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SERDP and ESTCP Webinar Series

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Sediment Volume Search Sonar

August 23, 2018

SERDP DOD • EPA • DOE | ESTCP

Welcome and Introductions

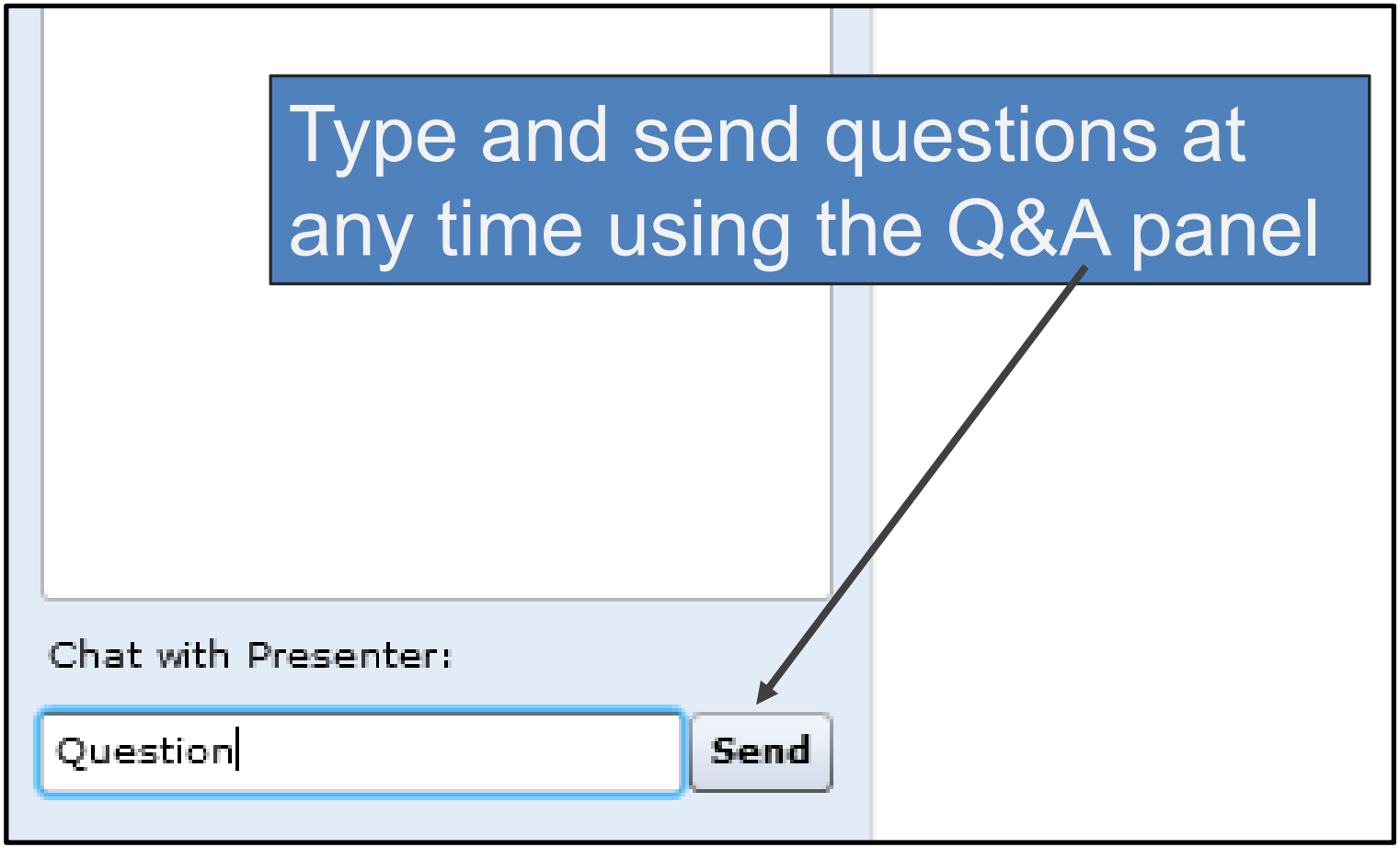
Jennifer Nyman, Ph.D., P.E.
Webinar Facilitator

SERDP DOD • EPA • DOE | ESTCP

Webinar Agenda

- **Webinar Logistics** (5 minutes)
  Dr. Jennifer Nyman, Geosyntec Consultants
- **Overview of SERDP and ESTCP** (5 minutes)
  Dr. Herb Nelson, SERDP and ESTCP
- **Sediment Volume Search Sonar** (50 minutes + Q&A)
  Dr. Daniel Brown, Penn State University
- **Final Q&A Session**

How to Ask Questions



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SERDP and ESTCP Overview

Herb Nelson, Ph.D.
Munitions Response Program Manager

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SERDP

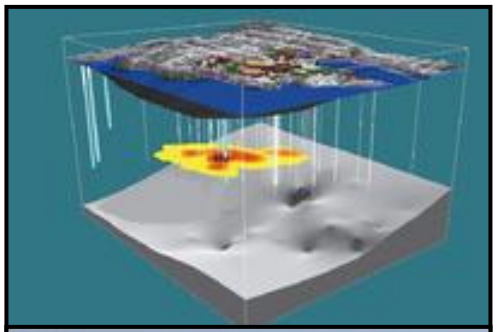
- Strategic Environmental Research and Development Program
- Established by Congress in FY 1991
  - DoD, DOE and EPA partnership
- SERDP is a requirements driven program which identifies high-priority environmental science and technology investment opportunities that address DoD requirements
  - Advanced technology development to address near term needs
  - Fundamental research to impact real world environmental management

ESTCP

- Environmental Security Technology Certification Program
- Demonstrate innovative cost-effective environmental and energy technologies
  - Capitalize on past investments
  - Transition technology out of the lab
- Promote implementation
  - Facilitate regulatory acceptance

Program Areas

1. Environmental Restoration
2. Installation Energy and Water
3. Munitions Response
4. Resource Conservation and Resiliency
5. Weapons Systems and Platforms





Munition Response

- Munitions on land
  - Classification
- Munitions underwater
  - Wide area and detailed surveys
  - Cost-effective recovery and disposal
  - Characteristics of munitions underwater, their environment and mobility

SERDP and ESTCP Webinar Series

Date	Topic
September 6, 2018	Informing Restoration Programs for Threatened and Endangered Plant Species
September 20, 2018	Plant Diversity and Biological Nitrogen Fixation in Longleaf Pine Ecosystems at Military Installations
October 4, 2018	SERDP & ESTCP Chlorinated Solvents Workshop Overview and Feature Project
October 18, 2018	Restoration of Chlorinated Solvent Contaminated Groundwater Sites: The Value of Information Challenge
November 1, 2018	Supporting DoD Installation Sustainability Through Informed Stormwater Management
November 15, 2018	Stormwater Impacts on Sediment Recontamination
December 13, 2018	Installation Energy and Water Program Area Webinar

For upcoming webinars, please visit

http://serdp-estcp.org/Tools-and-Training/Webinar-Series

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Save the Date!

A three-day symposium showcasing the latest technologies that enhance DoD's mission through improved environmental and energy performance

November 27-29, 2018

Washington Hilton Hotel

Registration is open

Sediment Volume Search Sonar

Daniel Brown, Ph.D.
Penn State University

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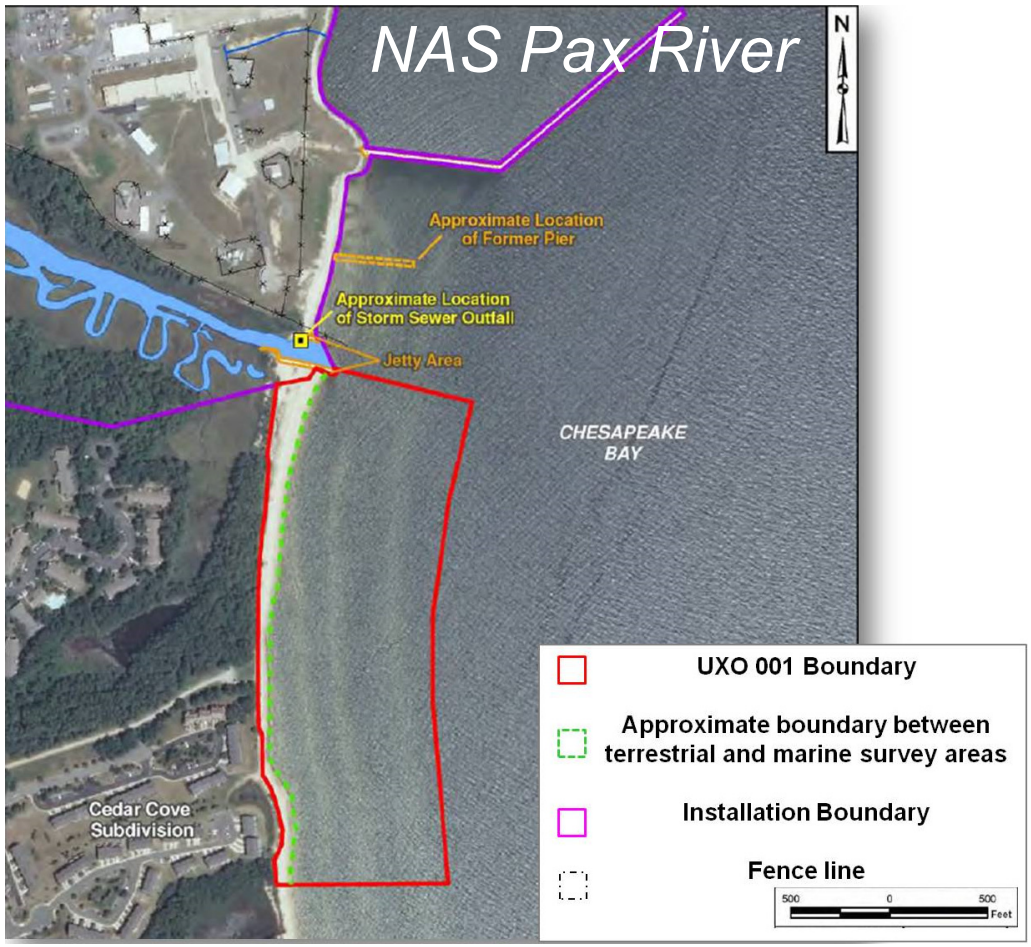
Agenda

- Problem statement and program overview
- Fundamentals of sonar imaging
- Modeling sensor performance
- Q&A Session 1
- Initial results from a prototype demonstration
- Q&A Session 2

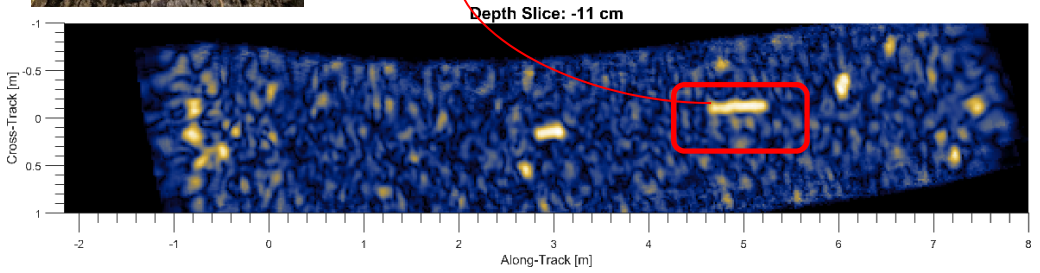
Shallow Water UXO Munitions Remediation Problem

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



Sediment Volume Search Sonar (SVSS)

- Design and demonstration of a system capable of very-shallow-water, buried-UXO imaging
- Technology development
  - Surface craft and sonar system for very shallow water
  - Sonar system design and signal processing for buried UXO imaging
- Project progress and results
  - Modeling and simulation effort is completed
  - Prototype field experiments have been conducted



SVSS Sensor Must Address Four Challenges

- Multipath reverberation interference
- Gain compared to existing systems
- Effect of platform motion
- Effect of sediment property variability

Program 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

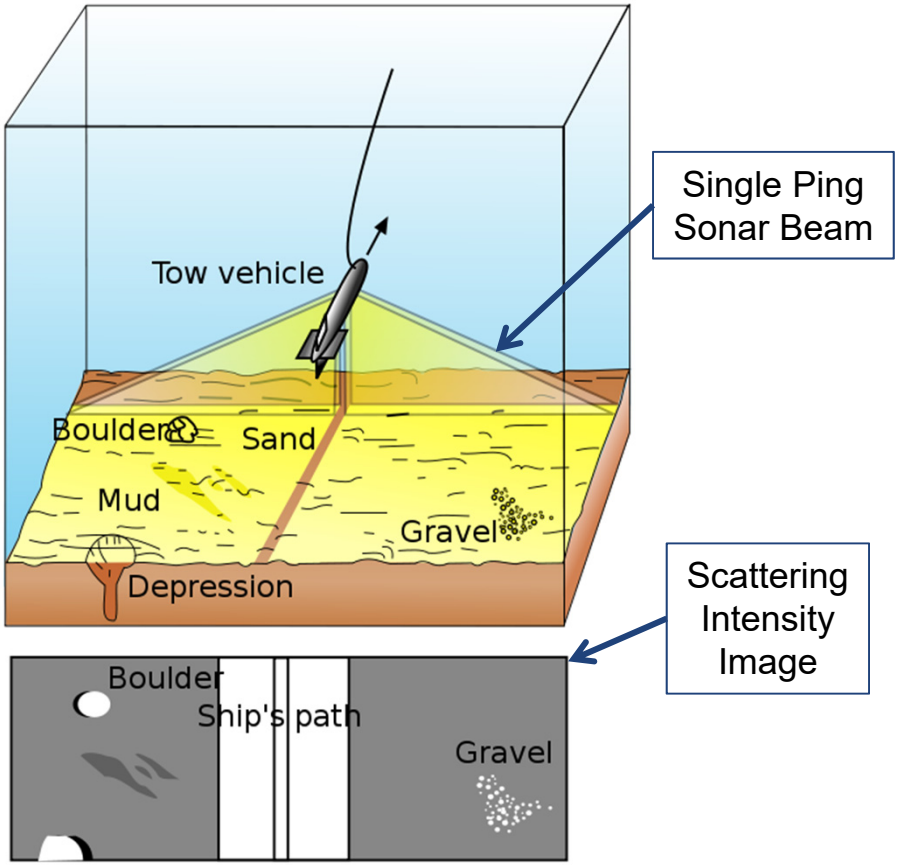
- Purpose-built hardware design based on lessons learned
- Further refinement of signal processing and data visualization
- Demonstrate performance for UXO detection

