

Unsteady Wave-Driven Circulation Cells Relevant to Rip Currents and Coastal Engineering

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LONG-TERM GOALS

The long term goals of this project are to predict waves, currents, sediment transport and morphological development in the nearshore ocean with accuracy and efficiency.

OBJECTIVES

The technological objectives of this project are to investigate the mechanics of wave-driven flow on complex topographies. Specifically, we are examining the occurrence, forms, and detailed causes of flow instabilities over complex topographies; the influence of three dimensional topographical features on large scale flow features, the forms and utility of simplified expressions in predicting flows, and the effects of flows on detailed morphology. We are also investigating the role of these flows on large scale morphological evolution.

APPROACH

The technical approach used here differs for the different sub-goals. The study of wave-driven flow instabilities over varying topographies uses tangent nonlinearities about steady base flows to derive a large stability matrix which is solved for stable and unstable eigenvalues. This may be thought of as extending the body work on shear waves over the past two decades (Holman and Bowen, 1989; Dodd et al., 2000; etc.) to more complex rip current topographies, and with more complex hydrodynamics including wave-current interaction. This work is largely being performed by the PI Kennedy and PhD student Yang Zhang.

The study of three dimensional topographic features on large scale flow patterns is a combination of theoretical and laboratory work. Theoretical work uses generation of circulation arguments combined with vortex dynamics to examine the influence of topographic features on wave driven vorticity transport and the overall flow features. This is compared with existing laboratory data to assess the accuracy of predictions and to describe overall regimes for three dimensional flow based on geometrical and wave parameters. This work is largely being performed by the PI Kennedy in concert with Dr. K. Haas of Georgia Tech and Dr. M. Brocchini of the University of Genoa, Italy, and their students.

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Some recent work has focused on wave and current-induced morphology change forced during large storm events. This work has relied on JALBTCX bathymetry datasets combined with wave and circulation modeling.

WORK COMPLETED

Major portions of the stability investigation have been completed, with a paper to be published in JGR-Oceans most likely in early 2008 (possibly late 2007). This is largely a numerical stability study, with comparisons to published laboratory and field studies. The chief finding has been the importance of the sinuous jet mode as a primary instability mechanism. This has helped to interpret results of other studies, which were necessarily limited in their observations. Figure 1 shows comparisons between the present study and laboratory and field studies. We have continued work on this area with preliminary computations mixed rip current/longshore currents.

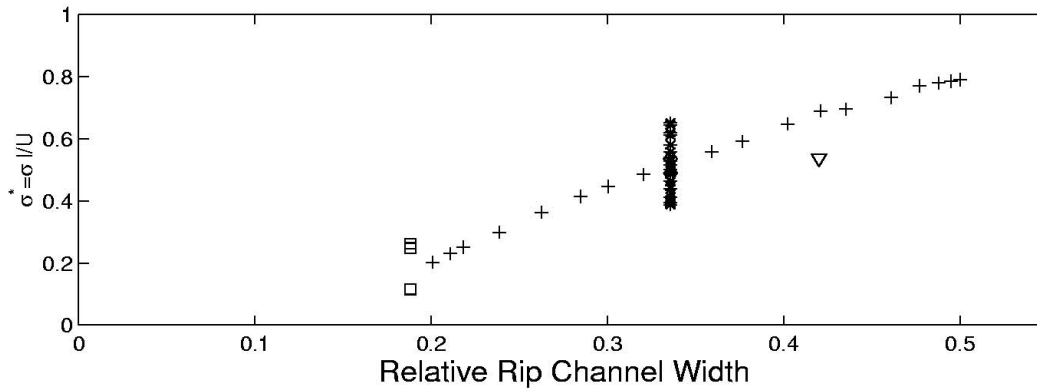


Figure 1. Dimensionless oscillation frequency compared to relative rip channel width (geometry). ($\square$) laboratory experiments of Haller and Dalrymple; (∇) Field experiments of MacMahan et al. (2004); (other symbols) present numerical results.

Work completed on three dimensional topographic features and their effects on wave driven flows has concentrated on an existing series of laboratory tests of wave-induced currents using identical wave forcing over several different topographies. Results have shown that for these maximum current velocities are quite insensitive to the ratio of bar length/rip channel width, while being strongly affected by wave properties. Although overall patterns are quite different, maximum longshore and cross-shore velocities are quite similar, which may prove quite helpful for predicting flows when detailed field bathymetries are not known. Two papers are in press and will be published in January, 2008.

In the past year, work has been underway on wave driven currents and unstable surf zone morphologies - particularly sand waves generated by longshore currents. This work was made possible through the fortuitous acquisition of JALBTCX bathymetry datasets showing post-hurricane surf zone sand waves. The work has so far concentrated on describing the forcing leading to the generation of these sand waves, with one paper submitted. The sand waves are particularly interesting because they are ephemeral - springing up during storms and disappearing afterward. Figure 2 shows an example of

the sand waves in the Florida panhandle. Proposed future work will look at the detailed mechanisms behind sand wave generation. Related work from the same dataset examines large scale sediment transport by waves and currents during severe storms, with emphasis on the direct evolution of large bathymetric inhomogeneities and their more distant effects. Figure 3 shows the strong evolution of a large scale pit over 2 years, demonstrating a natural experiment in sediment transport.

