Underwater UXO targets detection, mapping and classification from onepass dynamic data sets

Project Number MR23-9000

Principal Investigator: Fridon Shubitidze

PI's Organization: Dartmouth College

In Progress Review Meeting

01/13/2025

Project Team

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- Military Installation Contact: SERDP-ESTC

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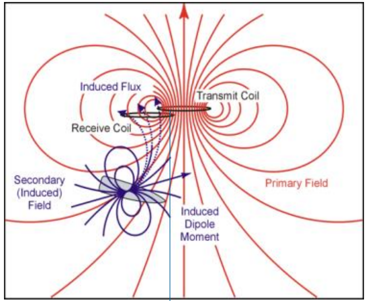
Overview:

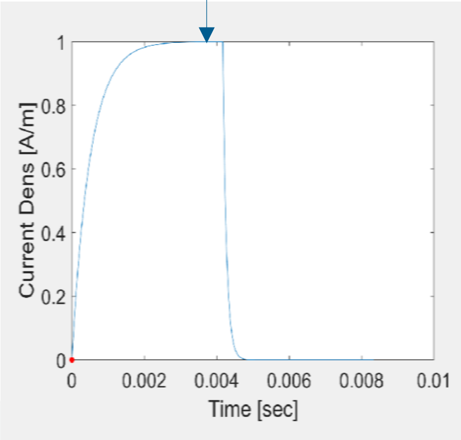
- The project's objectives:
  - Determine feasibility of using one-pass dynamic UW EMI sensors data sets for targets detection and classification
  - Understand and mitigate the sensor motion/orientation effects.
  - Process UW dynamic data sets.
  - Assess classification performance.

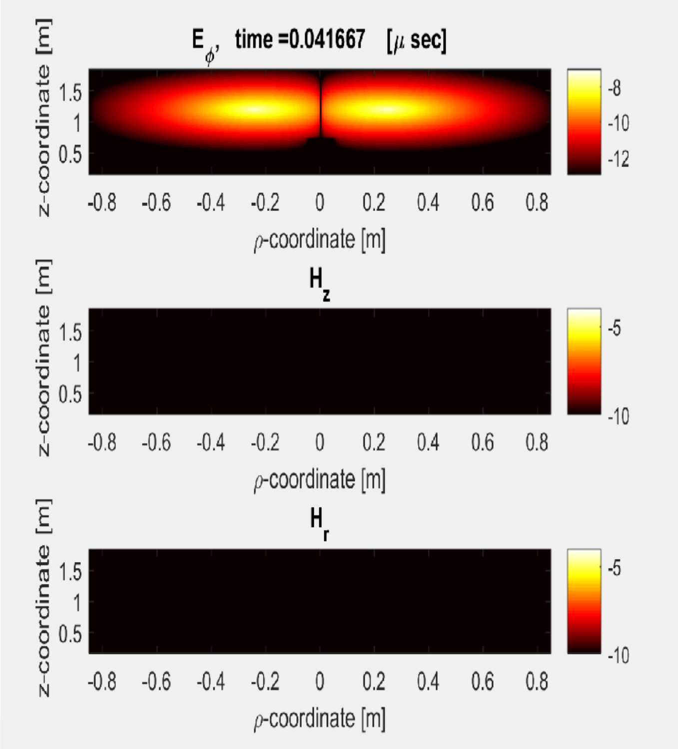
Bottom Line Up Front

- **Goal:** Evaluate the applicability of UW EMI systems and data processing algorithms for detecting, locating, and classifying UW targets using single-pass EMI data set.
- **Technologies tested**
  - Advanced background removal algorithms.
  - Advanced forward and inverse EMI models for data inversion and classification.
- **Results:**
  - Background noise was successfully removed, leading to improved target detection.
  - Understand and mitigate noise due to the sensor motion.
  - Target classification features were extracted, and anomalies were accurately classified.
- **Challenges:**
  - An increase in the sensor's standoff distance degrades target detection.
- **Support needed**
  - Additional UW EMI data from different systems are needed to fully assess the performance of sensors and algorithms.

EMI sensing in underwater environment





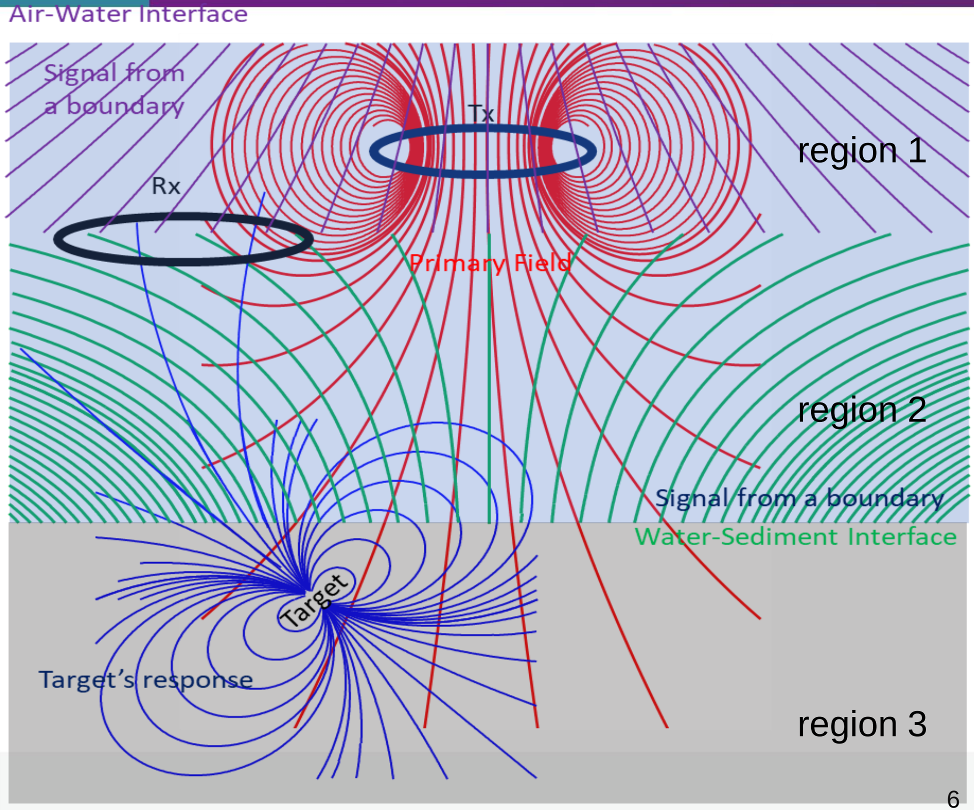


The Tx currents generate a primary magnetic field that penetrates the surrounding conductive medium and the metallic target.

The primary magnetic field is abruptly turned off, resulting in induced volume and surface currents within the conducting environment and the targets.

The induced currents produce secondary EM fields that are detected with a set of receivers

EMI sensing in underwater environment



- The total field in Region 2 is the sum of the fields produced by the transmitter coil (response from water), reflected fields from boundaries, and fields from a target.
- The fields in Region 1 are the transmitted fields.
- The total field in Region 3 is the sum of the transmitted fields and the response from a target.
- During dynamic data collection mode, the Rx coils move within a time-varying magnetic field, resulting in additional motion-induced signals.

