# Rip Currents Onshore Submarine Canyons

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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. Develop computationally fast and efficient Particle Image Velocimetry (PIV) imaging methods for analyzing video data for surface current measurements in the surf zone. Apply the PIV methods to video data obtained from past experiments and the 2003 NCEX experiment.

2. Participate in the 2003 NCEX experiment, specifically to obtain observations of surface currents in and around a rip current, alongshore variations in surf zone width, wave breaker angle, runup elevations, and bathymetry.

3. Provide observations to collaborative studies utilizing data assimilation methods to model nearshore circulation (PI's Ozkan-Haller).

## 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. Three primary field measurements were made during NCEX. The first are observations of surface current velocities spanning the scales of nearshore circulation obtained from PIV analysis of an array of 9 video cameras mounted at the edge of the 50-*m* high cliffs or on adjacent buildings bordering the NCEX field site. The over-lapping footprints for the camera array (nearly) continuously spans the

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shoreline, surf zone, and nearshore region within 400-500 m of shore along the 3 *km* length of the NCEX field site (Figure 1). The video data were transmitted directly to a receiving station at the end of Scripps pier and individual image frames digitized and stored at 3 *Hz* in real time during the experiment. Analysis using established techniques is presently underway using custom software developed during the experiment. An example of the mean (30 minute averaged) flow pattern is shown in Figure 2. These strong currents exhibited episodic, unsteady behavior (Figure 3) and can be examined with the suite of video data collected.

The second are observations of large-scale (3 *km*) alongshore variations in wave breaking patterns and shoreline positions; good proxies for the spatial and temporal forcing of alongshore pressure gradients in the surf (obtained from established analysis methods, Figure 4). The third are observations of the large-scale (sand bar) sea bed morphology (obtained from GPS-based nearshore survey systems, Figure 5). These observations are being contributed to the NCEX team for other wave, current, and bathymetric studies, for comparison with other data, and for input and verification of numerical models.

***Figure 1. Oblique photographs showing strong rip currents observed during NCEX. The rip currents are visible in the image by the foamy water extending offshore up to several surf zone widths. The surface flow during NCEX is being quantified using video-based PIV techniques applied to an array of 9 video cameras mounted on the cliffs visible in the image spanning 3 km of coastline.***

## WORK COMPLETED

As part of NCEX, we deployed a 9-element shore-based array of video cameras along a 3 km stretch of coastline and collected 45 days of digitized images sampled at 3 Hz. New remote sensing technologies (video Particle Image Velocimetry, or PIV) developed in collaboration with PI Holland (Naval Research Laboratory, Stennis Space Center) allow us to make large-scale measurements of surface currents within and around the surf zone. Analysis of the NCEX images is underway, and are being used to examine (1) nearshore rip currents, including fluctuating velocities and mean flow at the water surface, and (2) wave properties, including large scale alongshore variations in wave breaking patterns, surf zone width (a proxy for observing alongshore variations in wave energy), and shoreline swash oscillations. Observations of the spatial and temporal variation in wave energy (estimated from measurements of surf zone width) will be compared with spatial and temporal fluctuations in surface current velocities to determine the relationship of wave breaking to the forcing of nearshore circulation in the surf zone just onshore of a submarine canyon. The data will be used to examine the dynamics of rip currents, as well as for topographic evolution in the vicinity of the rips.

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**

Regions where alongshore currents converge cause strong, often narrow, seaward flowing rip currents that extend seaward up to many surf zone widths. The currents are often visible by the contrast between the lighter intensity foam and bubbles generated by breaking waves in the surf (Figure 1). These rip currents are not stationary in space and time (Figure 2) and thus require spatially large arrays of instruments. As part of this research we have developed Particle Image Velocimetry (PIV) video image processing methods to quantify the surface flow patterns over the large scales of the surf zone.

