Time-Lapse Volumetric Seismic Imaging of Water Masses at a Major Oceanic Confluence in the South Atlantic Ocean

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1 Introduction

- ❑ The western region of the South Atlantic Ocean is highly complex in terms of ocean circulation, water masses, and mixing at the continental shelf.
- ❑ It is mainly dominated by the Brazil Current (BC) and the Malvinas/Falkland Current (MC) at their intersection, known as the Brazil-Malvinas Confluence (BMC), creates a highly dynamic frontal zone. Oceanic fronts (i.e. regions of rapid lateral changes in temperature and/or salinity) are key sites of water mass modification, primary productivity, and ocean-atmosphere exchange.
- ❑ **We exploit an acoustic imaging technique that can record temperature changes within the water column over a large range of scales, capturing temperature distributions on 5-10 m length scales and yielding unprecedented time-elapse observations of a major oceanic front at BMC[1]. Rapid evolution of both sub-mesoscale and mesoscale structures are observed at greater depths than previously observed.**

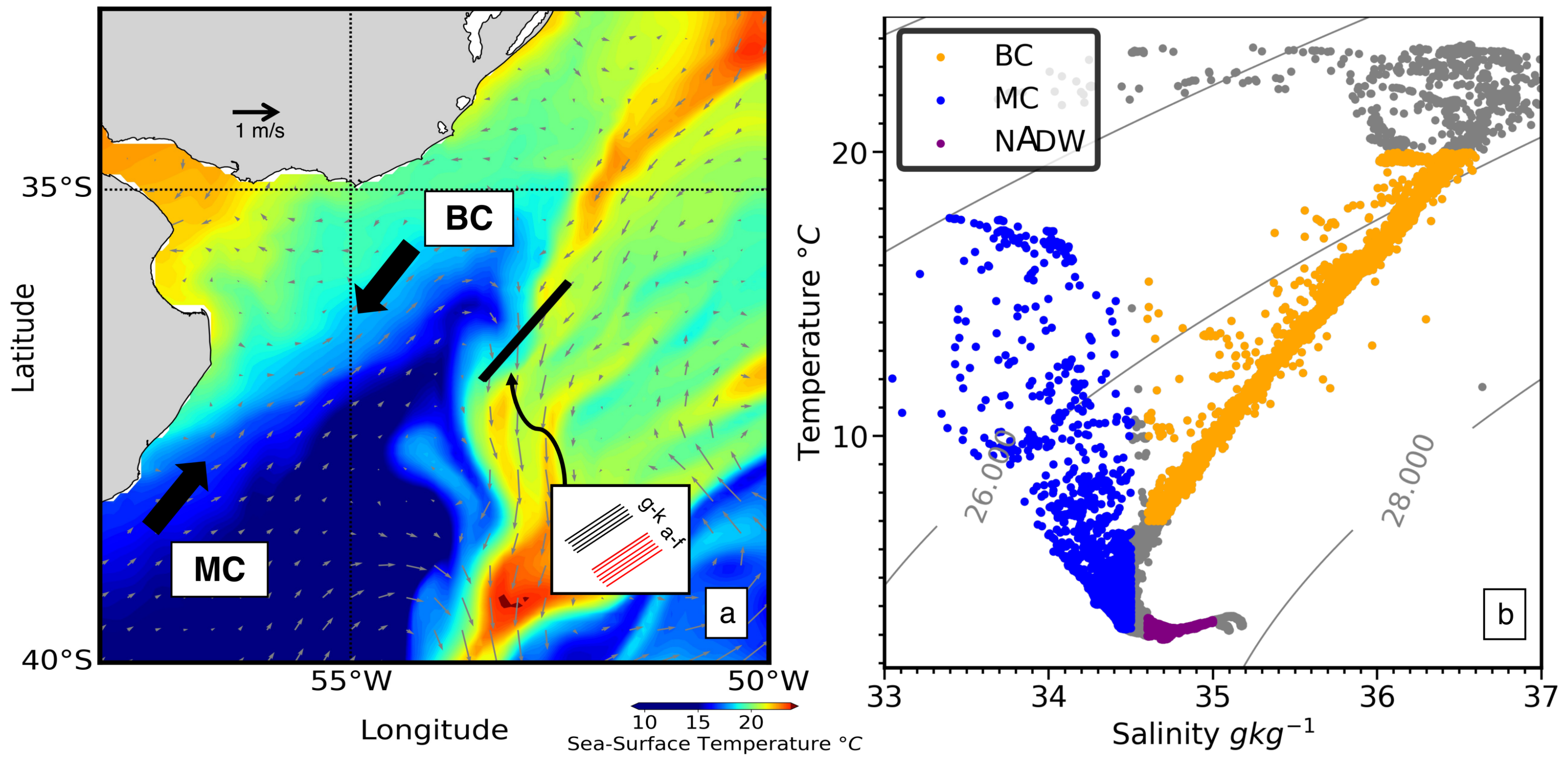


Figure 1:(a) Map of sea surface temperature for southwest Atlantic Ocean showing confluence of water masses; red/blue = warm/cold water masses for 13th February 2013 from AVISO satellite measurement; field of black arrows: sea surface geostrophic current velocities; black lines = loci of 11 seismic transects. (b) Temperature-salinity diagram based upon coeval hydrographic casts.

2 Seismic Image of a Major Oceanic Front

- ❑ Sound speed of ocean varies as function of temperature (70-80%), salinity (15-20%), and pressure. Impedance contrasts represent small changes in sound speed and therefore temperature. Positive/negative reflections are generated by temperature changes as small as 0.01℃.
- ❑ Dipping reflectivity (Figure 2b) is interpreted as a frontal interface separating a wedge of northern water from southern water. Rapid changes in physical properties that occur close to a front manifest on seismic profiles as bright reflections. The frontal interface, along which the strongest gradients occur, is clearly identifiable as bright dipping reflections. This reflectivity is typical of oceanographic fronts as imaged on seismic transects[2].
- ❑ A double-convex structure is found at a range of 60 to 100 km. Its core is centred at 750 m depth.

