A Direct Simulation-Based Study of Radiance in A Dynamic Ocean

PIs: Dick K.P. Yue (MIT) & Lian Shen (JHU)
Co-PI: Yuming Liu (MIT); Researcher: Kelli Hendrickson (MIT)

We develop direct simulation/physics-based forward and inverse capabilities for radiance prediction in a dynamic ocean environment. At low wind speeds, the radiance in the upper ocean is governed by the dynamics of nonlinear capillary-gravity waves (CGW); the free-surface turbulence (FST) and resultant surface roughness; and the radiative transfer (RT). As wind speeds increase, the physical process is further complicated by wind stress, steep breaking waves (SBW), bubble generation and transport, and scattering of radiance by bubble clouds. The direct simulation-based model we propose includes and integrates these relevant dynamical processes in the upper ocean surface boundary layer (SBL) into a physics-based computational prediction and inverse capability for the time-dependent radiative transport. At successive stages of the development, the RT capability will incorporate phenomenological models, direct-simulations, and closure modeling and parameterizations of the different processes at different/disparate scales.

We obtain the nonlinear evolution of a three-dimensional CGW field (length scale~O(100m)) including nonlinear gravity-gravity and gravity-capillary wave interactions using high-resolution phase-resolved direct wavefield simulations. Additional small-scale surface roughness due to FST (length scale~O(10m)) in the presence of the wavefield is obtained using direct numerical simulations (DNS) and large-eddy simulation (LES) of the turbulent flow together with large-wave simulation (LWS) of surface waves. Effects of surfactants on the CGW and on the FST can be included directly. For higher wind speeds, the effect of wind stresses are incorporated into the CGW and FST computations and the SBW dynamics (length scale~O(1m)) are modeled and estimated using a novel levelset-based interface capturing method. The bubble source is estimated from measurement data or SBW dynamics, and the subsequent bubble transport (length scale~O(10m)) is obtained using direct simulations. These coordinated methods provide a more realistic environment for the RT equations, with the use of best estimated or measured inherent optical properties.

The combined capability we develop provides direct forward predictions of the radiance distributions in the upper ocean. This capability can be used for understanding the basic features and dependencies of oceanic radiance on the wave environment, to provide guidance and cross-calibration for field measurements, and to validate and benchmark existing and new theories. Significantly, the proposed direct simulation also provides a framework, in conjunction with sensed radiance data, for the optimal reconstruction of salient features of the ocean surface (and possible disturbances creating these) and the above water scene.

This direct simulation-based study is intended as a relatively small but essential part of the overall coordinated basic research effort involving field measurement, laboratory experiment, and theoretical modeling to obtain the understanding of time-dependent oceanic radiance distribution in relation to dynamic SBL processes. This research paves the way for comprehensive investigation and inverse modeling of more complex SBL processes associated with natural and man-made events.