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14. ABSTRACT
The rip current field resulting from the transformation of surface gravity waves over offshore submarine canyons has been studied. Employing a wave transformation model and a wave-induced circulation model over observed bathymetry we find that wave height variations associated with undulations in the canyon contours cause rip current circulation cells with alongshore spacing of O(100m) even though the nearshore bathymetry displays no variations at these length scales. Further, the predicted rips correspond to observed rip currents during the Nearshore Canyon Experiment (NCEX). Motivated by these results we study the relationship between O(100m) scale variations in offshore bathymetric contours and the resulting rip current field in the nearshore.
We have then extended our work to the study of the rip current field during almost a month of the NCEX experiment ranging from Oct 9, 2003 through November 1, 2003. The location, strength and persistence of the rip current during this time and the predictability of the rip system as a function of the characteristics of the incoming wave field has been has been analyzed in detail.

15. SUBJECT TERMS
waves over submarine canyons, nearshore currents, rip currents

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Final report – Prediction of nearshore waves and currents: Model sensitivity, confidence and assimilation

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LONG-TERM GOALS

Our long term goal is to gain a thorough understanding of the processes affecting the wave and circulation fields in the surf zone, and to develop integrated observation and modeling systems that are able to continually observe and predict them.

OBJECTIVES

This proposal focuses on understanding the capabilities of wave and circulation models for the nearshore and analyzing the relationship of the predictions from these models to remote sensing data. Our objectives are geared towards the integration of wave and circulation models with remote observations (primarily from video-based observation) as we progress towards integrated observation-prediction systems and include efforts to

- evaluate the performance of nearshore wave and circulation models (predicting wave height, wave direction, longshore and rip currents) via statistically significant number of comparisons with observations. Data sources are Duck, NCEX and other locations covered by Argus. This is distinct from previous efforts since it will involve comparison with the *entire* (or nearly entire) available measurement period for waves and currents, yielding statistically relevant estimates of model skill.
- quantify the sensitivity of nearshore wave and circulation models to input and boundary conditions (in particular bathymetry and incident wave spectra). Assess confidence in the resulting estimates, assess predictability of the waves and circulation at a given site, and provide model error magnitudes and correlations for assimilation methods.

APPROACH

Our approach is to simulate the wave and circulation fields at two different field sites (Duck, NC and NCEX near La Jolla, CA) primarily during periods of concentrated field experiments using several representative wave and circulation models. The available data ranges from in-situ observations, to remote sensing observations of surf zone width, wave dissipation, and surface current velocities. Our goal is to carry out comparisons for a statistically significant number of runs. This type of model scrutiny is rare in the literature; yet studies that exist (e.g. Ruessink *et al.*, 2001) can draw significant conclusions about the applicability and robustness of a modeling system. By simulating a statistically significant number of data runs we will quantify model skill and define confidence limits on our predictions. Further, estimates of model sensitivities will lead to a better understanding about the required accuracy of model input and boundary fields (such as measured bathymetry). Finally, estimates of the magnitude and spatial correlation of model errors can be assembled. Such estimates are a crucial step towards employing data assimilation methods that will lead to integrated observation/prediction systems.

WORK COMPLETED

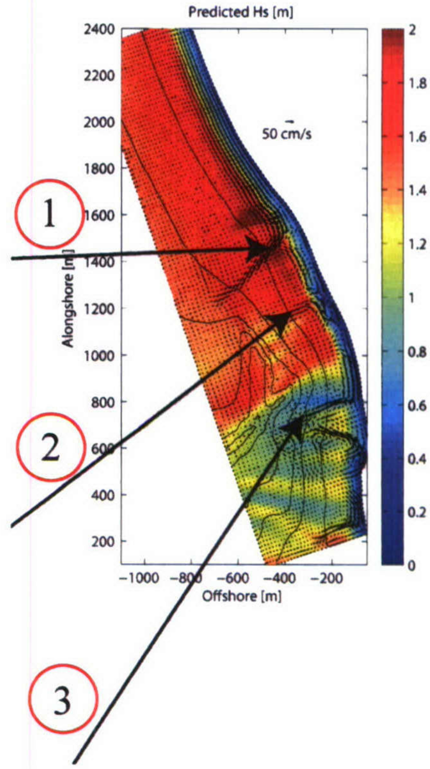
The rip current field resulting from the transformation of surface gravity waves over offshore submarine canyons has been studied. Employing a wave transformation model and a wave-induced circulation model over observed bathymetry we find that wave height variations associated with undulations in the canyon contours cause rip current circulation cells with alongshore spacing of O(100m) even though the nearshore bathymetry displays no variations at these length scales. Further, the predicted rips correspond to observed rip currents during the Nearshore Canyon Experiment (NCEX). Motivated by these results we study the relationship between O(100m) scale variations in offshore bathymetric contours and the resulting rip current field in the nearshore. To isolate the roles of possible bathymetric features, we construct a series of idealized case studies that include site characteristics found at NCEX that are conducive of rip current development, such as a curved shoreline, an offshore submarine canyon and undulations in the canyon contours. Results of this work have appeared in the Journal of Geophysical Research, Oceans.

