Project Summary

Intellectual Merit: Present bulk parameterizations of air-sea momentum fluxes used in most hurricane research and forecast models are based on extrapolation from field measurements in much weaker wind regimes, predicting monotonic increase of the exchange coefficients with wind speed. However, recent observational, theoretical, and experimental results demonstrate that air-sea momentum flux at high wind conditions strongly depends on the wave field and that the drag coefficient ceases to increase or even decreases at very high winds. These apparent inconsistencies may cause significant underestimation of the surface winds for storms of hurricane intensity (<980 mb) in the national hurricane forecast model (GFDL/URI coupled hurricane-ocean model) predictions.

Recently, the PIs of this proposal have developed a coupled wave-wind (CWW) model, which provides surface momentum fluxes that are consistent with recent observations. The model explicitly calculates the wave-induced stress and resulting drag coefficient for any given wave fields, even for complex seas driven by hurricanes. Numerical experiments using the CWW model clearly indicate that the behavior of momentum flux, especially its dependence on the wave age, at high wind speeds is completely different from that at weak wind speeds and that the momentum flux varies significantly depending on the relative position from the storm center due to influence of ocean waves. These results strongly suggest that proper estimation of momentum flux in hurricane conditions can be only achieved by incorporating an ocean wave model and a wave boundary model to the existing hurricane-ocean model.

We hypothesize that: (1) Surface momentum fluxes in hurricane conditions strongly depend on the ocean wave fields varying in time and space. The effect of breaking waves is significant under hurricane conditions. Momentum fluxes in hurricane conditions can be predicted accurately only if we use the CWW model including the breaking effect. (2) Hurricane intensity and maximum wind predictions are significantly influenced by the parameterization of the air-sea momentum flux. In particular, the spatial/temporal variability of the drag coefficient has major influence on the predictions. Therefore, the coupling of the CWW model to the GFDL/URI hurricane-ocean forecast model would lead to a systematic improvement on the forecast skill of hurricane intensity and wind structure.

To test these hypotheses, we set four specific objectives: (1) to incorporate the breaking wave effect in our CWW model, (2) to develop a coupled wind-wave-ocean hurricane prediction model by combining the CWW model and the GFDL/URI hurricane-ocean model, (3) to investigate how new flux parameterizations including surface wave effects affect hurricane intensity, track, and wind structure predictions using both idealized and real tropical storms, and (4) to compare the model results with existing and newly obtained experimental data in collaboration with scientists involved in the ONR CBLAST program and Korean Ocean Research Development Institute (KORDI).

Broader impacts: The broader impacts of the proposed work are evident in four areas: (1) The proposed work provides a basis for understanding how surface waves affect air-sea fluxes in high wind conditions and how the modified fluxes consequently impact hurricane predictions. Estimation of fluxes over sea surface is one of the most crucial issues in ocean and atmospheric modeling, including tropical cyclone and storm surge modeling. One of the main uncertainties regarding the flux parameterizations is the effect of ocean surface waves. (2) This research addresses social needs to mitigate and prevent possible natural hazards caused by hurricane-generated extreme wind, waves, and rain. The accurate forecast will lead to advance warning and preparation for potential hazards that mitigate damages of property and loss of lives. (3) The project involves the education and training of a graduate student, hence, contributes to the training of a new generation of scientists familiar with state-of-the-art environmental modeling. The student will learn both numerical techniques and theoretical approaches to estimate surface fluxes and to apply the results to hurricane predictions. (4) The proposed work promotes international cooperation by using hurricane-observing tower data from KORDI and in turn providing new air-sea modeling techniques to KORDI. The data from the tower will be brought to investigate the air-sea fluxes at high wind speeds and their impact on tropical cyclone predictions through the collaboration with KORDI.