Ocean Surface Wave Optical Roughness –
Innovative Measurement and Modeling

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LONG-TERM GOALS

I am part of a multi-institutional research team funded by the ONR-sponsored Radiance in a Dynamic Ocean (RaDyO) program. The primary research goals of the program are to (1) examine time-dependent oceanic radiance distribution in relation to dynamic surface boundary layer (SBL) processes; (2) construct a radiance-based SBL model; (3) validate the model with field observations; and (4) investigate the feasibility of inverting the model to yield SBL conditions. The goals of our team are to contribute innovative measurements, analyses and models of the sea surface roughness at length scales as small as a millimeter. This characterization includes microscale and whitecap breaking waves.

The members of the research team are:

- Michael Banner, School of Mathematics, UNSW, Sydney, Australia
- Johannes Gemmrich, Physics and Astronomy, UVic, Victoria, Canada
- Russel Morison, School of Mathematics, UNSW, Sydney, Australia
- Howard Schultz, Computer Vision Laboratory, Computer Science Dept, U. Mass., Mass
- Christopher Zappa, Lamont Doherty Earth Observatory, Palisades, NY

OBJECTIVES

Nonlinear interfacial roughness elements - sharp crested waves, breaking waves as well as the foam, subsurface bubbles and spray they produce, contribute substantially to the distortion of the optical transmission through the air-sea interface. These common surface roughness features occur on a wide range of length scales, from the dominant sea state down to capillary waves. Wave breaking signatures range from large whitecaps with their residual passive foam, down to the ubiquitous centimetre scale microscale breakers that do not entrain air. There is substantial complexity in the local wind-driven sea surface roughness microstructure, as is evident in the close range image shown in our FY07 report. Traditional descriptors of sea surface roughness are scale-integrated statistical properties, such as significant wave height, mean squared slope (e.g. Cox and Munk, 1954) and breaking probability (e.g. Holthuijsen and Herbers, 1986). Subsequently, spectral characterisations of wave height, slope and curvature have been measured, providing a scale resolution into Fourier modes for these geometrical sea roughness parameters. More recently, measurements of whitecap crest length spectral density (e.g. Phillips et al, 2001, Gemmrich et al., 2008) and microscale breaker crest length spectral density (e.g. Jessup and Phadnis, 2005) have been reported.

Our effort seeks to provide a more comprehensive description of the physical and optical roughness of the sea surface. We will achieve this by implementing a comprehensive sea surface roughness

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observational 'module' within the RaDyO field program to provide optimal coverage of the fundamental optical distortion processes associated with the air-sea interface. Within our innovative complementary data gathering, analysis and modeling effort, we will pursue both spectral and phase-resolved perspectives. These will contribute directly towards refining the representation of surface wave distortion in present air-sea interfacial optical transmission models.

APPROACH

I am working within the larger team (listed above) measuring and characterizing the surface roughness. We build substantially on our accumulated expertise in sea surface processes and air-sea interaction. The group plans to contribute the following components to the primary sea surface roughness data gathering effort in RaDyO (see Figure 1):

- <u>polarization camera measurements</u> of the sea surface slope topography, down to capillary wave scales, of an approximately 1m x 1m patch of the sea surface, captured at video rates. [Schultz]

- <u>co-located and synchronous orthogonal 75 Hz linear scanning laser altimeter</u> data to provide spatio-temporal properties of the wave height field (resolved to O(0.5m) wavelengths) [Banner, Morison]

- <u>high resolution video imagery</u> to record whitecap data, from two cameras, close range and broad field [Gemmrich]

- <u>fast response, infrared imagery</u> to quantify properties of the microscale breakers, and surface layer kinematics and vorticity [Zappa]

- <u>sonic anemometer</u> to characterize the near-surface wind speed and wind stress [Zappa]

Our envisaged data analysis effort will include: detailed analyses of the slope field topography; laser altimeter wave height and large scale wave slope data; statistical distributions of whitecap crest length density in different scale bands of propagation speed and similarly for the microscale breakers, as functions of the wind speed/stress and the underlying dominant sea state. Our contributions to the modeling effort will focus on using RaDyO data to refine the sea surface roughness transfer function. This comprises the representation of nonlinearity and breaking surface wave effects including bubbles, passive foam, active whitecap cover and spray, as well as microscale breakers.

WORK COMPLETED

Our effort in FY08 has been primarily in the detailed planning and execution of the suite of sea surface roughness measurements conducted during the 2 field experiments in FY08. The first experiment was conducted at the Scripps Institution of Oceanography (SIO) Pier from January 6-28, 2008 and was intended mainly as a test deployment. This was followed by instrumentation validation, refinements and the necessary logistics in preparation and execution of the RaDyO field experiment in Santa Barbara Channel during September 4-28, 2008.

I continued work on the analysis techniques for characterizing breaking crests. Routines for image rectification and detection of breaking crests have been developed.

