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Geostrophic currents in polar oceans - combining satellite altimetry measurements with model simulations

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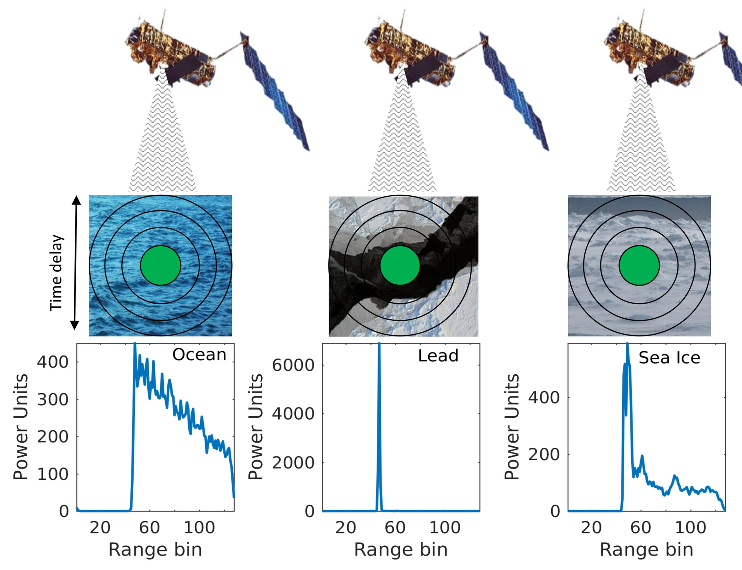
Motivation: Satellite altimetry has been providing valuable information about the sea surface and its temporal variations for more than 25 years. When combined with gravity models, information about mean and absolute dynamic ocean topography (DOT) can be derived – a quantity used to compute geostrophic currents.
Polar regions, especially the Arctic Ocean are among the regions on Earth that are most affected by climate change. Increasing temperatures and melting glaciers produce an enhanced fresh water inflow to the polar oceans, capable of evoking significant changes in the global ocean circulation system. Particularly in these areas, satellite altimetry observations are affected by seasonally changing sea-ice coverage and difficult ocean conditions leading to a fragmentary data sampling and reduced data reliability.
In order to overcome this problem, an ocean model considering major sea-ice drift patterns is used to fill data gaps with the aim to obtain a homogeneous DOT representation. For this purpose, the Finite Element Sea ice-Ocean Model (FESOM) is used. It provides daily water elevations with high spatial resolution. The combination is based on the spatially homogeneous information of the model and the high temporal resolution of 25 years of altimetry.

