

Internal Wave Energetics on a Shelf Break

Subhas Karan Venayagamoorthy* and Oliver Bartlett Fringer

Department of Civil & Environmental Engineering, Stanford University, Stanford, California, USA

This study focuses on understanding the energetics and dynamics of the interaction of first-mode internal gravity waves in a continuously stratified fluid with a shelf break. We present results of high-resolution 2- and 3-dimensional numerical simulations showing the interaction of internal waves with a shelf break. The interaction of an incoming nonlinear wave field with a near-critical to supercritical topography causes the formation of upslope surging bores that get ejected onto the shelf as propagating internal boluses. We present the energy flux distribution across the shelf break for a wide range of topographic slopes and Froude numbers, and we show that both the transmitted and the reflected energy fluxes are strong functions of the Froude numbers as well as the ratio of the topographic slope to the internal wave beam angle. The energy flux calculations show that the internal boluses that form due to the interaction of the incident waves with the slope are very energetic, especially for near-critical slopes. The interaction of these nonlinear internal waves with bathymetry can be effective in transporting mass onshore as well as raising diapycnal mixing levels in the coastal ocean.

INTRODUCTION

Understanding the dynamics of the interaction of internal gravity waves with topography is a pressing problem in oceanography. The interaction of internal waves with bottom features such as continental slopes, seamounts and ridges in the ocean can lead to instabilities and wave breaking, which result in strong mixing close to the boundaries. It has been hypothesized that this is a plausible mechanism through which oceanic mixing is sustained (Munk and Wunsch, 1998). Indeed, many field experiments have provided evidence to suggest that the oceanic internal wave field has considerable amount of energy to ignite intense diapycnal mixing near the boundaries (Ledwell et al., 1998; Polzin et al., 1997; Kunze and Toole, 1997).

Turbulence can be generated through a number of mechanisms when flow interacts with topography, such as lee wave generation, tidal-topographic generation of internal waves, internal wave reflection, and internal wave scattering (Kunze and Llewellyn Smith, 2004). Of these mechanisms, critical reflection and scattering of internal waves are those that can transfer energy toward smaller scales leading to turbulent dissipation and mixing. Although it is far from clear which mechanisms are most important, it is postulated that all but the critical reflection of internal waves are processes that can be described by linear theory. New field measurements taken over a continental slope suggest that critical reflection is a dominant mechanism for transferring low-mode internal wave energy to small scales and turbulence (Nash et al., 2004).

Internal waves obey simple, but unusual, reflection laws at a rigid boundary. Unlike in optics and acoustics where the angles of incidence and reflection are preserved with respect to the normal of the reflecting surface (classical Snell's law), internal waves preserve their angle with respect to the direction of gravity upon reflection. When a small-amplitude linear wave with a

wave characteristic slope, s , encounters a shelf break with topographic slope, $\gamma < s$, most of the energy is transmitted (forward-reflected), and the slope is said to be subcritical. The converse is true for a supercritical slope ($\gamma > s$) where most of the wave energy is reflected backward from the topography. A critical slope is obtained when $\gamma = s$, for which the reflected wave is parallel to the topography and focusing of wave energy takes place. This leads to enhanced dissipation and mixing in the bottom boundary layer. This has been observed in several field-scale measurements, notably by Eriksen (1985, 1998) and verified through many laboratory experiments (e.g. Cacchione and Wunsch, 1974, and Ivey and Nokes, 1989) as well as numerical simulations (e.g. Slinn and Riley, 1998; Javam et al., 1999; and Legg and Adcroft, 2003). For small-amplitude (linear) waves, the energetics are well understood from linear theory (Phillips, 1977; Craig, 1985); however, the energy partitioning across a shelf break for nonlinear internal waves is poorly understood and deserves more investigation.

Numerous in-situ and remote-sensing observations clearly show the presence of nonlinear internal waves (NLIW) in marginal seas and coastal waters (Ostrovsky and Stepanyants, 1989; Apel, 1985; Sandstrom and Oakey, 1995; Klymak and Moum, 2003; Hosegood et al., 2004; Scotti and Pineda, 2004; Carter et al., 2005). These waves can be generated in a number of ways, such as interaction (reflection) of long first-mode internal tides with bottom topography, lee-wave release, and wave-wave interactions. However, very little is known about the structure of these highly NLIW and their ultimate fate, especially as they propagate onshore into shoaling regions (Vlasenko and Hutter, 2002). These NLIW are likely to be one of the primary pathways through which the energy in the internal wave field is fed into the dissipative scales. Thus, understanding the dynamics of these NLIW has far reaching implications for numerous applications in the coastal environment. A key component in gaining improved understanding of NLIW deals with their energy flux budget. Our study aims toward a better understanding of the energy flux distribution for waves spanning the gap between the conditions where linear theory holds and those where NLIW occur.

In this paper, we present results from high-resolution 2- and 3-dimensional numerical simulations of the interaction of a first-mode internal wave field with an idealized shelf break. Our emphasis is to gain insight into the energetics and dynamics of the onshore propagating internal boluses that form as a result of

*ISOPE Member.

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