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Wave-current interaction process in sea surface boundary layer considering wave breaking in deep and shallow water

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The interaction between air and sea is one of the most complicated problems that can not be described in an exact and direct mathematical form due to interplay of several multiple-scale stochastic phenomena. Numerous researches in theoretical, experimental, and numerical approaches on air-sea interaction have been performed in terms of exchanging heat, momentum and water through the air-sea interface. On the long term, the convergence and divergence of oceanic heat transport provide source and sinks of heat for the atmosphere and partly responsible for the mean climate of the Earth. In large and long-term scale air-sea interactions, the understanding on how much the atmosphere and ocean influence each other is the key subject. On the other hand, the air-sea interaction process in small and short-term scale occurs quickly due to a turbulent nature of mechanical motions at sea surface layer. Waves at air-sea interface are a medium for momentum transfer from wind to those mechanical motions at sea surface layer.

Understanding on these air-sea interaction processes and implementation of such interaction model is very important in improvements of wave and current prediction, calculation of heat and water exchange, and turbulent mixing, material transport and many other applications. Recent researches on air-sea interaction using a coupled atmosphere-ocean model or a coupled wind-wave-current model consider it through a heat and water mass exchange, and a momentum transfer between air and sea. In most of numerical studies on air-sea interaction, the momentum transfer from wind waves to surface current is only considered in deep water through wave energy dissipation by whitecapping.

Due to the wave instability and breaking, some part of dissipated wave energy is generating turbulence in sea surface layer in both deep and shallow water. These intensive small scale motions are important in many applications dealing with air bubbles entrainment, vertical mixing of admixtures, heat and gas exchange, and many others. Here we assume the all dissipated wave energy is used for turbulent production in sea surface layer and for generating or enhancing the large scale motions such as currents. Therefore, the rest of the dissipated wave energy by wave breaking is changed into momentum to generate or enhance currents. Wave breaking phenomena considered in this study is whitecapping dominant in deep water and depth-induced wave breaking dominant in shallow water. Whitecapping mainly depends on the wave steepness whereas wave breaking in shallow water depends on water depth. Thus, wind wave energy dissipation due to whitecapping in deep water affects the upper layer of water column while the transformed momentum from dissipated wave energy due to depth-induced wave breaking in shallow water may have influence on the state of the entire water column.

In this study, we focus on the air-sea interaction, particularly the wind wave and currents interaction process of momentum, in deep and shallow water with consideration of turbulence production by wave breaking. We also introduce a new method to consider the role of depth-induced wave breaking in shallow water separately from the whitecapping in deep water. In addition, dissipation coefficients are introduced to take into account the turbulence production in sea surface layer due to wave breaking both in deep and shallow water.