Final Reports
For

Award #N0014-07-1-0556

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Title: Linking the Surf Zone and Inner Shelf: Cross-shore Transportation Mechanisms

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Final Technical Report

Linking the Surf Zone and Inner Shelf: Cross-shore Transport Mechanisms

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RSMAS Award Number: (N000140710556)

LONG-TERM GOALS

The long-term goals are to understand surf zone processes, in particular cross-shore exchange related to rip current systems through field observations and numerical modeling. Rip currents occur commonly on most beaches and dominate many. It is recognized that beaches with straight and parallel contours are not a stable morphologic configuration, whereas more complex beaches, which support the existence of rip current morphology, are stable and more common.

OBJECTIVES

The research objectives of the proposed work are two-fold. The first is associated with obtaining new observations of the cross-shore exchange between the surf zone and the inner shelf that utilize a suite of *in situ* and Lagrangian measurement systems. The second applies a numerical model (Delft3D) to evaluate the mechanisms responsible for the cross-shore exchange and relate the complex flow dynamics of the rip current system and its interaction with the surface wave field and bottom topography to the observations.

The specific experimental objectives are to observe:

1) the vertical structure of the flow from surf zone to inner shelf at the mean and very low frequency band(VLF, 0.0005-0.004Hz)
2) the propagation of surface drifters deployed in the rip currents just outside of the surf zone under a wide range of environmental conditions
3) the (re-) entering of surface drifters initially present on the inner-shelf into the surf zone

The specific numerical objectives are to evaluate:

4) The vertical flow model description at the wave-group scale from surf zone to inner shelf comparing with the Eulerian in-situ observations
5) The Stokes drift contribution to the modeled Lagrangian surface flow from surfzone to inner shelf using both Eulerian and Lagrangian observations
6) The description of the processes responsible for the cross-shore exchange between surfzone and inner shelf for a wide range of environmental conditions.

APPROACH

We (MacMahan, Reniers, Thornton, Swick, Brown, & Gallagher) conducted a Rip current EXchange experiment, REX, at Sand City, Monterey Bay, CA in May 2009. A combination of *in situ* Eulerian measurements, remote sensing techniques, and Lagrangian measurements were deployed. The Eulerian measurements consisted of an alongshore of self-contained ADCPs were deployed slightly seaward of wave-breaking spanning a rip channel and a CTD deployed within the surf zone. The alongshore array of bottom-mounted ADCPs captures the alongshore variability in vertical flow structure within a rip channel. 40 surfzone drifters with accurate GPS-tracking were deployed for three hours for nine different days under varying wave and tidal conditions to quantify the spatial variation in mean Lagrangian flow, dispersion, and diffusion. The GPSs after post-processing have an absolute position error of < 0.4 *m* and speed errors of < 3 *cm/s* (MacMahan et al., 2009).

Concurrent numerical model predictions of the local hydrodynamic conditions were performed to help in the deployment of the surfzone drifters and the execution of jet-ski surveys. These computations are based on the transformation of deep water directional spectra to the nearshore, including the wave groups to simulate the three dimensional infragravity time scale surfzone circulations.

WORK COMPLETED

We successfully completed the experiment and deployed the ADCPs across the rip channel. We performed 9 drifter deployments under various wave, tidal, and surfzone flow conditions. We performed 5 bathymetric surveys over the course of the experiment. The data has been quality controlled and used successfully in model-data comparisons (see below) which have been published in peer reviewed journals. Additional research and model-data comparisons are ongoing.

MODELING RESULTS

The cross-shore exchange of surfzone and inner shelf is examined with Delft3D model calculations. To that end we consider (*Lagrangian coherent structures*) (LCSs), a novel dynamical systems notion (Haller, 2000), which have recently been applied to shelf-scale circulation systems (e.g. Lekien et al., 2005). Here, LCSs are computed based on model predicted surface velocities to study the effects rip current pulses associated with flow motions at the VLF time scale on the transport and fate of floating surfzone material. LCSs wholly control the motion of passively advected tracers in unsteady flows. Consequently, LCSs provide an unambiguous means of identifying rip-current pulses.

The identification of LCSs is obtained with the finite-time Lyapunov exponent (FTLEs). The FTLE gives information on the maximum expansion or contraction rate for pairs of passively advected particles (e.g. representative for the surface drifters). The FTLEs are calculated with the MANGEN software package (Lekien et al., 2005, www.mangen.org). The computed unsteady surface velocity field of the nearshore circulation at a time t0 is seeded with an initially uniformly distributed set of particles (dx = 2 m, dy = 2 m). Next the particle position at τ-t0 is determined by calculating the advection with a fourth-order Runge-Kutta-Fehlberg algorithm and a third order interpolation for τ-t0 = 10 minutes. The time integration interval is set to 10 minutes representing the VLF flow dynamics observed in the rip current circulations. Choosing a larger time scale (i.e. $\tau > O(hr)$) introduces long-term diffusion and dispersion associated with the larger scale nearshore flow circulations thereby obscuring the VLF contribution (Brown et al., 2009). Calculating the FTLEs allows for identifying repelling ($\tau > 0$) and attracting ($\tau < 0$) LCSs by maximizing ridges of the FTLE field (e.g. Shadden et al., 2006).

