Surfzone-inner shelf interaction analyzed with a quintuple nested high resolution ocean model

Hideki Kaida [1] and Yusuke Uchiyama [1]

[1] Department of Civil Engineering, Kobe University, Japan

Abstract

Observational studies have recently rediscovered that littoral currents play a crutial role in the interaction between surfzone and inner shelf (*e.g.*, Lentz *et al.*, 2008). A synoptic, detailed numerical experiment is conducted to pursue this problem with a multi-nested coupling system consisting of ROMS-WEC (Uchiyama *et al*., 2010), SWAN and WRF at horizontal resolutions down to 20 m. Both the Eulerian and Lagrangian analyses clearly indicate that wave-driven three-dimensional currents significantly enhance horizontal and vertical mixing and dispersion. Lagrangian particle tracking exhibits that rip currents and undertows induce vertical secondary flow that plunges those particles downwards beyond the pycnocline, leading to markedly increased initial dilution and thus much faster relative dispersion tendency.

Keywords – Surfzone-shelf interaction, multiple nesting approach, atmosphere-wave-ocean coupling

1 Introduction

Recent observations have suggested that wave-induced three-dimensional littoral currents are substantially important for material transport between surfzone and inner shelf (e.g., Lentz *et al*., 2008). The surfzone acts as a barrier by cross-shore vertical recirculation due to breaking wave-induced flow to form an isolated water mass called 'sticky water' (Wolanski, 1994). However, a 3-D modeling framework that solves both the littoral and inner shelf currents concurrently has not been fully established, and therefore modeling studies for the surfzone-inner shelf interaction lags behind observational ones. In the present study, we examine the surfzone-inner shelf interaction using a high resolution 3-D ocean model with wave effects based on the novel ROMS-WEC framework (Uchiyama *et al*., 2010), that relies on an Eulerian wave-averaged vortex-force formalism, at a horizontal resolution of 20 m, coupled with an operational spectral wave model SWAN and a regional atmospheric model WRF to render an atmosphere-wave-ocean interaction.

2 Numerical Model

In order to properly represent both the surfzone and inner-shelf dynamics, a quintuple nested configuration is developed with ROMS and ROMS-WEC. A winter-spring storm season at Santa Monica Bay, CA, USA, is chosen for the experiment to account for stormy rough waves. The innermost (the fifth nest) solution at a horizontal resolution of 20 m (hereinafter L5, **Fig. 1**), that enables us to consider surfzone dymanics, is used for the following analyses. The present ROMS configuration consists of five nested domains with an offline, one-way nesting technique that downscales from 5 km horizontal resolution for the U.S. West Coast (L1) to L5 domain through L2, L3 and L4 intermediate domains at 1 km, 250 m and 75 m respectively. The outermost boundary condition is provided by a global oceanic reanalysis data set, SODA 2.0.4, to convey the basin-scale oceanic signals adequately. L5 is forced by the 2-hourly averaged L4 output inclusive of tidal signals as a boundary condition projected onto the L5 perimeters in time and space.
Sea surface wind stress, heat and radiation fluxes are given by a double nested WRF downscaling result with the innermost horizontal resolution of 6 km. Surface waves are considered in ROMS-L3, L4 and L5 by an offline coupling with a triple nested SWAN solution running on the corresponding ROMS grids. The computational period for L5 is from February 2008 to April 2008 when northwesterly swells are predominant.

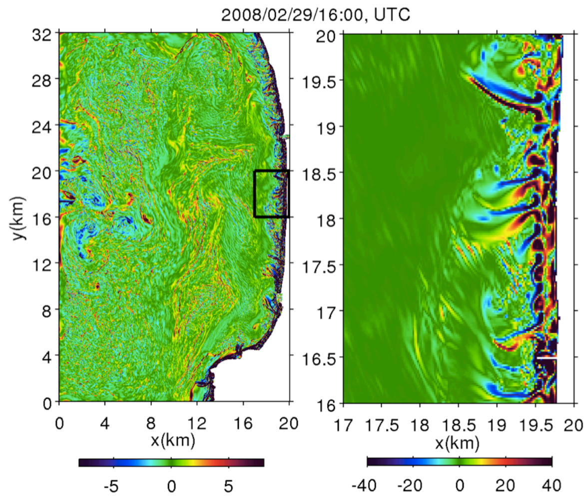

Fig. 1. Snapshot of surface normalized relative vorticity for L5. Left: full L5 model domain, right: nearshore zoom-in corresponding to the black frame in the left panel.

