Underwater Noise Level Study during Impact Pile Driving

FDOT Project No. BDV34 985-03, Katasha Cornwell, Office of Environmental Management, Project Manager

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Motivation

- Pile driving may make enough noise to kill/injure fish and other marine animals

- Florida does not have reliable local guidelines to predict anthropogenic noise during pile driving and it has been using CalTrans' "Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish" (Buehler et al. 2015)

- California guidelines were based mostly upon <u>percussion driving steel piles</u>. On Florida bridges, most drives are percussion drives <u>with concrete piles</u> or <u>vibratory drives with steel piles</u>.

Project Objectives

- Main Objective – Characterize underwater noise levels during impact pile driving throughout the State of Florida using Florida-specific conditions. In particular:
  - Florida geotechnical conditions
  - Understand the difference between concrete percussion drives, steel percussion pile drives, and steel vibratory drives

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Specific Variables of Interest

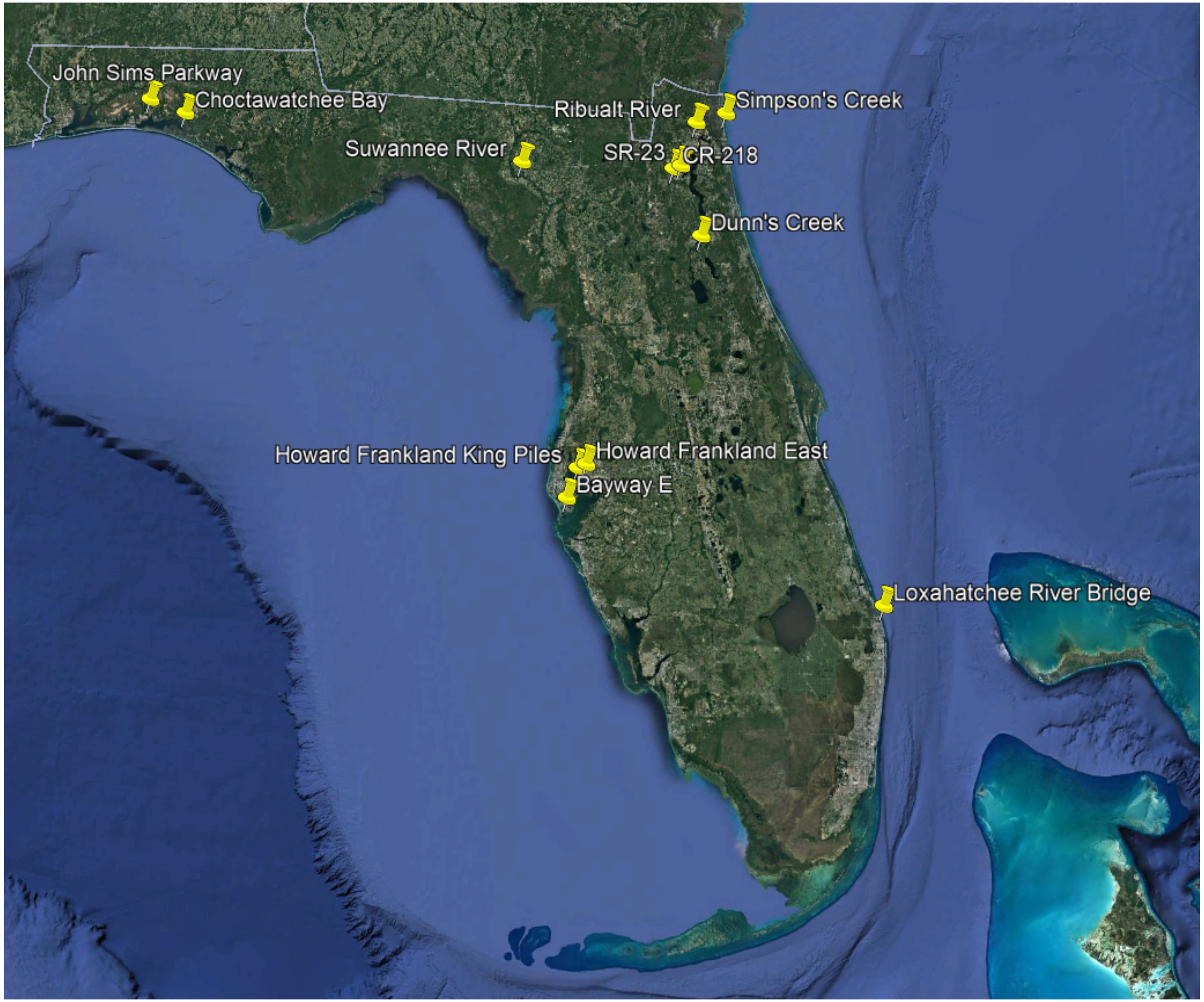
- Decibels
  - $dB = 10\log_{10}\left[\left(\frac{P}{P_{ref}}\right)^2\right]$
  - P = sound pressure (Pa)
  - $P_{ref} = 1\mu$Pa
- Sound Attenuation Coefficient
  - $TL = F\log_{10}\frac{R}{R_0}$
  - R = Range from sound source
  - R_0 = Reference range
  - F = Transmission loss coefficient. According to NMFS, F = 15
  - TL = Transmission loss (in dB)
- Sound Statistics
  - *Peak* = peak sound-level
  - *RMS* = root-mean-square sound-level
  - *SEL* = sound exposure level

$$SEL = 10\log_{10}\int (P/P_{ref})^2\,dt$$

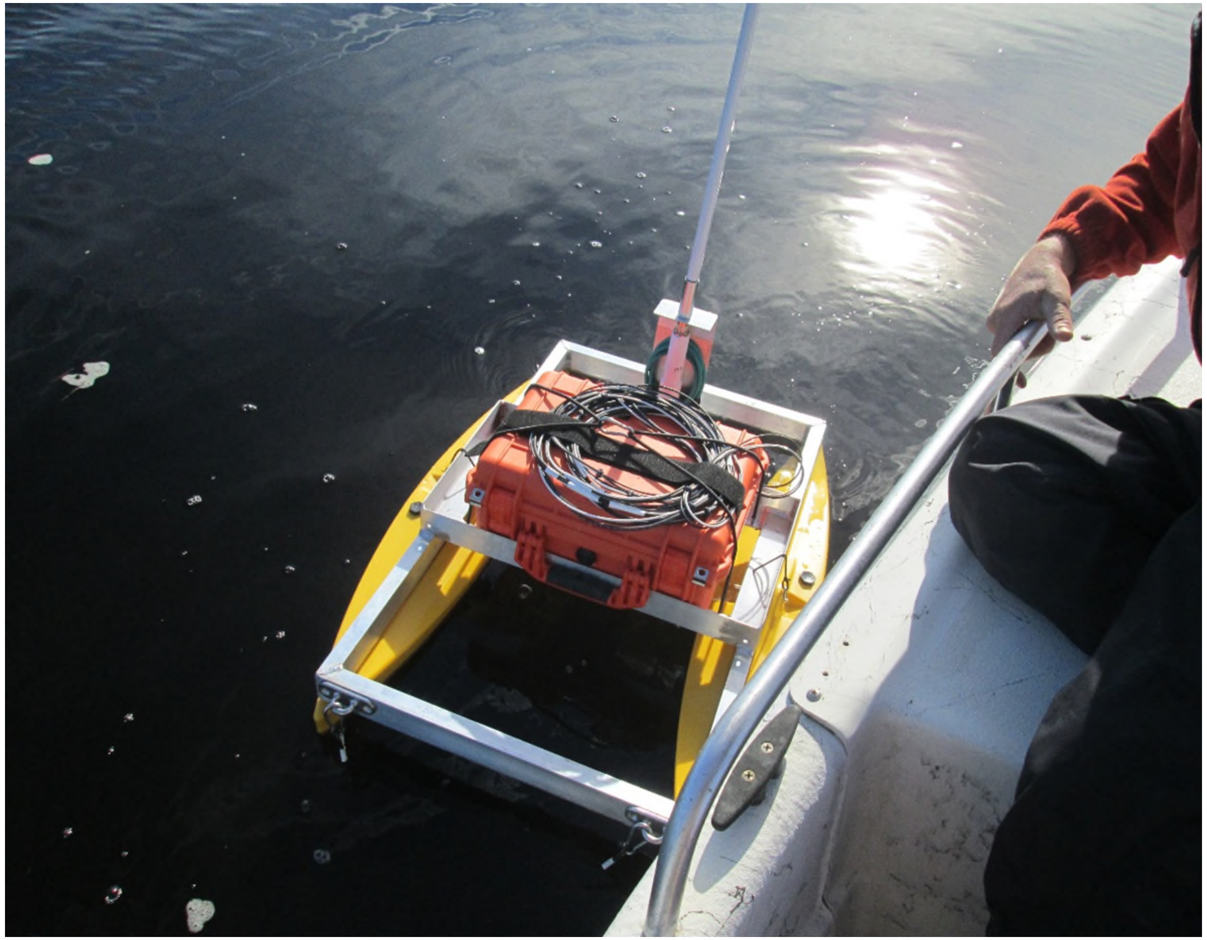
Updated Noise Guidelines (NMFS 2022)

