Analysis and Modeling of Radar Surface Signatures of Non-Linear Internal Waves

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LONG-TERM GOALS

The long-term goal of this project is to understand microwave surface signatures of internal waves in the ocean so that they can be remotely detected and better predicted.

SCIENTIFIC OBJECTIVES

The scientific objectives of this research are 1) to understand the transition from the linear perturbations of surface waves by internal waves studied in the past to the non-linear perturbations embodied by wave breaking, 2) to determine the conditions that make microwave surface signatures of internal waves visible, and 3) to understand better the generation, propagation, and dissipation of internal waves on the ocean

APPROACH

Our approach is to utilize the data collected in the first three years of the NLIWI project to determine the characteristics of internal wave signatures, model the expected changes in surface waves caused by internal waves, predict the resulting microwave backscatter, and, finally, compare the modeled backscatter with that observed. The available data include those from satellite, aircraft, and ships at a variety of incidence angles and copolarizations. For the shipboard data, coincident and collocated subsurface velocities and winds are available; for the airborne data, this is also nearly the case; for the satellite data, it is not the case. Our modeling effort centers on the conservation of wave action for waves longer than about one meter, augmented by a breaking model at shorter wavelengths. Our main concern is to understand for what incidence angles and polarizations breaking wave effects become important in microwave internal wave signatures.

WORK COMPLETED

We have analyzed our shipboard data from the South China Sea and the shipboard and aircraft data from the Atlantic Ocean off New Jersey. All data were collected at X-band and both HH and VV polarization. We have produced spatial images from the aircraft flights and time/space images from all

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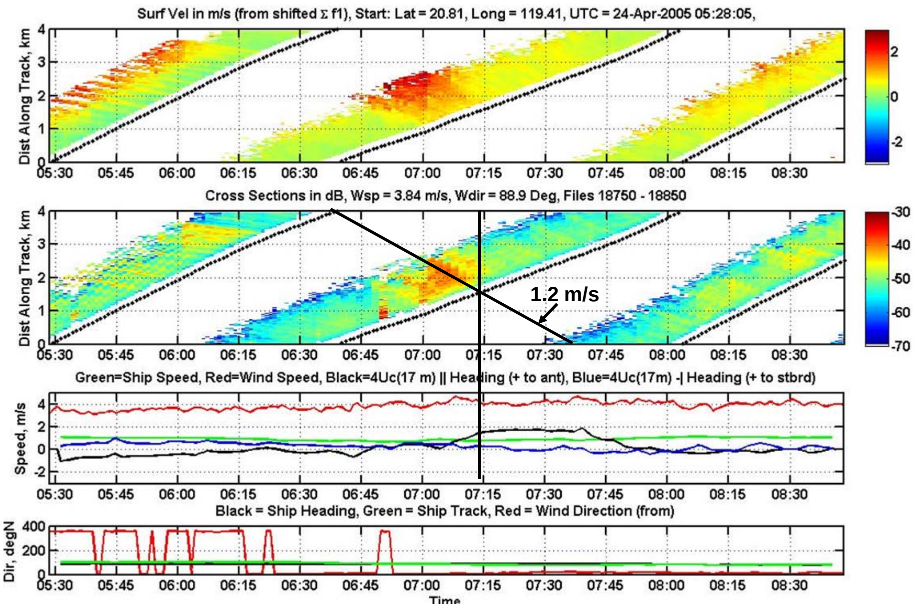

Figure 1. Images and data from shipboard measurements in the South China Sea in 2005. Top panel: space/time image of surface velocities wrapped at 4 km. The color scale is in m/s. Second panel: space/time image of normalized radar cross sections. The color scale is in dB. The black dots in these images show the ship track; the colors are data from the radar that looked in the direction of the ship's heading. Third panel: Ship and wind speeds along with current components along and perpendicular to the ship's heading. Bottom panel: Relevant directions in degrees true.

of the shipboard data. Figure 1 shows an example of a time/space image taken from the R/V Revelle in the South China Sea in 2005. The top two panels show radar images of surface velocity and normalized radar cross section, respectively, with the time axis wrapped at 4 km. The third panel from the top gives various speeds along with the current components parallel and perpendicular to the ship's heading from the onboard acoustic Doppler current profiler (ADCP). The bottom panel shows the ship's heading and track along with wind direction in degrees true.

From the ADCP current components, we can determine the direction of travel of the internal wave. In this case it is opposite the ship's heading since the internal wave (IW) velocity component parallel to the heading is positive and no IW signature is visible in the perpendicular component of current. The solid black lines in Figure 1 show the movement of the IW surface signature during the time the radar observed it and its location relative to the ADCP currents. From this information, we can determine the location of the maximum of the microwave surface signature of the internal wave relative to the near-surface current it induces. Figure 2 summarizes these locations for all our shipboard measurements as a function of the strain rates of the IW currents. Locations are shown as the fraction of the width of the internal wave by which the surface signature leads the velocity maximum. They are plotted against the maximum velocity divided by the IW width. Clearly steep internal waves produce maximum surface signatures that are farther forward of the wave crest than those produced by less steep internal waves.

