Analysis of Simultaneous Acoustic/Microwave Data

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LONG-TERM GOALS

The long-range objective of this project is to understand both acoustic and microwave scattering from rough water surfaces sufficiently well to be able to implement them in operational models and, if possible, to remotely sense microscale breaking on the sea surface.

SCIENTIFIC OBJECTIVES

The scientific objectives of this research are to apply acoustic and microwave techniques of surface backscatter to investigate the bound and breaking waves that have been shown to exist on rough water surfaces, both in the laboratory and on the ocean. The work is particularly aimed at determining the angular dependence of bound waves and their relationship to microscale breaking waves.

APPROACH

Our approach is to observe both acoustic and microwave backscattering from wind-roughened water surfaces in wind wave tanks, and to model the surface in a manner that will explain both types of scattering. The acoustic and microwave systems used are fully coherent so that Doppler spectra as well as backscattering cross sections can be obtained. Our wave tank arrangements are designed so that the acoustic and microwave systems both observe the surface at the same incidence angle. We use acoustic and microwave systems whose transmitted wavelengths are within 10% of each other

WORK COMPLETED

Prior to 2000, we had carried out measurements in the UW wavetank at 0.8 and 2 cm looking both up and downwind. The results of the measurements at 0.8 cm clearly showed that the backscatter could be explained as Bragg scattering from parasitic capillary waves riding on the front faces of longer waves (Plant et al., 1999a). Scattering from 2 cm waves did not appear to be due to parasitic capillary waves, however.

In order to further investigate surface scattering at these two wavelengths, we carried out a series of measurements in the large wind wave tank in Marseilles, France in the summer and fall of 2000.

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14. ABSTRACT
The long-range objective of this project is to understand both acoustic and microwave scattering from rough water surfaces sufficiently well to be able to implement them in operational models and, if possible, to remotely sense microscale breaking on the sea surface.

15. SUBJECT TERMS

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Microwave and acoustic data were collected with both 8 mm and 2 cm radiation at a variety of incidence angles, azimuth angles, and wind speeds. These data have allowed us to investigate the azimuth angle dependence of backscatter from bound and breaking waves and to compare the results at the long fetch (for a wavetank) in the Marseilles tank with the shorter fetch data collected at UW. The past year has been spent making this comparison.

RESULTS

The results of our investigations show that classical parasitic capillary waves are not the only small-scale waves produced by gravity waves. We base this conclusion on the phase speeds of the observed scatterers in our experiments. For classical parasitic capillary waves, these speeds must be the same as the intrinsic phase speed of the capillary wave (Fedorov and Melville, 1998) and, within experimental error, this was the case for 8 mm backscatter observed in the short-fetch UW tank (Plant et al., 1999a).

Figures 1 and 2 show that the phase speeds of the Bragg-resonant scatterers at this wavelength, capillary waves, do not match their intrinsic phase speeds at longer fetches. Figure 1 shows backscatter to the radar and sonar when both were looking uptank, into the wind and waves, at a fetch of 25.5 m. The areas between the dashed vertical lines in the figures are the spectral regions where backscatter from the water is not contaminated by any other scattering or noise. The red vertical line is the Doppler shift expected if the scatterer were moving at the intrinsic phase speed of the Bragg wave (wavelength = 6.2 mm). The blue vertical line shows the expected Doppler shift for a capillary wave moving with the speed of the dominant wave in the tank. Clearly these two Doppler shifts are quite different and in Figure 1 backscattered energy exists at both frequencies in the radar signal, but not the sonar. In Figure 2, the situation is just the opposite: backscattering from capillary waves moving with the dominant wave exists in the sonar signal but not the radar. The difference is the look direction. When both radar and sonar are directed upwind, as in Figure 1, the local incidence angle on the front face of the dominant wave is larger for the sonar than for the radar. This discriminates against scattering from capillary waves at this location in the sonar signal and augments it in the radar. When looking downwind, as in Figure 2, the opposite situation is expected and observed.

