

**Marine Physical  
Laboratory**



of the Scripps Institution  
of Oceanography  
University of California,  
San Diego

## **Project Report Liquid Robotics, Inc.**

# **Integration and Use of a High-frequency Acoustic Recording Package (HARP) on a Wave Glider**

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## Executive Summary

During the first two weeks of October 2009, a Scripps Institution of Oceanography (SIO) High-frequency Acoustic Recording Package (HARP) was integrated into a Liquid Robotics Wave Glider and recorded more than 3 days of wide-bandwidth acoustic data. The recording contains dolphin whistles and clicks along with anthropogenic sounds such as boat propulsion and sonar. Self-noise from the glider/hydrophone system was also characterized, including some suggested improvements on how to reduce some of these noises.

## Introduction

The following summarizes the integration of a HARP into a Wave Glider and reports on various sounds recorded. The Wave Glider with HARP was deployed offshore of the Big Island of Hawai'i (Figure 1) from 9 October to 13 October, 2009, resulting in 75 continuous hours of ocean acoustic data from ~10Hz to 100kHz.

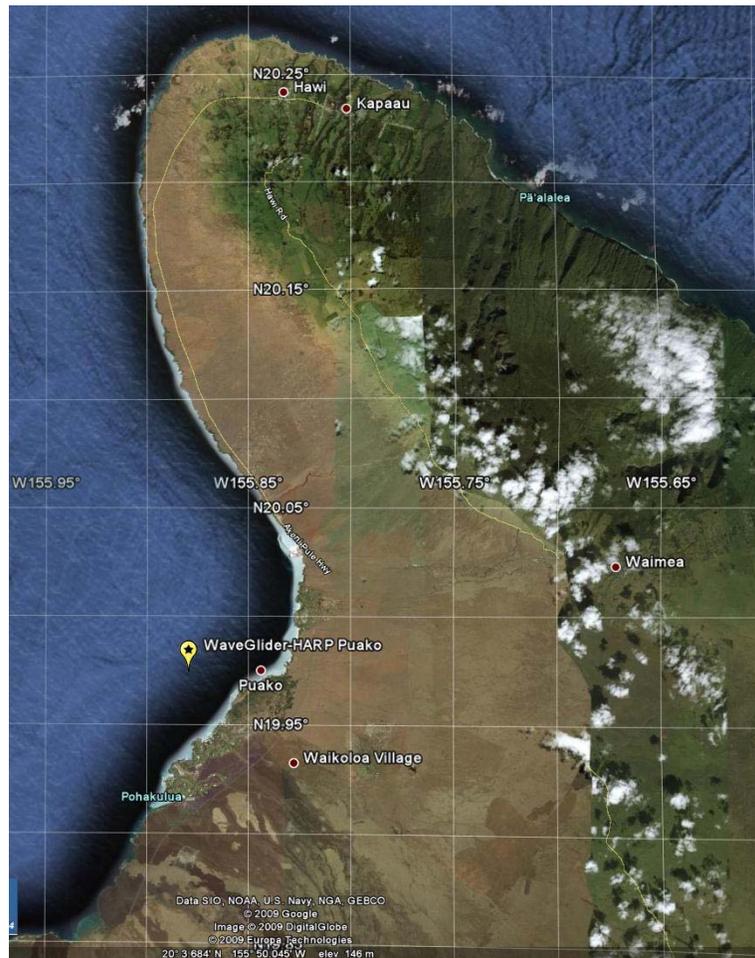


Figure 1. Site map of Wave Glider HARP October 2009 deployment about two of miles offshore of north-west end of Hawai'i near Puako Beach (yellow bubble-star).

## Wave Glider and HARP Integration

The HARP data logging system (Wiggins and Hildebrand, 2007) was re-packaged into the larger (forward) of two available dry boxes on the surface vehicle of the Wave Glider (Willcox et al., 2009). The HARP system includes low-power electronics (1/2W continuous data acquisition / 3W 20% duty cycle data storage), high-speed data sampling (200 kHz, 16-bit), 16 laptop disk drives (2TB), and 12V batteries for self-contained power (Figure 2).

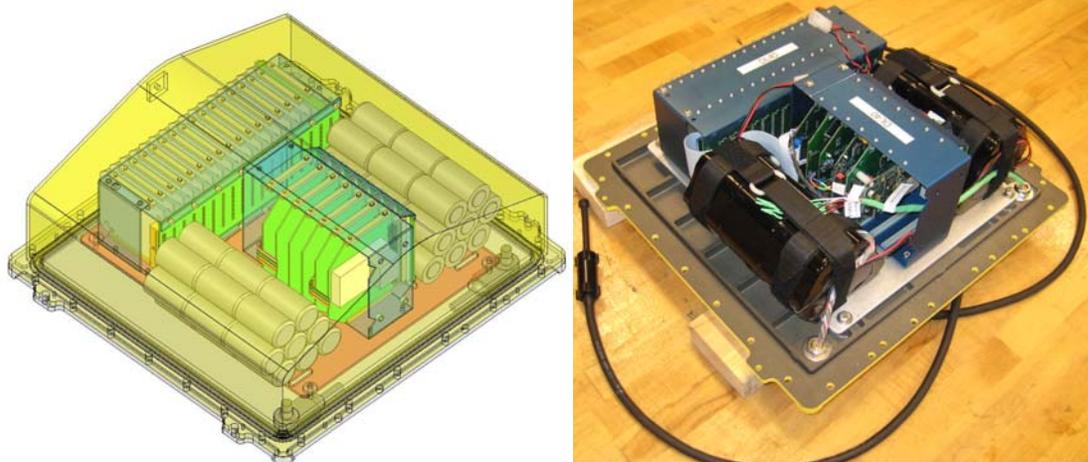


Figure 2. CAD drawing and photo of HARP data logger integrated onto the forward dry box lid of a Wave Glider. The data logger includes 2TB of data storage (blue rectangular cage at upper left) and two 12V alkaline battery packs for self power (black ‘cylindrical’ packs at lower left and upper right). One of the two cables is used for communication with the data logger during pre-deployment setup and after recovery, and the other is connected to the hydrophone.

The hydrophone was designed to be towed behind the Wave Glider and to have a small cross-sectional area (1” diameter) with a small diameter (0.25”) electro-mechanical cable to minimize drag while towing (Figure 3). The hydrophone consists of two transducers: Benthos AQ-1 cartridge for 10Hz- 2kHz and Sonar Research HS-150 for 2kHz-100kHz. These two sensors are amplified and filtered with electronics inside the oil-filled hydrophone tube. The conditioned analog signals are digitized and stored to disk by the HARP data logger. The hydrophone cable was about 10m long and was attached to the wing glider system, approximately 8m beneath the surface vehicle. While the HARP typically supplies 5V power to the hydrophone, for these tests the Wave Glider provided power to the hydrophone because of limited number of conductors available in the umbilical between the surface vehicle and the wing glider system.

