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Task 4: Environmental Impact Monitoring at WETS

Performance Assessment of Subsurface Logger for Ocean Waves (SLOW) Prototype

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1 Introduction

This report describes the design and initial testing of the Subsurface Logger for Ocean Waves (SLOW) at the US Navy Wave Energy Test Site (WETS) in Kaneohe, HI. The SLOW is a low-cost instrumented subsurface buoy designed for acoustic measurements of wave energy converters at close range with minimal flow noise. The SLOW was tethered to the top of a subsurface buoy that is part of the Azura wave energy converter (WEC) mooring system (30 m test site at WETS) by a diver on 01/13/16 and recovered by a diver on 1/26/16.

2 Methodology

To date, acoustic measurements of WECs at WETS have relied on either drifting spar buoys (SWIFTs) or fixed, bottom-mounted platforms (Sea Spiders). SWIFTs are primarily used to investigate spatial patterns in WEC sound at snapshots in time, whereas Sea Spiders provide essential information about how WEC sound varies in time across a range of operating conditions. The SLOW was designed in response to four challenges with Sea Spider deployments. First, a Sea Spider requires a work vessel with a winch or pinch puller to deploy and recover and a crew of at least three. This increases the cost of deployments and reduces the number of potential recovery windows. Second, the risk of entanglement with a WEC mooring system during deployment or recovery necessitates a stand-off distance of at least 100 m. Because the sound from WECs is relatively low intensity, at this distance, the WEC can be difficult to distinguish from other ambient noise. Third, it is difficult to precisely re-occupy Sea Spider locations due variability in line angle during deployment in moderate sea states. This complicates comparisons of WEC sound between deployments. Fourth, during long-period swell, near-bed wave orbital velocities are high enough to produce significant flow-noise. This pseudo-sound, associated with the movement of water past the hydrophone element, may mask WEC sound at frequencies up to 100 Hz.

2.1 SLOW Design

The SLOW (Figure 1) is designed to attach directly to a WEC mooring spread, permitting acoustic measurements within a short range of a WEC. Acoustic measurements at close range provide stronger signal-to-noise ratios (SNR), permitting more accurate identification and classification of WEC sound. This also allows measurement stations to be easily re-occupied. The SLOW is designed for near-surface deployment by a diver, which allows deployment from an unspecialized vessel. The SLOW is designed to passively track wave orbital motion via near-neutral buoyancy and reduce forces transferred through its mooring via a compliant tether. Because flow-noise is related to water velocity relative to the hydrophone element, this arrangement can mitigate flow-noise.

The SLOW is designed around a Loggerhead DSG-ST hydrophone, an autonomous, battery-powered hydrophone system with onboard A/D conversion and internal storage. The SLOW also supports both a MAT-1 IMU and HOBO Temperature and Depth logger (Table 1), which enable correlation of recorded sound with buoy motion, orientation and depth. The SLOW hull and instrument holsters are made from PVC to prevent corrosion and minimize cost. A small amount of positive buoyancy is necessary to keep the SLOW clear of the WEC mooring and ensures that the package will return to the surface in the event of line parting. Buoyancy is added to the SLOW in the form of a foam float collar, resulting in a net buoyancy of approximately 5 lbs. The float collar is positioned above the SLOW's center of mass to provide a righting moment when submerged. An eyebolt on the bottom of the SLOW acts as a hard-point for tethering the platform to WEC moorings. A threaded cap protects the hydrophone element during deployment and is easily removed and returned to the surface after the SLOW is tethered. The

SLOW tether is composed of synthetic line with a section of firehose to reduce abrasion. Overall tether length for the initial deployment was approximately 1 m.

