Modulation of Short Wind Waves by Long Waves and Effects on Radar Reflectivity

Mark A. Donelan
Division of Applied Marine Physics
Rosenstiel School of Marine and Atmospheric Science - University of Miami
4600 Rickenbacker Causeway, Miami, FL 33149
phone: 305-361-4717 fax: 305-361-4701 e-mail: mdonelan@rsmas.miami.edu

Brian K. Haus
Division of Applied Marine Physics
Rosenstiel School of Marine and Atmospheric Science - University of Miami
4600 Rickenbacker Causeway, Miami, FL 33149
phone: 305-361-4932 fax: 305-361-4701 e-mail: bhaus@rsmas.miami.edu

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LONG-TERM GOAL

- To determine the effect of long waves on the modulation of short waves in various levels of wind forcing.

- To isolate and quantify the effects of the modulation of the short waves on the radar reflectivity

OBJECTIVES

- To complete the analysis of an extensive data set on the modulation of short wind waves by long waves. The experiments were done in collaboration with Dr. William Plant (APL, U. of Washington) in the RSMAS Air-Sea Interaction Saltwater Tank (ASIST) facility. *(Year 1)*

- To conduct and analyze additional experiments in the RSMAS ASIST facility to clarify any issues that arise from the analysis of the existing data. These experiments will employ enhanced and innovative measurement techniques that were not available for the first set of experiments. *(Year 2 experiment, Year 3 analysis)*

- To relate these measurements to expected results in field conditions. *(Year 3)*

APPROACH

To determine the effect of long waves on the modulation of short waves and the effect that this modulation has on radar reflectivity, a series of laboratory measurements has already been conducted and additional measurements will be collected through this project. The wind-wave tank at the Canada Centre for Inland Waters (CCIW) and the Air-Sea Interaction Saltwater Tank (ASIST) facility at the University of Miami were used for the preliminary experiments discussed here. The ASIST facility will be used for the upcoming experiments in FY03 and FY04. ASIST provides an opportunity for all of the critical parameters for the modulation of radar reflectivity to be directly observed.

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Wave Measurements: The directional wave spectrum is remotely sampled using a triad of laser elevation sensors. An Argon-Ion (488 nm wavelength, 150 mwatts) air-cooled laser is equipped with beam splitters and mirrors to provide 3 vertical beams in an equilateral triangle of side 1 cm at any point in the tank. The intersection of these beams with the surface is detected by line-scan cameras at a rate of up to 1000 Hz. The cameras have a dynamic range of 2048 (pixels) and the range of heights is determined by the choice of lenses. Thus the elevation and local slope vector can be determined with high precision and high rate.

The two dimensional distribution of surface slopes is sampled using an Imaging Slope Gauge (ISG). It uses a uniform light source underneath the test section that shines through a mask with a known gradient in red, green and blue intensities. The light then passes through a Fresnel lens that focuses all light that has the same slope on the same point of the mask. This then allows an RGB camera to directly observe the water surface slope through the relative intensities of the three color components at each point of the image. The ISG images an area of the water surface of up to 45 cm (downwind) x 30 cm (crosswind) at a resolution of 640 x 240. These images are sampled at a rate of 120 Hz using two interleaved RGB cameras.

Turbulence Measurements: The principal turbulence measuring tool employed in this work is a Particle Image Velocimetry (PIV) system manufactured by Dantec. This state-of-the-art flow visualization and measurement system yields velocity vector maps in a 62 x 62 grid covering an area of size limited only by the optics. These maps are produced at a maximum rate of 15 Hz and multiple realizations of the flow at steady state are used to make the statistical error arbitrarily small. The structure function in the Inertial Sub Range (ISR) yields the dissipation rate via Kolmogoroff's $r^{2/3}$ law. The mean velocity profile and turbulent momentum flow may be deduced from these velocity vector maps.

In addition to the PIV measuring system (giving excellent spatial and limited (15 Hz) time resolution), we also employ thermal velocimetry to acquire point measurements of velocity at frequencies up to several kHz. The hot film probes are positioned on the downstream edge of the PIV measurement area allowing the use of the PIV (at 15 Hz) to keep the hot film devices in calibration.

