NON-LINEAR INTERNAL WAVES IN THE BANDA SEA ON SATELLITE SYNTHETIC APERTURE RADAR AND VISIBLE IMAGES

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1. INTRODUCTION

Intensive internal waves were discovered in many seas of Indonesian Archipelago [1-5]. They are generated as a result of interaction of strong tidal currents between the islands with the bottom elevations, sills, and shelf edge. Internal waves (IWs) are observed throughout year since the tropical waters are always stratified. Variable surface currents associated with internal waves modulate the sea surface roughness that can be registered by satellite optical sensors and Synthetic Aperture Radar (SAR). The main aim of our research was comprehensive study of non-linear internal waves in the Banda Sea. Their characteristics were estimated from satellite visible and SAR images.

2. DATA

Quick look (QL) and full-resolution SAR images of the Banda Sea acquired by ERS-1, ERS-2, Envisat and ALOS since 1997 till 2009 have been analyzed. The ERS-1/2 SAR has a spatial resolution of about 25 m and Envisat ASAR and ALOS PALSAR in wide swath mode have a resolution of 75 m. The QL images have a lower geometric and also a lower grey level resolution. In spite of this, internal wave-induced radar signatures in the Banda Sea could be delineated on these images. IWs were also detected on Terra and Aqua MODIS visible images [3, 4, 6] and on Landsat images mainly in sun-glint areas. Ancillary data used in analysis of satellite images and in interpretation of the revealed wave-like features included QuikSCAT-derived wind fields, SST fields, weather maps and bathymetry.

3. RESULTS

Clearly-defined signatures of internal waves were found on satellite images obtained during the "dry" southeast monsoon (approximately June to September) when the Indonesian Through Flow (ITF) reaches its maximum, during the "wet" northwest monsoon (approximately December to March, minimum ITF) as well as during transition months. Analysis of SAR and visible images allowed concluding that IWs were very likely generated by a sill between Alor and Atauro Islands in the Ombai Strait, one of the major passages of ITF. The IWs form packets propagating northward into the Banda Sea and have the classic appearance of rank ordered non-linear waves that depress the pycnocline [4-6]. Figure 1a shows two packets of IWs on Envisat ASAR images acquired on 18 April 2003. They were reliably detected within the whole Envisat swath. The length of several crests in the packets exceeded 350 km. The crests of solitons form almost correct semicircles, limited by the islands. Detailed examination shows, however, that the distance between different points on a crest and a source (sill) is not constant that can be explained by differences in phase velocity in different directions. The maximum wavelength of the soliton was approximately 12-15 km. The manifestation of the IWs on SAR images suggest a tidal generation mechanism. The tide at the sill region is predominantly semi-diurnal; tidal velocity there can exceed 3.0 m/s. Under this assumption, estimates of the phase speed of the waves were derived and found to vary from approximately 2.2 to 3.0 m s^{-1}.

The same estimates were derived by analysis of ERS-1 and ERS-2 SAR images acquired during the El Nino event on 17 and 18 October 1997, correspondingly. A strip of the images acquired on 18 October (Figure 1b) shows a radar signature pattern of solitary waves similar to the pattern visible on the SAR image which was acquired on 17 October. However, on this day the solitons were imaged at an earlier phase of the tidal cycle. Within the wave packet, the wavelength decreases monotonically. 15-20 and more solitons can be delineated on full resolution ERS-2 SAR images. The length of the packets reaches 80-90 km.

IWs waves were identified on several Terra and Aqua MODIS visible images [4, 6]. In sun glint area wave crests had negative brightness contrast against the background waters. 3-4 internal wave packets generated by successive semidiurnal tides can be observed on one image under cloudless conditions.

