Abstract View

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Effects of Vertical Viscosity on Kelvin Waves

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ABSTRACT

An analytic theory is presented for free, barotropic Kelvin waves subject to constant, vertical eddy viscosity on a semi-infinite, f-plane shelf of constant depth bordering a straight, vertical coast. A coastal boundary condition closes the solutions of Sverdrup (1927) and Fjeldstad (1929) by requiring that the component of vertically integrated, volume transport normal to the coast be zero just seaward of coastal boundary layers. This condition on offshore transport is then found to hold everywhere seaward of the coastal layers. One condition on the complex wavenumber components is the dispersion relation in which frictional bottom stress appears in an equivalent depth. The coastal boundary condition then fixes the wavenumber components. The effects of vertical viscosity are found to depend on the frequency ω' relative to the inertial frequency and on the Ekman number E or, more conveniently, the vertical scale $E^{1/2}$ of steady, bottom Ekman layers. Below a frequency dependent on $E^{1/2}$, low-frequency Kelvin waves are diffusive, rather than wavelike. These Kelvin "waves" have backward slanting cophase lines which at very low frequencies make the same angle to the coast as do the corresponding lines for steady flow. The offshore decay scale at low frequencies is greater than the Rossby radius, and the alongshore wavelengths are significantly shorter than the inviscid wavelength. There is no special behavior near the inertial frequency except that the cophase lines slant slightly forward at small $E^{1/2}$, and that the bottom boundary layer extends to the surface. In general, the alongshore attenuation per unit distance increases with increasing ω' or $E^{1/2}$. For $\omega' \ll 1$ the water motion forms narrow ellipses with Ekman veering in the quasi-steady bottom boundary layer. Near $\omega' \approx 1$, the ellipses are broader with a counter-clockwise sense (Northern Hemisphere) near the bottom and clockwise near the surface; there is still some veering of the ellipses, and the motion at depth tends to lead that above. For $\omega' \gg 1$, the ellipses are again narrow but tend to parallel the coast with little veering. The bottom boundary layer is thinner with a Stokes, rather than an Ekman, scale; and motion at depth loads significantly that above.

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