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A study of the spatial-temporal distribution and propagation characteristics of internal waves in the Andaman Sea using MODIS

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Abstract

This paper describes investigations of the internal waves in the Andaman Sea using Moderate Resolution Imaging Spectroradiometer (MODIS) imagery over the period of June 2010 to May 2016. Results of the spatial and temporal distribution, generation sources and propagation characteristics of internal waves are presented. The statistical analysis shows that internal waves can be observed in almost the entire area of the Andaman Sea. Most internal waves are observed in the northern, central and southern regions of the Andaman Sea. A significant number of internal waves between 7°N and 9°N in the East Indian Ocean are also observed. Internal waves can be observed year-round in the Andaman Sea, while most of internal waves are observed between February and April, with a maximum frequency of 15.03% in March. The seasonal distribution of the internal waves shows that the internal waves have mostly been observed in the dry season (February to April), and fewer internal waves are observed in the rainy season (May to October). The double peak distribution for the occurrence frequency of internal waves is found. With respect to the lunar influence, more internal waves are observed after the spring tide, which implies the spring tide may play an important role in internal wave generation in the Andaman Sea. Generation sources of internal waves are explored based on the propagation characteristics of internal waves. The results indicate that six sources are located between the Andaman Islands and the Nicobar Islands, and one is located in the northern Andaman Sea. Four regions with active internal wave phenomenon in the Andaman Sea were presented during the MODIS survey, and the propagation speed of internal waves calculated based on the semidiurnal generation period is smaller than the results acquired from pairs of the images with short time intervals.

Key words: internal waves, remote sensing, Andaman Sea, MODIS

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1 Introduction

The Andaman Sea is a marginal sea in the northeastern Indian Ocean. It is bounded by the Bruma continental coast and by the Peninsular Malaysia and Sumatra, and it includes deep basins as well as large shelf regions. It has a stable stratification because of the monsoon rainfall, surface runoff and the special bottom topography, and internal waves occur frequently in the Andaman Sea (Jackson, 2007; Hsu et al., 2014). The interactions of barotropic tides with irregular bottom topography generate internal waves with high amplitude known as large-amplitude internal waves in the Andaman Sea (Mohanty and Devendra Rao, 2017).

Internal waves were first found in the exploration of oil and gas in the Andaman Sea. In 1980, the Exxon oil company in the United States encountered strange waves when conducting exploratory mining in the south of the Andaman Sea, and the engineering was severely affected. Subsequently, Osborne and Burch (1980) observed a strange wave for the nonlinear internal waves according to the field observation data, and it is mainly produced by the interaction between semidiurnal tide and submarine topography; the amplitude can be up to 60 m in the south of the Andaman Sea. During one particular incident documented by a mariner in the Northern Andaman Sea during the passage of an internal soliton oil rig, a tilt of approximately 3° was observed (Fraser, 1998, 1999; Hyder, 2005). There has been some scientific study of internal waves in the Andaman Sea. Alpers et al. (1997) studied the generation and evolution of internal waves in the west of the Andaman Sea based on ERS-2 SAR satellite images and presented the general amplitude of the internal waves to be between 20–80 m, the wavelengths between 6–15 km, and the propagation speed greater than 2 m/s (Jackson and Apel, 2004). Xie (2004) used the ERS-1/2 satellite images from 1996 to 2004 to study the internal waves in the Andaman Sea. However, limited by using the satellite images, most internal waves are less than 200 m deep in the north Sumatra Island. Vlasenko and Alpers (2005) discovered the generation of secondary internal waves by studying the interaction of a large-amplitude internal solitary wave using a numerical model and synthetic aperture radar (SAR) image acquired by the European Remote Sensing satellite ERS-2 over the Andaman Sea. Hsu et al. (2014) identified several other internal wave sources using SAR and MODIS images in the Andaman Sea. The Andaman Sea stratification is characterized

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by two (or more) maxima in the vertical profile, and previous research (Da Silva and Magalhaes, 2016) has examined the possible generation locations and mechanisms for both mode-1 and mode-2 ISWs along the Ten Degree Channel. Zhou et al. (2017) analyzed the spatial and temporal distribution of the internal waves in the Andaman Sea with MODIS, Sentinel-1A SAR images from 2013 to 2015. Shimizu and Nakayama (2017) researched the effects of topography and earth's rotation on the oblique interaction of internal solitary-like waves in the Andaman Sea.

Most attention has been focused on the Andaman Sea for the investigation of internal waves. Because of the limited amount of remote sensing imagery, the surveys are frequently not comprehensive. This paper discusses the spatial-temporal distribution and propagation characteristics of internal solitary waves, nonlinear internal waves, and more than 1 300 MODIS satellite images from June 2010 to May 2016 are obtained to describe the internal wave in the Andaman Sea. Section 2 introduces the study area and data. The spatial-temporal distribution of internal waves in the Andaman Sea is introduced in Section 3. Section 4 presents the sources based on the propagation characteristics of internal waves in the Andaman Sea. The characteristics for different regions in the Andaman Sea are presented in Section 5, followed by conclusions in Section 6.

