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 and numerical models, and will be pursued as part of the Nearshore Canyon Experiment (NCEX) scheduled for the fall of 2003.

OBJECTIVES

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

2. Prepare for and 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, and runup elevations, and beach profiles and submarine topography.

3. Provide observations of surf zone surface currents, shoreline run-up, breaker angle, and surf zone width to collaborative studies utilizing data assimilation methods to model nearshore circulation (PI's Ozkan-Haller, Shore, Lippmann, and Kaihatu) and nearshore wave breaking (PI's Walker and Haller).

APPROACH

Three primary field measurements are supported by this grant. The first are observations of surface current velocities spanning the scales of a rip current (obtained from new PIV analysis of high-resolution shore-based digital video cameras; Holland, *et al.*, 2001). The second are observations of large-scale (5-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 of an array of shore-based video imagery). The third are observations of the large-scale (sand bar) seabed morphology (obtained from recently developed nearshore survey systems). These observations will be contributed to the NCEX team for other studies, for comparison with other data, and for input and verification of numerical models.

An array of seven shore-based video cameras will be mounted at the edge of the 50-m high cliffs bordering the NCEX field site. The over-lapping footprints for the camera array continuously spans the shoreline, surf zone, and nearshore region within 200-400-m of shore along the 5-km length of the NCEX field site. Shore normal transects of pixel intensity time series spaced approximately 250-m alongshore will be sampled continuously during daylight hours. The data will be stored in timestack images that can be used to detect wave breaking distributions and shoreline run-up. The video data will be transmitted directly to a receiving station at the end of Scripps pier and digitized in real time during the experiment. Analysis will follow using established techniques and data made available to modelers as soon as possible during NCEX. Owing to the time necessary to process the data, we expect that time delays of 2-24 hours will be likely.

We also plan to obtain high-resolution video imagery of a subset of the NCEX field site in order to focus on detailed observations of a single rip current. Owing to general experience at the field site, large rip currents often form just onshore and slightly to the north of the Scripps Canyon. Thus, we plan to deploy two high-resolution digital cameras near the Scripps Canyon area. The high-resolution video will allow for video observations of surface current time series at fast enough sampling frequencies to capture individual incident wave transformation across the width of the surf zone, as well as detail of the mean flow patterns associate with may rip currents that may form in the area.

WORK COMPLETED

The focus over the past 9 months has been on preparation for NCEX, and has two distinct lines. The first is preparing the video-related field hardware, video-data transmission system, and bathymetric survey equipment. Work has been done to test wireless video data transmitters over the distances expected at the field site, and synchronization of a large (up to 10 unit) array of video signals received at a single location. GPS time stamping and video-data storage capabilities have been well tested in previous experiments. Development and testing of remote video stations consisting of a video camera, wireless transmitter, and rechargeable 12 volt battery has been done. The bathymetric survey system has been completed and tested at the field site.

The second line of work has focussed on development of data processing software to sample the video data for wave breaking distributions, run-up, wave angle, and surface currents. Software exists from previous experiments to digitize 3 live video feeds simultaneously and produce timestack imagery that can be subsequently analyzed for breaker position and runup excursion. Software also exists (called VISSER) to sample pixel time series in small arrays to measure average wave angle. Software utilizing PIV methods to measure surface currents over large portions of the surf zone has been under development for several years, and is now capable of quantifying mean flow patterns over several hundred meters from the camera location using high-angle shore based video. Owing to the computationally intensive algorithms necessary in the PIV methods, time considerations become important when processing live video feeds. Significant improvements over the past year have shortened the time to process a single pair of images by an order of magnitude, and depending on the density of measurements desired, can be accomplished with reasonable accuracy in just a few seconds.

Of considerable importance to the accuracy of surface currents estimated from PIV analysis, is the removal of bias errors owing to image layover that arises from oblique look-angles and wave motions. The nature of the error occurs when transforming from image to ground coordinates because one dimension must be assumed, which in most cases is the elevation of the mean water level. When waves are present, this elevation changes rapidly enough to cause errors in the estimated velocities solely due to the changing elevation of the local water elevation. The magnitude of the bias error also depends inversely on the difference between the look-angle of the video and the sea surface slope. When the look-angle is equal to the seaward slope of the wave, the sea surface is obscured completely from view and the bias error is infinite. When the look angle is near vertical, the bias is zero. For intermediate look-angles, bias errors can be removed using iterative nonlinear solutions after assuming simple linear relationships between wave pressures, velocities, and phase speeds in shallow water.

