Predicting the Last-Mile Boundary Layer hydrodynamics in Coastal Zones, observations and models

Boundary layers play a crucial role in modeling geophysical fluid-dynamical flows, as they represent regions of ageostrophic dynamics where the physical balances of the main interior water mass break down. This study presents a combined analysis of observations and numerical modeling to examine and predict the “last-mile” boundary layer in coastal zones influencing coastal circulation. The study of Coastal Boundary Layer (CBL) hydrodynamics has received less attention in oceanic and coastal hydrodynamic studies due to challenges such as obtaining comparative measurements and developing interaction models between mesoscale and submesoscale oceanic dynamics and the coastal zone (Malanotte Rizzoli & Dell’Orto 1981; Brandini et al., 2017). This zone serves as an intermediary between areas of interest for coastal engineering and physical oceanography, hosting processes that significantly influence submesoscale vorticity production and the dispersion of biological floats, sediments, or contaminants along the coast. Predicting these dynamics requires high spatial and temporal resolution for both observations and simulations. This resolution can be achieved using X-band radar, which allows simultaneous measurement of waves and currents within 1-3 miles from the coastline, and high-resolution numerical models configured through multiple nesting techniques. In this work, we compare observations from X-band radar along the coast, capable of detecting last-mile coastal hydrodynamic features, with ultra-high resolution (<50 m) simulations of an ocean model that reproduces observed characteristics, including the generation of small vortices within the radar observation range (<2 km from the coast). The radars are located at Corniglia off the Cinque Terre (Ligurian Sea) and at Isola del Giglio (Tyrrhenian Sea). The results can be used for cross-validation of data produced independently by radar observations and numerical models, providing important insights into the dynamics of the CBL, particularly regarding the attenuation in the depth-averaged velocity profile and turbulent vorticity production. We discuss the hydrodynamic regimes contributing to the generation and development of the CBL, which show strong analogies with other boundary layers studied in geophysical fluid dynamics but are significantly influenced by coastal irregularities. Finally, we illustrate, through a coupled biogeochemical model, how this vortex production can contribute to the "fertilization" of ocean surface layers from coastal to shelf regions.

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