ESTCP

Enhanced Sensing for Detailed Surveys in Very Shallow Water

MR23-8364

Dr. Daniel C. Brown

Applied Research Laboratory – Penn State

In Progress Review Meeting

13 January 2025

Project Team

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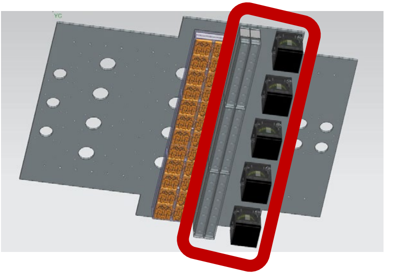
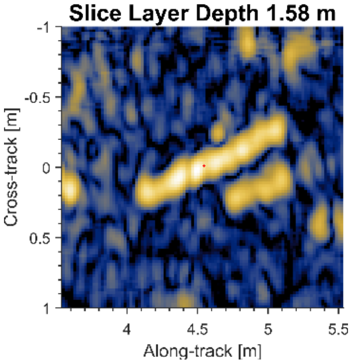
Bottom Line Up Front

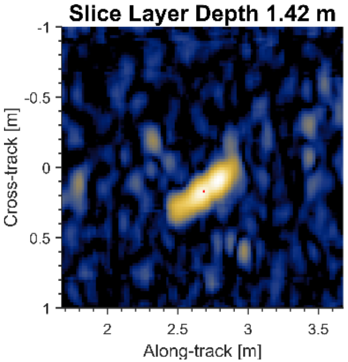
- SVSS (Sediment Volume Search Sonar) is a purpose-built detailed ordnance survey system for very shallow waver (<5m)
- Newly designed transmit and receive systems clearly demonstrate improved performance over baseline SVSS
  - The purpose built hardware is designed to operate over a wide range of frequencies, in very shallow environments, against buried ordnance
  - Leverages established signal processing, synthetic aperture reconstruction, data quality review, and post-mission analysis pipeline
- Initial engineering test at SERDP/ESTCP site
  - 18-23 Sept, 2024, Sequim Bay, WA; installed and supported by PNNL
  - These results are currently under analysis

Technical Approach

- Improve the performance of the baseline SVSS sensor by:
  - Design and integration of lower-noise, higher-resolution receiver hardware
  - Continued development of signal processing algorithms for 3D SAS in challenging environments
- Demonstrate the improved SVSS at the Sequim Bay test bed
- Provide open datasets to the MR research community



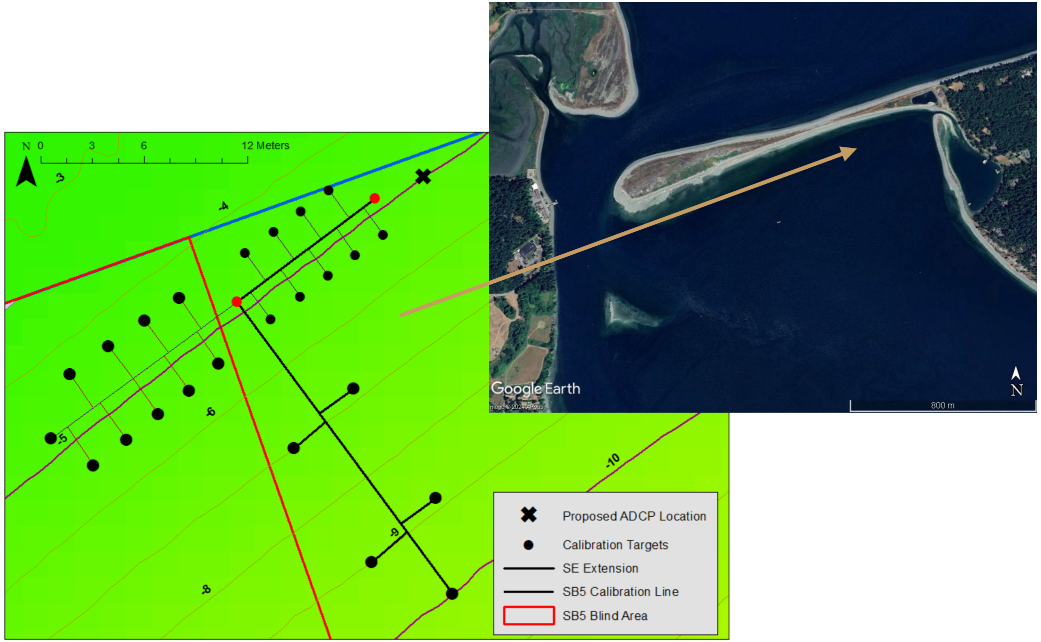




PNNL Sequim Bay
Engineering Demonstration Site

Initial engineering test in SERDP/ESTCP developed site

- Shallow water engineering demonstration site details
  - Water depth: 3+ meters
  - Target types:
    - Ordnance / Science / Clutter
- Test Schedule:
  - Unload SVSS: 9/17/2024
  - System Checkout: 9/17/2024
  - Testing: 9/18 – 9/23/2024
  - Load SVSS: 9/24/2024
  - Depart: 9/24/2024



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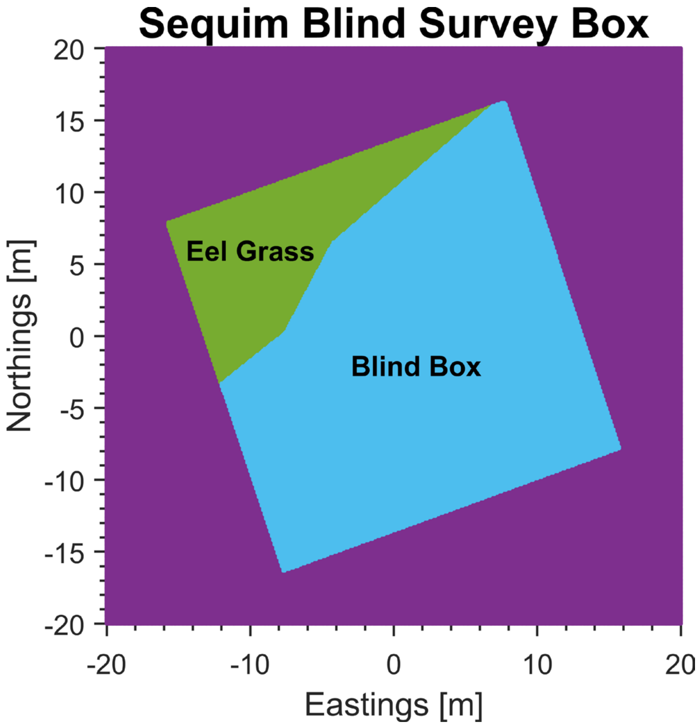
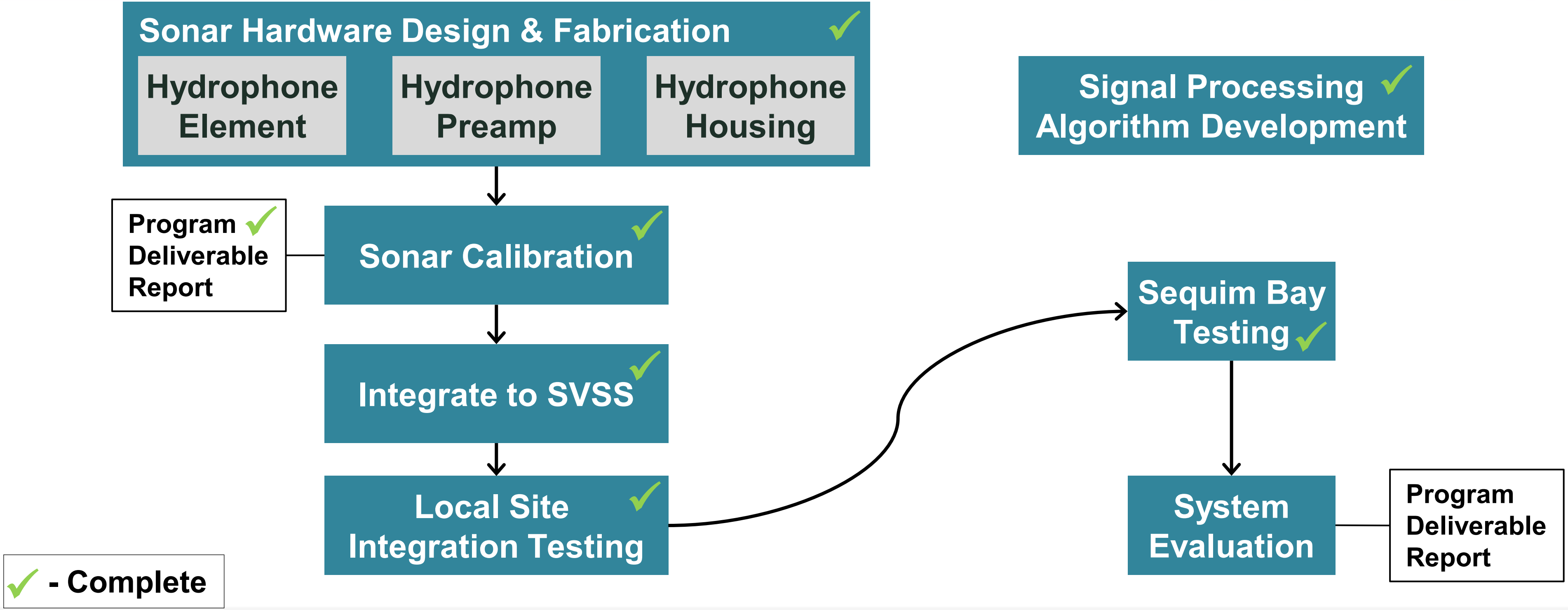
PNNL Sequim Bay - Blind Survey Box

