Final Report

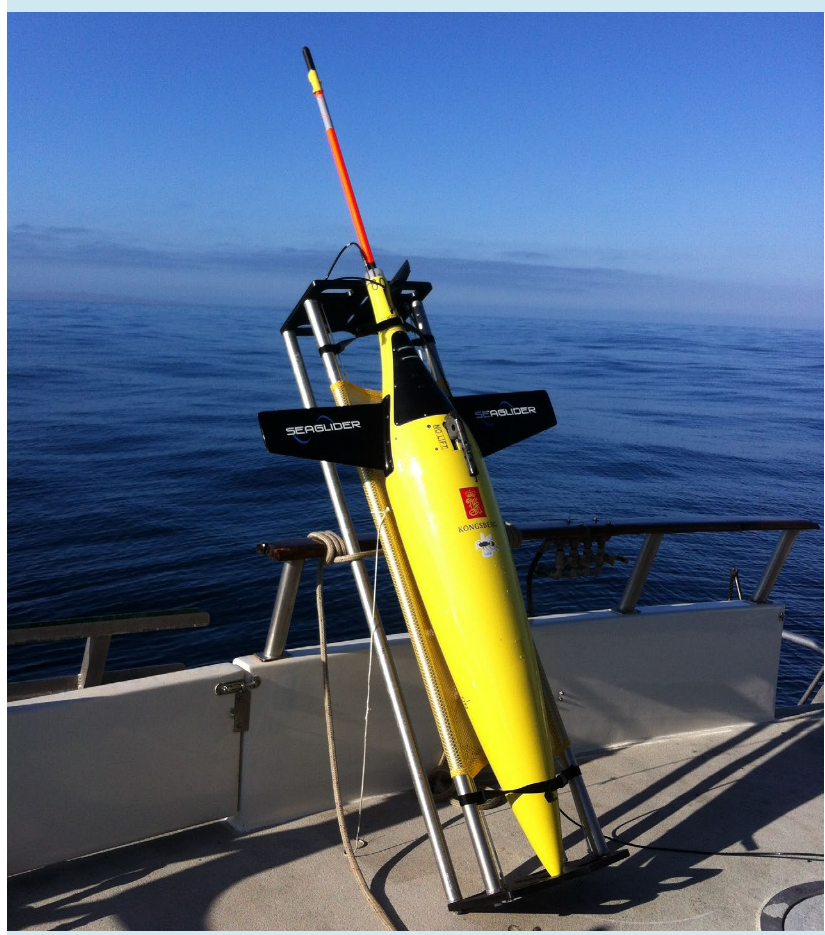
Assessment of ocean ambient sound levels in the northern Gulf of Mexico, May - June 2018

Submitted to:

The Bureau of Ocean Energy Management (BOEM), United States Department of the Interior

Contract No. M17PC00001, Task Order M17PD00011

BOEM
BUREAU OF OCEAN ENERGY MANAGEMENT



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Executive Summary

An acoustically-equipped Seaglider was deployed in the eastern and northern Gulf of Mexico from 10 May to 18 June 2018. A total of 724 hours of continuous, high-quality acoustic data were collected and analyzed for ambient noise levels from De Soto Canyon in the northeastern Gulf, through a deep-water area near the base of the continental slope, to Mississippi Canyon in the central Northern Gulf. Results indicate that (1) the glider's noise floor is sufficiently low that it can apparently record the quietest ocean soundscapes present in the Gulf, and its dynamic range is sufficiently high that it can record ambient sounds without clipping; (2) noise levels follow the general pattern of ocean noise elsewhere, with highest levels at low frequencies and a steady decline with increasing frequency to approximately 10 kHz; (3) noise levels in the deepest waters are higher than those in shallower water, possibly due to the ability of sound to propagate farther in deep water; and (4) noise levels were quietest in De Soto Canyon, likely due to lower levels of industrialization, and loudest in the deep-water area, possibly due to longer sound propagation distances.

The successful collection of data by the glider shows that it is a useful platform for assessing soundscapes across a wide area, and that it therefore effectively complements longer-lasting moorings that remain fixed in place. In effect, gliders provide effective spatial and depth coverage while fixed moorings provide effective temporal coverage.

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List of Abbreviations and Acronyms

A/D	analog-to-digital
BOEM	Bureau of Ocean Energy Management
dB	decibel (referenced to 1 µPa unless otherwise specified)
EAR	Environmental Acoustic Recorder
FLAC	Free Lossless Audio Codec
GB	gigabyte
GoMex	Gulf of Mexico
L_{eq}	Sound Level Equivalent
LTSA	Long Term Spectral Average
NUWC	Naval Undersea Warfare Center
OSU	Oregon State University
PAM	Passive Acoustic Monitoring
RH	Rockhopper acoustic recorder
SG	Seaglider™
SHRU	Single Hydrophone Receiving Unit (acoustic recorder)
SS0	Beaufort Sea State 0
SS1	Beaufort Sea State 1
UTC	Universal Time Coordinated
WP	waypoint

1. Objectives

The *Gulf of Mexico Passive Acoustic Monitoring Program* collaborative research project aims to document and describe soundscapes in the northern Gulf of Mexico (GoMex) region. The overarching objective of this project is to design and implement a passive acoustic monitoring program using a variety of data collection platforms including stationary and mobile instruments. Oregon State University is contracted to (a) collect data with an acoustically-equipped autonomous Seaglider **(Figure 1)**, and (b) provide information on the spatiotemporal patterns of ocean ambient sound levels across the glider's flight path. This preliminary report focuses on passive acoustic data collected in May and June 2018.

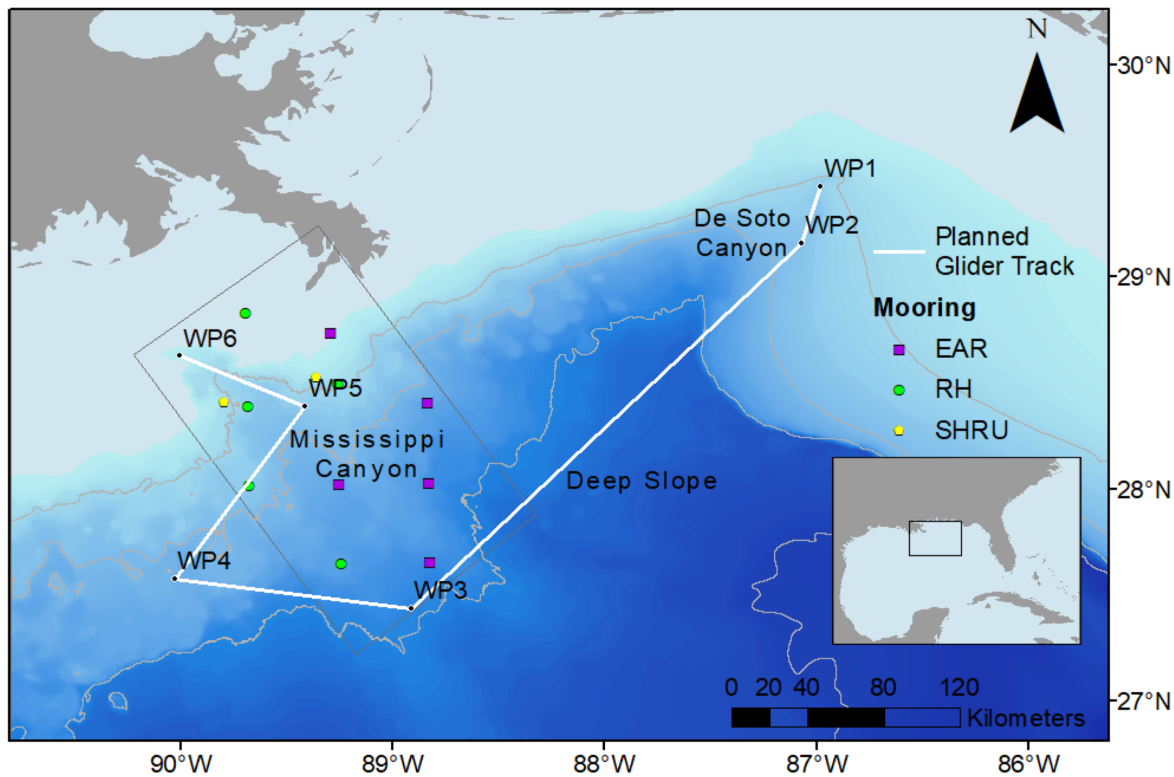


Figure 1. Map of planned glider track (white line) for a single 570 km flight. The glider was deployed in De Soto Canyon at Waypoint 1 (WP1) and recovered after transiting up through Mississippi Canyon toward WP6. Moored instruments are shown in red and green.

2. Data Collection

Acoustic data were collected with a single Seaglider (commercially available from Kongsberg Underwater Technologies, Lynnwood, WA, USA). The Seaglider operates using buoyancy; at the surface, it deflates an internal bladder to make itself less dense than seawater and starts to sink. Wings on the side convert downward motion to forward motion. The glider travels down and forward to a preset depth – here, 1000 m or 100 m above the seafloor, whichever is shallower – where it inflates the bladder, making itself less dense than seawater. It then travels up and forward to the surface, where it contacts a shore-based control station via a satellite link and uploads performance information for a pilot to review. Assuming all is well, the pilot starts the next dive, and this cycle is repeated throughout the deployment.

This glider, number SG639, was outfitted with an acoustic recording system, the Wideband Intelligent Signal Processor and Recorder (WISPR; available from Embedded Ocean Systems, Seattle, WA, USA). The system was programmed to record continuously at all depths below 25 m at a sampling rate of 125 kHz and a resolution of 16 bits, with sounds compressed for storage using the Free Lossless Audio Codec (FLAC). The system sensitivity can be seen in Figure 3.

