Sidescan Sonar Imaging of Underwater Targets with Different Geometries and Reflectivity

Midshipman 1/C Will Schabacker, USN, Class of 2024

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The backscatter of sound off bottom-mounted objects is a function of factors like object geometry, aspect, and surface and material properties. In this study sponsored by the U.S. Naval Research Laboratory, a series of custom acoustic targets were deployed on the bottom of the Severn River to determine how aspect, object geometry and surface material properties and roughness affect the detectability of underwater bottom-mounted objects using a dual-frequency Klein S4900 sidescan scan sonar (SSS) system.

Study Area and Methods

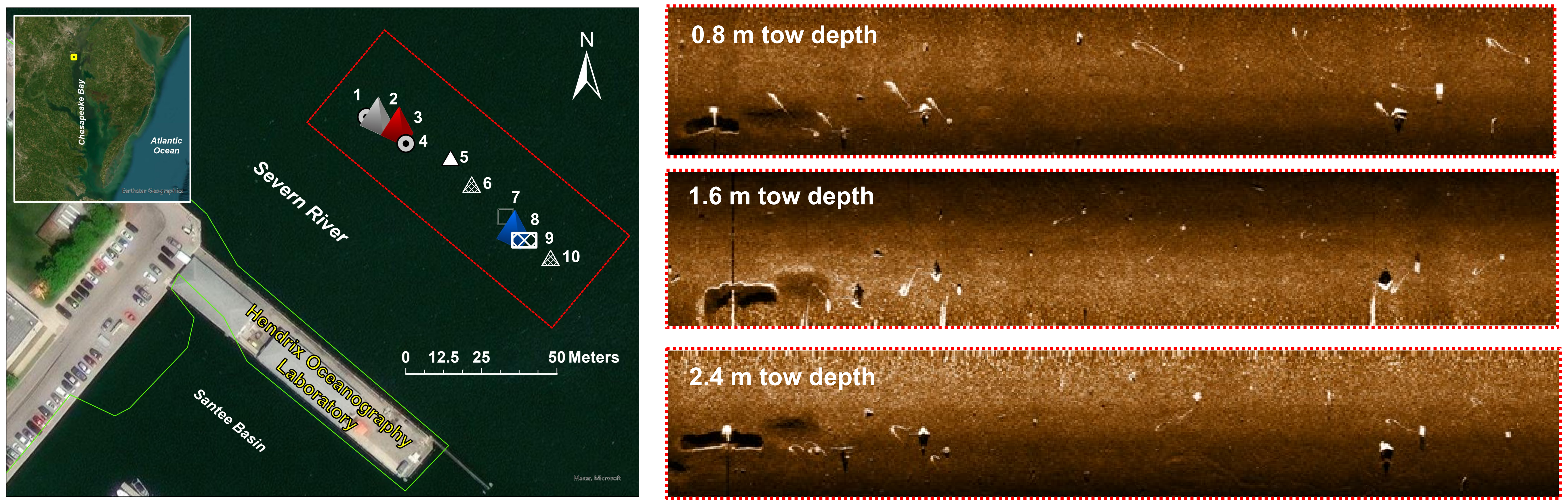


Figure 1. Map of study area at the U.S. Naval Academy (USNA) Hendrix Oceanography Lab pier, Annapolis, MD showing underwater target deployment. On 21 February 2024, 10 targets were deployed in the following order: 1 - cement control; 2 - Al-frame pyramid w/ bare Al sheet; 3 - Al-frame pyramid w/ Al sheet and Al mesh; 4 - cement control; 5 – 18" pyramid crab pot w/ silicone blanket; 6 - 18" pyramid crab pot; 7 - 36"x36" PVC frame; 8 - Al-frame pyramid w/ Al sheet and foam; 9 - 36"x24" crab pot and; 10 - 8" pyramid crab pot. The targets chosen for analysis were targets 1, 2, 3, 4, and 8. Targets were imaged during three separate surveys using a dual-frequency 455 kHz/900 kHz Klein S4900 sidescan sonar.

