Abstract View

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A Numerical Investigation of Mixed-Layer Dynamics

Pijush K. Kundu

Ocean Sciences Center, Nova University, Dania, FL 33004

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ABSTRACT

The structure of the stratified turbulent upper mixed layer of the ocean has been numerically investigated by using the turbulence closure model of Gibson and Launder, under the action of an impulsive wind stress τ_0 and zero surface heat flux. The values of buoyancy and Coriolis frequencies assumed are $N = 0.94 \times 10^{-2}\ \mathrm{s}^{-1}$ and $f = 10^{-4}\ \mathrm{s}^{-1}$, respectively. The solutions indicate that the turbulent diffusion terms, small in general, transfer kinetic energy downward, although its effect on the deepening is negligible. Let t_i be the time in inertial periods and u_* be the friction velocity. Then for $0.05 < t_i < 0.3$, the rate of increase of potential energy in the water column varies as $\partial(\mathrm{PE})/\partial t \propto t^{1/2}$, rising to a maximum of $\sim 1.1u_*^3$ and implying a mixed layer depth $h \propto t^{1/2}$ as in the Pollard-Rhines-Thompson (PRT) model. For $1 < t_i < 6$, $\partial(\mathrm{PE})/\partial t$ decreases only slightly from a quasi-steady value of $\partial(\mathrm{PE})/\partial t \approx 0.25u_*^3$, implying a deepening rate slightly smaller than the Kraus-Turner $h \propto t^{1/3}$. The reason for this difference in behavior for the two time ranges is the separation of the flow into a depth-independent inertial oscillation and a quasi-steady shearing flow that carries almost all the turbulent stresses in the water column. The mechanism for deepening is always the lifting of heavier mass by the locally generated turbulence at the base of the mixed layer. For very large times ($t_i > 12$), $\partial(\mathrm{PE})/\partial t$ drops sharply, and no deepening was detected with a vertical resolution of 1 m. The assumption necessary to derive the PRT energy equation, namely, that the depth-integrated dissipation nearly balances $\tau_0 \cdot (U_0 - \hat{U})$, where U_0 is the surface velocity and $\hat{U}$ the depth-averaged velocity, is approximately valid. For $t_i < 0.25$, the PRT bulk Richardson number criterion is equivalent to a local critical gradient Richardson number criterion, and is due to the self-similarity of the solutions and the consequent thickening of the "interface." The self-similarity breaks down for larger times, either because of the Coriolis forces becoming more important or because of the appearance of a sharp interface due to a nonlinear mechanism, whichever is earlier. An imposition of a kinetic energy input at the sea surface, so as to simulate the wind-wave flux, has certain desirable features.

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Headquarters: 45 Beacon Street Boston, MA 02108-3693
DC Office: 1120 G Street, NW, Suite 800 Washington DC, 20005-3826
amsinfo@ametsoc.org Phone: 617-227-2425 Fax: 617-742-8718
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