OregonWaveEnergy TRUST

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Wave Modeling Results

Baseline Observations and Modeling for the Reedsport Wave Energy Site

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on behalf of Oregon Wave Energy Trust

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Oregon Wave Energy Trust (OWET) is a nonprofit public-private partnership funded by the Oregon Innovation Council. Its mission is to support the responsible development of wave energy in Oregon. OWET emphasizes an inclusive, collaborative model to ensure that Oregon maintains its competitive advantage and maximizes the economic development and environmental potential of this emerging industry. Our work includes stakeholder outreach and education, policy development, environmental assessment, applied research and market development.

Wave Modeling Results

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Background

Offshore wave conditions along the Oregon coastline are measured at a handful of buoy locations where directional wave information is available. Most of these buoys are located in deep waters and incoming waves undergo changes as they travel from deep water onto the shelf where wave energy conversion arrays are likely to be deployed. These changes can be in the form of wave focusing or defocusing due to the presence of underwater banks, shoals, or canyons. Also, wave dissipation mechanisms such as bottom friction or wave breaking can be at play. Wave models can take into account such processes and produce predictions of the local conditions at the site of a wave energy conversion (WEC) array. Knowledge of local conditions can aid in the design of the devices for the specific local conditions to which they will be subjected and can also provide advance knowledge of wave conditions to power companies once a WEC array is in place.

The work performed herein was geared towards two goals. First, transformation of the wave field from deep water to the site of the buoy deployment was assessed. Second, preliminary predictions about the potential impact of the buoys on the wave field are made. The results are discussed separately below. Note that model code used herein is freely available soft ware and can be obtained through http://www.wldelft.nl/soft/swan/. Input files specific to this work can be obtained through the author.

Wave transformation

The Oregon wave climate is dominated by swells approaching from the southwest and more moderate waves approaching from the west or northwest in the intermediate periods. Using the deep water buoy at NDBC station 46089, we identified several representative wave conditions and show results herein for three of those conditions; namely, short-period waves approaching from the northwest that are typical of a local storm, a moderate swell condition from the west, and a large southwestern swell condition typical of winter storms. Details about these conditions are given in Table 1. Note that we utilize actual measured wave spectra from buoy 46089 as input.

Condition	T_p (sec)	H_s (m)	$_p$ (deg)	month
I	6.3	1.7	46 (NW)	July
II	12.9	4.2	-5 (W)	November
III	11.4	5.6	-44 (SW)	January

Table 1: *Characteristics of identified typical wave conditions I, II and III. Noted are peak period (T_p), significant wave height (H_s), and peak angle of incidence measured clockwise from North ($_p$) and the month this condition is most commonly observed.*

We utilized historical bathymetry assembled by the National Geological Data Center (NGDC) and created a model grid that covers a large portion of the Oregon coastline (see Figure 1). The southern boundary of the grid is near the OR-CA border and encompasses 267km in the alongshore direction. The offshore boundary of the grid is located just offshore of the shelf break and covers 86km in the cross-shore direction to the shoreline. There are several bathymetric features contained in the domain that may affect incoming waves. In particular, the Stonewall and Heceta bank systems have the potential of focusing waves near the WEC site when waves approach from the northwestern direction. In this case, the NDBC buoy 46229 is conveniently located in the lee of the banks; hence, comparison of model results with this buoy can lead to verification of refraction predictions. Note that a smaller model domain that would use measured wave spectra at 46229 was also considered, but this would only be advisable if we determine that focusing effects due to the banks are minor.

We determined grid resolution with standard convergence tests and arrived at 200m resolution in the alongshore direction and 100m in the cross-shore direction. The wave spectra are resolved with 5 degree bins in direction and a total of 21 bins in frequency between 0.05Hz and 0.25Hz.

