Characterization of eddy activity around Iceland from gridded altimetry, SWOT data, and modelling

Charly de Marez[1,*], Angel Ruiz-Angulo[1], Jonathan Gula[2], & Josué Martínez-Moreno[2]

[1] Háskóli Íslands, Reykjavík, Ísland

[2] Laboratoire d'Océanographie Physique et Spatiale (LOPS), Brest, France.

*Contact: charly@hi.is

Motivations

- Understanding the evolution of eddies is of primary importance: they impact biological activity (Chelton et al. 2011), tracer transports (Zhang et al. 2014), water column properties (Dong et al. 2014), and the evolution of climate through their impact on heat transport and air-sea interactions (Small et al. 2008, Palter et al. 2015, Sun et al. 2019).
- In a context of global warming, eddies therefore need to be thoroughly understood to better assess the long-term evolution of climate in global climatic models (Yang et al. 2022).
- Around Iceland, eddies are on the path of the Atlantic Meridional Overturning Circulation (AMOC, Buckley et al. 2016) upper cell and therefore impact the exchanges of polar waters and Atlantic waters over the Greenland-Scotland Ridge.

- **We discuss here the eddy activity around Iceland, to better understand the role of the mesoscale in in the AMOC.**

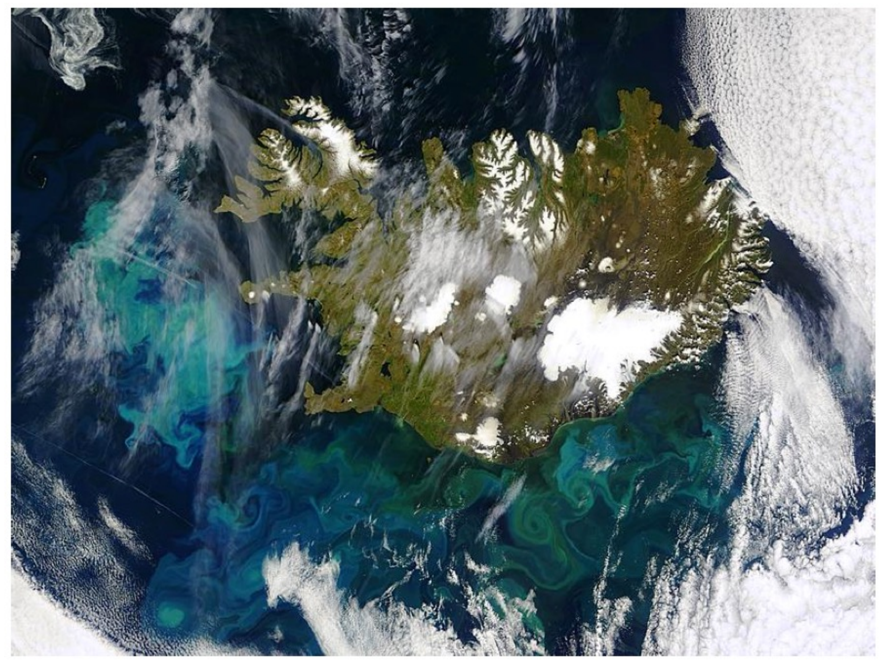

Fig. 1: Swirling patterns of ocean chlorophyll around Iceland highlighting the occurrence of mesoscale eddies (NASA Earth Observatory).