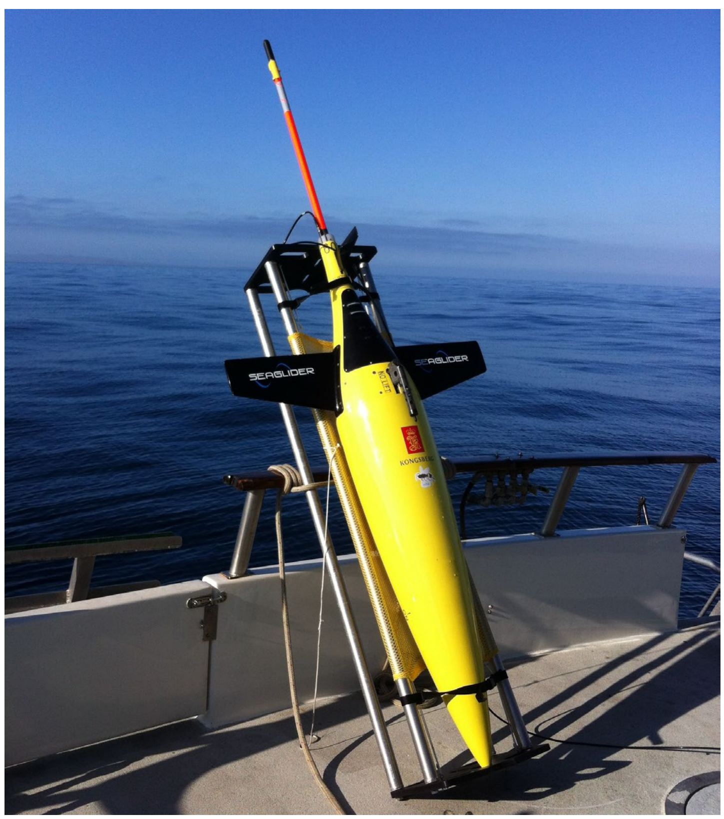


Figure 2. A Seaglider ready for deployment. The hydrophone is positioned just aft of the wings (in this photo, above the wings) inside the fairing behind the black panel.

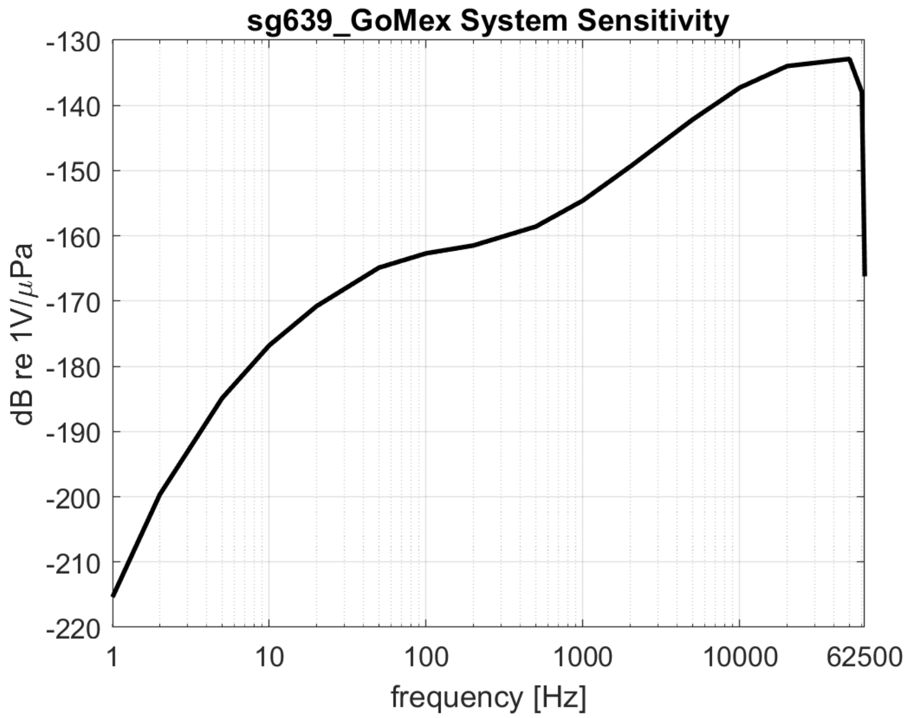


Figure 3. SG639 system sensitivity of glider SG639 as configured for the 2018 deployment in the Gulf of Mexico. Hydrophone sensitivity levels are as reported by the manufacturer (High Tech, Inc., Long Beach, MS, USA).

SG639 was deployed from a 30' chartered day vessel (Super Strike Charters, Venice, LA) near the top of De Soto Canyon on 10 May 2018 at 18:00 UTC at 29º 25.18', -87º 0.06' (Figure 4). The glider then transited out of the canyon along its southern slope, diving as deep as possible to follow the seafloor bathymetry. Once the glider reached water depths greater than 1100 m, dive depths were extended to their maximum range of 1000 m (Figure 5). The glider path was modified during the deployment as information on glider transit speeds and oceanographic currents were reported back to the pilot via satellite. The glider's programmed path was modified based on currents to ensure we would reach the top of Mississippi Canyon before running out of battery or storage space. The final path can be seen in Figure 4. The glider was recovered on 18 June 2018 at 13:30 UTC at 28º 38.44', -89º 53.67'.

The glider track was divided into three segments as indicated in Table 1 and Figure 4.

Table 1. Segments of the glider's deployment during which it was recording sound.

Segment name	Segment start location and time	Segment end location and time
De Soto Canyon	29.419722° N, 86.995378° W	28.675750° N 87.601150° W
	05/10/2018 18:13:48	05/19/2018 02:17:53
Deep Slope	28.676265° N 87.601155° W	27.518300° N 89.415167° W
	05/19/2018 02:23:52	05/30/2018 03:09:54
Mississippi Canyon	27.519063° N 89.415153° W	28.640717° N 89.894550° W
	05/30/2018 03:17:38	06/20/2018 13:27:48

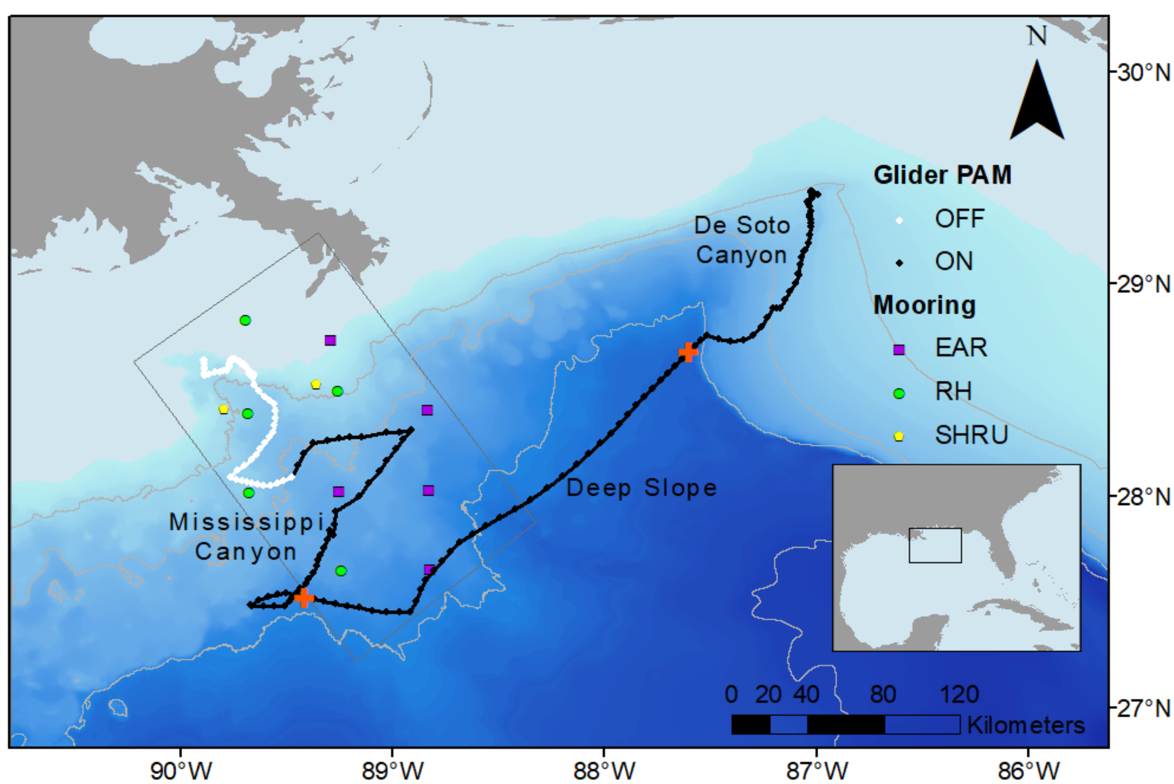


Figure 4. Glider track from 10 May to 18 June 2018. The black portions indicate when the PAM system was active while white sections indicate when it was off. The three named segments of the glider flight are shown in black; orange crosses across the glider track indicate segment boundaries. Yellow, green, and purple shapes indicate moored instruments. Inset: Location of this map within the Gulf of Mexico.