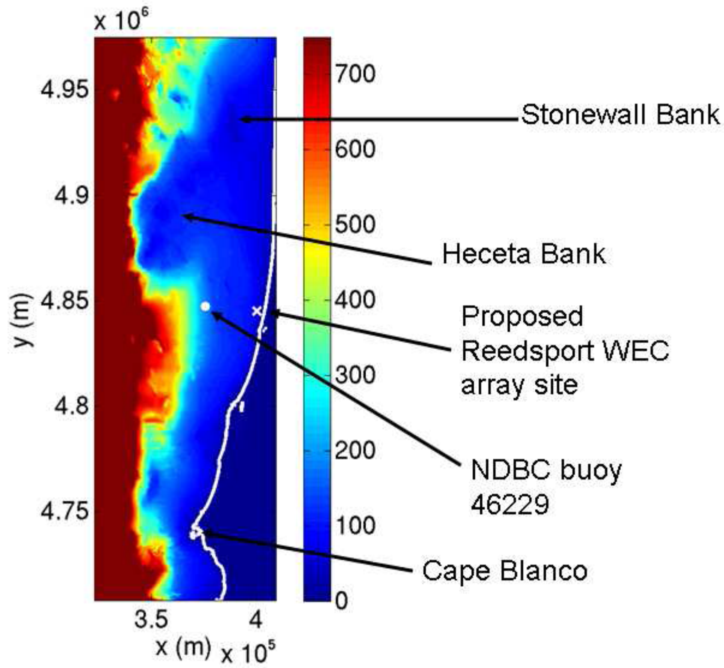

Figure 1: *Water depth within the computation domain. The Stonewall and Heceta Banks, the site of the proposed WEC array site, location of NDBC buoy 46229 and a few other sites are also included for reference.*

Using the bathymetry and incoming spectral information as input, we utilize the spectral wave transformation model SWAN (Simulating Waves Nearshore) for the identified representative wave cases and estimate the wave field in the entire domain. NDBC station 46229 at approximately 190m depth is used as a validation point, and we also determine the expected wave spectra at the proposed WEC array site.

Figure 2 shows results for the three identified ca ses, Figure 3 shows the evolution of the wave height across the shelf at an alongshore position that corresponds to the position of buoy 46229. For

Case I involving moderate short-period waves from the NW, waves evolve minimally over the shelf. This is because the wave period is relatively short (~6sec); and these short waves are still in deep water at the water depth of the banks. In contrast, the longer period waves associated with Cases II and III (~12sec) are affected by the presence of the banks. However, because of the primary direction of propagation, these effects are not significant near the site of the proposed WEC array. For Case III when waves approach at high angles from the south, Cape Blanco causes a shadow that results in reduced wave height at the proposed WEC site. The predicted reduction is also observed by buoy 46229 (see Figure 3). The waves that reach the WEC site under these circumstances have refracted around Cape Blanco and therefore display lower angles of incidence compared to locations further offshore (see Figure 3). In contrast, waves associ ated with Case II does not experience significant refraction at the transect corresponding to the WEC array site (see Figure 3). This is because these waves approach almost directly from the west and are therefore already perpendicular to the depth contours. For Case I, the period of the waves is very short, so the waves do not feel the bottom until quite shallow depths and wave angle reduction due to refraction processes is confined to a small area near the shore.

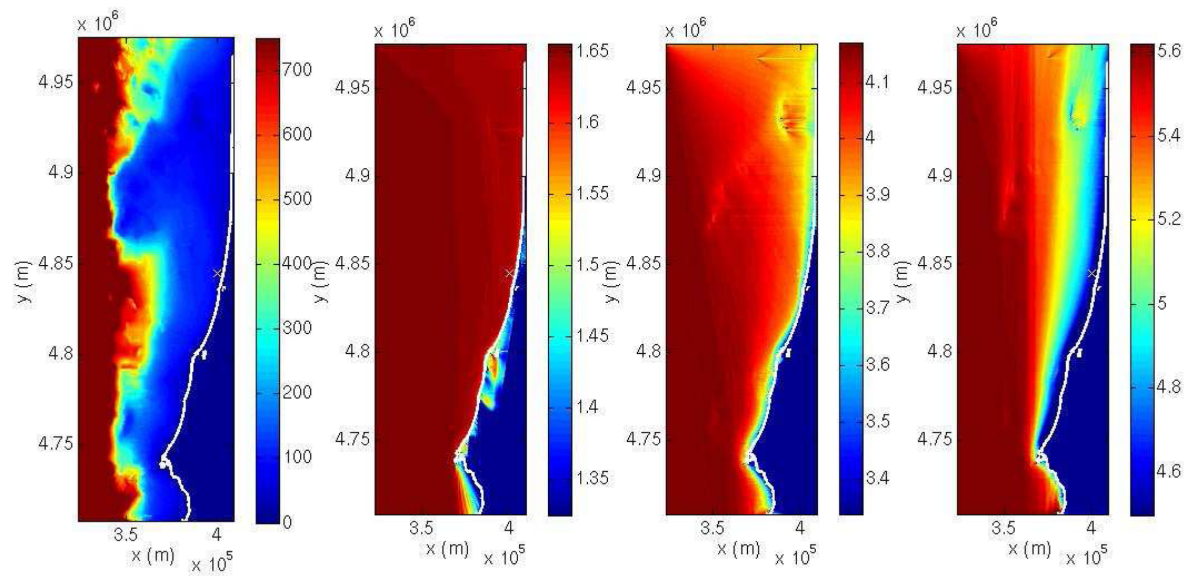

Figure 2: *panels left to right – water depth, wave height for wave conditions I, II and III (see Table 1). A right-handed coordinate system is used with x pointing east and y pointing north. Positions are indicated in northings and eastings in meters.The shoreline contour is outlined in white. The location of the proposed Reedsport WEC array is indicated with a white cross (near $y=4.85\times10^6$m). The color scale is indicated next to each panel. Note that it is different for each panel. The wave height scales indicate 20% variability around the offshore wave height to highlight the expected variability over the continental shelf.*

