Underwater UXO: A Look into SERDP and ESTCP's Current Research

Acoustic Technologies for Detailed Munitions Surveys

14 August 2024

Background

- **GOAL:** Detect, Classify, and Geo-locate military munitions in underwater environments
  - ♦ No current operational level solution for (buried) munitions

- SERDP studies using acoustics indicate:
  - ♦ Sonars in the kHz to 10's of kHz frequency range are viable solution.
  - ♦ Multiple data products from sonar data are useful, e.g., imaging, frequency/angle (acoustic color).

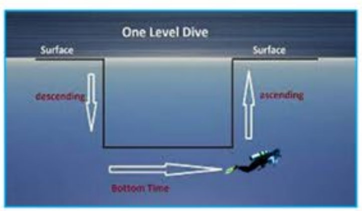
OUTLINE

- Overview of general challenges for marine surveys
- Some further details/thoughts on the geolocation challenge
- Platforms for Acoustics – operation within in the water column
- Acoustic sensing – Detection/Classification/Localization
  - current status of development
  - details

Challenges In Underwater Munitions Remediation

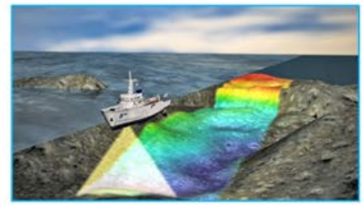
GPS is inaccessible to systems and divers operating underwater

Optical visibility will often be poor for divers recovering targets



Diver time on seafloor is limited by air supply and water depth

Nepheloid layers (suspended sediment) further hinders visibility



The bathymetry of the seafloor may be highly complex

In many areas the seafloor may be highly cluttered

The ocean sea-state (e.g. weather) is not always cooperative

The presence of marine life may need consideration

Due to these reasons, among others, underwater remediation is more complex than efforts on land

Geolocation Underwater

- Shipboard RTK GPS - often cm to 10's of cm accuracy
- Sensor package often offboard of ship
- Location of sensor package relies on GPS while on surface with Inertial Navigation System (INS) underwater
- $100,000.00 INS good to 0.2% of distance traveled (2 m over 1000 m)
- Feature based navigation in post processing can register different survey lines
- Geolocation to within 1-2 m is realistic for systems decoupled (tethered or autonomous) from the ship

Platforms for Acoustic Systems

- For shallow water (less than 5 meters) can be directly connected to the ship – ARL Penn State
- For deeper water - systems can be:

  - Tethered to ship – APL UW
  - Autonomous – NRL DC

- Operation is typically 3-4 knots (1.5 to 2 meters per sec)
- Parallel tracks are run 5 to 10 meters apart
- A 1 km^2 area can be surveyed in minimum of about 1 day maybe as much as several days

Technical Readiness Definitions (ESTCP acoustic systems at TRL6)

Technology Readiness Level 6: System/subsystem model or prototype demonstration in a relevant environment

Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment. Supporting information includes results from testing of a prototype system that is near the desired configuration in terms of performance, weight, and volume.

Technology Readiness Level 7: System prototype demonstration in an operational environment

Prototype near or at planned operational system. Represents a major step up from TRL 6 by requiring demonstration of an actual system prototype in an operational environment (e.g., in an aircraft, in a vehicle, or in space). Supporting information includes results from testing a prototype system in an operational environment.

Test Bed (TRL6) Efforts

- Pennsylvania – sensors directly connected to ship

  ARL – Penn State

- Sequim, Washington – sensors deployed on towbody

  APL-UW

- Boston – sensors deployed on UUV

  NRL DC

Sediment Volume Search Sonar (SVSS)

SERDP Development Projects

SERDP MR-2545 (2016-2021)

"Sediment Volume Search Sonar"

Prototype demonstration of ordnance imaging in very shallow water

SERDP MR21-1279 (2022-2024)
ESTCP MR23-8364 (2024-Present)

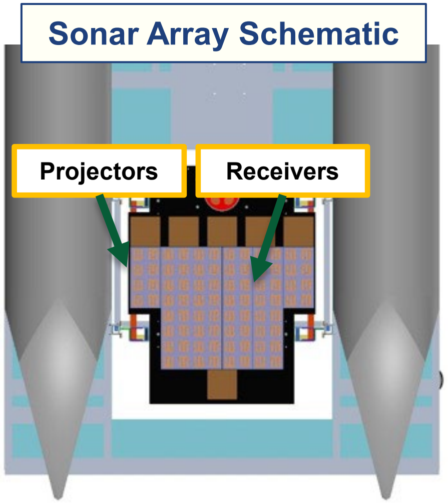
"Enhanced Sensing for Detailed Surveys in Very Shallow Water"

Purpose designed hardware development and future engineering demonstration at SERDP/ESTCP test site

SVSS provides a sensor and platform designed to conduct detailed ordnance surveys in very shallow water (<5 meters)

SVSS Sensor Characteristics

- Triple-hull pontoon boat deployable without any specialized equipment
- System design permits high-resolution survey in waters as shallow as 80 cm
- High-accuracy GPS and inertial navigation provides accurate absolute (lat/lon) target localization
- Gas propulsion and power permits long-duration site surveys



