Unmanned Surface Vessel Based Munition Detection, Mobility and Burial Monitoring, and Environmental Mapping in Surf Zone Environments and Demonstration of Deterministic Modeling Capabilities

MR 22-3303

Peter Traykovski

Applied Ocean Physics and Engineering Dept.

Woods Hole Oceanographic Institution

In-Progress Review Meeting

8/14/2025

Project Team

- Peter Traykovski
- Applied Ocean Physics and Engineering Dept.
- Woods Hole Oceanographic Institution

Bottom Line Up Front (Red is new for 2025)

- Round 1 (Spring 2023) Deployments of Surrogates at Martha's Vineyard Went Well
- Planned Round 2 (Fall 2023) Deployments of Surrogates at Martha's Vineyard delayed till fall 2024 due to timing of funding
  - Fall 2024 Deployment successful. Will show data
- Revised Unmanned Surface Vessel (USV) USBL SUXO tracking more difficult than anticipated, but proceeding well
  - Completed with interesting results from calm water and field use of this system at Martha's Vinyard showing it's potential and limitations
- Continued refinement of USVs for bathymetry in surf-zone going well
  - Investigating Multibeam sensors on these platforms
  - Integrated Coastal Solutions has production hulls. Working actively with FRF and USGS on use for their goals and data processing.
- Technology and Methods developed in this work and previous work is being used ESCTP demonstration work with Univ of Delaware and N.R.L.

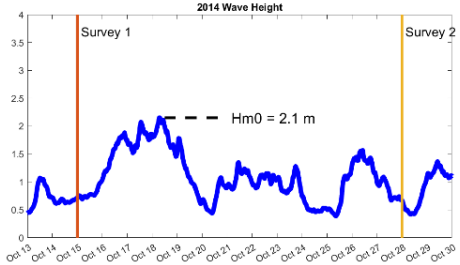
Technical Objective

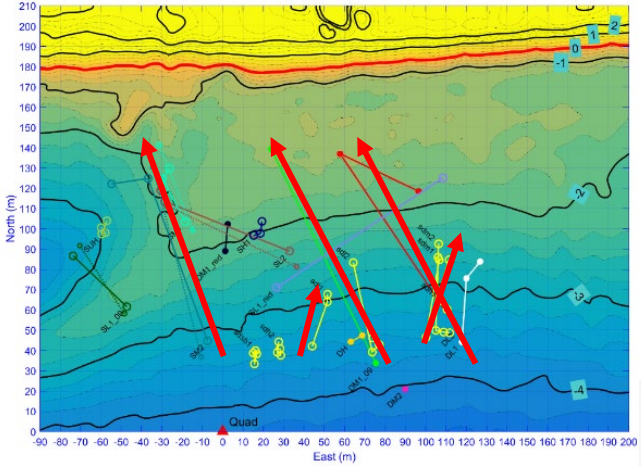
- Evaluate performance of predictive models for Munition Mobility, Burial and Bathymetric change based on observations
  - Conduct two set of measurements in spring and fall at Martha's Vineyard. Spring and Fall Deployments tend to have different sand bar migration characteristics
  - Develop USV based tracking technology for sUXO with embedded pingers. Less effort by divers needed
- Refine surf-zone capable USV for Bathymetry
  - Develop and evaluate precision MMU tracking buoy for this project and Maine work .. not in original proposal
- Evaluate Sidescan detection of unburied UXO in surf zone

Previous Results

UnMES Migration Classes	
None, Very Short	0 – 5 m
Medium	5 - 50 m
Far	50 m +

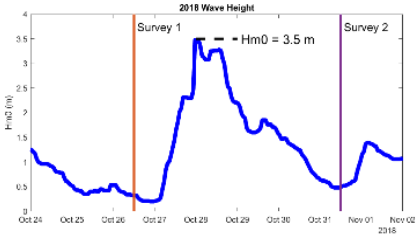
2014: 100 m + Far Onshore migration of low density (S < 2.5) sUXO

