Turbulent mixing and transport by breaking internal solitary waves on slopes

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Introduction

Using direct numerical simulations (DNS), we investigate the turbulent dynamics of breaking internal solitary waves on slopes. A Navier-Stokes code is employed in an idealized, laboratory-scale domain where an internal solitary wave of depression impinges upon a sloping bottom. A bottom-following curvilinear grid is used to capture the bathymetry accurately, and the vertical grid spacing $\Delta z^+ = O(1)$ near the bottom in the breaking region to resolve the near-wall flow. The energetics of the flow are analyzed in a volume-integrated sense using the background potential energy framework of [1], while transport is quantified using particle tracking.

Results

We first present results from [2] that focus on the energetics of the flow, quantifying dissipation and irreversible mixing as a function of time. Turbulence develops in regions of unstable stratification during wave breaking (figure 1a) and grows throughout the breaking event (figure 1b), leading to peaks in both dissipation and mixing. The bulk mixing efficiency is also calculated and shown to be near the canonical value of 0.2.

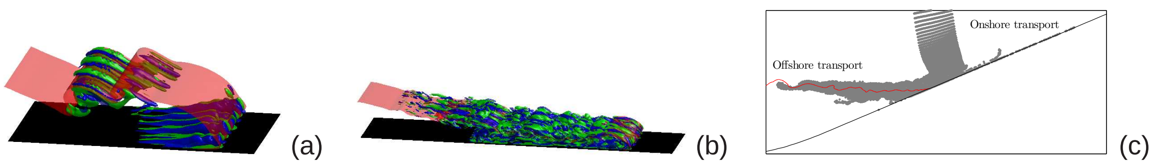

Fig. 1: (a) The development of turbulence in regions of unstable stratification during wave breaking. (b) Fully developed turbulence during the upslope surge of dense fluid after wave breaking. (c) Onshore and offshore transport of a particle plume at the end of the breaking event.

Next, we present transport results based on the motion of passive particles during wave breaking. Onshore transport occurs due to the upslope surge of dense fluid after breaking, while offshore transport occurs due to the intrusion of mixed fluid along the pycnocline (see figure 1c). This offshore particle layer resembles an intermediate nepheloid layer (INL), and forms due to irreversible mixing during wave breaking. Lateral (cross-stream) transport of particles also occurs due to the turbulence that develops during wave breaking, and is quantified using a lateral turbulent diffusivity. The nonhomogeneous nature of turbulence and the effects of cross-shore transport on the calucluated diffusivity are accounted for by binning particles in space and time, respectively. Lateral turbulent diffusivity values are elevated to roughly 40 times the molecular value κ. Lastly, diffusivity values are shown to agree well with predictions from a k-ϵ model.

Geophysical relevance

The geophysical relevance of the DNS results are discussed using the buoyancy Reynolds number $\mathrm{Re}_b = \epsilon/\nu N^2$, and the volume-integrated dissipation and mixing signal is compared to local dissipation and buoyancy flux signals that would be observed at fixed mooring locations. The lateral turbulent diffusivity is also presented as a function of initial cross-shore position, and is discussed in the context of the lateral spreading of biologically important scalars (e.g. nutrients, larvae, sediment, or dissolved oxygen) in the coastal ocean.

References

[1] Winters KB et al. *J. Fluid Mech*. **289**:115-128, 1995.
[2] Arthur RS & Fringer OB. *J. Fluid Mech*. **761**:360-398, 2014.

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