

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

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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 $O(100\text{m})$ 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 $O(100\text{m})$ 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 is in press in the Journal of Geophysical Research, Oceans.

RESULTS

Simulations of the wave and circulation field during the Nearshore Canyon Experiment indicate that features of the circulation field could be closely tied to undulations in the walls of the offshore canyon, especially evident in the 30m to 40m-contours (see Figure 1). Further, the predicted rip currents showed correspondence with rip currents observed in the NCEX video data (see Figure 2). We further performed a sequence of idealized tests to determine the relative importance of the large-scale structure of offshore bathymetric features (i.e. submarine canyons) and the finer details of those features (i.e. undulations) in controlling rip current location. Our results show that the a curved shoreline or an offshore submarine canyon are unable to produce the observed short-scale circulation systems (see Figure 2), while wave refraction over undulations in the canyon walls at length scales of $O(100\text{m})$ provides a sufficient disturbance to generate alongshore wave height variations that drive multiple rip currents for a variety of incident wave conditions (see Figure 3). Hence, these case studies showed that it was the specific details of the offshore bathymetry that dictated the refraction patterns responsible for driving rip currents in particular locations and that the number of rip currents was drastically reduced when no undulations were present. In other words, the development of the rip currents was controlled by the contour undulations rather than the presence of the submarine canyon.

Our analyses for various offshore wave conditions indicate that the presence of rip currents is closely tied to the period and direction of the incident waves. In particular, we found that waves with relatively short periods are generally unaffected by the presence of the canyon and rip currents do not form. Similarly, waves approaching at large angles of incidence induce a strong alongshore current which dominates the nearshore circulation.

Evaluation of the alongshore momentum balances indicates that the traditional balance outside the surf zone between the incident wave forcing and gradient in the mean water level is preserved, except where the rip current jet exits the surf zone and nonlinearity is dominant. Similarly, inside the surf zone and away from the circulation cell the balance is between the incident wave forcing and competing bottom friction. Within the circulation cell, either inside or outside of the surf zone, we see that the advective acceleration terms balance a large portion of the alongshore pressure gradient with bottom friction accounting for the remainder, indicating that the inertia of the current is important. The alongshore momentum balances also show that the initial rip current location is dictated by a balance between the gradients in radiation stress forcing and the pressure gradient induced by variations in the mean water surface elevation. Nonlinear processes, however, arise within minutes of the start of the simulation and have a pronounced effect on dictating the final location of the rip current. Hence, inertial effects are important in determining rip current location and a nonlinear modeling scheme is generally required for accurate predictions of rip current location.

