Sediment Volume Search Sonar

MR-2545

Daniel C. Brown
Applied Research Laboratory at the Pennsylvania State University

In-Progress Review Meeting

17 May 2018

MR-2545: Sediment Volume Search Sonar

Performers:

Applied Research Laboratory – Penn State

Applied Physics Laboratory – Univ. of Washington

Naval Research Laboratory – Stennis Space Center

Technology Focus

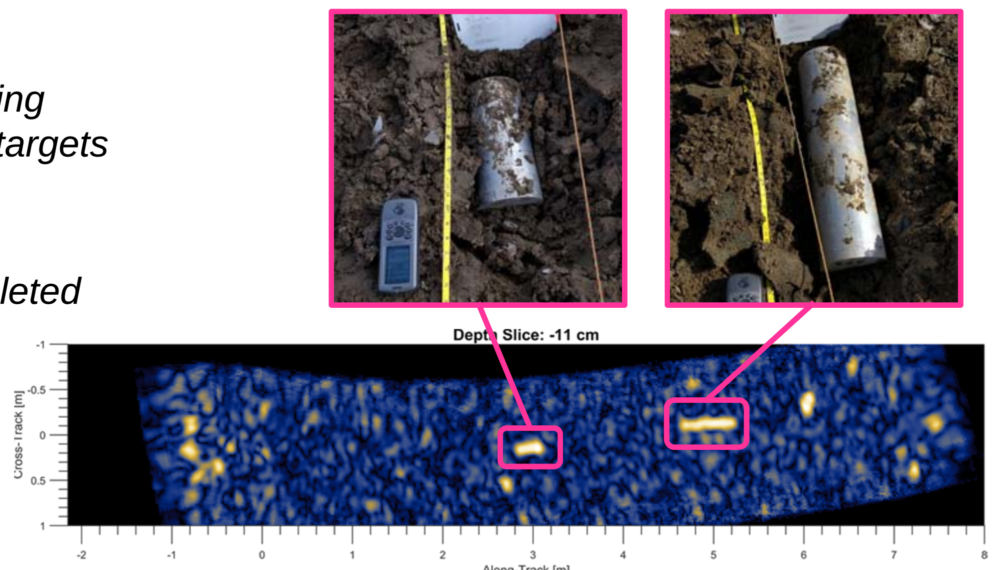
- *Sonar system design and signal processing for buried UXO imaging*
- *Focus on very shallow water (< 5 m) using surface craft*

Research Objectives

- *Determine hardware design and signal processing strategies for near-field imaging of buried UXO targets*

Project Progress and Results

- *Phase 1 modeling and simulation effort is completed*
- *Phase 2 prototype field experiments completed*



Technology Transition

- *Program goal is the design, demonstration and documentation of a system capable of very-shallow-water, buried-UXO imaging*

Social Media Content

- **Journal of the Acoustical Society – Express Letter**
  - *"**A simple model for computing acoustic scattering from the seafloor:** Researchers at the Applied Research Laboratory at the Pennsylvania State University have developed a simple model for simulation of acoustic scattering from the seafloor. This model utilizes an approach that is well suited to high-speed parallel implementation on general purpose graphics processors." http://doi.org/10.1121/1.4976584*
- **SAGEEP 2018 – Presentation**
  - *"Researchers at the Applied Research Laboratory at the Pennsylvania State University presented their work on a sensor designed to map buried unexploded ordnance using a sonar system. This sensor uses a novel form of synthetic aperture processing to make three-dimensional images of buried objects."*

Social Media Content

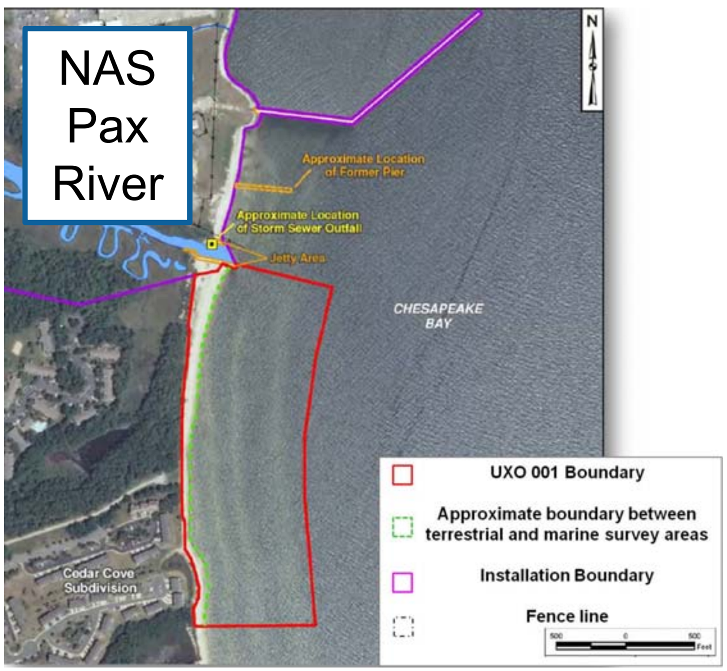
- **IEEE Oceans Charleston – Presentation/Paper**
  - *“**Successful demonstration of prototype sensors for munitions mapping:** Researchers at the Applied Research Laboratory at the Pennsylvania State University have recently conducted experiments to map buried ordnance using a novel form of synthetic aperture sonar.”* Link to paper when available.

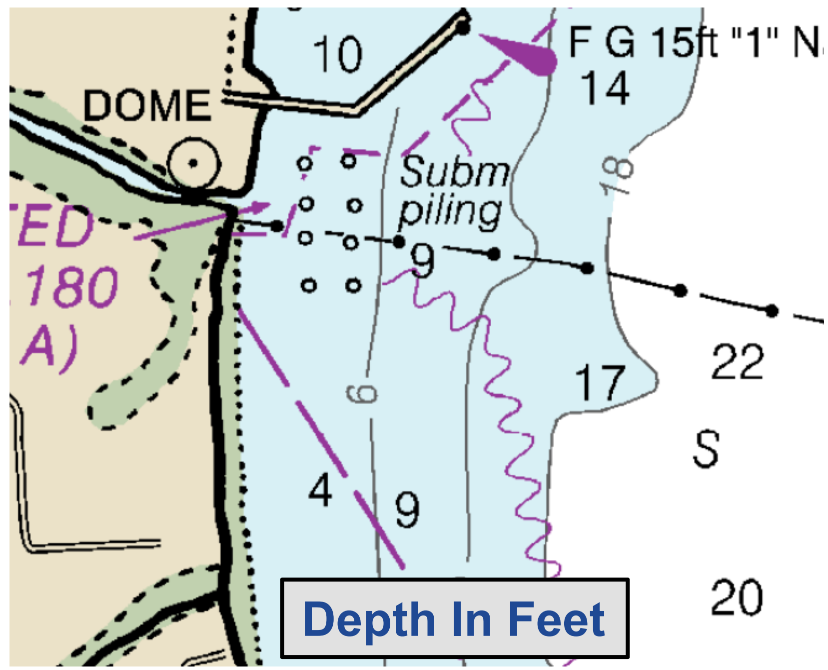
Project Team and Collaborators

- Applied Research Laboratory – Penn State
  - Dr. Daniel Brown, PI
  - Dr. Shawn Johnson, Co-PI
  - Mr. Cale Brownstead, Co-PI
  - Mr. Zack Lowe, Lead Engineer
- Applied Physics Laboratory – University of Washington
  - Dr. Aubrey Espana, PI
  - Dr. Steve Kargl, Co-PI
- Naval Research Laboratory – Stennis Space Center
  - Dr. Joseph Calantoni, PI
  - Mr. Edward Braithwaite, Lead Engineer

Problem Statement

- A capability gap exists for the detailed survey of UXO in very shallow water (1-5 meters depth)
  - ♦ The potential for human/UXO interaction is high in these shallow environments that make up a large fraction of SERDPs sites
  - ♦ Current COTS acoustic sensors and platforms are not well suited to conducting surveys in these water depths





Technical Objective

- The program will simulate, design, fabricate and demonstrate an acoustic sensor and platform capable of detailed UXO surveys in 1-5 meters water depth

Technical Approach

Phase 1 Simulation and Modeling

- Leverage/extend models for producing synthetic sonar data
- Adapt existing signal processing for volumetric imaging
- Analyze and quantify expected system performance

Phase 2 Prototype Demonstration

- Reconfigure existing test platform and sonar hardware
- Modify signal processing algorithms based on field data analysis
- Demonstrate performance for UXO detection