On the morning of 21 February 2024, a series of underwater targets were deployed off the Hendrix Oceanography Lab (HOL) pier (**Fig. 1**). The targets evaluated in this study were two 0.5 m diameter cement controls, and a series of three custom-built, 4-faced Al-frame pyramids with a 0.9 m x 0.9 m base and a roughly 0.7 m height. All pyramid targets were covered in 3 mm Al sheet. One target was left bare, one was covered with 10 x 10, 2 mm opening Al-wire cloth (www.mcmaster.com), and the other was covered in 255 mm thick, water resistant 35% sound absorbing polypropylene foam (www.mcmaster.com) (**Fig. 2a**). Targets were deployed near low tide in a line along a flat silty-sand bottom (*Archambault, Craft, and Schatz, 2023*) in a water depth of ~ 5.5 m (**Fig. *1***; **Fig. 2b**). A *Sontek CastAway CTD* (www.ysi.com/castaway-ctd) was used to collect a sound velocity profile which showed an average water column sound velocity of 1442 m/s. A dual frequency (455 kHz/900 kHz) *Klein S4900* SSS (www.kleinmarinesystems.com/product/system-4900) was deployed off a small boat (**Fig. 2c**) and used to conduct a series of survey tows over the targets at deployment (tow) depths of: 0.8 m, 1.6 m, and 2.4 m. Sidescan sonar data was exported as an .xtf file that was processed into imagery using *SonarTRX v.21* software (www.sonartrx.com/). **Figure 1** shows the three right beam images (900 kHz) (one from each tow depth) that were used in this study. Low-frequency (455 kHz) backscatter intensity values were extracted from recorded .xtf files using *SONAR2MAT* software (*Parnum et al., 2015*) and analyzed using *MATLAB R2023b*.

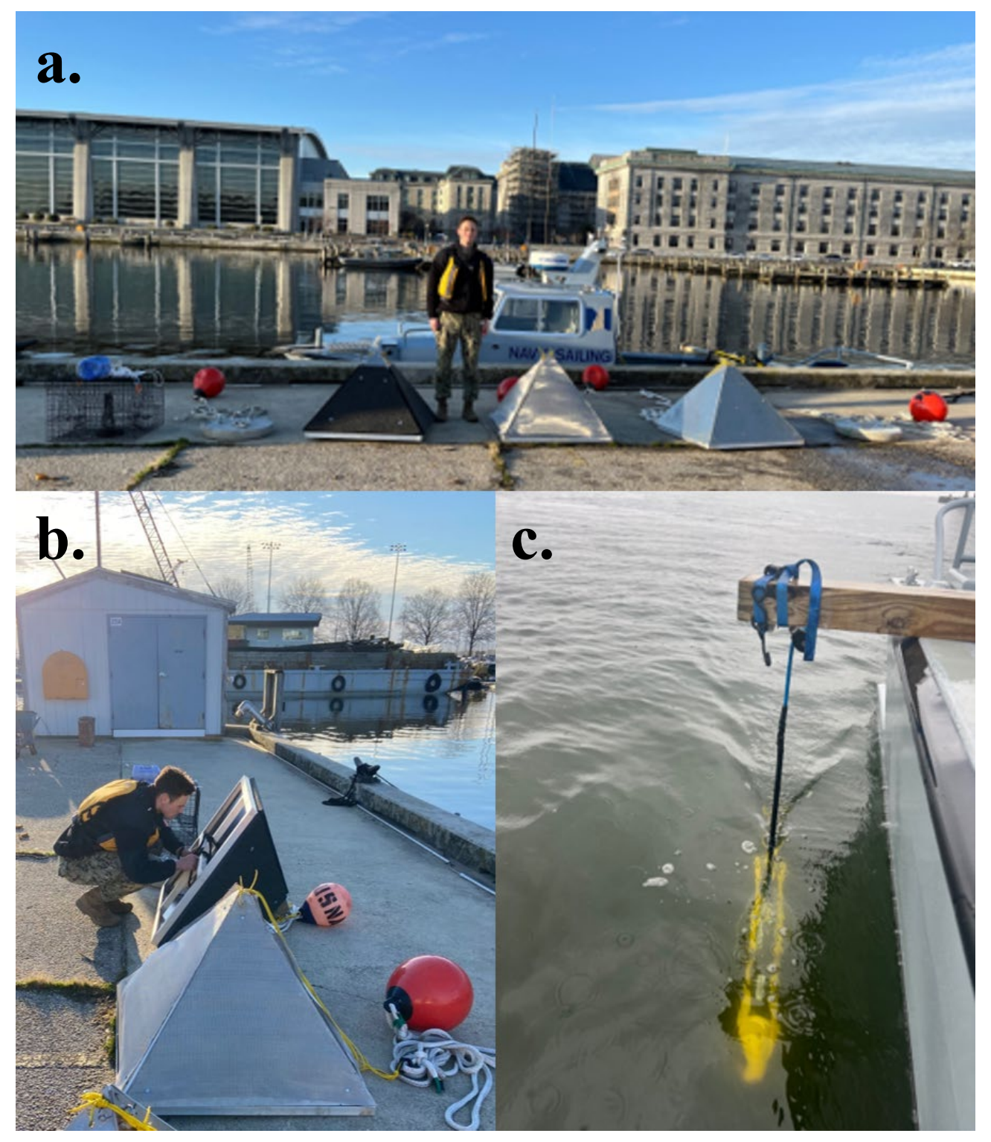
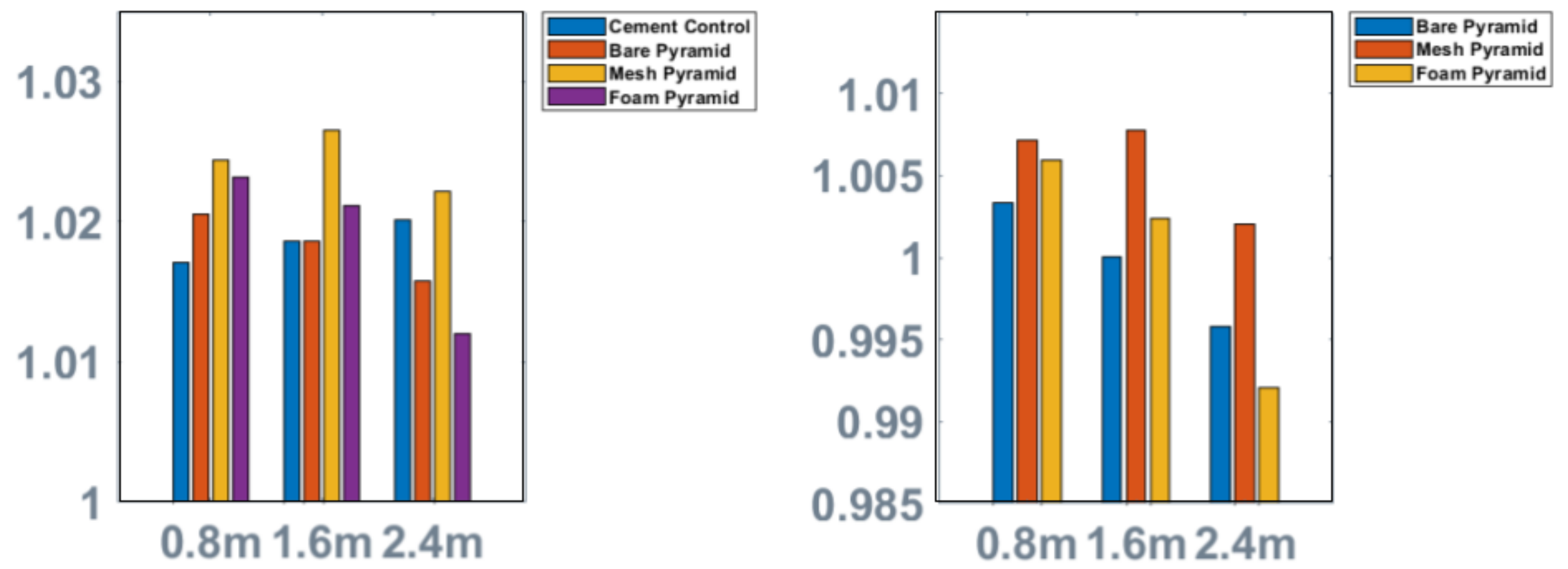


