



Shoaling of large-amplitude nonlinear internal waves at Dongsha Atoll in the northern South China Sea

Ke-Hsien Fu^a, Yu-Huai Wang^{b,*}, Louis St. Laurent^c, Harper Simmons^d, Dong-Ping Wang^e

^a Department of Marine Environment and Engineering, National Sun Yat-sen University, Kaohsiung, Taiwan

^b Institute of Applied Marine Physics and Undersea Technology, National Sun Yat-sen University, Kaohsiung, Taiwan

^c Woods Hole Oceanographic Institution, Woods Hole, MA, USA

^d School of Fisheries and Ocean Sciences, University of Alaska, Fairbanks, AK, USA

^e School of Marine and Atmospheric Sciences, Stony Brook University, USA

ARTICLE INFO

Article history:

Received 19 January 2011

Received in revised form

19 January 2012

Accepted 19 January 2012

Available online 30 January 2012

Keywords:

Internal waves

Shoaling

Bottom slope

South China Sea

Continental shelf

ABSTRACT

Shoaling of large-amplitude (~ 100 m) nonlinear internal waves over a steep slope ($\sim 3^\circ$) in water depths between 100 m and 285 m near Dongsha Atoll in the northern South China Sea is examined with an intensive array of thermistor moorings and a bottom mounted Acoustic Doppler Current Profiler. During the 44 h study period in May 5–7, 2008, there were four groups of large internal waves with semidiurnal modulation. In each wave group a rapid transition occurred during the shoaling, such that the front face of the leading depression wave elongated and plunged to the bottom and the rear face steepened and transformed into a bottom-trapped elevation wave. The transitions occur in water depths of 200 m and deeper, and represent the largest documented internal wave shoaling events. The observations repeatedly capture the detailed temperature and velocity structures of the incident plunging waves. Strong horizontal convergence and intense upward motion are found at the leading edge of transformed elevation waves, suggesting flow separation near the bottom. The observations are compared with the previous observations and model studies. The implication of the shoaling internal waves on coral reef ecology also is discussed.

© 2012 Elsevier Ltd. All rights reserved.

1. Introduction

In the northern South China Sea (SCS), large nonlinear internal waves ('internal solitary waves') with amplitudes exceeding 150 m have been observed (Klymak et al., 2006). These waves propagate westward across the basin, shoal and dissipate at the shallow continental shelf (Hsu and Liu, 2000; Zhao et al., 2004; Chang et al., 2006; St. Laurent, 2008; Alford et al., 2010). Two types of internal solitary waves have been identified: a-waves that arrive regularly at the same time each day, and b-waves that arrive an hour later each day (Ramp et al., 2004). Model studies suggested that the nonlinear internal waves are evolved from semidiurnal internal tides generated over the ridges in the Luzon Strait (Chao et al., 2007; Shaw et al., 2009; Warn-Varnas et al., 2010; Zhang et al., 2011; Li and Farmer, 2011).

The internal solitary waves begin as large depression waves in the deep basin. As they propagate up the continental slope, they transition into the elevation waves. Liu et al. (1998) found that the elevation waves over the shelf often are marked by a thick

bottom mixed layer. Using a modified Korteweg–de Vries (KdV) equation, they suggested that the incident depression waves first disintegrate into a dispersive wave train and then evolve into a packet of elevation waves. The critical/turning point occurs approximately at where the upper and lower layers have equal thickness that the nonlinearity coefficient in the KdV equation changes sign. Also, Hsu and Liu (2000) showed that the transition from waves of depression to elevation could be detected from the satellite remote sensing. The depression waves are marked by the bright and dark bands in the SAR image. The bright band is indicative of the strong surface convergence at the front face of the wave, which causes accumulation of short breaking surface waves. As the waves transition from depression to elevation, the surface patterns reverse to the dark and bright bands. As an example, Fig. 1 shows a MODIS image of three groups (A, B, C) of internal solitary waves near Dongsha Atoll in the northern SCS.