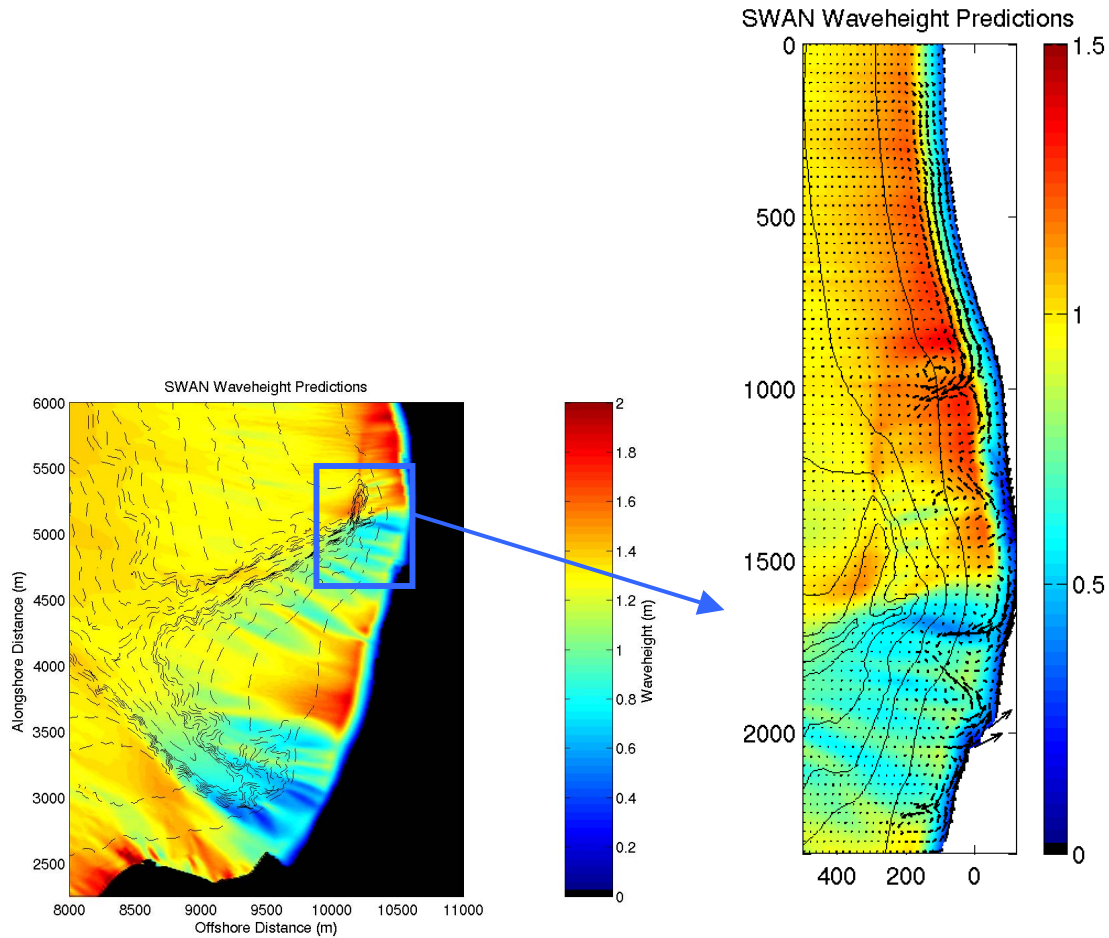


Figure 1: (left panel) Spatial variation of the predicted wave height (using SWAN). Note the focusing and defocusing patterns formed near the coast due to refraction over the undulating bathymetric features near the canyon walls. Dashed lines indicate contours every 10m. (right panel) the predicted mean circulation pattern near Blacks Beach overlaid on the wave height variation

