Near Shore Wave and Sediment Processes

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LONG-TERM GOALS

Long-term goals are to predict the nearshore wave-induced three-dimensional velocity field and induced sediment transport over an arbitrary bottom composed of sediments ranging from mud to coarse sand given the bathymetry, bottom type and offshore wave conditions.

OBJECTIVES

The interrelationship of wave-induced hydrodynamic and sediment processes over the vertical and morphologic processes at the bed are measured and modeled. The primary mechanism for changes in momentum flux that drive nearshore hydrodynamics is due to the dissipation by breaking waves, the processes of which are poorly understood. Bottom boundary layer measurements are obtained to determine bottom stress and dissipation. Sediment transport is measured in response to the measured alongshore and cross-shore currents, wave orbital velocities, and turbulent stresses. The small-scale morphology, which acts as the hydraulic roughness for the mean flows and perturbs the velocity-sediment fields, is measured as a function of time to examine cross- and alongshore variations. The sediment environments range from mud to coarse grain sand.

APPROACH

Process models for breaking waves, momentum mixing due to the interaction of alongshore and cross-shore vertical mean profiles, and bottom shear stress enhanced by the form drag of bedforms and by turbulence of wave breaking are compared with observations.

WORK COMPLETED

Work completed includes analysis of rip currents and their modeling for the RIPEX and NCEX experiments. A series of papers on the dynamics of rip currents were completed and are listed in the bibliography.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2006**	2. REPORT TYPE	3. DATES COVERED **00-00-2006 to 00-00-2006**
4. TITLE AND SUBTITLE **Near Shore Wave and Sediment Processes**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Postgraduate School,Oceanography Department,Monterey,CA,93943**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S)
		11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

RESULTS

A focus of our research has been to measure and predict rip current generation. We have conducted two field experiments measuring rip currents. The analysis and modeling of rip currents during the RIPEX and NCEX experiments are described in a series of papers described in the following. Field observations document the hydrodynamics of a morphologically-controlled rip currents utilizing a coherent cross- and alongshore arrays of co-located pressure and velocity sensors. During RIPEX, conducted at Sand City, California, the beach morphology was a low-tide terrace incised with quasi-periodic rip channels spaced O(125 m), representative of transverse bars. The relatively close spacing resulted in interaction between adjacent rip currents. By contrast, during the NCEX experiment at Torrey Pines, California, the morphology was a near planar beach with migrating rip currents creating subtle rip channel depressions O(1:300 slope) and separated rip current systems. Bathymetric non-uniformities directly outside the surf zone are shown to influence the kinematic non-uniformities within the surf zone, even with subtle surf zone bathymetric non-uniformities. The rip current observations at the two dissimilar beaches both showed the maximum rip current inside the surf zone with the rip current velocities decreasing rapidly offshore. The rip current velocities at mid-depth were negligible less than one surf zone width offshore. The rip currents are tidally modulated with the strongest velocities at low tide.

The results of our rip current observations and past field and laboratory experiments were synthesized in MacMahan et.al. (2006). Within the last decade, there have been a significant number of laboratory and field observations within rip current systems. An overview of rip current kinematics based on these observations and the scientific advances obtained from these efforts are synthesized. Rip current flows are partitioned into mean, infragravity, very low frequency (vorticity), and tidal contributions, and it is found that each contributes to the total. Data from the laboratory and the field suggest that the rip current increases with increasing wave energy and decreasing water depths. The maximum mean current occurs inside of the surf zone, where the maximum forcing is present owing to the dissipation of waves.

