OBSERVATIONS OF OCEANIC INTERNAL WAVES IN BAY OF BENGAL USING SYNTHETIC APERTURE RADAR

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ABSTRACT

Sea surface manifestations of internal waves in the shallow continental shelf waters of north Bay of Bengal have been observed almost all seasons imaged by Synthetic Aperture Radar (SAR) images of ERS1/2 and Envisat ASAR missions during the period 1993 to 2004. Especially in summer months shoreward propagating, strong surface signatures of internal wave packets are frequently fancied in shallow waters. Large number of short period, shoreward propagating rank ordered internal wave packets are revealed on continental shelf slope of north Bay of Bengal by Envisat ASAR image mode images.

1. INTRODUCTION

Oceanic internal waves are interesting and important phenomena to Oceanographers and they exist in all levels of the water column in deep oceans as well as in marginal areas. Generated mechanisms are believed to be tidal flow over underwater obstacles (Seamounts, shelf brakes, and troughs). Other proposed generation mechanisms are frontal boundaries and seasonal wind conditions, etc., amongst the variety of internal waves very energetic waves are created by reversing tidal flow over topography in a stratified environment (1). Finally the expressions of internal wave features allow the assessment of the subsurface hydrographic and velocity structure and mixed layer depth, in particular in combination with numerical models.

The manifestation of internal waves can be captured by a variety of remote sensing instruments, e.g., by ship radar, ground-based radar, photographic camera and imaging radar of airborne are well documented. Mainly internal wave has been detected by SAR from space borne, for example Envisat ASAR, ERS-1/2, Radarsat, SIR-C and so on. Satellite SAR images record a snapshot view of a vast two-dimensional internal wave field (2) in particular, on the continental shelf and in the coastal ocean a great diversity of internal wave behavior has been intimately projected by SAR profiles.

Internal waves manifest themselves on the sea surface in alternating bands of rough and smooth water, which appear as light and dark strips on Satellite images. The strips can be tens to hundreds of kilometers in length and persist on the surface for several days as the internal waves move through the ocean. In world oceans, Apel and Gonzalez (3), Alpers (4), da Silva et al (5), Liu et al (6), Valsenko and Alpers (7), etc has been carried out various studies on SAR internal wave imaging mechanism, backscattering features, and models.

In Bay of Bengal, using in situ measurements internal waves of varying period of heights are studied by Murthy P.G.K.(8), Sarma Y.V.B et.al (9), Antony M.K. et.al (10) and the depth of thermocline undergoes an annual cycle, as well as oscillations with periods equal to tidal cycles (11) and shorter period are also prominent because they occur between the shallow, low-density surface layer and the denser water below. Vertical oscillations or internal waves by convergence and divergence appear as long bands of alternately smooth and rough water on the surface (12). In this cogitation, on a SAR images acquired by the Envisat of image mode over north Bay of Bengal (18 - 20°N, 84 - 86°E), strong surface manifestations of distinct groups of shelf edge crossing and shoreward propagating numerous internal wave packets are imparted.

2. OBSERVATIONAL DATA

Number of SAR images in different missions are browsed for identification of internal wave signatures in North Bay of Bengal from 1991 to 2004. From those, Envisat Advanced Synthetic Aperture Radar (ASAR) of two images in Image Mode (Single Strip i.e. ~200X100 Kms) on 4th October 2003 at 0420 UTC, an attempt has been made to understand the propagation and behavior of internal waves.
Fig. 1(a) Portion of Envisat ASAR of image of coastal waters of North Bay of Bengal showing internal wave packets on 4th October 2003, 0421 h UTC. (b) Close look of the internal wave packet marked in the Fig.1(a). (c) Slice of image intensity across the wave packet in Fig.1b Lead wave is at the left.
3. DISCUSSION:

Sea surface manifestations of internal waves are imaged by twenty SAR profiles are observed in North Bay of Bengal from quick looks. The images span most calendar months and were spread out between 1993 to 2005. Of these imaging profiles, strong and huge surface internal wave signatures of SAR imaging profiles, on 4th October 2003 are used in this paper.

