Deutsches Geodätisches Forschungsinstitut (DGFI-TUM)
Technische Universität München

Monitoring Chukchi Sea circulation and Bering Strait flow reversals from satellite radar altimetry (2013–2023)

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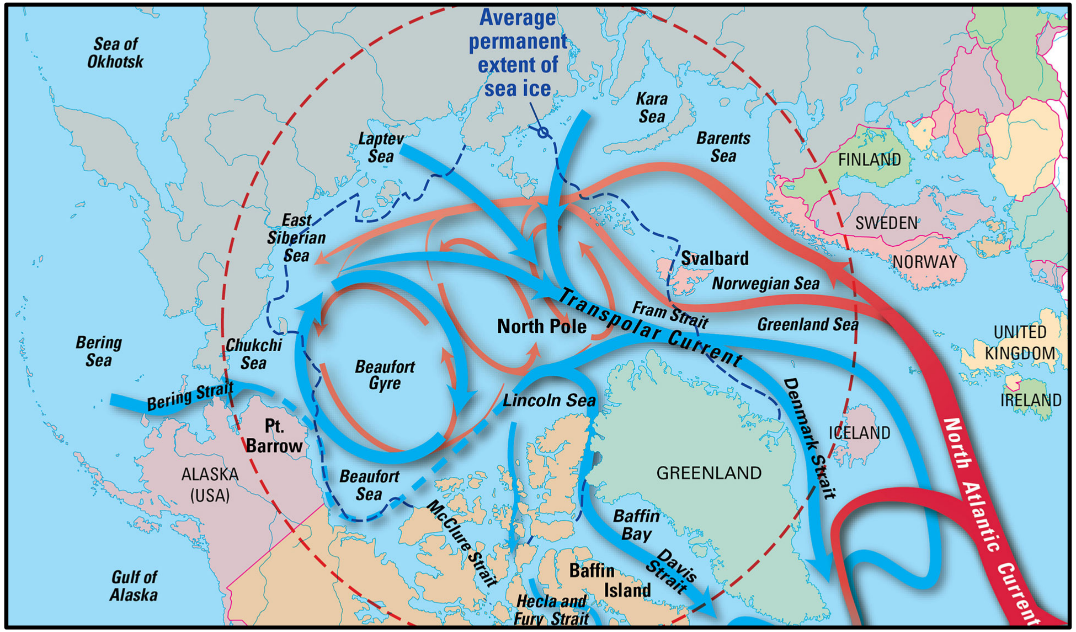
Siberian Coastal Current observed near the Chukotka Coast, Chukchi Sea, in August 2014; courtesy of A.A.Ostrovskii

3. ICCC workshop "Geodesy for Climate Research," 25.03.2025

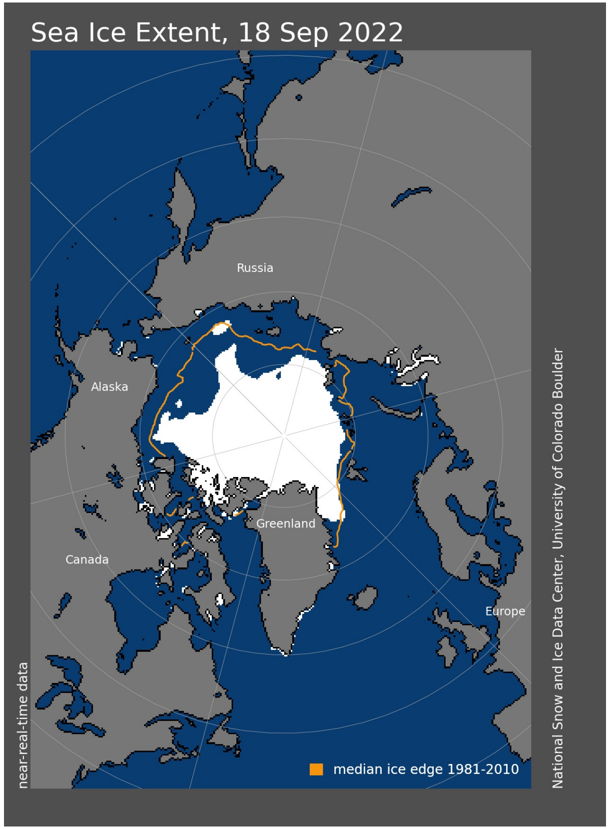
Motivation: Arctic is rapidly changing

- Chukchi Sea is the only oceanic gateway for Pacific waters entering Arctic;
- Pacific waters bring heat, freshwater, and nutrients to the Arctic, feed the Beaufort Gyre, influence Transpolar Drift and climate in Europe;
- Arctic is challenging to monitor (remote location, harsh environment, etc.);

→ Satellite altimetry provides precise information about the sea surface on various scales;



(Jack Cook, WHOI)



Summer Arctic sea ice extent is shrinking by 12.6% per decade as a result of global warming (NASA).

