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Bifurcation and the dynamics of nonlinear outflows

D. Nof

Department of Oceanography, Florida State University, Tallahassee, Florida, USA

The classical problem of a point source (situated along a southern boundary) emptying buoyant water into a (β-plane) ocean is considered. We take into account that such an inviscid outflow does not simply turn to the right. Rather, it bifurcates into two branches, a steady branch which does turn to the right (eastward) and an unsteady branch which periodically sheds eddies to the left (westward). This partition is because a simple turn to the right of the entire outflow leaves the outflow's longshore momentum flux unbalanced, creating a paradox. In contrast, the branching allows the westward drifting eddies (westward branch) to balance the momentum-flux of the steady current (eastward branch).

A simple, nonlinear analytical solution is presented. Using the idea that the eddies grow slowly relative to their rotation rate, we show that an intensely nonlinear (i.e., large Rossby number) outflow dumps most of its mass flux (Q) into the eddies (66%). (The remaining 33% goes into the eastward longshore current.) By contrast, a weakly nonlinear outflow (i.e., an outflow with weak anticyclonic vorticity - αf, where α is analogous to the Rossby number and is much smaller than unity and f is the Coriolis parameter) dumps most of its water into the downstream current [(1-2$\alpha)Q$]. Unexpectedly, this partition of mass turns out to be the same as the one taking place on an f-plane. (Note that this is not at all the case for the southward outflow, nor is it the case for either the eastward or westward outflow, where β alters the balance drastically.) Although the above partition of mass is independent of β, the size of the eddies generated by the above process is a function of β. It is given by [768g'Q/$\beta\pi f^2\alpha$(2-α)(1+2α)]$^{1/5}$, where g' is the reduced gravity. This gives a reasonable estimate for both the Gulf of Mexico Loop Current eddies' size and generation frequency. Numerical simulations are in agreement with the above nonlinear solution.