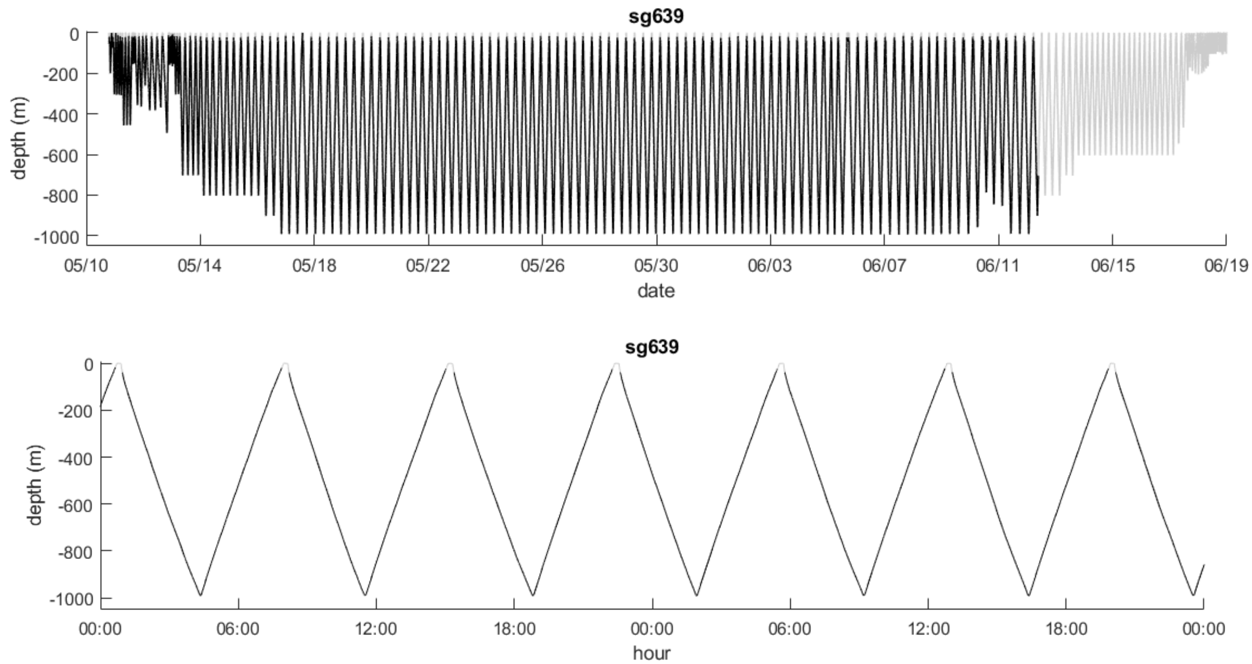


Figure 5. Dive profile of SG639 for the entire deployment (top) and a two-day period, 5/28/2018-5/30/2018 (bottom). Darker portions of the dive profile indicate PAM system on, lighter portions near the surface indicate PAM system off.

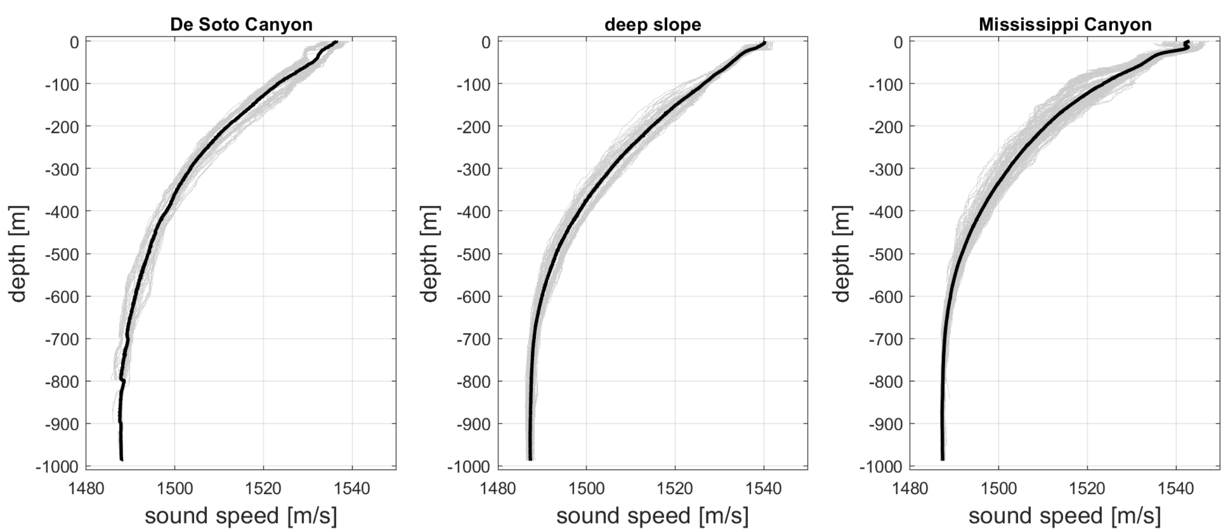


Figure 6. Sound speed profiles for each of the three glider survey regions, as calculated from temperature, depth, and salinity measured *in situ* by SG639. Gray lines indicate sound speed for each individual dive, and the thick black line is the mean sound speed across all dives in that region.

2.1 Issues Encountered

Flying the glider in the shallow parts of Mississippi Canyon proved slightly challenging. The glider functions better in deep water (>250 m) because it spends a larger fraction of its time moving up or down, when it is able to steer. When at the surface, it is not actively moving and is subject to surface currents; similarly, when it is at the bottom of a dive, changing from downward motion to upward, it passes through a state of neutral buoyancy, stops moving, and again is carried by currents. These two events happen every dive, but on a shallow dive, the time between the two is much shorter than on a deep dive, and the glider spends a larger, sometimes much larger, fraction of its time subject to currents. Additionally, shallow water currents are typically stronger and faster-moving than deep water currents. This is reflected in the final part of the glider's path (Figure 4), where the glider's track becomes progressively less straight as the glider encounters progressively shallower waters as it travels up Mississippi Canyon. Because of the difficulty of flying in shallow water, a quick recovery was initiated on June 18, and the glider was recovered that day, again from a 30' chartered day vessel (Super Strike Charters).

3. Acoustic Data Sets

SG639 collected a total of 724.9 hours of acoustic data spanning 783 hours from 10 May to 12 June 2018 in 21,824 two-minute files. A few files were shorter than two minutes because of operational conditions, as the glider stops recording when it ascends through 25 m depth.

The quality of the acoustic data collected with the glider was high. At high sound amplitude levels, no clipping was observed, and at low levels, the recordings did not show any evidence of system (electronic) noise being louder than the ocean noise being recorded. The recording system includes a "pre-whitening" filter to enable effective capture of ocean sound to happen without either clipping or hitting the noise floor.

The only issues encountered during the manual Q/A process were expected noises from the glider's motors during steering maneuvers (from ballast motors) and buoyancy changes (from buoyancy pump motor).

3.1 Issues Encountered

Recording stopped on 12 June because the recording system reached a capacity in which it could no longer store data. While there was sufficient storage space available for the glider to continue collecting data, and the system was in fact acquiring acoustic data from the hydrophone, as on-board detections were reported, the number of individual files stored on the compact flash card caused an issue with a delay in file writing time such no new files were able to be written, and no archival data was collected. In the future, sound file lengths will be increased (from 120 sec to 300 sec) to reduce the overall number of files and ensure this does not happen again.

3.2 Data Processing

Data were recorded at a sample rate of 125 kHz, meaning that the maximum frequency representable in the data was 62.5 kHz. Raw data were encoded in FLAC (.flac) files; these were uncompressed to make WAVE (.wav) files, which allow random access and are compatible with a wider variety of acoustic analysis software.

Data were resampled at two lower sample rates, 10 kHz and 1 kHz. This was done to expedite analysis of sounds under 5 kHz and 0.5 kHz, respectively; the smaller files are quicker to load and process than the larger ones.

Self-noise from glider operations – pumping of the buoyancy bladder, movement of ballast to steer and orient the glider – was removed using an automated detector and manual validation of detections. An energy sum detector was run in Ishmael (Mellinger et al. 2017) on the 10 kHz downsampled data files. No equalization was applied. Energy was summed from 800 to 1200 Hz, with 0.6 sec smoothing, 0.2 to 9999 s durations and a 0.1 s neighborhood setting. The threshold was set at 1.2, a low value chosen to ensure that no glider noises were missed. The detector performed well in periods of quiet ambient noise levels, but did trigger on louder noise levels when ships or airguns were present. A total of 16,268 detections were manually checked to ensure no false positives were included, resulting in 8,563 correct detections of glider motor noise. Correct detections of glider motor noise were removed from further ambient noise level calculations.

Noise analysis proceeded with the calculation of power spectral density levels (PSD; 1 Hz, 1 s resolution) using custom Matlab code. Spectral probability densities (Merchant et al. 2013) were also calculated for each region using the one hour mean levels. Levels were calibrated and seconds containing glider motor noise detections were removed. Mean hourly PSDs were calculated from the noise-removed data and noise spectra percentiles were calculated from the hourly means.

Long term spectral averages (LTSAs) were calculated for all three frequency range datasets (full bandwidth, 125 kHz sampling rate, downsampled to 10 kHz, and downsampled to 1 kHz). Noise was removed from each LTSA.

Noise spectra percentiles and spectral probability density plots were done separately for these three segments.

Additionally, hourly mean power spectral densities were compared across three glider depth bins (50-250 m, 400-600 m, and 800-1000 m).

Calibration information for these calculations came from the hydrophone manufacturer, High Tech Inc. (http://www.hightechincusa.com/products/hydrophones/hti92wb.html), who measured sensitivity of our individual hydrophone (-164.5 dB re 1 V/μPa) as well as the spectral sensitivity curve; and recorder system manufacturer EOS, Inc., who specified pre-amplifier gain and spectrum and A/D sensitivity.

4. Results - Ambient Sound Levels

A long-term spectral average (LTSA) calculated in Triton (Wiggins 2016) is shown in . This figure is similar to a spectrogram, except that here data from successive time slices are combined by averaging, rather than summing as in a spectrogram with a large FFT size.