Mesoscale eddy detection in gridded altimetry

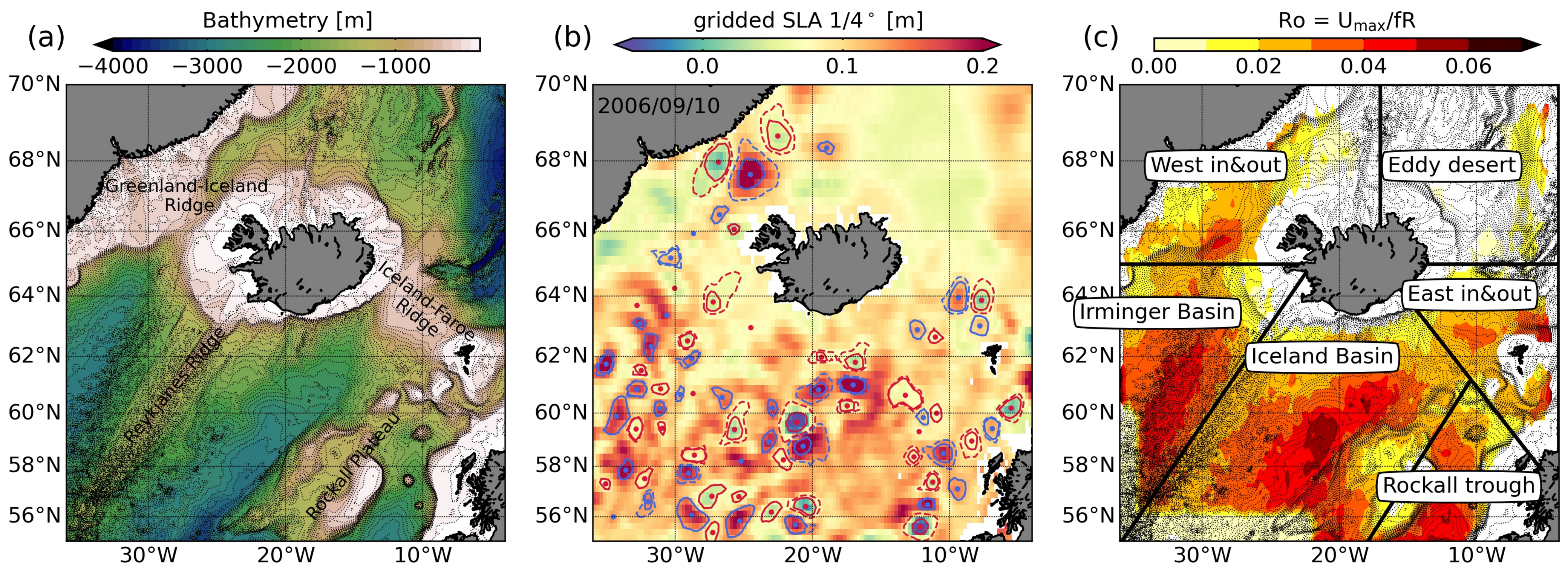

Fig. 2: (a) Bathymetry and topographic features within the area of interest. (b) Gridded ¼ degrees Sea Level Anomaly used for eddy detection, and result of eddy detection. (c) Box-averaged Rossby Number of detected eddies inferred from the eddy detection including the definition of sub-regions.

- We use the detection algorithm ***py-eddy-tracker*** developed by Mason et al. 2014, and widely used and validated since.
- The algorithm is implemented on daily AVISO 1/4 degrees gridded Sea Level Anomaly data from 1993-2022, over an area centered around Iceland.
- A comparison in the southeasternmost part of the domain with a detection using 1/8 degrees product shows little difference.
- Only the vortices that were tracked over a period longer than a month (with detection gaps of 3 days allowed) are considered to avoid false detections.

- Most of detected eddies (93%) are located South of 65°N, and an "Eddy Desert" appears Northeast of Iceland, most likely due to the weak forcings and currents there.
- The most probable radius of maximal velocity for detected eddies is R~30 km in all sub-regions (distributions of R peak at R~30 km), with a maximum geostrophic velocity of Umax~0.15 m/s.

- Most intense vortices are found in the Iceland Basin and the Rockall Trough, where large mesoscale eddies have already been observed to be of major importance for the local dynamics (Zhao et al. 2018, Smilenova et al. 2020).
- Despite its small extension and relatively small depth, the area East of Iceland appears to be an area of important mesoscale activities, with numerous eddies over the Iceland-Faroe Ridge