2 Data and method

Expedition works were carried out in the Andaman Sea and in part of Peter the Great Bay and part of the East Indian Ocean in an area of 0°–18°N, 86°–102°E. More than 1 300 MODIS images from June 2010 to May 2016 are collected to obtain the spatial-temporal distribution, source and propagation characteristics of internal waves in the Andaman Sea.

The MODIS sensor collects data over a 2 330 km wide swath providing nearly global daily coverage with 36 channels in the visible and infrared regions of the spectrum. A spatial resolution of 250 m was used in this study consisting of Band 1 (620–670 nm) and Band 2 (0.841–0.876 μm). The combined attributes of a fine spatial resolution, large swath area, and nearly global daily coverage, has for the first time allowed sunglint to be used to analyze and survey high-frequency nonlinear internal wave occurrences on a near-global scale. MODIS produces almost daily worldwide coverage, which results in a large volume of imagery, and its spatial resolution is fine enough to identify internal wave signatures with wavelengths greater than a few hundred meters. These characteristics make MODIS imagery particularly well suited for surveying and analyzing internal wave occurrences and for studying the spatial-temporal distribution and propagation characteristics of internal wave fields in the Andaman Sea.

The MODIS images are obtained on the NASA MODIS Rapid Response System website. The MODIS data is geometrically corrected by reprojection as a preliminary step, and then, the corrected data is imported into geographic information system software, and the crest lengths of internal wave packets are extracted by human-computer interaction.

3 Spatial and temporal distributions of internal waves

3.1 *Spatial distributions*

Beginning with June 2010, MODIS 250 m imagery was examined for internal wave packets or isolated soliton signatures during 6 years from June 2010 through May 2016 in the whole Andaman Sea and parts of the Indian Ocean, and the internal wave is extracted according the fore-front wave of the wave packet. The greatest number of surface manifestations of internal waves is observed in the study area. Figure 1 is the spatial distribution map of the internal wave. The crest line of the different colors in the Fig. 1 represents the different years internal waves were detected. The red curve shows the internal waves detected in 2016, the yellow curve shows the internal waves detected in 2015, the green curve shows the internal waves detected in 2014, the purple curve shows the internal waves detected in 2013, the dusty rose curve shows the internal waves detected in 2012, the hot pink curve shows the internal waves detected in 2011, the light orange curve shows the internal waves detected in 2010. The statistical analysis shows that internal waves can be observed in almost the entire area of the Andaman Sea where the bathymetrical contour is greater than 50 m. The smaller scale internal waves can be found around the northern continental shelf in the Andaman Sea. By observation, the distribution map also reveals internal waves exist mostly in the northern continental shelf, northern, central and southern Andaman Sea. Internal waves in the middle deep-water area of the Andaman Sea have been rarely detected, rather than unobserved as Zhou et al. (2017) mentioned, and a statistical result of water depth distribution of satellite-observed internal wave occurrence frequencies should be helpful in understanding this. It was also found that much smaller scale internal waves in the north continental shelf of the Andaman Sea are propagating northward.

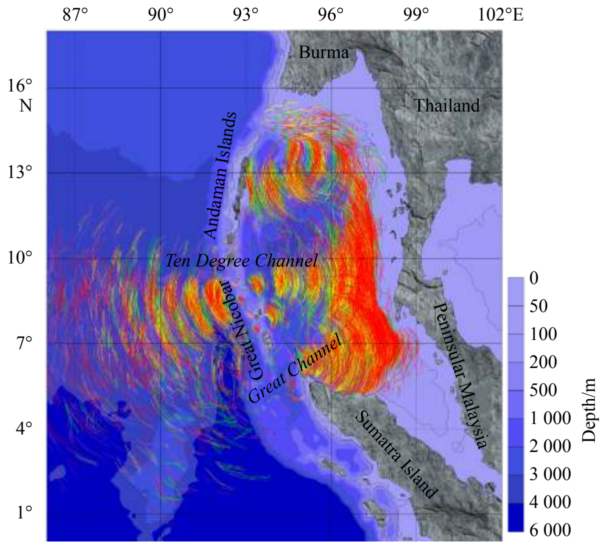

Fig. 1. The distribution map of internal waves observed in MODIS imagery from June 2010 to May 2016 in the Andaman Sea.

