

Study of Multiaspect and Multistatic Sonar Systems Using a Small-Scale Test Bed

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LONG-TERM GOALS

With the advancement of navigational systems for autonomous underwater vehicles (AUVs), additional geometries can be considered for synthetic aperture sonar (SAS) and similar line-scan target-scattering analysis techniques. Since SAS signal processing requires that the relationship between the source and receiver be known or corrected to within a fraction of a wavelength, at-sea multistatic SAS is difficult. Until this navigational precision is achieved, these additional geometries can be studied on a reduced scale using precise positioning systems. Given the relative ease of target placement, scaled experiments are ideal for studying the use of multistatic systems for detection and classification of buried targets. The goal of this project is to design and build a test tank at the Naval Surface Warfare Center – Panama City Division (NSWC PCD) and use it to investigate sonar scattering configurations at roughly a scale of 1:50. In addition to studying the impact of multistatic geometries, the data collected will be used to validate finite-element (FE) model simulations, investigate features for automated classification algorithms, test new data processing algorithms for isolating target signals, and investigate target physics.

OBJECTIVES

The objective of the second year of this three-year project is to enable and test the use of the small-scale test bed (SSTB) to study scattering by targets proud on the scaled sediment developed in FY09. Once having verified this capability, multistatic measurements of scattering by simple scaled metallic targets will be performed and analyzed.

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APPROACH

Although the scaled sediment had not yet been added to the tank setup, at the start of FY10, construction of the small-scale test bed had reached a point where initial free-field target scattering tests could be performed. Figure 1 shows a SAS image of multiple targets suspended in the free-field. The results of these measurements, conducted by Malvosio et al. [1], were promising; however, subsequent measurements on proud targets exhibited a significantly lower signal-to-noise ratio (SNR) than expected and revealed a data acquisition card (DAC) hardware incompatibility that prevented reliable data collection.

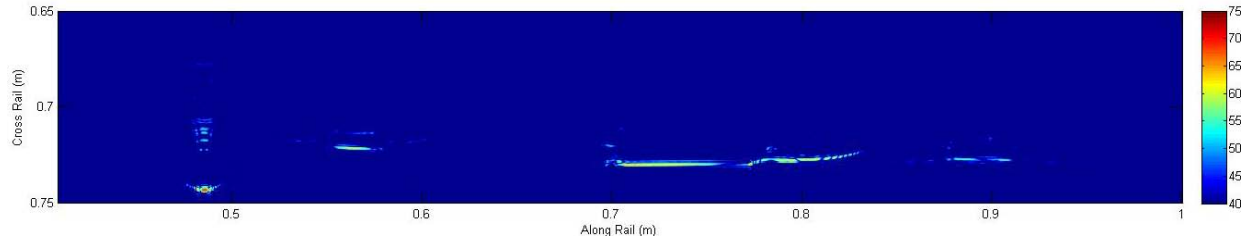


Figure 1: Monostatic synthetic aperture sonar (SAS) image of multiple free-field metallic targets. From left to right the targets are: a solid sphere, open-ended cylindrical shell, bullet-shaped cylinder and a larger open-ended cylindrical shell.

Several hardware, experimental setup, and signal-processing changes were needed to enable and optimize proud-target multistatic scattering measurements. Steps were taken to resolve the DAC computer compatibility problem. Electronic noise was further reduced by re-grounding the equipment and improving the received-signal cables. Changes were made to the source, source-receiver geometries and signal-processing techniques that also resulted in significant SNR improvements. A fast time-domain SAS beamforming algorithm was implemented that reduced processing time significantly.

Additionally, an existing water degassing system design [2] needed to be modified and installed to reduce the amount of dissolved gas in the water tank. The now completed system is capable of producing a 36% reduction (from equilibrium) in the level of dissolved oxygen in less than eight hours. Reducing the level of dissolved gas in the water above reduces gas bubbles trapped in the scaled sediment by causing them to dissolve into solution, mitigating the effects of bubble scattering on proud and buried-target scattering data. Low dissolved gas levels will also make the water more resistant to cavitation at the focus of the broad-beam ultrasonic transducers [2], permitting them to be driven at higher amplitudes.

Once sufficient SNR was achieved for proud-target experiments and the DAC problem was resolved, two multistatic test configurations were devised and tested. Experiments were conducted that demonstrate use of these configurations to study multistatic scattering by proud-targets on the scaled sediment. Tests also demonstrate application of multistatic SAS imaging techniques to proud-target scattering data collected in the SSTB facility.

WORK COMPLETED

Much work was completed to make the system fully operational for use in proud-target scattering measurements. This work included:

1. Resolving the data acquisition system problem
2. Additional control software development
3. Target fabrication
4. Placement of 4000 lbs of scaled sediment on the bottom of the water tank
5. Further reduction of instrumentation noise through hardware modifications
6. Development of replica acquisition techniques for pulse compression of long-pulse linear frequency-modulated chirps
7. Fabrication and implementation of a fixed-source multistatic setup
8. Implementation of a fast multistatic time-domain beam-forming algorithm for SAS
9. Design, fabrication and implementation of the water degassing system

Diagnosis and resolution of the data-acquisition problem was both difficult and time-intensive because the control computer would crash unpredictably during extended data collection runs. The data acquisition card (DAC) was tested in multiple computers and similar behavior was observed. In the end, discussions with the hardware manufacturer revealed an unexplained computer incompatibility that was resolved with the purchase of a particular computer system guaranteed to work by the manufacturer.

Design and fabrication of the water degassing system required modification of an existing design [2], shown to be effective for degassing an 80 liter tank, to adequately degas the relatively large volume of water (approximately 7000 liters) in the SSTB. The completed system can achieve the targeted level of dissolved gas in less than 5 hours.

Multistatic proud-target scattering measurements for two system configurations were made on the following solid metallic scaled targets: a stainless-steel sphere and a 45° aluminum cone. The multistatic side-scattering configuration (MSSC) is shown in Figures 2 and 3. The location of the narrow beamwidth (nominally 3°) source (black) is fixed and the two receivers (red) are scanned along parallel lines (green). MSSC time-series data and SAS images are shown for the proud 12.7 mm diameter solid stainless-steel sphere and the solid 45° aluminum cone in Figures 4 and 5, respectively, where the SAS image coordinate system is shown in relation to the rails in Figure 6. Bright features (circled in black) in the cone scattering SAS images, Figure 5, are attributed to bright time-domain features (yellow arrows) in the negative receiver position portion of the data; as the receiver position is decreased from zero to the negative limit, scattering angles approach the forward-scattering direction.

