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14. ABSTRACT The goal of this research was to survey microwave signatures of oceanographic features near the Philippine Island. To do this a dual-polarized, X-band Doppler radar was mounted on a ship cruising near the Philippine Islands and was used to image the surface signatures of oceanographic features. At the same time other investigators collected surface and subsurface data to determine environmental conditions and the characteristics of these features. By analyzing these data set together, we could determine how properties of current gradients, wind, and surface waves affect the observed microwave signatures. DISTRIBUTION STATEMENT A Approved for Public Release Distribution Unlimited						
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Final Report of a Shipboard Survey near the Philippines with a Coherent X-band Radar

William J. Plant
Applied Physics Laboratory
University of Washington
1013 NE 40th St
Seattle, WA 98105-6698

phone: 206-543-7836 fax: 206-543-6785 plant@apl.washington.edu

Grant # N00014-07-1-0559

<http://airs.apl.washington.edu/personnel/personnel.html>

OVERVIEW

The figures presented in this report are a subset of those placed on the website <http://www.satlab.hawaii.edu/onr/mindoro/wiki/index.php?n=RemoteSensingObservations.ShipborneMicrowaveRadar>. The features reported there and here are very unusual because backscatter at HH polarization is much larger than that at VV over long periods of time and space. It is difficult to overemphasize how unique this observation is. As a rule, VV sea return cross sections are stronger than those at HH polarization, except perhaps momentarily. This is the first time that such long-lasting reverse effects have been observed. The observations point the way to a new understanding of low-grazing angle backscatter at HH polarization, which is important since most ships' radars operate at this polarization. During the present project, neither sufficient time nor funding was available to fully investigate either the implications of this type of backscattering or the characteristics of the oceanic features producing it.

GOALS

The of this project was to survey microwave signatures of oceanographic features near the Philippine Islands.

APPROACH

Our approach was to mount a dual-polarized, X-band Doppler radar on a ship cruising near the Philippine Islands to image surface signatures of oceanographic features. We did this while other investigators collected surface and subsurface data to determine environmental conditions and the characteristics of these features. By analyzing these data sets together, we could determine how properties of current gradients, wind, and surface waves affect the observed microwave signatures.

WORK COMPLETED

In late May, 2007, we installed our coherent X-band radar called RiverRad on the R/V Melville in Kaohsiung, Taiwan before it set off on a cruise around the Phillipine Islands. The radar was installed above the bridge with its two parabolic antennas looking broadside, perpendicular to the ship's heading. One of these antennas operated vertically polarized on both transmit and receive to collect

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VV data; the other collected horizontally polarized, HH data. Figure 1 shows RiverRad on the Melville. An engineer from APL/UW, Gene Chatham, accompanied the ship on its journey from Taiwan to Manilla, Phillipines. After that, the radar ran automatically, storing data on surface roughness and velocity approximately every 30 minutes. Data were collected day and night during the entire cruise, which lasted from June 6 to July 3, 2007. The data have subsequently been reprocessed in the laboratory into images of normalized radar cross section and scatterer velocities; they are now ready for ready for further examination by the project team.



Figure 1. RiverRad mounted on the R/V Melville prior to the Philippine survey cruise. RiverRad's two parabolic antennas look to the side of the ship, perpendicular to the ship's heading.

RESULTS

Many interesting features were observed in RiverRad's images. In addition to myriad islands and boats, the images showed some very strong signatures associated with large-scale current gradients. Figures 2 and 3 show one such feature observed with HH polarization (Figure 2) and VV polarization (Figure 3). Clearly the signature is much stronger in the HH image than in the VV, a truly unique observation. This is characteristic of backscatter from strongly breaking waves, indicating that the current gradients causing the signatures are extremely strong. The identification of breaking waves as important in providing scatterers is strengthened by the magnitude of the scatterer velocities observed in the HH image. These range from -4 m/s to $+4$ m/s or higher. If the scatterers are bound to longer waves that are breaking, they will move along with these longer waves and therefore will achieve speeds approaching the phase speed of the wave that is breaking. This is the origin of the large observed velocities. The fact that the signatures contain mixtures of positive and negative velocities indicates that the imaged region is one where long waves come from a wide variety of directions.

Features similar to that shown in Figures 2 and 3 were observed in a variety of locations on the cruise and are documented on the website referenced above. Figure 4 shows the track of the Melville along with symbols indicating where surface features of current gradients were observed in the imagery of RiverRad. The majority of these features were seen on the west side of the islands and tended to concentrate near straits.