System Operation Concept

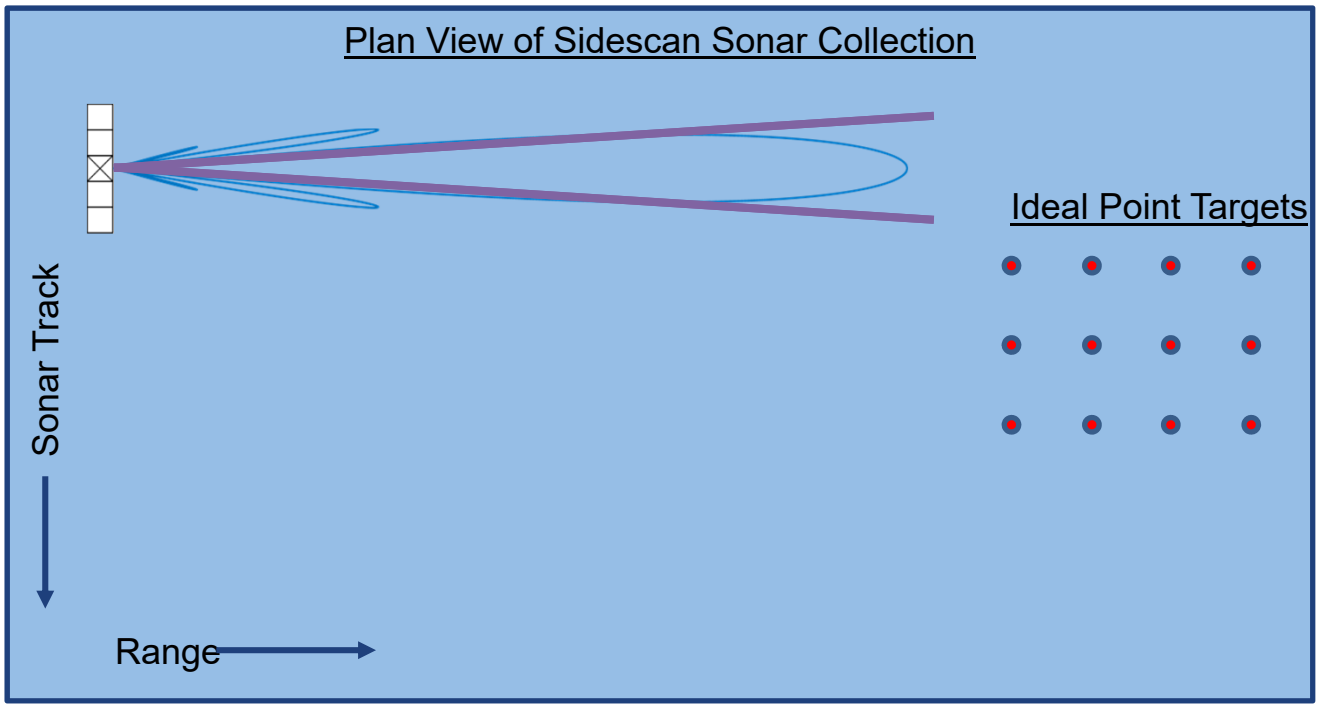
- SVSS is a 2D synthetic aperture sonar (SAS) designed to create 3D imagery in shallow water
- Uses SAS processing to create high-resolution imagery within the seafloor
- Following slides give a basic overview of sonar imaging technology

Real Aperture Sonar Concept

- An acoustic image is a spatial map of acoustic scattering intensity
- Map resolution determined by range, transducer size and frequency
- Pixel values are typically proportional to scattering intensity



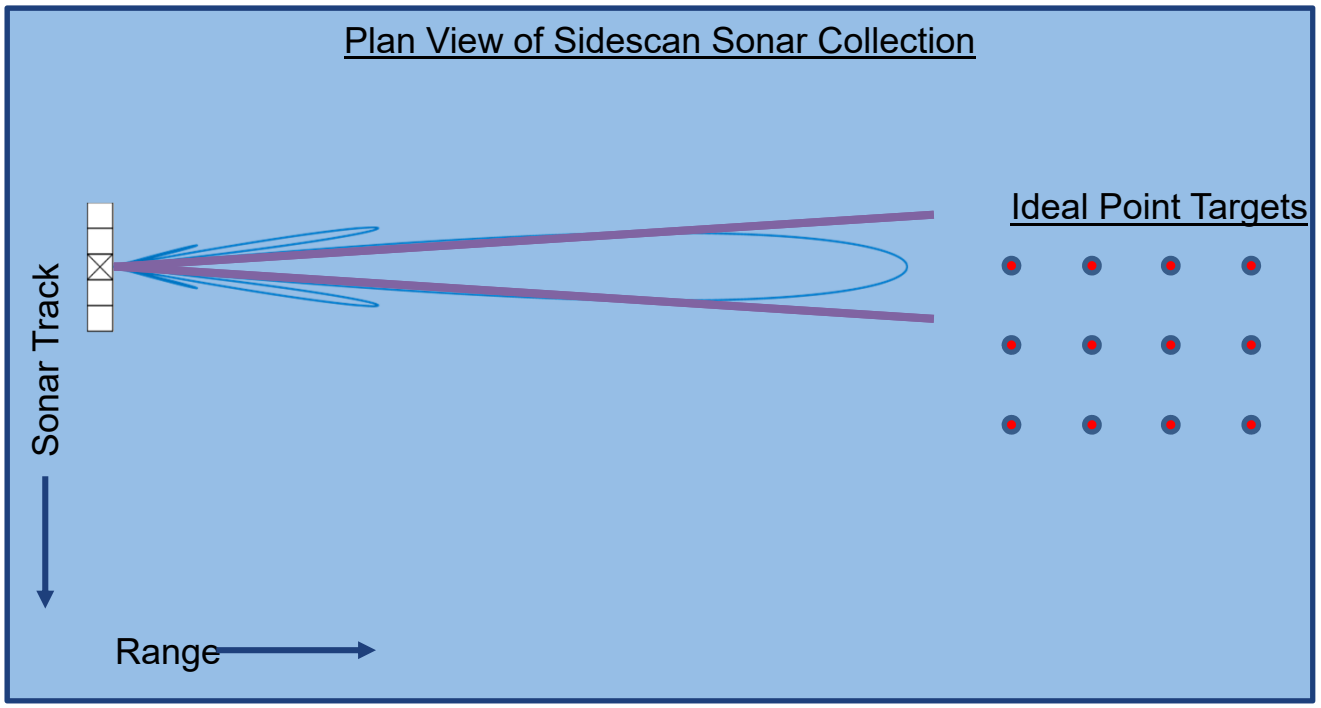
Imaging Sonar Concept



Sidescan Image

- **Color is proportional to scattering strength**
- **Along-track resolution degrades with range**

Imaging Sonar Concept



Sidescan Image

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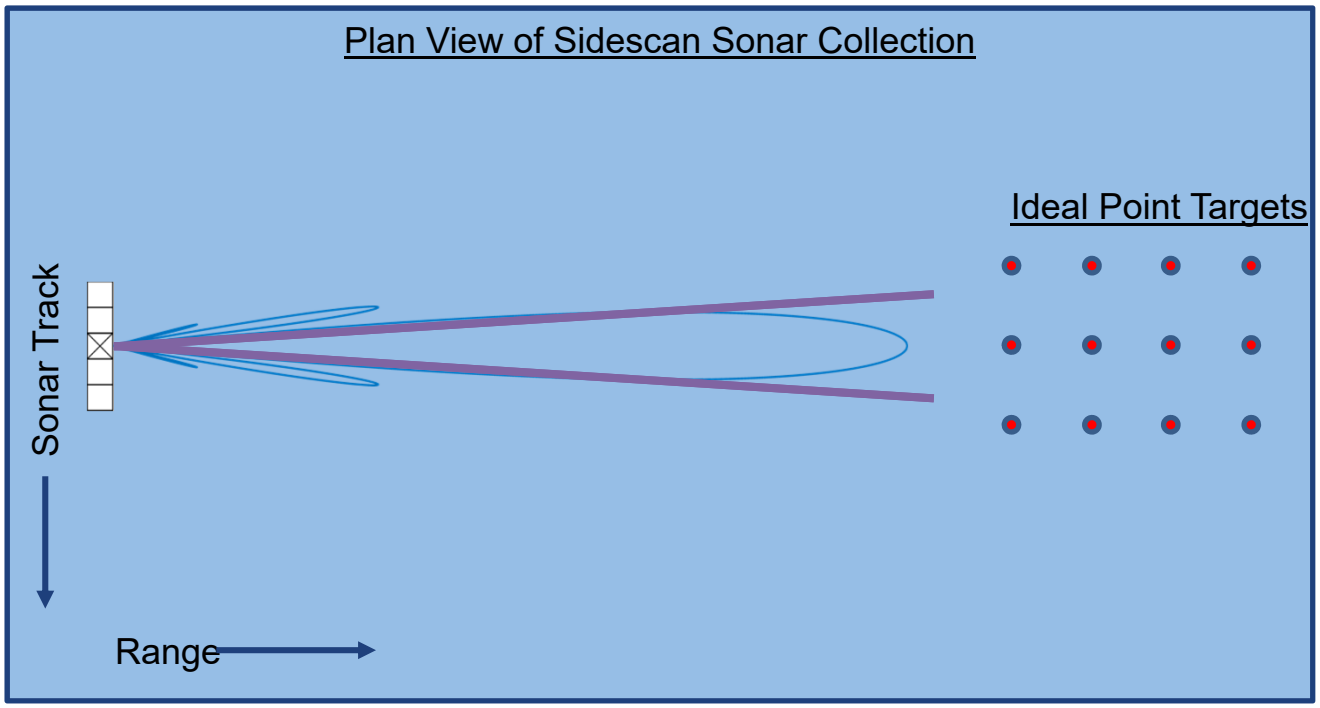
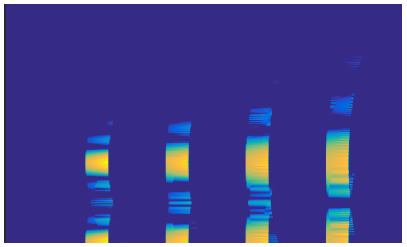
Imaging Sonar Concept



Sidescan Image



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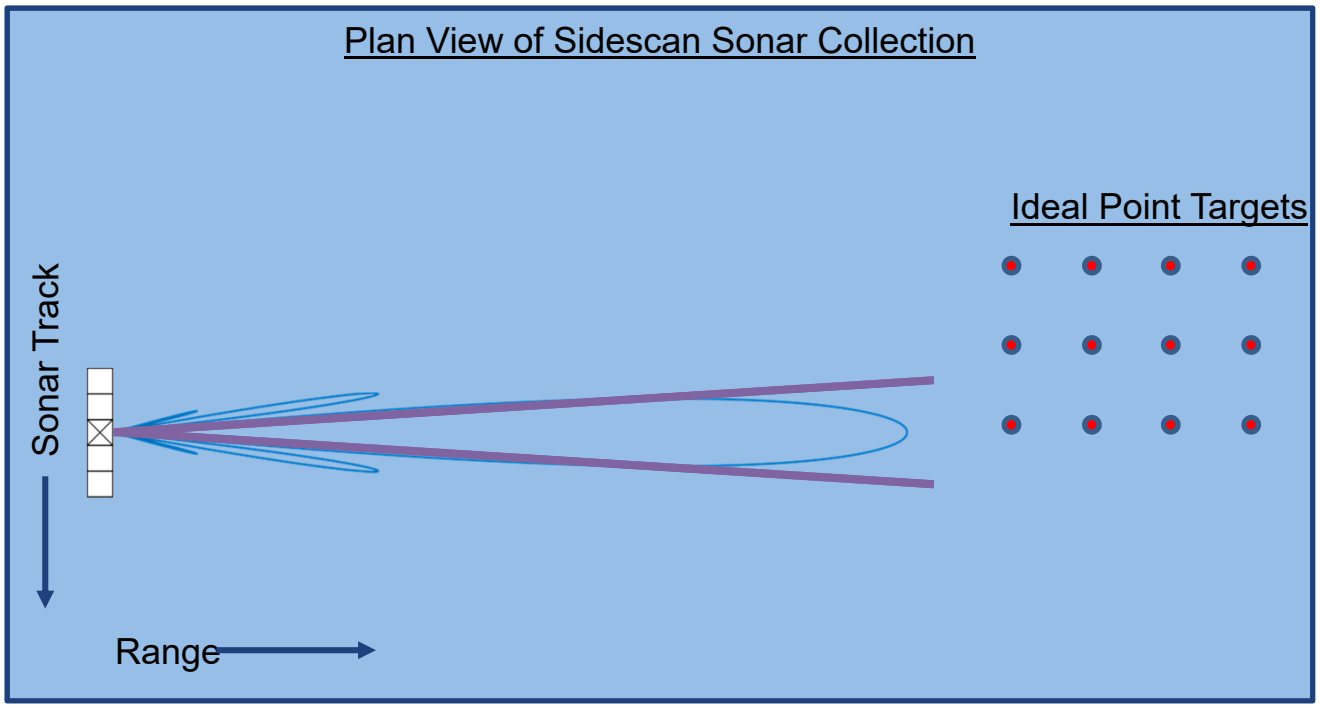
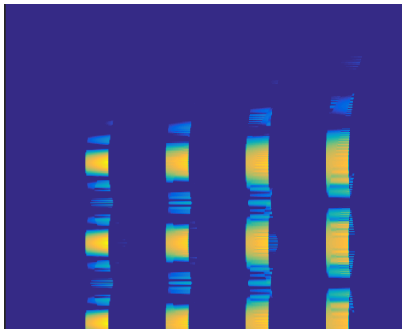
Imaging Sonar Concept



