ALFRED WEGENER INSTITUTE
PHYSICAL OCEANOGRAPHY

Large scale forcing of the Arctic sea level seasonality and implications for slope currents

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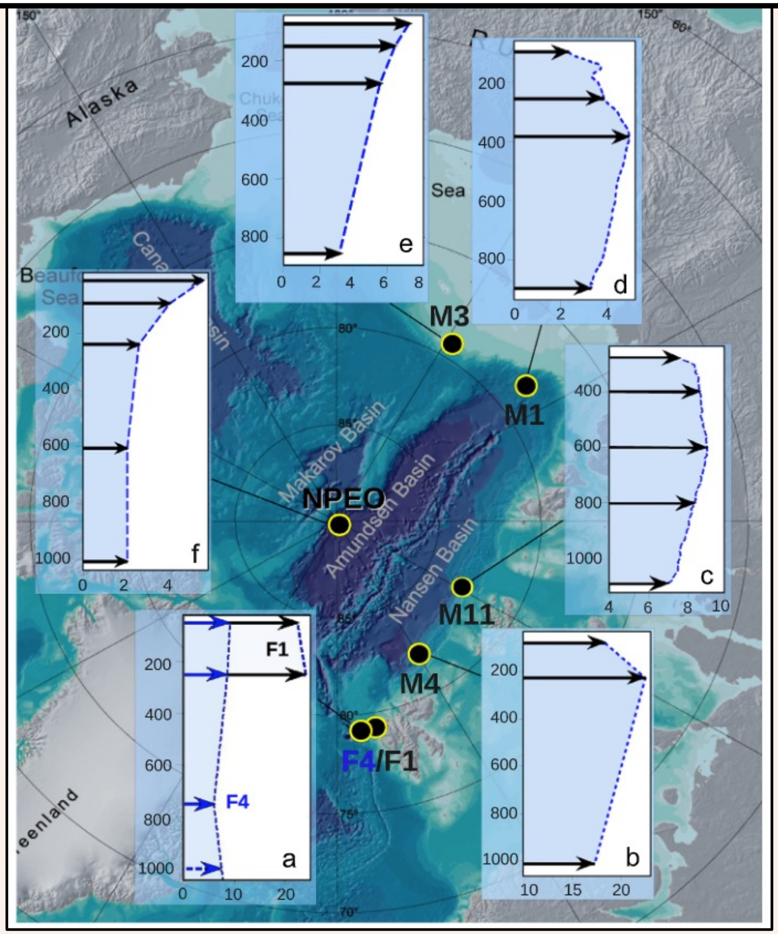
Background: **slope currents in the Arctic Ocean**

Studying the slope currents system entering the Arctic from the Nordic seas and flowing cyclonically below the ice is relevant for the understanding of the future Arctic given it is one major pathway of freshwater and salt exchange with the Atlantic Ocean. In situ observations of surface currents in the Arctic are though limited due to the presence of ice and the logistic challenges. For the same reason, its large scale forcing is also poorly understood.

A.V. Pnyushkov et al. / Deep-Sea Research I 101 (2015) 80–97



Could **satellite altimetry** measurements of **sea surface height (SSH)** and associated **geotrosphic currents** prove to be a viable tool to get insight into the **slope currents variability** in the Arctic, and understand its drivers?

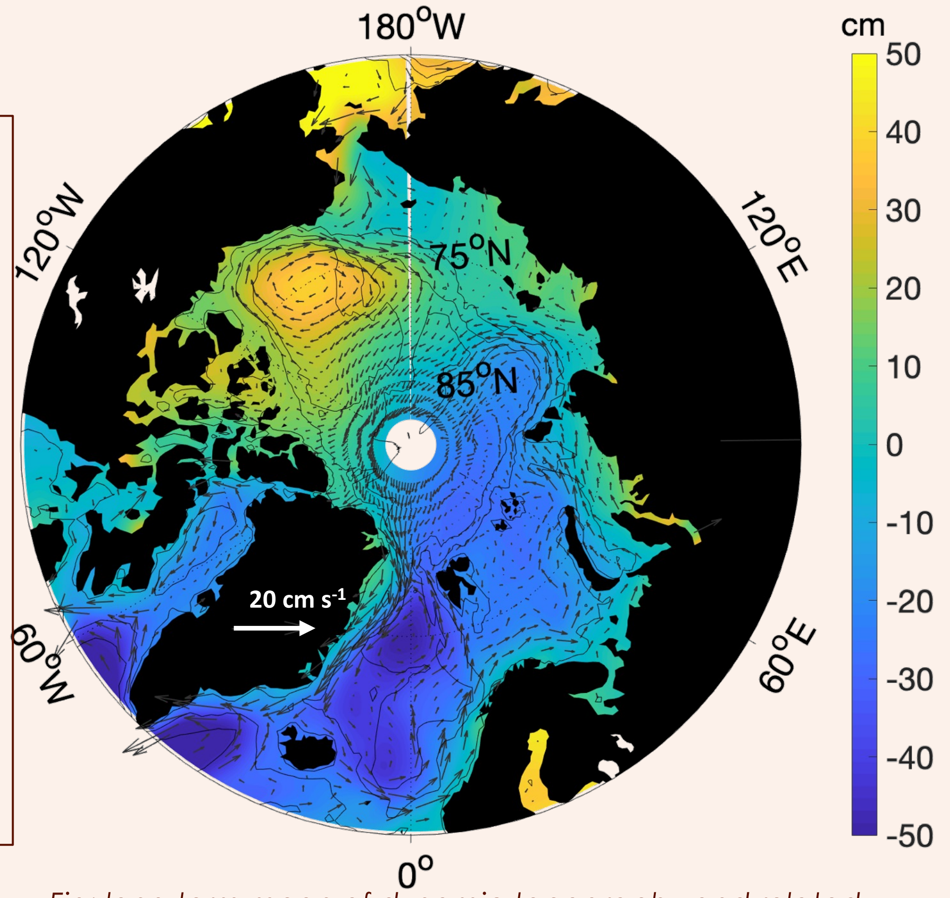
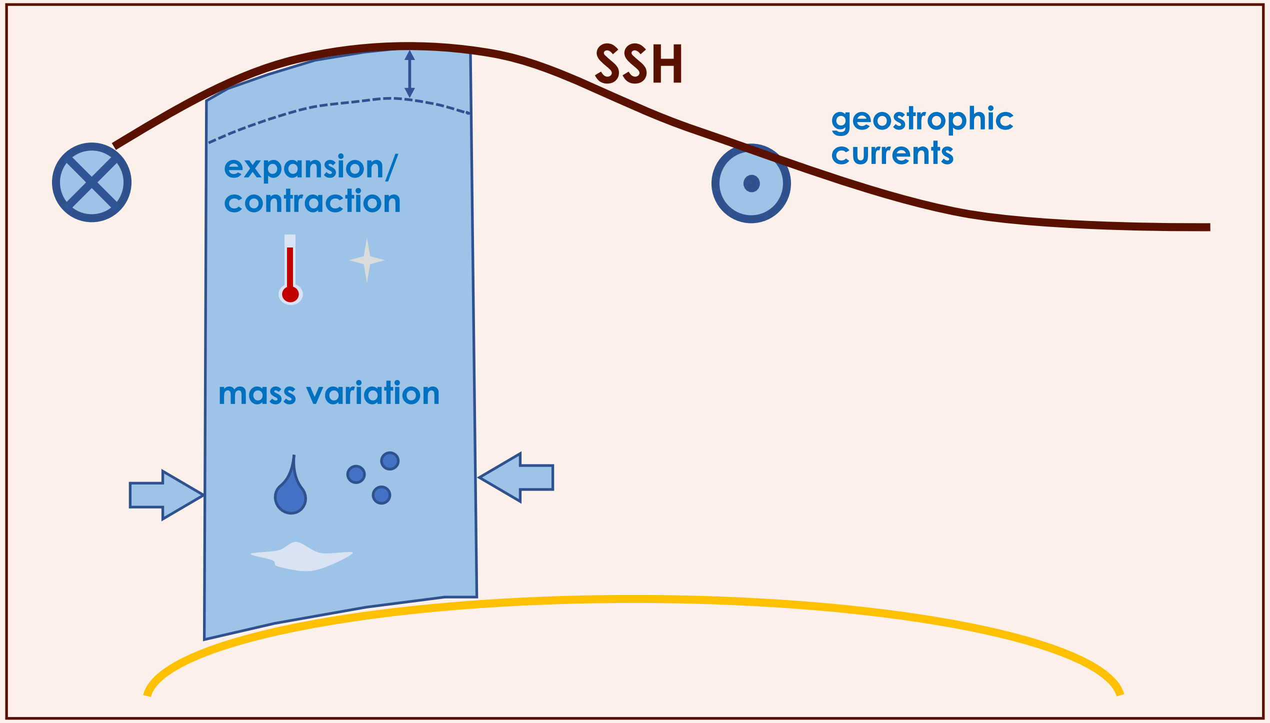


Fig: long term mean of dynamic topography and related surface geostrophic currents currents from the mapped altimetry product DTU17MDT (Technical University Denmark)

Background: **Altimetry in the polar oceans**

Altimetry data also available in ice-covered ocean. In these regions, the sea level "visible" from cracks in the ice called leads .* (a visualisation of ice movement simulation and leads evolution from MITgcm can be found here)



Variations in the horizontal slope of SSH modulate surface geostrophic currents.

