

Surf Zone Wave and Current Dynamics

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LONG-TERM GOALS

Ocean bubble production, persistence and transport results from complex interactions occurring between winds, waves, currents and the presence of biological and anthropogenic surfactants in the upper ocean (Thorpe, 1982; Hanson, 1993; Hanson, 1997; Hanson and Phillips, 1999). These processes are amplified in the surf zone as shoaling waves dissipate through interactions with local bathymetry. Existing capabilities to predict nearshore wave dissipation, sea foam and bubble formation, and resulting surf zone optical properties are extremely limited. Our long-term goals are to

1. Maintain a comprehensive long-term measurement program of cross-shelf and surf-zone hydrodynamic forcing including winds, waves, currents, water column properties, surf zone activity and bathymetry.
2. Apply this long-term observation set to statistically characterize the effects of hydrodynamic forcing on surf zone optical properties.
3. Develop and apply a robust modeling capability to investigate surf zone dynamics including wave energy dissipation and other nonlinear shallow-water wave transformation affects. The results of such a research program will directly facilitate the development of improved nearshore process modeling capabilities.

OBJECTIVES

Current research objectives are designed to support a multi-investigator Surf Zone Optics experiment that was conducted in the dynamic coastal environment at the US Army Corps of Engineers (USACE) Field Research Facility (FRF) in Duck, North Carolina. The FRF objectives are to:

1. Conduct an analysis of the rich historical data archive collected at the FRF to identify and quantify trends in surf zone forcing, water column properties and optical radiance properties.

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2. Measure the FRF surf zone dynamical forcing (winds, waves, currents) for an extended observation period to provide collaborating PIs with a detailed account of the forcing conditions related to bubble production and transport within the surf zone.
3. Host the multi-investigator Surf Zone Optics experiment at the FRF site from 7-17 September, 2010. Coordinate scientific activities and provide required logistics support to each of several participating teams.

APPROACH

Task 1. Dependence of Surf Zone Optics on Water Column Properties

This analysis will use a 5-year record of high-resolution digital Argus imagery obtained across the surf zone at the USACE FRF, coupled with corresponding wind, directional wave, conductivity-temperature-depth (CTD), and Secchi depth measurements obtained at or near the end of the USACE FRF research pier, which is approximately 560 m off the beach and at 7.5-m water depth. This work will be done in collaboration with Oregon State University (PI Rob Holman) and East Carolina University (Dr. Ryan Mulligan). The goal is to determine the dependence of optical radiance properties on forcing conditions and observed water column properties. The results should provide guidance on the degree of scatter that can be expected for sea foam coverage under various forcing conditions and assess the relative importance of basic water column properties on sea surface optical radiance.

Task 2. Surf Zone Observations

The focus of this task is to measure the dominant surf zone processes influencing bubble dynamics over an extended experimental period of at least 12 months duration. This measurement period will include the intensive experimental periods proposed by other collaborators involved with the Surf Zone Optics program. Specific observations include:

- Meteorology, including wind speed and direction
- Directional waves (9 stations)
- Vertical current structure (6 stations)
- Water column temperature and salinity structure
- Bathymetry surveys

Wave and current observations will be obtained using a new cross-shore wave array at the FRF. The array consists of 4 Nortek Acoustic Wave and Current (AWAC) sensors at depths of 5, 6.5, 8.5 and 11.2 meters and two Datawell directional Waverider buoys at depths of 17 and 26 m. These stations are in a direct line with a 3-m discus buoy, with wind and directional wave sensors, at 48-m depth (National Data Buoy Center Station 44014). For this project the array has been enhanced by adding two Nortek AquaDopp wave and current sensors inshore of the outer and inner bars (approximately 3.5- and 2-m depths) thus extending the wave array across the entire surf zone.

Task 3. Host Surf Zone Optics Experiment

The FRF staff and facilities were a host to the Surf Zone Optics experiment, conducted 7-17 September 2010 at the FRF. Technical and logistics support were provided.

WORK COMPLETED

Task 1. Dependence of Surf Zone Optics on Water Column Properties

In collaboration with Dr. Ryan Mulligan (East Carolina University), an initial exploration of the FRF hydrodynamic and surf zone optical records since 1984 was completed. Results are reported by Mulligan (2010) and excerpted in 'Results' below. Furthermore, a method was developed allowing us to extract surf zone width from historical Argus imagery.

