Internal Wave Propagation Observed by Shipboard Radar

Extra Function of Marine Radar Can Be Used as Ocean Observation Equipment

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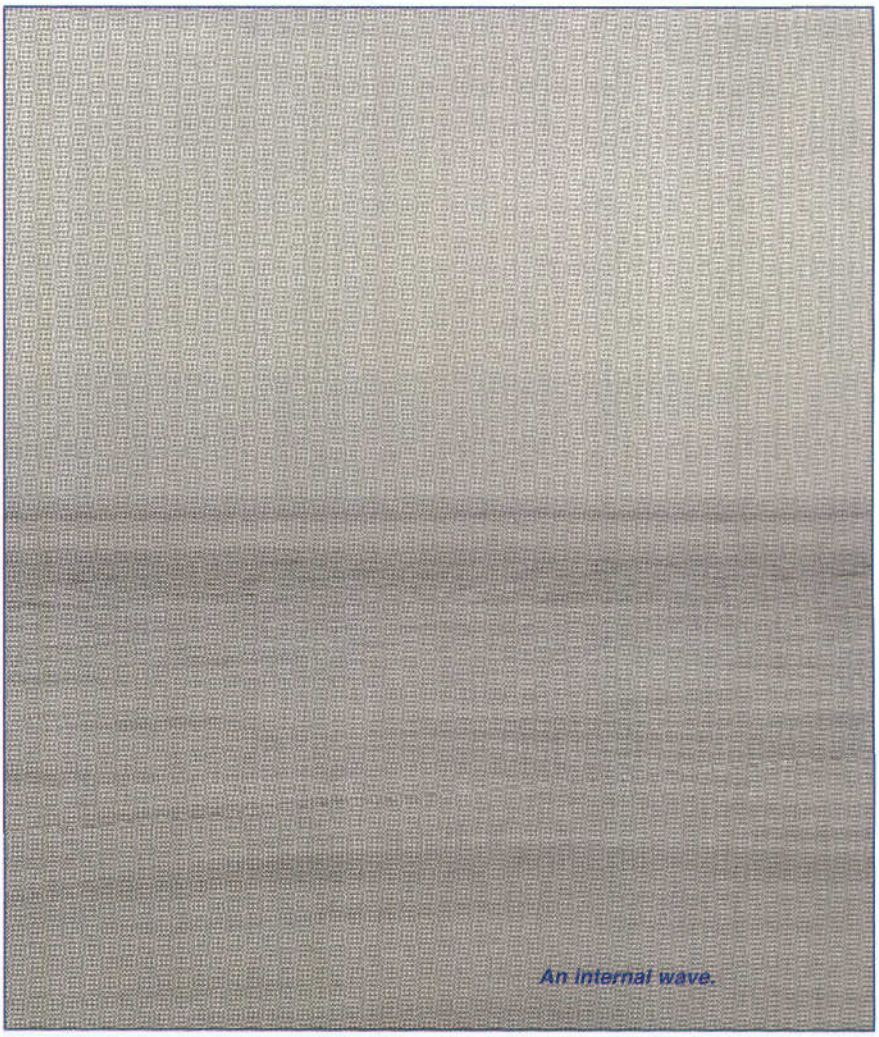


