Observational and numerical studies of tidal mixing enhanced over abyssal rough bathymetry

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We conducted complete microstructure measurements from the sea surface down to the bottom using a microstructure profiler, VMP-X, at 7 locations over the Izu-Ogasawara Ridge to image the vertical structure of bottom-enhanced tidal mixing over abyssal rough bathymetry. The observations were carried out on December 3-5, 2016 during the cruise of T/V *Shinyo-Maru* of the Tokyo University of Marine Science and Technology. The density stratification and the fine-scale vertical shear of horizontal current velocity were both simultaneously observed at each location using a Conductivity-Temperature-Depth profiler (CTD) with a Lowered Acoustic Doppler Current Profiler (LADCP). The bottom bathymetry was obtained from the multi-beam bathymetric data compiled by the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), whereas the barotropic tidal flow was obtained from the results of a 3-D tidal simulation (Niwa and Hibiya, 2014).

Bottom bathymetry roughness can be classified into "*weakly rough*", "*moderately rough*", and "*strongly rough*", whereas the barotropic tidal flow largely consists of a superposition of M_2 and S_2 tidal constituents so that its amplitude varies with the spring-neap tidal cycle. It is found that the vertical profile of the turbulent dissipation rates over the "*weakly rough*" bottom bathymetry under strong tidal flow and that of the turbulent dissipation rates over the "*moderately rough*" bottom bathymetry under weak tidal flow both exhibit a trade-off relationship between turbulent dissipation rates on the bottom and their vertical decay scales. Over the "*moderately rough*" and "*strongly rough*" bottom bathymetry under medium and strong tidal flow, such a tradeoff relationship is no longer recognized and the bottom-enhanced mixing region extends vertically upward over the bottom bathymetry.

Taking into account the bottom bathymetry, the density stratification and the amplitude of the barotropic tidal flow at the time of microstructure measurements as well as the background Garrett-Munk (GM) internal waves, we next carry out numerical simulations for the observed bottom-enhanced mixing process at each location. It is confirmed that most of the observed features mentioned above are consistent with the predictions based on the eikonal calculations by Hibiya et al. (2017). So long as tide-topography interaction is weak, the internal waves emanating from the bottom bathymetry are linear internal tides. In this case, as the dominant wavenumber of bottom bathymetry increases, the vertical group velocity of the generated linear internal tides decreases so that the internal tides emanating from the bottom bathymetry give up most of their energy to turbulent mixing processes through the interaction with the background GM internal waves within a short distance from the bottom bathymetry. As the tide-topography interaction becomes stronger, on the other hand, the generated internal waves transform from linear internal tides to quasi-steady internal lee waves while significantly increasing their vertical group velocity. Consequently, the quasi-steady internal lee waves carry energy available for turbulent mixing much further upward while losing it through the interaction with the background GM internal waves, creating vertically extended mixing hotspots over abyssal rough bottom bathymetry.

Keywords: Abyssal mixing, Tidal flow amplitude, Ocean bottom roughness