Low-frequency Ambient Noise Offshore of North Carolina and Florida 2007-2014 Final Report

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Executive Summary

Low-frequency (10 – 1000 Hz) ambient noise spectrum level measurements were made at six sites over a period of about 7 years (2007 – 2014) offshore of North Carolina and Florida on the Atlantic seaboard continental shelf and slope. Site-averaged ambient spectrum levels for the six sites are similar (within 10 dB) with levels around 60-65 dB re 1µPa^2/Hz near 1000 Hz, 70-75 dB re 1µPa^2/Hz at 100 Hz, and ~85-95 dB re 1µPa^2/Hz at 20 Hz.

Instrument strumming, presumably from tidal and ocean current flow, affected five of the six sites, including a deep (~900 m) water site near the region where the Gulf Stream heads northeast offshore. The sixth site, the other deep (~950 m) water site, had minimal or no acoustic masking from flow induced strumming and showed spectrum levels similar to those of other deep water recordings, including whale call seasonality, distance shipping, and correlation with wind events.

Introduction

Ocean low-frequency (10 to 1000 Hz) ambient noise provides a measure of both anthropogenic and natural sources such as sounds from ships, seismic exploration, whale calls, and near sea surface wind and waves (e.g., Hildebrand, 2009). To measure these sounds, hydrophone sensors are typically deployed with a recorder to provide a description of the regional soundscape. Hydrophone deployment depths and geographical locations are important for the types and levels of sounds recorded. Shallow water recordings can often have higher sound pressure levels than deeper sites owing to the sensor's close proximity to a noisy sea surface; on the other hand, McDonald *et al.* (2006) showed that for a deep water site in the Northeast Pacific exposed to the Asian-North American commercial shipping lanes noise levels were ~20 dB greater at 40-50 Hz than for a nearby (~165km) shallow water site without such exposure (McDonald *et al.*, 2008).

Other examples of site-specific ambient noise measures include: local commercial shipping (McKenna *et al.*, 2012), under arctic ice (Roth *et al.*, 2012), tropical Central and Western Pacific (Širović *et al.*, 2013) and ships and airguns in the Gulf of Mexico (Wiggins et al., in preparation). Often baleen whale calls are easily identified in low-frequency ambient noise spectra as tones or spectral spikes, such as blue (*Balaenoptera musculus*), fin (*B. physalus*), and humpback (*Megaptera novaeangliae*) whales; whereas, higher wind speeds are correlated with increased broad-band sound levels >200 Hz (e.g., McDonald *et al.*, 2008; Širović *et al.*, 2013).

Offshore of the Atlantic Coast states, averaged ocean ambient sound spectrum levels were measured between 10 and 1000 Hz at six locations on both the continental shelf and slope over a 7 year period. This report summarizes these measurements showing overall site averages are similar with levels within 10 dB of each other for frequencies above 20 Hz, including slope and deep water sites.

Methods

Passive acoustic monitoring for the presence of marine mammals, anthropogenic sounds, and ambient noise has been conducted in the Atlantic offshore of North Carolina since 2007 and offshore of Florida since 2009 using High-frequency Acoustic Recording Packages (HARPs - Wiggins and Hildebrand, 2007). Over a 7 year period, 24 HARP deployments accounting for about 3500 days of recordings were made at six primary sites (Figures 1 & 2; Table 1). Site 1 is offshore of Cape Hatteras, North Carolina; Sites 2-4 are in the US Navy's Cherry Point OPAREA; Sites 5-6 are in the US Navy's Jacksonville Range Complex offshore of Florida.

