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Laboratory experiments on depression interfacial solitary waves over a trapezoidal obstacle with horizontal plateau

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ABSTRACT

While shoaling from deep water in a stratified ocean, an internal wave may encounter different types of submarine topography. As it travels, the wave may generate vortex motion on a slope, turbulent mixing between the upper and bottom layer, and even waveform inversion on the plateau of a slope-shelf feature. Although many oceanographers have believed that the inversion from depression to elevation may commence at the turning point where the upper and low layer are equal in depth, this phenomenon has not been fully verified in field observations or numerical schemes. In order to clarify this unique phenomenon, a series of laboratory experiments were conducted on the evolution of an interfacial solitary wave of depression across a slope followed by a horizontal plateau on slope-shelf obstacle. Experimental results indicate the length of the plateau may become a proxy to determine whether the inverted waveform could maintain its strength or be weakened swiftly, which could inflict direct impact on the ecology of the local oceanic environment. Comparison on the internal flow field is also presented in this paper to illustrate the process of waveform inversion as an internal wave propagating over a trapezoidal, triangular ridge and uniform long slope, respectively.

1. Introduction

Interfacial solitary wave (ISW), as a kind of internal waves on the interface of a stratified fluid system, has been found in many parts of oceans and inland lakes. A large ISW affects not only oil drilling operations (Bole et al., 1994), but also produces turbulent mixing (Moum et al., 2003). It could cause nutrient pumping and induces fish forage (Corredor, 2008; Stevick et al., 2008). In the South China Sea (SCS), for example, an ISW with amplitude up to 170 m was observed, as well as with the velocity difference between the upper and bottom layer exceeding 2 m/s (Chang et al., 2008). Moreover, pilot whales were found to follow ISW in the SCS (Moore and Lien, 2007). Wang et al. (2007) also observed the ecological process induced by ISWs propagating beyond Dongsha Atoll (centered at 20°41′N, 116°48′E, including Pratas Island to its central-west), which is an isolated ring reef in the northwestern SCS. Based on the limited reports of field observations available, two of the most significant effects of submarine topography on ISW propagation are the strong turbulent mixing in the vertical water column and the ecological effect on local oceanic environment. These phenomena have frequently occurred on a slope-shelf topography or continental shelf.

An ISW of depression exists in a stratified ocean in which the upper layer (H_1) is less than the bottom layer (H_2). As it propagates shoreward toward a slope-shelf topography, the depth of the bottom layer may decrease, from $H_2>H_1$ to become $H_2<H_1$. At the turning point ($H_2=H_1$), waveform becomes unsettle and may commence the inversion into an elevation form as it continues shoreward. Hsu and Liu (2000) have presented a spatial distribution of large ISWs in the northern SCS, upon analyzing many SAR imageries found in the 1990s to early 2000s. From the successive order of the bright and dark bands on an imagery, a depression ISW can be identified with bright band ahead of dark band, while an elevation ISW with dark band leading the bright one, thus implying the existence of waveform inversion. This process of evolution (Fig. 1) was also reported by Zhao et al. (2004a).

From the ISW packets observed by satellites and ship borne sensors in the SCS (Fig. 2) from 1995 to 2001 (Zhao et al., 2004b), multiple-train of ISW packets could be found on a long plateau near the continental shelf (see insert in Fig. 2), while single-train ISW packets also existed in deeper water. On the other hand, ISWs were also detected in the vicinity of a submarine sill with short plateau (see transect at Strait of Gibraltar in Fig. 3; Vazquez et al., 2008), where the wave encountered a variable bathymetry with a shallow plateau in the middle connecting deep water section on

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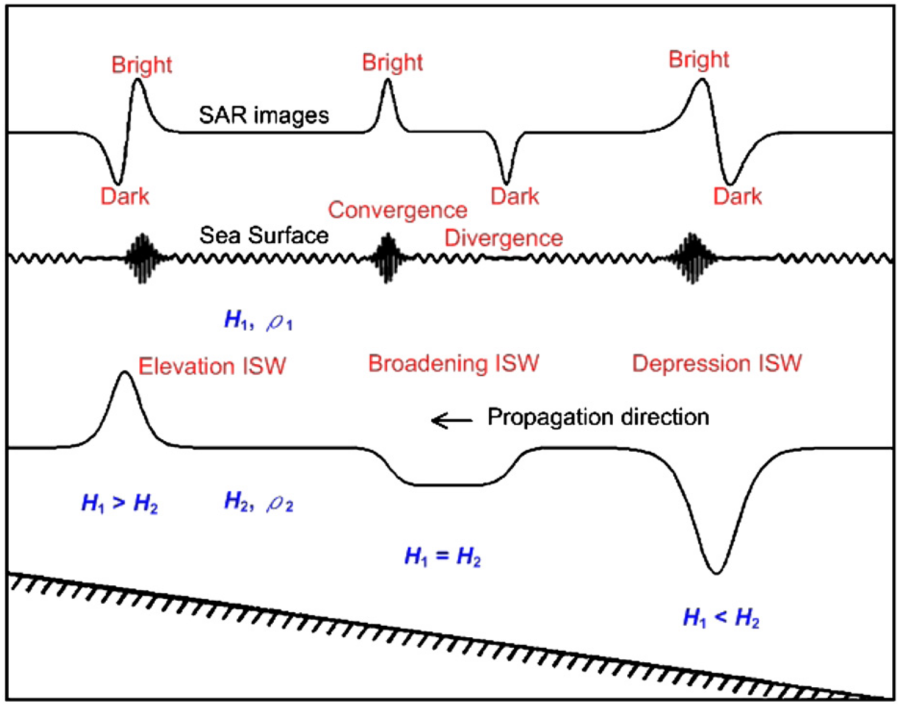

