WAVE MODELING TEST BED FOR RESOURCE ASSESSMENT

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INTRODUCTION

Hindcasts from third generation (3G) phase-averaged wave models are commonly used to estimate standard statistics for energy resource assessment and characterization. It is, therefore, important to investigate wave models and best modeling practices to evaluate and improve hindcast accuracy. We present results from hindcast simulations using two of the most widely used 3G phase-averaged wave models, WaveWatchIII (WWIII) (Tolman et al. 2010, 2014) and Simulating WAves Nearshore (SWAN) (The SWAN Team 2015). Results from the WWIII ST2 and ST4 physics packages are compared to investigate new source term formulations within the ST4 package, which, unlike its ST2 counterpart, models swell dissipation effects, and includes different growth and wave dissipation formulations. Results from the stationary (SWAN-S) and nonstationary (SWAN-NS) modes of the SWAN model are also compared to evaluate benefits of modeling the unsteady term in the spectral wave action balance equation.

METHODS

The model domain, which serves as the test-bed site, encompasses an area of 60 km by 60 km located off the Oregon coast near Newport, Oregon, which is shown in Figure 1 as the Central Oregon Domain. Figure 1 also shows the NDBC buoy locations, and the boundaries of the nested model grids. Three nested grids, within a global model grid, generate open wave boundary conditions for the local model domain. The nested grid scaling ratio is set to a value of approximately five to six to maintain a smooth transition between model results along the nested grid boundaries. This ratio results in a grid resolution of 265 m × 308 m for the local model domain.

The baseline models use 29 frequency bins, 24 direction bins, a logarithmic increment factor of 1.1 and a minimum frequency of 0.035 Hz, which results in a maximum frequency of 0.505 Hz. To the extent possible, the source term models for SWAN were selected to agree with those in WWIII.

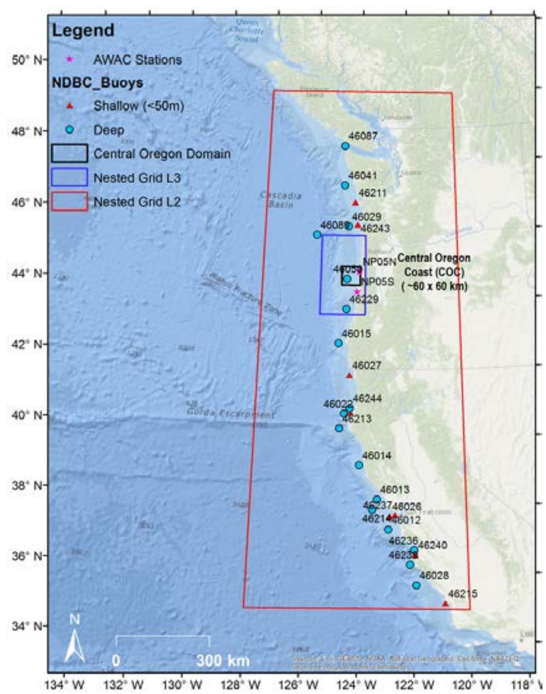

FIGURE 1 MODEL BOUNDARIES OF NESTED GRIDS (L2-L4) AND NDBC/AWEC BUOY LOCATIONS AT THE MODEL TEST BED.

Model skill is evaluated by comparing model results with observed data for six wave resource characterization parameters, including omnidirectional wave power (J), significant wave height (H_s), energy period (T_e), spectral width (ϵ_0), direction of maximum directionally resolved wave power (θ), and directionality coefficient (d_θ). Statistical error metrics include root-mean-square-error (RMSE), scatter index (SI), percent error (PE), correlation coefficient (R), bias (BIAS) and percentage bias (BIAS(%)). Computational requirements are assessed by calculating and comparing CPU-hours.

RESULTS

For the baseline model test case, a comparison of time series of the six IEC parameters show good agreement between parameters derived from WWIII, SWAN-NS, and SWAN-S hindcasts, and NDBC buoy measurements (Figure 2 and Figure 3). The computed performance metrics for each of the six IEC parameters, shown in Table 1, indicate that the model skills for all three model runs are similar. Correlation coefficients for J, H_s and T_e are all above 0.9. Comparison of SWAN-NS and SWAN-S results shows that model skill is only marginally improved with the unsteady term in the action balance equation.

