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# On the hydrostatic approximation in rotating stratified flow

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Hydrostatic models were and still are the workhorses for realistic simulations of the ocean dynamics, especially for climate applications. The hydrostatic approximation is formally first order in $\gamma=H/L$, where $H$ is the vertical and $L$ the horizontal scale of the phenomenon considered. For stratified rotating flow the dynamics can be separated in balanced flow and wave motion. It is shown that for the linear balanced motion the hydrostatic approximation is exact and for wave motion it is second order, obtaining the leading prefactors. The validity of the hydrostatic approximation therefore also relies on the ratio of the amplitude of wave motion to balanced motion. This ratio adds considerably to the quality of the hydrostatic approximation for larger scale flows in the atmosphere and the ocean.

Imposing the divergenceless condition is a linear projection of the dynamical variables in the subspace of divergenceless vector fields, for both the Navier-Stokes and the hydrostatic formalism. Both projections are local in Fourier space.

Calculating the difference of the two projections, the expression of the error, scaling and prefactors, done by the hydrostatic approximation is obtained. Analyzing the eigen-space of the projector, it is shown that for rotating-buoyant vortical-flow the hydrostatic-approximation is of third order for buoyant forcing, second order for horizontal and first order for vertical dynamical forcing.

Using the Heisenberg-Gabor limit it is shown that for large scale ocean dynamics, the difference of the dynamics of the projection-evolution operator between the two formalisms is insignificant. It is shown that the hydrostatic approximation is appropriate for realistic ocean simulations with vertical viscosities larger than $\approx10^{-2}$m$^2$s$^{-1}$. A special emphasis is on unveiling the physical interpretation of the calculations.