Locally, SSH varies depending on the underlying processes that drive **steric and mass variations** in the water column.

We used a recent gridded altimetry product, together with model output, to study the **seasonal variability** of SSH and associated geostrophic currents along the Arctic continental slopes.

* *see, e.g., Kwok et al. (2011), https://doi:10.1029/2010GL046063*

Methods: **gridded altimetry fields and model output**

SATELLITE DATA

SAGA

S*ea level*

A*nomaly and*

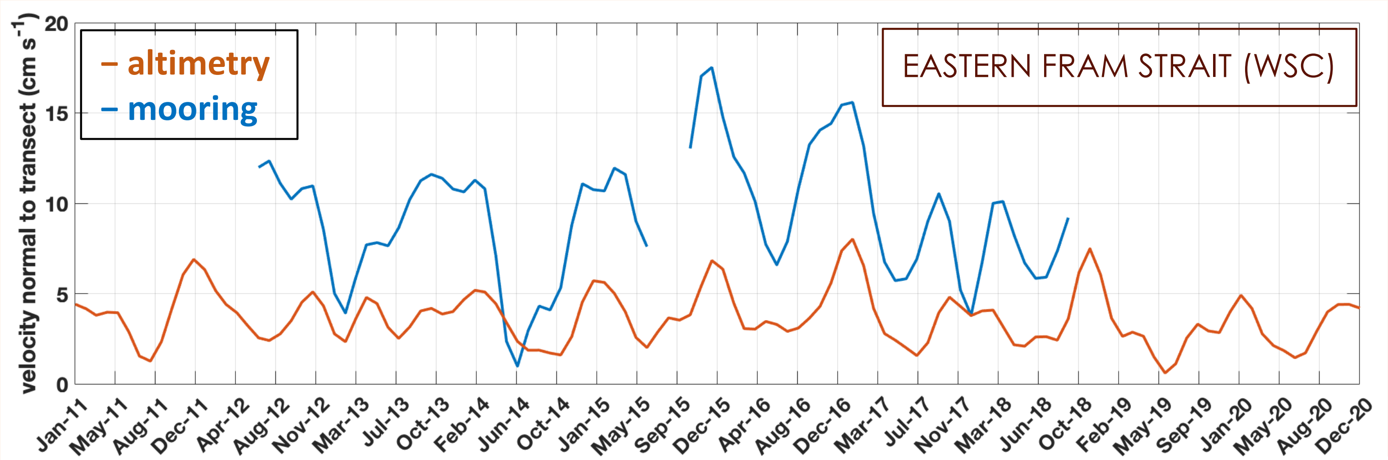
G*eostrophic velocity of the*

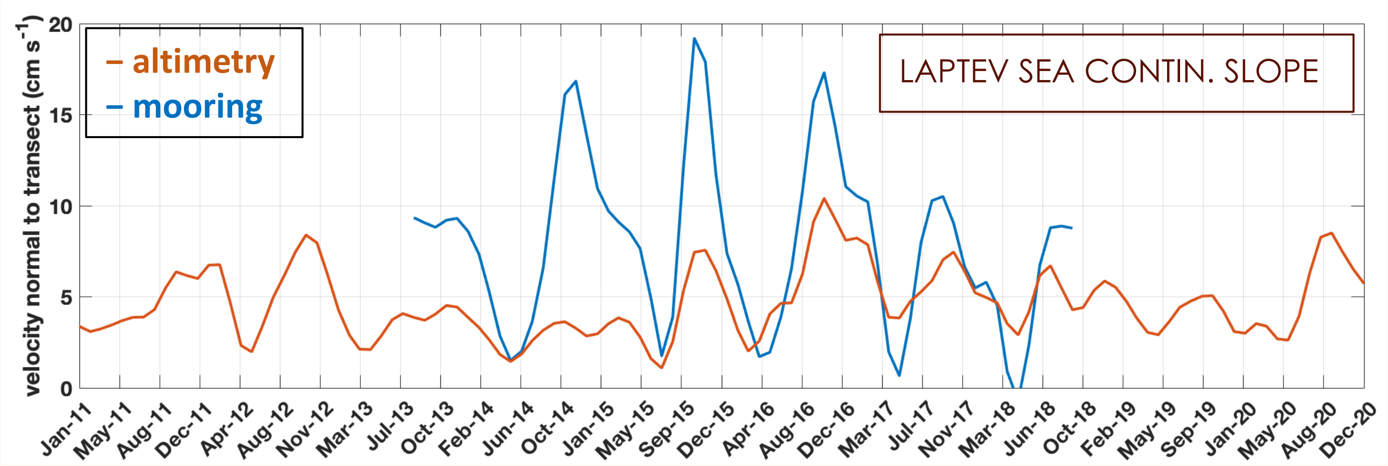
A*rctic ocean*

Doglioni et al. 2021 (under review):

Pan-Arctic monthly maps of sea surface height anomaly and geostrophic velocity from the satellite altimetry Cryosat-2 mission, 2011-2020.

https://doi.pangaea.de/10.1594/PANGAEA.931869





Figures: comparison of altimetry-derived geostrophic currents and surface currents (upper 50 m) from mooring arrays. (modified from Doglioni et al. 2022, under review in ESSDD, https://essd.copernicus.org/preprints/essd-2022-111/)

Methods: **gridded altimetry fields and model output**

In the study we use monthly maps, over the period 2011-2018, from:

SATELLITE DATA

SAGA

S*ea level*
A*nomaly and*
G*eostrophic velocity of the*
A*rctic ocean*

Doglioni et al (under review):

Pan-Arctic monthly maps of sea surface height anomaly and geostrophic velocity from the satellite altimetry Cryosat-2 mission, 2011-2020.

https://doi.pangaea.de/10.1594/PANGAEA.931869

(associated journal article under review in ESSDD: https://doi.org/10.5194/essd-2022-111)

MODEL DATA

FESOM

F*inite*
E*lements*
S*ea ice-*
O*cean*
M*odel*

FESOM 1.4, resolution of 4.5 km in the Arctic Ocean, sea ice– ocean coupling.

Using monthly mean maps from an historical run forced by atmospheric reanalysis data of JRA55-do v.1.3 (Tsujino et al., 2018).

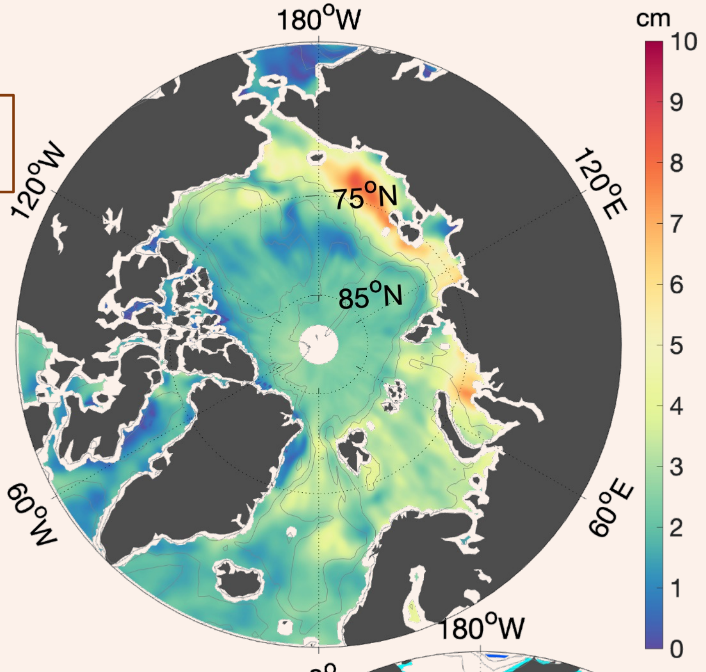
Methods: **seasonality and model validation**

SSH - Amplitude

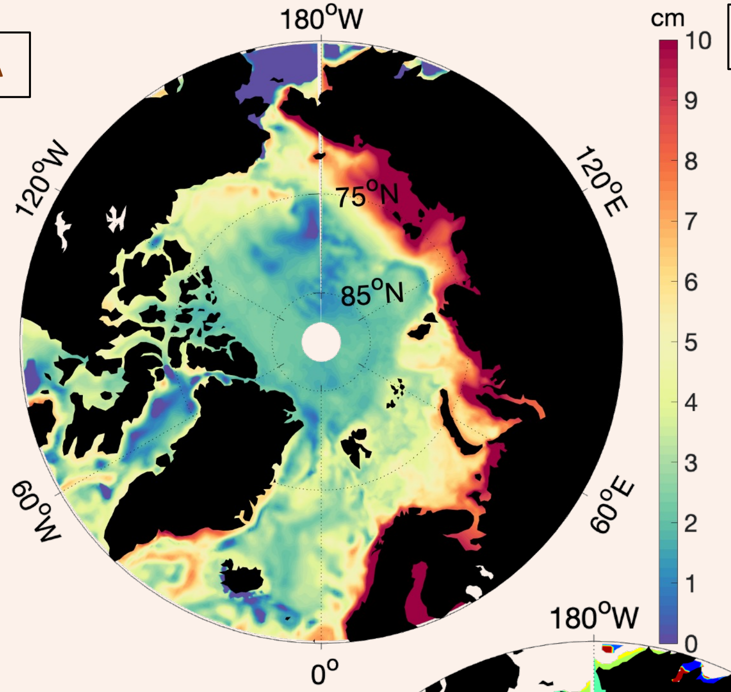
Altimetry and model data show and **enhanced amplitude** of the seasonal cycle on the **Eurasian shelf seas** and a **phase difference** between those and the deep basins (Nordic Seas, Eurasian Basin).