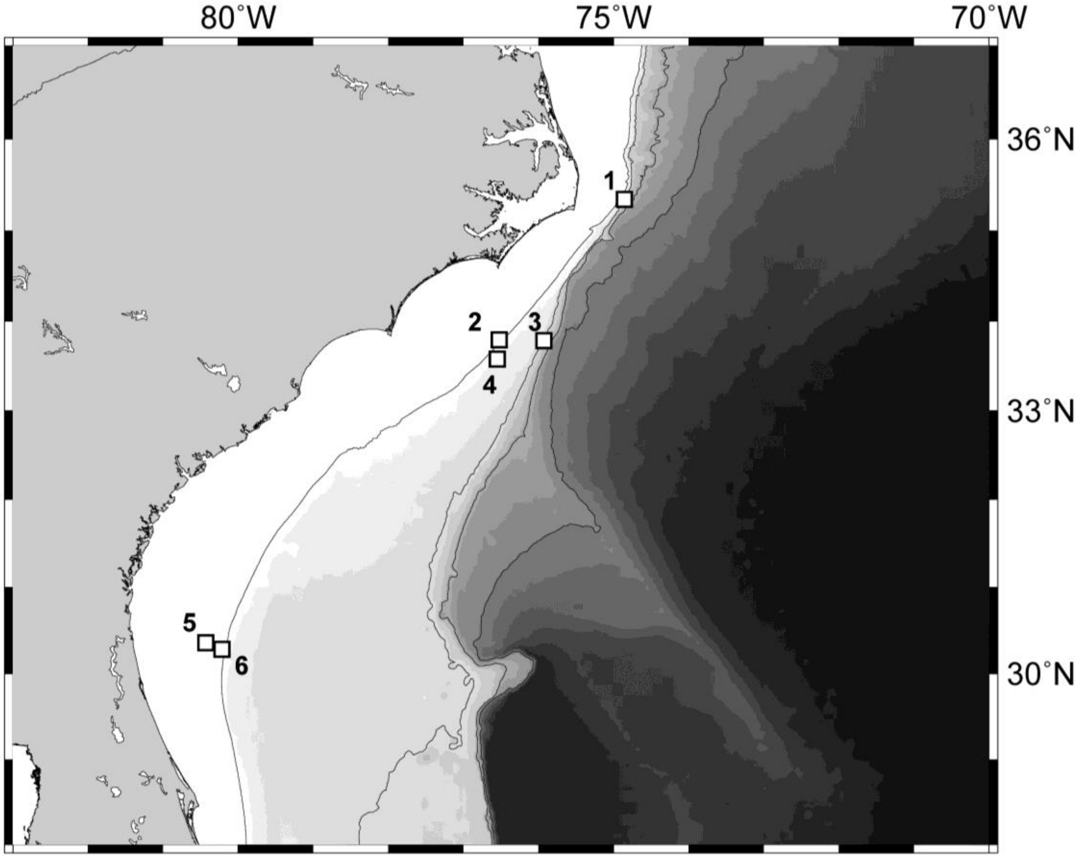

Figure 1. Atlantic continental shelf and slope acoustic monitoring sites. See Table 1 for deployment names and site depths. Contour lines are at 200, 1000, 2000, and 3000 m deep. Darker shading is deeper depths, land mass is solid medium gray on left.

Table 1. HARP site deployment names, depths, analysis periods, and number of analysis days.

Site	Deployment	Depth [m]	Analysis Period	# Days
1	Hatteras			
	HAT01A	950	03/16/12 – 04/10/12	26
	HAT02A	970	10/10/12 – 04/30/13	203
	HAT03A	970	05/30/13 – 03/14/14	289
				518
2	Cherry Point Shallow			
	USWTR01A	162	10/10/07 – 01/16/08	99
	USWTR02B	232	05/31/08 – 09/10/08	103
	USWTR03A	179	04/25/09 – 08/08/09	106
	USWTR04A	335	11/09/09 – 02/23/10	107
	USWTR05A	174	07/30/10 – 03/02/11	216
				631
3	Cherry Point Deep			
	USWTR06E	952	08/19/11 – 11/30/11	104
	USWTR07E	914	07/14/12 – 10/01/12	80
	USWTR08E	853	10/25/12 – 06/29/13	248
				432
4	Cherry Point South			
	USWTR04C	335	11/09/09 – 04/19/10	162
	USWTR05D	338	07/30/10 – 02/23/11	209
				371
5	Jacksonville West			
	JAX01B	37	04/02/09 – 09/04/09	156
	JAX04B	38	03/10/10 – 08/18/10	162
	JAX05B	37	08/27/10 – 01/31/11	158
	JAX06B	37	02/02/11 – 07/13/11	162
				638
6	Jacksonville East			
	JAX01A	82	04/02/09 – 09/15/09	167
	JAX02A	83	09/17/09 – 12/15/09	90
	JAX03A	89	02/22/10 – 07/29/10	158
	JAX05A	91	08/27/10 – 01/24/11	151
	JAX06A	91	02/02/11 – 07/13/11	162
	JAX09C	94	05/13/13 – 06/19/13	38
	JAX10C	88	02/18/14 – 08/22/14	186
				952
Total				***3542***

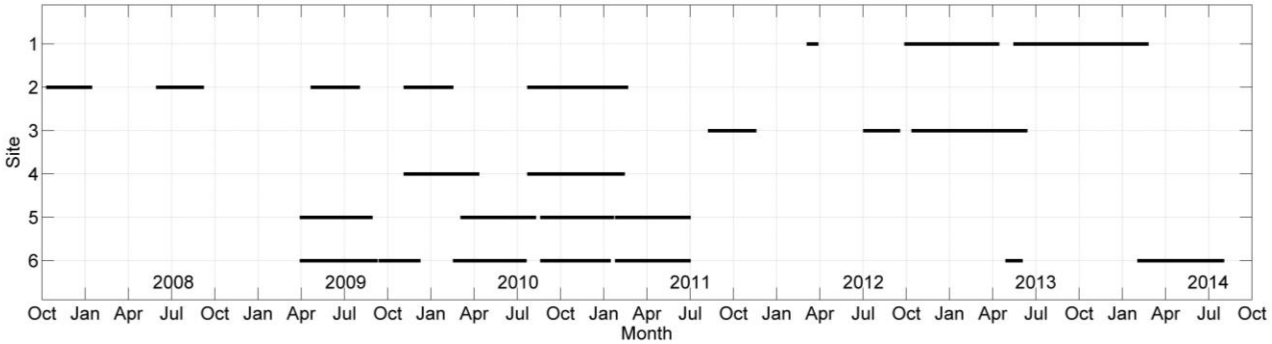

Figure 2. Atlantic HARP analysis periods (effort) for the six sites from October 2007 to October 2014.

HARPs are autonomous marine recorders capable of recording a wide range of sounds (10 Hz – 100 kHz) continuously over long periods (months – 1 year) with calibrated hydrophones. During a deployment, HARPs record sound pressure over the 10 Hz – 100 kHz frequency band over time. To facilitate processing mid- and low- frequency ambient noise, the data were decimated by a factor of 100 to produce an effective bandwidth of 10 – 1000 Hz. These decimated time series were transformed into the spectral domain with a fast Fourier transform using the Welch (1967) method incorporated into the acoustic analysis software package *Triton* (cetus.ucsd.edu/technologies_Software.html) and the high-level programing language MATLAB (www.mathworks.com). Spectrum levels were calculated in 1 Hz bins over 5 seconds using a Hann window and saved as Long-Term Spectral Averages (LTSA - Wiggins and Hildebrand, 2007). These 5 s LTSA spectral slices were used as a basis for longer term spectral averages; for example, one-day, one-month, or overall-site averages. HARP data files are written in 75 s segments, providing 15 spectral slices of 5 seconds each. To avoid electronic self-noise from disk writes contaminating the spectra, only the middle 5 spectral slices of each segment were used for averaging. Averages were calculated over each full day and partial days over 90% complete. Days with less complete recordings and those clearly contaminated, typically at the end and beginning of a recording when the hydrophone was not in the water or local deployment ship sounds were intense and long lasting, were removed and not used for analysis. Contaminated daily-averaged spectra were easily identified by comparing to overall deployment-averaged spectra then noting and removing extreme outliers. Daily-averaged spectra also were corrected for the calibrated instrument transfer function into sound pressure level spectral power density (dB re 1µPa^2/Hz).