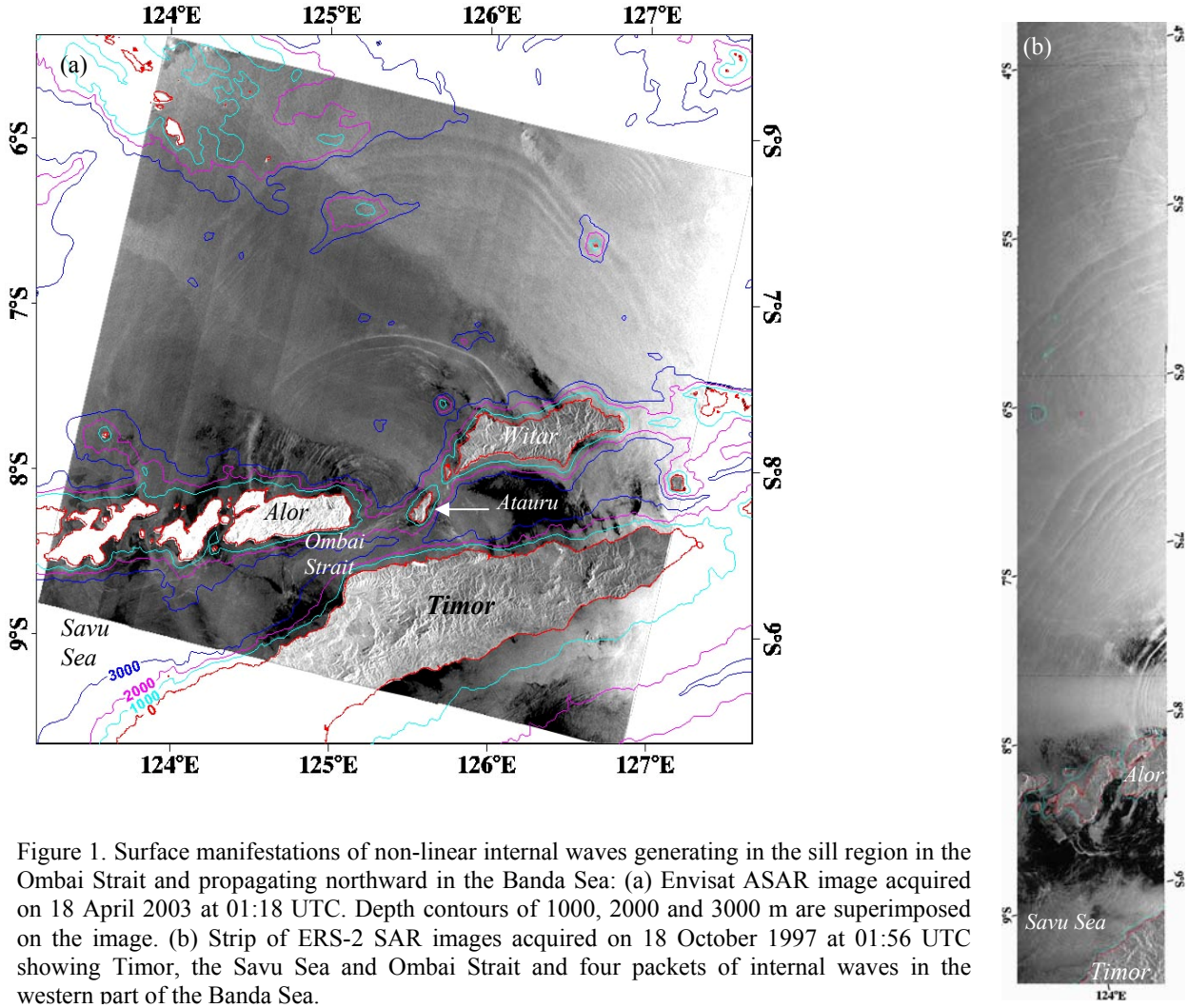

Figure 1. Surface manifestations of non-linear internal waves generating in the sill region in the Ombai Strait and propagating northward in the Banda Sea: (a) Envisat ASAR image acquired on 18 April 2003 at 01:18 UTC. Depth contours of 1000, 2000 and 3000 m are superimposed on the image. (b) Strip of ERS-2 SAR images acquired on 18 October 1997 at 01:56 UTC showing Timor, the Savu Sea and Ombai Strait and four packets of internal waves in the western part of the Banda Sea.

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4. REFERENCES

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