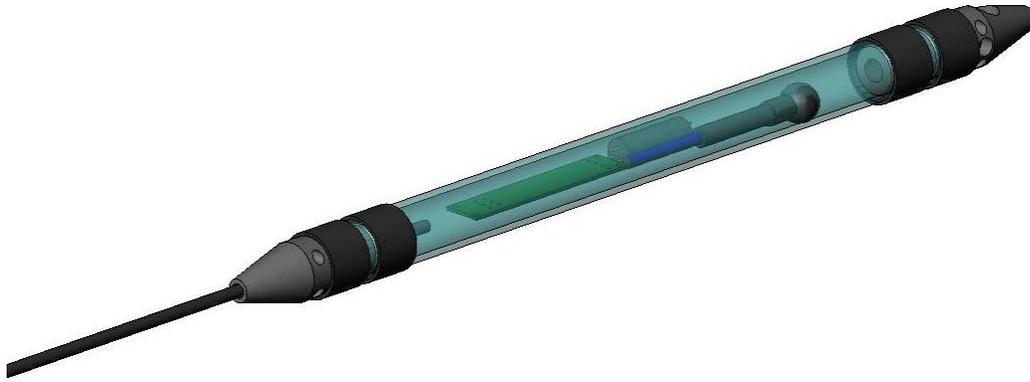


Figure 3. CAD drawing of towed hydrophone. The hydrophone cable is 0.25" diameter and 10m long, and is attached to the wing glider system about 8m below the sea surface. The ends of the hydrophone are PVC plastic; the outer tube is 1" diameter and made of polyurethane.

The Wave Glider with HARP was deployed on 9 October, 2009 in the Liquid Robotics test range offshore of Puako Beach, Hawai'i and was programmed to travel in a square about 300m along one side (Figure 4). An earlier test on 6 October, 2009 showed that the Wave Glider could successfully tow the hydrophone in low sea state conditions.

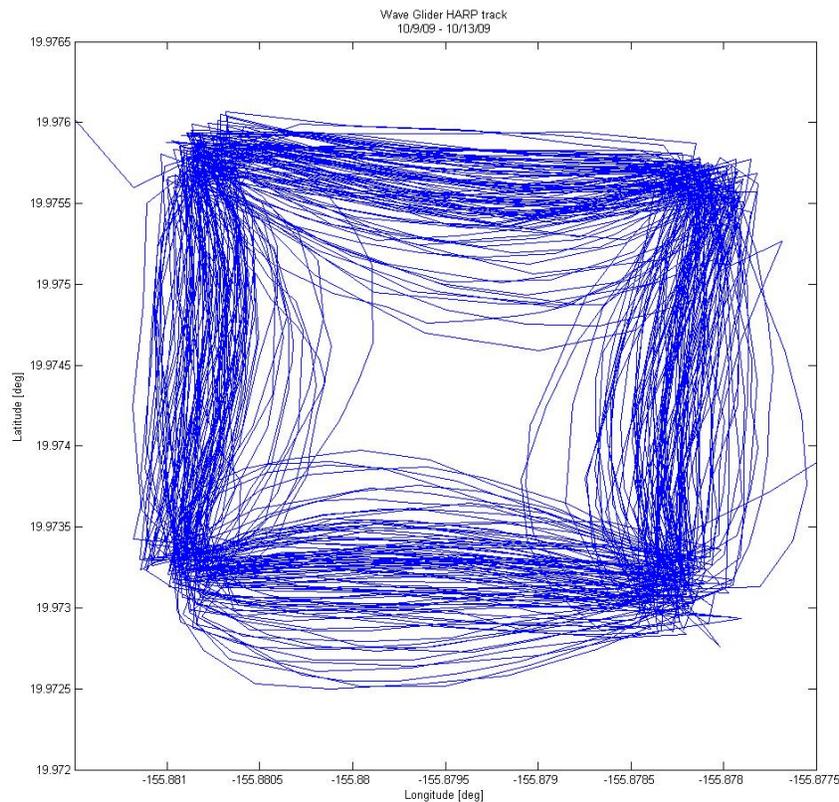


Figure 4. Wave Glider with HARP track 9-13 October, 2009 from GPS positions - approximately 300m along one side of the square track.

## **Acoustic Data**

Approximately 75 hours (3 days, 3hours) of acoustic data were recorded almost filling one 120 GB hard drive. The recording session started on 9 October, 2009 at 2300 GMT (all times reported are GMT – i.e., HST = GMT - 10 hrs.) and continued after recovery of the glider around 0230, 13 October, 2009.

Below are plots from the recording which show sounds from the environment (man-made and biologic) and self-noise. Plots may be Long-Term Spectral Averages (LTSAs), spectrograms, time series or spectra. LTSAs are essentially spectrograms averaged over longer periods than standard spectrograms (i.e. time resolution for LTSAs is 5 seconds vs 5 millisecond for typical spectrograms at 200 kHz samples).

## **Non-Biologic Sounds and Noise**

Characterizing non-biological, mechanical and electrical sounds and noise are presented first because these are more prevalent than biological sounds in this data set and because understanding these sounds is needed to extract biological sounds from the data (i.e., when signal-to-noise SNR values are low).

A typical spectra plot from a time period when no other obvious sound sources (man-made or biologic) were present shows that for this data set, most of the energy is in the lower frequencies – as is typical for ocean acoustics. However, around 5-10Hz the spectrum levels are consistently elevated beyond what would be typical, even for regions of high shipping density. Figure 5 shows time series and spectra (corrected for hydrophone sensitivity) for 1 second of data without other obvious noise sources. The 5-10 Hz noise is likely caused by hydrophone cable strumming as it is pulled through the water and may be reduced with a cable fairing. Also, the hydrophone cable is strain relieved at the connection point on the glider wing system with a nylon line. Better might be to use a length of elastic cord so that jerking action between the glider wing system and the hydrophone cable would be minimized.