Surf zone velocity data can also be obtained from Microwave Doppler radar that relies on small-scale ocean surface roughness. Comparison of radar and PIV data show high correlation in regions of large radar backscatter that corresponds to visibly broken and unbroken waves propagating across the surf zone (Puleo, *et al.*, 2002). Correlation coefficients between radial velocities sampled using the two methods at multiple locations across the surf zone typically exceeded 0.5 (maximum of 0.60) when high frequency (> 0.25 Hz) noise is excluded. Similarly, spectra were found to be coherent at the 95% level with a nearly zero phase shift near the broad spectral peak between 0.02 and 0.25 Hz. The PIV method is capable of estimating swash zone surface velocities when sufficient image texture is present, whereas the smooth water surface in the swash zone was not conducive to radar signal reflectivity.

RESULTS

Regions where alongshore currents converge cause strong, often narrow, seaward flowing rip currents that extend seaward up to many surf zone widths. The often sediment-laden rip currents are visible by the contrast between the lighter intensity foam and bubbles generated by breaking waves in the surf. These rip currents are not stationary in time and space and thus require spatially large arrays of instruments. As part of this research we have developed video image processing methods to quantify the surface flow patterns over the large scales of the surf zone. This image analysis methodology is known as Particle Image Velocimetry. In our application, surface flow can be mapped by observing time series of advection displacements in a similar manner as the seeded laboratory experiments.

An example 4-minute time series of the mean-corrected cross-shore and alongshore velocity fields obtained from a single location with our PIV analysis is shown in Figure 1. The raw PIV data and the bias-correct values are shown. Also shown are the measurements made *in situ* at the same location but near the seabed (these data were obtained by Dr.'s Guza, SIO, and Elgar, WHOI). The bias-corrected PIV estimates for cross-shore currents have slightly larger magnitude than the *in situ* measurements, and the coherence squared spanning incident band frequencies (0.1-0.2 Hz) is about 0.80. The signals are also coherent (0.40-0.60) at particular infragravity frequencies associated with shear and edge waves. The bias-corrected PIV estimates for alongshore velocities are incoherent throughout incident band frequencies (owing to the nearly shore-normal wave propagation), but are coherent (about 0.50) at specific infragravity frequencies. These data suggest that making accurate measurements of wave motions is possible provided the cross-shore resolution of the imagery is within about 0.40 m.

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 such as these are directly applicable to data assimilation models under development by collaborators (PI's Ozkan-Haller, Shore, Lippmann, and Kaihatu). Mean flows averaged over longer periods can also be obtained. An example 30 minute average of the mean flow obtained from an array of positions spanning the width of the surf zone are shown in Figure 2. Also shown are mean values obtained from *in situ* current meters located near the seabed (obtained by Dr.'s Guza, SIO, and Elgar, WHOI). Both the raw and bias-corrected mean PIV results are shown. Mean alongshore currents measured with PIV analysis agrees quite well with the *in situ* data across most of the inner surf zone, even at a range of over 350 meters from the camera. Further seaward the mean flow derived form PIV is degraded by errors owing primarily to video resolution degradation in the far field. The data show that mean alongshore flows can be quantified in the far field provided that the alongshore resolution of the video is within about 4-m. Increased resolution from, for example high-resolution digital cameras or more vertically-oriented video systems, will improve the PIV estimates in the far field.

