WAVE RESOURCE ASSESSMENT: PREDICTING THE PEAKS OF EXTREME WAVE CONDITIONS

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INTRODUCTION

The potential failure, loss or destruction of a renewable energy device depends on its resilience to highly energetic conditions. Resilience is enhanced with a design effective in mitigating for device failure. Design for failure mitigation will rely on criteria which accurately convey the most perilous conditions which the device will encounter. Hindcasts of wave conditions are often used for device design purposes. However, hindcasts generally under-predict the most extreme wave heights, leading to unrealistic conclusions about hazardous sea-states [6]. A seven year hindcast was performed as part of a wave resource assessment study for the Northwest National Marine Renewable Energy Center (NNMREC) [1]. While the hindcast produced output which encompasses the entire Pacific Northwest coast (see Figure 1), this project gives

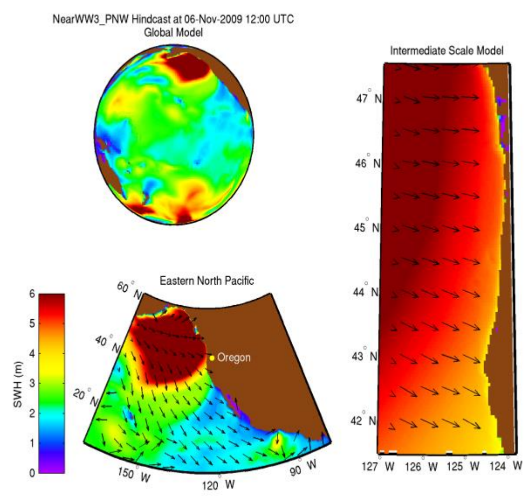

FIGURE 1 THREE NESTED GRIDS UTILIZED IN THE BASELINE MODEL. GARCIA-MEDINA ET AL [1].

special attention to the NNMREC wave energy converter test sites, which are located offshore of Newport, OR. This project focuses on studying the extreme events that occur during the seven year hindcast to understand when and why underprediction occurs. The project begins with a validation of model baseline performance using error statistics of bulk parameters. The validation is specifically focused on wave heights greater than six meters. Then a specific event is simulated with different model configurations to determine which implementation is best suited to capture peak extreme wave height. The different model configurations include permutations of wind input and physics package.

BASELINE MODEL

The baseline hindcast was performed with a spectral wave model, WAVEWATCH III [1]. Output spans the years 2004-2011 [1].

Model Implementation

The original simulation implements three nested grids of increasing resolution (see Figure 1). The outermost grid is a global grid at 1 degree by 1.25 degree resolution, the first nested grid is an Eastern North Pacific grid at 0.25 by 0.25 degree, while the the second nested grid spans the outer shelf of the Pacific Northwest Coast (approximately 41.5 degrees to 47.353 degrees North and from 125.25 and 123.75 degrees West) at a resolution of three arc-minute.

Model Validation

Validation of the hindcast for large waves is performed for a three-year period (between 2009-2011) by comparing the model output to buoy measurements. The buoy utilized is the National Data Buoy Center's (NDBC) Buoy 46050, which is the buoy closest to NNMREC's designated test sites.

Standard error metrics are computed and presented as a function of significant wave height (Hs) and energy