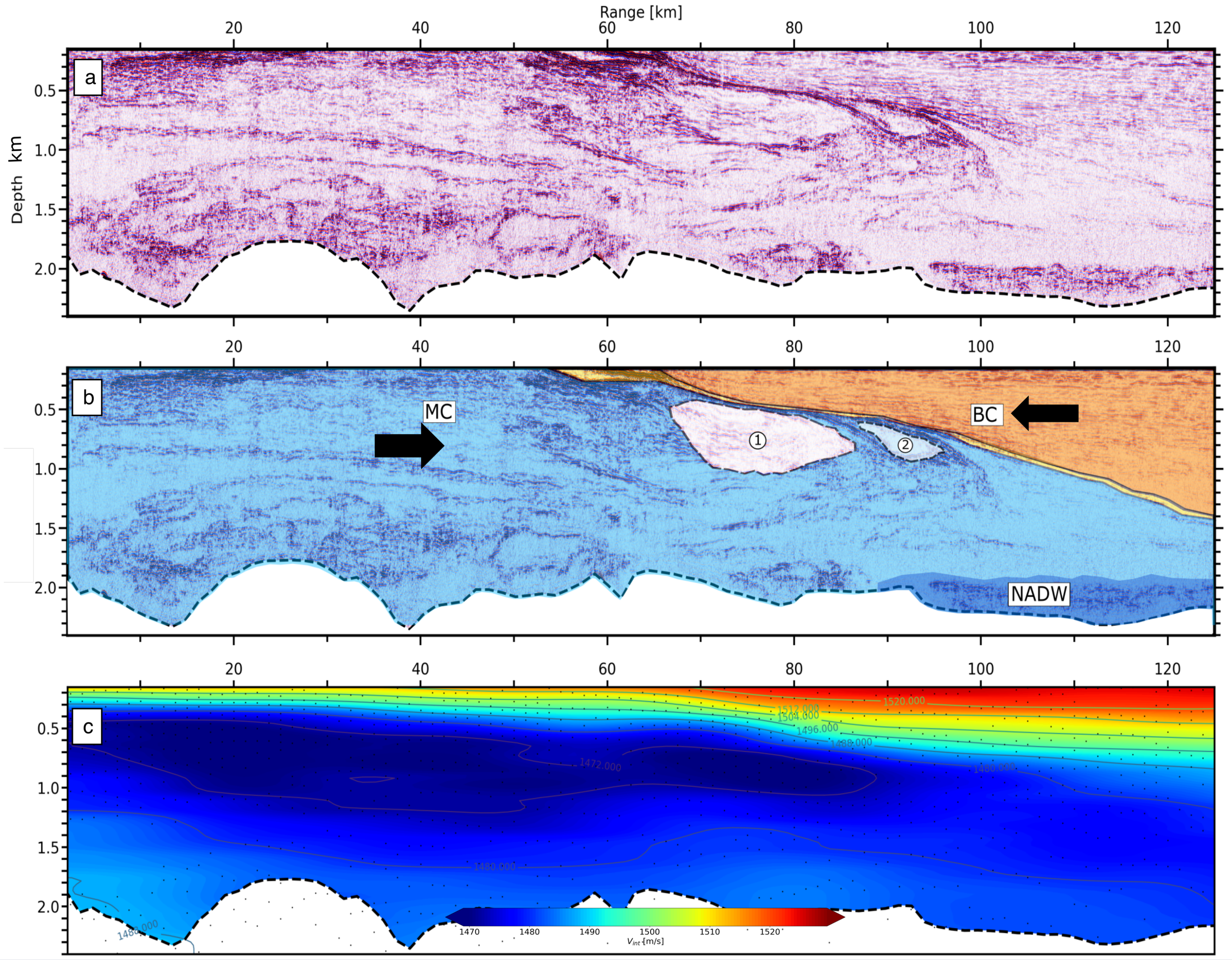


Figure 2:(a) Representative seismic section that crosses major oceanic front. (b) Generalized interpretation that emphasizes principal features. Orange shading = Brazil Current (BC); blue shading = Malvinas Current (MC); North Atlantic Deep Water (NADW); yellow dipping zone = discrete oceanic front dipping at <2° down to depth of around 1,500 m; tilted white blobs labelled 1 and 2 = lens-shaped features with diameters of 40 km and 10 km. (c) Interval sound speed as function of range calculated from RMS sound speed using Dix equation (i.e. long-wavelength component of sound speed). Sound speed is vertically and horizontally smoothed.

