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Subgrid modeling of moveable-bed bottom friction in wind wave models [1]

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Abstract

A subgrid moveable-bed bottom friction model is developed for use in large-scale wind wave models. This model defines a representative bottom roughness based on the local application of a discontinuous roughness model and a statistical description of depth, sediment and wave parameters for a finite area within the model (i.e., a grid box). The model reproduces the discontinuous attenuation behavior of swell in conditions of initial ripple formation as predicted by a small-scale model. It furthermore suppresses non-physical oscillations of swell energy and unrealistically strong dependencies of depth-limited wave heights on sediment parameters. An alternative interpretation of the model explains the (continuous) transition between the no-ripple and ripple regimes as sometimes observed in nature.

1. Introduction

In the modeling of wind-waves in shallow water, bottom-friction plays an important role (e.g., Shemdin et al., 1978; SWIM Group, 1985). The hydrodynamics of bottom friction for wind waves are fairly well understood (e.g., Weber, 1991). Modeling bottom friction, however, is complicated by interactions between waves and sediment. Wave–sediment interactions manifest as ripple formation and as apparent roughness related to sheet flow of sediment in the wave boundary layer. Ripple formation can have a dramatic effect on the bottom roughness length scale k_N (Nikuradse equivalent sand grain roughness); the roughness can range from skin friction with $k_N = O(10^{-4}\ \mathrm{m})$, to well developed ripples with $k_N = O(10^{-1}\ \mathrm{m})$. This large range of possible roughnesses qualitatively explains the large range of decay scales and friction factors observed for swell (Shemdin et al., 1978). A moveable-bed roughness model has been available for over a decade (Grant and Madsen,

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1982). Although this model appears to be well established in the sediment transport community, its has been implemented (to the knowledge of the present author) in a wave model only once (Graber and Madsen, 1988).

Recently, Tolman (1994) assessed the potential effects of moveable-bed roughness for wind waves using a modified version of the Grant and Madsen roughness model. By analyzing spatial decay scales of the wave field, Tolman has shown that moveable-bed roughness and initial ripple formation are potentially important for swell propagation in shelf seas away from the shore [that is, where horizontal scales of the bathymetry are O(10 km) or larger]. In such conditions, the roughness is governed by the decay rate of the wave field, as will be illustrated in section 2. Moveable-bed effects are not expected to dominate severely depth-limited wind seas, because such wave conditions usually result in vigorous near-bottom wave motion. Bed forms then are washed out and roughnesses are generally small and exhibit limited variability.

Tolman (1994) advocates a subgrid approach when a moveable-bed roughness model is implemented in a large-scale wave model because (i) the spatial decay scales for swell in conditions of initial ripple formation are generally not resolved by wave models, and because (ii) a single roughness might not be representative for an entire grid box in conditions of initial ripple formation. Note that subgrid modeling is not expected to be relevant for severely depth-limited wind seas, as the corresponding roughness regimes are generally far removed from the discontinuity of the roughness model. However, initial ripple formation does result in large changes of the roughness for mildly depth-limited wind seas, where subgrid modeling might influence model behavior.

The present paper addresses subgrid modeling of moveable-bed bottom friction. The starting point is the hydrodynamic model of Madsen et al. (1988) and a modified version of the roughness model of Grant and Madsen (1982) as used by Tolman (1994) (see section 2). This model is shown to result in quasi-random behavior in space, if the required depth and sediment parameters are described with minimal random variability. In section 3 and in the Appendix a statistical subgrid model is derived. In section 4 this model is applied successfully to an idealized swell case and to an idealized case of depth-limited wave growth. The latter case indicates that a subgrid approach is necessary to avoid nonphysical behavior of a wave model for mildly depth-limited wind seas. In section 5 the application of the present subgrid approach to other moveable-bed roughness parameterizations, and the smooth transition between the no-ripple and ripple regimes as observed by Amos et al. (1988) are discussed.

2. Moveable-bed bottom friction

The (local) bottom-friction source term used in the present study consists of the hydrodynamic model of Madsen et al. (1988) and a modified version of the roughness model of Grant and Madsen (1982) as defined by Tolman (1994).

The hydrodynamic model relates a bottom-friction source term S_b to the corresponding two-dimensional spectrum F. This spectrum can be either the wavenumber spectrum $F(k)$, the wavenumber-direction spectrum $F(k,\theta)$, or the frequency-direction spectrum $F(f,\theta)$.

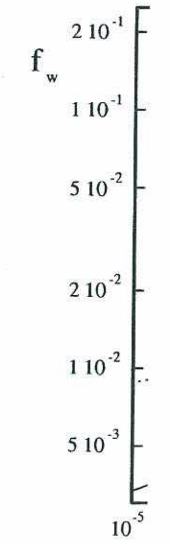

Fig. 1. The friction fact
function of the relative

$$S_b = -f_w u_r \frac{}{2g}$$

$$f_w = \frac{}{Ker^2(2\sqrt{}}$$

$$\varsigma_0 = \frac{1}{21.2\kappa\sqrt{f_w}}$$

$$u_r = \left(\frac{2\omega^2}{\sinh^2 kd}\right.$$

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$$\psi = \frac{f_w' u_r^2}{2(s-1)g}$$

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