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On generation and evolution of seaward propagating internal solitary waves in the northwestern South China Sea

Jiexin Xu [a,b], Zhiwu Chen [a], Jieshuo Xie [a,b], Shuqun Cai [a,*]

[a] State Key Laboratory of Tropical Oceanography, South China Sea Institute of Oceanology, Chinese Academy of Sciences, 164 West Xingang Road, Guangzhou 510301, China
[b] University of Chinese Academy of Sciences, Beijing 100049, China

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ABSTRACT

In this paper, the generation and evolution of seaward propagating internal solitary waves (ISWs) detected by satellite image in the northwestern South China Sea (SCS) are investigated by a fully nonlinear, non-hydrostatic, three-dimensional Massachusetts Institute of Technology general circulation model (MITgcm). The three-dimensional (3D) modeled ISWs agree favorably with those by satellite image, indicating that the observed seaward propagating ISWs may be generated by the interaction of barotropic tidal flow with the arc-like continental slope south of Hainan Island. Though the tidal current is basically in east–west direction, different types of internal waves are generated by tidal currents flowing over the slopes with different shaped shorelines. Over the slope where the shoreline is straight, only weak internal tides are generated; over the slope where the shoreline is seaward concave, large-amplitude internal bores are generated, and since the concave isobaths of the arc-like continental slope tend to focus the baroclinic tidal energy which is conveyed to the internal bores, the internal bores can efficiently disintegrate into a train of rank-ordered ISWs during their propagation away from the slope; while over the slope where the shoreline is seaward convex, no distinct internal tides are generated. It is also implied that the internal waves over the slope are generated due to mixed lee wave mechanism. Furthermore, the effects of 3D model, continental slope curvature, stratification, rotation and tidal forcing on the generation of ISWs are discussed, respectively. It is shown that, the amplitude and phase speed of ISWs derived from a two-dimensional (2D) model are smaller than those from the 3D one, and the 3D model has an advantage over 2D one in simulating the ISWs generated by the interaction between tidal currents and 3D curved continental slope; the reduced continental slope curvature hinders the extension of ISW crestline; both weaker stratification and rotation suppress the generation of ISWs; and the width of ISW crestline generated by K_1 tidal harmonic is longer than that by M_2 tidal harmonic.

1. Introduction

Internal solitary waves (ISWs) are ubiquitous phenomena in the ocean, especially in the northern South China Sea (SCS) [1,2]. These waves with their crestlines extending tens of kilometers carry enormous energy toward coastline [3]. During their propagation, they may cause significant diacynal mixing [4] and transport of water and materials [5], which play a vital role

* Corresponding author. Tel.: +86 20 89023186; fax: +86 20 84451672.
E-mail address: caisq@scsio.ac.cn (S. Cai).

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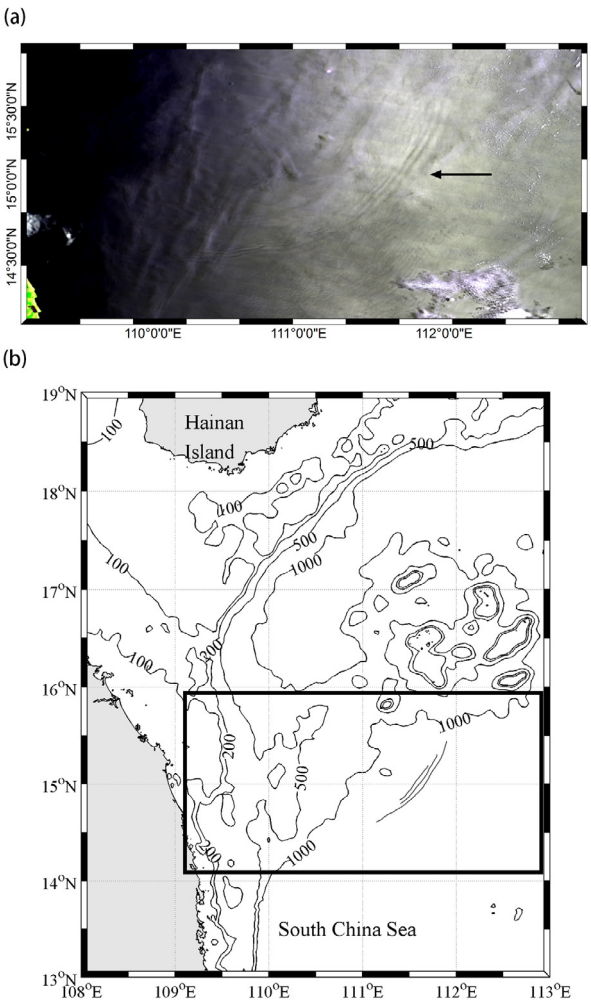

Fig. 1. (a) A MODIS (bands 1.3.4) 250 m-resolution visible image south of Hainan Island acquired at 0315 UTC, 10 August 2002, showing the faint signature of internal solitary wave packets propagating to the southeast [11], (b) bathymetry (unit in m) south of Hainan Island in the SCS with the ISW packet derived from the satellite image. The satellite coverage area is indicated by the box, and the ISW packet we concern is denoted by the arrows.

on the marine ecosystems [6]. ISWs can also induce strong shear current which is a potential threat to submerged engineering structures [7].

In recent years, remote sensing, in situ observations and numerical models were employed to improve our understanding of ISWs [8–10]. Most previous studies focused on the ISWs from the Luzon Strait to the northeastern continental shelf, e.g., Zhao et al. [2] compiled a map of distribution of ISWs in this area, revealing a process of their generation, propagation and dissipation, although the details of the processes remain unclear. It is generally thought that the ISWs in the northeastern SCS are originated from the interaction of barotropic tides with the submerged ridges in the Luzon Strait. Using high-resolution MODIS images, Jackson [11] found that the ISWs were also very active in the northwestern SCS; however, little is known about the generation origin and mechanism of the ISWs in this area. On the basis of three synthetic aperture radar images, Li et al. [12] proposed that the shoreward propagating ISWs were originated from the tide-topography interaction in the Luzon Strait; they traveled across basin and finally reached the continental slope in the northwestern SCS. However, by numerical simulation, Li et al. [13] suggested that the ISWs south of Hainan Island were generated locally, and the generation source site was the sill in the middle of the SCS. Although most ISWs detected by satellite in the northwestern SCS propagated shoreward, a packet of seaward propagating ISWs south of Hainan Island was detected by the MODIS on 10 August, 2002 (Fig. 1a, [14]). Fig. 1b shows the bottom topography south of Hainan Island and the ISW packet derived from Fig. 1a. It is suggested that the ISWs lied between 14°N–16°N, 111°E–112°E and propagated southeastward to the deep sea; this well-developed ISW packet included several rank-ordered solitons with crestlines in excess of 240 km. Up to date, no one has paid attention to the generation and evolution of such seaward propagating ISWs.

Topography, stratification and tidal currents are thought to be the three basic factors that influence the generation of ISWs. Previous studies used 2D numerical model to investigate the generation and evolution of ISWs in the northwestern SCS, ignoring the effect of horizontal varied topography. However, the horizontal varied topography may highly change the strength and