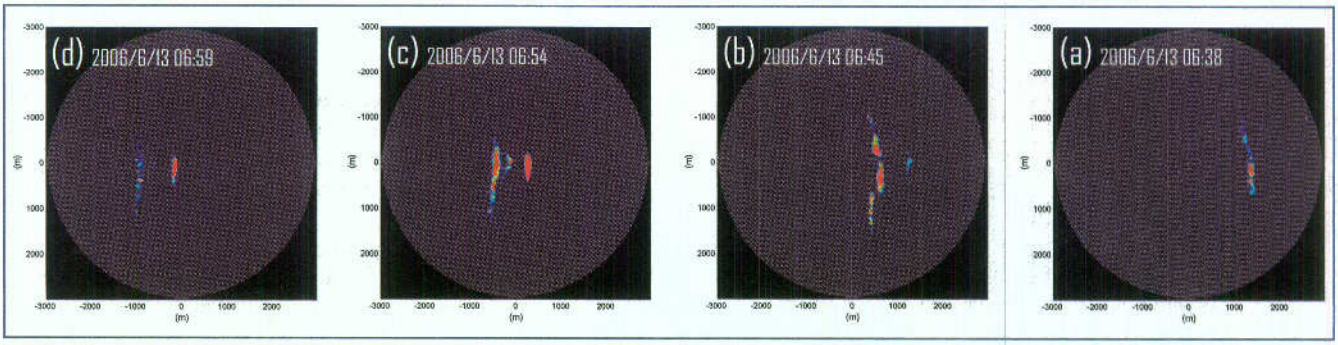
An internal wave.

Ocean surface gravity waves are mechanical waves that propagate along the interface between water and air. However, the internal waves are the kind of waves that travel within the interior of ocean. Internal waves are an important ocean mesoscale phenomena. It is important for the transport of momentum and energy within the ocean. It is also potentially dangerous for submarine navigation, offshore platforms and so on. Since internal waves often appear in the open sea and propagate in the space domain, oceanographers and remote sensing researchers have long recognized the potential of using satellite imagery for studying oceanic internal waves.

However, the spatial characteristics of internal waves have not been investigated clearly because satellites have limited resolution in the temporal domain. This article discusses the use of shipboard X-band marine radar to observe internal waves. Marine radar, originally used for navigational purposes, has now been reconfigured for internal wave observation by applying high-speed data acquisition and image processing technologies. It is a 3D internal wave observation device. Continuous propagation of internal waves can be recorded by the device. In addition, the original navigation function of marine radar is still kept. In 2005 and 2006, two field experiments were arranged to test this device. Internal waves were successfully recorded. They were also verified by *in-situ* measurement data, camera images and a moderate-resolution imaging spectroradiometer (MODIS) satellite image. The results of the field experiments show that the reconfiguration of shipboard X-band radar is feasible for internal wave propagation observation.

Background

An ocean internal wave is one type of gravity wave. It is generated on the interface between two fluids of differ-



Propagation of internal waves observed by a present marine radar system.

ent densities. Its scale is larger than surface wind waves. The wave height of an internal wave can be quite large, sometimes exceeding 100 meters and may be formed by tidal movement, turbidity currents, wind stress or passing ships. Internal waves are present in all levels of the water column, in deep oceans as well as in marginal coastal areas. Because the internal waves oscillate underwater, they are potentially dangerous for submarines, offshore platforms and ships. Ocean engineers' interest in internal waves is due to their role in submarine detection and the generation of anomalous drag on ships in fjords and some estuaries.

In addition to simulation by numerical modeling, field observation is one of the most important approaches to studying the internal wave. Although ordinary gravity waves are easily seen in day-to-day life, internal waves are much more difficult to observe without special instrumentation. In the past, single-point instruments, like temperature, salinity sensors, current meters and acoustic instruments, were often used for detecting internal waves. Since internal waves distribute in the space domain, many researchers use remote sensing technologies, such as satellite, to study internal waves. The surface expression of internal waves is minimal, but if the crests approach the surface they affect the reflection of light from the water. Excellent photographs of internal waves have been taken from the space shuttle. However, most of the satellites travel along their default track. It is difficult to obtain continuous images of internal waves that way. Hence, it is hard to describe the moving features and spatial characteristics of internal waves. New methods for obtaining continuous images of internal waves have to be developed.

