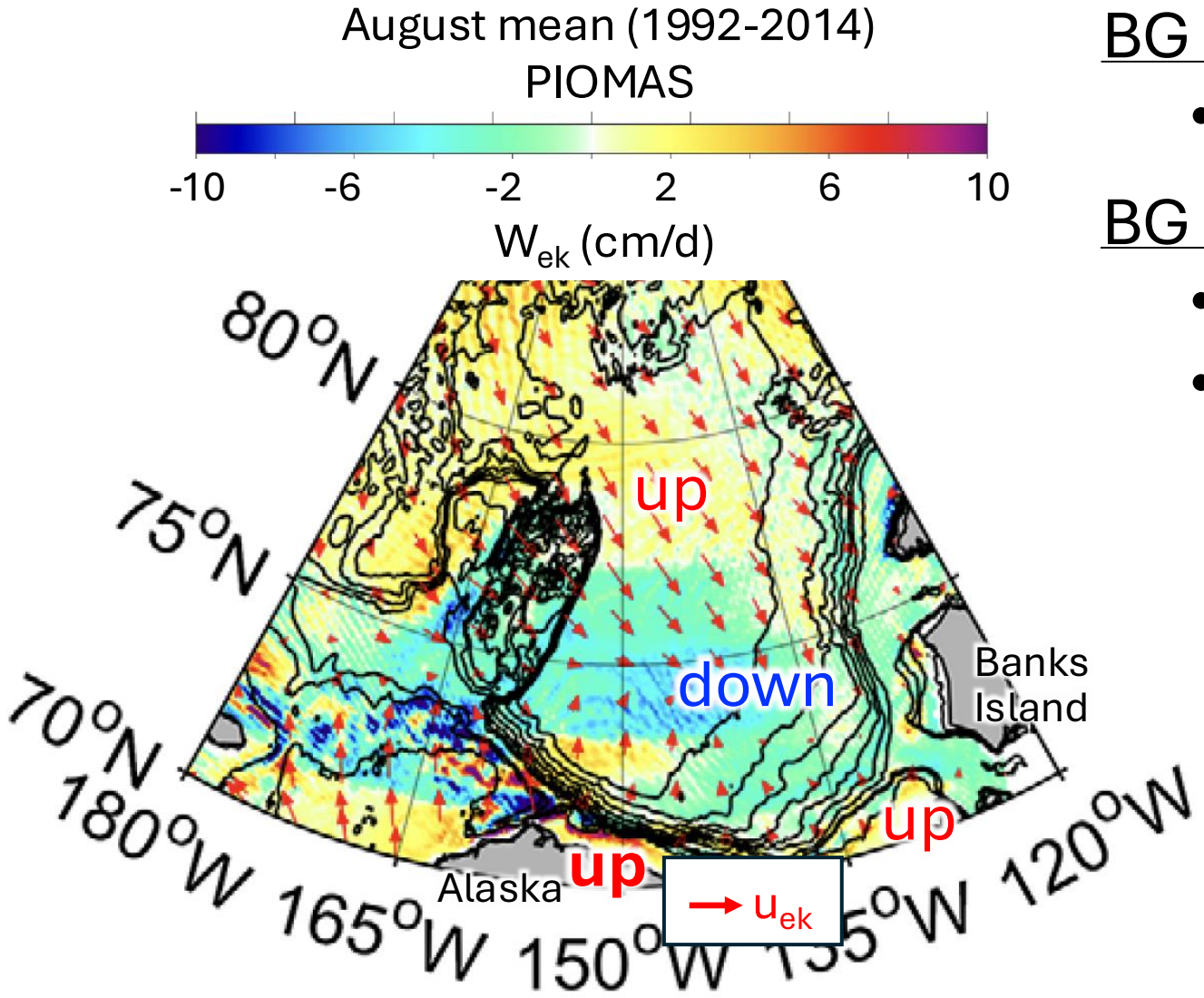


## BG interior:

- Weak downwelling

## BG rim:

- weak upwelling to the N
- stronger **upwelling** near Alaska

Zhong et al. (*JGR, 2018*)

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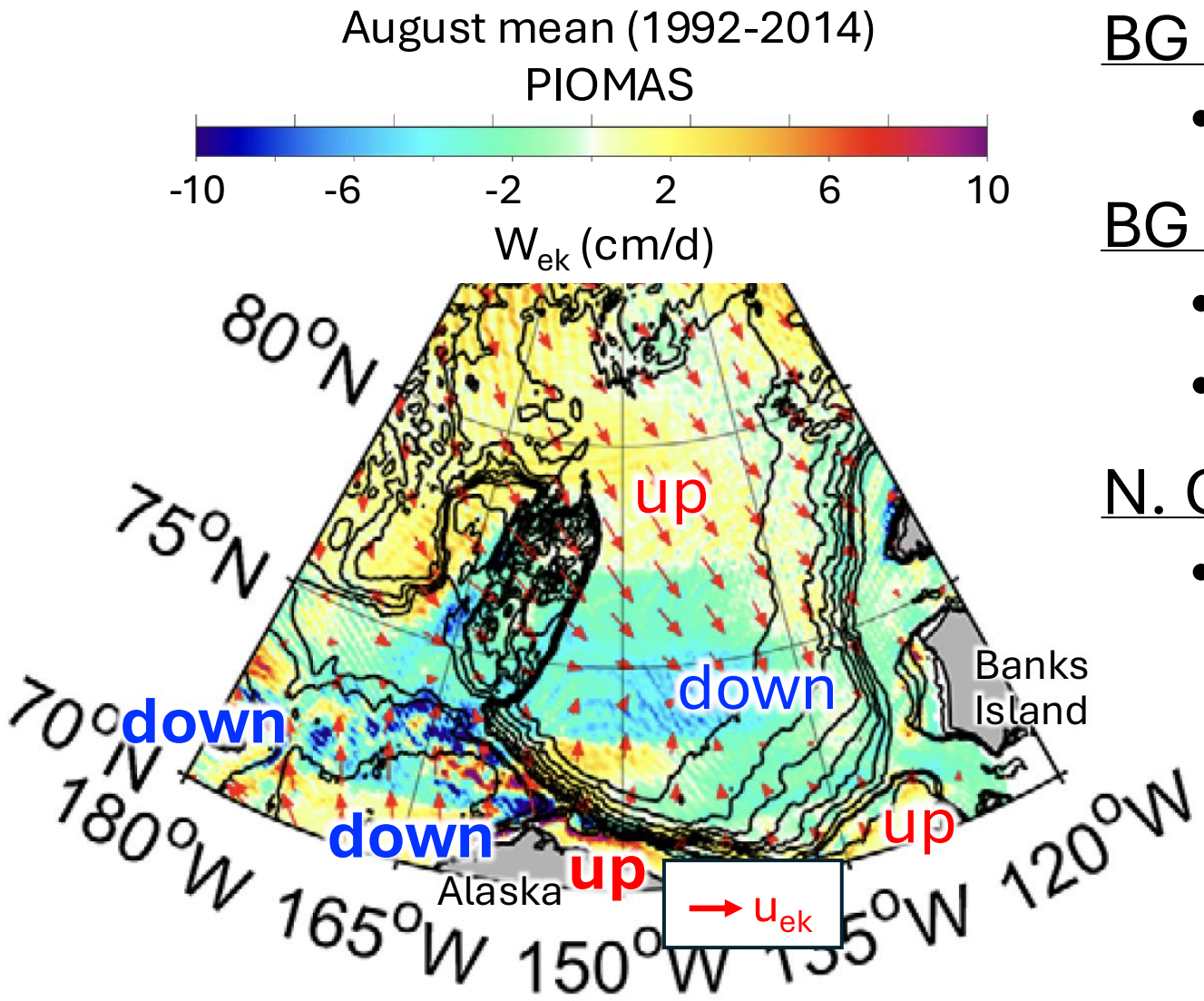


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## N. Chukchi Sea:

- Strong **downwelling**

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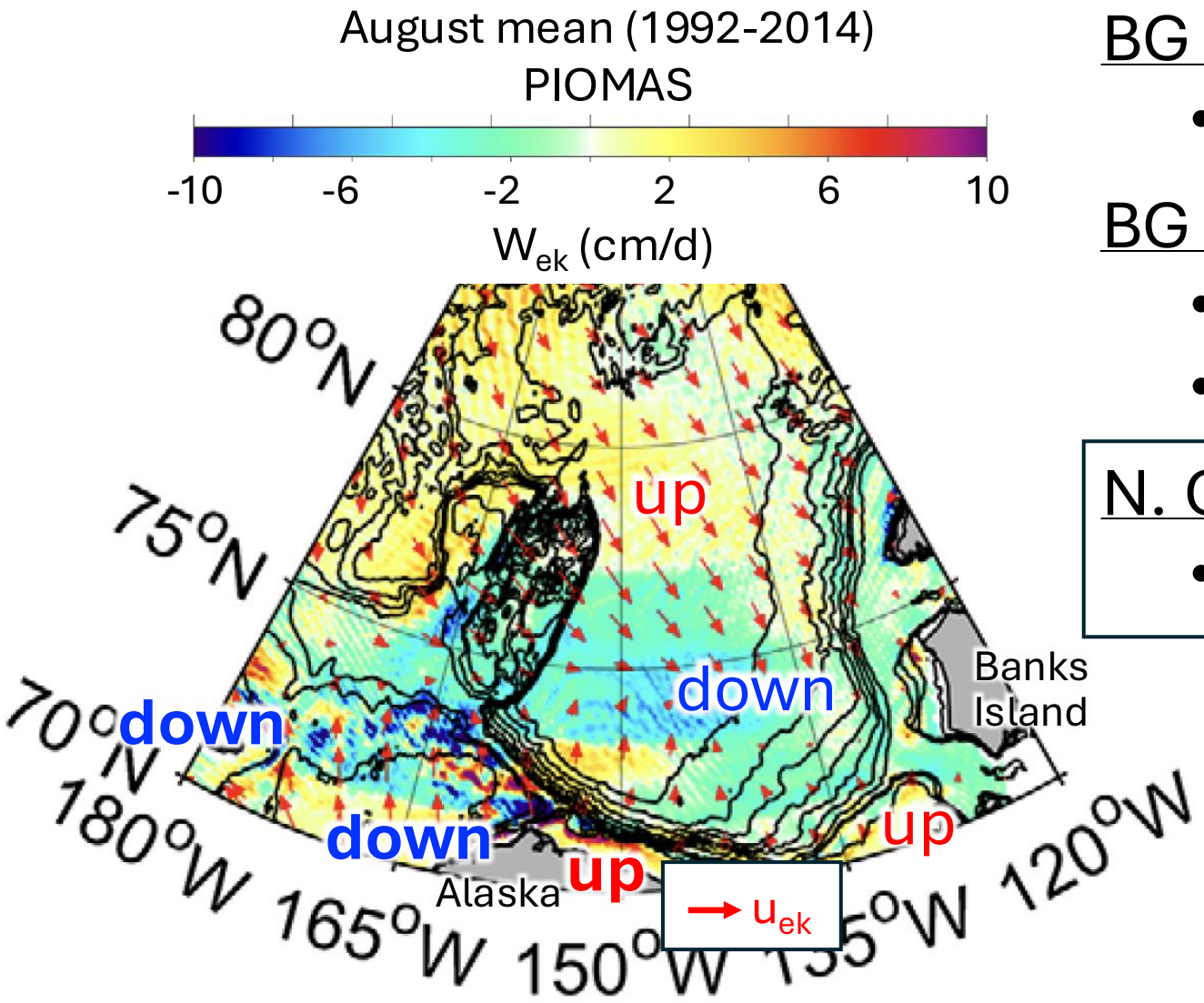


