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Nonlinear effects on western boundary current structure and separation: a laboratory study

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The role played by nonlinear effects in shaping the structure of barotropic western boundary currents (WBCs) and in determining WBC separation from the coast has been investigated through laboratory simulations by means of the 5-m-diameter Coriolis rotating basin at SINTEF (Trondheim, Norway) in the framework of the HYDRALAB-III project. The laboratory setup consists of two parallel rectangular channels separated by an island and linked by two curved connections: in the first channel, a piston is forced at a constant speed U ranging from 0.05 to 3 cm/s over a distance of 2.5 m, producing a virtually unsheared current at the entrance of the second channel. In the latter, a linear reduction of the water depth provides the topographic beta-effect that produces the westward intensification. Nearly steady currents are obtained and measured photogrammetrically over a region of about 1 m2.

The broad range of piston speeds permitted by the mechanical apparatus has allowed us to achieve an unprecedented coverage of the range of nonlinearity for WBCs in terms of experimental data, so that the cross-stream WBC profile could be analyzed from the nearly linear Munk-type case (e.g., for U=0.1 cm/s with T=30 s, where T is the rotation period of the basin) up to the more realistic highly nonlinear limit (particularly significant is the case U=1 cm/s and T=30 s, which is close to be dynamically similar to the Gulf Stream). Thanks to the large size of the rotating basin, cross-stream widths of the simulated WBC as large as 80 cm could be obtained. Moreover, in order to analyze the process of WBC separation, coastal variations have been introduced along the western boundary in the form of wedge-shaped continents with different coastline orientations, whose northern limit corresponds to an idealized Cape Hatteras. While weak WBCs follow the coast also past the cape, for sufficiently strong nonlinear effects the current detaches from the coast as a consequence of flow deceleration induced by the interaction with the inclined western boundary. It is interesting to notice that the transition between these two behaviors is marked by a case that is very close to the one that is dynamically similar to the Gulf Stream.