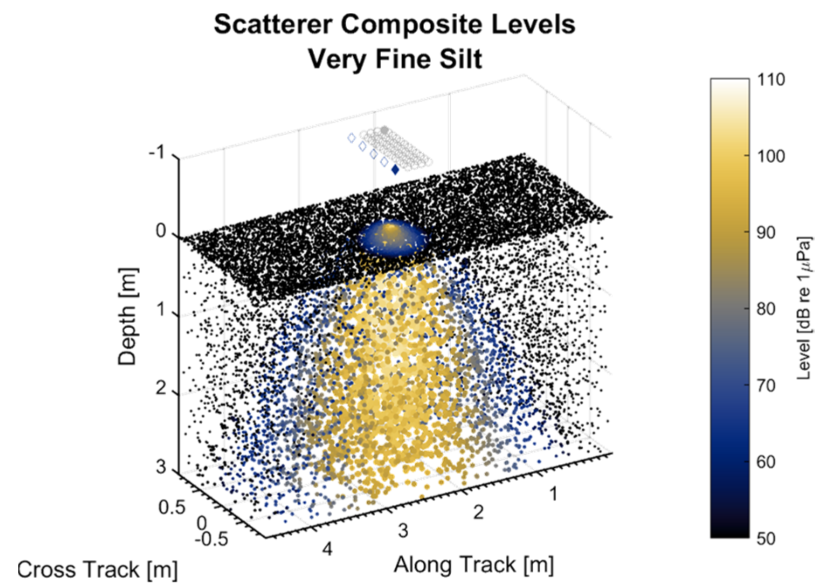
Phase 3 System Demonstration

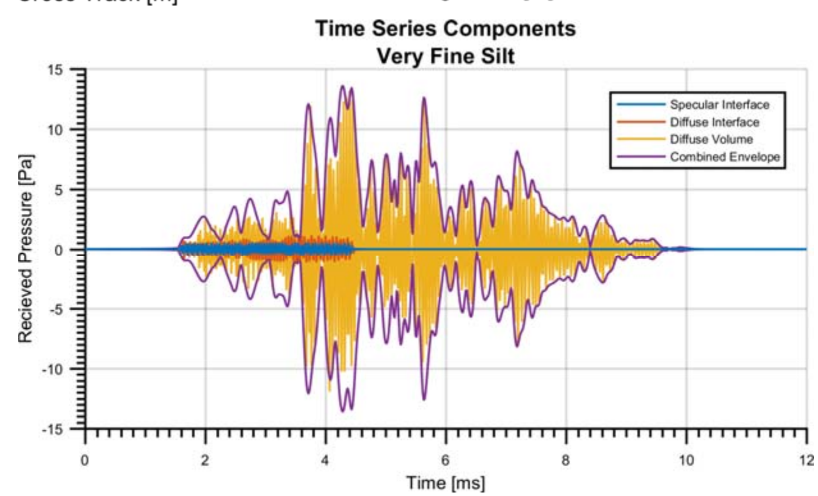
- Purpose-built hardware design based on lessons learned
- Further refinement of signal processing and data visualization
- Demonstrate performance for UXO detection

Each phase of the program concludes with a Go/No-Go decision point

Phase 1: Simulation and Modeling
Environmental Modeling

- Leverage the Point-based Sonar Scattering Model (PoSSM)
- Coherent simulation accounts for sonar motion, beam pattern, absorption, sediment type and backscattering strength, and bathymetry
- Produces time series suitable for SAS beamforming
- SVSS program extended PoSSM to include volume scattering / layered sediments and SVSS sonar geometry

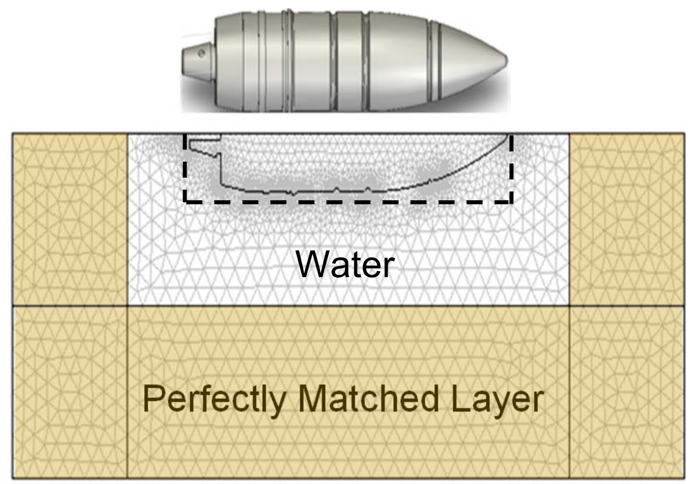


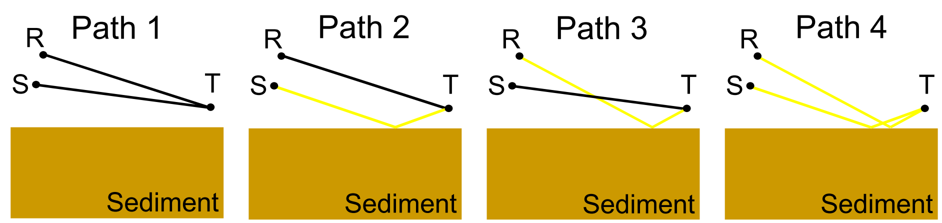


Phase 1: Simulation and Modeling
Target in the Environment Modeling

- Leverage recent collaboration with APL/UW Target in Environment Response (TIER) modeling effort
  - ♦ Combined finite element and propagation model for target signatures
- Past SERDP programs supported TIER model development and validation
- Extend TIER to include bistatic paths and SVSS sonar geometry
- TIER currently supports simulation of a number of UXO shapes