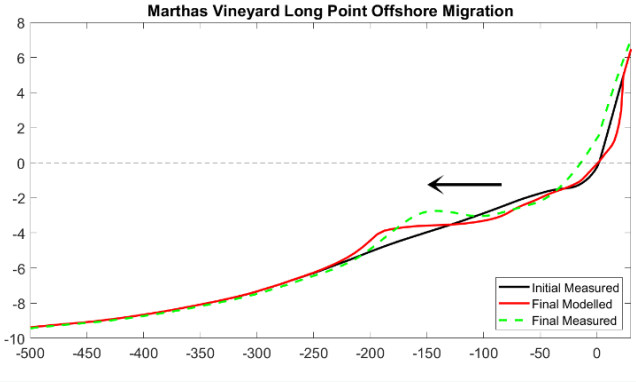




2018 Deep (1.5 m) Burial Due to Offshore Bar Migration

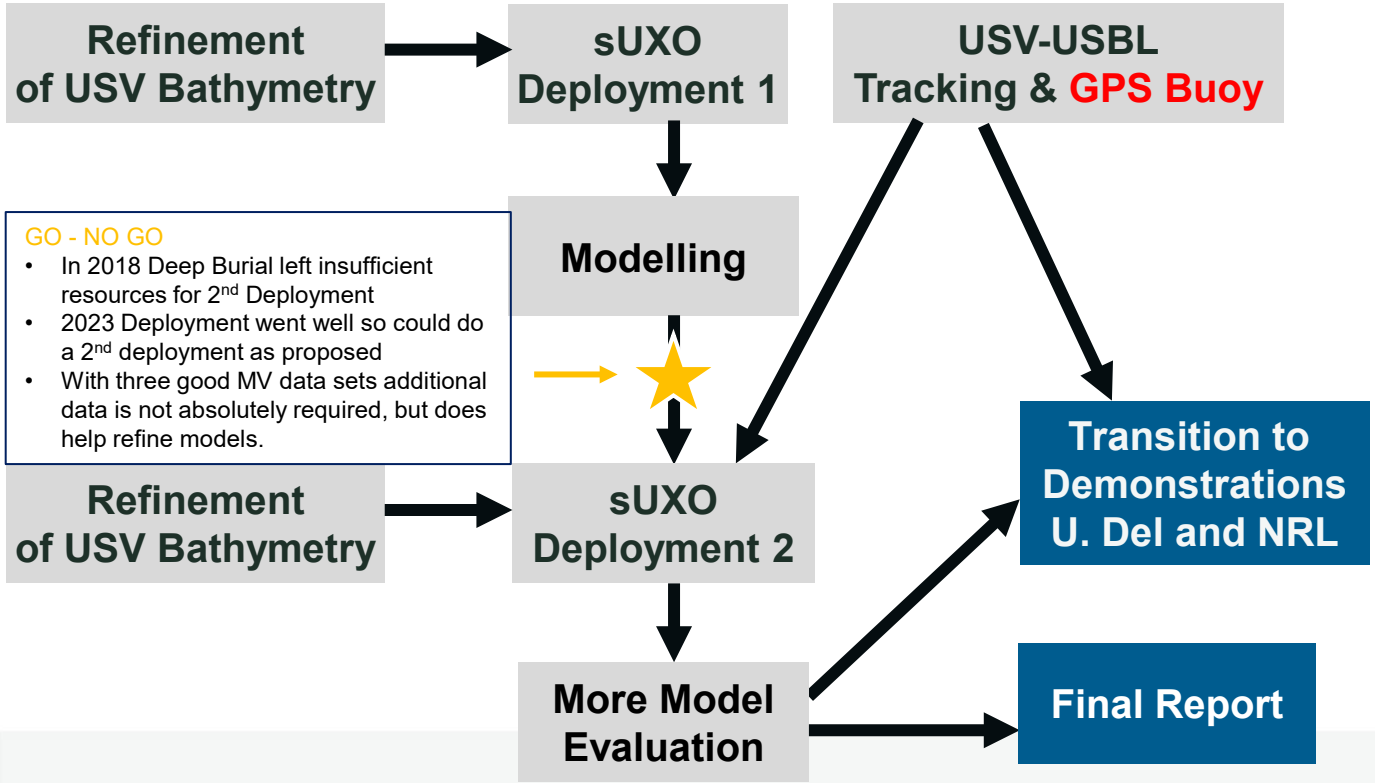
No (ΔX<5m) sUXO Migration for all Densities





This project Deployment #1 (Spring 2023) Moderate (0.5 m) Burial Due to Offshore Bar Migration
No sUXO Migration

Technical Approach



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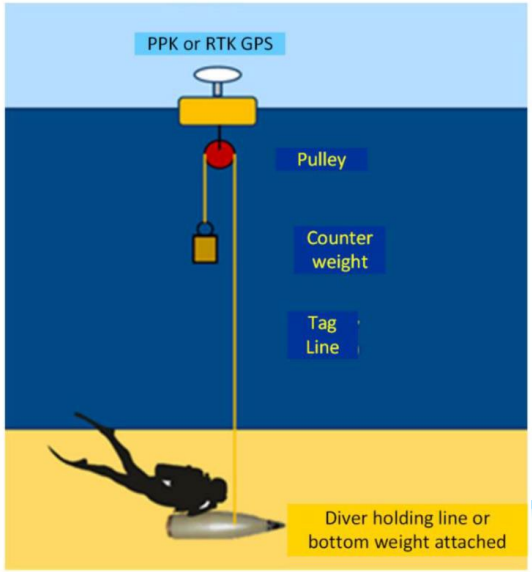
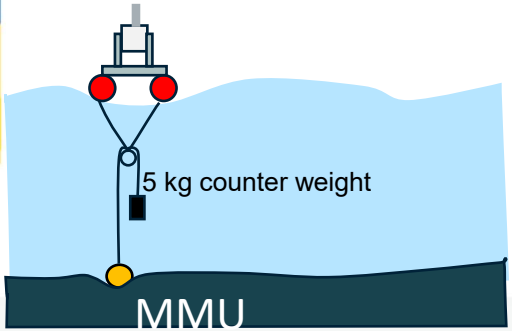
Results to Date

- GPS Buoy Development and Results
- USV sUXO Tracker Refinement
- Spring 2023 & Fall 2024 Martha's Vineyard Deployments

Development and Evaluation of a Precision GNSS sUXO Marking buoy





Concept by Stefano Biagini at CMRE .. We are extending to rougher conditions

Uses a Emlid m2 L1/L2PPK GNSS
Same as my surf-zone USV

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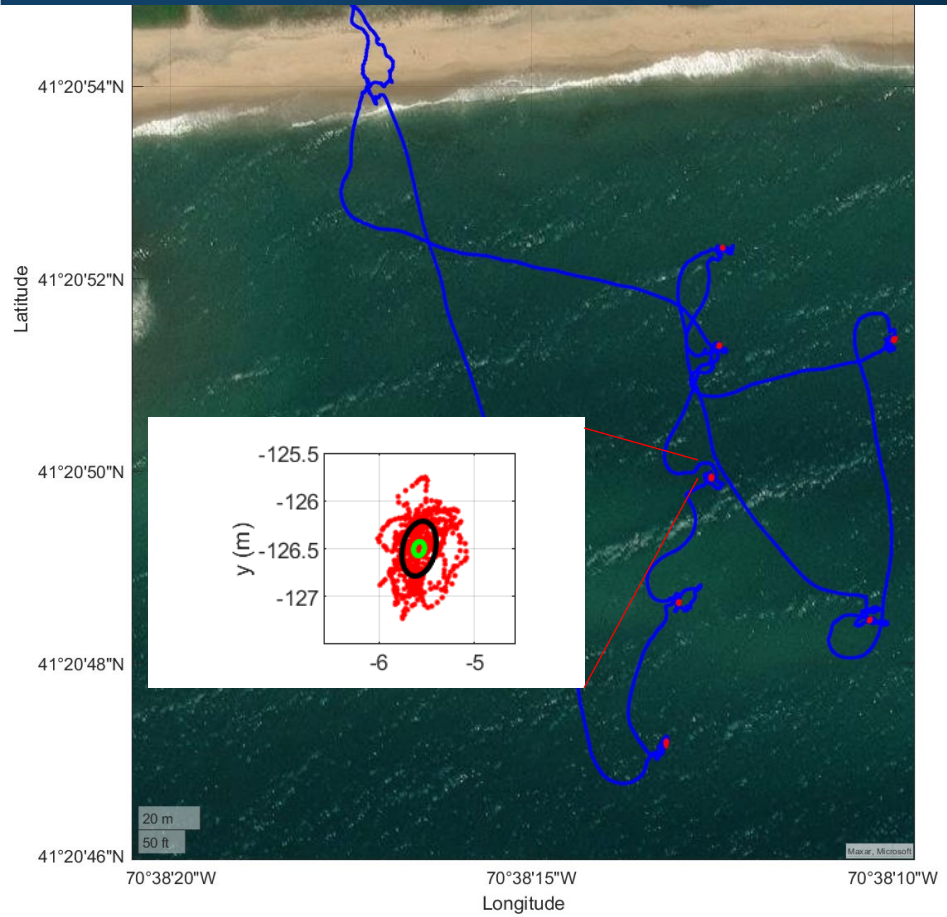
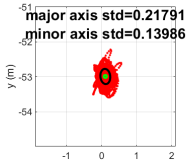
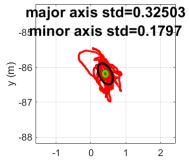
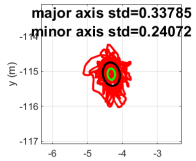
GNSS sUXO Marking buoy: Results