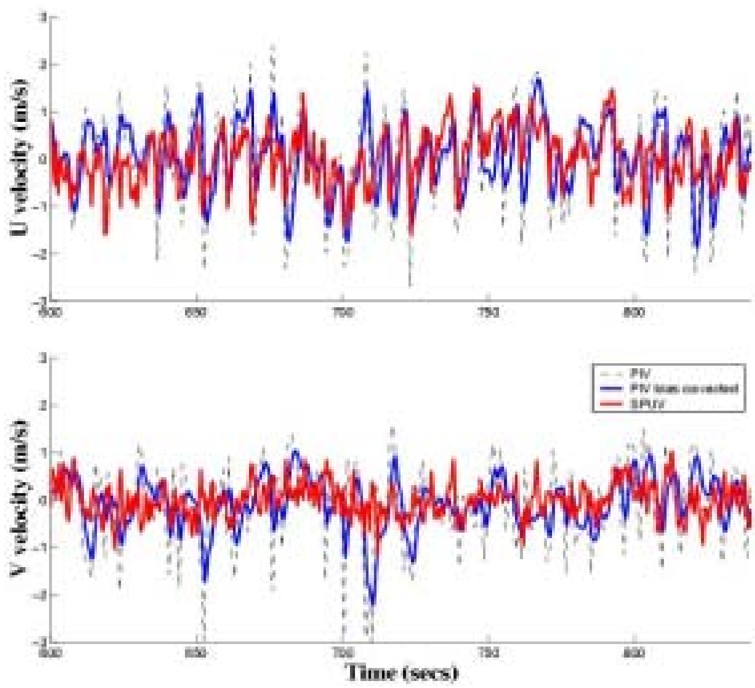

Figure 1. Comparison between 4-minute time series of mean-corrected surface velocities estimated from raw (dashed lines) and bias-corrected (blue lines) PIV methods and time series obtained from the same location but near the seabed with in situ current meters (red lines). Cross-shore velocities are shown in the upper panel and alongshore velocities are shown in the lower panel.

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 under the NRL Littoral Environmental Nowcasting System program for eventual Naval operational use.

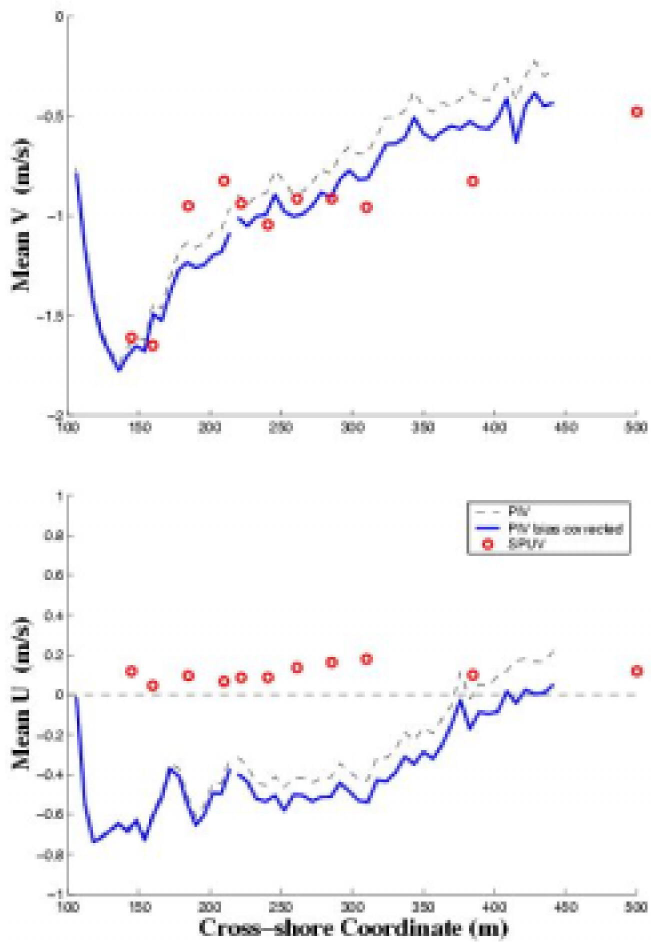

Figure 2. Comparisons spanning the width of the surf zone between 30-minute mean surface velocities estimated from raw (dashed lines) and bias-corrected (blue lines) PIV methods and time series obtained from the same location but near the seabed with in situ current meters (red circles). Mean alongshore flow is shown in the upper panel and mean cross-shore flow is shown in the lower panel.

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

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Puleo, J. A., G. Farquharson, S. J. Frasier, and K. T. Holland, 2002, Comparison of optical and radar measurements of surf zone velocities, *J. Geophys. Res.*, submitted.

PUBLICATIONS

Puleo, J. A., G. Farquharson, S. J. Frasier, and K. T. Holland, 2002, Comparison of optical and radar measurements of surf zone velocities, *J. Geophys. Res.*, submitted.