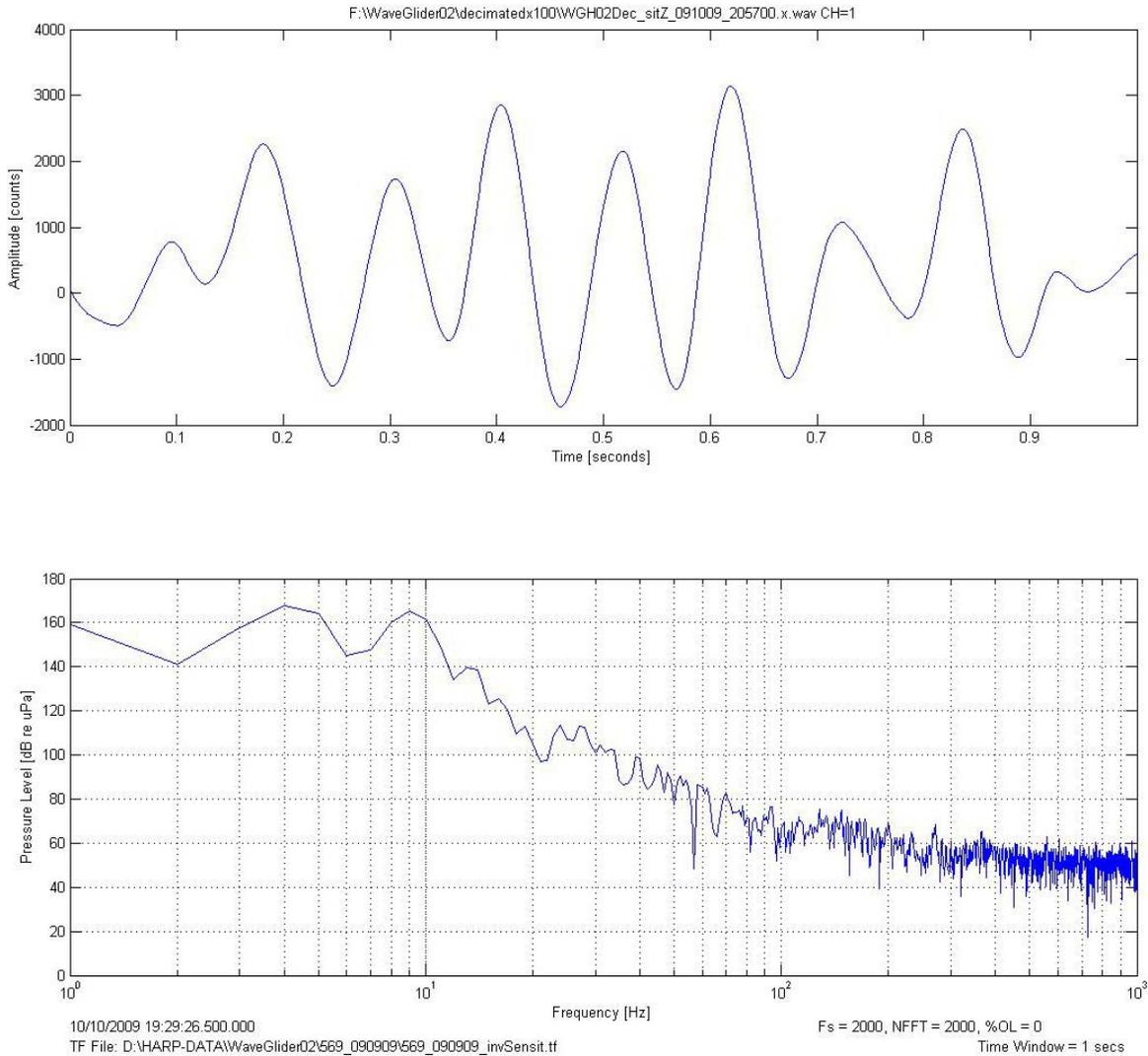


Figure 5. Amplitude time series (top) and spectrum level (corrected for hydrophone sensitivity) in 1 Hz bins for 1 second of data with minimal noise sources except 5-10 Hz, presumably cable strum.

To evaluate low frequency (<1000Hz) sounds recorded with a high sample rate, the data can be decimated (low-pass filtered and re-sampled at a lower rate) providing smaller data files which are processed faster and are easier to evaluate. Figure 6 shows LTSA, spectrogram and time series for the decimated data set. The LTSA spans the full 75 hours of deployment and shows periods of increased noise (0-10hrs, 22-30 hrs, 37-39 hrs, etc) and periods of lower noise levels (15-22hrs, 32-37hrs, 40hrs, etc). These differences in low frequency noise are likely related to differences in sea state which affects the dynamics of the Wave Glider. Both broad-band transient events and longer periods of low frequency (<200Hz) are present.