Internal waves have also been observed in the East Indian Ocean. Figure 1 also shows that internal waves have been detected between 1°N to 12°N in the East Indian Ocean, and a significant number of internal waves between 7°N and 9°N are observed. The internal waves appear to originate in the area between the Car Nicobar Islands and Great Nicobar propagating westward or eastward. They have not been observed by remote sensing beyond the 12°N area in the East Indian Ocean. Hsu et al. (2014) and Zhou et al. (2017) built an internal wave distribution of the Andaman Sea from MODIS and SAR images, respectively. In this paper, most internal waves are observed in the northern continental shelf, northeastern, central and southern Andaman Sea. In addition, the greatest number of surface manifestations of internal waves is extracted in the East Indian Ocean bounded by the western Andaman Sea using continuous 6 years MODIS imagery from June 2010 through May 2016.

3.2 *Temporal distributions*

In this section, we analyzed the temporal variation of internal waves in the Andaman Sea. The temporal distribution of monthly and lunar daily satellite-observed internal wave occurrence frequencies are introduced, where the monthly and lunar daily satellite-observed internal wave occurrence frequency is defined as (Zheng et al., 2007; Ho et al., 2009):

$$P_{\mathrm{m}i} = \frac{n_i}{\sum_{j=1}^{12} n_j} \quad \text{and} \quad P_{\mathrm{d}i} = \frac{n_i}{\sum_{j=1}^{30} n_j}, \tag{1}$$

where $P_{\mathrm{m}i}$ and $P_{\mathrm{d}i}$ are monthly occurrence frequency and lunar daily occurrence frequency, respectively. $n_i(n_j)$ is a number of total days in the i-th (j-th) month or lunar day of six years, at which the internal waves are observed.

Based on the 1 300 MODIS images containing internal waves over the period from June 2010 to May 2016, the statistical results of monthly satellite-observed internal wave distribution characteristics are depicted in Fig. 2. Internal waves in the Andaman Sea occur year-round. Figure 2 shows the monthly distribution of observed internal waves over 6 years. The MODIS survey revealed significant internal wave activity from February through April, reaching a peak in March with a maximum frequency of 15.03%. The low occurrence frequencies are in the summer (June to August) with a minimum frequency of 4.49% in June. The statistical results also demonstrate the seasonal variability of internal waves. The seasonal distribution of the internal waves shows that the internal waves are more frequent during the dry season (February to April) and less frequent in the rainy season (May to July). Overall, a double peak distribution for the occurrence frequency of internal waves is observed for the Andaman Sea.

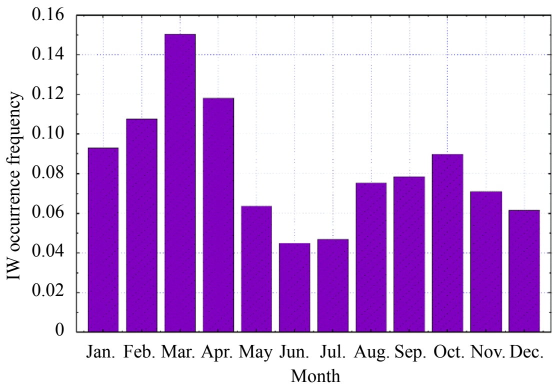

Fig. 2. Monthly distribution of satellite-observed internal wave (IW) occurrence frequencies in the Andaman Sea.

Because the generation, propagation and disintegration of internal waves depends on bottom topography and stratification, internal waves can show significant spatial variation. The change of stratification has an important influence on the internal waves. The stratification of the Andaman Sea has a significant half-year cycle and adheres to a bimodal structure of two shallow and deep. It is observed that the seasonal trends of the observed internal waves were consistent with stratification. Furthermore, during strong southwest monsoons that have occurred since the summer after the outbreak of continuous control surface wind field of the Andaman Sea, the wind stress intensity reaches the peak of the year, thereby decreasing the frequency of internal waves in the dry season (Su, 2012).

The statistical results of the lunar daily distribution of satellite-observed internal wave occurrence frequencies in the Andaman Sea are shown in Fig. 3. The diagram clearly shows that high occurrence frequencies are observed from the second to seventh lunar days and from the 16th to 23rd lunar days, which are days after spring tides. The highest occurrence frequency is 4.95% in the sixth lunar day. The lowest occurrence frequencies are distributed in the 12th and 27th lunar days, which are a couple days after neap tides. The lowest occurrence frequency is on the 12th lunar day and is 1.05%, which is about a quarter of the highest occurrence frequency. Internal waves in the Andaman Sea may occur every day; however, they occur more often after a new moon and full moon. The occurrence frequency statistics of internal waves with respect to Lunar cycles shows that more internal waves are observed after the spring tide, which implies the spring tide may play an important role in internal wave generation in the Andaman Sea.

