Observations of bands of strong turbulence associated with high wavenumber near-inertial wave shear below the Kuroshio origin using a tow-yo microstructure profiler

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The upstream Kuroshio flows through Okinawa trough and Tokara island chains. In these regions, latitude is near 28.9 degree N, as known as the critical latitude, where M_2 internal tides can be converted to near-initial internal waves of high vertical wavenumber through parametric subharmonic instability and associated strong turbulent mixing is expected (MacKinnon and Winters 2005, Hibiya and Nagasawa 2004). Furthermore, the Kuroshio has to go through the region near the continental shelf of East China Sea and shallow seamounts near the Tokara strait, where the lee wave generation by the geostrophic current over the topography and associated near-inertial waves (Nikurashin and Ferrari 2011) are likely to occur. Also, the Kuroshio is forced to meander to flow southward after it approaches off Kyushu, where the spontaneous generation of near-inertial internal waves is possible (Nagai et al. 2015). The in-situ observations by Rainville and Pinkel (2004) using the ADCP and LADCP show that large amplitude near-inertial wave shear of high vertical wavenumber is found in and below the Kuroshio thermocline. These near-inertial internal waves can be trapped on the south side and/or underneath the Kuroshio due to its strong negative relative vorticity and vertical shear of the horizontal geostrophic flow (Kunze 1985, Whitt and Thomas 2013), and possibly break into microscale turbulence. However, the in-situ observations of microscale turbulence is very limited in these regions. In this study, in-situ observations of microscale turbulence near the Tokara strait were conducted during Nov. 12-20 2016 using R/T/V Kagoshima-maru. The new underway tow-yo microstructure profiler (Underway-VMP) was used, and we successfully measured turbulence along and across the Kuroshio Front with 1-2 km lateral resolution. The shipboard ADCP measurements show bands of high vertical wavenumber shear nearly along isopycnal, which are reminiscent of the results by Rainville and Pinkel (2004). The ray path calculated assuming quiescent condition suggests that the observed shear bands are caused by the internal waves of near-inertial frequencies. The hodograph of shear and rotary spectra suggest that these internal waves propagate energy both up and downward directions. The measured turbulent kinetic energy dissipation rates along and across the Kuroshio show bands of strong turbulence >$O(10^{-7}$ W/kg) clearly associated with the high vertical wavenumber near-inertial shear, suggesting that propagating near-inertial waves underneath the Kuroshio induces the strong turbulent mixing. The comparison of observed turbulent dissipation rates with the strain based internal-wave parameterization by Kunzel et al. (2006) shows certain proportionality between the observations and the parameterization, which supports the conclusion that the measured strong turbulence is caused by the observed high vertical wavenumber near-inertial waves. The estimated vertical eddy diffusivity using the method of Osborn (1980) with observed dissipation rates and stratification, shows $O(10^{-4}$ $m^2/s)$ of eddy diffusivities on average within these bands of turbulent layers. These results suggest that the high vertical wavenumber near-inertial waves propagating in and below the Kuroshio near the Tokara strait could cause large impacts on the local watermass formations, tracer and momentum mixing, and associated biogeochemical responses in its downstream.

Keywords: Kuroshio, near-inertial shear bands, bands of strong turbulent layer