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Overview of Open Source Codes to Assess Environmental Effects on Ocean Wave Farms

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Introduction

The United States has a theoretical ocean wave energy resource potential of 1,594–2,640 TWh/year, enough to power between 143.5 and 237.6 million homes/year and contribute substantially to the United States' energy portfolio [1]. However, wave energy converters (WECs) are currently in the early stages of research and development at low technology readiness levels. Open ocean deployment data is from demonstration-scale projects, not from utility-scale deployments. As a result, researchers, developers, and regulators rely heavily on numerical models to understand the environmental effects of wave farms.

A suite of open source codes has been developed by Sandia National Laboratories focused on simulating the energy extraction of WECs to better understand and predict their potential environment effects.

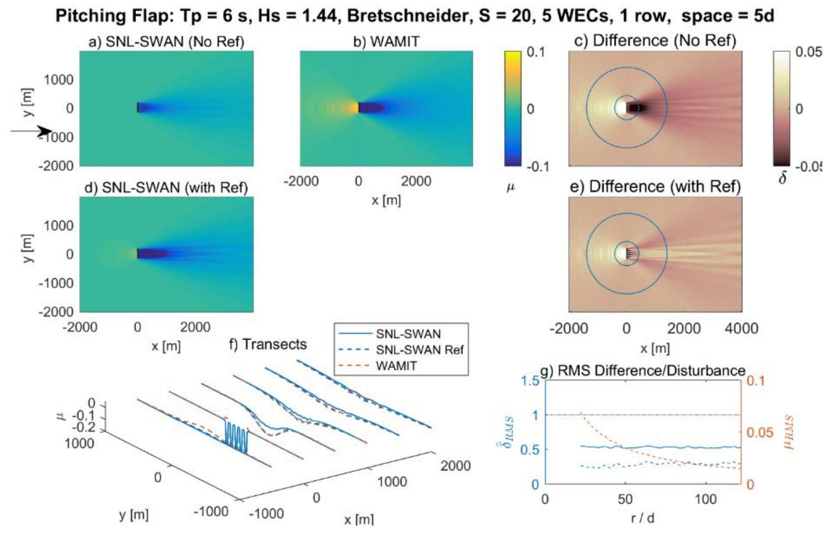

Figure 1. SNL-SWAN wave field with and without wave reflection, compared to wave field from WAMIT

Methods

SNL-SWAN is a modification of the open source SWAN code to include a WEC Module as an energy sink that extracts energy from the wave action balance equation according to the power performance of the WEC [2]. SNL-SWAN is used to simulate and predict the effect of wave farms of varying array sizes, configurations, and with different WEC types on the wave field. SNL-SWAN has been verified against well respected wave energy models such as WAMMIT, as shown in Fig. 1 [3].