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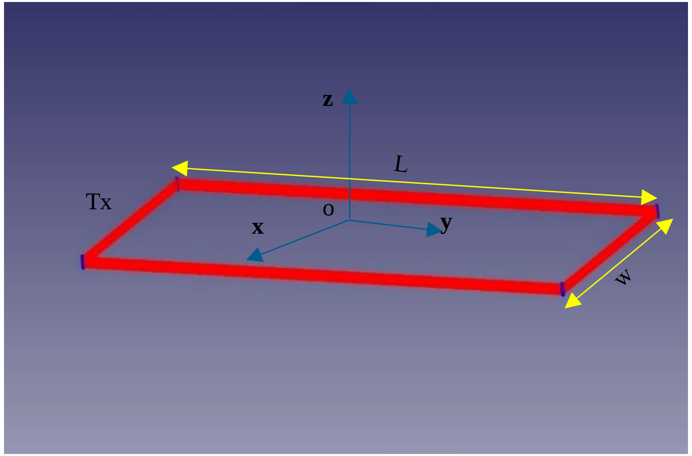
EMI field of Tx coil in Marine Environment

A Tx coil is placed in a conductive environment



Magnetic field

$$\mathbf{H} = \frac{1}{4\pi r^2}\left[\frac{2}{\pi^{1/2}} rQe^{-Q^2 r^2} + erfc(Qr)\right](\mathbf{J}\times\mathbf{R}); \text{ where } Q=\left(\frac{\mu\sigma}{4t}\right)^{1/2}$$

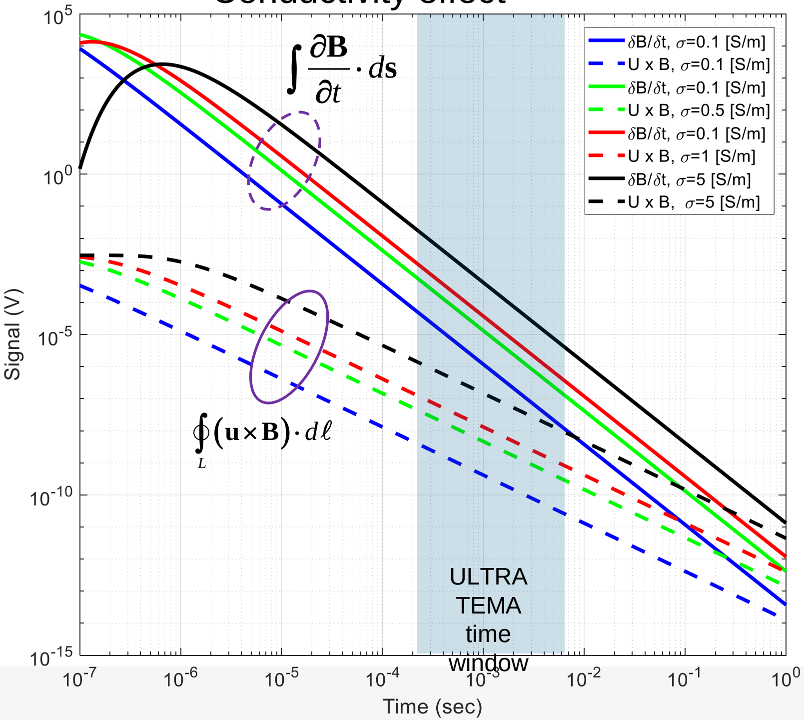
The time derivative of the magnetic field

$$\frac{\partial \mathbf{H}}{\partial t} = \frac{(\mu\sigma)^{3/2}}{16\pi^{3/2} t^{5/2}} e^{-\frac{\mu\sigma r^2}{4t}} (\mathbf{J}\times\mathbf{R})$$

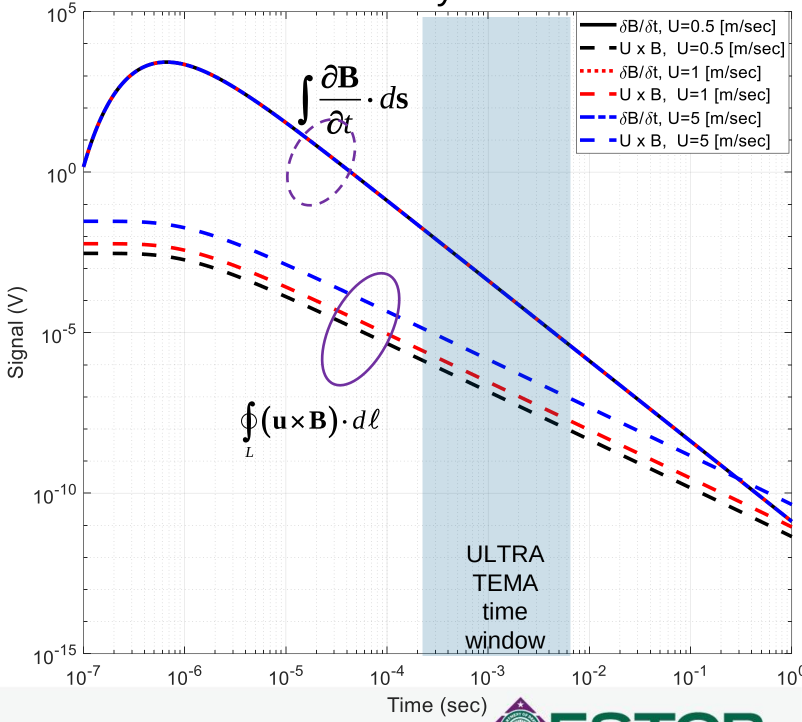
EMI Signals Induced in a Moving Rx Coil within Time Varying Field

$$Signal = \int \frac{\partial \mathbf{B}}{\partial t} \cdot d\mathbf{s} - \oint_L (\mathbf{u} \times \mathbf{B}) \cdot d\ell$$

Conductivity effect



Velocity effect



Technical Approach

Task 1: Select Bkg removal model

Task 2: Adapt Adv. Signal processing algorithm to UW data

Task 3: Apply to UW EMI data sets

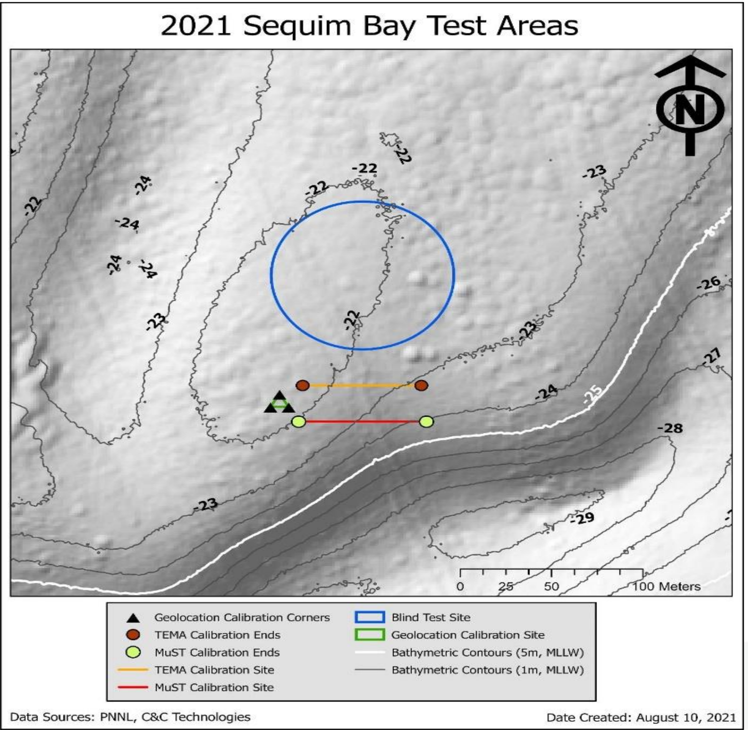
Task 4: Optimize models

Task 5: Process UW dynamic datasets and evaluate the performance of models for UW target classification.