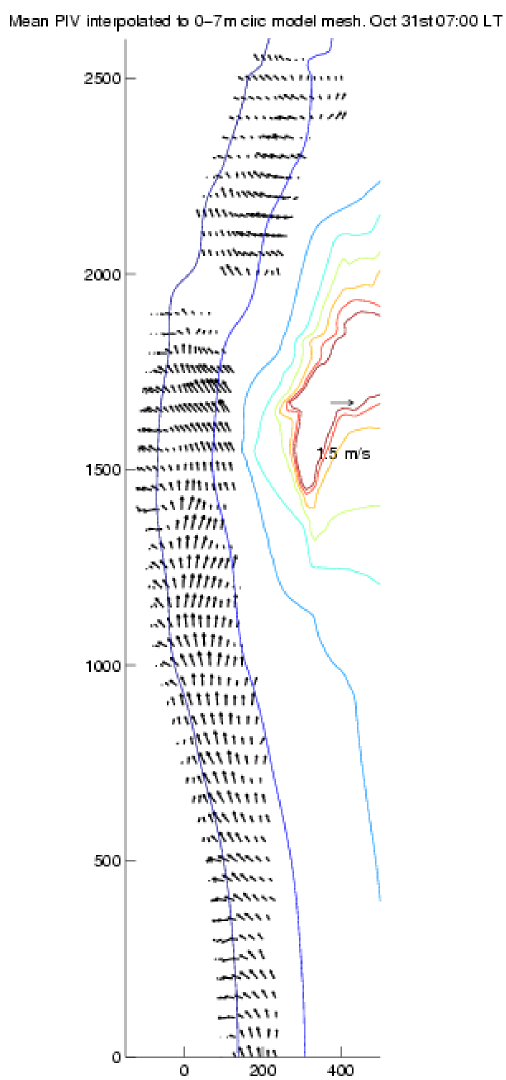


***Figure 2. Example 30 minute mean surface flow obtained during NCEX. The coordinates of the axes are in meters in a local coordinate. The 1.5 m/sec vector is shown for scale. Bathymetry contours are in 5 m depth increments starting at the shoreline***