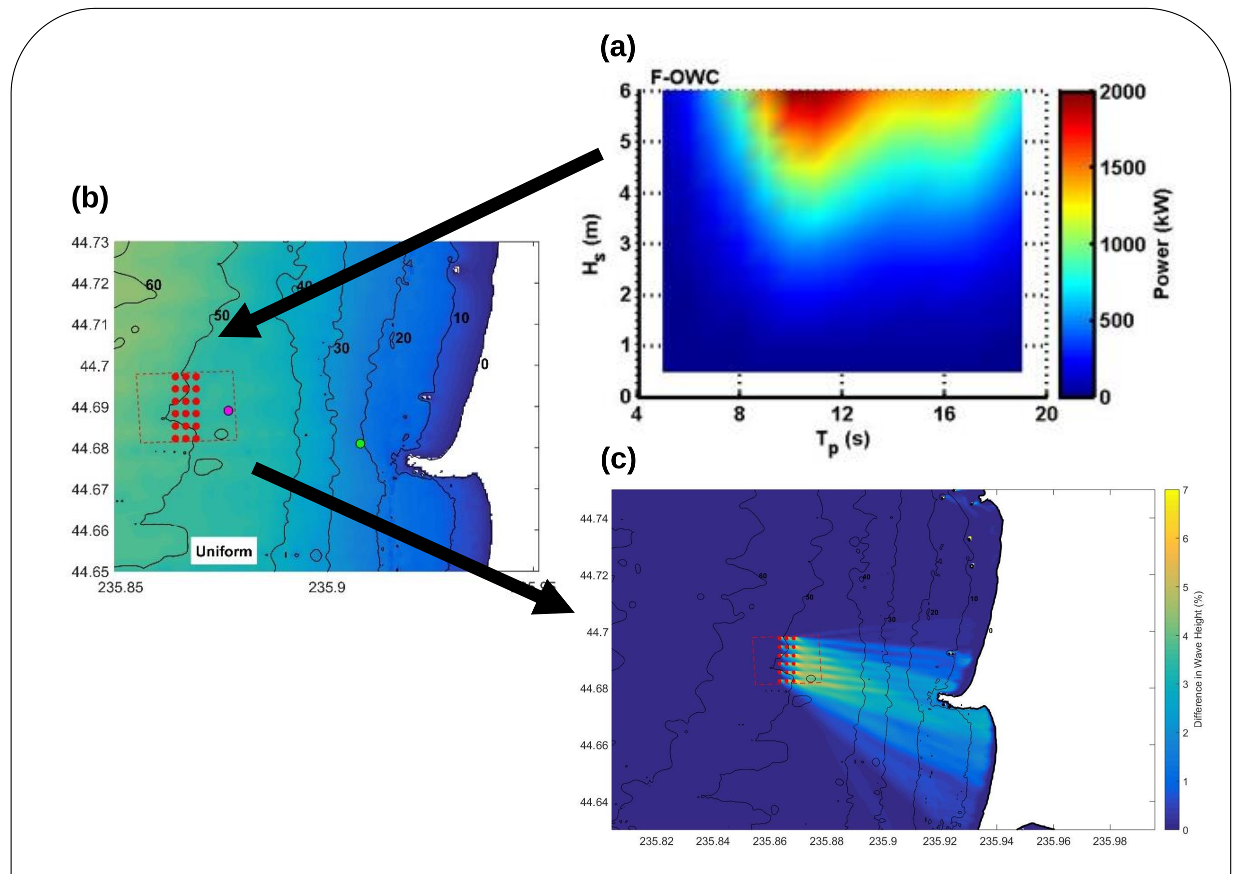

Figure 2. Device Power Matrix(a) applied to a WEC array(b) used by SNL-SWAN to simulate a wave shadow (c).

SNL-Delft3D is the Sandia modified version of Delft3D for MHK devices. Delft3D is an open source, multidimensional hydrodynamic and sediment transport model, capable of computing non-steady circulation, waves, and sediment transport phenomena resulting from forcing by tides and meteorological processes. Delft3D is developed and maintained by Deltares and comes with a suite of graphical tools to assist in grid-building, tidal analysis, bathymetric mapping tools, and rapid data analysis. [4].