Performance Objectives

Performance Objective	Data Requirements	Success Criteria
Quantitative Performance Objectives		
UW anomalies detection	UW blind data set and GT	•All anomalies located within 20 times their diameter from the transmitter are detected.
Accuracy of locating all seeded UW targets	Targets GPS locations	•Less than 0.75 meters distance between actual and predicted locations for buried anomalies. •less than 3.5 meters for proud and surface anomalies.
Targets classification	UW blind data set and TOI information	•All detected Targets of Interest (TOI) are classified accurately, while maintaining minimal false positives (less than 20% of TOI)."

Sequim Bay test site

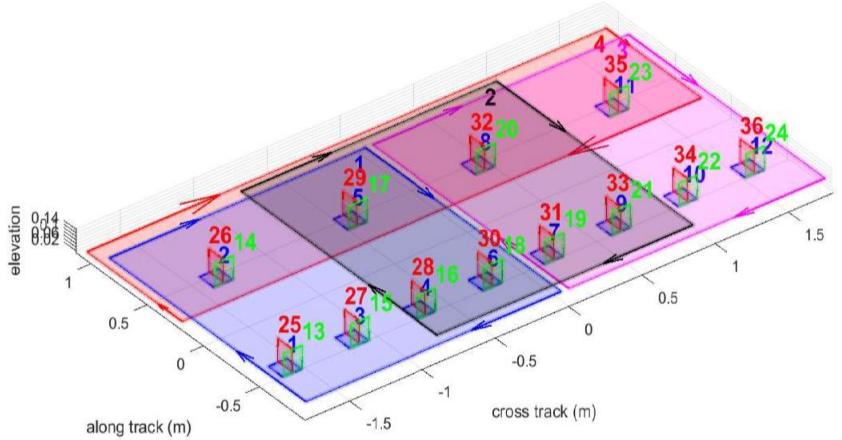


In 2019, the SERDP/ESTCP MR program established a testbed site at Sequim Bay, WA, featuring native UXO-free waters 5-30 meters deep with muddy and sandy sediments. This site is designed to evaluate various UW sensing technologies for detecting and classifying UW UXO targets in different environmental conditions.

The demonstration included two calibration lanes and a blind-test area. The first lane, 85 meters long, was set up for preliminary testing of the UltraTEMA sensor. It contained six medium and six large ISOs, positioned 2 meters off the centerline in different orientations: two along-track, two across-track, and two vertically.

The second lane, parallel to the first, was used to assess both the UltraTEMA and MuST systems. It featured various UXO surrogates (60mm and 81mm mortars, 40mm, 105mm, and 155mm projectiles) and clutter items (scuba tank, anchor, and cement block).

UltraTEMA: Single-Pass UW EMI detection and classification system



The UltraTEMA system consists of four transmitter coils and twelve vector receiver sensors. It measures complete EMI response of a target at each dynamic data point and provides 144 data value at each n^{th} (n=1,2, .., 25) time gate.

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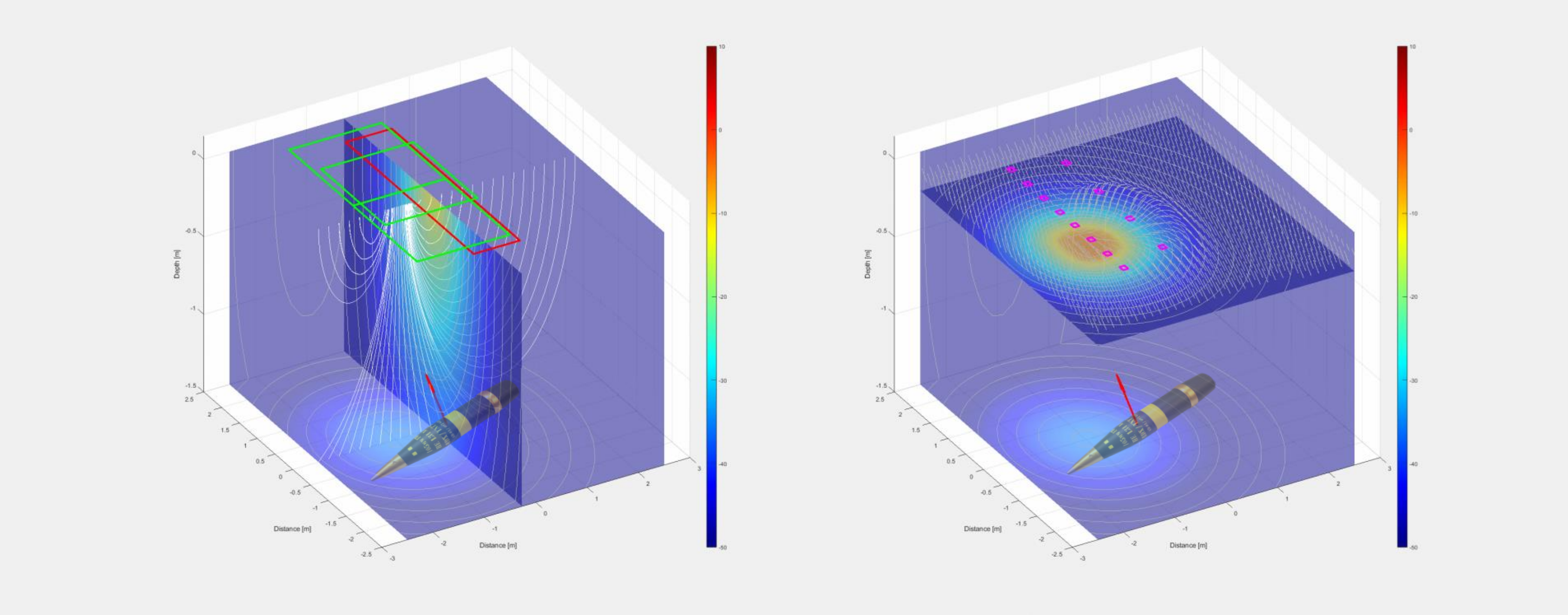
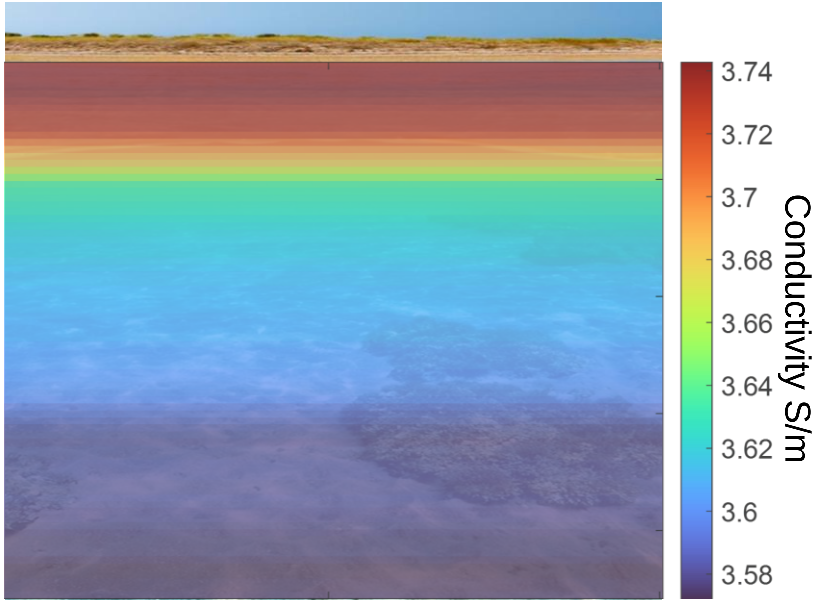
ULTRATEMA Operation principles