- Survey box selected to balance
  - Avoiding areas with seagrass
  - Providing shallow water testing
- These objectives are at odds
  - Eel grass grows in shallow water
- Shallow portion of the survey box is near eel grass line



Technical Approach Flowchart



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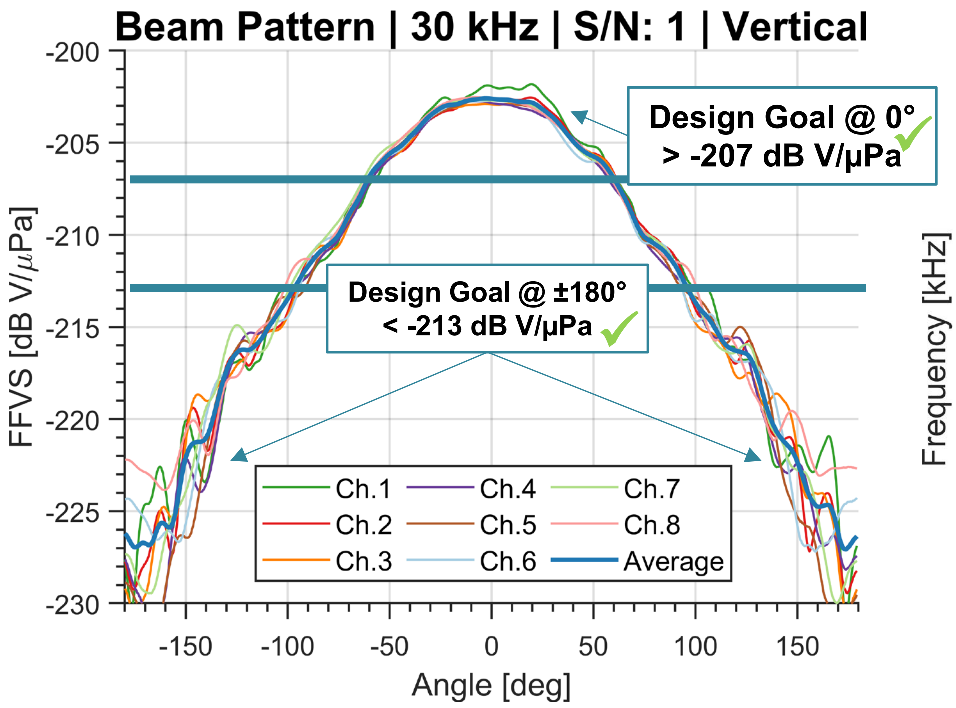
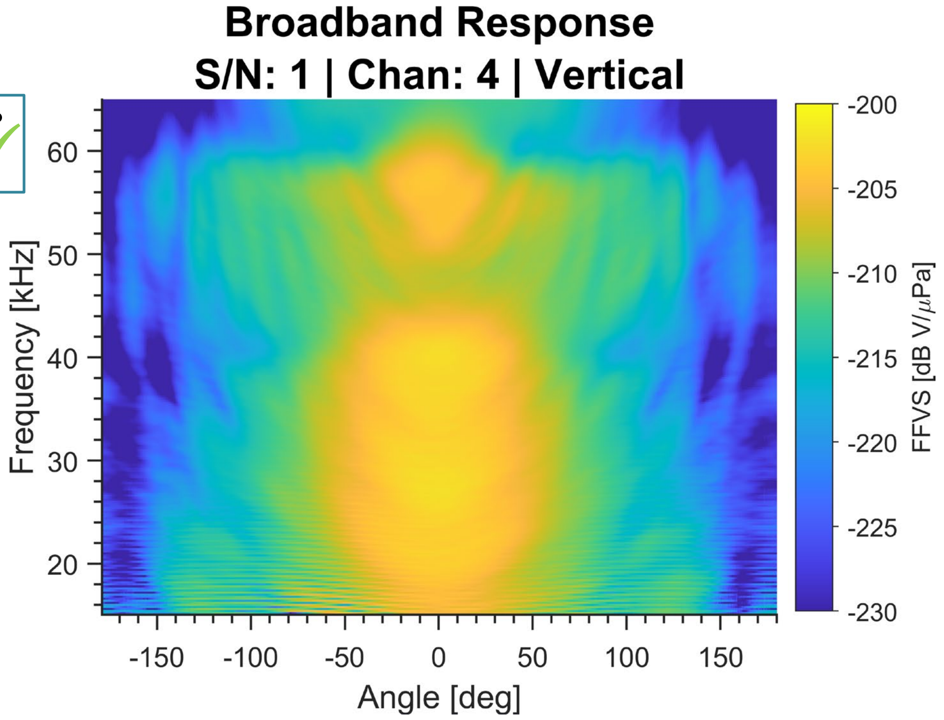
Hydrophone Performance Objectives

Performance Objective	Data Requirements	Success Criteria
Quantitative Performance Objectives		
Free-field voltage sensitivity	Acoustic test facility calibration	> -207 dB re V/μPa
Channel-to-channel matching	Acoustic test facility calibration	< 1 dB re V/μPa
Hydrophone bandwidth	Acoustic test facility calibration	15 kHz – 45 kHz (+/-3 dB)
Front-to-back Ratio	Acoustic test facility calibration	> 10 dB passive rejection
Qualitative Performance Objectives		
Compact design to support craft of opportunity	Mechanical dimensions	6x reduction in along-track hydrophone array length