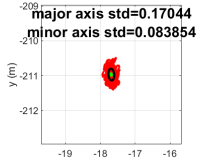


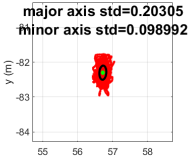
All major axis std=0.26447
All minor axis std=0.16537

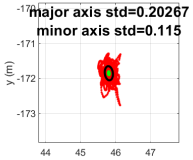












GNSS sUXO Marking buoy: Results

- Have yet to do a comprehensive analysis of all buoy data
  - Precision vs Wave height/period
- Have 7 data sets over a wide variety of Wave Conditions
  - Limited by conditions that I can get out and tie the buoy on!
  - Requires some knowledge of depth so counter-weight is not on bottom
- Typically, precision is better than 30 cm
  - Based on rms of wave filtered data
  - Hard to assess accuracy as don't have a better established method to determine true position.
  - Perhaps can use low tide (exposed, direct GNSS) vs high tide (with buoy/string) at Maine

Technology Development: USV based Surrogate UXO localization

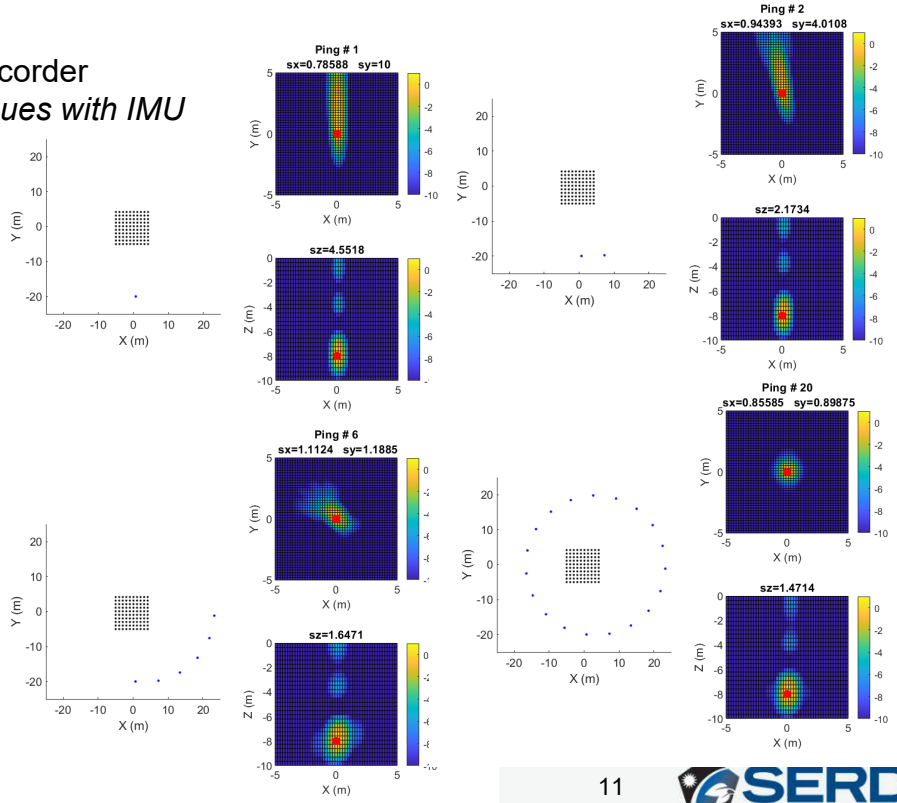
- The USV uses a 4-channel real aperture vertical array and synthetic aperture horizontal processing to localize pingers in 3D within +/-3 m horizontal
- Direction only based processing with incoherent averaging of convergent beam patterns

Based on RTSYS.EU
4 channel coherent recorder
- *Had timing sync issues with IMU*

Fixed now!

Simulations showing results after 1, 2, 6 and 20 pings with USV traveling in circle around target

Simulation tools allow examining different array and pinger configurations



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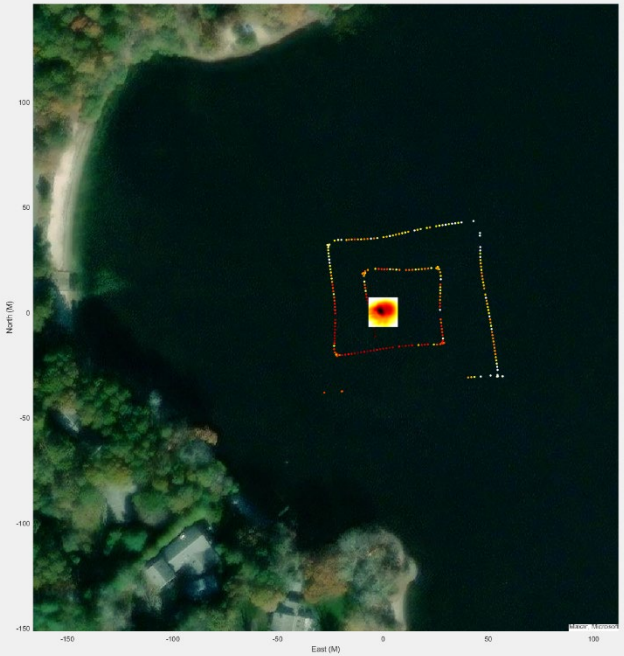
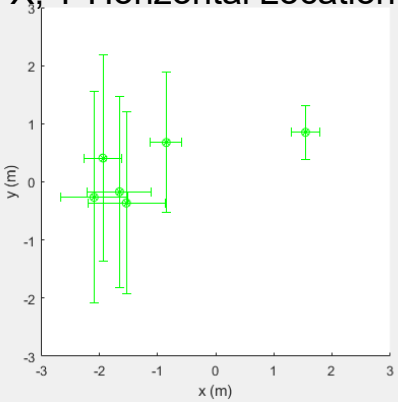
Results: Technology Development: Field (Pond) Test Results of USV Tracking