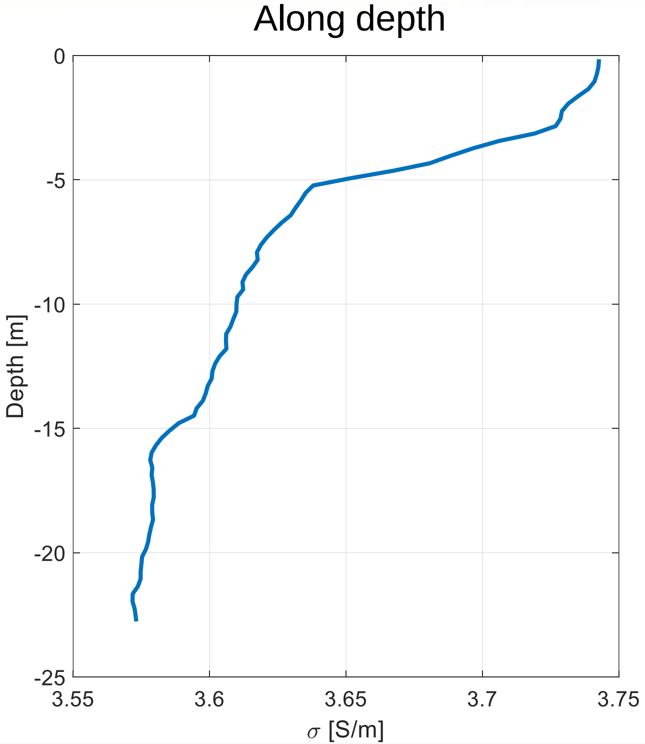


Conductivity Profile

Sequim Bay Calibration Area

2D Cross section





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Data acquisition

- A sensor is deployed in the marine environment.
- The Tx/Rx coils traverse through various conductive layers.
- The direct EMI signals from the Tx coils to the Rx coils are proportional to the conductivity of the medium.
- Changes in yaw, pitch, and roll alter the orientation of the Tx/Rx coils, placing them in different conductive environments.

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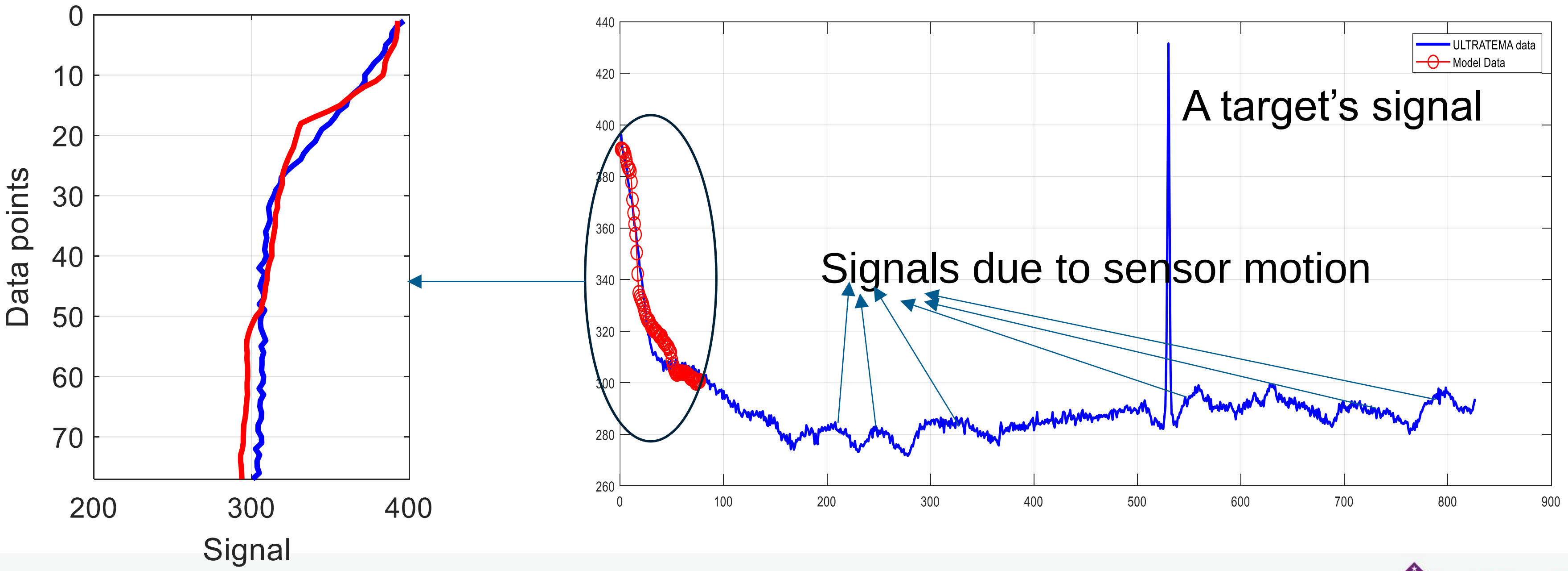
Sensor noise

Comparisons between modeled and actual ULTRATEMA background noise data



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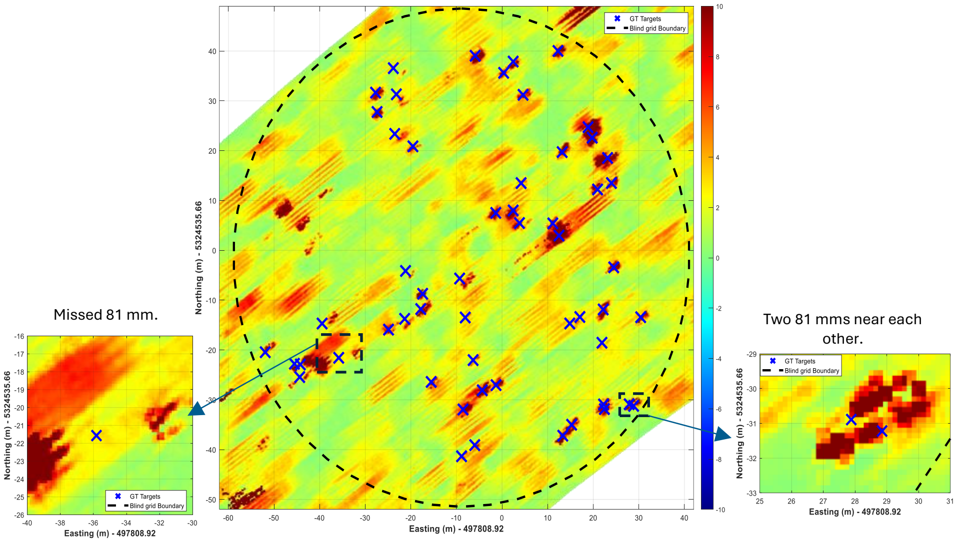
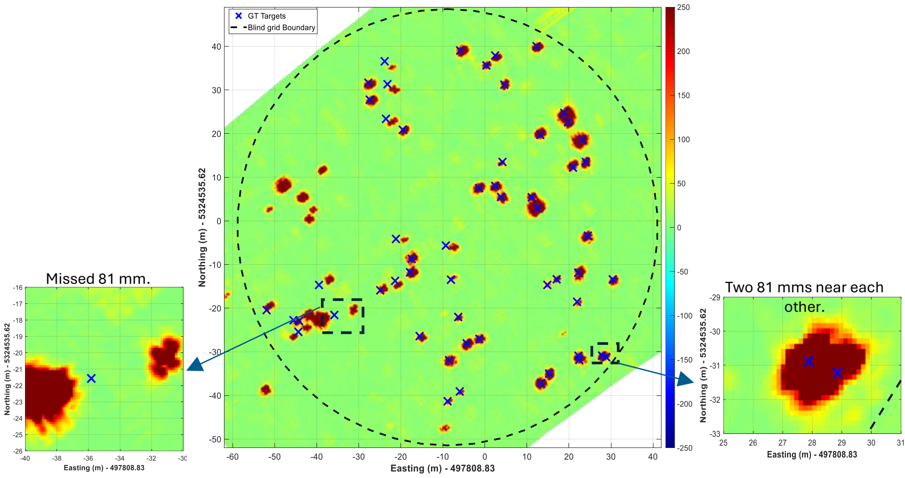
Detection maps