FE Mesh for 100-mm Aluminum UXO

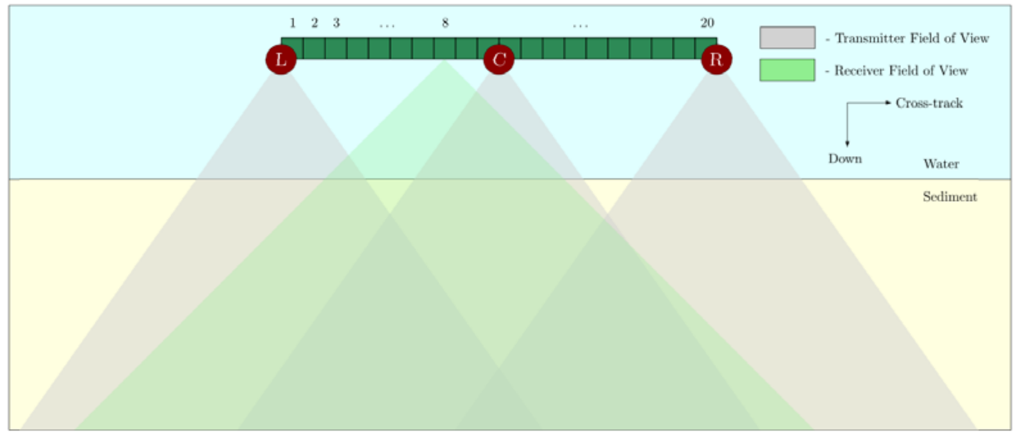


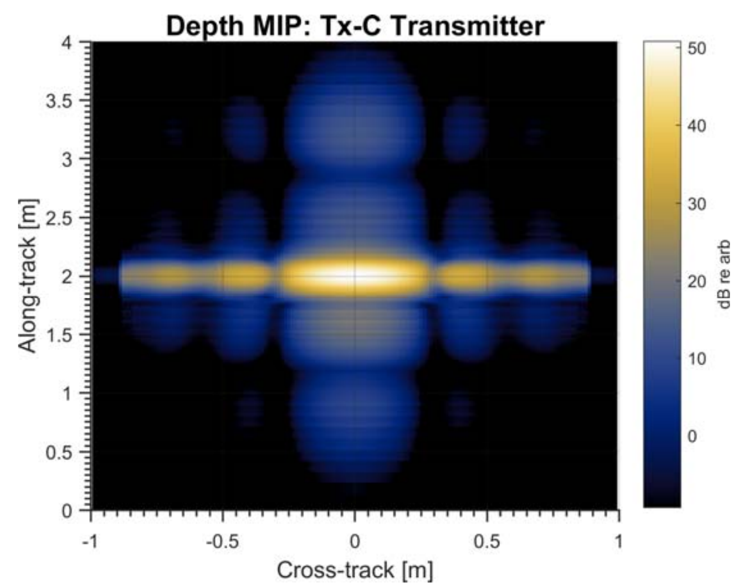


Images courtesy of APL/UW

Phase 1: Signal Processing Backprojection Imaging

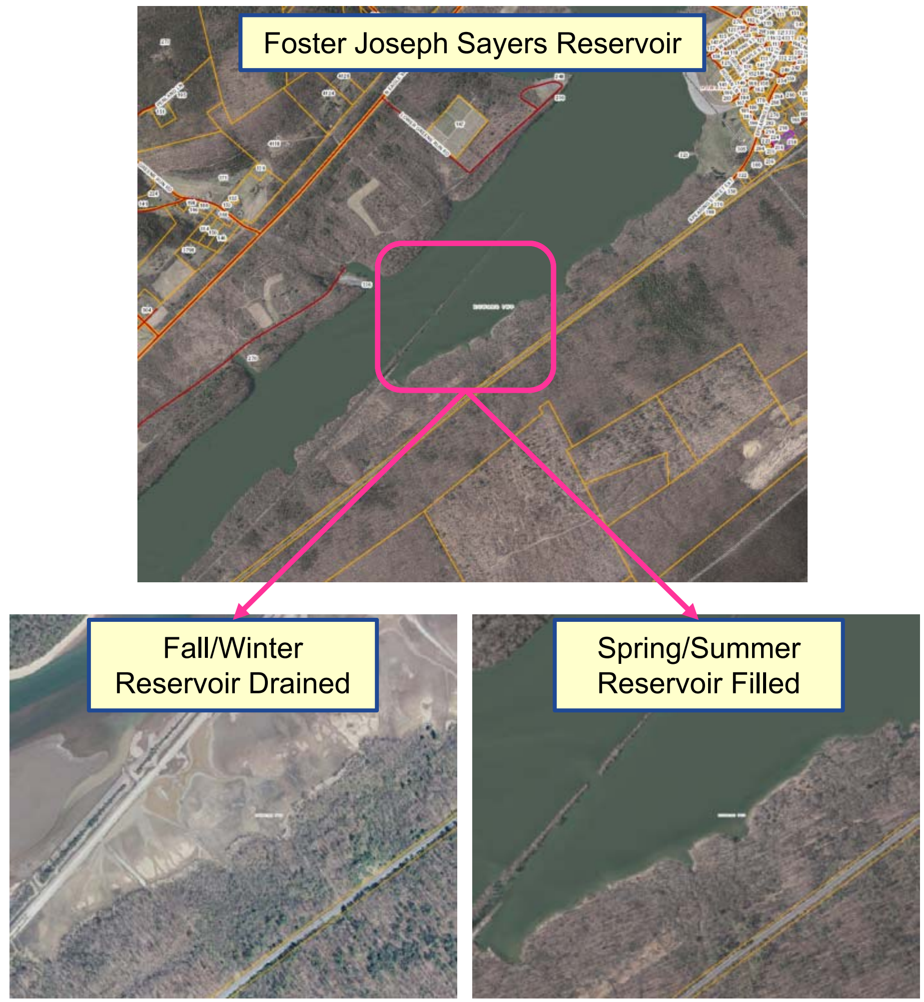
- Extend existing synthetic aperture beamformer to volumetric imaging
- Requires addressing two main topics:
    - ♦ Near-field “field of view”
    - ♦ Acoustic refraction at water/sediment boundary





Phase 2: Prototype Demonstration Field Testing

- Foster Joseph Sayers Reservoir
  - ♦ Flood control
  - ♦ Drained in late fall
- Winter lake draining permits UXO-like objects to be deployed with accurate ground truth
- Three planned lake trials
  - ♦ System Integration
  - ♦ System Functionality
  - ♦ System Demonstration



Phase 3: System Demonstration

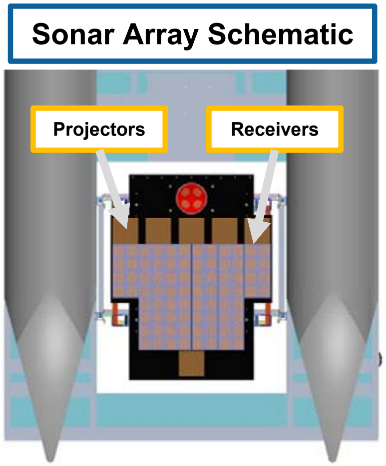
- Lessons learned from simulation and prototype demonstrations will be applied to the fabrication of a purpose built test platform.
  - ♦ Hardware leveraged in prototype may not be optimal.
- Potential areas for improvement:
  - ♦ Receive array design (geometry and acoustic performance)
  - ♦ Transmit array design (geometry and band of operation)
  - ♦ Surface craft design (sonar system deployment, onboard power)
- Significant effort on improving signal processing
  - ♦ Target strength estimation (calibrated spectral response)
  - ♦ Automated target detection

Completed SERDP-specific sensor/platform and signal processing will be demonstrated and delivered

PHASE 2: DEMONSTRATION RESULTS

SVSS Prototype Sensor Design

- Modeling and simulation results informed the prototype sensor design
  - ♦ Significant leverage of existing hardware for demonstration
- SVSS program developed a new array configuration
  - ♦ Expanded the receiver from 48 channels to 80 channels
  - ♦ Fabricated six new projectors
- Added a new high-frequency COTS sidescan sensor

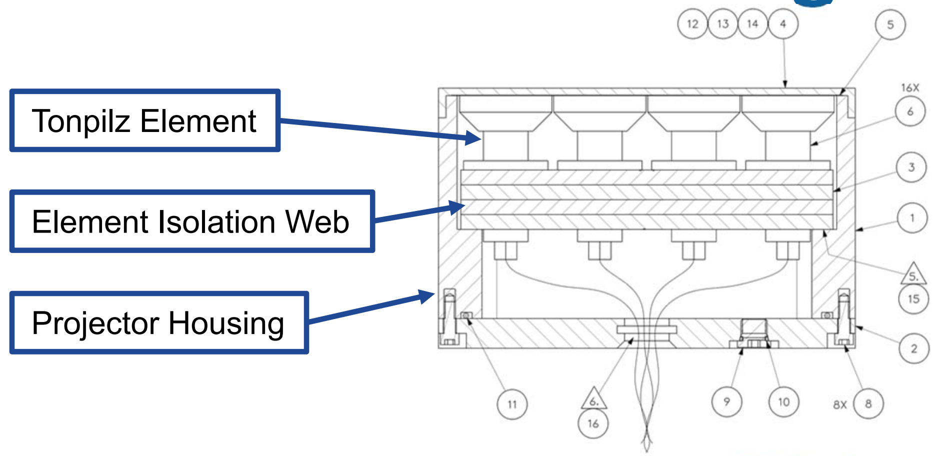


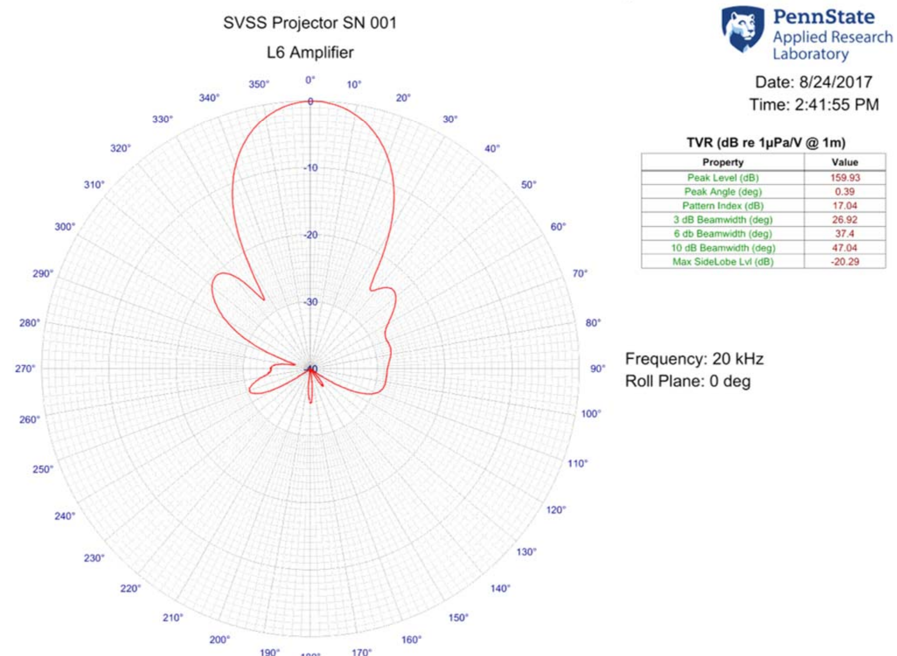
Sound Hunter Test Platform

80 channel receiver	Real-time kinematic GPS	Water temperature sensor
6 channel transmitter	Fiber optic gyroscopic navigator	40 TB data storage
High-frequency sidescan	Acoustically quiet battery power	Gas and electric propulsion

Projector Design and Fabrication Challenge

- SVSS requires five wideband acoustic projectors
  - ♦ Intended COTS supplier declared bankruptcy early in Phase 2
- ARL designed and fabricated projectors using surplus tonpilz elements
- Excellent “front-to-back” ratio for multipath rejection