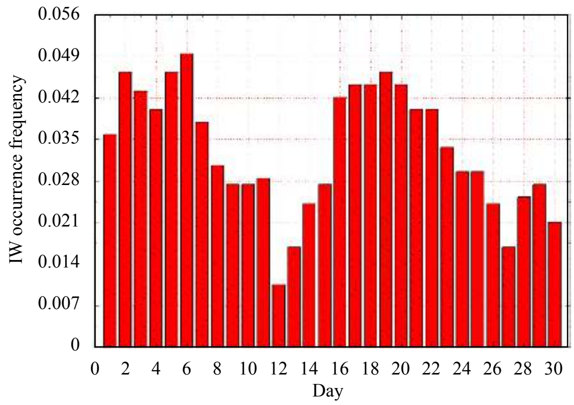

Fig. 3. Lunar daily distribution of satellite-observed internal wave occurrence frequencies in the Andaman Sea.

4 Sources of internal waves

The generation, propagation and disintegration of internal waves depend on the bottom topography and stratification. Internal waves almost always indicate wave propagation towards the coast and wave fronts parallel to local isobaths. In the Andaman Sea, there are multiple internal wave trains propagating in different directions, the direction variability is mainly explained by bottom topography features. Internal waves spread outward with irregular arc radiations from the source and disintegrate in the process of their transmission. Multiple nearly parallel waveforms become different radius arc in the wave groups and do vertical section for nearby the source of internal waves, because the internal waves that are far away from the source will twist out of shape by topography or other hydrological conditions. The sources of internal waves in different areas were determined based on the extracted crest lines of internal waves in the Andaman Sea.

Figure 4a shows the sources location distribution map of the internal waves in the northern Andaman Sea. There are two columns of groups of internal waves that are visible in the Fig. 4a: one propagating southeast towards the continental shelf (yellow curve), and one propagating southwest towards Andaman Islands (red curve) is visible immediately in the northern Andam-

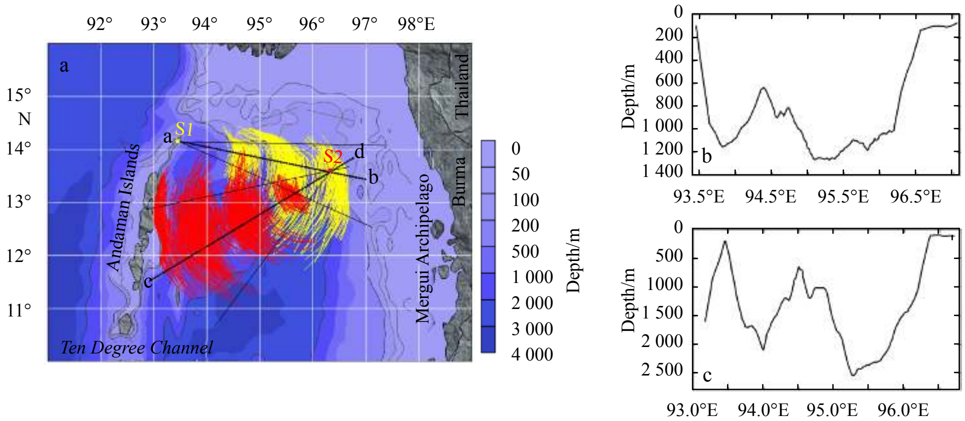

Fig. 4. The source locations distribution map of the internal wave in the northern Andaman Sea. The yellow curves show the internal wave propagating southeast toward continental shelf; the red curves show the internal wave propagating southwest toward the Andaman Islands. The two black lines a-b and c-d are cross lines selected along the propagation direction of internal waves representing the topography, respectively (a). Figures b and c are topography profiles of two black lines a-b and c-d, respectively.

an Sea. It is evident that the southeast propagating waves originate in the Northern Andaman by the ray tracing method, and the southwest propagating waves originate at the continental slope of the northern Andaman Sea.

The two black lines (a-b and c-d) in Fig. 4a, which are cross lines selected along the propagation direction of the internal waves, represent the topography. Figures 4b and c are topography profiles of the two black lines a-b and c-d, respectively. Regarding the internal waves propagating southeast towards the continental shelf the water becomes shallow suddenly close to the eastern continental shelf along the direction of internal wave propagation. It is obvious that the propagation speed of internal waves in the south is faster than the propagation speed of internal waves in the north, and the waveform is distorted. Regarding the internal waves propagating southwest towards Andaman Islands, the whole internal wave packet is propagated in deep sea area, which is less affected by topography and demonstrates little change in waveform.

The source locations distribution map of the internal waves in the central Andaman Sea are shown in Fig. 5a. The generation and propagation of internal waves in diversity are influenced by Nicobar Islands. The distribution map shows that the symmetric generation of internal waves between the Car Nicobar islands and Teresa Island, and a part of the internal waves propagating west toward the Indian Ocean, one propagates east toward the Andaman Sea. Where a small amount of internal waves east and west toward the Andaman Sea and the Indian Ocean in the Ten Degree Channel, between the Teresa Island and Card Royal Island, and between Card Royal Island and Little Nicobar. The symmetric generation of internal waves between the Carl Nicobar islands and Teresa Island are more active in the center of the Andaman Sea.