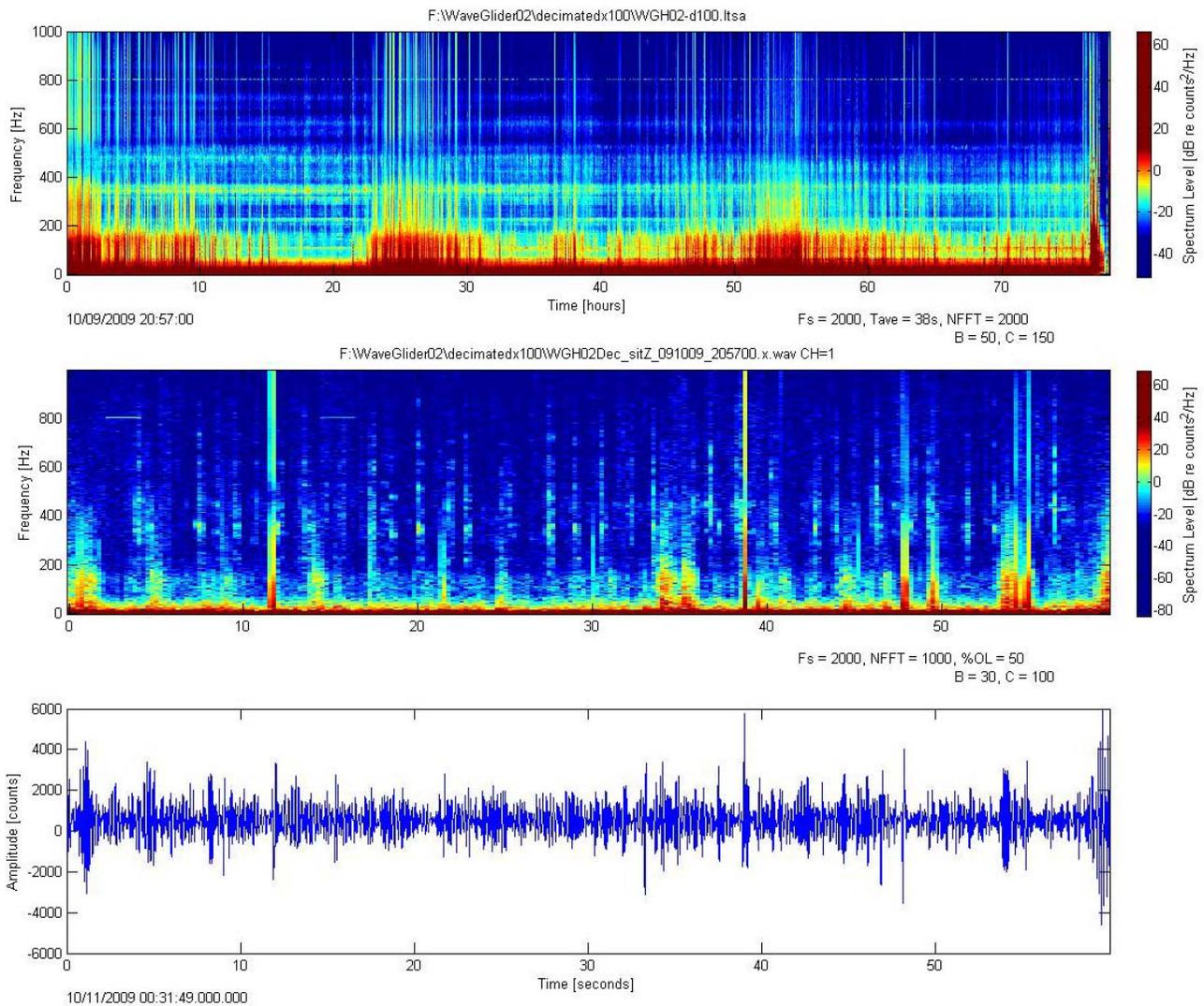


Figure 6. Decimated (low-pass filtered and re-sampled at 2000 Samples/sec) acoustic data from the Wave Glider with HARP. LTSA (top), spectrogram (middle) and time series (bottom) show intense low frequency noise, especially around 10 Hz and broadband impulsive events. The spectrogram and time series occur around hour 24 on the LTSA.

Higher frequency analysis shows both anthropogenic noise and vehicle self noise. A 50 kHz echo sounder can be seen clearly around 0.31h in the LTSA and in the middle spectrogram in Figure 7. Examination of the data show narrow-band, constant-tone electronic noise is picked up and recorded. Noise lines (horizontal) are at 4.8, 24, 32, 40, 48, 49, 64, 77, 82, 88, and 97 kHz, some more intense than others. The vertical pulses that extend across the full band in the LTSA are shown in the bottom spectrogram. They are 2 seconds long and occur though out the data set – perhaps these are from servo motors used to adjust the rudder. These 2 second bouts of noise often include click-like pulses.

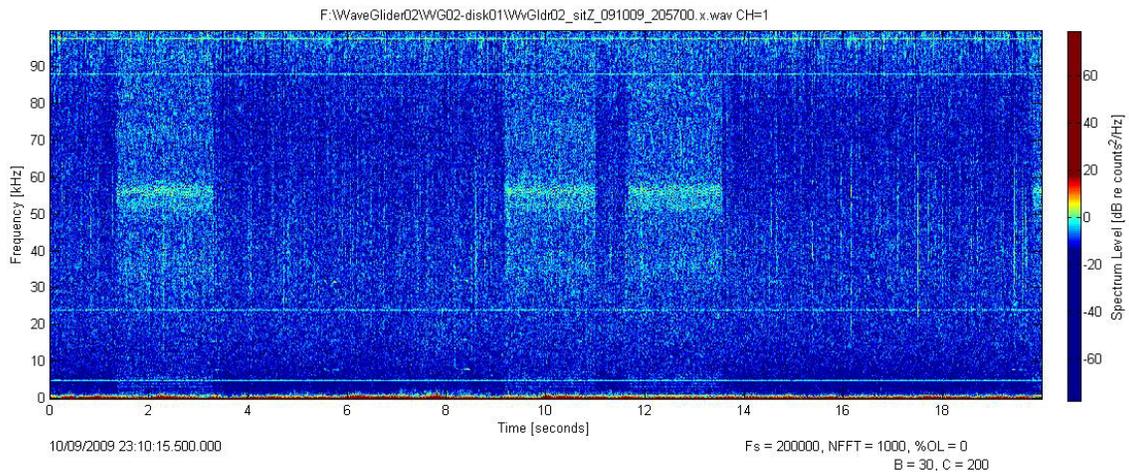
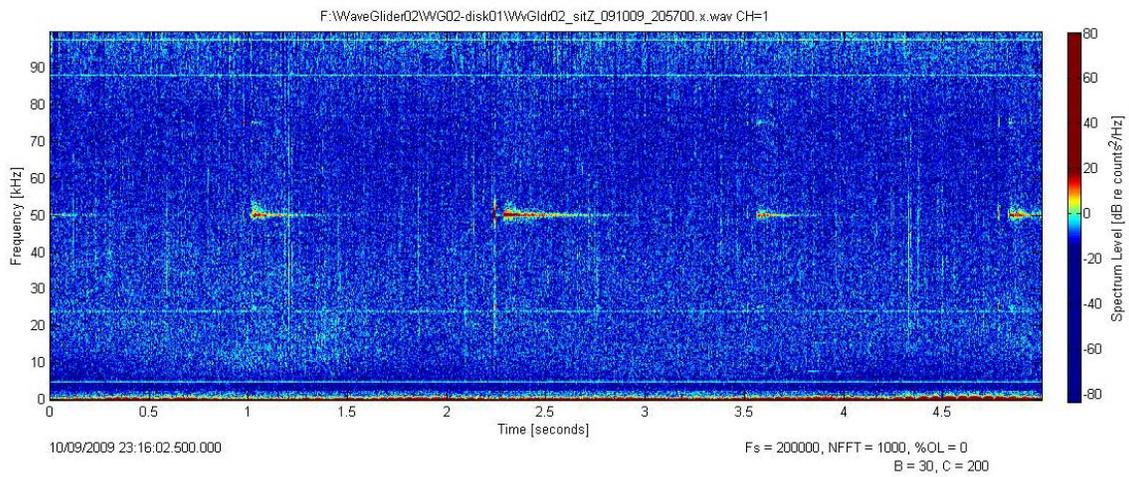
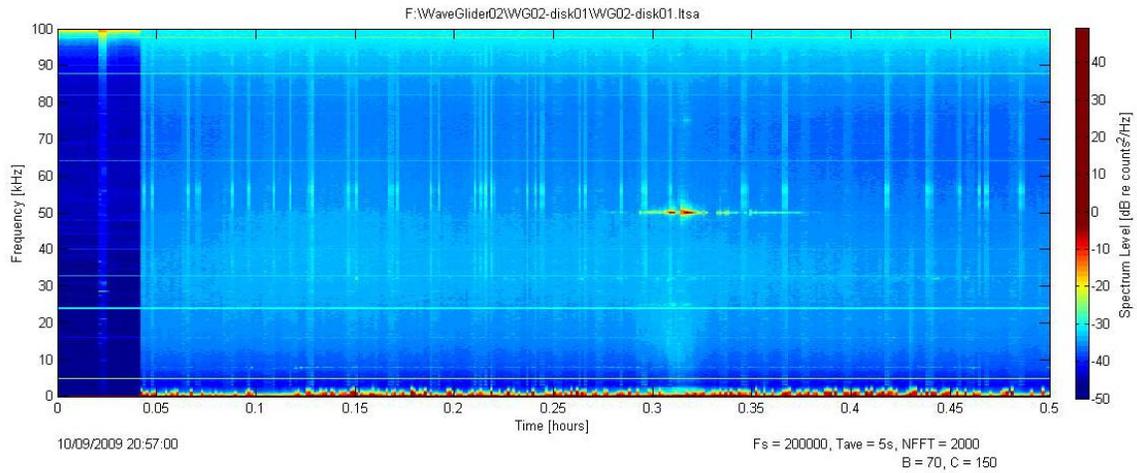


Figure 7. LTSA (top) and spectrograms (middle and bottom) from the beginning of the recording show noises typical to this data set. The first few minutes of the LTSA in Figure 7 show a pre-deployment ‘deck’ test of the HARP without the hydrophone powered. The transition from dark to light blue in the LTSA at 0.04h is when the in-water recording started at 2300. Also, the high-intensity (red) at low-frequencies in the LTSA shows that the system is in the water.