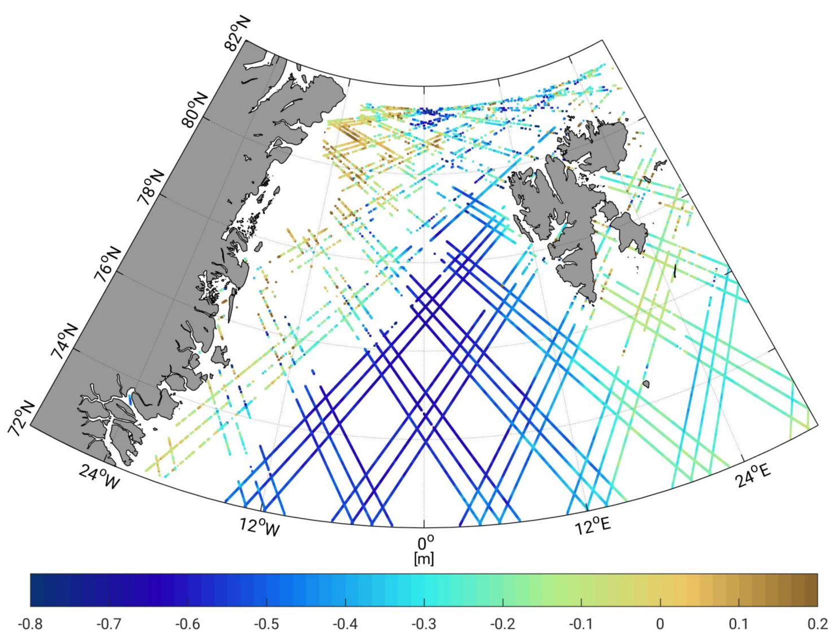
Input datasets

Observational database

- High-frequency along-track altimetry data (ENVISAT, ERS-2)
- Elimination of ice-contaminated observations by means of an unsupervised classification approach (K-medoids; Müller et al., 2017)
- Consistent along-track sea surface heights (SSH) for open ocean and sea-ice regions through the application of dedicated waveform retracking (ALES+; Passaro et. al, 2017)
- Dynamic Ocean Topography (DOT) by referring the SSH to a geoid (Optimal Geoid for Modelling Ocean Circulation, OGMOC; Fecher and Gruber, 2018)



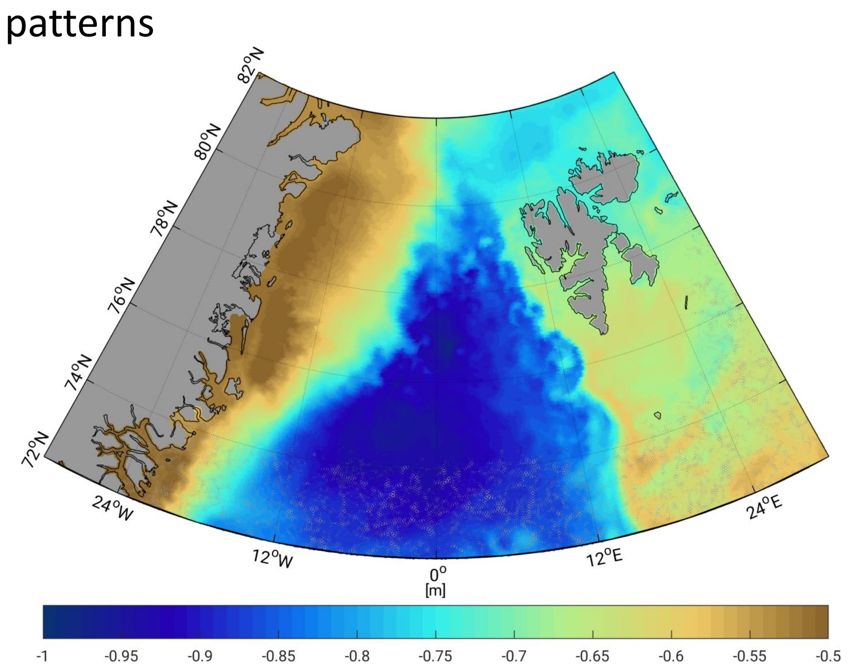
Examples of Envisat radar echoes for three different surface conditions