A third rip current experiment, RCEX, is planned for April-May 2007 at Sand City, California. The focus of this experiment is measuring the very low frequency (VLF) forcing of rip current systems and the vertical structure of the rip current. Analysis of the VLF vertical velocities (<0.005 Hz) during Duck 94 found show significant vertical structure in energy, phase, and rotation at low frequencies around 0.005 *Hz* not previously observed in the nearshore (Lippmann, et.al., 2006). At these low frequencies, most of the energy was associated with shear instabilities of the alongshore current. The coherence between the uppermost sensor and each successive vertically separated sensors drops off quickly with depth for both components of the flow, with as much as 70-80% coherence drop over the water column (ranging 1-3 *m* dependent on location). Additionally, the phase relative to the uppermost sensor are shown by rotary spectra to have shifts approximately linearly over depth, with as much as 50 degree phase lags from top to bottom. The bottom sensors sometimes lead and sometimes lag the surface. Spatially and vertically varying phase structure results in rotary coefficients that vary across the surf zone. The rotary coefficients are generally non-zero, indicating that these low frequency motions have rotary nature, with rotational directions (cyclonic or anti-cyclonic) and phase that depend on the position of the sensors relative to the sand bar and alongshore current profile. The non-uniform vertical structure has implications to the interpretation of field data and horizontal nearshore mixing. Similar vertical velocity structure is expected to occur with instabilities of rip currents.

1) RIPEX Experiment Results

During the RIPEX, an inverse relationship was found between sediment accreting on the transverse bar and eroding in the rip channel. The mean velocity magnitudes within the rip channel (transverse bars) increased offshore (onshore) with decreasing tidal elevations and increased with increasing sea-swell energy. Eulerian averaged flows were predominantly shoreward on the transverse bars and seaward within the rip channel throughout the experiment, resulting in a persistent cellular circulation, except during low wave energy. The rip current spacing to the rip channel width was less than or equal to two, which suggests that the rip currents are influenced by each other and that no two- dimensional bar return flow should be present. The vertical velocity profile on the bar indicated that the flow was predominantly shoreward. The flow field within the surf zone was depth uniform, except for significant shear occurring near the surface, owing to Stokes drift. The wave-induced transport hypothesis is evaluated (MacMahan et.al., 2006).

A non-linear wave model operating on the time-scale of wave groups was compared with measurements of infragravity motions during RIPEX (Reniers, et.al., 2005). The comparison considers a 20 day period during which significant changes in both the offshore wave climate and nearshore bathymetry occurred. The temporal variations in infragravity conditions during the experiment are strong, with computational results typically explaining 70 to 80 % of the observed infragravity motions within the nearshore. In contrast to the temporal variation, the alongshore spatial variation in infragavity intensity during the experiment is generally weak, even though the underlying bathymetry shows strong depth variations. This is due to the predominance of cross-shore infragravity motions, which experience only a weak coupling with the alongshore varying bathymetry.

Numerical computations (Reniers et. al., 2006) are used to explain the presence of Very Low Frequency motions (VLF's), with frequencies less than 0.004 Hz, in the rip current velocity signals observed during the RIPEX field experiment (MacMahan et.al., 2005). Observations show that the VLF-motions are most intense within the surf zone and then quickly taper off in the offshore direction. By comparing computed cross-shore and alongshore VLF-intensity distributions with observations in a qualitative sense, the most important contributions to the VLF-dynamics are established. Model computations show that VLF-velocities depend on turbulent lateral mixing where lower (higher) values of eddy viscosity yield stronger (weaker) VLF-motions. Wave-current interaction dampens the VLF-motions compared with the case without wave-current interaction. In the case without wave-current interaction, qualitatively similar results to the inclusion of wave-current interaction can be obtained utilizing an increased eddy viscosity. VLF-motions at neighboring rip-channels are seen to interact in the computations, with stronger interactions for an asymmetric rip-channel configuration. Finally, the intermittent forcing by the wave-groups is essential in obtaining the correct cross-shore VLF-intensity distribution suggesting this is the predominant mechanism responsible for the generation of the VLF-motions observed during RIPEX. Computations suggest that VLF-motions can occasionally propagate offshore but are mostly confined to the surf zone consistent with the presence of surf zone eddies. A quantitative comparison shows good correspondence between model computations and measurements, with generally increased (decreased) intensities during mean low (high) water levels.