Task 2. Surf Zone Observations

Data collected in support of this project include:

- FRF cross-shore wave and current array (July 2008 – present)
- Additional nearshore wave and current sensors (August 2010-present)
- Meteorology (continuous)
- Water levels (continuous)
- Daily CTD/Secchi depth
- Multi-line bathymetric surveys (6 September and 15 September 2010)

Figure 1 provides an FRF base map showing instrument and survey line locations.

Task 3. Host Surf Zone Optics Experiment

Comprehensive technical and logistics support was provided to the Surf Zone Optics experiment, conducted 7-17 September 2010 at the FRF. The experiment consisted of approximately 30 participants, comprising 9 separate project teams from 7 different organizations. FRF Activities included:

- Providing an overall test director and co-director (Hanson and Hathaway)
- Conducting twice daily (AM and PM) PI logistics meetings
- Developing and maintaining a master experiment schedule
- Developing and maintaining an experiment web site
- Maintaining an experiment FTP site
- Office and staging area space to project teams
- Internet support
- Facilities and equipment support including use of LARC, CRAB, Fork Trucks, Pier, Tower, and Garage

RESULTS

Task 1. Dependence of Surf Zone Optics on Water Column Properties

This historical analysis focused on NDBC wave parameters, sea surface temperature, and Secchi depths measured at Duck since 1984 (Mulligan, 2010). Sea surface temperatures were extracted from

almost daily CTD casts taken at the end of the pier. Secchi depth is also measured with each CTD cast at the end of the pier. The wave records are from a nearby NDBC buoy. The historical record of significant wave height, Secchi depths and sea surface temperatures are shown in Figure 2.

All 3 parameters depict strong seasonal variations, with high winter waves inversely correlated with Secchi depth and sea surface temperature. This is clearly depicted by the monthly mean and variance values for all 3 parameters shown in Figure 3. Although low wave energy in summer promotes improved water visibility, this is somewhat counteracted by (1) increased algae blooms during the warm months, and (2) coastal upwelling events with prevailing southwest winds. The high variance in sea surface temperatures and water visibility during the summer months (Figure 3) is primarily due to alternating cycles of wind-driven transport. The data was binned by wind direction and the rapid temperature decreases of up to 15 deg C are well correlated with southerly and southwesterly winds.

Larger waves, which dominate in winter months, stir sediment and result in monthly mean Secchi depths of 1-2 m. In summer months, smaller waves allow Secchi depths to reach monthly means of 3-4 m (with daily values of up to 8 m). A scatter plot of the H_s and Secchi depth data (Figure 4) shows that when H_s is greater than 2 m, Secchi depths are less than 2 m. Conversely, visibility in the water column can be up to 8 m when H_s is less than 1 m. The relationship follows a curve similar in shape to a hyperbolic cotangent.

We plan to examine the full CTD dataset to look for upwelling events, and to use temperature and salinity as water mass tracers to help differentiate between NC Shelf and Chesapeake Bay water. Estuarine water from Chesapeake Bay may be correlated with time periods of low visibility.

Furthermore we have developed an algorithm to extract time-series of surf zone widths from 2005-2010 ARGUS imagery by analyzing pixel intensity along cross-shore transects. Sample results appear in Figure 5. Surf zone widths from the time exposure images will be compared to the estimated extent of breaking from instruments in the cross-shore array.

Task 2. Surf Zone Observations

Near continuous data has been obtained from the FRF cross-shore wave and current array since deployment in summer 2008. As the example data set from Hurricane Earl (September 2010) in Figure 6 depicts, the array captures all phases of wave transformation across the shelf and through the surf zone. Furthermore, two complete 26-line bathymetric surveys were also completed to support the Surf Zone Optics experiment. Sample bathymetric survey results appear in Figure 7. All data have been processed and placed on the project FTP site. A comprehensive data analysis report will be distributed during year 2 of this project.

Task 3. Host Surf Zone Optics Experiment

In general, all project teams reported that experiment objectives were adequately met and all essential data were collected. Figure 8 provides a group picture of the experimental team.

IMPACT/APPLICATIONS

The data collected will lead to an improved understanding of hydrodynamic control of surf zone optical conditions.