Modeling swell dissipation effects with the WWIII ST4 package is found to generally improve the overall model results, as shown in Figure 4 and Figure 5; either directly in WWIII using the ST4 package, or indirectly in SWAN by inputting WWIII (ST4) open wave boundary conditions. RMSE, PE and SI are reduced only marginally, but observed reductions in bias towards over-prediction of measured values are reduced by half, ~0.1 m (5%). Conversely, model skills for predicting T_e are slightly reduced. PE slightly increases from ~12%, for the baseline model, to ~15%. Bias towards over-prediction of measured values increases from ~0.5 s to ~0.8 s.

A comparison between the predicted significant wave height time series from the WWIII model with finer spectral resolution, results from the baseline model, and observations at NDBC Buoy 46050, shows that increasing the spectral resolution, almost doubling the number of frequency bins, and increasing the direction bins by fifty-percent provides no improvement to WWIII model skill (predicting wave resource parameters).

The WWIII simulations required 31,488 CPU-hours, which is more than twice those required for the SWAN-NS simulations (13,572 CPU-hours), and more than forty times those required for the SWAN-S simulations (739 CPU-hours). The relative improvement in computational efficiency of SWAN-NS over the WWIII is not surprising given SWAN-NS uses an implicit numerical solver, while WWIII uses an explicit one. Stationary modeling with SWAN-S significantly reduces computational costs, but is not warranted when model domain dimensions exceed 100 km. The advantage of computational efficiency for SWAN indicates that SWAN is better suited for implementation of operational forecasting, which is critical to seastate-to-seastate control of WECs. The Nearshore Wave Prediction System (NWPS) (http://polar.ncep.noaa.gov/nwps/) implemented by the NCEP's Environmental Modeling Center (EMC) provides high resolution real-time operational forecasting for the US coastal waters. The high resolution nested model SWAN is driven by the operational WWIII model and improved National Digital Forecast Database wind.

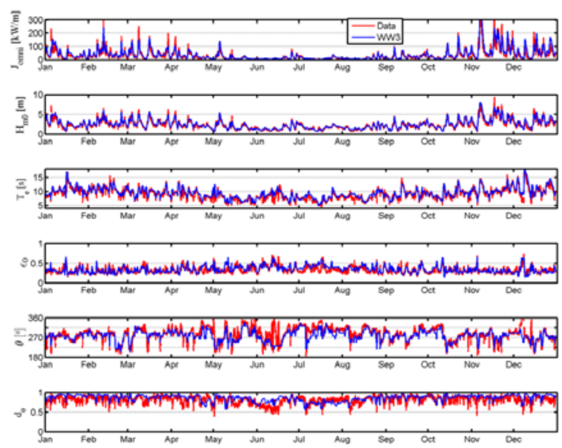

FIGURE 2. COMPARISON OF WW3 MODELED RESULTS AND OBSERVED DATA AT BUOY 46050.

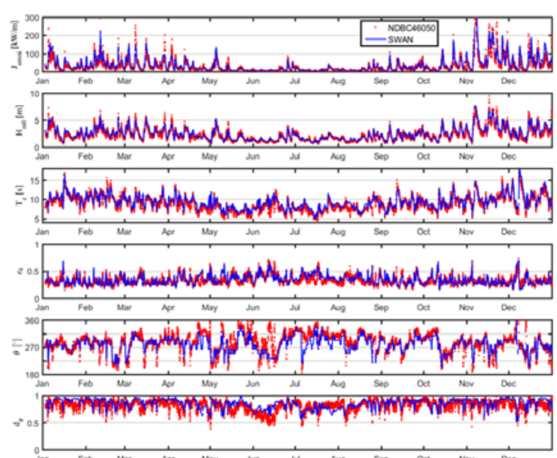

FIGURE 3. COMPARISON OF SWAN-NS MODELED RESULTS AND OBSERVED DATA AT BUOY 46050.