Figures 5b and c show topography profiles of the two black lines a-b and c-d in Fig. 5a, respectively. Topographical cross sections show that the water in the west of Nicobar Islands is deep and the depth changes slowly, wherefore the shape and propagation direction of internal waves is almost uninfluenced by water depth. However, in the east of Nicobar Islands, the internal waves propagate east toward the Andaman Sea where the submarine topography changes significantly, and the direction of propagation of internal waves has great change.

Figure 6a is the source locations of the internal waves in the

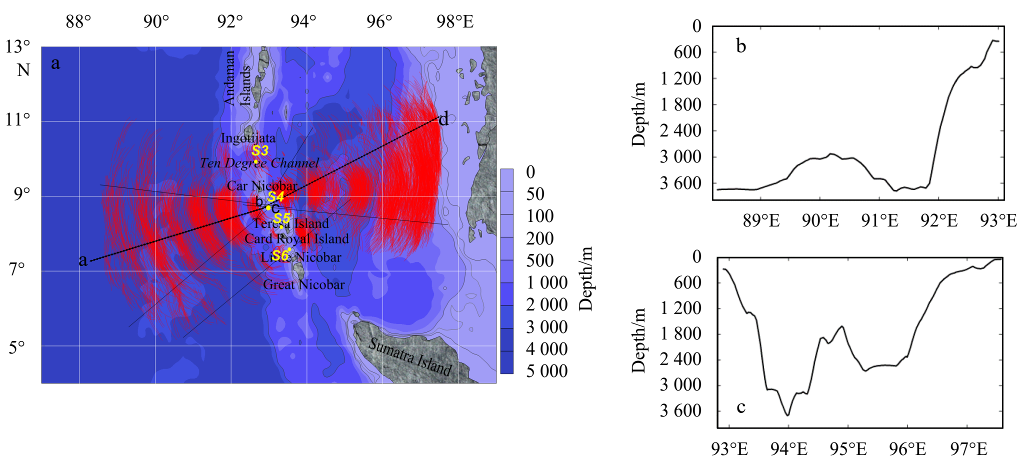

Fig. 5. Source locations distribution map of the internal wave in the central Andaman Sea. Two black lines a-b and c-d are cross lines selected along the propagation direction of internal waves propagating west toward the Indian Ocean and propagates east toward the Andaman Sea, respectively (a). Figures b and c are topography profiles of two black lines a-b and c-d, respectively.

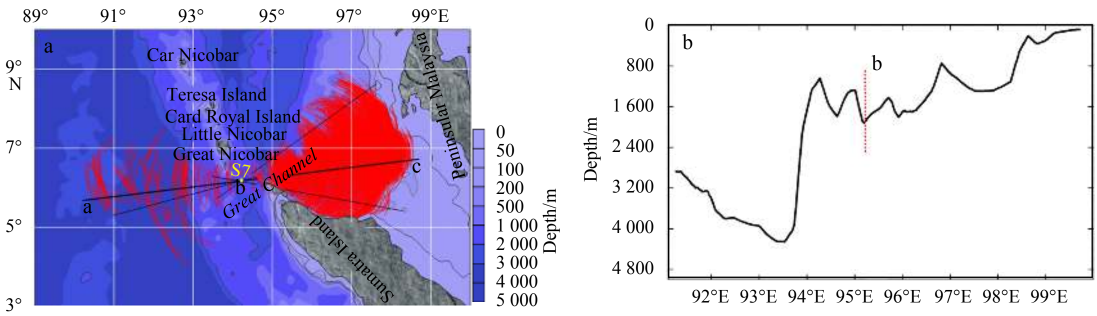

Fig. 6. Sources location distribution map of the internal wave in the southern Andaman Sea. The black lines a-b-c are cross lines selected along the propagation direction of internal waves propagating west toward the Indian Ocean and propagates east toward the Andaman Sea, respectively (a). Figures b is topography profiles of the two black lines a–b and b–c.

southern Andaman Sea. It is obvious that a significant amount of internal wave activity is propagating east towards the Andaman Sea, while westward propagation toward the Indian Ocean is rare. The internal waves originate at the Grete Channel between the Great Nicobar Island and Sumatra Island. Regarding the topography profiles of the two black lines a-b and b-c as shown in the Fig. 6b, the red dashed line is about the source locations of the internal wave. The water depth in this region changes rapidly from over 4 000 m in the Indian Ocean to approximately 1 000 m in the area around the Great Channel and the southern Andaman Sea. Internal waves may be less detected by remote sensing due to the depth of the water being deeper in the west of Great Channel and the thermocline being deeper.

The three-dimensional depth structure of the Andaman Sea is shown in the Fig. 7, and the generation source locations of internal waves in the Andaman Sea is proposed from S1 to S7. The results indicate that six sources are located between the Andaman Islands and Nicobar Islands, and one is located in the shelf slope of the northern Andaman Sea.