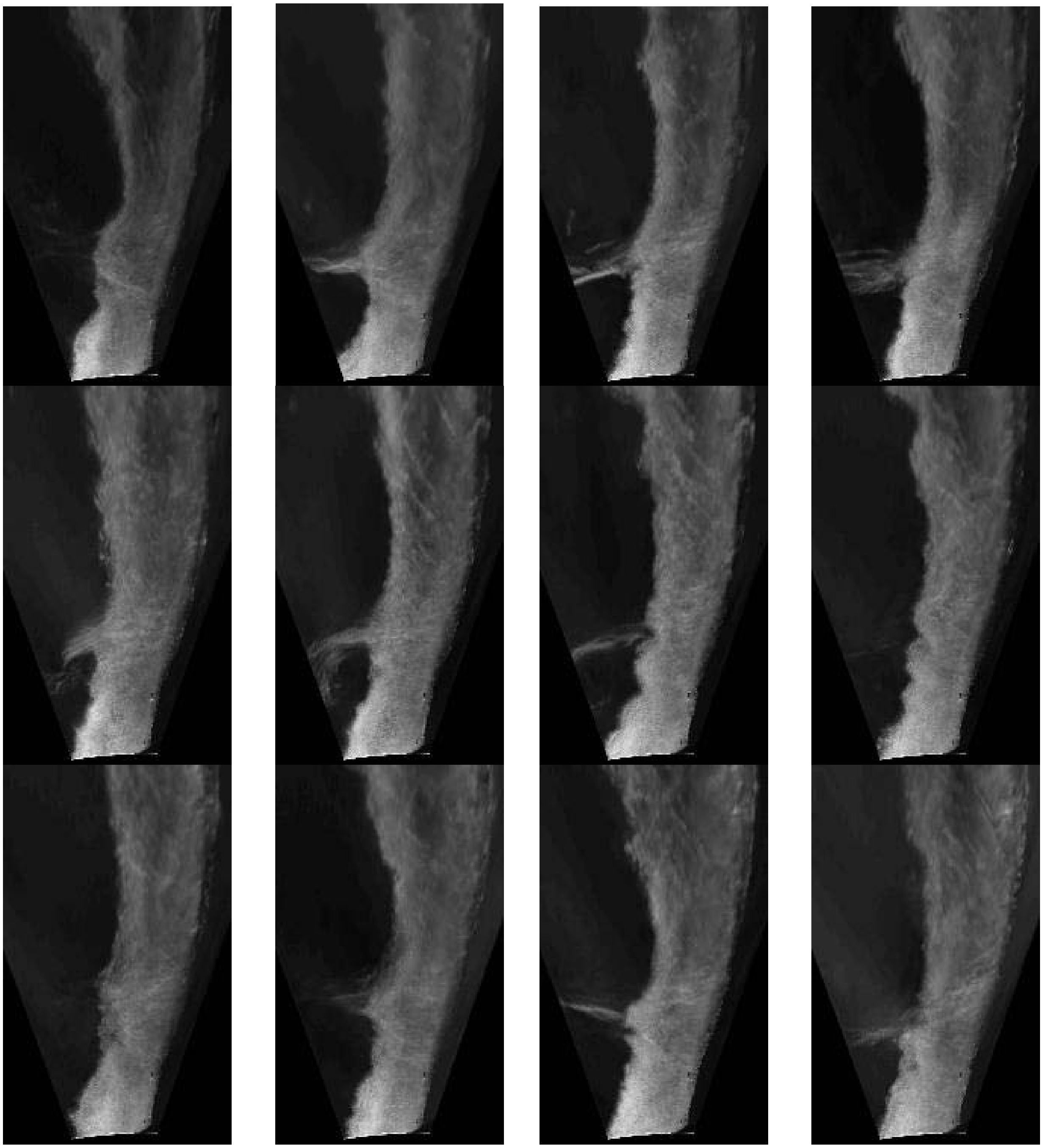

***Figure 3. Sequence of 3-minute variance images (read left-to-right) showing the episodic and unsteady nature of a rip current observed during the NCEX experiment. The light colors in the image indicate regions of wave breaking and movement of foam due to advection by surface flows. The shoreline is at the right-hand edge of the high intensity region, and offshore is to the left. The narrow stream of foam exiting the surf zone approximately 25% up from the bottom edge indicates the presence of a rip current. The current appears to pulsate and meander in an unsteady manner.***

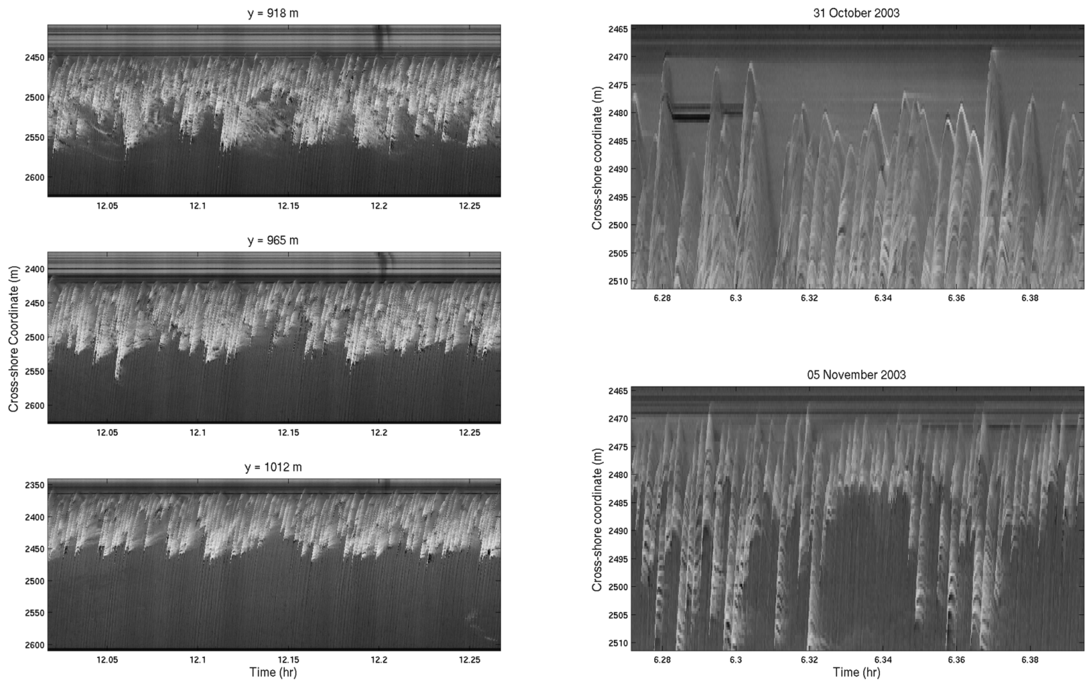


***Figure 4. (left panels) Example 15 minute timestacks obtained during NCEX at three alongshore locations separated by 47 m. Offshore is toward the bottom of each panel with waves progressing in time to the right. The width of the surf zone is indicated by the time varying most seaward location of breaking waves. Marked temporal modulations arising from spatially varying wave groups drive flows at similar time and length scales. (right panels) Example timestacks from NCEX showing the swash oscillations at the shoreline from a large wave day (top) and a small wave day (bottom).***