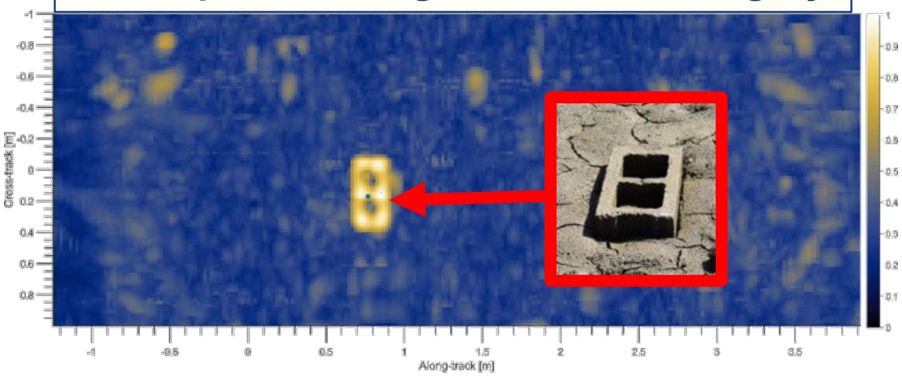
Platform and sensor provide a low-cost path for shallow-water detailed survey

SVSS Sensor Platform

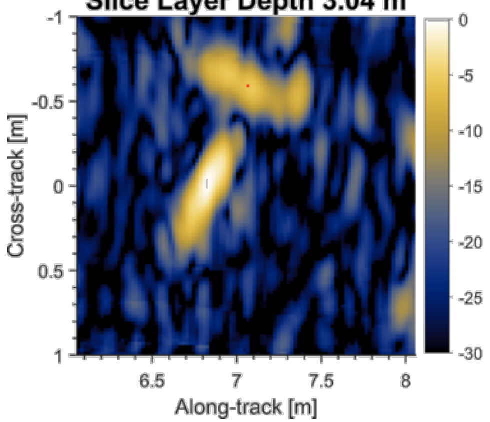
Multi-channel receiver	Real time kinematic GPS	Water temperature sensor
Multi-channel transmitter	Fiber optic gyroscopic navigator	Data storage
High-frequency sidescan	Acoustically quiet battery power	Gas & electric propulsion