The bistatic/monostatic quasi-forward scattering configuration (BFC) is shown in Figures 7 and 8. The rail-B source/receiver (red) is scanned while the rail-A receiver (black) is held fixed at the receiver position of closest approach to the target. This configuration permits acquisition of bistatic quasi-forward scattering and monostatic scattering data during one scan. BFC time-series data and the

corresponding monostatic SAS images for the stainless-steel sphere, the aluminum cone and a solid stainless-steel cylinder are shown in Figures 9, 10 and 11 respectively. Quasi-forward scattering data for the three different targets is dominated by non-target related signals. This time-domain data is qualitatively similar for all three targets, containing a direct source-receiver path and a one-bounce source-receiver path. Target scattering data is present; however, further analysis is needed to differentiate it from the one-bounce data.

RESULTS

Efforts in FY10 have demonstrated that the small scale test bed is fully operational for use in proud-target scattering measurements using scaled sediment. The data shown in Figures 4, 5, 9, 10, and 11 demonstrate two multistatic system configurations that can be used to study a broad range of scattering angles in addition to monostatic scattering. These configurations can now be used to test and evaluate analysis techniques that include imaging and spectral response methods for monostatic and a range of side and quasi-forward scattering angles. Cone scattering data in Figure 5 demonstrate that, for the particular source-target geometry used, bistatic scattering is strongest for scattering angles nearest the forward scattering direction. While not surprising, the dominance of forward scattering has rarely been considered in sonar detection schemes due to the difficulty in isolating the forward target response from reverberant bottom bounces of the source field. Nevertheless, due to the growing interest in fielding multiple sonar platforms operating cooperatively to increase search efficiency, others [3] have recently suggested revisiting this possibility. Numerous additional rail-source-receiver configurations are possible using the source-receiver combinations that have been verified in the present work.

Having the water degassing system fully operational will enable FY11 research on buried targets for ka (wavenumber-radius product) values ranging from $ka = 2.5$ to $ka > 50$. The validity of various multistatic configurations, including the two described above, for use in detection and classification of scaled buried targets can now be explored using this system.

IMPACT/APPLICATIONS

With the development of more sophisticated navigation and communication techniques, bistatic SAS on autonomous vehicles will become practical, and understanding the relationships between backscattered, forward-scattered, and multiaspect images will become increasingly important. The test bed developed here and the data taken over the next fiscal year will help determine its importance and drive new technologies. In addition, the test bed will be used to explore different approaches to gain target information from multistatic scattering data beyond imaging that could lead to improved classification techniques.

RELATED PROJECTS

This work is also synergistic with ONR supported scattering-physics and model-development research being carried out by R. Lim and D. Burnett at NSWC-PCD using T-matrix models and finite-element models of targets in realistic environments. Both of these efforts are funded under ONR321's Shallow-Water Autonomous Mine Sensing Initiative (SWAMSI) Program, which seeks to explore the advantages of bistatic and multistatic target detection/classification/identification approaches using sonar.

This work will also monitor ONR sponsored target scattering efforts such as research being conducted in evanescent detection of buried targets and feature sets for classification of underwater targets. The Strategic Environmental Research and Development Program (SERDP) is funding research efforts to evaluate bistatic/multistatic detection methods as well as new automated classification/identification methods based on sonar data for underwater Unexploded Ordnance (UXO) remediation. Leveraging data collection for these studies using controlled facilities like the scaled test bed is integral to their approach.

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- [1] P. C. Malvosio, J. S. Stroud, R. Lim, J. L. Lopes, B. R. Dzikowicz, “Small scale test bed for studying multiaspect and multistatic sonar systems,” *J. Acoust. Soc. Am.* **127**, p. 1748 (2010)
- [2] A. R. Kaiser, C. A. Cain, E. Y. Hwang, J. B. Fowlkes, and R. J. Jeffers, “A cost effective degassing system for use in ultrasonic measurements: The multiple pinhole degassing system,” *J. Acoust. Soc. Am.* **99**, 3857 (1996).
- [3] J. A. Bucaro, B. H. Houston, H. Simpson, L. R. Dragonette, L. Kraus, T. Yoder, “Exploiting forward scattering for detecting submerged proud/half-buried unexploded ordnance,” *J. Acoust. Soc. Am.* **126**, EL171-176 (2009).

PUBLICATIONS

P. C. Malvosio, J. S. Stroud, R. Lim, J. L. Lopes, B. R. Dzikowicz, “Small scale test bed for studying multiaspect and multistatic sonar systems,” *J. Acoust. Soc. Am.* **127**, p. 1748 (2010)