9-days of altimetry along-track DOT height observations

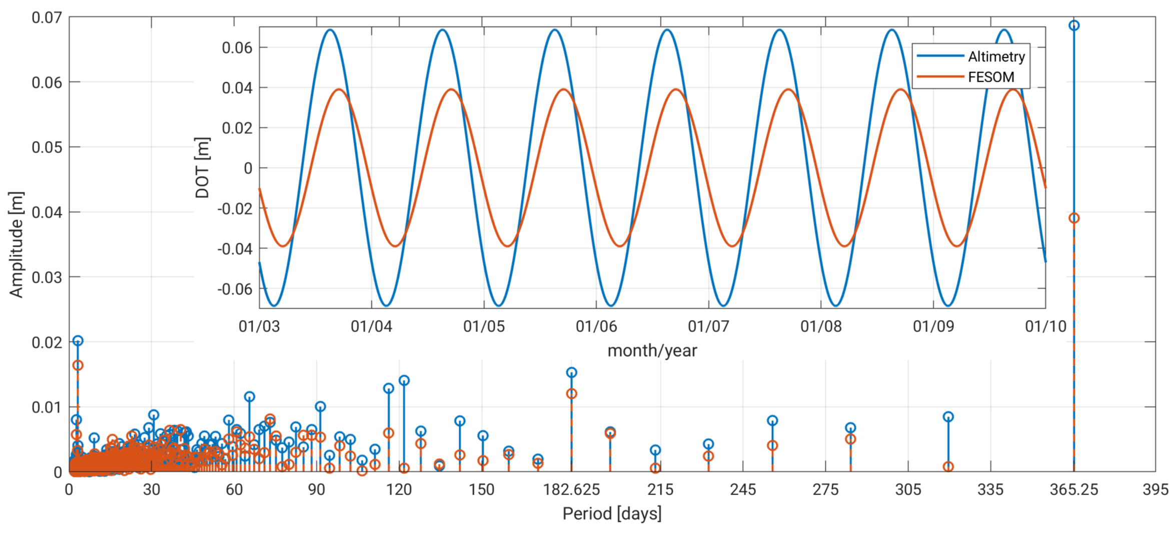
Model database

- Finite Element Sea-Ice Ocean Model (FESOM; Weckerle et al., 2017)
- Unstructured mesh ocean model
- Includes daily differential water heights
- the sea-ice component reproduces the major sea-ice drift patterns

