The interior submesoscale route to dissipation of balanced mesoscale energy

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An estimate of interior dissipation of mesoscale energy in the world oceans is presented based on high-resolution simulations of the non-hydrostatic Boussinesq equations in an idealized domain. Analysis of such simulations reveals that a developing baroclinic instability can lead to secondary instabilities that cascade a small fraction of the energy forward to unbalanced scales. In particular, mesoscale shear and strain resulting from the hydrostatic geostrophic baroclinic instability drive frontogenesis, and the fronts in turn support ageostrophic secondary circulation and instabilities. These two processes acting together lead to a quick rise in dissipation rate which then reaches a peak and begins to fall slowly when frontogenesis slows down; eventually balanced and imbalanced modes decouple. Dissipation of balanced energy by imbalanced processes scales exponentially with Rossby number of the base flow. We expect that this scaling will hold more generally than for the specific setup we consider given the fundamental nature of the dynamics involved. A break is seen in the total energy spectrum at small scales: While a steep $k^{-3}$ geostrophic scaling (where $k$ is the three-dimensional wavenumber) is seen at intermediate scales, the smaller scales display a shallower $k^{-5/3}$ scaling, reminiscent of the atmospheric spectra of Nastrom & Gage. At higher Ro, the vertical shear spectrum has a minimum, like in some relevant observations.