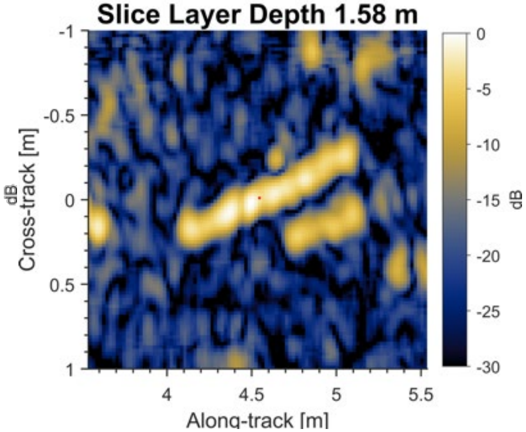
SVSS System Performance

SVSS provides high resolution imagery

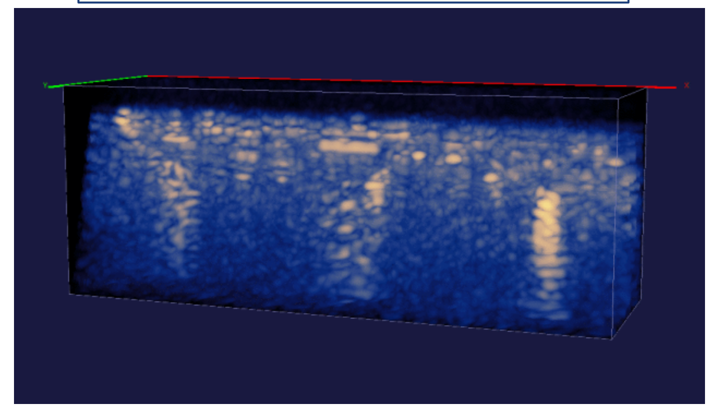


SVSS detects deeply buried objects

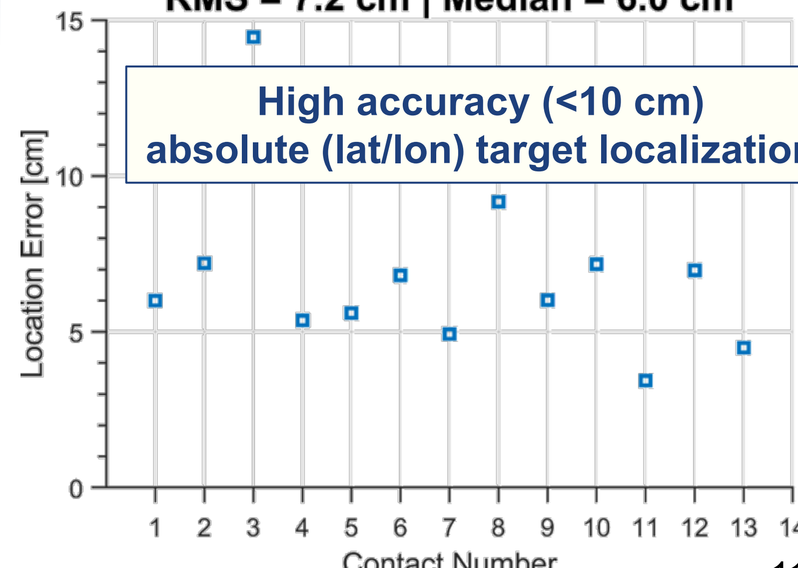




SVSS produces volumetric sub-bottom imagery



Contact Localization Error
RMS = 7.2 cm | Median = 6.0 cm

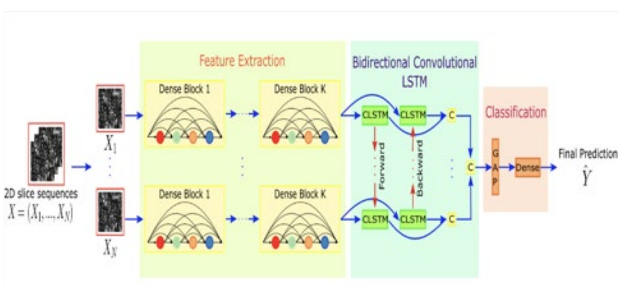


High accuracy (<10 cm) absolute (lat/lon) target localization

Partnering with machine learning researchers to automate target localization

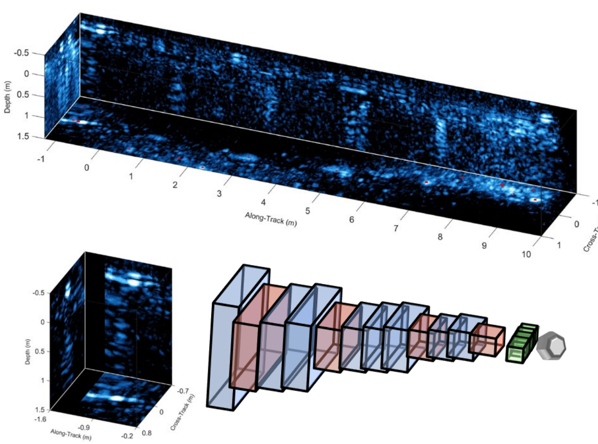
SERDP MR21-1330 (2021-2023)
Title: Prior Guided Informed Deep Learning for Detection and Classification of Underwater Military Munitions.
PI: Vishal Monga, Penn State University.

- Novel domain enriched machine learning approaches that exploit resonant scattering phenomenon to accurately distinguish UXO from clutter and between UXO types.
- Pronounced benefits in the regime of limited training data over state of the art alternatives.



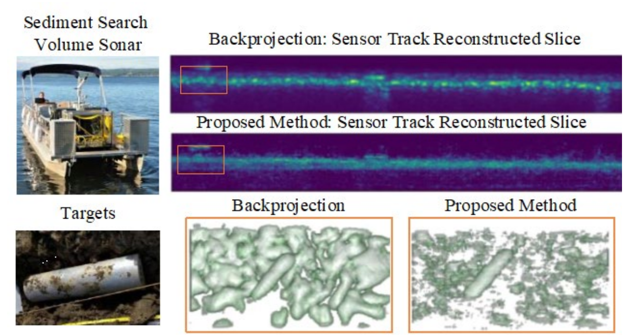
SERDP MR18-1444 (2020-2021) and SERDP MR21-3543 (2022-present)
Title: Advanced Sonar-Based Deep Learning for Underwater UXO Remediation.
PI: David Williams, ARL-PSU.

- Develop novel UXO detection and deep-learning-based classification algorithms for volumetric sonar data



SERDP MR21-1334 (2021-2023)
Title: Joint Beamforming and Automated Target Recognition for 3D SAS.
PI: Suren Jayasuriya, Arizona State University.

- Develop a suite of algorithms for enhanced beamforming and automated target recognition (ATR) for 3D SAS
- Leverage differentiable programming to merge physics-based knowledge with machine learning pipelines



