Surface Water and Ocean Topography (SWOT) observations unveil small mesoscale variability on the East Greenland Shelf

S. N. Jensen[1], O. B. Andersen[1], C. B. Ludwigsen[1], R. Gonçalves-Araujo[2], and L. de Steur[3]

[1]DTU Space, National Space Institute, Kongens Lyngby, Denmark, [2]DTU Aqua, National Institute of Aquatic Resources, Kongens Lyngby, Denmark, [3]Norwegian Polar Institute, Tromsø, Norway

FRESH4BIO

The SWOT mission provides SSH observations over a 120 km wide swath at unprecedented spatial resolution. This presents a unique opportunity to map small mesoscalea and submesoscale ocean dynamics that are not currently resolved by conventional altimetry. In Fresh4Bio we assimilate SWOT and nadir altimetry in a QG dynamical model, producing high-resolution maps of the SSH field along the East Greenland Shelf.

Key Points:

- 2-km ocean topography, geostrophic current, and relative vorticity in partly ice-covered Arctic derived from SWOT and nadir altimetry
- The maps reveal fine-scale ocean processes (20-100 km) in the Nordic Seas that were previously unresolvable by nadir altimetry
- SWOT reveals a 20-km anticyclonic eddy in agreement with SST and optical observations important to eddy biogeochemistry

Dataset covering the period June 2023 to September 2024 is available online at data.dtu.dk, doi:10.11583/DTU.29664665

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More information at the website fresh4bio.dtu.dk

1. Method: Back and Forth Nudging of a Quasi-Geostrophic Model

QG dynamic model based on conservation of potential vorticity, q :
(Ubelmann et al., 2015; Le Guillou et al., 2021)

$$\frac{\partial q}{\partial t} + J(\psi, q) = 0,$$

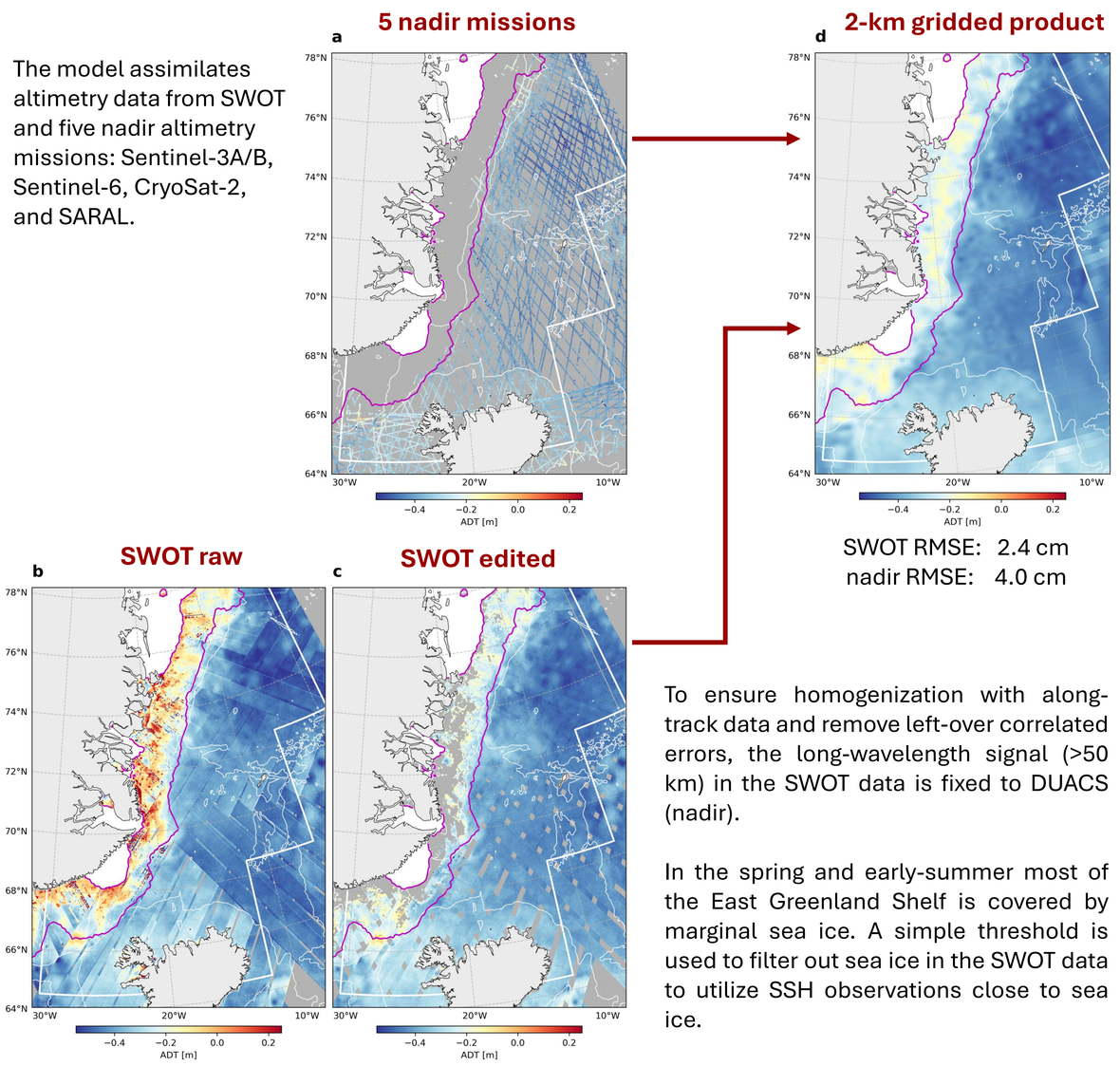
$$q = \nabla^2\psi + \frac{1}{L_R^2}\psi \longrightarrow \psi = \frac{g}{f}\mathrm{ADT}$$

