Rip Currents Onshore Submarine Canyons: NCEX Analysis

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LONG-TERM GOALS

The long-term goals of this research are to understand the dynamics of rip currents generated by large-scale variations in alongshore pressure gradients and wave forcing, and the impact of rip currents on nearshore bathymetry. These goals will be accomplished collaboratively using field observations obtained as part of the Nearshore Canyon Experiment (NCEX) held in the fall of 2003 and with numerical models.

OBJECTIVES

1. Continued analysis of video data obtained at NCEX, specifically to obtain dense, quality-controlled mean surface flow fields, wave breaking and surf zone width fluctuations, and shoreline swash oscillations.

2. Ongoing examination of the spatial and temporal variations in wave breaking patterns and its relationship to surface mean and oscillatory flow inside the surf zone.

3. Continued development of Kalman-type data assimilation methods for sequential forward models, and distribution of NCEX observations to collaborators for numerical data assimilation experiments and model testing (PI's Ozkan-Haller; Roelvink, *et al.*).

APPROACH

This research is a part of the Nearshore Canyon Experiment (NCEX), a large collaborative effort to examine the effects of abrupt submarine canyon topography on wave transformation, nearshore circulation, and surf zone bathymetric evolution. The thrust of the work is to collaboratively examine the generation, dynamics, and instability of rip currents - strong seaward flowing nearshore currents - and their impact on surf zone bathymetric evolution. These goals are being approached collaboratively through a combination of field observations and numerical modeling. Results of this research will lead to an improved understanding of the generation of rip currents in relation to large-scale pressure gradients and breaking patterns, the impact of rip currents bathymetric evolution, and increased understanding of data assimilation techniques that lead to improved numerical model performance.

Integral to this research is the development and exploitation of particle image velocimetry (PIV) video techniques to measure the large scale surface flow fields in and around the surf zone. In conjunction with estimates of wave breaking distributions, surf zone width, and run-up oscillations, qualitative examination of the forcing for rip currents and nearshore circulation can be done. These data can be utilized in numerical models to improve now-casting and fore-casting capabilities. Continued

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14. ABSTRACT
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comparison of the surface flow fields with sub-surface instrumentation will lead to better understanding of the vertical variation in mean and oscillatory flows as well as the dynamics of the nearshore surface layer.

WORK COMPLETED

Forty six days of the NCEX video data collection have been processed for surface velocity estimates spanning about 2 km of coastline. Corrections owing to fluctuating sea surface biases have been derived and tested, and can be applied to either the mean flows or the oscillating wave motions across frequency space. Time-averaged and variance imagery have also been processed for this same time period to allow a qualitative visualization of the surface flow patterns. These data are compared with the surface velocity estimates to ensure data consistency and utilized with model results (collaborative with PI Ozkan-Haller, Oregon State University). An array of 128 space-time transects of image pixels (called timestacks) spanning the surf zone have been processed to allow examination of the spatial and temporal variations in wave breaking patterns, surf zone width oscillations, and run-up spectra along the NCEX field site.

Detailed comparison of the surface flow velocities with a vertical stack of bi-directional current meters (collaborative with PI's Thornton and Stanton, Naval Postgraduate School) has verified the accuracies of the PIV video techniques. It has also led to an examination of the vertical flow structure of low frequency (infragravity band) motions. The data has revealed significant vertical structure in shear waves (instabilities of the mean alongshore current) not previously observed. Simple boundary layer theory has been developed (in collaboration with PI Bowen, Dalhousie University) that qualitatively explains the vertical behavior.

In collaboration with PI Ozkan-Haller (Oregon State University), the video-derived surface currents are being assimilated in a numerical model for nearshore circulation to test the ability of assimilation techniques to improve model performance and predictability. In addition to the Oregon State fully inverse data assimilation model, Kalman-type nudging techniques have been developed and implemented with the numerical model. The video data and nudging techniques are also being transferred to collaborators working on the Delft3D model to assist in their data assimilation efforts.