Species and Effect	Threshold (dB)	Measurement
Fish single strike injury	206	Peak
Fish > 2 g cumulative exposure injury (impact)	187	SEL
Fish < 2 g cumulative exposure injury (impact)	183	SEL
Fish > 102 g cumulative exposure injury (vibratory)	234	SEL
Fish < 102 g cumulative exposure injury (vibratory)	191	SEL
Fish behavioral change	150	RMS
Sea turtle single strike injury	206	Peak
Sea turtle cumulative exposure injury (impact)	187	SEL
Sea turtle cumulative exposure injury (vibratory)	234	SEL
Sea turtle behavioral change	160	RMS
Cetacean behavioral change (impact)	160	RMS
Cetacean behavioral (vibratory)	120	RMS

Site Locations



Data Collection – Buoy System



Data Collection Buoy

Deploying the Data Collection System

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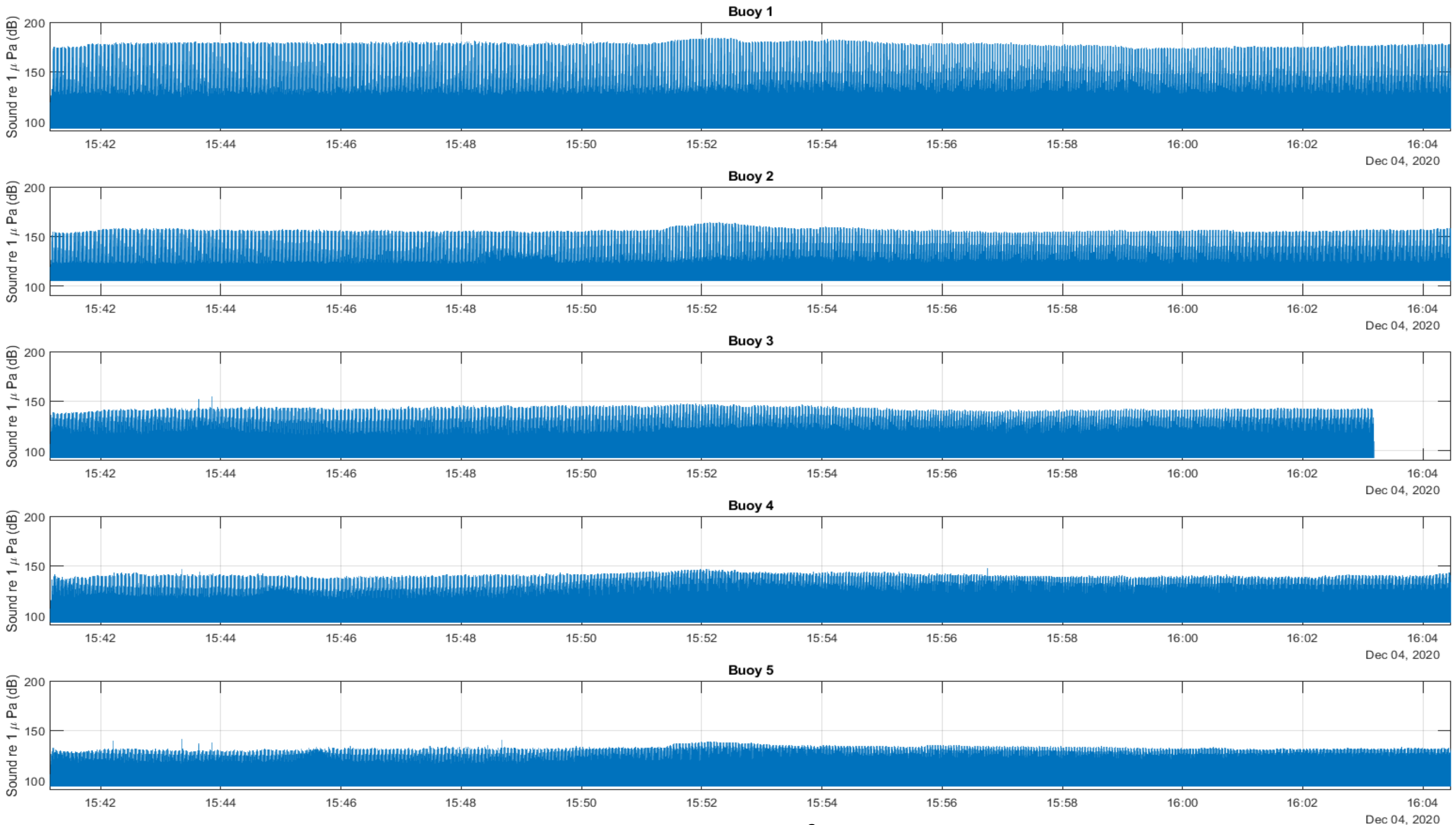
Sample Time-Series Data – CR 218