Altimetry data processing and currents calculation

- **SARAL** – “**S**atellite with **AR**gos and **AL**tiKa” – (near-polar, sun-synchronous orbit, global coverage up to 82∘N, the revisit time of 35 days, 2013–2023);

- Advanced algorithms for the determination of sea surface heights in the sea-ice-covered ocean: physical retracker ALES+ *(Passaro et al., 2018),* unsupervised classification for ice-ocean-leads *(Müller et al., 2017);*

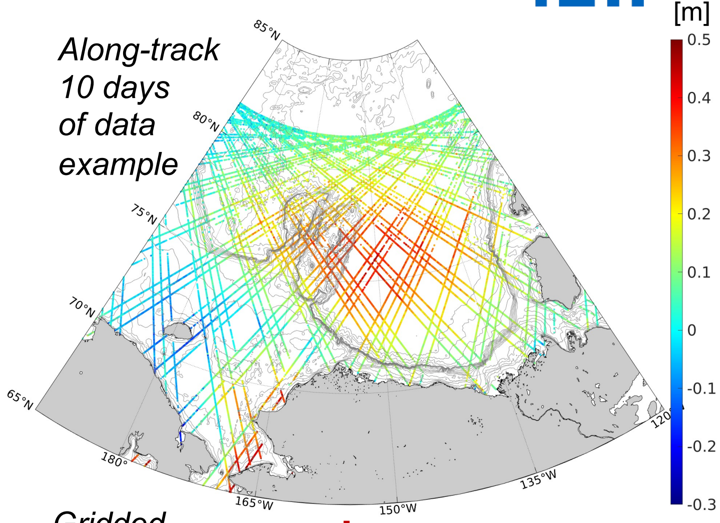
- Outlier rejection strategy (*Passaro et al., 2020);* computation of Dynamic Ocean Topography (DOT);

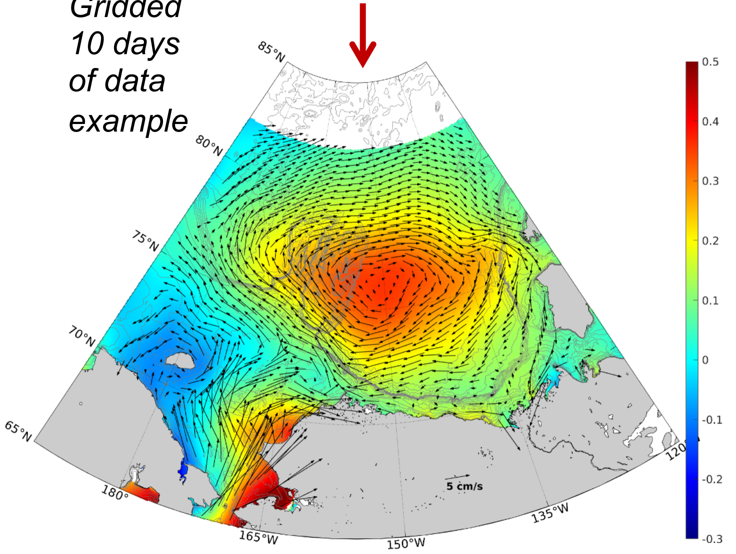
- Gridding on a triangular mesh using least squares adjustment and applying a Gaussian distance weighting: daily meshes of mean **10-day** fields; the spatial resolution of **~8 km**;

- Geostrophic flow components in zonal (u_g) and meridional (v_g) directions derived;

- Resulting currents evaluated against ADCP data in the Bering Strait *(r for the periods with less than 10% ice concentration is ~0.74)*

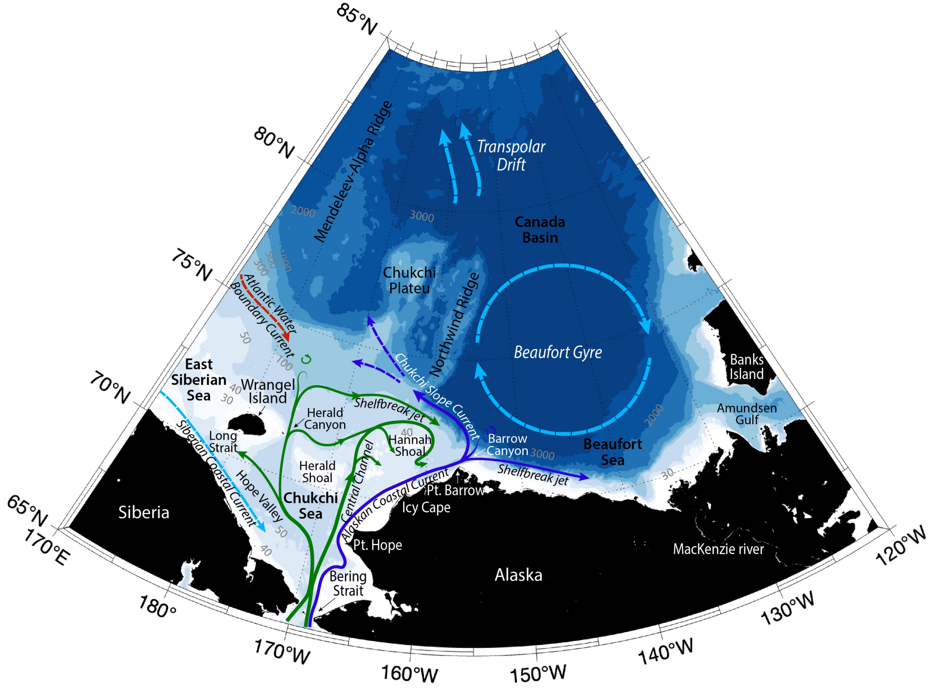
→ Bering Strait throughflow is largely geostrophic → and can be studied from satellite radar altimetry