Comparison between predicted and observed wave heights near the WEC array site for the example cases discussed so far is favorable (see Figure 3) . Longer term simulations over several months were also carried out (see Figure 4) and suggest that t he wave model performs generally well, but there are distinct periods of discrepancy between predictions and observations. The causes for these discrepancies are currently not known but may be related to inaccuracies in the historical shelf bathymetry (which are based on shelf surveys that are not recent), inaccuracies in the input wave conditions, or model physics that isn't represented well.

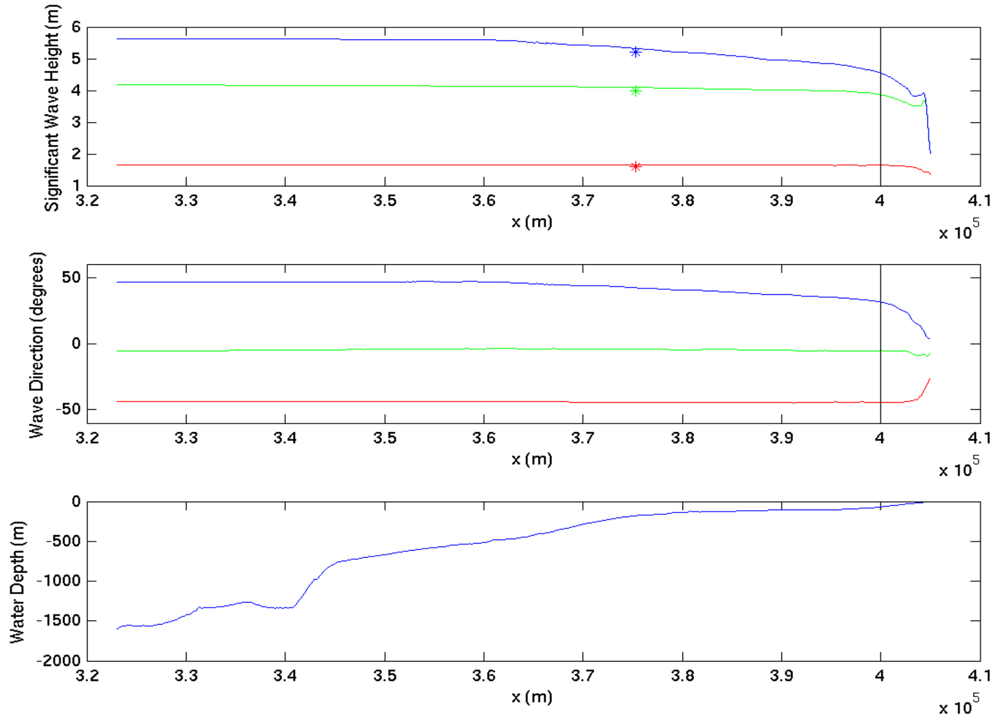

Figure 3: *Wave height (upper panel), wave angle (middle panel) and bathymetry (lower panel) along a cross-shore transect located at y=4847500m (which corresponds to the alongshore position of buoy 46229). The lines indicate results for waves from the NW (case I, red), from the W (case II, green) and from the SW (case III, blue). Symbols indicate measured wave height at buoy 46229.Wave angle is reported as 0 degrees if wave approach from the west. Waves approaching from the south (north) correspond to positive (negative) angles. Finally, the location of the proposed WEC array site is indicated with a black vertical line in each of the subplots.*

