Abstract View

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Depth Dependence of Bottom Stress and Quadratic Drag Coefficient for Barotropic Pressure-Driven Currents

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ABSTRACT

A level 2½ turbulence closure model is used to investigate the dependence on water depth H of bottom stress τ_b and quadratic drag coefficient C_d for a steady barotropic pressure-driven current in unstratified water when the current is the primary source of turbulence. For spatially uniform pressure gradient and bottom roughness z_0 the magnitude $|\tau_b|$ increases from small values in shallow water to a maximum (at a depth $\sim 0.004\ U_0/f$ where U_0 is the geostrophic current speed derived from the pressure gradient and f is the Coriolis parameter) at which the dynamics changes from being depth-limited to being controlled by similarity scales. As the depth increases further, $|\tau_b|$ decreases to its deep-water value that is 15% to 19% less than the maximum. The angle θ of the bottom stress relative to the geostrophic direction decreases rapidly from 90° in very shallow water, reaching its deep-water value ($\sim$ 11°–21°) at a somewhat shallower depth than does $|\tau_b|$. At the maximum stress θ is 8° larger than the deep-water angle. A set of computationally efficient formulas matched to the model results gives $|\tau_b|$ and θ for all combinations of U_0, H, f and bottom roughness z_0. Comparison with a variety of other models satisfying Rossby similarity over oceanographic ranges of parameters shows agreement of $\sim$ 10% for $|\tau_b|$ and $\sim$ 5° for θ.

The coefficient C_d of the quadratic drag law relating $|\tau_b|$ to the vertically averaged velocity is found to be approximated reasonably well by a formula from nonrotating channel theory in which the coefficient depends only on the ratio H/z_0. The direction of the bottom stress relative to the vertically averaged velocity is equal to the geostrophic veering angle ($\sim$ 11°–21°) in deep water and decreases to $\sim$ 5° for a range of intermediate depths ($\sim$ 0.004–0.01 U_0/f) where it is relatively independent of external Rossby number U_0/fz_0; the angle becomes less in shallower water.

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