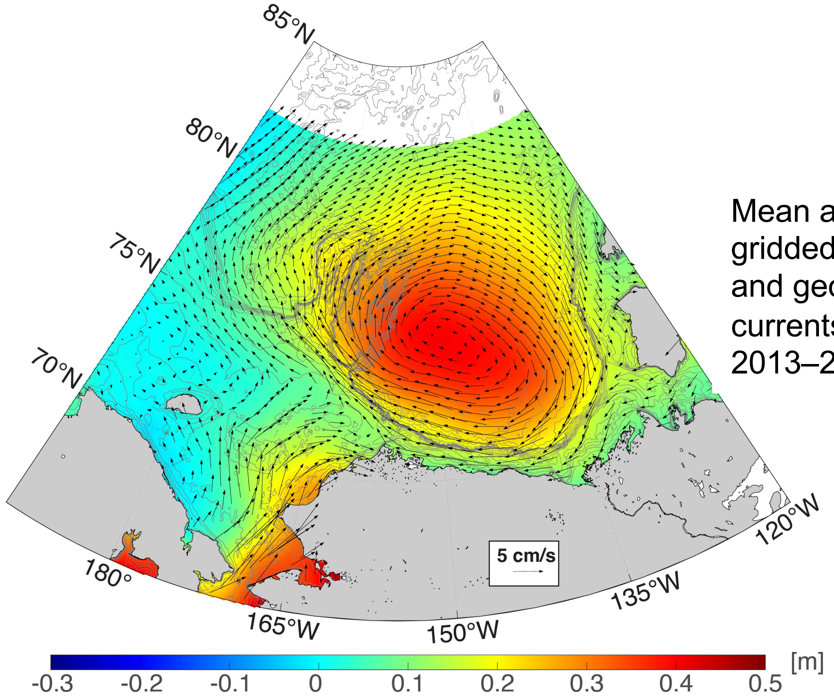




Chukchi Sea circulation from altimetry data

- Currents on the shelf are steered by bathymetric features and are prone to large spatial and temporal variability due to atmospheric forcing and seasonal ice cover;
- Flow through the shallow (50 m) and narrow (80 km) Bering Strait is northwards due to the “pressure-head” between the Arctic and Pacific; reversals are possible in the cold season;
- Almost all circulation features (*Alaskan Coastal Current*, *Bering Sea water branches*, *Siberian Coastal Current*, *Beaufort Gyre*, *Shelfbreak jets*) are evident from satellite altimetry:





Mean autumn gridded DOT and geostrophic currents for 2013–2023

Synoptic variability resolved: flow reversals in Bering Strait

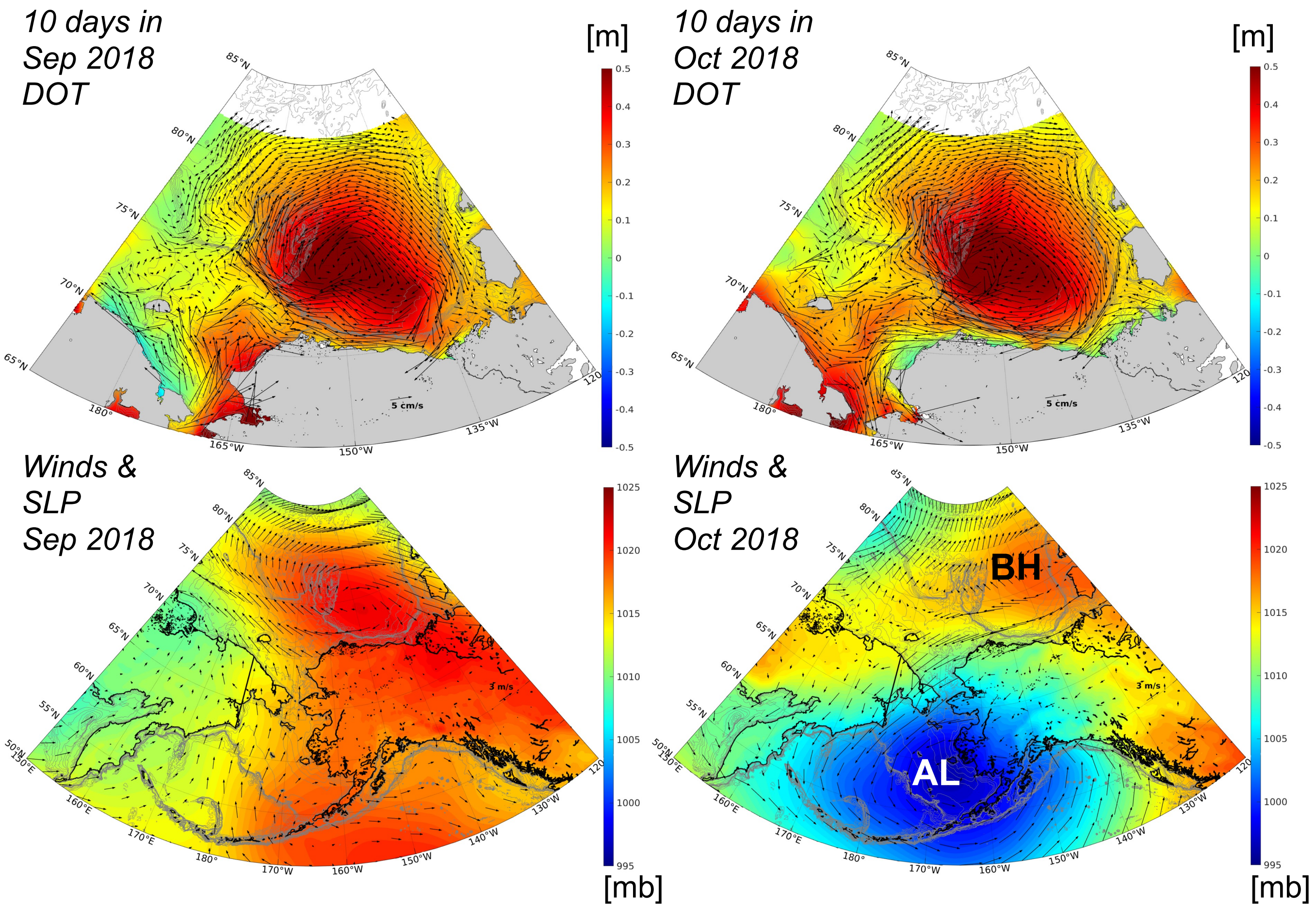
- High-resolution altimetry dataset can resolve synoptic variability, e.g.:

- Changes in DOT are evident in the Bering Strait area from 10-day fields;

- This is due to the Ekman transport of the coastal current from the Alaskan coast westward to Chukotka

→ A **reversal** of the current in the Bering Strait occurs

- This happens due to anomalously strong northerly winds over the region caused by the strong sea level pressure (*SLP*) gradient between the Beaufort High (*BH*) and the Aleutian Low (*AL*);

