Radiometric Measurements of the Microwave Emissivity of Foam

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Abstract- Radiometric measurements of the microwave emissivity of foam were conducted in May 2000 at the Naval Research Laboratory's Chesapeake Bay Detachment using radiometers operating at 10.8 and 36.5 GHz. Horizontal and vertical polarization measurements were made at 36.5 GHz; horizontal, vertical, +45, - 45, left circular, and right circular polarization measurements were obtained at 10.8 GHz. Surface foam was generated by blowing compressed air through gas permeable tubes supported by an aluminum frame and floats. Video micrographs of the foam were used to measure bubble size distribution and foam layer thickness. A video camera was boresighted with the radiometers to determine beam-fill fraction of the foam generator.

INTRODUCTION

Foam on the ocean surface increases the emissivity and brightness temperature measured by a passive microwave radiometer and is a key component of the wind speed signal measured by a linearly polarized radiometer. Accordingly the accuracy of physical wind speed retrieval algorithms is driven by the accuracy of a sea foam model. Understanding sea foam effect is also important for polarimetric radiometric observations of wind direction. Although estimates of sea foam emissivity have been made based on aircraft experiments over the ocean, the surface conditions were not controlled or thoroughly characterized. The experiment described here is intended to produce a set of foam emissivity measurements supported by a detailed characterization of the surface and foam properties.

EXPERIMENT DESCRIPTION

The foam generator, consisting of gas permeable tubes supported by an aluminum frame and floats, was positioned in the water and the cradle of a telescopic arm lift was used to position the two radiometers and the boresighted video camera over the water so that the foam generator could be viewed at incidence angles ranging from 30 to 60 degrees. The video camera was used to point the radiometers and to record images of foam coverage. A distance of 4.9 meters was maintained between the radiometer antennas and the center of the foam generator so that the generator was in the far field of the antennas and in order to minimize change in the solid angle subtended by the target foam generator as the incidence angle was varied. Beam fill fraction of the generator for all incidence angles is currently being evaluated but was greater than 0.9 for all measurements.

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VIDEO MEASUREMENTS

A video camera was boresighted with the radiometers during the experiments and a typical image from this camera is shown in Fig. 1. The fractional area foam coverage produced by the raft was determined from these images using the grey-scale analysis procedure described in Asher and Wanninkhof [1]. These data will be used to determine how well the foam filled the radiometer antenna footprint. Preliminary estimates indicate that the fractional area foam coverage in the footprint was approximately 0.95.

In addition to the surface video images shown in Fig. 1, an underwater video camera equipped with a telecentric macro zoom lens was used to photograph the bubble microstructure of the foam on the water surface. Fig. 2 shows an image of the interior foam structure which has been used to measure the bubble size distribution. Similar images taken at a lower magnification have been used to measure the total thickness of the foam layer. The bubble size spectra and foam thickness measurements will be used in numerical electromagnetic models for calculating foam emissivities. The approximate foam layer thickness for high level compressed air rate was 2.5 cm.

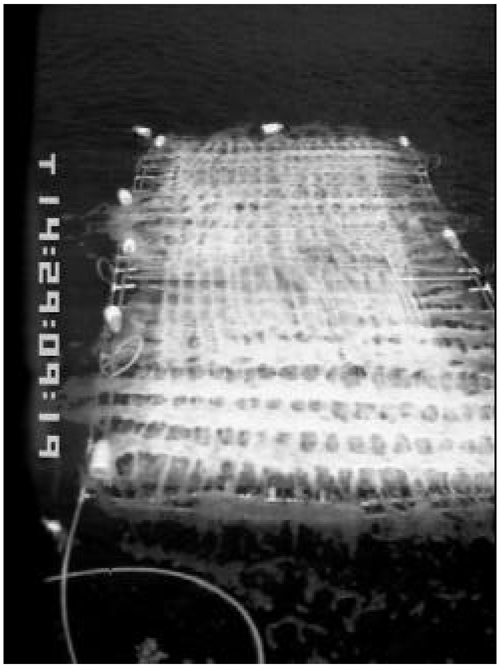

Fig. 1. Typical image of foam generated by the foam raft, taken by the crane-mounted video camera. The incidence angle is 40 degrees.