Figure 2. (**a**) Midshipman 1/C Will Schabacker with targets including the cement controls and the Al-frame pyramids; (**b**) Getting targets ready for deployment and; (**c**) the Klein S4900 dual-frequency sidescan sonar deployed.

Results and Discussion

Figure 3. (*to the right*) Average BSA$_{max}$/BSA$_{bkg}$ for the three targets and cement control, shown at the three sampling depths and (*far right*) average BSA$_{max}$/BSA$_{bkg}$ normalized to BSA$_{control}$ at the three different tow depths.

Table 1. (*below*) Four-by-three matrix of images of the Bare Al Pyramid, Al Pyramid w/ Al Mesh, and Al Pyramid w/ Foam targets and cement controls at the tow depths (0.8, 1.6, and 2.4 m). The ratio of maximum target backscatter amplitude (BSA$_{max}$) to background backscatter amplitude (BSA$_{bkg}$) is shown graphically below the target images.



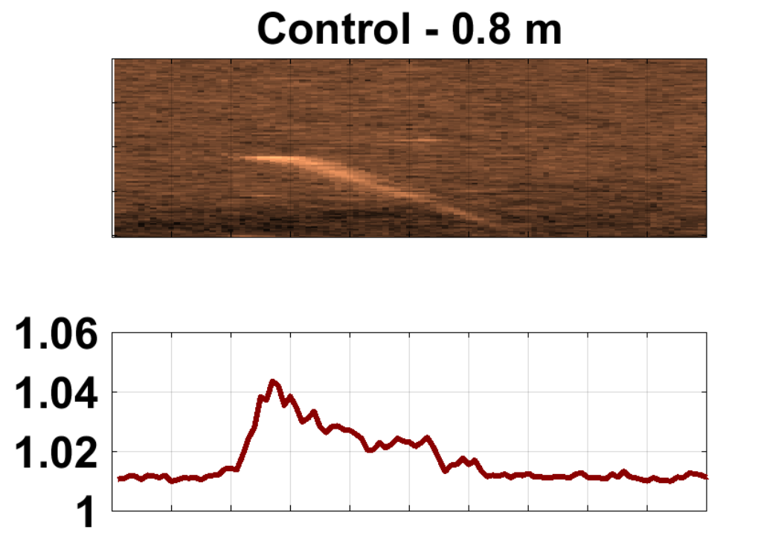
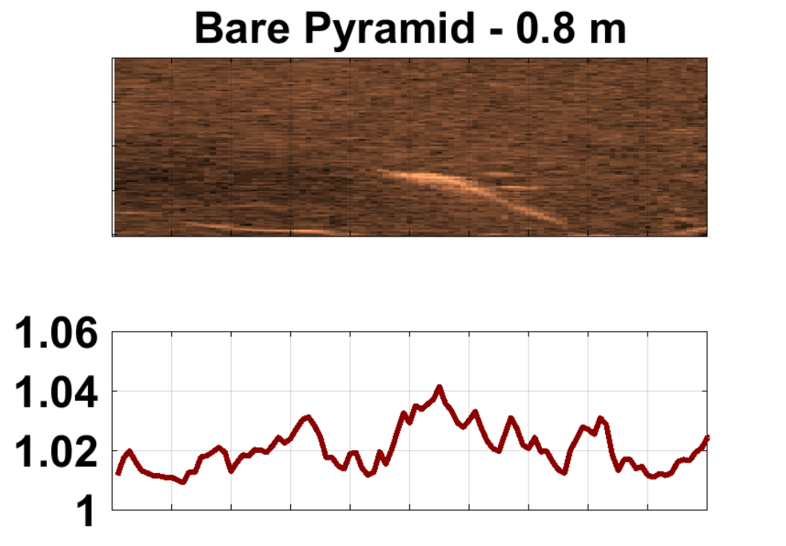
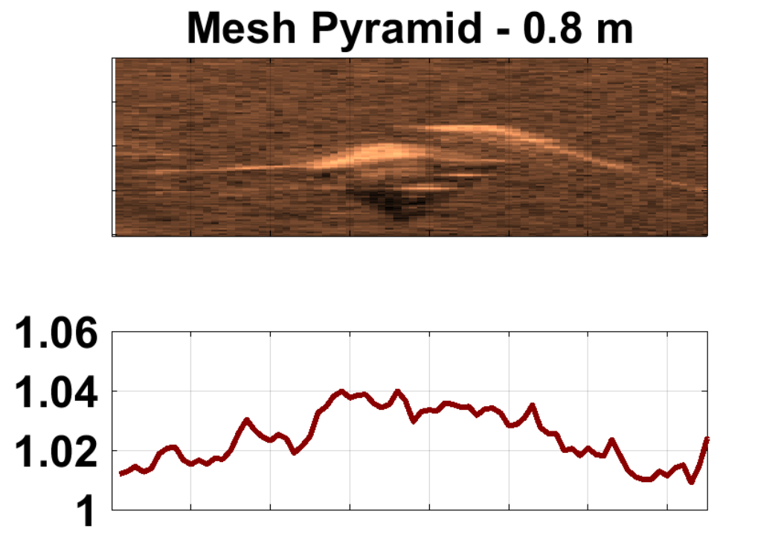
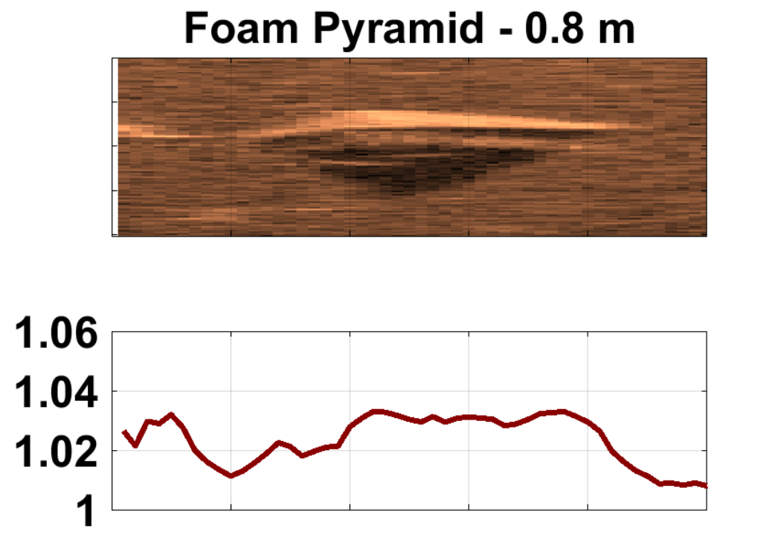
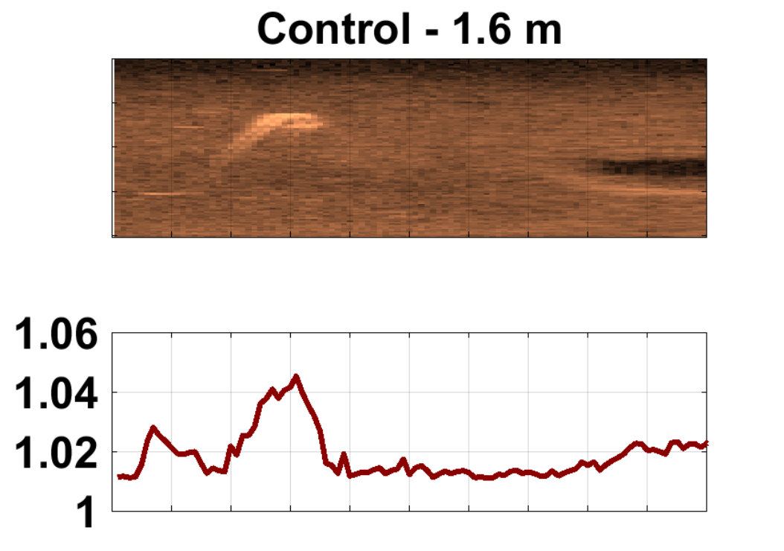
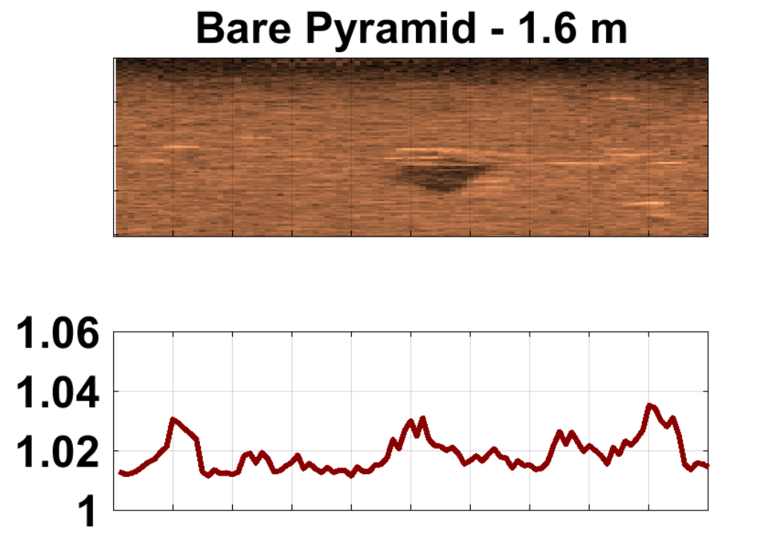
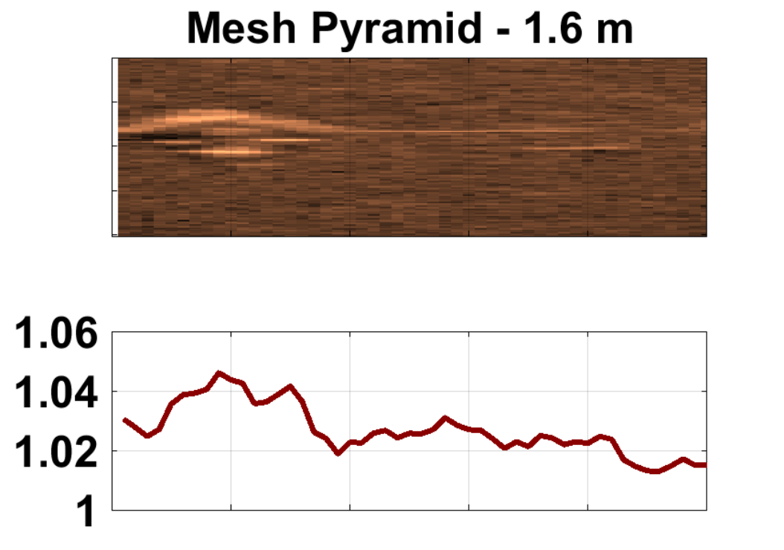
