Internal Wave Boundary Layer Interaction: two novel mechanisms for instability

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Introduction: It has been known for some time that internal wave induced currents can drive instabilities in the bottom boundary layer. In this talk I will discuss pseudo spectral simulations of two novel mechanisms of instability both related to internal wave induced flow over topography. In the first mechanism I will consider the shoaling of a long internal wave, such as an internal seiche in a lake. As heavier fluid moves upslope a gravity current, or bolus develops, and this may lead to both localized mixing and transport of tracers up the slope. When the fluid begins to move downslope an internal wave forms. In the footprint of this wave a large scale separation region develops, and modifies the manner in which the wave breaks and leads to localized instabilities in the pycnocline. In the second mechanism I will discuss the propagation of large internal solitary waves over topography. I will show examples of both separation of the wave induced currents over the topography, as well as instances when the prograde jet behind the wave leads to instability even when the main wave body does not induce separation.

Shoaling Waves: In Figure 1 I show the evolution of a shoaling seiche in a DNS (direct numerical simulation) of a laboratory scale seiche (the density field is shown). The upslope propagating bolus is clearest in panel (b), while the effects of boundary layer separation are clearest in panel (a). Boundary layer separation leads to the formation of a downslope jet away from the boundary and this in turn creates the mushroom like intrusion of light fluid visible near $x = -2.5$. Subsequent efforts were directed to answering the question of how these lab-scale results scale up to the field scale, with the take home message being that on the 1 km scale in a lake of moderate depth, 10 m, topographic slopes on the order of 0.01 lead to separation regions that can be 100 m long and that these modify the breaking behaviour of internal waves that form during shoaling, and significantly influence the spatial distribution of mixing.

Instability of Prograde Jet: In Figure 2 I show the instability of the prograde jet that forms behind a large internal solitary wave (panel (a) shows the horizontal velocity, (b-f) show the vorticity). In this instance the topographic slopes are not steep enough so that the wave-induced flow induces boundary layer separation. However, the prograde jet behind the main wave, which lacks the stabilizing influence of the large scale pressure distribution of the main wave, does roll up when passing over the crest of the topography and leads to local three-dimensionalization of the flow. In Figure 2 I show the instability over two successive hills (panels e and f show the second hill, and are at later times, compared to panels c and d), thereby demonstrating that the main wave is only slightly modified by the initial instability and retains the capacity to continue to trigger further instabilities as it passes over subsequent hills. Thus while the instability itself is not global, the capacity to induce it is maintained by the wave as it propagates downstream. Moreover, the topographic slopes needed to induce this type of instability are only around 0.05.

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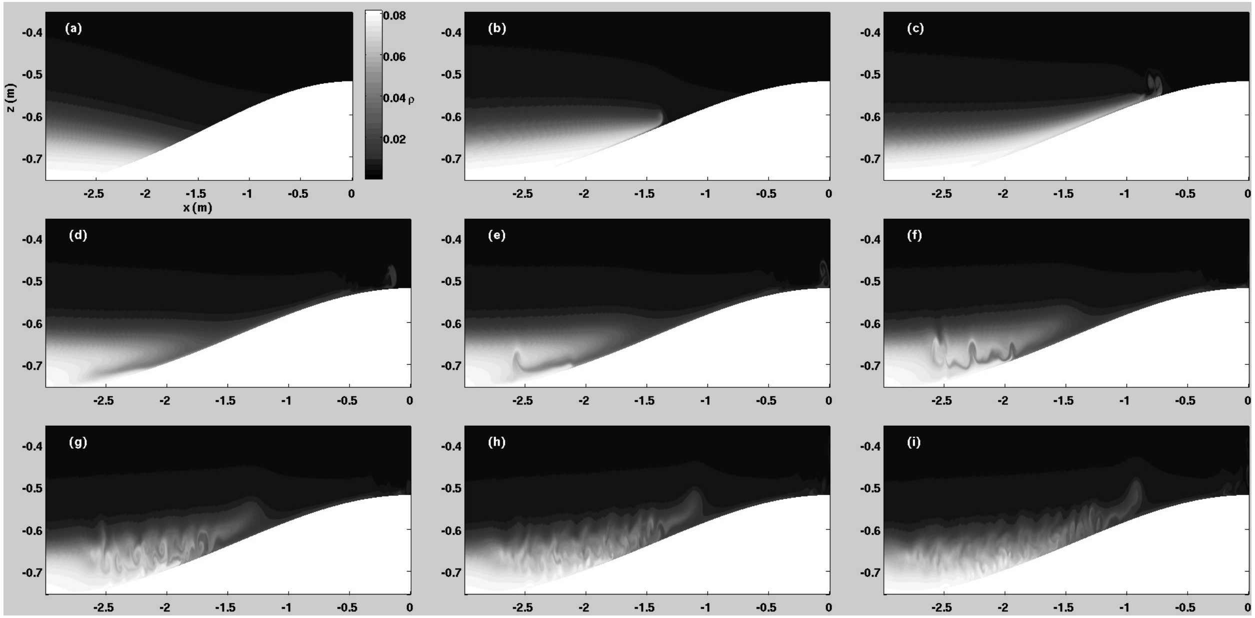

