Balance and imbalance in non-hydrostatic rotating stratified turbulence

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It is now well established that two distinct types of motion occur in geophysical turbulence: slow motions associated with potential vorticity and fast oscillations due to the spontaneous generation of inertia-gravity waves (IGWs). In real flows, deviation from balance in the form of inertia-gravity waves or "imbalance" have often been found to be small. Here we examine the extent to which balance holds in rotating stratified turbulence.

Using the non-hydrostatic fluid dynamical equations under the Boussinesq approximation, we examine a number of turbulence simulations spanning a range of different values of Rossby numbers ($Ro \equiv |\zeta|_{\max}/f$) and the frequency ratios ($c \equiv N/f$) where ζ is the relative vertical vorticity, f is the Coriolis frequency and N is the buoyancy frequency. We diagnose the level of balance/imbalance using two different techniques, one based on using time integration of the full equations to minimise the IGWs (Optimal PV balance), the second based on a simple asymptotic expansion in the Rossby number (nonlinear quasi-geostophic balance). Diagnoses of the level of balance in our simulations reveal the dominance of balance for surprisingly large Rossby numbers, up to nearly unity. Although unbalanced motions increase with increasing Rossby number, their influence is significantly weaker than the balanced motions. For Rossby numbers $Ro \leq 0.5$, the dynamics of rotating stratified turbulence is similar to quasi-geostrophic turbulence.