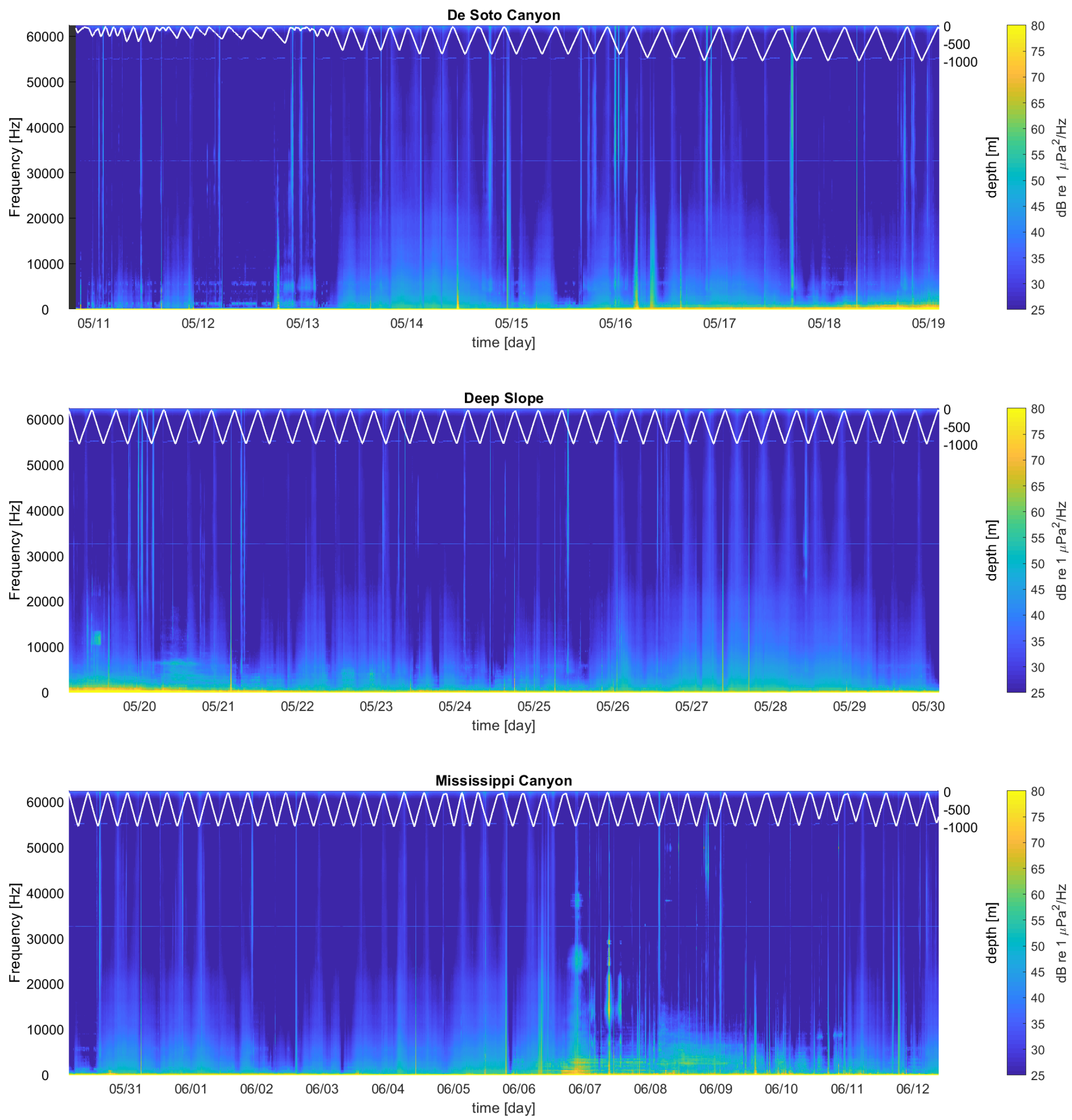


Figure 7. Long-term spectral average plot for the glider recording in each region at the full recording bandwidth. Parts of the recording with glider self-noise were removed before calculation. The LTSA was calculated by averaging over 60 seconds and 200 Hz. Glider noise has been removed. White line and right y-axis indicate the glider's dive depth at that minute.

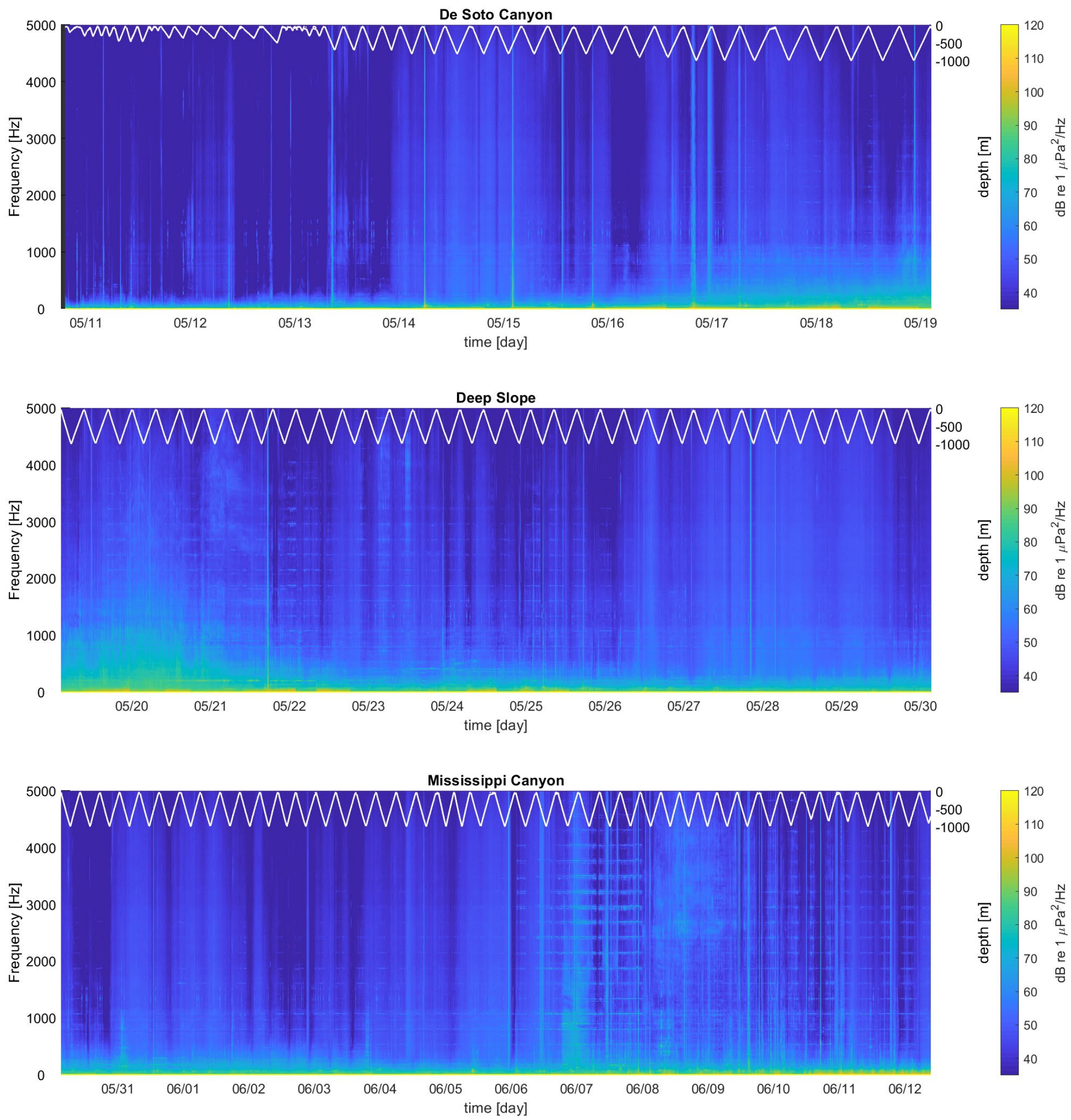


Figure 8. Long-term spectral average plot for the glider recording in each region for the 10 kHz downsampled data. The LTSA was calculated by averaging over 20 seconds and 10 Hz. Glider noise has been removed. White line and right y-axis indicate the gliders dive depth at each 20 second average.

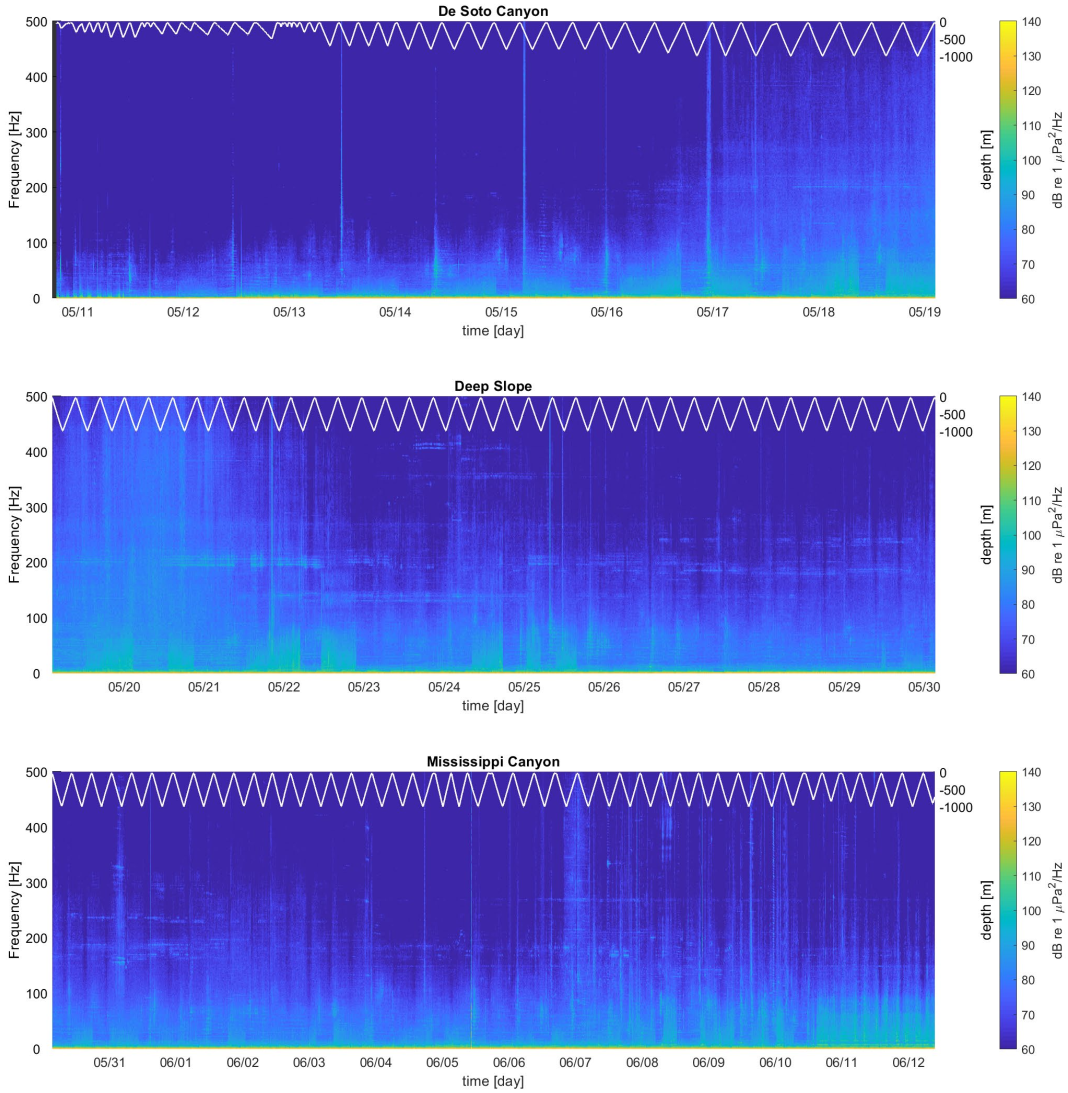


Figure 9. Long-term spectral average plot for the glider recording in each region for the 1 kHz downsampled data. The LTSA was calculated by averaging over 10 seconds and 1 Hz. Glider noise has been removed. White line and right y-axis indicate the gliders dive depth at each 10 second average.

