Abstract View

Volume 14, Issue 2 (February 1984)

Journal of Physical Oceanography
Article: pp. 364–377 | Abstract | PDF (947K)

On Wind-Driven Mixed Layers with Strong Horizontal Gradients—A Theory with Application to Coastal Upwelling

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(Manuscript received August 1, 1983, in final form November 1, 1983)

DOI: 10.1175/1520-0485(1984)014<0364:OWDMLW>2.0.CO;2

ABSTRACT

A theory of a two-dimensional wind-driven diabatic ocean mixed layer with strong horizontal gradients is formulated analytically. An equation that allows the relaxation of the strict Ekman balance—Coriolis force against wind stress—is derived from a careful consideration of the cross-gradient momentum balance. The relaxation scale depends implicitly on mixed-layer depth and density distribution which themselves are determined by mixing, entrainment and diabatic processes and in simple situations reduces to the familiar baroclinic Rossby radius of deformation. When mixed-layer depth or density contrast at the mixed-layer base becomes small, this relaxation scale becomes small and characterizes the width of high-gradient front-like features in the mixed layer.

The theory is applied to the situation of coastal upwelling. The reduced mixed-layer equations are solved numerically. Wind-driven motion divergence, initially on the scale of the Rossby radius, O(10 km), is induced by the presence of a coastline, and thins the mixed layer. Entrainment mixes 1ower layer water, virtually undiluted, into the surface water and drastically reduces the vertical density contrast. These twin effects reduce the width of the upwelling zone, consistent with scaling arguments. A front forms between dense upwelled water and light offshore water in the time that the vertical velocity associated with the coastal motion divergence takes to bring the pycnocline to the surface roughly 20 h in typical situations. Then the front is advected offshore by typical mixed-layer velocities of order 3 cm s^{-1}. Numerical solutions confirm the suggestion of scaling arguments that the horizontal width of the front is very narrow, though finite—of order of 100 m. Item is a slight double-celled circulation associated with this front, with motion convergence in the mixed layer inshore of it and divergence on its offshore edge.

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