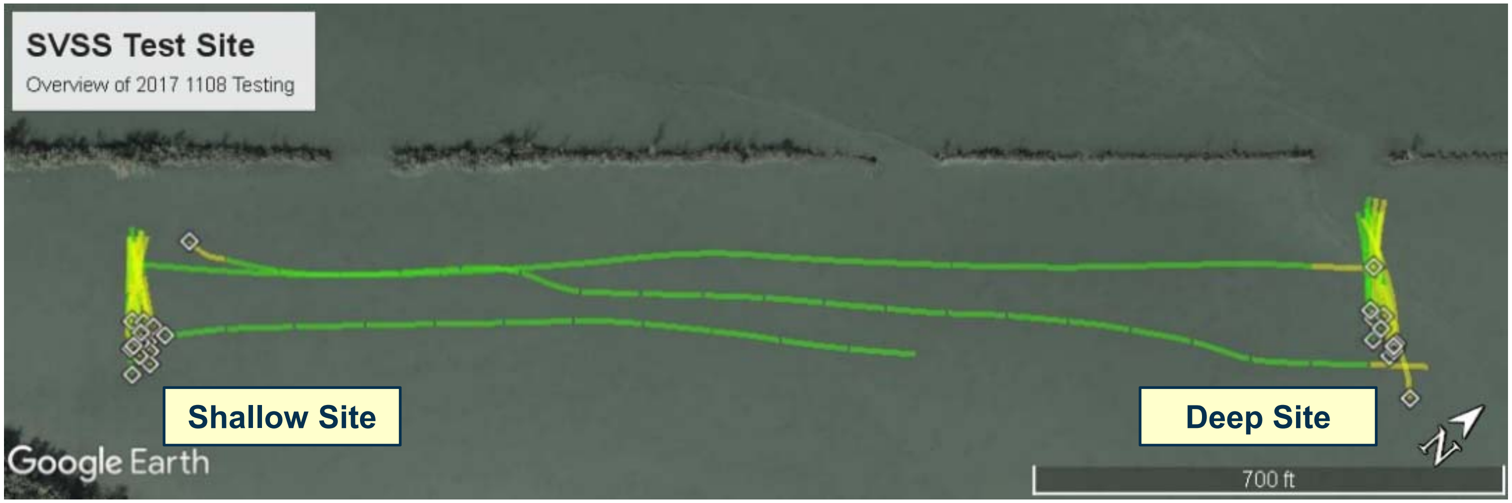




ARL/PSU Anechoic Test Facility

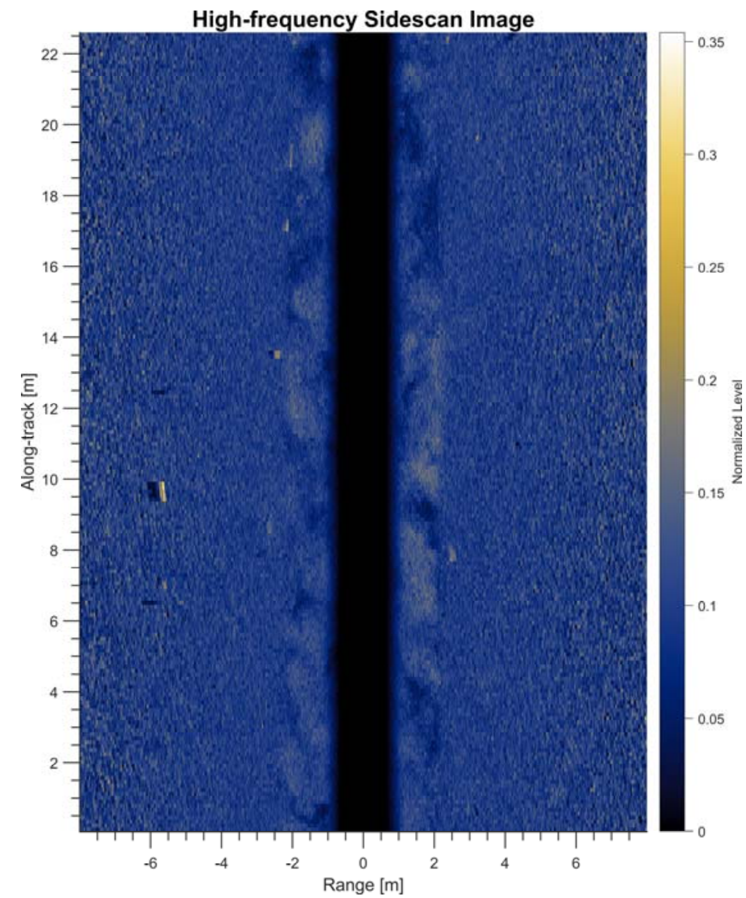
Prototype Integration and Testing in the Summer/Fall of 2017

- Hardware changes
  - Receive array expanded and reconfigured
  - Transmitter expanded
  - RTK GPS integrated
- Multiple experiments conducted at the test site
  - Early tests focused on debugging
  - Later tests focused on survey and imaging of deployed targets
  - Sediment samples collected to characterize test environment



High-frequency Sidescan Survey

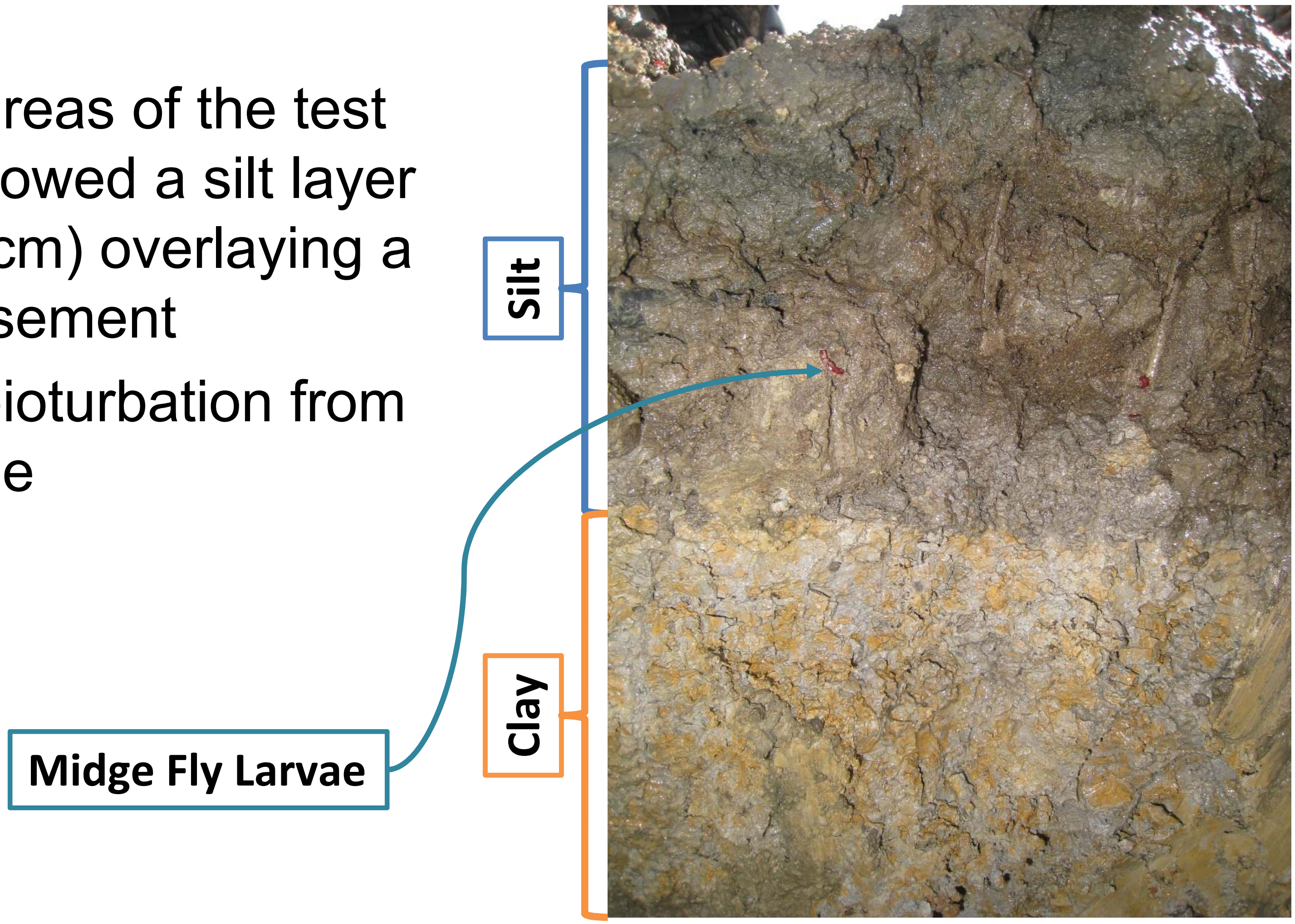
- Commercial sidescan sonar is used to give an overview of the test area.
- Boat operator uses real-time sidescan display to help guide boat operation
- Follow on effort will explore how to use this sensor more effectively