Raw Time-Series Data from CR-218

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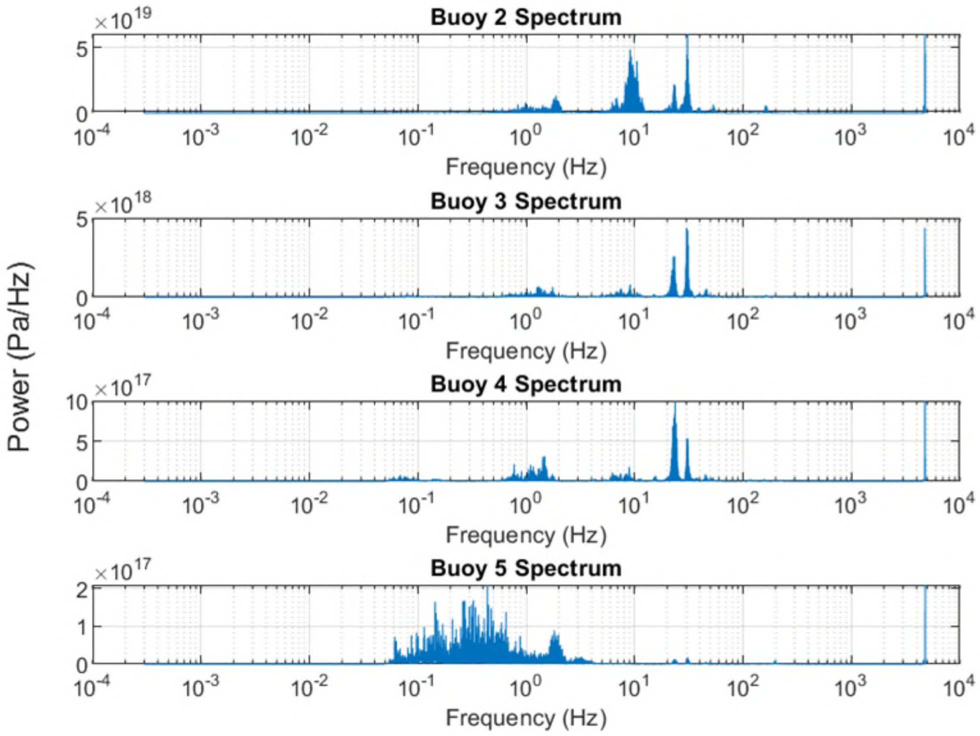
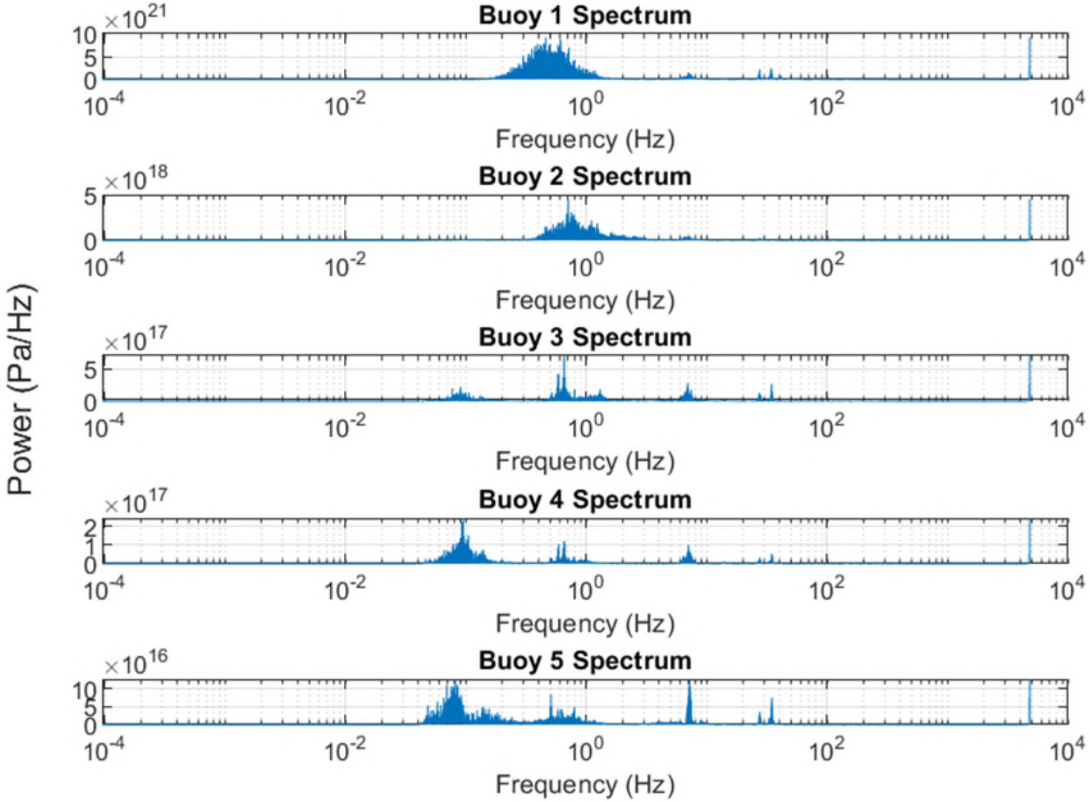
Sample Frequency Data – Howard Frankland



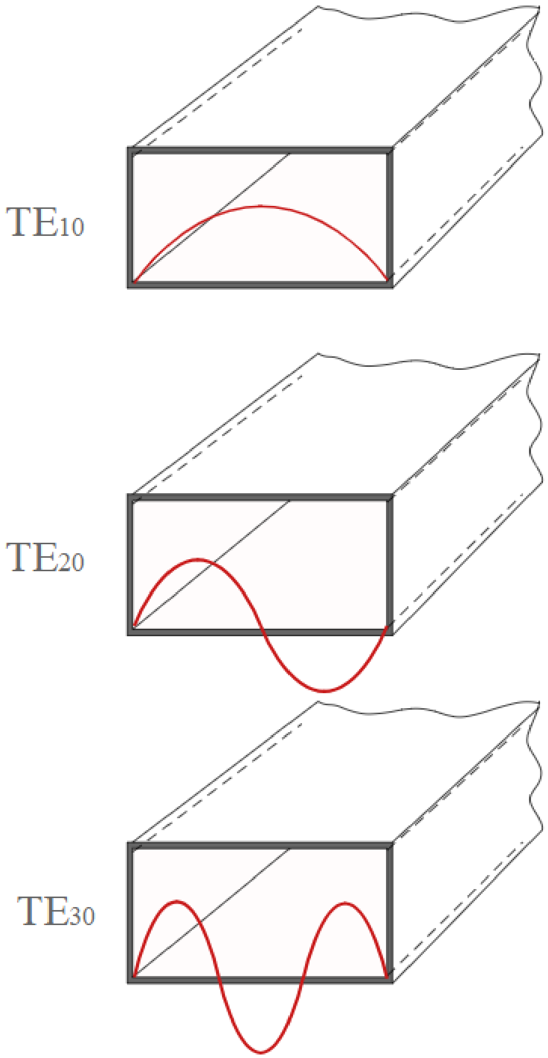
Spectral data from Howard Frankland East
(Steel King Piles)



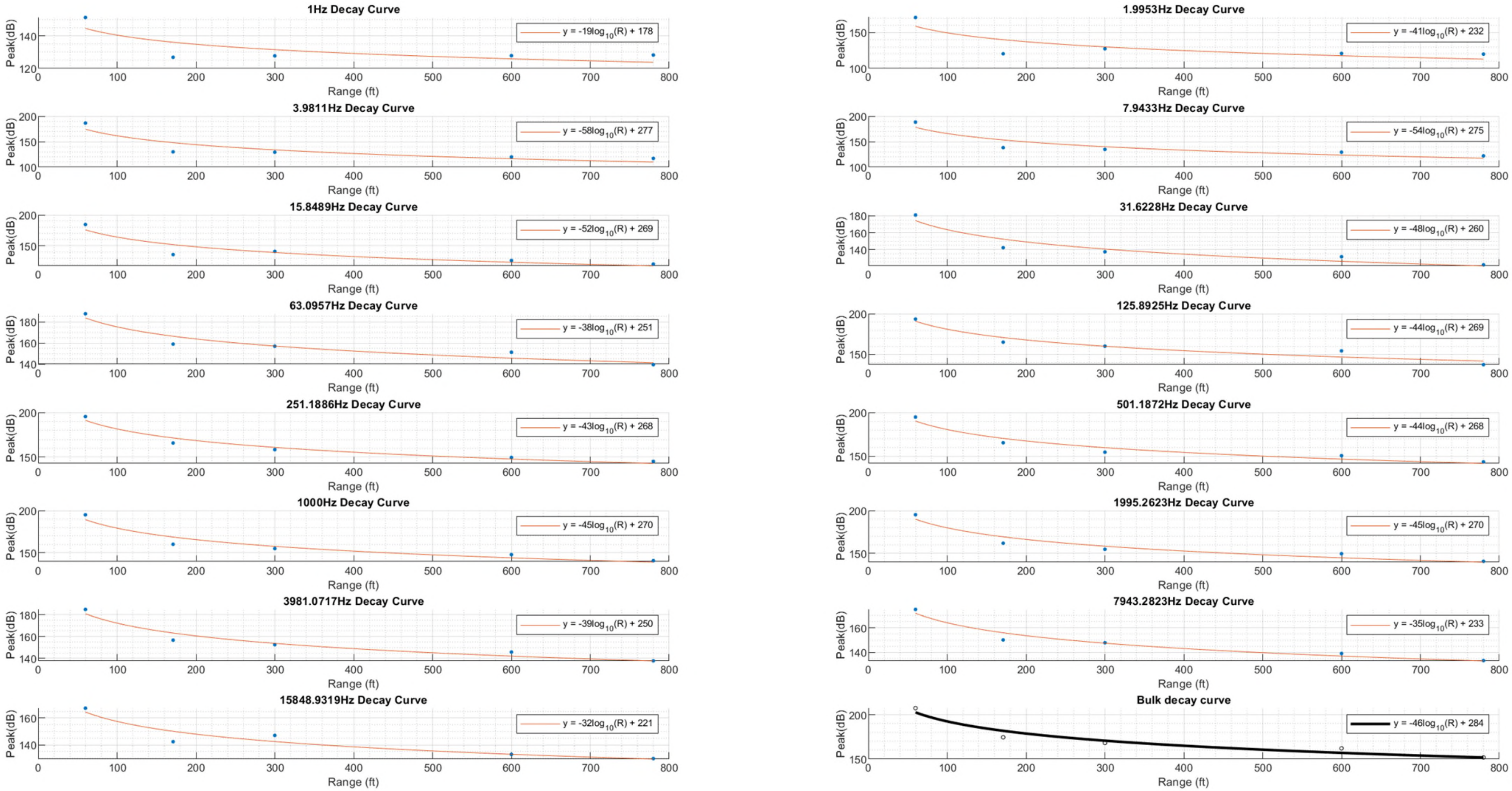
Spectral data from Howard Frankland West
(Concrete Piles)

