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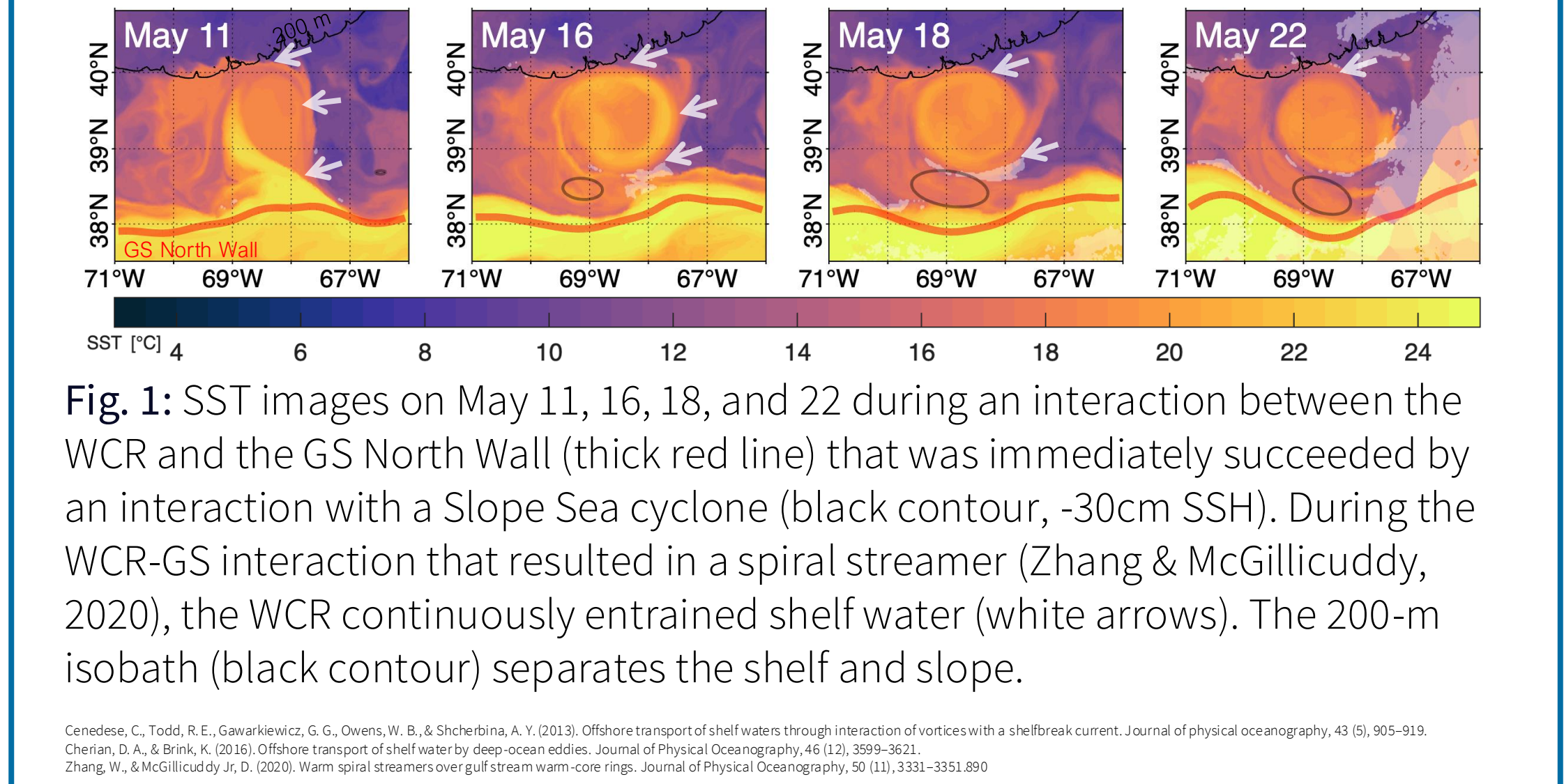
Mesoscale eddies in the Slope Sea

Warm Core Rings (WCRs)
WCRs are **anticyclonic** eddies that shed from **Gulf Stream (GS)** meander crests due to baroclinic instabilities. They are visible in satellite products by their **warm sea surface temperature (SST)** and high-pressure or **positive sea surface height (SSH)** anomalies. WCRs can **entrain streamers – cold, fresh, productive shelf water** – into the warm, salty, nutrient-poor **Slope Sea**, the region directly north of the GS and adjacent to the continental shelf. Shelf streamer export is a significant contributor to the heat and salt budgets of the region and also **impacts cross-slope circulation and physical and biogeochemical properties instantaneously and cumulatively**.

