Evolution of surface gravity waves over a submarine canyon

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Abstract: The effects of a submarine canyon on the propagation of ocean surface waves is examined with a three-dimensional coupled-mode model for wave propagation over steep topography. Whereas the classical geometrical optics approximation predicts an abrupt transition from complete transmission at small incidence angle to no transmission at large angles, the full model predicts a more gradual transition with partial reflection/transmission that is sensitive to the canyon geometry and controlled by evanescent modes. Model results are compared with data from directional wave buoys deployed around the rim and over Scripps canyon, near San Diego, California, during the Nearshore Canyon Experiment (NCEX). The coupled-mode model yields accurate results over and behind the canyon. Results are also compared with two widely used models which assume a gently sloping bottom: a parabolic refraction-diffraction model, and a spectral refraction model based on backward ray tracing. The parabolic refraction-diffraction model and the refraction model also capture the general variations in wave energy around the canyon, but respectively over- and under-estimate the low wave energy levels beyond the canyon.

INTRODUCTION

Observations of ocean swell transformation over the Scripps and La Jolla Canyons, collected during the Nearshore Canyon Experiment (NCEX), are compared with predictions of the 3D coupled-mode model for wave propagation over steep topography [*Athanassoulis and Belibassakis*, 1999 ; *Belibassakis et al.*, 2001]. Results are compared with two earlier models which assume a gently sloping bottom : a parabolic refraction/diffraction (Ref-dif) model [*O'Reilly and Guza*, 1993 adapted from *Kirby*, 1986a], applied in a spectral sense,

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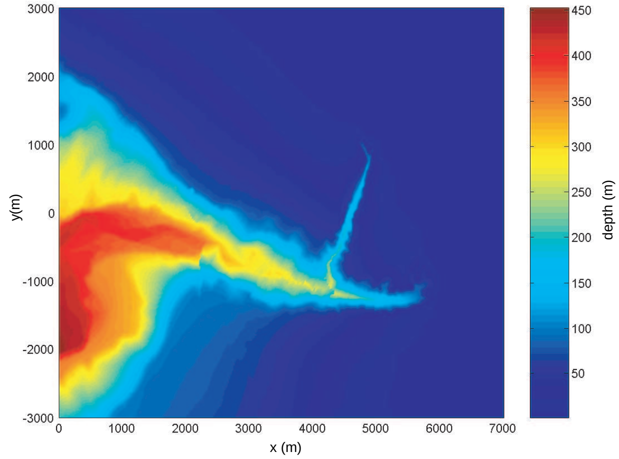

Fig. 1. Computational domain.

and a spectral refraction model based on backward ray tracing [*Dobson*, 1967 ; *O'Reilly and Guza*, 1993]. Comparisons of 3D models with field data are presented in the following section for a selected swell event observed during NCEX. Conclusions follow in final section.

WEST SWELL OVER SCRIPPS CANYON

The Refraction model, parabolic Ref-dif model, elliptic original (MSE) and modified (MMSE) mild slope models are compared with a coupled-mode (NTUA5) model (Athanassoulis and Belibassakis 1999). These models are applied to the real 3D bottom topography of the Scripps-La Jolla Canyon system, and compared with field data from directional wave buoys deployed around the rim and over Scripps canyon during NCEX.

Model Setup

The implementations of MSE, MMSE, NTUA5, and Ref-dif all use a computational grid contains $250 * 250$ points with a resolution of about 20 m (Fig. 1). The grid is rotated (45 deg.) to initialize the offshore boundary with the largest depths. Models are run for many sets of incident wave frequency and direction (f, θ). Transfer functions between the local and offshore wave amplitudes were evaluated at each of the buoy locations and used to transform the offshore spectrum. The refraction model directly computes transfer matrices between the offshore buoy and the buoys located close to the canyon.

Model-Data Comparison

A long west swell observed on 30 November 2003 at Torrey Pines wave buoy (located about 15 km offshore of Scripps Canyon) in the absence of wind sea was selected as case study. The narrow spectrum has a peak period of about 15.4 s, and a mean direction of 272 degrees, corresponding to an incidence angle θ_i (relative to the Scripps Canyon axis) of $65°$. The models predictions are compared with observations of six Datawell Directional Waverider buoys deployed around the head of Scripps Canyon (Fig. 2). Significant wave heights were computed from the measured and predicted wave spectra at each instrument location, including only the modelled frequency range (Fig. 3). The dramatic blocking effect of the Canyon is evident in the large reduction in wave height observed across the canyon.