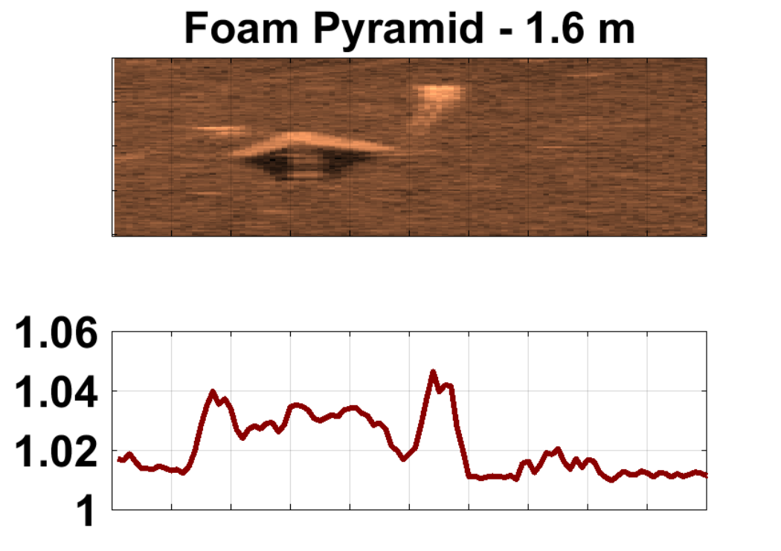
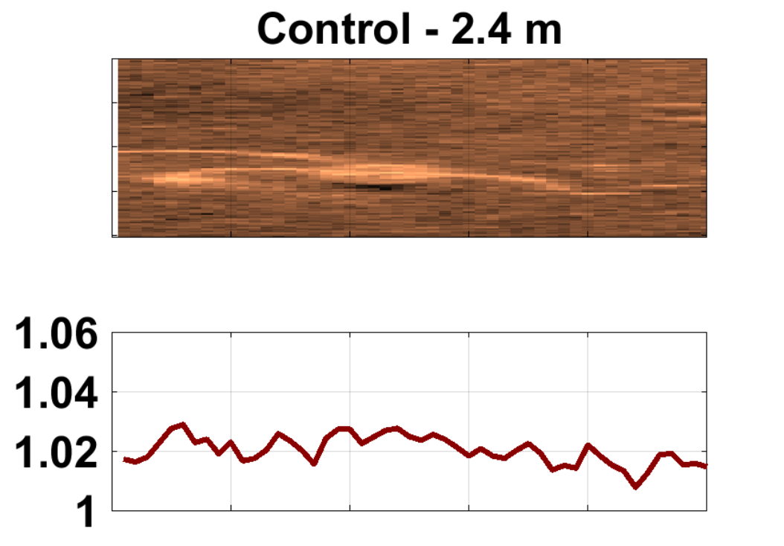
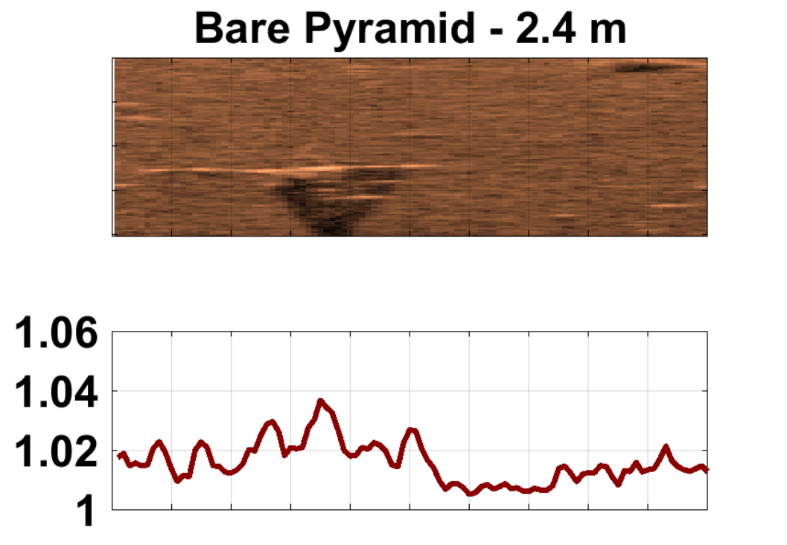
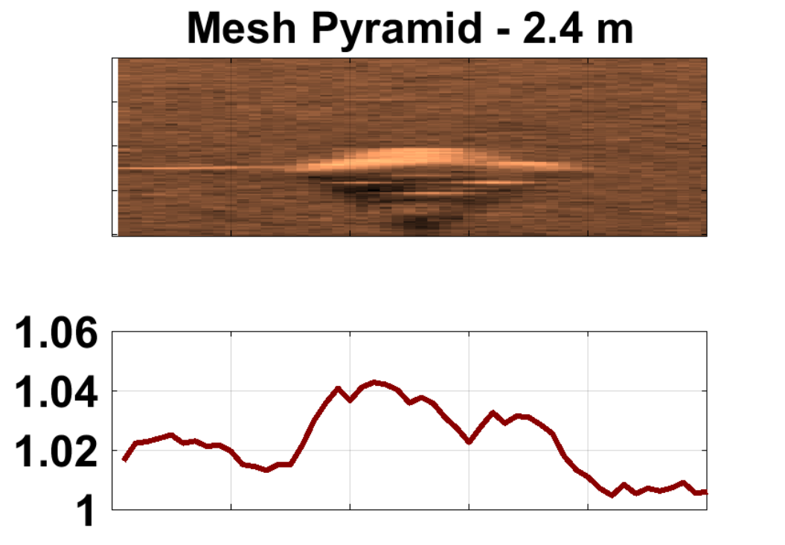
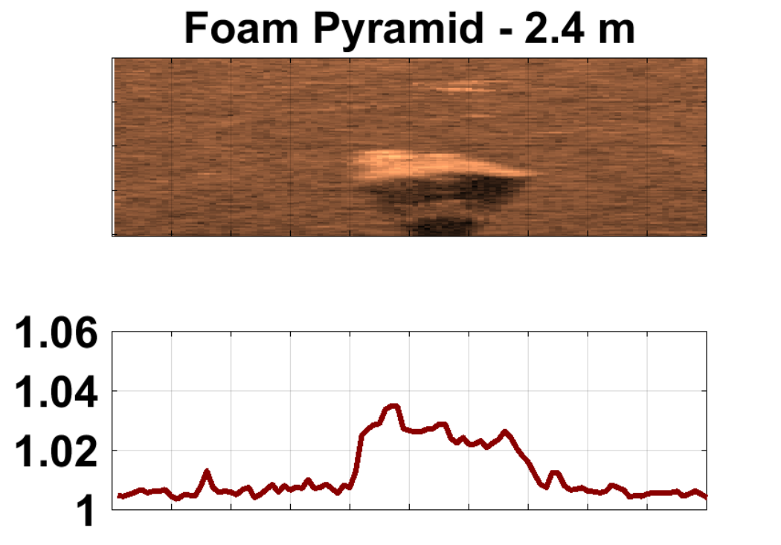
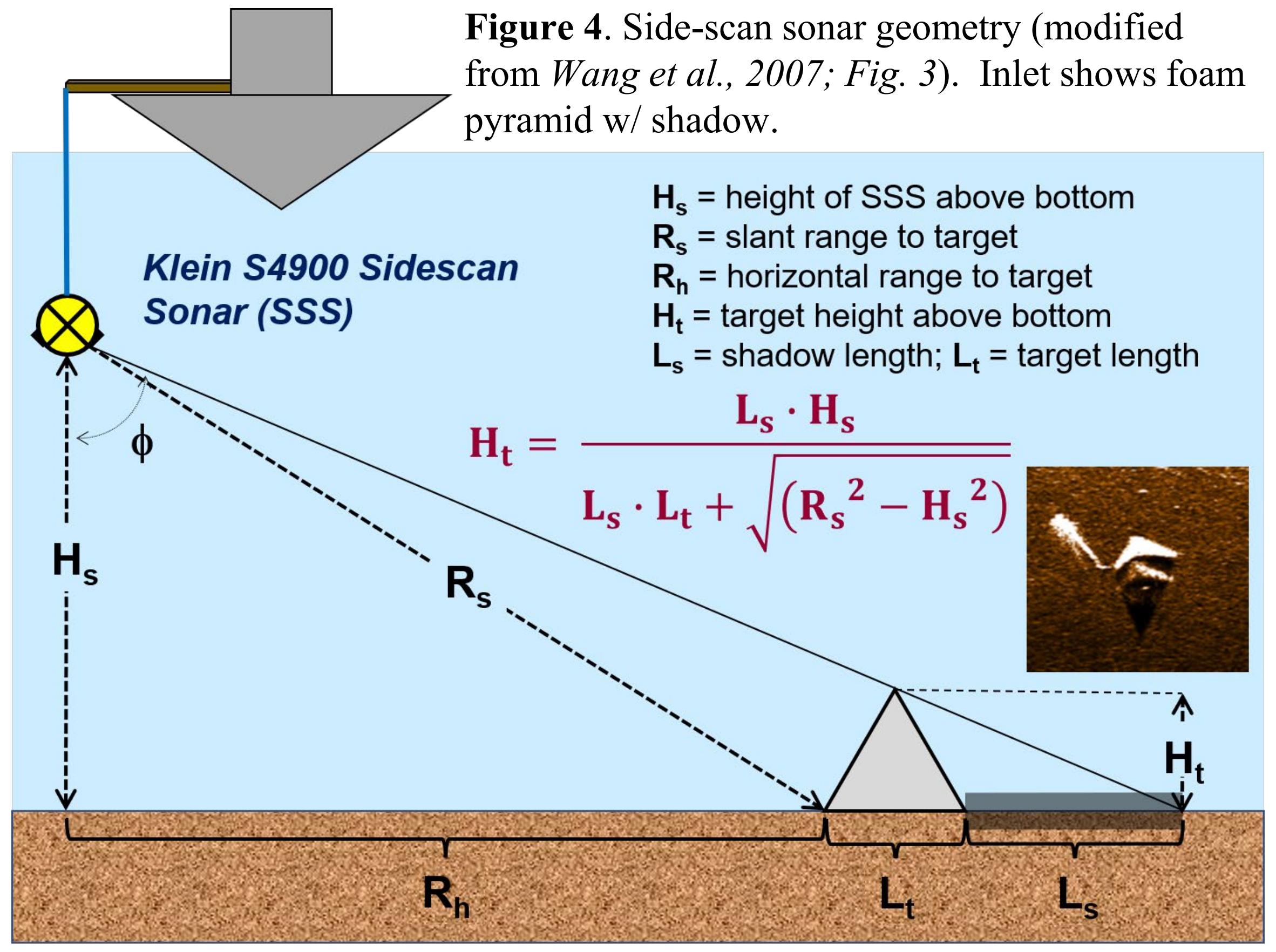
	Cement Control	***Bare Al Pyramid***	***Al Pyramid w/ Al Mesh***	***Al Pyramid w/ Foam***
0.8 m Tow Depth				
1.6 m Tow Depth				
2.4 m Tow Depth				