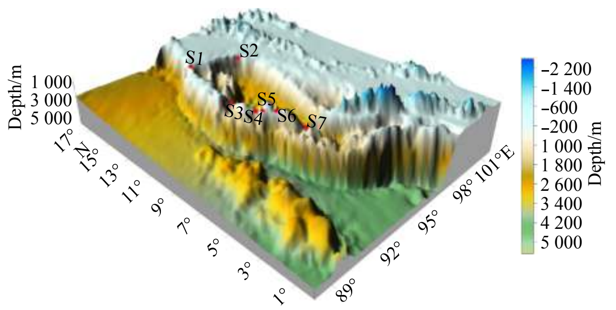

Fig. 7. Three-dimensional structure of sources location of internal waves in the Andaman Sea.

In conclusion, more than 1 300 MODIS images from June 2010 to May 2016 for a continuous 6 years were analyzed to obtain the sources distribution of internal waves in the Andaman Sea. The results show that there exist seven generation sources of internal wave from northern to southern of the Andaman Sea:

(1) nearby waters of northern Andaman Islands (S1);

(2) the continental slope of the northern Andaman Sea (S2);

(3) nearby waters of Ten Degree Channel (S3);

(4) the waters between Car Nicobar Islands and Teresa Island (S4);

(5) the region between Teresa Island and Carl Nicobar islands (S5);

(6) the waters between Card Royal Island and Little Nicobar (S6);

(7) the region between Great Nicobar Island and Sumatra Island (S7).

5 Internal wave characteristics

This section examines four regions of significant internal wave activity in the Andaman Sea that were found during the MODIS survey. The image showing the internal wave signatures in each region is presented along with the wave characteristics of propagation velocity, propagation distance, wavelength and source. There are four main areas in the Andaman Sea where internal waves are mostly observed: continental shelf of the northern Andaman Sea, northern Andaman Sea, central Andaman Sea and southern Andaman Sea.

5.1 *Continental shelf of the northern Andaman Sea*

The survey identified the largest number of small spatial scale wave occurrences in the continental shelf of the northern Andaman Sea. Farther to the north, the profusion of waves in this region is due to the estuarine diluted water from Burma. Figure 8 is a MODIS image acquired on 28 October 2011 at 04:15 UTC that shows internal wave signatures in the Continental shelf of the northern Andaman Sea. The imaged area is approximately 188 km×152 km. The imagery shows a large number of wave packets and fronts propagating in a variety of directions away from the Burma continental shelf. This finding indicates that there is a large number of internal wave sources in and among the small islands and shoals in the area. Internal waves generated at the shelf are shorter-scale and become ubiquitous in the region inside the 50 m isobaths. The wavelength is approximately 400 m propagating primarily to northeast toward continental shelf. The internal wave signatures are approximately 25 km from the coast of the Burma. The propagation of the internal wave is determined by the ocean depth and the density profile of the water column. The characteristics of these internal wave signatures are typical of continental shelf-generated internal waves observed in other areas of the world (Haury et al., 1979; Stanton and Ostrovsky, 1998; Jackson, 2007).

5.2 *Northern Andaman Sea*

The survey revealed an unexpectedly large amount of internal wave activity year-round in the northern Andaman Sea. The waves manifest themselves as groups of 3 to 4 waves that propagate across the sea to the southeast and the southwest. The imaged area is approximately 474 km×380 km, and the wavelength

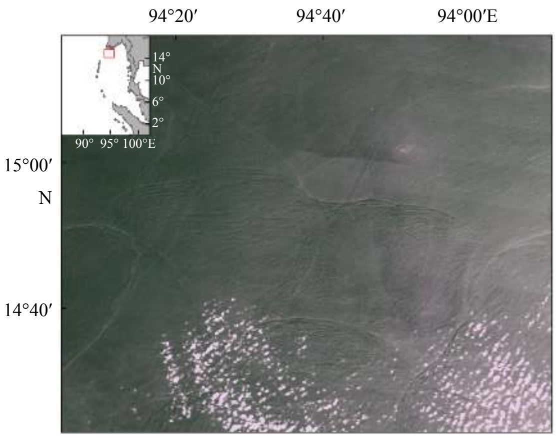

Fig. 8. MODIS image acquired on 28 October 2011 at 04:25 UTC showing the internal waves around the continental shelf of the northern Andaman Sea.

is approximately 1 000 m. The southeast propagating waves originate in (or near) the northern Andaman Sea and the southwestern propagating waves originate at the continental slope of the northern Andaman Sea, most likely near the sea (13.56°N, 96.25°E). Figure 9 shows a MODIS image acquired on 20 March 2015 at 04:25 UTC containing two direction propagation internal waves. Three groups of internal wave packets that are seaward propagating, with separation distances between packets of 97.87 km and 100.93 km, respectively, and indicated propagation speeds of approximately 2.19 m/s and 2.25 m/s assuming a semidiurnal generation period (Jackson, 2007; Rizal et al., 2012). Four groups of internal wave packets propagating southwest toward Andaman Islands are visible in the sea. The separation distances between packets is 85.05 km, 96.16 km and 104 km, respectively, indicating propagation speeds of approximately 1.9 m/s, 2.15 m/s and 2.33 m/s, assuming a semidiurnal generation period.

