RCEX: Rip Current Experiment

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LONG TERM GOALS

Long term goals are to understand processes that cause the formation and maintenance of quasi-stationary rip channel / shoal systems in the surf zone. It is now recognized that this 3D configuration of the surf zone bathymetry is widespread and more representative than the simpler straight and parallel beaches that have been studied in recent years. A combination of detailed field observations and concurrent numerical modeling of he system are being used in this research.

OBJECTIVES

The research objectives of the proposed work focus on obtaining new observations of the three-dimensional structure of the rip current system utilizing a suite of *in situ* instruments with the addition of repeated deployments of a fleet of 30 inexpensive surf zone drifters to measure mean flow patterns, vorticity, dispersion, and diffusion. The second related effort applies a numerical model (Delft3D) to evaluate the dynamics of the rip current system and its interaction with the surface wave field and bottom topography. These new observations will be used to validate Delft3D and extend our understanding of rip current processes.

The specific experimental objectives are to observe:

1) vertical structure of the rip current along the axis of a rip channel

2) vertical structure of the bottom boundary layer the bed with cm vertical resolution to determine bottom boundary layer stress, effective bed roughness and sediment transport within a rip channel

3) mixing and flow patterns in the rip current cell

4) rip current pulsations and spatial variability

5) offshore extent of rip current mean flow and pulsations

6) wave-current interaction and wave breaking patterns.

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14. ABSTRACT
Long term goals are to understand processes that cause the formation and maintenance of quasi-stationary rip channel / shoal systems in the surf zone. It is now recognized that this 3D configuration of the surf zone bathymetry is widespread and more representative than the simpler straight and parallel beaches that have been studied in recent years. A combination of detailed field observations and concurrent numerical modeling of he system are being used in this research.

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The specific numerical objectives are to evaluate:

> 7) wave-current interaction and the onset of breaking within a rip current,

> 8) wave-group forcing of nearshore circulation,

> 9) vortex dynamics and lateral diffusion associated with the offshore-directed rip current jet and onshore-directed wave mass flux.

APPROACH

Our extended nearshore research group (MacMahan, Stanton, Reniers, Thornton, Gallagher, Brown, Brown, Hendriquez, Stockel, Cowen, Wycoff, and Morrison) conducted a Rip Current EXperiment, RCEX, at Sand City, Monterey Bay, CA in April-May 2007. A combination of *in situ* Eulerian measurements, remote sensing techniques, and Lagrangian measurements were deployed. The Eulerian measurements consisted of two primary arrays:

> 1) A cross-shore array of co-located pressure and digital electromagnetic current meters (PUV) and ADCPs along the axis of the rip channel. A single bottom boundary layer frame equipped with a Bistatic Coherent Doppler Velocity and Sediment Profiler (BCDVSP) and a two axis scanned altimeter was deployed mid-surf zone within the rip channel. The BCDVSP measured the 3 component velocity profiles concurrently with sediment concentration profiles with 1cm vertical resolution, while the scanned altimeter mapped bedforms surrounding the BCDVSP profile. The cross-shore array of bottom-mounted ADCP's captures the cross-shore variability in vertical structure of the currents within a representative rip channel. The cross-shore array measured the cross-shore and vertical structure of a rip current and the offshore extent of the rip current mean velocities and pulsations.

> 2) An alongshore array of digital PUV sensors equipped with Paroscientific pressure sensors was deployed spanning the rip channel . The two-axis current and pressure PUV sensors provide data for analyzing alongshore wavenumber-frequency spectra of the oscillatory flows.

> 3) Remote sensing systems consisted of 3 fixed video cameras overlooking the experiment site. The center camera could sample full resolution color images at 5 Hz allowing PIV methods to be explored, and dye releases within the surf zone to be mapped. A K-band radar provided high temporal resolution imaging of the incendent wave filed over a 1 Km range.

MacMahan deployed 30 surf zone drifters with accurate GPS-tracking were deployed for three hours for seven different days under varying wave and tidal conditions to quantify the spatial variation in mean Lagrangian flow, vorticity, dispersion, and diffusion. High resolution velocity measurements over large area are required to map the complete cell circulation of rip currents. The GPSs after post-processing have an absolute position error of < 0.3 *m* and speed errors of < 3 *cm/s*.