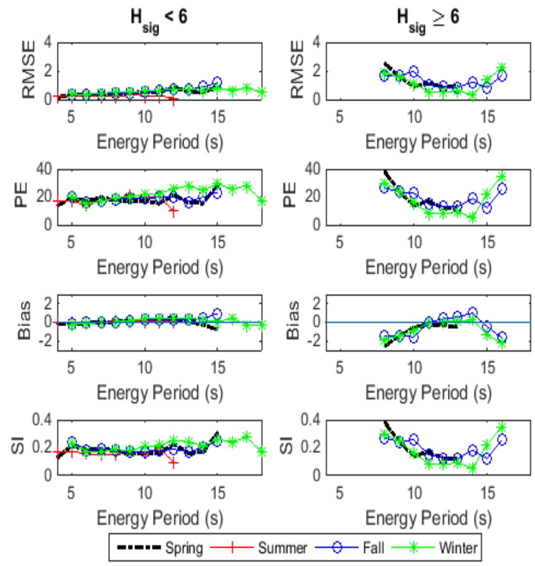

FIGURE 2 ERROR METRICS DIVIDED BY WAVE HEIGHT AND ENERGY PERIOD

period in Figure 2. Data points associated with significant wave heights greater than and including six meters are isolated in this validation for special consideration (see right panel). Error metrics considered include root-mean-squared-error, scatter index, percent error, and bias. A negative bias signifies a model underestimation, while a positive bias signifies a model overestimation. The model performs well for moderate conditions (see left panel of Figure 2) but poorly for extreme wave heights or energy periods (see right panel of Figure 2). Error values are, on average, higher for these extreme wave height values. More specifically, error values reach maxima for either relatively short or relatively long energy periods.

This validation will serve as a baseline from which future implementations of the model will improve.

MODEL CONFIGURATIONS

To optimize the model for

significant wave heights greater than six meters, the model inputs and operating mode are modified and resulting output is assessed. The new configuration utilizes a different wind input, which has increased spatial and time resolution as well as quality. The operational mode of the model has also changed in that a different physics package is utilized.

Input: Wind

The first parameter to be modulated is the wind input. The new wind input dataset has increased time resolution, spatial resolution and quality. The two wind input datasets to be compared are National Center for Environmental Prediction's (NCEP) Global Forecasting System (GFS) and Climate Forecast System Reanalysis (CFSR). The GFS wind data has a three-hour time resolution and 0.5 x 0.5 degree spatial resolution. In comparison, the CFSR dataset has an hourly time resolution and 0.312 x 0.312 degree spatial resolution. The CFSR is also of better quality in that NCEP has coupled oceanic and atmospheric processes, included a sea ice model in its analysis, and integrated interpolated satellite radiance data into the time series [2].

Physics Package: Dissipation Terms

The second parameter which is modulated is the utilized physics package. The baseline scenario implements the Tolman and Cholikov (1996) ST2 physics package, while the second model configuration implements the Ardhuin et al (2009) ST4 physics package [7,8].

The ST2 physics package is the default package for WWIII version 4.18, and the ST4 physics package is a new option associated with this WWIII version [3]. The ST2 physics package dissipates low and high frequency energy differently by using two distinct dissipation terms [3]. At the highest frequencies, a spectral roll off of f^{-5} is imposed [3]. Furthermore, the source term utilizes the air flow-wave interaction formulation as proposed by Chalikov and Belevich (1993) [3,4]. ST4

FIGURE 3 SIGNIFICANT WAVE HEIGHT TIME SERIES FOR SIMULATED EVENT

physics incorporates a dissipation term which considers the dissipation of the lower and higher frequencies to be interconnected; this dissipation term considers short and long wave interactions [3]. This term also treats dissipation differently in the turbulent or viscous regimes as nonlinear or linear, respectively [3]. It does not impose a spectral roll off for the highest frequencies, but a general shape of $f^{-4.5}$ occurs naturally in this region [3]. The source term is a modification of the Janssen (1991) formulation [3,5].

MODEL SIMULATION

The seven year hindcast time series is inspected to find large wave height (Hs ≥ 6m) events in which the model severely underestimates the peak wave height. While model performance is on average poor for extreme events, performance clearly decreases for certain events as opposed to others. One such event is chosen for simulation and closer inspection. The time series of this event is presented in Figure 4. It should be noted that this time series encompasses two events of significant wave height greater than six meters; the first occurs on November 17, 2009, and reaches a maximum wave height greater than nine meters, while the second occurs on November 19, 2009, and reaches a maximum wave height of approximately seven meters. The first event is a short-lived, significant increase in wave height, while the second sees a sustained significant wave height greater than six meters but no greater than seven meters.