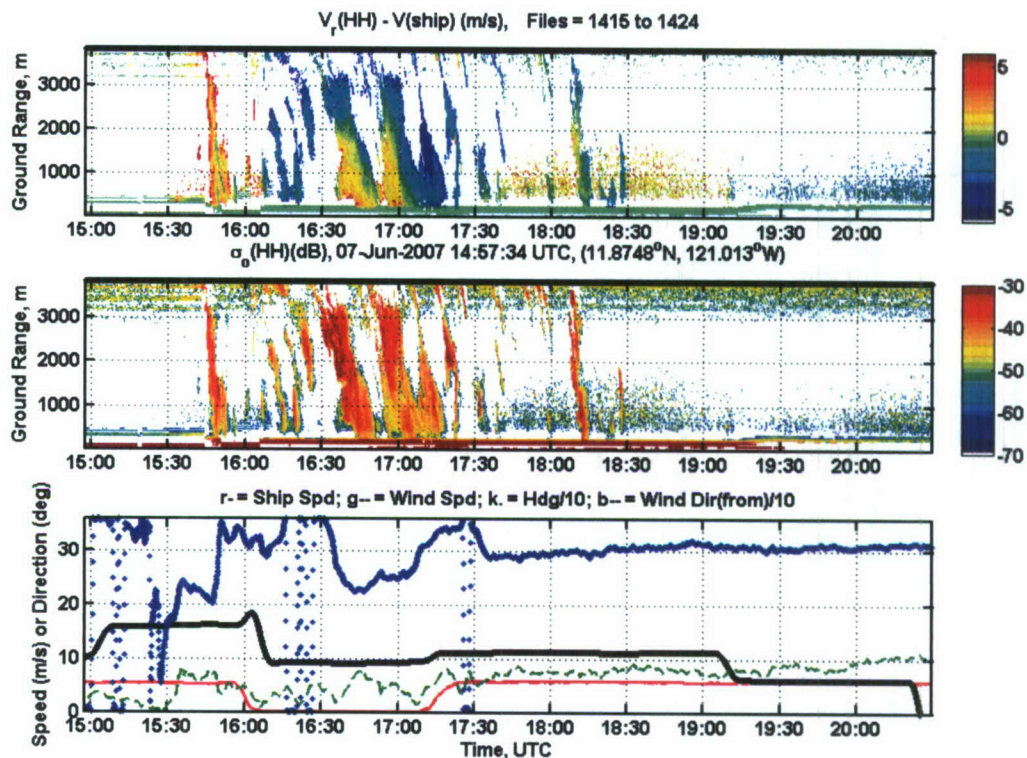


Figure 2. Image of a series of current gradients as observed by RiverRad's HH polarized antenna. Note that these features are very strong.