To provide a means of evaluating seasonal spectral variability, daily-averaged spectra were further processed into monthly-averages and plotted using the same monthly color scheme for each of the 24 deployments so that months from different years and sites could be compared; for example, August is always the same color (orange) independent of site or year. It is important to note that while incomplete days have been removed from analysis, incomplete months were not. It is possible to have only one or a few days at the beginning or end of a deployment used for the monthly-average estimate, potentially biasing those incomplete monthly-averaged spectra.

Overall site-averaged spectrum levels were obtained by averaging the daily-averaged spectra to avoid biases introduced by incomplete monthly-averages as noted above. Table 1 shows the relative effort for analysis days per site. Site 6, Jacksonville East, had the greatest effort with 7 deployments and over 950 days, while site 4 had the fewest, with only two deployments for ~370 days. The rest of the sites were between 400-600 days.

Results and Discussion

Site-averaged ambient spectrum levels for the six Atlantic Coast HARP sites were similar (within 10 dB) with levels around 60-65 dB re 1µPa^2/Hz near 1000 Hz, 70-75 dB re 1µPa^2/Hz at 100 Hz, and ~85-95 dB re 1µPa^2/Hz at 20 Hz (Figure 3). Monthly-averaged ambient sound pressure spectrum levels are shown for all 24 deployments grouped per site in the Appendix. The two deep water sites (1 and 3) had a flatter shape below about 60 Hz than the shallow water sites, and both sites showed a peak around 20 Hz also appearing seasonally in the monthly-averages (see Appendices A1 and A3) which were due to fin whale calls.

All sites, except site 1, had high levels (>95 dB re 1µPa^2/Hz) at 10 Hz. High spectrum levels below 30 Hz were likely caused by ocean currents and hydrophone support cable ‘strumming’ from these currents. Site 3, while relatively deep (~900 m), also appeared to be subject to ocean currents, perhaps caused by deep components of the northward traveling Gulf Stream. Site 1 (~960 m), on the other hand, had relatively low spectrum levels below 30 Hz (80-85 dB re 1µPa^2/Hz) allowing better signal-to-noise ratio (SNR) for the 20 Hz fin whale calls.

The band around 40 Hz is often associated with propulsion sounds from commercial ships. Sites 1 and 3 were exposed to the deep water where distant shipping sounds propagate well, as shown by the hump of increased levels near 40 Hz. Higher levels at 30-50 Hz for site 3 may have been caused by local shipping. Site 5, on the other hand, had the lowest levels (<80 dB re 1µPa^2/Hz) around 40 Hz because its shallow (37 m) deployment site was shielded from deep ocean shipping noise, may have had less local shipping traffic, and less cable strumming. In comparison to site 5, site 6, which was nearby but deeper (~90 m), had higher levels below 500 Hz, perhaps owing to higher ocean currents farther offshore. Site 4 had the highest site-average levels at 10 Hz, approaching 110 dB re 1µPa^2/Hz, but also the lowest levels above 100 Hz ~ 60 dB re 1µPa^2/Hz potentially relating to it having the lowest sampling effort (~370 days) and the site location.

At frequencies above 200 Hz, wind is a common source and can be correlated with spectrum levels. The site monthly-averaged spectrum levels in the Appendix show that this relationship appears to hold best for site 1, while all other sites appear to be affected by strumming at these higher frequencies or are at locations insensitive to noise generated by local wind.