Table 2. Target shadow height calculations (*Wang et al., 2017*; **Fig. 4**) for the Al Pyramid w/ Al Mesh, and Al Pyramid w/ Foam targets. The Al Pyramid w/ Al Mesh, and Al Pyramid w/ Foam targets produced the best shadows for target height estimation. The Al-frame pyramid height is ~ 0.7 m. In order to estimate target height above bottom (H_t), the height of the SSS above the bottom (H_s) was estimated as a water column height (depth) of 5.5 m minus the tow depth corrected for a 20° tow cable angle at a boat speed of 1-2 m/s. The slant range to target (R_s), horizontal range to target (R_h), shadow length (L_s), and target length (L_t) were manually determined from processed high resolution imagery (**Fig. 1**) using *SonarTRX v.21*.

	H_s (m)	R_s (m)	R_h (m)	L_s (m)	L_t (m)	H_t (m)
Mesh Pyramid (0.8 m)	4.8	13.0	12.9	1.7	0.5	0.56
Mesh Pyramid (1.6 m)	4.0	8.5	8.3	1.2	0.4	0.53
Mesh Pyramid (2.4 m)	3.2	10.7	10.4	2.0	0.6	0.51
Foam Pyramid (0.8 m)	4.8	13.3	13.3	2.1	0.3	0.67
Foam Pyramid (1.6 m)	4.0	7.9	7.7	1.2	0.4	0.57
Foam Pyramid (2.4 m)	3.2	12.0	11.7	2.3	0.6	0.52