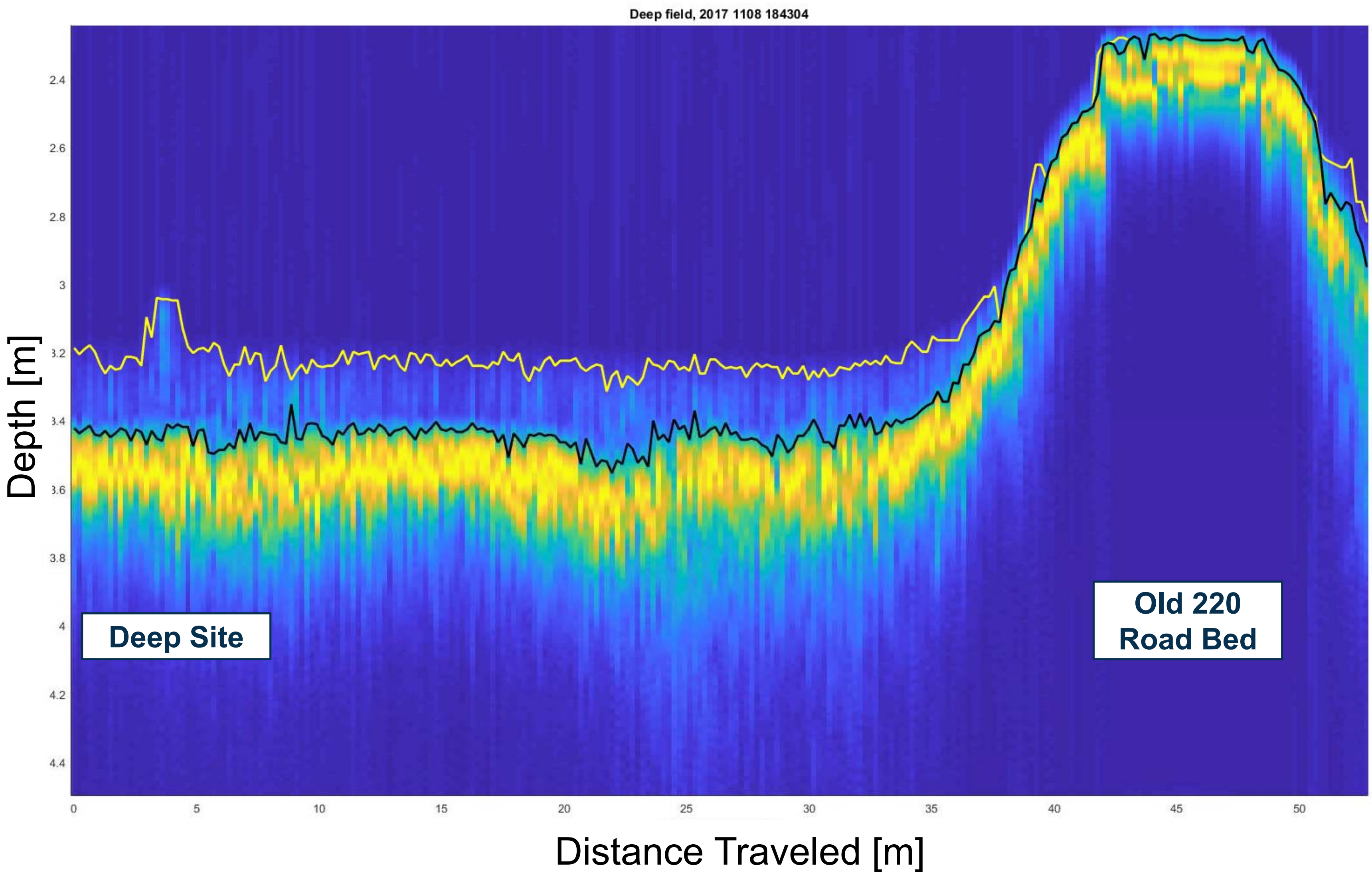
Sidescan data provides environmental characterization and some limited capability for larger surface ordnance.

Test Site Sediment Characteristics

- Some areas of the test sites showed a silt layer (10-15 cm) overlaying a clay basement
- Some bioturbation from fly larvae