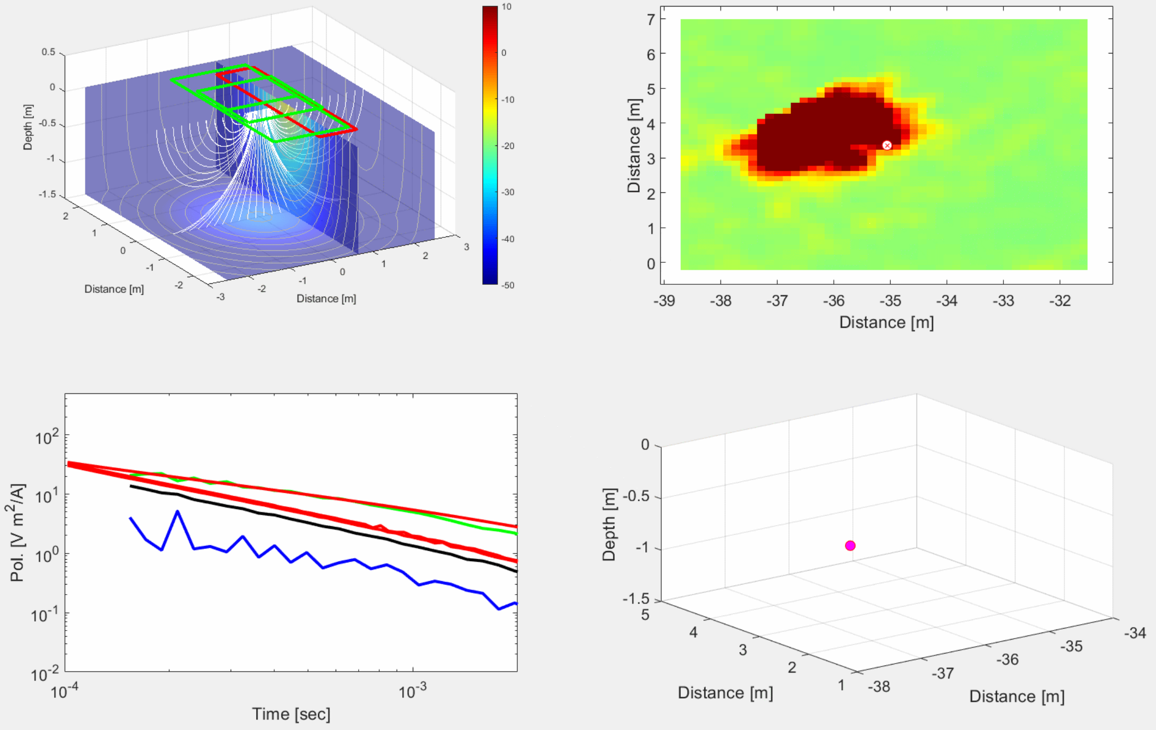
Incorrectly aligned EMI and GPS data



Correctly aligned EMI and GPS data

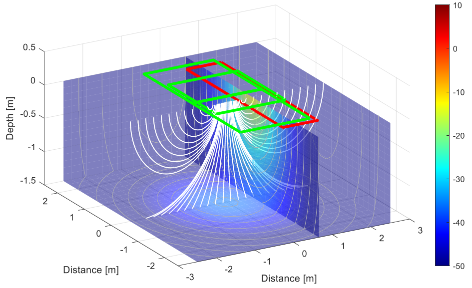


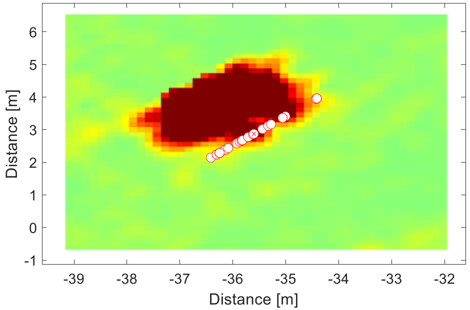
Results: Single-Pass data processing

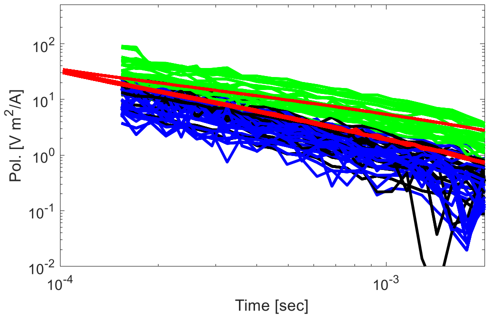


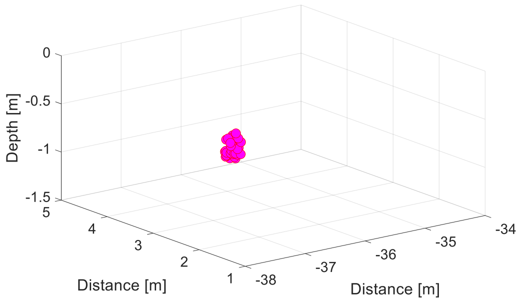
- A set of dynamic data points is identified around the target.
- An objective function is defined as the simple difference between two data points.
- The target's location and classification features are extracted from each objective function.

Results: Clustering polarizabilities and locations





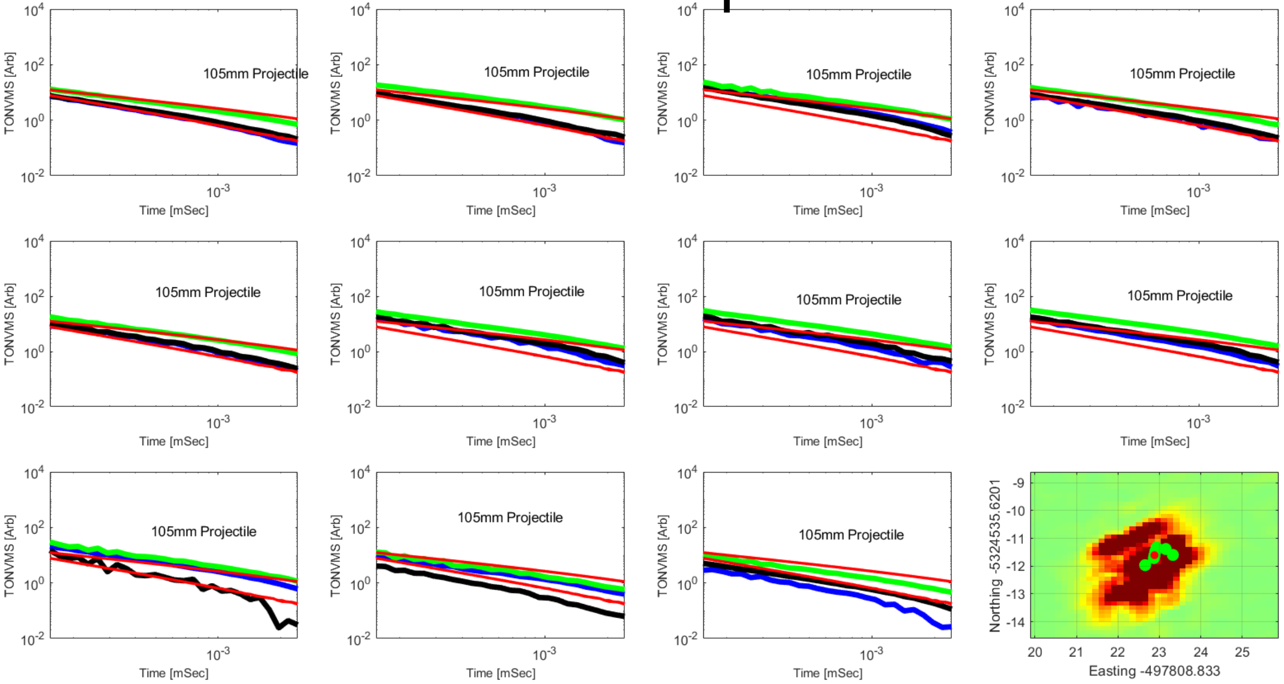




- The extracted noisy effective polarizabilities and their corresponding locations are discarded.
- The remaining locations are grouped into clusters.
- Within each cluster, the effective polarizabilities are sorted and stacked.

