Possibility of Internal Waves Detection by X-band Radar

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Abstract

Ocean internal waves are the oscillations underwater, they are dangerous for ship sailing, submarines and offshore platform. Due to the oscillations of internal waves distribute in space domain, more and more researches focued on detecting spatial characters of internal waves by satellite images recently. However, most of the satellites travel along their predetermined track, it is difficult to track the same internal wave continuously. This study discussed the possibility of detecting internal waves by using commerical X-band radar. We integrated Global Positioning System (GPS) and compass module with commercial X-band radar to simultaneously record the time-space information of the internal waves, and applied spatial filtering and Laplace filtering for smoothing other information except internal wave. The field experiment for detecting internal waves by X-band radar was arranged in 2005. According to our experiment, an internal wave was found and validated by satellite image and in-situ water temperature measurement. It showed that a simple, cheap and popular tool could be developed for internal wave detection and will benefit future studies on internal waves.

Introduction

Ocean internal waves occur within the water layers under sea surface. Due to the influences of water temperature and salinity, the internal waves would generate on the interface between two fluids of different densities. Internal wave is one of important ocean mesoscale phenomena. It is important for the transport of momentum and energy within the ocean. It has also potentially dangerous for submarine navigation, offshore platform and so on. With references to the factors that generate internal waves, Dong Qing et al. (2002) proposed that the tidal current was the main factor that causes the internal waves. Many researches of internal waves have been proposed recently, but the features of internal waves still can not be fully understood until now.

In the past, researches used single-point instruments for detecting internal waves, like temperature, salinity sensors, current meters, and acoustic instruments (Rodenas and Garello, 1997). Because internal waves distribute in large-scale region in space domain, more and more researches focused on detecting spatial characters of internal waves by remote sensing technologies recently. Satellite images were always used for detecting and studying internal waves (Connan et al., 1998). However, most of the satellites travel along their predetermined track, it is difficult to track the same internal wave continuously. New methods for obtaining continuous images of internal waves from remote sensing are still tried.

Although internal waves do not give rise to an elevation of the sea surface as the familiar surface waves do, they do influence the surface current. The sea surface current varies in magnitude and direction. It results convergent and divergent flow regimes at sea surface. Surface current interacts with the surface waves and modulates the sea surface roughness (Alpers, 1985). This interaction is the reason why oceanic internal waves become visible on satellite images and shipboard radar images. Fig. 1 shows the relationship between internal waves and surface roughness. The pattern of internal waves on radar image should be similar to wind waves which are shown as Fig. 2. They are interlaced by lighting and dark bands. Due to the wavelength of internal can be larger than several hundreds meter, it is easy to identify the difference between wind waves and larger internal waves.

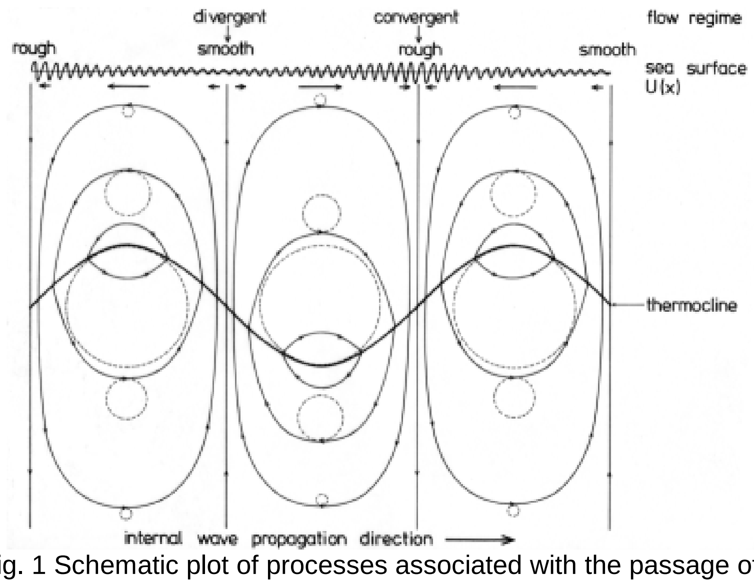

Fig. 1 Schematic plot of processes associated with the passage of a oceanic internal wave.[adopted from Alpers(1985)]

