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The Stokes drift of internal gravity wave packets

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Associated with planar surface gravity waves is the Stokes drift - a net horizontal flux of mass and momentum induced by the waves. For horizontally localized wave packets, the drift at the surface is balanced by a return flow at depth which leads to a localized irrotational mass balance moving with the travelling wave group. In contrast, because they are an exact solution of the fully nonlinear equations of motion, planar internal gravity waves have no Stokes drift. However, horizontally periodic and vertically localized internal wave packets do have a horizontal wave-induced mean flow analogous to the Stokes drift for planar surface waves. This arises as a direct consequence of the divergence of the vertical flux of horizontal momentum and results in a mean horizontal transport of mass and momentum. The outstanding question is how the surrounding flow responds when an internal wave packet is horizontally as well as vertically localized.

Herein we examine the wave induced mean transport associated with a horizontally and vertically compact Boussinesq internal gravity wave packets in an unbounded two-dimensional uniformly stratified ambient. Through a separation of scales expansion for a steady quasi-monochromatic wave packet, we show that to leading order in spectral bandwidth the only induced mean flow that is admissible is in the horizontal direction, the magnitude of which does not vary along the horizontal, but which does depend on the size of the domain. A closer examination that accounts for the transient passage of the wave packet reveals that the dominant response is a long horizontal disturbance whose extent is established by the horizontal group velocity of internal waves having vertical scale set by the wave packet's vertical extent. This disturbance is local to the wave group in the vertical direction, but global in the horizontal direction. Hence we term this mode the "global" wave induced mean flow. At higher order in bandwidth, Lagrangian particles travel through the centre of the packet in the direction opposite to the group velocity. This Lagrangian transport in both the horizontal and the vertical direction is local to the group and so is referred to as the "local" wave induced mean flow.

Fully nonlinear numerical simulations validate the magnitude, direction and scaling of both the "global" and the "local" wave induced mean flow for internal gravity wave packets. We discuss the impact of the Stokes drift and response fields upon modulational stability, momentum transport, and wave breaking in the ocean and atmosphere.