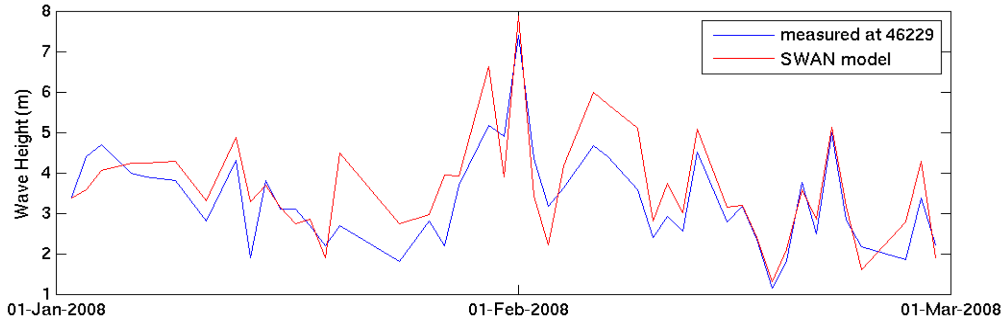

Figure 4: *Comparison between predicted (red) and observed (blue) wave height at NDBC buoy 46229 over 2 months of simulations.*

The model simulations also provide detailed information about the expected wave spectra conditions at the site of the proposed WEC array. For the three example cases discussed herein, the wave spectra are shown in Figure 5. As a result of this work a wave model domain has been setup that adequately addresses wave modifications over features (banks, capes, canyons) on the shelf. Validation of the model results will be ongoing as part of the wave forecasting work that is part of the NW National Marine Renewable Energy Center (NNMREC) and also as part of a new NOAA Sea Grant project (beginning February 2010) related to the prediction of waves along the entire OR coast.

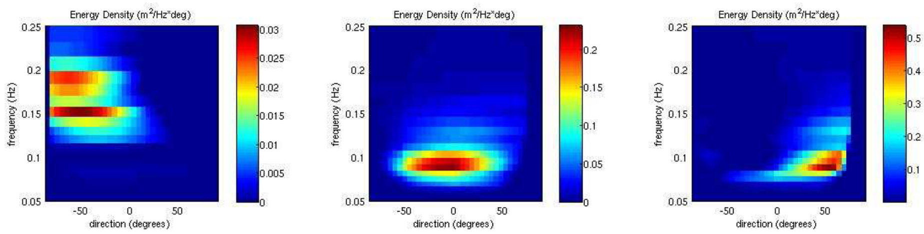

Figure 5: *Wave energy spectrum at the proposed location of the WEC array. Panels left to right at for Cases I, II and III. Values for the angles in these plots are relative to waves approaching directly from the W (indicated as 0 degrees). Positive (negative) angles correspond to waves approaching from the south (north).Color scales for each panel are indicated. Note that they differ for each case.*

Potential impact of buoys on wave field

A second goal of this work has been to make preliminary predictions about the potential impact of WEC buoys on the wave field. A detailed wave-structure interaction model that accounts for the detailed mooring characteristics of the buoys as well as their movement is beyond the scope of this project. Such a model would also require very large computational resources, so that the assessing an array of devices would not be feasible. Our approach has, therefore, been to use a high resolution sub-domain and represent the buoys empirically as stationary structures that absorb a certain amount of wave energy. For this purpose, we used a test case that accurately represents the conditions at the proposed WEC array site (e.g. water depth, distance from shore, slope of shelf at this location) and used very high spatial resolutions so that we could represent individual buoys as stationary structures in the model domain. We experimented with cylindrical or straight structures. Their size and energy absorption characteristics are then the empirical coefficients that can be altered to produce shadowing behavior similar to an actual wave buoy. Note that the behavior of each kind of device may be different, and detailed wave-structure modeling of the type discussed above will aid in the calibration of the coefficients. Such detailed modeling is planned as part of the NNMREC. However, direct observations of the shadow zone for a device are even more important, both to validate any detailed wave-structure interaction model, and also to calibrate coefficients in the model setup here.

Results from our empirical modeling for an array of 5 WECs are shown in Figure 6. The size and severity of the predicted shadow regions is a direct function of the size of the structures and their level of energy absorption. The values for these characteristics need to be calibrated with observations, which are not currently available. Therefore, the results shown herein are only a suggestion about the kind of wave height variability that may exist in the lee of an array of WECs. In this case (Figure 6), ~15% variability in the wave height is predicted directly in the lee of the array.