Sidescan Image



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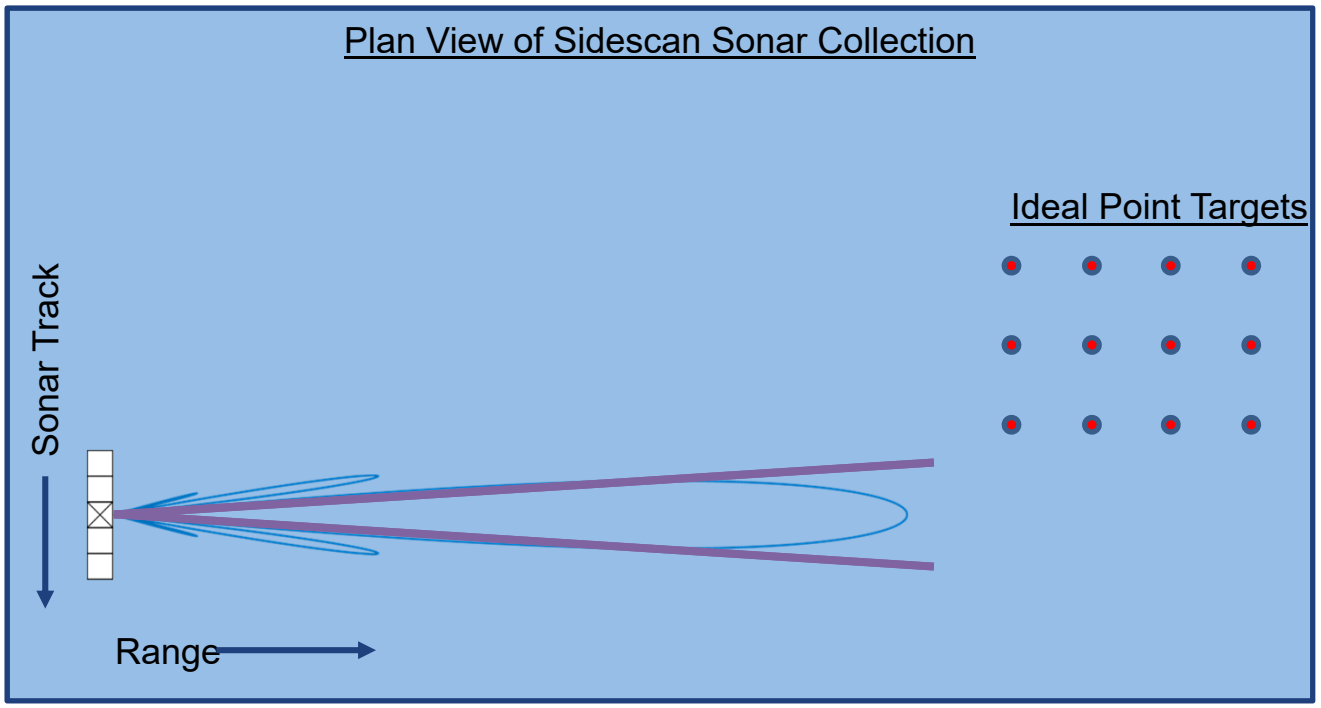
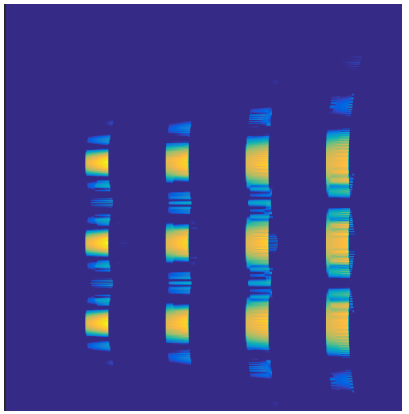
Imaging Sonar Concept

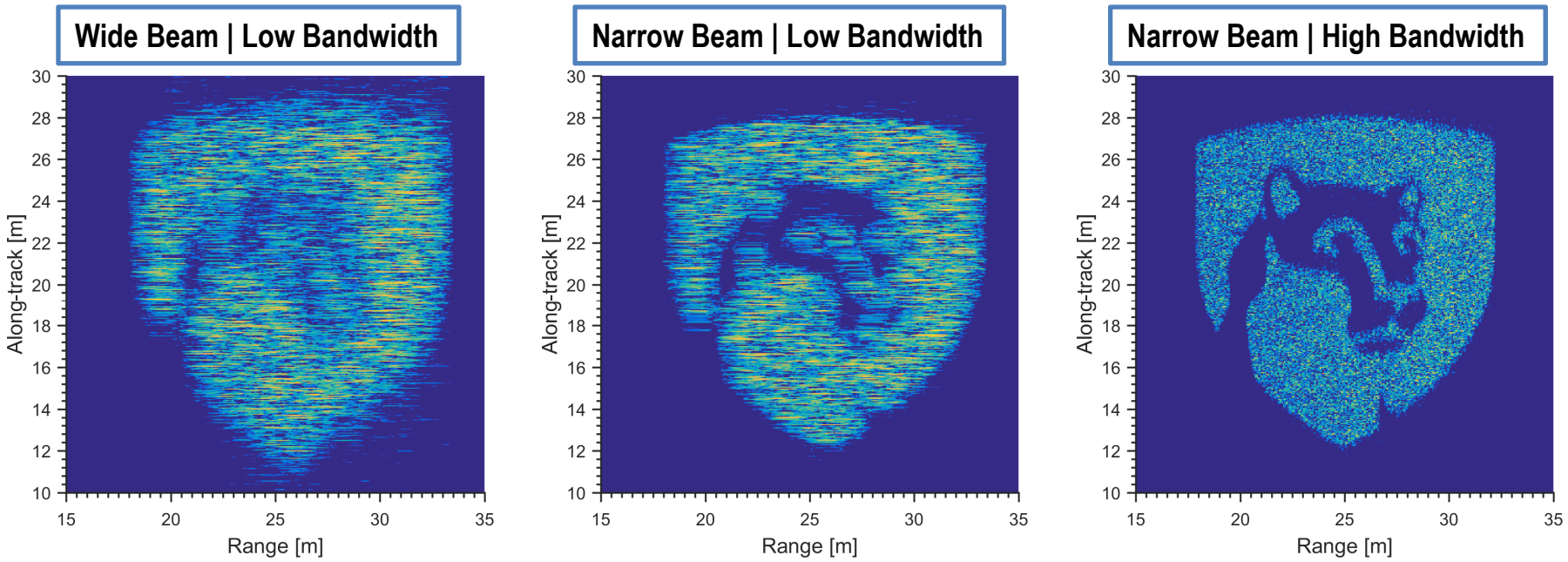


Sidescan Image



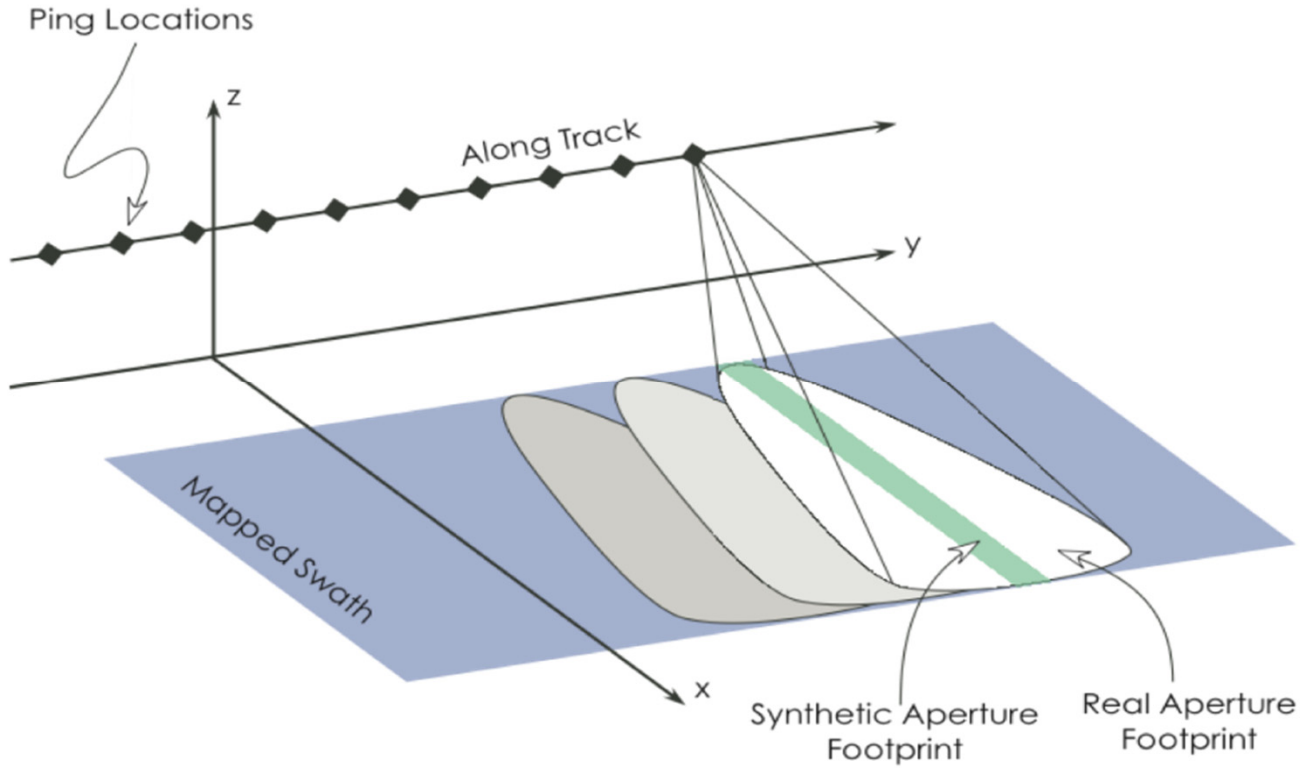
- **Color is proportional to scattering strength**
- **Along-track resolution degrades with range**

Improving Sensor Resolution Improves Image Quality and Interpretability



Higher resolution imagery allows an operator to detect smaller targets or additional target features

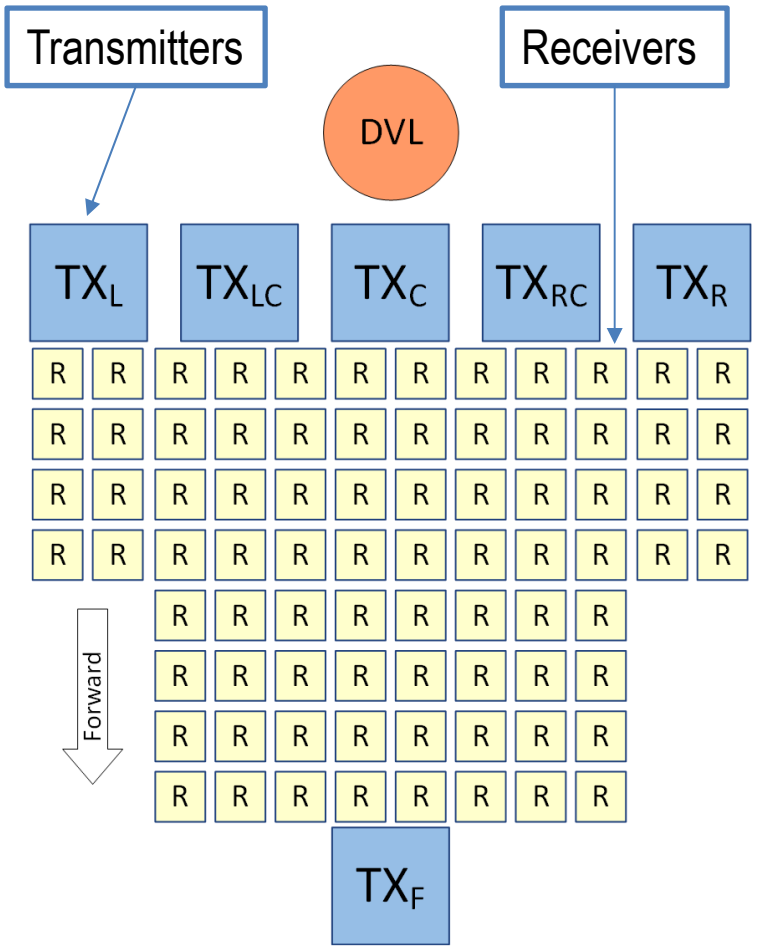
Synthetic Aperture Processing Achieves High-Resolution Imagery



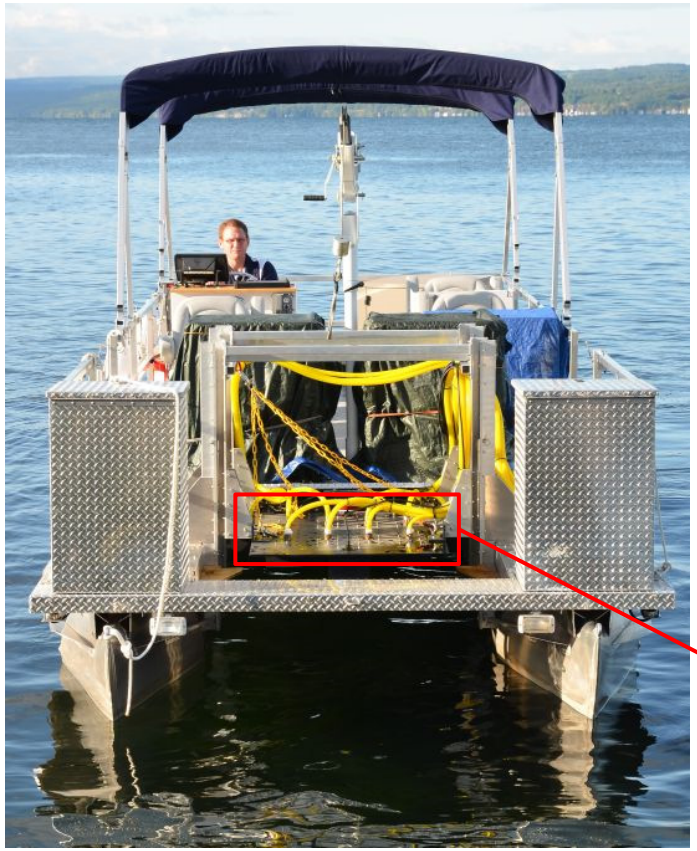
Using synthetic apertures processing enables the detection of buried ordnance

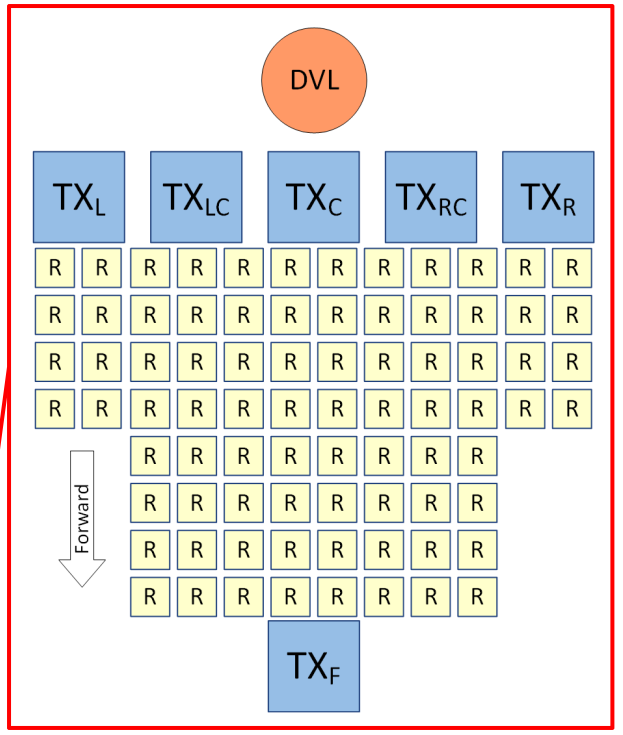
Two-Dimensional Synthetic Aperture for Three-Dimensional Sonar Imagery