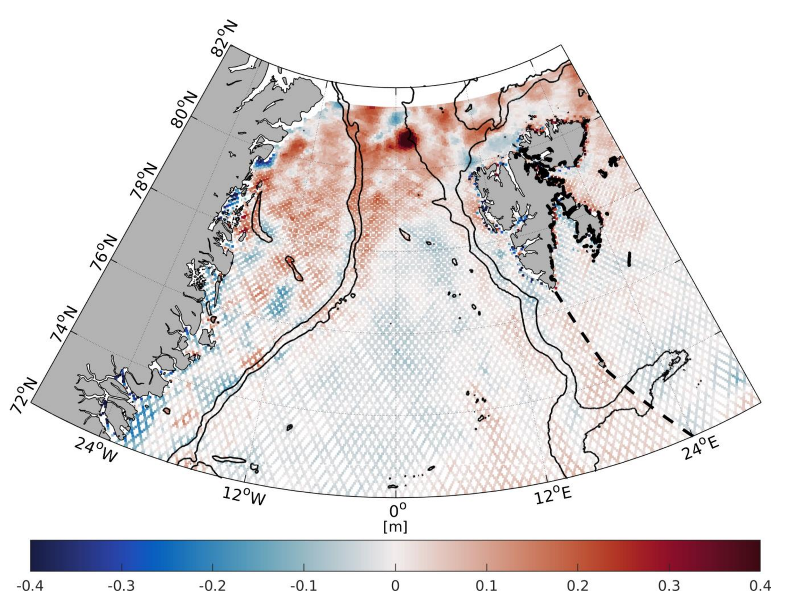


FESOM differential water heights for 2009-Apr-15

Comparison: modeled and observed DOT representations



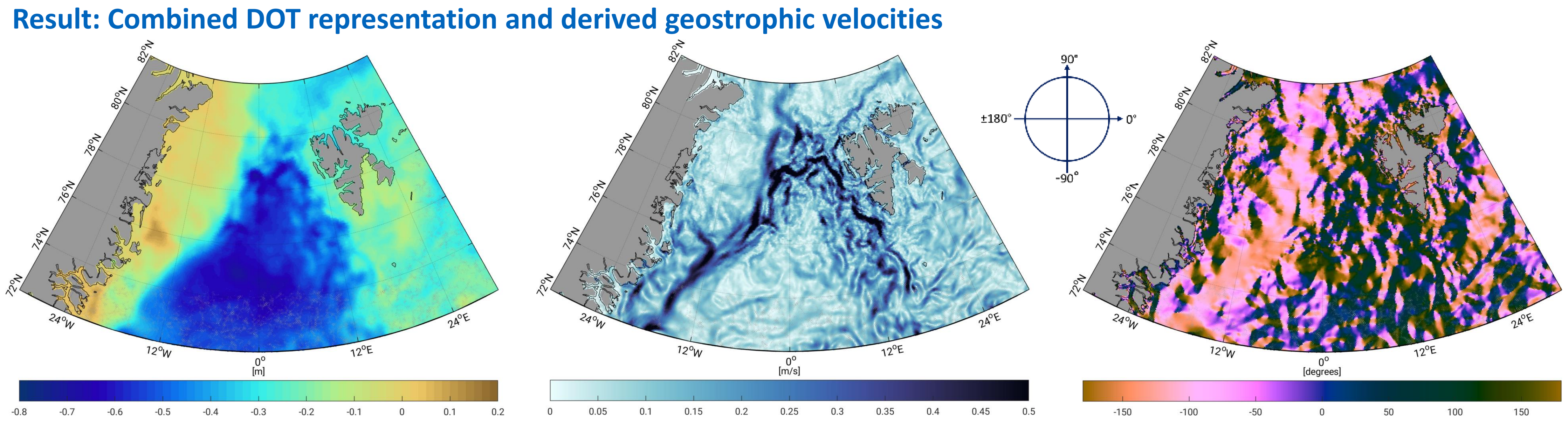
Amplitude spectrum and estimated annual signal based on along-track data between 2003 and 2009



Differences between altimetry and FESOM residual DOT between 2003-2009 (in along-track bins)

- Comparison is based on spatio-temporal pattern and frequency analysis (Müller et al., 2019)
- Identical dominant frequencies in both data sets (mainly annual signal)
- Stronger smoothing and phase difference of model due to insufficiently consideration of freshwater inflow (e.g. glacier runoff) and coarse atmospheric forcing models
- Local differences due to geoid errors in higher latitudes
- Residual signals highly correlated, especially in the central Greenland Sea

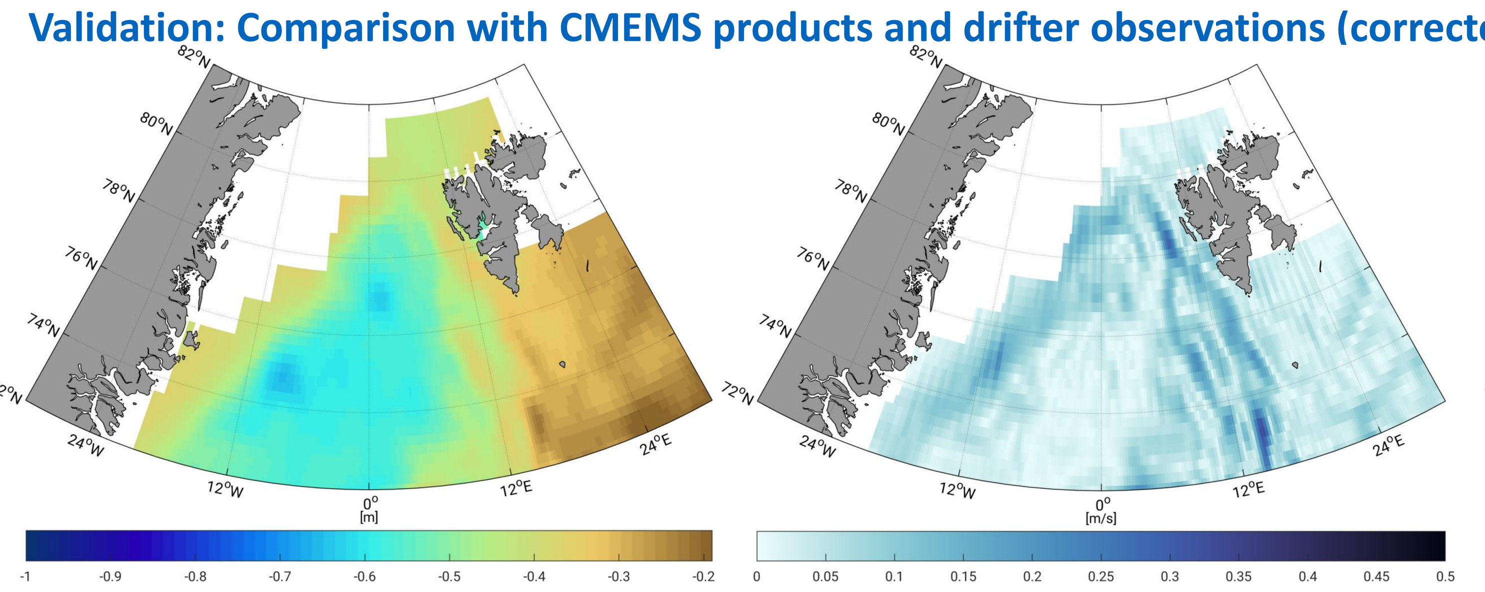
Result: Combined DOT representation and derived geostrophic velocities