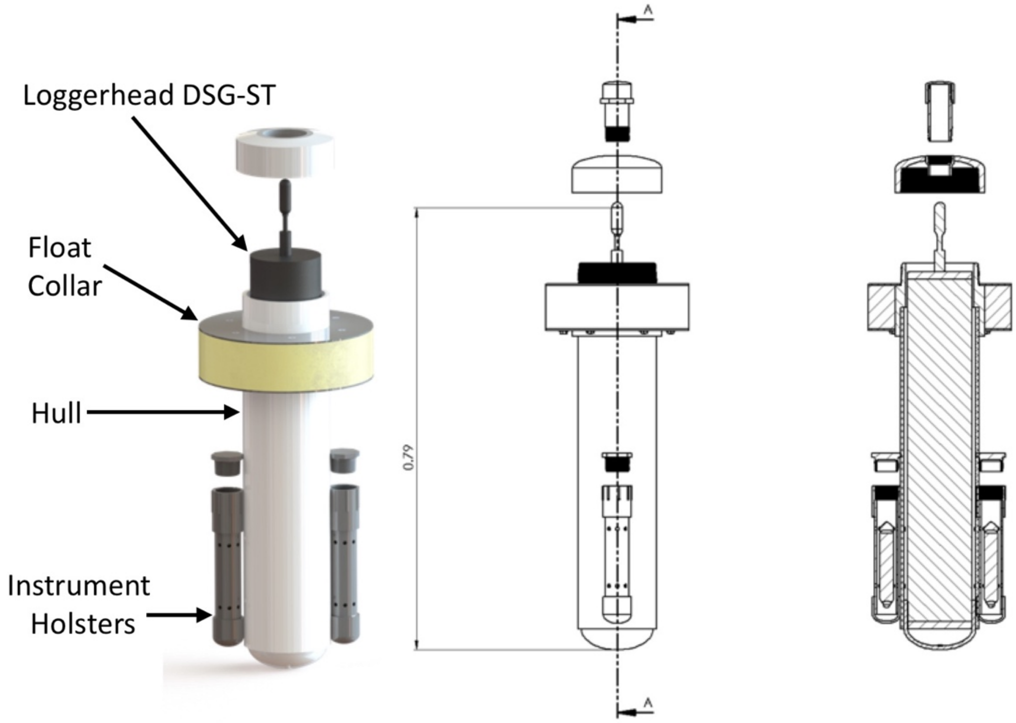

Figure 1: Subsurface Logger for Ocean Waves (SLOW) Version 1.0

Table 1: SWIFT Instrumentation

Instrument	**Model**	**Measurement**
Hydrophone	Loggerhead DSG-ST	Underwater sound pressure
Inertial Motion Unit (IMU)	Lowell Instrument MAT-1	Acceleration and orientation
Depth and Temperature Logger	Onset HOBO U20	Water depth and temperature

2.2 SLOW Deployment

The SLOW was successfully tethered to the top of a subsurface buoy at the 30 m test site, approximately 60 m away from the Azura WEC, at 0910 on 01/13/16. The as-deployed configuration is shown in Figure 2. The SLOW was deployed by a single diver and the overall time required for deployment was approximately 15 minutes. This is at least a factor of two reduction relative to a Sea Spider deployment.

Figure 2: Prototype SLOW attached to WEC mooring

The hydrophone on the SLOW recorded at a sample rate of 48 kHz for 60 minutes every 90 minutes. The IMU recorded at 64 Hz and the pressure logger recorded at 1 Hz.

2.3 Acoustic Measurements

2.3.1 Hydrophone Calibration and Acoustic Data Processing

The Loggerhead DSG-ST used in the SLOW (SN 437570) was calibrated using a GeoSpectrum M351 field calibrator, which produces calibration tones at 10, 26, 70, 100, and 250 Hz.

Acoustic data sampled continuously at 48 kHz was linearly detrended and buffered into windows of 48 kSamples with 50% overlap. A hamming window was applied to the resulting windows, which were then processed with a fast Fourier transform to produce power spectral density (PSD) estimates with frequency resolution of 1 Hz. One-third octave levels were calculated by integration of PSD estimates over 10 minute sequences.

