Ocean Surface Wave Optical Roughness –
Innovative Measurement and Modeling

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LONG-TERM GOALS

We are part of a multi-institutional research team that is seeking to contribute innovative measurements, characterization and modeling of the sea surface optical roughness. This includes microscale and whitecapping breaking waves, and foam cover, in addition to ocean waves of many scales. The long term goals are to enhance present knowledge of the time-dependent oceanic radiance distribution in relation to the above dynamic sea surface boundary layer features. These new findings would then be incorporated into a composite radiance-based radiative transfer model with a surface wave model, and the coupled model results validated with field observations. The feasibility of inverting the coupled model to yield information on the surface boundary layer is an allied goal. Due to the untimely passing of Dr. Tanos Elfouhaily, his role has been taken on by Dr. Bertrand Chapron, RSMAS, University of Miami, Miami and IFREMER, Brest, France

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

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range from large whitecaps with their residual passive foam, down to the ubiquitous centimeter scale microscale breakers that do not entrain air. Figure 1 illustrates the typical complexity of the wind-driven sea surface roughness microstructure. Traditional descriptors of sea surface roughness are scale-integrated statistical properties, such as significant wave height, mean squared slope (eg. Cox and Munk, 1954), 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 (eg. Phillips et al, 2001, Gemmrich, 2005) and microscale breaker crest length spectral density (eg. 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 observational 'module' within the RADYO field program to provide optimal coverage of 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.

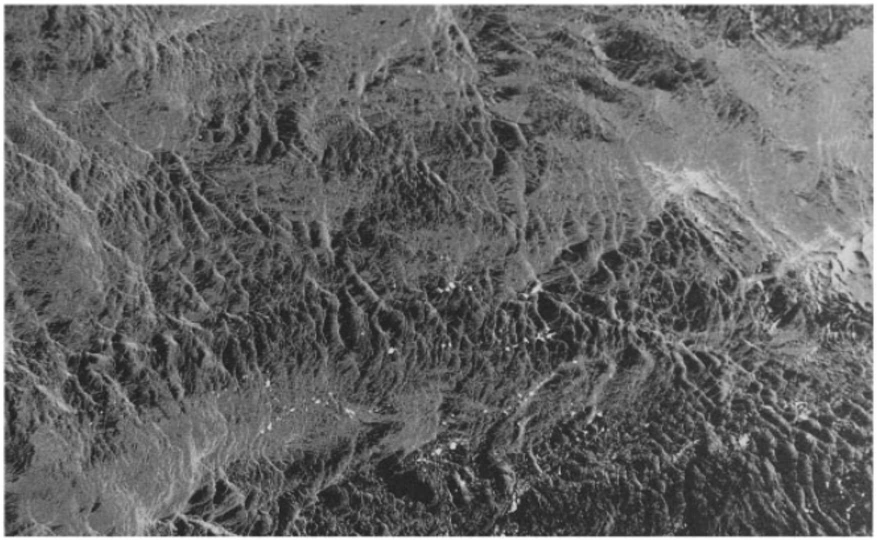

Figure 1. Image of the fine structure of the sea surface roughness, taken during 12 m/sec winds (blowing from top left to lower right) and 3m significant wave height. The field of view is 4m x 2.6m.

APPROACH

We will build substantially on our accumulated expertise in sea surface processes and air-sea interaction. We are working within the larger team (listed previously) measuring the surface roughness. Between us, the group plans to contribute the following components to the primary sea surface roughness data gathering effort in RaDyO:

- <u>stereophotogrammetric determination</u> of sea surface topography, for both large scale and small-scale wave fields

- co-located orthogonal 75 Hz linear scanning laser altimeter data to provide spatio-temporal properties of the wave height field (resolved to O(0.5m) wavelengths)

- high resolution video to record whitecap data, from two cameras, close range and broad field

- fast response, infrared imagery to quantify properties of the microscale breakers, and surface layer kinematics and vorticity

- sonic anemometer to characterize the near-surface wind speed and wind stress

- polarimetric camera to capture surface normal fields down to capillary wave scales at video rates.

