A PORTABLE, REAL-TIME PASSIVE ACOUSTIC SYSTEM AND AUTONOMOUS HYDROPHONE ARRAY FOR NOISE MONITORING OF OFFSHORE WAVE ENERGY PROJECTS

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INTRODUCTION

Information on the underwater sound generated by operating wave energy converters (WECs) in the open ocean remains limited. The published studies on full-scale devices have been restricted to individual types of WECs [1] and limited by instrument difficulties [2], providing an inconclusive view of the broad range of possible noise level amplitudes and affected frequencies. The resulting lack of understanding and uncertainty surrounding the potential for acoustic impacts on marine ecosystems from elevated noise levels associated with WEC project activities has brought about a conservative regulatory process for permitting and licensing in U.S. waters. Underwater exposure of living marine resources to anthropogenic sound emissions associated with wave energy development activities is regulated by NOAA's National Marine Fisheries Service, which currently applies standardized root mean square sound pressure level (SPL*rms*) threshold noise exceedance criteria to determine WEC project compliance [3,4].

The U.S. Northwest National Marine Renewable Energy Center (NNMREC) is currently in the licensing process for a grid-connected, full-scale testing facility known as the South Energy Test Site (SETS) off the central Oregon coast near Newport, OR (Fig. 1) in the Pacific Northwest. The

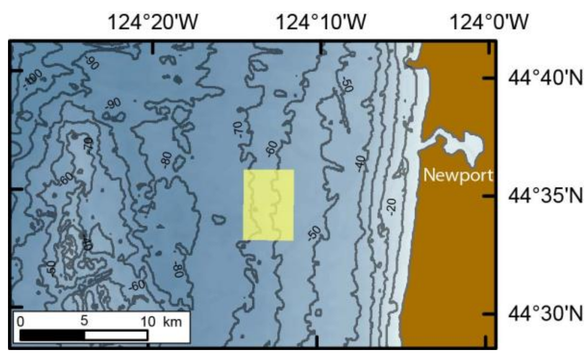

FIGURE 1. MAP SHOWING THE LOCATION OF THE AREA DESIGNATED FOR THE NORTHWEST NATIONAL MARINE RENEWABLE ENERGY CENTER (NNMREC) GRID-CONNECTED SOUTH ENERGY TEST SITE (SETS) ON THE CENTRAL OREGON COAST.

2.65 square mile area designated for SETS is offshore of the 3-mile territorial state boundary and therefore falls under Federal licensing and permitting regulatory framework. Within that framework, passive acoustic measurements of project noise levels is a key component of the environmental monitoring required for licensing of the facility.

MONITORING REQUIREMENTS

The SETS facility under consideration will consist of 4 testing berths, aligned in an alongshore sense, each capable of housing 4-5 operational WEC devices, for a total testing capacity of up to 20 devices at any time. Uncertainties surrounding the variability of noise emissions generated by different WEC technologies that could be tested at SETS, as well as how noise radiated by individual classes of WEC designs may change with sea state and environmental conditions raise concerns for regulatory agencies overseeing licensing and environmental compliance of the facility. If environmental conditions cause SETS area noise levels to exceed acoustic threshold criteria at any time, the entire project is deemed out of compliance regardless of whether a particular WEC, berth or set of berths are responsible. Additionally, timely reporting and communication of acoustic exceedance events to the regulatory agencies is required, presenting significant challenges for acoustic monitoring of the facility and suggesting a strong need for real-time observation capabilities.

MONITORING SYSTEM

At SETS, measurements of WEC-generated noise levels during a variety of environmental and vessel traffic conditions will be conducted using an autonomous array of shallow water moored hydrophone systems surrounding the project site in addition to specialized, real-time seafloor-mounted hydrophone systems within each WEC berth.

Real-time Acoustic Observing System (RAOS)

Real-time data delivery to shore has traditionally been a product of seafloor cabled systems. To address measurements of WEC-generated noise levels through a variety of environmental conditions, we present here a new and unique specialized, battery-operated portable seafloor platform hydrophone system and surface mooring within each berth, capable of reporting more WEC-specific noise levels in near real-time.