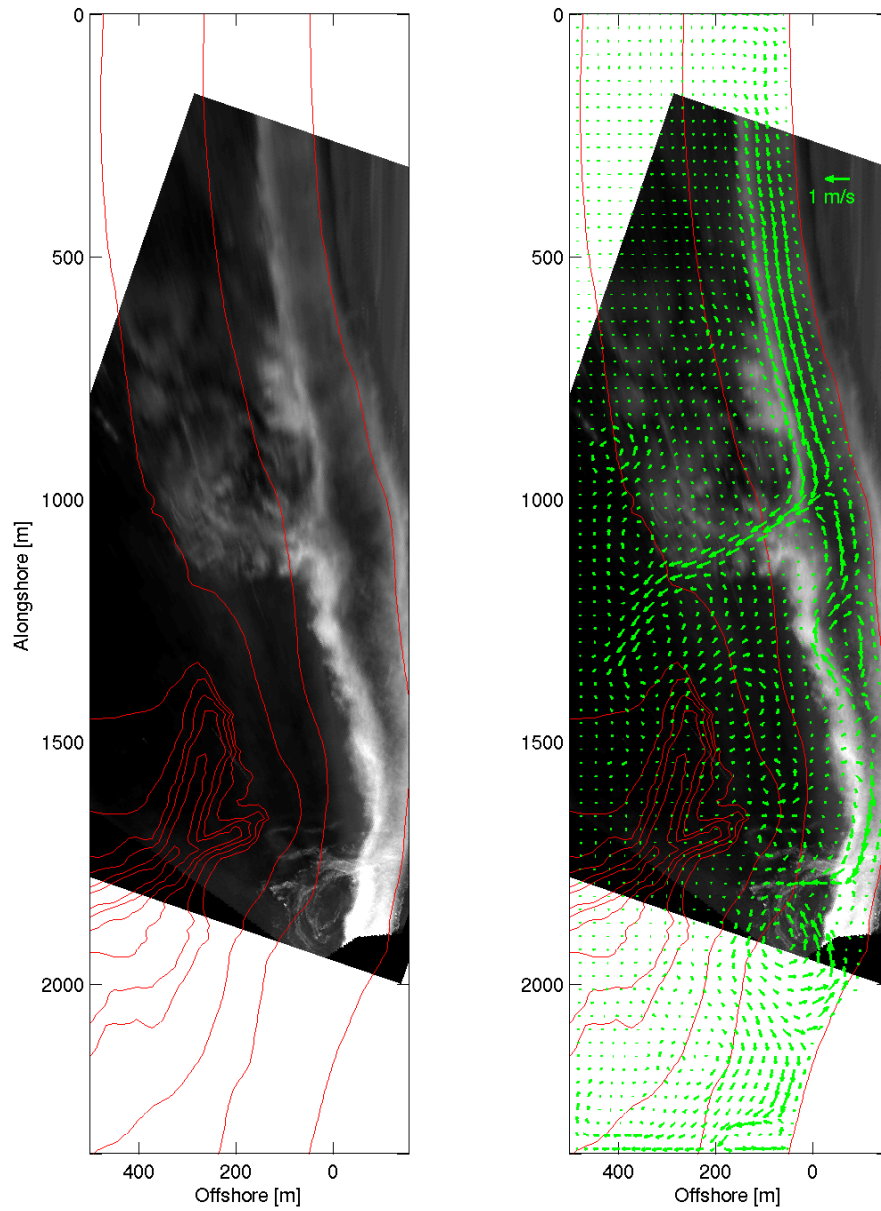


Figure 2: (left panel) Argus image for October 10, 2003 overlaid onto the circulation model grid. Red lines indicate bathymetry contours. Evident are two rip currents around $y=1000\text{m}$ and $y=1750\text{m}$. (right panel) Current vectors resulting from the circulation model simulation are overlaid onto the Argus image. It is evident that the predicted rip currents correspond closely to the observed rips.