Percentile levels for each of the three segments of the glider track are shown in **Figure *10*** and and spectral probability density plots are shown in . These represent the mean hourly measured noise levels in these regions of the Gulf of Mexico. As with most areas of the ocean, noise levels were highest at lower frequencies and decreased with frequency up to approximately 10 kHz, the leveled off up to approximately 50 kHz. The rise seen from 50-62.5 kHz is probably due to an artifact – compensation for system roll-off – rather than an actual rise in ocean noise at these frequencies. As mentioned above, there is no sign of a noise floor or recording floor, most likely due to the design of the recording system. There are, however, spikes in the 99th-percentile curve and to a lesser extent in the 95th-percentile curve. These appear in spectrograms as harmonic bands and are currently unknown in origin; they may be due to industrial noise in the ocean, or it's possible that some glider noise eluded the noise-removal process and thus these are artifacts.

Noise levels in the Deep Slope region were highest, though only slightly higher than those in Mississippi Canyon. This could be due to these areas having a higher level of industrialization than De Soto Canyon. In addition, the deeper waters of the Deep Slope region may allow sound to propagate farther; in effect, the glider in this region hears noise from a wider area than it does in shallower water.

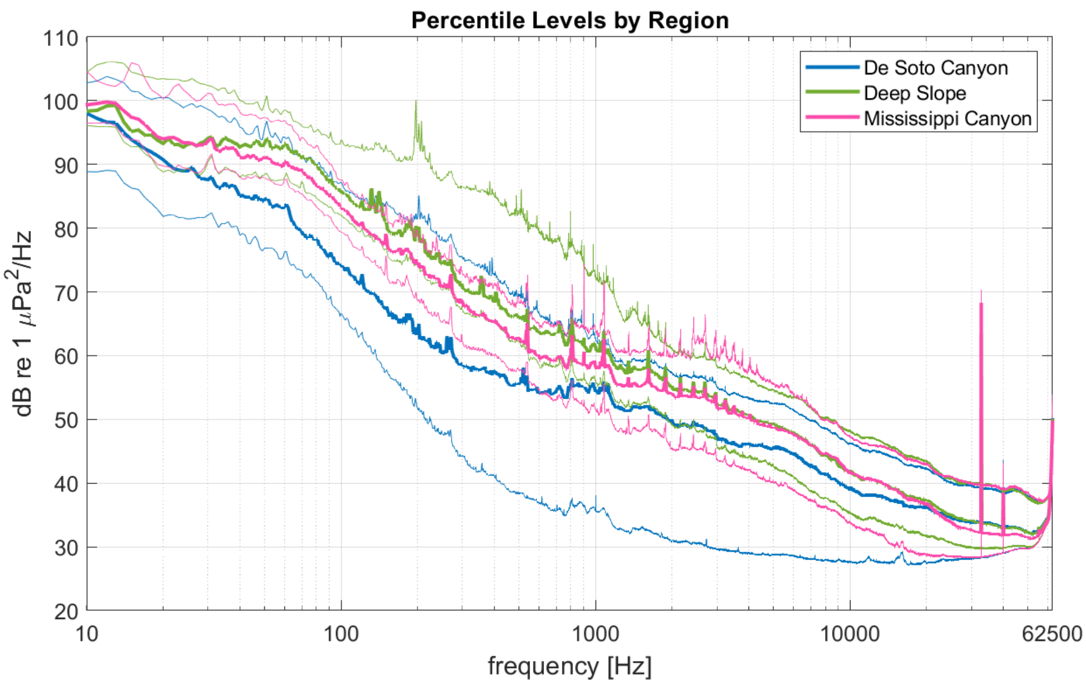
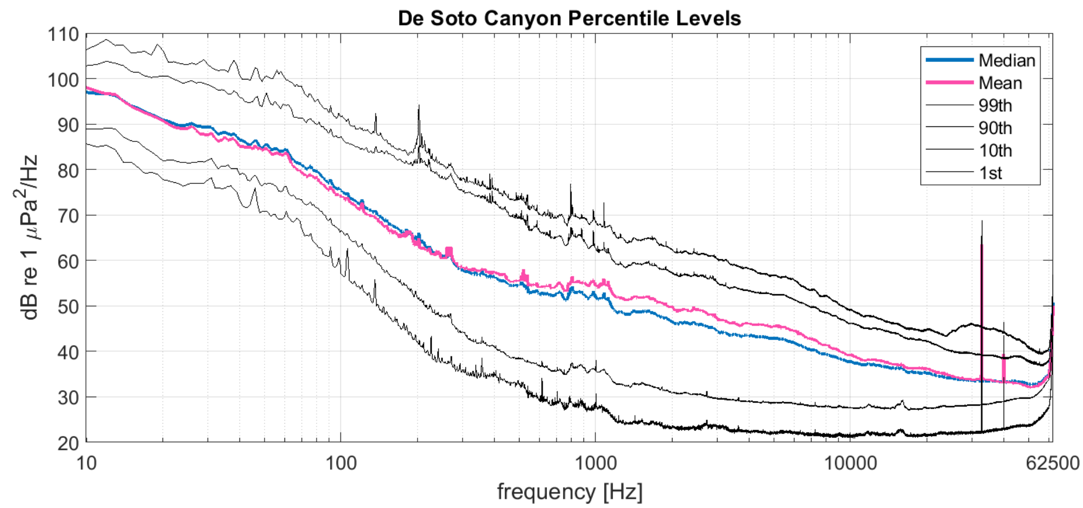
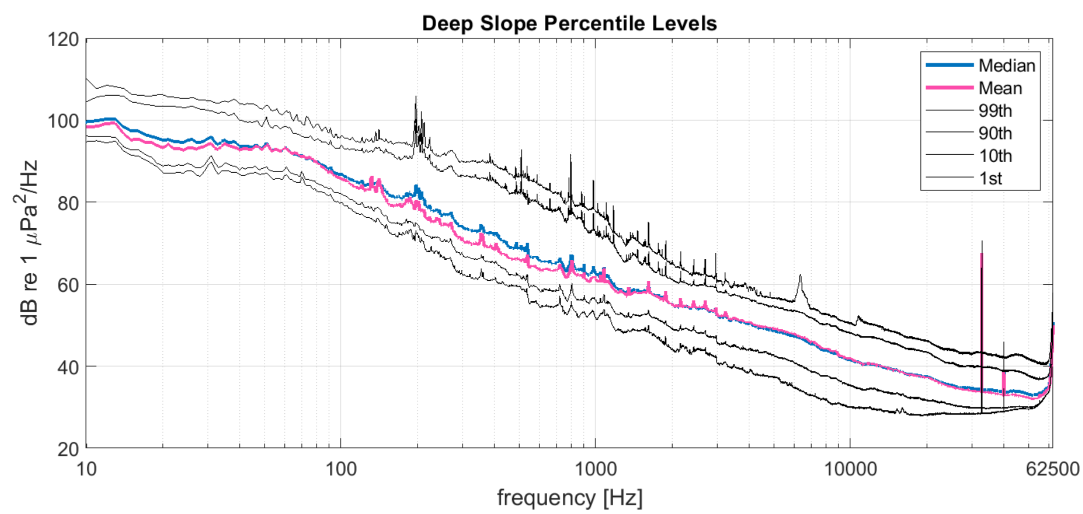
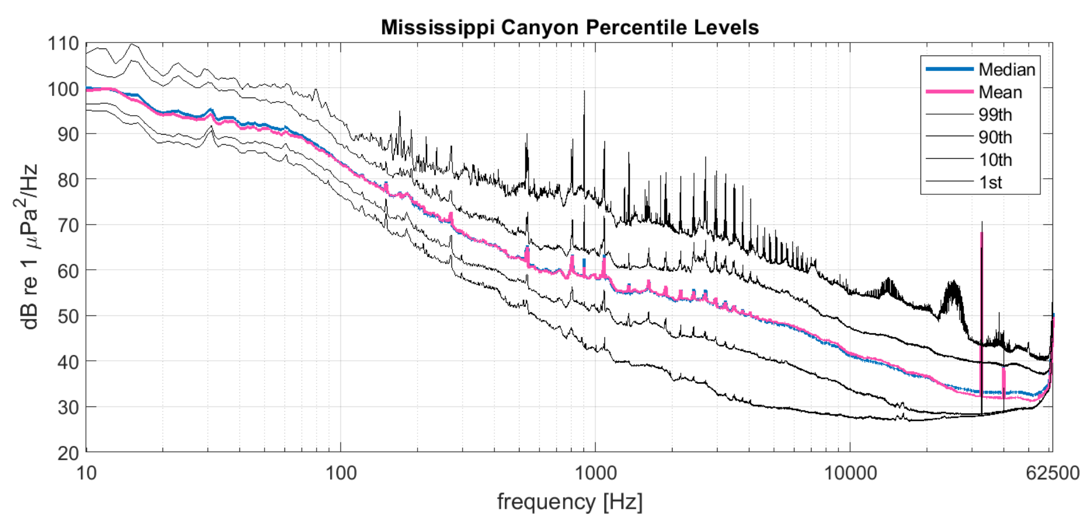


Figure 10. Median (thick line), 90th (upper thin line), and 10th (lower thin line) percentile levels for De Soto Canyon (blue), the deep slope region (green), and Mississippi Canyon (pink). In this and succeeding plots, the spikes in sound level at 32 and 40 kHz are artifacts.