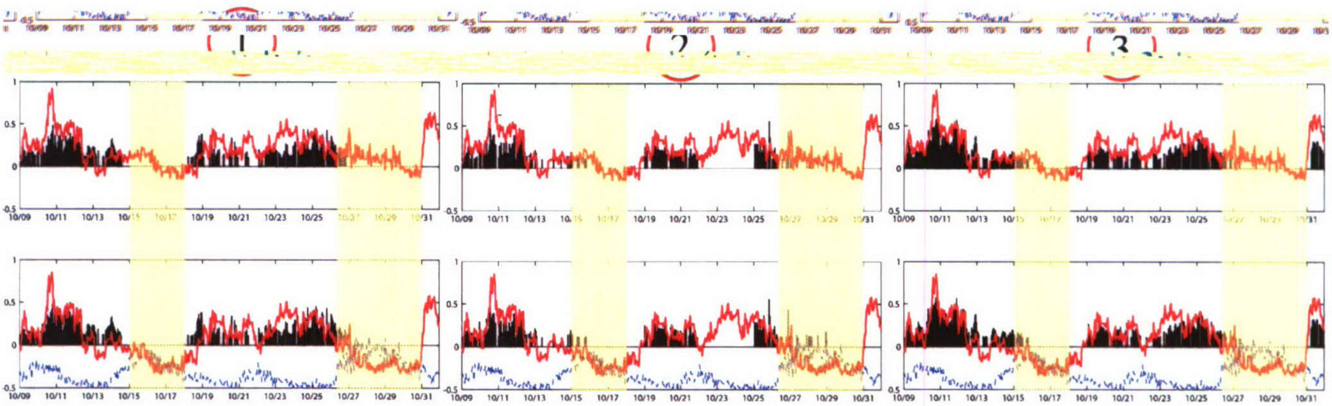
We have then extended our work to the study of the rip current field during almost a month of the NCEX experiment ranging from Oct 9, 2003 through November 1, 2003. Observed tide levels and incoming wave spectra are utilized for every hour during this period of time. Transition from one condition to the next is carried out over a few minutes and simulations are carried out for the whole hour, resulting in a continuous prediction of the velocities and mean surface elevation for a period of 23 days. The location, strength and persistence of the rip current during this time can now be analyzed in detail.

RESULTS

Analyzing results from the circulation model, we defined a rip current as any cross-shore velocity exceeding 10 cm/s exiting the surf zone. The outer edge of the surf zone was determined as the location of initial onset of breaking in the wave model. This analysis was performed for each hour of the 23-day simulation. Using this long time series we separated the results into northern sea/swell conditions and southern swell conditions. For northern sea/swell conditions rip current velocities were linearly related to variations in wave energy (r^2=0.75) during conditions with significant wave height larger than 0.75m. Consequently we refer to these conditions as high-energy waves. For all northern wave simulations rip currents developed for all recorded wave heights. However, we found that the alongshore location of the rip currents depended on the peak period. In particular, northern seas generated rip currents near Blacks beach and further north, whereas northerns swell generated rip currents throughout the domain including south of the Scripss pier. For southern swell conditions few rips, if any, were predicted. Southerns swell in general was not as energetic as northern waves; however, sensitivity analysis using larger soutern waves indicated that rips would still not be predicted. Figure 1 demonstrates the frequency and strength of observed rip currents at 3 of the 8 locations we tracked. Figure 2 and Figure 3 show the correspondence between of predicted currents and Argus video images as well as in-situ current observations.