Slope Sea cyclones
Deep-reaching, coherent cyclones form within troughs of large-scale meandering currents such as the GS. When a trough develops as the current meanders southward, the combined effects of the pressure drop and density increase throughout the water column lead to the formation of these cyclones in the Slope Sea. First observed to frequently form around 68°W (Savidge & Bane, 1999a), cyclones also form at 64°W and 58°W (Chen et al, 2025, under review). They are visible in satellite altimetry due to their low-pressure or **negative SSH** anomalies and are easily identified in *in situ* measurements by their **positive vorticity** and **strong (up to 50 cm/s) subsurface currents** (Godin, 2024).

Interactions between WCRs and the GS

When the southern edge of a WCR interacts with the GS for >1 day, such as during a spiral streamer formation (Zhang & McGillicuddy, 2020) where buoyant GS water is entrained into the WCR, the **trajectory of a shelf water streamer** that is continuously entrained by the WCR during the interaction can be **injected into the GS North Wall**, as opposed to wrapping around the ring (Fig. 1). The transfer of buoyant GS water to the WCR also **increases the ring’s baroclinicity** and radial pressure gradient (Cherian & Brink, 2016), resulting in a **greater transport of shelf water** (Cenedese et al., 2013; Wang et al., in prep). These events tend to be succeeded by interactions between the ring and Slope Sea cyclones (Fig. 1).



Acknowledgements and more information

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For more information on this study and related work, scan this QR code:



SUMMARY

- Interactions between WCRs and Slope Sea cyclones influence cross-scale circulation and exchange
- WCR-cyclone interactions can modify the ring’s structure, giving rise to submesoscale ageostrophic motion in the ring’s periphery where shelf water streamers are located
- From 2021-2025, 85% of interactions between WCRs and the GS North Wall were immediately succeeded by WCR-cyclone interactions that modified the ring’s structure
- These transient events impact the physical and acoustic properties of the Slope Sea and GS North Wall and cumulatively impact cross-shelf and cross-slope exchange

Interactions between WCRs and cyclones

Satellite and *in situ* observations suggest that an **encounter between a WCR and a Slope Sea cyclone can modify a ring’s structure** (Figs. 2 & 3). Here we focus on one WCR from 2023, but historical satellite measurements reveal that WCR modification during an interaction with a cyclone is **not a unique occurrence** (see QR code). **Cyclone interactions also tend to immediately succeed WCR-GS interactions**; from 2021-2025, this occurred **85% of the time**. Fig. 2 shows the evolution of the ring’s radius and eccentricity during the interaction in April 2023, as determined from SSH and SST. The impact of the interaction on the ring’s subsurface velocity structure is seen in Fig. 3. A comparison between the early (T1 – April 7-8) and late (T2 – April 17) stages of the interaction reveals that the azimuthal and along-axis velocities in the offshore section of the ring had intensified by T2.