Figure 11 (next page). Noise levels at the (progressing from top to bottom) 99th, 90th, 50th (blue), 10th, and 1st percentiles for the three segments of the glider track from east to west. The mean is in pink. The Deep Slope area generally has the loudest noise, with Mississippi Canyon somewhat quieter (except at the very lowest frequencies) and De Soto Canyon quieter still. The origin of the spikes in the 99th-percentile curve (top curve), and to a lesser extent 90th-percentile curve, is currently unknown.


De Soto Canyon Percentile Levels
Median
Mean
99th
90th
10th
1st
dB re 1 μPa²/Hz
frequency [Hz]
10
100
1000
10000
62500
20
30
40
50
60
70
80
90
100
110


Deep Slope Percentile Levels
Median
Mean
99th
90th
10th
1st
dB re 1 μPa²/Hz
frequency [Hz]
10
100
1000
10000
62500
20
40
60
80
100
120


Mississippi Canyon Percentile Levels
Median
Mean
99th
90th
10th
1st
dB re 1 μPa²/Hz
frequency [Hz]
10
100
1000
10000
62500
20
30
40
50
60
70
80
90
100
110

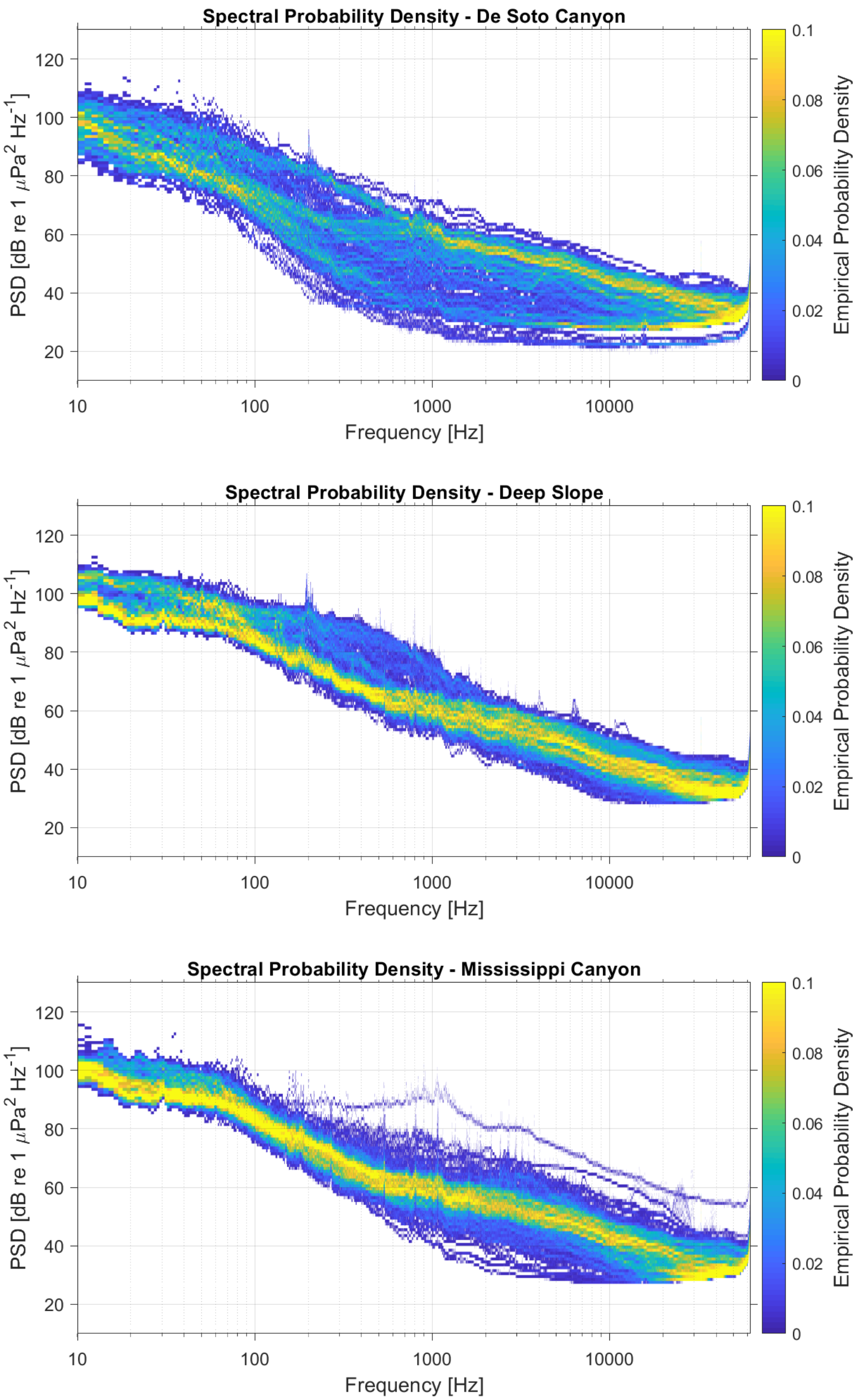


Figure 12. Spectral probability density of the soundscapes of the three regions progressing from east to west. These represent the amount of sound present at each frequency and amplitude and are calculated from hourly mean PSD levels.

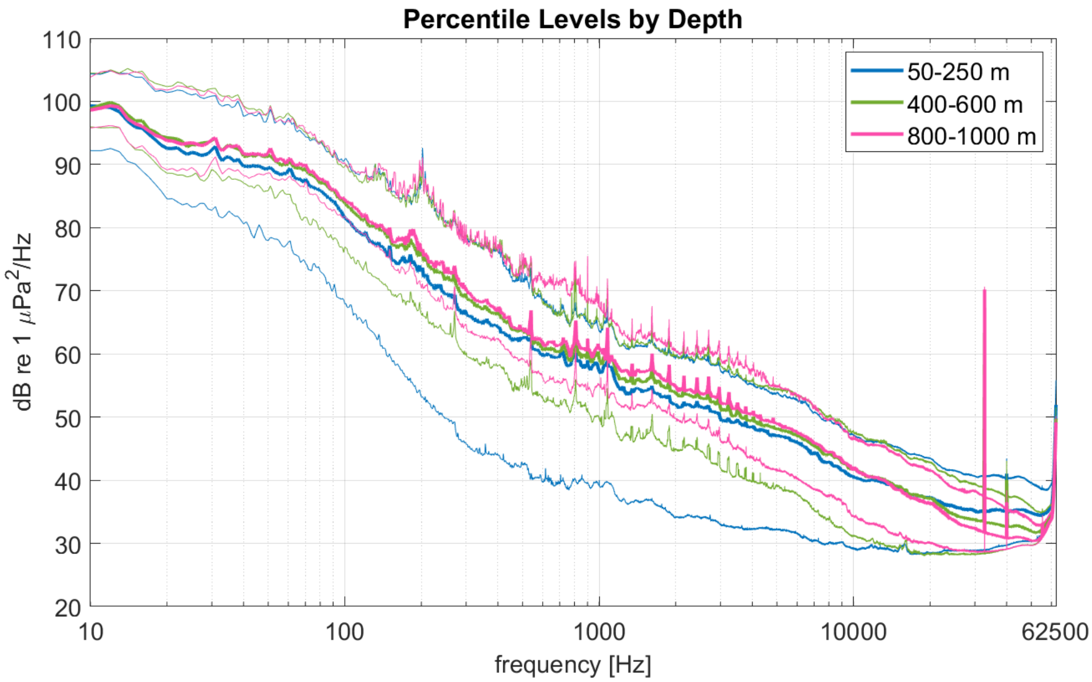
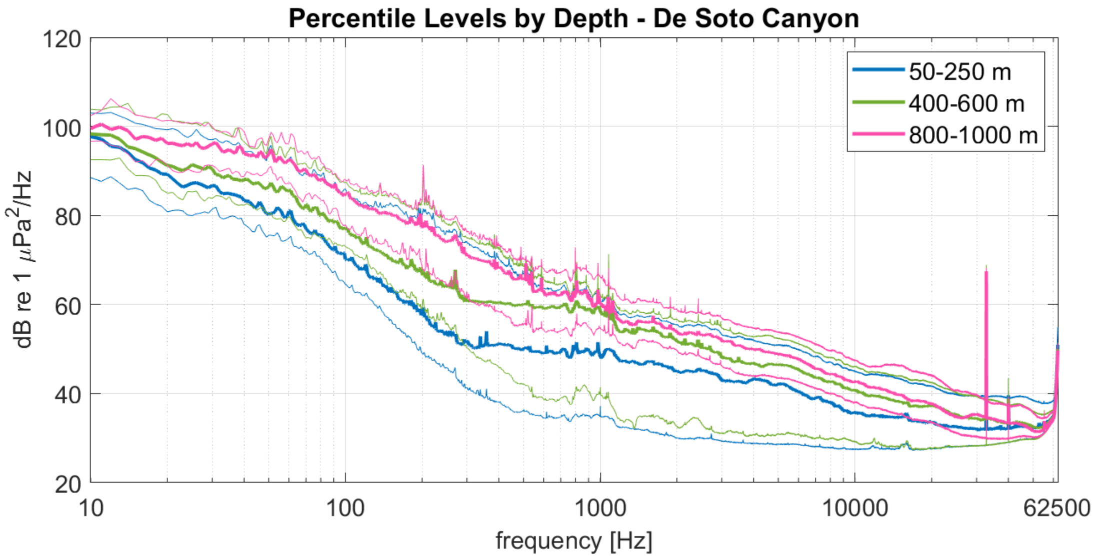
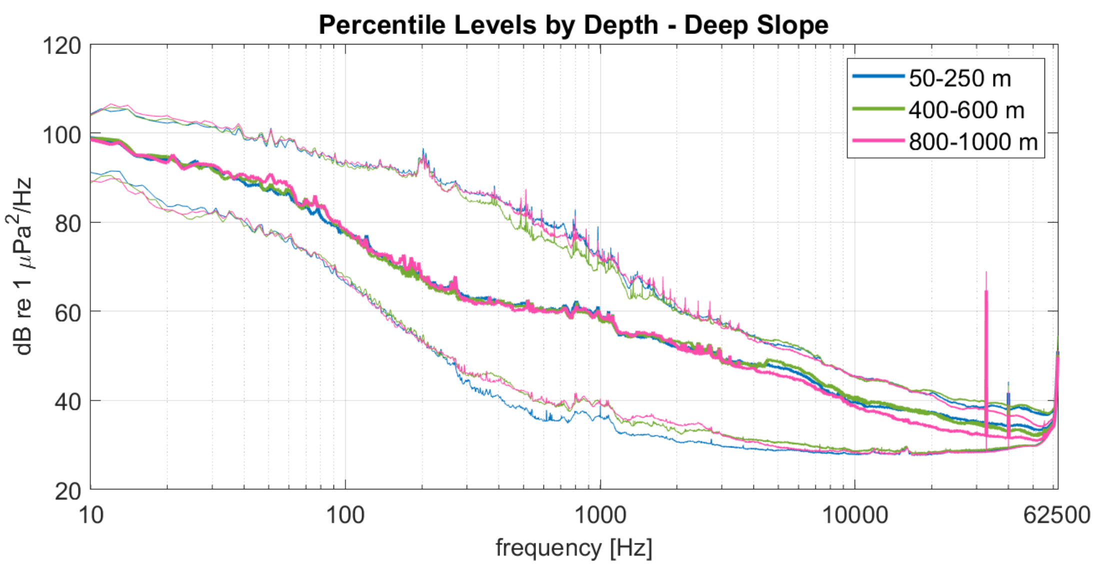
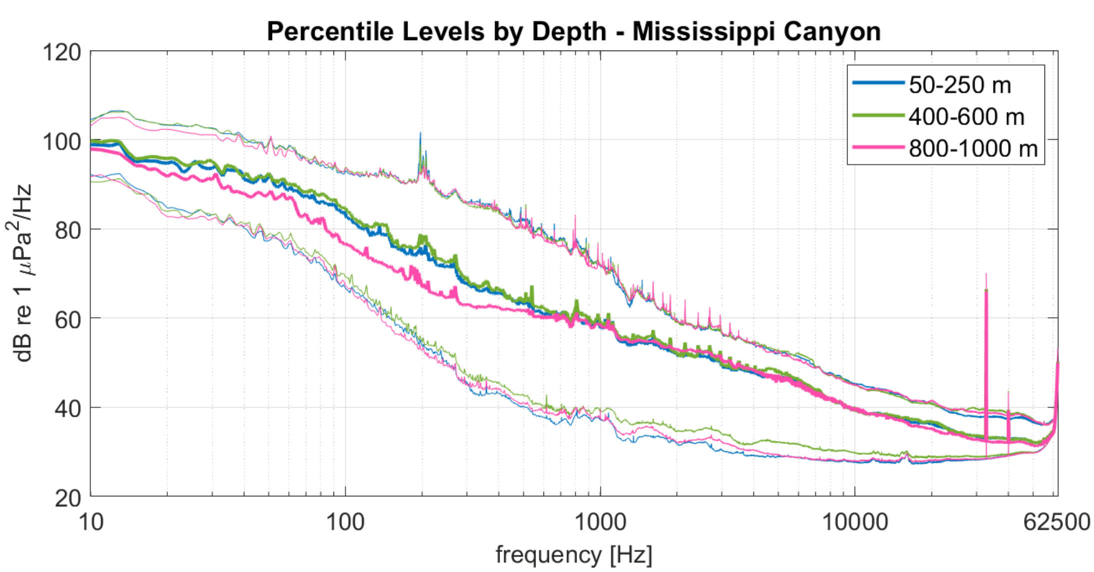