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## BG interior:

- Weak downwelling

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- weak upwelling to the N
- stronger **upwelling** near Alaska

## N. Chukchi Sea:

- Strong **downwelling**

**??**

Pacific inflow
into the BG/Arctic Ocean

Subduction
at the shelf break
(*Timmermans et al., 2014*)

Canyon flows
in Barrow & Herald
(*Spall et al., 2018*)

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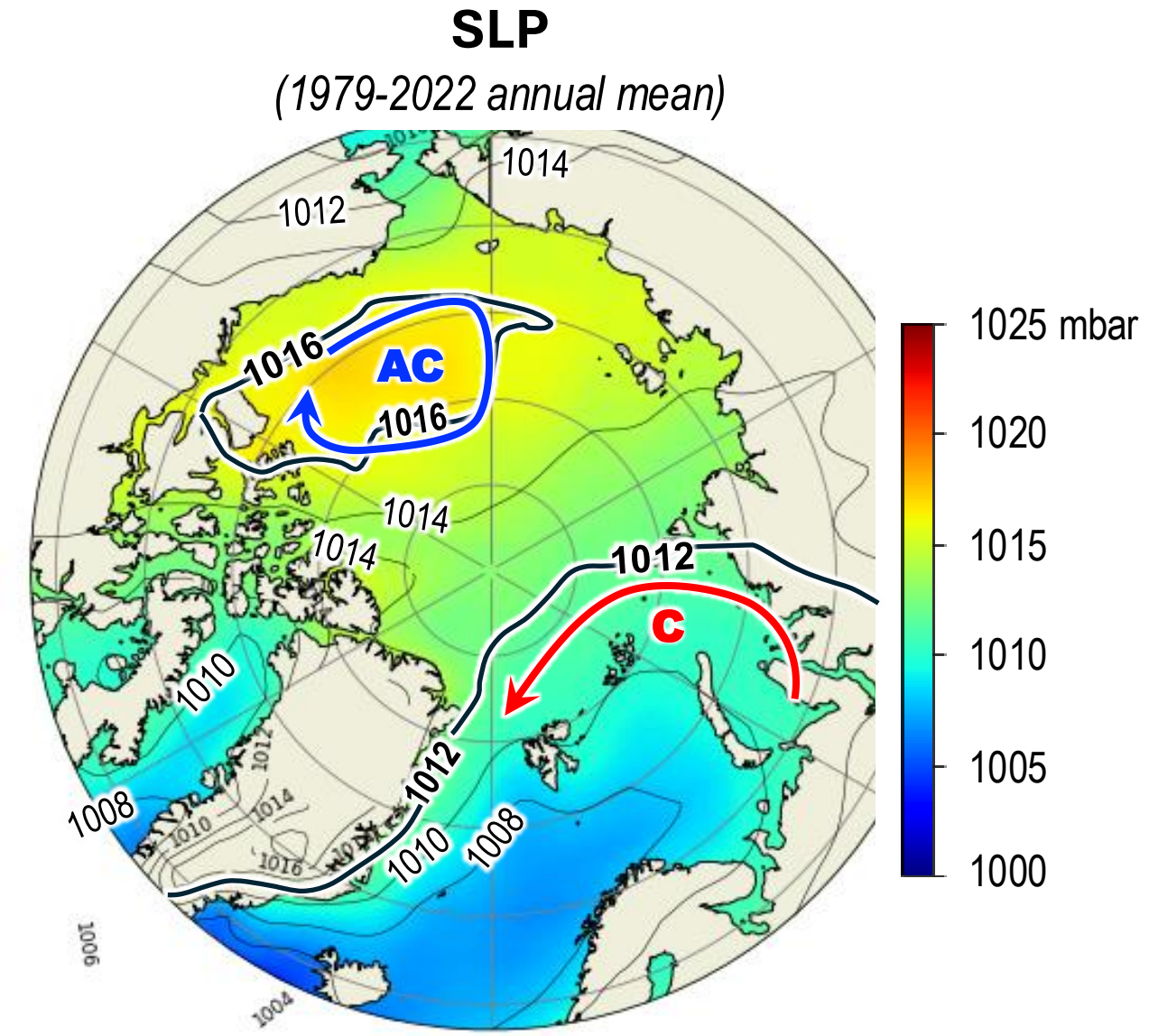
# The Arctic Seas (65-90ºN)

**Anticyclonic** surface stress:

- *Convergence/downwelling/pumping*

**Cyclonic** surface stress:

- *Divergence/upwelling/suction*



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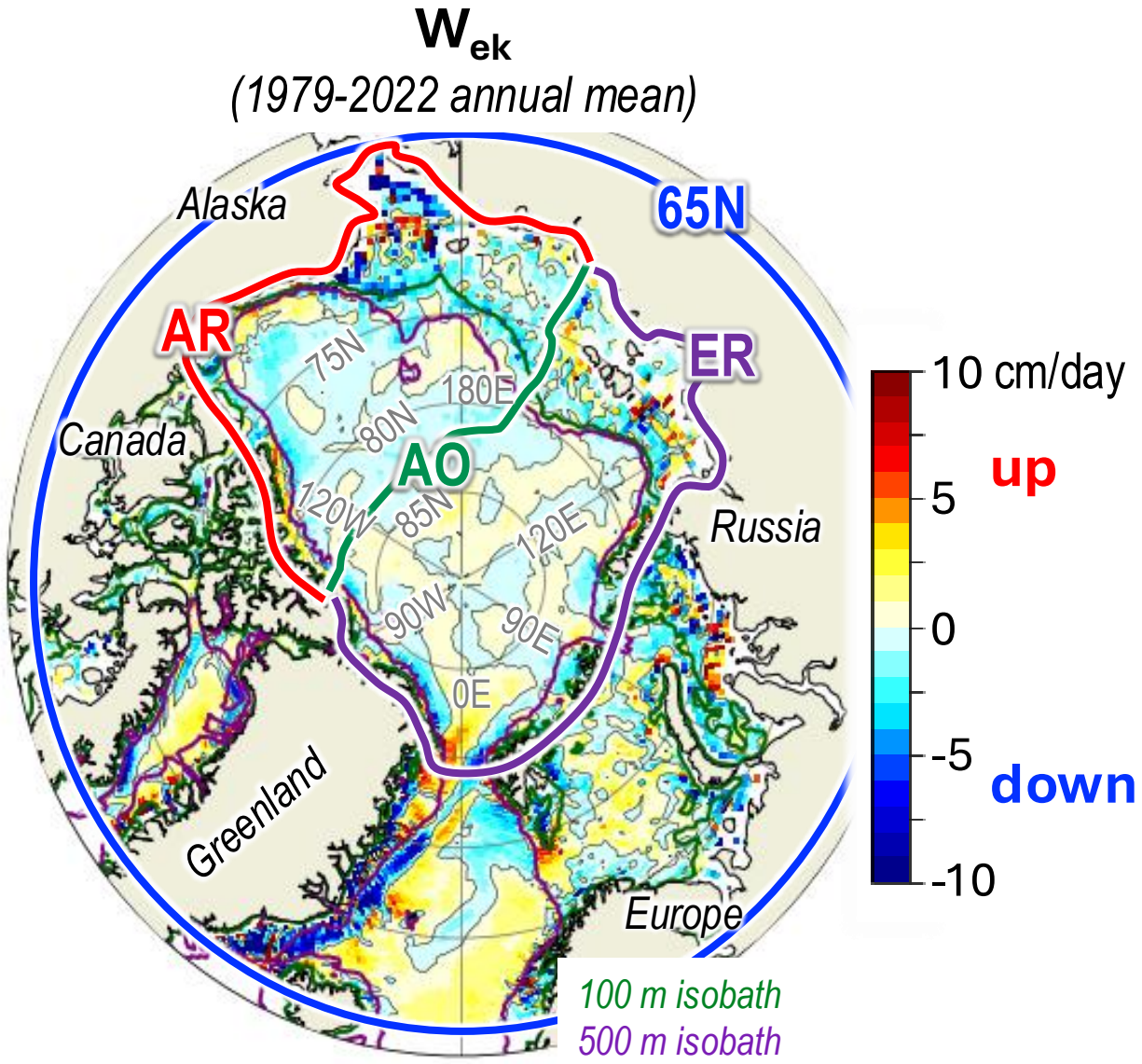
CAMAS Monterey
April 2026