Hydrophone Sensitivity and Directivity





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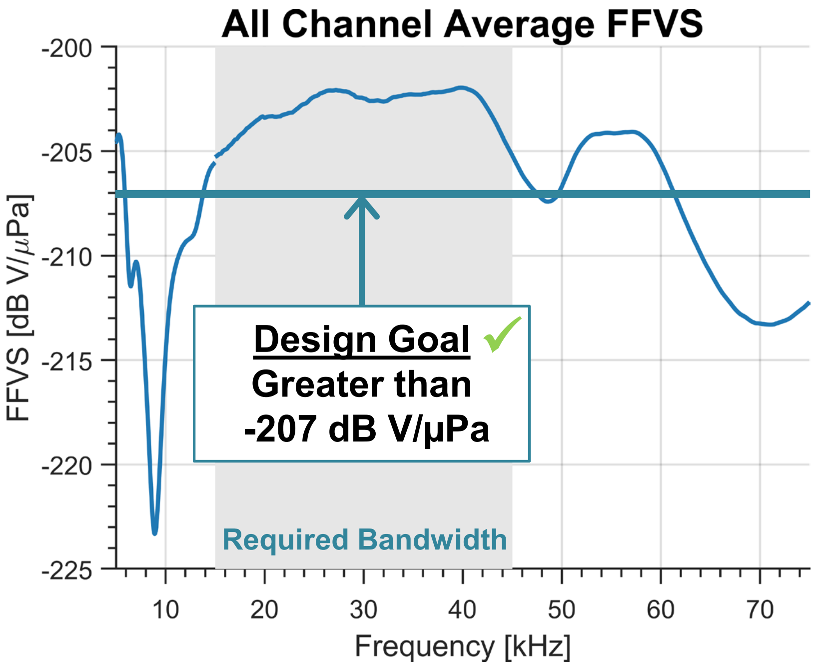
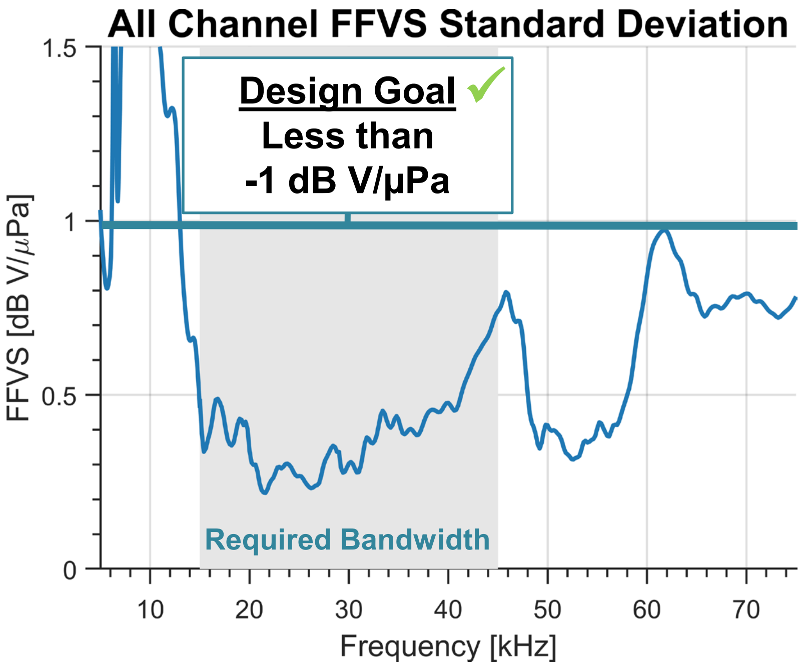
48-Channel Calibration Result Summary





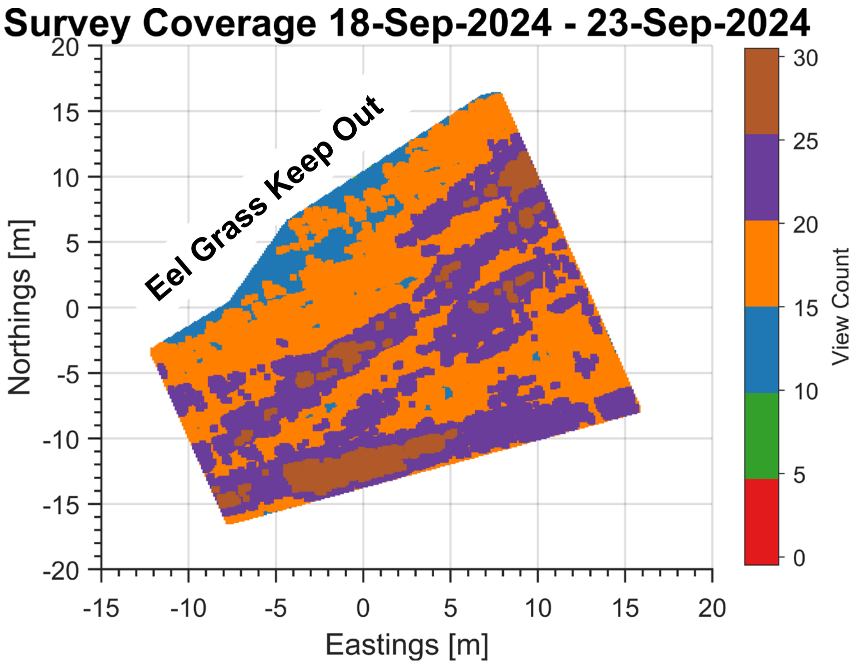
Hydrophone documented to exceed all design criteria in Program Deliverable Report

Data Production Objectives

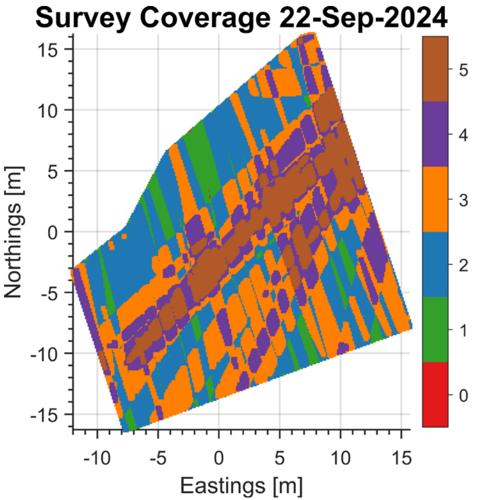
Performance Objective	Data Requirements	Success Criteria
Training Data Development	Raw sonar and navigation data	More than 5 views for each calibration line target
Blind Field Survey Coverage	Navigation data	100% coverage within 2 m
Data Quality Reporting	Raw sonar and navigation data	Automated DQR and KML reports generated for each track
Software Quality Testing	Factory acceptance test report	Software used for image reconstruction has been through a factory acceptance test

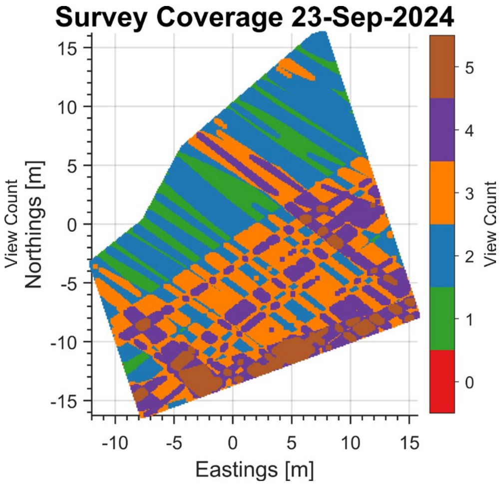
Blind Field Survey Coverage

Full Event Survey Coverage



Low Tide (2 Hour) Survey Coverage





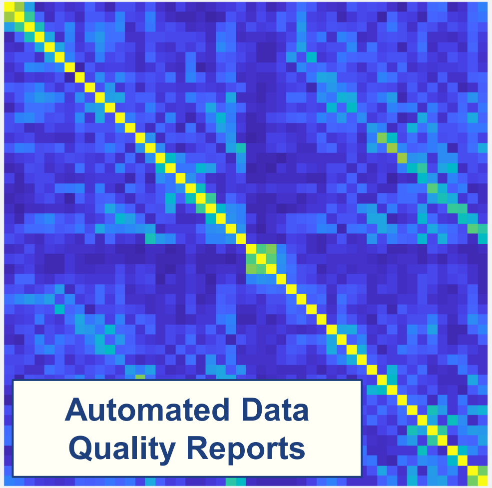
Shallow water testing achieved surrounding low tide events