Data and tools are shared widely within SERDP's AI/ML research community

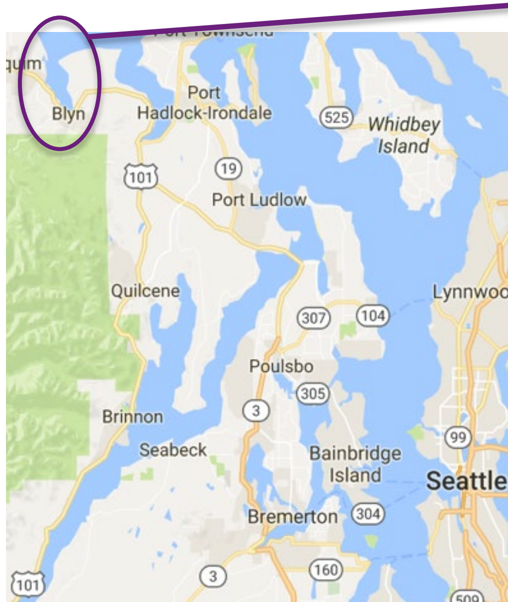
Sequim Test Bed

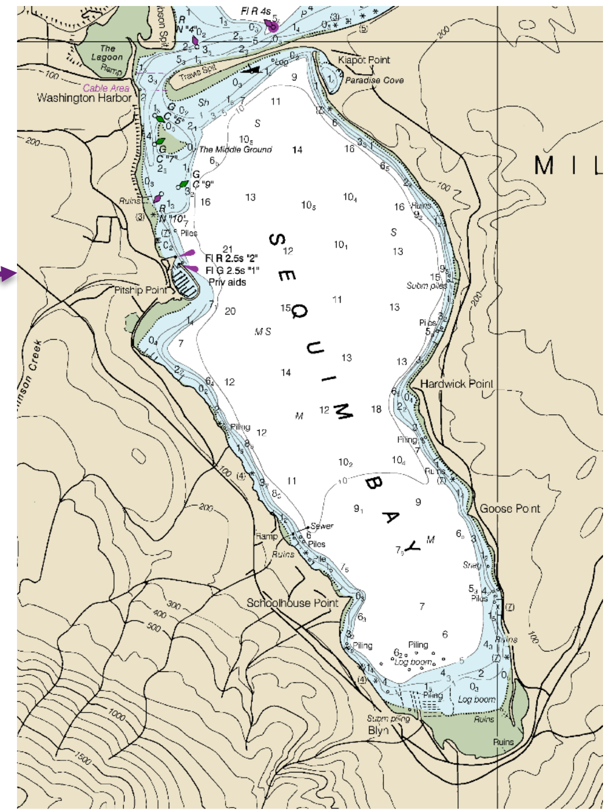
MuST Towbody Hardware

- FOCUS-3 towbody manufactured by MacArtney Underwater Technology
- Three sonar systems mounted on the FOCUS-3
  - Low-frequency, high-grazing angle, high-bandwidth acoustics system (EdgeTech Buried Object Scanning System — eBOSS)
  - High-frequency, mid-to-low-grazing angle side scan sonar (EdgeTech 2205)
  - High-frequency Multibeam sonar (RESON T50)
- Shipboard handling system for the FOCUS-3
- Shipboard data acquisition as well as analysis hardware and software

Sequim Test Bed

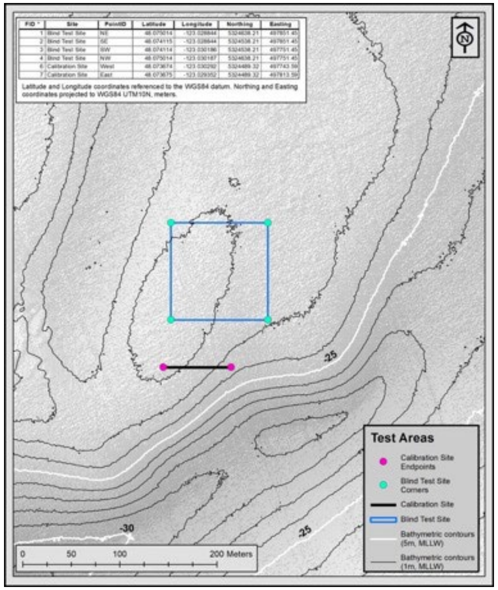
- Sequim Bay
  - average water depth of approximately 20 m
  - relatively flat bottom and a variety of bottom types
  - local DOE facility for support:
    - test bed construction
    - on-site laboratory facilities



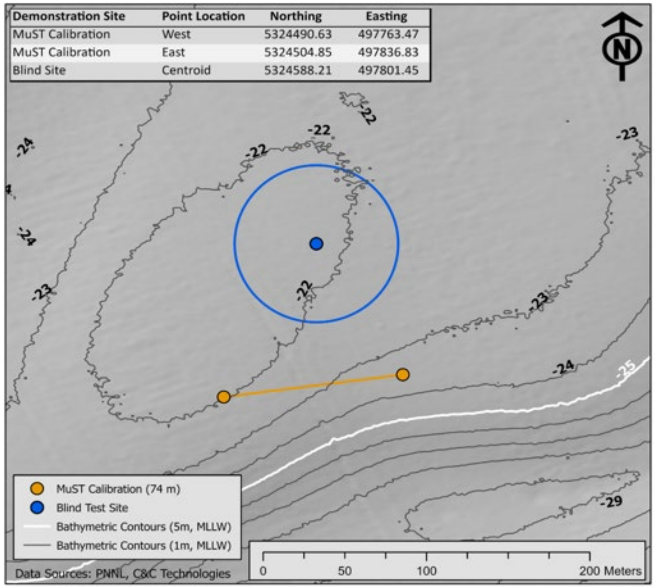


Sequim Test Bed

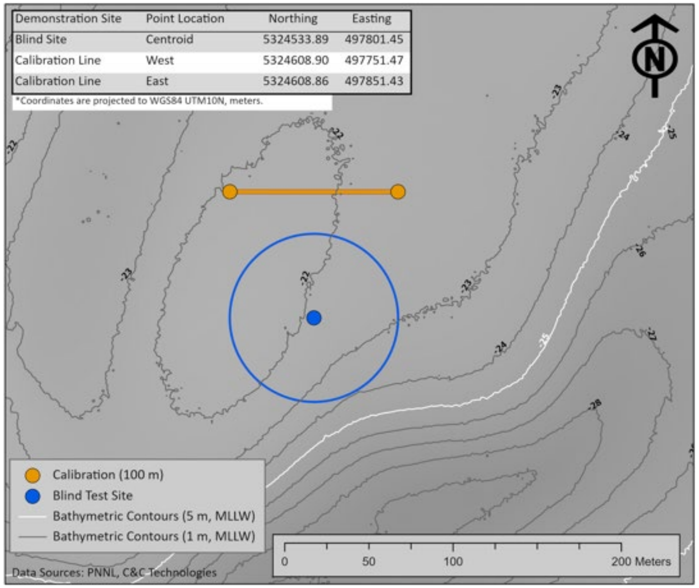
Sequim Bay Informal Demonstration - 2020



