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Bound Wave Effects in Microwave and Acoustic Backscatter from Rough Water Surfaces

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Abstract – Simultaneous backscattering measurements with radar and sonar in the large wind wave facility in Marseilles, France shows that bound and free waves coexist on the water surface. By observing the surface from above and below, we were able to show definitively that the bound waves ride on the front face of the dominant wave in the tank. Because of the large width of the tank, we were able to vary the azimuth angle of both the radar and sonar, which viewed a common surface area, and observe the dependence of both free and bound waves on azimuth angle.

I. EFFECTS OF SURFACE TILT ON BACKSCATTER

Effects due to bound, tilted waves were studied in simultaneous microwave/acoustic (radar/sonar) backscattering studies using 2 cm radiation in the large wind wave tank at Marseille, France. The radar and sonar both looked in the same azimuthal direction at the same incidence angle. In the wave tank, the presence of tilted gravity-capillary waves that are traveling at speeds larger than their intrinsic phase speed were detected in mean cross sections and Doppler spectra. The three-meter width of the tank allowed these effects to be examined for a wide range of incidence and azimuth angles. Tilting of the bound waves was evident in the different levels of cross section measured with radar and sonar. For a flat, slightly rough surface, HH radar and sonar cross sections at the same incidence angle are nearly the same (Plant et.al., JGR, 104(C11), p25853, 1999). If the scatterers are tilted, however, (Figure 1) the system for which the local incidence is smallest exhibits the largest cross section. If bound waves ride on the downwind face of longer waves, then radar cross sections should be largest when both systems look upwind and sonar cross sections should be largest when both systems look downwind.

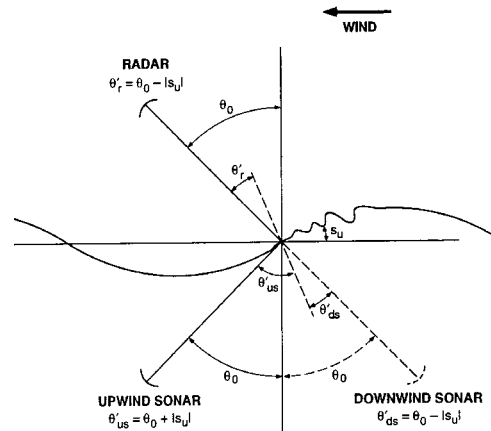


Figure 1. Geometry of the scattering arrangement for an upwind-looking radar and both an upwind and downwind-looking sonar. The data in this paper were taken with the radar and sonar looking in the same horizontal direction at the same nominal incidence angle, θ_0 .

II. OBSERVATIONS

Although the presence of free waves changes this picture a bit, the observations shown in Figures 2-5 indicate that this does occur. In Figure 2, looking upwind, the sonar cross section is below that of both radar polarizations for all wind speeds. Looking downwind in Figure 5, the sonar cross sections have moved up while the radar ones have moved down; at several wind speeds, the sonar cross sections are higher than the radar ones.

Additional confirmation of the free/tilted-bound wave picture is provided by the Doppler spectra also shown in Figures 2-5. These were obtained at a friction velocity of 20.2 cm/sec. Bragg scatterers moving at the intrinsic phase speed of the resonant surface wave would have a Doppler shift of 18 Hz, and peaks at this frequency are observed in all spectra. In

addition, however, a second peak is observed in many of the spectra at a frequency corresponding to that produced by a scatterer moving with the dominant wave in the tank, about 40 Hz. For the spectra taken looking upwind (Figure 2), this peak appears in the radar spectra because the radar responds more strongly than the sonar to a bound wave riding on the front face of the dominant wave (Figure 1). Figures 3 and 4, taken at azimuth angles to the wind of 60° and 120° , respectively, show no bound wave peaks. This indicates that the angular width of the bound waves is less than 60° . For the case where the radar and sonar are both looking downwind (Figure 5), the bound wave peak occurs in the sonar spectrum. Again, this is because it is the system with the smallest local incidence angle in this configuration.