3 Results

3.1 SLOW Dynamic Performance

Analysis of the SLOW's azimuth and elevation angles throughout the deployment provides insight into its dynamic performance (Figure 3). Significant wave height and energy period (measured by CDIP buoy 198) are plotted over eight days (top) and compared to the mean and standard deviations of azimuth and elevation calculated over 30-minute windows (middle and bottom). It is evident from the steady mean in the azimuth angle that the SLOW generally aligns with the direction of waves and currents. The SLOW is forced into a significantly tilted orientation in higher sea states, as indicated by change in the mean elevation angle of up to 30 degrees from vertical relative to near-vertical mean orientation during calm seas at the start of the deployment. The standard deviation of elevation shows that the SLOW is frequently in motion, likely oscillating with passing waves. While the standard deviation of elevation decreases at higher sea states, this is likely a consequence of the SLOW being forced to the extreme of the tether.

Throughout the deployment, the foam collar providing buoyancy to the SLOW gradually compressed, reducing the buoyant force on the SLOW and increasing its wet-weight. This may have also contributed to the change in mean orientation. Foam rated for higher pressures should be used in future deployments.

As the SLOW is intended to be a passive wave follower, platform motion is expected. However, received sound levels can be affected if the hull or float collar are in the path of arriving sound, particularly at frequencies greater than 1 kHz. Further, although hydrophones are nominally unidirectional, previous in-water calibration has shown a directional sensitivity at frequencies greater than 10 kHz. Because the majority of sound produced by the Azura WEC is at frequencies less than 1 kHz, orientation changes are unlikely to affect results, but could be a consideration for the use of the SLOW to characterize higher-frequency sound from another WEC.