3D Locations variation based on multiple loops of USV

Location based on single loop of USV



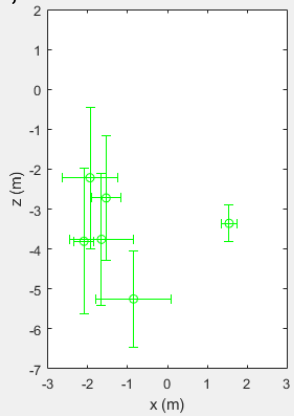
X, Y Horizontal Location



- Target was at 2.5 m depth
- ~2 m rms variation of vertical locations
- Not good enough for burial depth yet
- Work still in progress

- ~1 m rms variation of horizontal locations
- Some indication of PPK GPS Position Errors
- Better sync with GPS/IMU and a better IMU is next

X, Z Vertical Location



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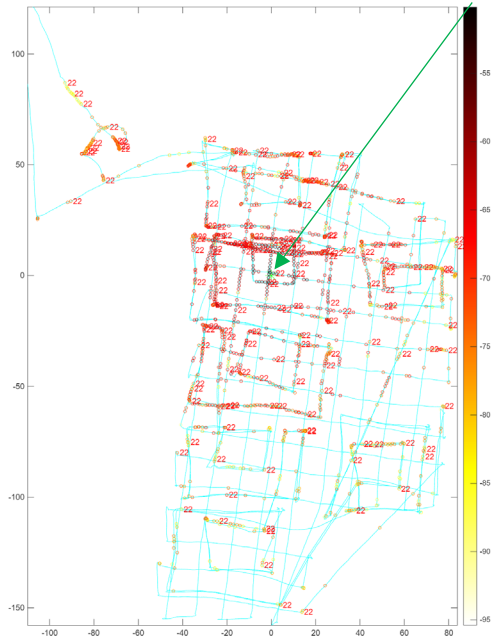
MV Field use of USV based SUXO Tracking

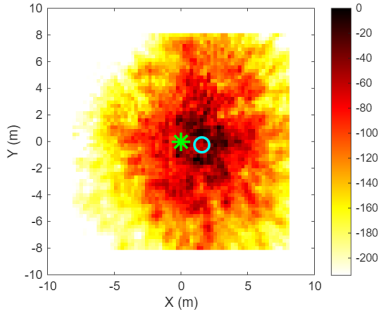
GPS Bouy is

Ground Truth (*)

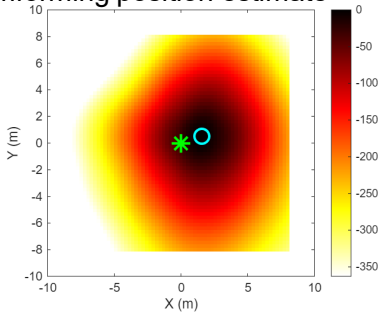
Location of received pings from L2



Synthetic and real aperture beamforming position estimate

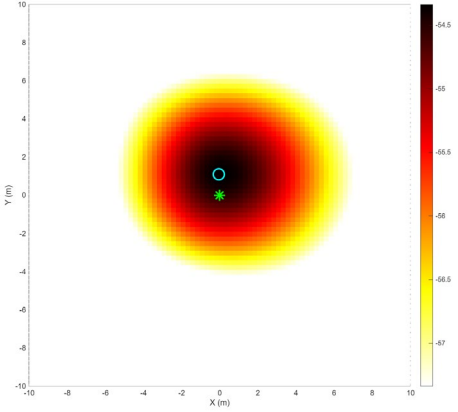


Synthetic aperture only beamforming position estimate



Amplitude Only position estimate

- Peak of surface fit to amplitude
- Requires lots of receptions near the target to get a good surface
- Easy with a USV!



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MV Field use of USV based SUXO Tracking

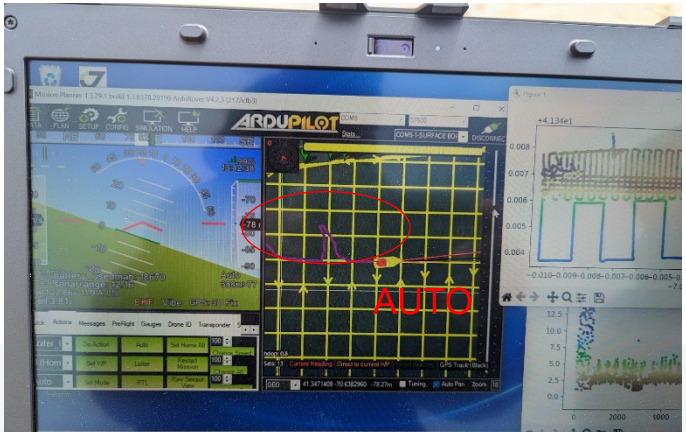
Object Name	InCoherent Mean Position Error	Coherent Mean Position Error	Amplitude Surface Mean Postion Error	InCoh Position Spread	Coh Position Spread
L1	2.3	2.2	2.4	3.7	2.8
L2	1.7	1.6	1.1	3.9	2.8
L3	6.6	4.7	7.1	5.0	3.0
L4	4.0	3.6	4.0	3.9	2.9
L5	1.3	1.2	1.6	3.8	3.0

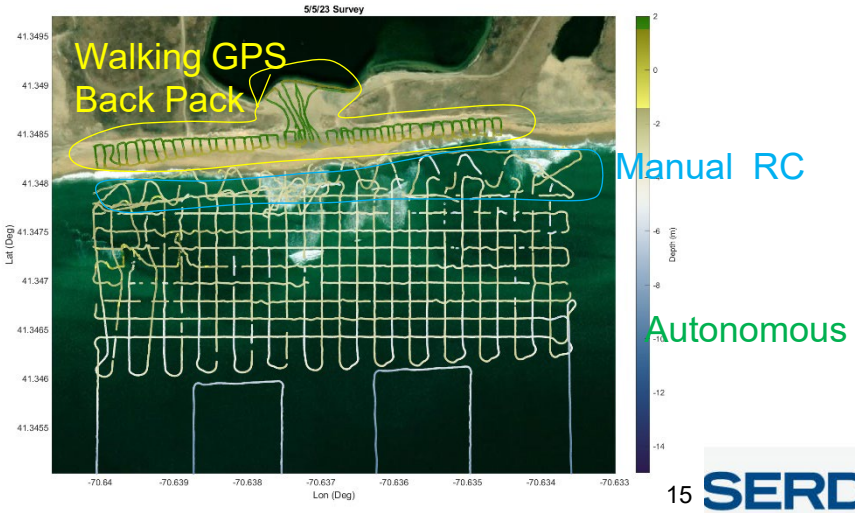
Summary: 1 to 4 m accuracy should be achievable without Scuba Operations. No burial estimates possible with this method.

