Wave-current interaction in morphological change on a barred beach

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Abstract

Current effect on waves (CEW) is examined for formation of rip channel systems with a barotropic modeling framework. The model consists of an Eulerian phase-averaged shallow water equation based on a vortex-force formalism, WKB ray equations, and a bed evolution equation with the Soulsby-Van Rijn's total sediment flux formula. CEW acts on reducing the offshore extent of seaward rip currents through wave refraction on the currents, leading to modifying the budget of sediment flux and associated surf-zone topography. Inclusion of CEW results in shoaling rip channels, deepening offshore mounds, and elongating alongshore spacing of rip channels with normal incidence of offshore waves.

Keywords - wave-current interaction , rip channel, sediment transport

1 Introduction

Recently, Garnier *et al.* (2008) showed a self-organization of rip channel systems arising from the deformation of a longshore bar by using a barotropic wave-current interaction model with sediment transport. However, they did not properly consider the effects of CEW. Kaida and Uchiyama (2012) found that CEW is responsible for reducing the offshore extent of rip currents through the wave refraction by currents that changes momentum balance substantially. Therefore, we anticipate that the morphological evolution of rip channel may change with or without CEW. In the present study, we demonstrate a self-organization of rip channel systems arising from the deformation of a longshore bar by a phase-averaged barotropic numerical model with sediment transport with an attention paid to the influence of CEW. We then quantitatively examine the modulation associated with CEW on morphological evolution of rip channel influenced by wave, current and sediment flux.

2 Numerical Model

In the present study, the model relies mainly on a novel mathematical framework by Uchiyama *et al.* (2009) based on the multi-scale asymptotic theory of an Euler wave-averaged vortex force formalism (McWilliams *et al*., 2004), accounting for the two-way mutual interaction between waves and currents around the surf zone. The hydrodynamic model consists of the shallow-water equation for slowly-evolving Eulerian phase-averaged mass and momentum conservation. The wave model is based on WKB ray equations for spectrum-peak waves, consisting of a wave action density conservation equation and a wavenumber conservation equation along with the linear dispersion relation. The sediment transport model is composed of the depth-integrated horizontal sediment flux **q** based on the total (*i.e.*, suspended and bed) load model (Soulsby and Van Rijn, described in Soulsby, 1997) and the divergence of the horizontal sediment transport.

$$\mathbf{q} = \alpha\left\{\left(\mathbf{u} + \mathbf{u}^{st}\right) - \gamma\left|\mathbf{u}_b\right|\nabla z_b\right\} \tag{1}$$

$$\beta\frac{\partial z_b}{\partial t} + \nabla\mathbf{q} = 0 \tag{2}$$

where β is an acceleration factor (= 100) to enhance the much slower temporal evolution of the morphological process than that of the current and wave fields.

3 Result

3.1 Mobile Bed Experiment

The first result is from the mobile bed cases where the initial topography (**Fig. 1**) is set to be alongshore uniform. The size of the domain is chosen to be 384 m (x) × 2048 m (y) with an anisotropic rectangular grid spacing of dx = 4 m and dy = 8 m. The imposed offshore wave condition is normal incidence with H_{rms} = 1.0 m (H_{rms}: the RMS wave height) and the peak wave period of 10 s. A grid-size (4 × 8 m) bottom perturbation z_{b} (z_{b}: upward bed level perturbation measured from the initial resting depth h) is placed at (x, y) = (48, 1024) m with a height of 10 cm as a "seed" of instability on the topographic model day 5 (the hydrodynamic model hour 72) when alongshore-uniform waves and littoral currents are fully developed. The present model successfully demonstrates that an alongshore-uniform barred topography evolves into a rhythmic rip channel system through intrinsic instability triggered by the small topographic disturbance. Normal incidence of waves result in (nearly) steady rip channels, whereas alongshore topography migration occurs with retaining the rip channels under obliquely incident waves (not shown). CEW is found to be responsible for widening the rip channel spacing and reducing sediment load in the offshore of the rip channels, attributed to a noticeably different rip channel system from that without CEW (**Fig. 2**). The

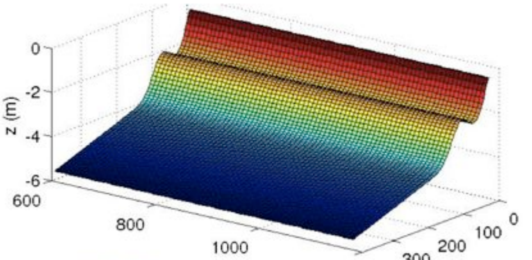

Fig. 1: Initial topography of an alongshore-uniform single barred beach mimicking a sandy beach in Duck, NC. The bar crest is located at x = 80 m.