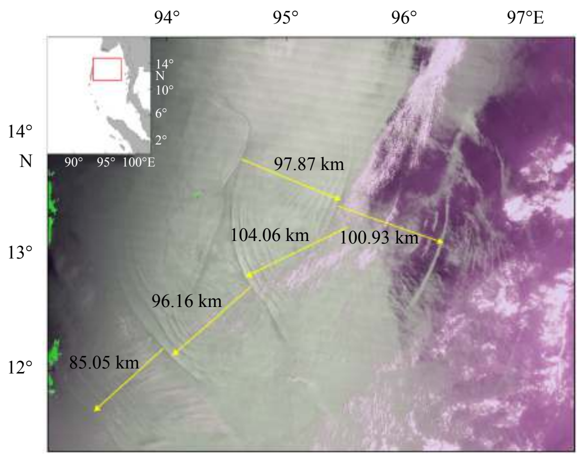

Fig. 9. MODIS image acquired on 20 March 2015 at 04:25 UTC showing the internal waves around the northern Andaman Sea.

5.3 *Central Andaman Sea*

The MODIS survey showed an unexpectedly large amount of internal wave activity in the central Andaman Sea and part of Indian Ocean. Figure 10 is a MODIS image acquired on 20 March 2011 at 07:10 UTC showing the symmetric generation of internal waves between the Carl Nicobar Islands and Teresa Island. The imaged area is approximately 481 km×379 km, and the wavelength is approximately 500 to 800 m. The packets appear to the west of the islands and propagate across the eastern equatorial Indian Ocean and shoal near Sri Lanka, which was generated on the previous tidal cycle. The separation distance between packets of 104.11 km gives a propagation speed of approximately 2.32 m/s, assuming a semidiurnal generation period (Jackson, 2007; Rizal et al., 2012). The internal wave packets on the east side of the Nicobar Islands develop into the well-known internal waves that propagate across the southern portion of the Andaman Sea. The separation distance between packets is 114.56 km indicating a propagation speed of approximately 2.56 m/s.

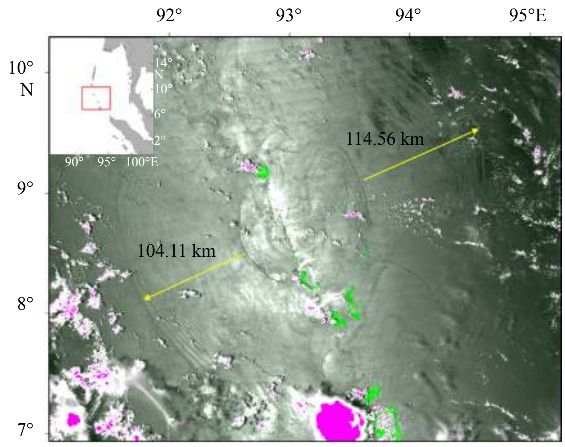

Fig. 10. MODIS image acquired on 20 March 2011 at 07:10 UTC showing the internal waves around the central Andaman Sea and part of Indian Ocean.

5.4 *Southern Andaman Sea*

The survey also revealed an unexpectedly large amount of internal wave activity in the southern Andaman Sea. Figure 11a shows a MODIS image acquired on 18 July 2011 at 04:15 UTC containing these eastward propagating waves. It was found that the Aqua-MODIS images show more cloud cover. The imaged area is approximately 482 km×379 km. Four distinct internal wave packets are visible in the image propagating to the Andaman Sea. These waves can have crest lengths in excess of 400 km, and the shape seems to be affected by the local bathymetry. The internal solitary wave signatures originating at the strait between Great Nicobar Island and Sumatera Island are shorter-scale and extending more than 400 km into the Andaman Sea. The packet separation distances are 105.69 km, 104.96 km and 80.42 km, corresponding to propagation speeds of approximately 2.36 m/s, 2.34 m/s and 1.79 m/s, respectively, assuming a semidiurnal generation period (Jackson, 2007; Rizal et al., 2012).