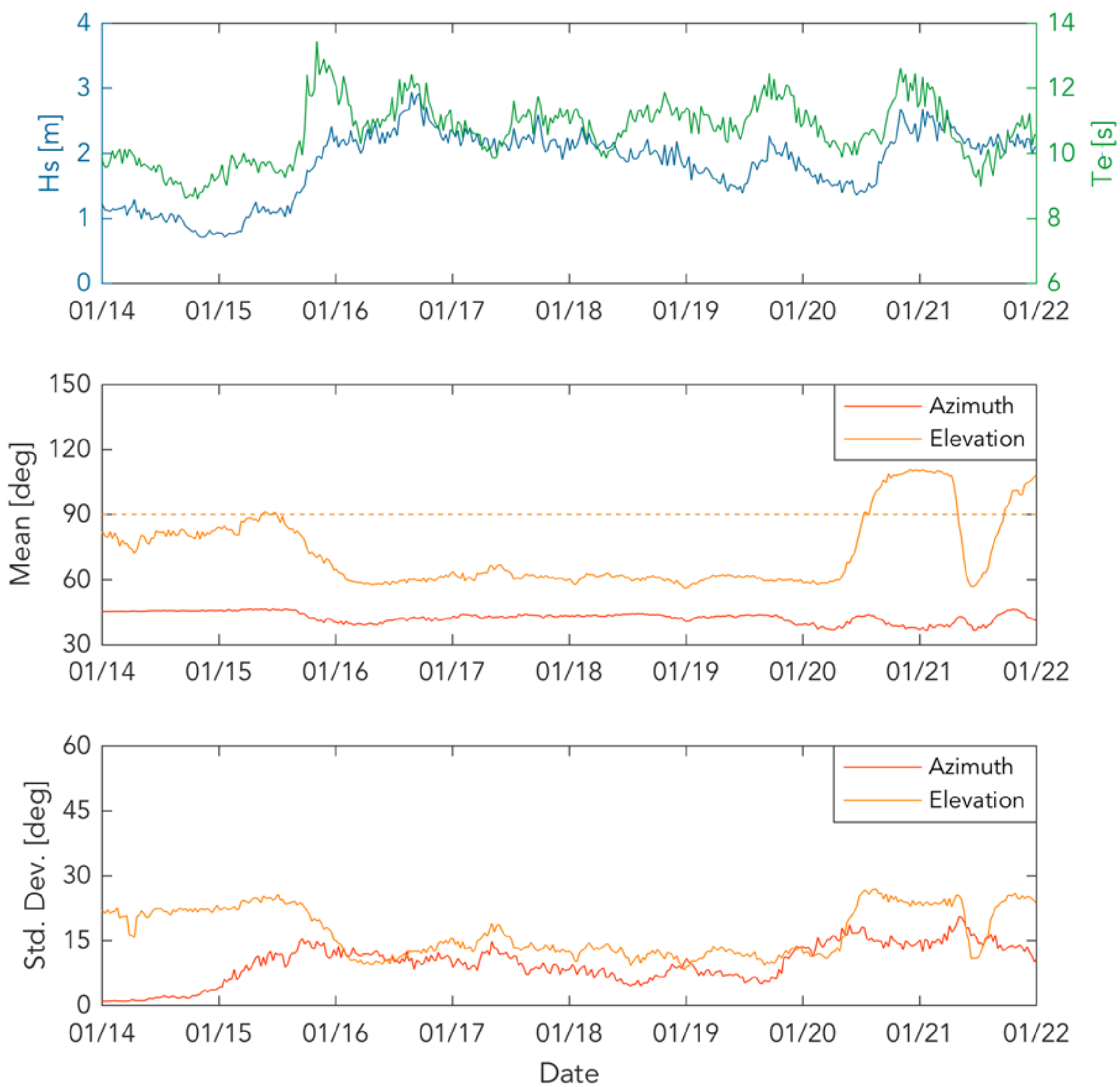

Figure 3: Significant wave height (Hs) and energy period (Te) over eight days of deployment (top). Mean (middle) and standard deviation (bottom) of SLOW orientation expressed as azimuth and elevation angles. Note: 90 degrees elevation (dashed line, middle) indicates vertical orientation.

3.2 Identification of Flow-Noise, Self-Noise, Background Sound, and Azura Sound

This section describes flow and self-noise, background sound, and sounds originating from the Azura WEC. Representative spectra from 30 seconds of recorded sound for two different sea states are shown in Figure 4.