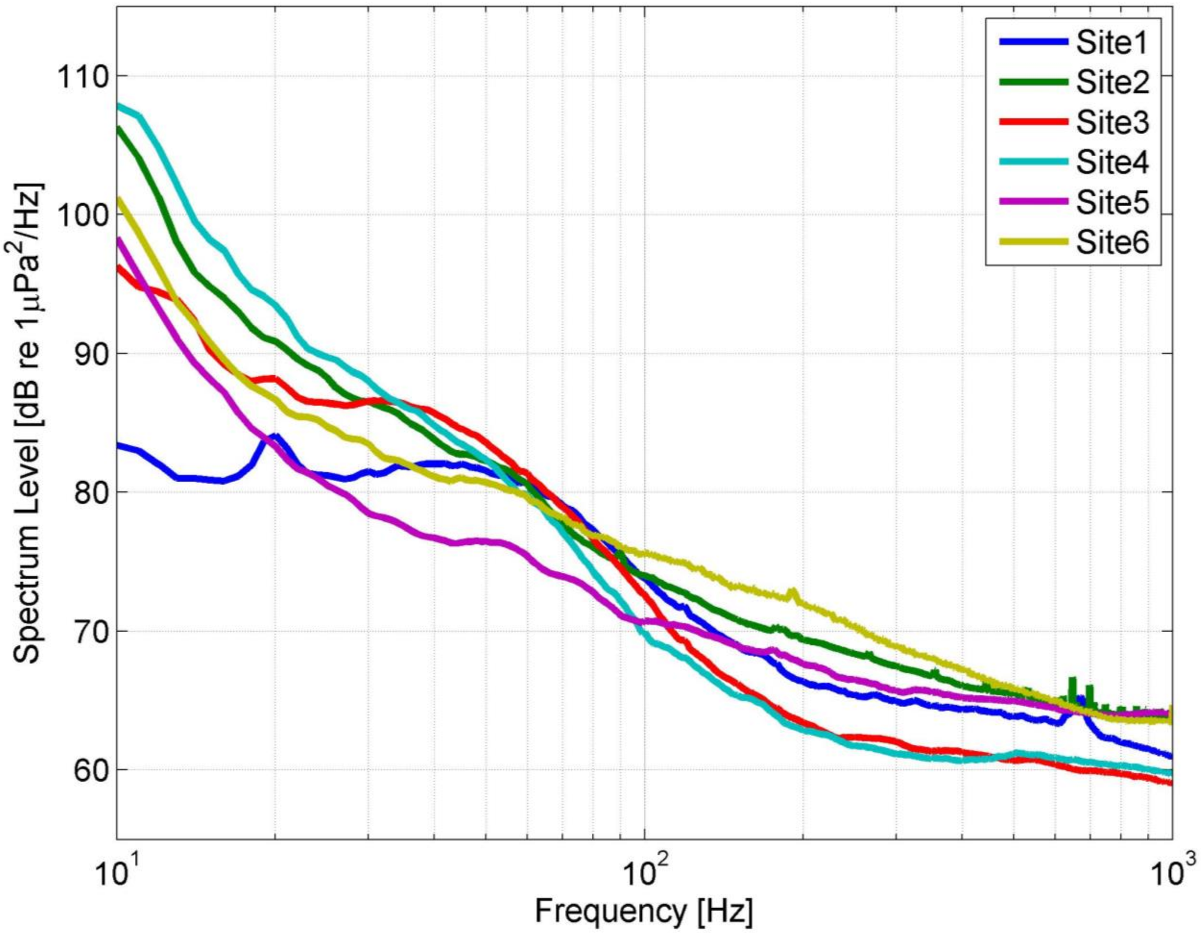

Figure 3. Site-averaged Atlantic ambient spectrum levels. Site 1 tone ~20 Hz is related to fin whale calling. High levels at 10 Hz are due to ocean currents. Elevated levels near 40 Hz are typically commercial shipping related. Levels >200 Hz often are correlated with wind speed. See Figure 1 for site locations and Table 1 and Figure 2 for site effort.

Conclusions

Measuring deep ocean ambient noise is challenging offshore of the Atlantic Coast states because of the large expanse of the continental shelf, especially offshore of Florida. Shallow water deployments typically have higher ambient noise levels because the hydrophone sensor is in close proximity to the sound sources at or near the sea surface. For five of the six sites in this report, tidal and subsurface ocean currents caused instrument strumming resulting in increased sound spectrum levels, even at the deep (~900 m) site 3. Instrument design could be modified to reduce strumming, but flow noise from these strong currents would still have an acoustic masking effect with high spectrum levels across the band. Alternatively, the sound pressure time series could be filtered to remove periods of strumming, but results would likely become biased to low flow conditions such as during slack tide or waxing and waning moon cycles when tidal flows are low or become correlated with the seasonality of the Gulf Stream flow. However, evaluating data during low strum periods may be required to find discrete sounds of interest in the recordings.

The deepest site, off Cape Hatteras (~960 m – site 1), showed sound spectrum levels with characteristics similar to other deep water sites, including marine mammal seasonality (20 Hz), commercial shipping (40 Hz) and local wind (>200 Hz). The lack of strumming at this site suggests that the deep currents affecting the other deep water monitoring location (site 3) are minimal or not present, as the direction of the Gulf Stream changes and heads northeast before reaching the location of site 1.

Acknowledgments

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References

Hildebrand, J. A. (**2009**). "Anthropogenic and natural sources of ambient noise in the ocean," Mar Ecol Prog Ser **395**, 5-20.

McDonald, M. A., Hildebrand, J. A., and Wiggins, S. M. (**2006**). "Increases in deep ocean ambient noise in the Northeast Pacific west of San Nicolas Island, California," The Journal of the Acoustical Society of America **120**(2), 711-718.

McDonald, M. A., Hildebrand, J. A., Wiggins, S. M., and Ross, D. (**2008**). "A 50 Year comparison of ambient ocean noise near San Clemente Island: A bathymetrically complex coastal region off Southern California," The Journal of the Acoustical Society of America **124**(4), 1985-1992.

McKenna, M. F., Ross, D., Wiggins, S. M., and Hildebrand, J. A. (**2012**). "Underwater radiated noise from modern commercial ships," The Journal of the Acoustical Society of America **131**(1), 92-103.

Roth, E. H., Hildebrand, J. A., Wiggins, S. M., and Ross, D. (**2012**). "Underwater ambient noise on the Chukchi Sea continental slope from 2006--2009," The Journal of the Acoustical Society of America **131**(1), 104-110.

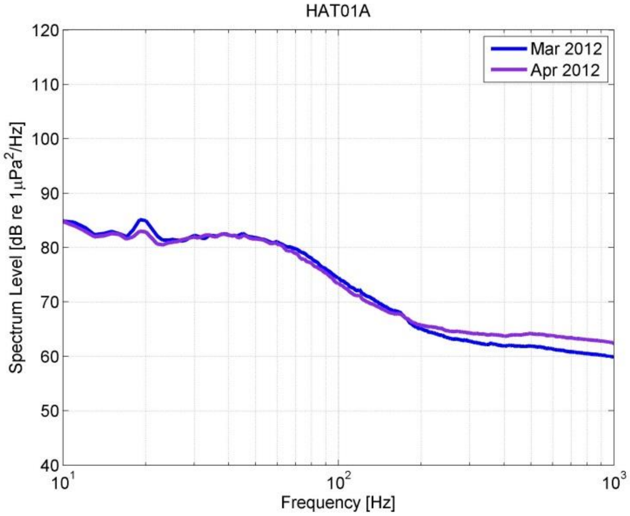
Širović, A., Wiggins, S. M., and Oleson, E. M. (**2013**). "Ocean noise in the tropical and subtropical Pacific Ocean," The Journal of the Acoustical Society of America **134**(4), 2681-2689.