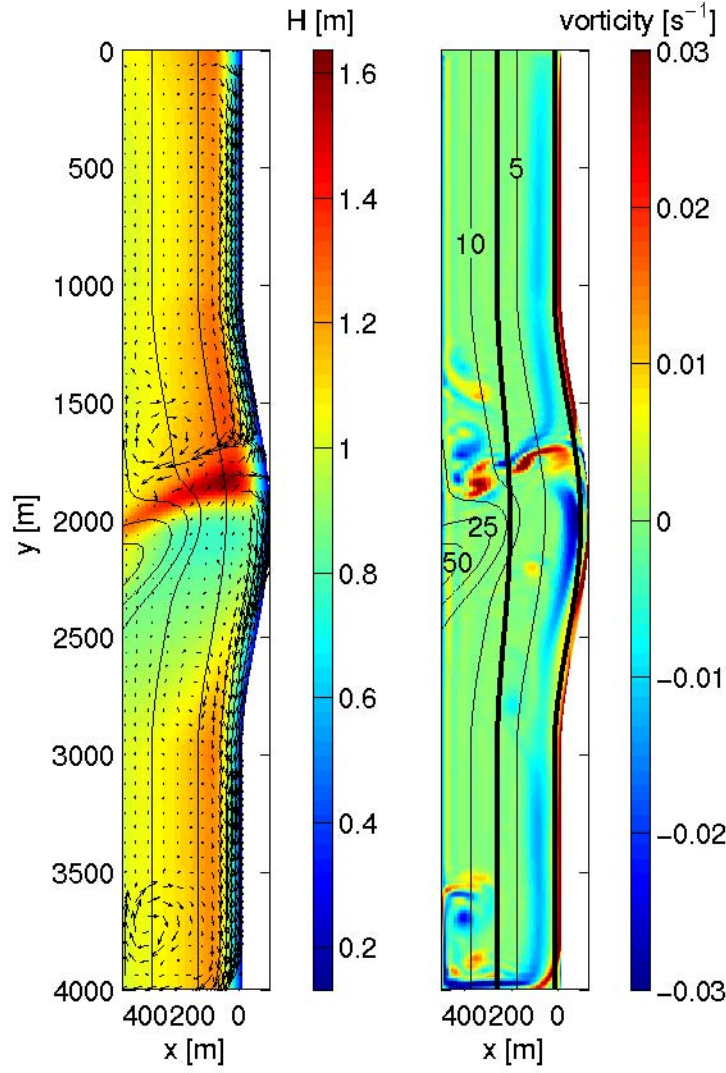


Figure 3: Circulation for an idealized canyon with smooth walls (left panel) Current vectors resulting from the circulation simulation overlayed onto the wave height variation. Bathymetry contours are indicated with thin solid lines. The circulation field contains one strong rip current to the north of the canyon tip. (right panel) Snapshot of the vorticity field indicating the location of the rip current.

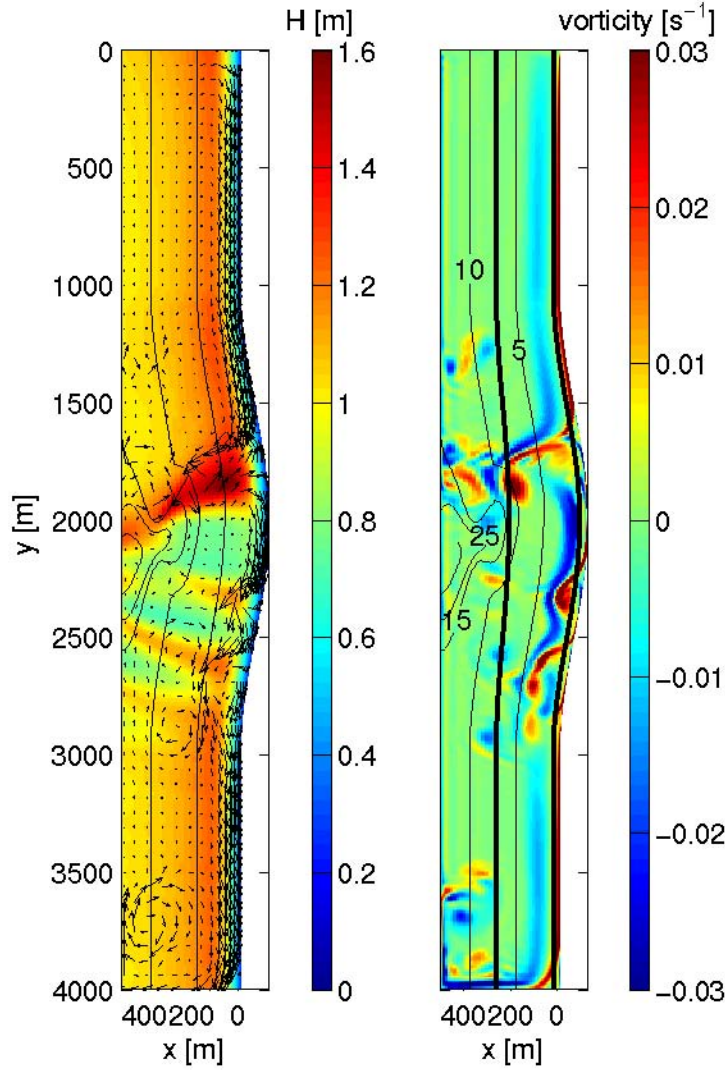


Figure 4: Circulation for an idealized canyon with undulating walls (left panel) Current vectors resulting from the circulation simulation overlayed onto the wave height variation. Bathymetry contours are indicated with thin solid lines. The circulation field contains multiple rip currents. The rip current to the north of the canyon tip is still present. However, multiple additional rip currents result due to the effects of the undulating canyon contours. (right panel) Snapshot of the vorticity field indicating the locations of the rip currents.

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 forecasting circulation in the nearshore region. Alternately, the advances made herein can be incorporated into any such tool that the Navy may already be using.

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.*, [in press, refereed], 2005.