TABLE 1 PERFORMANCE METRICS FOR BASELINE SIMULATIONS

Statistic	Model	RMSE	PE (%	SI	Bias	Bias (%)	R
J (kW/m)	WWIII	20	59	0.64	6.1	19.7	0.91
	SWAN-NS	19	62	0.62	6.3	20.2	0.91
	SWAN-S	20	65	0.63	6.5	20.9	0.91
H_s (m)	WWIII	0.42	19	0.19	0.16	7.3	0.94
	SWAN-NS	0.44	21	0.20	0.18	8.1	0.94
	SWAN-S	0.45	22	0.20	0.19	8.4	0.94
T_e (s)	WWIII	0.98	12	0.11	0.50	5.6	0.90
	SWAN-NS	0.95	12	0.11	0.52	5.8	0.91
	SWAN-S	0.96	12	0.11	0.51	5.7	0.91
ϵ_0 (-)	WWIII	0.07	20	0.20	0.01	1.6	0.68
	SWAN-NS	0.06	20	0.19	0.00	0.7	0.72
	SWAN-S	0.07	20	0.20	0.00	1.1	0.71
θ (degree)	WWIII	22.8	8	0.08	-6.9	-2.4	0.74
	SWAN-NS	22.2	12	0.08	-6.6	-2.3	0.75
	SWAN-S	22.6	13	0.08	-6.6	-2.3	0.74
d_θ (-)	WWIII	0.10	15	0.13	0.05	6.2	0.48
	SWAN-NS	0.10	14	0.12	0.04	5.1	0.55
	SWAN-S	0.10	14	0.12	0.04	5.0	0.55

The present study establishes a test bed for evaluating other 3G phase-averaged wave models and physics packages, testing modeling methodologies, developing best practices, and identifying improved data products for model inputs. Future studies are needed, including evaluation of unstructured-grid models, wind forcing data products, model performance in predicting large waves and waves in shallow water environments.

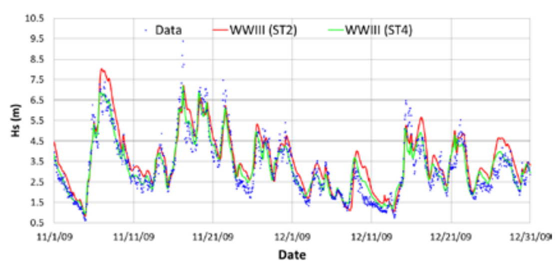

FIGURE 4 COMPARISON OF SIGNIFICANT WAVE HEIGHTS FROM WWIII-ST2 (RED), WWIII-ST4 (GREEN) AND BUOY MEASUREMENTS (BLUE DOTS).

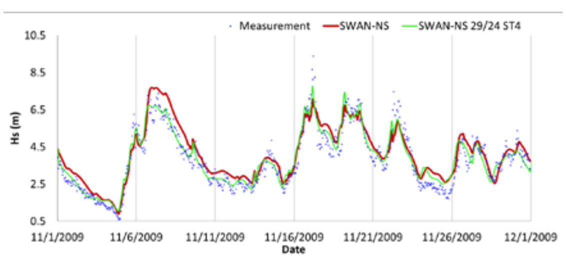

FIGURE 5 COMPARISON OF SIGNIFICANT WAVE HEIGHTS FROM SWAN-NS-ST2 (RED), SWAN-NS-ST4 (GREEN) AND BUOY MEASUREMENTS (BLUE DOTS).

CONCLUSIONS

Model skill is evaluated for two of the most widely used 3G phase-averaged wave models, WWIII and SWAN, WWIII physics packages, ST2 and ST4, and stationary and nonstationary modes of SWAN. For the baseline model test case, a comparison of the six IEC parameters time series shows good agreement between WWIII simulations and NDBC buoy measurements. Predicted time series for these six parameters from the SWAN model, both in nonstationary and stationary modes, are comparable to those from the present study's WWIII (ST2) model; and likewise provide confidence in the SWAN model settings; although small differences between WWIII and SWAN simulations are observed.

ACKNOWLEDGEMENTS

This study was funded by the Wind and Water Power Technologies Office (WWPTO) within the Office of Energy Efficiency and Renewable Energy (EERE), U.S. Department of Energy. The authors thank members of a steering committee charged with external review of this study, including Tuba Ozkan-Haller of Oregon State University, who served as chairperson, Bryson Robertson of the Institute of Energy Systems, at the University of Victoria, Arun Chawla from NCEP at NOAA, Tim Mundon from Oscilla Power™, Inc. and Levi Kilcher from National Renewable Energy Laboratory.

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