A Real-time Acoustic Observing System (RAOS) unit will be deployed at a distance of up to 100 m from the outer-most WEC in an active berth depending on the WEC array configuration. This new, portable acoustic monitoring system, developed at the NOAA/Pacific Marine Environmental Laboratory Acoustics Program, includes satellite (Iridium™) and cell-phone telemetry based on service area availability for active monitoring and reporting of passive acoustic data. Each RAOS system consists of a mooring and a separate instrument platform spaced 10-30 m apart on the seafloor (Figure 2); 1) a surface buoy with satellite/cell-phone receive and transmission capabilities, 2) a subsurface lander instrument platform with the hydrophone sensor mounted 1 m above the seafloor including real-time acoustic signal processing and data archiving capability.

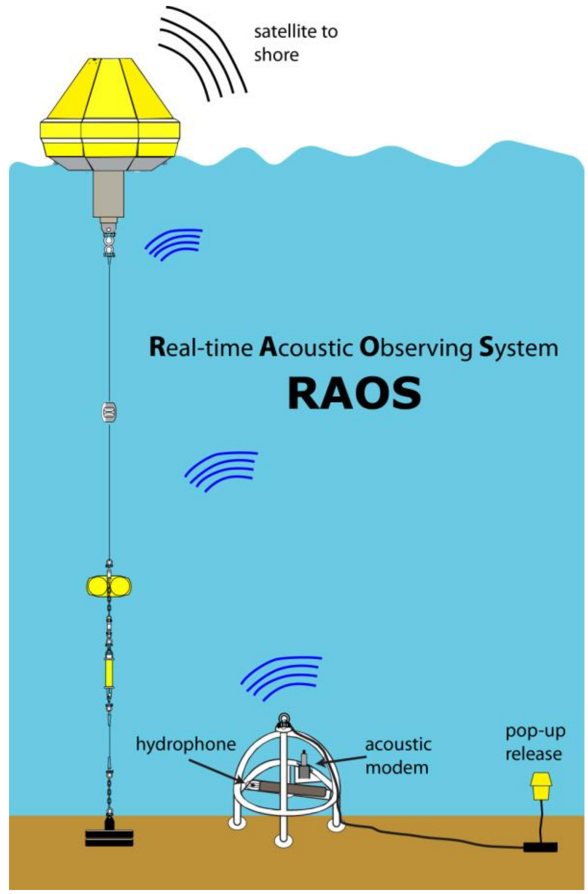

FIGURE 2. A SCHEMATIC OF THE RAOS SYSTEM. A PORTABLE, REAL-TIME ACOUSTIC OBSERVING SYSTEM TO BE DEPLOYED AT EACH WEC TESTING BERTH SATISFYING TIME CRITICAL REPORTING OF PROJECT NOISE LEVELS.

The hydrophone lander instrument has a configurable onboard event detection system that can be programmed to calculate SPL_{RMS} received levels in real time. If a noise threshold exceedance event occurs, the seafloor hydrophone system communicates with the surface buoy via underwater acoustic modem, which is programmed to send diagnostic information via Iridium satellite or cell-phone communication to shore. This information will include time of the event, dB_{RMS} level, and importantly, a small spectrogram surrounding the event to distinguish the sound source (e.g. passing vessel, WEC noise, flow noise, wind/breaking surf noise). The RAOS system can be configured for deployment durations up to 7.5 months, recording continuously at 62.4 kHz. The endurance of the system can be extended beyond a 7.5 month time frame using duty cycled recording intervals as needed. These systems located near each berth will provide important real-time event monitoring capabilities of project-related noise, as well as the ability to track data collection efforts and insure data quality in a timely manner.