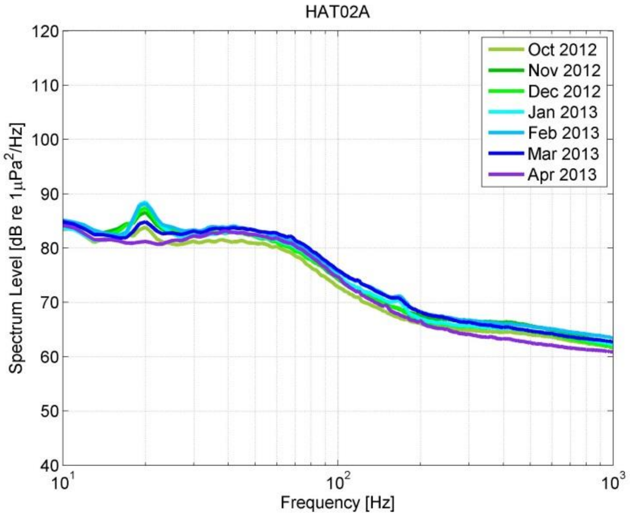
Welch, P. D. (**1967**). "The use of fast Fourier transform for the estimation of power spectra: A method based on time averaging over short, modified periodograms," IEEE Trans. Audio Electroacoustics **AU-15**, 70-73.

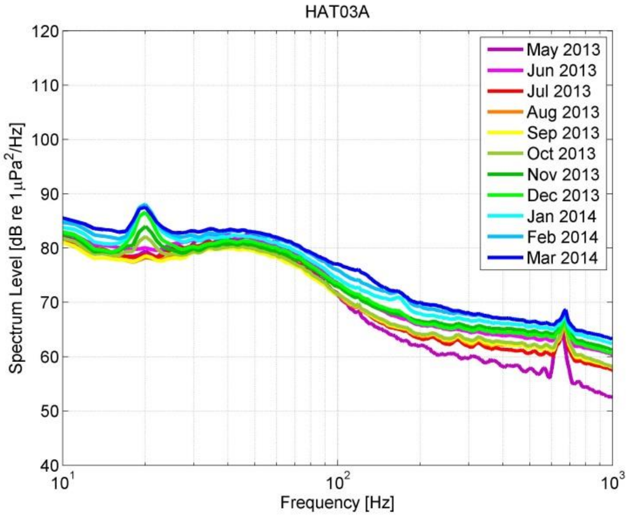
Wiggins, S. M., and Hildebrand, J. A. (**2007**). "High-frequency Acoustic Recording Package (HARP) for broad-band, long-term marine mammal monitoring," in *International Symposium on Underwater Technology 2007 and International Workshop on Scientific Use of Submarine Cables & Related Technologies 2007*,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