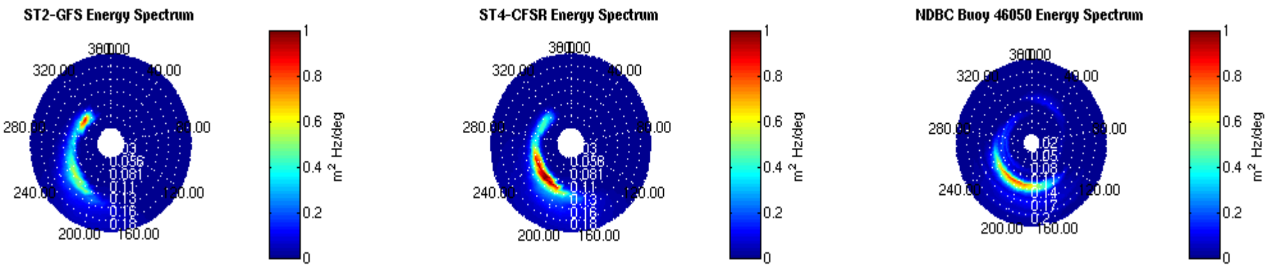

FIGURE 4 SPECTRAL OUTPUT FOR ST2-GFS, ST4-CFSR AND NDBC BUOY 46050 NOV. 17 1700

RESULTS

The most significant improvement in model performance occurs between the baseline model ST2 with GFS input (ST2-GFS), and ST4 with a CFSR wind input (ST4-CFSR). Comparisons are made with each model output and NDBC Buoy 46050 measurements. A significant wave height time series for each model is presented in Figure 3. With a focus on the peak wave height of the November 17 event, the ST4-CFSR combination clearly outperforms the ST2-GFS combination, with a maximum Hs of 8.4 m and 6.9 m, respectively. The second event on November 19, however, shows a slight overestimation by ST4-CFSR during the event onset. Error statistics of significant wave height is also used to quantify model performance. RMSE and bias of significant wave height for wave heights less than six meters and greater than six meters are presented in Table 1.

The ST4-CFSR combination outperforms the ST2-GFS combination in all categories of RMSE and bias except for bias for waves less than six meters. The RMSE for greatest wave heights, however, has decreased by 39%, and the bias shows a slight overestimation (0.16 meters) as opposed to underestimation (-0.65 meters) of the greatest wave heights.

TABLE 1. RMSE AND BIAS: SIGNIFICANT WAVE HEIGHT

Model	**RMSE**		**BIAS**	
	ST2-GFS	**ST4-CFSR**	**ST2-GFS**	**ST4-CFSR**
Hs < 6m (m)	0.89	0.85	0.51	0.66
Hs ≥ 6m (m)	1.00	0.61	-0.65	0.16

Finally, spectral analyses are also considered. Example energy spectra are presented in Figure 4. These spectra evolve during the first event development at approximately 1700 November 17. The ST2-GFS combination underestimates energy in certain direction and frequency bins, but overestimates in others with respect to the measured spectra as well as the ST4-CFSR combination. It suggests that the energy emanates from a northern direction and is of low frequency signature, while both the ST4-CFSR and NDBC spectra show the peak energy to be originating from a more southerly direction and of higher frequencies.

SUMMARY

For the first extreme wave event of this time series (that occurring on

November 17), capturing the peak wave height has clearly improved with a superior wind input and different physics package. It is interesting to note that the ST4-CFSR model does overestimate wave height during event onset (see Figure 3, November 16 and 19). Spectral comparisons of the most severe overestimation (see Figure 3, November 19), demonstrate that both ST2-GFS and ST4-CFSR overestimate energy in the northern direction and of lower frequency. Furthermore, the ST4-CFSR model overestimates in southern directions and in higher frequencies during this time. In most conditions, the ST4-CFSR model implementation predicts the peak wave height with greater skill than the ST2-GFS model.

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