# The Arctic Seas




**AR: Amerasian Region**

**ER: Eurasian Region**

*equal areas*

**AO: Arctic Ocean = AR + ER**

**65N: 65-90°N**

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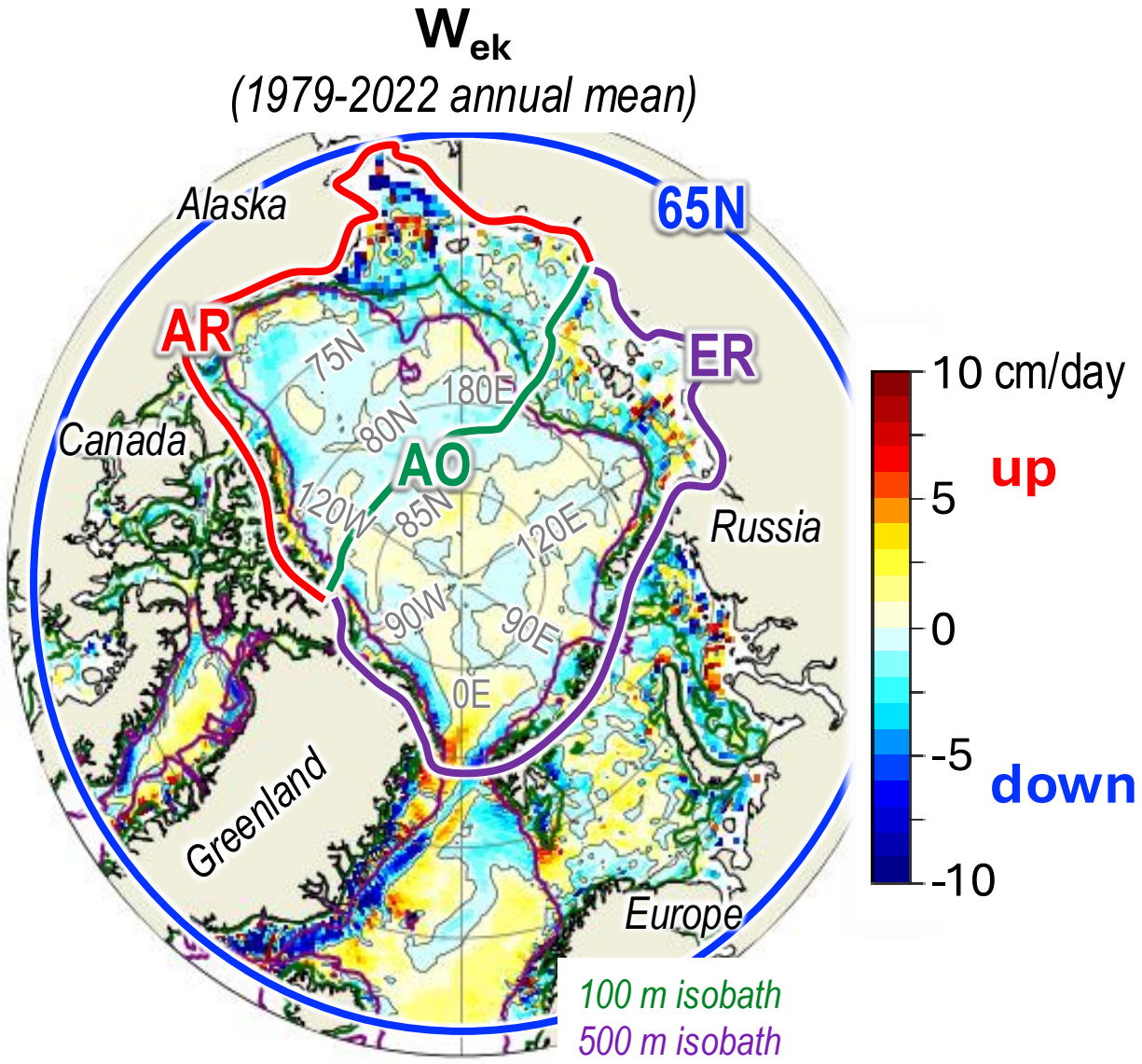
April 2026

# The Arctic Seas




**AR: Amerasian Region**

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**65N: 65-90°N**

Strong convergence/**downwelling**:

- Chukchi *(Pacific inflow)*
- W, N of Svalbard *(Atlantic inflow)*
- Outer East Greenland Current

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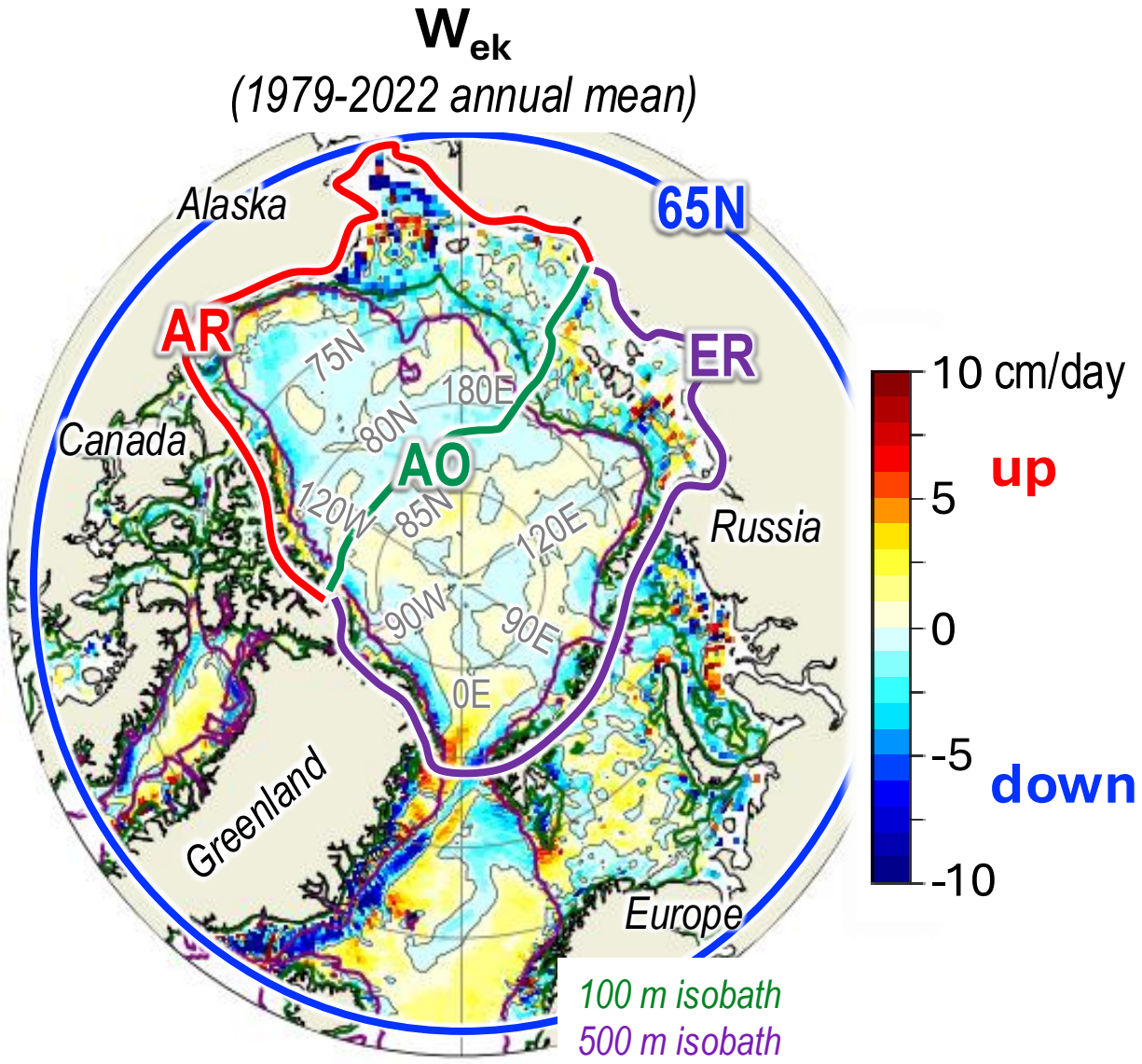
April 2026

# The Arctic Seas




**AR: Amerasian Region**

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**65N: 65-90°N**

Strong convergence/**downwelling**:

- Chukchi *(Pacific inflow)*
- W, N of Svalbard *(Atlantic inflow)*
- Outer East Greenland Current

Weak divergence/upwelling:

- ER & southern basins

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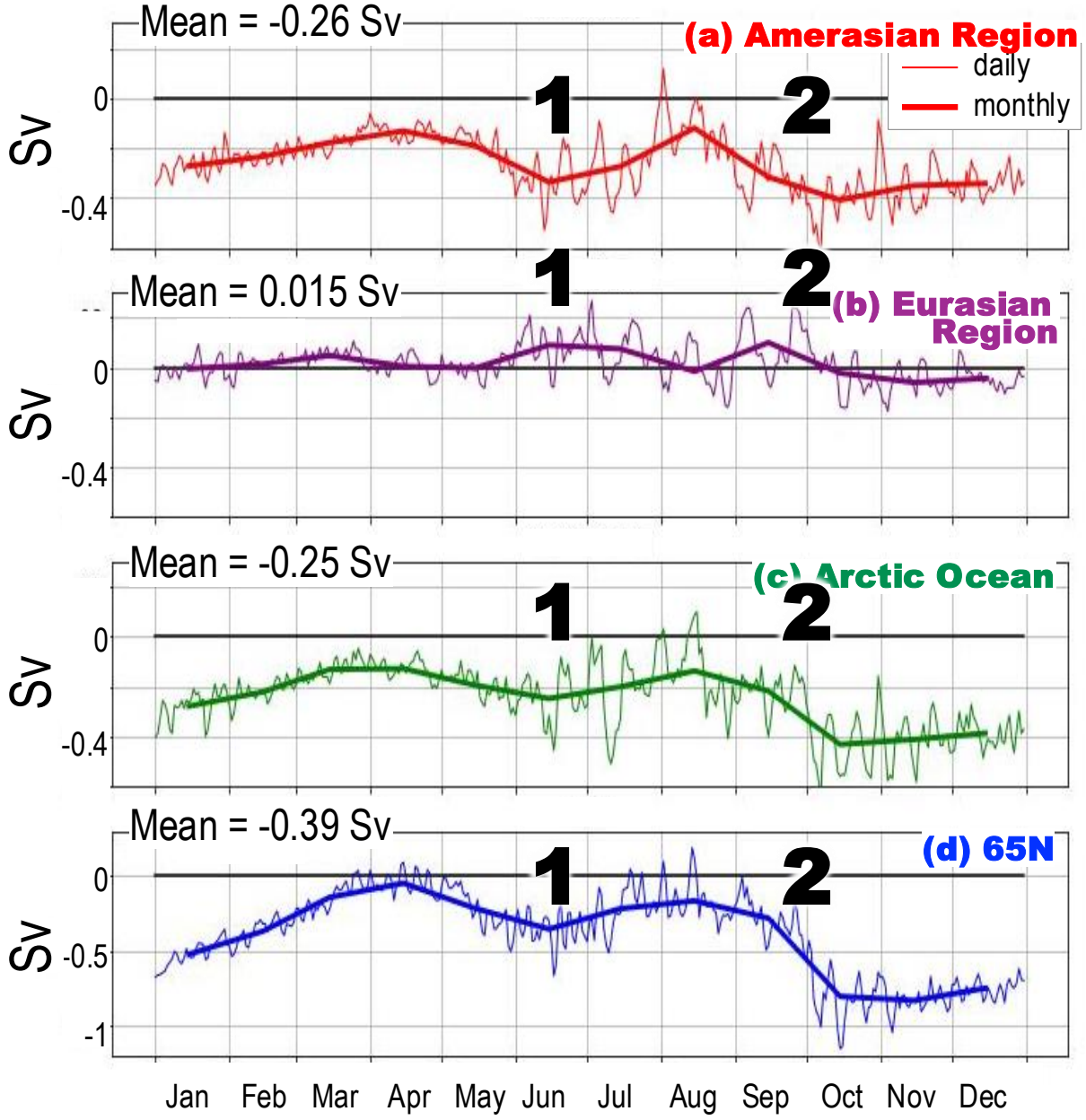
# Mean Seasonal Cycle *(1979-2022)*