Marine radar was originally used for detecting blocks of land while navigating by water. Recently, X-band marine radar has started to be used for sea state observation. A previous study showed that internal waves can be detected by marine radar-distinctive surface roughness patterns caused by surface currents when an internal wave passes.[1] Although internal waves do not give rise to an elevation of the sea surface as familiar surface waves do, they do influence the surface current. The sea surface current varies in magnitude and direction. It results in convergent and divergent flow regimes at the sea surface. Surface currents interact with the surface waves and modulate the sea surface roughness.[2] This interaction is the reason why oceanic internal waves become visible on satellite and shipboard radar images. Hence, the pattern of internal waves on radar images should be similar to wind waves. They are interlaced by light and dark bands. Since the length of internal waves can be larger than several hundred meters, it is easy to identify the difference between wind waves and larger internal waves.

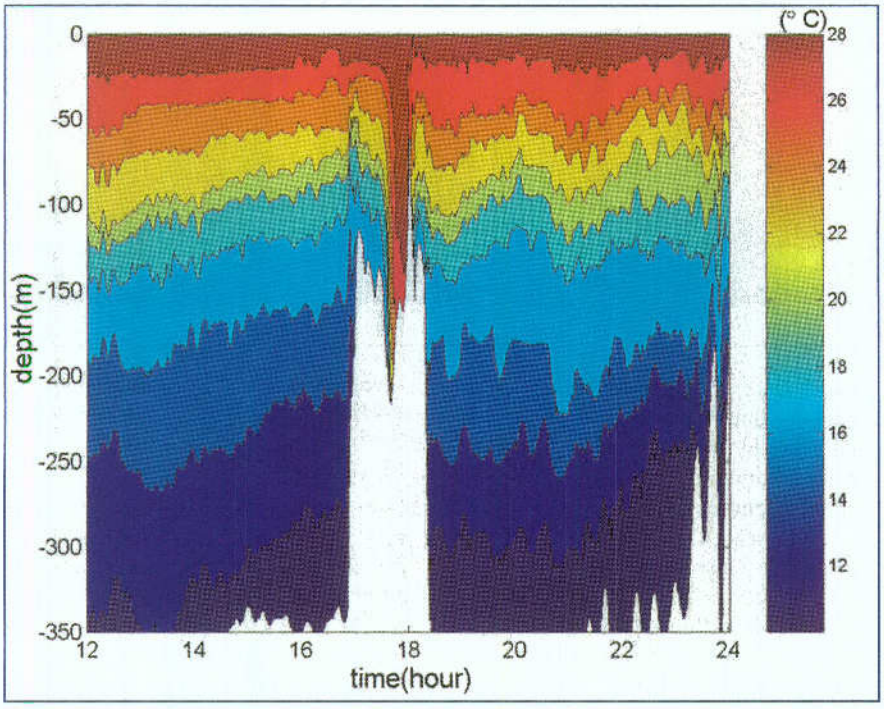
This article presents a method to observe internal waves by refitting the X-band marine radar on a vessel. Field temperature and salinity profiled from moored sensors and satellite images were used to verify the findings of internal waves by the X-band marine radar.

Radar Observation System

Remote sensing techniques for the ocean can be performed from coastal ground, ship, aircraft or satellite. The types of sensors include infrared, optical and radar. Radar is one of the most popular equipments. According to the principle of radar imaging, passive radar measures the electromagnetic radiation emitted by the Earth, while active radar possesses its own radiation source and receives echoes from the sea surface. The original navigation marine radar is active radar. It is the microwave band that indicates the wavelength of the electromagnetic wave within 0.1 centimeters to 100 centimeters. Its resolution has to be very fine to distinguish ships and land for navigational purposes. On the other hand, the sea clutter is also echoed to radar receivers due to the roughness of the sea surface.

The composition of an internal wave radar observation system includes a marine radar, compass, global positioning system (GPS) and a data acquisition computer. The compass provides ship motion data for radar signal correlation. GPS records the location of ships for radar signal calibration too. These components occupy very little space on the ship and are very easily arranged. In addition to the original navigational functions of shipboard marine radar, it becomes a tool for internal wave observation by equipping these simple units.