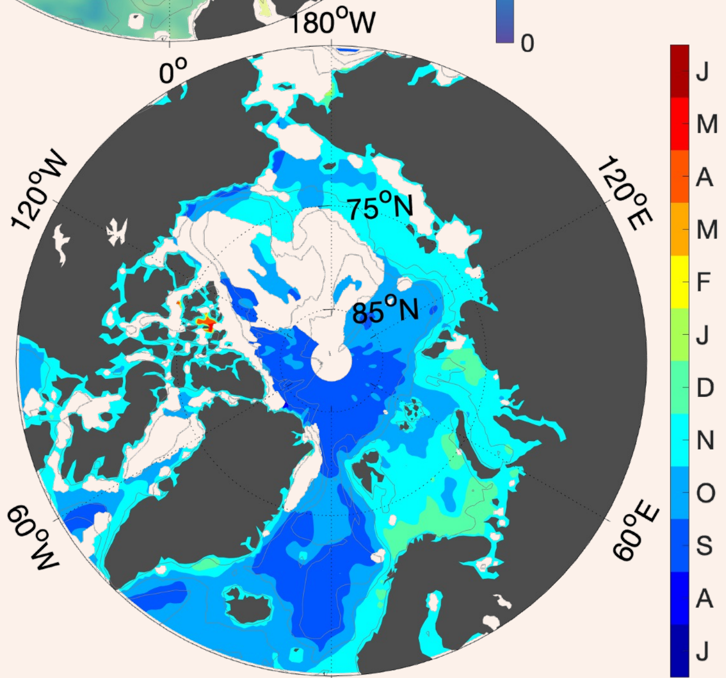
SSH - Phase

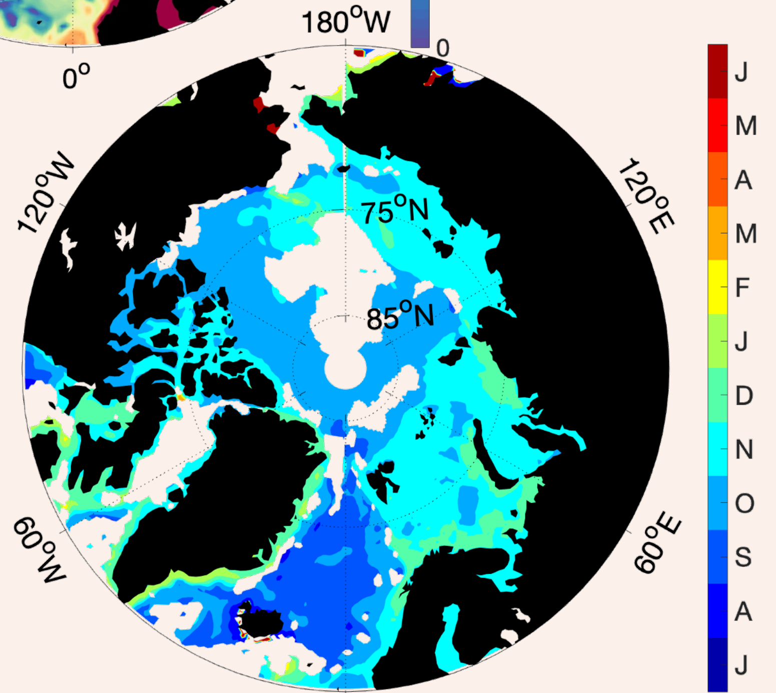
SATELLITE DATA



MODEL DATA







Methods: **seasonality and model validation**

SSH - Amplitude

Altimetry and model data show and **enhanced amplitude** of the seasonal cycle on the **Eurasian shelf seas** and a **phase difference** between those and the deep basins (Nordic Seas, Eurasian Basin).

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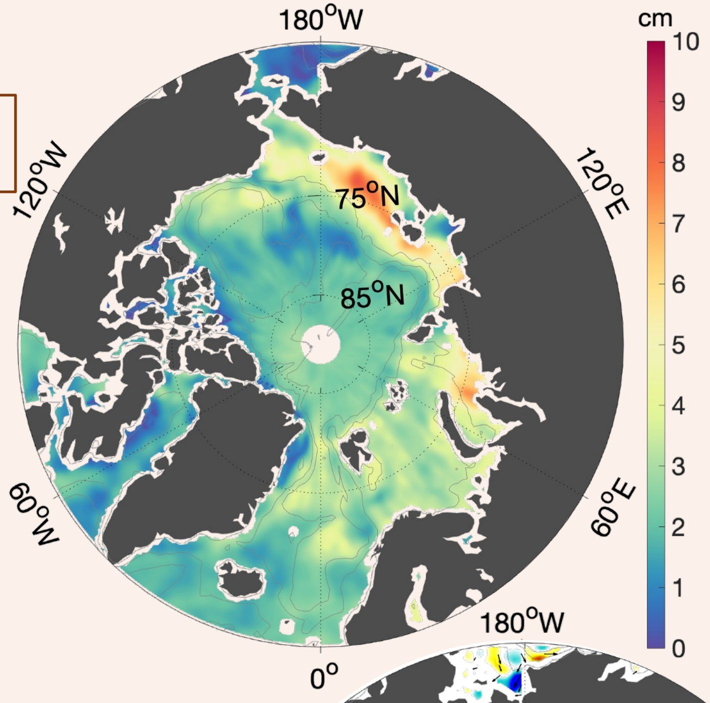
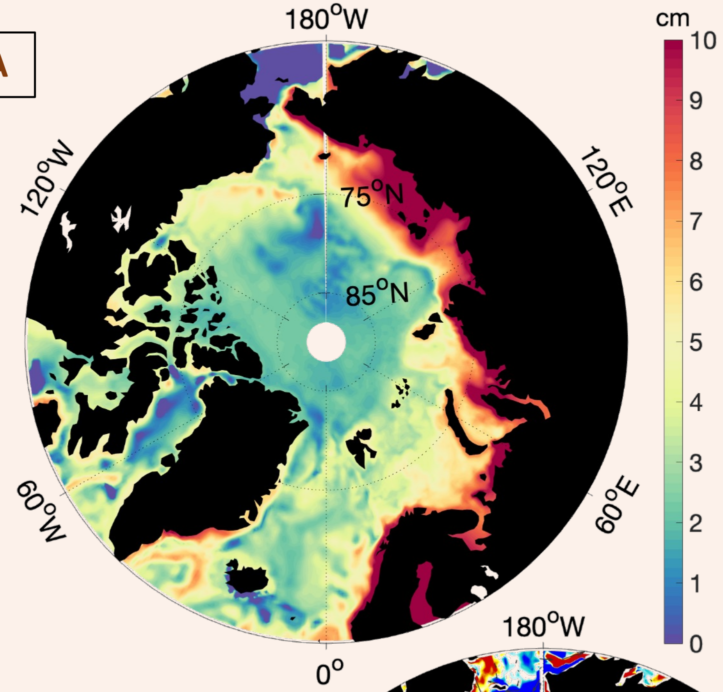
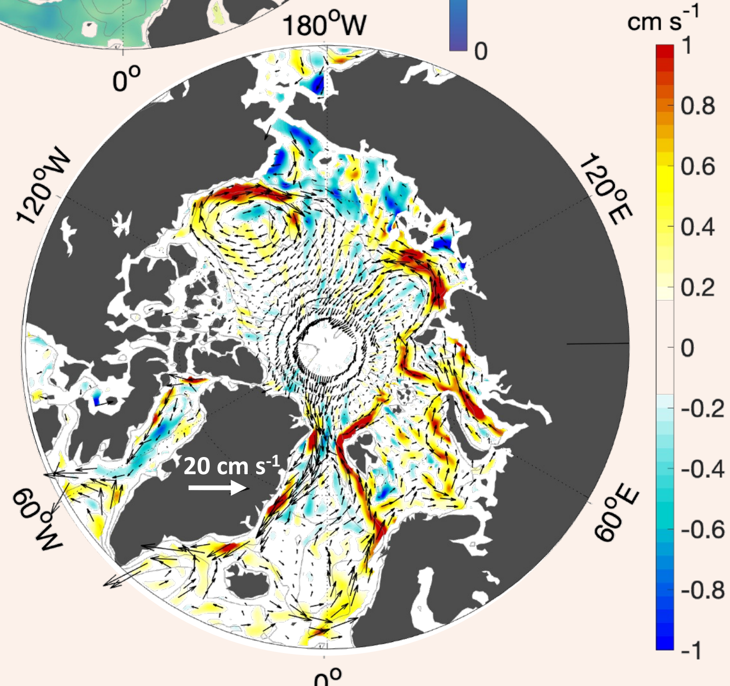