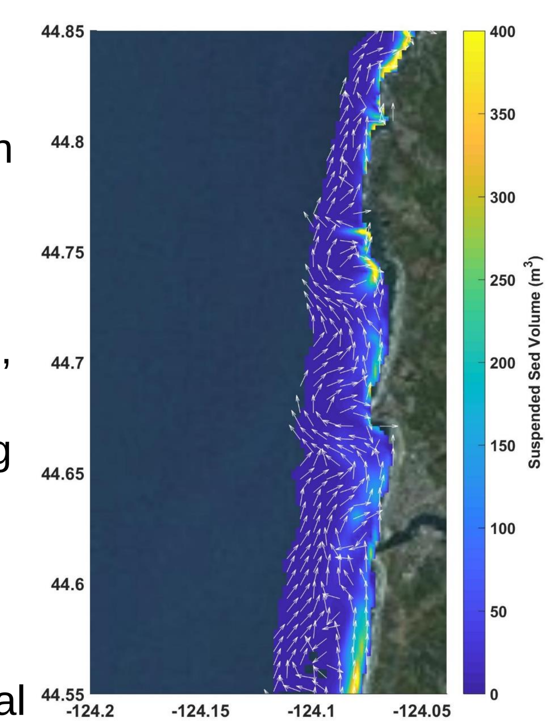

Figure 3. Near shore recirculation model run with SNL-Delft3D

SNL-SWAN and SNL-Delft3D have been designed to be run together as a coupled simulation. The coupled Delft3D-SNL-SWAN (SNL-Delft3D) model allows for evaluating tidal and wave-driven circulation, including wave-current interactions that influence both nearshore circulation, wave parameters, and sediment transport.

Results

Performing a fully coupled Delft3D-SNL-SWAN model allows for an evaluation of changes in hydrodynamic and sediment transport parameters in the presence and absence of WECS in the environment. Two key parameters of importance to nearshore morphological change are maximum shear stress and bed elevation change. Fig 4 shows normalized changes in shear stress and bed elevation in the presence and absence of WECs for two wave events with the highest annual probability of occurrence at the Oregon Coast.

The two cases shown are typical of summer and winter (Fig 4, normalized shear stress and Fig 5, bed elevation change) conditions on the Oregon Coast.

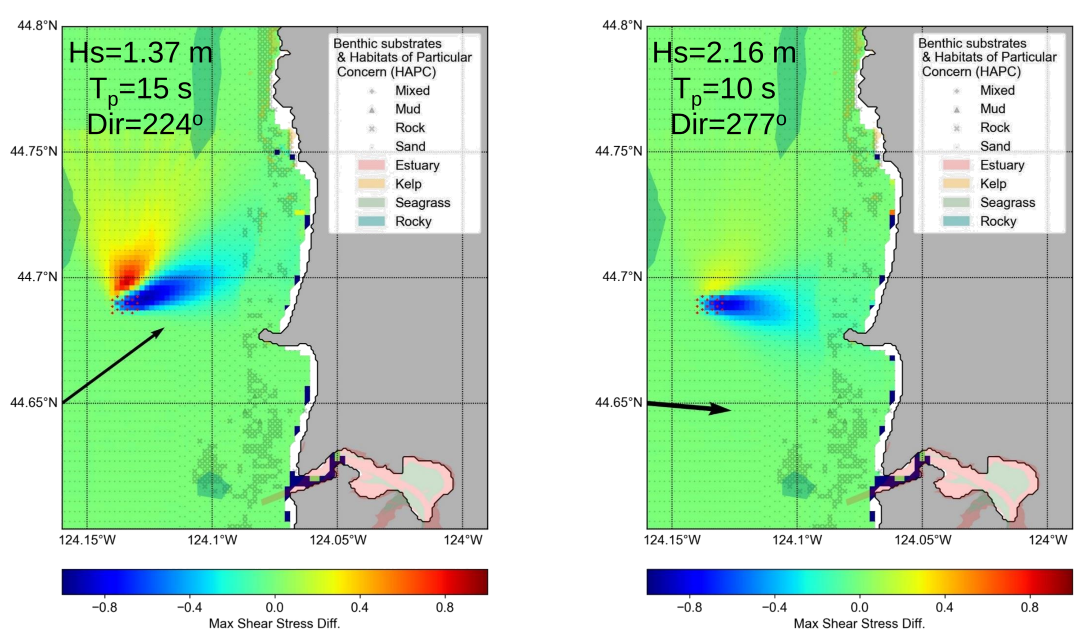

Figure 4. Normalized changes in bottom shear stress, typical of summer (**left**) and winter (**right**) conditions. Peak wave direction is indicated by the black arrow.