RELATED PROJECTS

The ONR Waves NOPP project will use data from the FRF cross-shore wave and current array to develop and test new source terms for the next generation nearshore numerical wave model(s).

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- Thorpe, S.A., 1982. On the clouds of bubbles formed by breaking wind-waves in deep water, and their role in air-sea gas transfer, *Philos. Trans. R. Soc London*, A 304, 155-210.

PUBLICATIONS

- Hanson, J.L., H. C. Friebel and K. K. Hathaway, 2009. Coastal wave energy dissipation: observations and STWAVE-FP performance, 11-th International Workshop on Wave Hindcasting and Forecasting, 18-23 October, Halifax, NS.
- Hanson, J.L., H.C. Friebel, and K.K. Hathaway, Coastal Wave Transformation: Observations and Modeling, WISE 2010 25-29 April 2010, Brest, France.



Figure 1. Base map of FRF observations supporting the ONR Surf Zone Optics program.

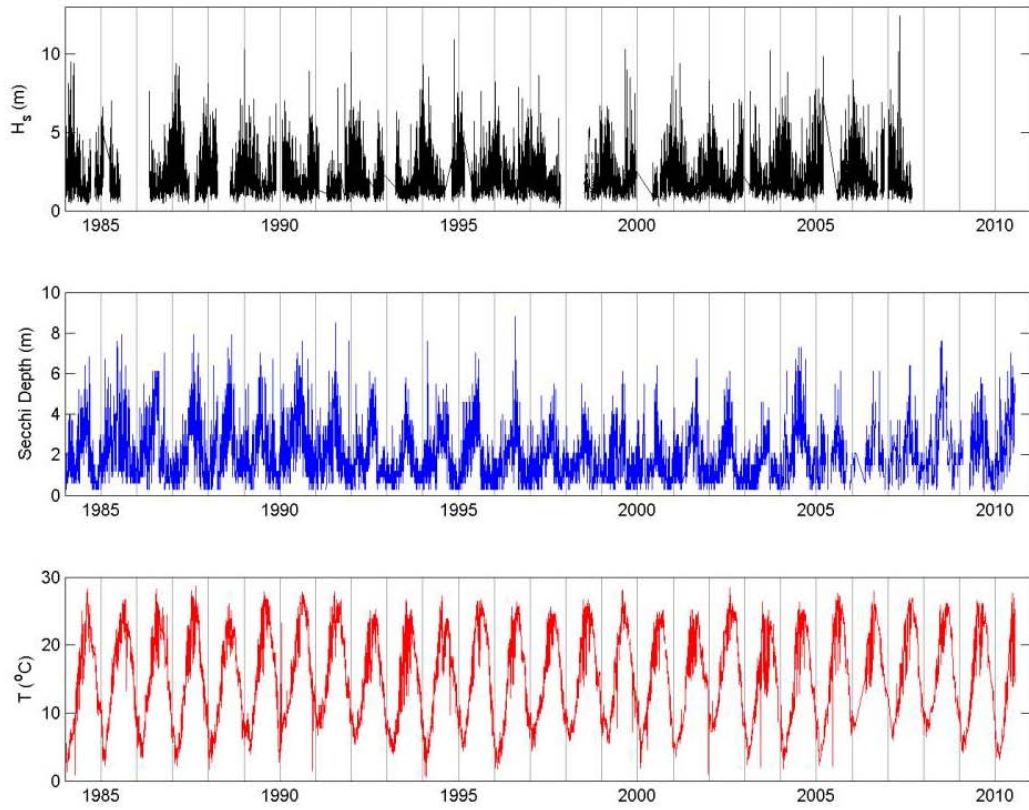


Figure 2. FRF historical significant wave height, Secchi depth and sea surface temperature observations since 1984. Note that the wave record is from a nearby NDBC buoy.