RESULTS

Observations of the vertical variation in low frequency motions (frequencies about 0.005 Hz) show significant vertical structure across the surf zone (Figure 1). In particular, nearly linear phase shifts of up to 45 degrees are observed in both the cross-shore and alongshore components of the flows. The bottom sometimes leads and lags the surface depending on the location in the surf zone relative the maximum location of the mean alongshore current as well as other factors not fully understood (including the strength of the alongshore current and shear magnitude, eddy mixing, and bottom drag). Additionally, rotary analysis shows that the ellipse orientation changes as a function of depth, and that the rotary coefficient is non-zero and can change sign in the vertical indicating that the surface flow of these long period motions can be opposite to that of the near bottom flow. The vertical variation in phase and rotation leads to a sharp drop-off in the coherence, even for co-located sensors separated vertically by as little as 1 meter. The observed vertical structure adds significant complexity to the behavior of low frequency motions in the surf zone not previously observed in the field or considered in depth-averaged models. The turning and rotational changes in the currents have implications to surf zone mixing and sediment transport that should be considered in numerical model formulations.

Following the work of Prandle (1982), simple boundary layer theory with a vertically uniform eddy viscosity, l, and quadratic bottom drag formulation qualitatively predicts the observed structure. The formulation is similar to the that found for tidal flows on the continental shelf, except that the Coriolis parameter does not enter into the solutions. Instead, the solutions depend on the parameter

$$p = \left(\frac{i(kV - \sigma + V_x}{\lambda} \right)$$

where s and *k* are the radian frequency and wavenumber, respectively, of the oscillatory wave motion, and V and V_x are the mean alongshore current and its cross-shore shear, respectively. Theoretical vertical phase variations using typical values have similar structure as the observations (Figure 2), with up to 45 degree phase shifts over the water column for a range of infragravity frequencies. The sign of the phase shift depends on the Doppler shifted frequency relative to the mean current shear. Consideration of the rotary components shows that the phase shifts and amplitude structure leads to turning of the currents with depth and a rotational sign change across the vertical (Figure 3), also similar to that observed in the field.

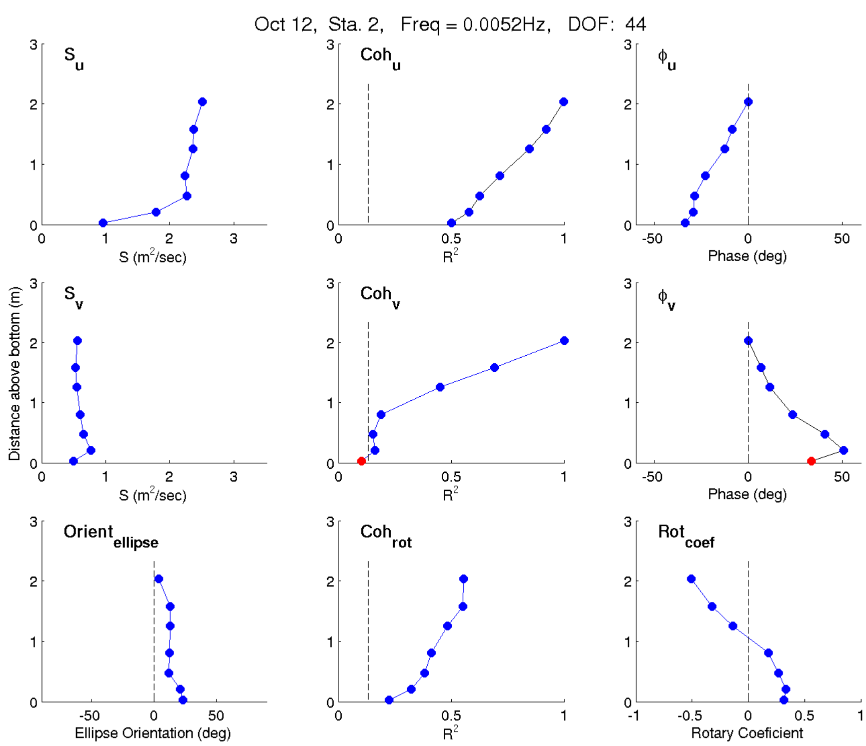

Figure 1. The vertical structure of low frequency motions observed on the seaward flank of the sand bar. The upper and center panels show the energy, coherence, and phase structure for the cross-shore and alongshore components of the flow, respectively. The lower panels show the vertical variation in rotary components (ellipse orientation, rotary coherence, and rotary coefficient).

