Simultaneous Operation of Mobile Acoustic Recording Systems off the Washington Coast for Cetacean Studies System noise level evaluations

Conference Paper · October 2015

DOI: 10.23919/OCEANS.2015.7401830

Simultaneous Operation of Mobile Acoustic Recording Systems off the Washington Coast for Cetacean Studies

System noise level evaluations

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***Abstract*—Acoustic monitoring of cetaceans was conducted using two buoyancy-driven AUVs in a deep-water canyon north of the Navy's QUTR range off the Washington coast in April 2015. The two AUVs operated were the acoustically-equipped QUEphone, which is an APEX™-based acoustic profiler float from Teledyne Webb, and the Seaglider™ from Kongsberg. A passive acoustic monitoring device, WISPR, from Embedded Ocean Systems (EOS) was installed on both AUVs. With one 512-GB CF card and level-2 Free Lossless Audio Codec (FLAC), WISPR recorded sound continuously for 12 days at a 125 kHz sampling rate with 16-bit resolution. The Sealider's record showed high levels of flow noise below 100 Hz during ascent, 16 dB higher than during the descent. The Seaglider's CTD generated 1-sec long line noise at 53.37 kHz at 5 to 10 sec intervals, while the Seaglider's mass shifter generated 3-sec long band-limited noise below 10 kHz. The QUEphone's acoustic record was generally quieter than the Seaglider primarily due to the fact that it is nearly stationary platform with less mechanical and electrical components to generate system noise. Despite higher system noise levels, the Seaglider detected twice as many calls/clicks resulting from its ability to actively stay in the target area where the population density of marine mammals was higher, while the QUEphone drifted away from the target area with the prevailing ocean currents.**

Keywords—Acoustic glider, Acoustic profiler float, Marine mammals, noise

I. Introduction

Passive acoustic monitoring (PAM) is now widely used for acoustic environmental characterization and monitoring including marine mammals, seismic and anthropogenic noise studies. It has been typically conducted by fixed autonomous hydrophones, providing non-real-time data, covering small areas over long time spans [1][2]. This method provides relatively noise-free acoustic records at low cost. However, when used for high frequency studies such as detecting high frequency marine mammal calls, the high attenuation at these frequencies limits the detection ranges from a few hundred meters to a few kilometers. In contrast, mobile platforms can supply near-real-time data over larger spatiotemporal scales. These systems are deployed from a vessel, communicate via satellite with shore stations for navigation and control updates, and report in near-real time upon detecting marine mammal or other sounds of interest [3][4]. Acoustically equipped gliders are buoyancy-driven devices that are capable of traversing long distances over weeks to months of autonomous operation. Autonomous profiler floats, e.g., APEX™-based QUEphones, drift with currents or park on the seafloor, rising to the surface upon detecting sounds of interest, and are suitable for up to 2 to 3 weeks of operation depending on the battery capacity [5]. Both platforms are buoyancy-driven, deep-diving vehicles capable of descending to 1000 m (glider)–1500 m (float). While gliders can be steered remotely, profiler floats simply drift with the ocean current. The advantage of the float lies in its comparatively low cost, approximately 1/4 of the cost of a glider.

As compared to propeller-driven Remotely Operated Vehicles (ROVs), buoyancy-driven Autonomous Underwater Vehicles (AUVs) are relatively quieter platforms due to a lack

Living Marine Resources (LMR) Program and Office Naval Research, US Navy

of mechanical propulsion noise. They move slowly, typically 25 cm/s for the Seaglider and almost stationary for the QUEphone, helping to reduce operational system noise. Nevertheless, noise contamination unique to each AUV exists from the differences in electro-mechanical components including buoyancy engine, rudder, and pitch controllers [3][6] specific to each vehicle. Noise contamination also arises from the electronics, including the processor and sensors, in addition to flow noise influenced by the pressure housing of each system, and the speed with which they move through the water. All of these noises, except for the flow noise, are intermittent and easily differentiated while detecting acoustic events manually. Nevertheless, running a real-time autonomous detector on the high-performance processor may lead to false positive or negative detections and elevated estimates of ambient noise levels. A few studies on the glider's rudder and CTD-generated noises by Wall et al. [7] and Tarun et al. [8] exist, but no comprehensive, systematic studies have been performed for evaluating all of the system component noise levels.