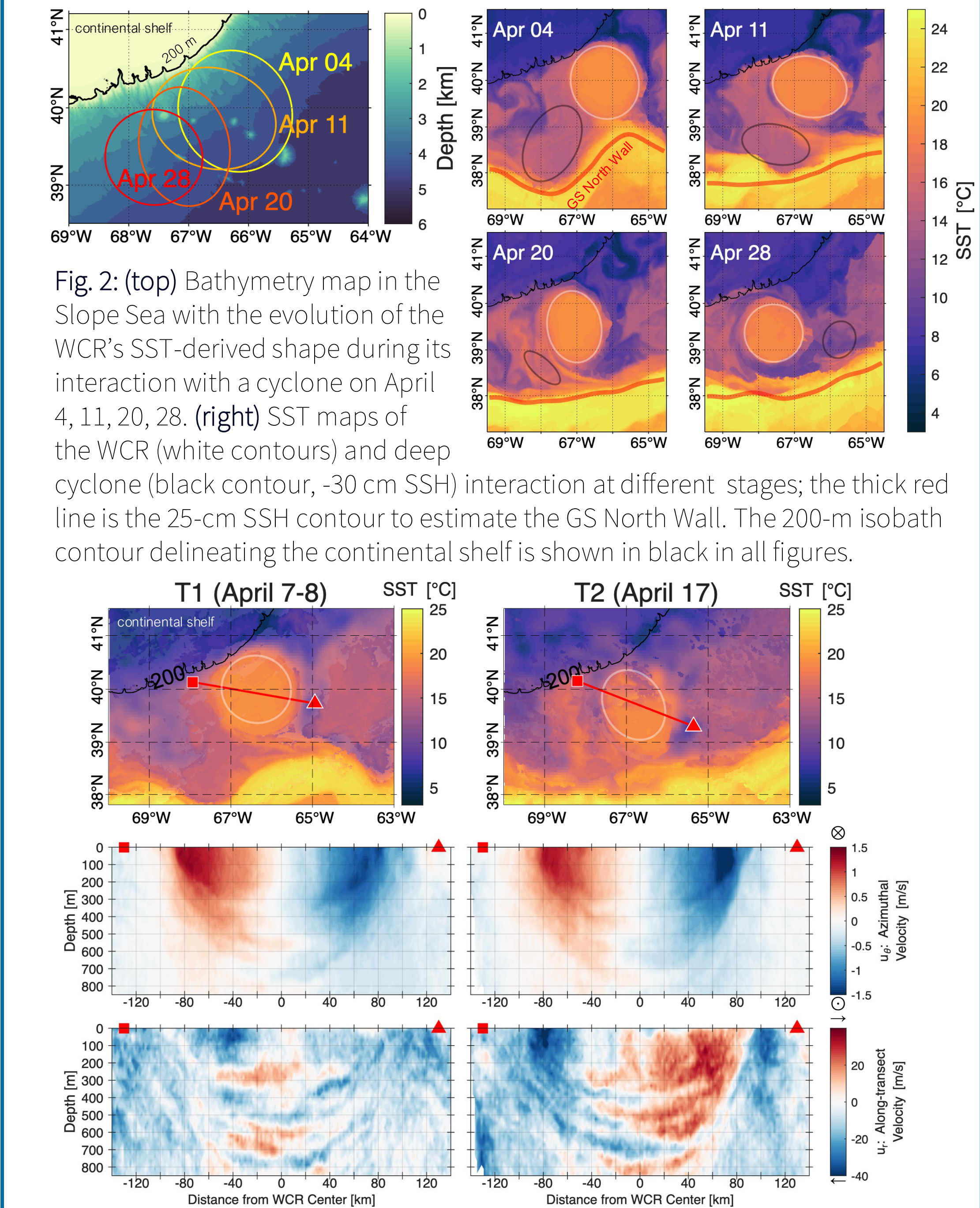


Fig. 3: (top) SST maps of the WCR during two transects (red lines) from April 7-8 (T1, left column) and April 17 (T2, right column). (middle) Azimuthal or spin velocities through WCR on T1 and T2. The red squares and triangles on each plot indicate the onshore and off-shore sections of the ring, respectively, in reference to the SST maps. (bottom) Along-transect velocities on through the WCRs on T1 and T2. The red and blue arrows show a region of convergence in the offshore section of the ring. Data were collected as part of the NESMA program.

Effects on cross-slope exchange

Modifications to the WCR velocity structure during its interaction with a cyclone result in shear and strain within and along the edge of the WCR. A **shelf streamer** that is present around the ring periphery at this time is also impacted by these mesoscale-driven modifications. One effect is **frontogenesis** that is caused by these **deformation-induced horizontal motions** that then induce **submesoscale motion**, such as **subduction** as in Zhang & Partida, 2018. During T2 (April 17), frontogenesis in the offshore streamer that had been entrained by the WCR is visible in the near-surface density measurements (Fig. 4), implying submesoscale motion in the subsurface. This represents a mechanism by which **meso-scale interactions** (WCRs and cyclones) **drive submesoscale processes** (frontogenesis and ageostrophic motions in the shelf streamers).