Reniers ran 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.

Figure (1) Deploying the Bottom Boundary Layer frame into the rip channel during RCEX, with the temporary side supports in place. The frame was supported within the channel by two poles that had previously been jetted in. The BCDVSP and scanned altimeter can be seen near the center of the cross-shore support beam

Jeff Brown (University of Delaware graduate student), Rob Wyland (NPS tech), Ron Cowen (NPS tech), Jim Lambert (NPS Tech), Jon Morrison (NPS student), Jamie MacMahan (NPS) constructed the surf zone drifters. MacMahan(NPS), Stanton(NPS), Reniers (RSMAS), Thornton(NPS), Gallagher (Franklin and Marshall), Brown, Brown, Hendriquez (Delft), Stockel (NPS tech), Cowen, Wycoff (NPS tech), and Morrison were responsible for instrument deployment, maintenance, data archiving, removal, drifter depoyments, and bathymetric surveys.

Currently, there are 5 students utilizing the dataset for Masters thesis. Two students (Jeff Brown and Jenna Brown) are from the University of Delaware and three students (Jon Morrison, Sarah Heidt, and Andrea O'Neil) from the Naval Postgraduate School. In addition Martijn Henriquez (University of Delft) will use the data obtained from the near bed observations of velocity and sediment fluxes as part for his PhD thesis to examine intra-wave sediment transport processes.

WORK COMPLETED

We successfully deployed alongshore array of PUVs and a cross-shore of ADCPs within a rip channel. Despite the extreme logistic challenge of deploying the simple bottom boundary layer frame (Figure 2) within the active rip channel with no breaks in the wave conditions, a short bottom boundary layer data set was measured over a 3 day period. The observation was truncated by an unpleasant interaction of kelp with the boundary layer frame during a strong wave event. Seven drifter deployments were made under various wave, tidal, and coastal current conditions. Five bathymetric surveys were made over the course of the experiment using both walking surveys and jet-ski altimeter/ DGPS survey methods. We are finalizing the data quality control and have begun efforts focusing experimental objectives.

Delft3D has been coupled to the global wave model Wavewatch III, where the freq. directional spectra from Wavewatch III are used as input to the embedded SWAN model within Delft3D to calculate the transformation of deep water wave conditions to the nearshore zone. The SWAN-derived nearshore wave conditions were subsequently used as input for the wave group modeling suite within Delft3D resulting in predictions of the three dimensional surfzone circulation patterns on the infragravity time scales and longer. Next the combined three dimensional Lagrangian/Eulerian flow field was extracted from the Delft3D flow computations and used to predict the dispersion of surfzone drifters (Reniers, yearly ONR report 2007).

Though the results are preliminary, the experiment was highly successful in providing many necessary observations for evaluating rip current dynamics.