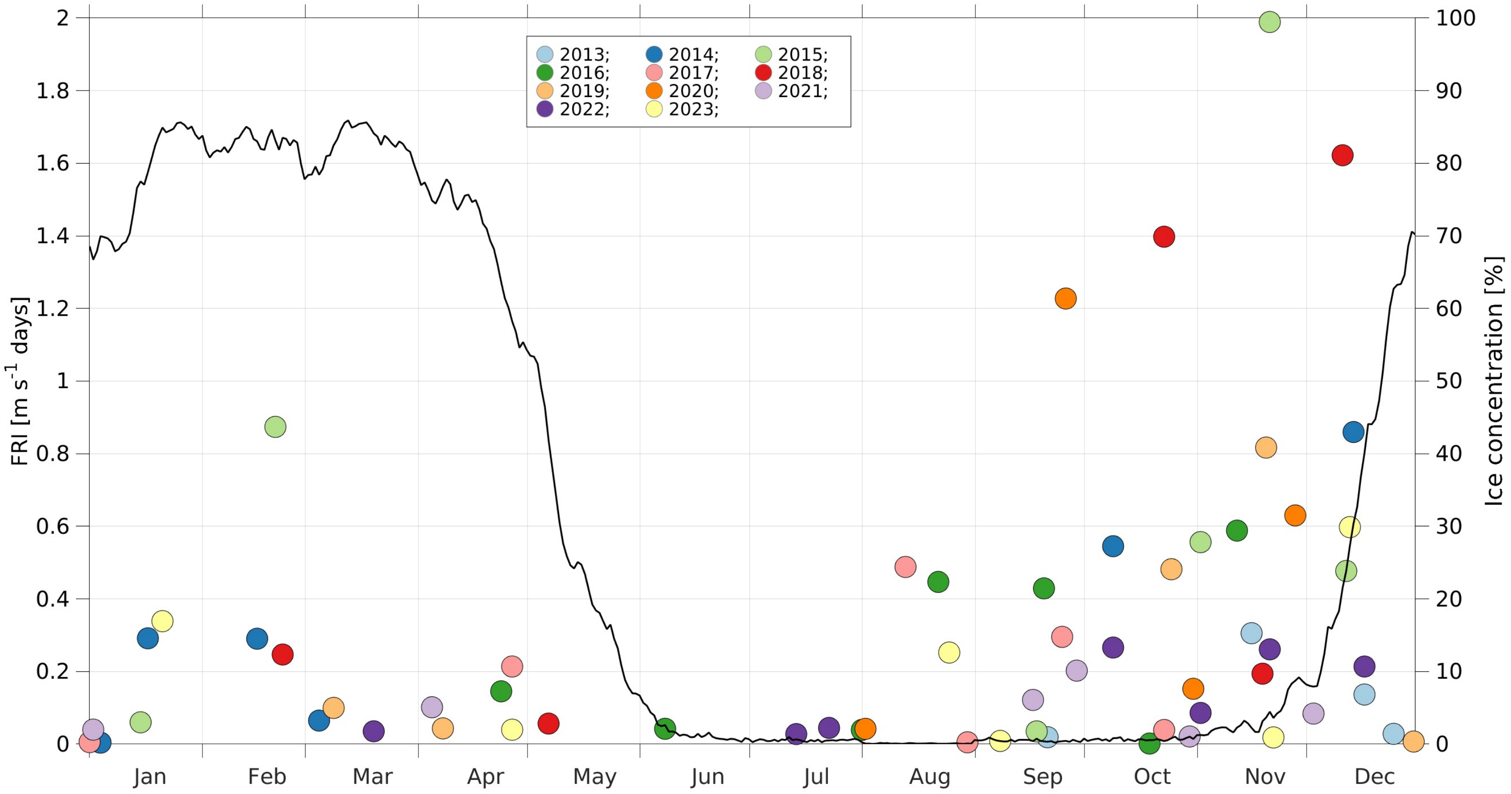


Assessing the strength of flow reversals

- 62 southward flow events (colored markers) recorded over 2013–2023
- Flow reversal integral (*FRI*) allows to assess the strength of each reversal (U_r – along-strait flow, t_1 & t_2 – the start & end times of each reversal)

$$FRI = \int_{t1}^{t2} U_r(t)\,dt$$

- Clear seasonal variability and dependence on the ice cover (black line) are evident