We deployed a QUEphone and Seaglider off the coast of Washington in April 2015. Since 2001, Scripps Institution of Oceanography has maintained a High-frequency Acoustic Recorder Package (HARP) in the same area off the coast of Washington. Analysis of previous HARP recordings has revealed the acoustic presence of six baleen and at least nine toothed whale species in this area, including Stejneger's, Cuvier's, and Baird's beaked whales [9]. Unfortunately, as of August of 2015, the recovery of the HARP instrumentation has not taken place for the year, so we are not yet able to compare the AUV-derived records and marine mammal detections against hydrophone data from the fixed platform. Instead, here we compare the QUEphone and Seaglider's acoustic data and evaluate the system noises of these buoyancy-driven AUVs.

II. PAM System And AUVs

A. PAM

The PAM system used in this experiment is called WISPR (*Wideband Intelligent Signal Processor and Recorder*) from Embedded Ocean System (EOS, WA). It is based on an advanced digital signal processor (DSP), the Blackfin BF537™, from Analog Devices. As a result of the low-noise differential analog section and the 24-bit analog-to-digital converter, it achieves a very high signal-to-noise ratio of 110 dB. The electronic noise level of the system is well below the ambient noise level at sea-state zero, maximizing the listening range and detection performance in a wide variety of ocean conditions.

While logging the data in FLAC (Free Lossless Audio Codec) format, WISPR is capable of running sophisticated detection algorithms, *ERMA* (Energy Ratio Mapping Algorithm), onboard [4][5][10] for species identification. The maximum sampling rate of the system is 125 kHz, covering the frequency range of nearly all cetaceans except for porpoises. Its footprint is 2.5″ × 3″ and small enough to fit inside the APEX™ profiler float. Tests conducted in 2010 at AUTEC and in 2011 at SCORE indicated that the detection performance was comparable to the M3R system [5][11]. It has one differential A-D channel for acoustic input, and has one CF card slot. With a 512 GB CF card using level 2 FLAC, it is capable of recording sound for approximately 40 days with an average power consumption of approximately 1.2 Watts. Table 1 summarizes the system performance of the WISPR system.

TABLE 1. WISPR system specifications.

Core processor	Analog Device DSP BF537™ with 64 MB (500 MHz/250 MHz)
A/D sampling	125 kHz/93.75 kHz/62.5 kHz (24 bits-16 bits
Audio channel	1 differential (+/-5V input range)
Data storage	1 CF card slot (512 GB- 40 days @125 kHz with FLAC 2)
File compression	FLAC2/3
OS	µCLinux
Language	Fully programmable in C
Detection algorithm	ERMA for beaked whale
Network port	1 (10MB TCPIP)
Serial ports	2
Power Consumption	~ 1.2 Watts (6 V- 20 V) or 75 mA @ 15V

The hydrophone used for both AUVs is an HTI92WB from High Tech Corporation (MS), which has an internal preamplifier with a 25-Hz, 1-pole high-pass filter, and sensitivity of -165 dB re 1V/1µPa at 1 kHz. The hydrophone signal is further amplified by the WISPR's pre-amp with a frequency-dependent gain curve approximately equal to the inverse of typical deep water ambient noise, taking advantage of the 16-bit dynamic range. Fig. 1 shows the system sensitivity from 1 Hz to 62.5 kHz with gains of 0 and 3.

B. Seaglider and QUEphone

The two acoustic platform AUVs used for this experiment are the Seaglider and the QUEphone (Fig. 2). The QUEphone is based on the APEX float™ from Teledyne Webb (MI) and converted for passive acoustic studies. For the Seaglider, to minimize the flow noise around the hull, the hydrophone was installed in the middle of the 1.1 m tall antenna pole. For the QUEphone, the hydrophone was mounted on the end cap, where normally a CTD sensor would be installed.

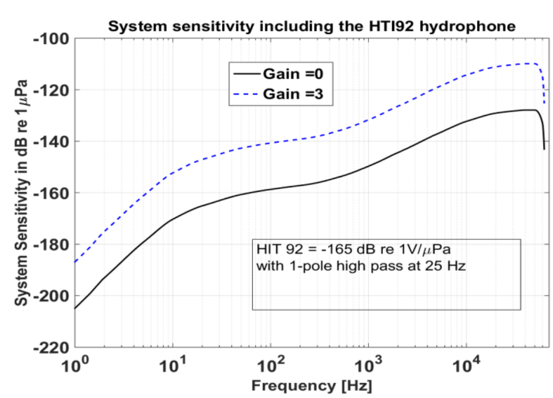

Fig. 1. System sensitivity combined with the hydrophone response. The pre-amp has variable gains of 0 to 3 with a 6 dB increment.

