2pUWa2. Monterey Bay ambient noise profiles using underwater gliders

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In 2012, during two separate week-long deployments, underwater gliders outfitted with external hydrophones profiled the upper 100-200 m of the Monterey Bay. The environment contained various noises made by marine mammals, ships, winds, and earthquakes. Unlike hydrophone receivers moored to a fixed location, moving gliders measure noise variability across a wide terrain. However, underwater mobile systems have limitations such as instrument and flow noise, that are undesired. In order to estimate the system noise level, the hydrophones on the gliders had different gain settings on each deployment. The first deployment used a 0 dB gain during which the ambient noise recordings were dominated by the glider. The second used two hydrophones, one with a 0 dB gain and the other with 20 dB. Apart from system sounds, the higher-gain hydrophone also recorded far-away sources such as whales and ships. The noise recordings are used to estimate the spectrograms across depth and record time. The spectrograms are integrated with the glider engineering data to estimate histograms of noise power as a function of depth and glider velocity. The statistics from the two different deployments are compared to discuss the value of gliders with external hydrophones in ambient noise studies.

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INTRODUCTION

In 2012, during two separate week-long deployments, underwater gliders outfitted with external hydrophones profiled the upper 100m of the Monterey Bay. Underwater gliders with external hydrophones are a new development with potential for mapping ambient noise. Unlike hydrophones receivers moored to a fixed location, moving gliders measure noise variability across a wide terrain. The overall objective in these experiments was to measure the ambient noise variability across depth at various locations in the Monterey Bay.

Gliders have been used for acoustic applications such as detecting low frequency sources (Howe and Boyd (2008)), whales (Moore et al. (2007)) and fish sounds (Wall et al. (2012)). The works by Howe and Boyd (2008) and Moore et al. (2007) used internal hydrophones. The work by Wall et al. (2012) used external hydrophones, but to detect nearby fish sounds. For making accurate measurements of low intensity ambient noise sounds, moving platforms such as gliders contend with instrument and flow noise in the sounds recorded by the external hydrophone. The system noises could potentially overwhelm the background noises recorded by the glider. A significant portion of the glider deployments discussed in this paper, dealt with measuring the noise levels due to the instrument. Two types of gliders were used in this experiment. The first was a Slocum glider (Webb et al. (2001)) that was deployed during June 2012. The second was a Spray glider (Sherman et al. (2001)) deployed during October 2012. Figure 1 shows a map of where the two gliders were deployed. The Slocum glider recorded acoustic sounds between 22-June to 25-June. The Spray glider on the other hand recorded acoustic sounds during 15-October to 20-October. Although the gliders have different construction, they operate using the same principle. Neither of the gliders rely on propellers to move. Instead, both the gliders use a pump that transfers mineral oil back and forth between the external and internal bladders. This changes the center of buoyancy of the instrument by which it either glides up or down. The gliders then control the pitch and roll are by shifting battery packs around. At the end of each dive the gliders come to the surface and transmit compressed science/engineering via Iridium calls. The gliders have a pumped CTD to make environmental measurements.

In order to add acoustic capability to these gliders hydrophones were attached externally. For the Slocum glider, the hydrophone was placed around the mid-section of the glider. In the Spray glider, two hydrophones were placed in the wet-bay which is near the tail section. The hydrophones used were Acousondes, which are autonomous acoustic recording devices (Burgess (2008)). The Acousondes used two different settings for sensitivity, by varying the gain levels. Two different gain settings of 0 dB and 20 dB were used, in order to see if the higher gain settings would cause clipping of acoustic sounds recorded by the glider. The first deployment with the Slocum glider used a gain setting of 0 dB which recorded sounds between 80 dB to 145 dB. For the second deployment with the Spray, the first Acousonde used a 0 dB setting accompanied with a second Acousonde at a higher gain setting of 20 dB which recorded sounds as low as 55 dB. The sounds recorded by the less sensitive Acousondes were only the high intensity noises made by the glider. The Acousonde with the higher gain recorded both the glider noises and also ambient sounds such as wind and ships. This article discusses both the types of noises.

ACOUSTIC SOUNDS RECORDED BY THE GLIDER

Figure 2 shows a record of the absolute pressure level recorded by the gliders across two hours. The figure also shows the corresponding depths of each glider. The Slocum glider dove to a depth of more than 200 m. The Spray on the other hand did more shallow dives that were only up to a depth of 100 m. Both the gliders spent considerable chunks of time at the surface to
upload glider engineering and science data. While the gliders are at the surface they sloshed around and made a lot of noise, which explains the high sound levels when the glider is at the surface (depth \( \approx 10 \text{ m} \)). The plot shows that when the gliders were at the bottom most point of their dive they recorded intense sounds which are comparable to the recording at the surface. The noises recorded at the deepest part of the dive are due to the buoyancy pump. Apart from the extreme levels recorded while at the surface and the bottom, the gliders while diving also recorded sounds such as the ballast pump (around 60 m for the Spray) and the battery packs that were moved around. The noise recorded by the 20dB hydrophone attached to the Spray, shows more detail (in the low sound levels) than the recording by its 0 dB counterpart. The 20 dB recording shows higher noise levels on its dive-up than the corresponding depths on its dive down. The higher level of noise in the dive-up part is due to the CTD pump. The maximum pressure recorded by the Slocum are slightly higher than the Spray.