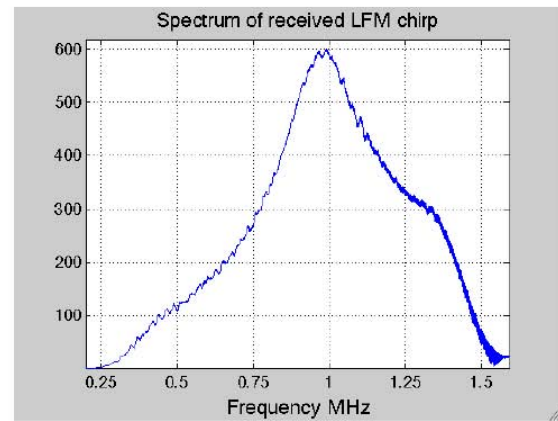
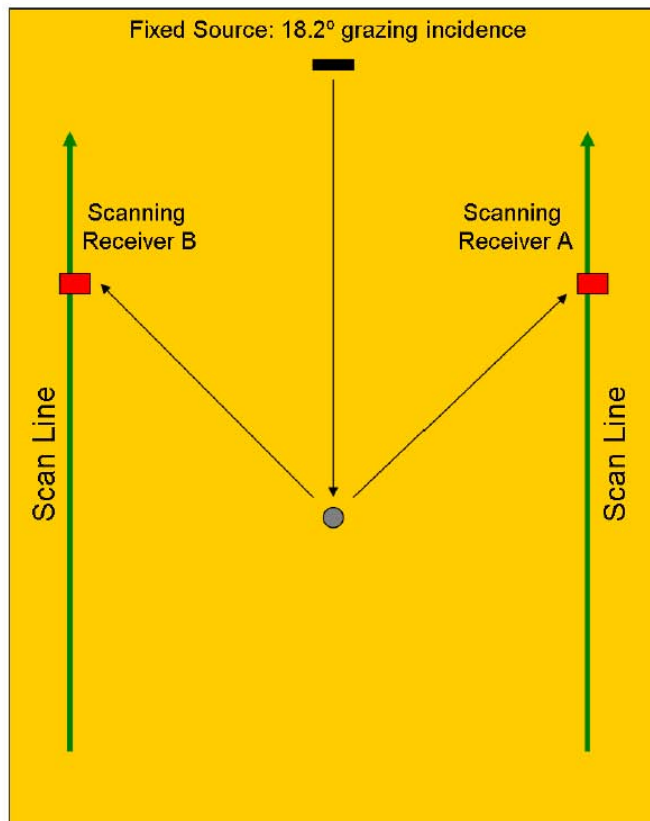


Figure 2: Multistatic side-scattering configuration (MSSC) as viewed from above (left panel), where the location of the narrow beamwidth source (black) is fixed and the two receivers (red) are scanned along parallel lines (green). 3" diameter ultrasonic transducer (upper right). MSSC system response (lower right).

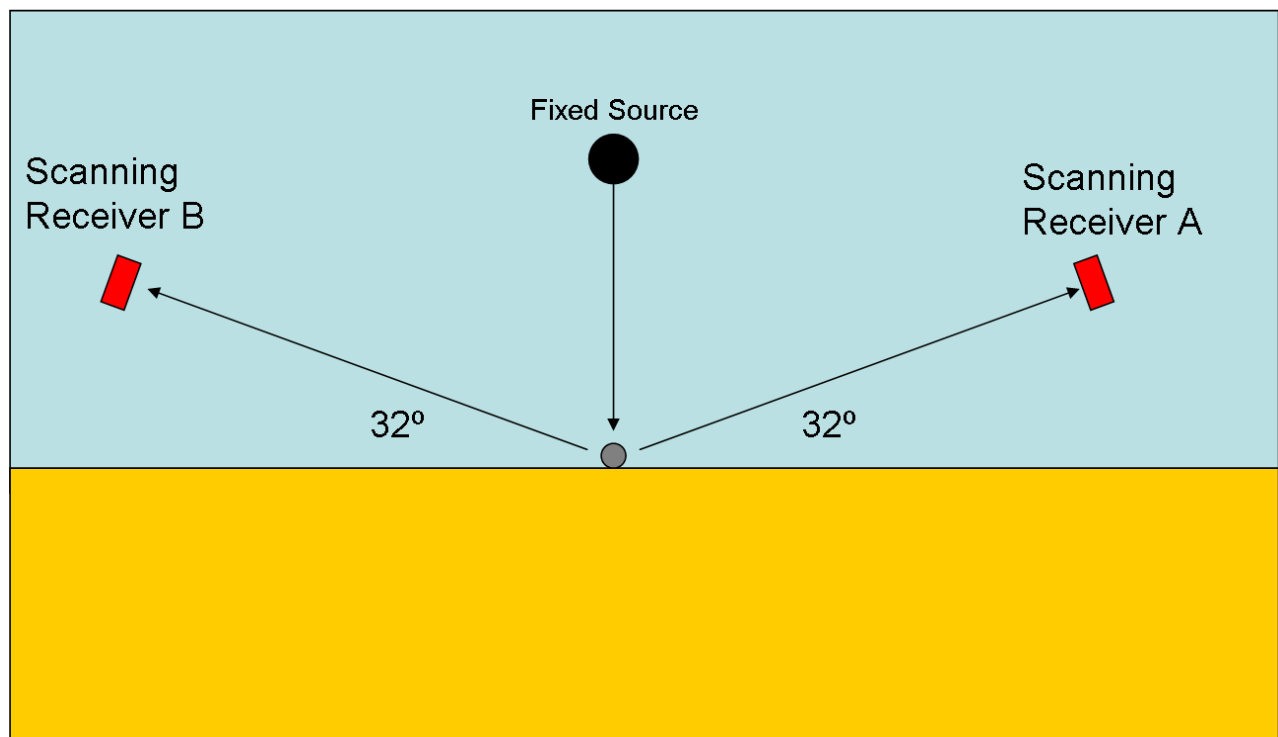


Figure 3: Multistatic side-scattering configuration as viewed along the scan-line, where the location of the narrow beamwidth source (black) is fixed and the two receivers (red) are scanned along parallel lines. A sphere (not to scale) is located in the proud-target position.