Total vertical transport (Sv) = $W_{ek}$ * Area




**Double-peak structure**

**1**. Spring/summer:

- ?! *(not sure)*

**2**. Fall:

- Stronger wind
- Looser ice

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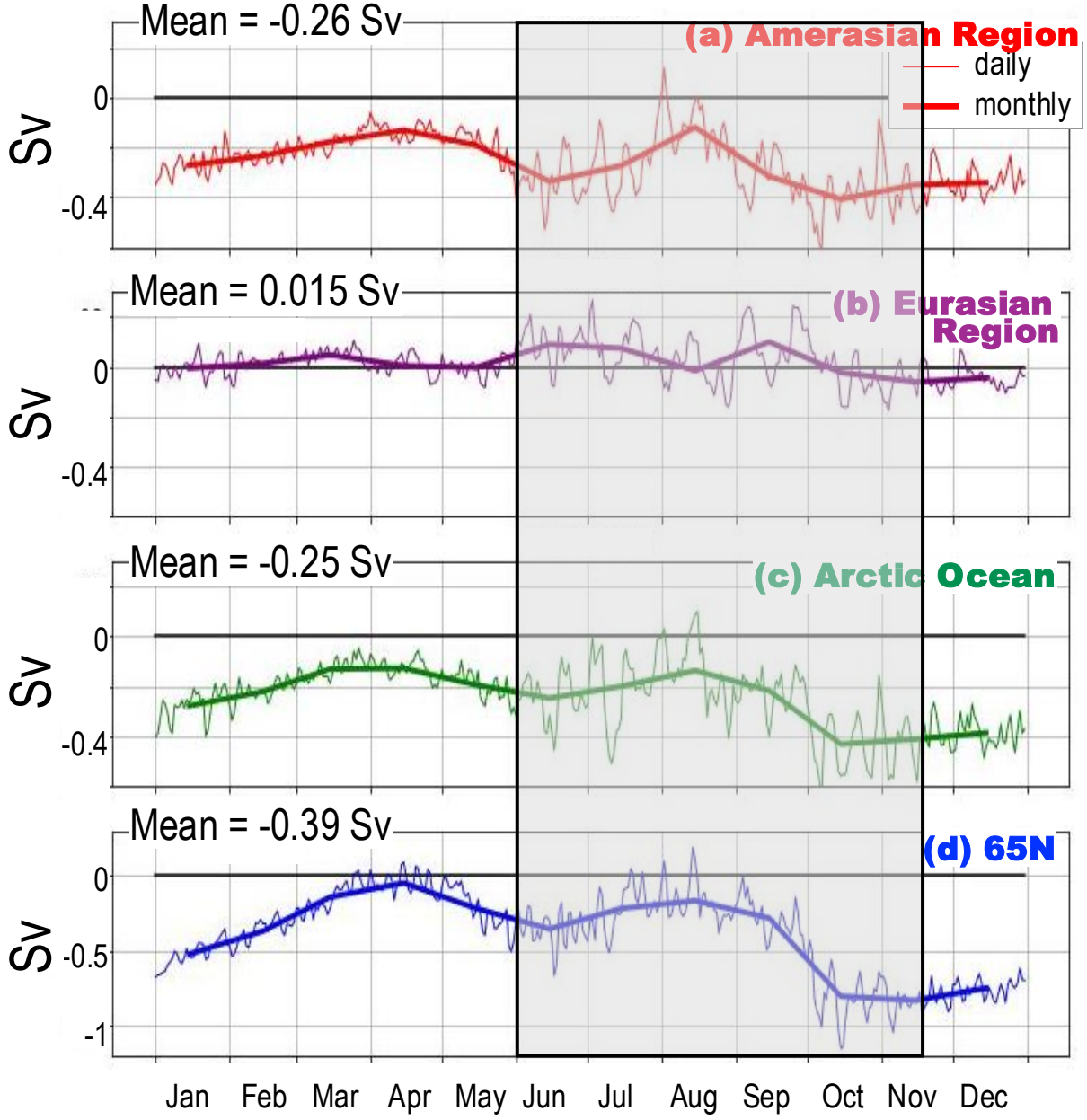


## Double-peak structure

1. Spring/summer:
   - ?! *(not sure)*
2. Fall:
   - Stronger wind
   - Looser ice

**Higher daily amplitudes in summer/fall**

- synoptic storms

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# Mean Seasonal Cycle *(1979-2022)*

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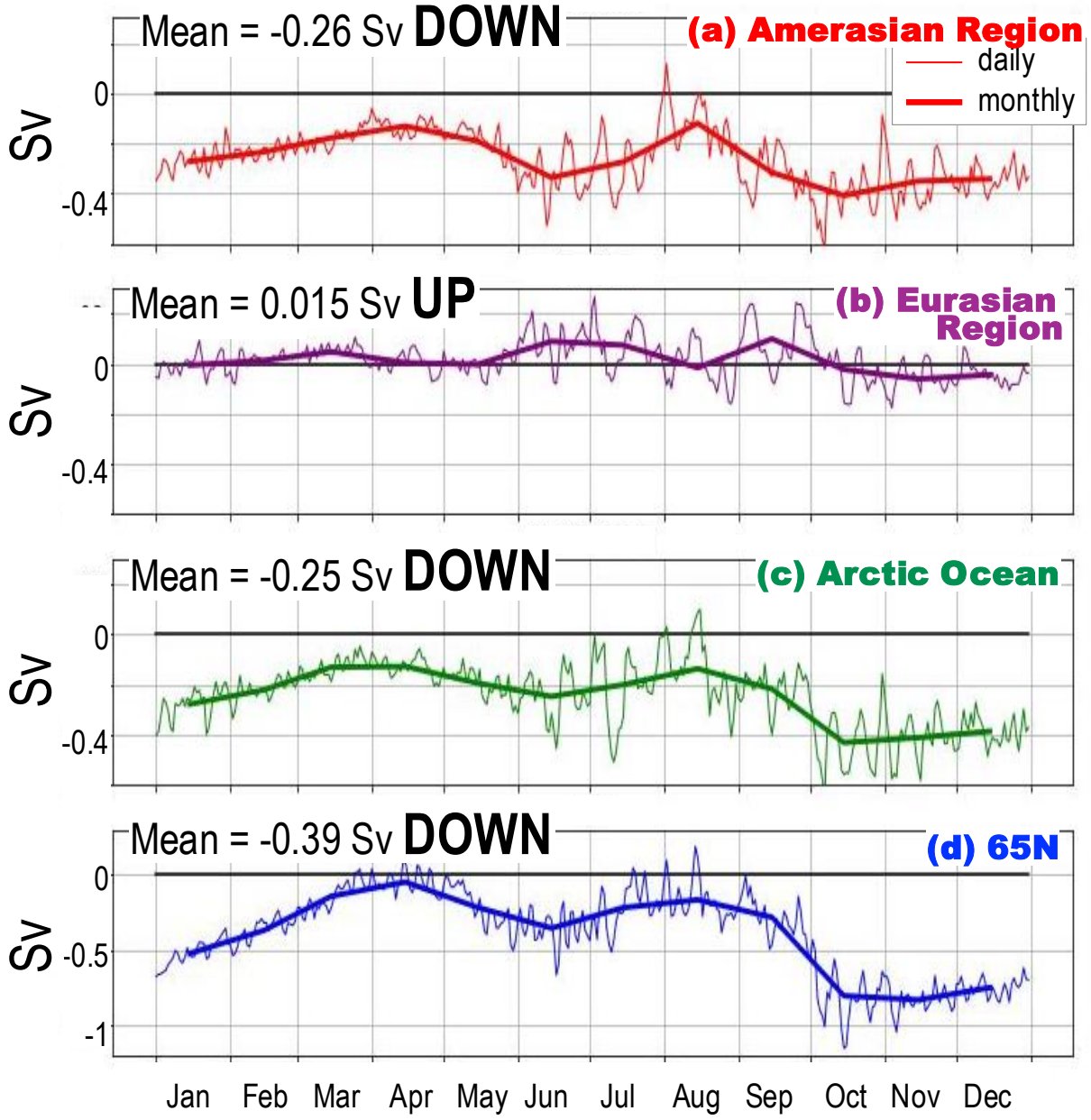


Net **surface convergence**
over the Arctic Seas

(& Arctic Ocean: $W_{ek}$ = -1.1 m/year)

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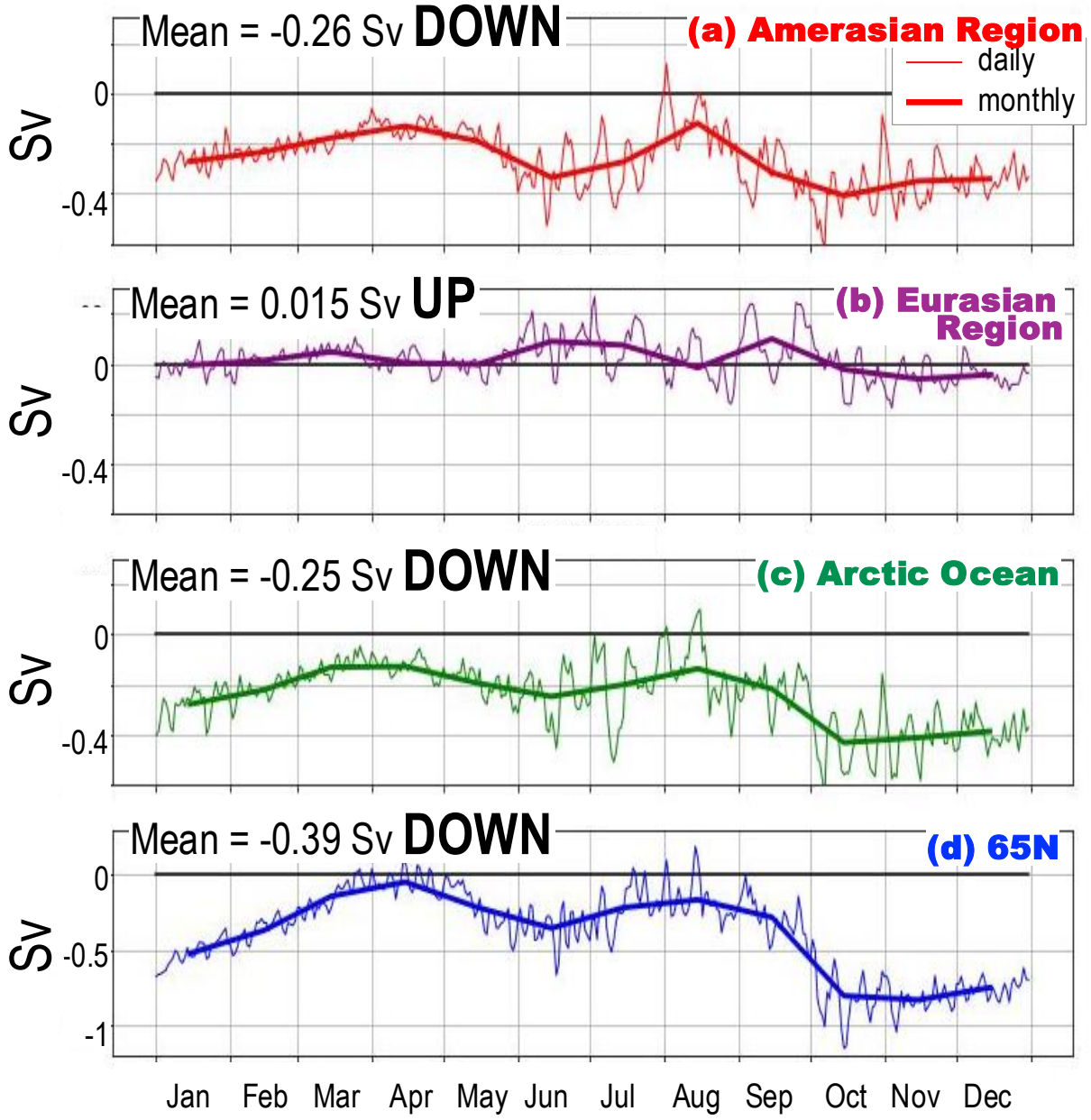