Further suggestions that two different types of capillary waves are produced by steep gravity waves comes by comparing data taken in the UW tank at 5 m fetch and in the Marseilles tank at 25.5 m fetch. Figure 3 shows that the backscatter to both radar and sonar is much higher at the low wind speeds where parasitic capillaries dominate both the radar and sonar returns at short fetch. Furthermore the Doppler offsets for the two systems are identical at short fetch up to friction velocities of 0.3 m/s while at longer fetches they are both higher and different for the different systems. At higher wind speeds, radar cross sections are consistent at all fetches but the sonar return at the short fetch is much lower than at long fetch. We interpret this to indicate that parasitic capillaries dominate the scattering from bound waves at short fetches where the dominant wave is short enough to generate them but that other roughness, probably generated by gently spilling or “crumpling” gravity waves (Duncan et al., 1994; Longuet-Higgins, 1992), dominates the bound wave contribution at longer fetches.

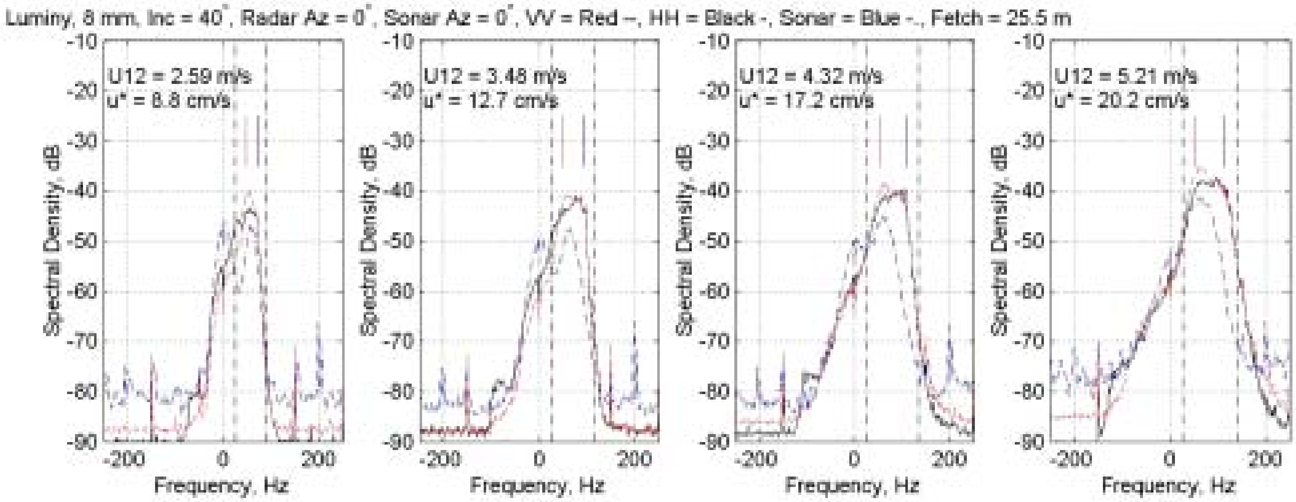

Figure 1. Radar and sonar Doppler spectra looking upwind in the Marseilles tank. The vertical red line is the location of scattering from Bragg waves moving at their own phase speed; the blue one shows the Doppler frequency if they move at the dominant wave phase speed. The radar shows backscatter at the latter frequency as well as the former.