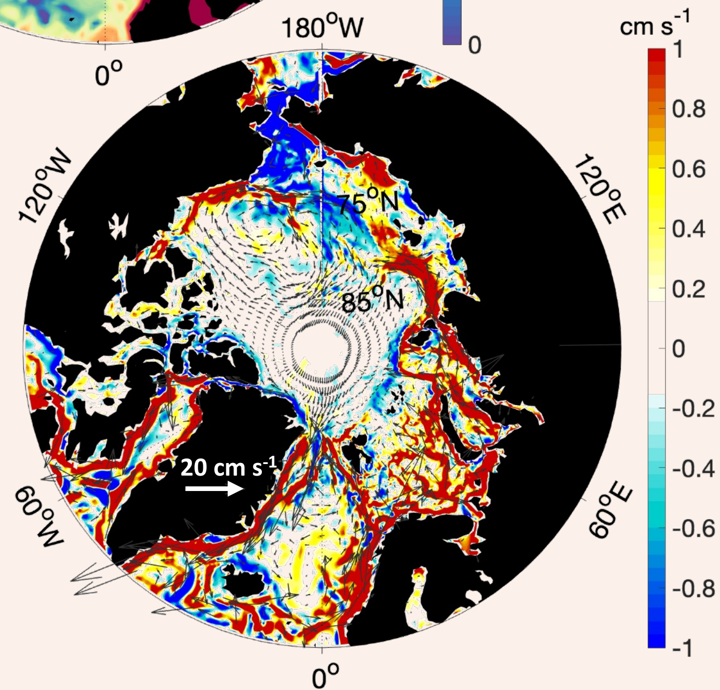
MODEL DATA



geostr. velocity: Oct to Dec

A consistent **acceleration in fall/winter** appears in the geostrophic velocity along the continental slopes in the Eurasian Arctic.



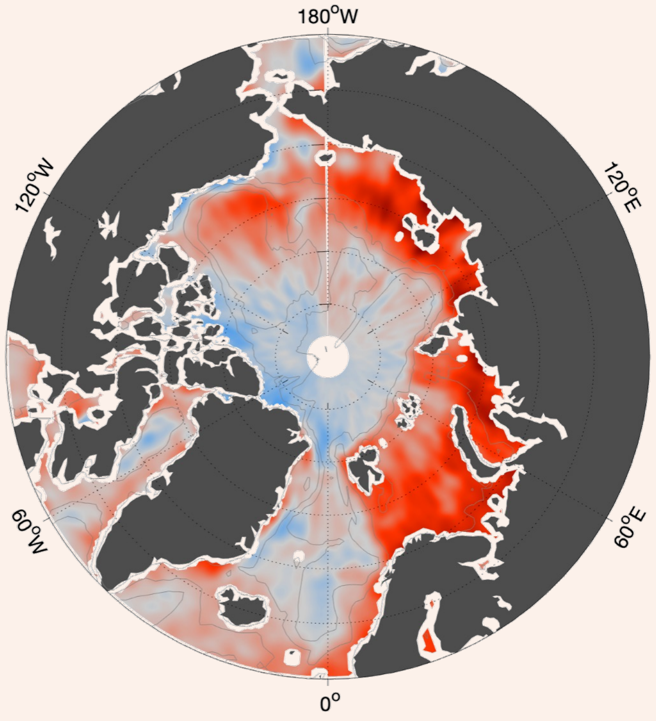


Results: **seasonal differences** OND - JJA

„winter“ = OND „summer“= JJA

SSH (η)

SATELLITE DATA



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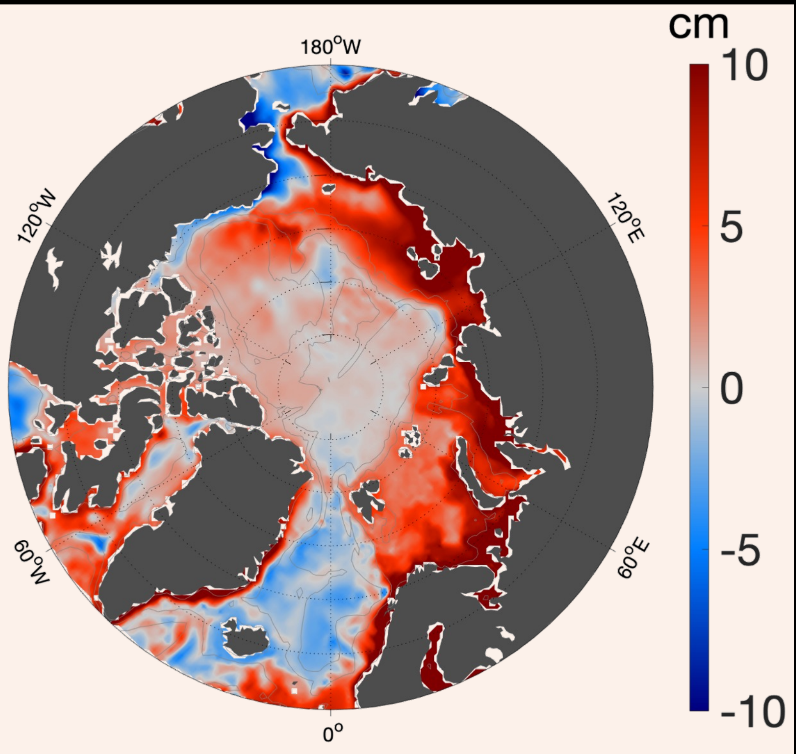
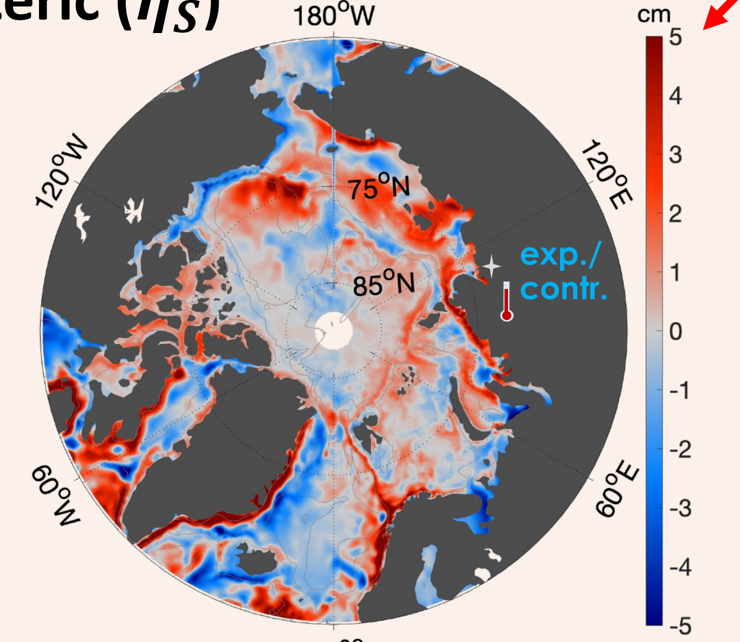
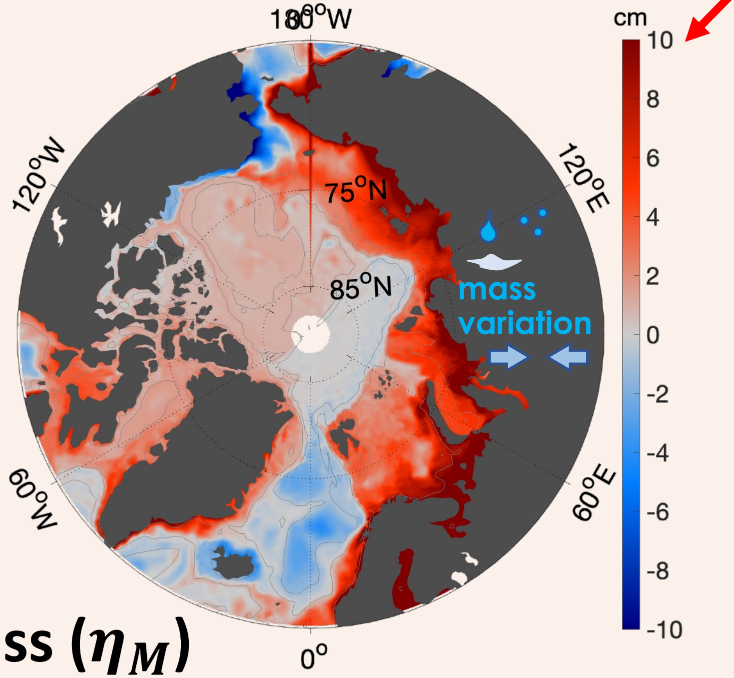


steric (η_S)





mass (η_M)

Both altimetry and model data show that the **SSH gradient across the Eurasian shelf break** is sharper in winter than in summer, resulting in stronger slope currents.