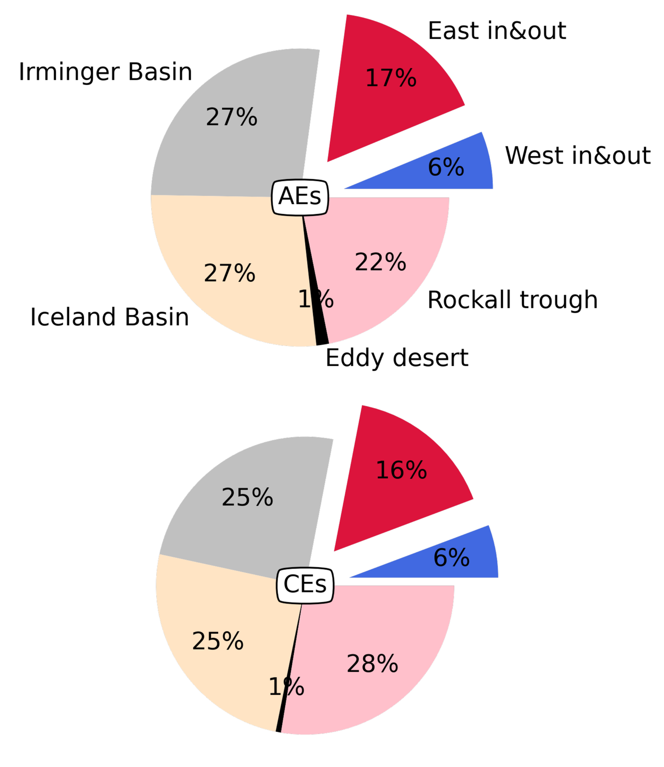

Fig. 3: Proportion of detected eddies per sub-region for Anticyclonic Eddies (AEs, top) and Cyclonic Eddies (CEs, bottom), normalized by the surface of each sub-region.

- **Due to its importance for the exchanges between the Nordic Seas and the North Atlantic Subpolar gyre, we further investigate the eddy activity in the "East in&out" area, using higher resolution altimetry and numerical modelling**

Statistical description of the mesoscale eddies East of Iceland

- We focus on the area East of Iceland, re-detecting mesoscale eddies using 1/8 degrees product for a finer measure of eddy characteristics.
- Most eddies are located on the Iceland-Faroe Ridge, particularly, the western part.
- Composite eddies have a quasi-axisymmetric shape, with a tendency for small (R<25 km) AEs to be more elongated along the zonal direction.
- Azimuthal velocities have a radial Gaussian-like profile, with small eddies having larger azimuthal maximum velocities.
- Small eddies are more frequently detected during late wintertime (mainly due to mixed-layer instabilities).
- Majority of eddies don't live longer than 2 months.
- **The area East of Iceland is rich in mesoscale activity, but the detection from standard altimetry reaches its limits due to the coarse resolution of the grid, and the small extension of the mesoscale**

→ we need higher resolution!