Post-Survey Automated Quality Assurance Reporting

| Legend: ● Moderate ● Minor ● Informational | ☑ Expand all ☐

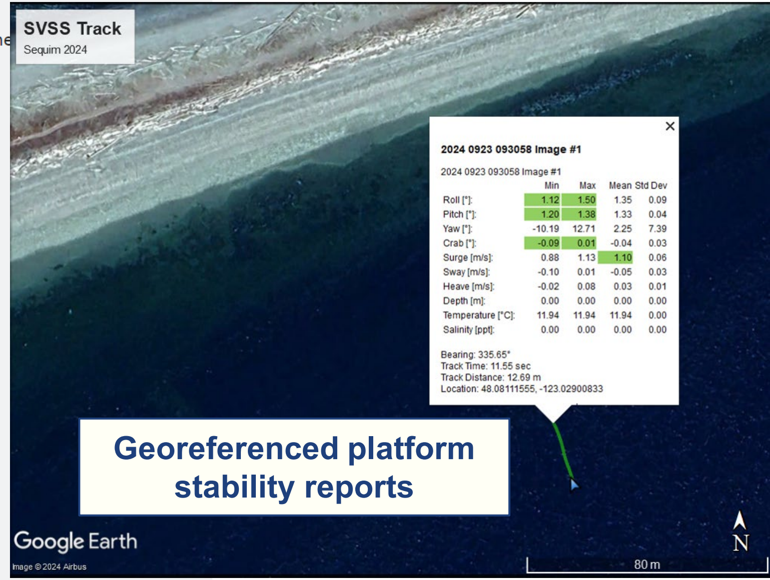
2024 0918 173121

- **2,029 pings, 1.3 GB, 33s, 10.9 meters**
  LF/down 2,029 pings, 1.3 GB, 33s, 10.9 meters
- **Auto-correlation**
  LF/down



Automated Data Quality Reports

- **Crab**
  Range observed: -1.7° → 4.1°
  Rate of change observed: -3.8°/sec → 3.5°/sec
- **Depth**
  Range observed: 0.0 meters → 0.0 meters
  3 images had observations that were only the default value of 0 me
- **Heading**
  Range observed: 49.6° → 60.4°
  Rate of change observed: -1.9°/sec → 0.9°/sec
- **Latitude**
  Range observed: 48.0810° → 48.0812°
  Rate of change observed: 0.0000°/sec → 0.0001°/sec
- **Longitude**
  Range observed: -123.0293° → -123.0289°
  Rate of change observed: 0.0000°/sec → 0.0003°/sec
- **Navigation data rate**
  Rate: 20.0 Hz
  Range observed: 20.0 Hz → 20.0 Hz
- **Pitch**
  Range observed: 1.0° → 1.1°
  Rate of change observed: -0.2°/sec → 0.2°/sec
- **Roll**
  Range observed: 0.3° → 0.8°
  Rate of change observed: -0.6°/sec → 0.7°/sec
- **Sound speed**
  Calculated sound speed
  Range observed: 1,454.4 meters/sec → 1,454.4 meters/sec
- **Synchronization lost in navigation minor issue**
  LF/down 1 occurance, 14,019 skipped bytes, worst consecutive: 14,019 skipped bytes
- **Vehicle speed**
  Range observed: 1.0 meters/sec → 1.1 meters/sec
  Rate of change observed: -0.1 meters/sec² → 0.1 meters/sec²



	Min	Max	Mean	Std Dev
Roll [°]:	1.12	1.50	1.35	0.09
Pitch [°]:	1.20	1.38	1.33	0.04
Yaw [°]:	-10.19	12.71	2.25	7.39
Crab [°]:	-0.09	0.01	-0.04	0.03
Surge [m/s]:	0.88	1.13	1.10	0.06
Sway [m/s]:	-0.10	0.01	-0.05	0.03
Heave [m/s]:	-0.02	0.08	0.03	0.01
Depth [m]:	0.00	0.00	0.00	0.00
Temperature [°C]:	11.94	11.94	11.94	0.00
Salinity [ppt]:	0.00	0.00	0.00	0.00

Georeferenced platform stability reports

Reporting Generated Per Survey Line with Unique Identification

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Software Factory Acceptance Testing

- SVSS imagery is reconstructed using the Advanced Synthetic Aperture Imaging eNgine (ASASIN)
  - Creates data products in open data formats to enable dissemination of results
- ASASIN in active development since 2011
  - Actively supported by multiple Navy programs fielding more than 7 sonar systems
- Software releases undergo a factory acceptance test covering 200 discrete tests and generating over 400 images

ASASIN Factory Acceptance Test

Inspection and testing of the ASASIN code and functionality to support qualification.

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This document defines acceptance tests to verify proper functionality of the ASASIN software. The tests include verifying that the software complies with strict static code analysis, operates properly under normal and acceptable but anomalous circumstances, and produces quality output products that meet expectations.

This document is applicable for the delivery of ASASIN on Windows distributions with a graphical user interface as well as Linux distributions for embedded, autonomous operations. Each section provides a brief introduction to describe the test objectives.

The Factory Acceptance Test is acceptable if there are no defects. Many tests provide space for documenting results and acceptance criteria (in parenthesis), which shall result in a defect should results not match expectations. Any unexpected result or failed instruction shall result in a defect.

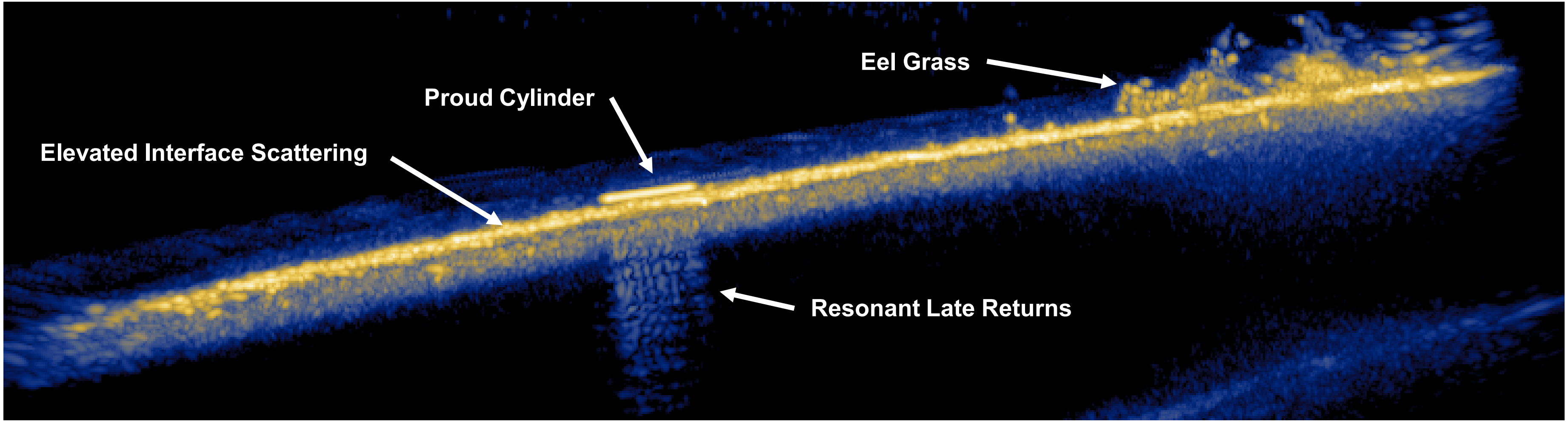
Completed by	Date	Revision
Steve Wagner	9/12/2024	1.12.0