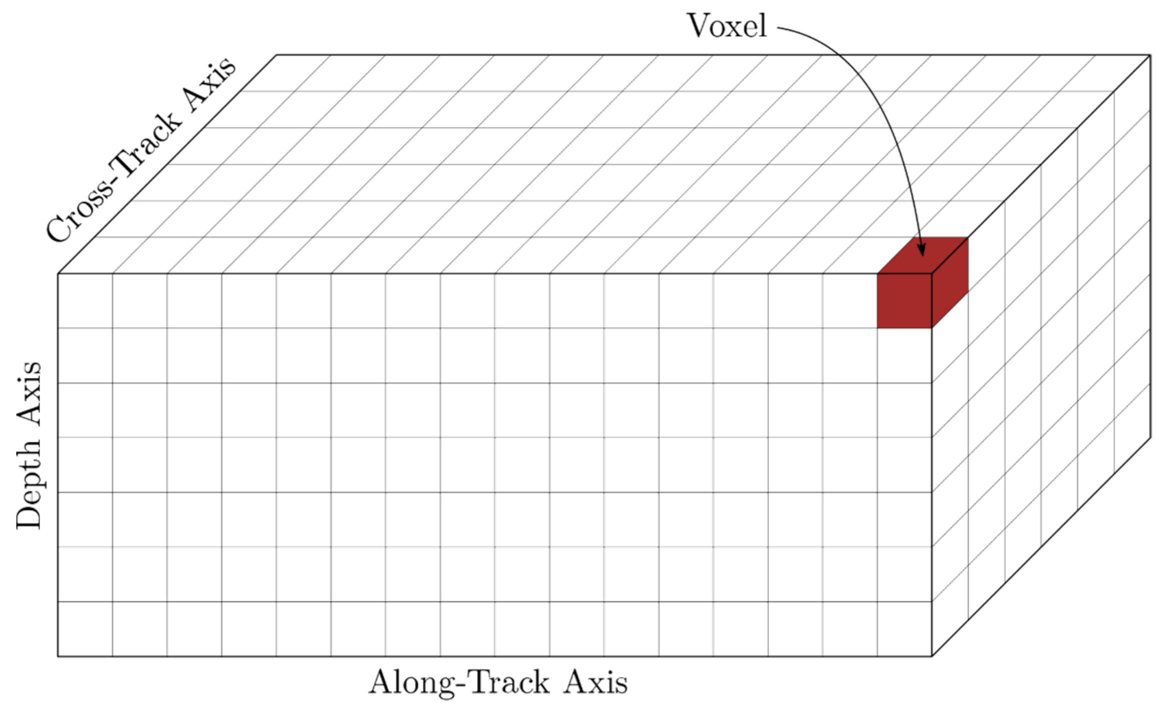


Sediment Layering in Sub-bottom Profile

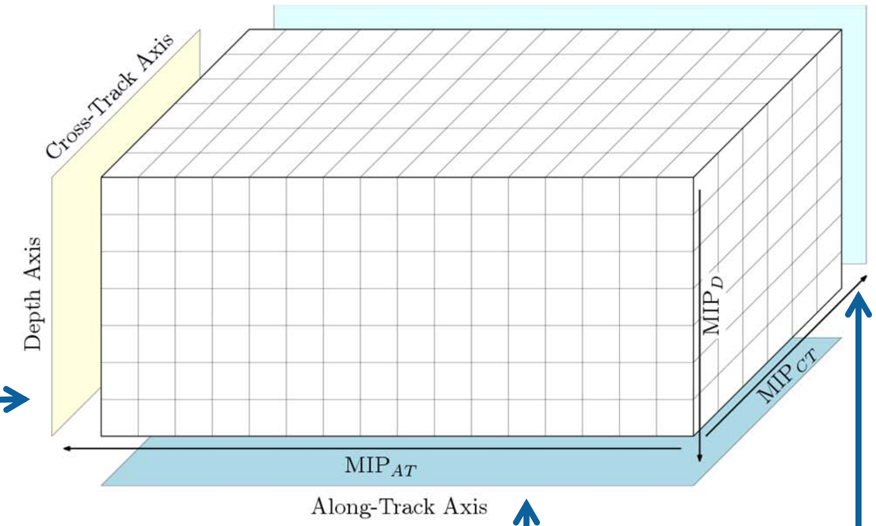


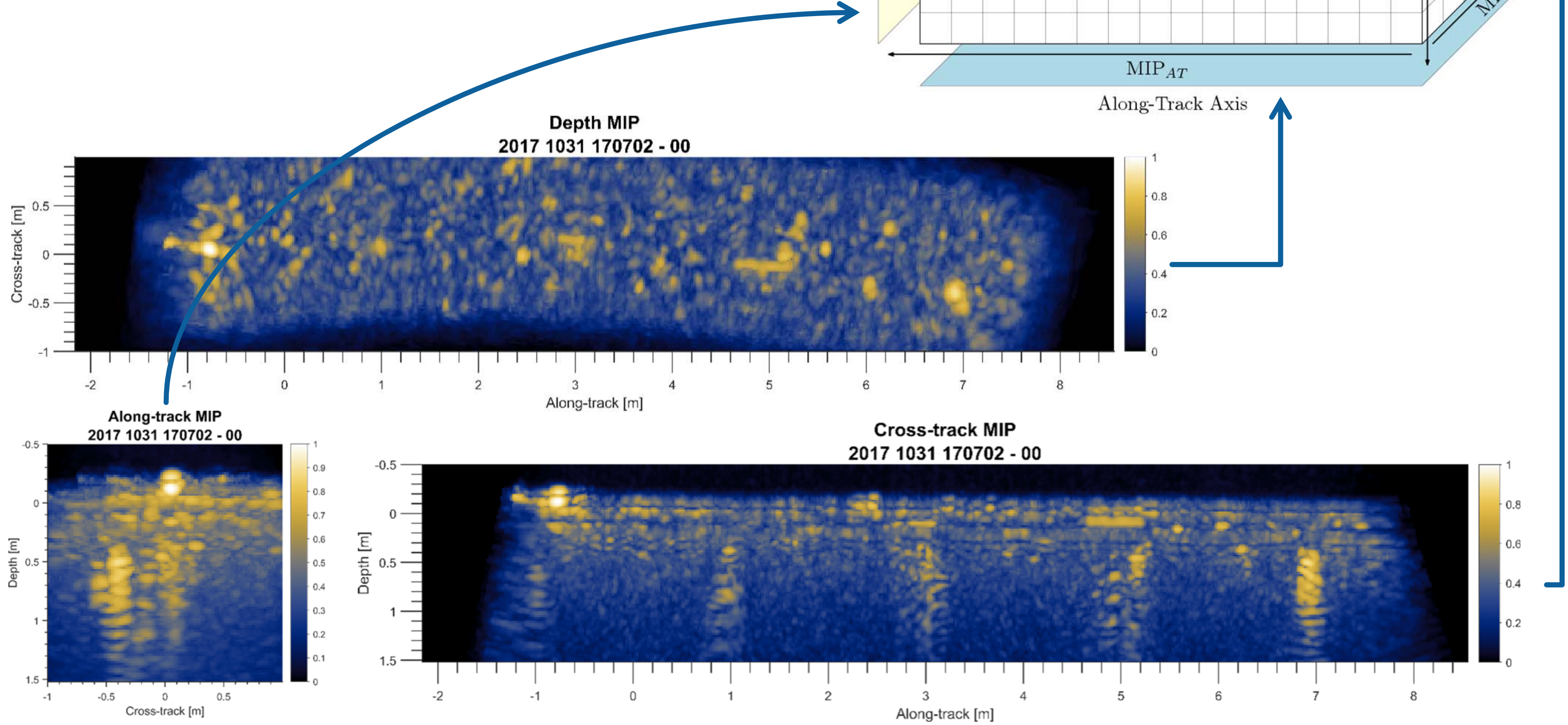
Three-dimensional Image Visualization

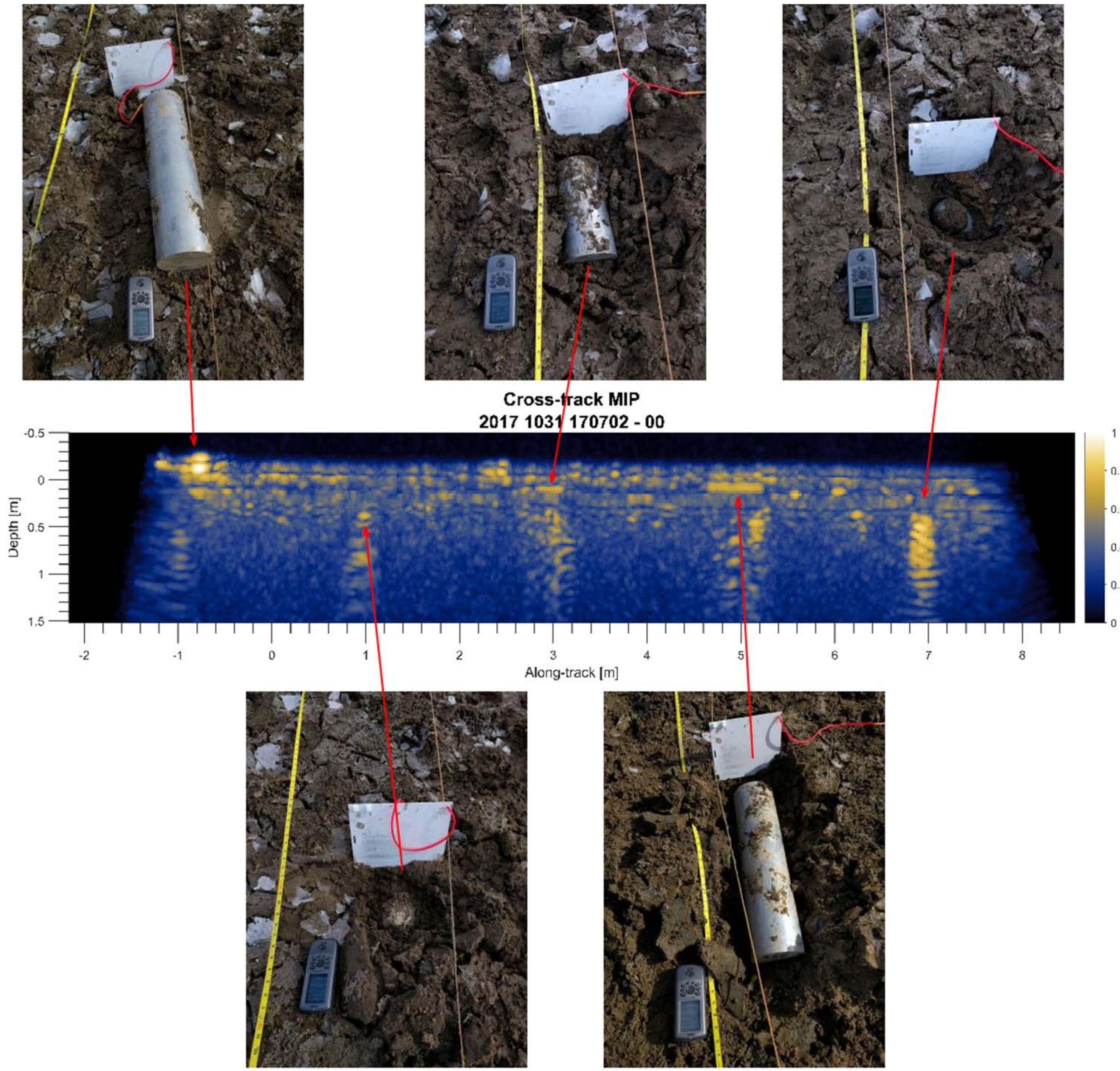
- SVSS creates three dimensional data
  - ♦ Imagery consists of voxels (instead of pixels)
- Visualization techniques
  - ♦ Projections
  - ♦ Slices
  - ♦ 3D Viewer



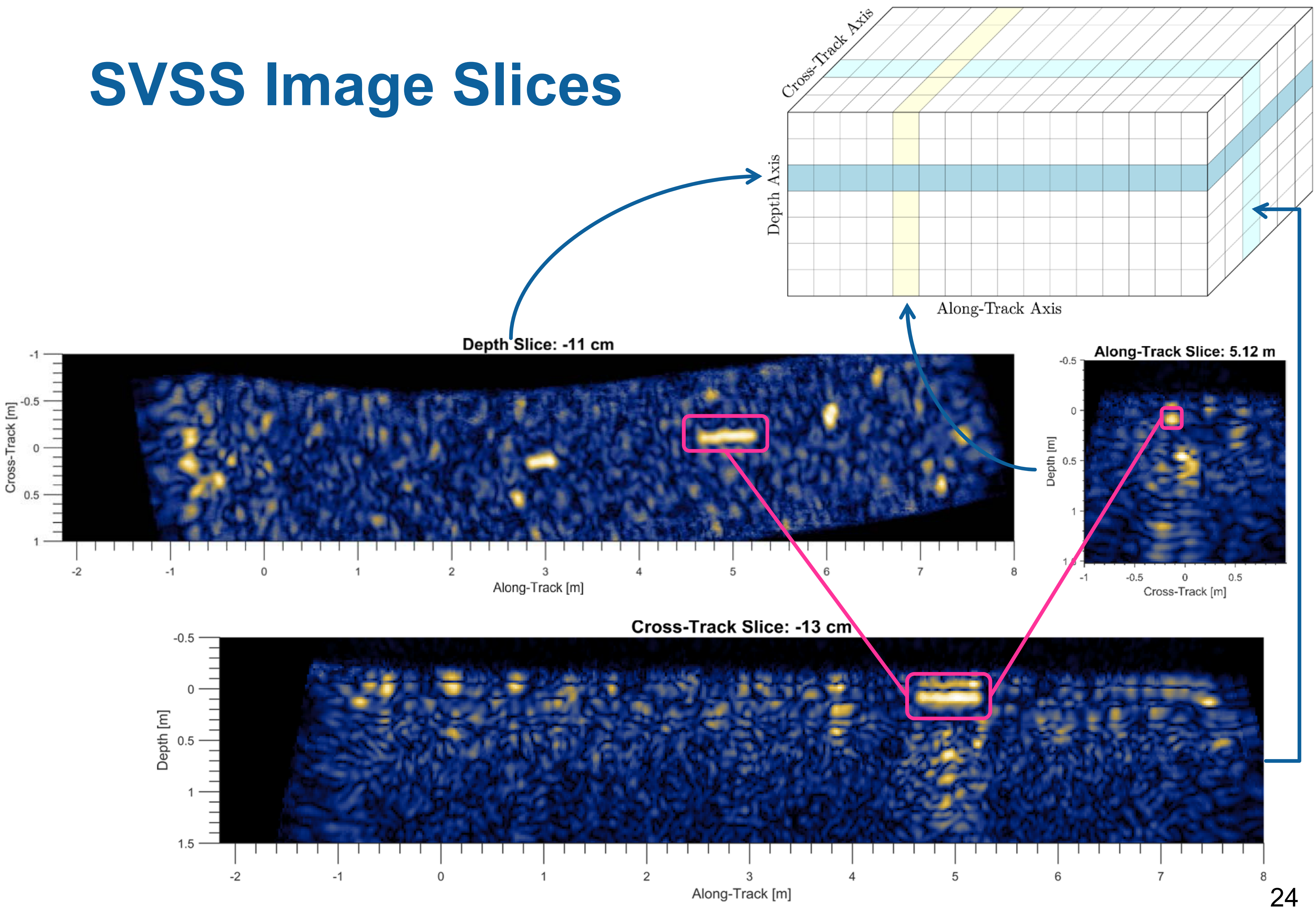
SVSS Maximum Intensity Projections (MIPs)