Cutoff Frequency

- $f_{min} = \frac{\pi - \frac{\rho_s}{\rho_w}}{2\pi \sin(\psi_c)} \frac{c_w}{H}$
- $\psi_c = \cos^{-1}\left(\frac{c_w}{c_s}\right)$
- For $H \sim 10\ ft, f_{min} \sim 100\ Hz$
- $\lambda_{max} = \frac{c}{f_{min}}$
- $\lambda_{max} \sim 15\ m$



Sample Octave Analysis Data – Howard Frankland East (Peak Data)



Octave Decay Curves

More with Transmission Loss

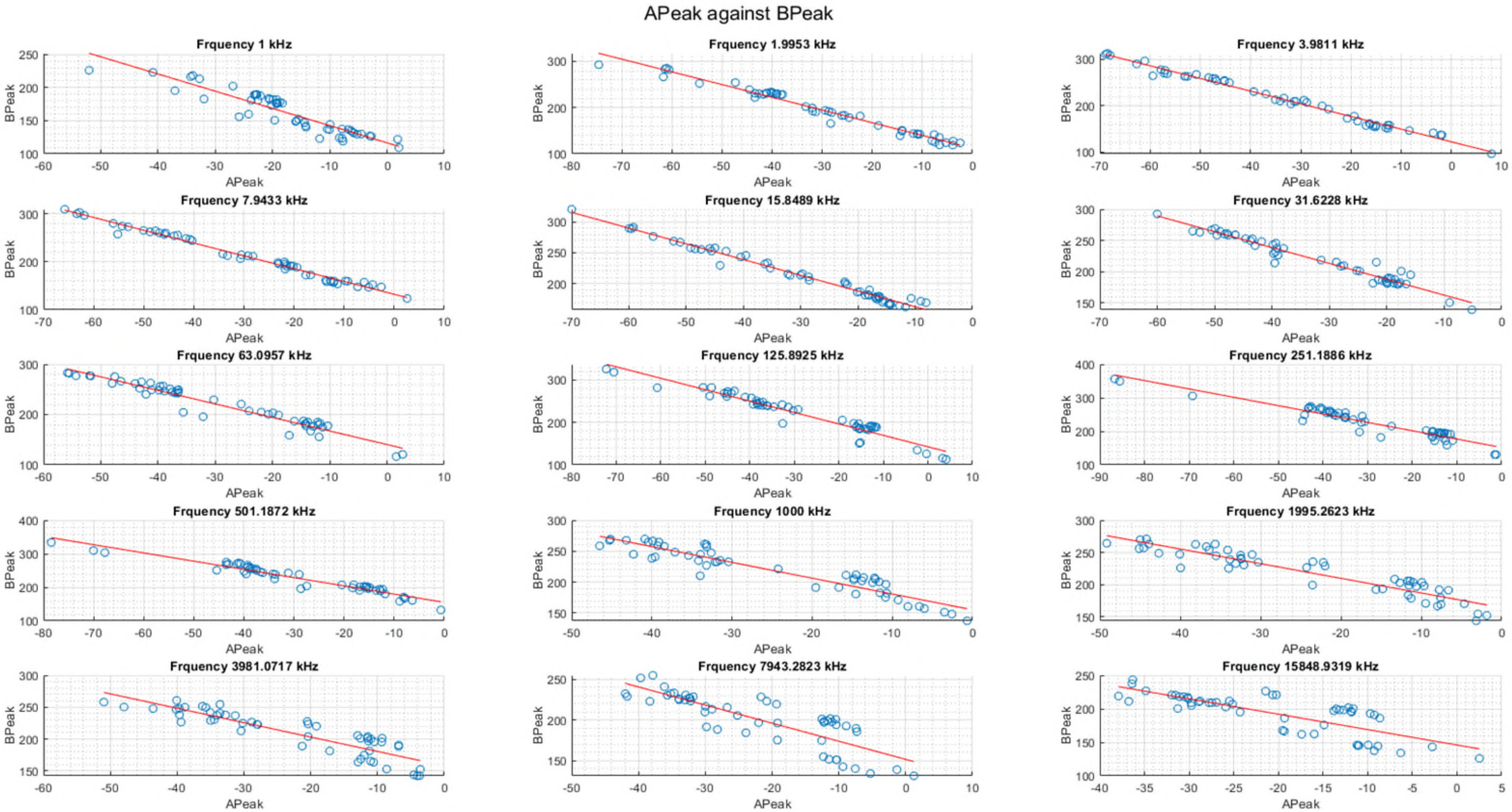
Ainslie et al. (2014)

- $TL = L_s - L_r = A\log_{10}\left(\frac{R}{R_0}\right) + B$
- $L_r = (L_s - B) - A\log_{10}\left(\frac{R}{R_0}\right)$
- $L_r = b - a\log_{10}\left(\frac{R}{R_0}\right)$