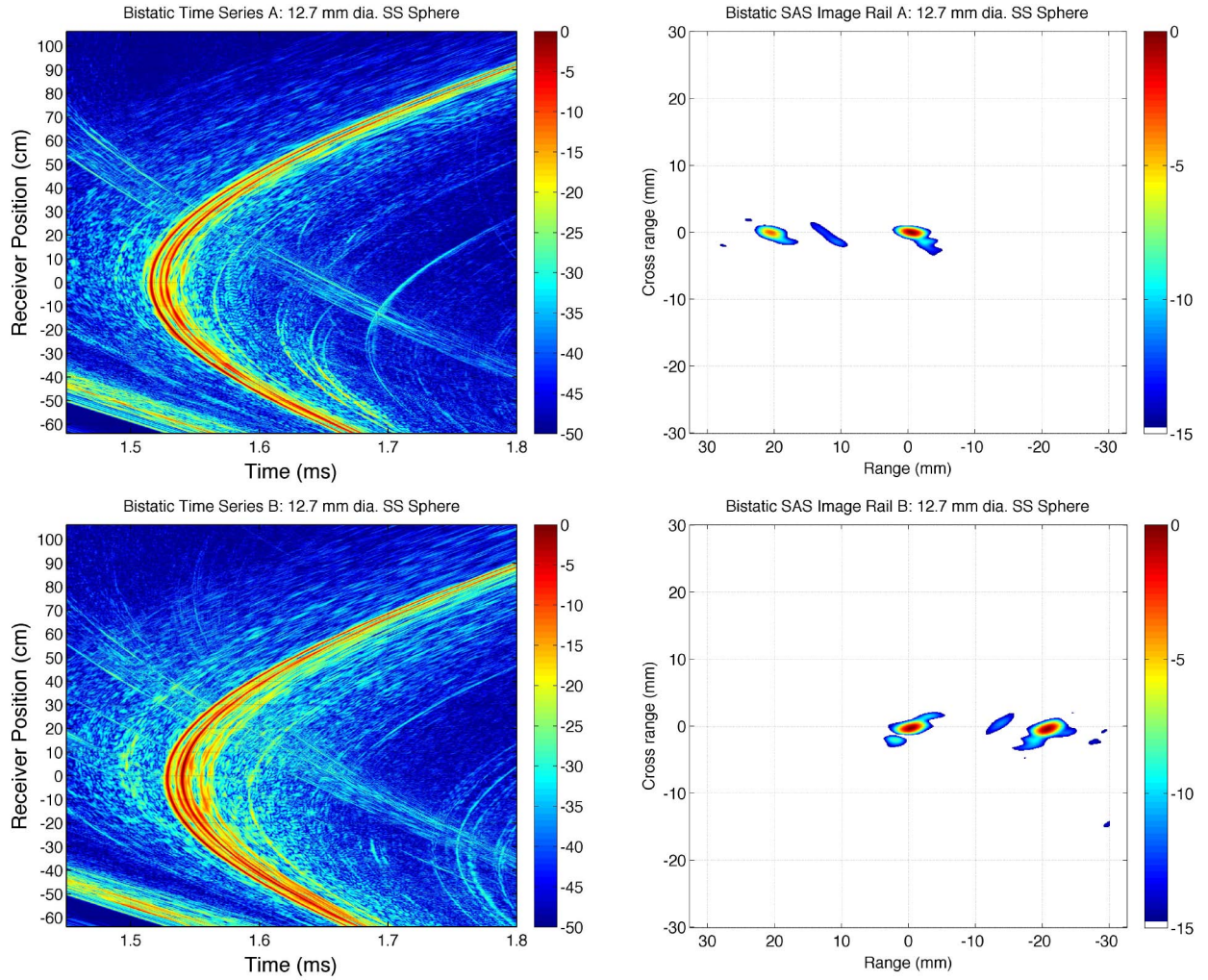


Figure 4: Multistatic side-scattering configuration results for the 12.7 mm diameter stainless-steel sphere. Bistatic time-series data recorded along rail A (upper left). SAS image for rail A (upper right). Bistatic time-series data recorded along rail B (lower left). SAS image for rail B (lower right). All data is displayed on a dB scale relative to the brightest pixel in each plot.