The RAOS system was successfully deployed and recovered for a 7-day testing period ~ 20 km off Newport, OR in 60 m of water near Stonewall Bank in early September 2015. The system was configured to detect and report the acoustic presence of killer whales (*Orcinas orca*). Due to the lack of killer whales in the area at this time of year, recordings of killer whale vocalizations were played through a set of ranges leading up to the RAOS station location prior to recovery operations of the buoy system. During the testing period, significant wave heights and winds measured at the nearby NOAA-NDBC station 46050 (http://www.ndbc.noaa.gov/station_page.php?station=46050) reached maximum levels up to H_s = 2.8 m and sustained wind speeds of 11 m/s with gusts to 13 m/s. The environmental conditions experienced during the majority of the testing period were well below annual mean values for wave heights in the area [5] (H_s = 2.42 m). The RAOS system performed satisfactorily throughout the deployment, but has not been tested in higher sea state conditions which could affect the efficacy of submarine acoustic communications. The system is currently under further development for improved communications via cell-phone for larger bandwidth and data transmission from the SETS area ~ 6 nm offshore.

Moored Autonomous Hydrophone Array

The SETS project site will also be surrounded by four autonomous hydrophone moorings (Figure 3) with sensors placed at 10 m above the seafloor to allow for long-term studies of project noise, directional propagation and received levels during WEC testing activities. Accurate timing inherent to the hydrophone data acquisition systems and the configuration of the array designed around the perimeter of the SETS project site will potentially enable detection and localization, or at least bearing information, for discrete WEC-generated signals, provided signal generated by the WECs is of sufficient amplitude above the ambient noise level to be detected by the outer hydrophone sensors of the array. The array surrounding the project site will be deployed prior to the first WEC installation of each test with hydrophone systems deployed at ~ 2 km spacing, two on each side from the east and west boundaries of the testing berths. This spacing is required to allow for adequate travel time differences in the propagating WEC-generated signals for array-based localization and/or bearing efforts. The acoustic data are archived by the logging systems and bearing/ localization calculations will not be performed until the entire array is recovered after a period of several months.

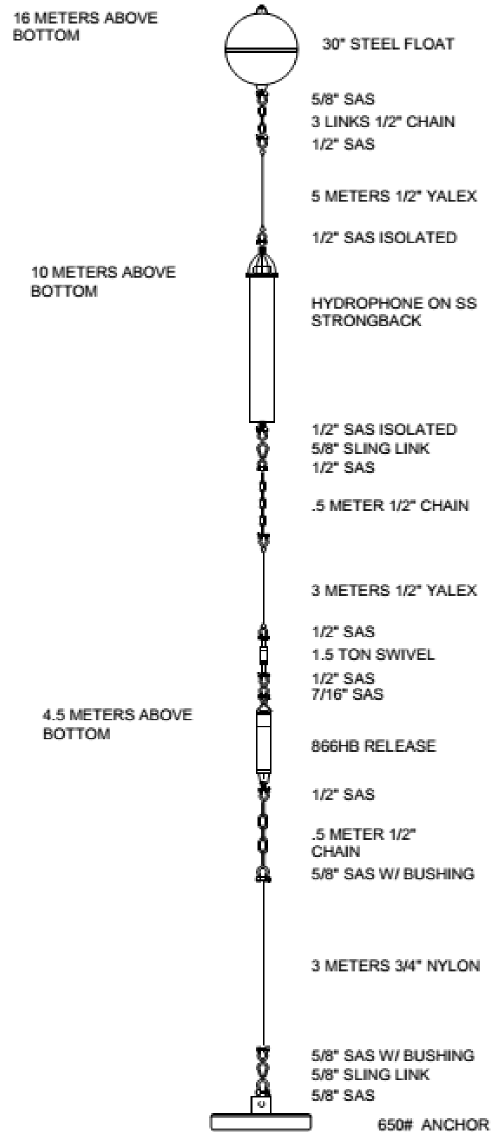

FIGURE 3. AN AUTONOMOUS HYDROPHONE MOORING. FOUR UNITS WILL BE DEPLOYED SURROUNDING THE SETS PROJECT AREA.