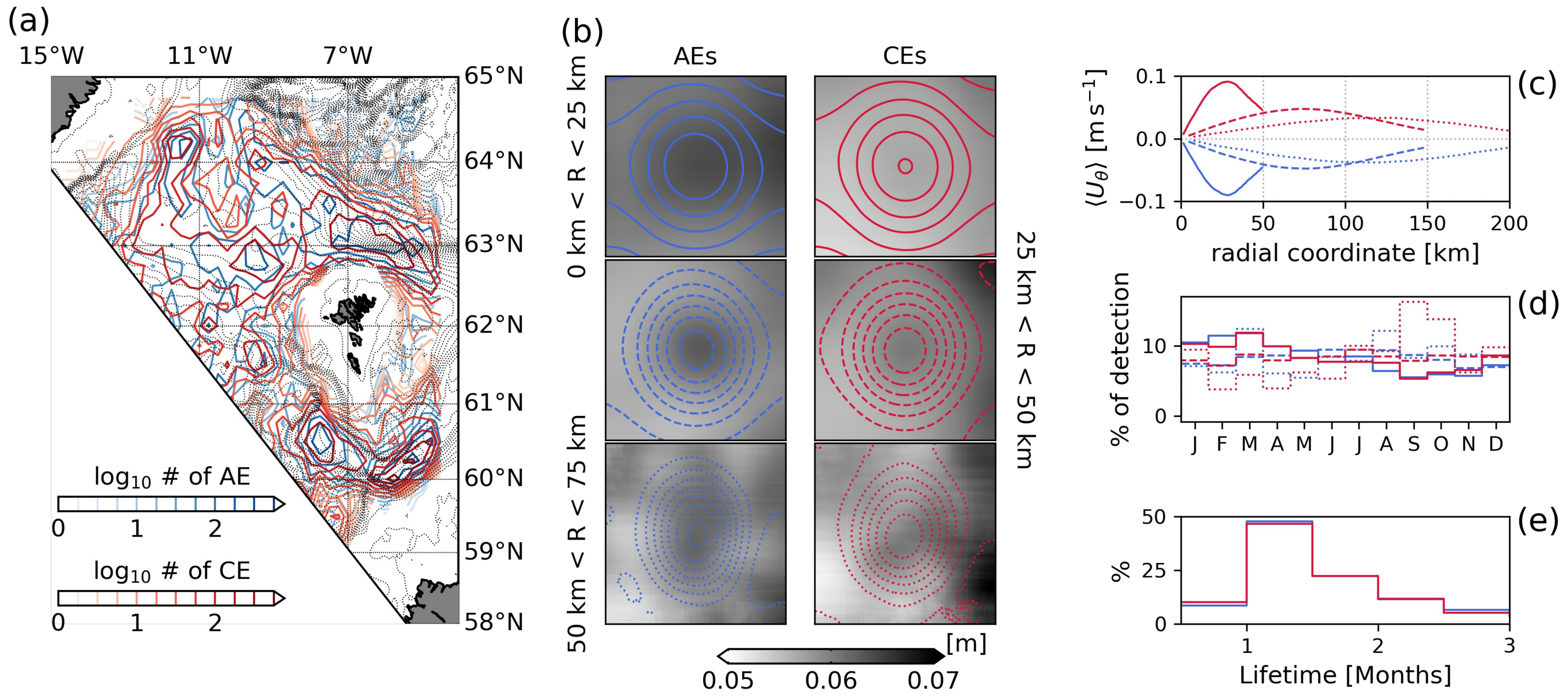

Fig. 4: (a) Distribution of detected AEs and CEs in the sub-region. (b) Composite shape of detected eddies; contours show SLA levels with a spacing of 1 cm; color show the standard deviation of the composites. (c) Average profile of azimuthal velocity. (d) Period of detection. (e) Eddy lifetime.

Insights into the mesoscale turbulence from SWOT data

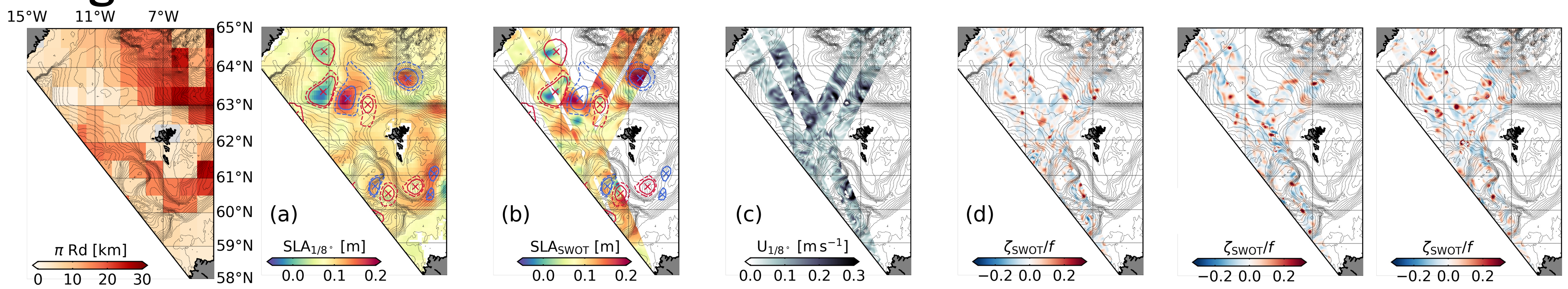

Fig. 5: First mode Rossby deformation radius Rd (time-averaged ECCO reanalysis

Fig. 6: Meso- to submeso-scale activity East of Iceland on 10/06/2023. (a) Detection of mesoscale eddies (contours) from 1/8 degrees gridded altimetry (color). (b) SWOT KaRIn 2-km resolution smoothed SLA in passes #5 and #16, the eddy detection from gridded product is superimposed. (c) Geostrophic velocity norm derived from SWOT SLA. (d) Normalized vorticity derived from SWOT SLA.