Of major significance to our group's effort was Schultz's successful DURIP application to build a full polarization camera for use in RaDyO. Further details on progress with this development are given in the companion ONR RaDyO Annual Report by Schultz.

RESULTS

Figure 1 below shows the instrumentation deployed in the field testing phase on the Scripps Pier. I deployed 2 video visible imagery cameras. Our group also deployed two orthogonal line scanning lidars (Banner/Morison), a polarimetric (Schultz) and an infrared (Zappa) and visible (Gemmrich) imagery cameras to measure small-scale surface roughness features and breaking waves. All instrumentation was positioned on the boom so that they were nesting on a common footprint. Environmental conditions during this test deployment were rather benign and no suitable data for analysis of whitecap characteristics were obtained. However, the deployment proved valuable in refining the instrumentation for the field experiment in Santa Barbara channel onboard R/P FLIP. The same suite of instruments was deployed during the FLIP cruise. In addition, Zappa deployed an environmental monitoring system (sonic anemometer, water vapor sensor, RH/T/P probe, motion package, pyranometer, and pyrgeometer).

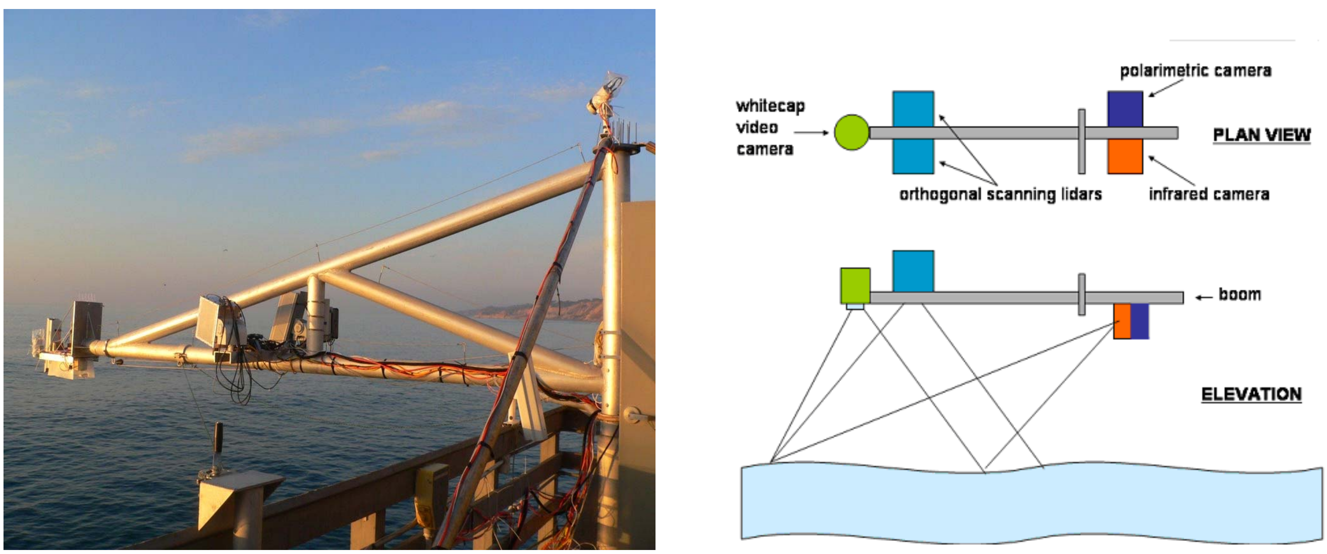

Figure 1. The left panel shows the instrumentation test set-up from the end of the Scripps Pier. The right panel shows a schematic of instrumentation packages deployed. The end of the boom was about 8m above the mean water level. The approximate field of view of the various instruments is shown. Another wide angle whitecap video camera was mounted well above the boom.

One camera was mounted on the end of the starboard boom next to the scanning lidar package. The second camera was mounted on the crow's nest to provide a wider perspective on larger scale breaking events (Figure 2-4). The individual data acquisition systems were synchronized to a common network server which allows the various data sets to be interrelated to within <0.1 seconds. In this way breaking wave properties can be related to the phase of the underlying waves.

A wide range of conditions prevailed during the field experiment in the Santa Barbara channel (September 4-28, 2008) where the wind speed U_{10} ranged from light and variable, up to 12 m/s. The scale of wave breaking ranged from micro breakers to small-scale breakers with air entrainment (Figure 2) to breaking dominant waves with up to 1.5m wave height (Figure 3-4). These data will be analysed in term of breaking crest length density, foam coverage and whitecap persistence.

