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Detecting breaking ocean waves through microwave scattering

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New remote-sensing observations indicate that water droplets produced by breaking waves generate bright microwave radar returns.

Remote sensors operating at electromagnetic wavelengths cannot significantly penetrate ocean water but are effective at observing surface phenomena (such as waves and winds). Radar remote sensing can also be used to measure ocean currents and the presence of surfactants or slicks. These capabilities are presently being exploited to track the Gulf of Mexico oil spill, for example.

For radars transmitting at microwave frequencies, breaking (or nearly breaking) waves generate much stronger returns than would be expected based on existing scattering models. For example, Figure 1 shows an image from a marine radar operating from shore at Newport (Oregon).[1] Linear features running vertically are indicative of breaking ocean waves. Relating these bright returns to an accurate count of the number of breaking waves has a number of applications. For example, wave breaking is an important mechanism for air-sea interaction that influences the generation and strength of tropical storms and hurricanes. Identification of breaking waves is also important for maritime operations, where wave breaking presents a primary danger. Finally, closer to shore, observations of wave breaking would allow a better understanding of the complex driving forces of the nearshore currents that erode beaches.

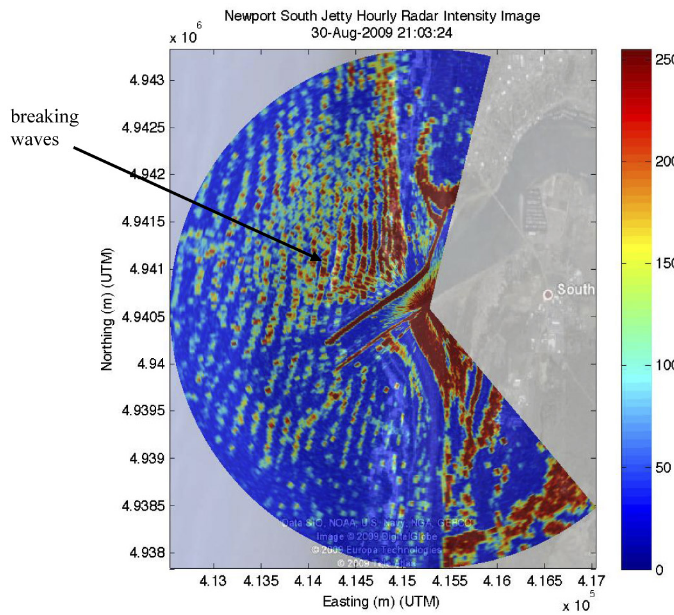

Figure 1. Marine-radar image from Newport (Oregon). Colors represent normalized backscattered intensity. UTM: Universal transverse Mercator coordinate system.

Where waves are not breaking, the radar backscatter from the ocean surface is generally well described by the Bragg scattering mechanism and the two-scale model of slightly rough surfaces.[2] However, the hydrodynamic conditions in areas of active wave breaking are significantly different from regions of nonbreaking waves. Hence, the conditions governing scattering of microwave radiation and the data captured in radar images also change. Inside the breaking-wave crest (or 'wave roller'), air and water are mixed continuously, and a volume of entrained bubbles and ejected droplets propagates with the crest (see Figure 2). As a breaking wave passes, resurfacing bubbles and remnant foam are left in its wake. For microwave sensors, sea water is a lossy medium from which bubbles and foam induce high absorption. This is corroborated by observations showing a lack of microwave scattering from trailing foam.[3] On the other hand, polarimetric decomposition of radar data[4] indicates that as waves evolve through the breaking process, scattering appears random and the wave roller acts as depolarizer. This is indicative of volumetric scattering (scattering from discrete particles), distinctly different from scattering from an impenetrable surface. This is consistent with previous findings,[5] which added a correction term to the microwave cross section that could be attributed to sea spray as a source of scattering.

Recently, we treated the wave breaking roller as a volumetric scatterer composed of a population of salt-water droplets embedded in air that travels with the breaking-wave crest.[6]

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Figure 2. *Water droplets produced by a breaking ocean wave.*

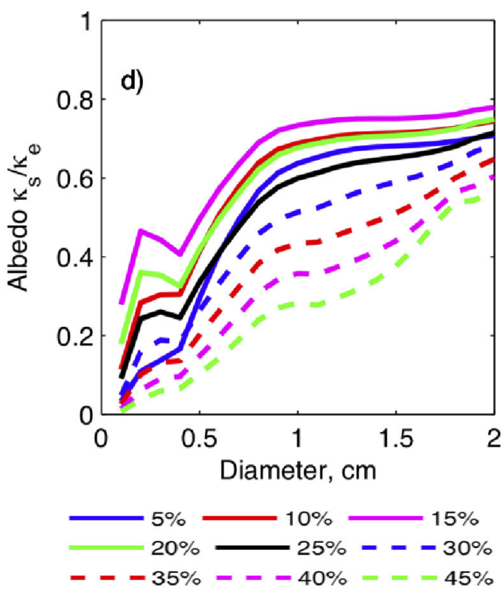

Figure 3. *Albedo of salty droplets at 9.36GHz as a function of particle diameter and volume fraction.* κ_s, κ_e*: Scattering and additional absorber opacities.*

The upper boundary of the droplet layer is the atmosphere, its lower boundary the ocean. The scattering model closely follows earlier work,[7–9] which was developed for microwave sensing of snow and derived directly from dense-media radiative-transfer theory.[10] The model depends only on a few physical parameters and requires no calibration constants.[6] The necessary parameters are the microwave frequency and the properties of the droplet medium (permittivity, particle diameter, and volume fraction). Potential clustering of the droplets is addressed with a 'stickiness' parameter.

Figure 3 shows example calculations of the albedo of salty droplets, allowing clustering when excited by a microwave radar operating at 9.36GHz. Water-droplet diameters are in the range $0.05 < d < 2$cm, similar to observed droplet sizes.[11] Different lines represent volume fractions in the range f_v = 5–45%. At diameters smaller than the Rayleigh limit ($d \approx 3$mm), the albedo increases sharply but is dominated by absorption. Larger diameters exhibit an increase in albedo, leveling off at ~0.7. In comparison to particles without clustering (not shown), clustering enhances scattering. The explanation is that for mid-range volume fractions and small diameters, the stickiness allows particles to form clusters that effectively behave as particles of larger diameter. The maximum albedo is reached for a volume fraction of only 15%, a value expected for the upper layers of the wave roller. This suggests that scattering from water droplets generated by breaking waves can be significant.

This model for microwave scattering from a droplet layer shows promise in explaining the high radar returns observed from breaking ocean waves. This volumetric approach is innovative considering that the unbroken ocean surface is highly reflective at microwave frequencies. Hence, surface scattering has been the typical approach to modeling radar returns from the ocean. Our further work will test our radar-scattering model predictions against observations to develop a more accurate model for wave imaging using radar. We expect this to lead to improved observations and real-time predictions of dangerous wave breaking in nearshore areas and better quantification of the role of wave breaking in air-sea interaction processes within large storms.

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