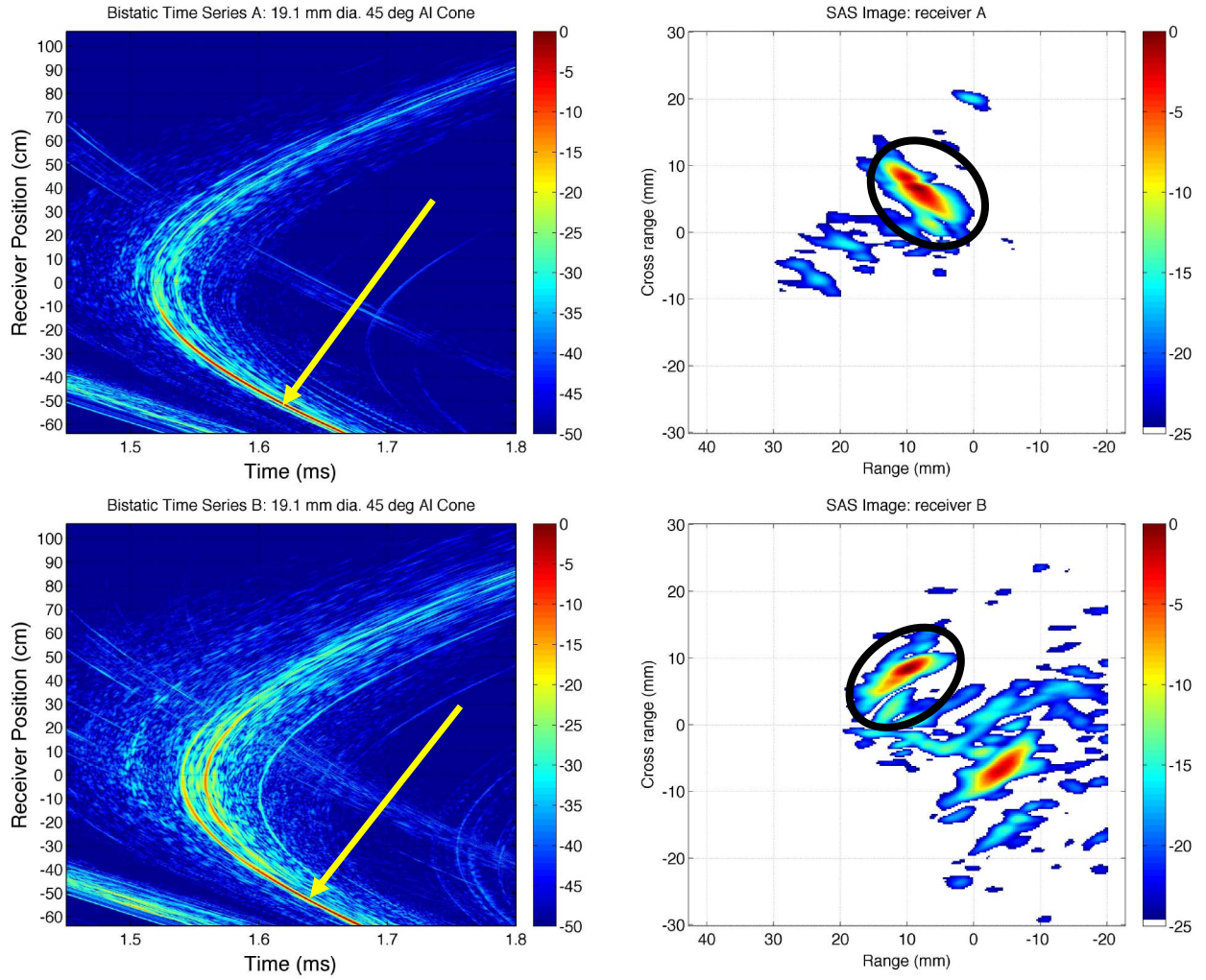


Figure 5: Multistatic side-scattering configuration results for the 19.1 mm base diameter, 45° solid aluminum cone. Bistatic time-series data recorded along rail A (upper left). SAS image for rail A (upper right). Bistatic time-series data recorded along rail B (lower left). SAS image for rail B (lower right). All data is displayed on a dB scale relative to the brightest pixel in each plot. The bright image features (circled in black) corresponding to bright time-domain arcs (yellow arrows) in the negative receiver position region are caused by a specular glint from the curved cone surface.

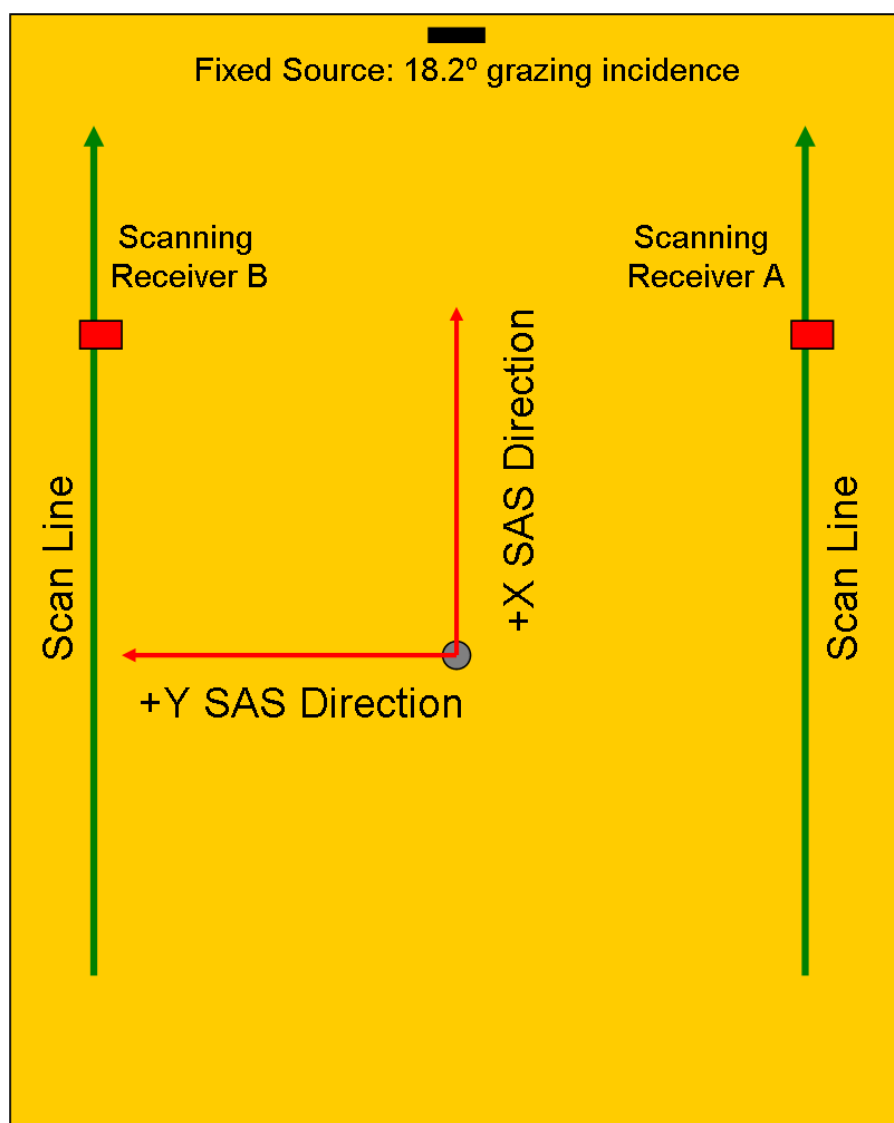
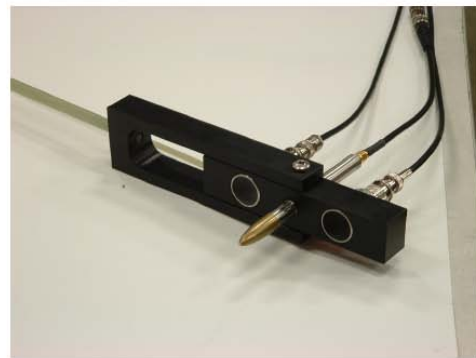
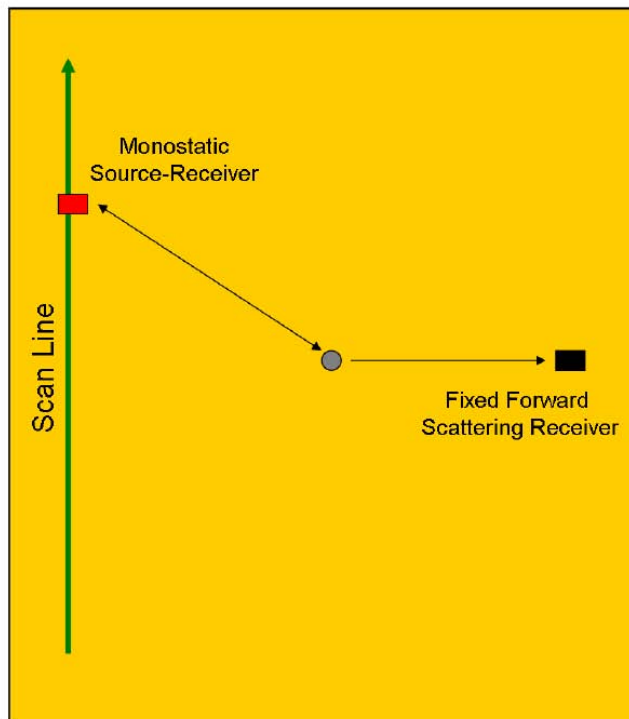


Figure 6: The SAS plane, which is located parallel to the sediment-water interface, bisects the target. Red arrows indicate the directions of coordinate axes. The coordinate system origin is located at the target center.