By separating SSH into its **steric** and **mass component** using model output, we find that this consistent **large-scale behaviour** is attributable to **variations in ocean mass.**

Results: **seasonal oscillation in slope currents speed**

FOCUS ON EURASIAN ARCTIC

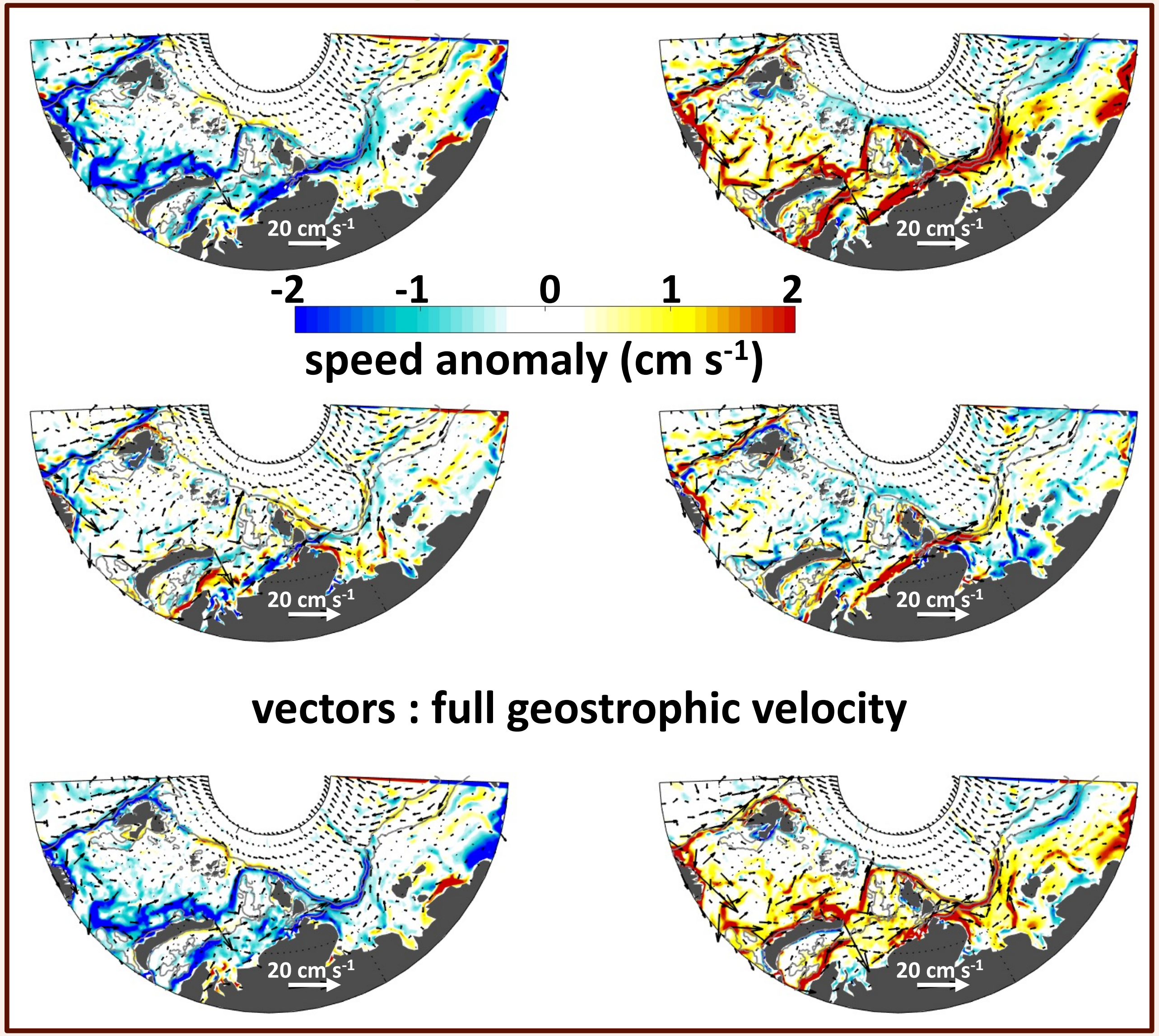
GEOSTROPHIC SPEED ANOMALY RELATED TO CHANGES IN . . .

Jun-Jul-Aug **Oct-Nov-Dec**

…η

…η_S

…η_M



The **geostrophic speed anomaly** induced by differential sea surface height changes (**η**) can be split into anomaly related to **steric height changes** (η_S) and anomaly related to **ocean mass changes** (η_M).

Speed anomaly related to changes in $\boldsymbol{\eta_S}$ is much more **localised** and confined to regions where **density driven currents** are present (e.g., along the eastern coasts of the Kara Sea, where the Ob-Yensey freshwater plume propagates).

Speed anomaly related to changes in $\boldsymbol{\eta_M}$ displays a **consistent large-scale behaviour** and are located along the **bathymetry gradients** in the eastern Nordic Seas, the Eurasian Basin and the Barents Sea.

Discussion: **drivers of ocean mass seasonality**

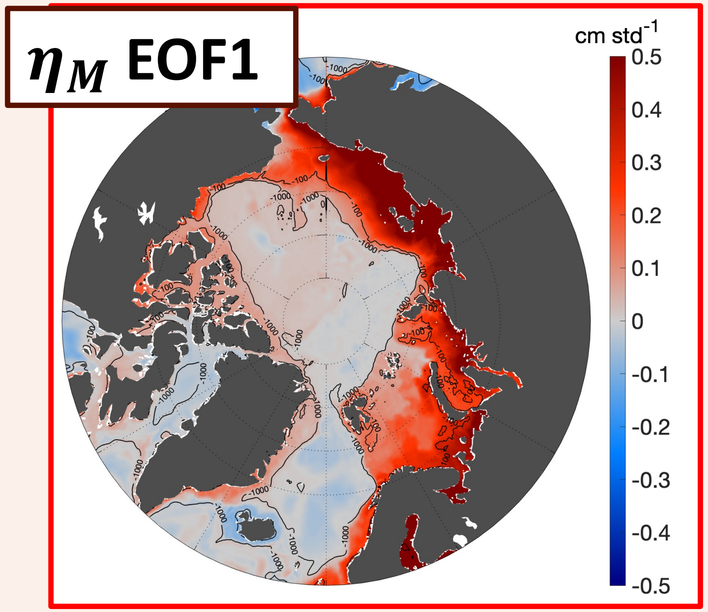
(1) Can Ekman transport across the shelf break explain the variability of ocean mass on the shelf seas?

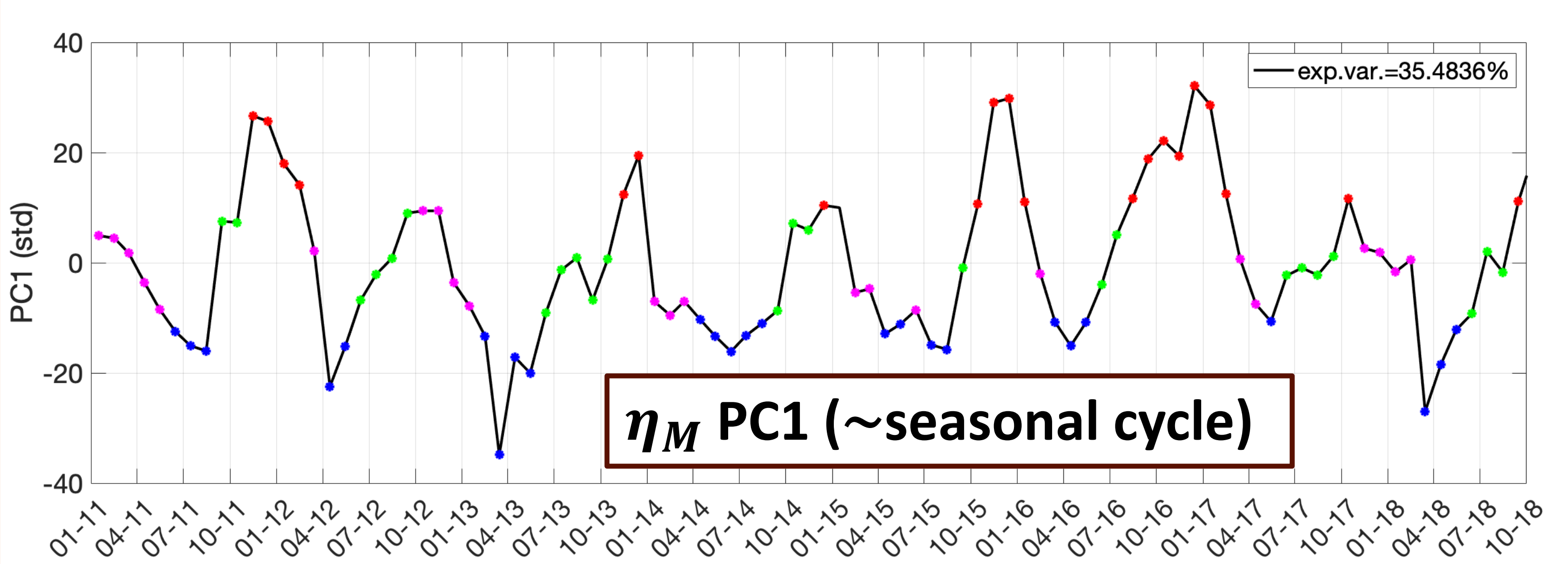
→ We computed surface wind stress composites using atmospheric reanalysis data of JRA55-do v.1.3 (Tsujino et al., 2018).

(2) How can we explain the sharp divide at the shelf edge?

Discussion **(1) : wind stress composites**

We applied Empirical Orthogonal Function (**EOF**) analysis to the $\boldsymbol{\eta_M}$ to derive its dominant spatio-temporal patterns of variability. The Principal Component (**PC**) of the first EOF shows a clear seasonal oscillation of $\boldsymbol{\eta_M}$ on the shelf seas, which we used to distinguish **four periods** of ocean mass **decrease**, **minimum**, **build up and maximum** in this region.