Net **surface convergence**
over the Arctic Seas

(& Arctic Ocean: $W_{ek}$ = -1.1 m/year)

AR >> ER

AO controlled by AR

***(most is in the Chukchi!** …not the BG)*

*…basin-only AR << total region AR*

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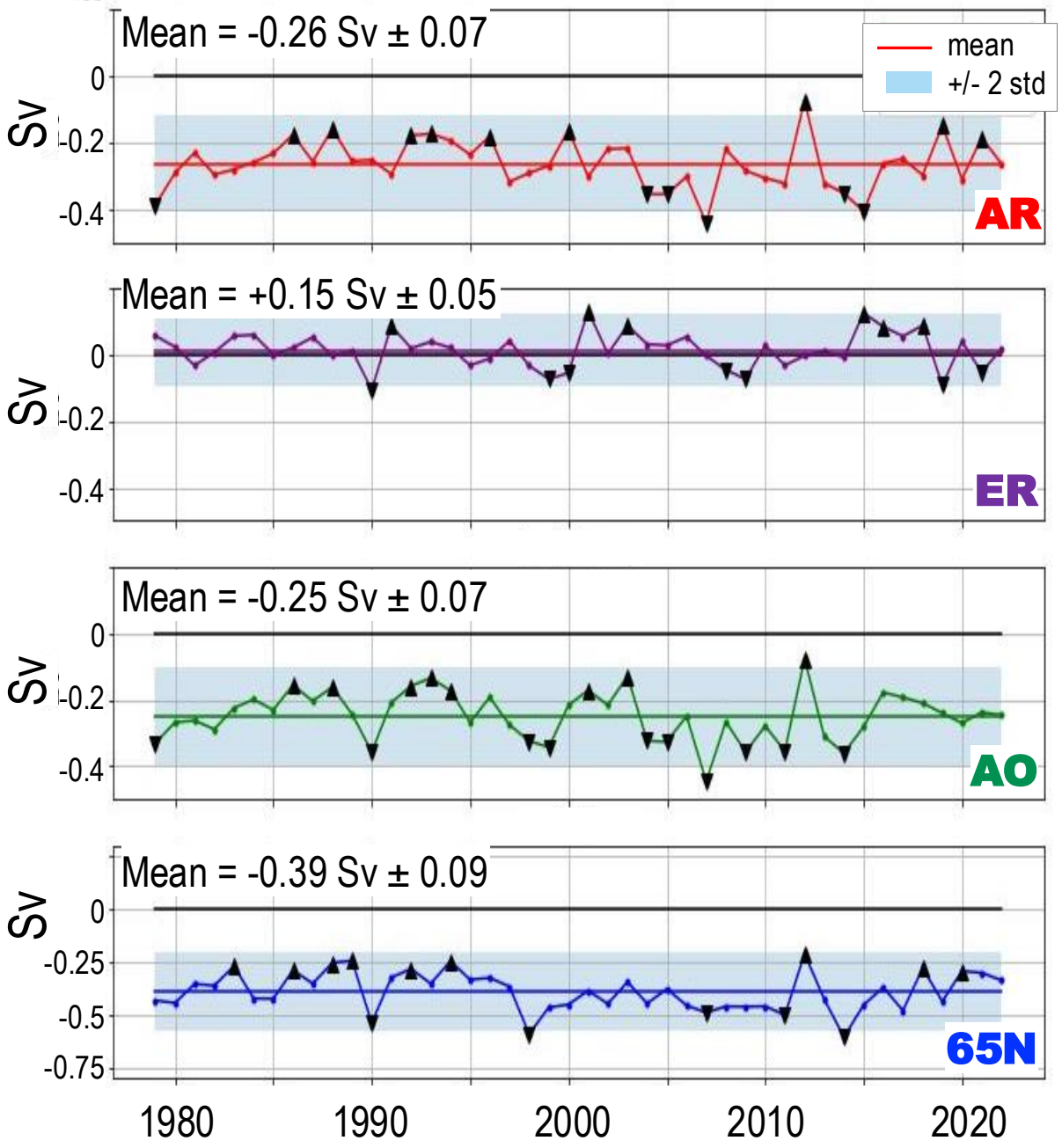
# Interannual variability




**No long-term trends**

*(it's all about interannual var's)*

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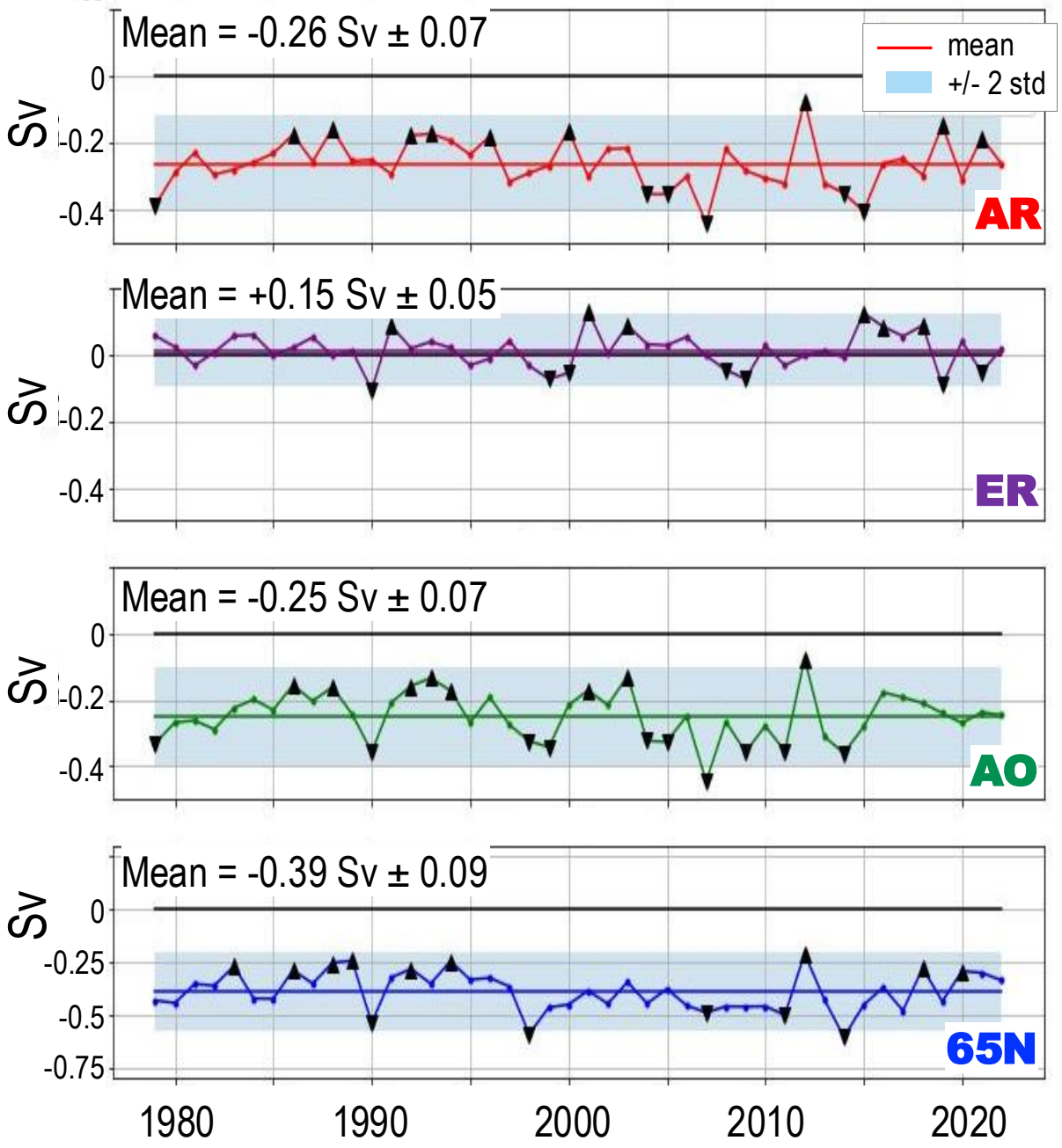
# Interannual variability




**No long-term trends**

*(it's all about interannual var's)*

**AR** & **ER** are only weakly correlated:

***The 2 regions are independent***

*…however, the correl. is increasing recently*

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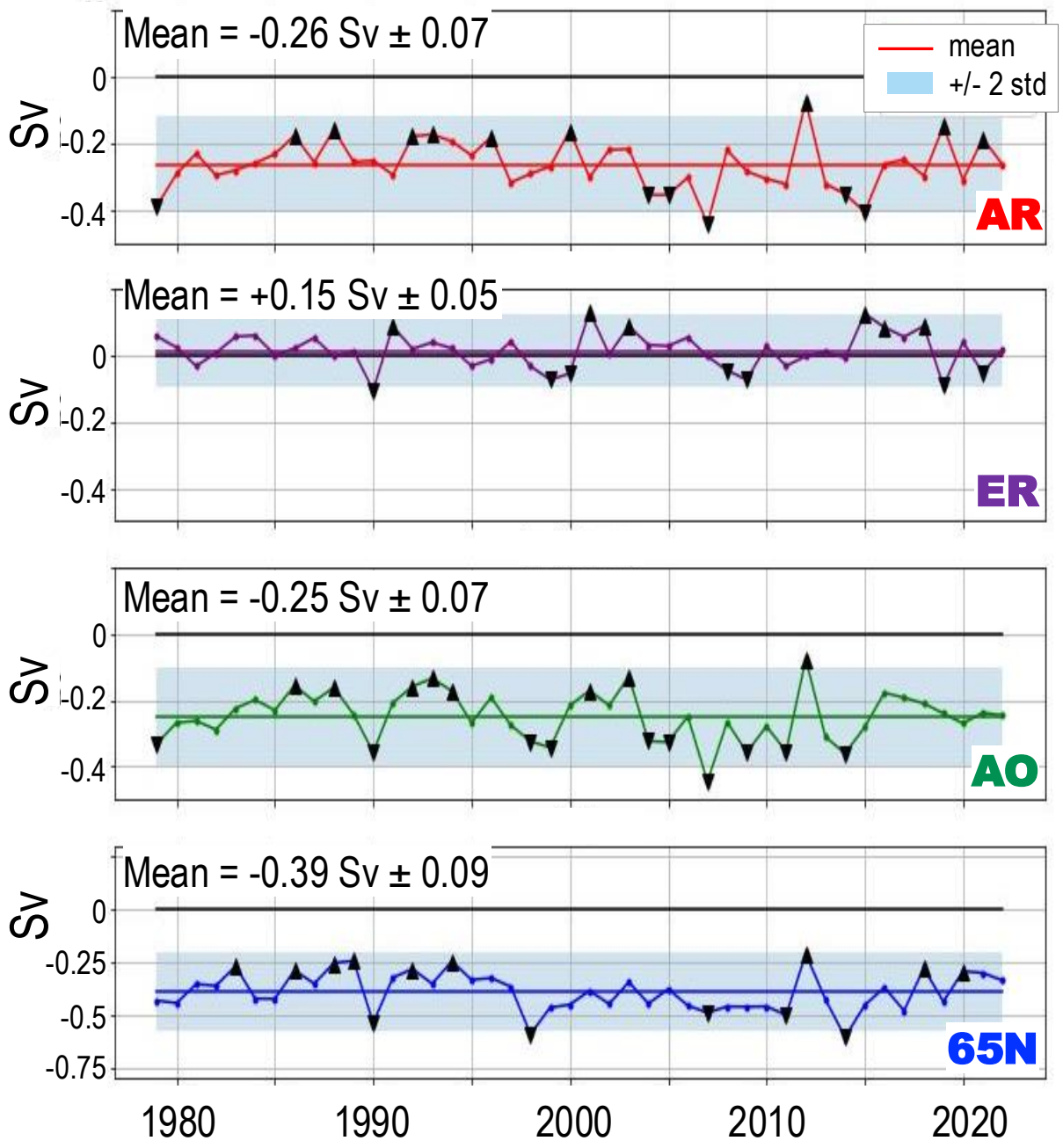
# Interannual variability