Figure 1: *(right)Predicted significant wave height (color contours) overlayed by predicted velocity vectors. Identified are 3 major rip currents starting with the first rip at the Blacks beach site progressing south. (below, upper panels) Significant wave height (red) shifted down by 0.75m and resulting rip current strength for the three identified rip currents (black bars). (below, lower panels) Significant wave height shifted down by 0.75m for waves approaching from the north (red) and south (blue). Rip currents are consistently present during energetic northern waves but not during southern waves even if they are equally energetic (see last shaded area in each plot).*





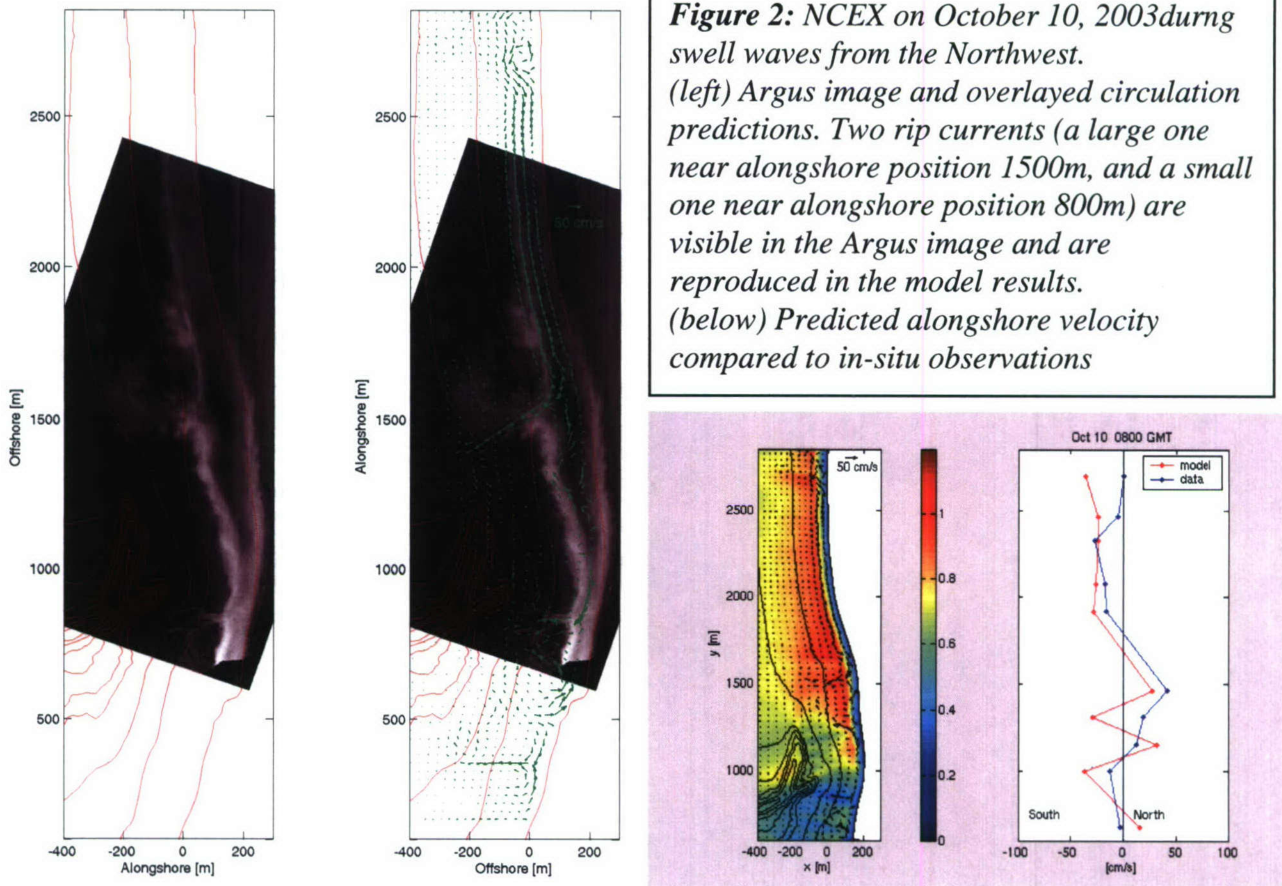


Figure 2: *NCEX on October 10, 2003durng swell waves from the Northwest. (left) Argus image and overlayed circulation predictions. Two rip currents (a large one near alongshore position 1500m, and a small one near alongshore position 800m) are visible in the Argus image and are reproduced in the model results. (below) Predicted alongshore velocity compared to in-situ observations*

IMPACT/APPLICATIONS

As part of this study we found that the development of the rip currents was controlled by the contour undulations rather than the presence of the submarine canyon. This suggests that rip currents could also be present for situations with undulating offshore contours that are, on average, parallel to the shoreline of an otherwise planar bathymetry. This result was, in fact, obtained in early simulations for such a simplified bathymetry. This finding has important ramifications for nearshore scientists because often times highly resolved surveys are only conducted in the surf zone where in-situ data is concentrated. In situations where the offshore bathymetry dictates nearshore circulation patterns, future modeling efforts will be hindered without high-resolution offshore surveys. We are currently assessing the accuracy with which offshore bathymetry needs to be available for accurate prediction of rip current locations.