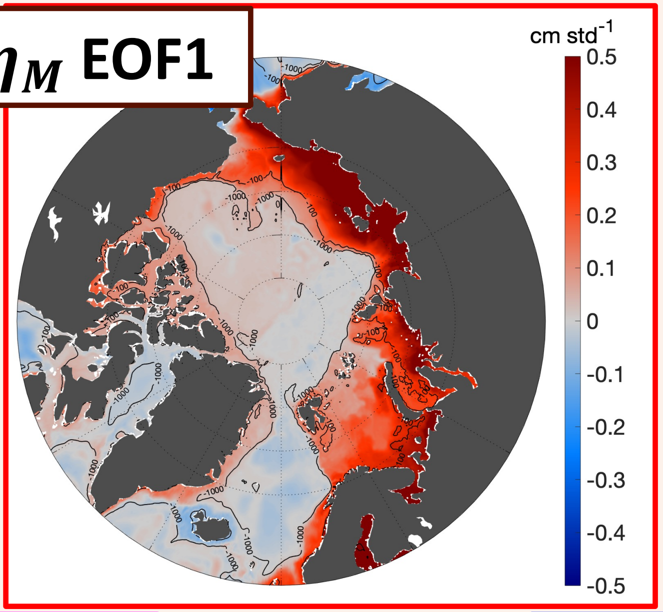


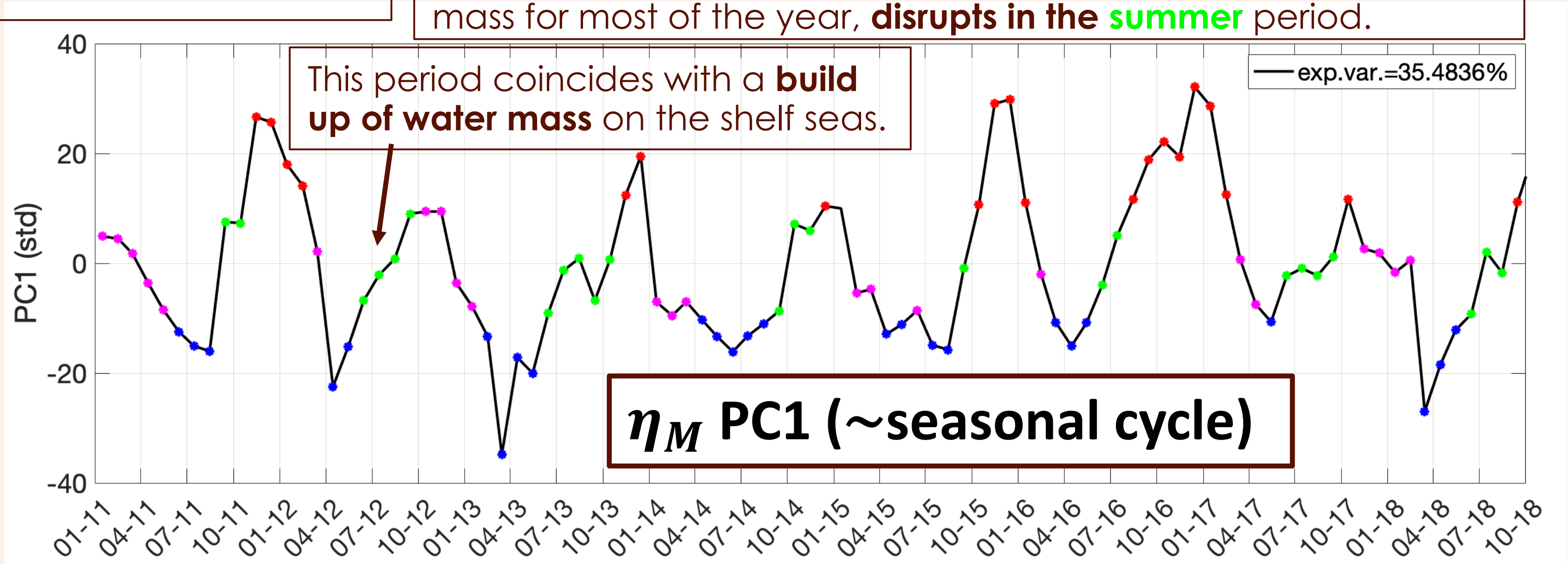
For each of these periods, we computed a **composite average** of wind stress at the ocean surface (wind fields from JRA55-do v.1.3). The **surface ocean stress ($\boldsymbol{\tau_o}$)** was computed via bulk formulas, where ice-covered (τ_{io}) and ice free (τ_{ao}) areas were distinguished by using sea ice concentration (A) at ach model grid cell:

$$\tau_o = A\,\tau_{io} + (1-A)\,\tau_{ao}$$

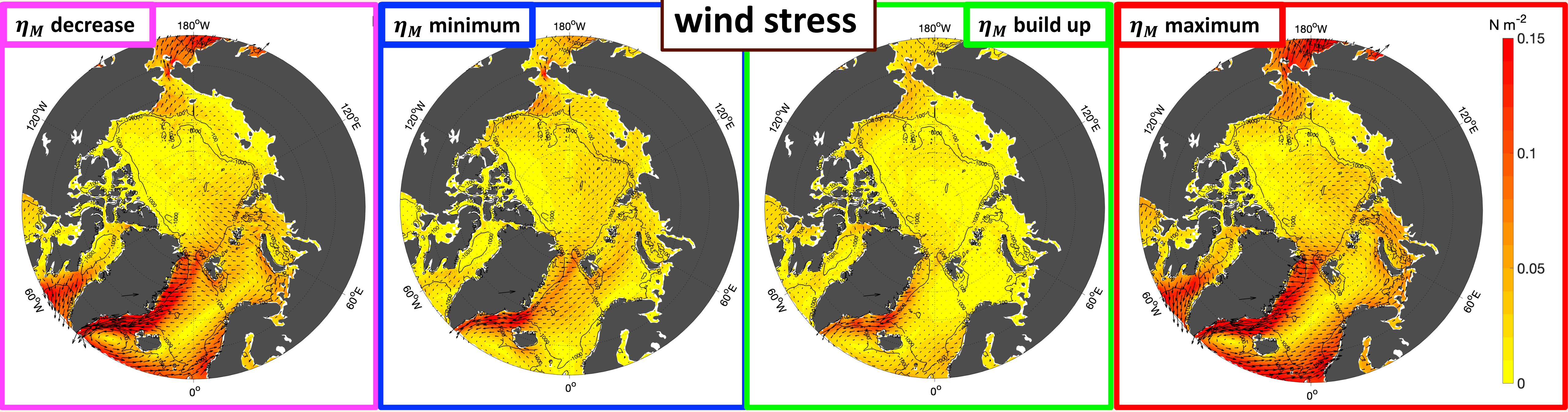
Discussion **(1) : wind stress composites**

The **cyclonic wind cell over the Barents Sea**, diverging water mass for most of the year, **disrupts in the summer** period.





wind stress



Discussion **(1) : Ekman transport**

Ekman transport:

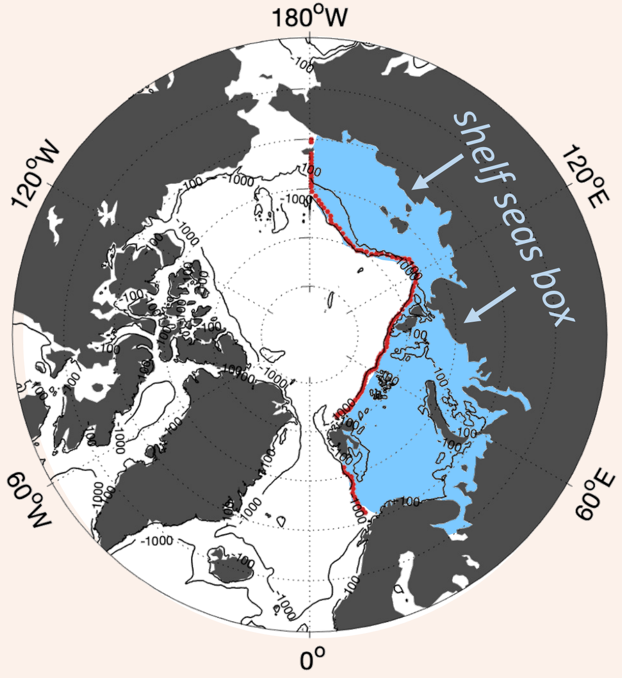
$$\mathbf{U} = (U, V) = \frac{1}{\rho_0 f}(\tau_o^y, -\tau_o^x)$$

The **time-integrated Ekman transport** across the shelf break, into a "shelf seas box", is **in phase** with the η_M seasonality.

This could explain a build up of water mass in the shelf seas during summer.

However, the equivalent sea surface height cumulated via Ekman transport is **one order of magnitude larger** than the η_M seasonality.

What could **balance** the transport of mass onto the shelves?