Geostrophic streamfuntion ψ is related to altimetry observations, Absotute Dynamic Topography (ADT)

Forward nudging:
$$\frac{\partial q}{\partial t} = \mathscr{M}(q,t) + K\left(q^{obs} - q\right), \quad 0 \le t \le T$$
$$q(t) = q_0$$

Backward nudging:
$$\frac{\partial q}{\partial t} = \mathscr{M}(q,t) - K\left(q^{obs} - q\right), \quad T \ge t \ge 0$$
$$q(t) = q_T$$

The model assimilates altimetry data from SWOT and five nadir altimetry missions: Sentinel-3A/B, Sentinel-6, CryoSat-2, and SARAL.



To ensure homogenization with along-track data and remove left-over correlated errors, the long-wavelength signal (>50 km) in the SWOT data is fixed to DUACS (nadir).

In the spring and early-summer most of the East Greenland Shelf is covered by marginal sea ice. A simple threshold is used to filter out sea ice in the SWOT data to utilize SSH observations close to sea ice.

Figure 2: Altimetry data (heights referenced to geoid) in the 10-day period between 10 and 20 June 2024: (**a**) DUACS L3 nadir altimetry from five missions: Sentinel-3A/B, Sentinel-6, CryoSat-2, and SARAL, (**b**) SWOT with only cross-over correction applied, (**c**) SWOT edited using sea ice threshold, DUACS long-wavelength correction, and quality flags. (**d**) Assimilated product (foreground) and DUACS (background). White masked area has> 75% sea ice concentration, and the magenta lines mark the 75% and 5% ice lines. Thick white line shows the domain of the model. Thin white lines are 500 m and 2000 m depth contours.

