Dynamics of Alboran Fronts: Processes for Vertical Velocities Development

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Key Points:

• Frontal intensification in the Alboran Sea was investigated using multi-platform observations and a realistic simulation in spring 2018.
• Western Alboran Gyre Front is intensified by frontogenesis, instabilities, and Ekman effects driven by the Atlantic Jet and westerly winds.
• Filamentogenesis mechanism leads the Eastern Alboran Gyre Front intensification driven by the southeastward intrusion of a cold filament.
• Vertical velocities are amplified by a single (two) across-front ageostrophic secondary circulation in the Western (Eastern) front.

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Abstract

Significant lateral density gradients occur throughout the year in the Alboran Sea, giving rise to two main fronts: the Western Alboran Gyre Front (WAGF) and Eastern Alboran Gyre Front (EAGF), where large vertical velocities often develop. To improve the understanding of the processes that underlie the development of the vertical velocities in the WAGF and EAGF, the periods of frontal intensification were analyzed in the perspective of the frontogenesis, instabilities, non-linear Ekman effects, and filamentogenesis mechanisms, using multi-platform in-situ observations and a high-resolution simulation in spring 2018. The spatio-temporal characteristics of the WAGF indicate a wider, deeper, and longer-lasting front than the EAGF. Additionally, the WAGF shows a larger magnitude and deeper upwelling and downwelling regions. The WAGF intensification and vertical velocities development are explained through i) frontogenesis, which shows a sharpening of surface buoyancy gradient in the presence of lateral strain rate associated with the Atlantic Jet; ii) conditions for symmetric and ageostrophic instabilities generation, which are satisfied in the mixed layer; and iii) nonlinear Ekman effects, that are enhanced by the persistent western wind blowing along the frontal direction. These mechanisms participate to generate and strengthen an ageostrophic secondary circulation responsible for vertical velocity intensification in the front. In the case of EAGF, the intensification and vertical velocities development are explained by the filamentogenesis mechanism in both the model and glider observations through a cold filament advected in the interior of the Mediterranean Sea. The EAGF intensification is characterized by a sharp and outcropping density gradient at the center of the filament, where two asymmetrical ageostrophic cells develop across the front with narrow upwelling region in the middle.

Plain Language Summary

The processes responsible for vertical velocities development at the main fronts of the Alboran Sea were analyzed combining a high-resolution realistic simulation and glider observations in spring 2018. The two fronts were found to be governed by different spatio-temporal dynamics. In the Western Alboran Gyre Front, the vertical velocities are amplified by an across-front ageostrophic circulation generated by the intensification of the front, which is the result of a horizontal density gradient increase, the presence of instabilities, and frontal winds that are associated with the Atlantic Jet and westerly winds.
On the other hand, in the Eastern Alboran Gyre Front, the vertical velocities development is associated with an across-front complex pattern described by two asymmetric ageostrophic motions produced by the frontal intensification, which are the consequence of a cold filament advecting in the interior of the Mediterranean Sea. As a result, sharp and outcropping density contours are observed in the front.

1 Introduction

Vertical velocities associated with meso- and submeso-scale structures (Mahadevan, 2016; McWilliams, 2016) generate important vertical fluxes of carbon and other biogeochemical tracers from the surface layer to depths below the mixed layer (Ruiz et al., 2019; Oguz et al., 2017). Vertical velocities are commonly very weak and characterized by small scales which make them difficult to measure. The Alboran Sea in the Western Mediterranean basin is a highly dynamic system (Renault et al., 2012). The Western and Eastern Alboran Gyre fronts are characterized by strong density gradients produced by the encountering of colder and lighter waters coming from the Atlantic Ocean with warmer and saltier waters that recirculate in the Mediterranean basin. The gradients generate large vertical velocities, which are characterized by the interaction of eddies, meanders, fronts, and filaments. These features are illustrated by high-resolution satellite images of the ocean surface (Lehahn et al., 2007; Navarro et al., 2011; Renault et al., 2012; Pascual et al., 2017), as it is illustrated in Figure 1.

The meso- and submeso-scale structures are generated in the Western Mediterranean basin are visible for instance in images of ocean color (Figure 1a) and sea surface temperature (SST) (Figure 1b). The ocean color imagery presents a large eddy where the larger concentrations of chlorophyll located on its outer part are associated with the Western Alboran Gyre Front (WAGF) (Oguz et al., 2017). On the other hand, the SST image shows a penetrating and elongated meander associated with the Eastern Alboran Gyre Front (EAGF) that introduces cold water to the interior of the Mediterranean Sea (Ruiz et al., 2019).

These oceanic fine-scales (1–100 km in horizontal, 0–1 km in vertical, and few days to several months in time dimensions) are dominated by the effects of Earth’s rotation, which constrain the motion to be largely horizontal to satisfy the geostrophic and thermal wind balance. However, as a smaller spatio-temporal scale is approximated, the ageostrophic