.75" diameter source and
needle-hydrophone receiver

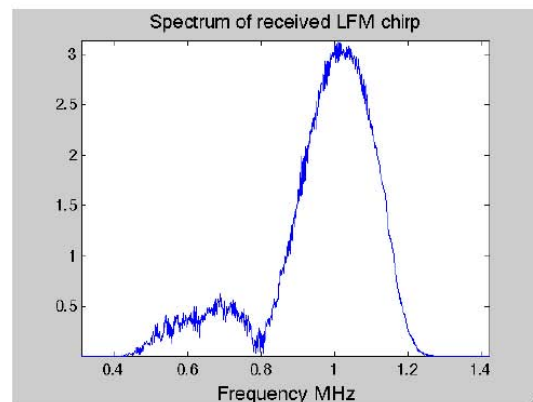


Figure 7: Bistatic/monostatic quasi-forward scattering configuration (BFC) as viewed from above (left), where the broad beam source/receiver (red) is scanned on rail B while the rail A receiver (black) is held fixed at the position of closest approach to the target. The source and needle-hydrophone receiver (upper right). BFC system response (lower right).

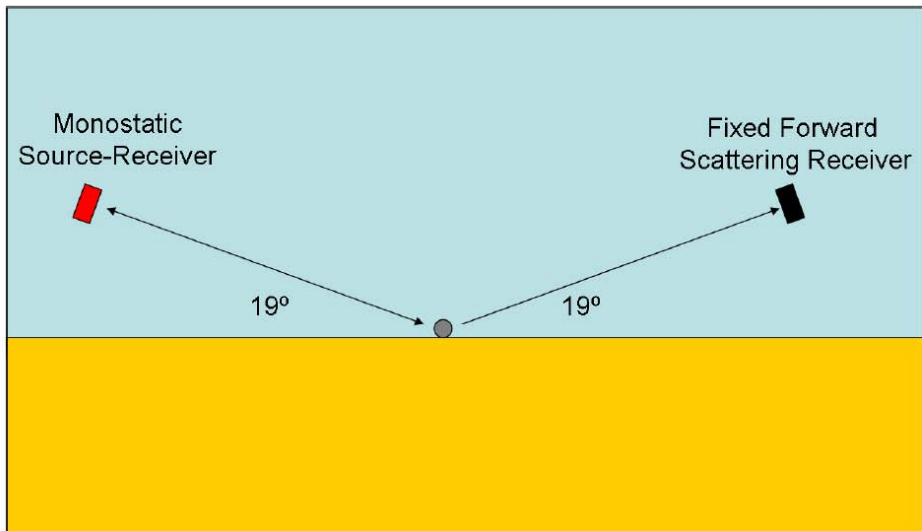


Figure 8: Bistatic/monostatic quasi-forward scattering configuration as viewed along the scan-line, where the broad beam source/receiver (red) is scanned on rail B while the rail-A receiver (black) is held fixed at the position of closest approach to the target. A sphere (not to scale) is located in the proud-target position.