RESULTS

Boundary Layer Observations

Bottom boundary layer structure was resolved with Stanton's BCDVSP and scanned altimeter over 4 tidal cycles before a strong wave system injected air bubbles across the water column severely limiting data yield from the two acoustic instruments, and subsequently "took the system out". During the observation time, the bed within the rip channel was dominated by 5-10cm high offshore migrating orbital ripples. The wave and current boundary layer are particularly interesting within the rip channel, with the largest sediment suspension events forced by the strongest shoreward bores, but with a net offshore suspended sediment flux arising from the strong offshore rip current flow. An example of the strong suspension events can be seen in the 50 second profile timeseries of the near bed velocity structure and sediment sediment levels. The very strong shoreward bore flows and unstable bedforms result in unusually strong, high concentration suspension events compared with typical surf zone conditions. This data set is being combined with similar observations made on the rip channel cell shoals during the RIPEX experiment made at the same site to analyze the differing sediment transport mechanisms dominating the cross shore transport within a rip channel and over the adjacent shoal.
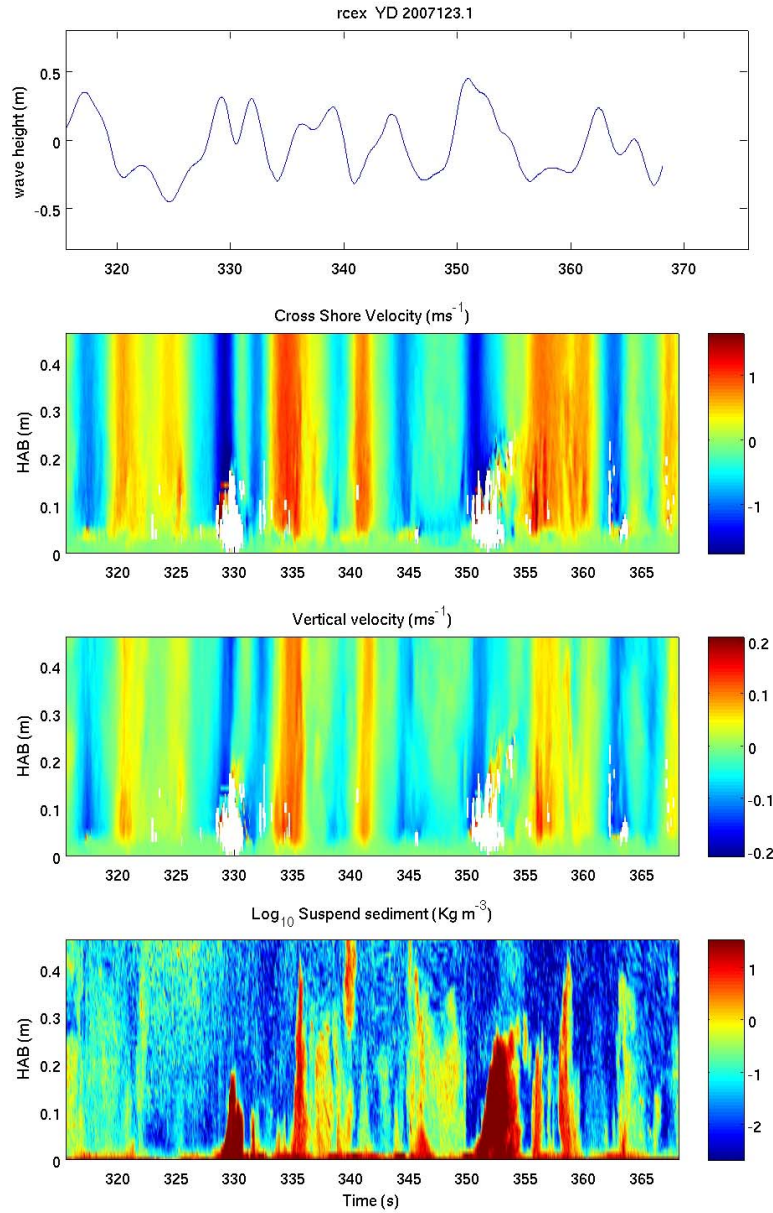
Figure 2. A 50 second sample of surface wave height, cross shore velocity profile, vertical velocity profile and log 10 ff sediment concentration profiles (top to bottom panels) measured by the BCDVSP. The very high sediment concentration plugs entrained up from the bed obscure parts of the velocity profile in the middle 2 figures due to strong scattering effects, but sediment fluxes are being calculated based on an interpolation method across these data dropouts. High apparent sediment levels between 0.3 and load

Lagrangian Observations

For the first time, the natural flow patterns of a rip current were obtained (Figure 3) using MacMahan's drifters. The common view that rip currents transport material offshore in a steady stream is not supported by the drifter observations. Instead, semi-enclosed circulation patterns are observed within

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the surf zone. In the deeper rip channel, the surf zone drifters moved quickly offshore, but instead of exiting the surf zone they turned and moved alongshore, before returning to the shoreline over the shallower shoal, closing the loop. The closed-loop pattern represents clockwise and counter-clockwise eddy circulation cells. The average time to complete a full revolution was approximately five minutes. Episodic rip current bursts caused an occasional drifter to escape the surf zone and transferred sediment and bubbles offshore, but were surprisingly infrequent (only 10% of the drifters that entered the rip currents exited the surf zone).