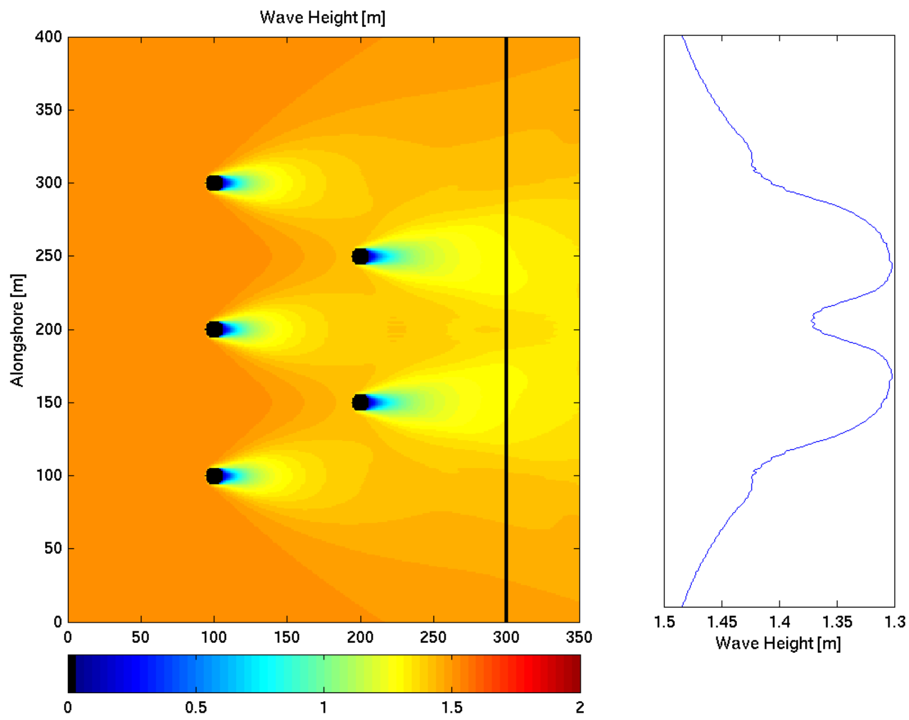

Figure 6: *Potential effect of 5 WECs arranged in an array. The left panel shows wave height in a region immediately surrounding the array. A transect at the cross-shore position of 300m is indicated. The right panel shows the wave height along this transect.*

The resulting variability in the wave height near a shoreline that is about 4km shoreward of the array is depicted in Figure 7. In the absence of a WEC array waves propagating towards shore experience a small decrease in wave height as they start feeling the presence of the bottom, then go on to shoal as the wave speed slows down and finally break near the shoreline. In this case, the surf zone is only ~100m wide. Next we carried out simulations that included the WEC array that we already examined in Figure 6. The array was placed about 4km from the shoreline. These simulations suggest that the small-scale variability (at the length scale of the distance between the structures) diffuses within about 1km of the array. The remaining larger-scale depression in the wave height persists to the shoreline, but at a reduced magnitude of about 3%. Calibration and validation of these results hinges on observations of the wave heights in the vicinity of an actual device.

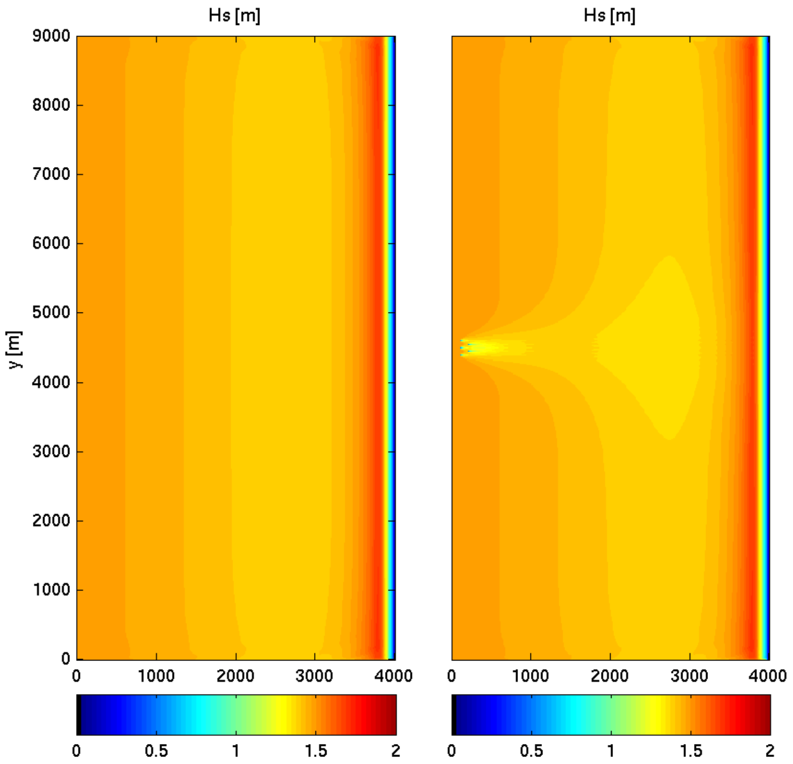

Figure 7: *(left panel) Wave height over a planar shelf with no WEC devices. Waves travel from the offshore boundary on the left-hand-side towards shore.*
(right panel) Wave height including the effect of a WEC array placed