Many theoretical and laboratory studies have examined the shoaling of depression waves over a sloping bottom (Helfrich and Melville, 1986; Liu et al., 1998; Vlasenko and Stashchuk, 2007). Field studies, on the other hand, have been relatively few, due to difficulties in obtaining high-resolution spatial and temporal sampling. Shroyer et al. (2009), for example, followed a group of nonlinear internal waves as they shoaled over a gentle slope

* Corresponding author. Tel.: +886 75252055; fax: +886 75255270.

E-mail address: yhwang@nssysu.edu.tw (Y.-H. Wang).

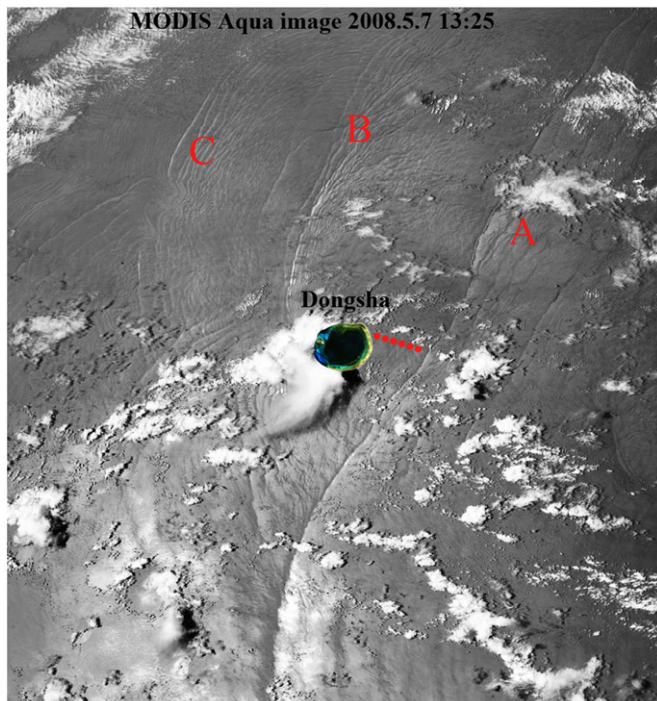


Fig. 1. MODIS image near Dongsha Atoll of South China Sea on 13:25 May 7, 2008 (GMT+8). The diameter of the atoll is about 25 km. Three groups (A, B, and C) of nonlinear internal waves are identified on the image with each group separated by 12 h. The dotted line marks the orientation of the mooring line. The B-group corresponds to the May 7 event.

(0.5°), and Bourgault et al. (2007) investigated shoaling of nonlinear internal waves over a steep slope (3°) with a mooring array. These studies are conducted in the shallow water, and the observed internal wave amplitudes are small (~10 m). In contrast, during the Asian Seas International Acoustics Experiment (ASIAEX) in the northern SCS, Orr and Mignerey (2003) followed a group of large-amplitude (40–70 m) internal solitary waves over a gentle slope (1°) on the outer shelf. The leading depression waves were found to disintegrate into a packet of elevation waves in water depths of 150–180 m. These waves were the mode-1 with opposite flows in the upper and lower layers, and the wave polarity changed from counterclockwise over a depression wave to clockwise over an elevation wave. In their study interface however was in the mid-depth well above the bottom. Duda et al. (2004) described the same shoaling events based on an array of moored thermistor and ADCP moorings.

In this study, we describe rapid transition of large-amplitude nonlinear internal waves up a steep slope (3°) near Dongsha Atoll in the northern SCS based on measurements from a dense array of thermistor moorings and a bottom mounted ADCP. Section 2 describes the field work, Section 3 describes the results, and Section 4 presents a discussion with comparison to the previous studies.