Figure 13. Percentile levels by glider depth, calculated from the hourly mean power spectral densities, in three depth bins: 50-250 m (blue), 400-600 m (green), and 800-1000 m (pink). Thick line is median (50th percentile), upper thin line is 90th percentile, and lower line is 10th percentile.

Figure 14 (next page). Percentile levels by glider depth, calculated from the hourly mean power spectral densities, in three depth bins: 50-250 m (blue), 400-600 m (green), and 800-1000 m (pink), for each region. Thick line is median (50th percentile) , upper thin line is 90th percentile, and lower line is 10th percentile.


Percentile Levels by Depth - De Soto Canyon
50-250 m
400-600 m
800-1000 m
dB re 1 μPa²/Hz
120
100
80
60
40
20
10
100
1000
10000
62500
frequency [Hz]


Percentile Levels by Depth - Deep Slope
50-250 m
400-600 m
800-1000 m
dB re 1 μPa²/Hz
120
100
80
60
40
20
10
100
1000
10000
62500
frequency [Hz]


Percentile Levels by Depth - Mississippi Canyon
50-250 m
400-600 m
800-1000 m
dB re 1 μPa²/Hz
120
100
80
60
40
20
10
100
1000
10000
62500
frequency [Hz]

5. Discussion

The glider successfully collected acoustic data from a continuous track spanning De Soto Canyon to Mississippi Canyon. To our knowledge, the glider measurements from the Deep Slope area represents the first measurement of noise levels in off-shelf waters of the Gulf; other measurements were all made on the continental shelf or close to the shelf break. Acoustic noise measurements from all three segments of the glider track should be valuable information for studying Gulf soundscapes and the impacts of noise on organisms there.

Sound Speed

Sound speed at depths below 100 m was similar in all regions but varied shallower than 100 m, as is true in many parts of the world. De Soto Canyon had the lowest surface sound speeds, while Mississippi Canyon had the fastest surface sound speeds, likely due to the influx of warmer water from the Mississippi River. The difference was not huge, with a mean sound speed difference of only about 6 m/s between the two areas. What was notably different between areas was the presence of a surface duct in Mississippi Canyon caused by a non-decreasing sound speed profile in a layer shallower than 20 m. This duct has the potential to keep a larger fraction of acoustic energy generated in that shallow layer near the surface than in regions without the duct (Urick 1983).

Sounds Heard

Some of the types sounds received appeared in long-term spectral averages (LTSAs) as follows:

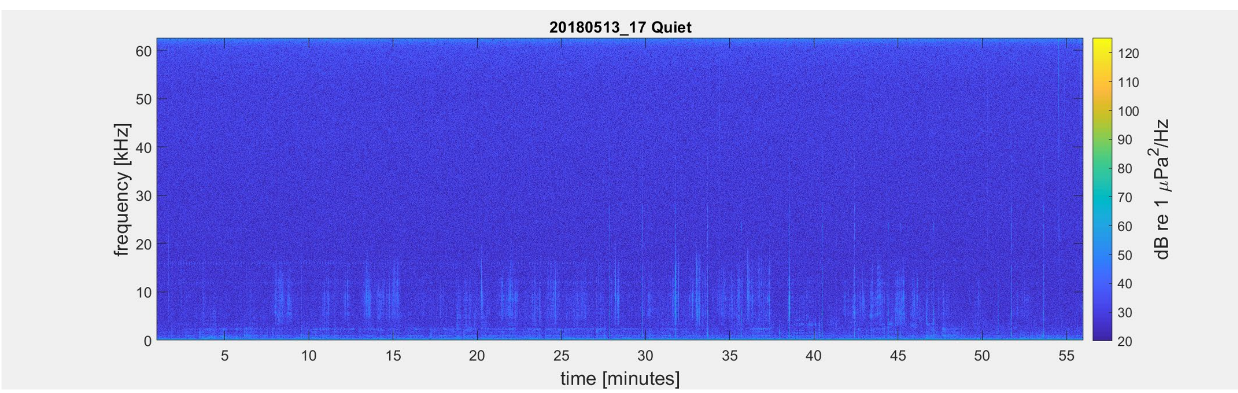


Figure 15. Sounds in De Soto Canyon believed to be ‘regular clicks’ (echolocation sounds) from sperm whales, visible in the 3-15 kHz band. LTSA resolution: 1 Hz, 1 s. Time periods with glider self-noise were removed from analysis and do not appear.

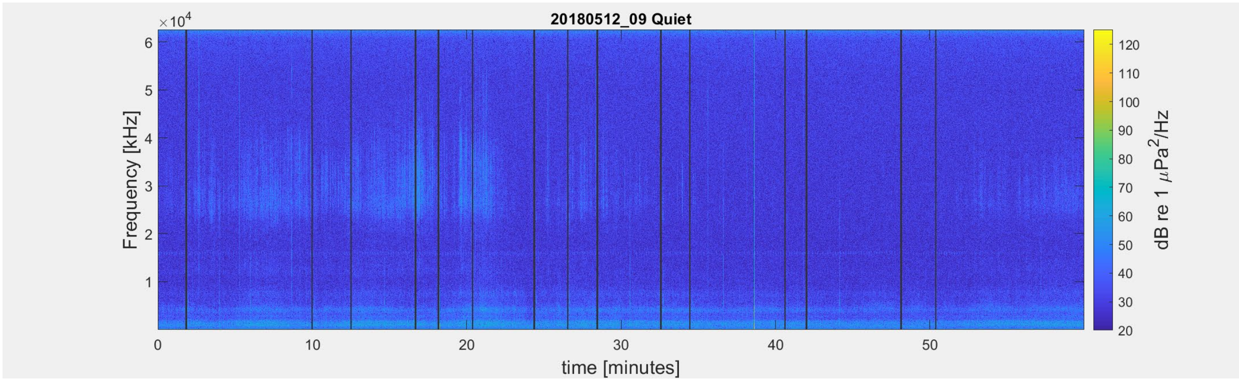


Figure 16. Sounds in De Soto Canyon believed to be dolphin echolocation clicks, visible mostly above 20 kHz but with some sound down to 10 kHz. LTSA resolution: 1 Hz, 1 s. Note that vertical scale ranges from 0 to 60 kHz. Time periods with glider self-noise were removed from analysis and appear as vertical black bars.