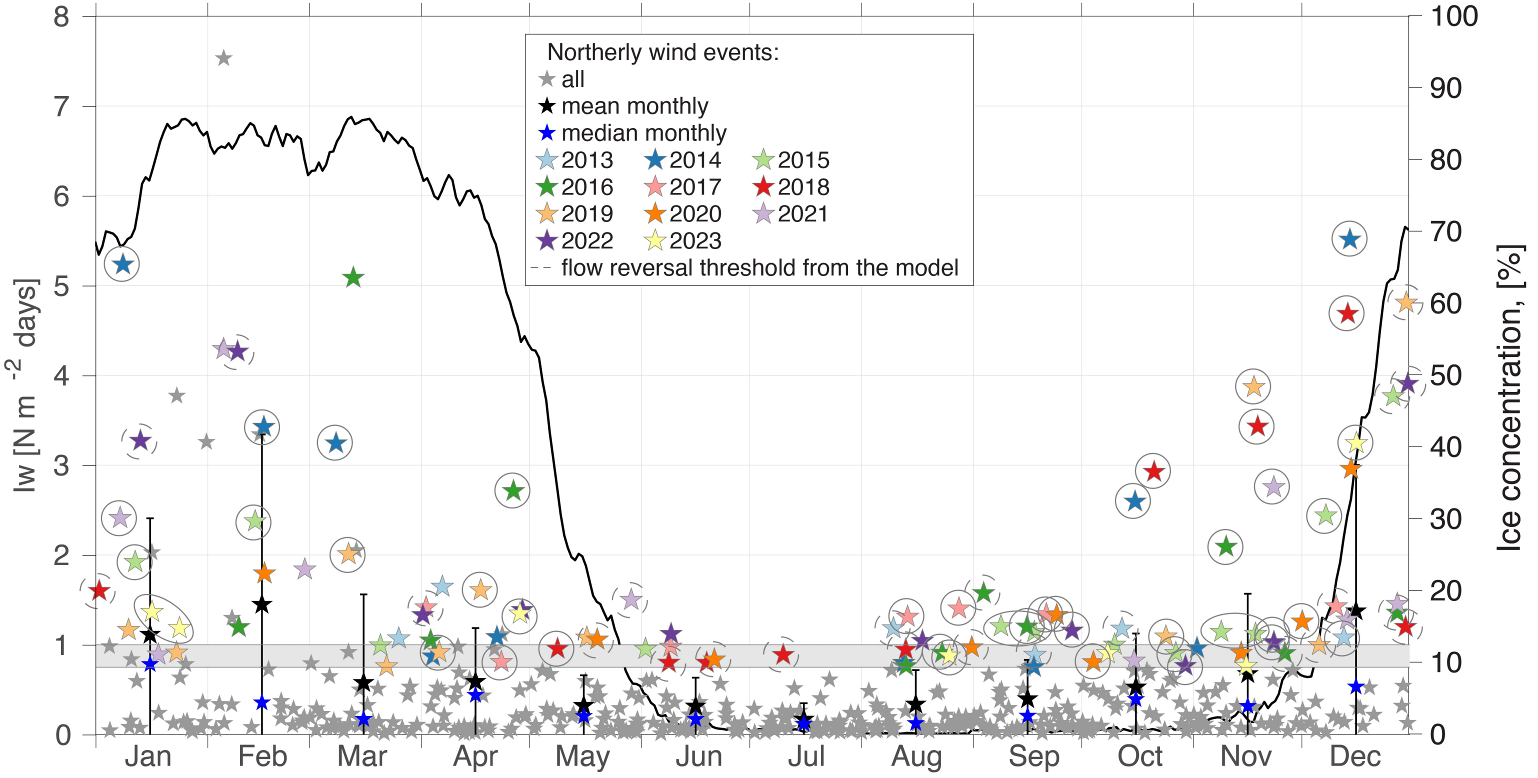


Atmospheric forcing of the reversals: northerly storms

- Windstress reversal integral (I_w) for all northerly storms over 2013–2023 (T_a – the along-strait component of the windstress, t_1 & t_2 – the start & end times of each storm):

$$I_w = \int_{t1}^{t2} \tau_a(t)\, dt$$

- Storms with $I_w > 1$ can cause a transposition of the coastal current from Alaska to Chukotka and result in a reversal
- Indeed: 42 storms resulted in a reversal (solid circle) and 23 slowed the northward current in the strait (dashed circle)