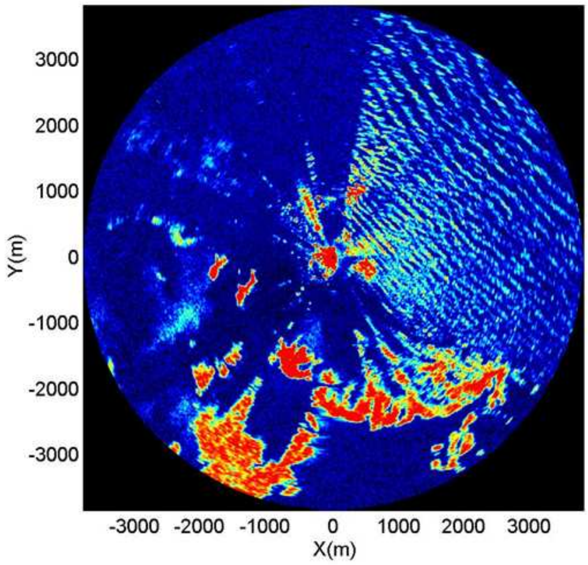

Fig. 2 The radar image of gravity waves (the right-up part)

X-band radar was used for ship navigation originally. It has been proved that it is possible to measure ocean surface waves and current by using X-band radar (Borge et al., 1999) (Gangeskar, 2002) (Wu et al., 2005). Due to the advancement of signal acquisition technology recently, it is possible to acquire internal wave information from radar hardware and record it as digital format. Considering internal waves are associated with variable surface currents which influence the surface roughness patterns (Brandt and Alper, 1994), it should be possible to detect the events of internal waves from sea surface patterns showing on X-band radar images. In this study, we discussed the possibility of detecting internal waves by using X-band radar.

Methodlogy

For the sake of making it possible to detect internal waves by X-band radar, we integrated Global Positioning System (GPS) and compass module with commercial X-band radar to simultaneously record the time-space information of internal waves.

Internal waves backscatter can be obtained from commercial radar if the ship is near the region of internal waves. The commercial radar is used by x-band marine radar in this study. The time, location and direction of internal waves can be recorded simultaneously accompanying with global positioning system (GPS) and compass module too.

In order to obtain high resolution internal wave image, high sampling rate AD technology is necessary. The radial resolution (Δ_r) of radar image is determined by sampling rate (S_r) and the speed of electromagnetic wave (V_e). In this study, 10 MHz for sampling radar backscatter was used. It can be known that the spatial resolution of radar image is 15 m/pixel.

$$\Delta_r = V_e/(2S_r) \quad (1)$$

The lateral resolution (Δ_l) of radar image is related to the pulse repetition rate (P) of radar antenna.

$$\Delta_l = (2\pi R)/(P \cdot T_r) \tag{2}$$

T_r is the time to rotate one circle of radar antenna, R is the radius of radar observing region. Rotating speed with 24 r.p.m. and the pulse repetition rate (P) with 2100 Hz of radar antenna were used here. That is to said, the lateral resolution of radar image is about 6 m/pixel where the distance between radar and the target is about 5000 m. It is enough to describe the wavelength of internal wave which is about several hundred meters at least. The process for acquiring internal wave information is shown as Fig. 3, and the original internal wave image without any image processing is shown as Fig. 4 (The left one). It can be found obvious noise appears on the radar image.