RADIOMETRIC MEASUREMENTS

The approach to data analysis is patterned after the method given by Hollinger and Kenney [2] for a test tank study of oil film thickness. For each polarization the emissivities of a calm water surface and a foam covered water surface were computed using

$$E_W = \frac{T_{A,W} - T_{A,SKY}}{T_W - T_{A,SKY}} \tag{1}$$

and

$$E_F = E_W + \frac{T_{A,F} - T_{A,W}}{(f)(h)(T_W - T_{A,SKY})} \ . \tag{2}$$

Here E_W and E_F are the emissivities of calm water and a foam covered surface. $T_{A,F}$, $T_{A,W}$, and $T_{A,SKY}$ are the radiometer antenna temperatures looking at foam (generator on), water (generator off), and sky respectively. For the purpose of this paper, antenna temperature is defined as the normalized apparent radiometric temperature at the antenna, weighted by the antenna pattern. T_W is the physical temperature of the water and foam; f is the fraction of the surface covered by foam and h is the beam-fill fraction of the foam generator in the antenna pattern. Beam-fill fraction

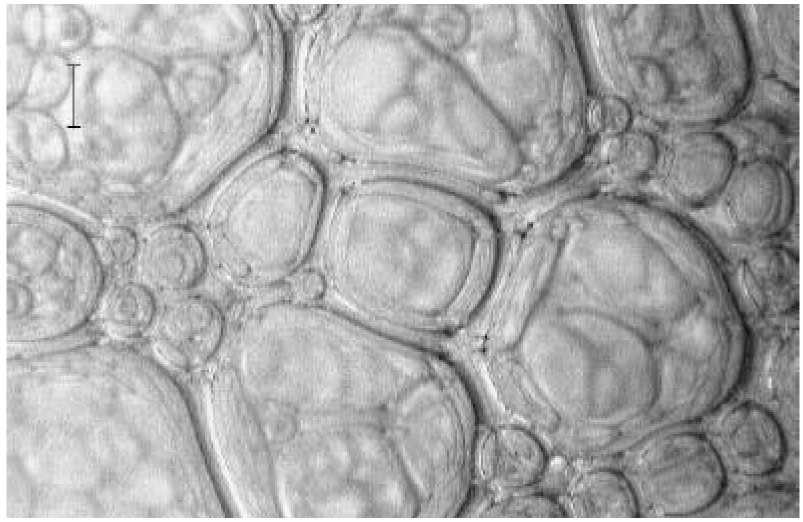

Fig. 2. Typical image of the bubble microstructure in the foam interior as recorded by an underwater camera mounted near the center of the foam raft. The scale bar shown in the upper left corner represents a distance of 500 micrometers.

and foam fraction are being computed but for the preliminary results given here the values of $h = 1$ and $f = 0.95$ have been used. Fig. 3 shows 36.5 GHz emissivity plots for vertical (V) and horizontal (H) polarizations where (1) and (2) have been used to compute the emissivities of calm water and foam-covered water surfaces. NRL model calm-water emissivities are compared to experimental results with good agreement. The high foam V polarization is roughly constant at ~0.9 over the range of incidence angles but the high-foam H polarization decrease gradually from ~0.85 at 30 degrees to ~0.7 at 60 degrees. This decrease in emissivity with incidence angle resembles somewhat the calm water H polarization results but displaced upward by approximately 0.5. Fig. 4 shows the high-foam H & V emissivities at 10.8 GHz with model and measured emissivities for calm water also plotted in the figure. Fig. 5 and Fig. 6 show 10.8 GHz emissivity plots for – 45 degrees and left circular polarization respectively. Plots of + 45 degrees linear and right circular polarization are very similar. The – 45 degrees linear and left circular polarization plots agree fairly well with each other and they are in turn roughly in agreement with the high foam average value of 10.8 GHz H and V taken from Fig. 4. The power in –45 or left circular is expected to be equal to the average of the power in the V and H polarizations. Stogryn [3] developed analytic expressions to represent the emissivity of sea foam at microwave frequencies based on a survey of published radiometric measurements. His analytic expressions are plotted as a function of incidence angle in Fig. 7 for a frequency of 10.8 GHz and the H and V results from Fig. 4 are also plotted for comparison. His expressions were for

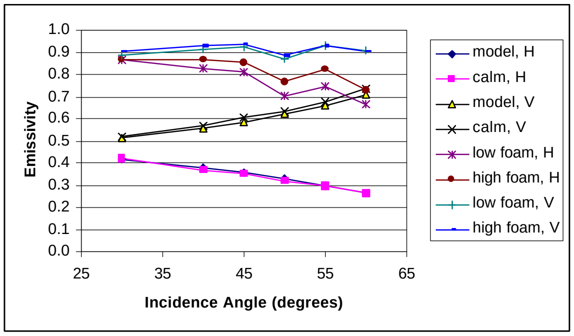

Fig. 3. Emissivity results at 36.5 GHz. Horizontal and vertical polarization, high and low foam. NRL model values for calm water are shown with the experimental measurements.