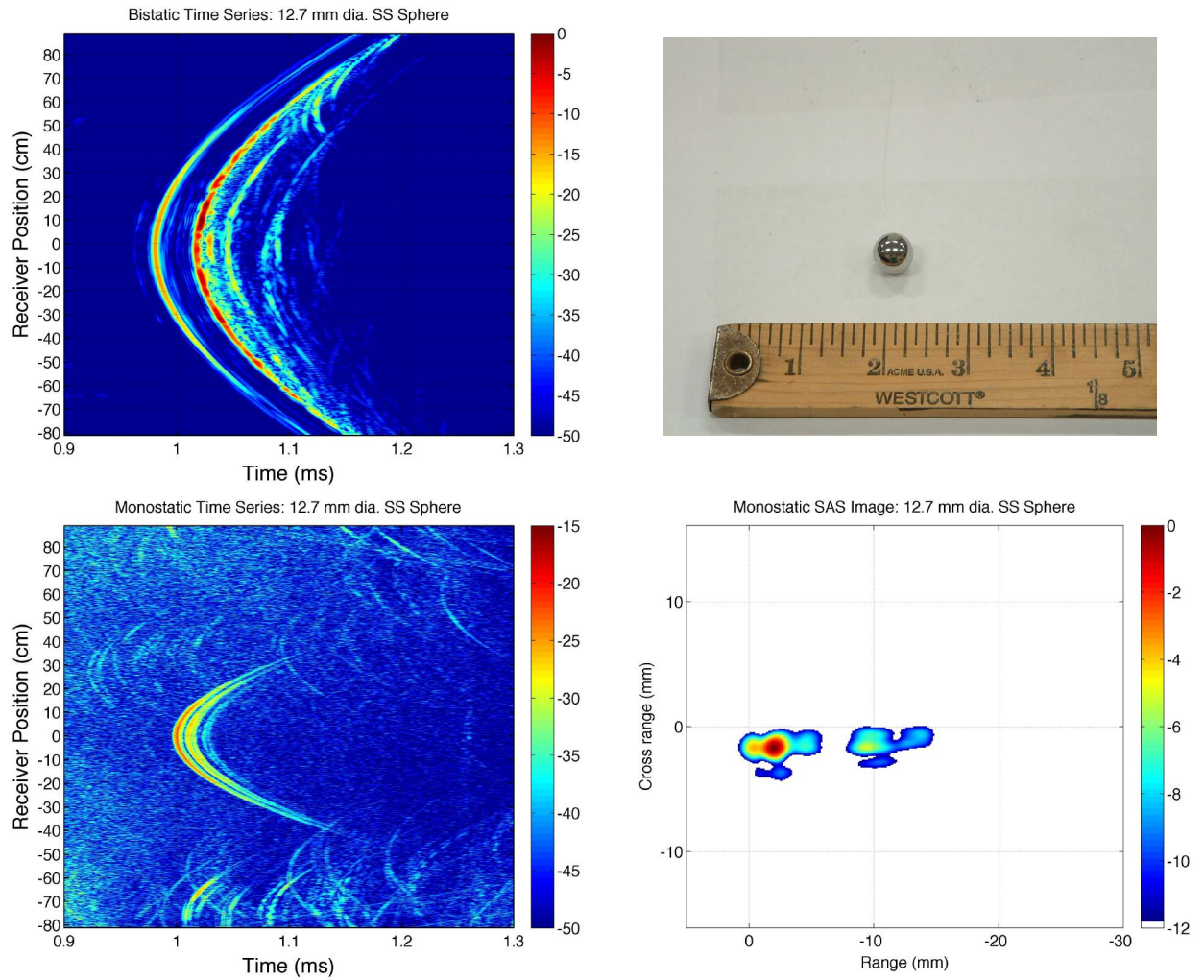


Figure 9: A 12.7 mm diameter stainless-steel sphere (upper right) was suspended in the proud configuration on the scaled sediment. Bistatic quasi-forward scattering time-series data (upper left). Monostatic backscattering time-series data (lower left). Monostatic SAS image (lower right). The SAS coordinate system used is that of Figure 6, with the y-axis direction reversed.

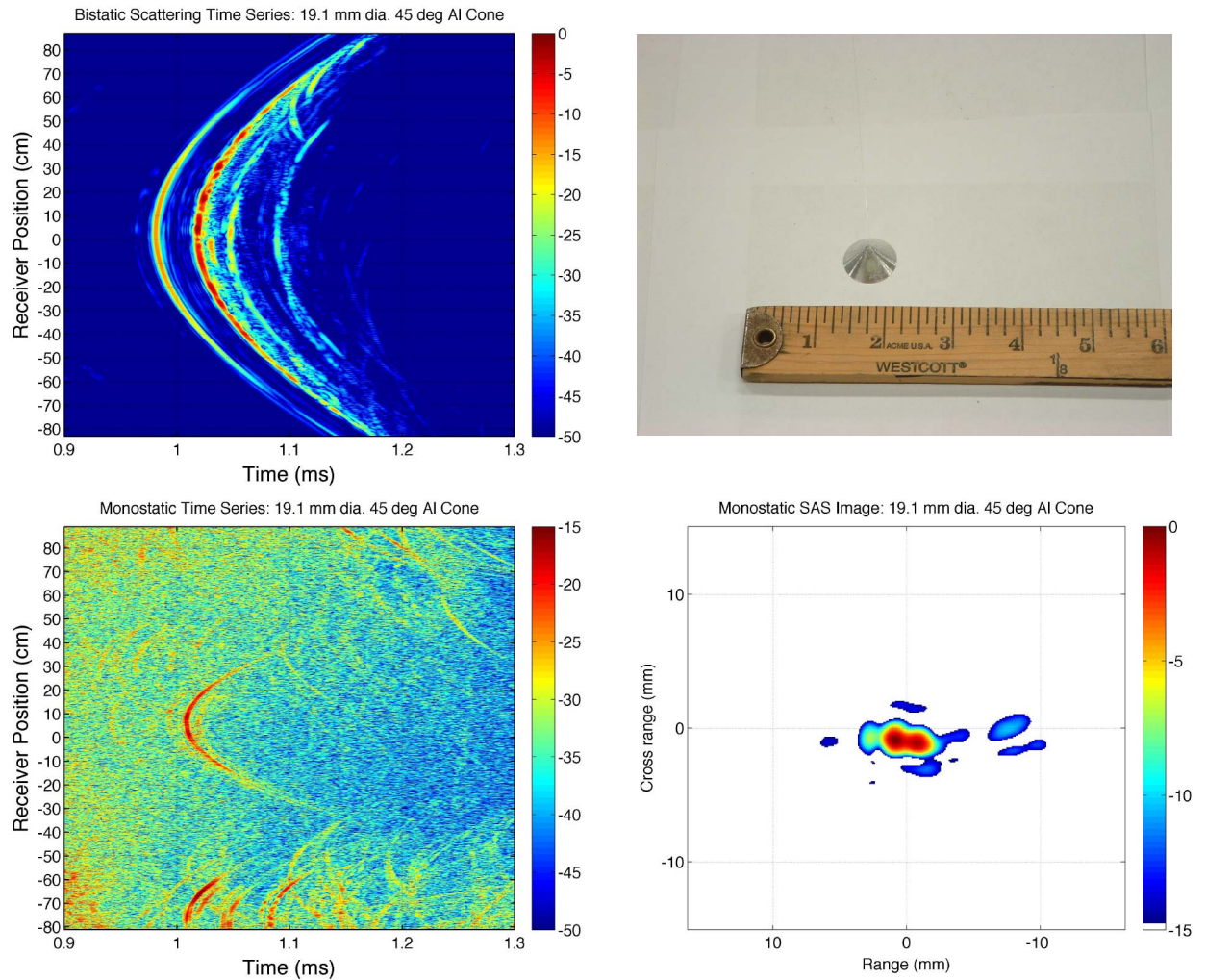


Figure 10: A .75" base diameter solid Al 45° cone (upper right) was resting on the scaled sediment in the proud configuration. Bistatic quasi-forward scattering time-series data (upper left). Monostatic backscattering time-series data (lower left). Monostatic SAS image (lower right). The SAS coordinate system used is that of Figure 6, with the y-axis direction reversed.