The image of 4th October 2003 at 0420 UTC, shelf waters of North Bay of Bengal is analyzed. The analysis applied to SAR images of internal waves occurring the North Bay of Bengal on Indian Continental shelf edge. Fig. 1a & 2a shows the SAR images, the images showing the variations in the relative intensity due to changes in sea-surface roughness. Substantial number of shoreward propagating internal waves are observed. In detail, about hundred Kilometers spatial coverage and thirty meters spatial resolution processed images showing several long groups of internal wave packets are propagating towards the coast.

A general look of SAR profiles (Fig.1a and Fig.2a); ascertained groups internal wave packets were usually characterized by several dominant features. Initially single wave of depressions propagating towards the coast and immediately when crossing the continental shelf edge those evaluated as rank ordered internal wave packets. The individual oscillations are non-sinusoidal, with predominantly downward displacements, the amplitudes are rank ordered with the largest at the front of the packet and the smallest at its rear; wavelengths and crest lengths are also rank ordered, with the longest waves again at the front of the group and the number of individual oscillations with in the packet increases as its moves towards the coast.

In particular lower left corner of the Fig.1a, larger internal wave packet, having seven crests analyzed and their wavelengths and crest lengths decreased towards the trailing edge of the group. Close look of that packet showed in Fig.1b. The typical wave separation between internal waves has been derived from an image intensity slice taken across the wave packet showed in Fig.1b. In Fig1c., the slice from which typical separations can be deduced as ~700 m (13). It is to note that the wavelength and crest length of the IW packet decreasing significantly from the front to the back of the packet, exhibiting the non-linear dispersive wave nature.

Fig.2a, is the continuation frame of the Fig.1a, one can see clearly that the generation of rank ordered large number of internal waves as a packets from the single wave of depressions, when those are crossing at the shelf edge slope. Dark regions in Fig.1a&2a, referable to areas where surface roughness is reduced due to the presence of material on the water surface, or imputable to reduced wind speed, or wave-current interactions.

Fig.2b. is the close look of central packet of the second SAR image (Fig.2a), which is having nearly twelve crests and transect profile, is employed in Fig.2c and their averaged wavelength is ~600m. It is interesting to note that the number of internal wave in each packet are increasing from top to bottom of the first and second SAR images (Fig.1a&2a) and decreasing the wavelengths.
Fig. 2a. Continuation of Fig. 1a, Clearly showing two groups of rank ordered internal wave packets on shelf edge.
4. SUMMARY AND CONCLUSIONS:

The observed substantial signatures on the SAR profiles are the modulation by internal wave induced surface currents to surface capillary waves, which major backscatterer energy of the transmitted pulse of the SAR antenna. The stronger modulation current is the greater the gray level contrast or backscattering coefficient in the imagery. On the other hand, the modulation current depends on the amplitude of the internal wave. Hence the gray level contrast on a SAR image profile can be used some extent as an indicator of internal wave amplitude but vicenary relationship between them still needs to be accomplished.

The observed diversity of internal wave behavior is an indicator of the complexity of the dynamic environment on the continental shelf. For instance the sharp changes in bottom topography at the continental shelf and the fresh water runoff originating from the Mahanadi River may caused the vertical stratification of sea water as a complicated horizontal structure.

Surface signatures of internal waves in the shallow continental shelf waters as well as in deep waters are observed almost in all seasons in north Bay of Bengal imaged by SAR profiles. Short period, long groups of internal wave packets are revealed at shelf break on Envisat ASAR images having with large crest lengths. Initially single wave of depressions propagating towards the coast and those evaluated as rank ordered internal wave packets by interaction with the shelf edge slope, exhibiting the non-linear dispersive wave nature.
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REFERENCES