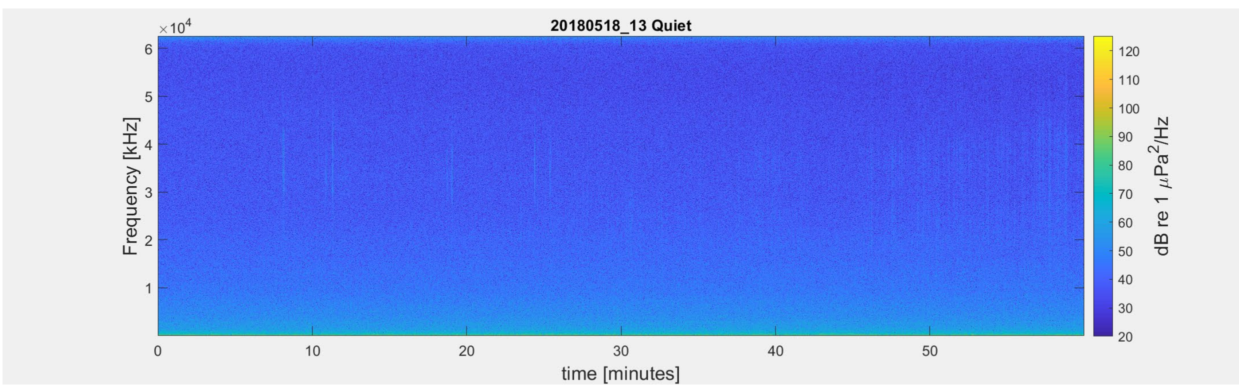


Figure 17. Sounds in De Soto Canyon believed to be beaked whale echolocation clicks, 25-45 kHz. LTSA resolution: 1 Hz, 1 s. Note that vertical scale ranges from 0 to 60 kHz. Time periods with glider self-noise were removed from analysis and do not appear.

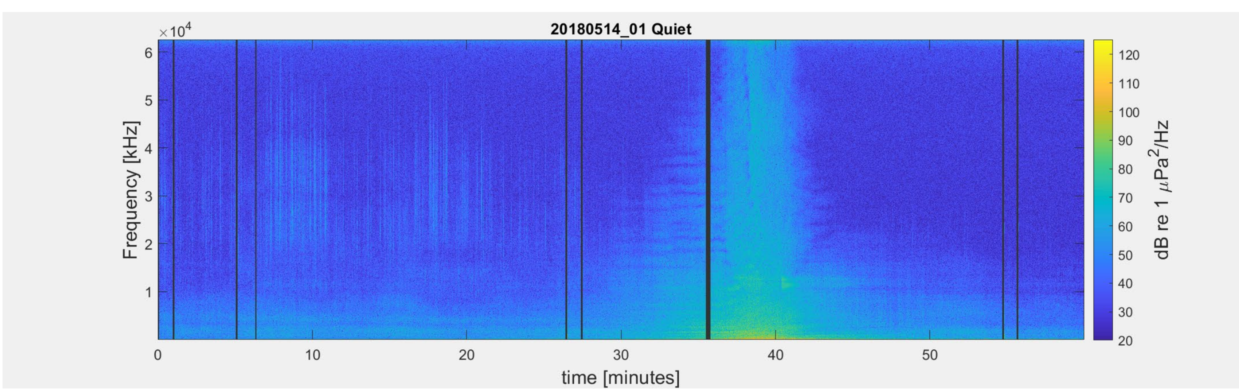


Figure 18. Sounds in De Soto Canyon believed to be dolphin echolocation clicks (0-30 min) and the noise of a passing vessel (30-55 min). LTSA resolution: 1 Hz, 1 s. Note that vertical scale ranges from 0 to 60 kHz. Time periods with glider self-noise were removed from analysis and appear as vertical black bars.

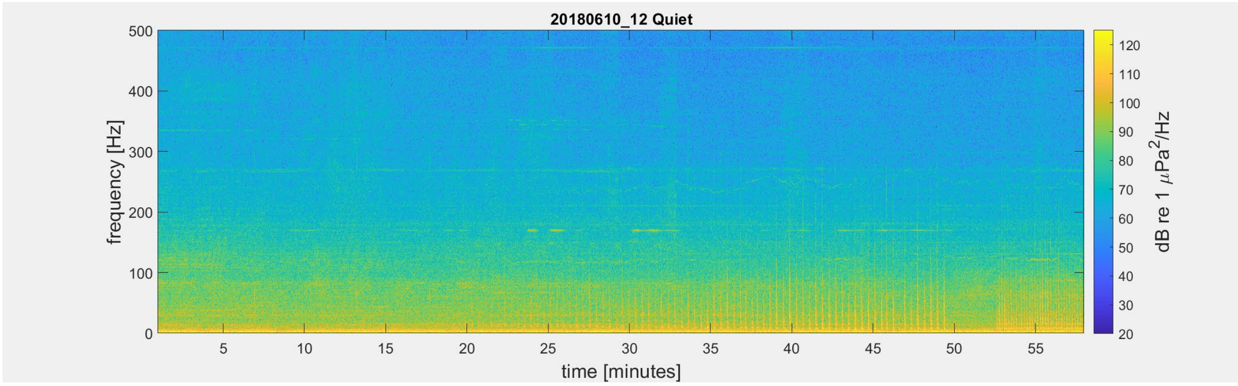


Figure 19. Sounds in Mississippi Canyon from seismic airguns (appearing as regularly-spaced vertical bars), mostly below approximately 100 Hz, as well as other noises from unknown sources scattered throughout. LTSA resolution: 1 Hz, 1 s. Note that the vertical scale here ranges from 0 to 500 Hz, a much smaller range than in LTSAs above. Time periods with glider self-noise were removed from analysis and do not appear.

Noise Levels across Regions

As shown in Figures 10-12, noise levels were lower De Soto Canyon than in the other two areas, particularly below 1 kHz. The difference was most pronounced between 70 and 400 Hz, where median sound levels in De Soto Canyon were approximately 9 decibels (dB) quieter than in Mississippi Canyon and 12 decibels quieter than the Deep Slope region. Differences in median levels persisted, but lessened, as frequency increased up to 20 kHz. The differences were even higher for quiet sound levels (the 10th percentile), where De Soto Canyon was 15 dB quieter than Mississippi Canyon and 18 dB quieter than the Deep Slope region in the 500-1000 Hz band. At louder sound levels (the 90th percentile), De Soto Canyon and Mississippi Canyon were within 3-4 dB but the Deep Slope region was notably louder – up to 15 dB louder in the 200-800 Hz band.

De Soto Canyon is likely quieter than the other two regions because there is significantly less industrial development there – fewer vessels, less drilling, less other mechanical activity. This could be compounded by the shallower depth (Figure 4), which probably limited long-distance sound propagation. The Deep Slope, in contrast, had the deepest depths encountered and the highest sound levels, again perhaps due to both higher levels of industrialization, as well as the greater water depth permitting sound propagation over longer distances and hence the reception of sound from more sources.

Noise Levels by Depth

De Soto Canyon had the greatest differences in sound level with depth (Figure 14). This was most pronounced at 300 Hz, where the median levels of the shallowest (50-250 m) recordings were ~8 dB quieter than the mid-depth (400-600 m) ones, which in turn were ~8 dB quieter than the deepest ones. Differences in median levels with depth were present, though to a lesser extent, from 10 Hz up to 40 kHz, above which the median levels converged. This effect existed for the quieter levels (10th percentile) as well, and in fact was more pronounced for those levels, with nearly a 20-dB difference between the shallowest (50-250 m) and deepest (800-1000 m) regions.

Mississippi Canyon also had differences in median sound levels with depth, though to a lesser degree. Median sound levels at the shallow (50-250 m) and middle (400-600 m) depths were nearly equal, while the deepest depths (800-1000 m) were ~5 dB louder in the 70-300 Hz band. At quiet (10^{th} percentile) and loud (90^{th} percentile) sound levels there were few differences with depth.

The Deep Slope region had the least differences by depth, with the median, 10^{th} percentile, and 90^{th} percentile levels showing little difference across the three depth bands measured at most frequencies. There was a bit of difference, however, from ~15 kHz to ~40 kHz, with the median sound levels at deeper depths (800-1000 m) 2-4 dB louder than those at shallower depths (50-250 m and 400-600 m).

It is not known what accounts for the differences in sound levels with depth. The glider spent more time diving in shallow (< 500 m) waters in De Soto Canyon (Figure 7), and it's possible that the greater differences in sound levels by depth reflect the fact that sound cannot propagate as far in such shallow bathymetry. That is, the glider recorded less sound at shallow depths because the places in De Soto Canyon where it was diving shallowly – the upper parts of the canyon – were quiet, while the places where it was diving deepest – the lower part of the canyon, closer to the heavily industrialized parts of the Gulf of Mexico – were louder at all depths. However, the presence of differences by depth in Mississippi Canyon, with deeper depths again louder than shallow ones, argues that it is in fact louder at deeper depths than near the surface. (As shown in Figure 7, the large majority of dives in Mississippi Canyon were to depths of nearly 1000 m, so there is no spatial difference between places where "shallow" and "deep" recordings were made.) It's not readily apparent why deeper depths were louder than shallow ones; one possibility again is that because of acoustic propagation paths, deep places receive sound from a larger area than shallow ones.

Efficacy of Glider for Sound Monitoring

The Seaglider was able to record sound from a 500+ km-long path (Figure 4) over a span of approximately 6 weeks, covering both highly industrialized (Mississippi Canyon) and lightly industrialized (De Soto Canyon) areas and finding relatively large differences (> 10 dB) in sound levels between them. Although the glider produced some self-noise, we were able to remove this noise to derive accurate measurements of ambient sound levels. The glider's noise floor is sufficiently low that it can record the quietest ocean soundscapes present in the Gulf, and its dynamic range is sufficiently high that it can record ambient sounds without clipping.

In addition to large spatial coverage, two other advantages of glider flights were observed. As the glider moved, it also measured data for sound speed profiles (Figure 6) along its path, profiles that are very helpful for potential studies of sound propagation as a most important piece of data for propagation modeling is the sound speed profile. In addition, the glider measured sound in different depth ranges (Figure 14), revealing differences by depth that are not observable from most acoustic instrument platforms.

The successful collection of data by the glider shows that it is a useful platform for assessing soundscapes across a wide area, and that it therefore effectively complements longer-lasting moorings that remain fixed in place. In effect, gliders provide effective spatial and depth coverage while fixed moorings provide long-duration temporal coverage.

6. Bibliography

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