Appendix

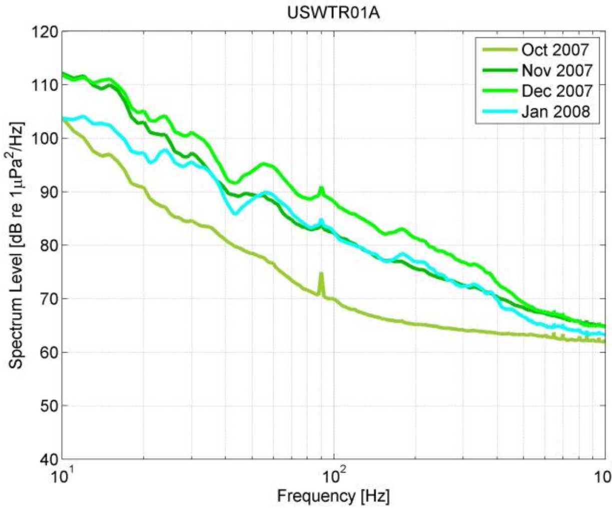
A1. Site 1 Hatteras

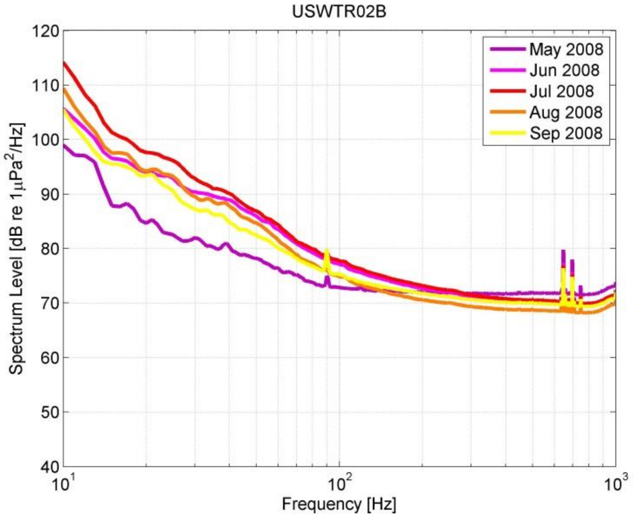


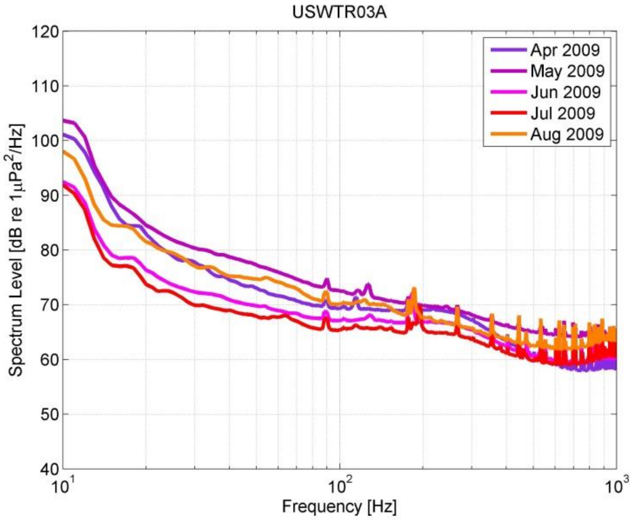


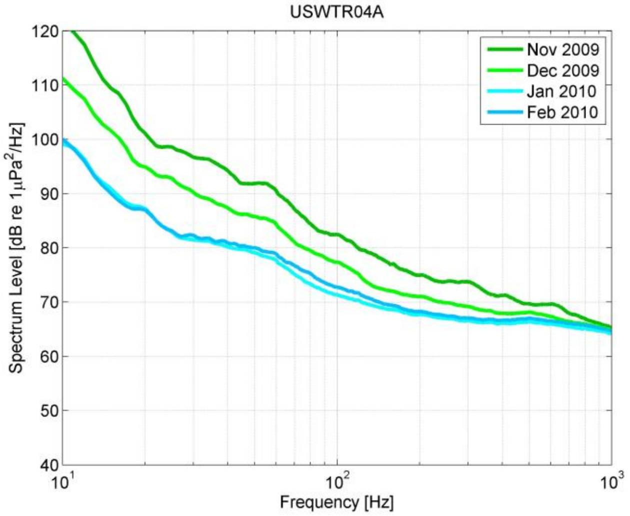


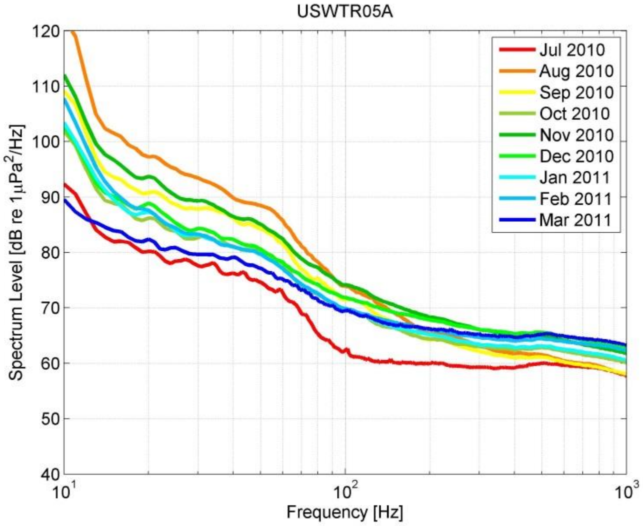
A2. Site 2 Cherry Point Shallow



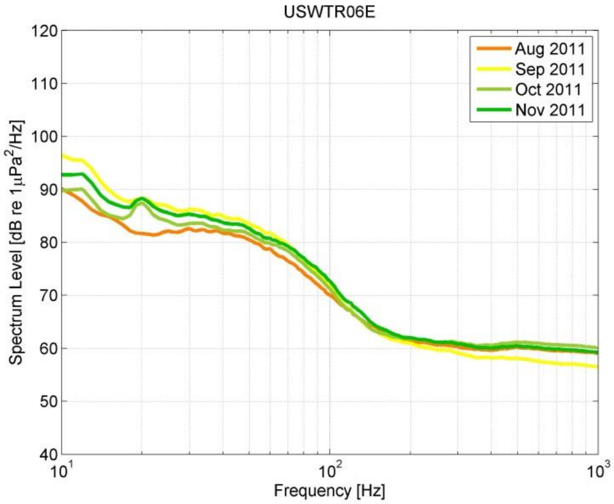


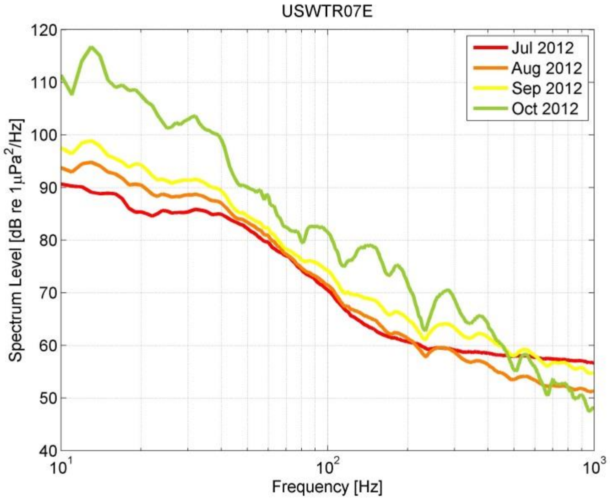


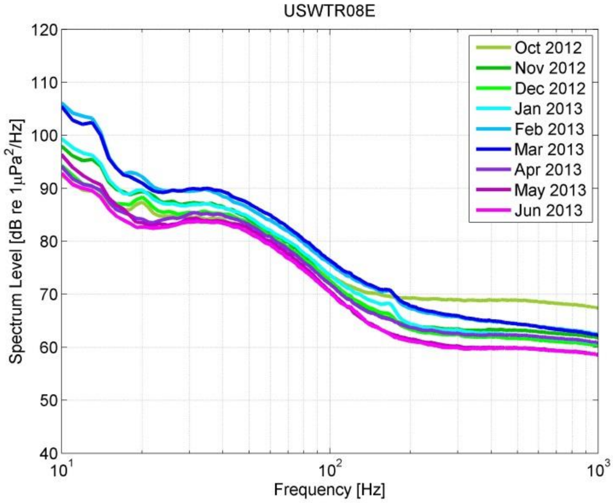