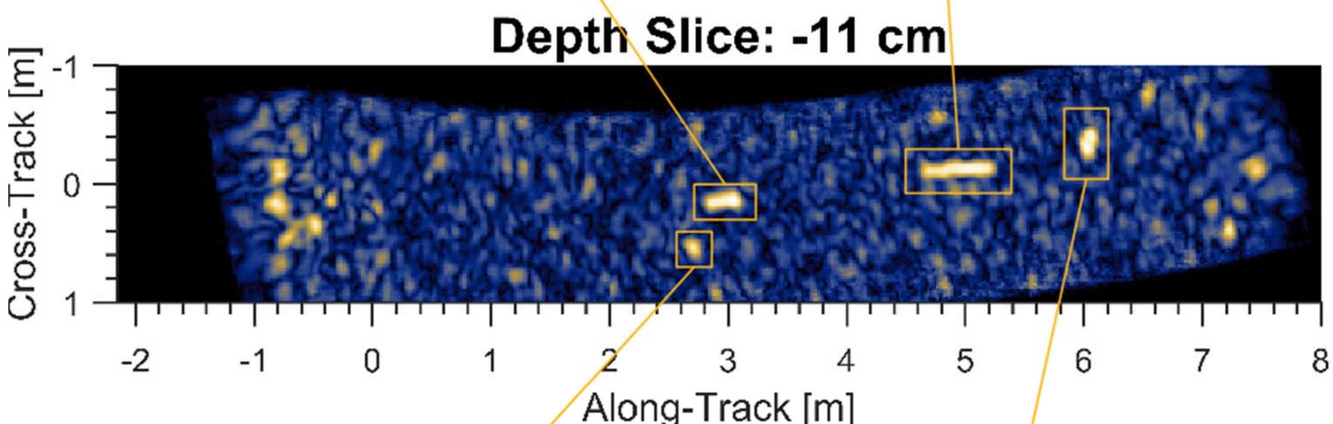



Cross-track MIP
2017 1031 170702 - 00
Depth [m]
Along-track [m]

SVSS Image Slices



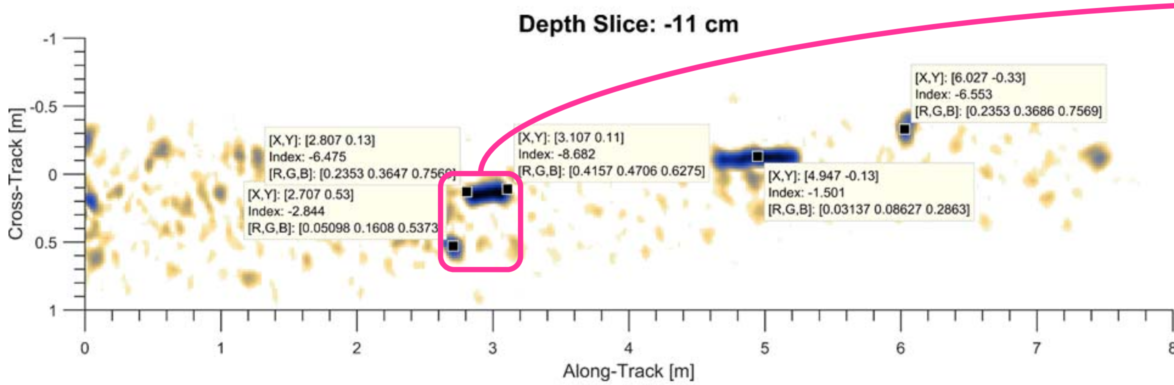
Targets Planted by ARL/PSU

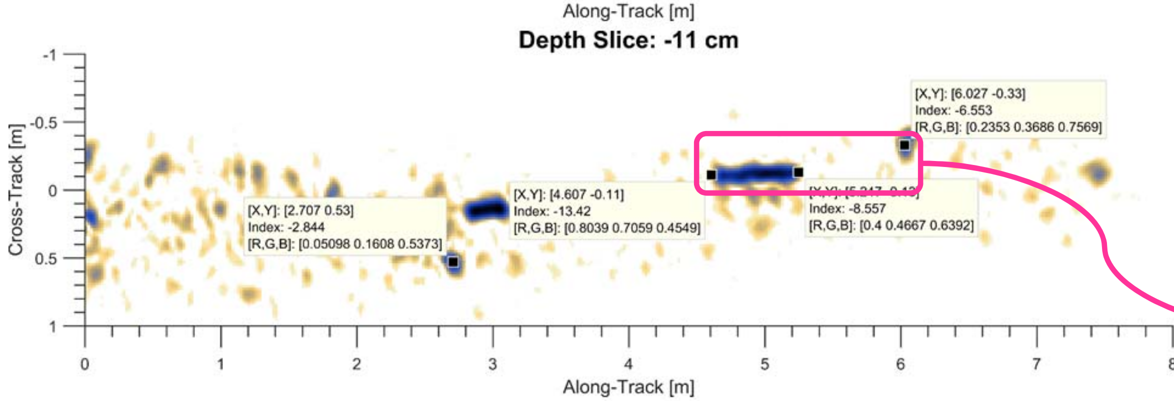


Clutter Recovered by ARL/PSU

Accurate Relative Target Location

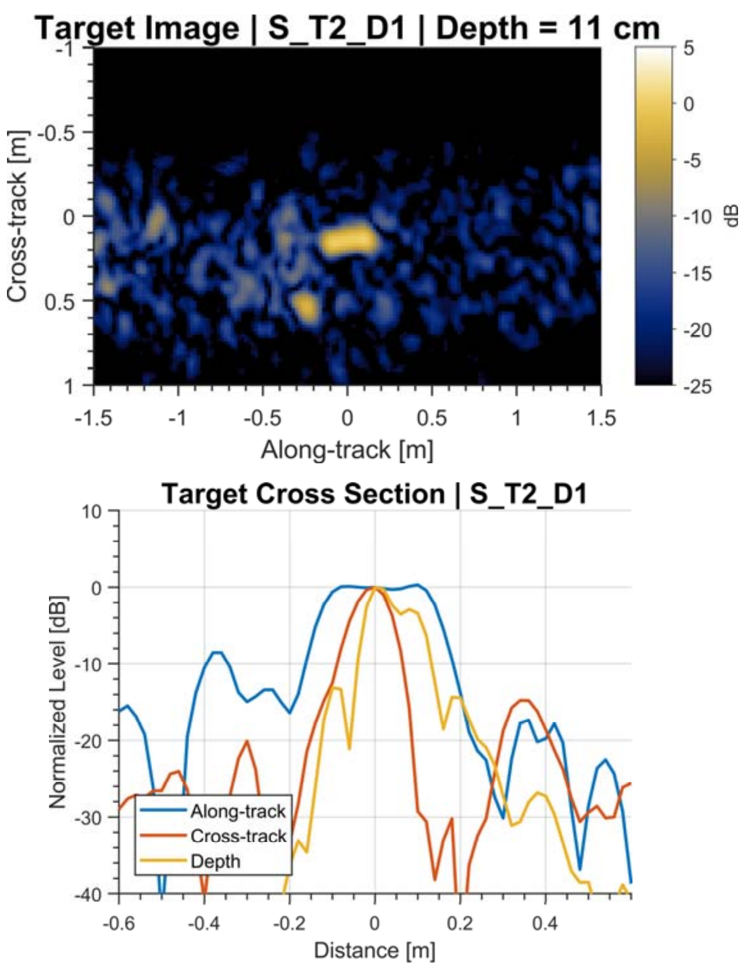
targetName	testSite	position	targetState	targetId	targetDepthString	targetDepthCm	orientation	latitudeHemis	latitudeDeg	latitudeMin	latitudeSec	longitudeHemis	longitudeDeg	longitudeMin	longitudeSec	offsetInstallM	offset1031M	offset1108M	posSource	posQual
S_P06_T3D1	S	P06	T3D1	3	1	3	120	N	41	0	5.09010021	W	77	40	43.92166455	0.338854998	0	0.258457752	2017 1031 170702 0	1
S_P07_T2D1	S	P07	T2D1	2	1	5	129	N	41	0	5.04681761	W	77	40	43.85881784	1.503199872	0	0.230042367	2017 1031 170702 0	1