- SVSS is a 2D SAS designed to create 3D imagery in shallow water
- Prototype stage leverages an existing test platform



SVSS Mounted to Existing Test Platform



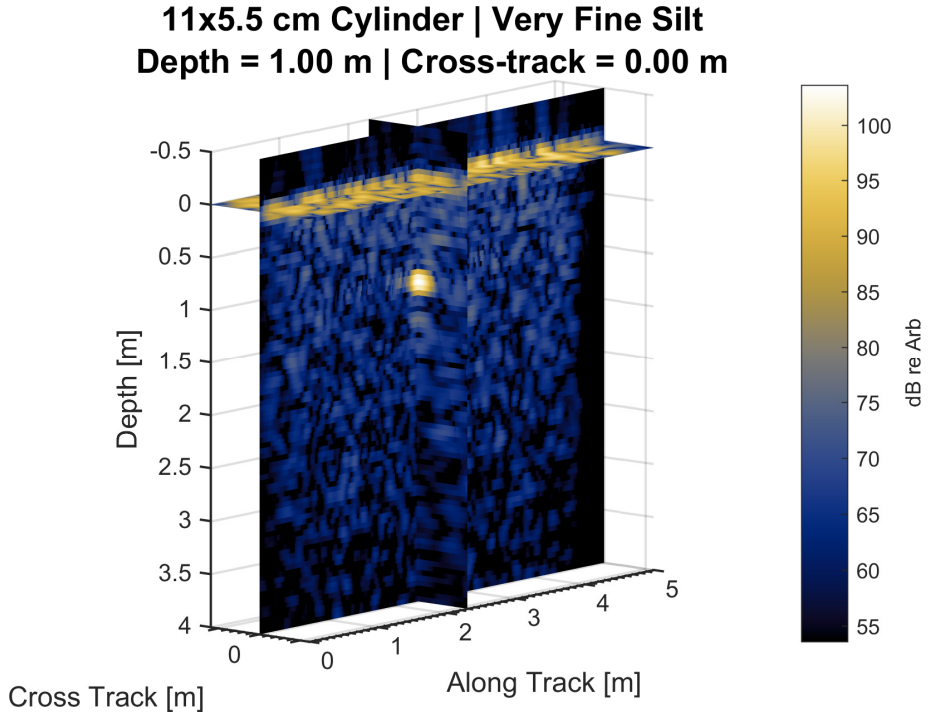


Modeling SVSS Performance

Modeling and Simulation to Support SVSS Design

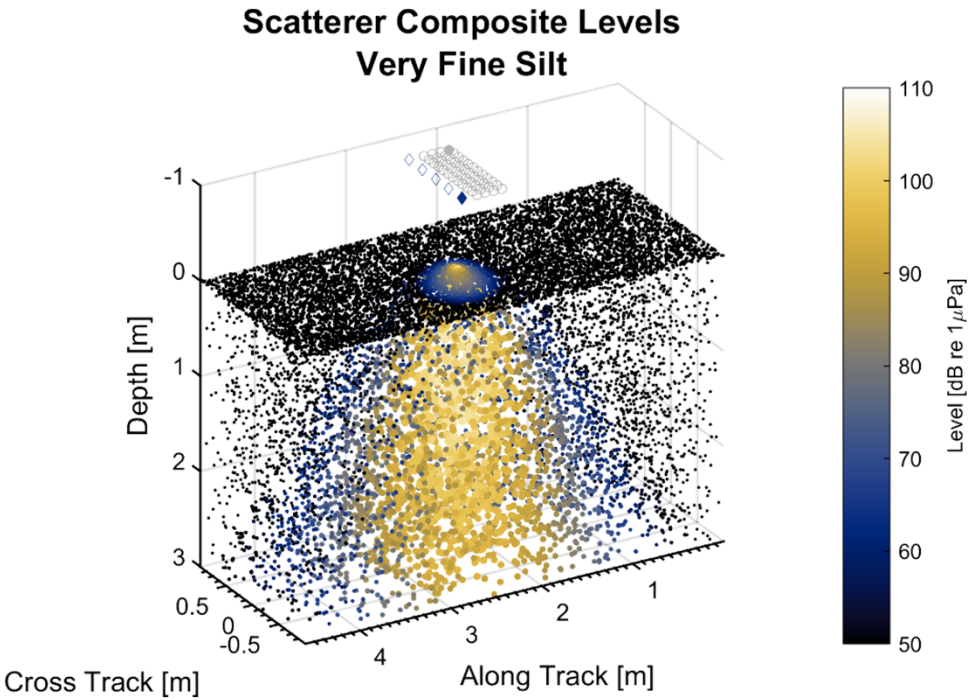
- Approach
  - Leverage a pair of existing models and adapt them to the buried UXO problem
- Environmental model
  - Applied Research Lab, Pennsylvania State University
- Target model
  - Applied Physics Laboratory, University of Washington
- Combined models produces synthetic data that can be processed to form 3D imagery

Simulated 3D Buried UXO Image



ARL/PSU - Point-based Sonar Scattering Model (PoSSM)

- PoSSM is a 'model-of-models' simulation engine for the scattered pressure field
  - Representative time series
  - Element-level calculations
  - Frequency dependent
  - Calibrated output
  - Expected field spatiotemporal coherence
- MATLAB for development
- C++ / CUDA accelerated kernel



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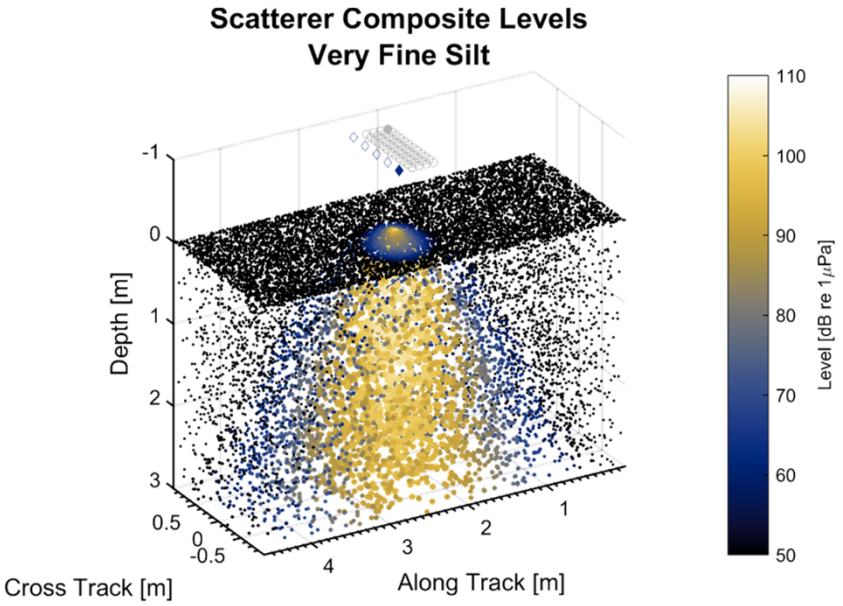
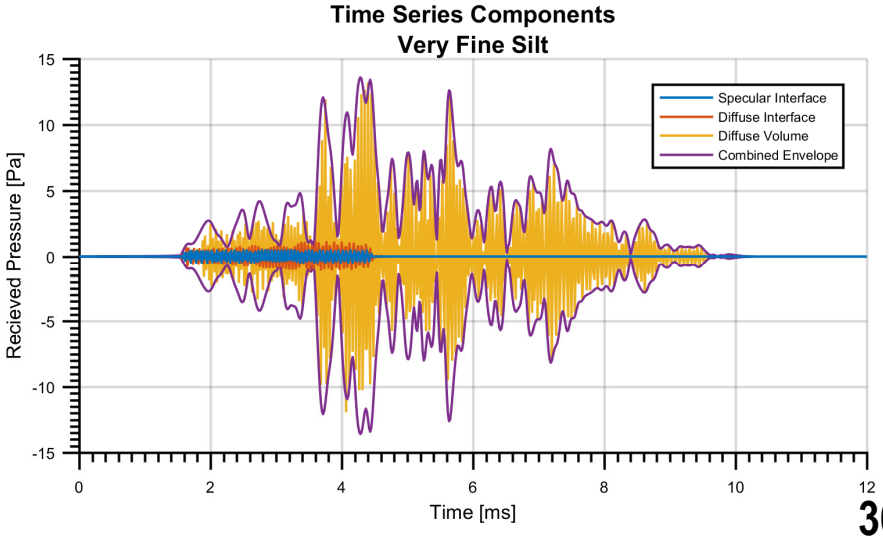


- Scattered field is calculated for individual points
- Separate calculation for interface/volume and specular/diffuse scattering

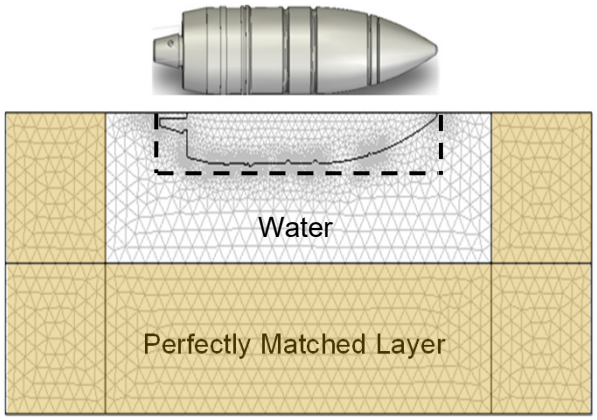
PoSSM provides a flexible model for generation of coherent time series for environmental scattering

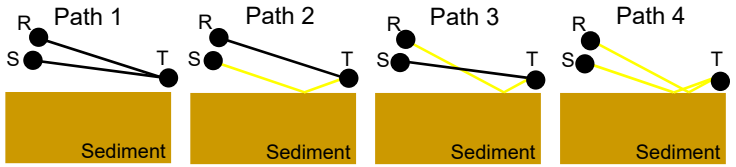


APL/UW - Target in the Environment Response

- APL/UW Target in Environment Response (TIER) target signatures
- TIER combines Finite Element and propagation model for target scattering
- TIER supports simulation of a number of UXO shapes
- Extend TIER to include bistatic paths and SVSS sonar geometry

FE Mesh for 100-mm Aluminum UXO

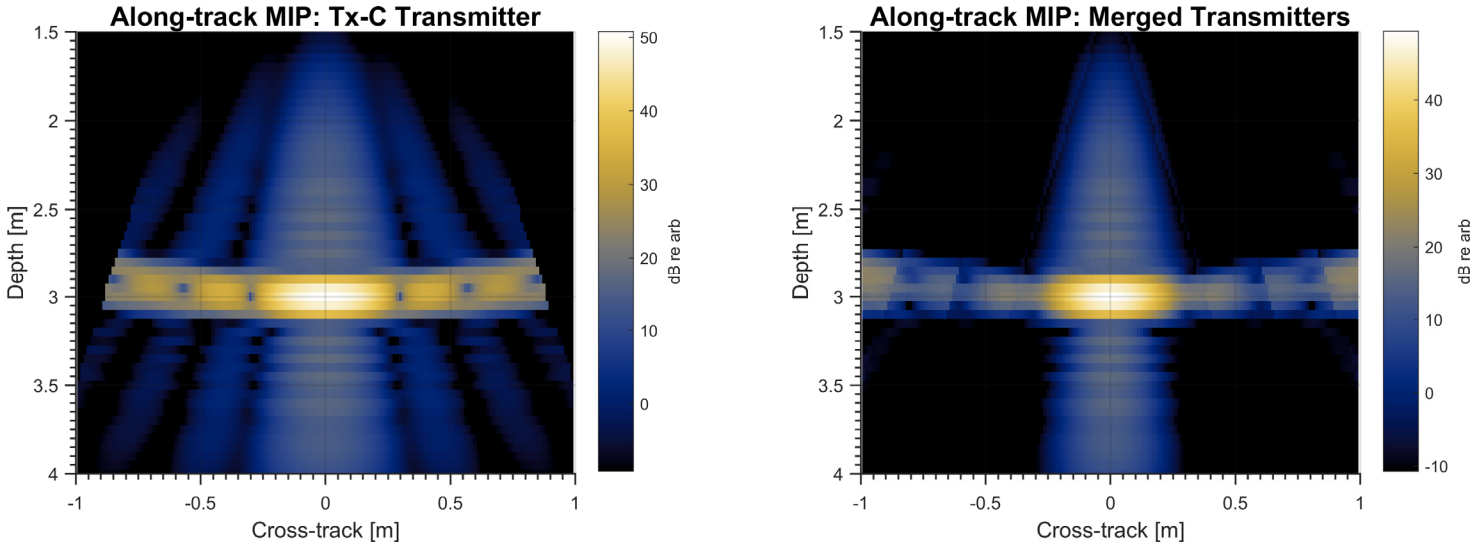




Resolution Target Simulations

Five Transmitter Design Improvements

- Coherent addition of cross track transmitters improves system performance
- Full gains realized at larger target depth from sensor



Multi-transmit design provides improvements over standard, single-transmit system designs