Co-incident with these measurements, the radar backscatter is sampled using specially designed C and Ku band Doppler radars. These innovative and precise measurements of the air-sea interface are combined to provide the information required for a detailed understanding of the transfer function between the wave parameters and radar reflectivity.

WORK COMPLETED

A series of experiments to study the modulation of short waves by longer waves including wind forcing was conducted at the Canada Centre for Inland Waters (CCIW) and at the ASIST facility.

CCIW Experiments: These experiments were conducted in a 32 m long-wind wave tank with a Ku-band dual polarized (VV and HH) radar at a fetch of 14 m. At the same location a single laser beam intersected the surface from below. The water (of depth 22.5 cm) contained a small quantity of fluoroscein, which was excited by the 488 nm laser beam. The elevation information was captured by a line-scan camera, as described above, while the emergent refracted beam was captured on a large Fresnel lens above the tank. The focused beam was detected on a 4-port position detector, allowing local surface slope measurements to be made at rates up to 1000 Hz. These local elevation and slope measurements are combined in the Wavelet Directional Method (Donelan et al., 1996) to yield instantaneous information on the distribution of wave energy among various wavenumbers.

ASIST Experiments: The first set of experiments in the ASIST facility were conducted in February, 2001. C-band (upwind) and Ku-band (downwind) dual polarized Doppler radars illuminated the water surface at an incidence angle of $\pm 45°$. Within the radar footprint three laser elevation sensors were positioned in a triad with spacing between beams of 1 cm to precisely determine the two components of the surface slope at a rate of 500 Hz. The near-surface air and water velocities and turbulence were measured using thermal velocimetry and a digital Particle Image Velocimeter (PIV).

The wind forcing was varied over a range of 0-15 m/s measured at the centerline of the tank. Monochromatic long-waves were generated with frequencies from 0.1 Hz to 1.0 Hz and with maximum slopes from 0.05 to 0.3. For each run the time-varying Doppler backscatter was observed with the radars. The upwind and crosswind slopes were simultaneously sampled for runs of duration 262 seconds. This run length provided reliable statistics for the relationship between local wave slopes and the radar backscatter.

The second set of experiments in the ASIST facility was conducted in June, 2001. An imaging slope gauge (ISG) was installed and calibrated. ISG images were collected at a rate of 120 Hz. The two-dimensional distributions of surface slopes were observed at the same location that was simultaneously sampled with the C-band Doppler radar.

RESULTS

In Figures 1 and 2 the phase of the long waves (1.0 Hz paddle waves of wavelength 126 cm) is used as an index to isolate the "phase-averaged" energy density of the short waves. The phase averages are assembled in 10 degree bins (asterisks) and the 4-point running average is also indicated (dashed line). The figures show the modulation of 2 cm (Ku-band, Figure 1) and 5 cm (C-band, Figure 2) for three wind speeds (3.2, 2.6 & 1.8 m/s) measured at 20 cm above the mean water level. The modulation depth for the 2 cm waves is about 5 while that for the 5 cm waves is about 2. The pattern of modulation is quite complex and the phase of the principal component seems to vary with both wavelength and wind speed, although the most frequent location of the peak of the short wave energy density is at the crest or ahead of it on the leeward face of the wave.

