A numerical study on turbulence of the tidally-induced bottom boundary layer in the rotating frame

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The tidally-induced bottom boundary layer (TBBL) which is formed above the ocean bottom by tidal currents makes a contribution to water mixing through shear instability. Its properties and mixing effects have not been understood so much under the Earth's rotation. In this study, therefore, we execute three-dimensional numerical experiments to investigate the turbulent TBBL in the rotating frame under a neutrally stratified condition.

The governing equations are the non-hydrostatic equations of motion and the equation of continuity under the rigid-lid approximation. The model basin is a rectangular one connected periodically in both horizontal directions. A no-slip (free-slip) condition is imposed at the bottom (the sea surface). The background tidal flow is given by an analytically determined oscillating flow. We execute four experiments changing the temporal Rossby number Ro_t = sigma / f, 0.5, 0.95, 1.05 and 2.0, where sigma and f are the tidal frequency and the Coriolis parameter. The time-series of velocity field of ten tidal cycle length is used for the following analysis after the statistically steady state is established.

The turbulent flow shows similarity in the vertical profiles of mean velocity and the Reynolds stresses, when they are normalized by the 'outer scales', i.e. the frictional velocity u_Λ and delta = u_Λ / |f + sigma|(sigma is positive when the tidal ellipse rotates anti-clockwise). The vertical profile of the normalized mean velocity coincides with that of the turbulent Ekman layer. To the contrary, similarity is not found in the perturbation field (velocity and length scales). This is because inertial waves are excited to enlarge velocity scale and to suppress length scale in the upper region when Ro_t is nearly unity.

Next, to investigate the mixing effect of the turbulent TBBL, we estimate the apparent diffusivity by executing passive tracer experiments in the obtained velocity field. The diffusivity shows similarity again when normalized by the outer scales. This shows that the inertial waves make little contribution to the mixing probably because breaking waves does not occur due to the low Reynolds numbers of the experiments (1000-4500). This similarity means that the diffusivity can be estimated by the latitude (f) and the tidal frequency (sigma) and amplitude (u_Λ). Applying the results to the actual situation, the effective mixing may occur when Rot is nearly unity, i.e. near the critical latitude. The dimensional apparent diffusivity reaches 400-600 cm^2/s with the tidal amplitude of 8.5cm/s when Ro_t is 0.95 and 1.05, while 50 cm^2/s at most when Ro_t is 0.5 and 2.0.

While we obtained basic characteristics of the turbulent TBBL under the neutrally stratified condition, stable stratification needs to be taken into account to further understand the turbulent TBBL in the real ocean.