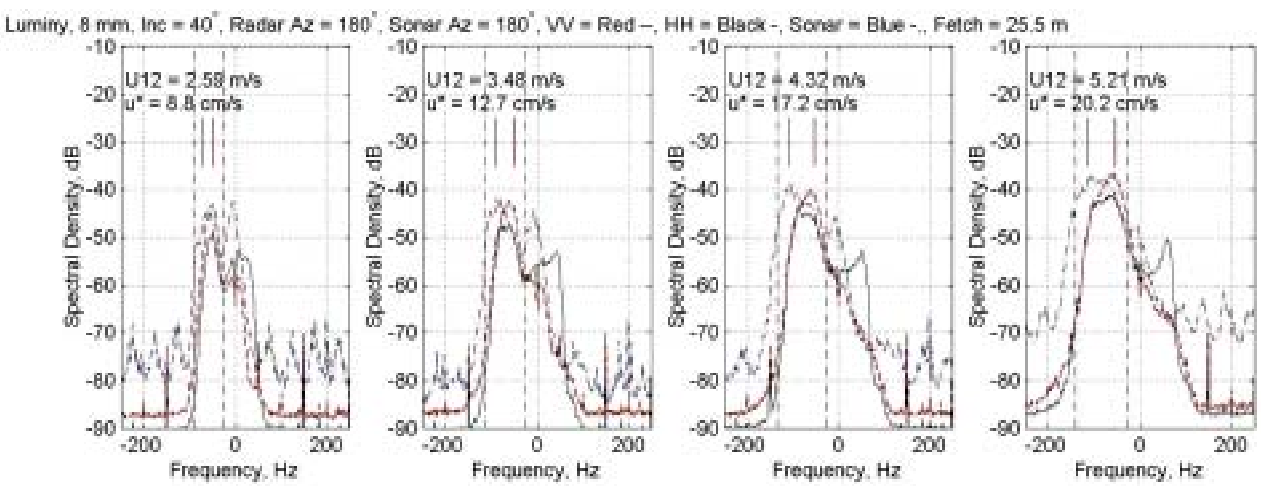

Figure 2. Radar and sonar Doppler spectra looking downwind in the Marseilles tank. Here the sonar shows the backscatter at the Doppler shift expected of a scatterer moving at the dominant wave phase speed.

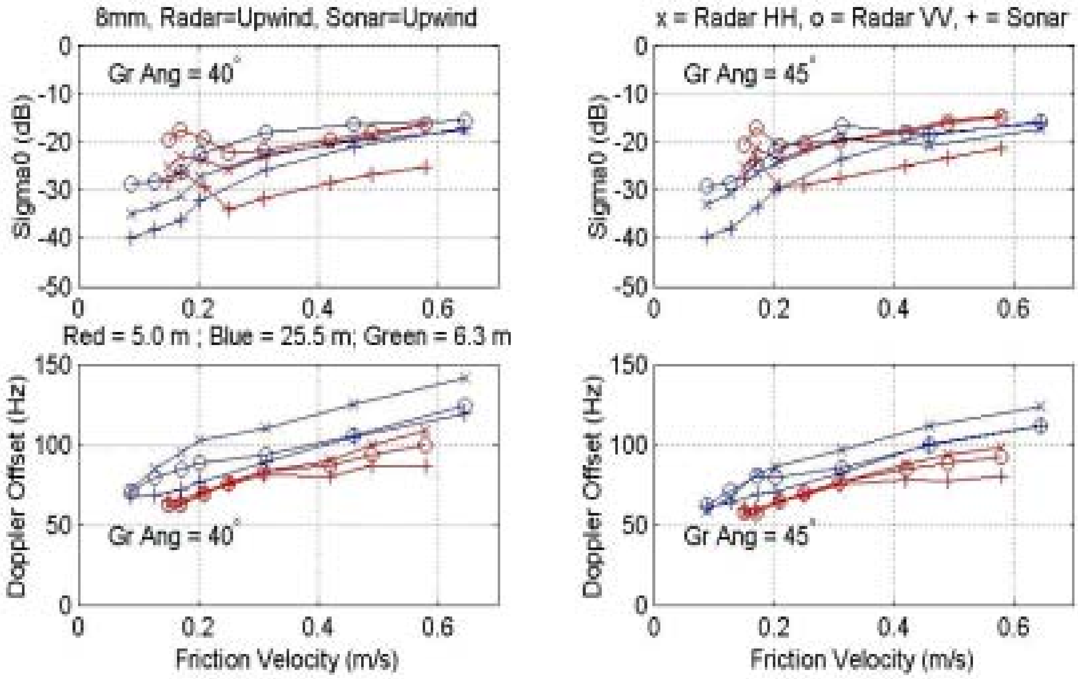

Figure 3. Cross section (top row) and Doppler offset (bottom row) versus friction velocity at incidence angles of 45º and 50º at fetches of 5 and 25.5 m. The elevated values of cross section and the collapsed values of Doppler offset at short fetch and low wind speed are not seen at long fetch indicating the dominance of parasitic capillaries only at short fetch.