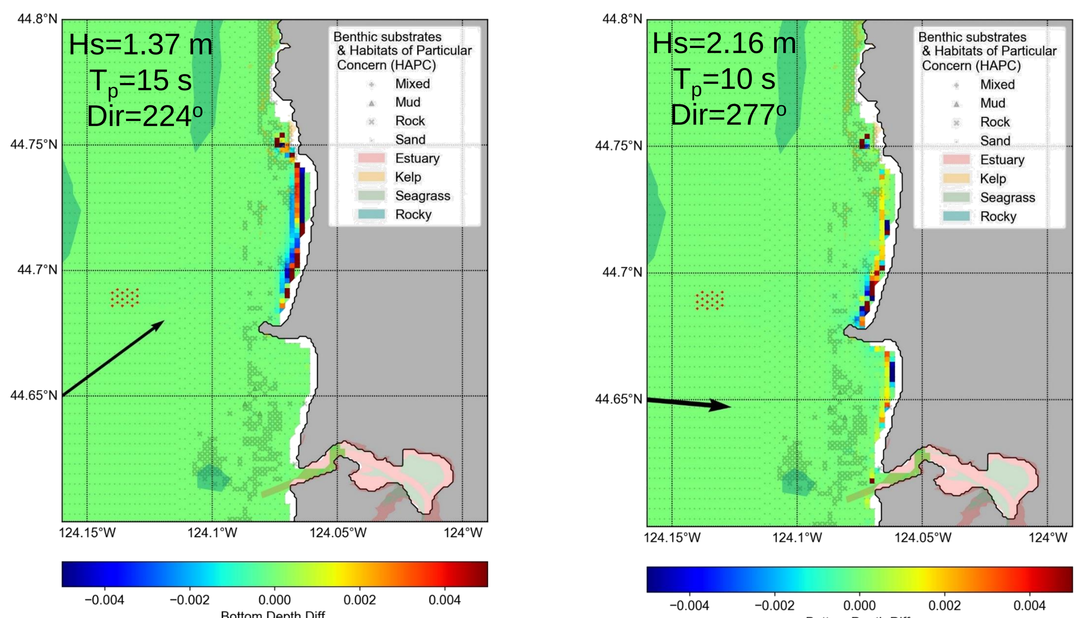

Figure 5. Normalized changes in bed elevation, typical of summer (**left**) and winter (**right**) conditions.

Changes in normalized shear stress are mainly observed in the vicinity of the WECs. Modeled bed elevation changes between the presence and absence of WECs are what may be expected due to wave shadowing in coastal transport. The presence of WECs, and the resulting wave shadowing, while minimal, results in enhanced deposition in the nearshore (<20 m water depth), followed by corresponding reduced deposition in adjacent offshore cells. These changes are on the order of 0.5% relative to baseline conditions. An increase in wave period, from 10 seconds to 15 seconds (Fig 4), is accompanied by greater changes in nearshore morphology.

Conclusions

The development of SNL-SWAN by Sandia National Laboratories (SNL) allows users to investigate the interaction between a WEC or WEC array and the wave environment. SNL-SWAN when coupled with a hydrodynamic and sediment transport model such as Delft3D, developed by Deltares Inc, allows for the direct investigation of WEC array effects on the physical environment (e.g. waves, currents, seabed) and the associated site ecology. Ongoing development of these tools has shown how the coupling of SNL-SWAN with Delft3D-Flow can quantify the interaction between device(s) and the hydrodynamic environment at a real-world site.

References

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[3] G. Chang, K. Ruehl, C. A. Jones, J. Roberts, and C. Chartrand. "Numerical modeling of the effects of wave energy converter characteristics on nearshore wave conditions", Renewable Energy, vol. 89, pp 636-648, 2016.
[4] Deltares, "Delft3D Open Source Community." [Online] https://oss.deltares.nl/web/delft3d.

Acknowledgments

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Further information

Link to software and SNL-SWAN
http://snl-waterpower.github.io/SNL-SWAN/

Links to software and SNL-Delft3D
http://energy.sandia.gov/snl-delft3d-cec/
https://github.com/SNL-WaterPower/SNL-Delft3D-CEC