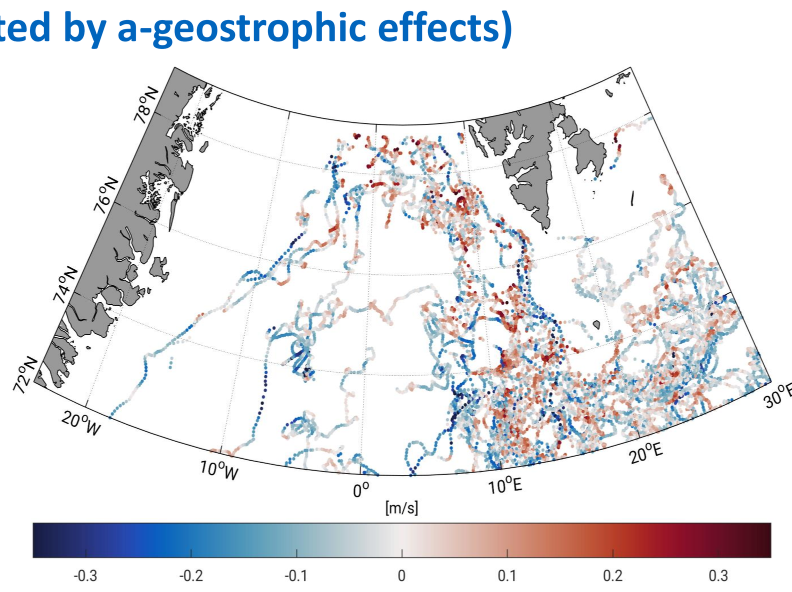
Combined DOT with altimetry height reference (left), derived absolute geostrophic velocities (middle) and flow direction (right) for 2009-Apr-15.

- Combining the along-track observations with the FESOM model.
- Principal Component Analysis (PCA) approach is used to fill the spatial data gaps due to sea-ice and orbit configuration.
- Bridging areas, where altimetry is missing. Absolute level, annual signal and temporal variability is preserved from altimetry.
- ➢ Spatio-temporal consistent representation of DOT and geostrophic currents

Validation: Comparison with CMEMS products and drifter observations (corrected by a-geostrophic effects)

