Physics-based Parameterizations of Air-sea Fluxes at High Winds
Extension of CBLAST

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LONG-TERM GOALS

The long term goal of this project is to provide a new set of parameterizations of air-sea fluxes, which can be used as boundary conditions for high-resolution numerical models of ocean, atmosphere, and coupled ocean/atmosphere systems. The new parameterizations will be constructed based on physical processes of the exchange of mass, momentum, heat, moisture, energy at the interface between the ocean and the atmosphere, and will be valid for the whole range of wind speeds.

OBJECTIVES

We will extend the ongoing CBLAST studies by focusing on the following two areas:

* We will continue the basic study of the wave boundary layer. We will complete the inclusion of surface wave breaking effects on airflow. Specifically, two new physical processes will be included in the model:
- momentum and energy flux into breaking waves due to the form drag of breaking crests
- effect of spatial sheltering of shorter waves due to flow separation behind longer breaking waves.
We will investigate how different surface wave fields affect air-sea momentum flux and scalar (heat, humidity) fluxes across the wave boundary layer.

* We will validate our coupled WBL/WW3 model by simulating the wave field under hurricanes observed during the CBLAST field programs and comparing the model results and available observational data. We will compare the directional surface wave spectrum from our model against direct SRA observations. We will compare the drag coefficient from our model against direct observations from aircraft.

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APPROACH

The purpose of the new wave boundary layer (WBL) model is to predict the neutral drag coefficient for given 10-meter wind speed vector, surface wave spectrum, and breaking wave statistics. We have developed such a model without including the breaking wave effects (Hara and Belcher, 2004; Moon et al., 2004). Here, the model will be extended to include the effect of enhanced form drag by breaking waves as well as the effect of airflow separation due to breaking waves. If the breaking wave effects are set to be zero in the new model, it becomes identical to the existing nonbreaking model. The new wave boundary layer model will be constructed based on the following three components: (1) spatial sheltering due to air flow separation behind breaking wave crests, (2) conservation of momentum inside the wave boundary layer, (3) conservation of energy inside the wave boundary layer.

Coupling between the new WBL model and the WAVEWATCH III (WW3) model is made as described by Moon et al. (2004). Specifically, the spectrum near the peak is explicitly calculated using the WW3 model and the high frequency (tail) part is parameterized using the equilibrium wave spectrum model as described in 3.1. The resulting complete wave spectrum is then used to estimate the roughness length and the neutral drag coefficient.

We will investigate the wave spectrum and the roughness length (or neutral drag coefficient) under five Hurricanes - Fabian (2003), Isabel (2003), Frances (2004), Ivan (2004), and Jeanne (2004) - investigated during the CBLAST experiment and validate our model results against observations. In order to create more realistic wind forcing for the WBL/WW3 coupled model, we will also develop a new method of generating wind fields in hurricanes by blending the HRD winds and the message-based wind fields.

These tasks will be carried out by a graduate student under the supervision of the three PIs.

WORK COMPLETED

We have made progress in developing the new wave boundary layer model including the breaking wave effects. As a first step we examined a limiting condition where the wind input to breaking waves is much larger than the input to nonbreaking waves. A coupled model of breaking wave statistics, wind stress, and mean wind profile was developed under such conditions. A manuscript based on this model has been submitted for publication in Journal of Physical Oceanography (Kukulka et al., 2006).

RESULTS

Coupled equations are derived governing the turbulent stress, wind speed, and the breaking wave distribution (total breaking crest length per unit surface area as a function of wave number), based on the assumption that in the equilibrium range of surface wave spectra the wind stress is dominated by the form drag of breaking waves. It is assumed that smaller scale breaking waves are sheltered from wind forcing if they are in airflow separation regions of longer breaking waves (spatial sheltering effect). Without this spatial sheltering, exact analytic solutions are obtained; with spatial sheltering asymptotic solutions for small and large scale breakers are derived. In both cases, the breaking wave distribution approaches a constant value for large wave numbers (small-scale breakers). For low wave numbers, the breaking distribution strongly increases with wind forcing. If the equilibrium range model is extended to the spectral peak, the model yields the normalized roughness length (Charnock coefficient) of growing seas, which increases with wave age and is roughly consistent with earlier laboratory observations (Figure 1). Model results suggest that the wind stress over fully developed seas is not dominated by the form drag of breaking waves.