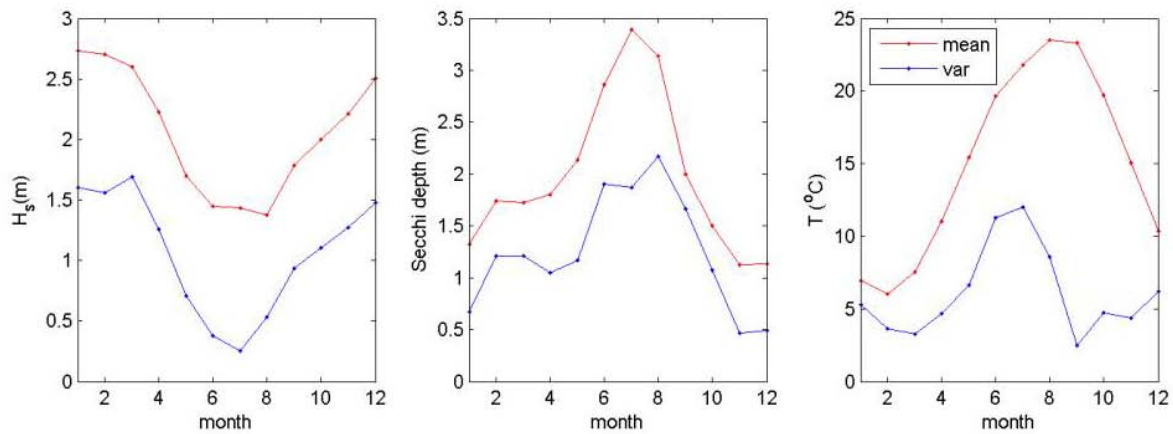


Figure 3. Monthly mean and variance values for FRF significant wave height, Secchi depth and sea-surface temperature measurements since 1984.

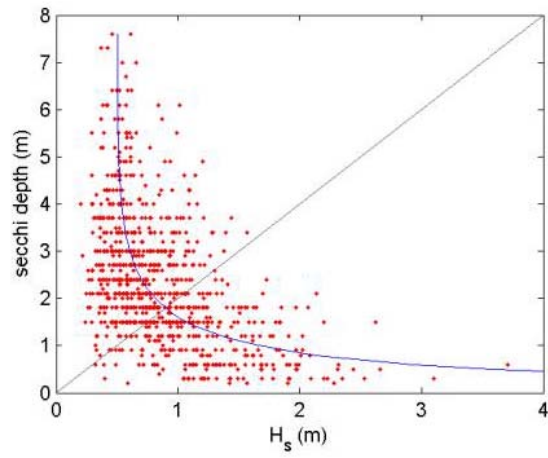


Figure 4. Scatter plot of FRF 17-m buoy wave heights vs. pier Secchi depths 2005-2010.

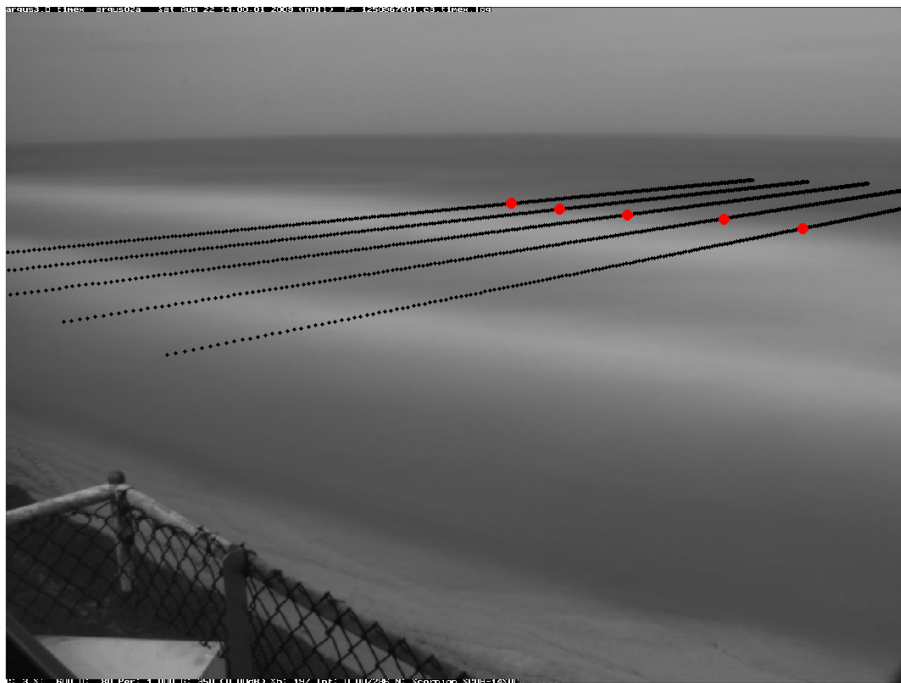


Figure 5. Argus 10-minute time exposure image taken on 1900 UTC August 22 2009 prior to the peak wave height for Hurricane Bill from camera C3, showing pixel transects (black dots) and selected surf zone limit (red dots).

