Numerical Simulation of the Generation and Evolution of Internal Tides and Solitary Waves at Sofala Shelf Break

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We investigated the dynamics of internal tides (ITs) around the Sofala shelf in the Mozambique Channel based on a 3-D hydrostatic numerical simulation. Two distinct sources of ITs and their basic propagation properties were identified. The depth-integrated period-averaged baroclinic energy flux indicated IT propagation away from the generation sites, particularly toward the east and the southeast. The convergence and divergence of the baroclinic energy flux were attributable mainly to special bathymetry features. Based on these results, 2-D nonhydrostatic experiments were performed to simulate the generation and propagation of baroclinic tides along the main energy path. The model reproduced the two distinct generation processes of internal solitary waves (ISWs): the disintegration of the interfacial mode 1 IT and the beam-induced local generation in the open ocean. The IT beam emanated from the critical slope region, then moved downward toward the deep ocean, where it reflected at the bottom. It then impinged on the pycnocline and created a strong disturbance, which further evolved into an ISW after propagation of approximately 20 km. The simulation also captured the interlaced properties of the two wave types, 60–80 km from the shelf-break region, similar to the available observations.

INTRODUCTION

Internal waves are ubiquitous oceanic phenomena, the motion that transfers energy and momentum in the stratified ocean interior (Garrett and Munk, 1979). Internal tides (ITs), a special type of internal wave with tidal frequency, are observed frequently over continental shelves and slopes. This wave is generated mainly via interactions between the barotropic tide and the steep shelf break, after which it propagates both onshore and offshore (Vlasenko et al., 2014; J Xie et al., 2015). In certain cases, the propagation of an IT could ultimately disintegrate into a large amplitude internal solitary wave (ISW) or ISW train because of the balance of nonlinear steepening and nonhydrostatic dispersion (Helfrich and Melville, 2006). The conservation properties of nonlinear ITs and ISWs provide available mechanisms for long-range propagation of mass and momentum within the oceans that could result in distant sources and sinks. For example, using mooring and altimeter data, Zhao et al. (2010) identified the long-range propagation of low-mode ITs from the Hawaiian Ridge, while shorter-scale ISWs have been observed propagating over basin-scale distances (Alford et al., 2015; Da Silva et al., 2015; Xu et al., 2016).

Efficient tidal forcing, dramatically varying bathymetry, and suitable stratification might provide the necessary mechanism for generating ITs. However, the quantitative characteristics of the generated waves are complicated by realistic environmental conditions. There are two perspectives regarding generated ITs: the “mode,” which assumes that the generated wave field comprises the sum of elementary baroclinic modes, and the “beam,” which is based on the method of wave characteristics (Vlasenko et al., 2005). From the mode perspective, it is widely accepted that higher modes dissipate easily around the source region, while lower modes, in the form of interfacial ITs, could propagate far away. During propagation, disintegration processes could lead to the generation of ISWs/trains. The other alternative, the beam, represents the propagation (downward or upward) of IT energy depending on the wave characteristics. The impingement of the beam on the pycnocline gives rise to a secondary generation mechanism of interfacial disturbance known as “local generation” that possibly could excite ISWs given sufficient disturbance (Gerkema, 2001; Da Silva et al., 2007; Akylas et al., 2007; Grisouard et al., 2011). Originally, this conjecture was used to explain the observed ISW properties in the Bay of Biscay, where synthetic aperture radar (SAR) imagery clearly displayed a bimodal distribution of ISWs (New and Da Silva, 2002). Following the wide application of remote sensing data and numerical models, several other regions with local generation of ISWs have been identified, e.g., the Estremadura Promontory (Da Silva et al., 2007), the Mascarene Ridge in the Indian Ocean (Da Silva et al., 2015), and the Sofala shelf in the Mozambique Channel (MC) (Da Silva et al., 2009).

The Sofala shelf in the MC has been identified as an area likely to generate ITs (Shriver et al., 2012; Zhao et al., 2016). This speculation is in agreement with Baines (1982), who estimated the energy fluxes from several shelf regions and showed that the MC was among the 12 most energetic regions for IT generation. Subsequent analysis by Da Silva et al. (2009), based on SAR imagery of nonlinear internal waves, further confirmed the active baroclinic process around the shelf-break region, especially the wide existence of ISWs/trains toward the open ocean. However, until now, no detailed analysis on the IT’s energy budget around its source region or on its ultimate fate has been performed. As a source area, the mesoscale processes within the MC play an important role in the transportation and modification of the water mass of the Agulhas Current (Beal et al., 2011). Therefore, the dynamic processes of ITs around this region deserve further examination.

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