Our envisaged data analysis effort will include detailed analyses of the stereographic topography and laser altimeter/scanning altimeter wave height data, statistical distribution 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 the 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 role in FY06 has been primarily in the detailed planning of the suite of sea surface roughness measurements that we will undertake during FY07-09, the instrumentation needed to make these measurements and the initial development of new techniques to characterize the various roughness features. We participated in the two intensive FY06 planning meetings at URI in November 2005 and Scripps (UCSD) in April 2006.

We also conducted an initial field test of a laser scanning altimeter from the USACE Duck Pier Facility in October, 05 and validated an analysis methodology for automated digital photogrammetric analysis of sea surface stereo imagery, gathered during the observational field study of Banner et al (1989).

Members of the group (Zappa, Schultz and Banner) also conducted a pilot study to evaluate the potential of polarimetric imaging system to provide accurate surface slope topography of the sea surface This effort is summarized in a companion ONR Annual Report by Zappa et al.

In collaboration with our former colleague, the late Dr.Tony Elfouhaily, we began developing an analysis package for characterizing surface roughness. This approach seeks a robust ‘individual wave’ decomposition capability so that local physical roughness elements can be detected and characterized along with their space-time phasing, thereby overcoming the classical Fourier spectrum issue of bound versus free wave contributions in assessing true physical sea surface roughness. This work will continue from FY07 with the recent addition of Dr. Bertrand Chapron to the group.

RESULTS

(a) Validation of 'large-scale' stereo photogrammetry

Analysis of the results obtained in Figure 2 indicated that we could recover local elevation as least as accurately as a trained human observer operating an analog stereo image reader. We were able to conclude that this technique should be viable for recording larger scale wave roughness and its time variation, especially under conditions when cloud cover is present.

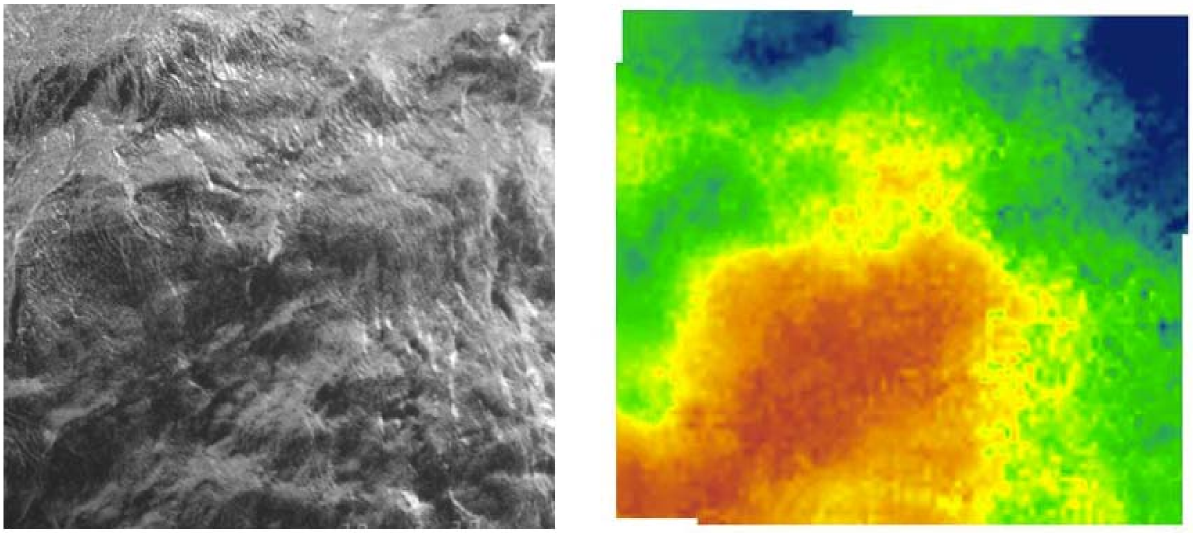

Figure 2. Left hand stereo image (left panel) and automated algorithm reconstruction of sea surface topography (right panel) for a 3m x 3m patch of sea surface taken from an open ocean platform. The wind speed was approx. 12 m/s. The color coding is from red (high) to blue (low), representing an absolute height range of 335 mm across the image. The background mean slope has not been removed from the reconstructed topography.

