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On the Instability of Buoyant Coastal Currents

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The fate of buoyant water discharged into the coastal ocean from river or meltwater runoff is a problem of preeminent interest in coastal management, physical oceanography, and climate research. In the northern hemisphere, buoyant water introduced into the ocean is expected to turn to the right of the discharge location and form a buoyant gravity current flowing along the coast. Whilst the fate of coastal discharges has been intensively studied from field observations, laboratory experiments, analytical theories, and numerical simulations, the mechanisms responsible for the observed instability of buoyant currents produced from coastal discharges are not completely understood.

Here the instability of a coastal buoyant current produced from the discharge of glacial meltwater is studied using idealized numerical experiments with a primitive-equation circulation model. It is found that glacial water released from the coast produces a surface plume in front of the release location, turns to the right, and leads to a buoyant current flowing at a speed of O(1 m/s) along the coast. Over the course of the numerical integration, the coastal current becomes unstable and develops dipolar vortices along its offshore boundary. The vortices are the largest near the glacial water inflow and migrate away from the discharge location at a speed of O(1 cm/s). They are asymmetric, with the region of cyclonic flow occupying a larger area than the region of anticyclonic flow, given them the appearance of breaking “backwards” relative to the direction of the current. The vortices occur for both free-slip and no-slip conditions imposed along the coast, suggesting that their development is not associated with vorticity continuously generated by the frictional retardation of the flow at the boundary. Numerical results are compared to laboratory results published in the literature and interpreted in the light of the theory of the baroclinic instability in a two-layer model (a surface buoyant layer flowing relatively to a deeper heavier layer). The implications of our results for the simulation of buoyant coastal discharges with coarse-resolution ocean models, such as used in climate studies, are clarified.