Simple Spreading Loss Model

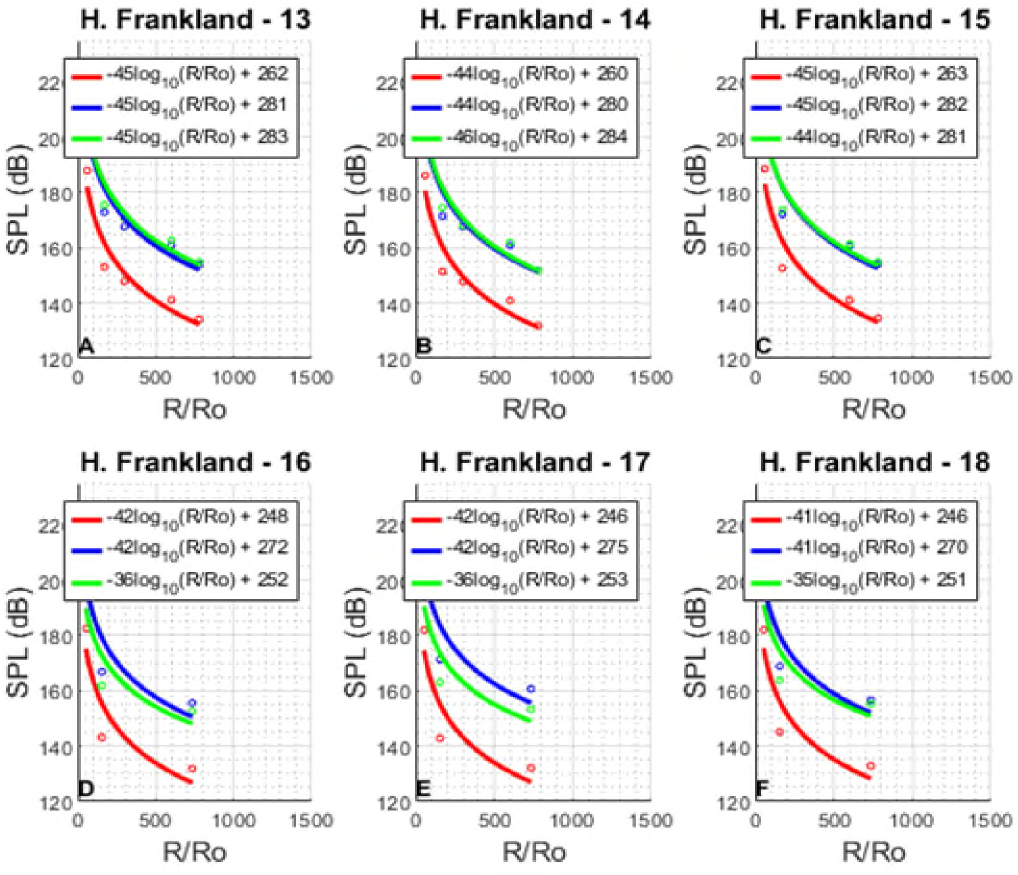
- $TL = L_s - L_r = F\log_{10}\left(\frac{R}{R_0}\right)$
- $L_r = L_s - F\log_{10}\left(\frac{R}{R_0}\right)$
- According to NMFS, *F* = 15