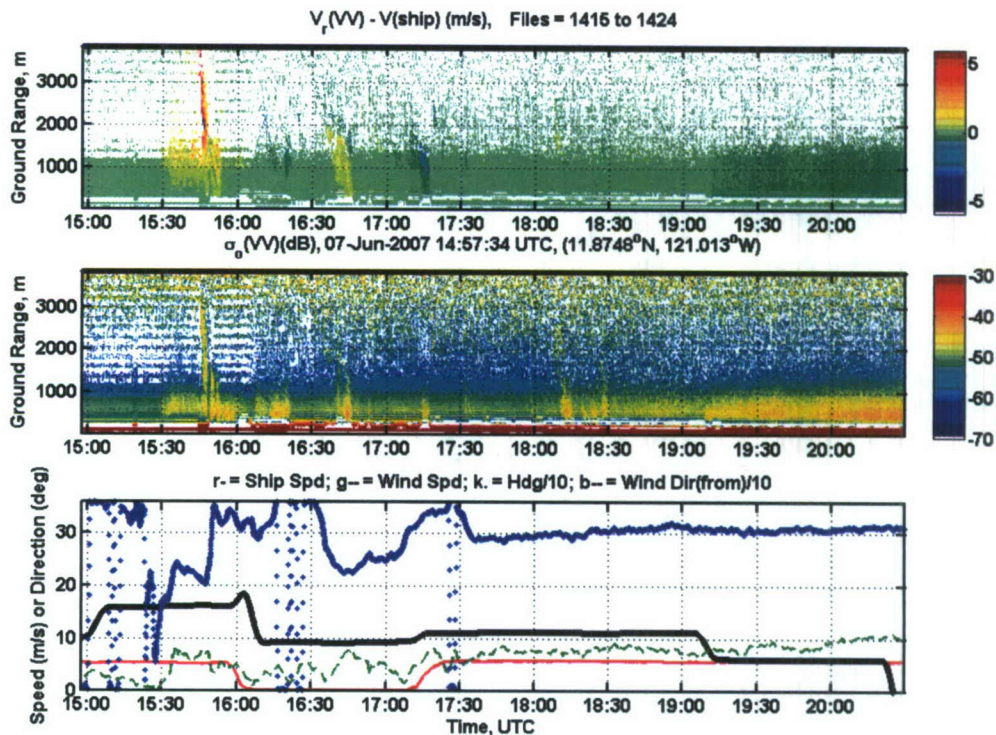


Figure 3. Image of the same feature as shown in Figure 2 but now at VV polarization. Note that the features do not show up nearly as well in this image as in the HH one.