3 Time Elapse Seismic Reflection Imaging

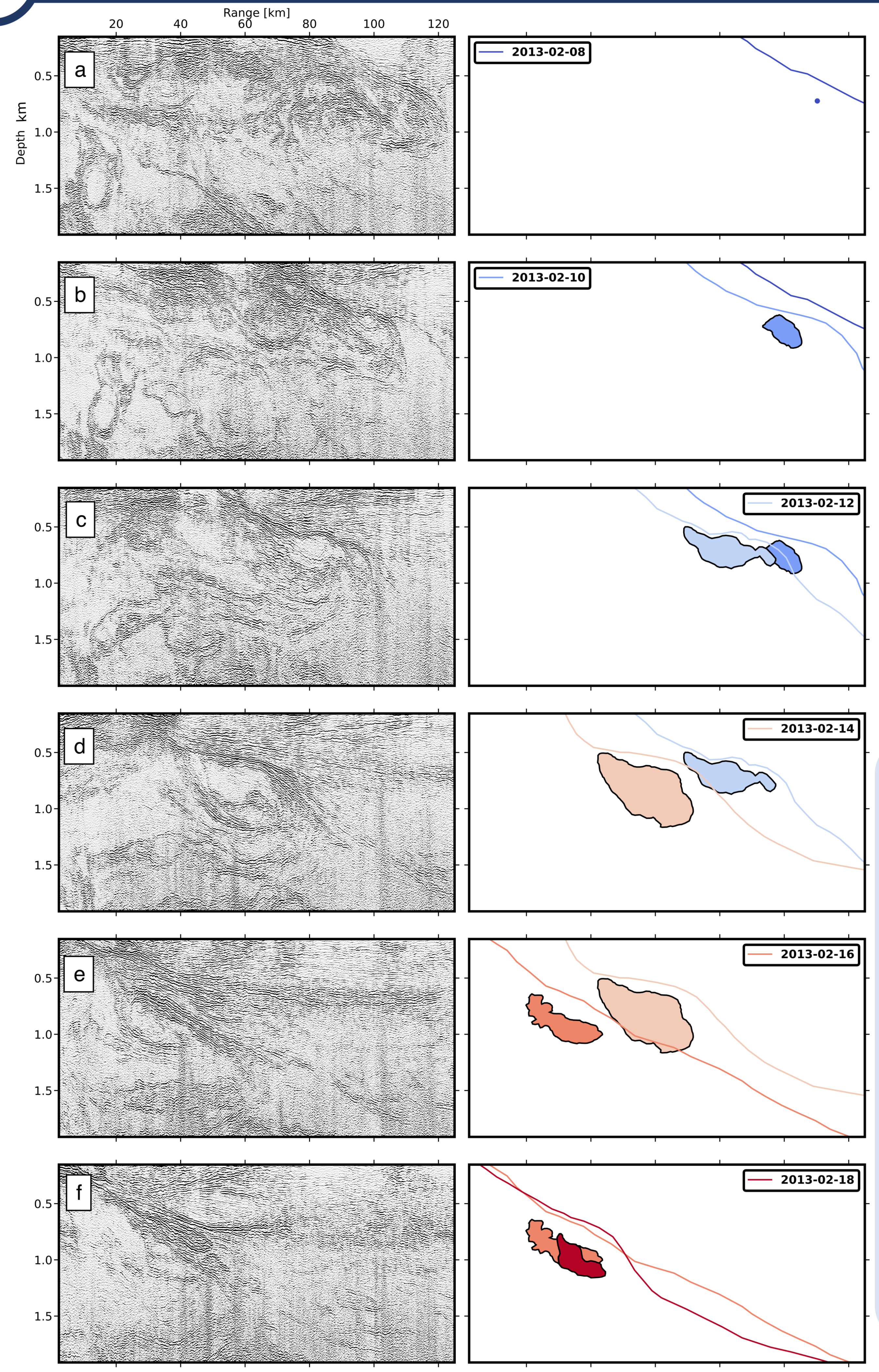