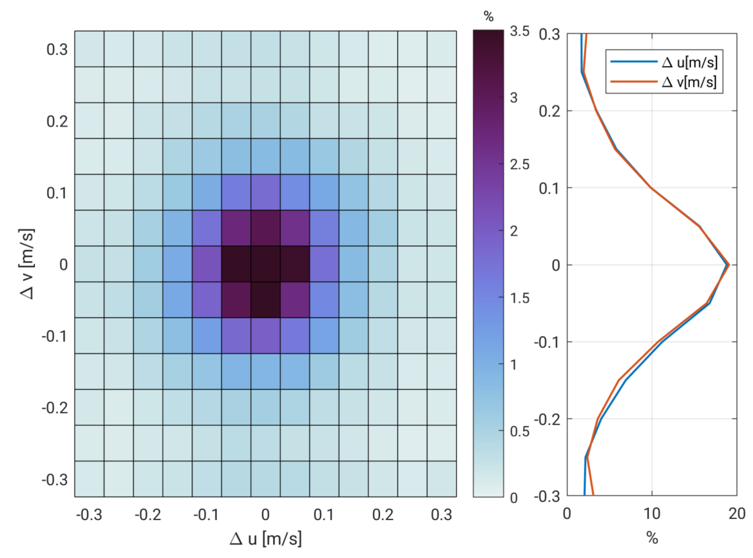


Multi-mission altimeter satellite gridded DOT and absolute geostrophic velocity provided by CMEMS for 2009-Apr-15. White areas indicate data gaps, due to sea-ice coverage.



Differences of absolute geostrophic velocities of comb. data minus drifter observations in 2009.

- CMEMS grids show smoother DOT and circulation patterns with data gaps in sea-ice areas
- In-situ data is available between 1995-2012, with a data gap of about 6 years
- The pointwise comparison between daily combined geostrophic surface currents and in-situ velocity observations shows no systematic deviations
- 67% of all differences are smaller than 10 cm/s



Scatter plot of the differences (comb. – in-situ) showing an unbiased 2D distribution in 1995-2012

Outlook

- ➢ Improved high-resolution geoid model including newest altimetry marine gravity field data will help to reduce artificial elevations and slope gradients.
- ➢ In-situ drifter observations enable pointwise comparisons
- ➢ Study impact of different ocean models on combination approach

References and Acknowledgements :

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We thank ESA for providing ERS-2 and Envisat RA-2 data and CMEMS for providing surface drifter observations and global ocean gridded L4 sea surface heights and derived variables

World Ocean Circulation User Consultation Meeting, 21 – 22 Feb. 2019, ESA-ESRIN, Frascati (Rome), Italy

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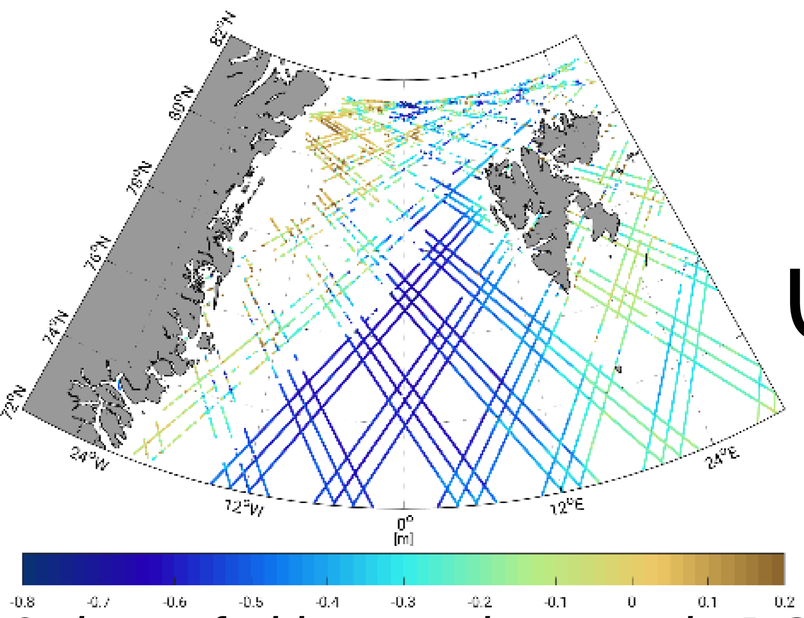