Frequency Correlations Between A and $(L_s - B)$

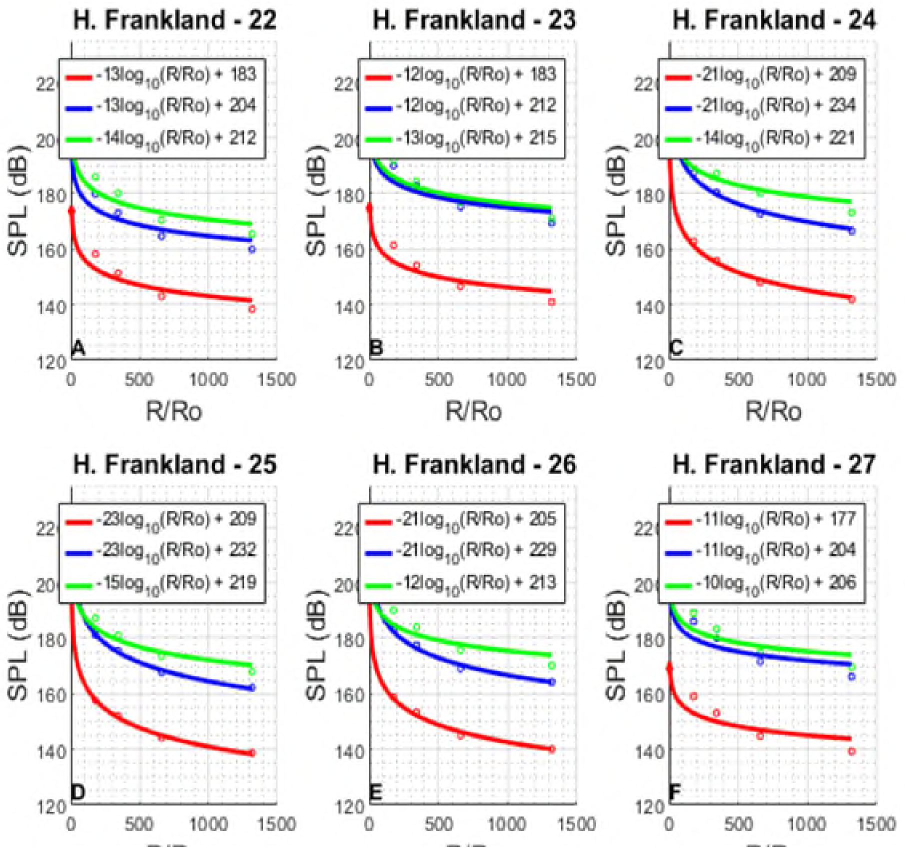


Frequency-Dependent Correlations Between A and $(L_s - B)$

Examples of Bulk Attenuation Curves

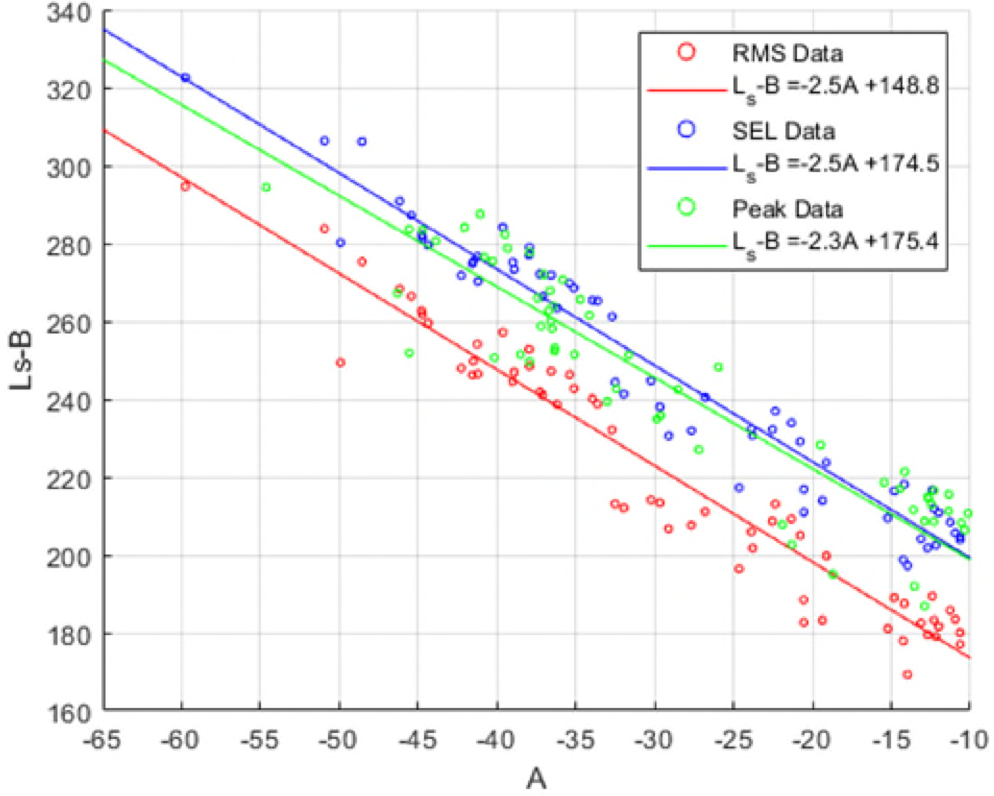


Bulk sound decay curves from west side of Howard Frankland Bridge

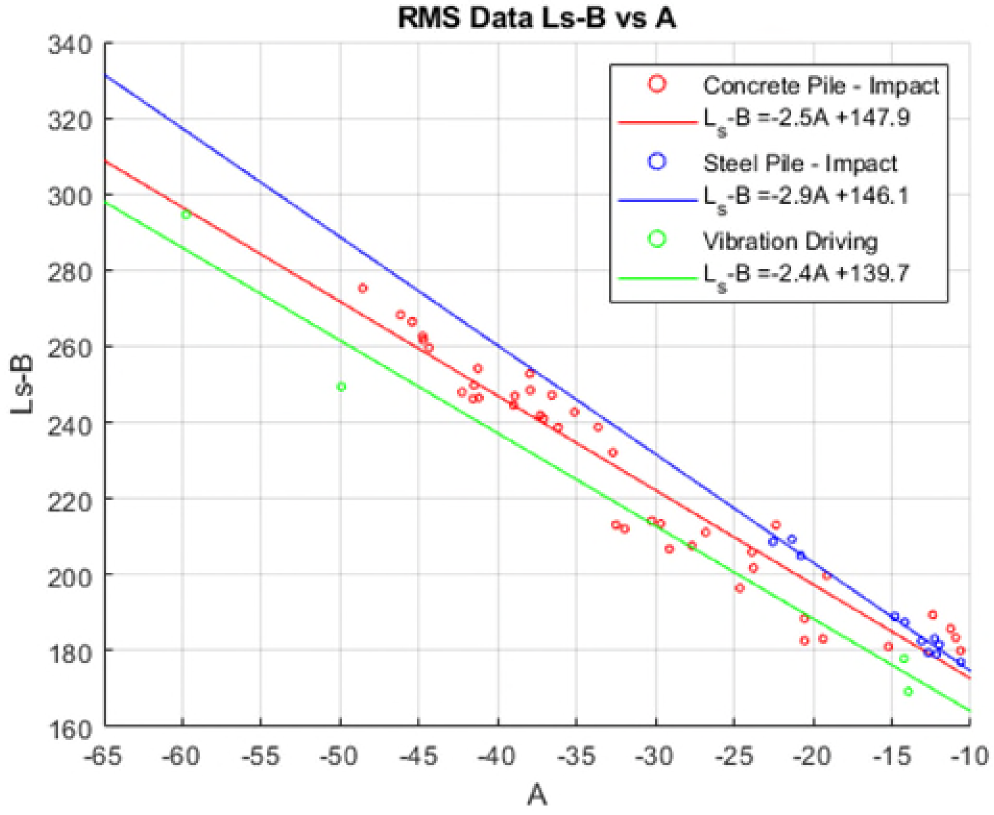


Bulk sound decay curves from east side of Howard Frankland Bridge

Correlations Between A and $(L_s - B)$



Bulk Correlations Between A and $(L_s - B)$



RMS Correlations Between A and $(L_s - B)$

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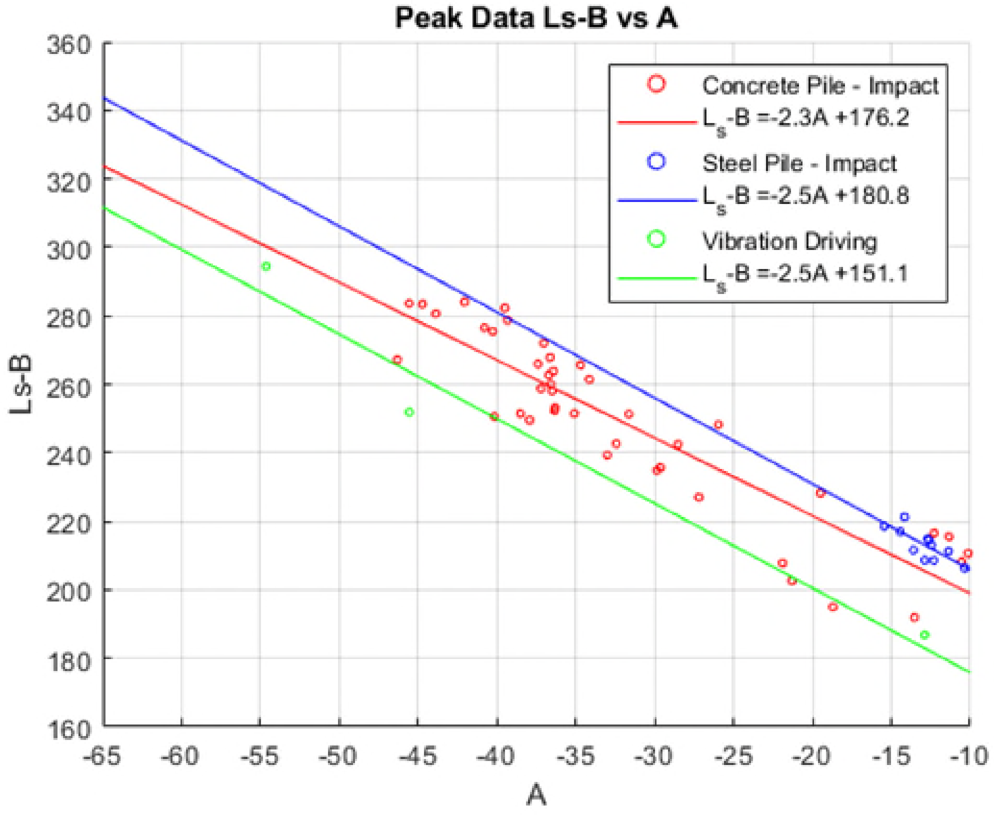
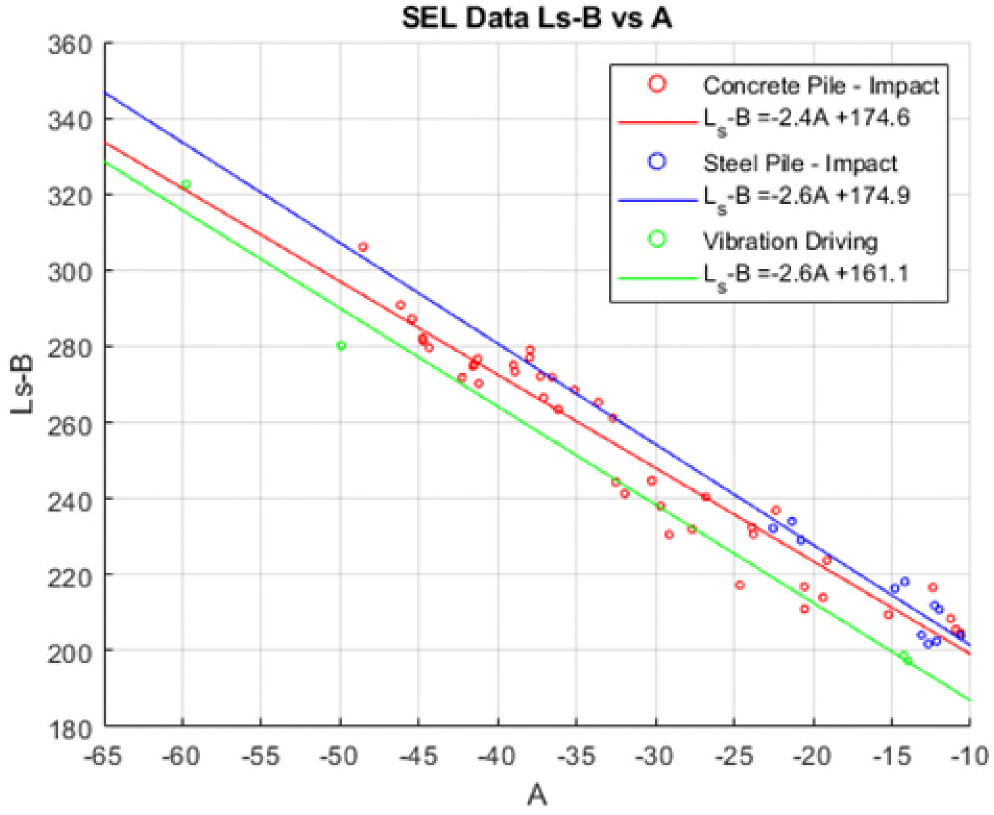
Correlations Between A and $(L_s - B)$