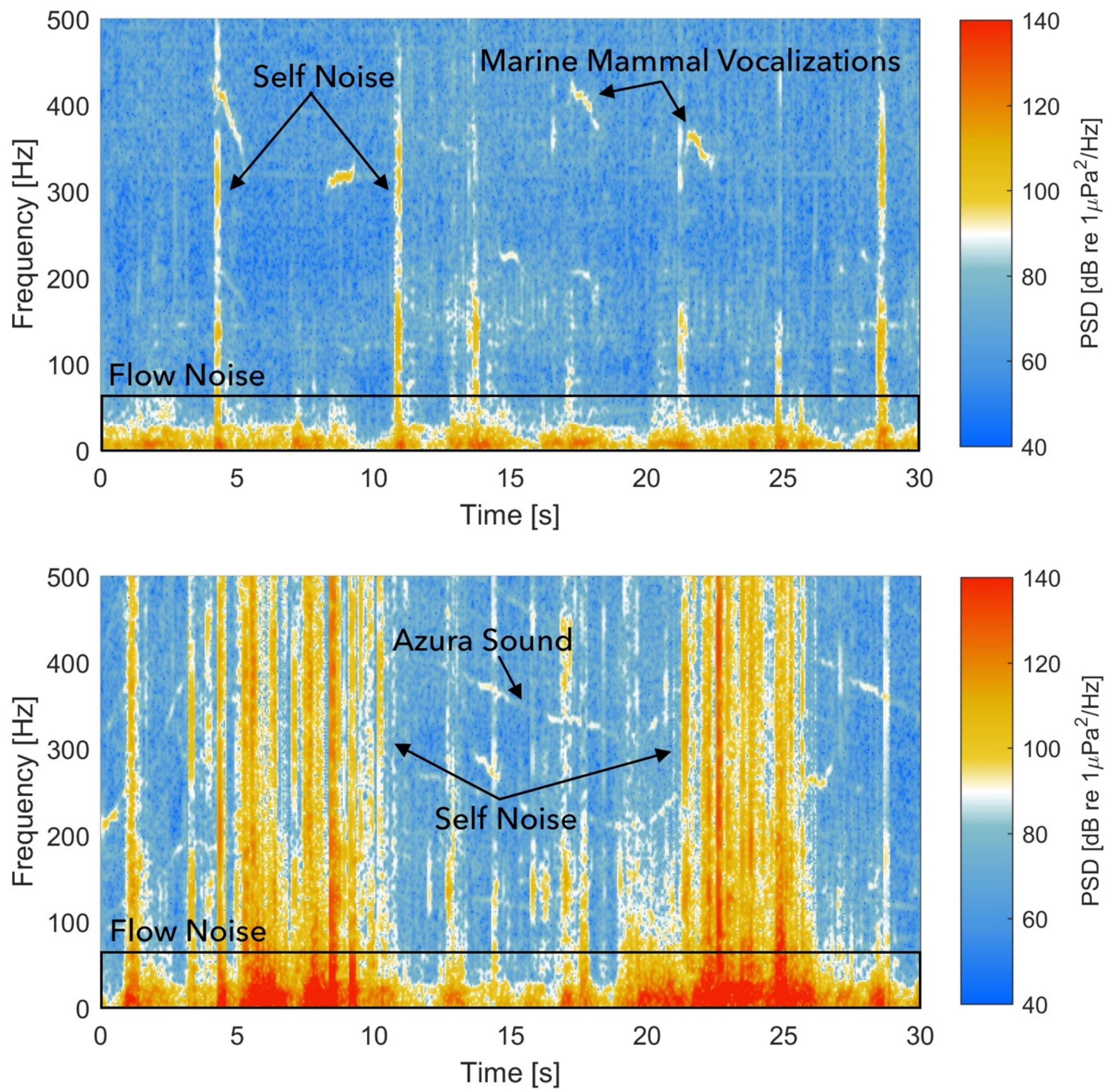

Figure 4: Spectrograms of sound recorded by SLOW at representative wave conditions. (Top: Hs = 0.8 m, Te = 10.0 s. Bottom: Hs = 2.6 m, Te = 11.3 s)

In calmer conditions (Hs = 0.8 m, Te = 10.0 s), flow noise is intermittently present at frequencies below 50 Hz. Impulsive, broadband self-noise is also observed and appears to originate from rattling of attachment hardware. Marine mammal vocalizations are notable between 250 and 500 Hz. The Azura does not produce significant sound under these conditions.

In higher sea states (Hs = 2.6 m, Te = 11.3 s), flow noise is considerably more intense and extends to frequencies as high as 100 Hz. Broadband self-noise is more frequent and more intense, and is possibly associated with impacts between the SLOW and the top of the subsurface buoy. Azura sound (a periodic “moan/whine” from the generator with time varying frequency) is detectable, but self-noise frequently masks this signal.