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***Interannual var's in the Arctic Ocean/Seas are controlled by the Amerasian Region***

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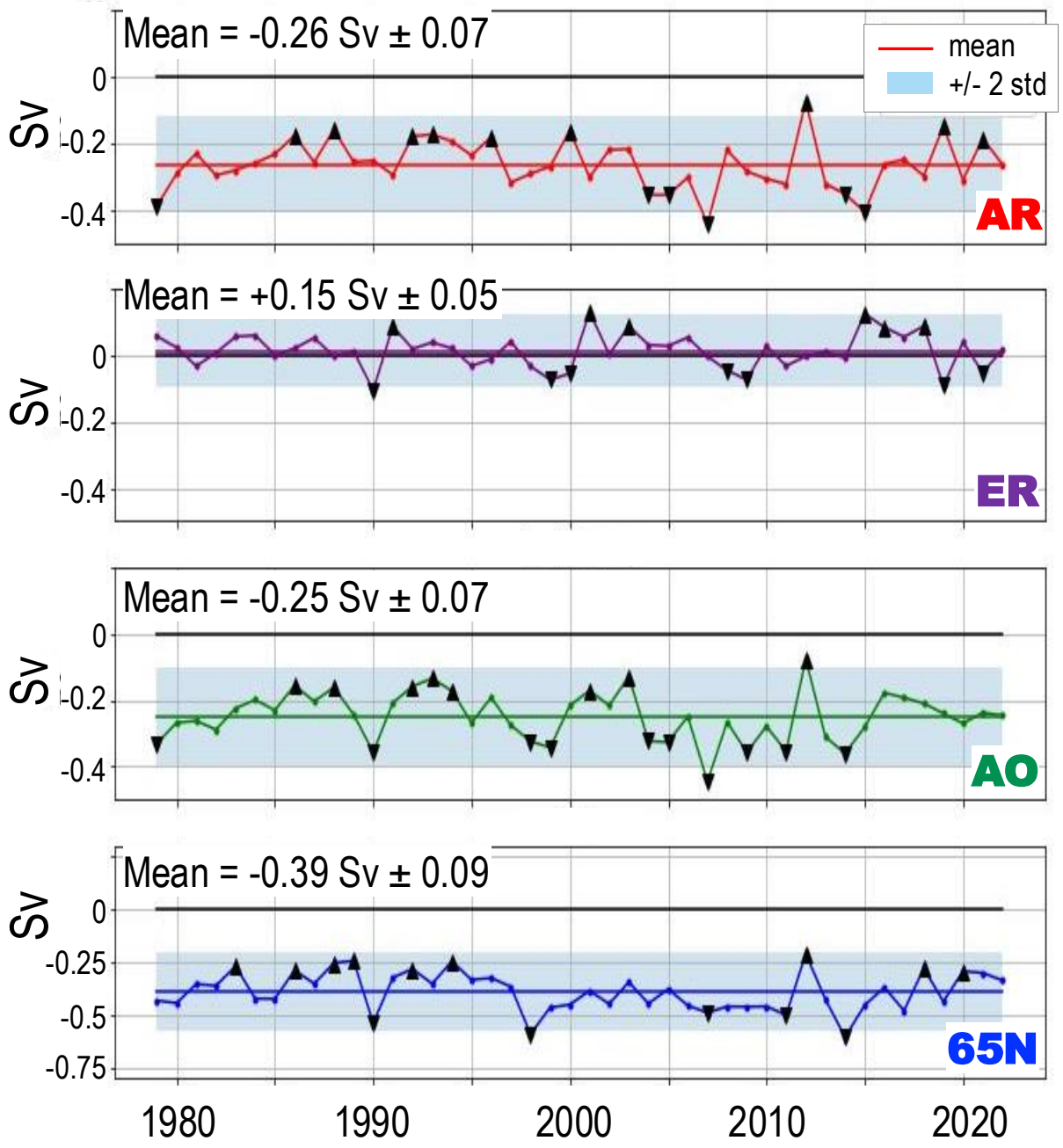
# Interannual variability




**<u>No long-term trends</u>**

*(it's all about interannual var's)*

AR & ER are only weakly correlated:

***The 2 regions are independent***

*…however, the correl. is increasing recently*

*Interannual var's in the Arctic Ocean/Seas are controlled by the Amerasian Region*

**What's increasing?**

- Interannual variance
- Correlation with the Arctic Osc. index

➢ ***The ocean response to wind forcing***

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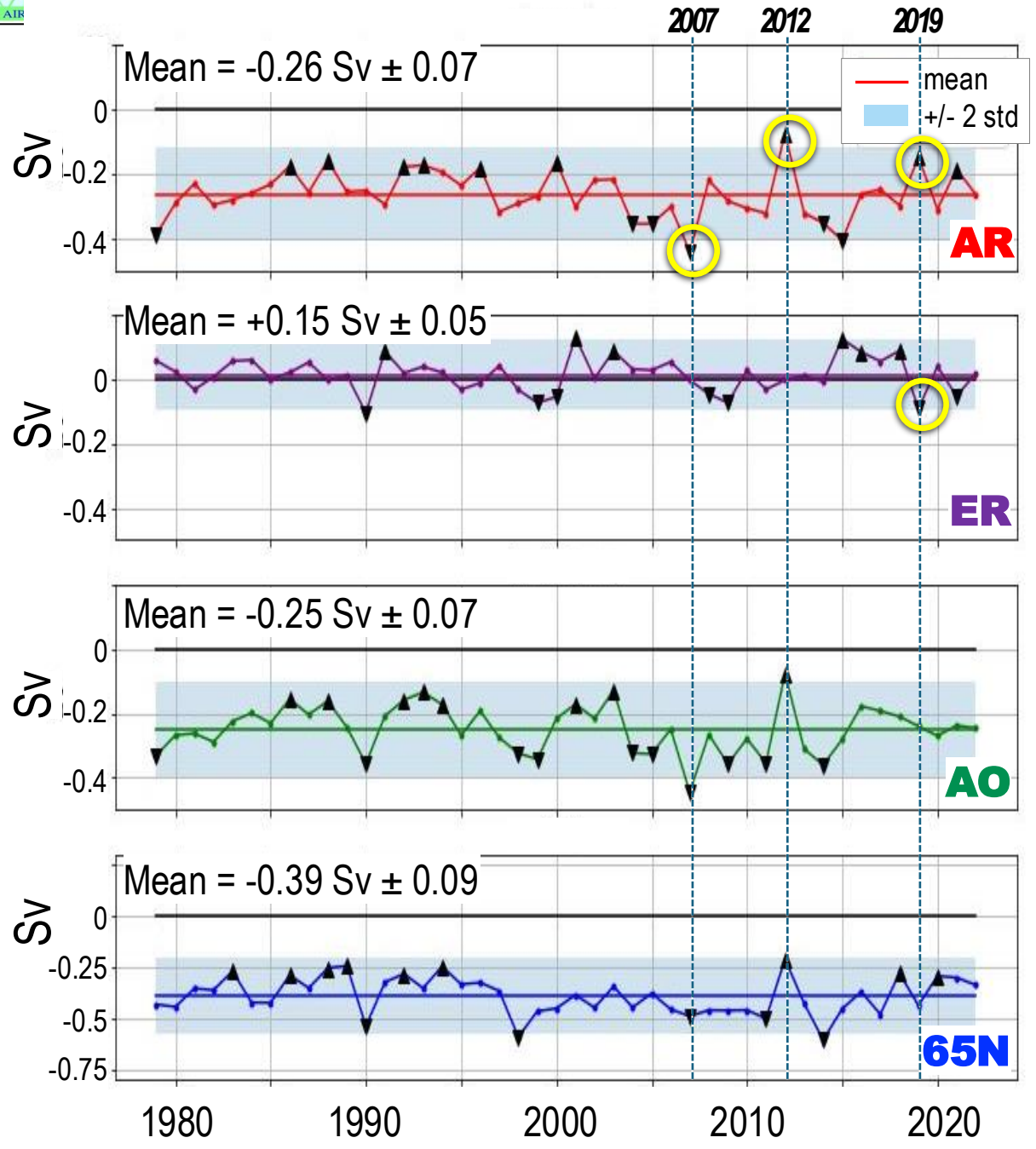
# Interannual variability




"Interesting years"

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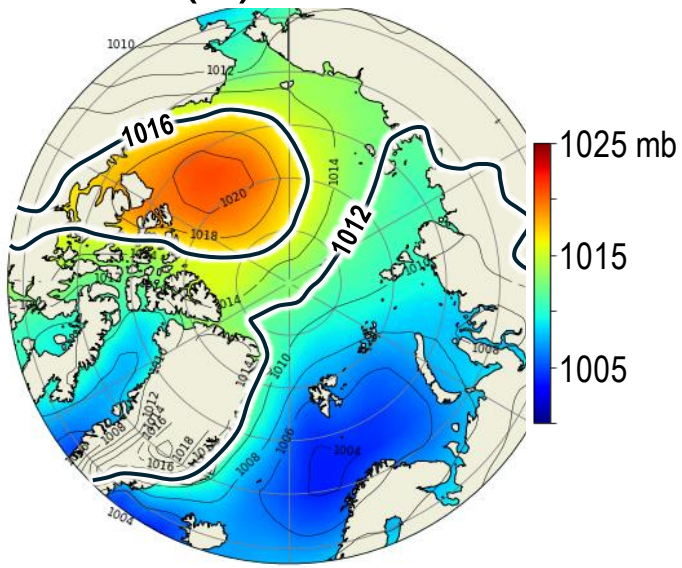
# What happened in 2007?