Peak Correlations Between A and $(L_s - B)$



SEL Correlations Between A and $(L_s - B)$

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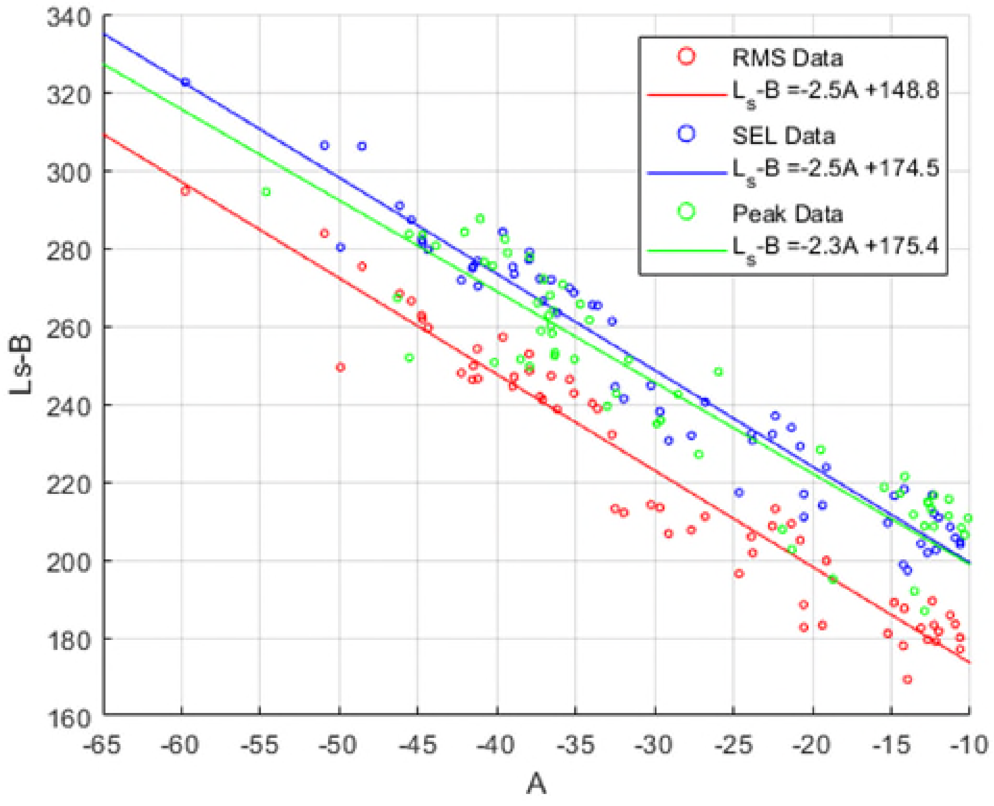
Example Problem

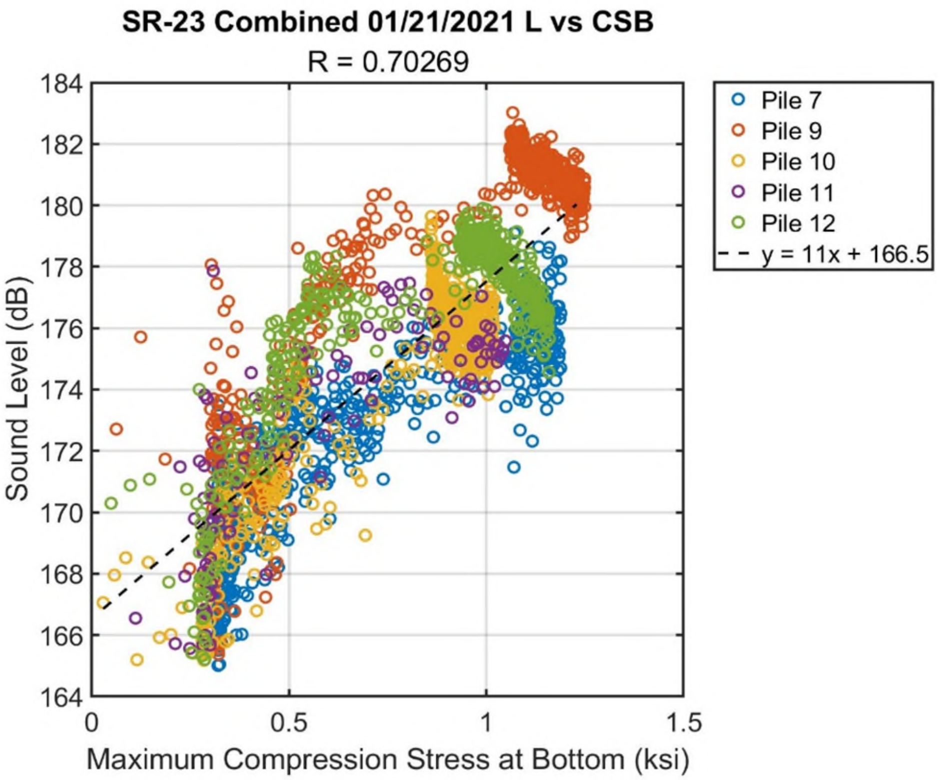


Bulk Correlations Between A and $(L_s - B)$

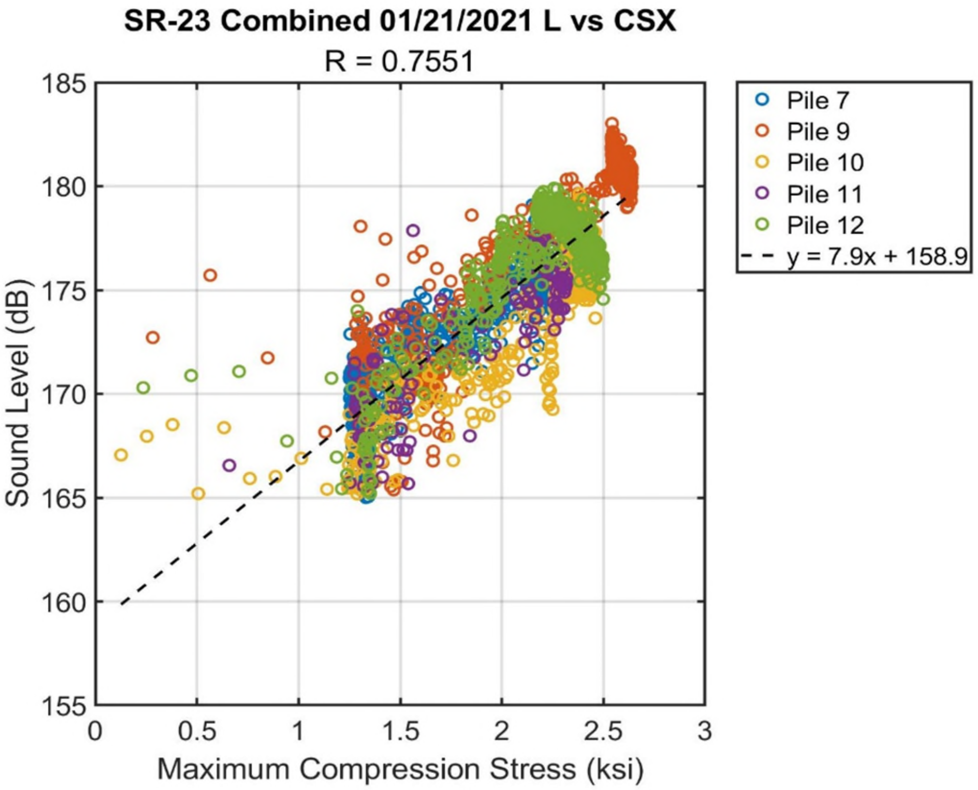
During a drive, one measured a PEAK SPL of 220 dB 20 ft from the pile. Find the distance required to get below the peak threshold which is 206 dB.