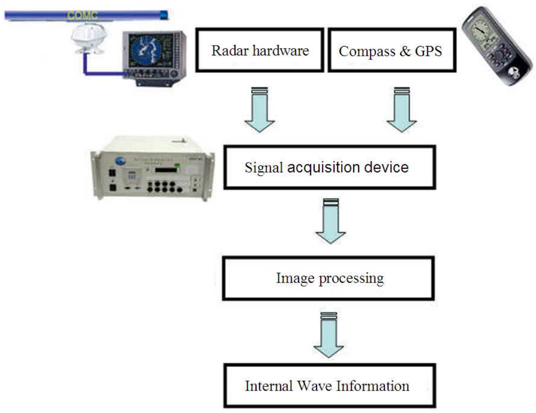

Fig. 3 The process for acquire internal waves information

The information detected from backscatter images of X-band radar includes internal waves, surface waves, as well as noise. We tried to apply spatial filtering for smoothing other information except internal wave. For the sake of enhance the visional effect of internal from x-band radar image, different kinds of image processing methods were tested. Comparing with internal waves and other features on X-band radar image, it can be found that the gray value scale of internal wave is much larger than others. Hence, it was tried to apply spatial filtering for smoothing other information except for internal wave. For a image size of $M \times N$, the mask [$w(s,t)$] size of $m \times n$ was applied. The spatial filtering equation can is shown in Eq. (3).

$$g(x,y) = \sum_{s=-a}^{a} \sum_{t=-b}^{b} w(s,t) f(x+s, y+t) \tag{3}$$

$a = (m-1)/2$ and $b = (n-1)/2$. In order to get a complete filtering image $g(x,y)$, $x = 0,1,2,..., M-1$ and $y = 0,1,2,..., N-1$. It is found that the background noise of internal wave image can be reduced effectively if the mask size for spatial filtering is larger than 5×5. In general, the wave length of ocean surface waves is less than 400 m. To separate the internal waves information from surface waves image, the low pass filter can be applied here. However, the small scale internal waves would be eliminated too.

For the sake of detecting the location and scale of internal wave, Laplace filtering was also applie. For a image of $g(x, y)$, the second order derivatives of the image in x direction and y direction can be defined as following.

$$\frac{\partial^2 g}{\partial x^2} = g(x+1, y) + g(x-1, y) - 2g(x, y) \tag{4}$$

$$\frac{\partial^2 g}{\partial y^2} = g(x, y+1) + g(x, y-1) - 2g(x, y) \tag{5}$$

Eq. (4) and Eq. (5) can be combined as Eq. (6):

$$\nabla^2 g(x, y) = g(x+1, y) + g(x-1, y) + g(x, y+1) + g(x, y-1) - 4g(x, y) \tag{6}$$

For the Laplace filtering image $I(x, y)$ can be defined as the following.

$$I(x, y) = \begin{cases} g(x, y) - \nabla^2 g(x, y) & if \quad \nabla^2 g(x, y) < 0 \\ g(x, y) + \nabla^2 g(x, y) & if \quad \nabla^2 g(x, y) > 0 \end{cases} \tag{7}$$

The Laplace filtering result is shown as Fig. 6. It can be found that most of the background noise can be separated from radar image except for the backscatter which is very close to the image center. Due to it is stronger than internal wave backscatter, the background noise of image center still can not be eliminated completely. But the background noise in the other regions of image can be eliminated obviously.