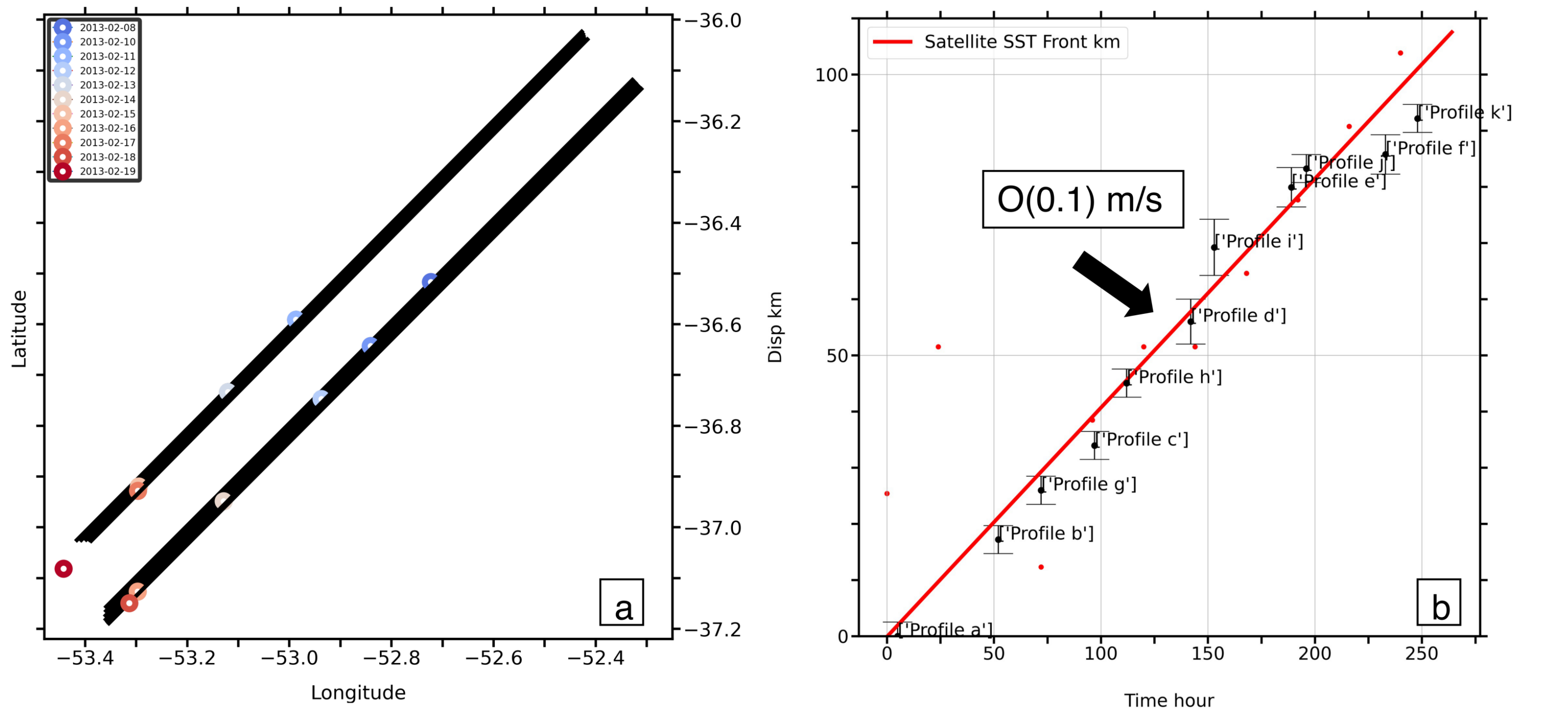