Results: Background: Yellowfin Surf Zone USV

Developed in MR20-1494. Has dramatically improved our ability to measure bathymetric change.

- Robust waypoint autonomy in breaking waves
- One to two person launch and recovery
- Survey bathymetry before after each storm
- New in 2023:
- Realtime depth data transmission to base station
  - Allows adaptive mission preconfirmation and QC
- Some overheating issues:
  - Sourced new motor controller with better thermal regulation
- Jet Drive runs aground gracefully and safe, but clogs with seaweed
  - 2024: Dual “Weed shedding” dual thruster fully functional
  - Integrating Multibeam and Camera into dual thruster model





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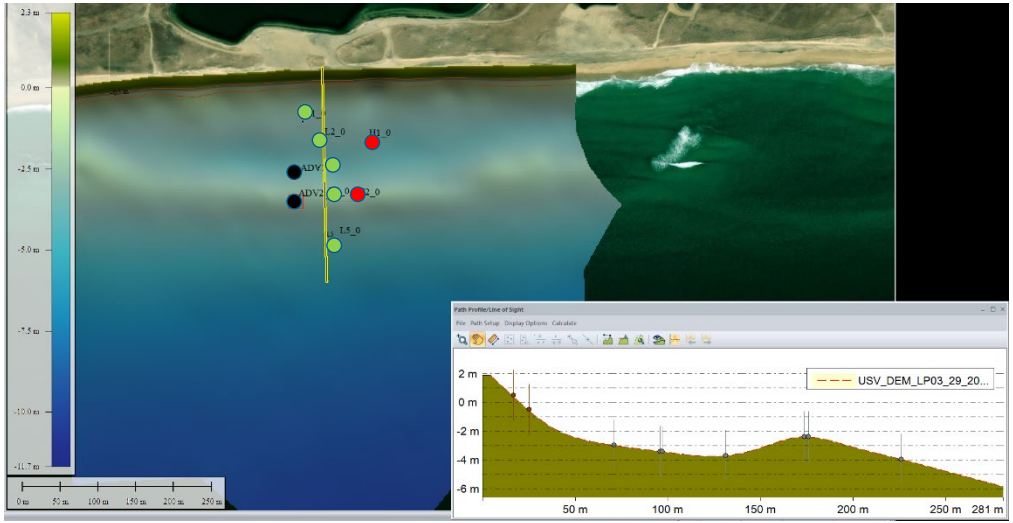
Results: Spring 2023 Deployment at Long Point Wildlife Refuge, Martha's Vineyard

Pre-Deployment Survey

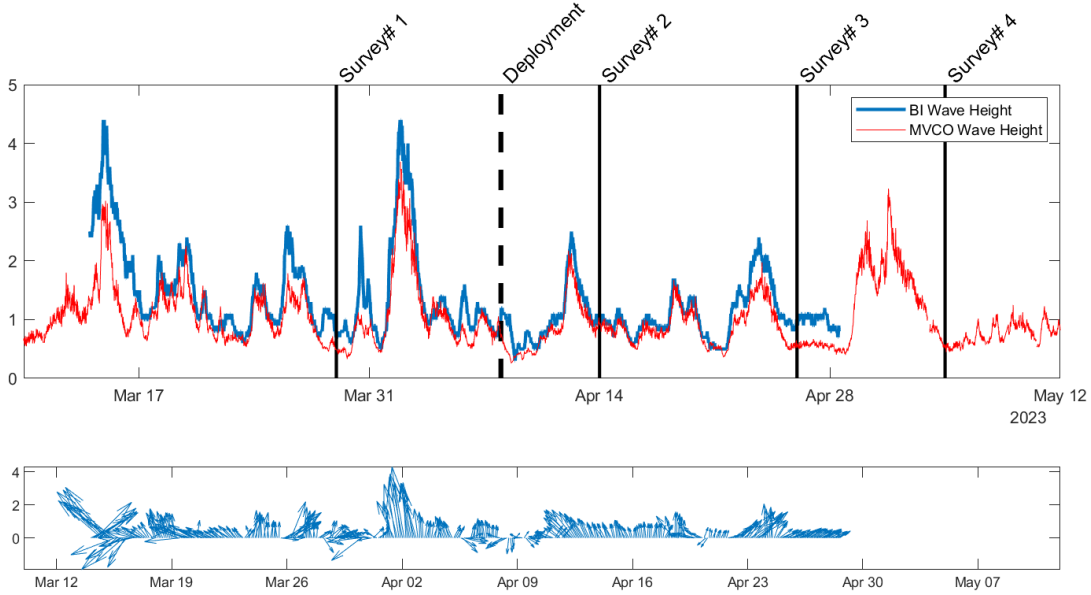


Cross-Shore array of:

