Fates and dynamical roles of pinch-off mesoscale eddies originated from the Kuroshio Extension Jet

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Mesoscale eddies are ubiquitous in the world ocean that frequently collide with currents, leading to substantial alteration of the associated dynamics. For instance, the Kuroshio plays a major role in preconditioning the coastal environment around Japan through poleward heat and material transport from the subtropics, while its path is known to meander occasionally by eddy collisions. Pinch-off mesoscale eddies that detach intermittently from the Kuroshio tend to travel westward as Rossby waves and have been found to collide with the Kuroshio again to alter oceanic and coastal environment through alteration of the Kuroshio path.

For realization of such processes, we applied the eddy detection algorithm used in Liu et al. (2012) to ARMOR3D. The ARMOR3D dataset is a 3D global currents and density data set that is reconstructed from a combination of extensive satellite data and in situ observations based on the geostrophic thermal wind relation and statistical methods as described in Guinehut et al. (2012). By conducting several sensitivity tests, we introduced constraints on vorticity magnitude of detected mesoscale eddies and their relative positions to the Kuroshio path to determine pinch-off eddies near the Kuroshio Extension (KE) region. It was found that the constraint on vorticity magnitude of the detected individual eddies greater than $0.15f$, where f is the local Coriolis frequency, throughout eddy lifetime is significant to successfully isolate pinch-off eddies.

With this constraint, we discovered that most of the detected pinch-off eddies are cyclonic on the south side of the KE region, while anticyclonic eddies are predominant on the north side. The former occurred 2.5–3 times as often as the latter, although in the entire North Pacific, cyclonic eddies occurred only 12.1% more frequently than anticyclonic eddies. Hence, it is considered that this cyclone dominance in the pinch-off eddies from the Kuroshio is a unique feature. We also succeeded to determine pinch-off eddies that collide again with the Kuroshio by introducing another constraint, which is the threshold distance between the Kuroshio path and terminal positions of pinch-off eddies traveled westward. In several selected cases with these constraints, comparisons of the surface temperature and salinity before and after the eddy collisions clearly exhibit that the alteration of the Kuroshio path due to eddy collisions is quite influential in modifying the oceanic structures. It was also found that the pinch-off eddies occasionally interact with other mesoscale eddies to modify the upper-ocean structure pronouncedly.

The Kuroshio path in the KE region is known to vary on annual to decadal time scales, where it was rather stable for 1993-1995 and 2002-2005, whereas largely meandered unstably for 1996–2001 and 2006–2009. During the first unstable periods, the number of cyclonic pinch-off eddies were significantly increased in the area between 144 °E and 150 °E for 1996–2001. However, no significant increase was observed during the other unstable period for 2006–2009. More than 70% of the pinch-off eddies that collided with the Kuroshio appeared during the unstable periods, suggesting that the stability of the Kuroshio path in the KE region is a key influencer on vigorous generation of such colliding pinch-off eddies.

Keywords: pinch-off mesoscale eddy, Kuroshio, eddy tracking algorithm, ARMOR3D

