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Analyses of characteristic surface signatures on numerically-simulated wind-driven gravity-capillary waves

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An image-processing technique, employing empirical mode decomposition and physical-based combination algorithm, is developed to extract the distinct surface signatures attributed to various flow processes governing interfacial scalar transfer, including gravity waves, capillary ripples, Langmuir cells and quasi-streamwise turbulent eddies. The combination strategy is based on the characteristic length scales and directionalities of the signatures induced by the responsible flow processes. The image-processing technique is applied to analyze surface imageries, including temperature, gas flux, velocities and roughness, computed from direct numerical simulation of wind-driven gravity-capillary waves and the underlying turbulent flow. The analyses reveal two major findings: First, quasi-streamwise vortices, which arise from the turbulent shear layer, dominated the contribution to interfacial signatures at low wind speeds (surface shear velocity of water $u^* < 0.3$ m/s). For gravity-capillary waves under immediate wind condition (0.3 m/s $< u^* <$ 0.7 m/s), the contribution partitions to interfacial gas flux and thermal variance by the four flow processes are of the same order of magnitude; capillary ripples contribute to the minimum. Second, high correlation between the distributions of temperature and gas flux is observed (correlation coefficient $\approx$ 0.8 to 0.9), indicating that the spatial and temporal distribution of the surface thermal image is a good proxy tracer of interfacial gas flux. Decomposed images induced by various flow processes reveal that this high correlation is prevailed by the streaky signatures attributed to Langmuir cells and quasi-streamwise turbulent eddies.

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