Figure 3: Series of time-lapse images from seismic transects that show evolving structure adjacent to front. Left panel: seismic transects; right panel: interpretation of seismic transects in left panel. Coloured line = front, coloured polygon = tracked eddy, labels at corner represent imaging time of correspondent seismic transects (first seismic transect acquisition started at hour [0]) for seismic profiles in Group A (a-f) of **Figure 1**.

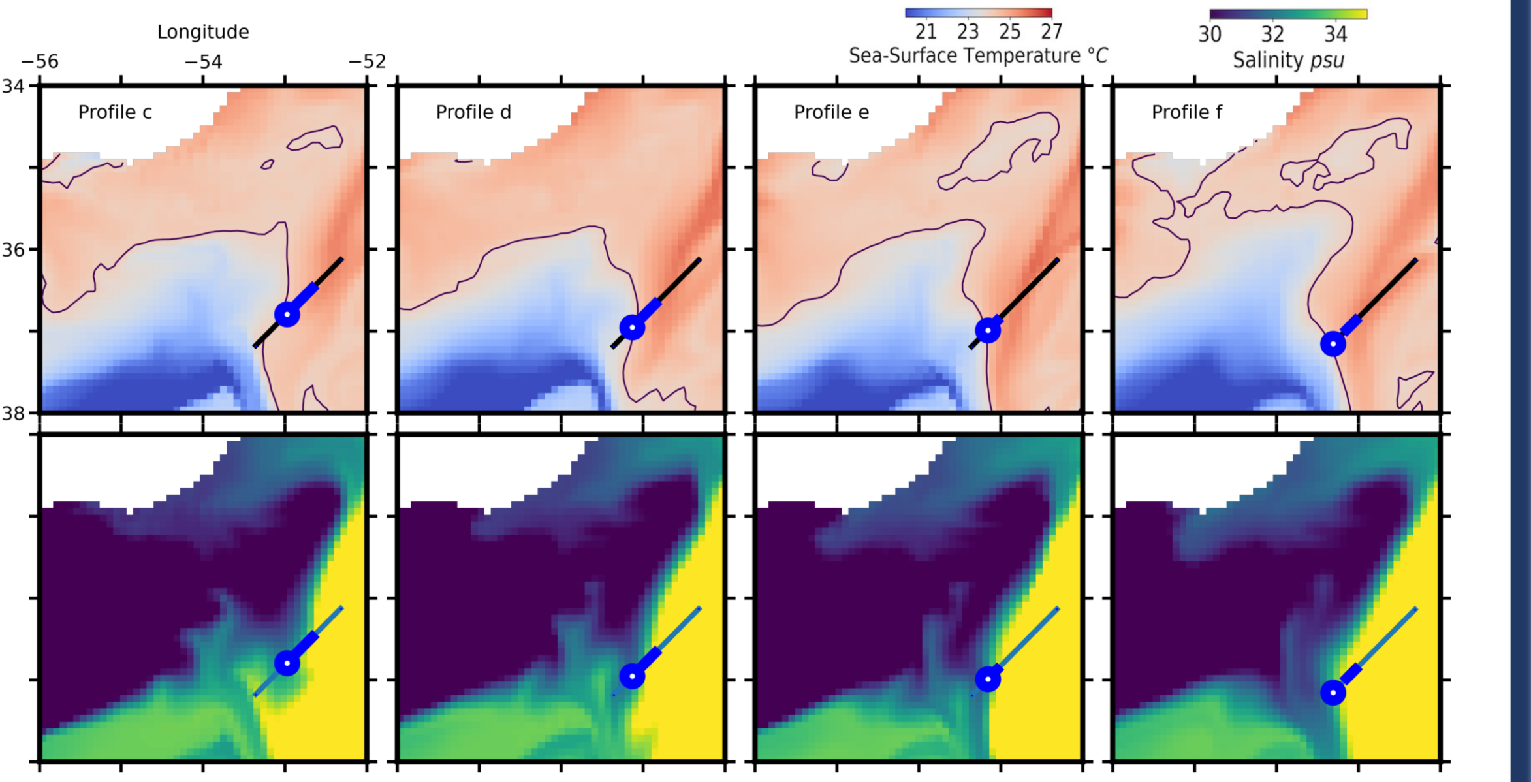
Two water masses appear with different features throughout 11 seismic transects. In Figure 3b, on right-hand side of front, Brazil Current is manifest by densely layered flat reflections, indicating that this water mass is strongly stratified. On left-hand side of front, Malvinas Current exhibits more complex structures, such as swirling reflections and lens with transparent cores, which may indicate either homogeneity or enhanced mixing.

Figure 4: (a) Front visibly migrating south-westward on series of seismic transects. Coloured circles = frontal outcrop at sea surface, coloured by hour. (b) Displacement of frontal outcrop at sea surface in southwest direction.



4 GLORYS12V1 Reanalysis Simulation

Figure 5: Map of SST (upper panel) and SSS (lower panel) calculated from GLORYS12V1 for southwest Atlantic Ocean showing confluence of water masses. Black lines = locations of seismic lines; thin black lines = SST contoured every 1°C, blue circles: frontal outcrop at sea surface; blue bar: eddy projected to sea surface.