Over the three days of recordings, there are six intense noise events (Figure 8) ranging from 0.5h to around 3h in duration all with somewhat different frequency characteristics and different intensities suggesting these may not be self-noise but from some other unknown source. These may be sonar sound un-related to the Wave Glider or HARP.

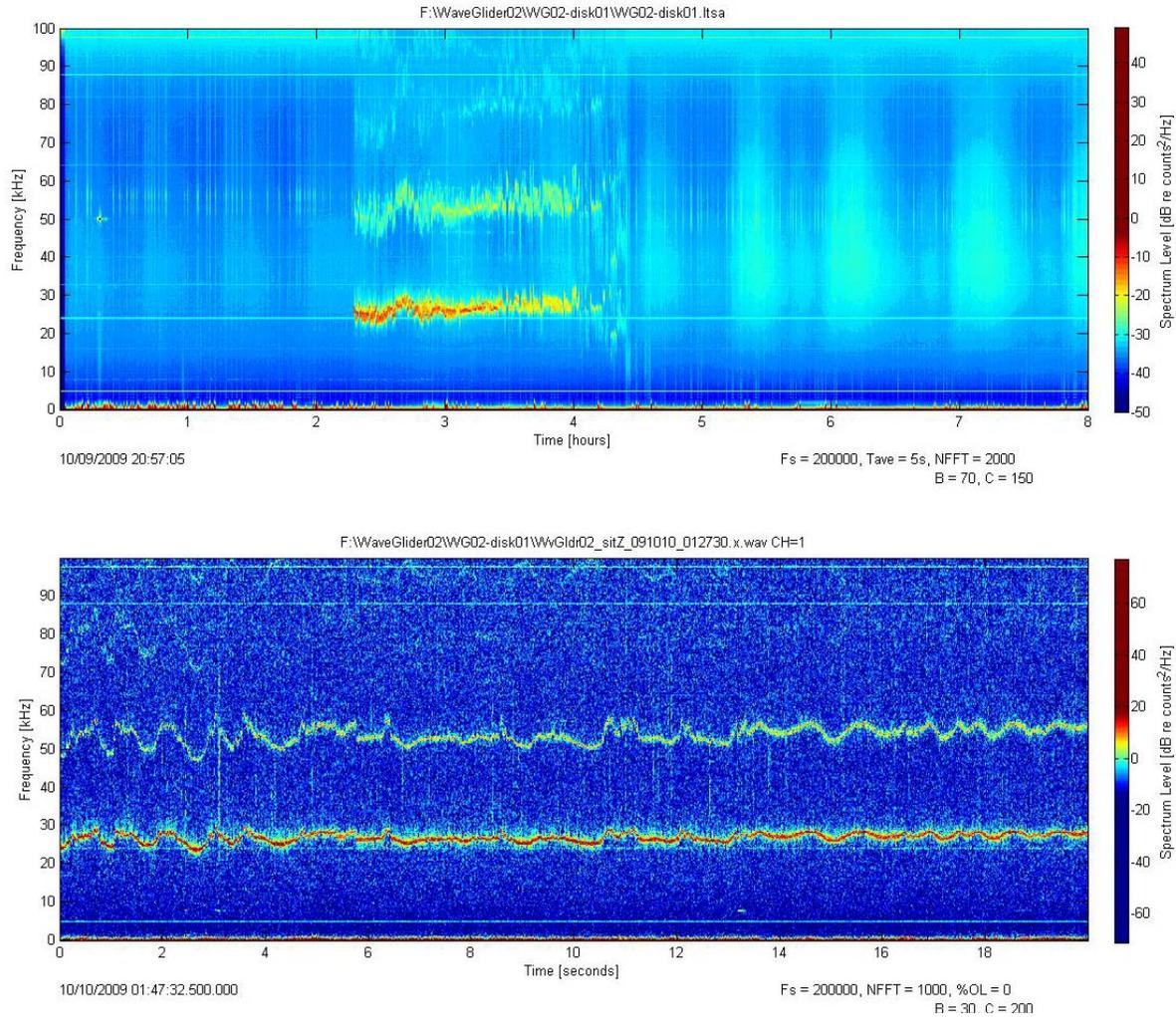


Figure 8. LTSA (top) of first 8 hrs of data shows intense noise from about 2.25h to around 4.5h. This noise (bottom spectrogram plot) is a frequency modulated (FM) tone around 25 kHz with harmonics at 50 kHz and some energy at 75 kHz and near 100 kHz. Also, broadband (25-70 kHz) periodic (~1hr) noise intervals can be seen in the LTSA (eg. 6-6.5hrs).

Periodic (every ~ 1hr) broadband noise intervals are seen in Figure 8 from about 25kHz to about 70kHz, lasting about one-half hour on the LTSA plot. These are likely from some sort of flow noise, ocean current or breaking bubbles as they are well correlated with the glider track direction. For example, the track corresponding to hrs 6 to 7 from Figure 8 is shown in Figure 9. The broadband noise interval is from the start of the track

in the lower right corner to the upper left corner lasting 40 minutes. Even the small loop in the upper right corner of the track can be seen as a small noise interval around 6.75h in Figure 8. These noise periods appear to be direction related and because of their high frequency content could be caused by cavitating bubbles – i.e., breaking bubbles as the vehicle heads into the swell/wind, but not when going down swell/wind. Comparison to metrological data could provide some insight to the source of these noise periods.