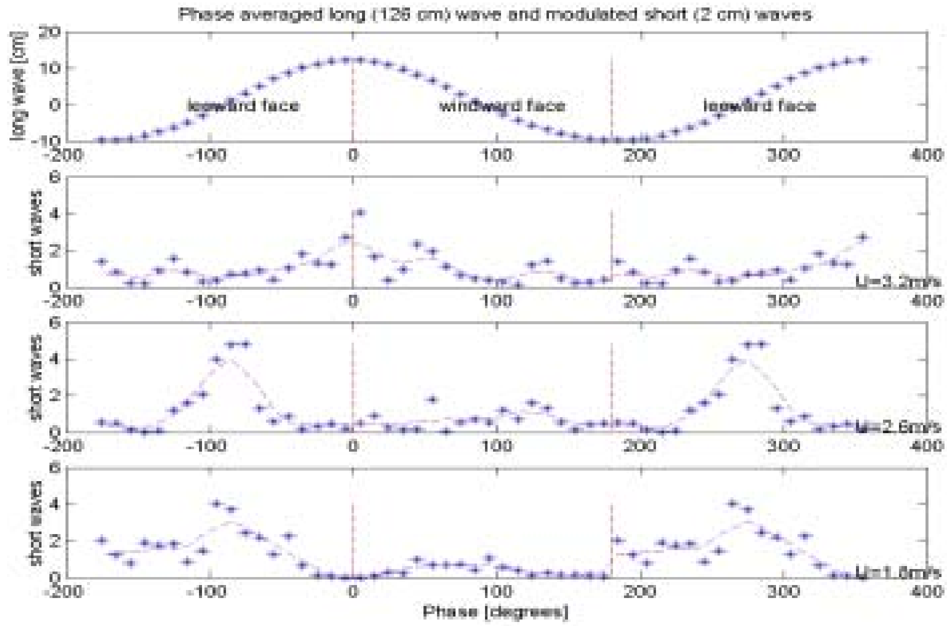

Fig. 1. Modulation of 2 cm wind-generated waves by 126 cm paddle-generated waves. The phase of the 126 cm wave is shown in the top panel. In the three lower panels, the short wave energy density is averaged on the phase of the long wave in 10 degree phase bins (*); a further 4-point running average is shown by the dashed red line. The conditions in these three panels differ only in the strength of the wind measured at 20 cm height.

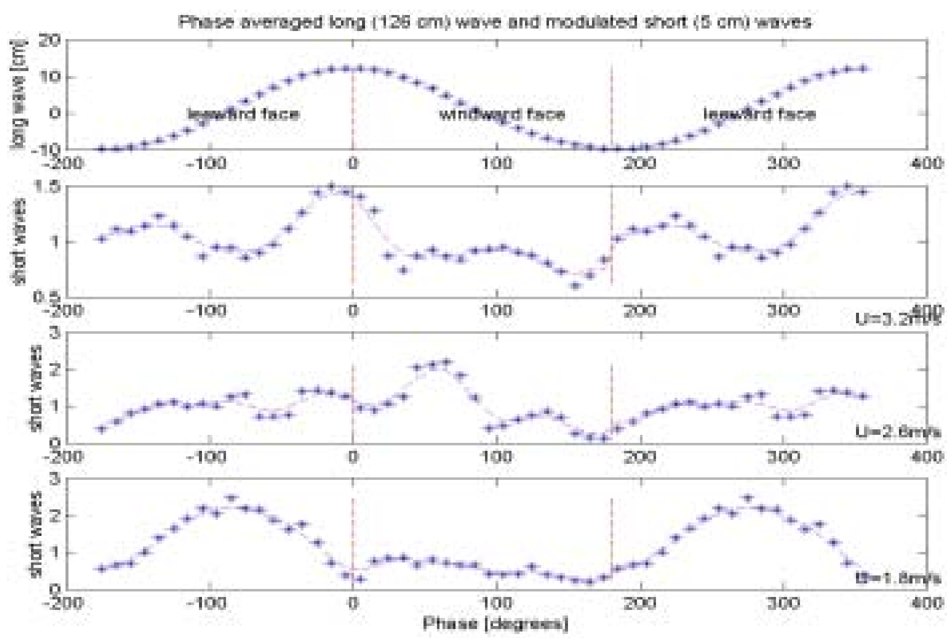

Fig. 2. Modulation of 5 cm wind-generated waves by 126 cm paddle-generated waves. The phase of the 126 cm wave is shown in the top panel. In the three lower panels, the short wave energy density is averaged on the phase of the long wave in 10 degree phase bins (*); a further 4-point running average is shown by the dashed red line. The conditions in these three panels differ only in the strength of the wind measured at 20 cm height.

IMPACT/APPLICATIONS

This project is focused on basic improvements to the modulation transfer function that allows radar backscatter to be related to ocean surface wave properties. Advanced techniques are applied to make radar and wave measurements that are collocated in both space and time without disturbing the wave field. This will provide the necessary data to validate and improve expressions for the transfer function. The improved formulation can then be used to estimate surface wave properties from space or airborne radars.

TRANSITIONS

As this work is at an early stage, transitions have been limited.

RELATED PROJECTS

"Bound Waves and Microwave Backscatter from the Ocean"; William J. Plant (P.I.); ONR Grant # N00014-00-1-0075.

REFERENCES

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