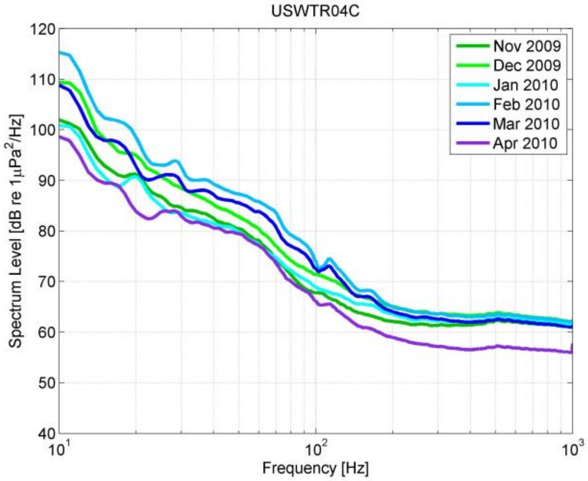
A3. Site 3 Cherry Point Deep

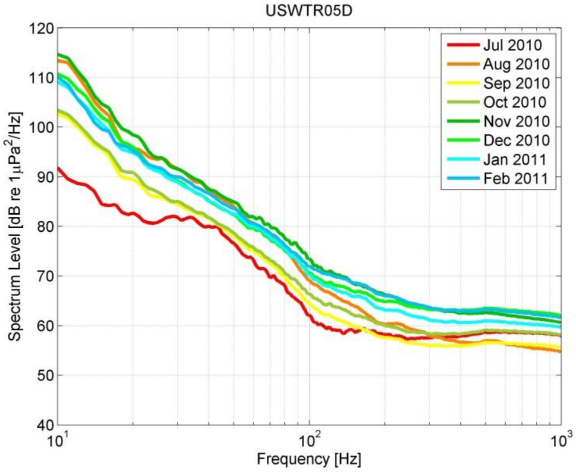






A4. Site 4 Cherry Point South





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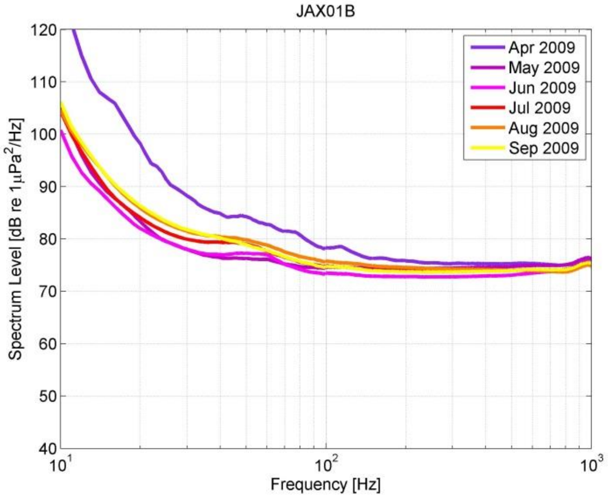
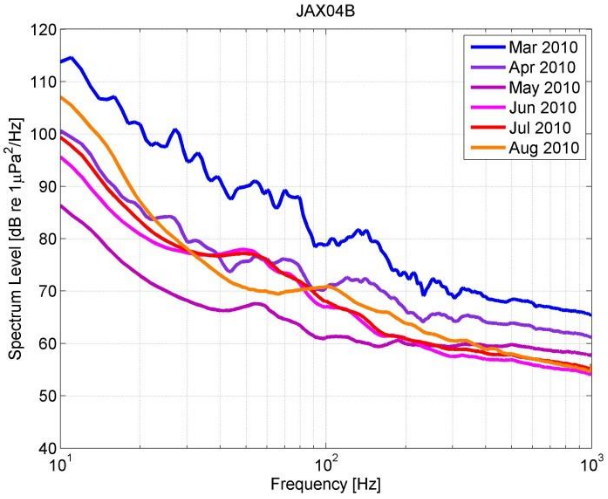
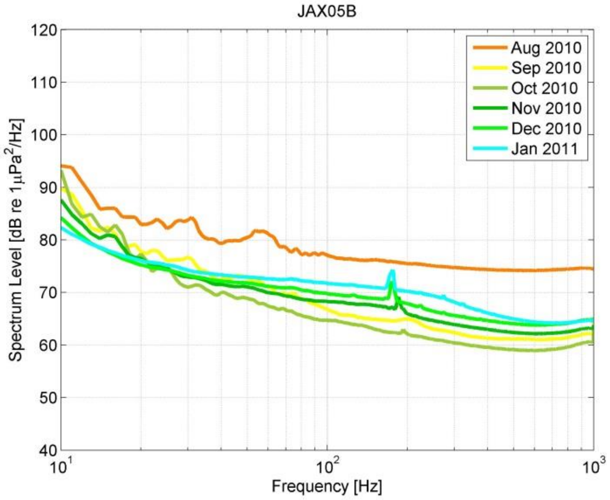
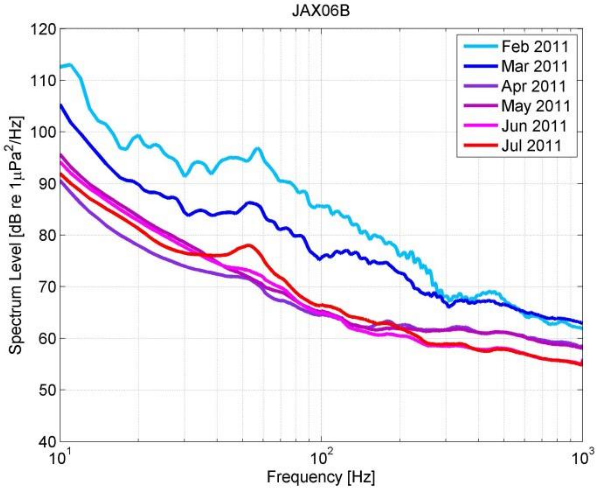
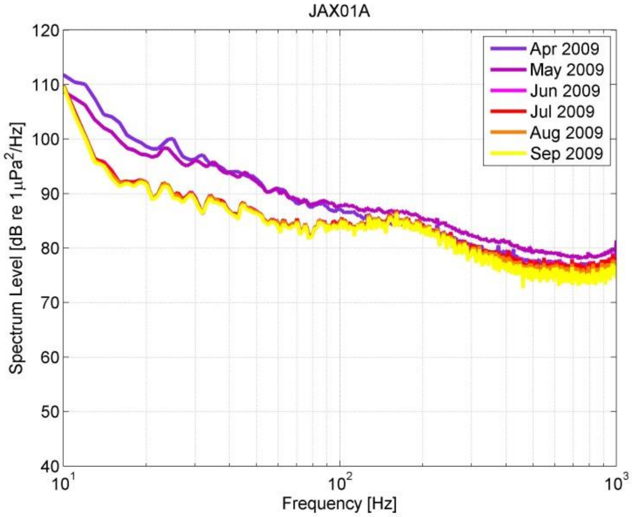