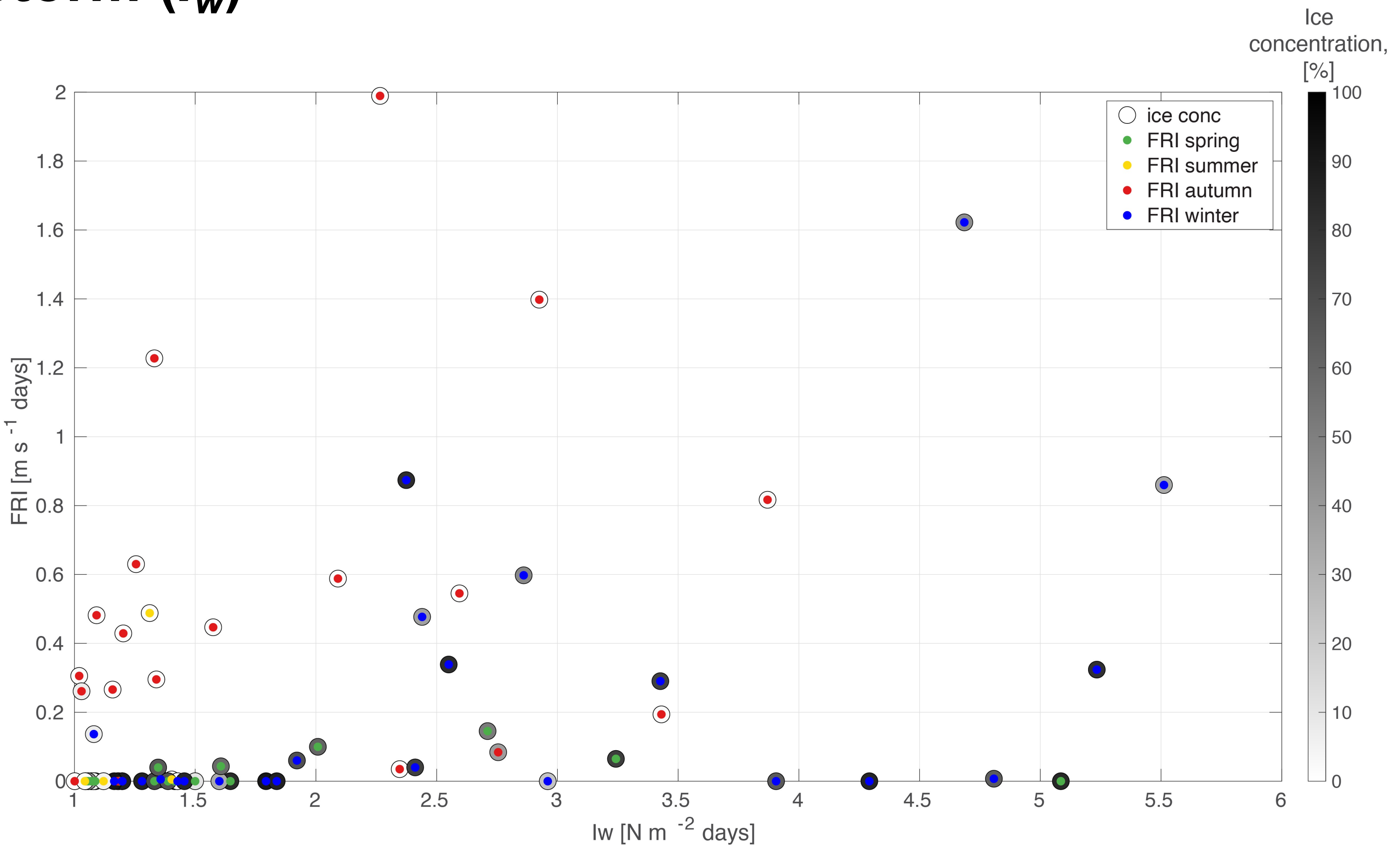


Relationship between the strength of a reversal (*FRI*) vs the strength of a storm (I_w)

- Apart from the winter r=0.5, the connection between I_w and *FRI* is not straightforward: stronger winds do not always cause stronger reversals;

- In the summertime, the far-field forcing over the East Siberian Sea drives the flow;

- Ice modulates the flow.

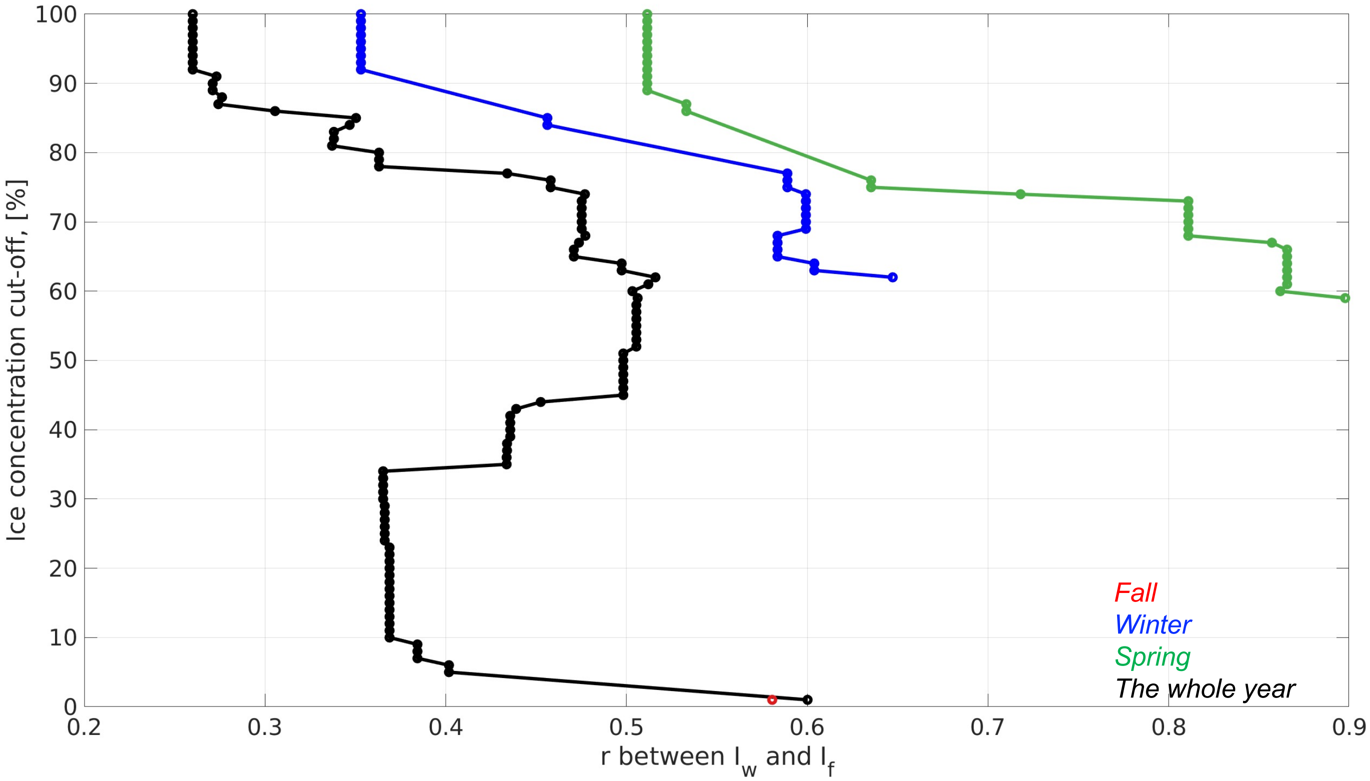


Impact of ice cover

- As the flow sometimes doesn't reverse but slows down in response to the strong wind, we assess not the *FRI*, but the negative flow anomaly (I_f) for all the strong storms over 2013–2023;

- Out of 78 strong storms, 76 had a negative I_f ;

- Ice transfers momentum from the atmosphere to the ocean: the highest I_w– I_f correlations were observed in the cold season during partial ice cover.