Fig. 2. Seaglider™ and APEX float™

Identical PAM systems were installed inside the AUVs, set to record 1-channel acoustic data continuously at 125 kHz sampling rate while running an algorithm for beaked whale detection. While at the surface, each unit was programmed to send a short detection summary, GPS locations, and engineering data to the shore over an Iridium™ satellite connection. Although the Seaglider Lithium battery is large enough to run the WISPR for 70 days, the 512 GB CF card limits the operation to 40 days, whereas the QUEphone uses a smaller alkaline battery package, which limits the duration of operation to approximately 16 days. For this dual AUV operation, acoustic data files were set to 2 minutes in duration. No raw acoustic records were transmitted because of the limited bandwidth of the Iridium satellite, restricting transmissions to only the detections of beaked whale clicks during the last dive sequence.

C. Area monitored

The two AUVs were deployed on April 6 and recovered on April 18, 2015, after 12 days of continuous operation. The acoustically surveyed area was located outside the northwest corner of the Navy's QUTR range off the coast of Washington (Fig. 3). The Seaglider (SG607) repeated a total of 68 1000-meter dives (purple lines) at ~5–6 hour intervals while moving at an average horizontal speed of ~20 cm/s. It repeated a triangular navigation path with the HARP as one of the way points (green circle: 47°30'8"N, 125°21'9"W). The Seaglider's three navigational waypoints were separated by approximately 7 km. SG607 remained within the small canyon (~1500 m deep) northwest of Quinault Canyon during the entire 12-day operation.

The QUEphone (Q2, path in red) was deployed 8 km northeast of the intended coordinates due to a miscommunication. For the first two days, it remained within 5 km of the HARP and within 10 km of the Seaglider. On April 8, 2015, lacking the capability to maintain station, it began drifting north in the prevailing ocean current toward Quillayute Canyon at an average horizontal speed of ~2.5 cm/s (~2.2 km/day). After 10 days, it had moved approximately 22 km to the north and was recovered at 47°42'59"N, 125°19'57"W. Q2 repeated one dive a day for 12 days on a 24-hour cycle (i.e., a 3-hour dive to 800 m parking depth, 17.5 hours in park at 800 m, a 3-hour ascent to the surface, and communication with the shore station every day at approximately 16:00 UTC).

Average vertical speed of the Q2 was 8 cm/s during the descent and ascent. The direction of the deep water current was not certain and there was a risk of the Q2 hitting the canyon wall; therefore, the parking depth was set to 800 m to avoid collisions.

III. Data Analysis

A. Seaglider's system noise

Fig. 4 shows the time series and spectrogram of the Seaglider's acoustic record at a depth of 140 m when it was ascending at 18:26 on April 12, 2015. The time series shows many downswing-spike-like noises. These spike noises began to appear at ~300 m depth during the ascent, and their frequency of occurrence increased gradually as it climbed to the surface.

The spikes appeared during the ascent phase only, and were not observed during the dive or apogee phases. The wide-band nature of the impulsive pulse (~20 µsec to ~50 µsec) added significant wide-band noise to the spectra. The interval between spikes shortened as it got shallower; at ~300 m ~1 min separation and 10 to several hundreds of milliseconds (msec) separation at ~50 m and above. In the top 50 m layer, the spike noises dominated the time series and made detections of any marine mammal calls difficult, particularly the beaked whale clicks, with click intervals on the order of 100 msec.

