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Entrainment and mixing processes in downslope gravity currents.

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Downslope density currents play a significant role in vertical water exchange in near-shore zones of lakes, seas and oceans. Entrainment and mixing processes at the density currents' interface has been described by many authors (e.g., Barenblatt, Benjamin, Britter & Linden, Simpson, Turner, Holyer & Huppert, Baines), however further understanding is still required.

Main objective of the present work is the analysis of mixing processes, associated with density current propagating along the bottom, based on examination of simulated flows. The simulations were carried out by using a non-linear two-dimensional XZ-model, which solves the following system of equations: $D\omega/Dt = (g/\rho_0)\,(\partial\sigma/\partial z) + \nu_T\Delta\omega$; $\Delta\psi = \omega$; $D\rho/Dt = k_T\Delta\rho$; $Dc/Dt = k_T\Delta c$, where ω – is the flow vorticity, ψ – stream function, $g=982$ cm/s^2, $\rho_0=1$ g/cm^3 – fresh water density, ρ – saline water density, x, z - horizontal and vertical coordinates, respectively; t – time; $D/Dt = \partial/\partial t + u\partial/\partial x + w\partial/\partial z$; $\Delta = \partial^2/\partial x^2 + \partial^2/\partial z^2$; $\nu_T = \nu_0 + c\cdot\nu_{eff}$, $k_T = 0.5\nu_T$ – turbulent diffusivity and viscosity coefficients, $\nu_{eff} = \sqrt{}\mathrm{Re}\cdot\nu_0$; $\mathrm{Re} = u_0\cdot h_0/\nu_0$; $\nu_0 = 0.015$ cm^2/s; $\nu_{eff} = 0$ at $t=0$; $c=c(x, z, t)$, $0.0\leq c\leq 1.0$ - dimensionless concentration of tracer of the bottom current water mass.

For description and comprehension of specific features of mixing processes in downslope currents the approach suggested by Baines (J. Fluid Mech. 2001, vol. 443) is used, based upon employing local parameters and local averaging. Following Baines, four dimensionless parameters were chosen for the description of the basic flow: slope angle θ, Richardson number $\mathrm{Ri} = g'd^3\cos q/Q^2$, Reynolds number $\mathrm{Re} = Q/\nu$ and $M = Q/(g'D^3)^{0,5} = QN^3/g'^2$ – the ambient fluid stratification coefficient; here, ν – kinematical viscosity, d - average thickness of the downflow. Two important additional parameters were defined: N – buoyancy frequency, and an associated parameter D – the depth below the source where the initial density of the fluid in the tank equals to that of the inflow. Local values of Q, volume flux, and N are used, as well as $g'(z,t) = g\Delta\rho(z,t)/\rho$, where $\Delta\rho(z,t)$ is the difference between the mean density of the downflow at height z, and the environmental fluid at the same level.

Turbulent transfer is described using entrainment coefficient E_e, detrainment coefficient E_d, upper fluid layer drag coefficient k and bottom drag coefficient C_{DL}, which are derived out of three basic characteristics obtained during laboratory experiments: downflow average thickness d, level of the outflow of the remaining fluid at the bottom of the downflow z_b and the form of the profile of net downslope flux Q(z) and mean outflow velocity from the downflow V(z).

Overall, 30 flows were simulated using grids 501x221, 701x321 and 1001x521 ($\Delta x=\Delta z=0.05$) were examined. Results of the analyses gave estimates for entrainment velocity and mixing efficiency for the downslope density current propagating in two-layer fluid.

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