Influence of the large-scale mean flow shear on the turbulent mixing in the Southern Ocean

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The Southern Ocean is a special area where the Antarctic Circumpolar Current (ACC), the bottom-reaching geostrophic flow with vigorous eddies, coexists with the energetic internal waves such as wind-induced near-inertial waves and bottom-generated internal lee waves. In this region, the existing finescale parameterization (e.g., Gregg et al. 2003) tends to overestimate the actual turbulent dissipation rates ε (e.g., Waterman et al. 2014). This suggests that the applicability of the existing finescale parameterization, formulated on the basis of wave-wave interaction within the background internal wave field, to the turbulent mixing processes in the ACC region is limited.

The previous theoretical studies (Waterman et al. 2014, Kunze and Lien 2019) speculated that the interaction between bottom-generated internal lee waves and the background mean flow shear might suppress the local turbulent dissipation, causing the overestimates of ε by the existing finescale parameterization. Their hypothesis (hereinafter, referred to as Waterman’s hypothesis), however, is too simplified to explain the observed phenomenon.

In the present study, assuming that the observed magnitude of the background flow shear coexists with the internal wave field, we carry out a series of eikonal calculations (e.g., Henyey et al. 1986) to see whether or not the overestimates of ε by finescale parameterization can be explained in terms of the wave-mean flow interactions.

First, we examine how a single bottom-generated lee wave packet interacts with the background Garrett-Munk (GM) internal wave field (Munk 1981) with the sheared mean flow. Although the amount of energy absorbed into the background wave field does not change even when the mean flow shear with the observed magnitude is incorporated, the mean flow shear significantly shortens the lifetime of the lee wave packet so that the turbulent mixing is enhanced. Second, we examine the evolution of various internal wave packets consisting of the GM internal wave field in the presence of the mean flow shear. In such a realistic situation, the mean flow shear efficiently promotes the breaking of low-wavenumber, near-inertial internal waves, again resulting in enhanced turbulent mixing. The finescale parameterization estimating ε only in terms of the internal wave spectrum, therefore, underestimates ε in the presence of the sheared mean flow. All of these are quite contrary to Waterman's hypothesis. It should be noted, however, that how much the finescale parameterization would underestimate ε depends on the strength of the WKB scale separation between each test wave and the background wave field assumed in the eikonal calculations.

Observed results in the Southern Ocean have shown that the finescale parameterization tends to overestimate ε in the existence of the sheared mean flow (e.g., Waterman et al. 2014), which seems to be inconsistent with the present eikonal calculations. Takahashi and Hibiya (2020, Ocean Sciences Meeting), however, show that such overestimating tendency is due to the distortion of the vertical wave number spectra of internal wave energy, which is correlated with the geostrophic shear.

Keywords: Antarctic Circumpolar Current, turbulent mixing, wave-mean flow interaction