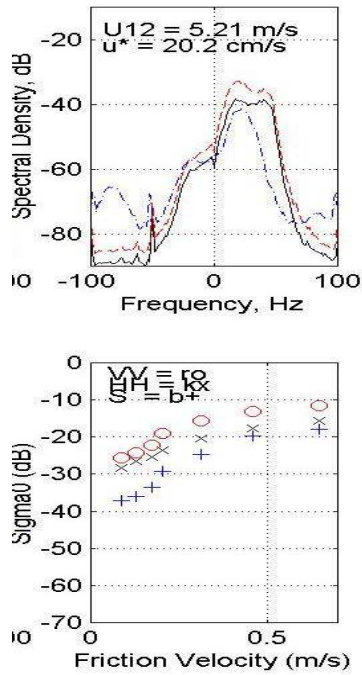


Figure 2. (top) Doppler spectra of radar and sonar. Red dashed line is VV radar, black solid line is HH radar, blue dashed line is sonar. (bottom) Radar and sonar cross sections versus friction velocity. Azimuth angle = 0° (Upwind); incidence angle = 40° .

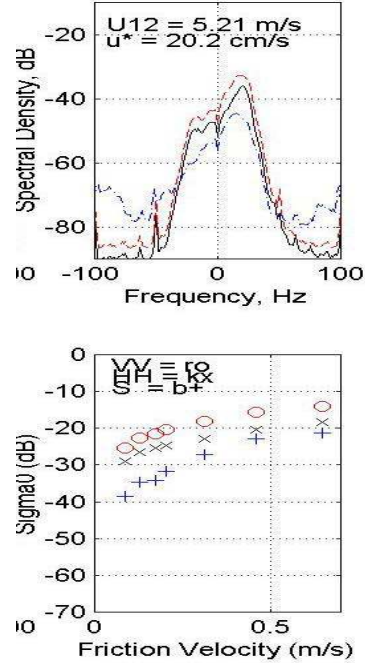


Figure 3. Same as Figure 2 but for an azimuth angle of 60 degrees with respect to the direction from which the wind comes.

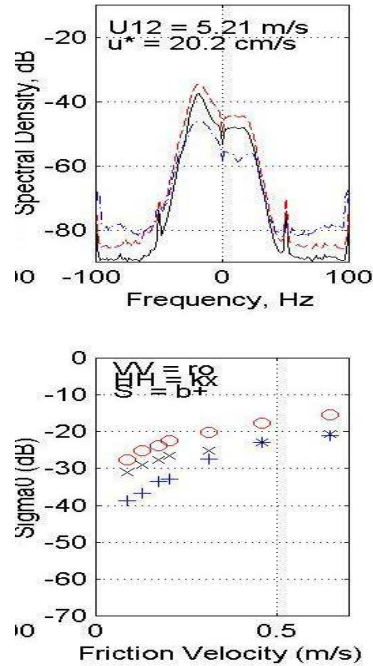


Figure 4. Same as Figure 2 but for an azimuth angle of 120 degrees with respect to the direction from which the wind comes.

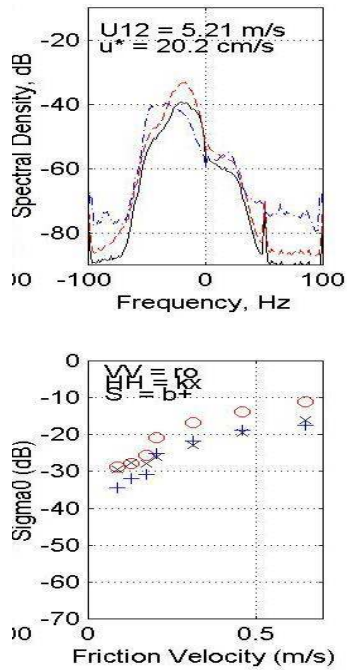


Figure 5. Same as Figure 2 but for an azimuth angle of 180 degrees with respect to the direction from which the wind comes (downwind).

III. CONCLUSIONS

The work presented here confirms that both freely propagating wind waves and bound waves that ride on the front face of longer waves exist in a wind wave tank and produce signatures in both radar and sonar backscatter. By working in a wide wave tank, we could determine that the angular width of the bound wave spectrum is narrower than that of the free waves. Although not shown here, the incidence angle dependence of the sonar cross sections suggested that scattering from bubbles did not influence our results in this fresh-water tank. The 2 cm wavelength of both microwave and acoustic radiation and the incidence angles observed lead to the conclusion that the bound waves observed here are too long to be parasitic capillary waves.

REFERENCES

Plant, W.J., P.H. Dahl, and W.C. Keller, Microwave and acoustic scattering from parasitic capillary waves, *J. Geophys. Res.*, 104, 25,853-25,866,1999