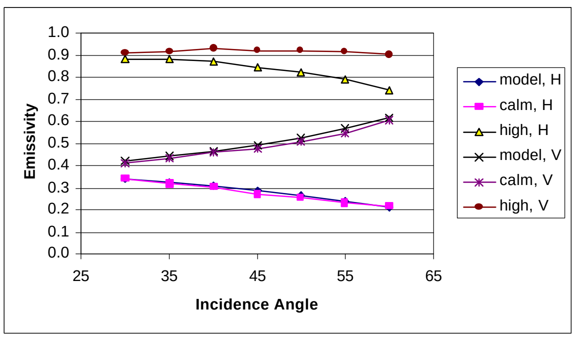

Fig. 4. High-level foam and calm water emissivity at 10.8 GHz, horizontal and vertical polarization. NRL model for calm sea water also shown.

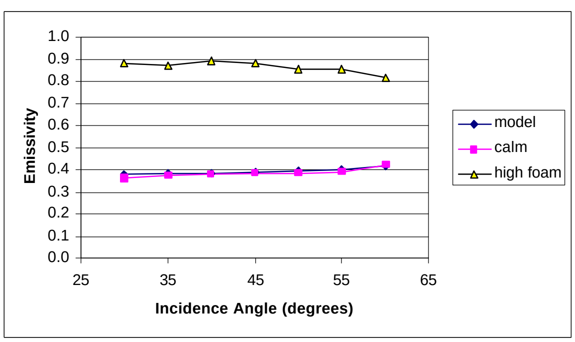

Fig. 5. High-level foam and calm water emissivity at 10.8 GHz for – 45 degree linear polarization.

the frequency range 13.4 < frequency < 37 GHz so that 10.8 GHz is below the intended range. His equations predict emissivities that are smaller than the observed values. In addition, the angular dependence of his model shows a slight decrease in V polarization emissivity with incidence angle that is not seen in the experimental results. The slope of his H polarization curve, however, is in approximate agreement with the experimental curve.

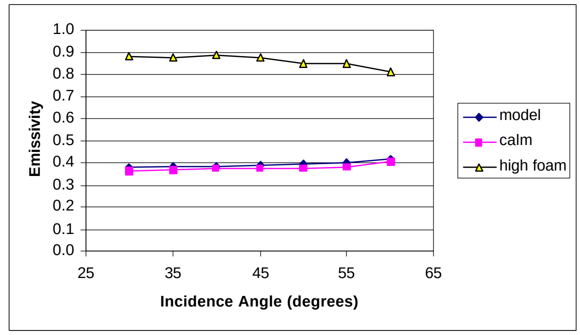

Fig. 6. High-level foam and calm water emissivity at 10.8 GHz for left circular polarization.

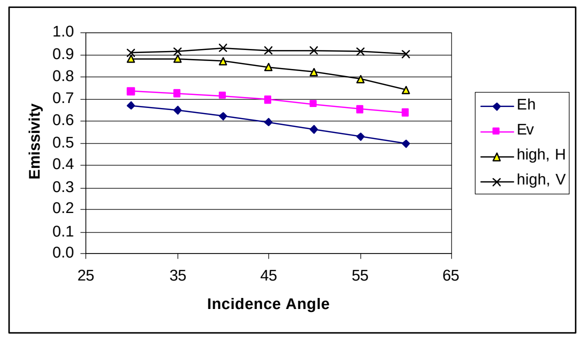

Fig. 7. Eh and Ev are model plots from Stogryn [3]. High H and High V are the 10.8 GHz H and V emissivity plots taken from Fig. 4.

SUMMARY

Radiometric measurements of foam at 10.8 and 36.5 Ghz were performed using a foam generator floating on the seawater surface and radiometers mounted on a telescopic arm lift. Results show vertically polarized emissivities greater than 0.9 over a range of incidence angles while horizontally polarized emissivities decrease from ~0.9 to about 0.7 as the incidence angle increases to 60 degrees. Minus 45 degree linear and left circular polarization emissivities at 10.8 GHz agree well with averages of vertical and horizontal polarization emissivities.

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