Monte-Carlo simulations were performed based on local bathymetry, hydrophone array configuration and a conservative error estimate for coherent signal identification across the hydrophone array up to 1 second showing localization error fields for discrete WEC-generated signals. Figure 4 includes the positions of each sensor in the 4 element perimeter array (black squares) surrounding the designated SETS facility boundary in red. The contour lines indicate the expected error or uncertainty associated with localization of a particular signal in a latitudinal and longitudinal sense given a 1 second error in timing of the identified signal. A 1 second timing error is considered large for a small array of this size and we are likely to be able to identify WEC signals with much higher timing accuracy.

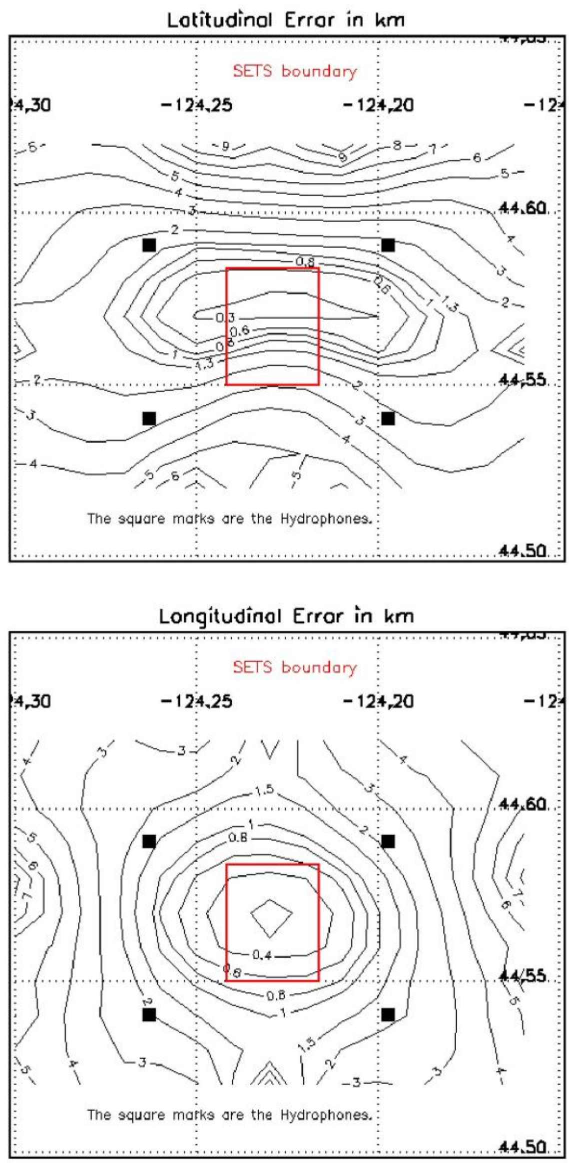

FIGURE 4. ERROR SIMULATIONS IN LATITUDE (TOP) AND LONGITUDE (BOTTOM) FOR THE 4 ELEMENT HYDROPHONE ARRAY (BLACK SQUARES) SURROUNDING THE SETS TESTING FACILITY (RED BOUNDARY).

Therefore, these modeled error fields represent maximum values ranging from mostly below ~ 500 m in longitude and between 300 m and 2 km in latitude within the SETS boundary (red box). Broader latitudinal spacing will improve modeled error estimates at the risk of reducing signal detection capabilities with the increased range from the WEC sources to the hydrophone receivers.

CONCLUSIONS

The regulatory requirements for environmental monitoring of WEC project-related noise levels in U.S. waters are conservative, resulting from uncertainties in device emission amplitude levels and the affected frequencies. Here we present a new portable, battery-operated real-time system for acoustic monitoring of WEC projects being applied to NNMREC's grid-connected SETS testing facility off the coast of Oregon. Using onboard programmable detection algorithms, the RAOS system is able to report noise level estimates in real time and perhaps more importantly, send back small spectrograms and snippets of data to identify sound sources. This will avoid "false" detections of WEC project noise exceedance events that may instead be the result of a passing ship, fishing activity, flow noise or some other sound source unrelated to the project. Additionally, the RAOS may be of interest to WEC developers as another point of condition health data during device testing operations.

ACKNOWLEDGEMENTS

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