The cause of the spike noise appears to be related to the saturation of the pre-amp signal from nearby surface wave action. The sensitivity of the WISPR PAM reaches as high as -128 dB re 1V/µPa at 50 kHz with ~50 kHz bandwidth. The inverse of the pulse width is ~20 kHz to ~50 kHz, which is similar to the bandwidth of the pre-amp. A sudden change of water pressure related to surface wave action can change the pitch angle of the large surface area of the glider. Because of the Seaglider's large wing area, surface waves push or pull, making abrupt changes of the pitch angle and, therefore,

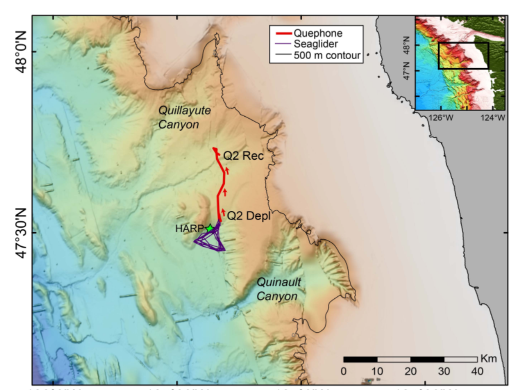

Fig. 3. Map of the Washington coast, where QUEphone (Q2) and Seaglider (SG607) were deployed 40 NM offshore of the Washington coast. Red line is the path that Q2 profiled during the 12-day monitoring. Green circle is the HARP which was one of the way points that SG607 navigated (purple lines) within a small canyon (~1500 m deep) northwest of the Quinault Canyon.

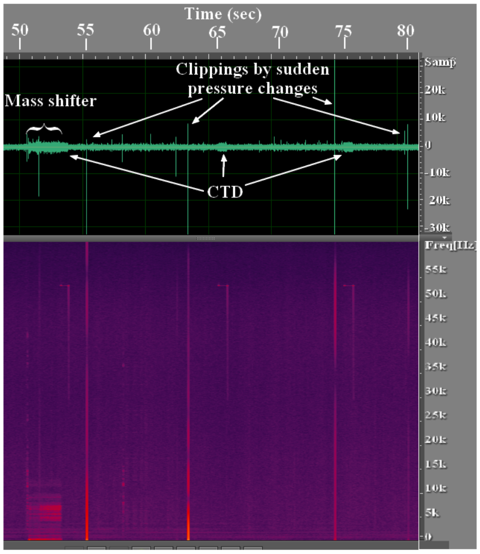

Fig. 4. Time series (top) and spectrogram (bottom) of SG607 acoustic record at 140 m during ascent. Occurrence of the spikes increased as it ascended near the top 300 m. Mass shifter noise appeared when it changed the pitch or roll angle. CTD noise appeared at every 10 sec.

hydrostatic pressure. A small but sudden hydrostatic pressure change can saturate the pre-amp easily because of its large gain. Also, in support of this hypothesis is the fact that these spikes did not appear when the Seaglider begins diving near the surface. At the beginning of each dive, the pitch angle is near vertical, making the dive fast and smooth, whereas on ascent near the surface, the Seaglider's pitch angle is ~20° or less.

Spectrograms also show two other types of noise associated with the Seaglider's system, i.e., CTD and mass shifter noise. The CTD was was turned on periodically to measure conductivity, temperature, and depth at 5 to 10 sec intervals. When enabled, it generates 1 sec long line noise at 53.37 kHz followed by a short (~200-msec long) wide-band noise between 30 kHz and 53.37 kHz. Similarly, the Seaglider's mass shifter generated wide-band mechanical noise below 10 kHz with a duration of 3 sec. During the descent and ascent, the mass shifter moves, changing the roll angle for steering creating noise at irregular intervals.

Fig. 5 shows ocean ambient noise spectra measured during 1) start of descent in top 50 m (black); 2) descent at 774 m (solid blue); 3) apogee at 987 m (green dash); and 4) ascent (red dot) at 774 m. To minimize the flow noise, we mounted the hydrophone on the antenna pole (2.5 cm dia and 110 cm long) 50 cm away from the aft of the Seaglider's cowling. Despite this, noise appeared at the beginning of descent and during the entire ascent phase. Noise levels below 100 Hz were as high as 16 dB above the 20 Hz levels during the quieter phases of apogee and descent. The SG607 was not ballasted well. The higher noise level during the ascent was most likely a result of the vehicle moving faster during the ascent as well as hydrodynamics of the Seaglider. Except for the top 50 m layer, the vertical speed during descent was slower than the ascent speed (~8 cm/s vs. ~16 cm/s). Noise spectra during the descent stayed low and was almost identical to levels during the apogee phase. There was almost no time that the Seaglider was stationary except when it was communicating with the satellite at the surface. Even during periods of apogee it kept moving horizontally with a vertical speed near zero.