Classification and Analysis Objectives

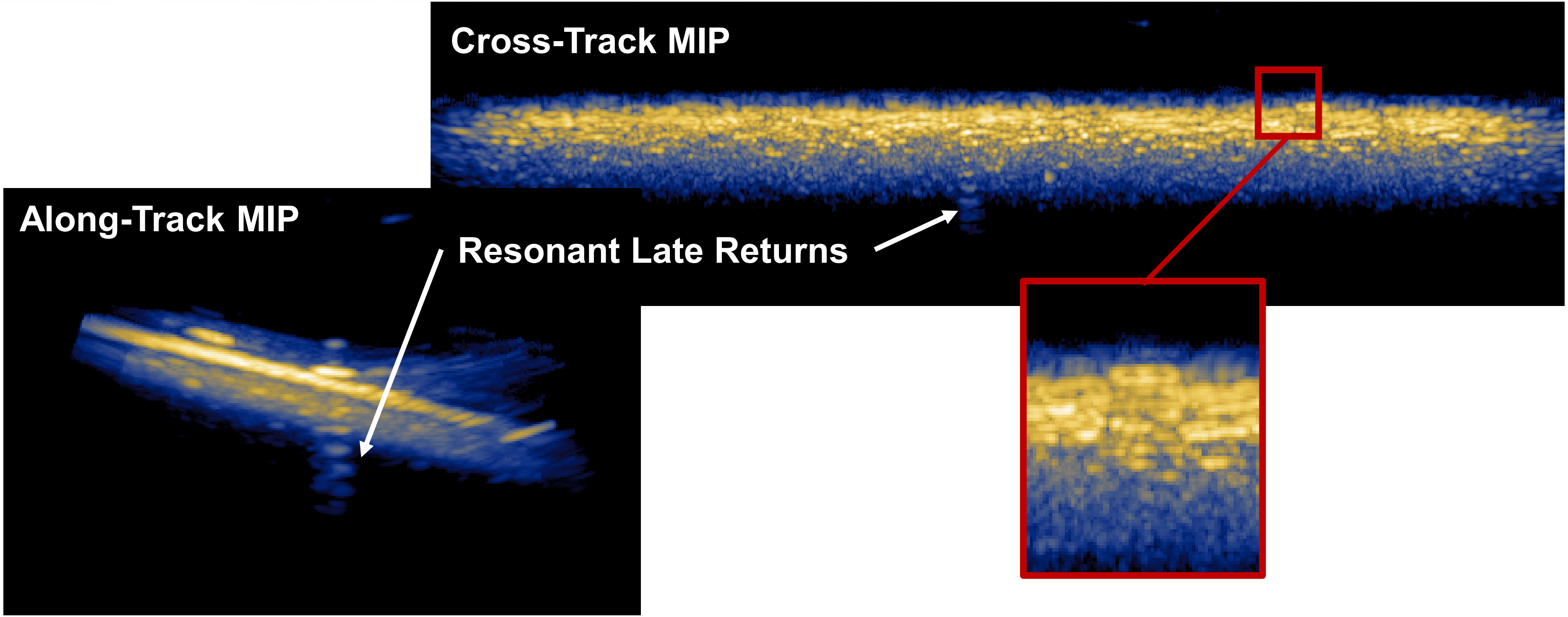
Performance Objective	Data Requirements	Success Criteria
Target Detection Performance – Large Munitions	Estimated positions of detected and classified munitions	PdPc > .9 and less than 10 false alarms in search area
Target Detection Performance – All Munitions	Estimated positions of detected and classified munitions	PdPc > .5 and less than 10 false alarms in the search area
Target Localization Accuracy	Estimated positions of calibration line targets	Error mean less than 50 cm and standard deviation less than 25 cm

Sequim Bay site has a highly sloped seabed

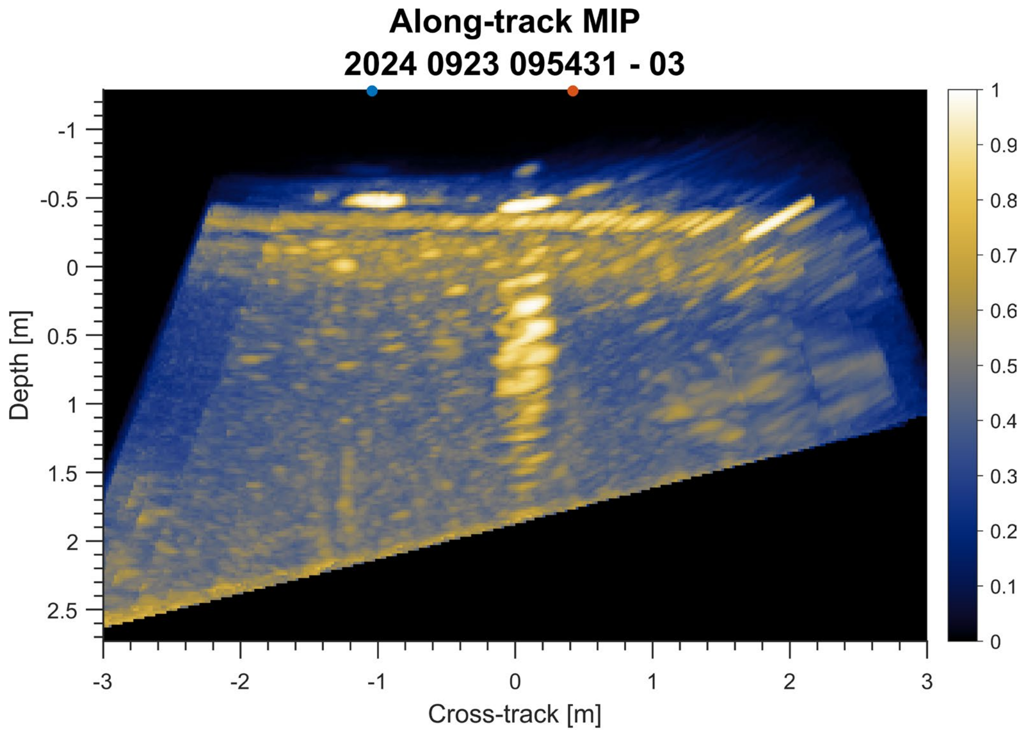
Cross Track Maximum Intensity Projection