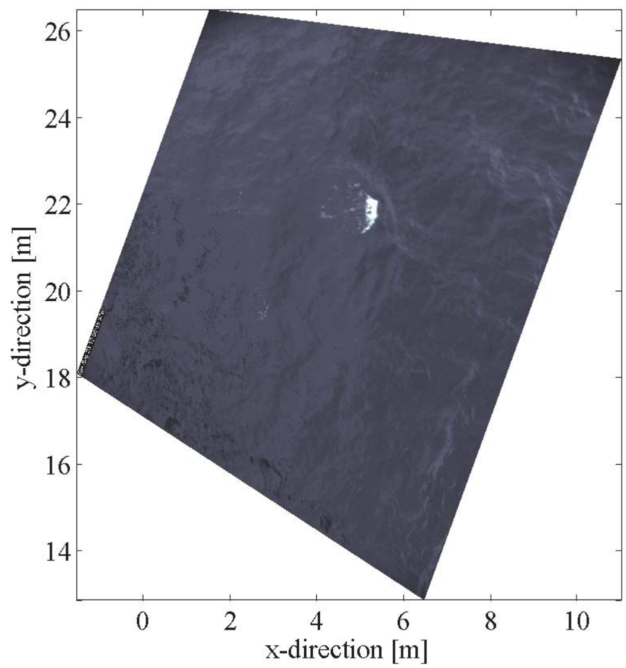

Figure 2. Small scale breaking crest observed with Camera 1, located at the end of the starboard boom, 9m above the water.

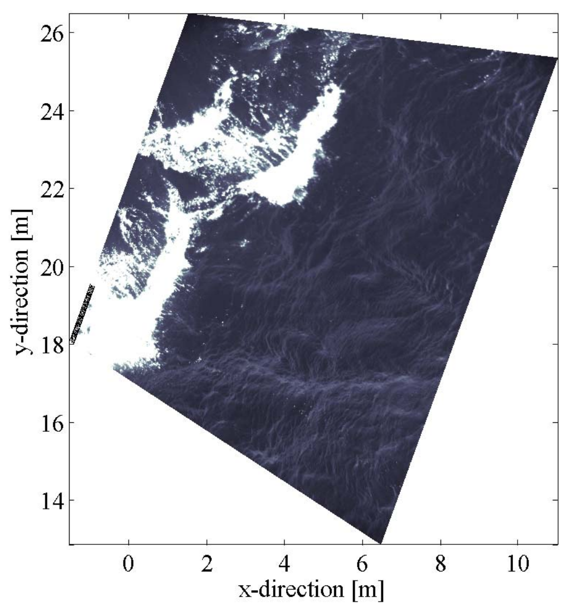

Figure 3. Large scale breaking crest observed with Camera 1, located at the end of the starboard boom, 9m above the water.

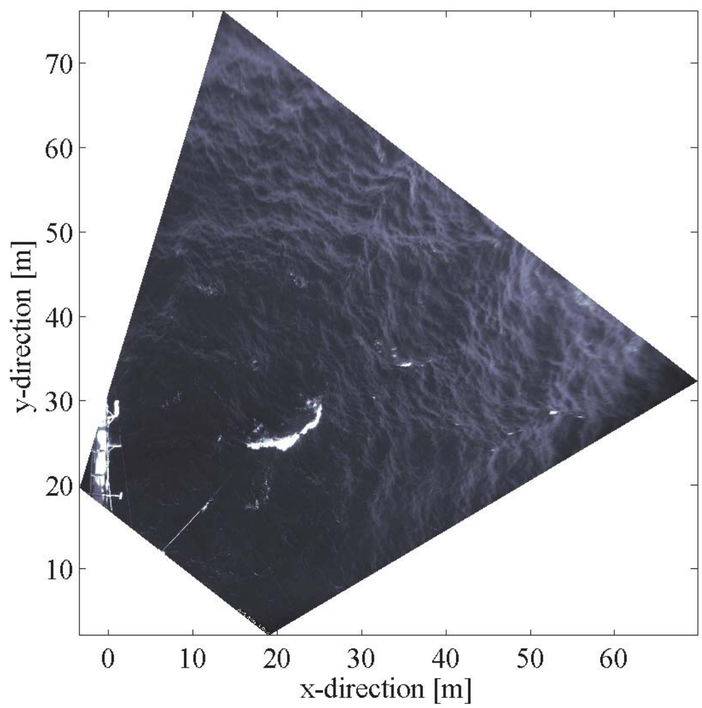

Figure 4. Large scale breaking crest observed with Camera 2, located at 26m above the water. The starboard boom can be seen partially at the left side of the image.

IMPACT/APPLICATIONS

This effort will provide a far more detailed characterization of the wind driven air-sea interface, including wave breaking (whitecaps and microscale breaking). This is needed to provide more complete parameterizations of these processes, which will improve the accuracy of ocean optical radiative transfer models and trans-interfacial image reconstruction techniques.

RELATED PROJECTS

The present project is related to the current ONR project **WAVE ENERGY DISSIPATION AND THE DISTRIBUTION OF BREAKING CRESTS**, in which Andrew Jessup (APL, UW) is the principal investigator and I am a Co-PI (via subcontract). In this project we look at breaking crest length distributions and co-located subsurface energy dissipation measurements in a strongly forced wave field in a lake and in Pudget Sound. While the wave scales in RaDyO and the lake/sound experiments are different, common aspects of the data analysis will be transferred to our RaDyO data sets.

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