Results: Extracting Classification Features of Targets

Extracted effective polarizabilities



105 mm Projectile

Scoring Inputs: Not Blind results

Ranked Detection List Example

All Detected Objects

Rank	Easting	Northing	Dig
1	497802.13	5324503.49	1
2	497758.88	5324537.97	1
3	497801.99	5324494.04	1
…	…	…	…
52	497833.25	5324523.74	1
53	497771.66	5324546.91	0
53	497769.48	5324538.04	0
…	…	…	…
93	497810.67	5324570.99	0

Likelihood of Being A UXO

Demonstrator's Dig Threshold

- 93 detections, with 51 dig decisions
- Processing steps:
  1. The detection map was created, and a list of detected anomalies was generated.
  2. Data points were extracted around each detected anomaly.
  3. Each data point was inverted to estimate the magnetic source(s) polarizabilities and locations. Th extracted locations were then clustered, and polarizability within each cluster was combined.
  4. The cluster source locations were used as the estimated locations of anomalies, and the combined polarizabilities were used for classification.
  5. Anomalies were ranked using a library matching technique through automatic classification.
  6. The ranked targets were reviewed to remove duplicate sources and produce the final list.

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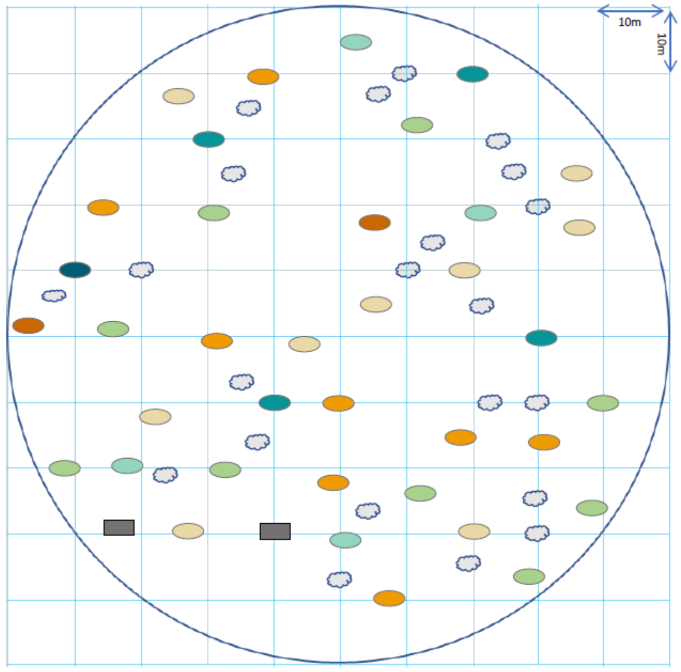
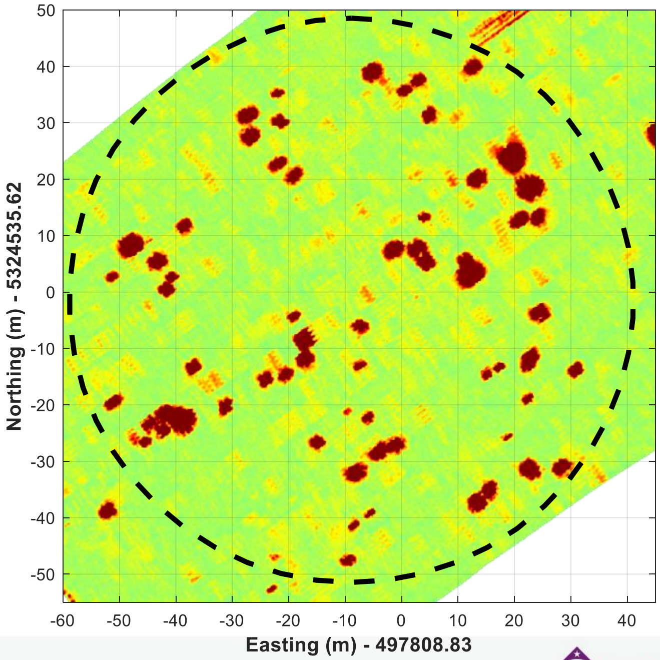
2022 Sequim Bay Blind Site: Bird view

Targets layout



EMI detection heat map



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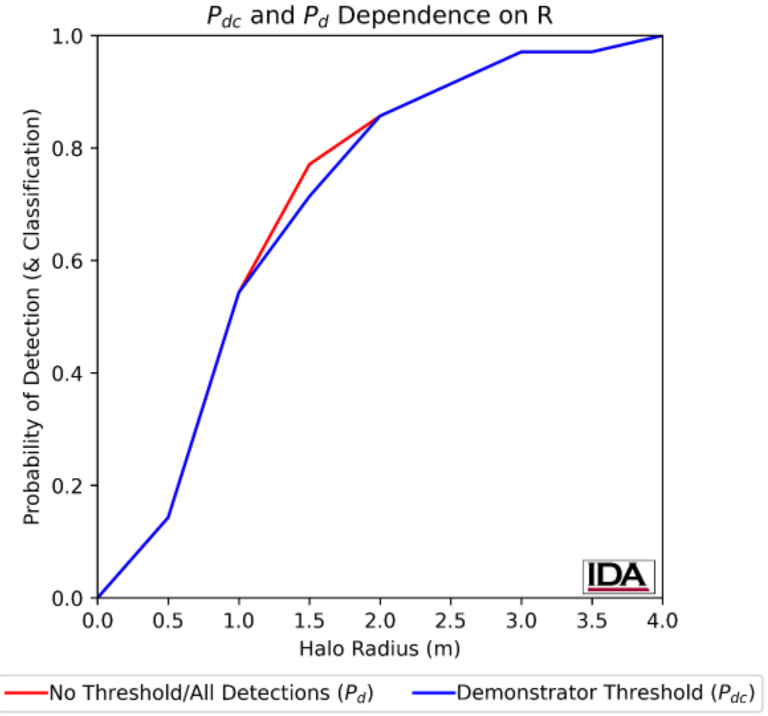
Classification Summary Statistics

Halo Radius (m)	FP	FN	TP	P_{dc}
0.5	42	30	5	5
1.0	28	16	19	19
1.5	22	10	25	27
2.0	17	5	30	30
2.5	15	3	32	32
3.0	13	1	34	34
3.5	13	1	34	34
4.0	12	0	35	35



- Best detection/classification performance happens at r= 4 m
- Performance stabilizes, so ROC curve primarily reflects detection/classification rather than geolocation