- NOAA/NMFS Method
  - $r = (10^{\frac{L_S - L_r}{15}})r_0$
  - $r = (10^{\frac{220\ dB - 206\ dB}{15}})(20\ ft) = 172\ ft$
- New Method
  - $A = \frac{L_m - a_1}{a_1 - \log_{10}\left(\frac{r}{r_0}\right)}$
  - $A = \frac{220\ dB - 175.4\ dB}{2.3 - \log_{10}\left(20\frac{ft}{1ft}\right)} = 44.65$
  - $r = \left[10^{\frac{2.3(47.45)+175.4dB-206dB}{44.65}}\right]1ft = 41.18\ ft$

PDA Data

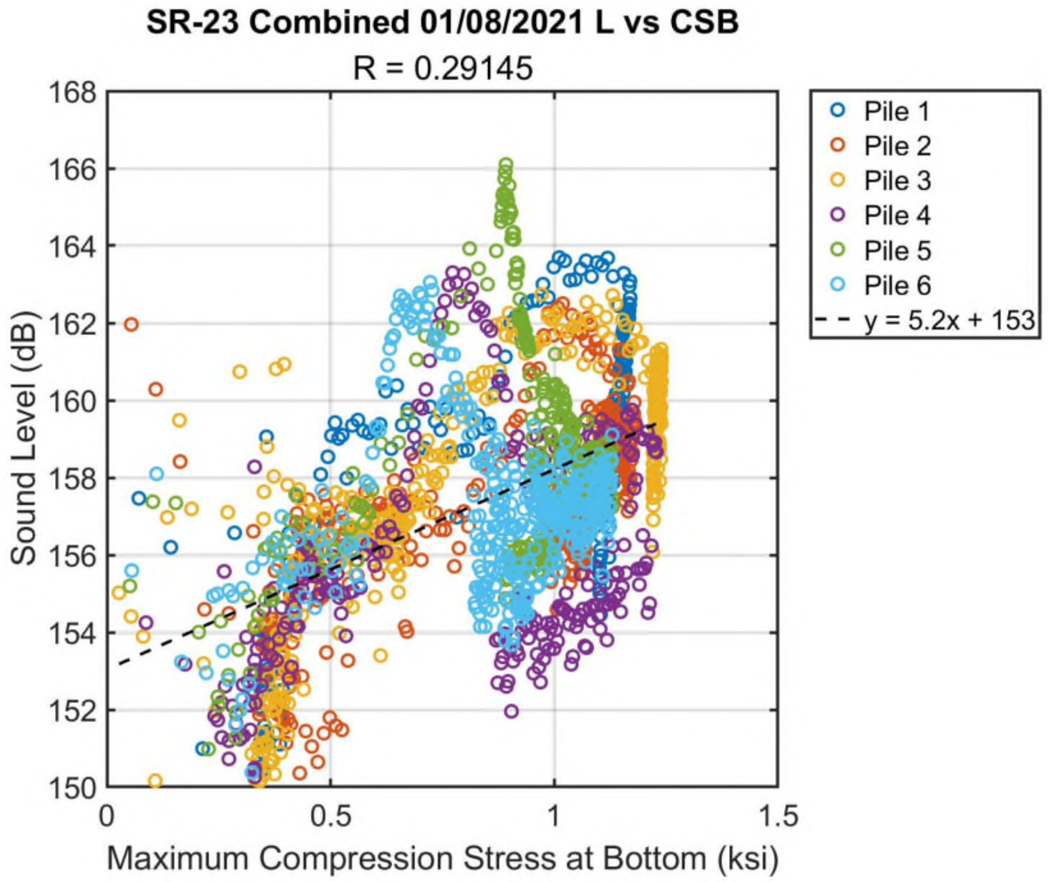


Correlation Between Sound-Level and CSB at SR-23 on 1/21/2021

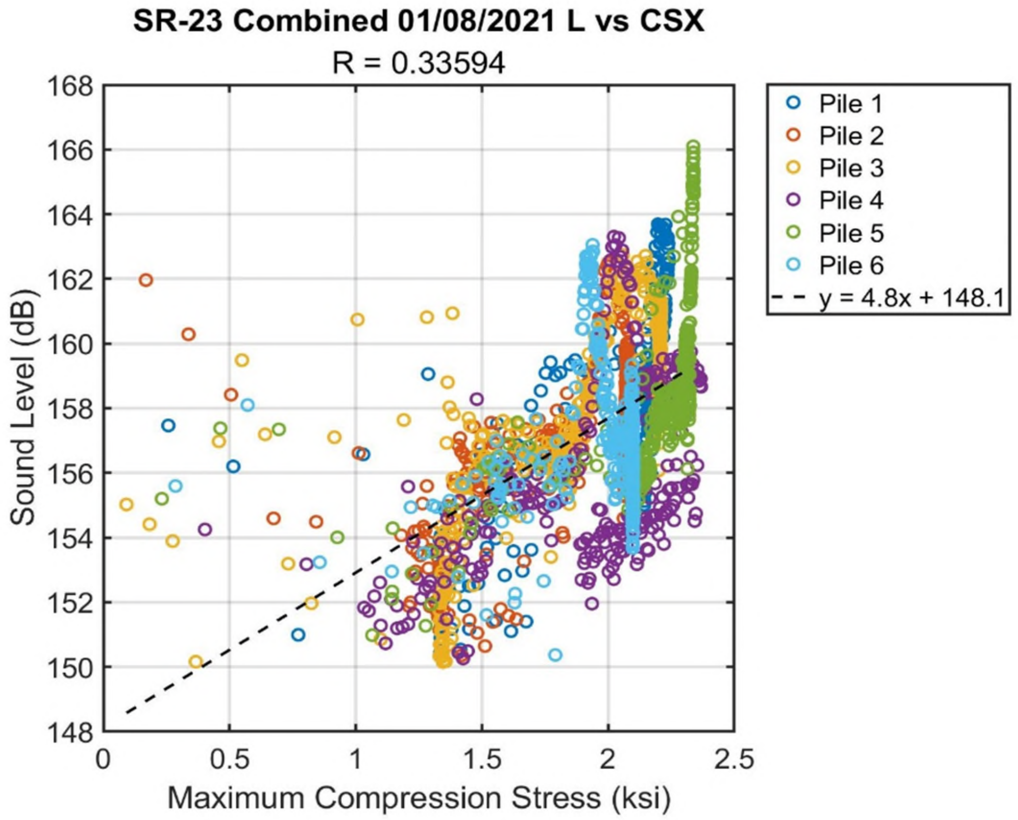


Correlation Between Sound-Level and CSX at SR-23 on 1/21/2021

PDA Data



Correlation Between Sound-Level and CSB at SR-23 on 1/8/2021



Correlation Between Sound-Level and CSX at SR-23 on 1/8/2021

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Ongoing Work

PDA Data

- Each strike is a unique signal that will decay
- $L_r = b - a\log_{10}\left(\frac{R}{R_0}\right)$
- Can *b* and *a* be correlated to PDA data?

Modeling TL

- Data show similar decay curves in each octave band. Can model be improved by including a frequency component, and might this mean a universal model for all pile-types?

Upcoming Drive Sites

- Manatee River Bridge (D1, ongoing)
- North Causeway Bridge (D4, early 2023)
- Broward River Bridge (D2, September 2022)
- Jupiter Inlet Bridge (D4, ongoing, will return fall of 2022)
- Brooks Bridge (D3)
- Anna Maria Bridge (D1)

Thank you!