Fig. 7: Same as Fig. 5(d) on 29/04/23 (left) and 04/05/23 (right)

- Newly released SWOT data (L3_LR_SSH, v0.3, 1-day orbit phase, AVISO, CNES, NASA) unveils unprecedent details on the surface geostrophic turbulence.
- Comparison between the detection from classic gridded altimetry and high-resolution SWOT data shows that SLA signal previously interpreted as large eddies is in fact composed of a combination of several structures with small horizontal extension eddies due to the reduced deformation radius (Rd) on the Iceland-Faroe Ridge.
- Relative vorticity derived from SWOT data shows that the surface dynamics above the Iceland-Faroe Ridge is highly turbulent and reaches the limit of geostrophic assumption.
- **The inflow of North Atlantic waters into the Norwegian Sea through the Iceland-Faroe Ridge region is most likely highly variable, and impacted by locally generated small structures that <u>cannot be sufficiently described by standard gridded altimetry.</u>**

Perspective: process analysis from high resolution simulation

- We make use of the realistic simulation GIGATL1 (Gula et al.) to investigate small-scale processes related to eddy activity East of Iceland
  - CROCO simulation solving hydrostatic primitive equations
  - High horizontal (1 km) and vertical resolution (100 σ-levels)
  - Tides and hourly winds

- Preliminary analysis of the simulation show that a strong northeastward current flows above the Western Valley (westmost part of the IFR).
- The current subsequently retroflects East and becomes unstable, generating intense eddy activity on the IFR.
- Eddies at the surface have a radius of ~10 km, similar to the one observed in SWOT data.

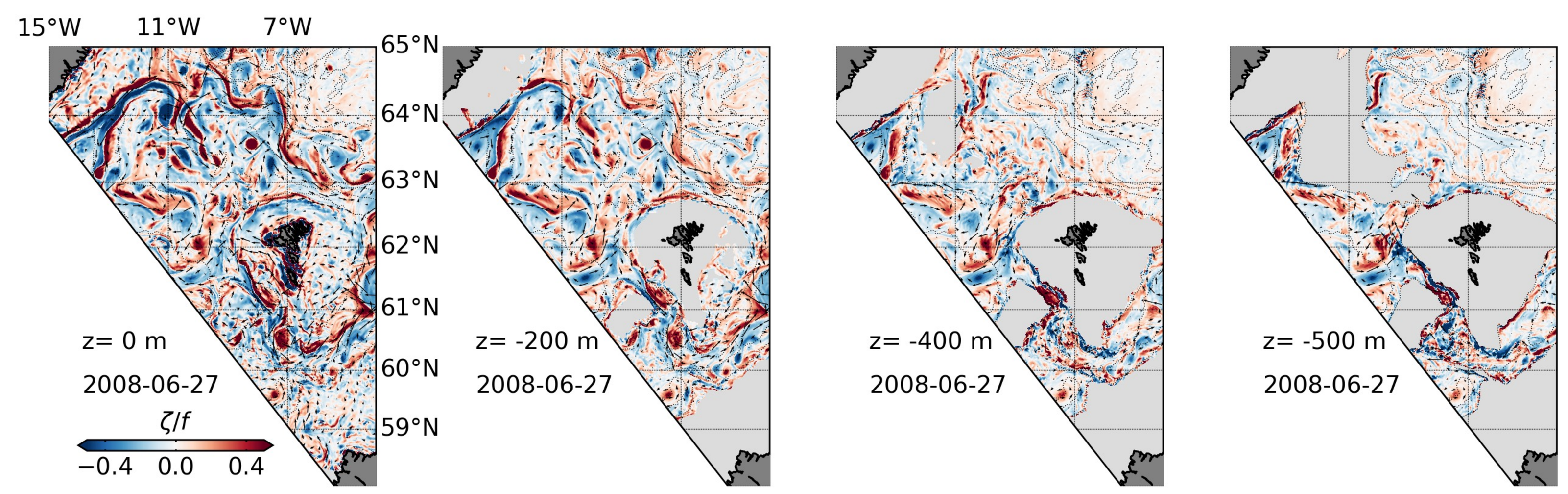

Fig. 8: Normalized relative vorticity snapshots at different depths from high-resolution (1-km) realistic simulation.