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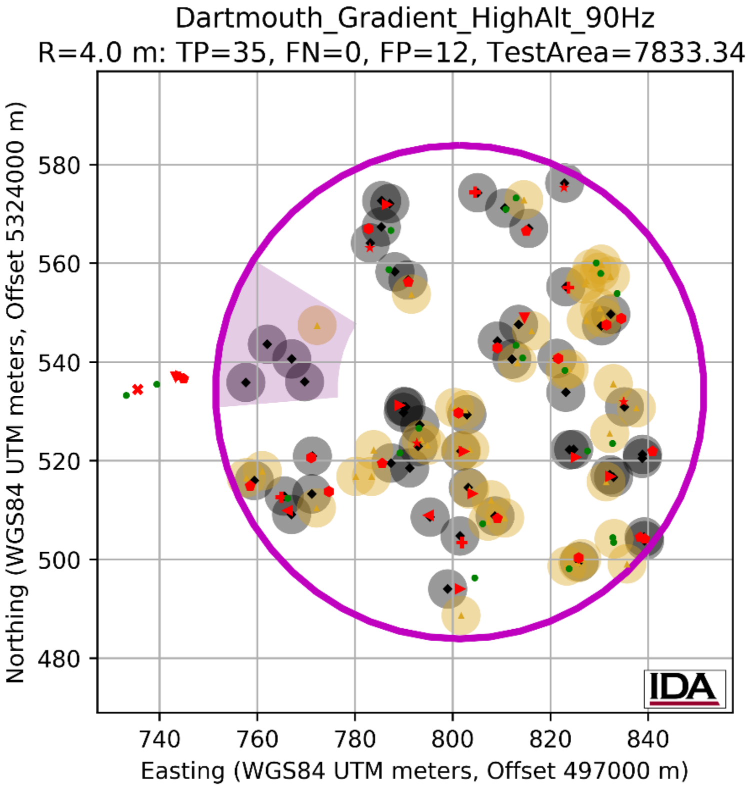
Detection and classification in Exclusion Area

The exclusion area shows four dig decisions and two no dig decisions, agreeing with the number of objects pulled out of the testbed



In the exclusion area, the detection list includes four dig decisions and two no-dig decisions, which matches exactly with the number of TOI and clutter objects removed from the testbed. This suggests that the objects were likely removed from the testbed after the UltraTEMA collected data.

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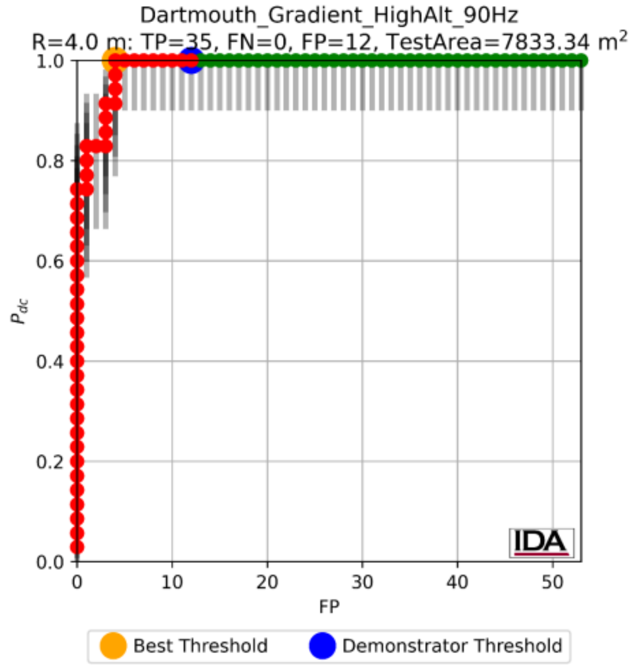
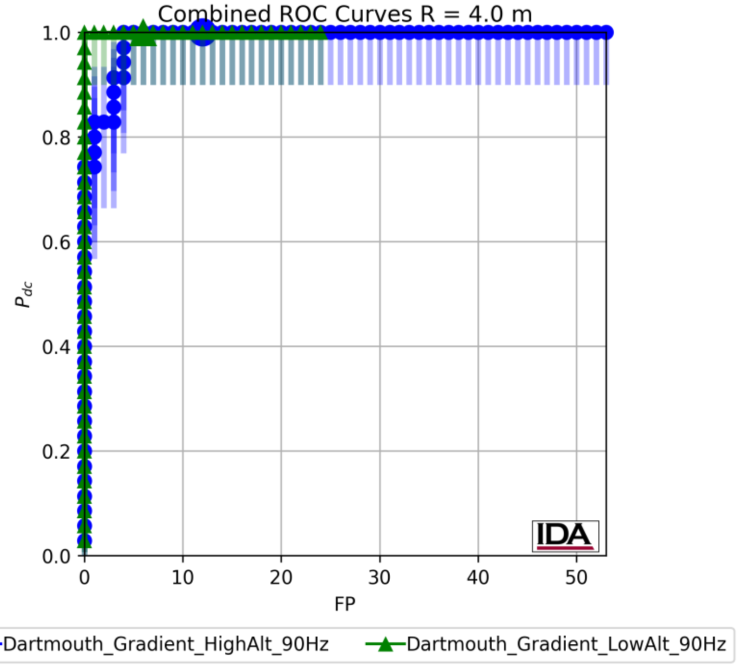
ROC Curves for high altitude data

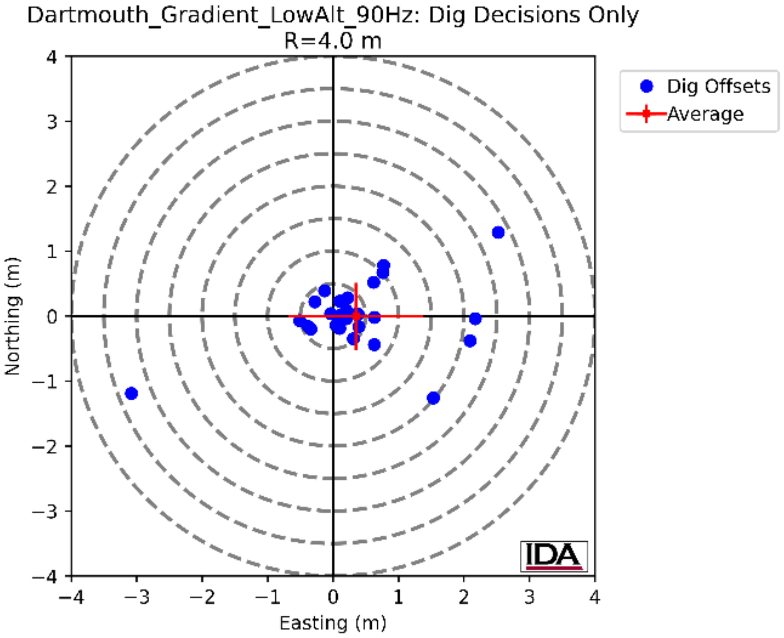
High Altitude

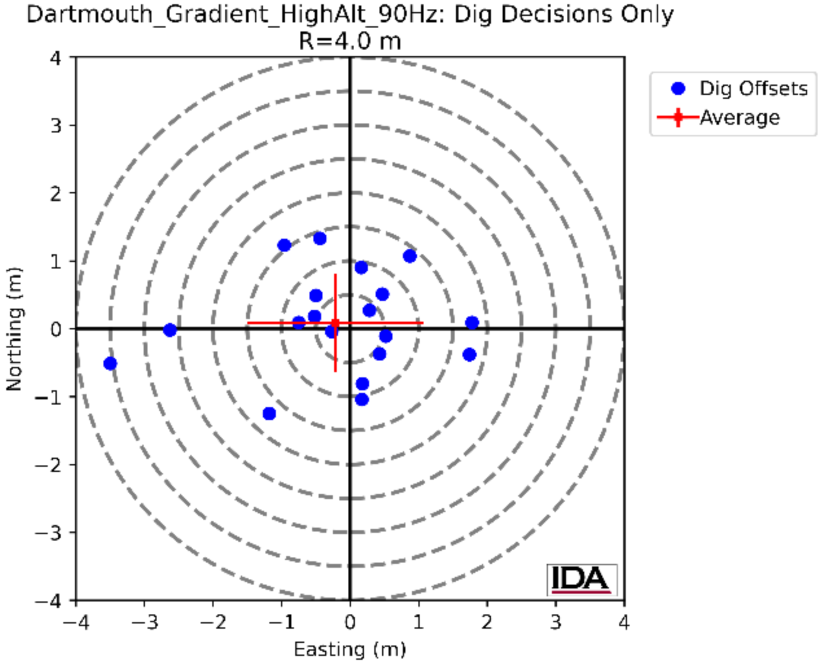


Comparison between low and high altitude ROCs.