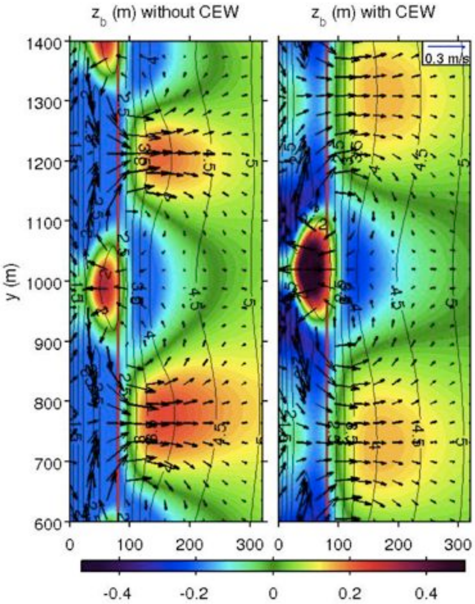

Fig. 2: Modeled topography on the topographic model day 100 reaching a quasi-steady state. Left: without CEW, right: with CEW. Color: perturbation topography z_b where positive and negative values correspond to accretion and erosion, contours: bottom topography $h^* = h - z_b$, and vectors: barotropic Eulerian velocity.

alongshore wavelength of the rip channel spacing is estimated to be 400 m without CEW whereas 500 m with CEW.

3.2 Immobile Bed Experiment

We then make use of the steady-state rip channel topography (**Fig.2** left) frozen (immobile) for a comparative twin experiment with and without CEW, in order to examine effects of CEW on the rip channel formation on the identical topography. Since waves and currents are modulated by CEW, a resultant sediment flux imbalance occurs for the case with CEW. The sediment flux divergence shows that the steady-state rip channel topography without CEW to change asymptotically towards that with CEW (**Fig.3**). Since the alongshore sediment flux at x = 120 (m) is found to be largely dominated by the transport term (**Fig.4**) and $\mathbf{u} >> \mathbf{u}^{st}$ (not shown), the associated morphology is considerably controlled by the wave-driven Eulerian velocity **u**, that is modulated by CEW. In order to determine causes of the change in **u**, we diagnose a momentum budget in a simplified manner. Amplified wave height near the bar crest in the rip channels and wave ray bending (refraction) by currents through CEW lead to an increase of breaker wave dissipation and a change in pressure gradient force through modified wave set-up/down distribution. All these modification by CEW act to attenuate the offshore extent of the rip currents, resulting in reduction of the offshore sediment transport and widening the rip channel spacing. This result is consistent with the findings in Kaida and Uchiyama (2012).

4 Conclusion

Inclusion of CEW results in shoaling rip channels, deepening offshore mounds, and elongating alongshore spacing of rip channels with normal incidence of offshore waves. There is a strong correlation between the sediment flux and the nearshore currents affected by CEW. The topographic change estimated from the sediment flux divergence show that the steady-state rip channel topography without CEW tends to change towards that with CEW.

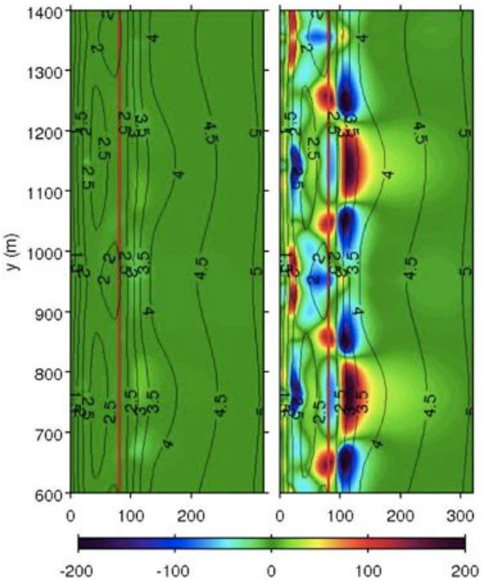

Fig. 3: Sediment flux divergence on the steady-state rip channel topography without CEW (same as **Fig.2** left). Left: without CEW, right: with CEW. Color: sediment flux divergence (red indicates erosion while blue is accretion), contours: bottom topography h^*.

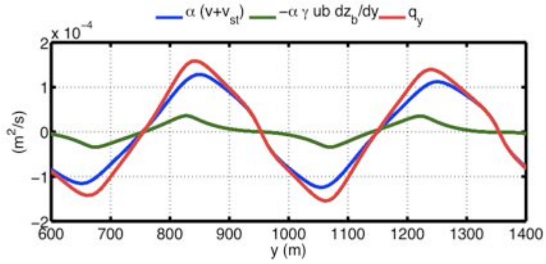

Fig. 4: Terms in the alongshore sediment flux (1) at x = 120 m. Red line: alongshore total sediment flux, blue line: transport term (the first LHS term), green line: downslope term (the second LHS term).

Acknowledgements

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