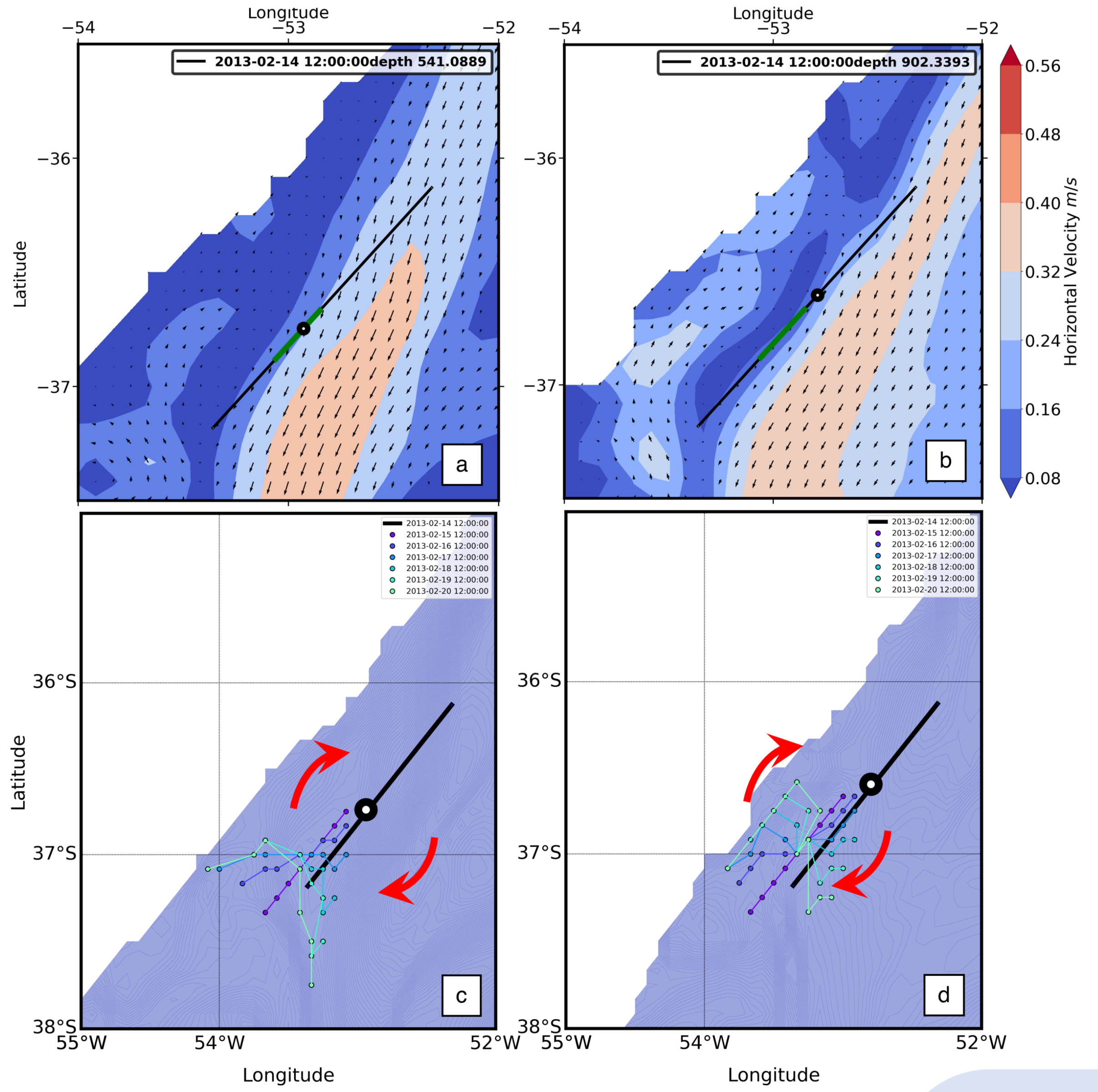