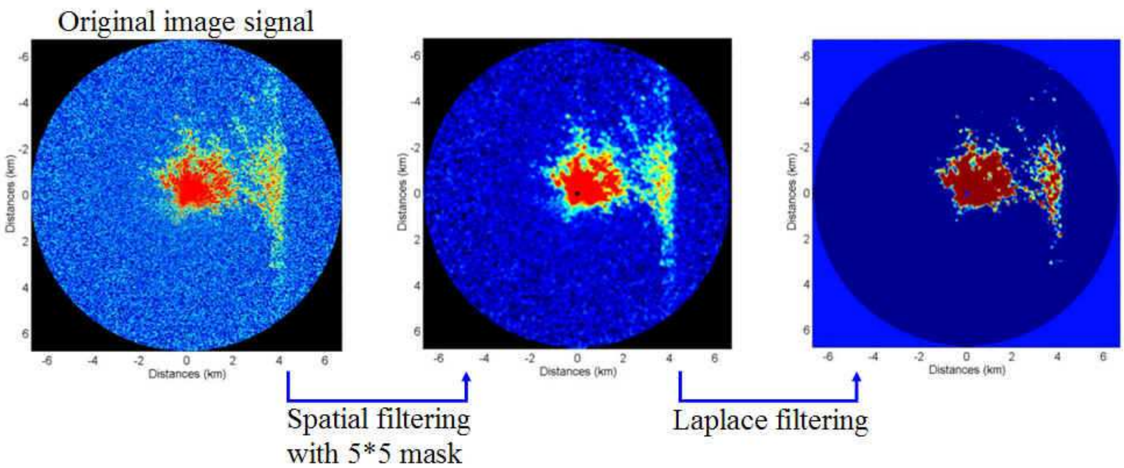

Fig. 4 The internal wave image with spatial filtering and Laplace filtering

Experiment description

The experiment for detecting internal waves by X-band radar was arranged in May, 2005 by using the researching vessel. The vessel traveled to South China Sea from 13th to 17th for the purpose of seeking out internal waves (Fig. 5). A probable internal wave was found (Fig. 6) from X-band radar images when the vessel arrived Pratas Islands in South China Sea at 17:00 on May 15th. The width and moving speed of this internal wave were about 0.3 nm and 3.5 nm/hr.

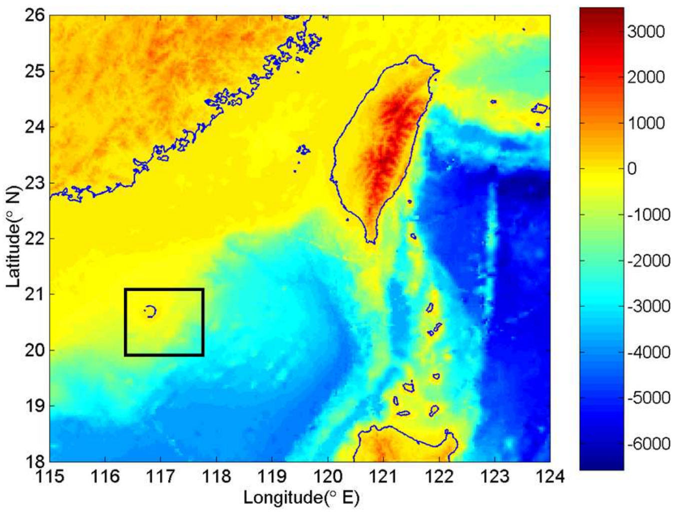

Fig. 5 The Region which is detected internal waves in this study

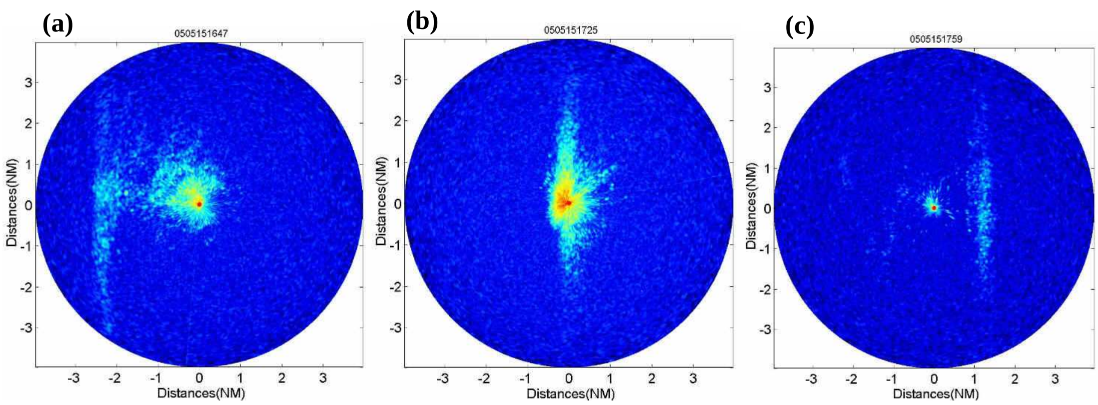

Fig. 6 Internal wave images which were observed from X-band radar
(a) 16:47 on May 15th; (b) 17:25 on May 15th; (c) 17:59 on May 15th