For this conclusion to be valid, bubble scattering must not significantly affect the sonar backscatter measurements, and bubble scattering was evaluated as follows. First, a representative bubble size distribution was obtained from recent experimental work on bubbles also conducted in the Marseilles wave tank at the same fetch (De Leeuw and Leifer, 2000). Next, this spectrum was used in a model for sonar bubble scattering (Dahl and Kapodistrias, 2002) to estimate an equivalent sonar backscattering cross section (i.e., RCS) associated with bubble scattering. Results are shown in Fig. 4 for the 2 cm wavelength sonar system equivalent to Ku-band radar, and they indicate that only for the highest wind speeds (of order 10 m/s, or friction velocities of 0.6 m/s) and at higher incidence angles (> 40º) does scattering from bubbles become a significant factor compared with that associated with rough surface scattering. (Note: this finding does not apply to acoustic data taken in a marine environment where bubble populations can differ markedly.) Importantly, the sonar measurements made at the highest friction velocity (0.65 m/s) remain well above the simulated bubble scattering results for the same friction velocity. Note that for the 8 mm sonar system (equivalent to the Ka-band radar), the relative influence of bubble scattering is less because there is less of a contribution from resonant scattering from bubbles at this acoustic frequency.

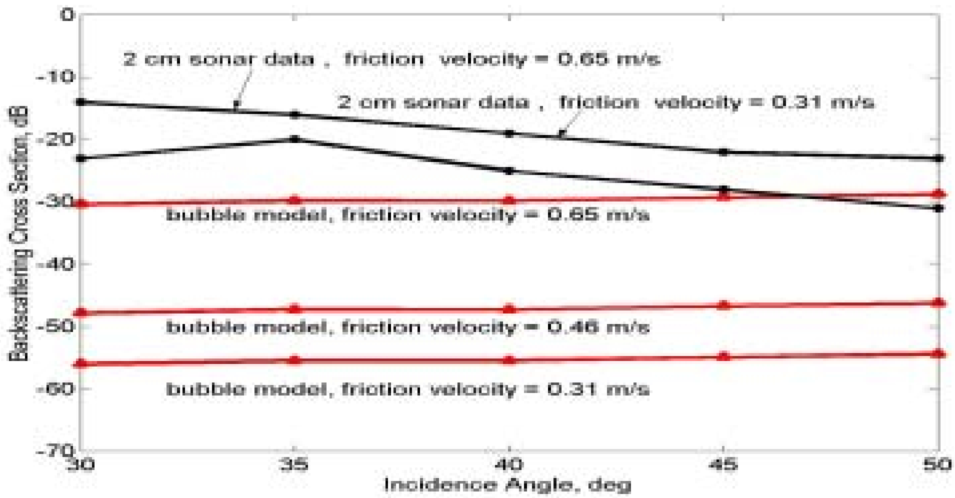

Figure 4. Measurements of the sonar backscattering cross section (RCS) at Ku-band versus incidence angle at two friction velocities, 0.65 m/s and 0.31 m/s (black lines), compared with model estimates of the RCS at same friction velocities assuming scattering from bubbles (red lines).

IMPACT/APPLICATION

The results of this work support previous measurements that have shown the importance of bound, tilted short waves for understanding rough surface scattering both in wind wave tanks and on the ocean (Plant, 1997; Plant et al., 1999b; Plant et al., 1999c). Although we have not demonstrated it in this report, a variety of data, including our Marseilles data, show that bound wave effects are more prominent at high incidence angles than at low ones. Thus their effects are important for developing scattering models at moderate to high incidence angles, especially at horizontal polarization. Abundant evidence exists that signatures of surface and subsurface vessels appear most prominently in microwave imagery taken at horizontal polarization and high incidence angles. Bound waves are undoubtedly one reason for this. Thus the work carried out in this project is directly applicable to non-acoustic ASW and other ocean imaging.

TRANSITIONS

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

RELATED PROJECTS

This project has many parallels with a project run by the Office of the Secretary of Defense to investigate the microwave signatures produced by submarines. The basic understanding of microwave scattering, especially at high incidence angles, produced in this project furthers these attempts to detect submarines. Finally, knowledge of acoustic scattering obtained from this joint microwave/acoustic study benefits programs on acoustic scattering from the sea surface and near-surface bubbles sponsored by ONR Code 321OA.

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