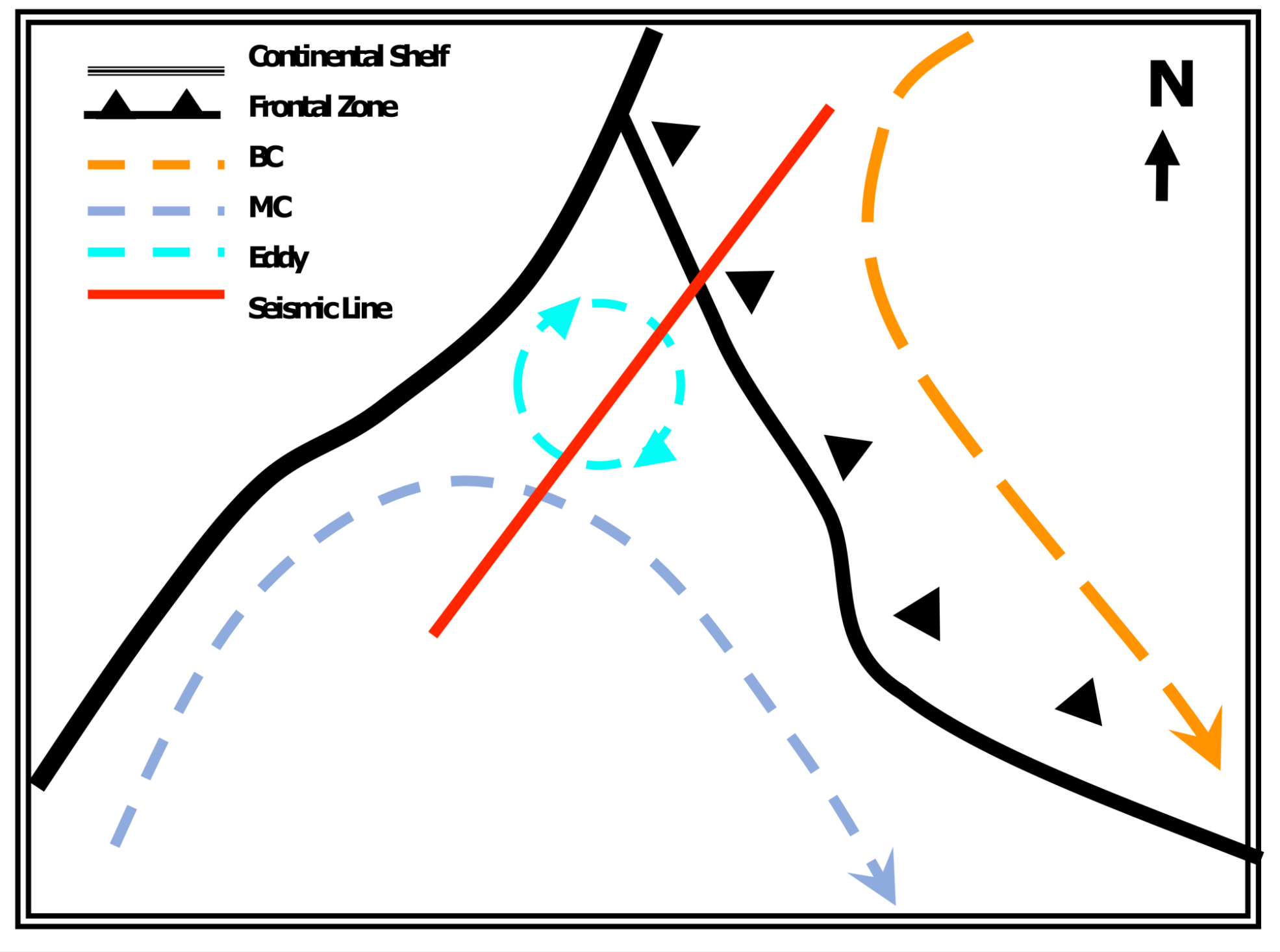