(a) **SLP**




Big, strong Beaufort High

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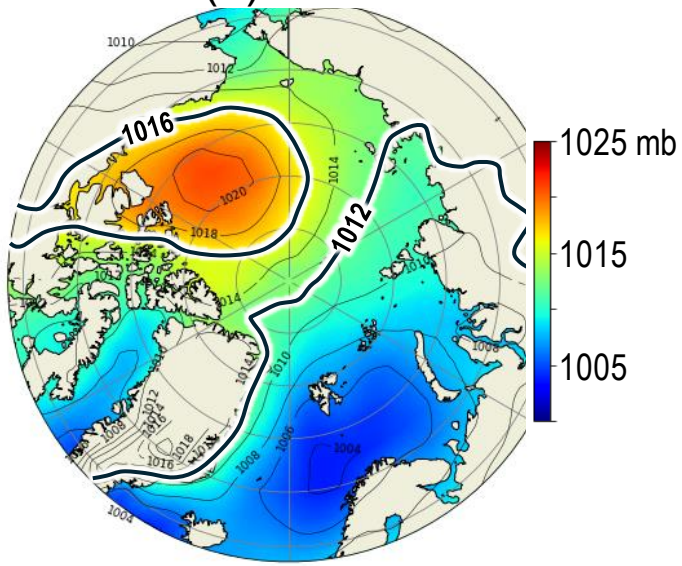
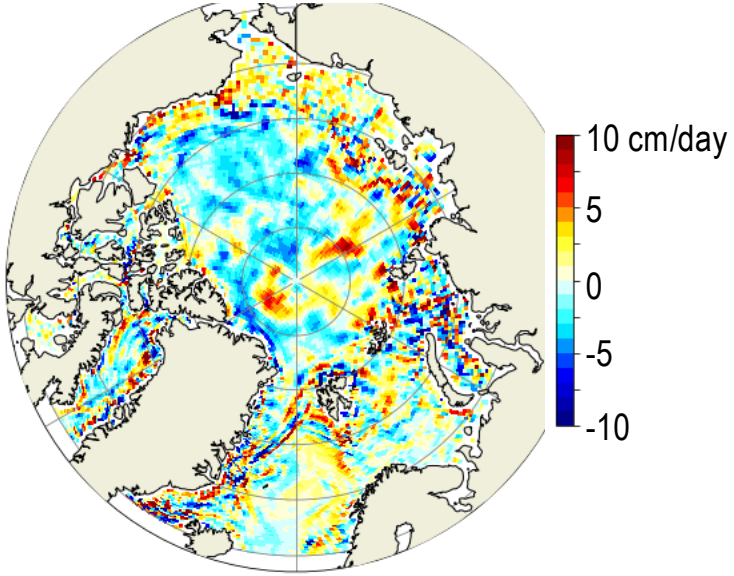
# What happened in 2007?

(a) **SLP**




Big, strong Beaufort High

(b) **Wek anom**




Large area of anom. downwelling (blue)

Michael Steele
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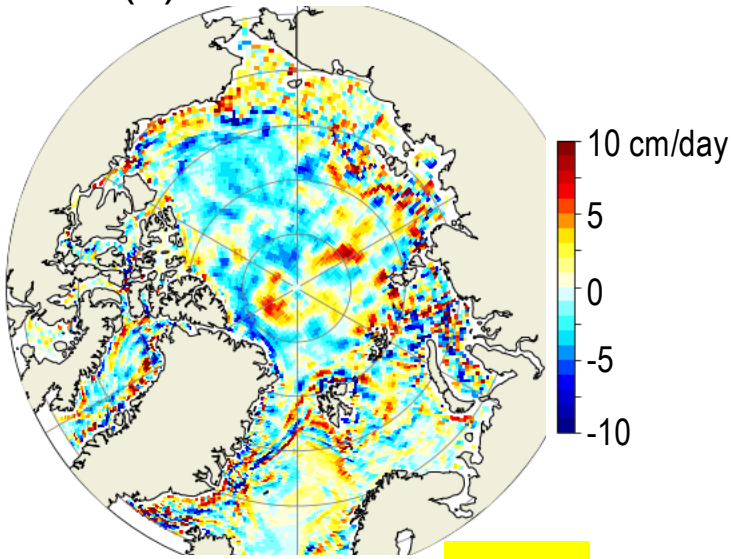
University of Washington



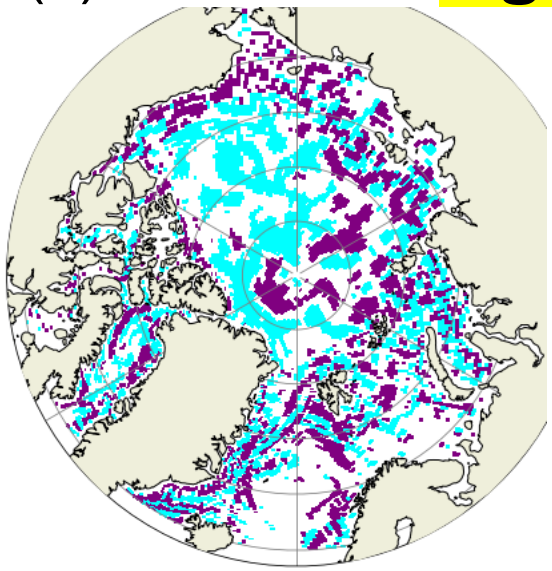
# What happened in 2007?

(b) **Wek anom**




Large area of anom. downwelling (blue)

(c) Wek anom **sign**




Anom. **convergence** surrounded by a ring of anom. **divergence**

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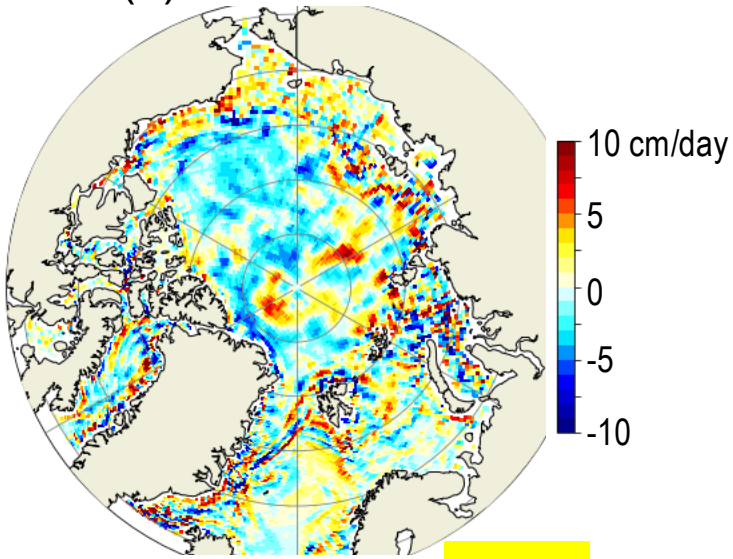


Large area of anom. downwelling (blue)

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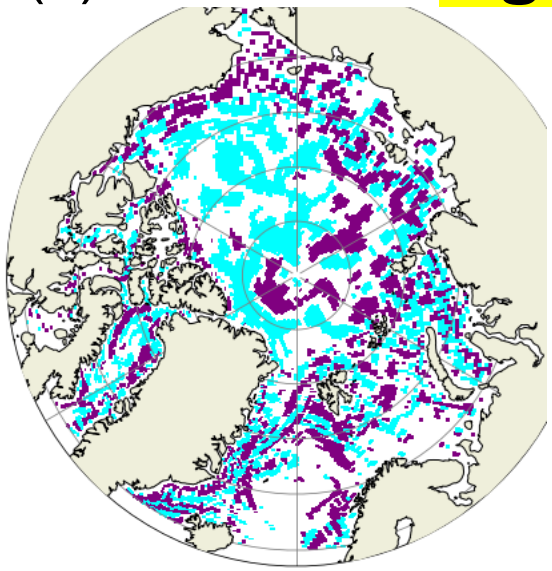


Anom. convergence surrounded by a ring of anom. divergence

...but where is the div/conv **enhanced** vs. **flipped**?

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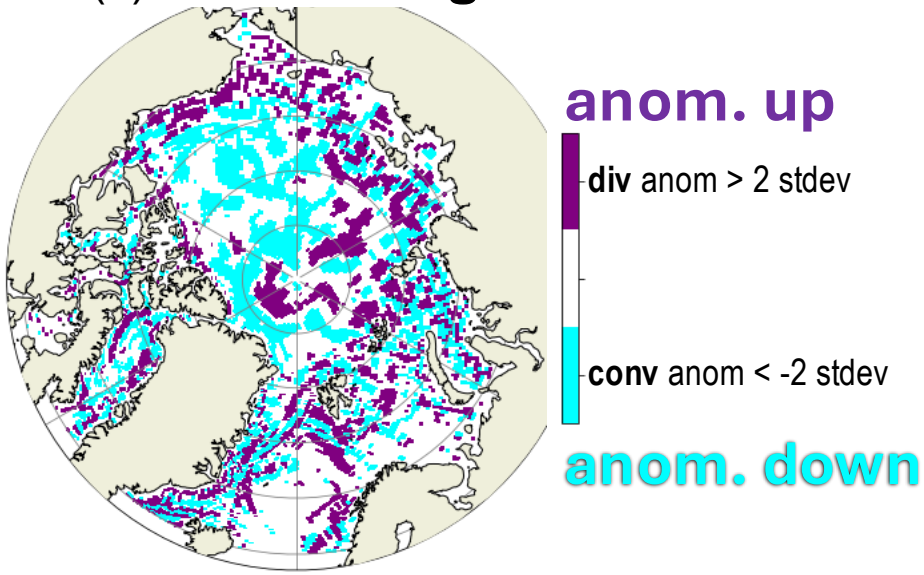
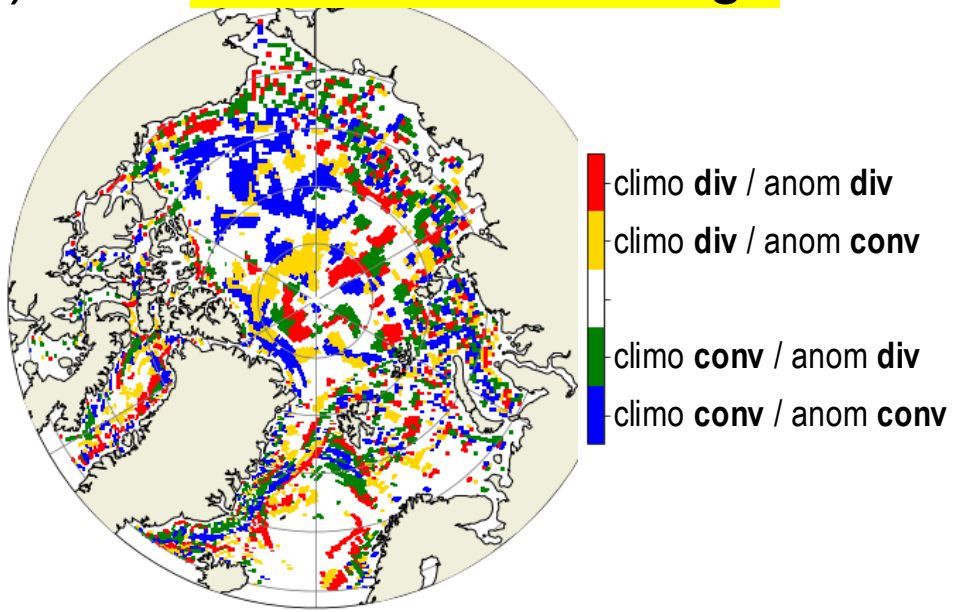
# What happened in 2007?