TRANSITIONS

The work on the project will lead to a robust modeling tool which is capable of predicting the time-varying circulation field in the nearshore region. The model code developed herein will be available to the engineering and science communities. The resulting model can at a later date be transitioned to allow for operational use in hindcasting, nowcasting and ultimately forcasting circulation in the nearshore region. Alternately, the advances made herein can be incorporated into any such tool that the Navy may already be using.

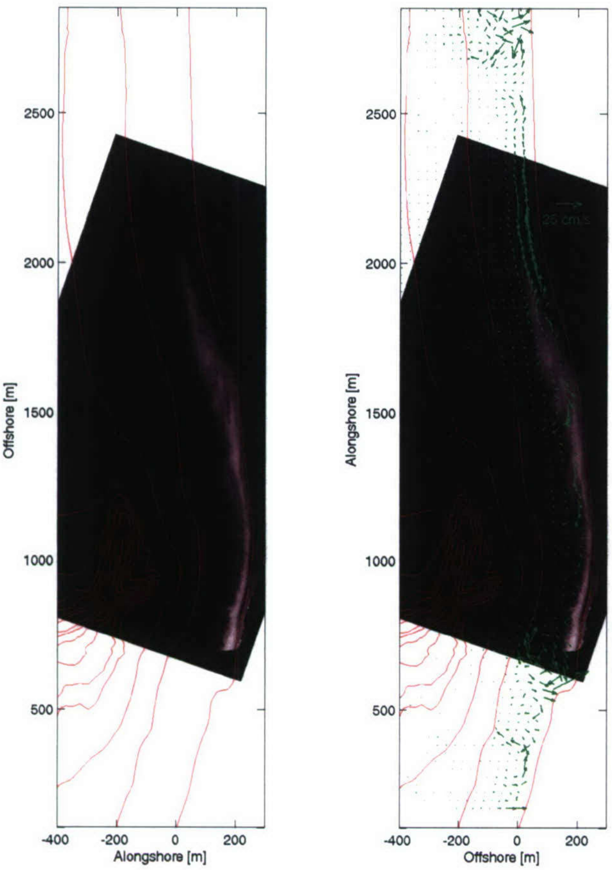
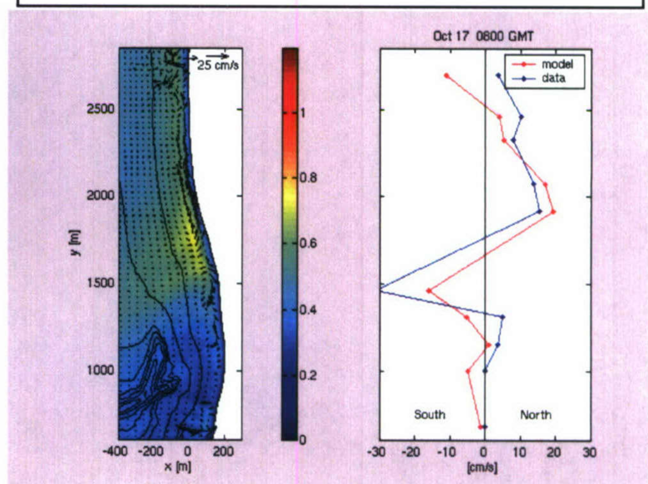


Figure 3: *NCEX on October 17, 2003 during swell waves from the Southwest (left) Argus image and overlayed circulation predictions. Two rip currents (a large one near alongshore position 1500m, and a small one near alongshore position 800m) are visible in the Argus image and are reproduced in the model results. (below) Predicted alongshore velocity compared to in-situ observations*



RELATED PROJECTS

This projects relates most closely to other projects that deal with the collection and processing of field data at the two sites of interest, namely Duck, NC and NCEX. Hence our collaborators include the video and radar remote sensing group (Lippmann, Holland, Holman, Frasier), in-situ group (primarily through Drs. Guza and O'Reilly).This study utilizes some models that are explicitly a part of the NOPP-funded nearshore community model effort. Both the NOPP-model and Delft3d are now available for use and can be utilized as it becomes necessary. The focus here is not in a specific model but rather on the underlying physics that form the basis for the models. The findings that will result from this study should be beneficial to researchers using a variety of wave and circulation models.

PUBLICATIONS

Long, J.W., and H.T.Özkan-Haller, Offshore controls on nearshore rip currents, *J. Geophys. Res.*, 110, C12007, doi:10.1029/2005JC003018, 2005.

Long, J.W., and H.T.Özkan-Haller, Temporal Response of Wave Group Forced Vortices, *J. Geophys. Res.*, in review, August 2007.