(b) Surface roughness analysis

In the data analysis, additional to state-of-the-art Fourier (e.g. Elfouhaily et al, 2003) and wavelet techniques, we investigated a novel riding wave analysis (RWA), presently under development. This approach provides an 'individual wave' decomposition capability so that local physical roughness elements can be detected and characterized along with their space-time phasing, thereby overcoming

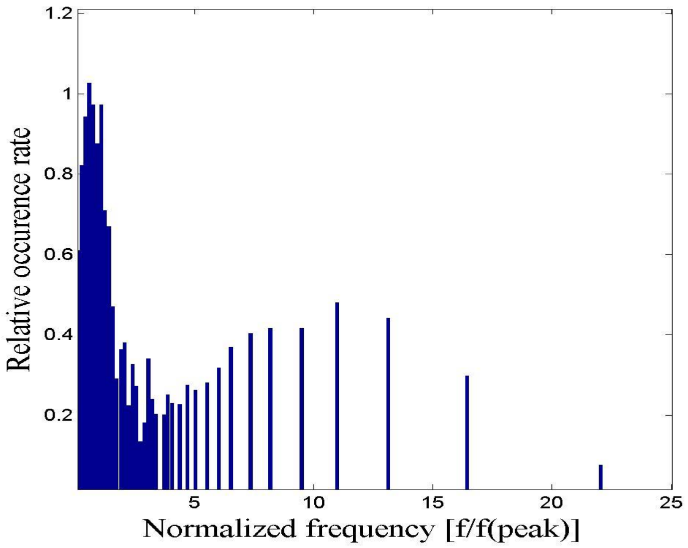

Figure 3. Riding wave analysis histogram showing the relative occurrence rate of different physical wave roughness scales for wave wire surface data. The horizontal axis is shown in terms of the local frequency relative to the dominant wave frequency. The windspeed U_{10} was about 11m/s. This clearly shows the bimodal nature of the sea surface roughness element distribution for different scales.

the classical Fourier spectrum issue of bound versus free wave contributions in assessing true physical sea surface roughness.

Figure 3 shows a histogram of the counts of actual physical roughness elements compared to the number of Fourier modes, against the center frequency of the analysis bins normalized by the spectral peak frequency of the wind sea. The wave wire data is from the North Sea, under 11 m/s wind forcing.

IMPACT/APPLICATIONS

A more detailed characterization of the wind driven air-sea interface, including wave breaking (whitecaps and microscale breaking) is needed to provide more accurate parameterizations of these processes for radiative transfer models and trans-interfacial image reconstruction techniques. The improved parameterizations will improve the precision of the

RELATED PROJECTS

The present project is related generically to our current ONR sea surface wave project in the CBLAST Hurricane DRI entitled: ‘Wave breaking influence in a coupled model of the atmosphere-ocean wave boundary layers under very high wind conditions’. While the wind speed regimes in RaDyO and CBLAST Hurricanes are very different, common elements in these two projects include the need to better understand and parameterize the breaking process and how it occurs at the different wave scales.

Our CBLAST effort has resulted in a capability for forecasting wave breaking of the dominant waves. These forecasts validate well at moderate wind speeds of around 12 m/s. Validation of hurricane breaking waves awaits the data processing by other PIs within the CBLAST project. Our effort has also highlighted the need to better understand breaking at the shorter scales, where the breaker frequency statistics appear to fall off towards shorter scales. However, balancing wind input to short waves with breaker dissipation rate, present modeling suggests that short wave breaking statistics should increase towards shorter scales. We are planning to revisit this issue with the new insights that our RaDyO datasets will provide.

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