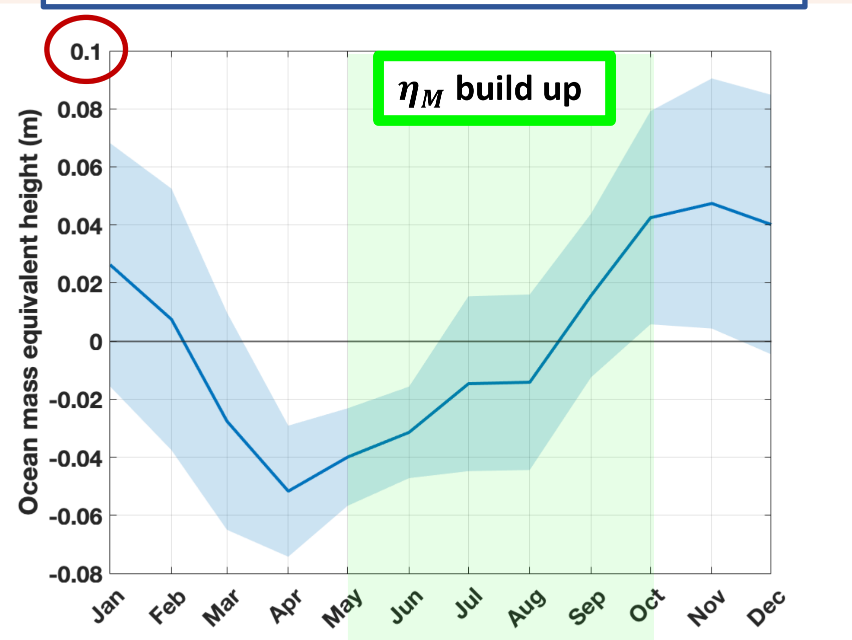


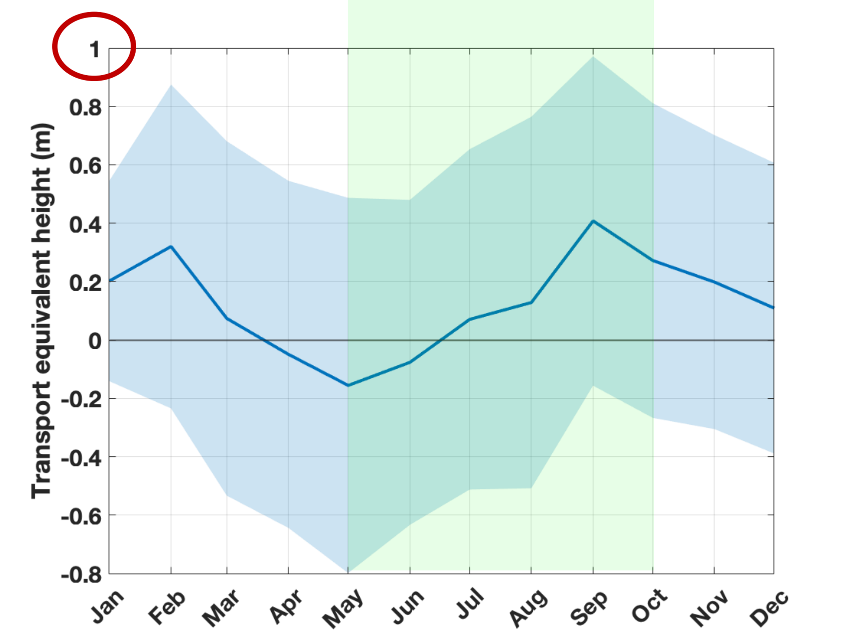
η_M (shelf seas average)

Time-integrated Ekman transport (equivalent height)

… to be continued..

Climatologies period 2011-2018





Discussion: **drivers of ocean mass seasonality**

(1) Can Ekman transport across the shelf break explain the variability of ocean mass on the shelf seas?

(2) How can we explain the sharp divide at the shelf edge?

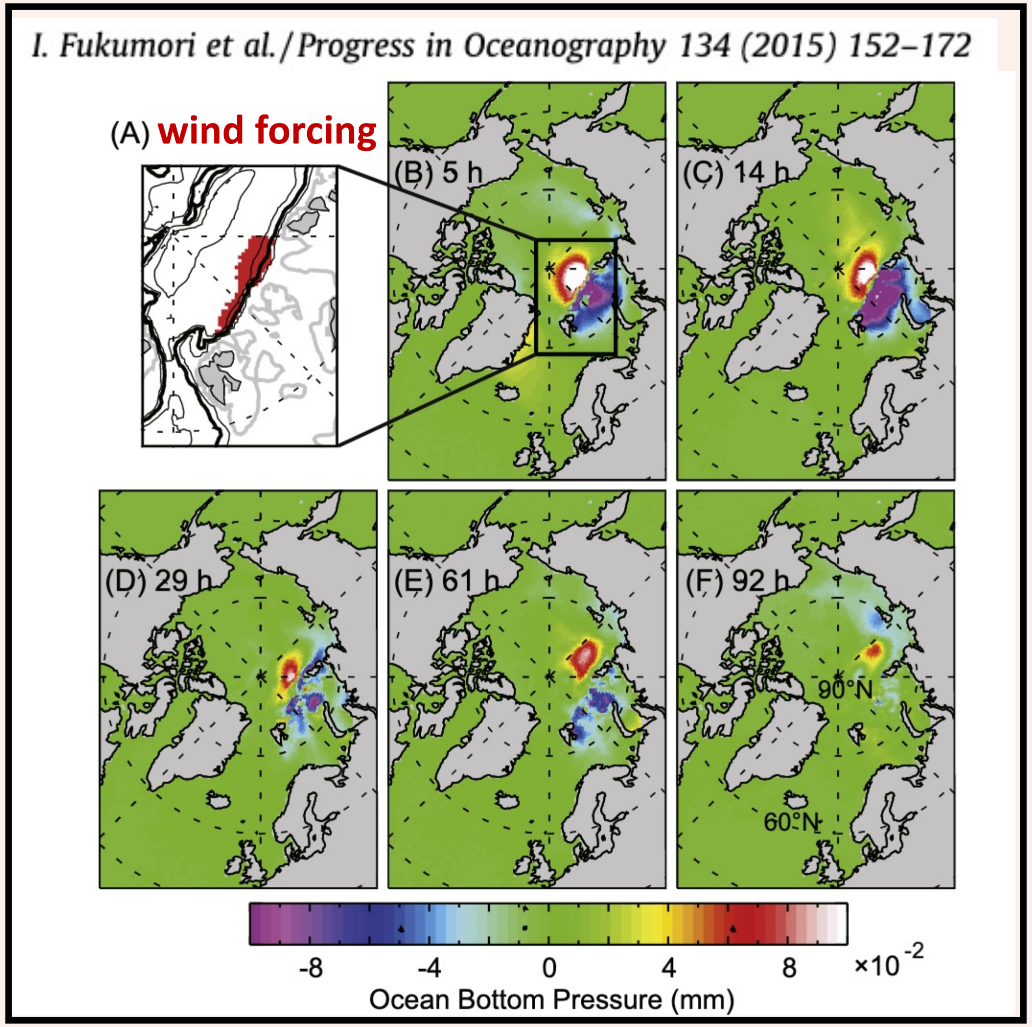
Discussion **(2) : mass anomaly propagating eastwards ?**

How can we explain the sharp divide at the shelf edge?

Fukumori et al. (2015): →
wind forcing, applied along the shelf break for 1 h, induces mass anomaly propagating eastwards.

Is it possible that a wave-like behaviour on seasonal time scales, induced by seasonally intensified winds, is responsible for the decoupling of shallow and deep regions? How?

… to be continued..



Summary:

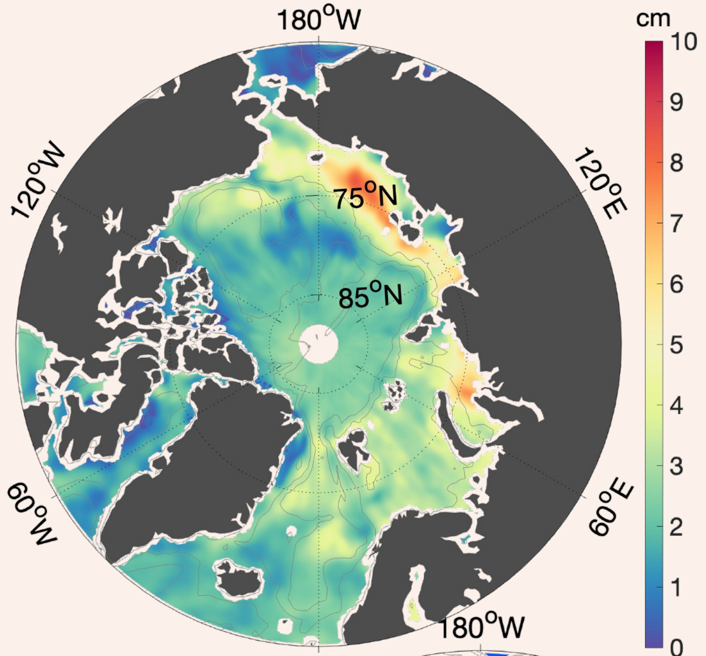
- Good **agreement** seasonality **altimetry / model**
- Large-scale **wintertime acceleration** of slope currents
- **Ocean mass variability** accounts for large part of slope currents seasonality
- **Where** does all the water transported to the shelf seas in the Ekman layer end up?

