Intrusive gravity currents in two-layer stratified media

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The oceans and atmosphere exhibit regions of rapid vertical density variation, such as the thermocline and tropopause. Consequently, horizontal, density-driven flow along a sharp interface arises in a variety of natural settings. Such flows are commonly referred to as interfacial gravity currents or intrusions and have been the subject of many previous investigations. Here, the intrusion speed is predicted using conservation of mass, momentum and energy. For the special case in which the intrusion density equals the depth-weighted mean density of the upper and lower layers, the theory of Holyer and Huppert (1980) predicts that the intrusion occupies one-half the total depth, its speed is one-half the interfacial long-wave speed and the interface ahead of the intrusion remains undisturbed. For all other intrusion densities, the interface is deflected vertically by a long wave that travels ahead of the intrusion and thereby changes the local upstream conditions. In these cases, the conservation equations must be matched to an exact solution of the two-layer shallow water equations, which describe the spatial evolution of the nonlinear wave. We obtain predictions for the intrusion speed that match closely to experiments and numerical simulations, and with a global energy balance analysis by Cheong, Keunen and Linden (2006). Since the latter does not explicitly include the energetics of the upstream wave, it is inferred that the energy carried by the wave is a small fraction of the intrusion energy. However, the new more detailed model also shows that the kinematic influence of the upstream wave in changing the level of the interface is a critical component of the flow that has previously been ignored.