By far the loudest system noise occurred during active periods of the hydraulic pump (purple): twice for 4 to 5 minutes in the beginning of the descent and ascent phases of each dive. It was so loud that it clipped the pre-amp signal, making detection of any acoustic events impossible. Although the pump noise spectrum does not represent the true values because of clipping, it shows wide-band characteristics with peak levels at least 60 dB higher than the sea-state 1 noise level at 2 kHz [12].

As described earlier, the spike noises (green) occured in the top 300 m layer during the ascent for the last 20 to 30 min of each dive. Wind speed at the nearby NDBC buoy 46041 (47.357°N, 124.731°W) at 06:50 on April 8, 2015, was 5.4 m/s (sea-state 1). The spike noise spectrum is ~10 dB higher than the sea-state 1 noise, and is high enough not only to contaminate the ambient noise measurement but also to lead to erroneous detections of marine mammal clicks with an inter-clicking interval and frequency range similar to these spikes [9].

Fig. 6 summarizes the noise spectra of the Seaglider's self-noises. The red line is the background noise during the apogee. Again, as for the CTD noise, its 1-sec long continuous 53.37 kHz signal (light blue line) is ~45 dB above the sea-state 1 background noise. Although line noise is relatively easy to distinguish, its trailing edge has a 200-msec long wide-band noise (30 kHz to 53.5 kHz) that resembles clicks associated with some species of beaked whales [9].

The mass shifter's band-limited noise (yellow line) below 10 kHz, also appearing in Fig. 6, is 15 dB higher than the sea-state 1 background noise. The noise duration of 3 sec can make detection of some marine mammals' call/clicks, e.g., sperm whales [13], difficult.

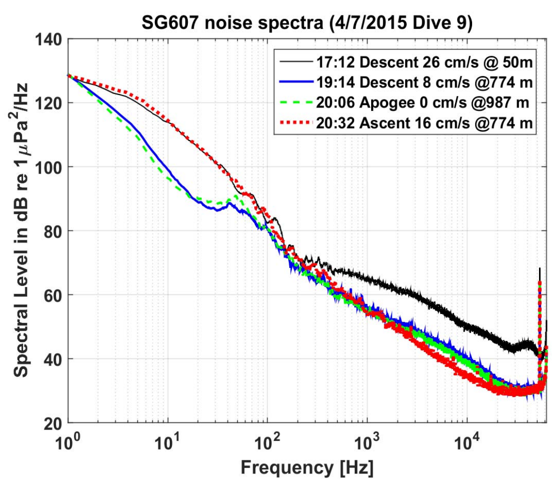

Fig. 5. Ocean noise spectra measured by the Seaglider (SG607) during the descent at 50 m (black), descent at 774 m (blue solid), apogee (green dashed), and ascent at 774 m (red). Fast water flow increased the noise level below 100 Hz during the ascent. System sensitivity is removed and acoustic spectral level is calibrated relative to $\mu Pa^2/Hz$.

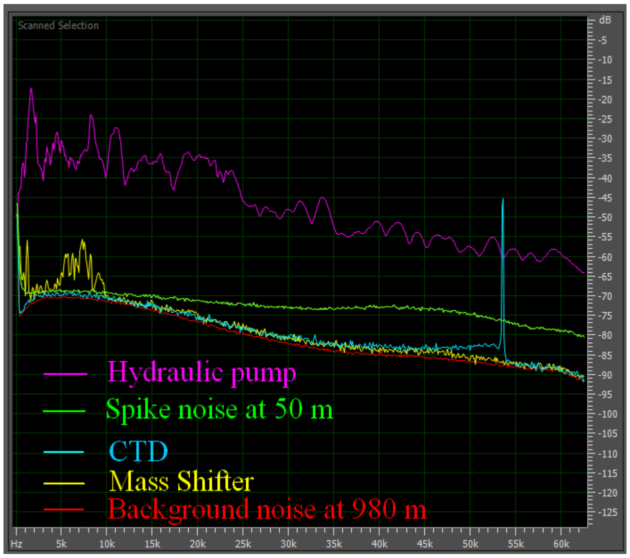

Fig. 6. Seaglider's self-noises during dive 65. Hydraulic pump noise was the highest (purple). The red line is the background noise level during the apogee at 980 m when the wind speed was 5.4 m/s. Near the surface during the ascent, spike noise level rose (green). CTD noise had a peak at 53.37 kHz, which was ~45 dB higher than the sea-state 1 noise. Mass shifter's noise is in yellow. Noise levels are relative to voltage.