Slope orientation influences image interpretation



Removing image slope and background normalization improves interpretability



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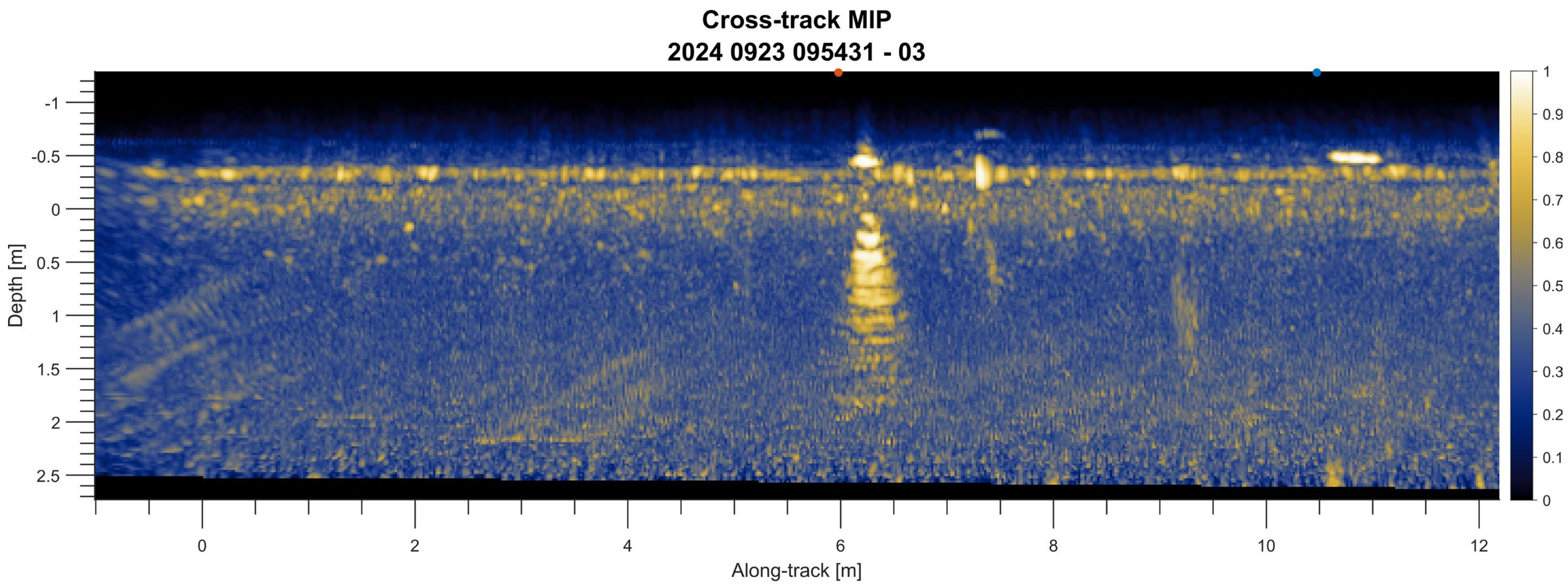
Removing image slope and background normalization improves interpretability



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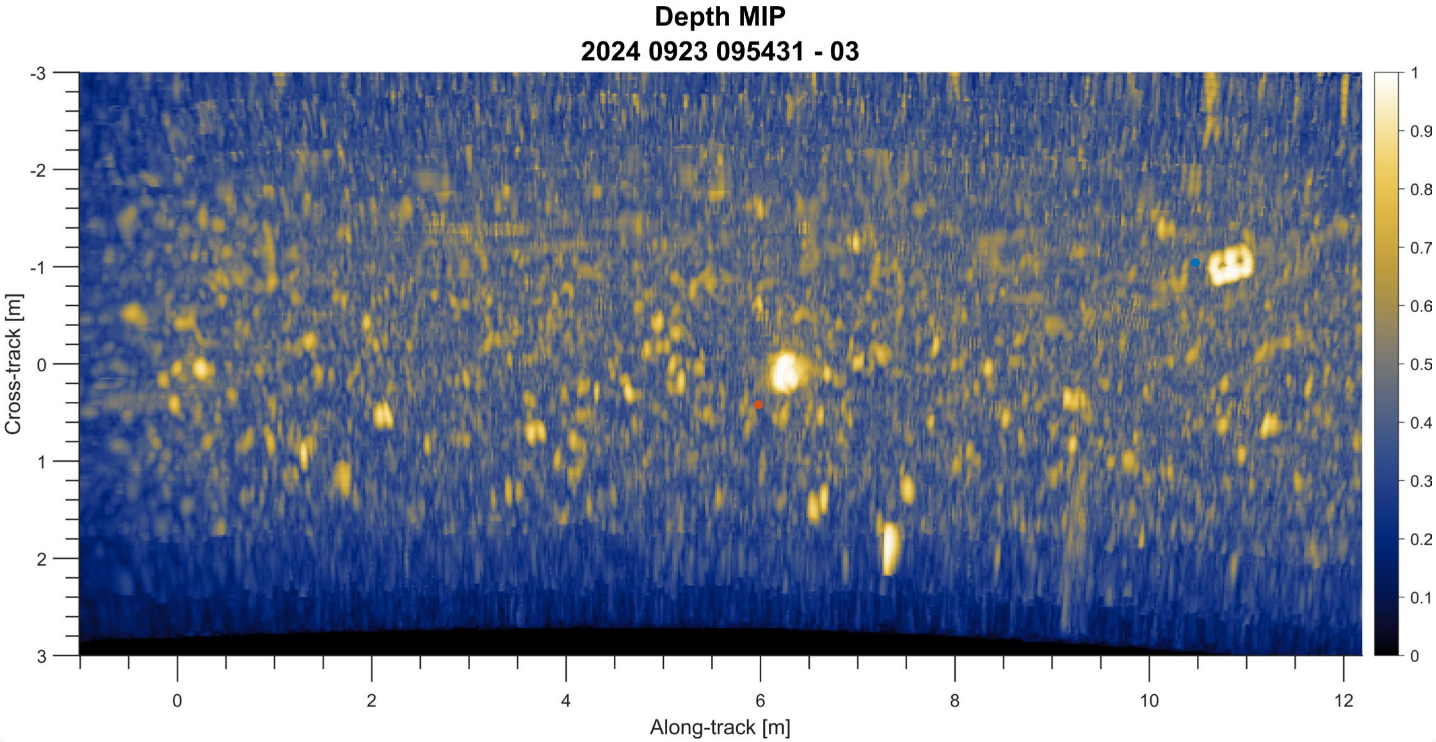
Removing seabed slope and background normalization improves interpretability