Fig. 1. A schematic diagram showing depression, broadening and elevation ISWs, associated with convergent and divergent zones on the sea surface, and different signatures in the SAR imagery (Zhao et al., 2004a).

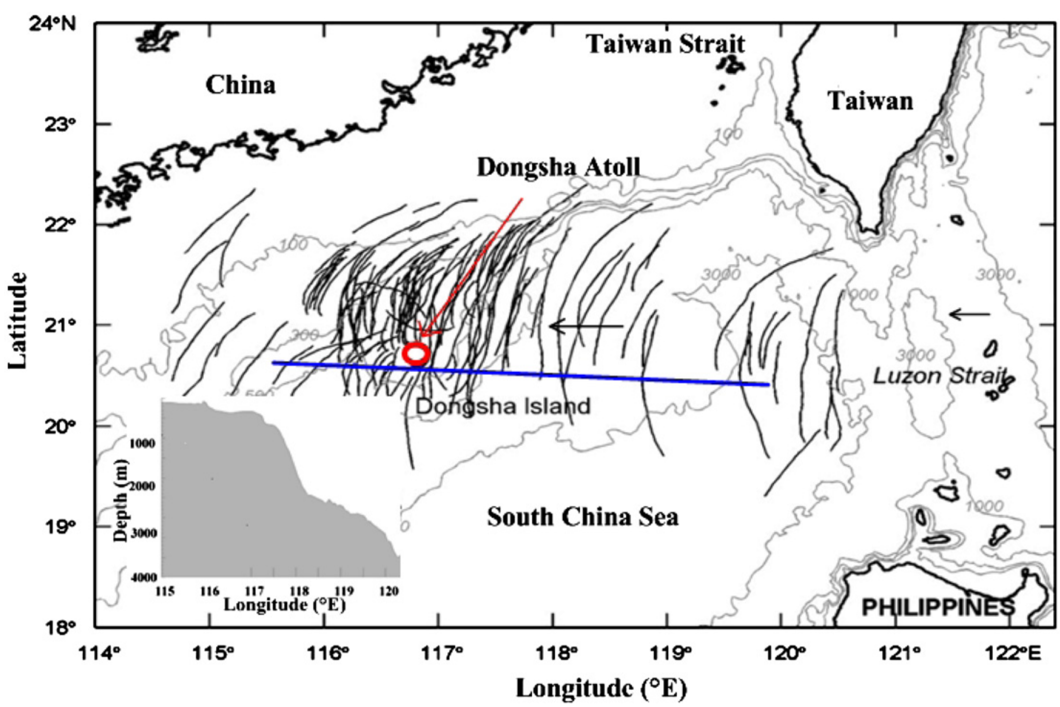

Fig. 2. Distribution map showing ISW packets observed over variable bathymetry by satellites and ship-borne sensors from 1995 to 2001 (Zhao et al., 2004b).

either side. In this region, large-amplituded internal waves induced by barotropic tidal flows were observed to propagate over a sill with short plateau into the Mediterranean (insert in Fig. 3).

Several researchers (e.g., Orr and Migneret, 2003; Ramp et al., 2004) supported the viewpoint of waveform inversion after a turning point, based on limited results of field observations during the Asian Seas International Acoustics Experiment (ASIAEX 2002), which was undertaken by oceanographers from the United States and Taiwan in 2002. More recently, Reeder et al. (2008) recorded internal waves using moored acoustic source at a continental shelf site (with slope-shelf topography) in the northern SCS and found large internal waveform evolution as it entered shallow water from the shelf edge (Fig. 4). As the wave approached the shelf edge from 4.5 km away, where the depth of the mooring site was about 116 m, waveform became asymmetric and reduction in amplitude was visible. In general, satellite imagery offers an indirect means for identifying the