Figure 11b shows a MODIS image acquired on 18 July 2011 at 07:15 UTC, the Aqua-MODIS image was acquired 3 h after the Terra-MODIS pass. The packets W1, W2, W3 of internal waves were acquired on 18 July 2011 at 04:15 UTC by Terra-MODIS, and the packets W1', W2', W3' of internal waves were acquired three hours later by Aqua-MODIS, respectively. It is possible to estimate the propagation speed of individual wave packets in this pair of MODIS. The red curve in Fig. 11a is the extracted wave crest lines from the Aqua-MODIS image. The crest separation distances of 28.63, 25.72 and 25.47 km were calculated as shown in the Fig. 11a (See the yellow segment), the image acquisition time interval was three hours giving a propagation speed of approxim-

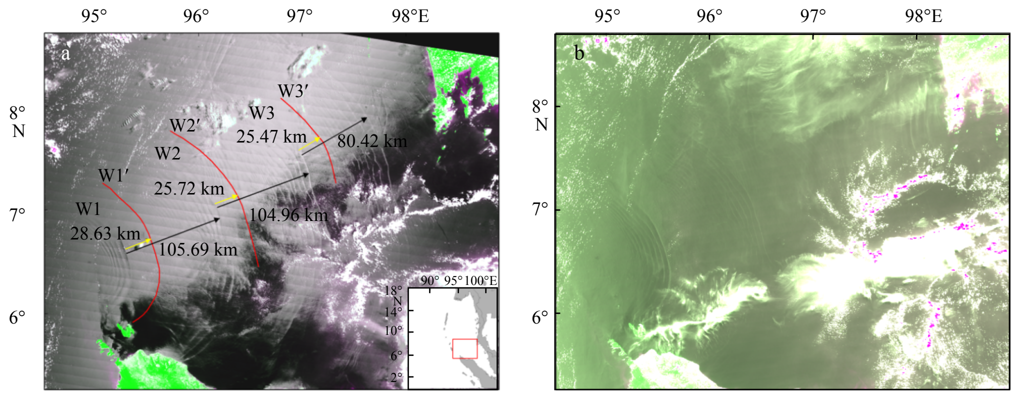

Fig. 11. The internal waves images acquired on Terra-MODIS (18 July 2011 at 04:15 UTC) (a); and the internal waves images acquired on Aqua-MODIS (18 July 2011 at 07:15 UTC) in the southern Andaman Sea (b).

ately 2.65, 2.38 and 2.35 m/s in the southern Andaman Sea.

It can be found that the propagation speed of internal waves based on the semidiurnal generation period is less than the pairs of the images. The speed difference between the calculations using semidiurnal tide period and the pairs of MODIS data is reasoned to be due to time differences. During the long tidal period, the characteristics of internal waves change as they propagate over long distances in water with varying currents and/or bottom topography (Hong et al., 2015). Internal wave propagation velocity is determined to the first order by the wavelength, the ocean depth and the density profile of the water column. By using pairs of MODIS with images separated in time by only a few minutes to a few hours, it is possible to estimate the propagation speed of individual wave packets more accurately than by computing a velocity from the distance between packets with assumptions about generation time.

6 Conclusions

Internal waves occur frequently in the Andaman Sea because of its special bottom topography and stratification. More than 1 300 images from June 2010 through May 2016 were analyzed to observe the internal waves in the Andaman Sea. The results of the spatial-temporal distribution, sources and propagation characteristics of internal waves are presented.

The statistical analysis shows that internal waves can be observed over almost the entire area of the Andaman Sea, where the bathymetrical contour is greater than 50 m. More internal waves are observed in the northern, central and southern regions of the Andaman Sea than in other areas. A significant number of internal waves between 7°N and 9°N in the East Indian Ocean are also observed. Internal waves in the middle deep-water area of the Andaman Sea have been rarely detected. Internal waves can be observed year-round in the Andaman Sea, while most of internal waves are observed between February and April, with a maximum frequency of 15.03% in March. The low occurrence frequencies are distributed in the summer from June to July with a minimum frequency of 4.49% in June. The seasonal distribution of the internal waves shows that the internal waves have been observed mostly in the dry season (February to April), while fewer internal waves are observed in the rainy season. The double peak distribution of the occurrence frequency for internal waves is found. The occurrence frequency statistics of internal waves with respect to Lunar cycles shows that more internal waves are observed after the spring tide, which implies the spring tide may play an important role in internal wave generation in the Andaman Sea.

The generation sources of internal waves are explored based on their propagation characteristics. There exist seven sources of internal waves for the northern to southern areas of the Andaman Sea: nearby waters of northern Andaman Islands, the continental slope of the northern Andaman Sea, nearby waters of Ten Degree Channel, the waters between Car Nicobar islands and Teresa Island, the region between the Teresa Island and Carl Nicobar islands, the waters between Card Royal Island and Little Nicobar, the region between Great Nicobar Island and Sumatra Island. The results indicate that six sources are located between the Andaman Islands and Nicobar Islands, and one is located in the northern Andaman Sea. Four regions with active internal wave phenomenon in the Andaman Sea were presented during the MODIS survey. The propagation speed of internal waves calculated based on the semidiurnal generation period was smaller than the results acquired from pairs of the images over short time intervals.

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