The onshore-directed velocities are slightly faster over the shallow-water shoal than in the rip channel. This is explained by considering a closed-loop system and conservation of mass, where the velocity of water is inversely proportional to the cross-sectional area, such that the total discharge of water remains constant. Since the rip channel is deeper than the neighboring shoals, its velocity is smaller.
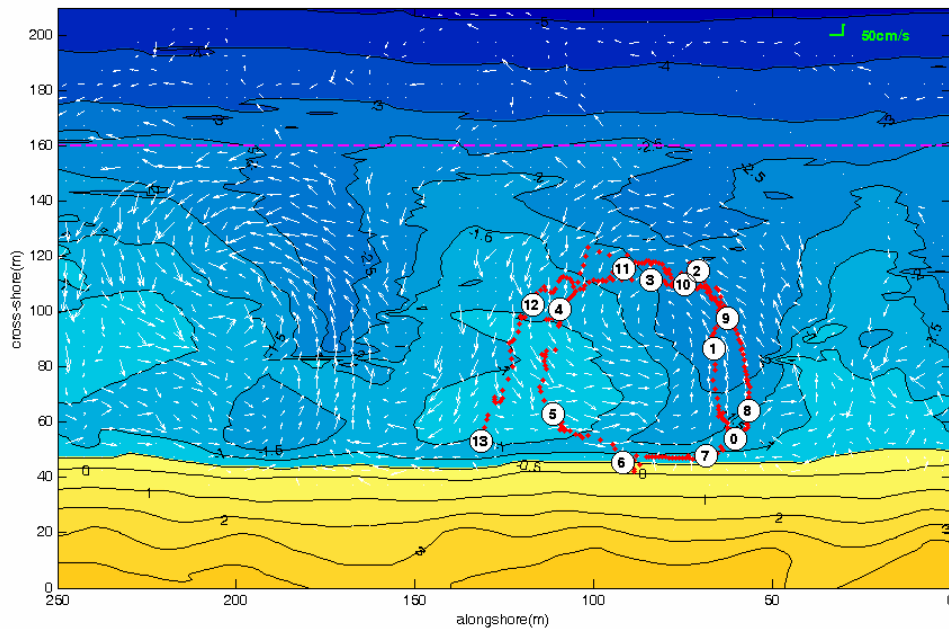

Figure 3. Three-hour and 5m-square bin averaged velocity estimates (white arrows) computed using a forward-difference scheme of positions obtained from GPSs mounted on surf zone drifters developed by MacMahan, and deployed on May 4, 2007 at Monterey Bay, CA, a natural beach with persistent rip currents. Small white dots represent 5m-square spatial bins with less than five observations. The green arrows and text in the upper right-hand corner provide vector scales. The dashed magenta line represents the cross-shore extent of the surf zone determined through time-averaged video imaging. A GPS was placed on a human (red-dotted line). The white circles on the red-dotted line with numbers represent minutes starting at zero minutes for the human drifter track. Two human track revolutions are plotted. The local bottom morphology is contoured and shaded in the background, where blue represents water and yellow represents sand.

These semi-enclosed surf zone circulation patterns have significant importance to the Navy personnel moving across the surf zone. A GPS placed onto a person moved similarly to the drifters (Figure 1). These new results suggest that if a swimmer remains calm and afloat, they will be returned to shallow

water within five minutes. However, there are times, though infrequent (10%), that they may exit the surf zone.

Owing to the large number of spatial drifter observations and the coherence between the velocity vectors, the spatial distribution of vorticity within the surf zone was estimated for the first time (Figure 2). The hot and cold colors represent the rotational direction and amplitude of vorticity.

In Situ Cross-shore Rip Current Array

We are currently evaluating the cross-shore distribution of rip current velocity, which appears to rapidly decay outside the surf zone. The vertical structure of the rip current differs significant than that of undertow, which is dependent on wave height and tidal elevation, which influence the strength of the rip current. The cross-shore shape of the vertical profile varies across the surf zone.

We are evaluating the importance of wave-current interaction with the rip channel. Preliminary results indicate that wave-current interaction may not be important, as originally hypothesized, and other factors may be responsible for time-averaged breaking patterns.

IMPACT/APPLICATIONS

The detailed spatial maps of velocity and vorticy will increase our understanding of rip current dynamics. The new observations will be compared to Delft3D model estimate. We still in the prelimary stages of data quality and data analysis.

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Website: http://www.oc.nps.navy.mil/~macmahan/RCEX_webpage