Extras

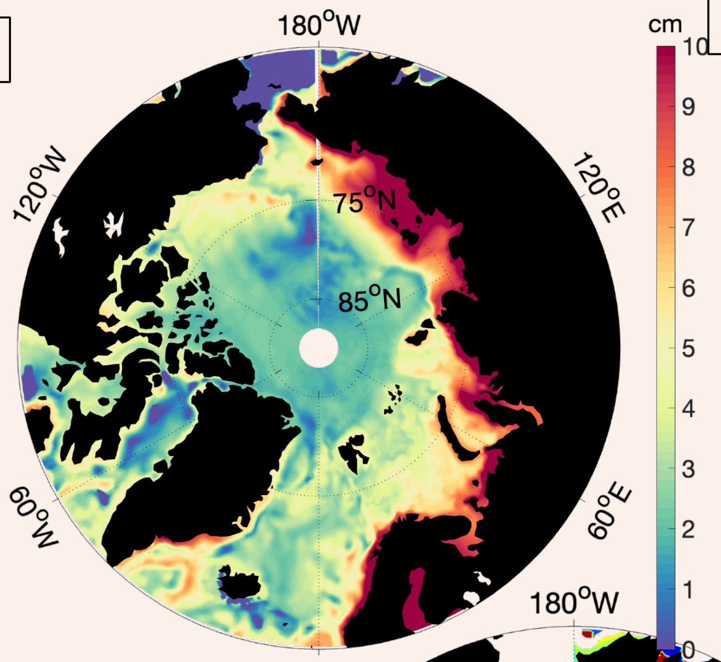
Methods: **seasonality and model validation**

Amplitude

SATELLITE DATA



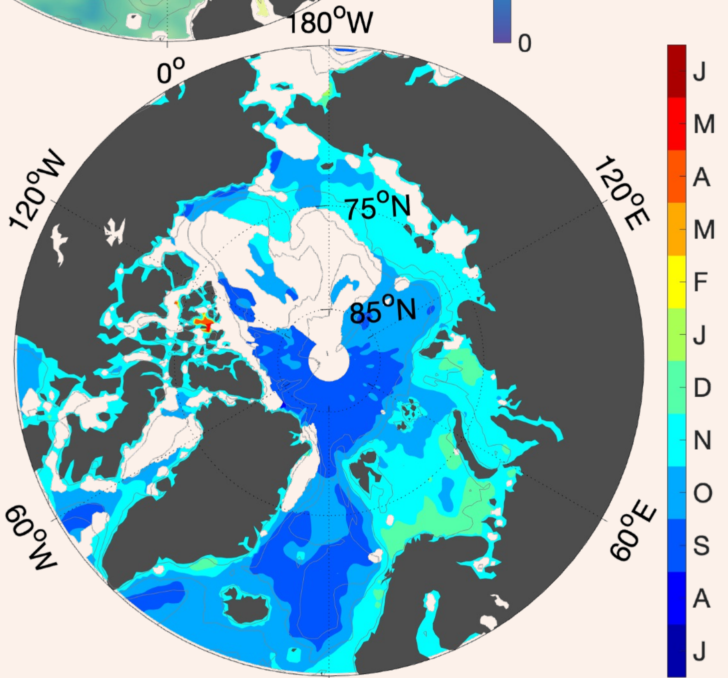
MODEL DATA

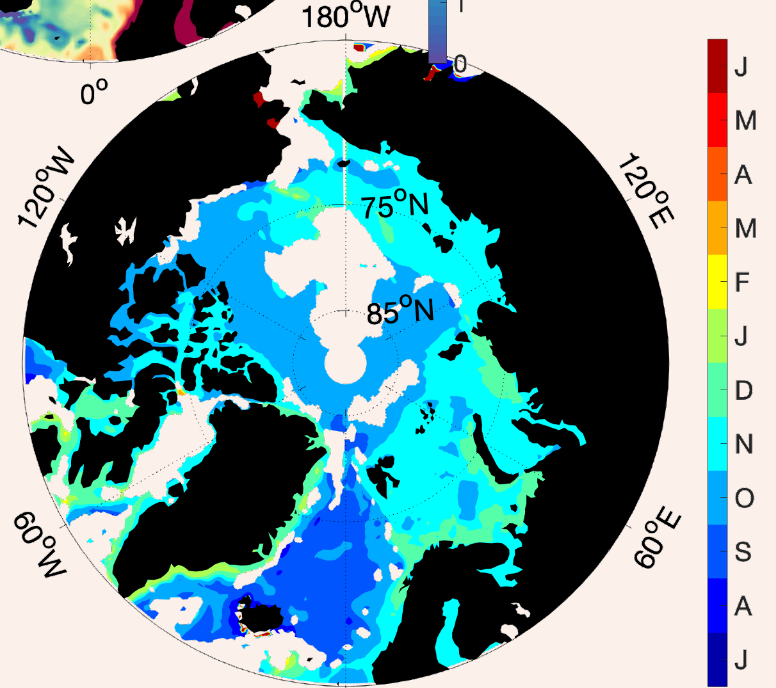


SSH seasonal cycle

$$\eta_{seas} = A \cdot sin\,(2\pi \cdot \frac{\varphi}{P})$$

Phase

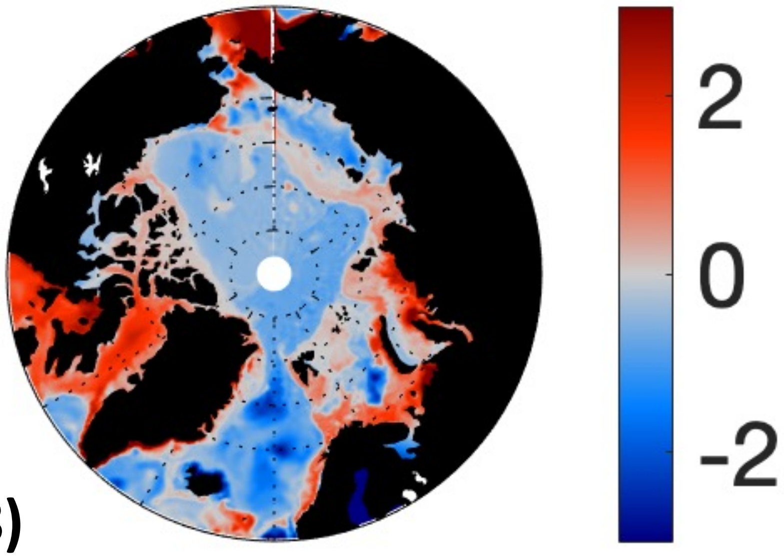


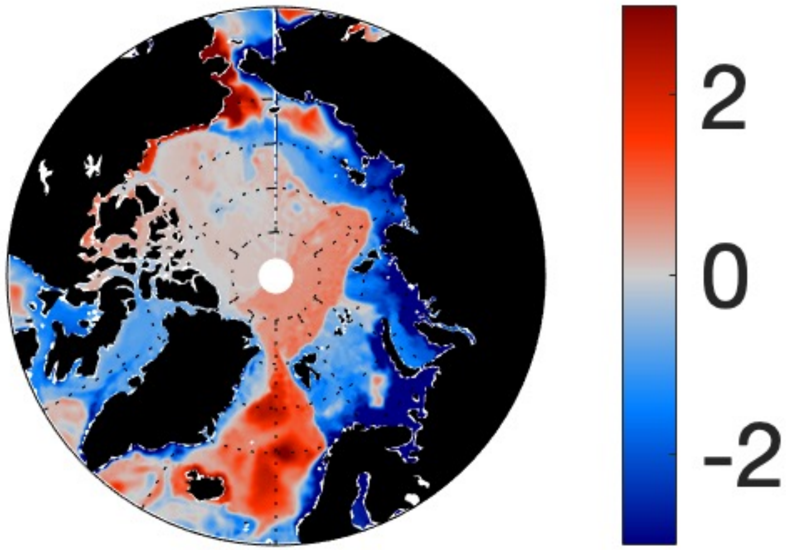


Mass Eq. Height anomalies

Jan-Feb-Mar **Jun-Jul-Aug**

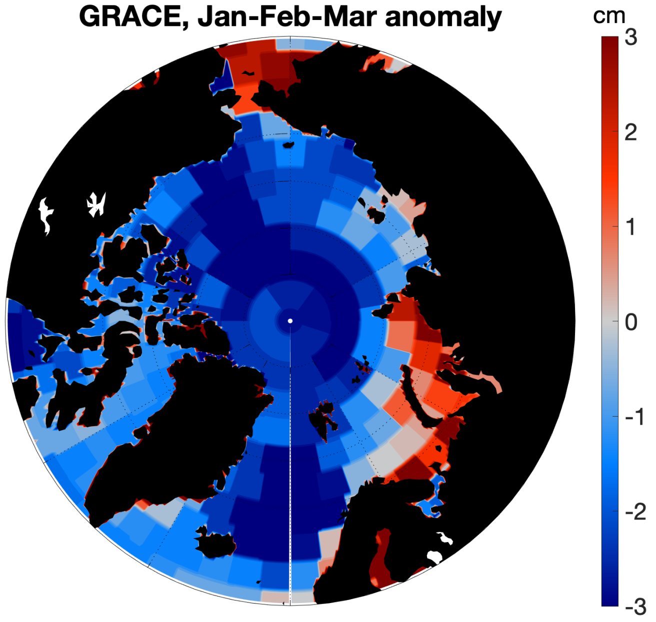
FESOM (ref. 2011-2018)





GRACE JPL mascons (ref 2011-2018)

GRACE, Jan-Feb-Mar anomaly



GRACE, Jun-Jul-Aug anomaly