Resolution Target Simulations

Five Transmitter Design Improvements

- Coherent addition of cross track transmitters improves system performance
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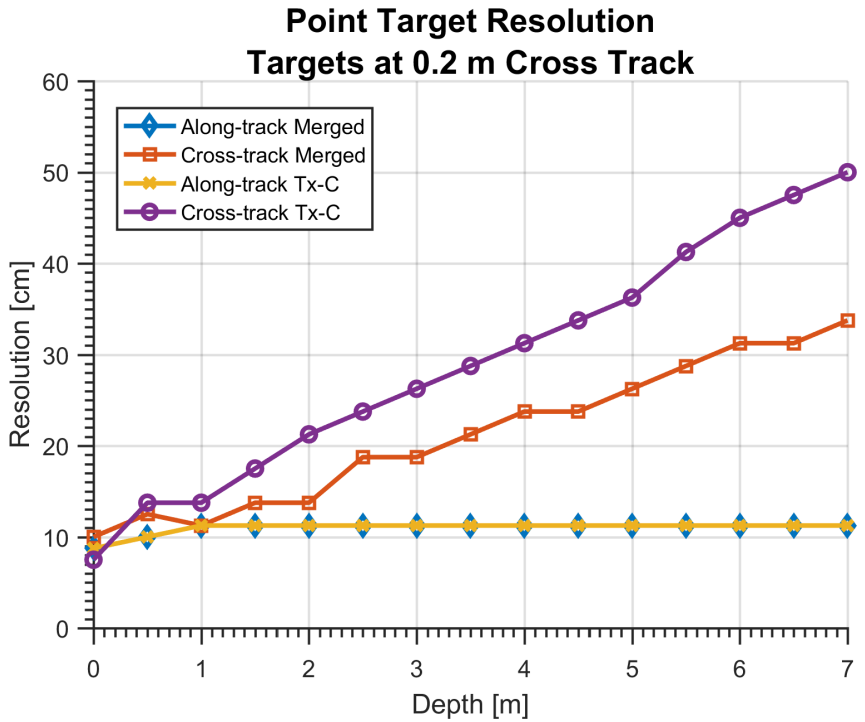
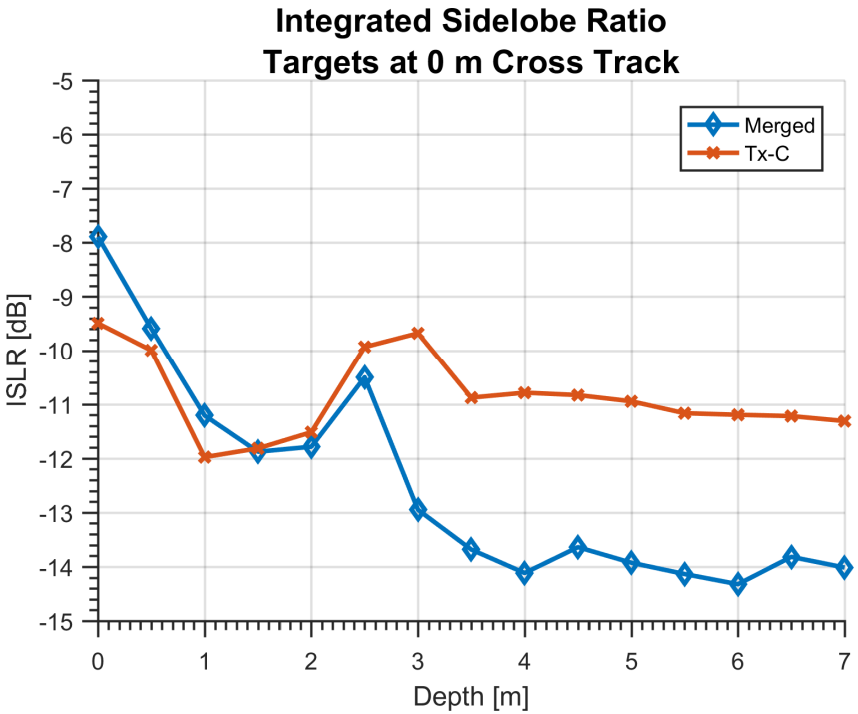


Five transmitter, two-dimensional synthetic aperture formation improves cross track imaging resolution

Resolution Target Simulations

Five Transmitter Design Improvements

- Target/background separability is measured using the integrated sidelobe ratio
- Multi-transmit approach shows gains over single projector

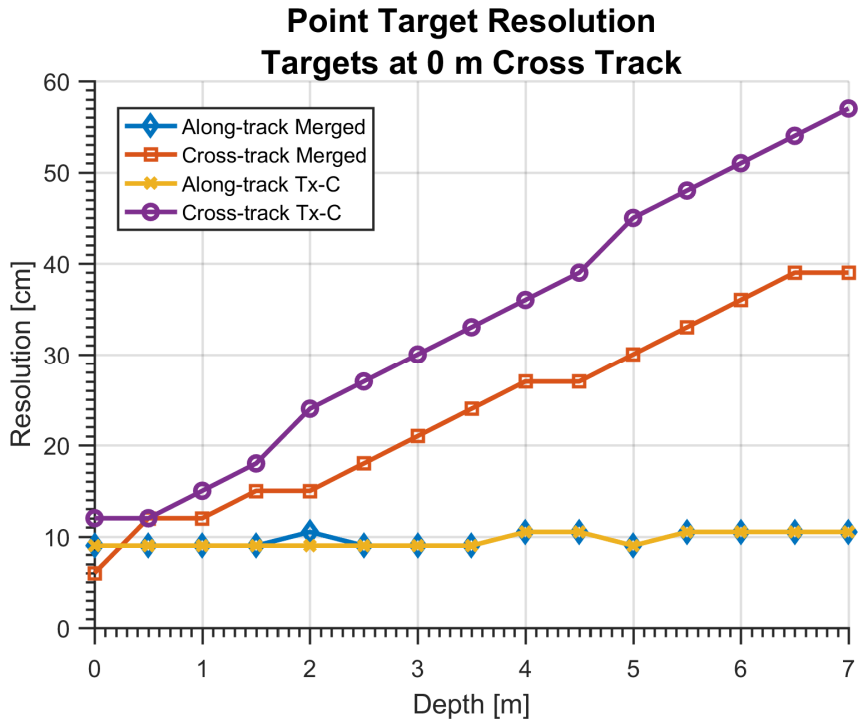


Five transmitter, two-dimensional synthetic aperture formation improves rejection of sediment interference

Resolution Target Simulations

Impact of Sediment Sound Speed Mismatch

- Refraction at the sediment/water boundary is modeled
- Adapting the image formation process can recover the system resolution



Including refraction effects in the image formation process can recover system resolution

Resolution Target Simulations

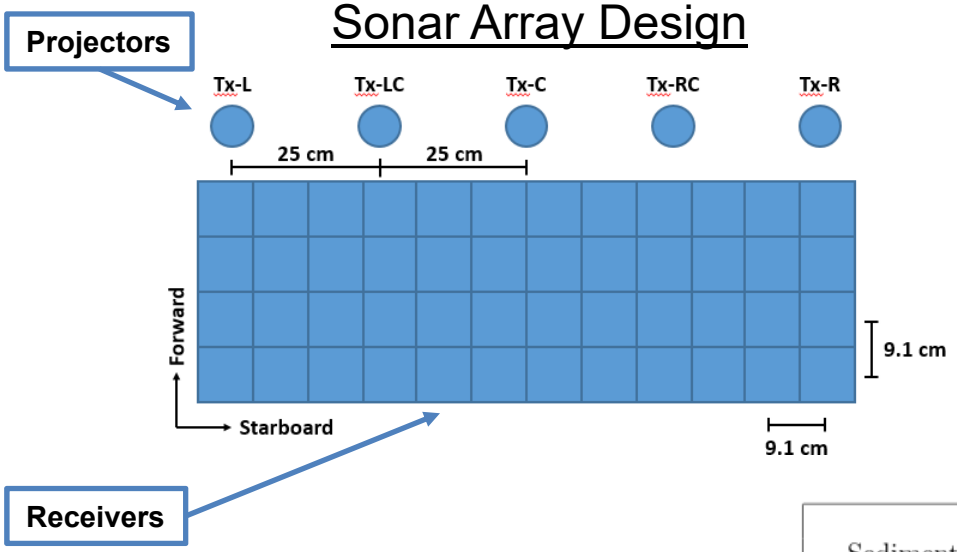
Framework to Address Program Challenges

- Demonstrate advantages of multi-transmit design
- Quantify system theoretical resolution
- Investigate impact of environmental mismatch
- Learn how to adapt existing image formation algorithms to 3D signal processing

PoSSM/TIER Environmental Simulation Parameters

- PoSSM and TIER were used to evaluate system performance across a range of environments
  - Prototype simulation design used subset of receivers

Sonar Array Design



Sonar Operating Band
15-25 kHz

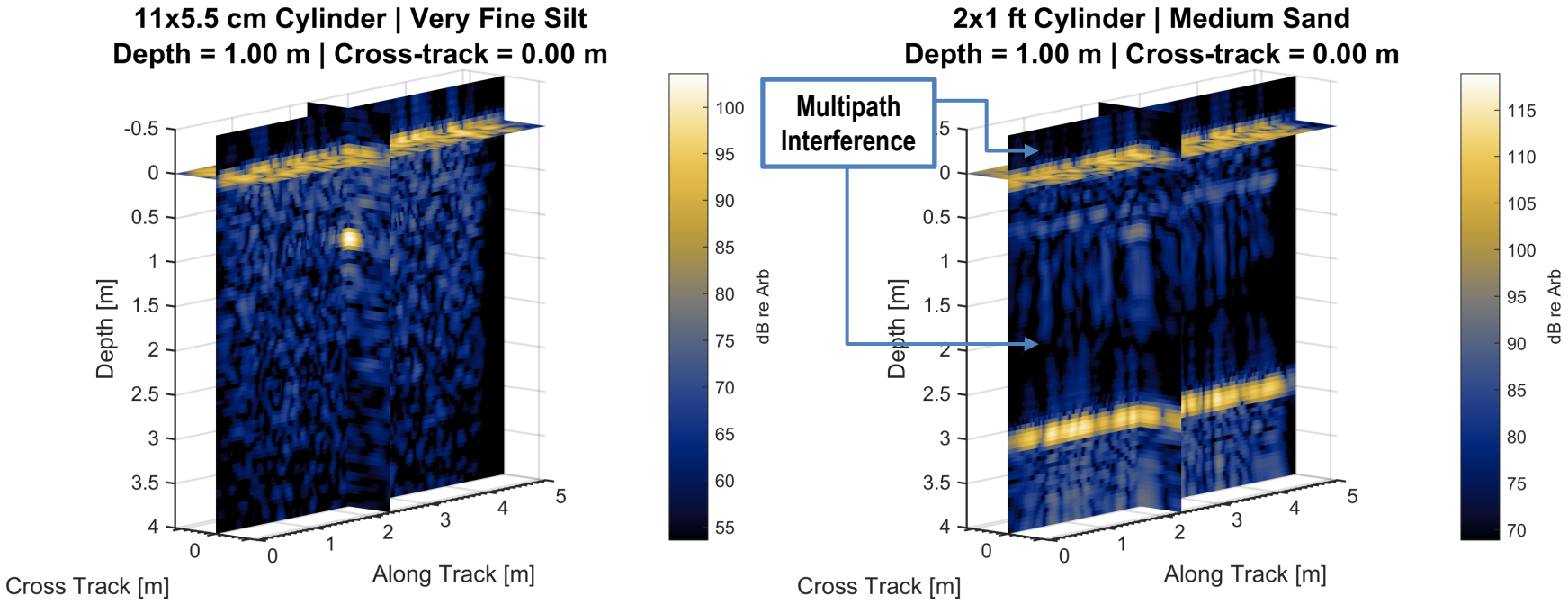
Simulated Targets

TIER Target Name	TIER Target ID Number	Material	Length [cm]	Diameter [cm]
Large Cylinder	221	Steel	61.0	30.5
Small Cylinder	224	Steel	11.0	5.5
Sphere	225	Steel	N/A	11.0

Sediment Types

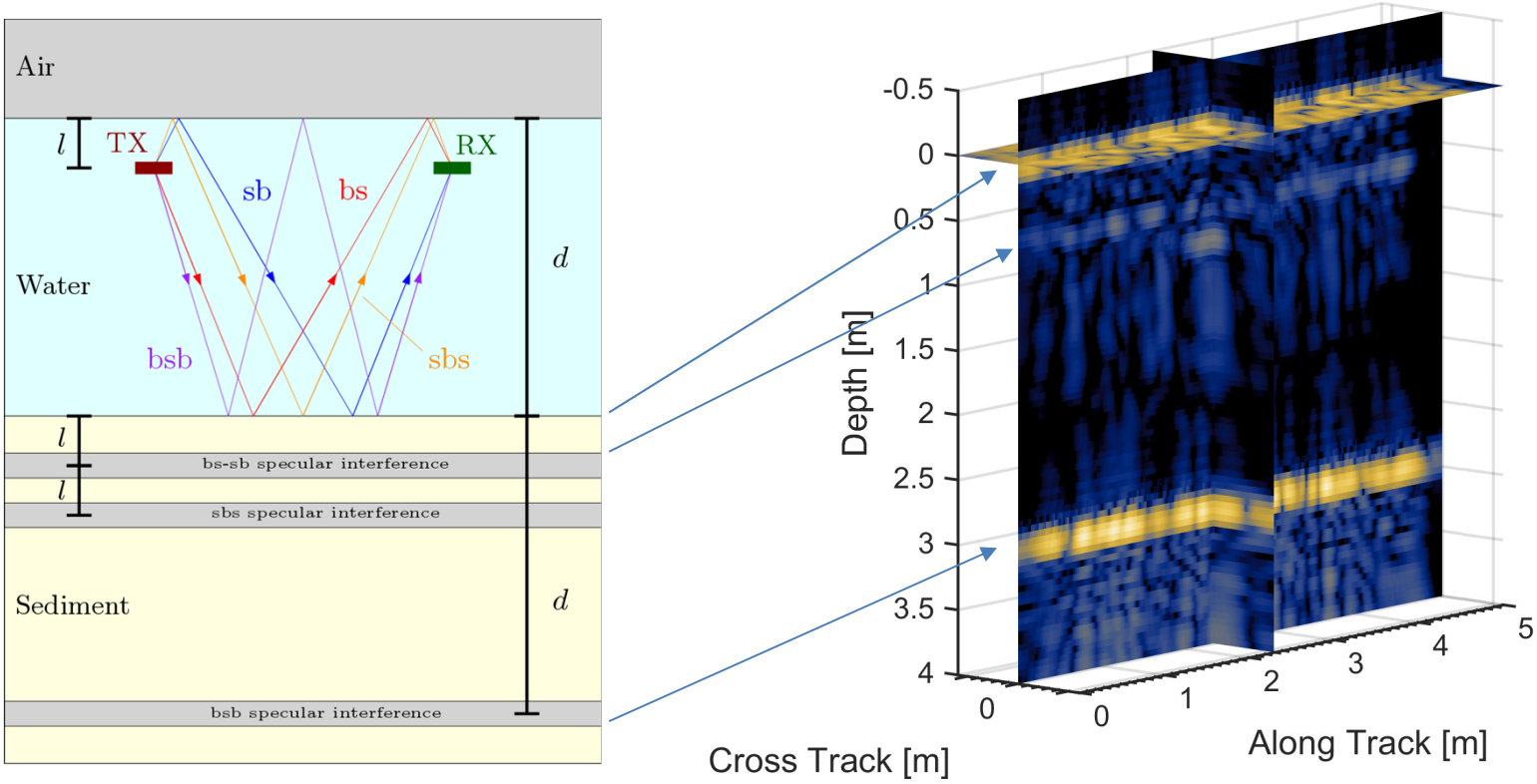
Sediment Name	Sediment Density [kg m^{-3}]	Sound Speed [m s^{-1}]	Attenuation Coefficient [dB m^{-1}]	Spectral Strength [$m^{(4-\gamma)}$]	Spectral Exponent [Unitless]	Vol. Scat. Strength [dB m^{-1}]
Medium Sand	1845	1767	10.0	1.410E-4	3.25	-20.0
Very Fine Silt	1147	1476	1.4	1.638E-5	3.25	-28.6
"Water Sand"	1845	1500	0.0	1.410E-4	3.25	-20.0