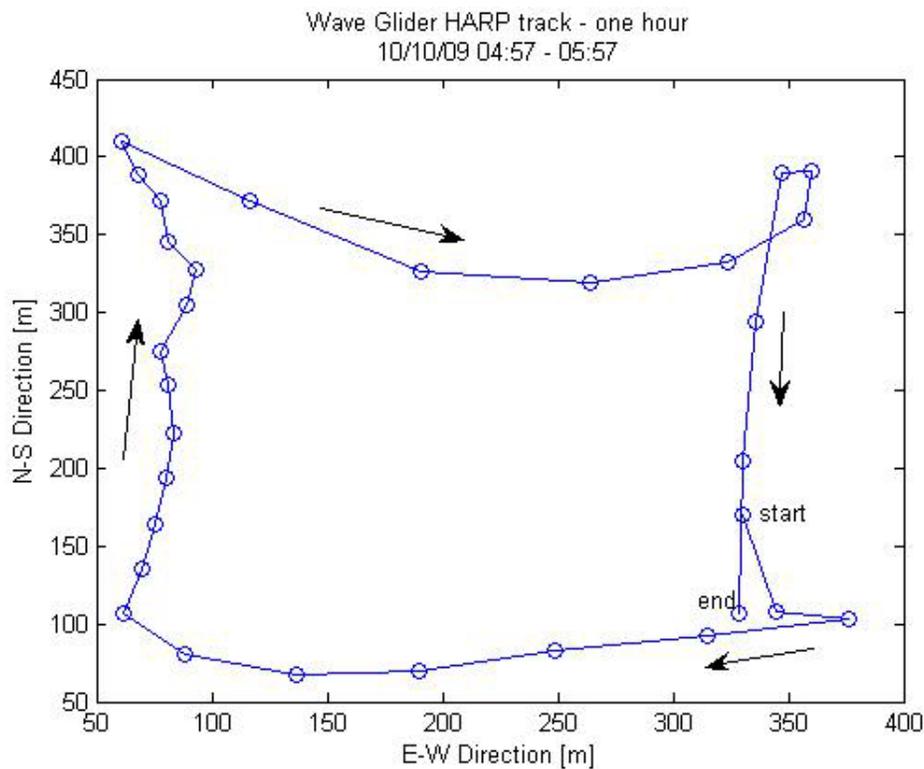


Figure 9. One hour track of Wave Glider HARP from GPS log shows one complete square transversed. Locations are every 2 minutes. Track corresponds to LTSA plot Figure 8 between hours 6 and 7. The broadband noise intervals in the LTSA are correlated with the lower E-W and left S-N legs, and even the loop in the upper right can be seen as a small noise interval near 6.75h in Figure 8. Perhaps these noise intervals are related to breaking bubbles.

## Biological Sounds

Throughout the data, there are mechanical impulsive sounds that appear like dolphin clicks making it difficult to differentiate these sounds from dolphin clicks. However, temporal patterns and coincident occurrence with dolphin whistles can aid in identifying dolphin clicks. The following are examples of dolphin (presumably spinner) whistles and clicks that have been band-pass filtered to enhance the figures.

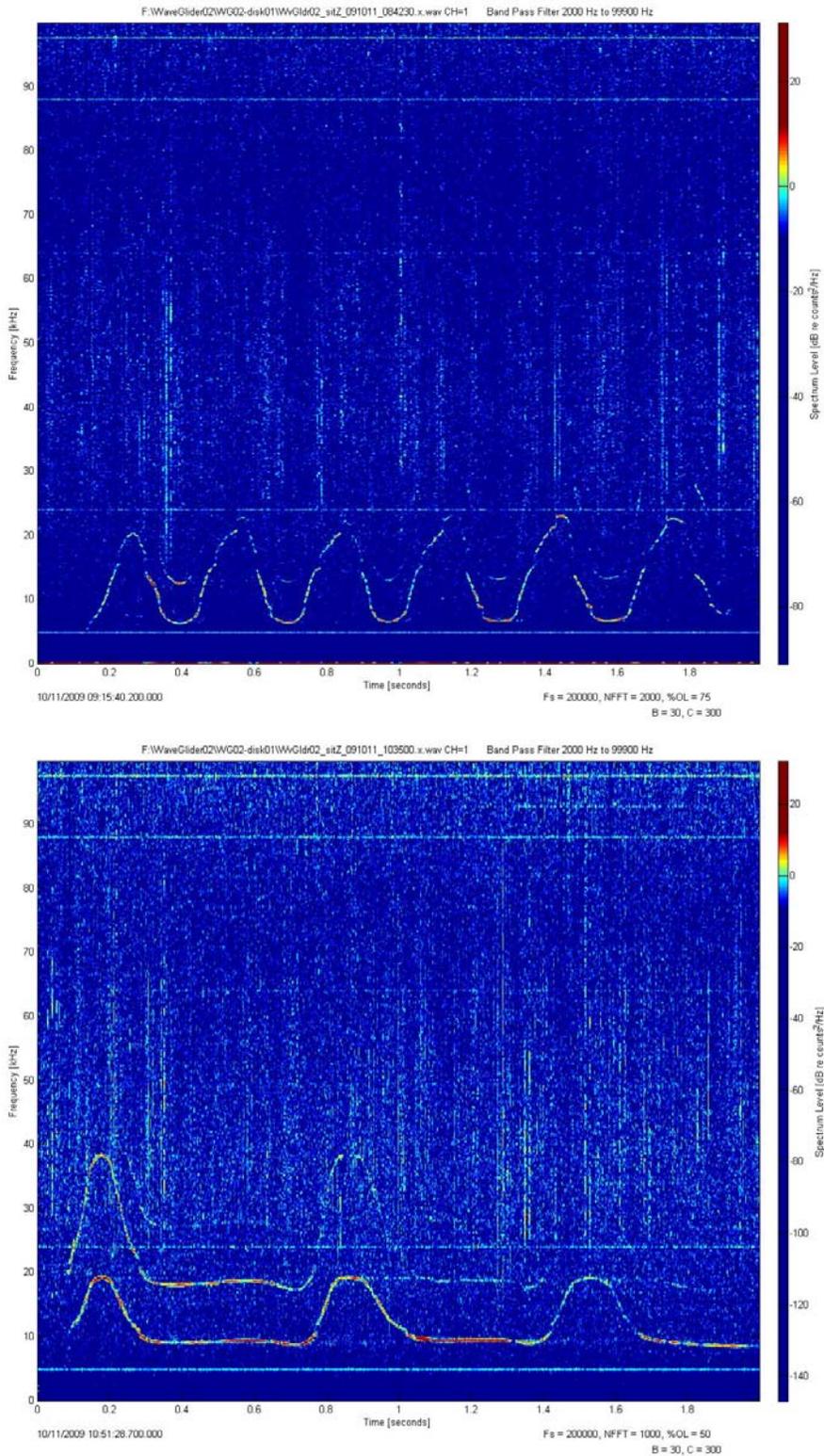


Figure 10. Spectrograms of dolphin whistles show harmonics as high as 40 kHz and typical frequency modulated patterns.