B. *QUEphone's noise*

Compared to the Seaglider, the QUEphone is a much simpler platform without a mass shifter, CTD, compass, or tilt sensor, all of which can generate mechanical or electrical noises. Average vertical speed is 8 cm/s, which is significantly slower than the Seaglider speed against the water (<40 cm/s).

Fig. 7 shows the noise spectra during the three phases of the QUEphone (Q2): descent (blue), park, i.e., constant depth, and ascent (gray). It stayed in parking depth at 800 m for most of the day (17.5 hours) while drifting with ocean current without any significant flow noise, except for when it was moving down to the parking depth and then up for 3 hours each for satellite communication. The noise spectra below 100 Hz show no indication of flow noise and they are almost identical. However, during the ascent, the noise level between 5 kHz and 50 kHz (gray line) was lower than the previous two phases (by 9 dB maximum), attributed to the lower wind speed during the ascent. Wind speed at the NDBC buoy 46041 during the descent and park (21:50 April 6, 2015) was 4.1 m/s (sea-state 1). During the ascent at 00:50 on April 7, 2015, it was 0.6 m/s (sea-state 0). The frequency range at which wind can dominate the ocean noise spectrum is 1–50 kHz [12]. The calmer surface conditions resulting from lower wind speed explains the decreased noise level during the ascent.

Fig. 8 shows the relative spectral levels of the QUEphone's hydraulic pump (blue) and background noise (red). Again, the pump noise saturated the pre-amp; therefore, the spectral curve does not represent the true noise spectrum of the pump, but it appeared that the peak was ~60 dB above the sea-state 0 to 1 background noise (red). It is band-limited to below 35 kHz. Above 35 kHz it is significantly lower than the Seaglider's pump noise. The background noise spectrum shows a small peak of the processor's CPU clock at 32.768 kHz.

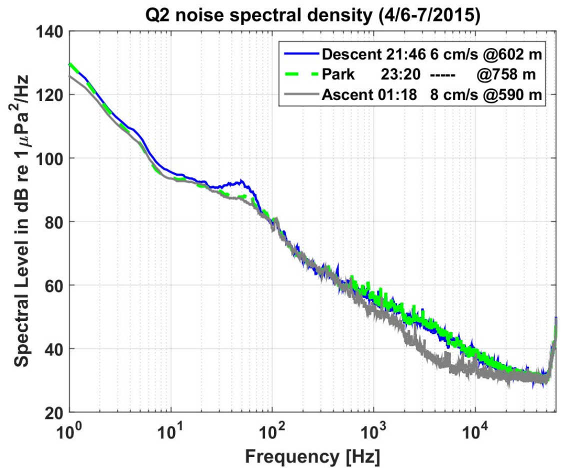

Fig. 7. Ocean ambient noise measured by the QUEphone (Q2) during descent, park, and ascent phases. Wind speed during the descent and park was 4.1 m/s, whereas during ascent phase it was 0.9 m/s.

C. *Comparison of QUEphone and Seaglider*

Q2 and SG607 were in the same area for the first two days from April 6 to April 8, 2015. Fig. 9 shows the comparison of the ambient noise measured by Q2 and SG607 at the same time period (00:31–01:39 April 8, 2015) and at the same depth (800 m) when they were in the same canyon within 10 km. On April 8, 2015, the two AUVs were still close to each other; therefore, the acoustic noise environments were still almost identical. Noise spectra of Q2 during parking and the descent phase of SG607 are almost identical. However, SG607's noise level below 100 Hz during ascent was significantly higher than the other two.

The flow noise of the Seaglider during the ascent can lead to a higher assessment of noise levels below 100 Hz. It also can make the detections of baleen whales, whose calling frequency is between 15 to 30 Hz [14], harder.