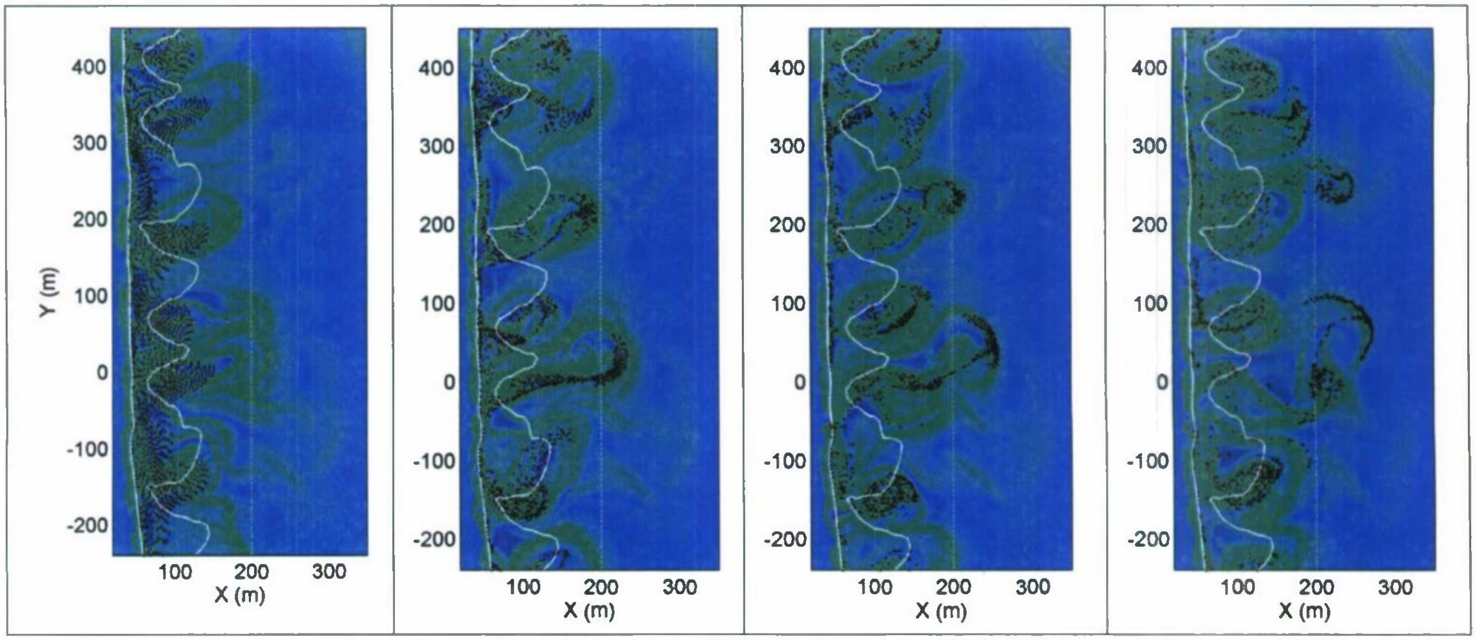

Figure 4. Snapshots of FTLE field in s^{-1} and computed drifter positions 1, 3, 5 and 9 minutes (black dots in panels 1 to 4 from left to right) after virtual drifter seeding for yearday 124 drifter field deployment displaying the time evolution of attracting LCSs associated with VLF dynamics. Initially uniformly distributed drifters quickly converge along the LCS material lines (green ridges corresponding to high FTLE values) forming narrow streaks with occasional exits from the surfzone (indicated by the dashed white line) at locations of high VLF intensity. Bottom contours at 1.5 m depth and shore line (solid white lines) given as a reference.

The computed LCSs in the nearshore display many thin layers of high FTLE-values centered loosely around a core. Each layer represents a transport barrier and as a result surface floating material, represented by the virtual drifters, is trapped between the layers moving in a circular fashion. The space between the adjacent FTLE-ridges is often very narrow, resulting in the collection of surface floating material in thin streaks. This is amply demonstrated in the rapid transition just after the deployment of the virtual drifters (compare panels 1 and 2 in Figure 4), where the initially widely distributed drifters quickly converge along the LCSs. Only in the inner core the drifters can move freely resulting in patch-like distributions (e.g. around Y = -150 m). At locations of rip currents the LCSs are elongated in the cross-shore allowing the transport of drifters offshore. Once the drifters reach the offshore extent of the LCS they can only move in the alongshore direction, thereby generally re-entering the surfzone. Only occasionally the outer LCS filaments peel off and become detached from the inner layers. If this happens at the outer surfzone, material trapped by the detaching filament(s) is transported offshore outside of the surfzone (around Y = 0 m and Y = 250 m in Figure 4) with the drifters slowly converging on the transport barrier forming a thin line (panel 4 in Figure 4). This transport barrier corresponds to the outer edge of the unsteady diverging rip flow corresponding at the time scale of the VLF-motions.

The effect of VLFs on the ejection of surfzone floating material on a rip channeled beach has been assessed by calculating LCSs within the nearshore surface velocity field obtained with a verified three dimensional wave and flow model resolving the wave group dynamics. The LCSs explain the occasional exit of surface drifters from the surfzone due to VLF motions as the outer FTLE-filaments detach from the nearshore rip circulation.

In addition, the frequently observed narrow streaks of remnant surface floating material outside of the surfzone on rip channeled beaches is explained by the closely spaced thin material transport barriers identified as ridges in the FTLE field. In contrast, the distribution of surface floating material within the surfzone can be quite patchy where drifters collect at the cores of the LCSs. Details on the modeling can be found in Reniers et al. [2009] and Reniers et al. [2010].

IMPACT/APPLICATIONS

These new observations are important for calculating the transport of surface drifters but also sediment fines, algae, bubbles and other organic matter and as a result will also impact the predictions of both water clarity and water qualitity. The observations will be further evaluated with Delft3D.

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