(c) Wek anom **sign**




Anom. **convergence** surrounded by a ring of anom. **divergence**

(d) Wek **climo** + **anom** sign




**Blue:**

- Climo conv, anom conv (*stronger BG conv*)

**Yellow:**

- Climo div, anom conv (*expanded BG conv to the North*)

**Red:**

- Climo div, anom div (*stronger BG rim div N Alaska*)

**Green:**

- Climo conv, anom div (*expanded BG rim div NW Alaska*)

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# Conclusions

- The **Arctic Seas are convergent** at the ocean surface.
- The seasonal & interannual var. of ocean surface conv/divergence in the Arctic Seas is controlled by vars. in the **Amerasian Basin** (*mostly, the **Chukchi Sea**!*).
- Ocean surface conv/divergence is more variable recently, owing to **stronger wind-ocean coupling**.
    - (*not discussed!)* When the **BG shifts westward** toward the N. Chukchi Sea, its convergent area partly overlaps with the Pacific inflow convergence, creating "**super-convergence**."

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Thank you!

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# Supplementary Figures

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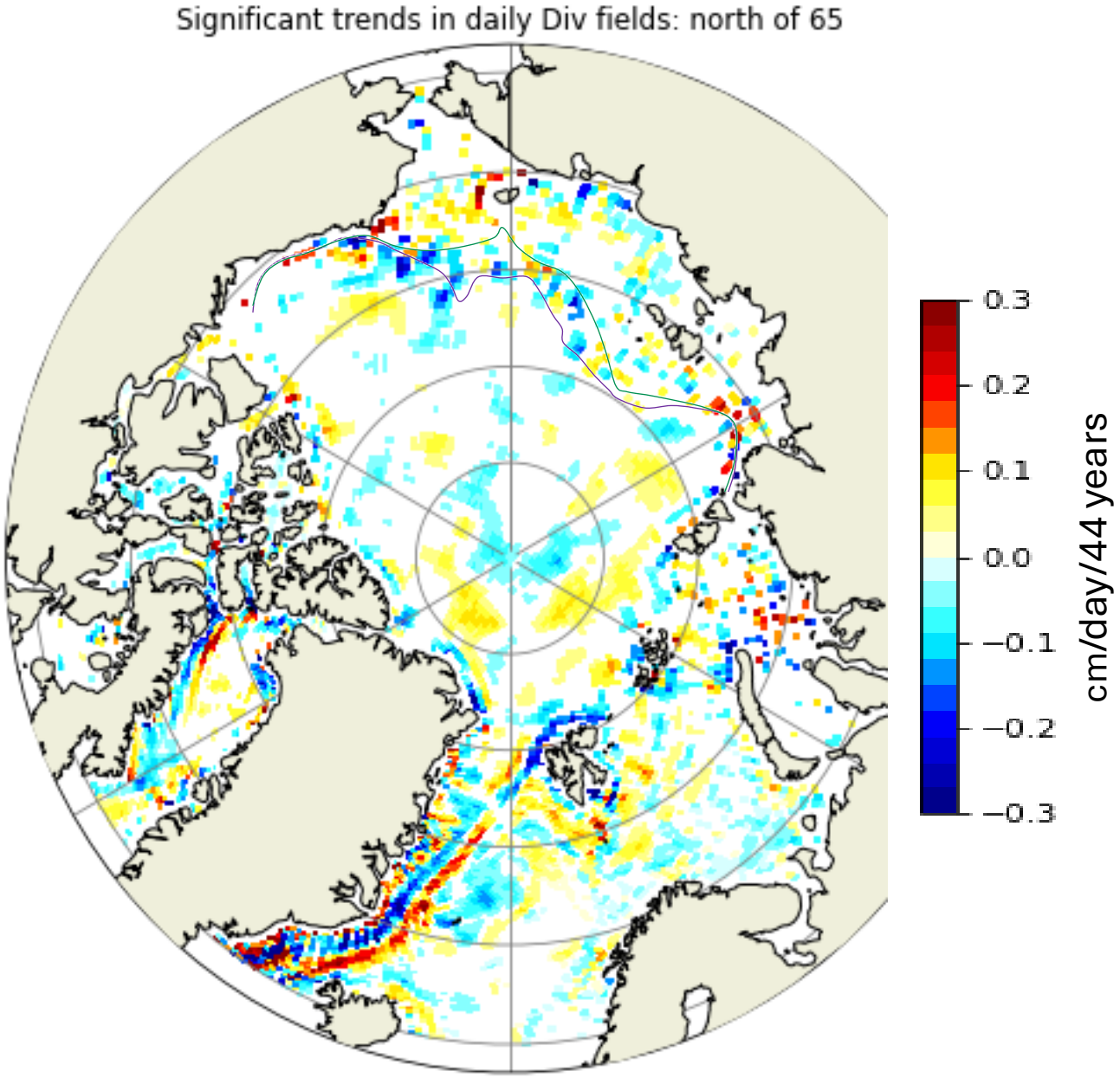
# $dW_{ek}/dt$ *(1979-2022)*



## Long-term linear trends



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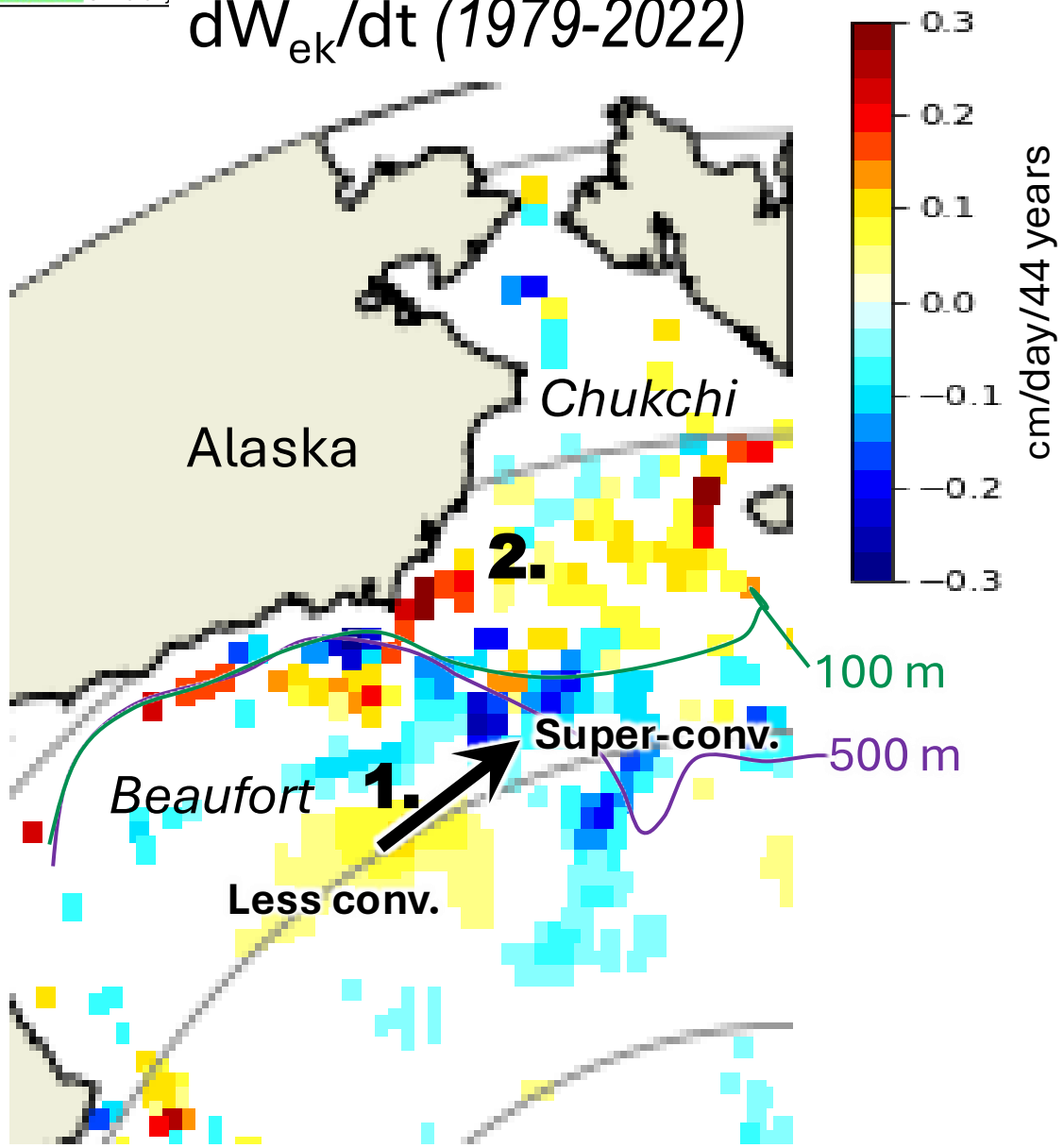
# Long-term linear trends




1. "**Super-convergence**:" Westward shift of BG convergence/downwelling[1], now overlapping with the N. Chukchi Pacific inflow convergence area

2. Accompanying "rim divergence" decreases the N. Chukchi Pacific inflow convergence to the south, especially in Barrow Canyon

   *(4-color analysis confirms it's a decrease in the "usual" convergence there)*

[1]*Armitage et al. (The Cryosph, 2017)*
*Reagan et al. (JGR, 2019)*

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U.S. National Science Foundation
2022-2027

## What are "microplastics?"

< 5 mm in diameter

# Lost at Sea: Where Is All the Plastic?

Richard C. Thompson,[1]* Ylva Olsen,[1] Richard P. Mitchell,[1] Anthony Davis,[1] Steven J. Rowland,[1] Anthony W. G. John,[2] Daniel McGonigle,[3] Andrea E. Russell[3]

[1] *University of Plymouth, UK*

- The 1st "microplastics" paper
- 2004, Science Magazine
- 1 page long
- > 9,000 citations! *(Google Scholar)*