Sequim Bay Formal Demonstration - 2021



Sequim Bay Informal Demonstration - 2022



Analysis – 2020/2021

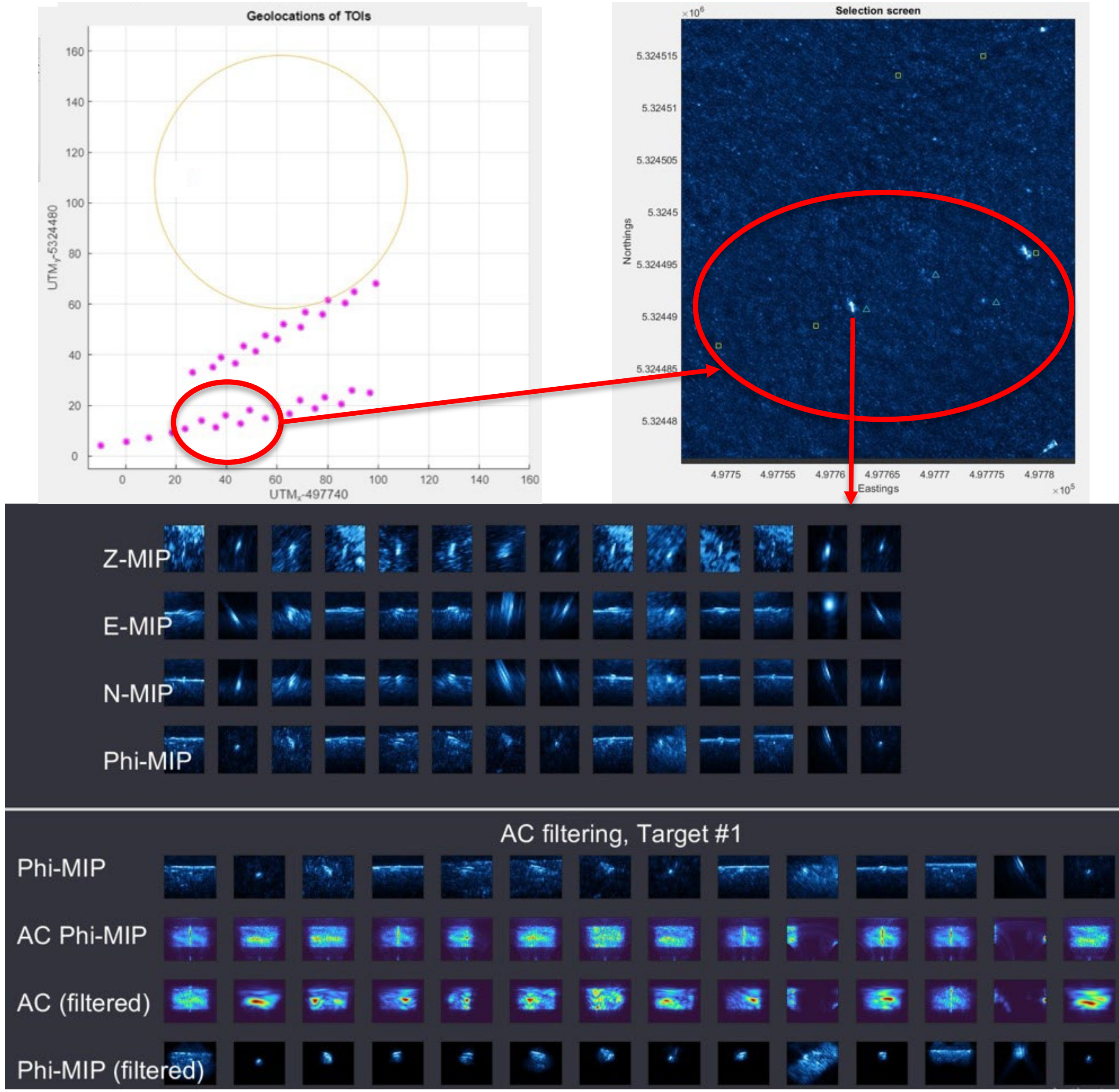
Registered
Mosaic

Training Data Set
Extracted,

Classifiers trained,

Detect/Classify
In Blind test area

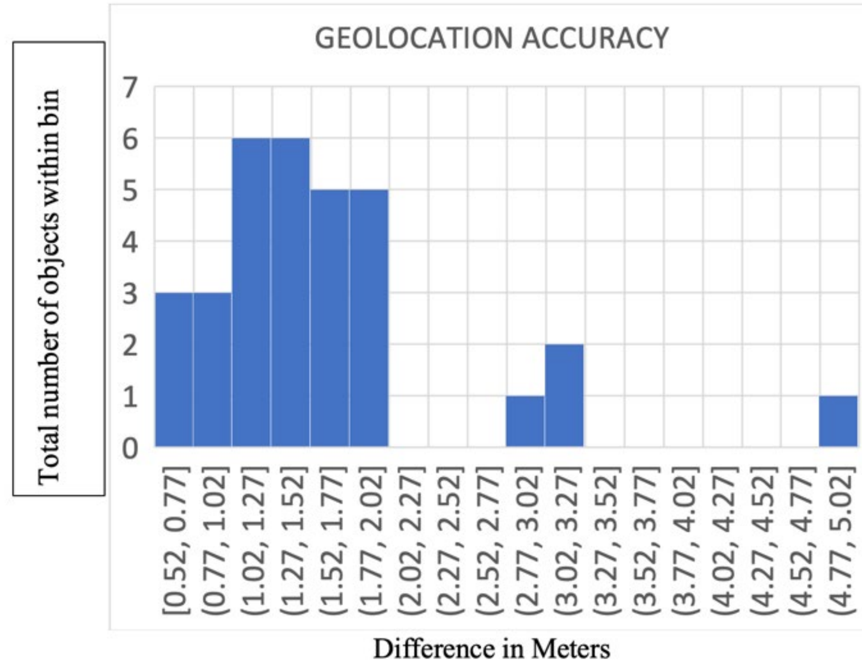
Results scored

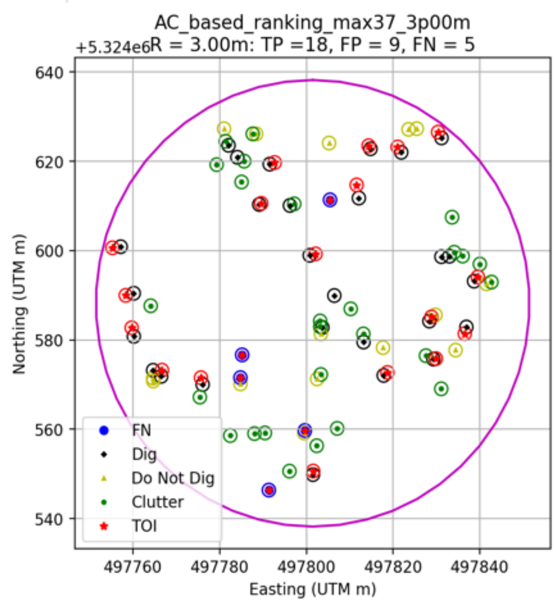


Results – 2021Test

		eBOSS only		eBOSS + sidescan	