9-days of altimetry along-track DOT height observation

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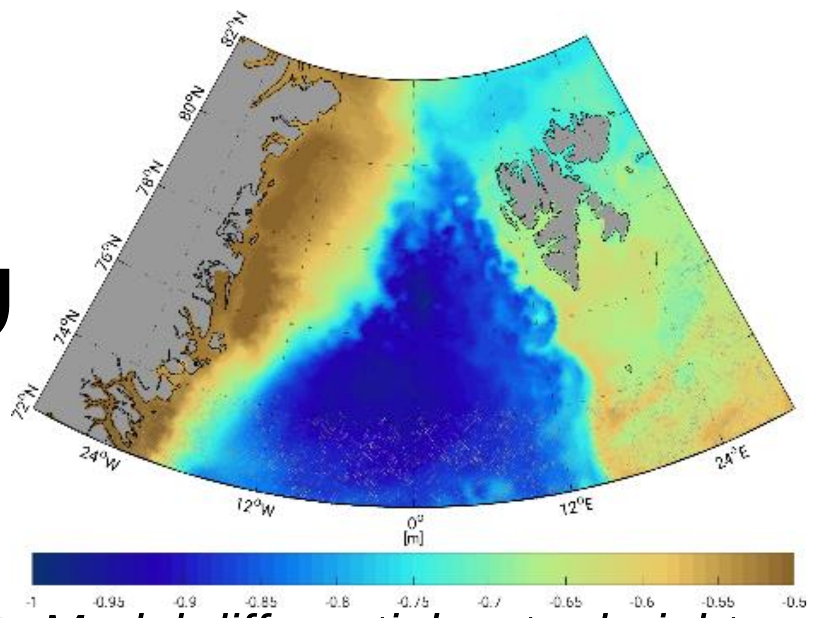
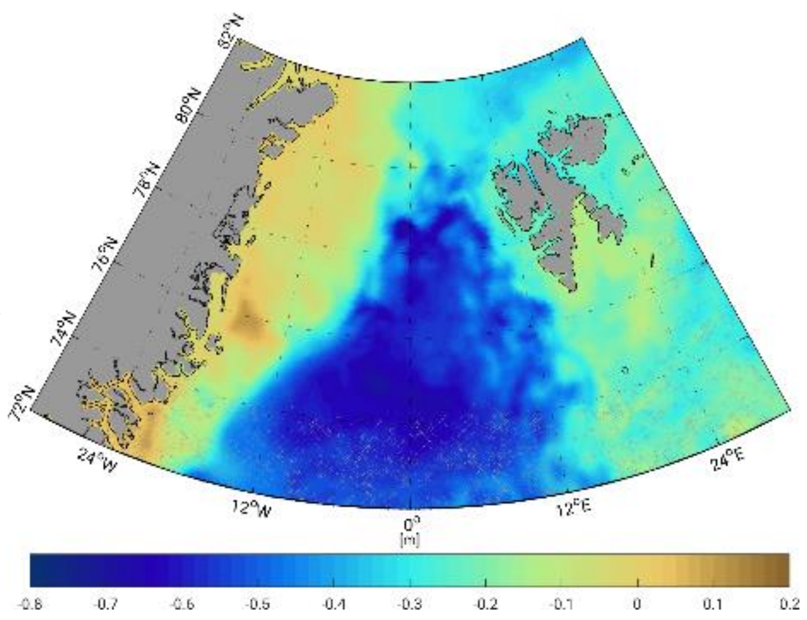
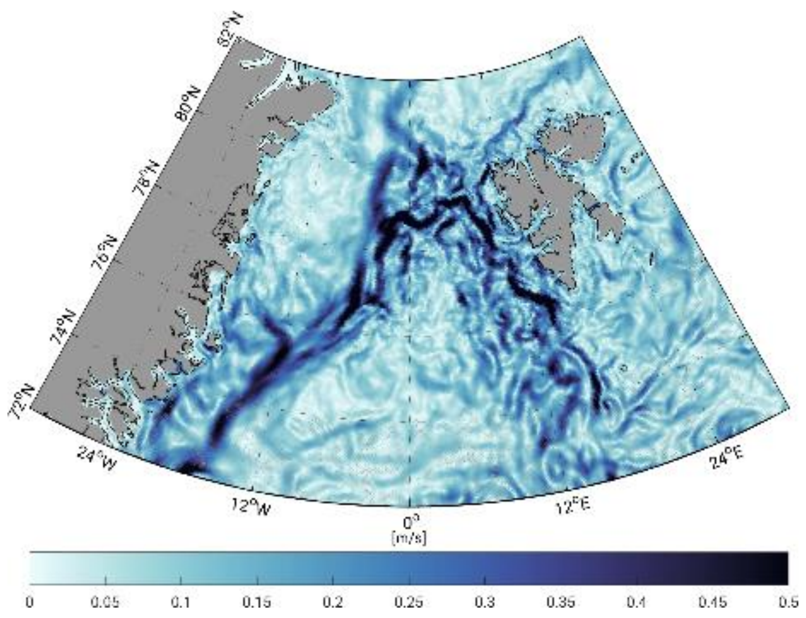