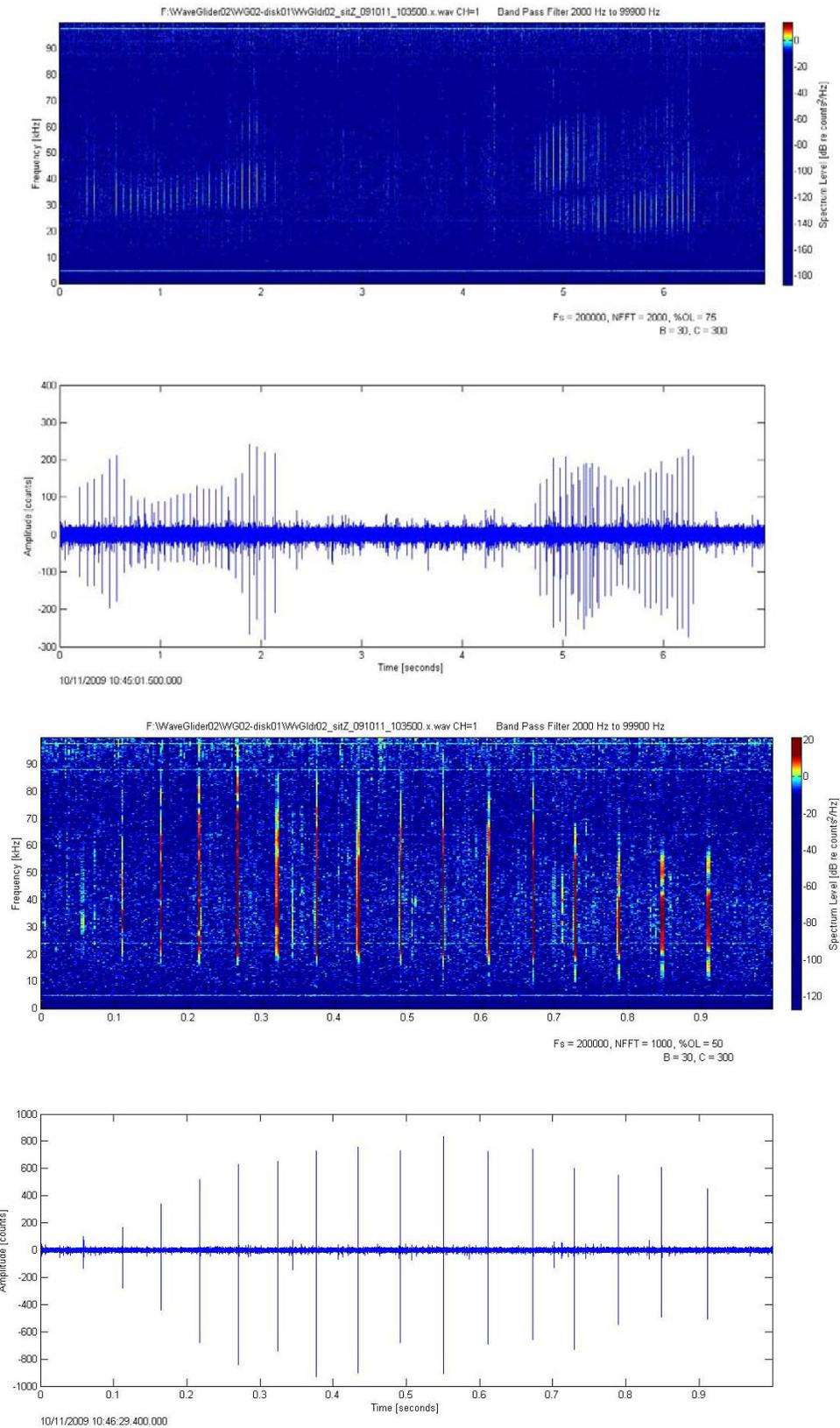


Figure 11. Spectrograms and corresponding time series show amplitude and temporal characteristics of broad-band clicks. The variations in timing and amplitude suggest these are dolphin clicks.

## Conclusion

A HARP was successfully integrated into a Wave Glider and deployed near Puako Beach, Hawai'i in October 2009. A HARP hydrophone with ~ 10m of cable was towed aft of the glider wing system and did not significantly impede the mobility of the Wave Glider such that typical testing (square) tracks were transversed over 3 days of the deployment.

Very low frequency (~ 10Hz) noise, presumably from cable strum, is the dominate noise source at these frequencies throughout the recording. Cable strum might be reduced by including a fairing on the cable. Low frequency (<1000Hz) impulsive type noise events may be reduced by replacing the nylon line strain relief for the hydrophone cable with an elastic strength member, such as a bungy cord.

There are track direction-dependent, broad-band noise (20kHz-70kHz) periods that last around 30 minutes and may be caused by breaking bubbles from the surface vehicle. Other broad-band pulses lasting 2 seconds throughout the recording are presumed to be vehicle related based on their consistent duration, and likely may be from energized servo motors used to adjust rudder headings.

Dolphin whistles and clicks were recorded during the 3-day, near-shore deployment showing that broad-band recordings of marine mammals can be made from a Wave Glider. Longer deployments of the Wave Glider with a HARP in regions with known marine mammals, for example singing humpbacks in the winter off of Hawai'i, should provide unique data sets with which to further our understanding of these captivating animals.

## References:

Wiggins, S. M., and Hildebrand, J. A. **2007**. High-frequency Acoustic Recording Package (HARP) for broad-band, long-term marine mammal monitoring, in *Symposium on Underwater Technology and Workshop on Scientific Use of Submarine Cables and Related Technologies, 2007*, pp. 551-557.

Willcox, S., Manley, J., and Wiggins, S. **2009**. The Wave Glider, an Energy-Harvesting Autonomous Surface Vessel, *Sea Technology*, 50 (11), 29-32.

## Addendum

On 11-12 March 2010, a Wave Glider with HARP was deployed offshore of Hawai'i to record singing humpback whales (Figure A1). Improvements to the towed hydrophone system were made which reduced strum and impulses on the cable and decreased the low frequency self noise while underway (Figure A2). A fairing was attached to the cable reducing low frequency strum and a flexible coupling attaching the cable to the wing reduced shock impulses from wing motion.