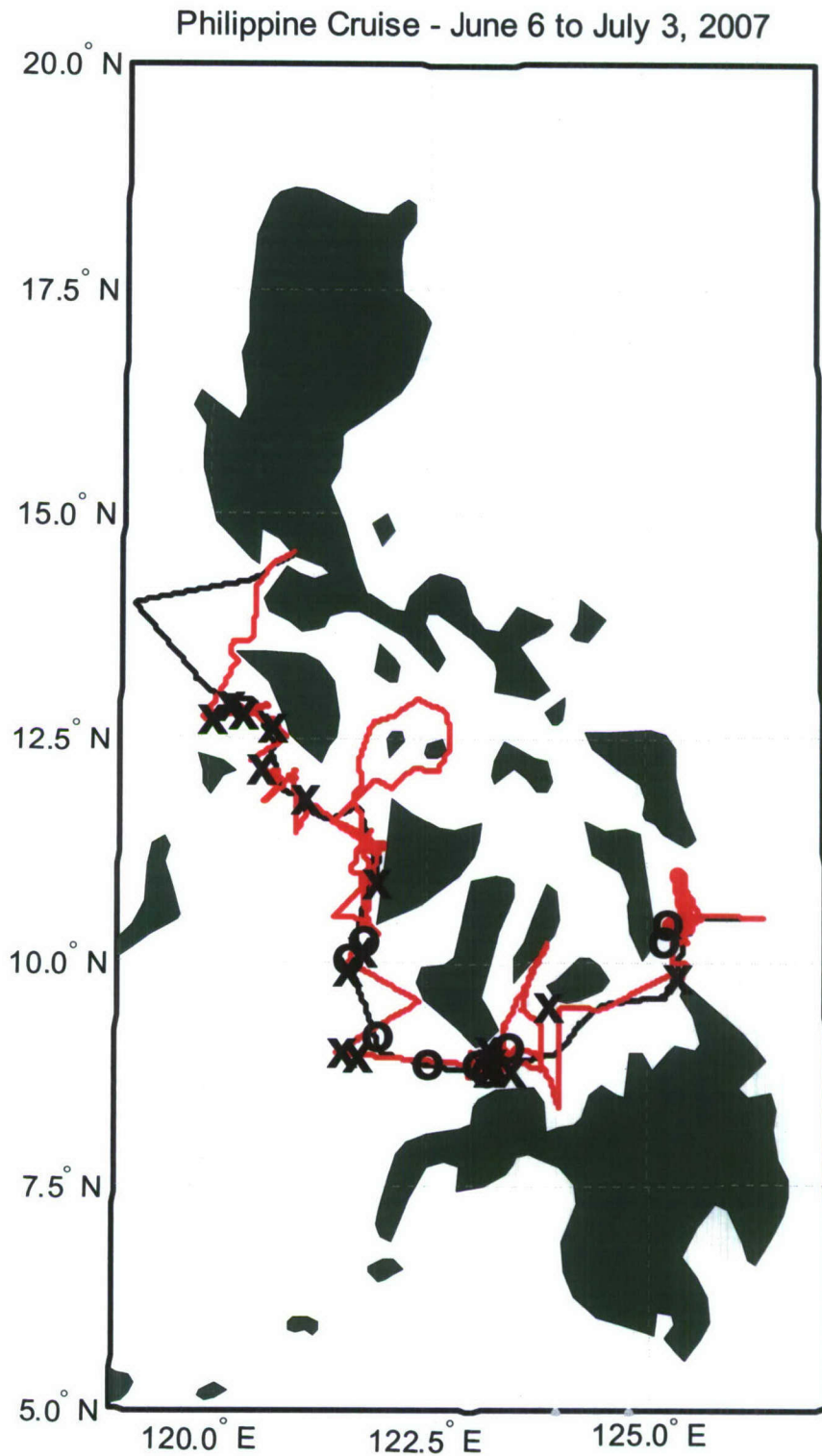


Figure 4. Track of the R/V Melville during its survey cruise of the Philippine Islands from June 6 to July 3, 2007. The black curve is the outbound leg; the red is the return leg. Symbols: X = strong surface signatures observed by RiverRad; 0 = weaker signatures seen.

MEASURING AND MODELING THE NORMALIZED RADAR CROSS SECTION OF THE SEA FOR BACKSCATTER

William J. Plant, William C. Keller, Kenneth Hayes, Gene Chatham
Applied Physics Laboratory, University of Washington, Seattle, WA, USA
plant@apl.washington.edu

The normalized radar cross section (NRCS) of the sea is usually represented by $\sigma_o(VV)$ when vertical electric fields are used for both transmission and reception and by $\sigma_o(HH)$ when the fields are horizontal. This paper shows that a composite surface-type theory, the multiscale model of Plant (2002), can explain $\sigma_o(VV)$ at all incidence angles. The model predicts $\sigma_o(HH)$ values that are too low at incidence angles above 45° , however. These types of models always predict $\sigma_o(HH)$ less than or equal to $\sigma_o(VV)$ for long time averages. Here we report measurements on the ocean at low grazing angles which show that $\sigma_o(HH)$ can far exceed $\sigma_o(VV)$ for long periods of time and large spatial distances in some situations. These suggest that multiple scattering from dihedral-like surfaces may be involved in low-grazing-angle HH backscatter.

Recent ship-based measurements using a calibrated, coherent, dual-polarized, X-band radar have determined the magnitudes of $\sigma_o(VV)$ and $\sigma_o(HH)$ and their dependence on wind speed and azimuth angle at grazing angles of one to two degrees. When the ocean surface is disturbed only by wind, the measurements show that $\sigma_o(VV)$ shows wind-speed and azimuth-angle dependences similar to those at the lower incidence angles used in scatterometry. Furthermore, the multiscale model of ocean backscatter (Plant, 2002) fits the absolute level, the azimuth angle dependence, and the wind speed dependence of $\sigma_o(VV)$ very well at low grazing angles if shadowing is taken into account. For $\sigma_o(HH)$, the story is very different. At grazing angles of 1° to 2° , it is largest looking upwind and smallest looking downwind. It is always smaller than $\sigma_o(VV)$ but is much larger than predicted by the multiscale model at these angles.

The fact that the multiscale model cannot predict the large values of $\sigma_o(HH)$ that are observed at incidence angles above about 45° suggests that scattering processes other than those described by standard composite surface theory may be important at these angles for HH polarization. Plant (1997) has suggested that Bragg scattering from bound, tilted rough patches may account for some of the increase in $\sigma_o(HH)$ over composite surface theory. However, since this process also increases $\sigma_o(VV)$, a limit exists on the amount by which $\sigma_o(HH)$ may be increased by adding these bound scatterers without causing $\sigma_o(VV)$ to disagree with measurements. This limit is insufficient to account for the observed values of $\sigma_o(HH)$ up to incidence angles of 80° (Plant, 1997, 2003).

While the situations documented here with $\sigma_o(HH) > \sigma_o(VV)$ probably relate to an ocean surface disturbed by current gradients as well as the wind, they clearly require a non-Bragg type of scattering such as that from steep features associated with breaking waves. It is reasonable to assume that such processes also occur for an ocean surface that is disturbed only by the wind but to a much lesser extent. Many researchers studying backscatter from breaking waves have suggested that surface features resembling dihedral corner reflectors may account for short-lived instances of $\sigma_o(HH) > \sigma_o(VV)$ (Wetzel, 1986; Trizna, 1997; Fuchs et al., 1999; Lee et al., 1999; Sletten et al., 2003). Because of Brewster damping, such structures backscatter to a much lesser extent at VV polarization than at HH and therefore yield $\sigma_o(HH) > \sigma_o(VV)$. Here we take tentative steps toward a statistical

model of backscatter from a random distribution of dihedral corner reflectors which may represent breaking wave effects.

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