2) NECX Experiment Results

During the NCEX experiment, morphologically controlled rip currents slowly migrated (12.5 m/day) to the south through our cross- and alongshore arrays of co-located pressure and velocity measurements, and were present for approximately 15 days (MacMahan et al., 2006). This provided an opportunity to evaluate the hydrodynamics of a rip current system. Cross-shore velocity (one-hour average) profiles along the axis of the rip current are well documented for the first time in the field. The maximum mean offshore velocity was 0.5 m/s and occurred inside of the breakpoint, hypothesized to be influenced by the roller. The velocity decreases rapidly seaward of the breakpoint less than one fourth surf zone width in distance offshore. Low frequency rip current pulsations are found forced by infragravity motions, similar to observations at RIPEX. Mode 2 edge waves were a dominant response of energy within the surf zone and have similar alongshore length scales as the rip current morphology. The infragravity rip current pulsations are minima in the vicinity of the rip current owing to the deeper channels, consistent with shallow water long wave theory. Very low frequency motions were not isolated to the vicinity of the rip current and increased during increases in sea-swell energy and low tides, with a maximum velocity occurring at the break point. VLFs are maxima in the vicinity of the rip current, and have cross-shore distributions with a maximum in the surf zone for the case of both rip currents and undertow. Rip current VLFs are hypothesized to be a combination of surf zone eddies forced by directionally spread random waves and rip current shear instabilities, as the energy is qualitatively consistent with results by Reniers et al. [2006].

High resolution bottom boundary layer instruments were deployed at the intersection of the long shore and cross shore PUV array during NCEX within the tidally modulated surf zone. Acoustic Doppler measurements of the BBL turbulence structure and sediment transport were made with 1cm vertical resolution over a 0.6m range above the bed. A scanned acoustic altimeter and a new laser-based bed mapping system showed a dominance of flat, sheet flow conditions, although significant ripple fields associated with large local bed level changes were observed in discrete events during the observations. Sediment transport models under the typically non-linear, surf-zone bores are being evaluated in on-going analyses, and the influence of wave breaking induced turbulence on sediment suspension is being studied with this data set.

An analysis of bottom roughness changes based on the cm-resolution velocity profiles during the experiment using both direct stress estimates and log-layer estimates of friction velocity and effective roughness is being made for selected higher tide sections of the data set. These field observations are being compared with measurements made using the same instruments in the large OSU wave flume during CROSSTEX. Repeated broadband wave sequences were measured just offshore of the surf zone above a natural sand beach, providing a controlled 2D version to contrast with the NCEX observations (Stanton 2006).

NCEX DATA

Complete time series (at 1 Hz) from the NPS PUVs and spectra from the offshore directional ADCP deployed at the 2003 NCEX experiment may be downloaded from the web at:
http://www.oc.nps.navy.mil/~stanton/ncex linked with http://science.whoi.edu/users/pvlab/NCEX/

These data sets are provided in ASCII text format in two separate subdirectories. The detailed file formats are described in corresponding "readme" files at the above web location. General information about the locations, sample rates, and operating times of all NPS instruments in NCEX are also provided in the file "ncex_locations_nps_metadata.txt".

IMPACT/APPLICATIONS

Transient rip currents are generated by wave groups forced by directionally spread short waves resulting in very low frequency motions, slowly propagating surf zone eddies. These surf zone eddies then act to perturb the bathymetry generating initial rip channels that trap eddies, giving a feedback to make the rip channels grow and increase the rip current strength, which determines the location of the rip currents.

TRANSITIONS

Efforts are ongoing in the transitioning of the Delft3D hydrodynamics model as an operational surf model. Testing and evaluation of the model have been completed and work to integrate the model with data fusion is being accomplished under the Beach Wizard program.

RELATED PROJECTS

Collaborative modeling and data comparisons of wave, current and morphology using Delt3D is being performed by Ad Reniers at Delft University.

Data acquired under this work is being used to test the Delft3D hydrodynamics model under the Beach Wizard program.

Field observations of BBL stress, turbulence and sediment transport from NCEX are being compared the same measurements made with more idealized 2D wave conditions in the large flume tank experiment, CROSSTEX.

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