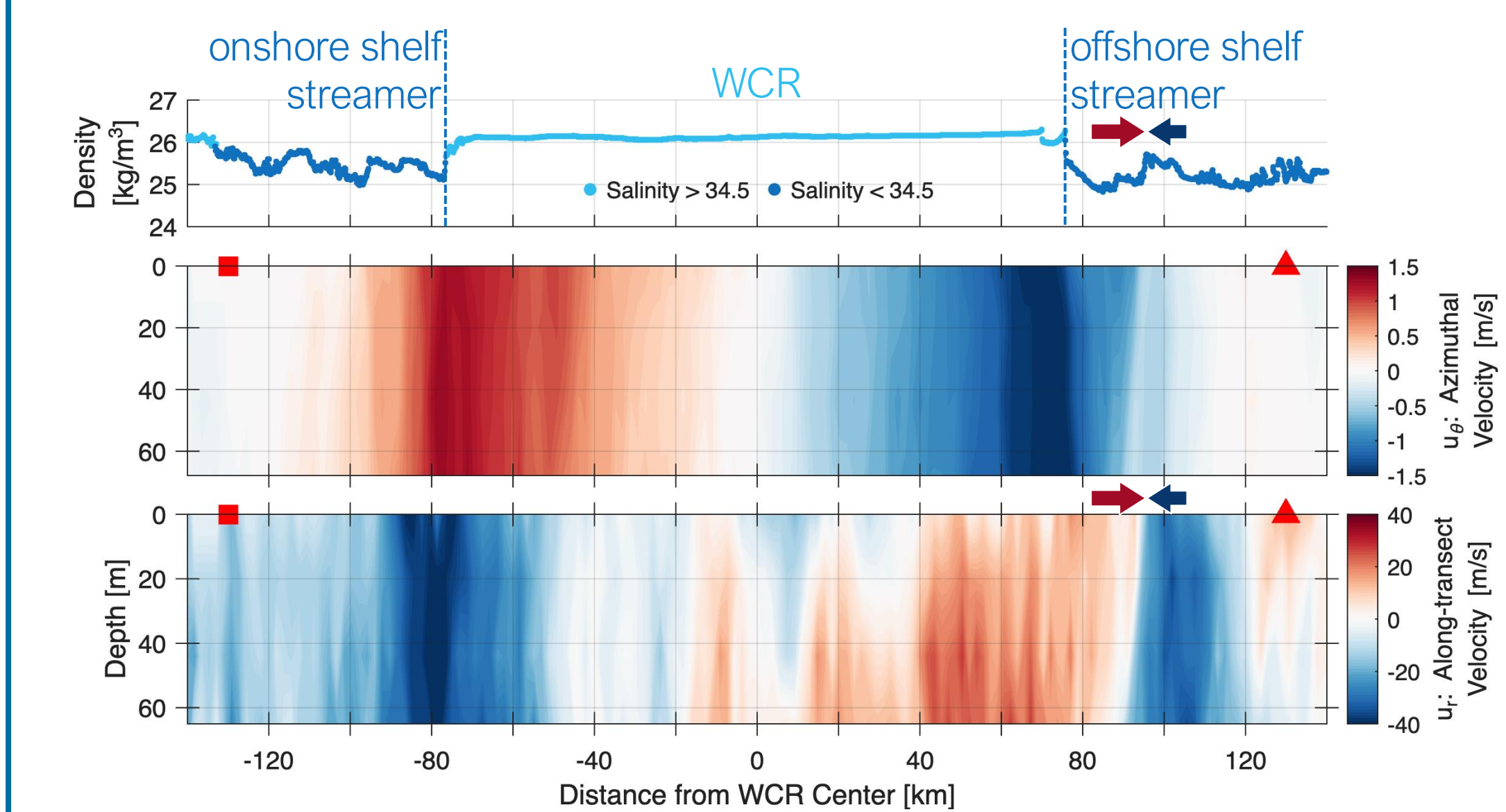


Fig. 4: (top) Near-surface density along the T2 transect (Fig. 2) showing the location of the WCR (light blue dots, salinity > 34.5) and shelf streamers (dark blue dots, salinity < 34.5). (middle) Azimuthal or spin velocity along the same transect in the upper 65 m of the transect. The red square and triangle indicate the onshore and offshore sides of the transect, in reference to Fig. 2. (bottom) Along-transect velocities through the same transect. The red and blue arrows, also present in the near-surface density plot and in Fig. 2, indicate a region of along-transect convergence within the offshore streamer that suggests frontogenesis.

Implications and future work

The 85% likelihood for WCR-cyclone interactions to immediately succeed WCR-GS interactions that tend to increase streamer transport (Wang et al., in prep) implies that a significant volume of shelf water is subject to submesoscale motions driven by the WCR’s deformation. Assuming (1) that a WCR present in the western Slope Sea entrains a streamer 75% of the time, (2) an average lower-bound transport estimate of 0.26 Sv associated with WCR-GS interactions (Wang et al., in prep), and (3) that each WCR-cyclone interaction modifies a WCR’s structure, then **~8.2 x 10⁶ m³/yr of shelf streamer water would be subject to mesoscale-induced submesoscale motion, potentially representing a mechanism for Slope Sea ventilation**. Refinement of this estimate and investigation into the dynamics of the inter-action will involve further analysis of a realistic model (Fig. 5).