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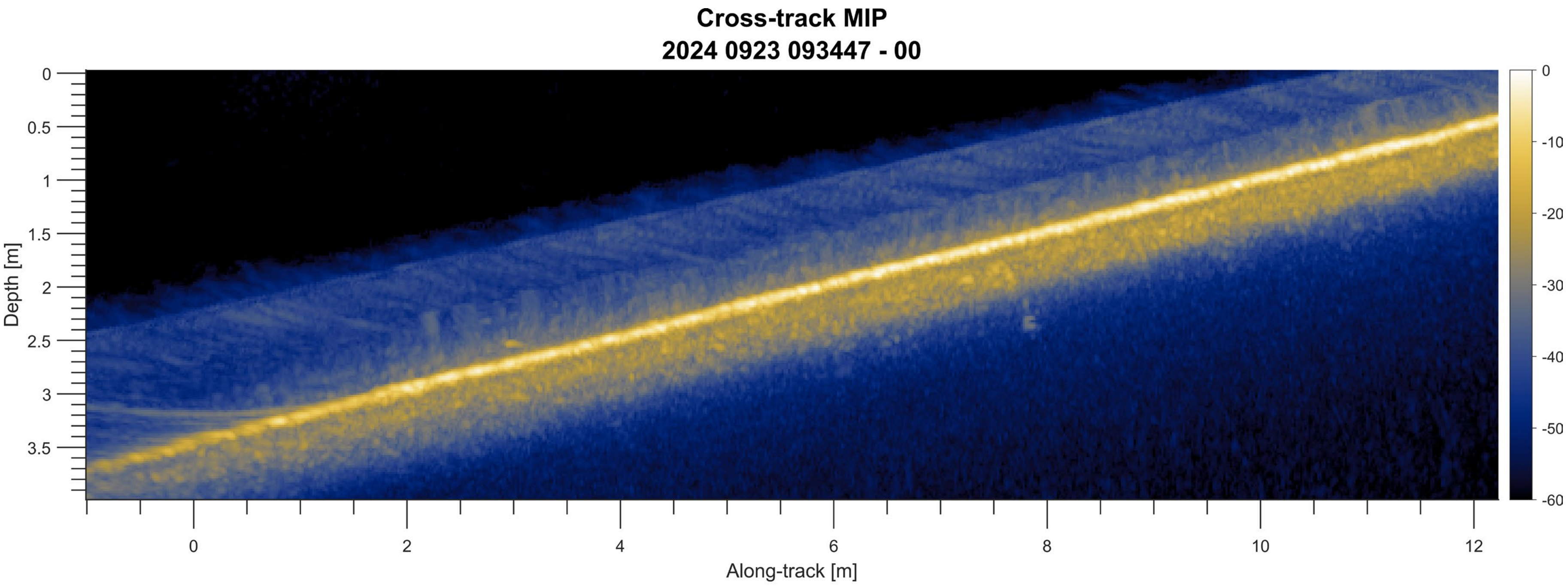
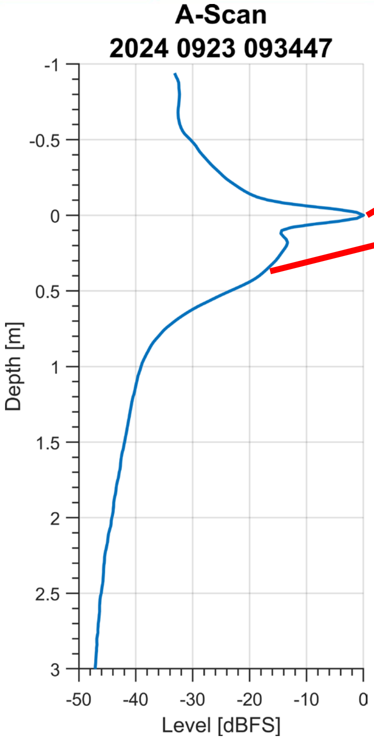
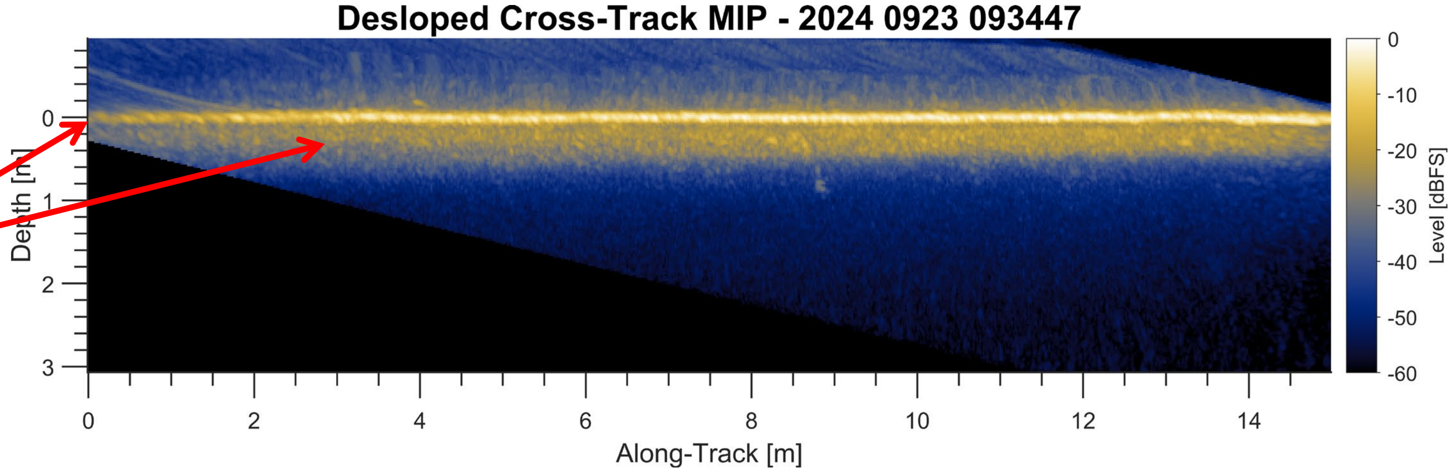
Elevated scattering is present due to shell hash at sediment-water interface



Desloping output allows visualization and quantification of this interface scattering





- Interface scattering strength appears to have a +15 dB enhancement over sub-bottom strength in the upper 15 cm. Aligns with PNNL diver observation of a shell hash layer during deployment

Issues

- October – November 2024 stop work while FY25 funding increment arrived has delayed analysis of Sequim trial data

Next Steps

- Major Remaining Activities
  - Sequim Bay Engineering Demonstration Data Analysis
  - Engineering design for craft-of-opportunity
- Reporting Dates
  - Engineering Demonstration Report: March 2025
  - Final Report: Jan 2026

Technology Transfer

- A SVSS system has been designed leveraging commercial-off-the-shelf components wherever possible and purpose-built components where required for acoustic performance
- Leverages government-rights-asserted established signal processing, synthetic aperture image reconstruction, data quality review, and post-mission analysis pipeline.
- The design of the sonar system is well documented through a full drawing package. This package could serve as the basis for commercial manufacturing.
- The datasets generated by this project are well curated and widely distributed across Munition Response machine learning researchers
- Informal discussions with site managers at Pearl Harbor, Mare Island, and Vieques

BACKUP MATERIAL

These charts are required and will be used by the Program Office but may not be presented.

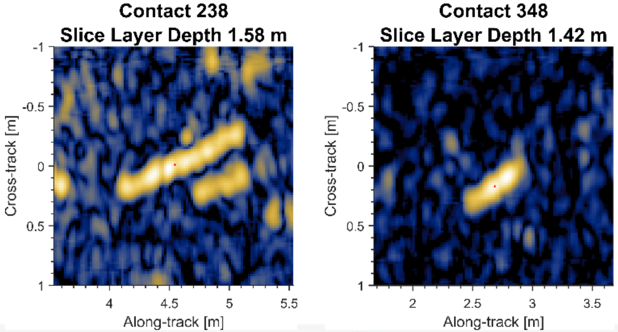
MR23-8364: Enhanced Sensing for Detailed Surveys in Very Shallow Water

Performers: Applied Research Laboratory – Penn State

Technology Focus
- *Development and demonstration of a sensor designed for detailed munitions response survey in very shallow water (less than 5 meters)*

Demonstration Site
- *Sequim Bay Test Bed*

Demonstration Objectives
- *Engineering demonstration of detailed survey in very shallow water*



Project Progress and Results
- *Purpose built hydrophone system designed / integrated / testing on test platform*
- *Demonstration in September 2024*

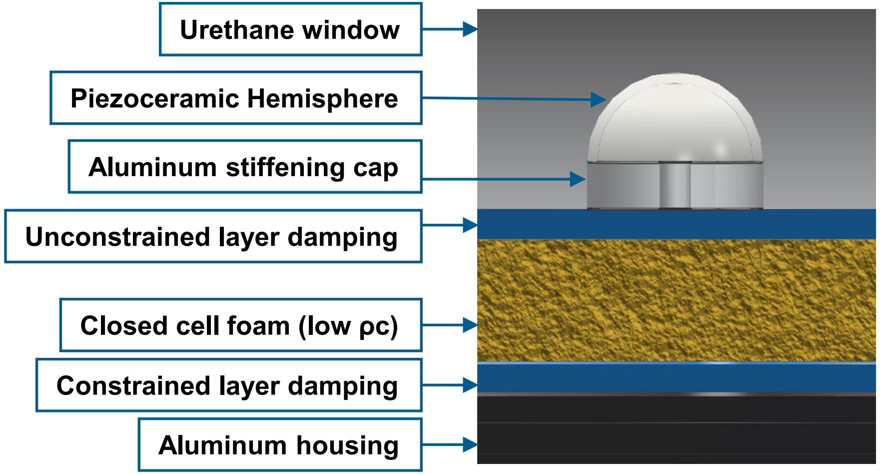
Implementation Status
- *Initial discussions held with managers from multiple munitions response sites*