To verify the surface flow measurements, PIV-based surface velocities were compared with an *in situ* vertical array of bi-directional flow meters (PI's Thornton and Stanton, NPS). The surface flow averaged over 1 hour compares well with the subsurface flow out to distances up to 400 m from the camera. In addition to mean surface flow estimates, the PIV data can resolve oscillatory wave motions where the resolution of the image footprint is good. Where infragravity and shear waves are strong, arrays of PIV time series can be used to estimate the alongshore wavenumber spectra.

When the fluctuations induced by individual wave propagation are removed, a smooth pattern of the wave-averaged flow can be produced with good confidence. Wave-averaged quantities are directly applicable to data assimilation models under development by collaborators (PI's Ozkan-Haller).

Bathymetry and foreshore profiles were also obtained during NCEX (Figure 5). The survey data can be found at http://cdip.ucsd.edu/models/ncex/bathy/mini_grid/index.html.

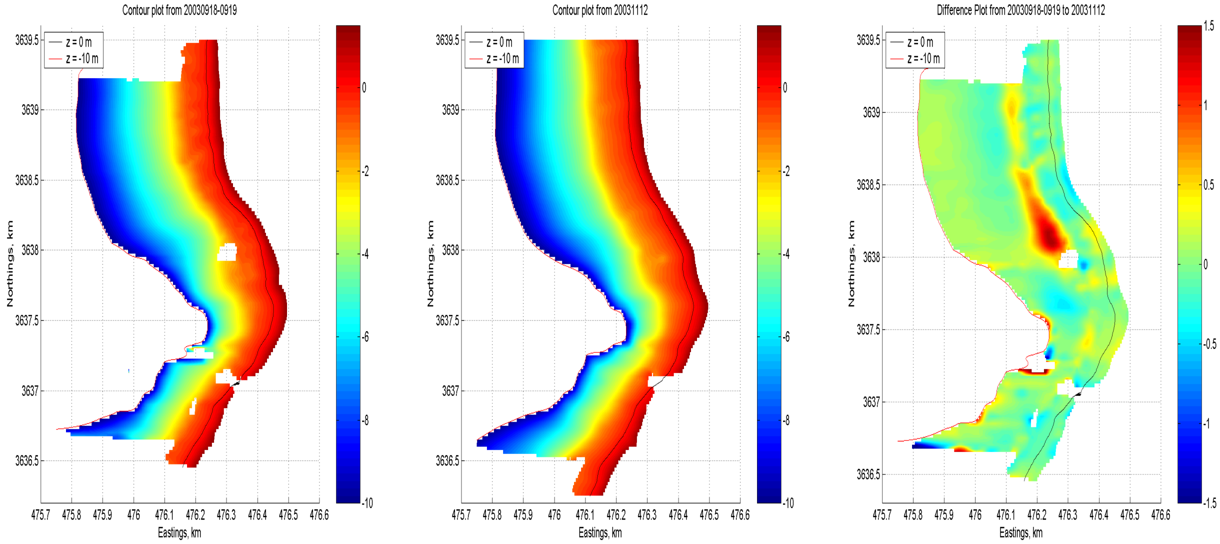


***Figure 5. Bathymetry measured near the start of data collection in mid September (left panel), at the end of the experiment in mid November (center panel), and the total change (right panel). The development of a nearshore bar field with strong alongshore variability was observed during the 7 week NCEX experiment. Apparent large changes in the bathymetry near the steep canyon walls are an artifact of the sampling and smoothing methods that cannot account for the steep gradients in those regions.***

## 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.

## PUBLICATIONS

Lippmann, T. C., D. Welsh, and J. Shore, 2004, Observations of nearshore surface currents in the surf zone, *Proc. 29$^{th}$ Intern. Conf. Coastal Eng.*, in press.