Figure 1: Evolution of experimental-scale shoaling internal seiche.

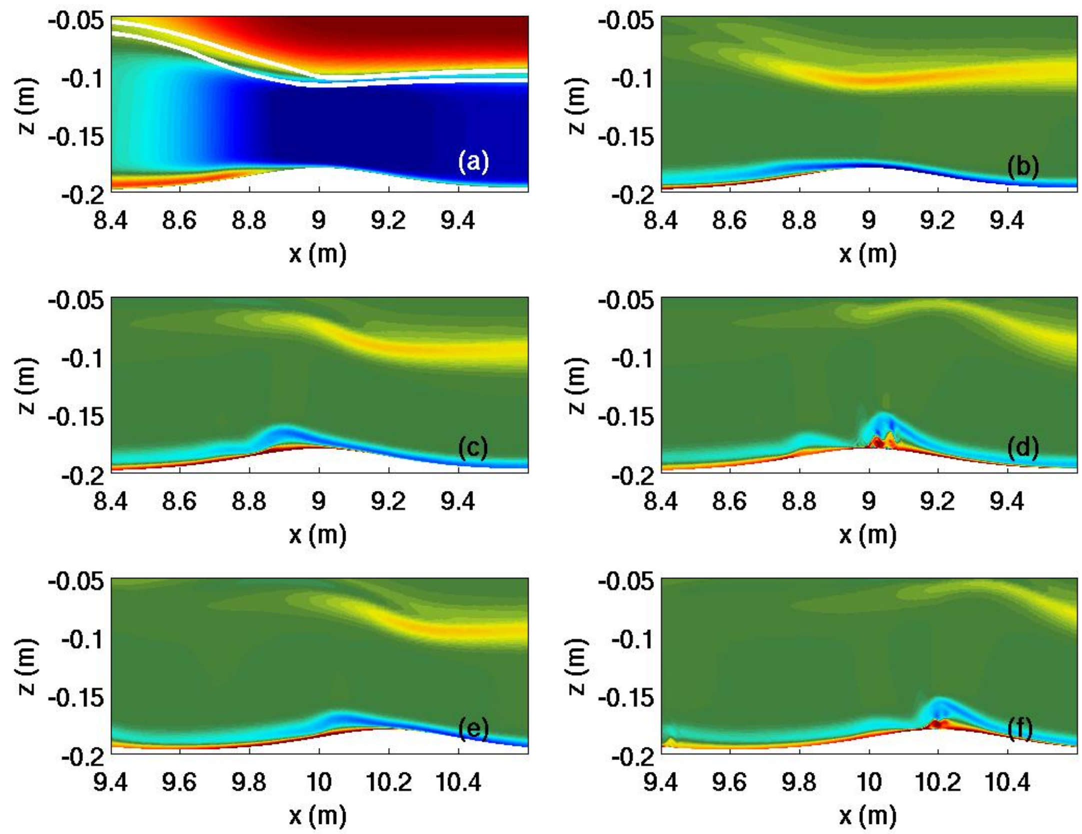

Figure 2: Instabilty of the prograde jet behind an ISW of depression. (a) u, (b-f) $\omega = u_z - w_x$.