		Actual class		Actual Class	
		TOI	clutter	TOI	clutter
predicted class	TOI	18	9	18	5
	clutter	5	13	5 (3)*	17

• the 3 in parentheses is the false negative number if 60 mm UXO are ignored. That is, 60 mm UXO treated as unresolveable for the MuST deployed 5 m above the bottom

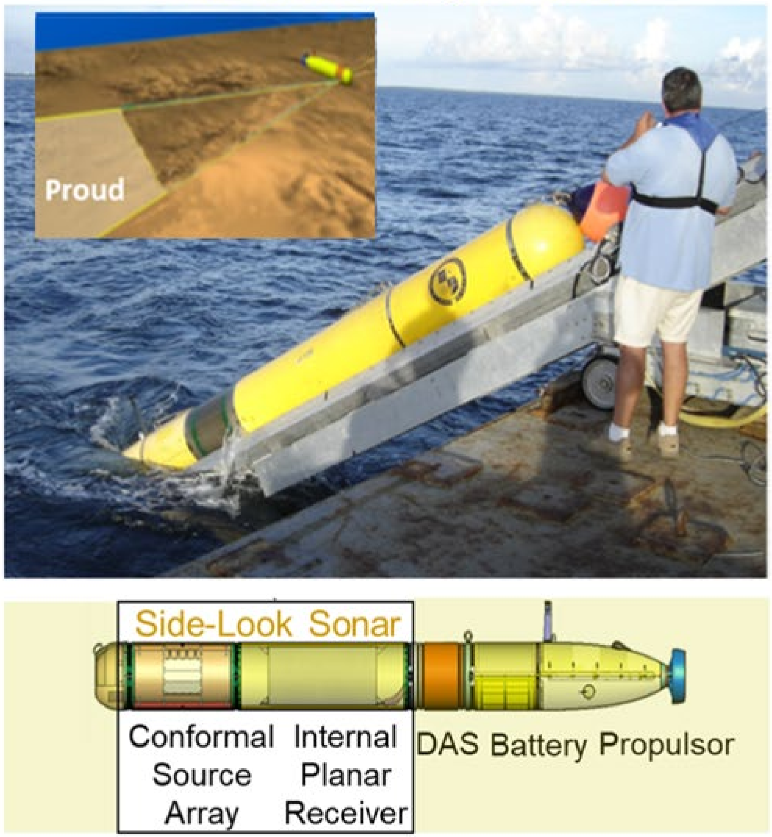




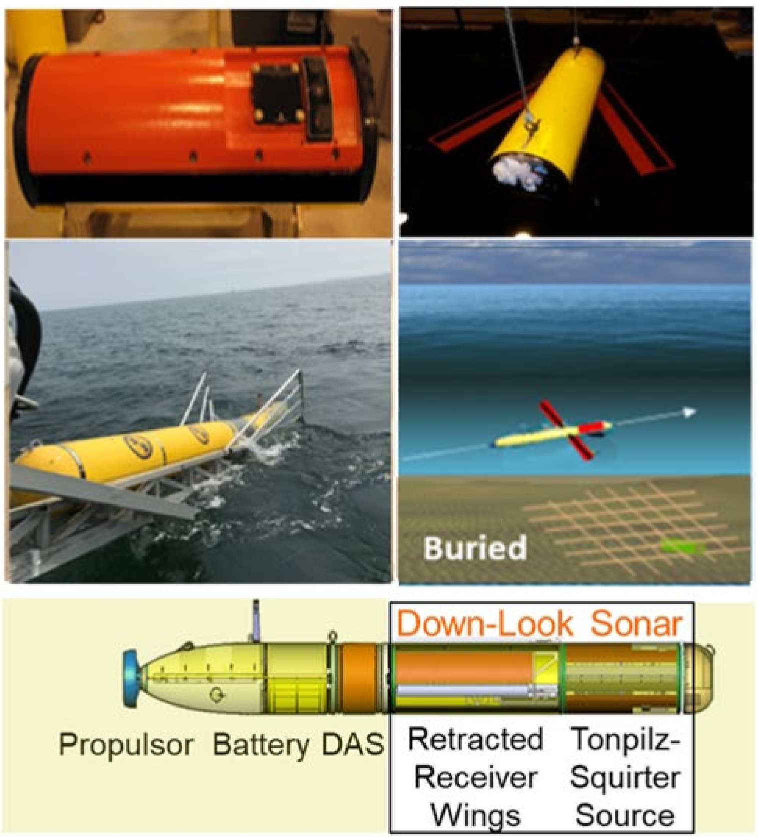
AUV-Based Structural Acoustic Sonars - *Sonar Systems*

