Wake eddies and lee waves generated by the North Equatorial Current and tidal flows at Peleliu, Palau

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Abstract. The North Equatorial Current (NEC) transports water westward across the tropical Pacific into the western Pacific, where it flows past numerous islands and over submarine ridges. As the currents flow over and around this abrupt topography, momentum and energy are transferred downslope into lee waves and wake eddies. At the south point of Peleliu Island, a combination of strong NEC currents and tides flow over a steep, submarine ridge. Small (∼1-km diameter) wake eddies are observed in the lee, generated every tidal cycle. As each eddy recirculates and encounters the incident flow again, the associated front contains interleaving temperature structures with 1–10 m horizontal extent. Turbulent dissipation exceeds $10^{-5}$ W kg$^{-1}$ along this tilted and strongly sheared front. Thus energy cascades suddenly from the NEC via the submesoscale to turbulence. Farther downstream, a train of such submesoscale eddies can be seen in spice, extending at least 50 km. Internal lee waves are also observed over the submarine ridge. The mean form drag exerted by the waves (i.e., upward transport of eastward momentum) is sufficient to substantially reduce the westward flow if not for other forcing, and is as large as the bottom drag at about 0.5 Pa. The observed turbulent dissipation rate is also consistent with local dissipation of lee wave energy.
1. Introduction

Steady flow past a point and submarine ridge produces wake eddies and lee waves as the flow goes around and over topography [Warner and MacCready, 2009]. The incident flow loses both energy and momentum to both wake eddies and lee waves, which in turn can either deposit the energy and momentum locally or transport energy and momentum away from the topography. Palau is a particularly good site for observing these processes, as the topography rises steeply into the North Equatorial Current (NEC) and open ocean conditions are noted at the reef edge at hourly to interannual time scales [Schönau and Rudnick, 2015; Colin, 2018; Schramek et al., 2018]. At the south point of Peleliu Island, we observed energy from the NEC, which has scales from the mesoscale (>100 km) to basin scale (>1000 km), cascade dramatically into 1-km lee waves and submesoscale (typically length scales <10 km) wake eddies (Figure 1), then into fronts at 1–10 m scales, and finally into turbulence at 1 cm scales.

At the north point of Palau (Velasco Reef; green square in Figure 1a), a broad spectrum of eddying wakes is observed. The strength of an eddying wake is measured in part by the Rossby number, which is the ratio of the eddy’s rotation [or vorticity; Rudnick et al., this issue] to Earth’s rotation: $Ro = \zeta/f = (\partial_x v - \partial_y u)/f$, where $f$ is the Coriolis frequency and distance $(x, y)$ and currents $(u, v)$ are positive eastward and northward. Very near the separation point, small scale ($\sim$ 1-km diameter) high vorticity $(Ro \sim 30)$ wake eddies are seen, which are strongly influenced by tidal flow [MacKinnon et al., 2019]. Farther afield, a mesoscale wake is observed with a lateral scale of $\sim$ 70 km, comparable to the size of the topography [in this case Velasco Reef; Zeiden et al., 2019]. During periods of westward flow, the observed cyclonic (anticlockwise) wake had an average $Ro = 0.3$, and exceeded 1 during periods of strong flow. The relationship between the submeso- and