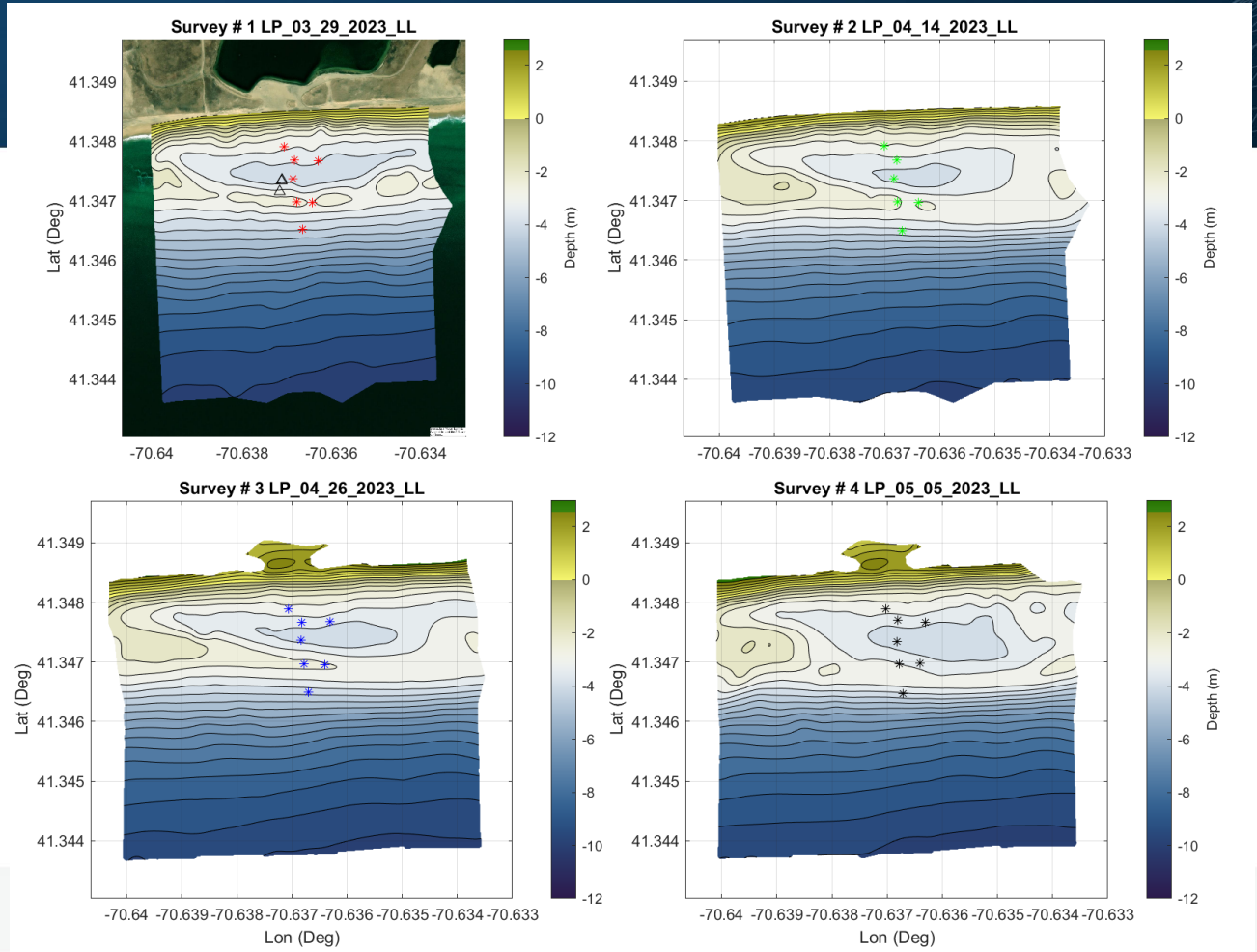
- 5 low density (S=2.5, 65 lbs) L=75,D=15 cm
- 2 higher density (S= 4.0, 95 lbs) **L=75,D=15 cm**
  - Smart sUXO, Optical Burial and Orientation Sensors
- 2 ADVS
  - Bar crest
  - Bar trough

  Geotech->Cobbles under 10 to 30 cm sand
- Offshore Waves from MVCO

Results: 2023 Waves from WHOI MVCO



Results: 2023 Surveys



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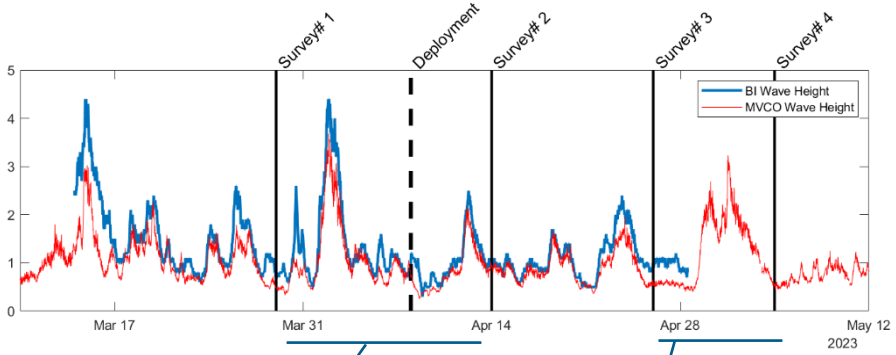
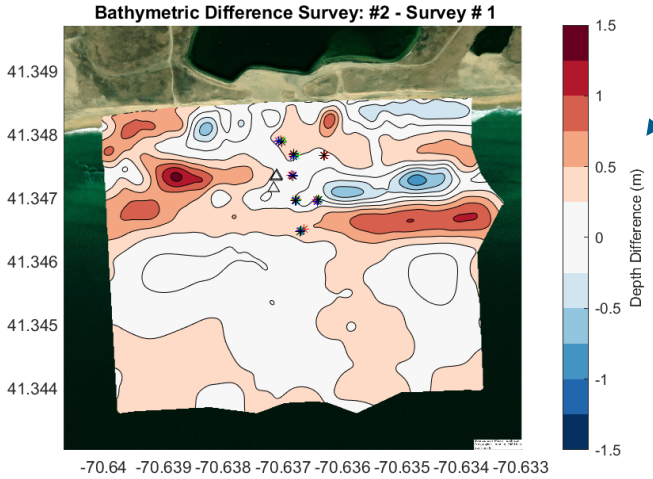
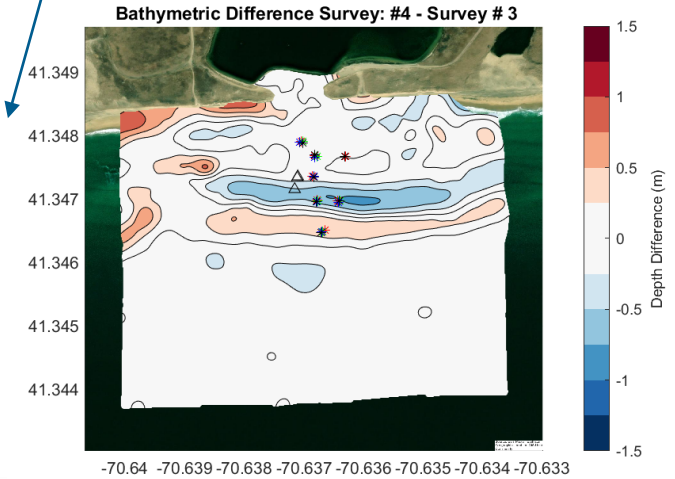
Results: 2023 Bathymetric Change & Very Little Munition Migration