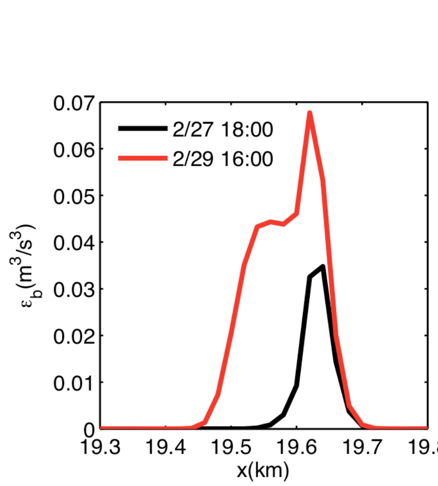

Fig. 2. Cross-shore profiles of kinematic wave dissipation rate ε_b [m^3/s^3] at y = 18 km from the L5 SWAN solution. Red line: ε_b for the strongest rip currents.

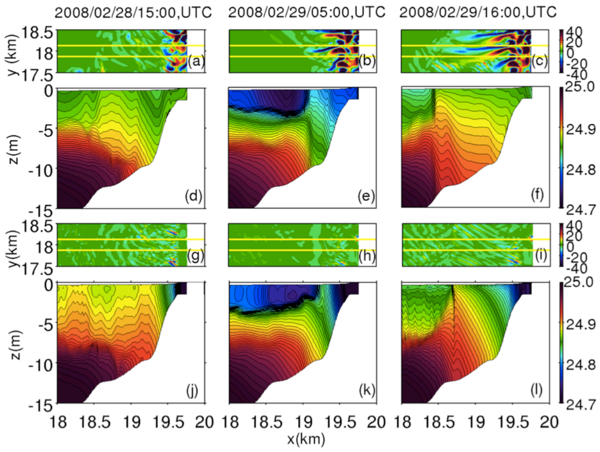

Fig. 3. Sequential plots of surface normalized relative vorticity (a-c, g-i) and density anomaly σ_t [kg/m^3] averaged alongshore within the control volume L (d-f, j-l). Panels a-f: case A (with wave breaking), panels g-l: case B (without wave breaking, *viz*., $\varepsilon_b = 0$).

Table 1 Computational configurations for three dimensional Lagrangian particle tracking experiment.

Case No.	ε_b	Particle release position and number of particles N released from each site
A1	ON	Inside the surfzone, $N = 600$
A2	ON	Outside the surfzone, $N = 1660$
B1	OFF	Inside the surfzone, $N = 600$
B2	OFF	Outside the surfzone, $N = 1660$

3 Sensitivity test with/without breaker effect

A snapshot of normalized relative vorticity in L5 shows an example of offshore-directed strong rip currents erupting from the surfzone (**Fig. 1**). These rip currents are driven by strong wave breaking on the alongshore-variable topography (**Fig.2**). We loosely define a breaking point as an interface with the maximum ε_b to consider cross-shore water/material exchange between the onshore surfzone and the offshore inner-shelf with respect to this breaking point. To quantify the contribution of wave-driven littoral currents due to wave breaking to the cross-shore material transport between them, we take an advantage of the vortex-force based ROMS-WEC. A comparative test run is carried out to eliminate only the breaker effect among the other wave effects such as vortex force and Bernoulli head, by vanishing ε_b. Case A stands for a control run where ε_b is considered, while ε_b vanishes in case B. We confirm that null ε_b is almost fully accepted in the model within a few hours after vanishing ε_b, and 4 days later case B successfully eliminates littoral currents while retaining the offshore overall flow field as compared to that for case A (not shown).