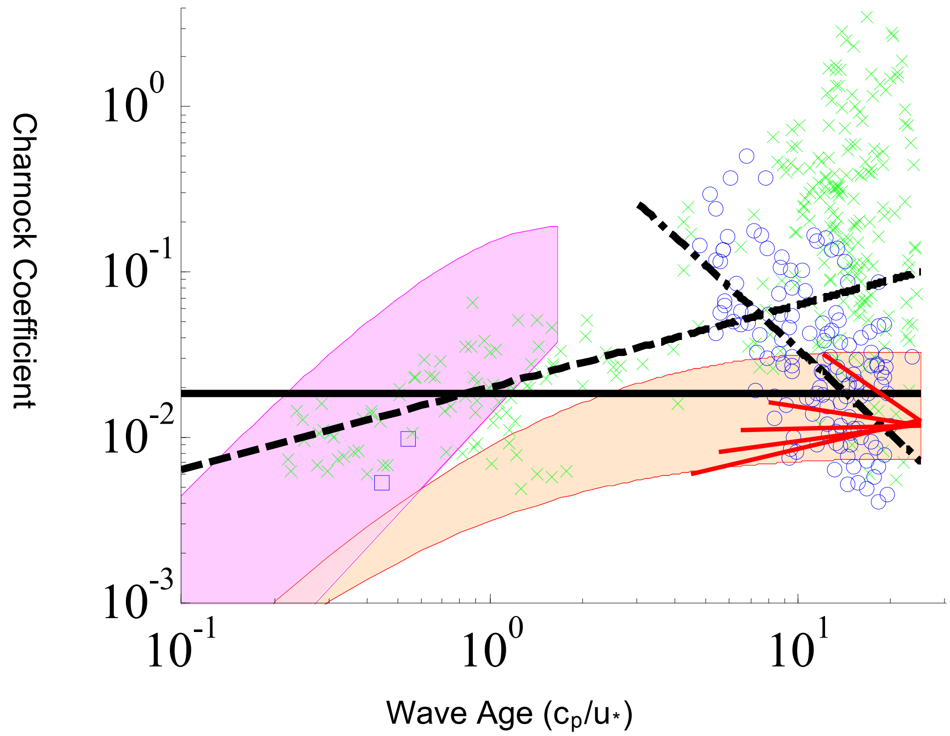

Figure 1: Nondimensional roughness length (Charnock coefficient) versus wave age. Pink area is the range of results with breaking waves only (THIS STUDY). Red area is the range of results with nonbreaking waves only. Red lines are results with wind speed 10, 20, 30, 40, 50 m/s from top to bottom (from Moon et al 2004). Dashed line and dash dot line are empirical estimates by Toba et al. (1990) and Drennan et al. (2003), respectively. Green crosses are data compiled by Toba and Ebuchi (1991). Blue circles are field data from Drennan et al. (2003). Blue squares are laboratory data from Donelan et al. (2004).

IMPACT/APPLICATIONS

This program of work promises a one dimensional (1d) model of the atmospheric and oceanic boundary layers in the vicinity of the air-sea interface that accounts for both breaking and non-breaking waves. The model will, given the ten meter wind speed, temperature and humidity and surface wave parameters, produce wave breaking statistics, wind and current profiles, fluxes and flux profiles and the turbulent kinetic energy budgets through the 1d air and water wave boundary layers. These results may be used as a basis for any future modeling efforts of ocean-atmosphere interaction processes.

RELATED PROJECTS

TH has a NSF(OCE) project (2005-2008) to validate and improve the new wave boundary layer model including breaking wave effects against laboratory observations performed at University of Miami.

New knowledge gained from our study is being incorporated in coupled atmosphere-wave-ocean numerical models under a NSF(ATM) project (2004-2007) by IG and TH. Current numerical wave models are not capable of predicting accurately short wind waves at frequencies much higher than the spectral peak. Instead they patch a parameterized form of spectra. More accurate information about short wind wave spectra and their breaking statistics resulting from this study will improve the accuracy of the numerical wave prediction and will thus enhance the performance of coupled numerical models.

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PUBLICATIONS

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