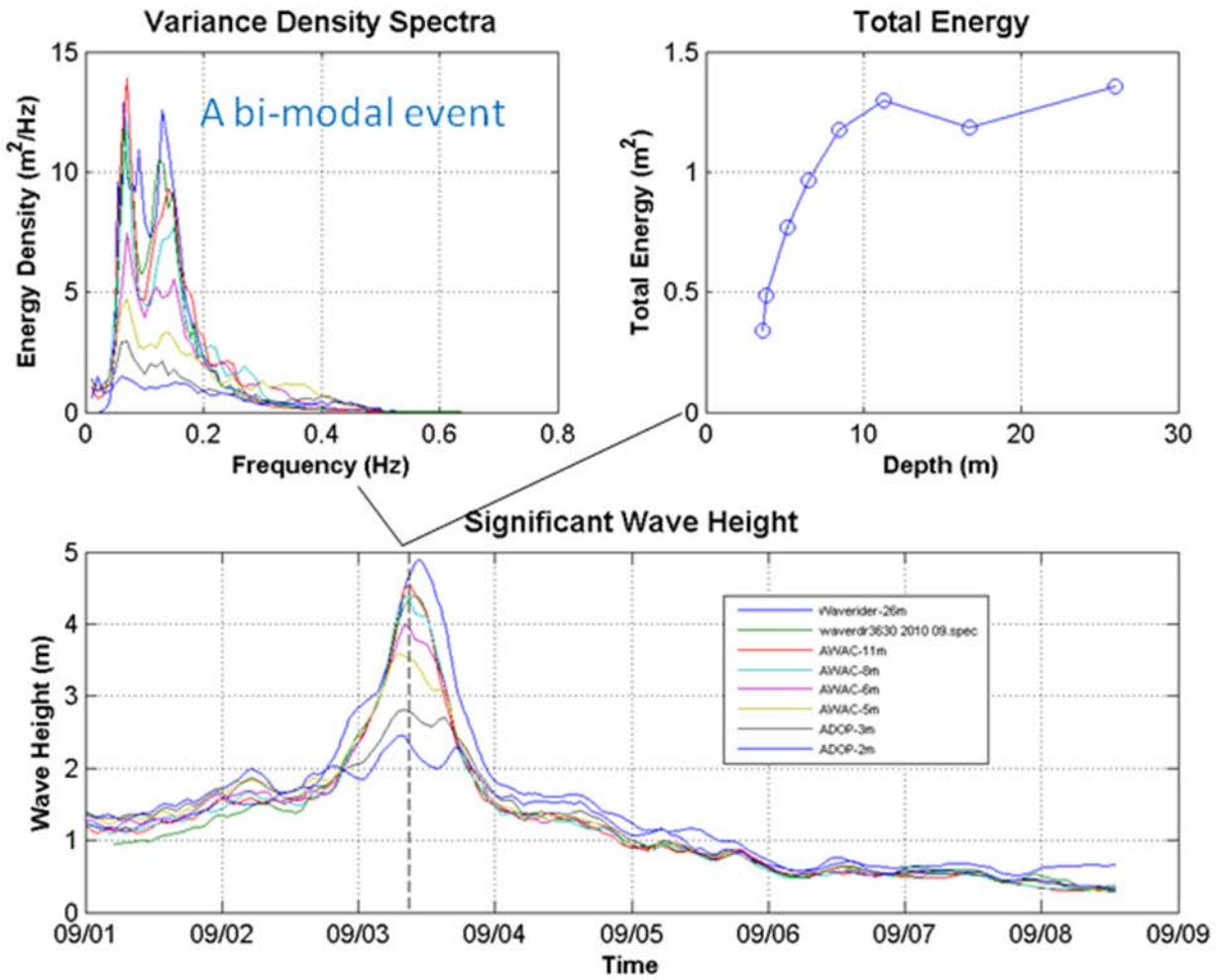


Figure 6. FRF cross-shore wave array data from Hurricane Earl (September 2010). Upper left panel: energy-frequency spectra from peak of event; Upper right panel: Total energy across the array at the peak of the event; Lower panel: time series of significant wave heights from all array elements.