Verification

To validate the authenticity of the internal waves from radar images, satellite image and water temperature data were adopted here. From MODIS (Moderate Resolution Imaging Spectroradiometer) website, we found a satellite image detected in South China Sea at 13:20 on the same day (Fig. 7). The internal wave was detected 3.5 hrs later when the vessel anchored near the Island Pratas. By calculating the travel time, it is validated that the internal wave shown in the satellite image is the one observed by the X-band radar system on the vessel. The second proof came from the in-situ water temperature. The sea temperature sensors were arrayed with the mooring chain which was connected to the research vessel. Hence, the profile (vertical distribution) of sea temperature can be obtained at the same time. The sea temperature measuring results from 12:00 to 24:00 on May 15th is shown in Fig. 8. It can be found that the sea temperature sensors were lifted up from 17:00 to 18:00. According to Fig. 2, the lifting and lowering forces should be caused by internal waves. So the sea temperature sensors may be lifted up or lowered down while the internal waves were passing. Because the sensors were fixed by the mooring chain which was attached to the research vessel, the downward phenomenon of the sensors was not so evident. This measurement results presented the feature of seas temperature while an internal wave was passing.

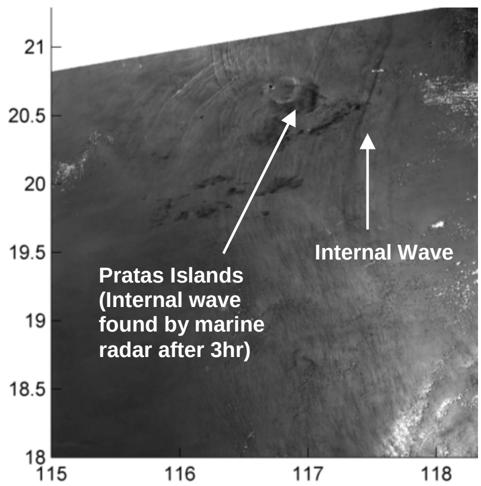

Fig. 7 Satellite image (MODIS) taken at 13:20 on May 15th

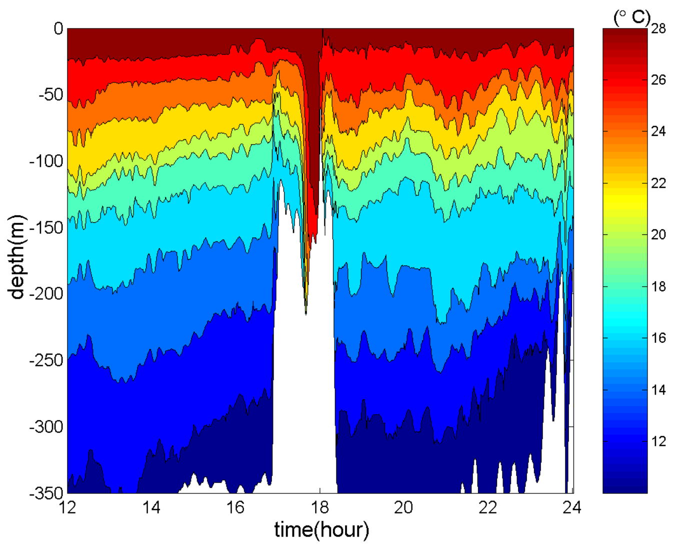

Fig. 8 Sea temperature profile on May 15th

Summary

X-band radars are quite popular on most of the ships. We presented the possibility of detecting internal waves by applying X-band radar. It is a 3D internal wave observation device.

Continuous propagation of internal waves can be recorded by the device.

In order to enhance the visional effect of internal wave from x-band radar image, different kinds of image processing methods were tested. It can be found that most of the background noise can be separated from radar image except for the backscatter which is very close to the image center.

According to our experiment, an internal wave was found and validated by satellite image and in-situ water temperature measurement. The study improves the function of shipboard marine radar. It shows that a simple, cheap and popular tool could be developed for internal wave detection and will benefit future studies on internal waves.

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