SVSS Evaluated Across a Range of Environments/Targets



SVSS will provide a buried target imaging capability in water depths less than 5 meters

Modeling Multipath Interference Impact on Sensor Performance



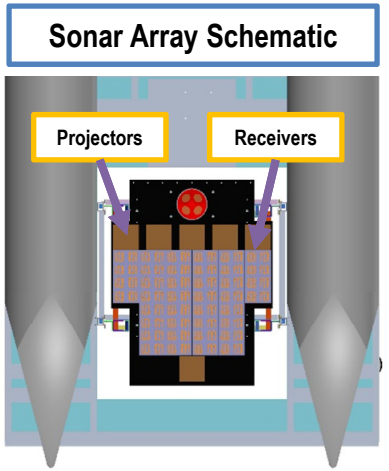
<u>Design Requirement</u>: Multipath mitigation will require at least 20 dB passive rejection from the projector and receiver design

Q&A Session 1

Phase 2
Prototype Field Experimentation

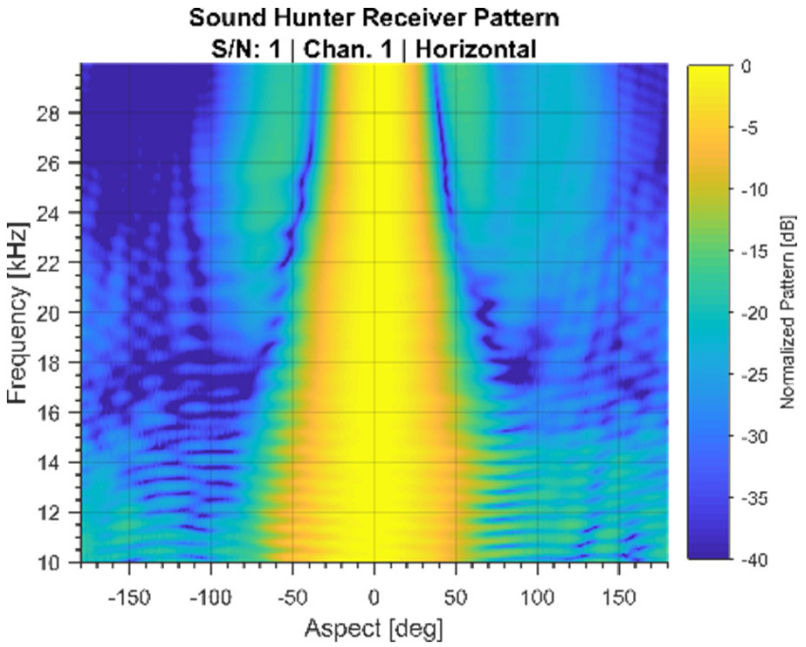
SVSS Prototype Sensor Design

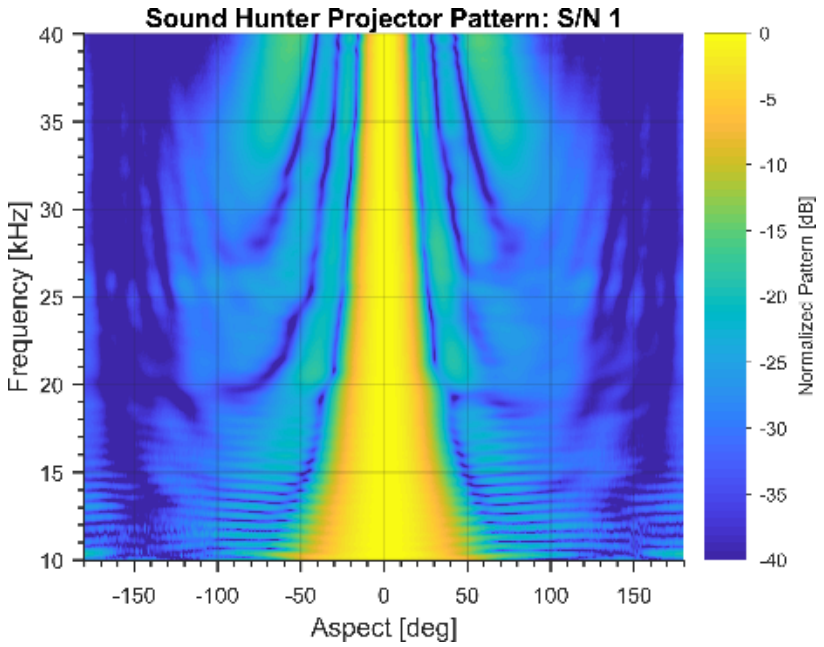
- Modeling and simulation results informed the prototype sensor design
  - Significant leverage of existing hardware for demonstration
- Surface craft permits operation in water depths less than 1 m
- Reconfigurable data acquisition system for experimentation



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 and Receiver Design

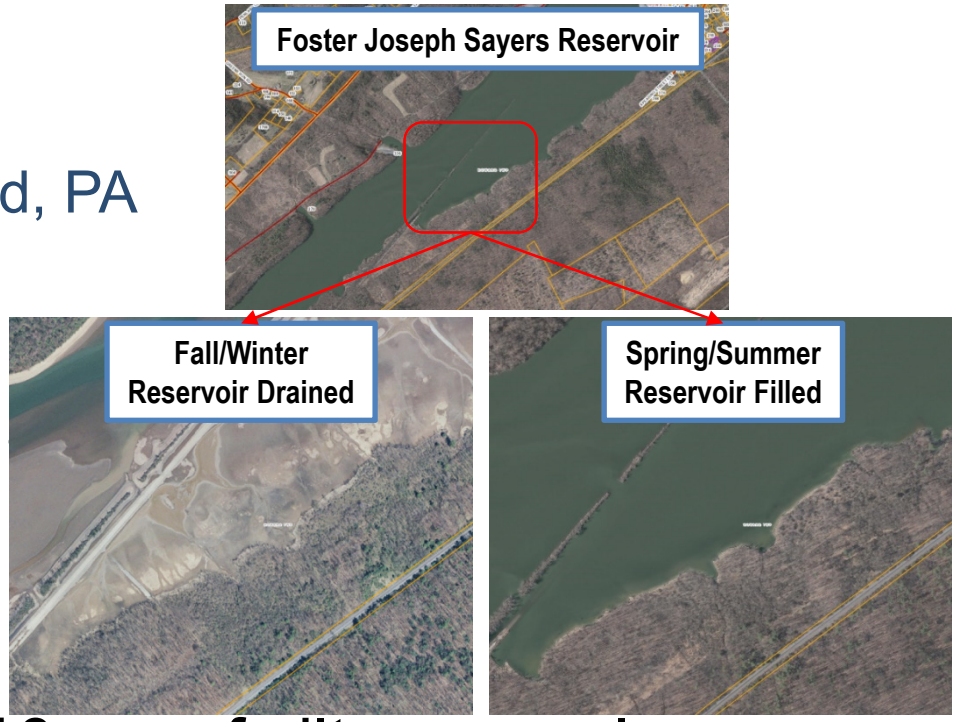




<u>Design Requirement Realized</u>: Projector and receiver provide at least 25-35 dB of passive rejection of multipath interference

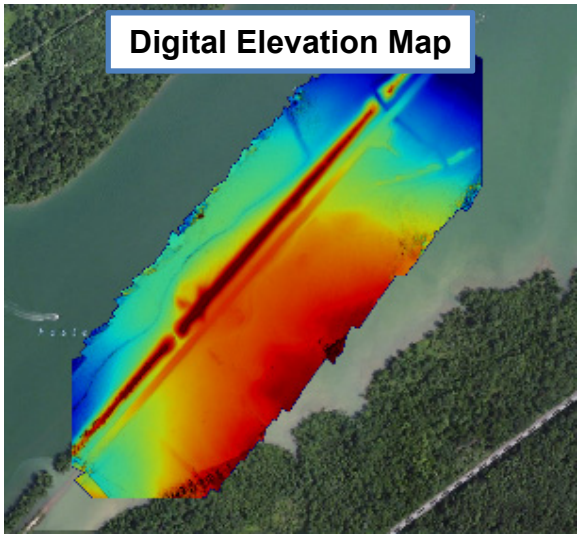
SVSS Test Site Preparation

- Foster Joseph Sayers Reservoir
  - Flood control lake at Howard, PA
- Winter "draw down" provides access to lake-bed for establishing field with accurate ground truth
- Early site characterization found ~10 cm of silt over a clay basement



Winter lake "draw down" provides a unique opportunity to install targets with high-fidelity ground truth

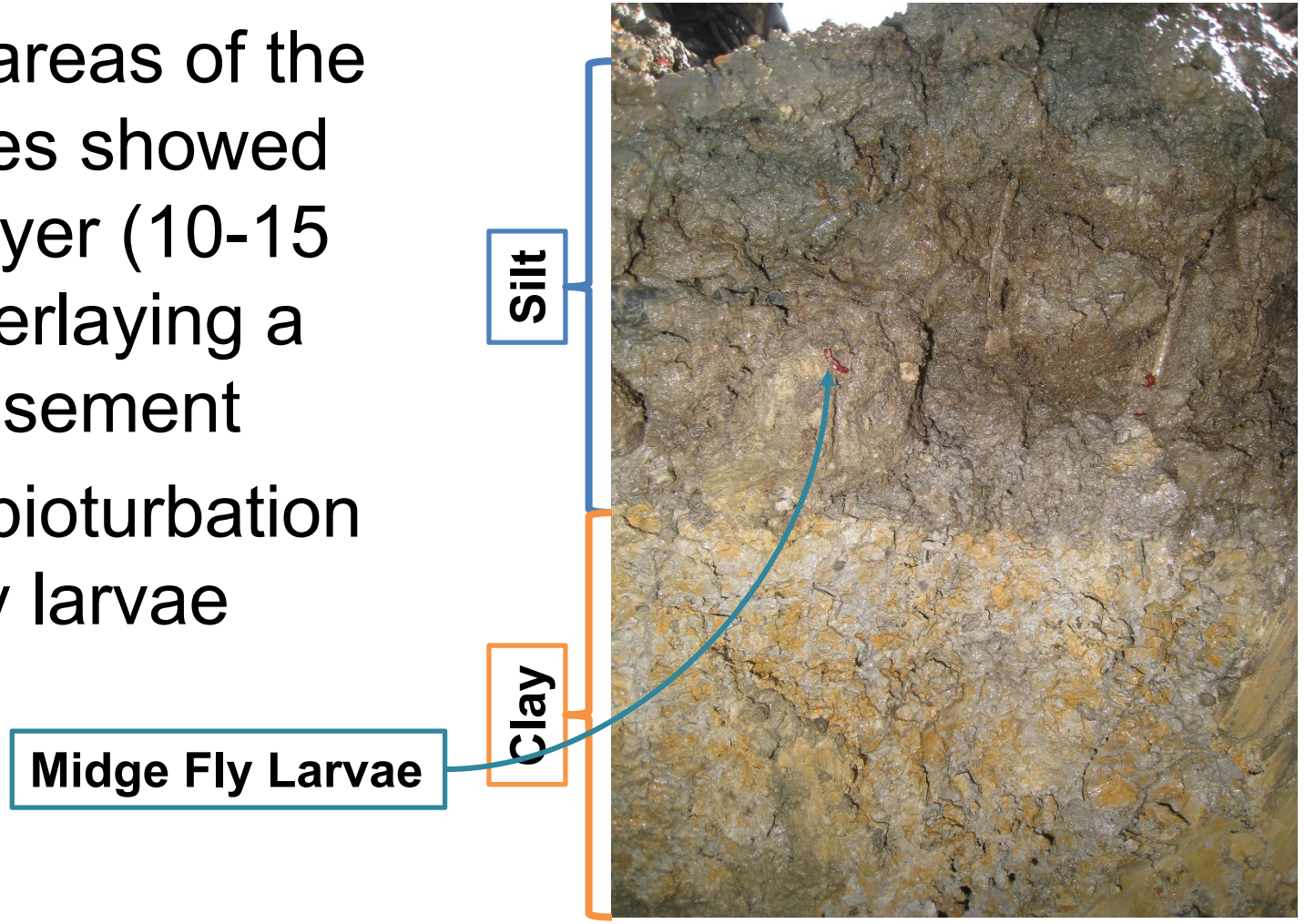
Target Installation and Characterization



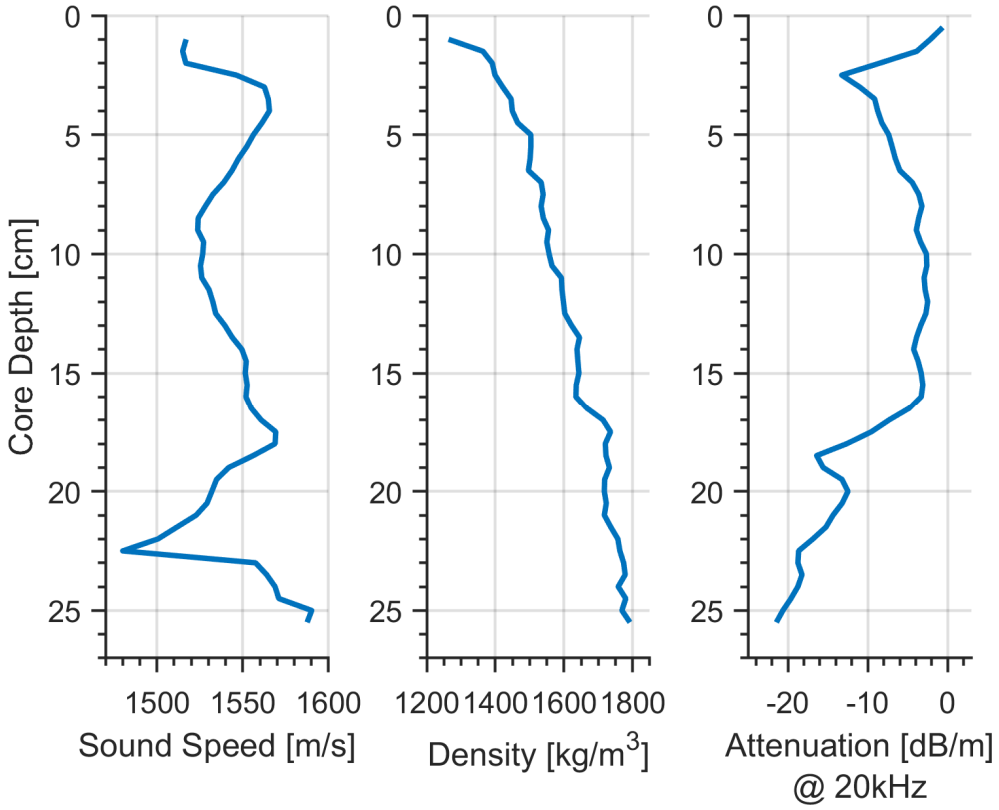
Target location, burial depth and orientation were recorded