2. Geostrophic Currents and Relative Vorticity

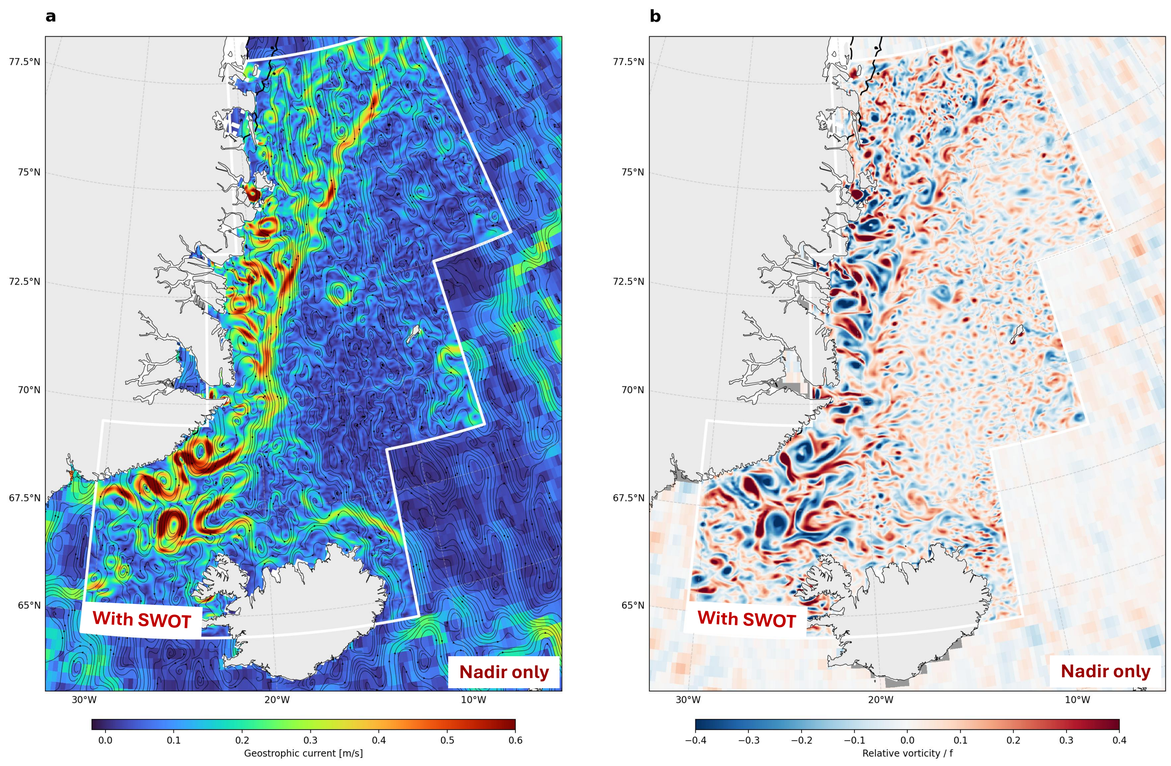
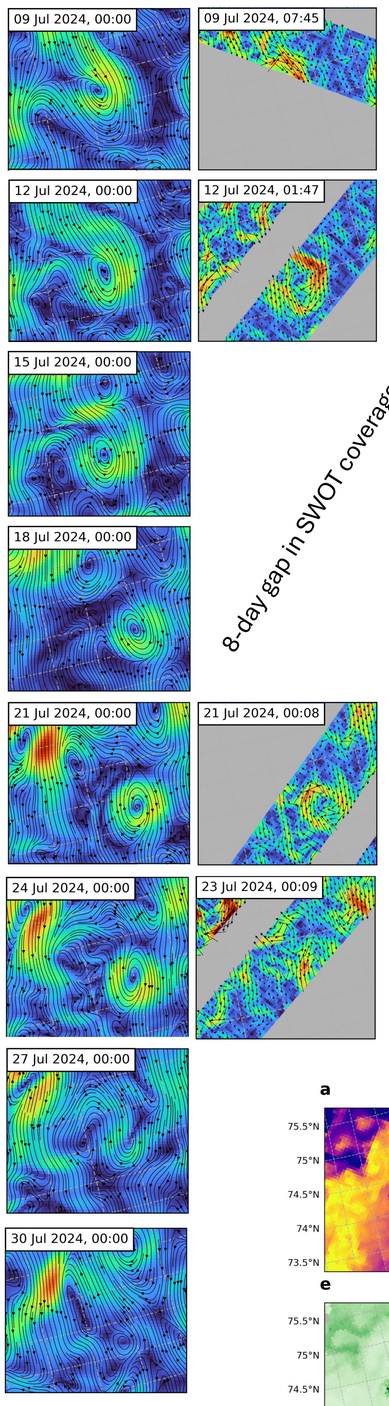


Figure 2: SWOT derived fields (foreground) and DUACS (background) on 6 September 2024. **a)** Geostrophic currents. **b)** Relative vorticity

3. Case Study of a 20-km Mesoscale Eddy



A small anticyclonic mesoscale eddy seen in SST data as a cold anomaly (figure 3) is detected by SWOT.

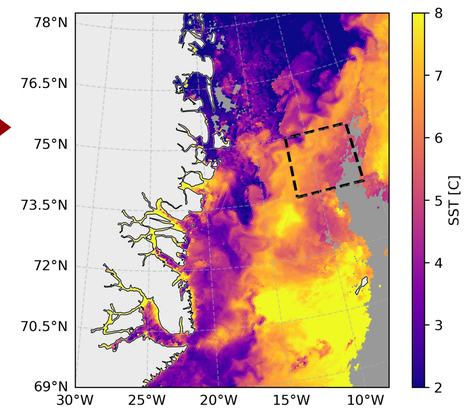


Figure 3: SST data (OSI-203-a) from 17 July 2024 showing the location of the eddy.

