Geophysical Research Abstracts,
Vol. 11, EGU2009-2382-1, 2009
EGU General Assembly 2009

# Numerical simulations of coupled sea waves and boundary layer dynamics

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Wind-wave dynamic and thermodynamic interaction belongs to one of the most important problems of geophysical fluid dynamics. At present this interaction in a parameterized form is taken into account for formulation of boundary conditions in atmospheric and oceanic models, weather forecast models, coupled ocean-atmosphere climate models and wave forecasting models. However, the accuracy of this parameterization is mostly unknown. The main difficulty in experimental and theoretical investigation of small-scale ocean-atmosphere interaction is the presence of a multi-mode (and, occasionally, non- single-valued) nonstationary interface. It makes impossible many types of measurements in close vicinity of the physical surface, and highly complicates construction of numerical models. Existing approaches on the wind-wave interaction problem are based on assumptions that a wave field can be represented as superposition of linear waves whilst the process of wind-wave interaction is a superposition of elementary processes. This assumption is acceptable only for very small amplitude waves due to: (1) wave surface cannot be represented as superposition of linear waves with random phases as a result of nonlinearity leading to formation of ‘bound’ waves, focusing energy in physical space and wave breaking; (2) dynamic interactions of waves with the air (for example, long waves modify the local flow, which influences energy input into short waves, while short waves create local drag that affects the flow over large waves). In general, all waves “spring, burgeon and fall” in the environment provided by the entire spectrum; (3) energy input into waves of even moderate steepness is concentrated rather in physical space than in Fourier space. Hence, a Fourier image of the input is often not quite representative.

The new approach to the problem is based on coupled 2-D modeling of waves and boundary layer in joint conformal surface-following coordinates. The wave model is based on full potential equations, while an atmospheric model is based on Reynolds equations with 2nd order closing. Hundreds of long-term numerical experiments for different initial wave spectra were carried out to investigate statistical structure of the wave boundary layer (WBL) and particularly, for construction of effective beta-function, taking into account real shapes of waves, occasional separation of boundary layer and the effect of parameterized wave breaking. Naturally, beta-function determined in such a way, has a wide scatter, however extensive statistics allows to derive that function with high accuracy. Data on vertical distribution of spectral components of wave-produced momentum flux are used for construction of 1-D model of WBL. It is shown, that most of the momentum flux to waves is concentrated in a high wave number part of spectrum where dispersion relation is actually not valid. Wind waves form rough surface, so all of the momentum flux is absorbed by waves, while local tangent stress is negligibly small. The approach allows to investigate WBL structure for arbitrary wind conditions and wave spectra. It is shown that wide scatter for drag coefficient can be easily explained by different wave conditions. For example, decrease of effective surface roughness at storm winds can be explained by dumping of high-frequency waves by foam.