Figure 3 shows a histogram of the mean pressure levels recorded by the three different Acousondes. The histograms pertain to 1 second averages of the acoustic pressure over a period of 2 days (23-Jun to 25-Jun for the Slocum and 16-Oct to 18-Oct for the Spray). The low gain Acousonde for the Slocum and the Spray apparently occupy the same pressure levels. The high gain Acousonde clearly has more dynamic range than the other two. Fig. 3 shows that the high sensitivity Acousonde records the low sounds and the high sounds (without any clipping). The rest of this paper discusses only the sounds recorded by the high gain Acousonde.

Figure 4 shows the spectrogram of sounds recorded by the Acousonde with the higher sensitivity. The spectrogram shows that the high intensity sounds such as the sloshing of the glider at the top, the bladder pump, the ballast pump, and the battery packs being moved around are all broadband in nature. The bulk of the broadband noises are concentrated in the lower frequencies 0-3 KHz. The up-dives similar to Fig. 2 are more noisy than the down-dives. The up-dives show more energy for frequencies 0-1 KHz and also in the 8-10 KHz bands.

The acoustic measurements made by the glider at different depths were used to estimate ambient noise levels across depth. For ambient noise profiles the glider depths 20-100 m were divided into 5 m blocks. Depths at the top (< 20 m), and the bottom (depth > 100 m) were not included because of the high amount of glider noise at those depths. The acoustic measurements made by the glider in each of the 5 m blocks were averaged to obtain mean noise levels. The
**FIGURE 2**: The absolute pressure levels and the glider depths overlaid on each other (during June 24 06:00:00 to 08:00:00 for the Slocum and October 16 00:00:00 to 02:00:00 for the Spray). The top plot shows the sound recorded by the Slocum glider and the bottom plot shows the sounds recorded by the two hydrophones attached to the Spray.
noise levels were estimated (from the spectrogram in Fig. 4) at frequencies 4 KHz, 5 KHz, 6 KHz, and 7 KHz. Other frequencies were avoided due to contamination from CTD pump induced noise on the dive-up portion 2. Fig. 5 shows the depth-dependent noise profile measured during the dive in Fig. 2. The middle of the dive (around 60 m) shows high ambient noise levels because of the ballast pump induced machine noises discussed before. Barring the outliers caused by the machine noise, the ambient noise levels increase gradually with depth. The ambient noise levels vary by about 1.5-2 dB from depths of 20 m to depth of 100 m. In addition to that, the ambient noise levels decrease with frequency. For frequencies between 4 KHz to 7 KHz the ambient noises decrease by about 1.5 dB per KHz.

Other interesting ambient noise sounds recorded by the glider

The glider also recorded other sounds that are worth mentioning. Fig. 6 shows the noise level in the 4 KHz band (via a spectrogram with a one minute time resolution) that receives significant contributions from the wind (Wenz (1962)). For comparison, with the acoustic noise, the plot also shows the wind measurements made by the nearby M1 mooring (Fig. 1). The plot shows that the low level noises (50-60 dB) track the wind speeds at M1. Fig. 7 shows noise recorded due to a passing ship. The noises are mainly concentrated in the frequencies 0-500 Hz. The glider is not too far from shipping lanes and so recorded other ship signatures similar to the one in Fig. 7

CONCLUSION

The glider experiments discussed in this paper are an important first step in using gliders with external hydrophones for ambient noise measurements. The ambient noise profiles at different frequencies, the measurements of wind and ship induced noise, all show that the glider can be used to perform a variety of noise studies. The experiments measured the glider induced noise, which are unnecessary interference for ambient noise studies. The discussion in this paper will help design better experiments and processing techniques to minimize interference from glider noise.
**Figure 4:** Spectrogram of sounds recorded by the high gain Acousonde. The spectrograms uses a 1024 point FFT (frequency resolution of 25 Hz).

**Figure 5:** Ambient noise (mean absolute pressure levels) across depth in 5 m blocks for the acoustic recording in Fig. 4. Other frequencies were avoided due to contamination from CTD pump induced noise.
**Figure 6:** Acoustic noise (20 dB Acousonde) in the 4 KHz band and the wind velocity measured at M1.

**Figure 7:** Spectrogram of a ship recorded by the glider (20 dB Acousonde) on Spray. The spectrograms used a time resolution of 5 seconds.
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REFERENCES