- The eddy has a diameter of 20 km and an amplitude of 5 cm. It has a cold core and high chlorophyll-a levels.
- It has a lifetime of 2 weeks. Its formation and break-up can be observed in the model.
- Figure 5 shows how the eddy location and shape as seen in SST and chlorophyll-a are well captured in the SWOT derived maps. The eddy is not seen in DUACS.

Figure 4: Geostrophic currents at 3-day intervals between 9 and 30 July 2024 from assimilation (**left**) and from raw SWOT data filtered with a 4x4 boxcar filter (**right**)

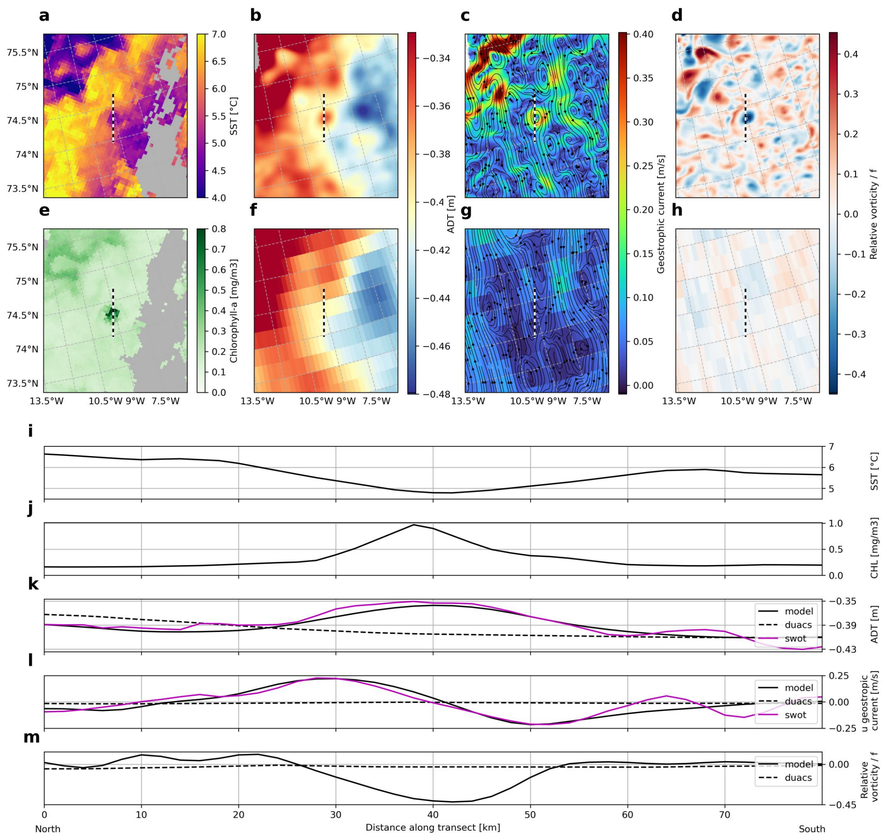


Figure 5. Observations of the 20 km anticyclonic eddy shown in Figure 2. (**a**) Sea surface temperature (17 July). (**b**) ADT, (**c**) geostrophic currents, and (**d**) relative vorticity, derived by assimilation of SWOT and nadir altimetry (21 July). (**e**) Surface chlorophyll-a concentration (17 July). (**f**) ADT, (**g**) geostrophic currents, and (**h**) relative vorticity, from DUACS (21 July). (**i**-**m**) Variables along 1D transect marked by black/white line in (**a**-**h**): (**i**) Sea surface temperature, (**j**) Surface chlorophyll-a concentration, (**k**) ADT, (**l**) east-west component of geostrophic current, (**m**) relative vorticity. Magenta lines in (**k**) and (**l**) are from the raw SWOT data (for computation of geostrophic current the data has been filtered with a 4x4 boxcar filter).

References:
Ubelmann, C., Klein, P., Fu, L.-L. (2015), Dynamic Interpolation of Sea Surface Height and Potential Applications for Future High-Resolution Altimetry Mapping. Journal of Atmospheric and Ocean Technology, doi:10.1175/JTECH-D-14-00152.1
Le Guillou, F., Metref, S., Cosme, E., Ubelmann, C., Ballarotta, M., Le Sommer, J., et al. (2021), Mapping Altimetry in the Forthcoming SWOT Era by Back-and-Forth Nudging a One-Layer Quasigeostrophic Model. Journal of Atmospheric and Oceanic Technology, doi:10.1175/JTECH-D-20-0104.1