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 Core Analysis

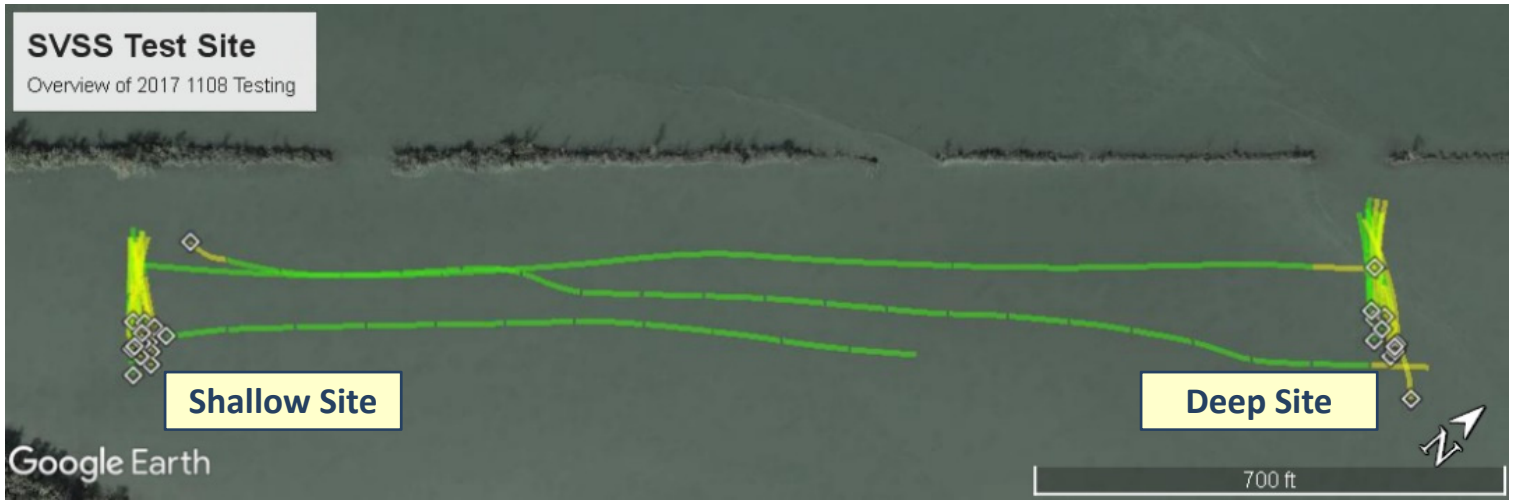


Sediment Name	Sediment Density [kg m^{-3}]	Sound Speed [m s^{-1}]	Attenuation Coefficient [dB m^{-1}]
Medium Sand	1845	1767	10.0
Very Fine Silt	1147	1476	1.4
"Water Sand"	1845	1500	0.0
Measured (median)	1602	1542	12.5

Single sediment core collected near test site does not show silt/clay transition. Additional cores were collected 03/30/18

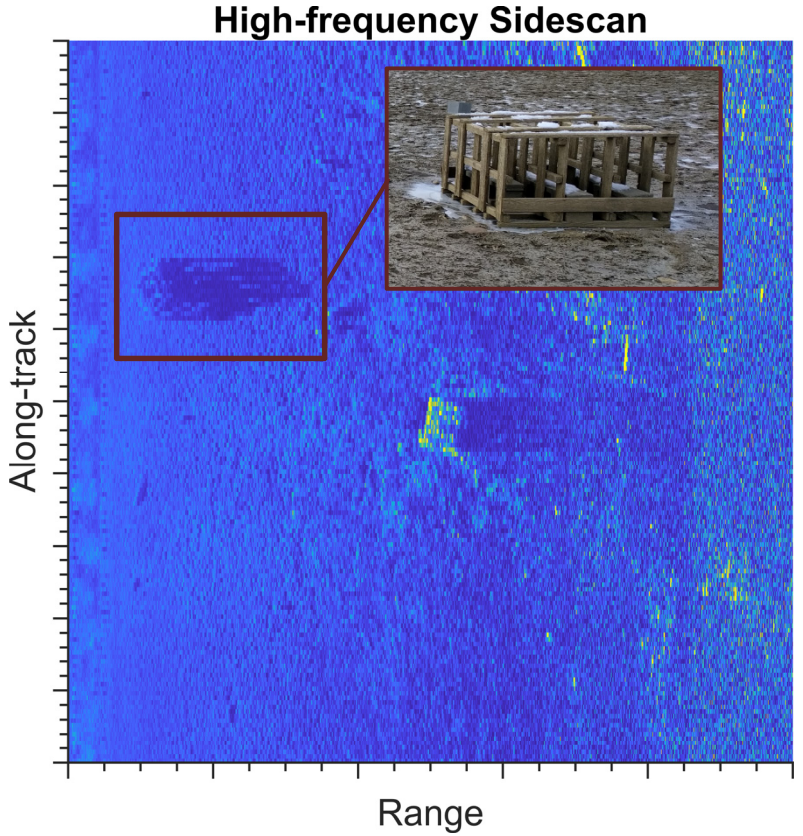
Prototype Integration and Testing in the Summer/Fall of 2017

- 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 test focused on survey and imaging of deployed targets
  - Sediment samples collected to characterize test environment



High-Frequency Sidescan Survey

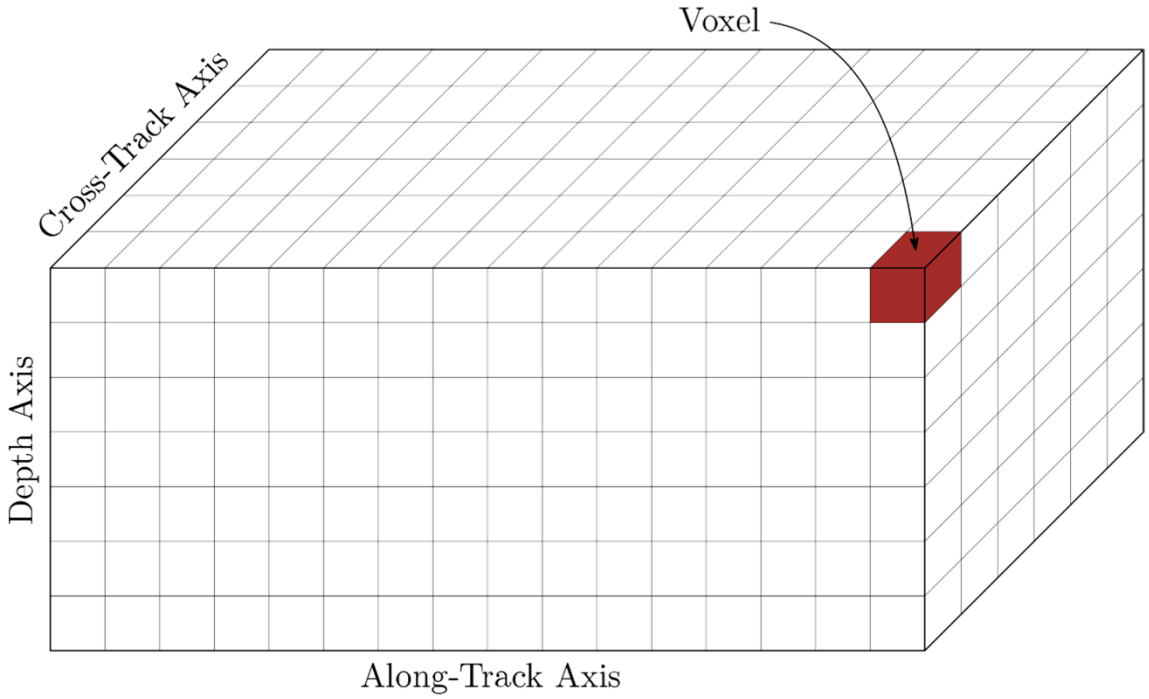
- Commercial sidescan sonar is used to give an overview of the test area
- Boat operator uses real-time sidescan display to help guide boat operation



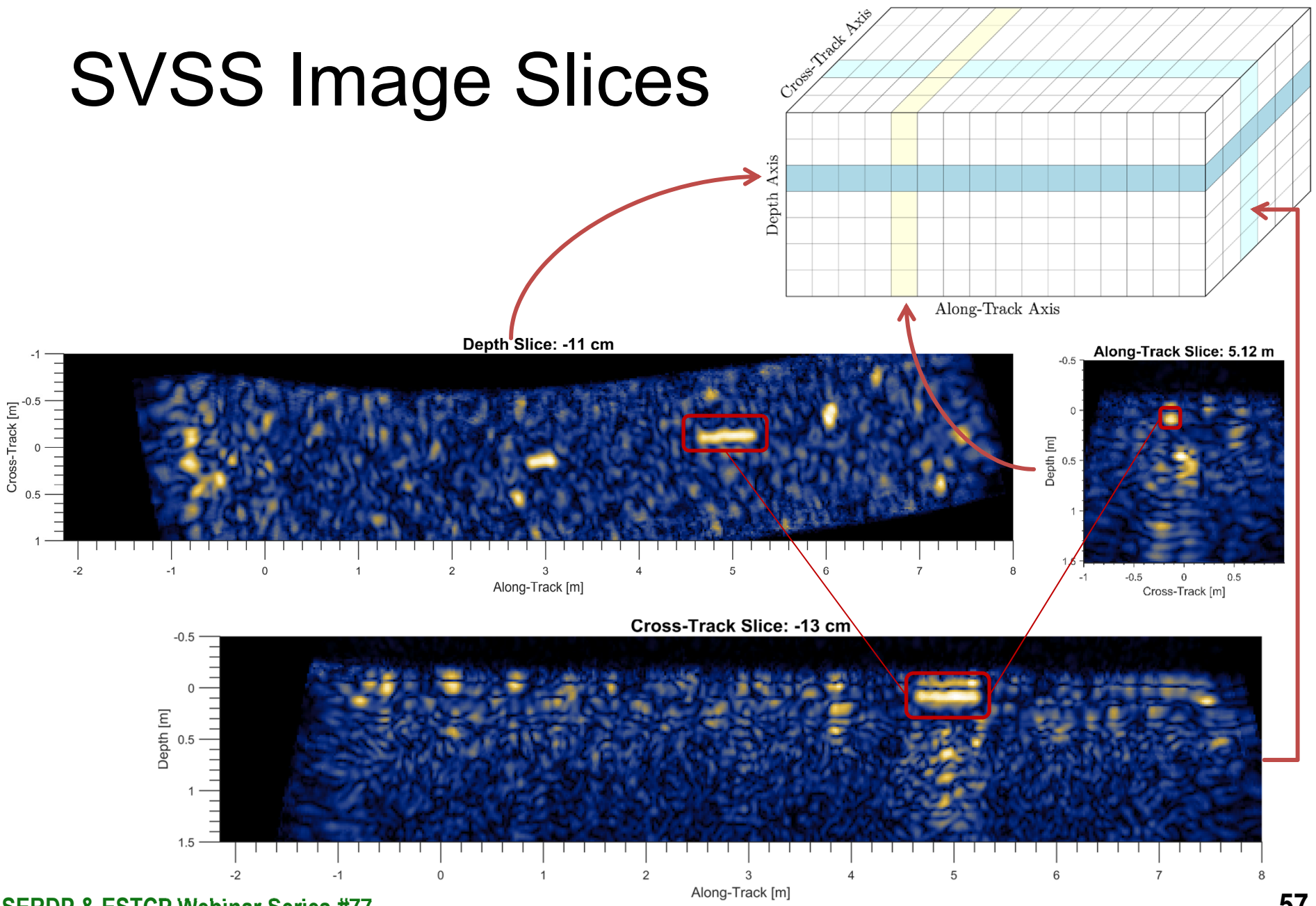
Sidescan data provides environmental characterization and some limited capability for larger surface ordnance

SVSS 3D Sonar Imagery

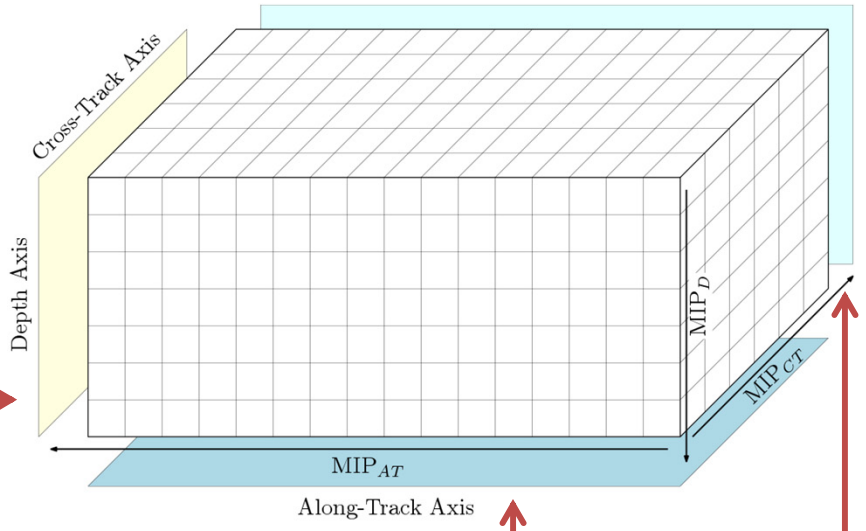
- SVSS creates three dimensional data
  - Imagery consists of voxels (instead of pixels)
- Visualization techniques
  - Slices
  - Projections
  - 3D Viewer