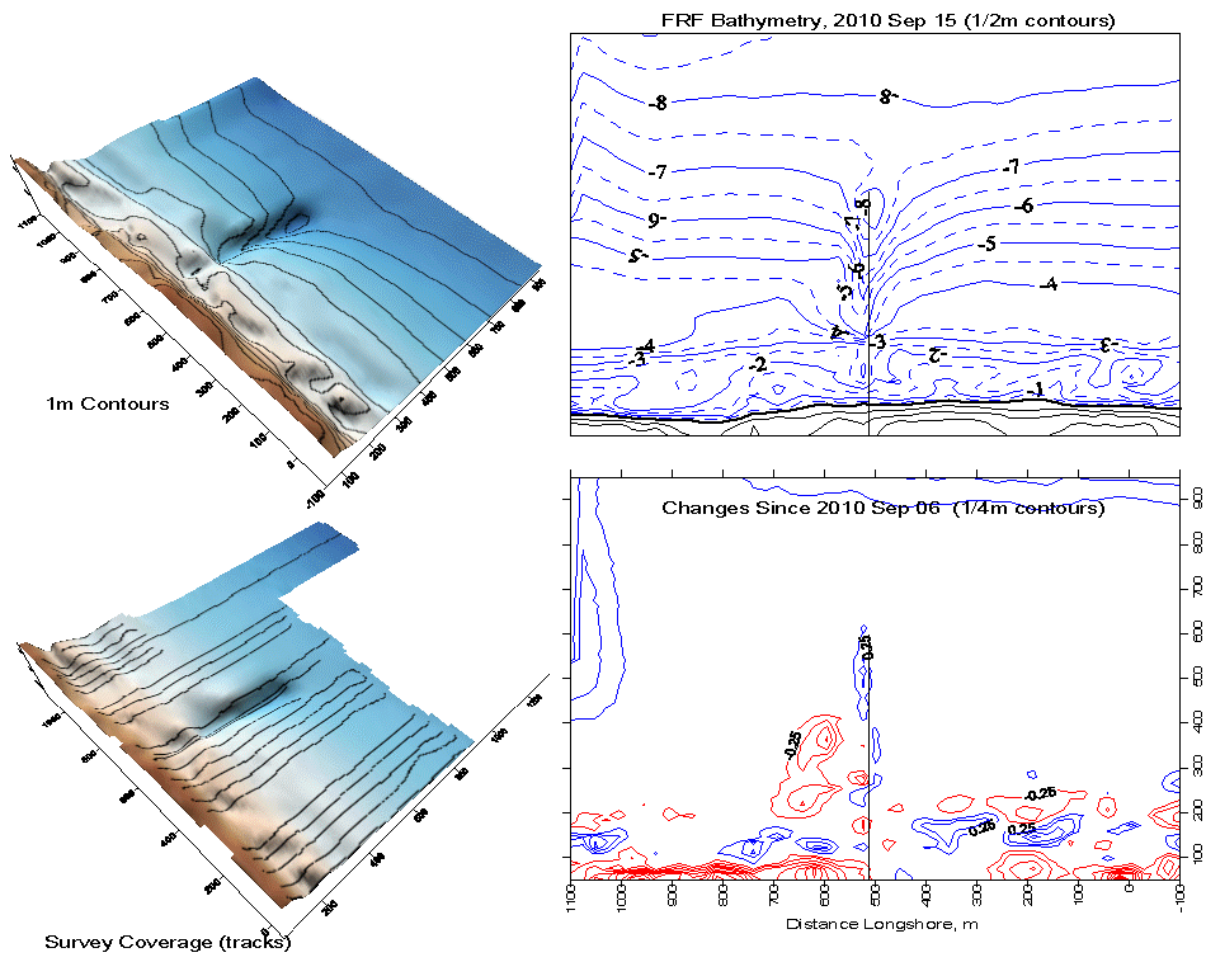


Figure 7. Results of 15 September 2010 bathymetric survey.



Figure 8. Surf Zone Optics experiment team at project cookout.