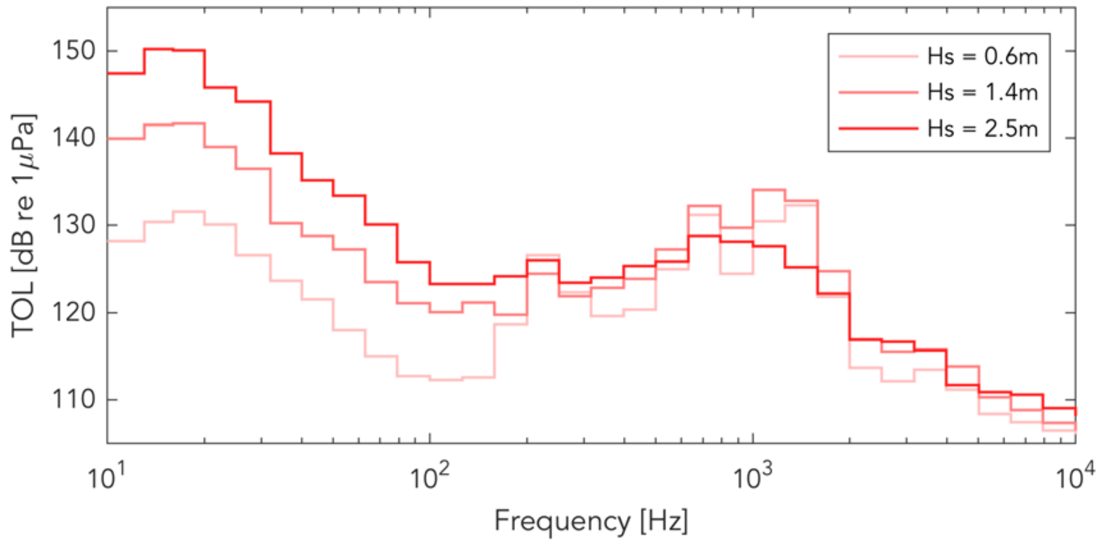

Figure 5: 1/3-octave levels (TOL) measured by SLOW. Darker lines indicate higher significant wave height.

One-third octave levels for three different significant wave heights are shown in Figure 5. Levels at frequencies below 200 Hz vary significantly with sea state. Based on the results presented in Figure 4, it appears that flow noise plays a significant role, though wind noise is also known to contribute at these frequencies in shallow water. At higher frequencies, levels show limited sea state dependence.

4 Conclusions

While easier to deploy and recover than a Sea Spider and allowing measurements closer to the Azura WEC, the SLOW V1 did not effectively mitigate flow-noise below 50 Hz. IMU data and video of SLOW motion captured by Sea Engineering divers suggests that the tether length (1 m) is responsible for the limited flow-noise reduction. In the presence of larger, longer waves, the SLOW reaches the extent of its tether before a wave has passed, resulting in higher relative velocities during latter portions of a wave orbital and, consequently, records significant flow-noise. In addition, self-noise dominates the spectra in higher sea states and appears to be primarily caused by motion of the attachment hardware and possible impact of the SLOW with the subsurface buoy.

A redesigned SLOW (V2) is currently in development which aims to address the performance concerns of the first prototype, while retaining its ease of deployment. In contrast to the first prototype, an alternative concept for the SLOW V2 would be a negatively buoyant recording system secured by a longer tether line (15-20 m) running from the top of the instrument platform to an “overhead” WEC mooring or hawser. These changes would permit the SLOW V2 to translate freely with larger wave orbitals without the changes in orientation caused by reaction forces from a short tether. The longer line would result in greater deployment depth, which would reduce the wave forcing on the SLOW V2 and reduce acoustic surface effects, such as multipath interference and vanishing of sound pressure near the water surface (pressure release). The synthetic tether line would be replaced with rubber cord, and a heave plate (up to 1.0 m diameter) would be added to the body of the instrument package. Because WEC sound would generally arrive from above, the hydrophone would be positioned at the top of the instrument package, thereby eliminating the risk of acoustic shadowing by the heave plate.

Hydrodynamic modelling using Proteus DS has shown that the complaint rubber cord and heave plate can help to reduce vertical motion of the instrument package caused by motion of the hawser or subsurface buoy. A backup safety line would be included in case of failure of the rubber cord. Finally, machined high-density closed cell foam would replace the poured foam used on the first version, ensuring that buoyancy remains constant throughout deployment.

5 Acknowledgement

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