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Comparison of free-surface and rigid-lid finite-element models of barotropic and baroclinic instabilities

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Barotropic and baroclinic instabilities are well-known processes in geophysical fluid dynamics. The existence of atmospheric and oceanic meanders can be explained by the instability of zonal currents with respect to wave disturbances of small amplitude. Most theoretical and numerical results – e.g., stability conditions, growth rates, wavenumber of fastest growing mode – have been obtained by considering rigid-lid or, at best, quasi-geostrophic formulations. They both eliminate fast-propagating surface inertia-gravity waves and permit to focus on processes that evolve more slowly without computing an extraneous variable. We propose to compare free-surface and rigid-lid finite element one-layer and two-layer models and assess their ability to represent barotropic and baroclinic instabilities. In particular, we study how both models satisfy stability conditions and conserve integral properties such as total energy and potential vorticity. Energy conversions from basic state kinetic and potential energies to perturbations is examined. We also investigate the role of the free surface and how it influences the results obtained with rigid-lid models.