Comparison Between Location offsets





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Issues

- NA

Next Steps

- Adapt these models to other existing EMI sensor data.
- Submit the final Demonstration Plan by 1/30/2025.
- Process the UW EMI blind dataset.
- Classify the targets.
- Evaluate the performance of advanced models for detecting and classifying UW targets.

Technology Transfer

- The numerical models and classification results will be presented at conferences and published in peer-reviewed journals.
- The final report will provide a detailed overview of the technologies and results for the broader UXO community.
- Additionally, the UW data processing modules and target classification algorithms will be adapted for use with other UW EMI systems.

BACKUP MATERIAL

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

MR23-9000: Underwater UXO targets detection, mapping and classification from onepass dynamic data sets

Performers: Dr. Fridon Shubitidze, Dartmouth College

Technology Focus

- Evaluate the applicability of UW EMI systems and data processing algorithms for detecting, locating, and classifying UW targets using single-pass EMI data set

Demonstration Site

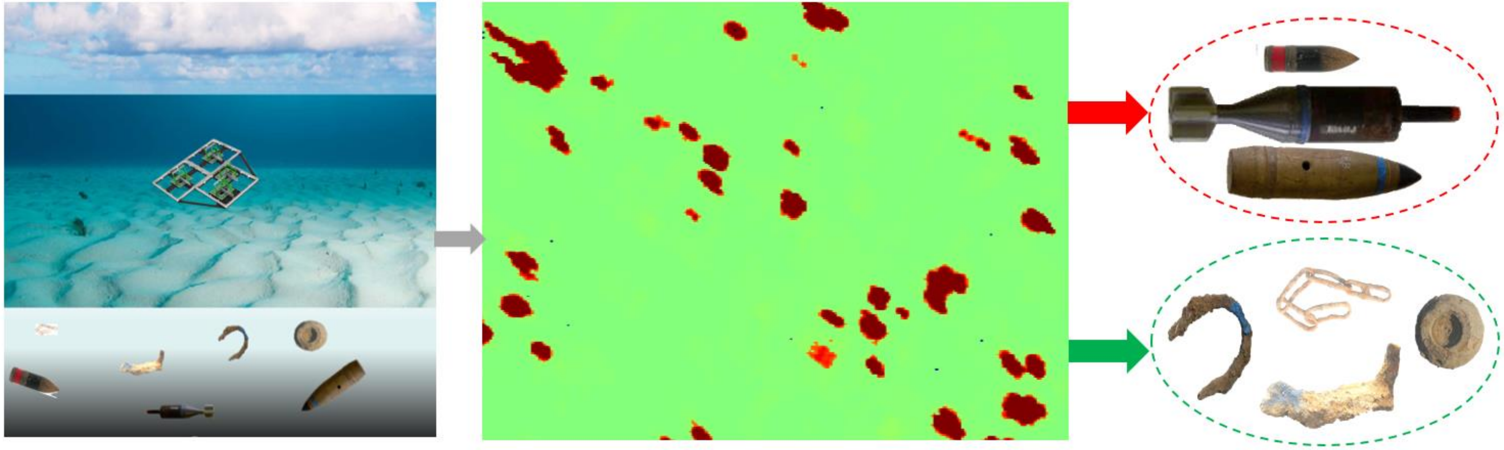
- *Sequim Bay, WA*

Demonstration Objectives

- *Detect and classify all TOIs from one pass EMI data set.*

Project Progress and Results

- Background noise was successfully removed, leading to improved target detection.
- Target classification features were extracted, and anomalies were accurately classifie



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Status of Funds for Federal Performers

- Report on the status of funds for each MIPR received by a directly funded Federal performer. Provide information on each fiscal year for which there has not been 100% expenditure of funds. If you or your co-performer do not understand how to fill this out, contact your Program Manager in advance of the IPR.

FY20XX Funds			
Directly Funded Federal Performer(s)	**Funds Received**	**Funds Obligated***	**Percent Funding Obligated**
Federal Performer A - Direct Cite MIPR			
Federal Performer A - Reimbursable MIPR			
Federal Performer B - Direct Cite MIPR			
Federal Performer B - Reimbursable MIPR			

* Funds put on contracts and/or purchase orders that have been issued, and funds associated with internal labor or travel expenses that have been incurred.

Publications

- F. Shubitidze, I. Shamatava, B. Barrowes:, 2024 ”An orthogonal auxiliary source technique for solving forward and inverse EM problems”, IEEE ComCas20024, July 9-11, Tel-Aviv, Israel.

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Literature Cited

1. Stephen Billings and S. Lin-Ping, SERDP-Project # MR-2412: "Determining Detection and Classification Potential of Munitions Using Advanced EMI Sensors in the Underwater Environment" Final report.
2. S. Cazares, M. Tuley, and E. Ayers, "The UXO Classification Demonstration at Former Camp Butner, NC," 2011 [Online]. Available: http://serdpestcp.org/content/download/12777/151554/version/1/file/IDA_Camp+Butner_Report_1-13.pdf.
3. F. Shubitidze et al., "A complex approach to UXO discrimination: Combining advanced EMI forward models and statistical signal processing," SERDP MR-1572 Final Report, January 2012.
4. F. Shubitidze, J. P. Fernández, B.E. Barrowes, I. Shamatava, A. Bijamov, K. O'Neill, D. Karkashadze, " The orthonormalized volume magnetic source model for discrimination of unexploded ordnance", *IEEE Transactions on Geo-Science and Remote Sensing, Digital Object Identifier 10.1109/TGRS.2013.2283346*
5. Stephen Billings, Richard Funk, Jeff Gamey, September 2022, UltraTEM Marine towed system for detection and characterization of buried ordnance, ESTCP MR19-5073 Sequim Bay Demonstration Plan,

Acronym List

AGC	Advanced Geophysical Classification
cm	Centimeter
CRREL	*Cold Regions Research and Engineering Laboratory*
DAQ	Data acquisition
DoD	Department of Defence
EMI	Electromagnetic induction
ERDC	*Engineering Research and Development Center*
ESTCP	Environmental Security Technology Certification Program
µs	Microsecond
ISO	Industry Standard Object
kHz	*Kilo Hertz*
MAS	Method of auxiliary source
mm	Millimeter
ms	Millisecond
MuST	Multi-Sensor Towbody
ONVMS	Orthogonal normalized volume magnetic source
ONV/SMS	Orthonormalized volume or surface magnetic source models
PI	*Principal investigator*
Rx	*Receiver*
SERDP	Strategic Environmental Research and Development Program
TD	Time domain
TRL	*Technical Readiness Level*
Tx	*Transmitter*
UltraTEMA	Ultra transient electromagnetic Array
USACE	*United States Army Corps of Engineers*
UXO	Unexploded ordnance
UW	Underwater