The strength of the hardware system is the high speed and high resolution acquisition of radar backscatters from the ocean. A card with a 10-megahertz sampling rate and 14-bit resolution for digitalization is installed in the data acquisition computer. The simultaneous sampling card acquires sea clutter and trigger signals to form the radar image. The resolution of radar images is influenced by the sampling rate, pulse repetition rate (PRR) of radar antenna, radar rotation speed and radar installation height. Marine radar with 24 revolutions per minute and 2,100-hertz PRR is enough for internal wave observation, because its period is much longer than one minute. In this study, the vessel for the field test was equipped with marine radar, which satisfies the requirement. Since the high-speed data acquisition card (10 megahertz) is used in this study, the radial resolution of the radar images of the present system is 15 meters per pixel. This is sufficient for internal wave detection.



A profile of water temperature when the internal wave is passing.

Radar backscatter contains signals from internal waves, surface waves and background noise. Image processing methods have to be applied to enhance the presentation of the internal wave. The main scattering mechanism from surface wind waves is the Bragg resonant process, which is generated by the waves on the surface that are of the same order as the electromagnetic wavelength. Because there is a wide roughness band on the ocean surface when an internal wave is passing, the backscatter characteristics are quite different from wind waves and internal waves. Hence, the smoothing and spatial filtering skills on radar images are used to eliminate the noise and enhance the internal wave signal on the radar backscatter.

Field Experiment

There were two field experiments arranged in 2005 and 2006 to test the performance for the present system. In 2005, the radar on the fishing boat *HaiFu* was refitted to observe an internal wave in the South China Sea from May 13 to 17. From June 12 to 15, 2006, the Coastal Ocean Monitoring Center used the *Taiwan Ocean Research Vessel No.3* (*OR3*) to detect the internal wave at Luzon Strait between Taiwan and the Philippines. The radar on *OR3* was refitted to be the internal wave observation tool in addition to its original navigation function. At the Luzon Strait, internal waves happen very frequently. They are normally found every day in the early morning under good weather and sea state situations. The purpose of the kernel project is to study the mechanism of internal wave generation in this area. This study is one of the sub-

projects that aims to observe the propagation of internal waves.

Results and Verification

The present system did observe internal waves in 2005 and 2006. The clean internal wave images were processed at five pixels by five pixels by smooth and spatial Laplace filter skills. The waves propagate from right to left. The study found that this was an internal wave package. Two internal waves were observed in the 2006 experiment. When internal waves are far from the vessel, only one internal wave is observed, because the second internal wave is shadowed due to the Earth's curvature. When the internal wave moves close to the vessel, say within 1.5 kilometers, the entire internal wave package can be observed. This distance is correlated to the installation height and power of the radar. The average propagation speed is about 3.2 knots per hour for this case. The surface bandwidth of each internal wave is around 200 meters. The distance interval between two internal waves is about 500 meters.

To verify the finding of an internal wave by present marine radar systems, MODIS satellite images and *in-situ* water temperature data in the profile were collected. The researchers found an internal wave signature on a MODIS image that was taken three hours before the one observed by radar. The study confirmed that this was the one observed by the estimation of time and the location of the internal wave on the satellite image. In addition, simultaneous *in-situ* measurements were also arranged in the experiment. One mooring with temperature sensors was deployed. From the data of the water temperature profile, it was again confirmed that there is a huge wave motion underwater. The amplitude of the internal wave was more than 100 meters.

Conclusions

Internal waves are an important phenomena in the ocean. However, researchers still have limited knowledge of them. By using the shipboard marine radar and equipping a computer with high-speed data acquisition, the backscatter from the sea surface can be extracted. GPSs and compass data are also required to correct the radar backscatter. Since the marine radar was originally installed on the vessel, the cost of this system was decreased on the hardware. The study improves the function of shipboard marine radar. It is a useful method to observe the propagation of internal waves.

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