Three-dimensional transient rip currents: Effects of topography on low-frequency motions

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Abstract. Alongshore shear instability associated with longshore currents driven by obliquely incident waves, and normal mode instability of offshore-directed rip currents under a near-normal incident wave condition are analyzed with the ROMS-WEC model (Uchiyama *et al.*, 2010). The coupled wave-current model successfully reproduces 3-D shear waves during the SandyDuck field measurement. Rip current-induced coherent eddies (surf eddies) are generated ubiquitously on a surveyed beach topography, having significant depth-dependency that leads to faster decay of enstrophy and kinetic energy than 2-D surf eddies. VLFs (very low frequency motions) are excited with a steady wave forcing either with the 3-D or 2-D models. The feedback mechanism of current effects on wave (CEW) is found to be essential to impel the VLF-EKE (eddy kinetic energy) shoreward. Alongshore irregularity in the beach topography is responsible for enhancing the shore-confined VLF-EKE substantially.

Keywords: rip current, topography, VLFs, the ROMS-WEC model, CEW, shear instability

1. Introduction

Surf zones act as a barrier between inner-shelf and shoreline by wave-driven 3-D littoral currents. However, the barriers are occasionally collapsed by offshore-headed rip currents and associated lateral circulation known as rip cells (e.g., Bowen *et al.*, 1969). Offshore eruption of rip currents occurs rather intermittently, leading to the VLFs (very low-frequency motions) at periods longer than 300 seconds. Randomness and groups in the imposed irregular waves are considered to be candidates causing the VLFs that are principally confined near the shore according to the field measurements (Reniers *et al.*, 2007). In turn, Uchiyama and McWiiliams (2011) demonstrated that turbulent rip currents readily develop on a realistic topography forced by steady wave forcing with a 3D wave-driven circulation model based on ROMS (Regional Oceanic Modeling System) tightly coupled with a WKB spectrum-peak wave model (ROMS-WEC; Uchiyama *et al.*, 2010). The present study aims at investigating the contradiction between the two studies by using the ROMS-WEC model. We view wave refraction on ambient currents (CEW), three-dimensionality of rip currents, and complexity

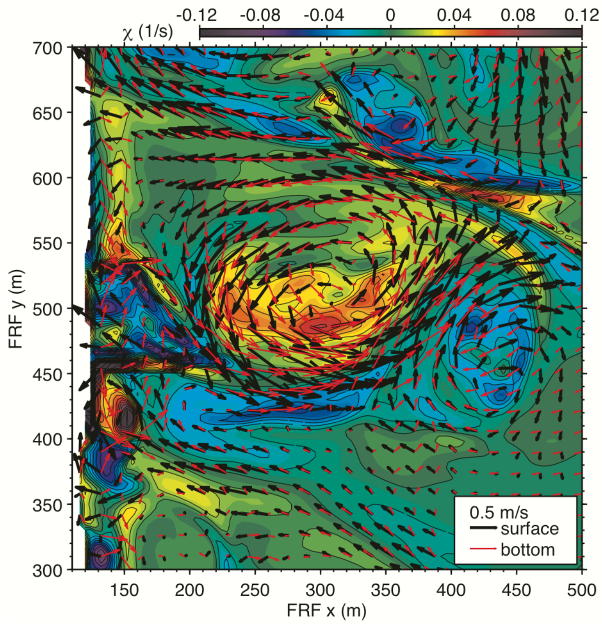

Figure 1 Plan view plot of instantaneous snap shot of the 3-D rip cells on a surveyed beach topography at Duck, NC, USA, 218 minutes after the initialization. Velocity vectors (black: near the surface, red: near the bed) on barotropic relative vorticity (colored contours) .

of beach topography as key players that attribute to the shore-confined VLF variability. Therefore we carry out series of comparative, 2-D and 3-D littoral current simulations under steady offshore wave forcing on the surveyed topographies.

2. Results and summary

Following the pioneering work done by Uchiyama and McWilliams (2011), two surf zone problems on a realistic topography are analyzed in the present study. One is shear instability associated with longshore currents driven by obliquely incident waves (e.g., Uchiyama *et al*., 2009), and the other is normal mode instability of offshore-directed rip currents under a near-normal incident wave condition (e.g., Weir *et al*., 2011; see **Fig. 1**). The ROMS-WEC model successfully reproduces 3-D shear waves during the SandyDuck field measurement campaign. They found in 3-D rip-induced coherent eddies (hereinafter referred to as *surf eddies*) that littoral currents have significant depth-dependency leading to vorticity stretching and titling effects and to faster decay of enstrophy and kinetic energy than 2-D surf eddies.

Subsequently, we pay particular attentions to effects of inclusion of CEW and randomness of the topography. CEW is found to be of inevitable importance in refractive wave ray bending that induces attenuation of the offshore extent of rip currents (Yu and Slinn, 2003), impelling the VLF eddy kinetic energy (EKE) much to the shore. Irregularity of the bottom topography is then systematically examined by introducing a parameter that control alongshore-topographic variability. The more the alongshore irregularity is taken into account, the more the surf eddy kinetic energy emerges. The present findings have a pronounced impact on changing our insight and understanding of the mechanisms for the VLF pulsation associated with wave-driven currents.

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