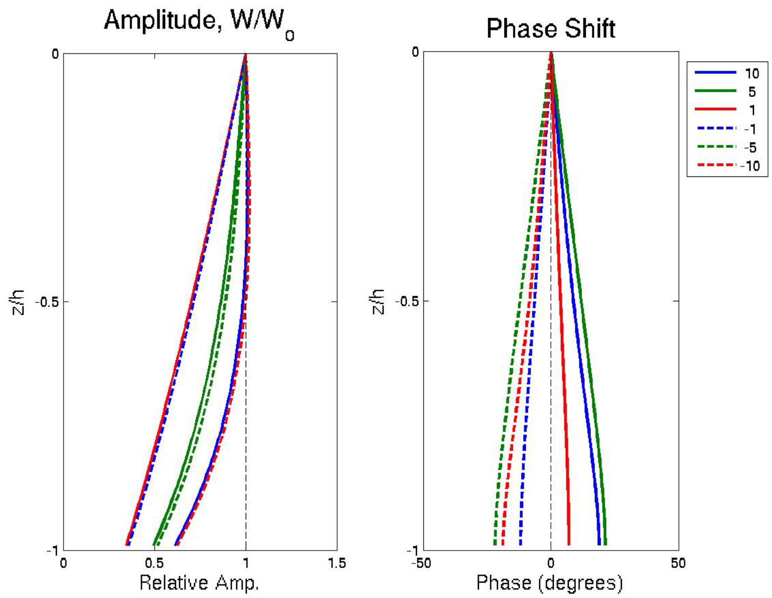

Figure 2. Amplitude and phase shift in the vector velocity of low frequency motions relative to the surface value as a function of the parameter p predicted by simple boundary layer theory. Results are given for a bottom drag coefficient of 0.05, and cross-shore shear of the mean alongshore current of 0.03 s^{-1}. The vector velocity can be decomposed into cross-shore and alongshore components of the flow to give similar structure as that observed in field data.

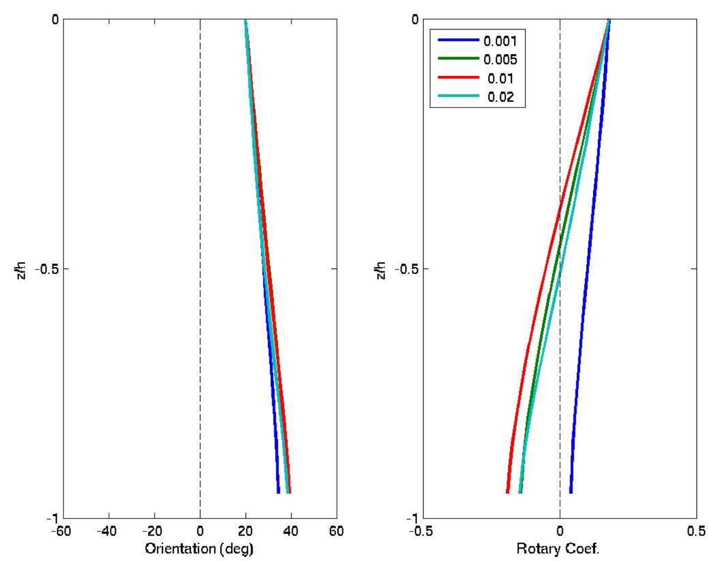

Figure 3. The vertical structure of rotary parameters for as a function of frequency (Hz). Ellipse orientation is shown in the left panel and the rotary coefficient is shown in the right panel. The theory qualitatively shows similar behavior as that observed in the data, including a turning of the current with depth and a rotational direction change in the vertical.

IMPACT/APPLICATIONS

Improvements in the sampling and modeling of wave breaking have lead to improved models for ensemble-averaged wave transformation and the forcing for mean flow. Development of remote sensing methods for measuring surface currents over large areas of the surf zone can be used to verify circulation models in the nearshore where *in situ* instrumentation is difficult to deploy.

TRANSITIONS

Many of the surf zone characterization techniques relating to this effort are being transitioned via collaborators (PI Holland) under the NRL Littoral Environmental Nowcasting System program for eventual Naval operational use.

RELATED PROJECTS

Video data analysis of the 1990 Delilah, 1994 Duck94, 1996 MBBE, 1997 SandyDuck, and 2001 RIPEX experiments are being examined in collaboration with other ONR-funded scientists making *in situ* observations of wave and current properties.

REFERENCES

Prandle, D., 1982, The vertical structure of tidal currents and other oscillatory flows, *Cont. Shelf Res.*, **1**(2), 191-207.

PUBLICATIONS

Shore, J., T. J. Kassebaum, and T. C. Lippmann, 2005, PC based analog video data collection technique for nearshore waves and currents, *J. Ocean. Atmos. Tech.*, *sub judice*.