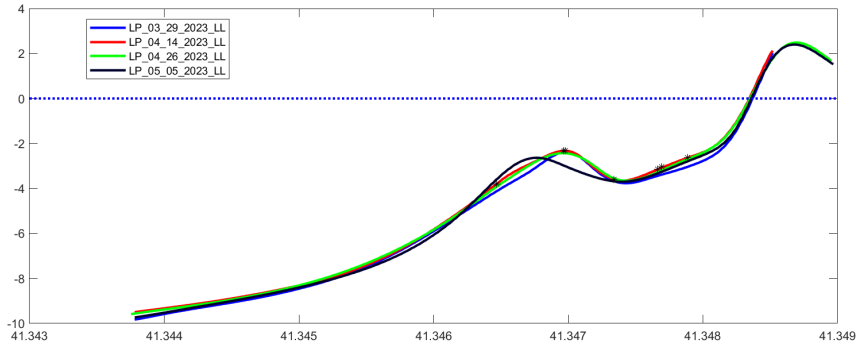


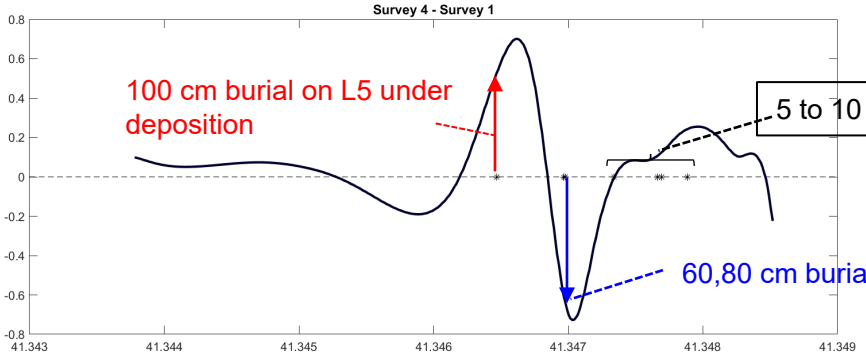


UXO location changes less than error of position technique (Surface floats)



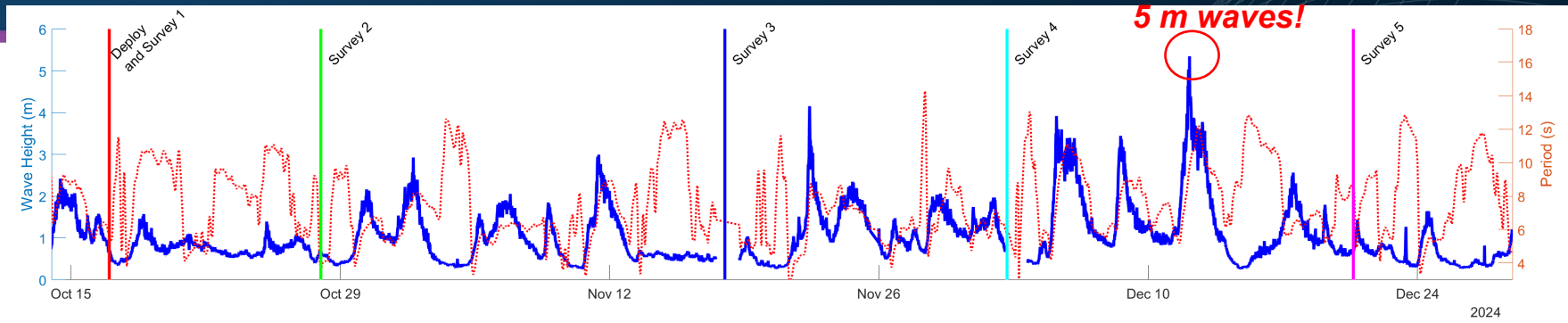
Results: Spring 2023 Deployement Burial due to Bathymetric Change

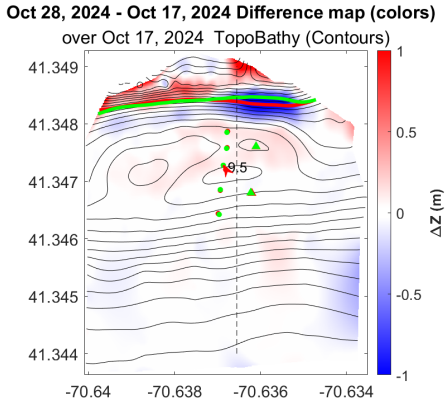


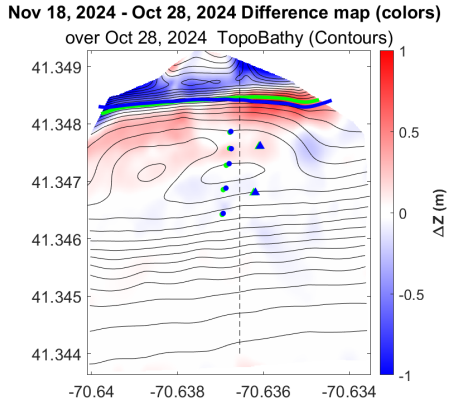


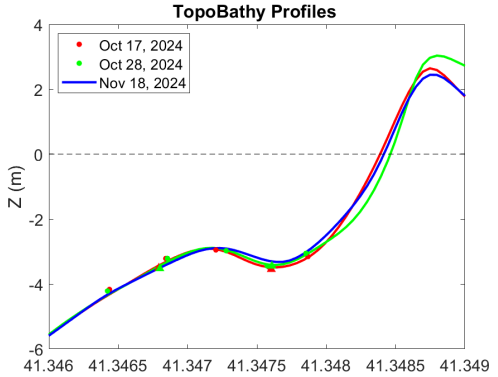
- Scuba diver team measured burial depths on recovery
- sUXO buried 5 to 100 cm
- Maximum burial depth under bar crest