4 Eulerian view: stratification

We focus on the energetic rip event that mostly develops from 2/28 15:00 to 2/29 16:00. A control volume L (17,875 m $\le y \le$ 18,125m) is defined to examine the alongshore-averaged vertical structure of water density anomaly σ_t. From a calm littoral current situation under a mild wave condition to an early stage of development of the rip currents (left and middle panels in **Fig. 3**), deep dense water is brought up to the surface in both cases. When rip currents develop (right panel in **Fig. 3**), most of the lighter water mass still remains near the shoreline in case B, although it disappears in the surfzone in case A. This suggests that the barrier structure around the surfzone is more easily destroyed through cross-shore mixing between the surfzone and the offshore enhanced by the rip currents. In other words, wave-induced cross-shore currents diminish the isolated water mass formed around the surfzone.

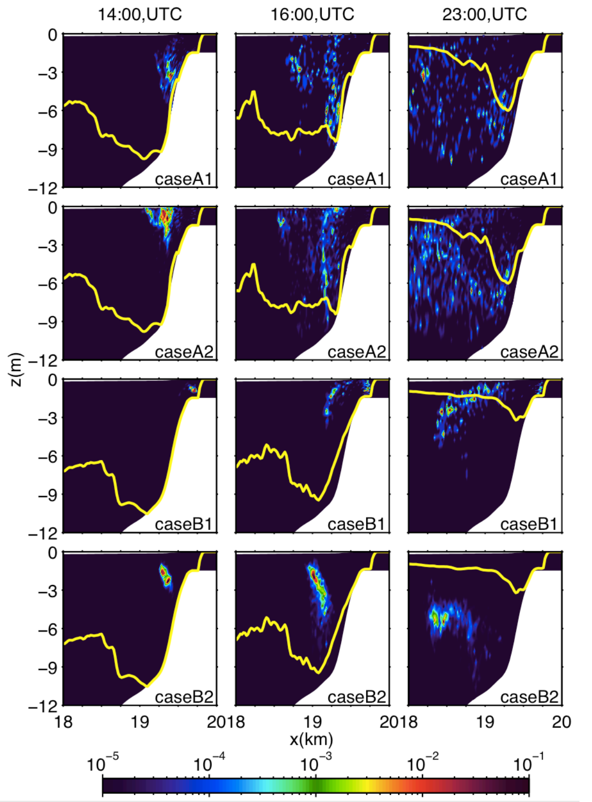

Fig. 4. Temporal evolution of alongshore integrated Lagrangian PDFs of the particles on 2/28/2008. Left: 1 hour, middle: 3 hours, right: 10 hours after the release. Yellow curves in each panel indicate the KPP-estimated surface boundary (mixed) layer depth.

5 Lagrangian view: particle tracking

An offline, 3-D Lagrangian passive particle tracking using the simulated L5 flow field is conducted to assess effects of littoral currents on cross-shore mixing and dispersal. Among several different cases we have conducted, four typical cases for the duration of the strongest rip currents are presented as listed in **Table 1**. In cases A1 and B1, all the particles are released in the surfzone. Alongshore-integrated Lagrangian PDF in **Fig. 4** illustrates that littoral currents transport the particles laterally to finally dilute out of the surfzone for case A1, whereas some particles remain in the surfzone if ε_b vanishes (case B1). The particles released in the offshore (cases A2 and B2) behave differently, while littoral currents bring them back to the surfzone due to horizontally circulating littoral cell structure with a substantial influence of the vertical shear associated with 3-D littoral currents. As a consequent, littoral currents have a pronounced impact on enhancing the cross-shore dispersion of the particles, consistently with the Eulerian result in Sec. 4.

References

[1] Letnz, S. J., M. Fewings, P. Howd, J. Fredericks, and K. Hathaway, Observations and a model of undertow over the inner continental shelf., J. Phys. Oceanogr, Vol.38, pp.2341-2357, 2008.

[2] Uchiyama,Y., J. C. McWilliams and A.F. Shchepetkin, Wave-current interaction in an oceanic circulation model with a vortex force formalism: Application to the surf zone, Ocean Modell., Vol. 34:1-2, pp. 16-35, 2010.

[3] Wolanski, E., *Physical Oceanographic Processes of the Great Barrier Reef,* CRC Press, Boca Raton, Florida, 194 pp, 1994.