Side- and Down- Look Structural Acoustic Sonars
…on a Bluefin 21 Autonomous Underwater Vehicle (AUV)

Side Looking Sonar



Down Looking Sonar

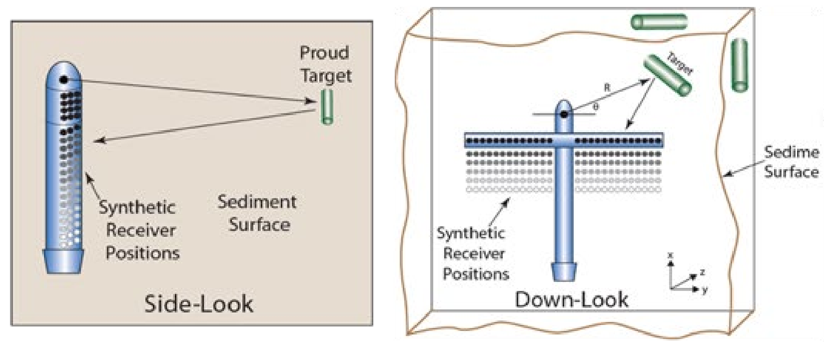


AUV-Based Structural Acoustic Sonars - *Methodology*

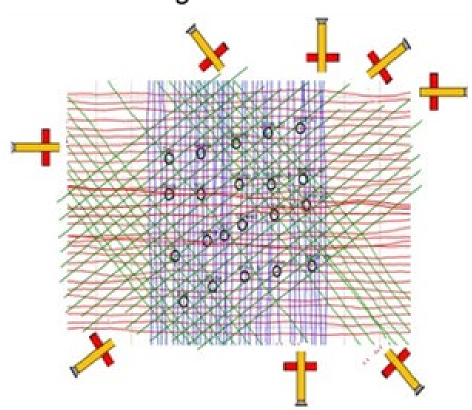
(At the Site)

SA Sonars Prosecuting
Proud & Buried UXO

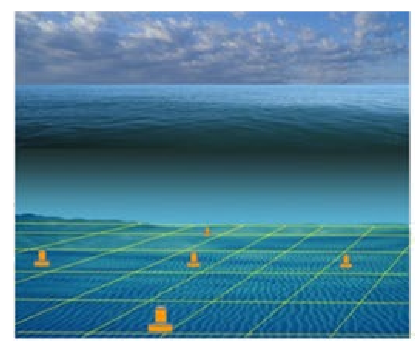
Collecting Echoes from the Sediment
Surface & Volume with Synthetic/Real Arrays



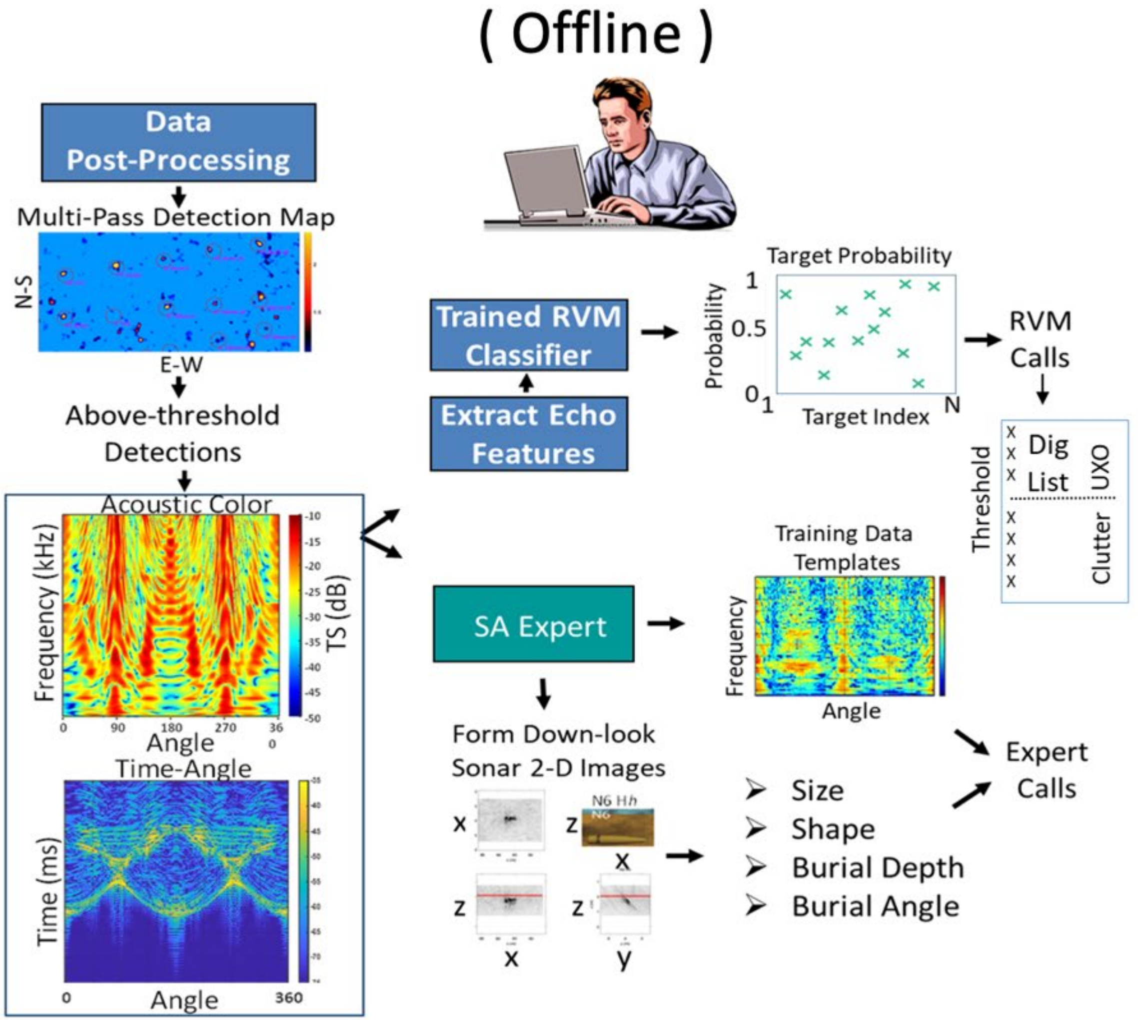
Mow-the Grass AUV Flights
in Eight Directions