Phase speeds of the internal waves can be deduced from the slope of the slanting solid line shown in Figure 1 and the IW direction information from the ADCP. Phase speeds determined in this manner from the radar data are summarized in Figure 3. They show clearly that phase speeds of non-linear internal waves depend on their amplitude. Phase speeds of the steeper waves that occur in shallow water increase less rapidly with amplitude than those of internal waves in deep water whose slopes are smaller. Both are well fit by a two-layer fluid model with a rigid lid for a judicious choise of parameters.

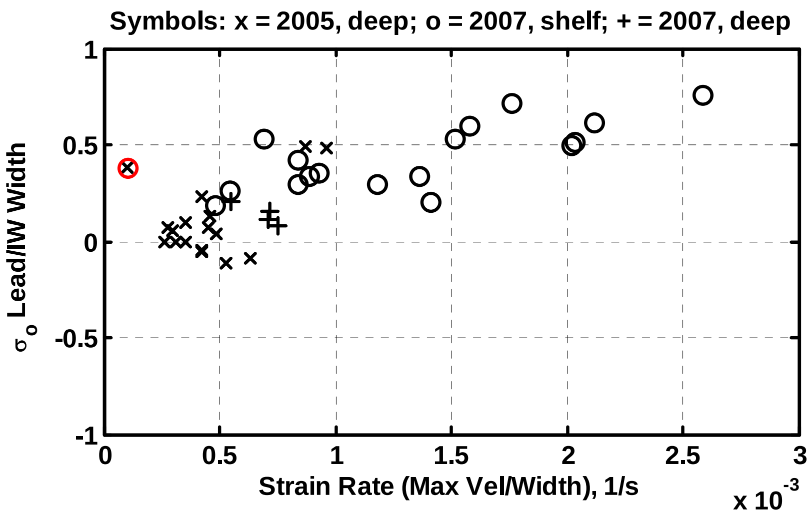

Figure 2. Fraction of the internal wave width by which the cross section maximum leads the interanl wave crest versus the ratio of the maximum internal wave near-surface velocity to the width.

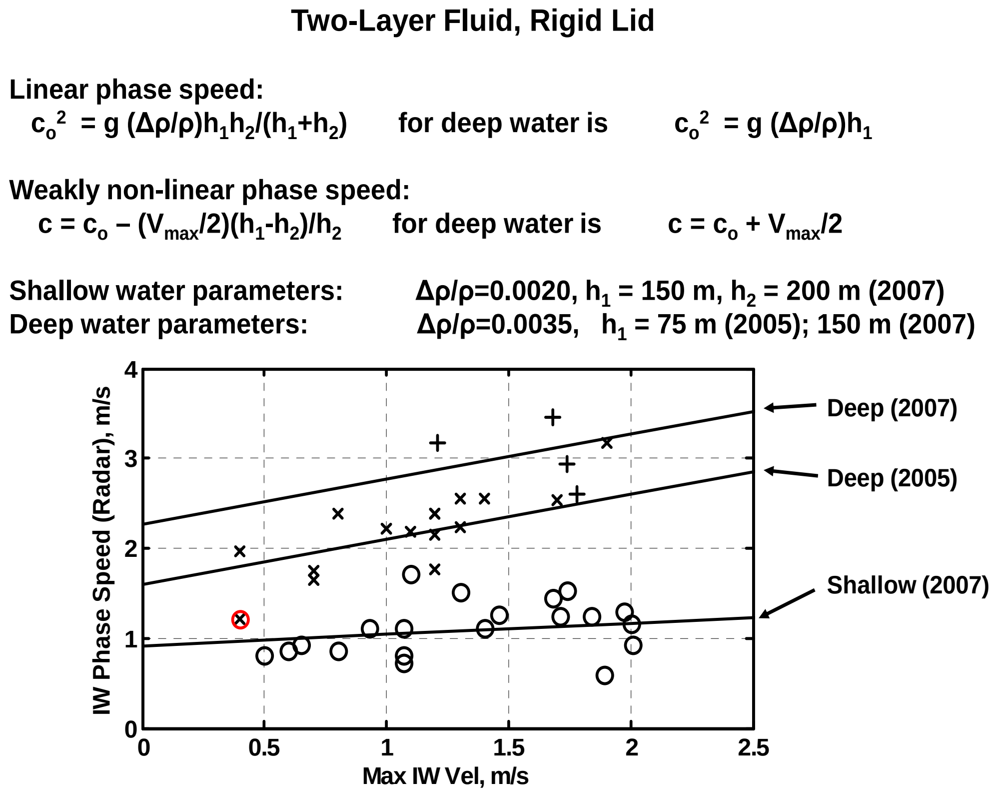

Figure 3. Internal wave phase speed measured by shipboard radar plotted versus the maximum near-surface velocity of the internal wave as measured by the shipboard acoustic Doppler current profiler (ADCP). Solid lines are predictions of a model using the two-layer, rigid-lid approximation with the parameters shown in the figure. The internal wave (IW) phase speed increases with the maximum IW near-surface velocity, that is, with the IW amplitude.