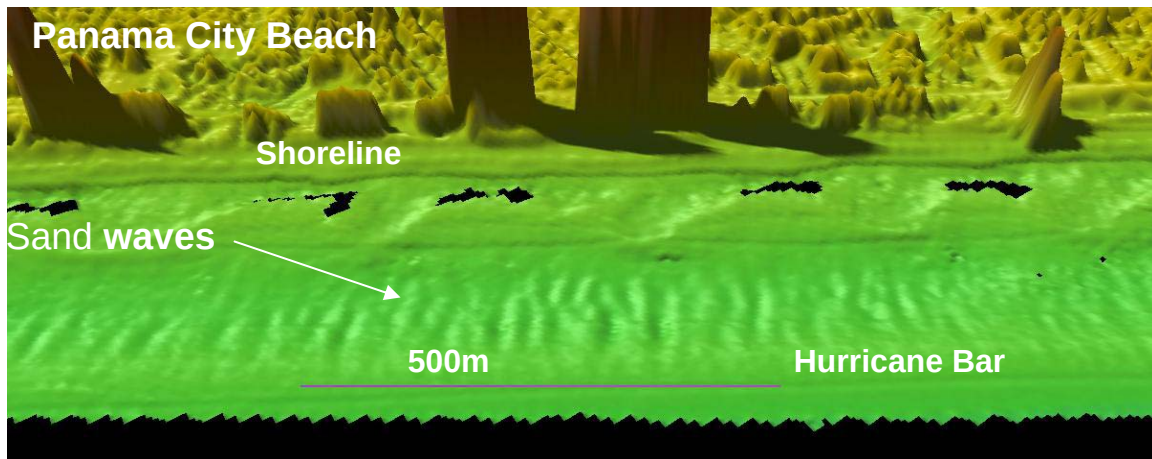


Figure 2. Topographic and bathymetric lidar after Hurricane Dennis showing section of sand waves.

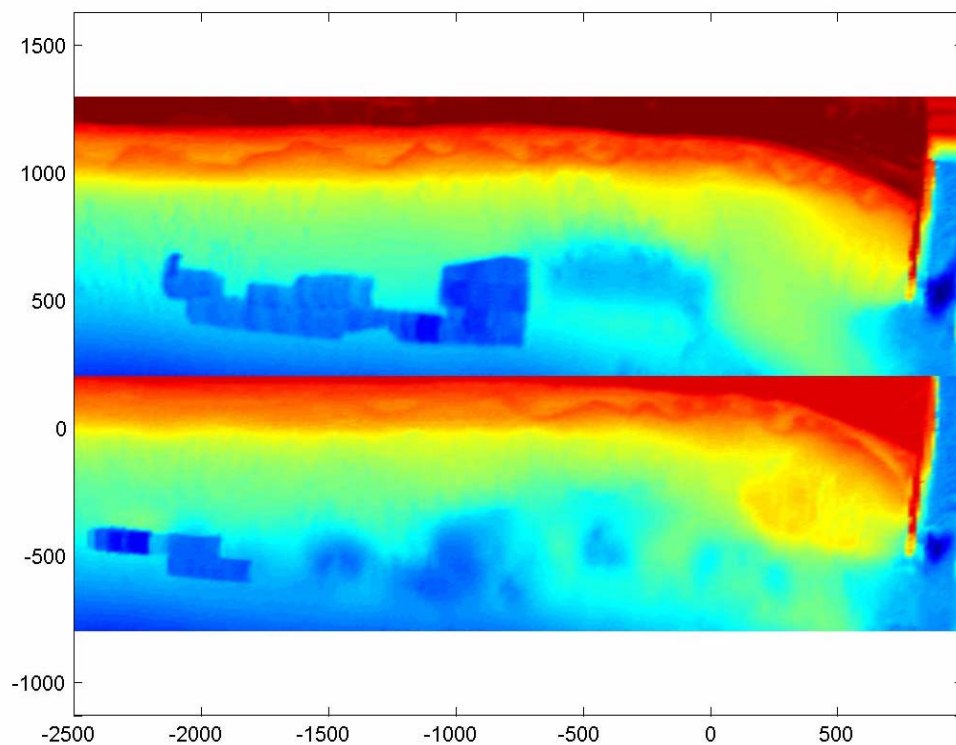


Figure 3. Evolution of a large scale bathymetric inhomogeneity. Top, 2004; bottom, 2006.

RESULTS

For the work on the stability of wave-driven flow, there are several significant results:

- Vorticity-driven antisymmetric and symmetric instabilities are found for a wide range of moderate and strong rip currents. These may be thought of either as an oscillating jet (Haller and Dalrymple, 2001), or as an oscillating circulation cell (MacMahan et al., 2003).
- Instabilities exist for low strength rip currents that are entirely dependent on wave-current interaction. Their basic mechanism is a feedback between rip jet oscillations and the resulting changes in wave breaking patterns. This is entirely different from classic vorticity-driven instabilities.
- The stability or instability of a wave-driven nearshore circulation cell is strongly dependent on bottom frictional dissipation. This reinforces previous findings for shear waves on longshore uniform topographies.

For work on three dimensional topographic effects the most significant result is:

- Maximum longshore and cross-shore velocities are insensitive to some details such as bar length

For work on morphological evolution, the most significant results are:

- Sand waves can be generated by strong longshore currents in the surf zone. This is significant because they have never before been unequivocally observed.
- Surf zone sand waves are destroyed quickly after strong longshore current events by orbital wave velocities, which are much more persistent than longshore currents.

IMPACT/APPLICATIONS

There are several potential future impacts arising from this work:

1. Stability work will improve understanding of current pulsations for wave driven flow in landing zones which, when matured, may be transitioned into operational use.
2. Stability work may also lead to the development of new Reynolds stress closures for turbulent fluctuations of wave-driven flow, which will be useful in modeling applications.
3. Work on the sensitivity of flows to detailed topography may lead to simplified prediction methods for operational use, where the detailed topography is almost never known.
4. The identification and description of bathymetry changes during strong storms will lead to an improved understanding of medium and large scale sediment transport .

RELATED PROJECTS

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