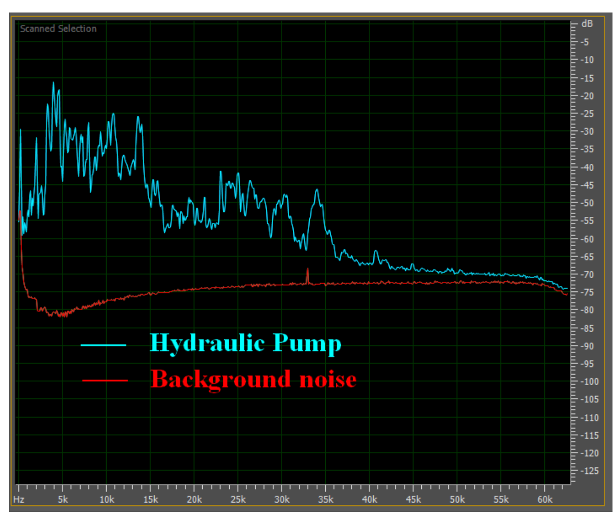

Fig. 8. Noise spectrum of hydraulic pump of the QUEphone and background noise. Noise level is relative to volt.

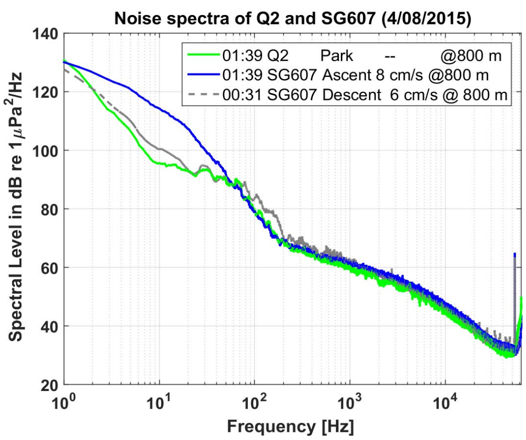

Fig. 9. Comparison of ambient noise spectra measured by QUEphone (Q2) and Seaglider (SG607) on April 8, 2015. The green line represents the Q2 noise level during parking mode. The gray dashed line is SG607's noise during descent, and the blue line is during its ascent. Wind speed at 01:50 was 6.1 m/s.

Table 1 summarizes the detection results of marine mammal calls/clicks of the two systems. The acoustic records were manually processed to pick the calls/clicks. Four species were identified, including Risso's Dolphins, Pacific Whitesided Dolphins, Stejneger's Beaked Whales, and Killer Whales. The number of species identified is significantly lower than the HARP (six baleen and nine toothed whale species). We attribute this to the fact that these marine mammal appearances are seasonal, and these two AUVs were operated for only 12 days in April, whereas the HARP was recording year round.

The total numbers of encounters was 15 by the QUEphone and 30 by the Seaglider. Overall, SG607 detected more calls than Q2. This is primarily a result of the Seaglider being able to stay within the targeted canyon area where marine mammal sightings and acoustic detections have been reported in the past, suggesting higher population density in that area. Additionally, Q2 was not deployed and drifted away from the targeted area.

TABLE 1. Detection results.

	Seaglider (SG607)		QUEphone (Q2)	
`Species	Number of Encounters	Total Duration Recorded (Hr)	Number of Encounters	Total Duration Recorded (Hr)
Risso's Dolphins	1	0.95	0	0
Pacific White-sided Dolphins	7	10.92	8	10.86
Stejneger's Beaked Whales	16	2.52	3	1.13
Killer Whales	6	3.32	4	1.75

IV. Discussions

Self-noise of the two buoyancy-driven AUVs, the Seaglider and the QUEphone, were examined. Six types of noises, including hydraulic pumps, water flow, CTD, mass shifter, spikes near the surface during the ascent, and the microprocessor are discussed.

Hydraulic pump noise was by far the loudest among the six noise sources, clipping the pre-amp in both systems. The Seaglider's hydraulic pump noise covered the entire spectral range below the aliasing frequency (62.5 kHz), whereas the QUEphone hydraulic pump noise was somewhat band-limited to below 35 kHz. In both systems, the hydraulic pump noise level was at least 55 to 60 dB higher than the sea-state 1 noise at 2 kHz.