Figure 4. Side-scan sonar geometry (modified from *Wang et al., 2007; Fig. 3*). Inlet shows foam pyramid w/ shadow.



H_s = height of SSS above bottom
R_s = slant range to target
R_h = horizontal range to target
H_t = target height above bottom
L_s = shadow length; L_t = target length

$$H_t = \frac{L_s \cdot H_s}{L_s \cdot L_t + \sqrt{\left(R_s^{\,2} - H_s^{\,2}\right)}}$$

Table 1 shows closeup images of each Al pyramid and the cement controls at the three tow depths and plots of BSA for each target. The plot is a unitless ratio of the backscatter laterally across the image (BSA$_{max}$) to an average backscatter value from the background (BSA$_{bkg}$). Foreign objects other than the targets artificially raise BSA. In some cases, like the cement control at 2.4 m and the mesh pyramid at 0.8 m, it was not possible to crop out all of the foreign objects without losing some of the target as well. Those images do not have distinct peaks in BSA like some of the others. The BSA$_{max}$/BSA$_{bkg}$ value is highest for the Al Pyramids w/ Mesh at all tow depths. Backscatter amplitudes for the Al Pyramid w/ Foam were higher than the Bare Al Pyramid in all but the 2.4 m tow, when the Bare Al Pyramid return was higher (**Fig. 3**). It was challenging to draw distinct conclusions from these results. *Quinn et al. (2005)* detailed challenges similar to the ones faced in this study while surveying submerged archaeological material including distortions from the digitization of the incoming signal. Additionally, when objects are imaged out of context, they cannot be distinguished. In **Table 1**, there is no way to tell which pyramid is which without comparing BSAs. When the background is cluttered with other debris (such as nylon ropes used for target deployment) or targets are spaced close together, they are even harder to distinguish. One clear way of identifying targets with a vertical height off the bottom is by the acoustic shadow. *Wang et al (2007)* demonstrated a model to determine target height from shadow length that was used to estimate the height of target pyramids in this study (**Table 2; Fig. 4**). The mean calculated height was 0.56 m +/- 0.06 m as compared to an actual height of 0.7 m (not accounting for the target sinking into the bottom). This shows that shadow length is an effective method of identifying objects with a vertical height off the bottom.

- ***Factors such as aspect, object geometry, and surface material properties and roughness as well as background environment complicate the detection of underwater bottom-mounted objects using SSS***
- ***Acoustic shadow is an effective method of identifying objects with a vertical height off the bottom***

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