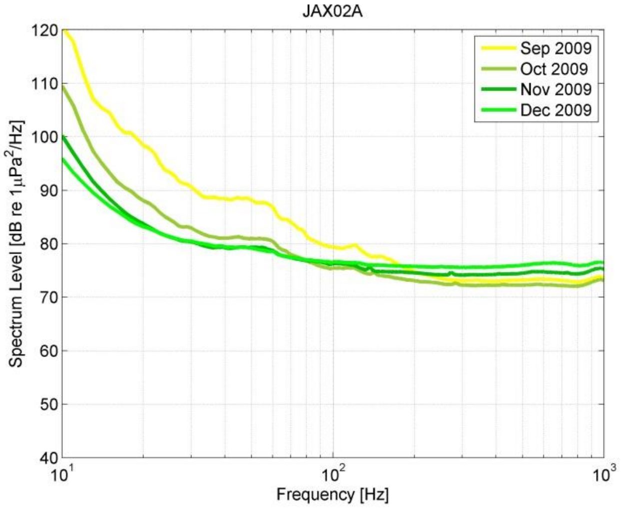


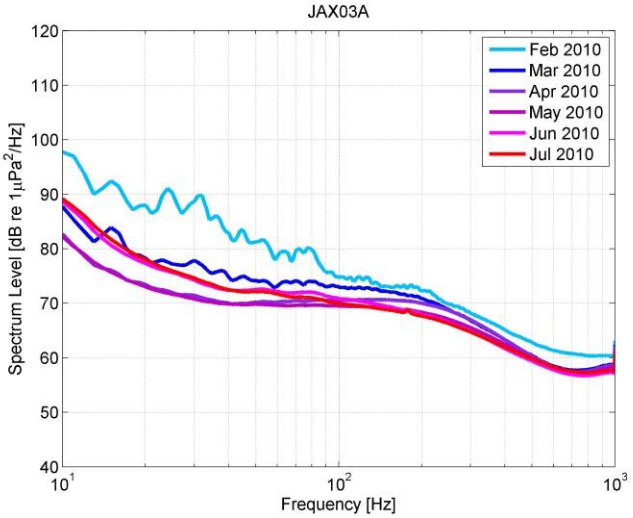


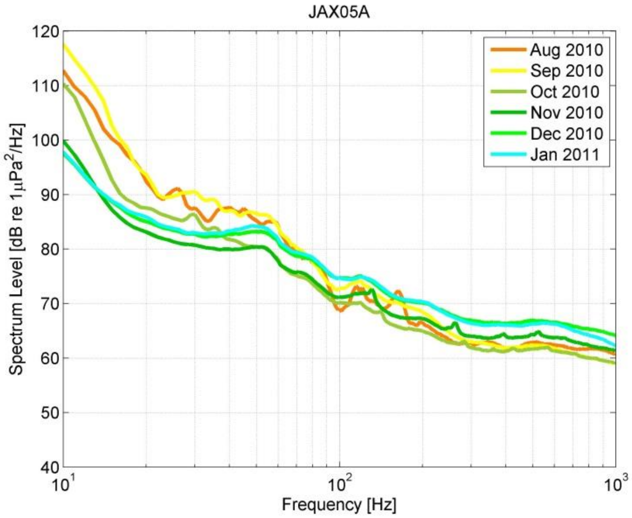


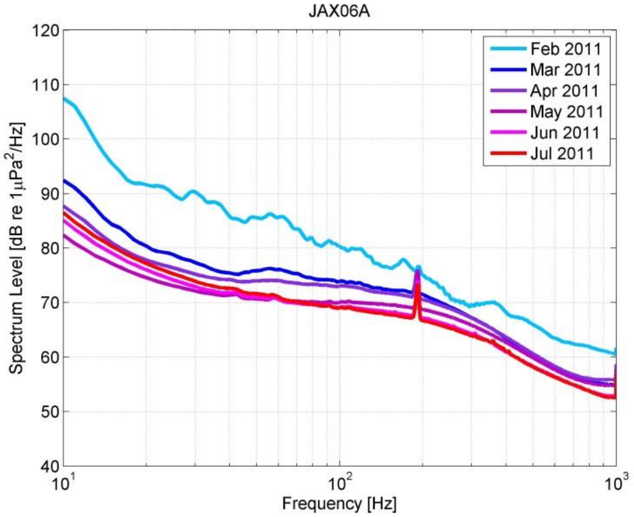
A6. Site 6 Jacksonville East











A6. Site 6 Jacksonville East (cont.)