Proud Lincoln Hat Navigation
Monuments Deployed To
Enhance Target Localization

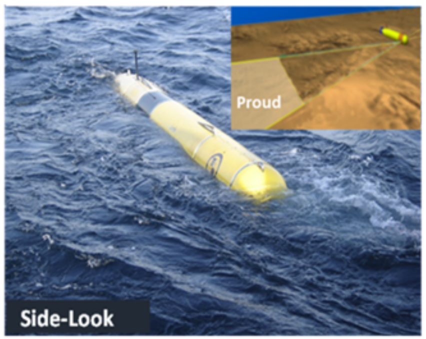


AUV-Based Structural Acoustic Sonars - *Methodology*



AUV-Based Structural Acoustic Sonars - *Performance*

Side-Look Prosecuting Proud Targets



Classification Performance

PdPc = 100% Pfa = .04

Location Accuracy

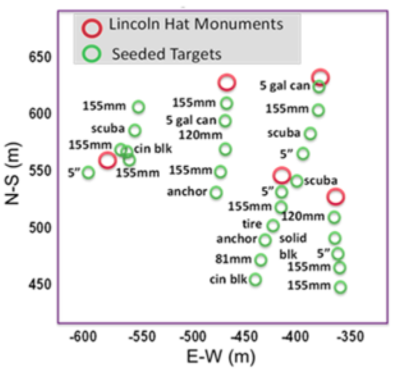
<ΔE> = 0.5m; <ΔN> = 0.24m

σE = 0.47m; σN = 0.23m

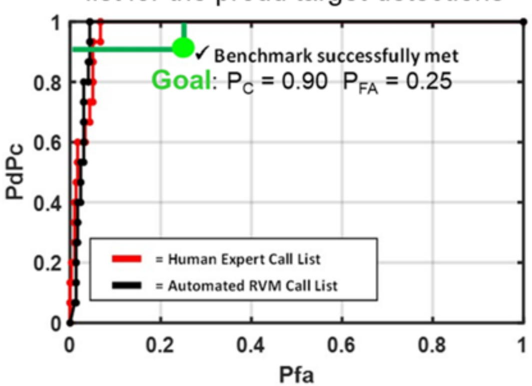
Coverage Rate

2.3 Acres Per Hour

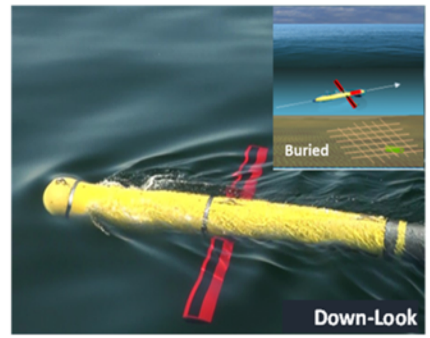
Proud Target Test Field in Boston Harbor



ROC curve from blind test RVM call list for the proud target detections



Down-Look Prosecuting Buried Targets



Classification Performance

PdPc = 100% Pfa = 0.07

Location Accuracy

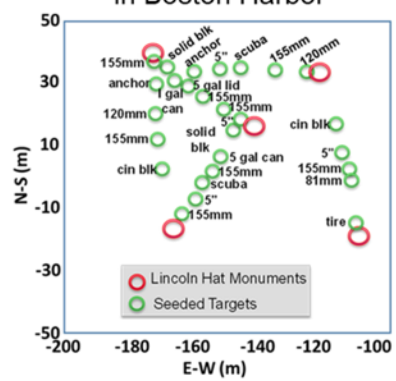
<ΔE> = 0.93m; <ΔN> = 0.80m

σE = 0.51m; σN = 0.68m

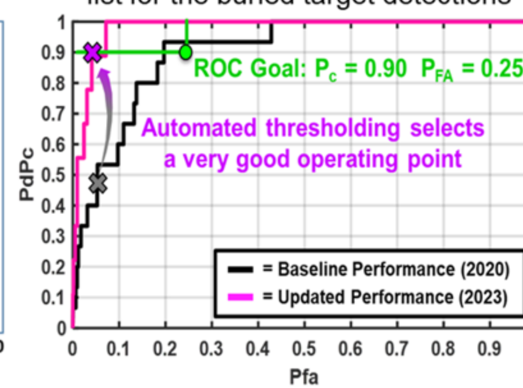
Coverage Rate

0.70 Acres Per Hour

Buried Target Test Field in Boston Harbor



ROC curve from blind test RVM call list for the buried target detections



SUMMARY

- Current down-looking acoustic sensor hardware/analysis chains have many similarities regardless of platform
- There is still much to be gained in the signal processing chain
- In the end, however, regardless of sensor, you cannot do in the ocean what you can do on land
- The realities of working in the ocean will require stake holders to look at the remediation problem differently