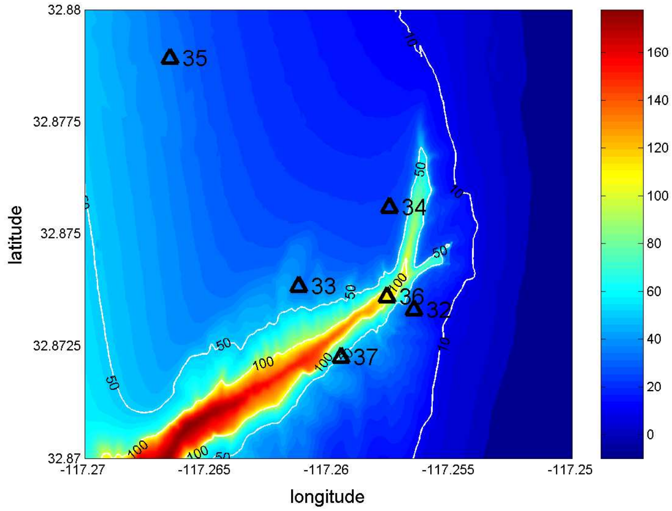

Fig. 2. Location of directional wave buoys at the head of the Scripps canyon

Up-wave of the canyon (instruments 33, 34, 35), all models are found to be in fairly good agreement with the observations, with little variation between these sites and the offshore wave height. Over and down-wave of the canyon (instruments 32, 36, 37), MSE, MMSE and NTUA5 agree reasonably well with the data, whereas Ref-dif overestimates the wave height. The parabolic approximation used in our version of Ref-dif does not account for the back-scattered wave field, leading thus to overestimation of the wave height over and down-wave the canyon. Additionally, Ref-dif is based on a small angle approximation (Kirby 1986), and thus may not accurately account for waves scattered by the canyon at large angles relative to the grid orientation. On the other hand, the refraction model underestimates the wave height at sites 32, 36 and 37. This under-prediction is consistent with the absence of wave diffraction or tunnelling through the canyon at large incidence angles.
Overall predictions of the refraction model are in fairly good agreement with observations [see *Peak*, 2004, for comparisons for the entire experiment], demonstrating that refraction is the dominant process in swell transformation across Scripps Canyon.

CONCLUSIONS

Observations of long period swell across a submarine canyon were compared with various mild-slope models and the coupled-mode model NTUA5 valid for arbitrary bottom slope [*Athanassoulis and Belibassakis*, 1999 ; *Belibassakis et al.*, 2001]. The NTUA5 model and elliptic mild slope equation models all yield accurate results whereas the parabolic Ref-dif model and the refraction model respectively over- and underestimate the low wave energy levels behind the canyon. The overestimation of the refraction model may be interpreted as the result of wave diffraction or tunnelling, i.e. a transmission of waves to water depths greater than allowed by Snel's law, which cannot be represented in the geometrical optics approximation. The refraction model thus predicts that all the wave energy is trapped for large incidence angles relative to the depth contours, although a small fraction of the wave energy is in fact transmitted across the canyon. On the other hand, the Ref-dif model, which is based on a parabolic approximation, and is limited to moderate variations in wave direction, cannot represent the reflection, which leads to overestimation of the transmitted wave amplitude.

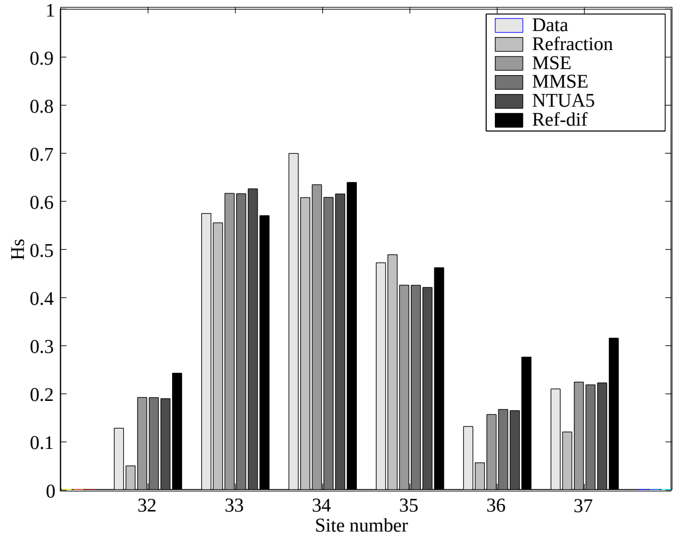

Fig. 3. Comparison of predicted and observed significant wave height at each instrument location.

Key Words

Waves, Refraction, Reflection, Propagation.

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