Flow noise affected the record of the fast-moving Seaglider when it was ascending and did not affect the slow-moving QUEphone at all. Below 100 Hz during the ascents, it was as much as 16 dB higher than the quieter descent period. Flow noise contamination was also observed in the top 100 m during descent, when it was diving fast near a vertical angle. The flow noise was high even when the glider's vertical speed was similar to the QUEphone's vertical speed at 8cm/s. However, the velocity of the Seaglider against the water is a vector sum of vertical and horizontal velocities. Without accelerometers and ocean current information, the exact speed of the vehicle against the water is difficult to estimate. From the navigation log calculated from the rate of depth change and pitch angle, it seemed SG607's water speed was ~15 cm/s during descent and ~40 cm/s during ascent. Faster speed against the water during the ascent and eddies generated by the Seaglider body including the wings, explains the higher level of flow noise below 100 Hz.

The Seaglider's CTD generates a unique noise of 1-sec long 53.37 kHz continuous sine wave followed by 200 msec wide-band noise from 30 kHz to 53.5 kHz. It is most likely an electrical interference picked up by the hydrophone pre-amp. The wide-band noise of the CTD signal is similar to the beaked whale's clicks. The 1-sec long 53.37 kHz signal had a level of 45 dB above the sea-state 1 noise level. The beaked whale's individual clicks are on the order of hundreds of microseconds long, with an inter-clicking interval on the order of 100 msec. The CTD noise repeats at 5 to 10 second intervals. The signal characteristics are quiet unique; therefore, detection algorithms or human operators can easily differentiate the CTD noise from beaked whale clicks. The QUEphone, on the other hand, is not equipped with a CTD, removing similar concerns for data processing.

The mass shifter generates sound with many harmonics, including spectral content below 10 kHz for a duration of 3 sec. It had a peak of 25 dB above the sea-state 1 noise level occurring when the glider changed its roll or pitch angle. A detection algorithm or human operator should not have any problem in distinguishing the marine mammal calls from this noise.

The wide-band spike noise appeared in the Seaglider's ascent within the top 300 m. It appeared when sudden fluctuations of the vehicle's pitch angle occurred from surface wave motion saturating the high-gain hydrophone pre-amp.

Most of the spikes were downswings with pulse widths of ~20 to ~50 µsec. The number of spikes gradually increased as the Seaglider ascended to the surface. In the top 50 m, the spikes dominated the time series at varying intervals between tens to several hundreds of milliseconds. Because the pulse widths and intervals are similar to beaked whale clicks, lots of errors occurred in the real-time automatic detections of the processor near the surface during the ascents. Spike noises did not occur during the descent or ascent below 300 m. To reduce the sudden pressure change effects, one may want to use a pressure-compensated hydrophone but it may not be cost effective. The QUEphone did not have any spike noise issues.

The QUEphone had a minor microprocessor clock noise at 32.768 kHz with the level just above sea-state 0 to 1 noise, which would not affect detection performance. Overall, the QUEphone is quieter as an acoustic platform, but lacks the capability to steer itself against the current, resulting in an inability to stay in the area where the concentration of targeted species is high. As a result, its detections of marine mammal species are fewer than the Seaglider.

On the other hand, as a tool for ambient noise measurements, the Seaglider's system noises, in particular the constant flow noise during ascent, could lead to significant errors in noise spectral estimates. The 10–50 Hz band is the shipping noise frequency range that has been shown to be on the rise, with potential significant impacts to marine ecosystems [15][16]. Because of this, the Seaglider's acoustic data may not be as useful as the free-drifting QUEphones.

Unfortunately, the seafloor-fixed hydrophone record of the HARP was not available at the time of writing. Comparisons of the detection performance and noise evaluation among the three different systems will be a subject of future study.

ACKNOWLEDGMENT

We thank Dr. Greg Schorr of the Cascadia Research Collective (WA) for operating a small boat to deploy the AUVs. We are also thankful to Capt. Dan O'Hagan of Washington Fish & Wildflife (WA) for helping us recover the two AUVs. David Borg-Green at NOAA–PMEL modified the Rudics communication server program for QUEphone. Dr. Barbara Hickey of the University of Washington and Dr. Mike Kosro, Oregon State University, kindly gave us advice on the deep water current system off Washington coast. Susan Merle at NOAA–PMEL provided graphics support. Kate Johansson at Kongsberg gave us useful discussions on the Seaglider's speed in the water. This is NOAA–PMEL contribution number 4380.

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