Ice concentration	r year	r winter	r spring	r summer	r fall
0–10% (open sea)	0.37 (29)	– (2)	– (2)	– (5)	– (20)
10–70% (partial ice)	0.71 (19)	0.62 (11)	0.81 (7)	– (0)	– (1)
70–100% (full ice)	– (28)	– (20)	– (8)	– (0)	– (0)

Take-aways

- Satellite altimetry provides precise information on the sea surface at different spatial and temporal scales and can be used for studies of the *synoptic* variability (compared to existing *monthly* datasets) in the Arctic Seas:
- E.g., anomalously strong storms (due to changing atmospheric patterns, primarily – intensified and shifted eastwards Aleutian Low) can cause Ekman transport and a *reversal* of the Pacific water inflow through the Bering Strait;
- The highest correlations between the strength of a storm and the relative change in the magnitude of the Bering Strait throughflow occur during the cold season and partial ice cover: ice transfers momentum from the atmosphere;
- This has potential consequences for the freshwater and heat transport on the Arctic shelf (and consequently the Arctic Basin), as well as on the ecosystem of the region;
- The work continues: we aim to provide a high-resolution SSH + currents dataset for the entire Arctic from cross-calibrated multi-mission satellite altimetry, which can be used for oceanographic studies.

Learn more

- Read the study published *Open access*:
Pisareva, M.N., Müller, F.L., Passaro, M., Schwatke, C., Dettmering, D., Seitz, F. ***Chukchi Sea circulation and Bering Strait flow reversals from reprocessed satellite altimetry***. Ocean Dynamics 75, 26 (2025).
https://doi.org/10.1007/s10236-025-01672-9

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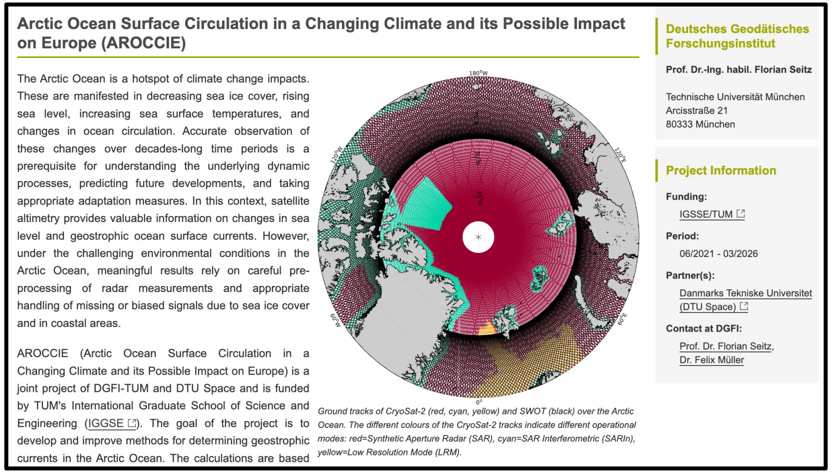
Arctic Ocean Surface Circulation in a Changing Climate and its Possible Impact on Europe
https://www.dgfi.tum.de/en/projects/aroccie/



Arctic Ocean Surface Circulation in a Changing Climate and its Possible Impact on Europe (AROCCIE)

The Arctic Ocean is a hotspot of climate change impacts. These are manifested in decreasing sea ice cover, rising sea level, increasing sea surface temperatures, and changes in ocean circulation. Accurate observation of these changes over decades-long time periods is a prerequisite for understanding the underlying dynamic processes, predicting future developments, and taking appropriate adaptation measures. In this context, satellite altimetry provides valuable information on changes in sea level and geostrophic ocean surface currents. However, under the challenging environmental conditions in the Arctic Ocean, meaningful results rely on careful pre-processing of radar measurements and appropriate handling of missing or biased signals due to sea ice cover and in coastal areas.

AROCCIE (Arctic Ocean Surface Circulation in a Changing Climate and its Possible Impact on Europe) is a joint project of DGFI-TUM and DTU Space and is funded by TUM's International Graduate School of Science and Engineering (IGGSE). The goal of the project is to develop and improve methods for determining geostrophic currents in the Arctic Ocean. The calculations are based

Ground tracks of CryoSat-2 (red, cyan, yellow) and SWOT (black) over the Arctic Ocean. The different colours of the CryoSat-2 tracks indicate different operational modes: red=Synthetic Aperture Radar (SAR), cyan=SAR Interferometric (SARIn), yellow=Low Resolution Mode (LRM).

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Project Information

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Partner(s):
Danmarks Tekniske Universitet (DTU Space)

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