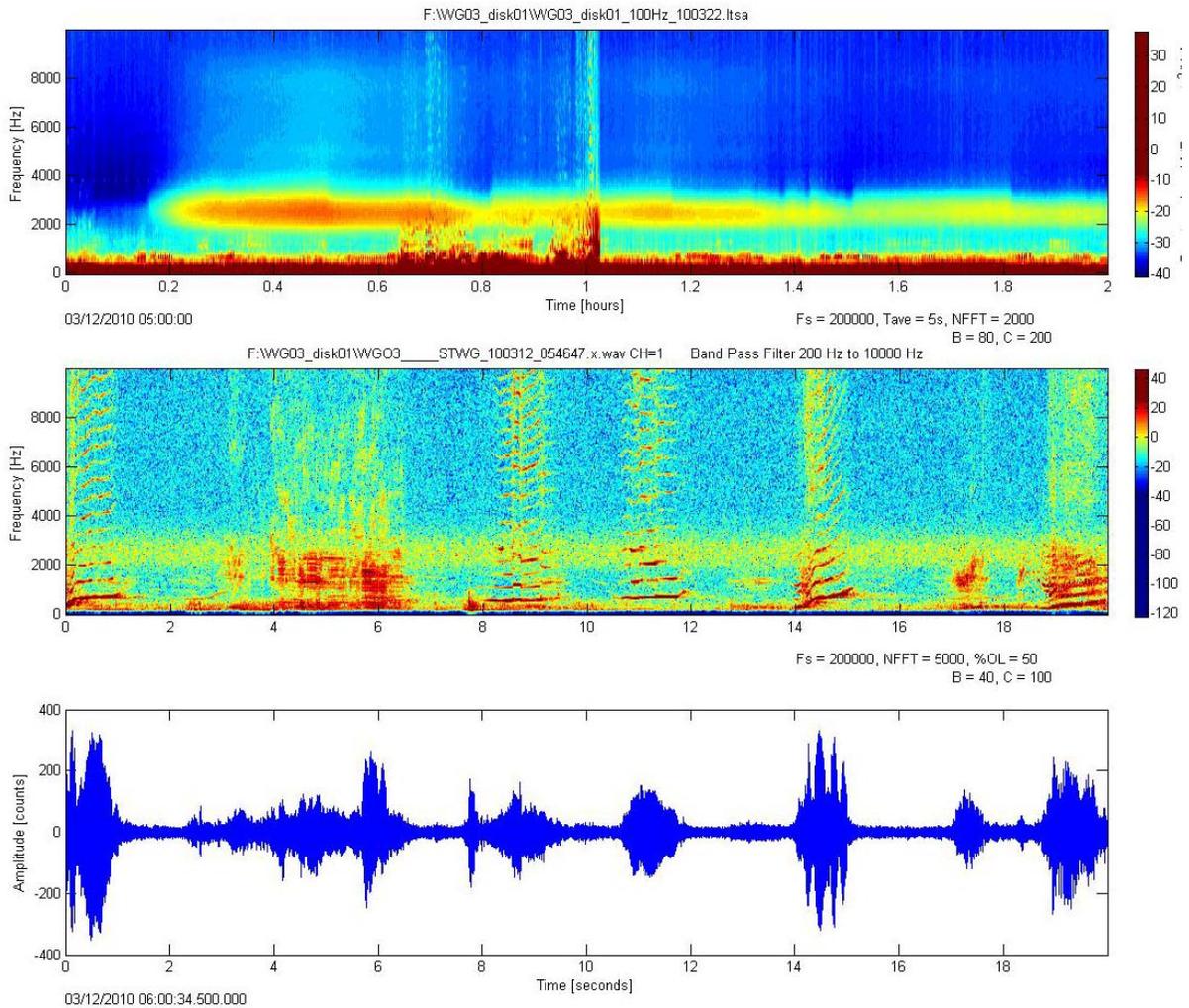


Figure A1. LTSA (2hrs), spectrogram and time series (20 seconds) of humpback song offshore of Hawai'i from 12 March, 2010. The data for this spectrogram and time series were band pass filtered from 200 Hz to 10 kHz to better show the humpback calls.

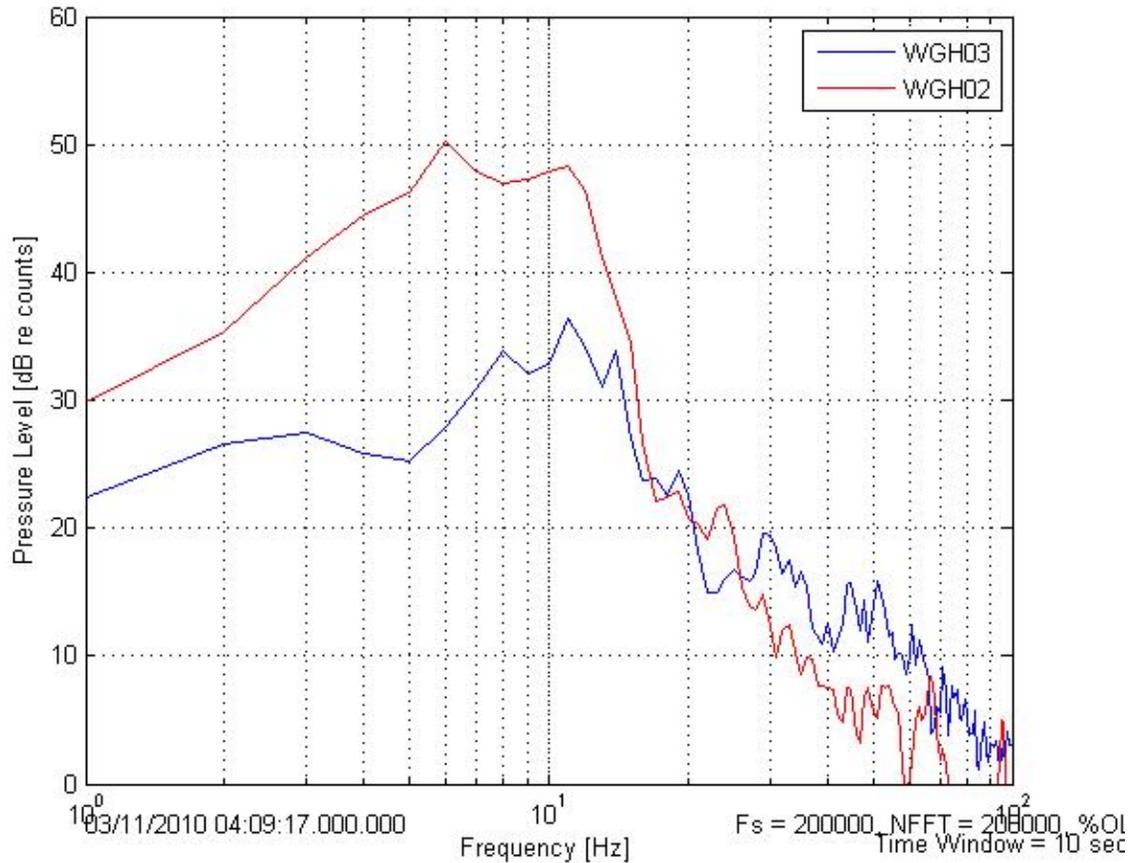


Figure A2. Comparison of relative spectrum levels between 1 and 100 Hz. The blue spectrum is from 12 March 2010 which used a cable fairing and flexible coupling and the red spectrum is from the October 2009 deployment without fairing and non-elastic line coupling. There is 10-25 dB reduction in self noise below 15 Hz, significantly improving the quality of recorded acoustic data.