Recovering high spatio-temporal resolution topography of capillary-gravity waves in an open ocean environment

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The complex relationship between capillary waves, gravity waves and swell is at the heart of many oceanographic research questions involving wave-wave interactions, radar remote sensing, and air-sea interaction. However, measuring the full two-dimensional, time varying structure of millimeter scale waves in the open ocean has proven difficult. The major shortcomings of the most remote sensing and *in-situ* methods have been the inability to extract sufficient information about the full two-dimensional slope field and to construct an instrument that does not disturb the air–sea interface.

By taking advantage of recent advances in imaging polarimeter, we developed the Polarimetric Slope Sensing (PSS) method, which recovers the instantaneous surface topography of a water surface in the form of a two-dimensional map of orthogonal surface slopes [*Zappa et al.*, 2008]. The PSS method relates the change in polarization of reflected skylight to the orientation of the surface normal at the point of reflection. The orientation of the surface normal vector within the field-of-view of each pixel is decomposed into the angle between the incoming light ray and the surface normal vector (θ) and the tilt of the plane formed by the incoming light ray, the surface normal vector and the reflected light ray (ϕ). The incidence angle (θ) is directly related to the degree of linear polarization (DOLP) and the orientation (ϕ) is directly related to the polarization orientation of the reflected light (Φ) through

$$\mathrm{DOLP}(\theta) = \sqrt{\frac{S_1^2 + S_2^2}{S_0^2}} \quad \text{and} \quad \Phi(\phi) = \frac{1}{2}\tan^{-1}\left(\frac{S_2}{S_1}\right)$$

where (S_0,S_1,S_2,S_3) are the Stokes parameters measured by the imaging polarimeter.

Based on the outcome of laboratory experiments [*Zappa et al.*, 2008], we built a new prototype imaging polarimeter specifically designed for oceanography applications. The imaging polarimeter (IPol) captures four simultaneous 782 x 582 pixel images (corresponding to the four Stokes parameters) at 60Hz. The IPol employs a single objective lens and a highly efficient polarizing beam splitter design with a CCD at each of the four exit apertures. The design results in near perfect registration of the four Stokes parameter images with approximately 95% of the input signal reaching the four CCD detectors. The IPol along with two scanning lidars were deployed on R/P Flip in Santa Barbara Channel during the ONR Radiance in a Dynamic Ocean (RaDyO) experiment. The IPol was suspended approximately 9 meters above the mean water level where it imaged a surface footprint of 1m x 1m with a spatial resolution of 1.5 mm. In this talk we present initial results from the RaDyO experiments including time-lapse videos of sea surface slope topography, total mean squared slope and wavenumber-frequency spectra. Figure 1 shows x-and y-component images from the IPol camera during RaDyO. Our results are compared with the classical Cox and Munk results [*Cox* *and Munk*, 1954a; b] in Figure 2 as well as more recent laboratory and field measurements using scanning laser slope gauges.

The success of the PSS technique opens up many new possibilities to advance studies in air–sea interaction processes that are controlled by the sea surface microstructure. For example, increasing evidence accumulated over the past two decades in laboratory experiments indicates that the air–sea gas transfer, such as for the sparingly soluble gas CO_2, strongly correlates with water surface roughness or the mean-squared slope of short wind waves [*Bock et al.*, 1999; *Jähne et al.*, 1987; *Zappa et al.*, 2004].

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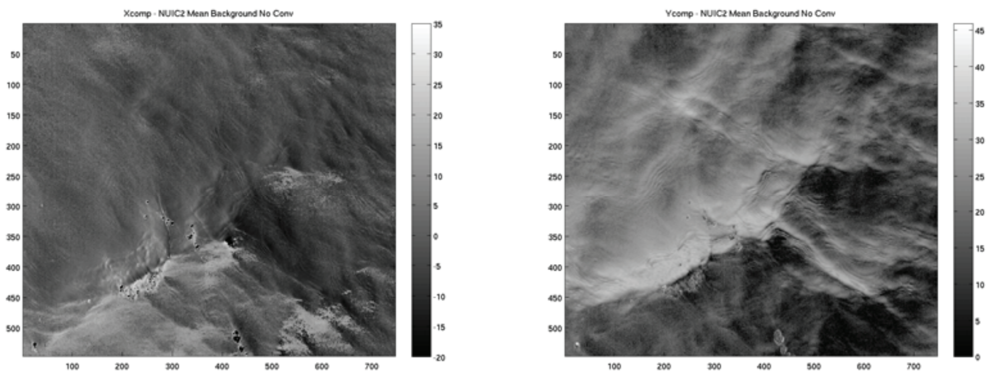

Figure 1. X- and Y-component images of ocean surface slope taken using the IPol camera during the RaDyO experiment in Santa Barbara Channel from R/P Flip in September 2008.

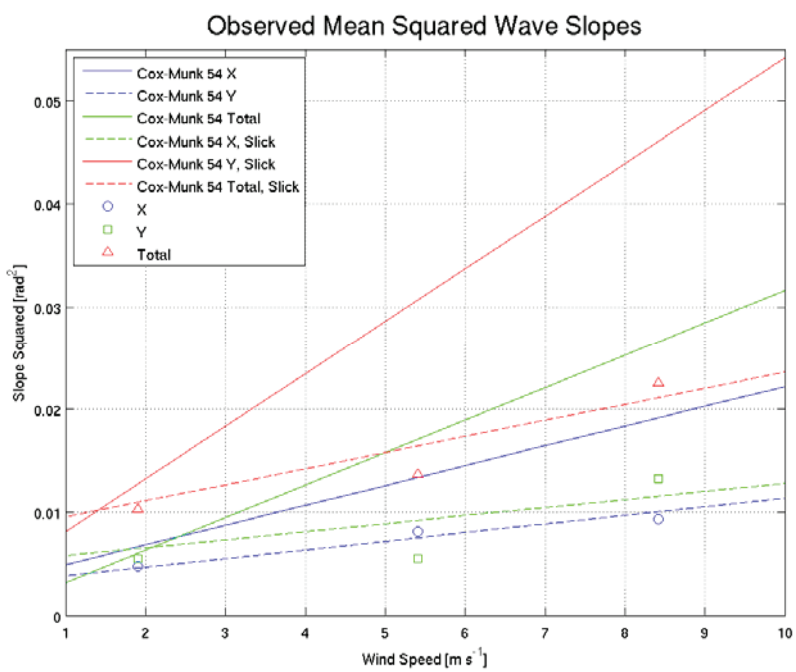

Figure 2. Mean-square wave slope from images of ocean surface slope taken using the IPol camera during the RaDyO experiment in Santa Barbara Channel from R/P Flip in September 2008. Note that the results compare well with the Cox-Munk relationships for slick conditions which is consistent with the surfactant levels in the region during the experiment.