Plain Language Summary

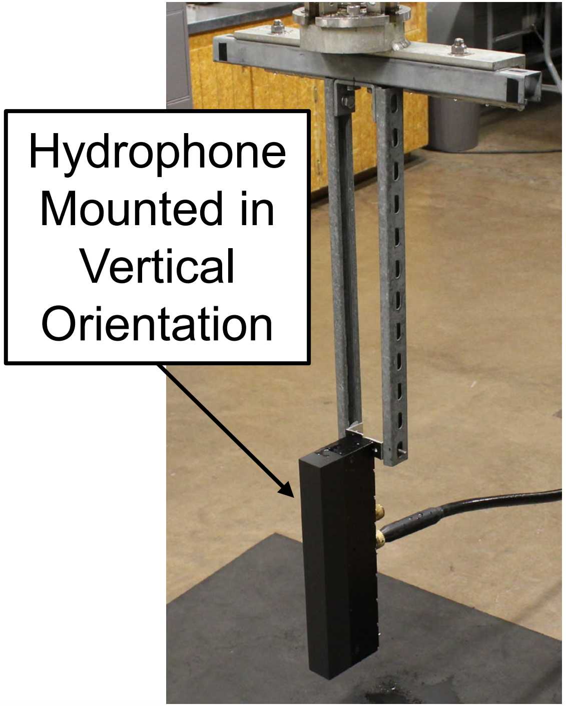
- Detailed ordnance survey in very shallow and confined waters present a number of logistical challenges for sonar systems. This effort seeks to develop a sensor suitable for operation in these challenging areas
- Shallow water regions are of particular importance due to the higher likelihood of human presence
- This is achieved through the design of a custom sonar system meant to operate from a shallow draft surface craft
- When paired with automated target recognition algorithms, this system will provide a means to conduct detailed surveys in near-shore munitions response sites

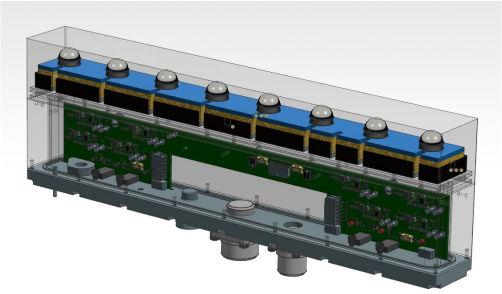
Impact to DoD Mission

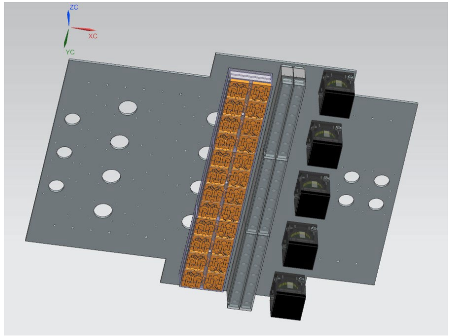
- A custom hydrophone array has been designed for generation of very high-resolution imagery of the seabed and sub-bottom
  - This array has been calibrated and tested and has exceeded all design criteria
- This design may be applicable to other DoD missions

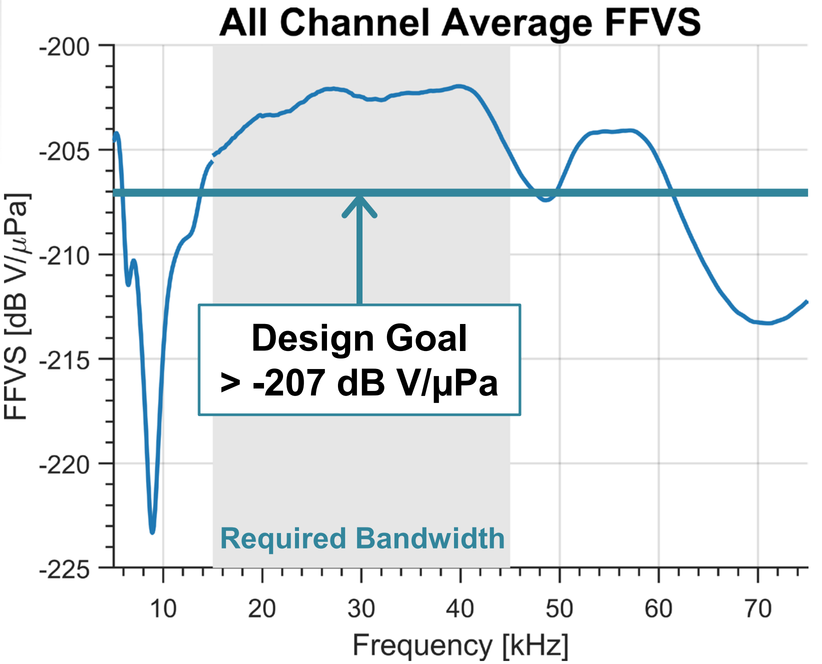


Impact to DoD Mission – Additional Figures









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Publications – Directly Supported

- K. S. Dalton, D. C. Brown, and T. E. Blanford, “Combining range-general and range-specific techniques for late-time focused image reconstruction,” JASA Express Letters, vol. 4, no. 3, p. 36001, Mar. 2024.
- D. C. Brown, S. F. Johnson, J. H. Philtron, and C. F. Brownstead, “Acoustic Modeling for Volumetric Sonar Systems,” in OCEANS 2022: Hampton Roads, 2022.
- H. R. Kurdila, G. Goehle, and D. C. Brown, “Morphological Component Analysis of Long-Duration Ringdown from Elastic Objects Imaged with the Sediment Volume Search Sonar,” in OCEANS 2022: Hampton Roads, 2022.
- K. S. Dalton, T. E. Blanford, and D. C. Brown, “Simulating elastic targets for sonar algorithm development,” Proceedings of Meetings on Acoustics, vol. 46, pp. 1–11, 2022.

Publications – In Collaboration

- T. Hoang, K. S. Dalton, I. D. Gerg, T. E. Blanford, D. C. Brown, and V. Monga, "Resonant Scattering-Inspired Deep Networks for Munition Detection in 3D Sonar Imagery," IEEE Trans. Geosci. Remote Sens., vol. 61, pp. 1–17, 2023, doi: 10.1109/TGRS.2023.3324223.
- G. D. Vetaw, B. Cowen, D. C. Brown, D. P. Williams, and S. Jayasuriya, "Learning-Based Tone Mapping to Improve 3D SAS ATR," in Proc. IGARSS 2023, 2023, pp. 6995–6998. doi: 10.1109/IGARSS52108.2023.10281904.
- A. Reed, J. Kim, T. Blanford, A. Pediredla, D.C. Brown, and S. Jayasuriya, "Neural volumetric reconstruction for coherent synthetic aperture sonar", ACM Trans. Graph., vol 42, no. 4, 2023.
- A. Reed, T. Blanford, D.C. Brown, and S. Jayasuria, "SINR: Deconvolving circular SAS images using implicit neural representations", IEEE Journal of Selected Topics in Signal Processing, 2022.
- T. Hoang, K. S. Dalton, I. D. Gerg, T. E. Blanford, D. C. Brown, and V. Monga, "Domain Enriched Deep Networks for Munition Detection in Underwater 3D Sonar Imagery," in IGARSS 2022 - 2022 IEEE International Geoscience and Remote Sensing Symposium, 2022, pp. 815–818.
- G. Goehle, B. Cowen, J. D. Park, and D. C. Brown, "Enveloped Sinusoid Parseval Frames," in OCEANS 2022: Hampton Roads, 2022, pp. 1–10. doi: 10.1109/OCEANS47191.2022.9977041.
- G. Goehle, B. Cowen, T. E. Blanford, J. Daniel Park, and D. C. Brown, "Approximate extraction of late-time returns via morphological component analysis," J. Acoust. Soc. Am., vol. 153, no. 5, pp. 2838–2854, 2023, doi: 10.1121/10.0019415.

Acronym List

- ARL – Applied Research Laboratory
- FFVS – Free Field Voltage Sensitivity
- PNNL – Pacific Northwest National Laboratory
- ROC – Receiver Operating Characteristic
- SVSS – Sediment Volume Search Sonar