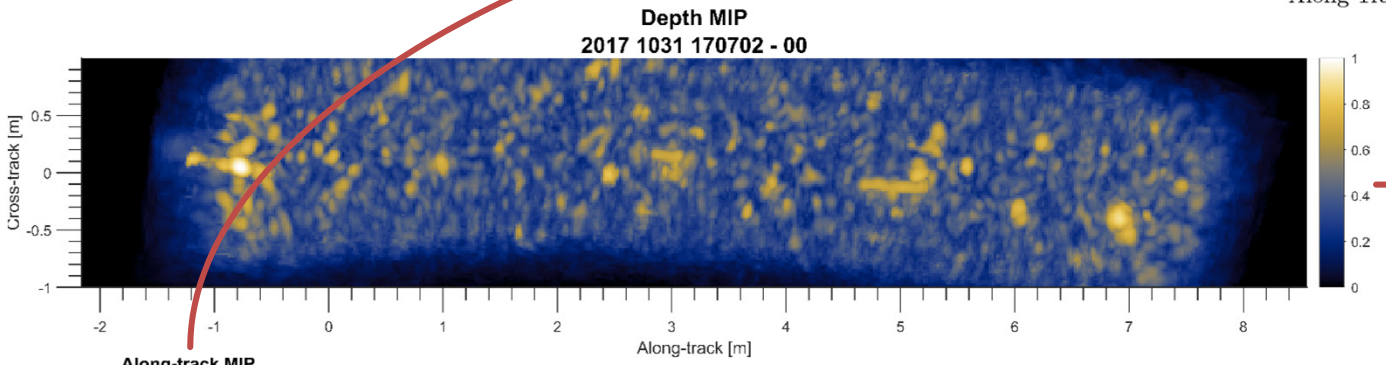


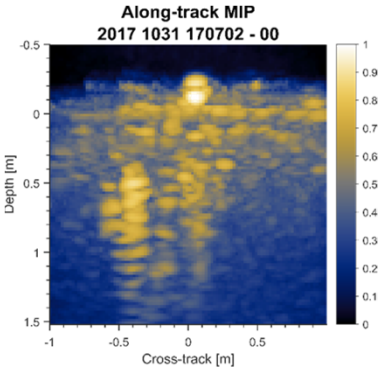
SVSS Image Slices

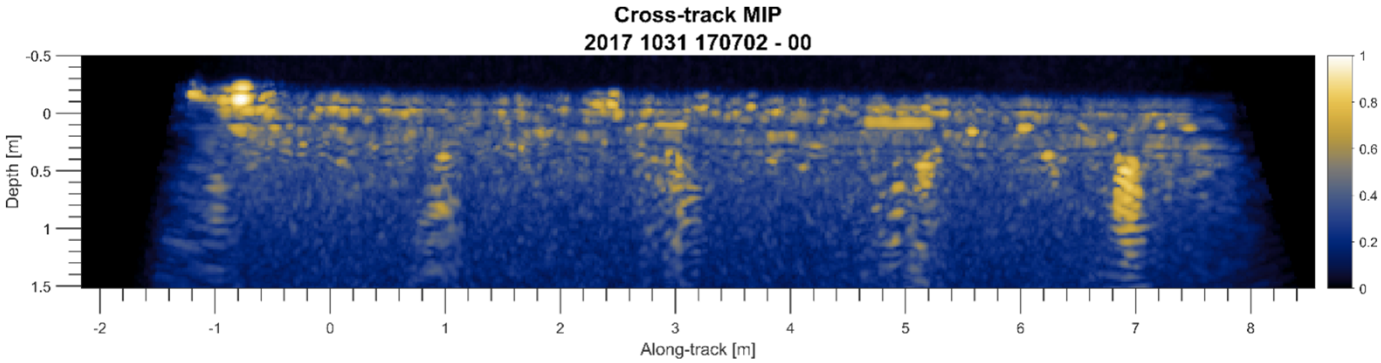


SVSS Maximum Intensity Projections (MIPs)

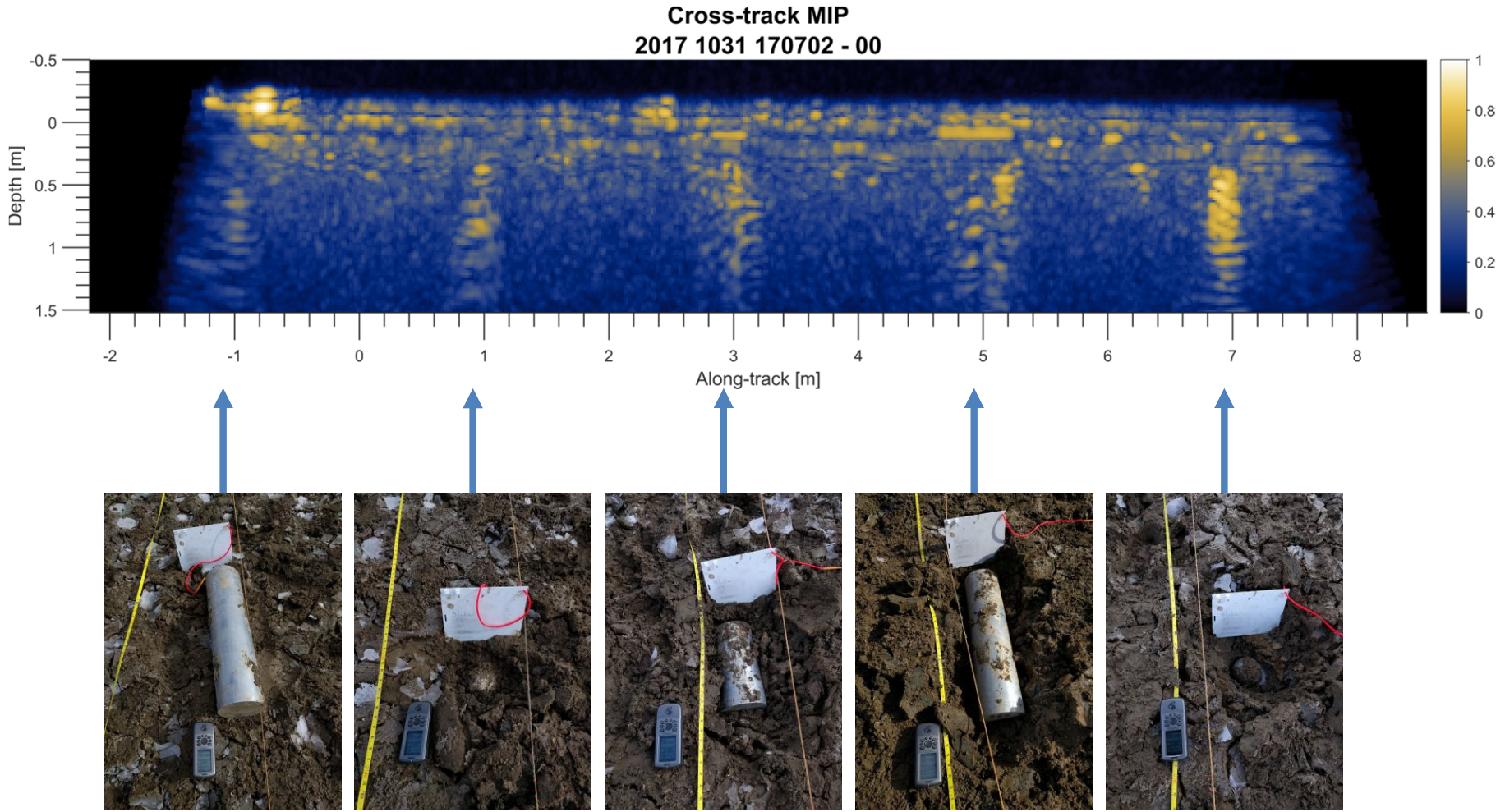




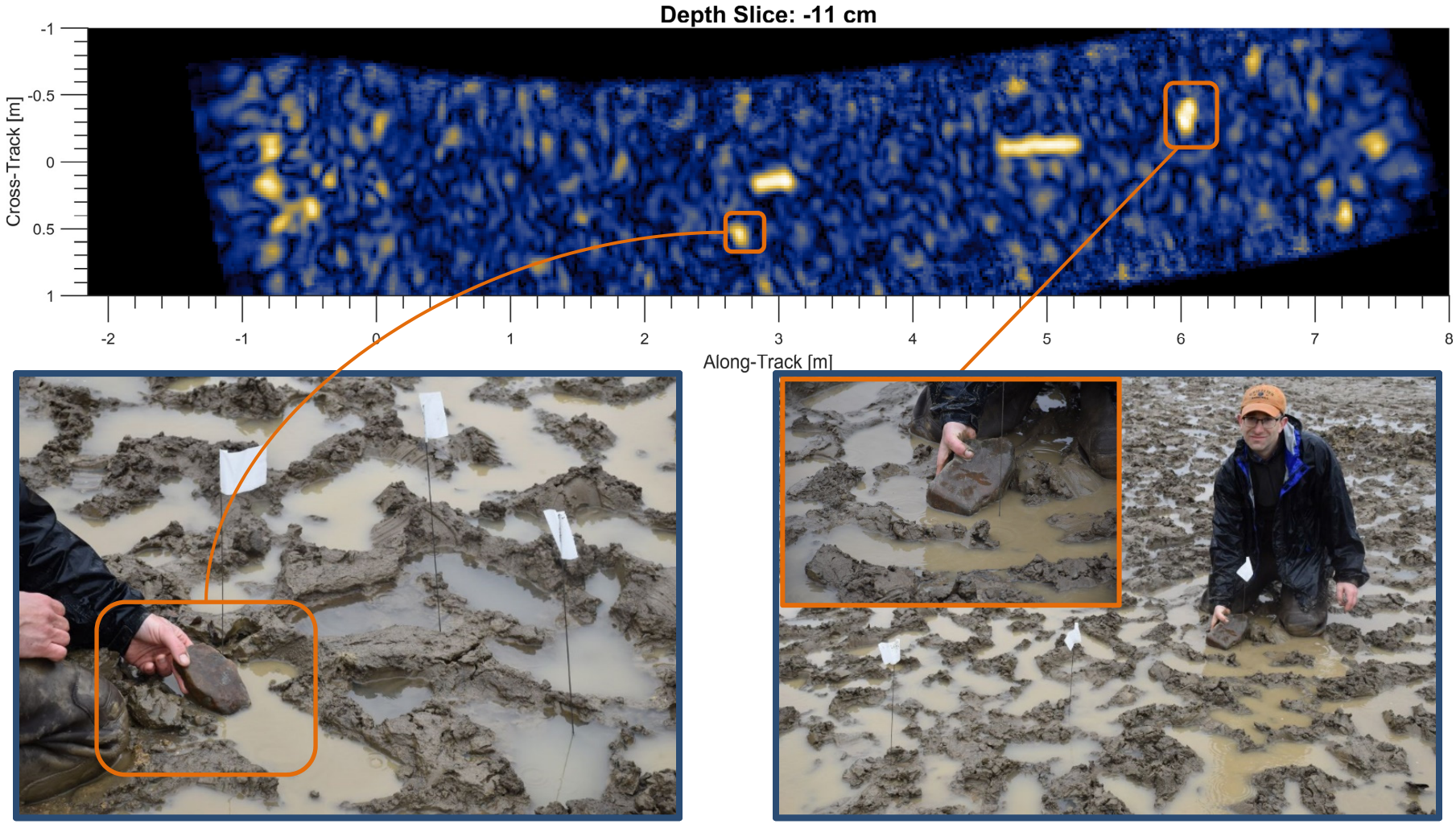




Multiple Targets Detected in Track



Ground Truth of Clutter Targets

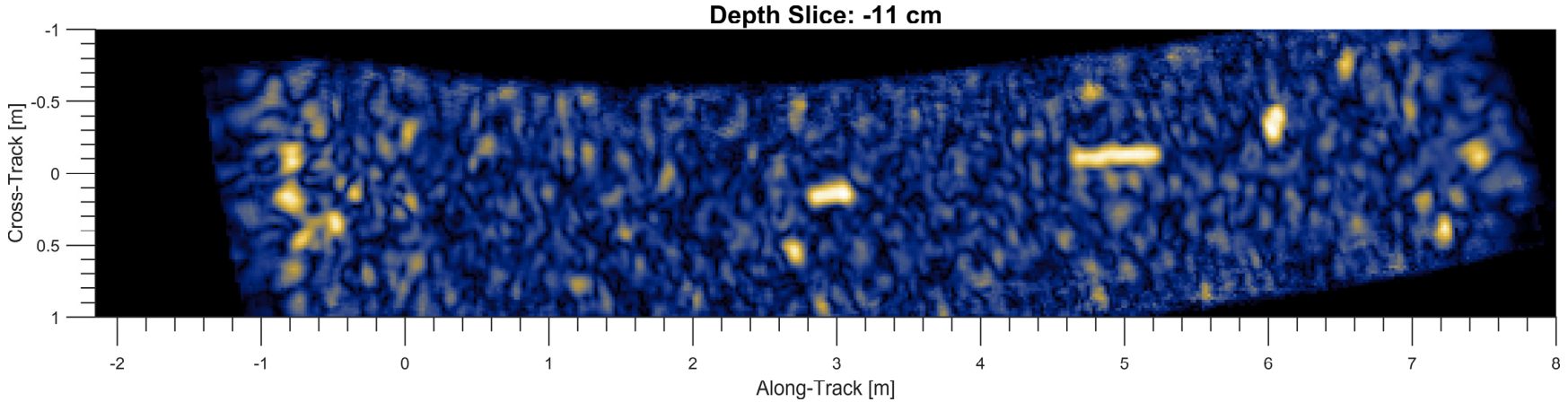


Next Steps

- Immediate plans for 2018 are to install inert ordnance in the test area
  - Installation completed 3/30/2018
- Include a range of burial depths in the shallow testing site
- Improve sediment characterization
  - 8 sediment cores collected from each test site
- Further characterize sensor performance

Conclusions

- Multi-phase effort to address the shallow-water buried-ordnance problem
  - Modeling and simulation
  - Prototype demonstration
- Demonstrated capability for target detection of fully buried target shapes



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For additional information, please visit
https://www.serdp-estcp.org/Program-Areas/Munitions-Response/Munitions-Underwater/MR-2545

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Q&A Session 2

The next webinar is on September 6, 2018

Informing Restoration Programs for Threatened and Endangered Plant Species

Survey Reminder

Please take a moment to complete the survey that will pop up on your screen when the webinar ends