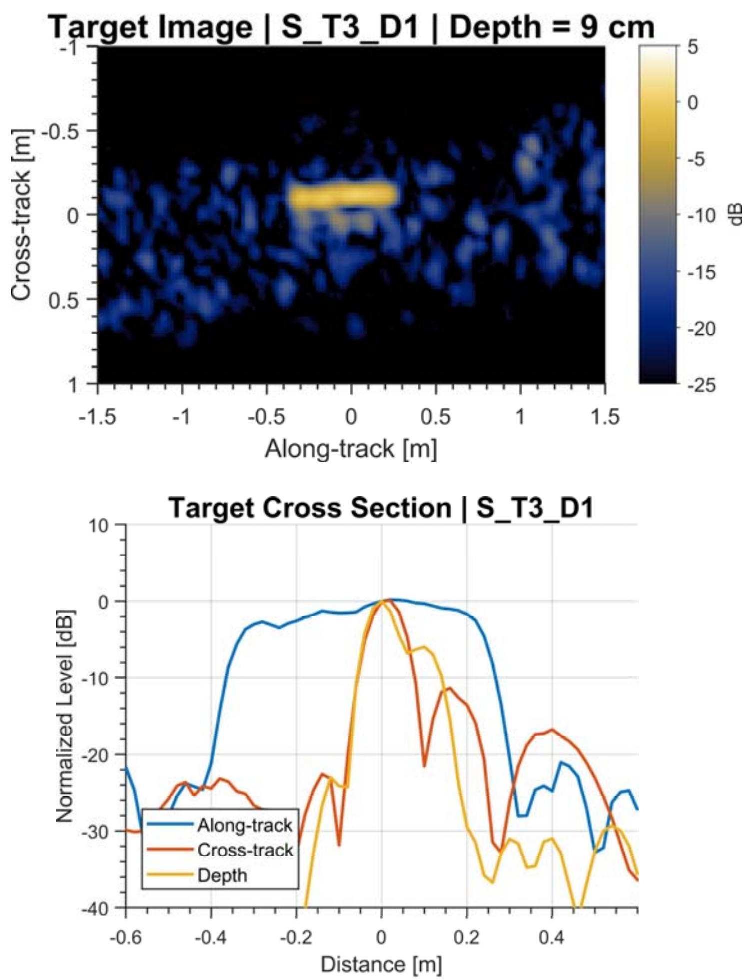


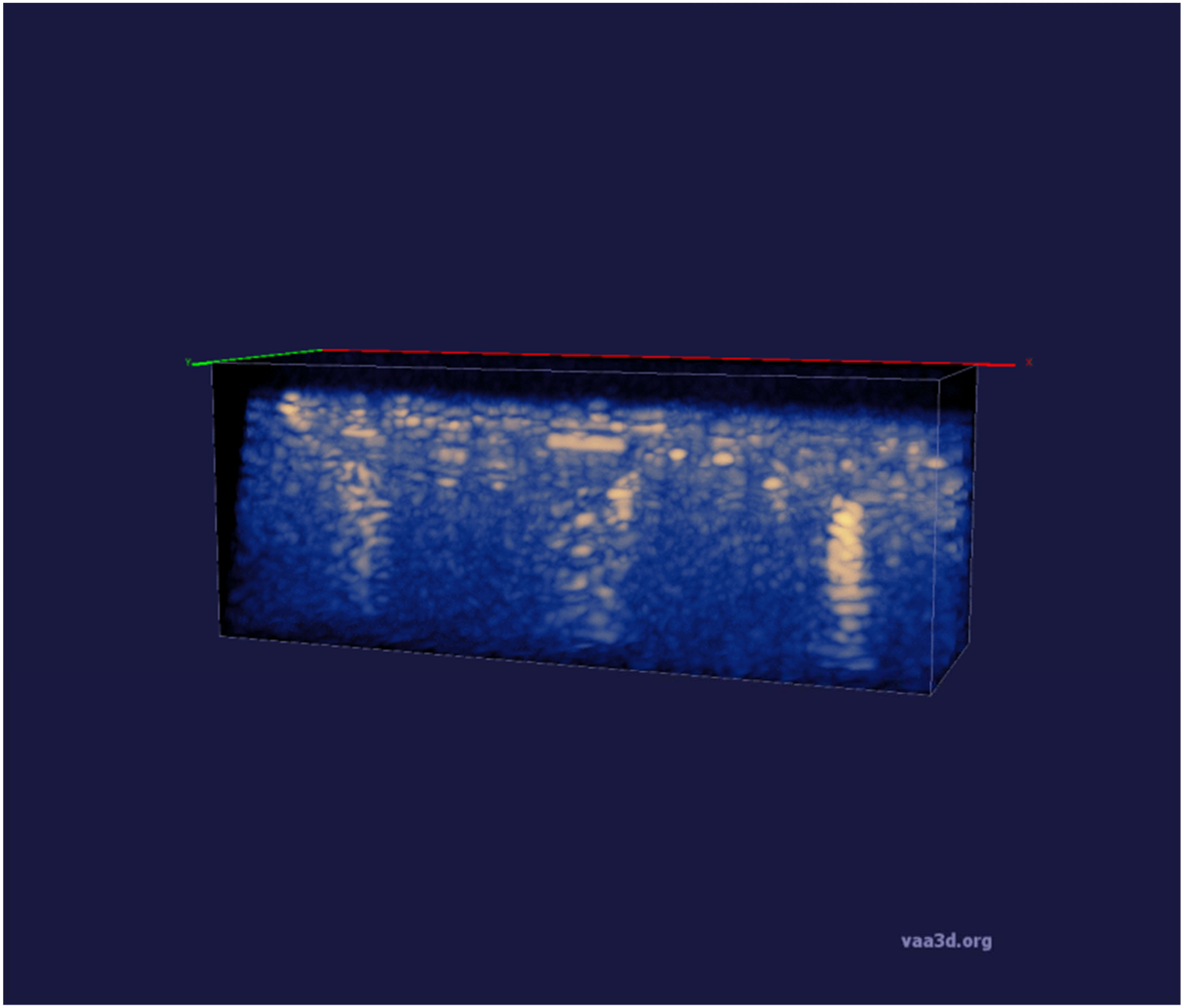
Measuring Target Dimensions from Imagery

<u>Short Cylinder: L = 30.5 cm</u>



<u>Long Cylinder: L = 61.0 cm</u>

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Phase 2 Results Conclusion

- Prototype SVSS sensor was developed leveraging existing hardware
  - ♦ Projector fabrication and receive array expansion
- Demonstrations were conducted at the Foster Joseph Sayers Reservoir test site
  - ♦ Two “survey” tests conducted in late 2017
- SVSS generated three-dimensional imagery of targets
  - ♦ 11 of 12 cylindrical targets were located in the resulting imagery

Phase 2 testing has demonstrated that the SVSS sensor is capable of buried UXO detection in very shallow water.

Re-planning Year 1 of Phase 3

- Phase 2 demonstrated the prototype SVSS is capable of imaging buried targets at the test site
  - ♦ Projector development pushed testing to late 2017
  - ♦ Limited dataset precluded a complete SVSS characterization
- ARL/PSU has proposed re-planning the first year of Phase 3 for expanded testing of the prototype SVSS
  - ♦ More thorough characterization will improve final system design
  - ♦ Delaying final system design allows for additional consideration of potential test sites in the system design
  - ♦ Additional testing will provide time for scientific studies

Early Phase 3 Topics

- Data collection against realistic ordnance
  - ♦ Several inert UXO were installed in the test site in March 2018
- Enhanced target detection
  - ♦ Non-linear image normalization techniques are needed to reduce high-level interface scattering
  - ♦ Techniques should be developed to exploit elastic phenomena
- Improved sediment characterization
  - ♦ Sediment cores were collected during March 2018 installation
  - ♦ Model/data comparisons will be conducted to better understand the relevant scattering processes

Early Phase 3 Topics

- Wideband transmitter study
  - ♦ Waveform design to best utilize the Phase 2 projectors
  - ♦ Determine frequency bands for best performance
- Ensuring area coverage / multi-pass data fusion
  - ♦ Operator displays to guarantee 100% survey area coverage
  - ♦ Fusion (possibly coherent) of data from multiple passes

Action Items

- "Dr. Andrews noted that project will need to re-brief with the Board in year four of the project since the requested funds exceed $1M."
  - ♦ Type: SAB
  - ♦ Due Date: 06/16/2019
  - ♦ Status: PENDING

Year 4 as proposed exceeds $1M, and falls in Phase 3 of the project after the next go/no-go decision point. We will continue monitoring this and coordinate with the SAB if executed as planned.

A re-planned phase 3 will expend less than $1M in year 4

Transition Plan

- The program plan is to generate system documentation and data used for demonstration of capabilities
  - ♦ Phase 2 and Phase 3 each include a number of field demonstrations of the SVSS under SERDP funding
  - ♦ Result of Phase 3 will be a system capable of sub-bottom imaging of buried UXO
- User community “buy in” will be achieved by open sharing of documentation and data collected in field demonstrations

BACKUP MATERIAL

Publications

- Peer Reviewed Publications
  - ♦ D.C. Brown, S.F. Johnson and D.R. Olson, “A point-based scattering model for the incoherent component of the scattered field”, J. Acoust. Soc. Am., vol. 141, no. 3, pp. EL210-EL215, 2017
- Conference Publications
  - ♦ Paper in preparation for IEEE Oceans Conference.
- Presentations
  - ♦ D.C. Brown, S.F. Johnson and C.F. Brownstead, “Sediment Volume Search Sonar”, SAGEEP 2018.