Figure 6: Upper panel: horizontal current velocity fields at depths 541 m (a) and 902 m (b) calculated from GLORYS12V1 product. Colour represent absolute magnitude of velocity. Black line = Seismic line; black circle = front outcrop; green bar = surface projection of mesoscale eddy at correspondent depths. Lower panel: tracked particles at depths 541 m (c) and 902 m (d) by using velocity fields for the period of interest (2013/02/15-2013/02/20). Black line = seismic line; black circle = front outcrop; connected dots = tracked particles coloured by dates, denoted in legend.

Figure 7: Schematic cartoon of a proposed generation mechanism of the mesoscale eddy observed in seismic image.



We observe a mesoscale eddy at depth 500-1000 m that is embedded with front in the western boundary of South Atlantic Ocean. Tracked particles (Figure 7c,d), which are released daily through the confluence area down to 1800 m, flow along the MC from 40° S to 36° S and are deflected clockwise by the BMC. This flow suggests that the observed eddy is cyclonic and related to MC recirculation, as a result of the combination of the steep continental slope and geometry of the BMC (Figure 7). Previous study found mesoscale eddy can be generated by interaction currents with topography due to frictional effects and mixing in the wake of topography[5].

Seismic image shown ocean interior is rich in deep meso- and submeso-scale structures. They might play a significant role in redistributing water properties.

Key References

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[5]Gula, J., Blacic, T. M., & Todd, R. E. (2019). Submesoscale coherent vortices in the Gulf Stream. Geophysical Research Letters, 46, 2704– 2714.