Finally, because data were collected from both an airplane and a ship in the New Jersey experiment, we were able to determine the behavior of the maximum cross sections produced by the internal waves for various wind speeds and incidence angles. We have shown in a previous report that the variation of this maximum with azimuth angle is very small. For the data shown in Figure 4, the angle between the antenna and the upwind direction was always between 45 and 135 degrees, that is, cross wind, and the antenna always looked either into the internal wave propagation direction (upwave) or along it (downwave). Figure 4 summarizes the behavior of the maximum cross section produced by the interal waves for a variety of wind speeds, for upwave and downwave looks, and for both HH and VV polarizations. The figure shows that for incidence angles less than 70^o, the maximum VV cross section was generally larger than the maximum HH cross section, although the difference was smaller than is usual in the absence of internal waves (see last year's report). However, at the low grazing angles observed from shipboard, HH cross sections became significantly larger than VV. We interpret these observations of the incidence angle dependence of the HH/VV polarization ratio to indicate that breaking waves play a significant role in producing microwave surface signatures of internal waves.

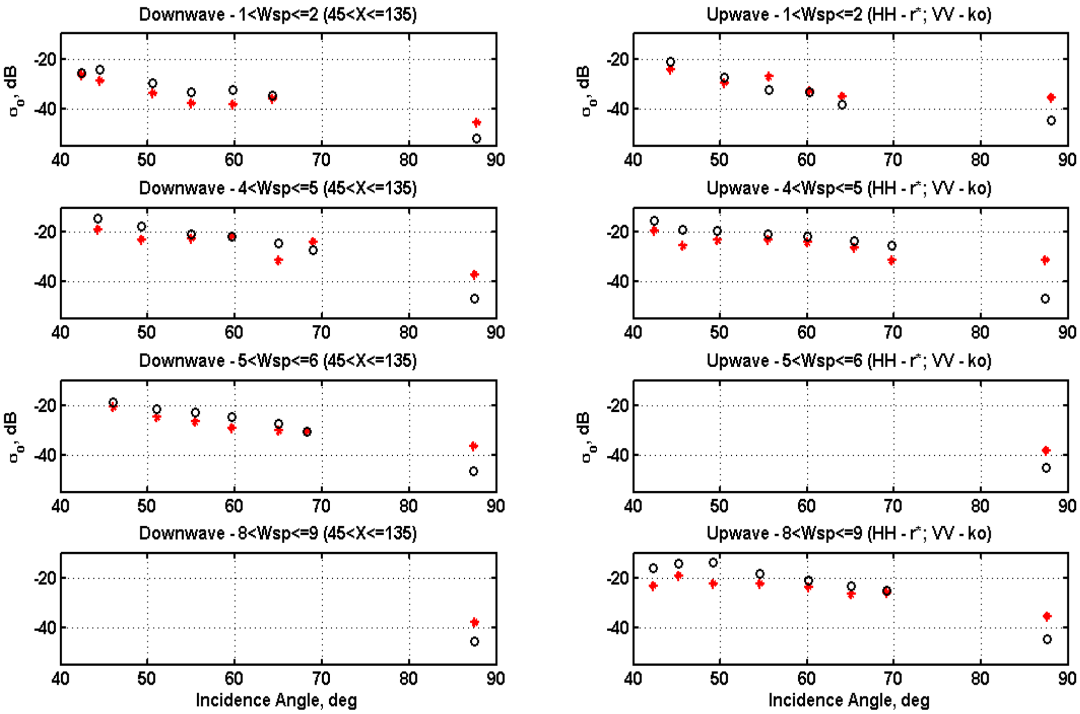

Figure 4 summarizes the behavior of the maximum cross section produced by the interal waves for a variety of wind speeds, for upwave and downwave looks, and for both HH and VV polarizations.

IMPACT/APPLICATION

This study will help establish the relationship between remotely observed microwave signatures of internal waves on the sea surface and the properties of the internal waves. This will aid in the prediction of internal wave location and amplitude for use in submarine navigation and acoustic propagation calculations in the internal wave field.

TRANSITIONS

The results of this project have not yet been transitioned for operational use.

RELATED PROJECTS

This project is part of the NLIWI experiment and is strongly related to the WISE/VANS experiment and to the Surface Wave 06 acoustic experiment.