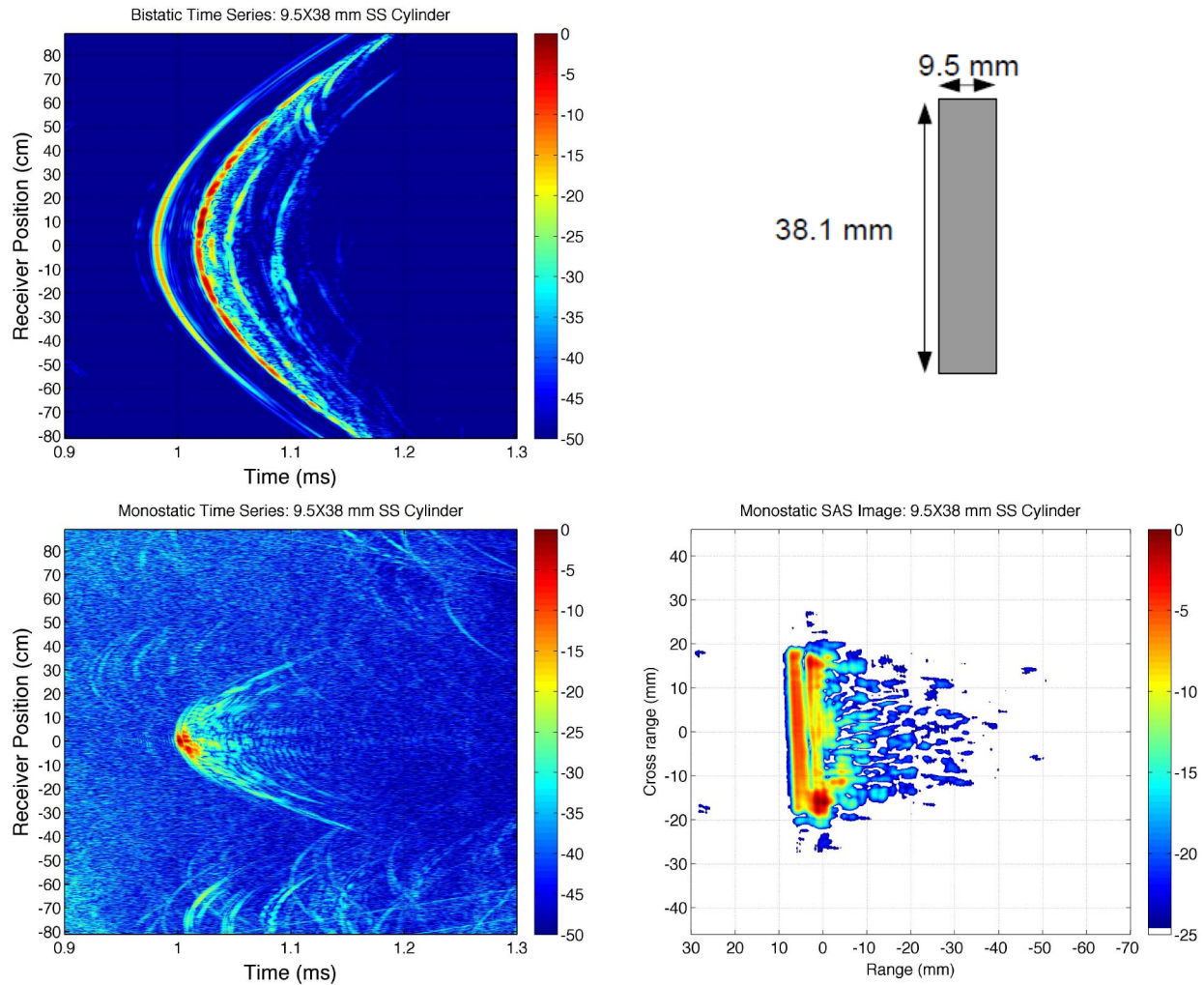


Figure 11: A 9.5 mm diameter by 38 mm stainless-steel cylinder (upper right) was suspended in the proud configuration on the scaled sediment. Bistatic quasi-forward scattering time-series data (upper left). Monostatic backscattering time-series data (lower left). Monostatic SAS image (lower right). The SAS coordinate system used is that of Figure 6, with the y-axis direction reversed.

Study of multiaspect and multistatic sonar systems using a small-scale test bed

Principal Investigators:

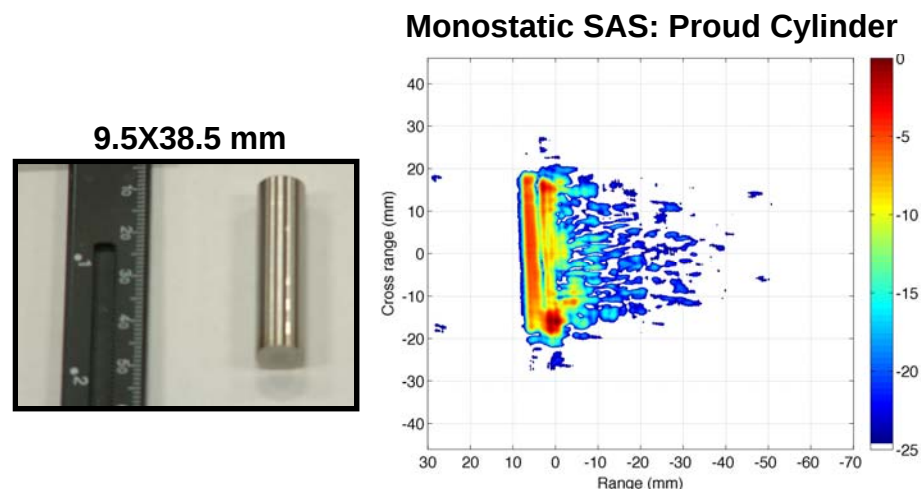
- Jon La Follett, Patrick Malvosio, John Stroud, Joseph, Lopes, Raymond Lim (NSWC PCD)
- Benjamin Dzikowicz (NRL)

Problem:

- Multistatic sonars can provide additional target classification information
- Common multistatic imaging methods require the source-receiver geometry to be known to within a fraction of a wavelength
 - At-sea testing of multistatic sonar configurations is difficult due to accuracy of position information

Objectives:

- To design and build a test tank to investigate a variety of these different geometries at roughly 1:50 scale
- To test existing analysis methods and to develop and evaluate imaging and spectral analysis methods for use in various multistatic configurations for proud and buried target detection and classification



Performing small scale measurements with full scale implications

Technical Approach:

- Construct tank with scaled sediment bottom
- Perform scattering tests on proud and buried simple geometric shapes (spheres and cylinders) to:
 - relate multistatic and monostatic signatures
 - investigate multistatic spectral signatures
 - develop data analysis techniques for multistatic (including forward scattering) data