Model differential water heights (~DOT)



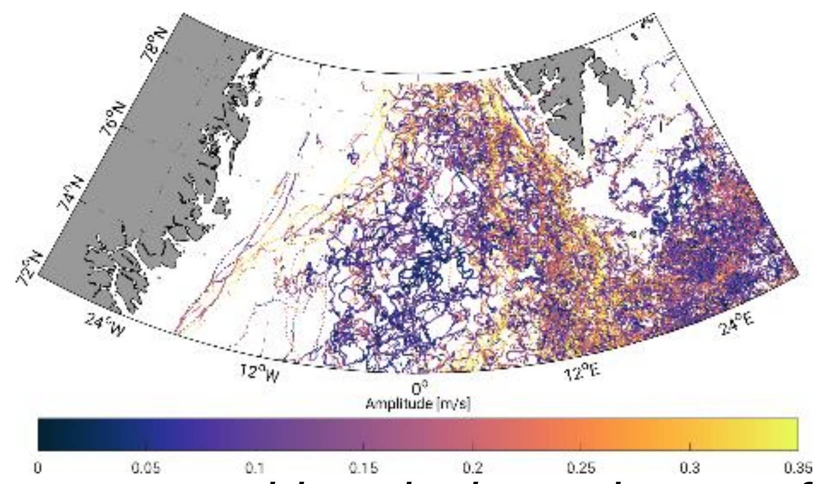
Combined Dynamic Ocean Topography (DOT)



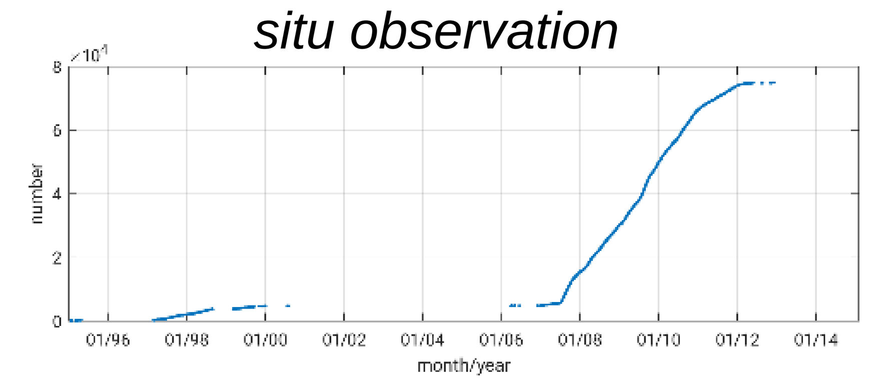
Combined geostrophic currents

Summary:

- Bridging periods and areas, where Altimery is missing (e.g. sea-ice, irregular data distribution)
- The temporal variability is given by altimetry, whereas the spatial signal is provided by the model
- ✓ **Enable spatio-temporal consistent representation of DOT and geostrophic currents**



abs. geostrophic velocity and num. of in-situ observation



Outlook and Recommendation:

- We recommend the further **improvement of high-resolution geoid models** incl. newest marine gravity data to reduce artificial elevations
- We recommend further investigations on the **use of in-situ surface drifter velocities** to enable pointwise comparison