2. Observations

The field study was carried out onboard the Taiwan research vessel *Ocean Researcher 3* (OR3) in May 5–7, 2008 on the east side of Dongsha Atoll (Fig. 2). Eight thermistor strings were deployed over a steep slope. Because of heavy fishing activity in the study area, OR3 was stationed around the moorings to prevent fishing vessels from disturbing the field experiment. The moorings were in place for approximately 2 days. Seven moorings were

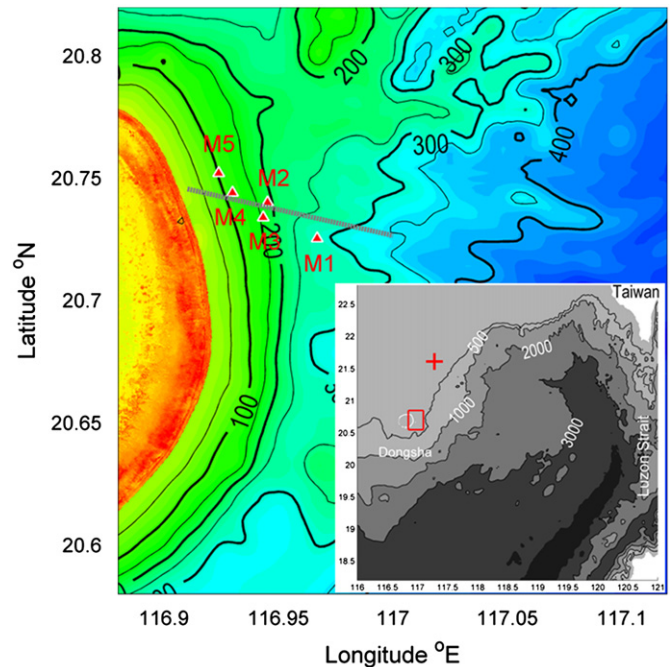


Fig. 2. Map of depth contours east of the Dongsha Atoll with the mooring stations marked, M1–M5 in water depths of 285 m, 195 m, 155 m, 110 m and 100 m. The dashed line marks the orientation of the mooring line. The inset shows map of the northern South China Sea. Dongsha Atoll is located about 400 km southwest of Taiwan. The ASIAEX site (+) is about 100 km north of Dongsha Atoll.

successfully recovered. The analysis was based on five moorings, M1–M5, in water depths between 100 m and 285 m (Fig. 2). Data from the other two moorings were corrupted and were not included. There were 46 temperature loggers (13 Star-Oddi DST Centi-TD of accuracy ± 0.1 °C; 33 Vemco Minilog 8-bit of accuracy ± 0.3 °C) distributed about evenly on the 5 mooring lines. The vertical resolutions were 20 m on M1, M2 and M3, and 10 m on M4 and M5. The sampling rate was set at 30 s. At M3 (water depth=155 m), an upward looking 300 kHz ADCP (RDI Workhorse Sentinel 300) was attached on the mooring line at a depth of 125 m, which sampled velocity profiles every minute with a bin size of 8 m.

3. Results

Fig. 3 shows 44-h temperature records from 16:00 local time (GMT+8 h) May 5 to 12:30 May 7 at M3. The data were presented in two 24-h panels, following Ramp et al. (2004). In each 'day' (24-h period) there were two groups of large-amplitude nonlinear internal waves of depression. Each group included several large-amplitude (> 100 m) and numerous moderate-amplitude (~60 m) waves. The semidiurnal period was obvious: the wave groups arriving in the 2nd day were delayed by about an hour or two from the corresponding groups in the first day. The interface (thermocline) was approximately delineated by the 23 °C isotherm with the mean depth at about 80 m. During the passage of wave packets the warm surface waters sometimes were displaced down to the bottom.

The shoaling of large depression waves was examined based on temperature records from moorings M1–M5 in water depths from 285 m to 100 m over a distance of about 5 km. Fig. 4 shows a major shoaling event in the evening of May 6. A large depression wave with amplitude of about 80 m arrived at M1 at 20:40, displacing the thermocline down to almost 200 m depth. The initial waveform was symmetric. However, as the depression

Download English Version:

<https://daneshyari.com/en/article/4532453>

Download Persian Version:

<https://daneshyari.com/article/4532453>

[Daneshyari.com](https://daneshyari.com)