Geophysical Research Abstracts
Vol. 13, EGU2011-13139, 2011
EGU General Assembly 2011

On the impact of macroscale wave-current dynamics in the interfacial exchange processes

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For slightly soluble, nonreactive gases, the transfer processes across the air-water interface are controlled by the aqueous-phase hydrodynamics in the vicinity of the interface. In the ocean boundary layer, the interactions between shear-currents induced by wind and gravity waves play an important role in developing and evolving the turbulence underneath. To study the turbulent structures induced by wave-current interactions, a three-dimensional, hydrodynamical, wind-driven, turbulent boundary-layer flow numerical model is carried out (Tsai and Hung 2007). This mathematical modeling resolves an incompressible and Newtonian flow field which is governed by Navier-Stokes equations and the continuity equation. The simulation domain is bounded by the periodic boundaries in the horizontal directions, a fully-nonlinear free-surface on the top, and a free-slip boundary at the bottom. The evolution of a gravity-capillary wave in wavelength 7.5 cm with the initial steepness 0.25 is performed. A normal wind forcing with an average magnitude of 0.6 dyne/cm2 and a wind-shear stress with an average magnitude of 1.64 dyne/cm2 act on the surface continuously. We assume that these forces approximately represent the momentum input from air into water at a wind speed of 4.8 cm/s at a reference height of 20 cm. The formation of along-wind vortex pairs associated with the nonlinear interaction between the surface wave and shear-current induced by wind shear are observed in the simulation results. In this study, the heat is treated as a passive scalar tracer and the temperature field is resolved by solving a convection-diffusion transport equation simultaneously with the instant velocity field. The temperature structure is shown to be well-correlated with the along-wind vortex-pairs structure; which infers that the transfer mechanism is highly dependent on the wave-current interaction.

We apply the eddy-renewal model (Hara et al. 2007) by specifying the along-wind vortex-pairs as the dominant eddies to estimate two important parameters: the bulk temperature and the interfacial flux. A validation of the model is conduced from the simulated temperature data. It shows that the turbulent-convection effect on transport has the same order of magnitude as the diffusivsity effect in the thin boundary layer. Moreover, the different depths of the bulk field in between upwellings and downwellings reveal a possible enhancing exchange mechanism.

Reference:

Hara, T., E. Vanlnwegen, J. Wendelbo, C. S. Garbe, U. Schimpf, B. Jaehne and N. Frew (2007), Estimation of air-sea gas and heat flux from infrared imagery based on near surface turbulence models, An experimental study on gas transfer at water surfaces, Transport at the Air-Sea Interface – Measurements, Models and Parametrizations. (Eds. C. S. Garbe, R. A. Handler & B. Jaehne), Springer-Verlag, 241-254.

Tsai, W. T. and L. P. Hung (2007), Three-dimensional modeling of small-scale processes in the upper boundary layer bounded by a dynamic ocean surface, J. Geophys. Res., 112, C02019.