Fall 2024: Difference maps & UXO Migration









One of the low density (s=2.5) migrated 9.5 m. High density sUXO stationary

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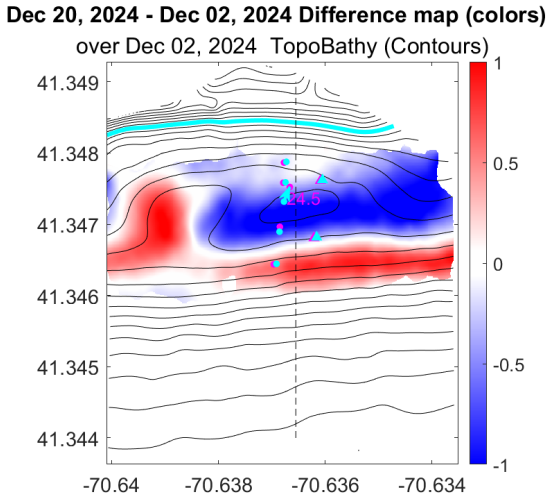
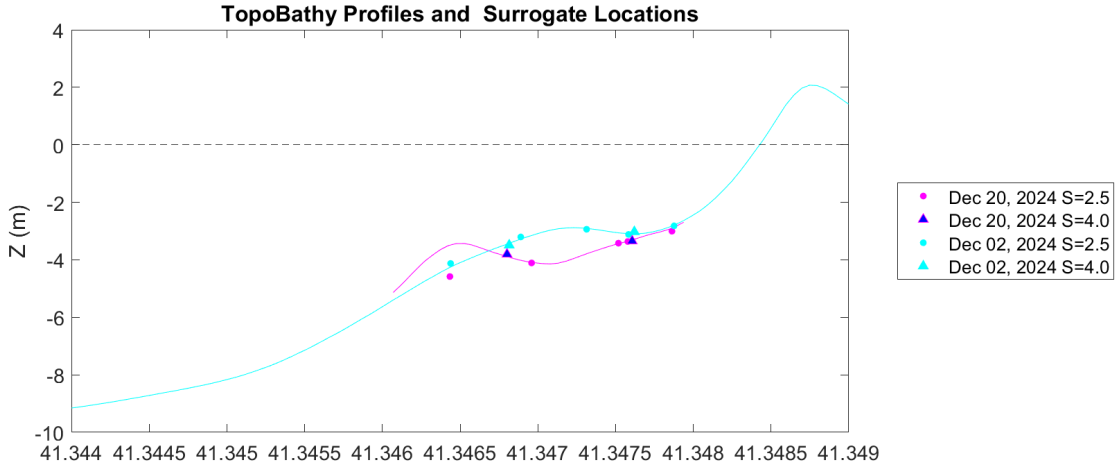
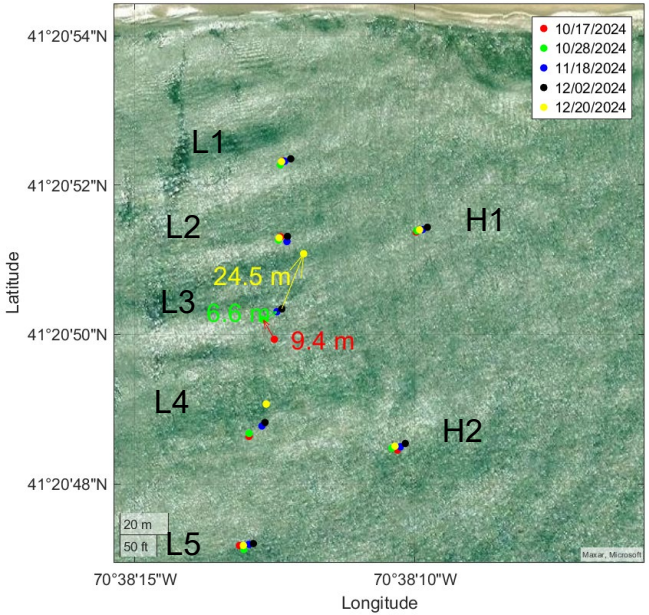
Fall 2024: Difference Map for survey 4 and recovery

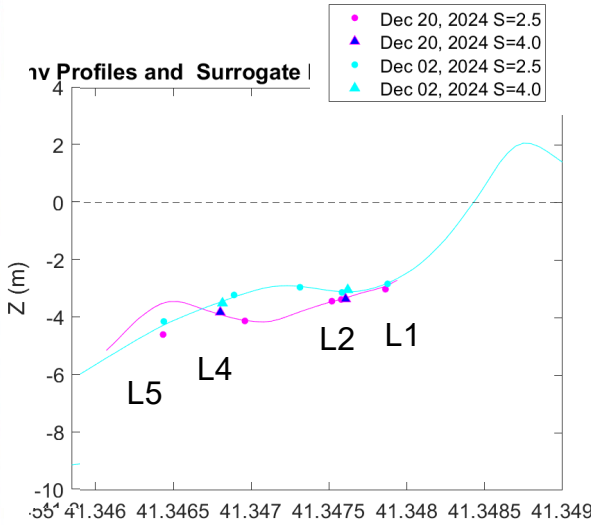
5 m wave event results in 24 m migration of low density sUXO on crest of bar (survey 4), became trough at recovery





Fall 2024 Deployment Migration & Burial





Final Burial, L (S=2.5), H (S=4)	
L1: 100 cm	
L2: 12 cm	H1: 80 cm
L3: 15 cm	
L4: 30 cm	H2: 85 cm
L5: 100 cm	

- Burial at erosive zone L2 – L4 generally less than depositional (L5) or neutral (L1)
- High Density H1, H2 buried Deeply despite erosion. Possibly Liquefaction or Erosion then Deposition

Medium (5 -50 m) Migration of *S*=2.5 sUXO
In region of bar migration

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Summary of results so far based on MV observations

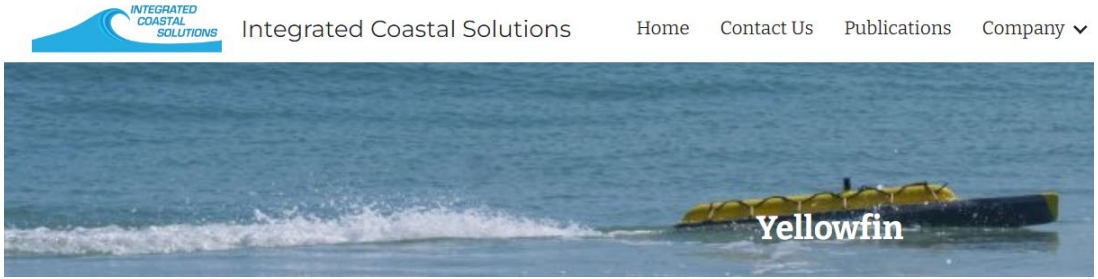
- Low Density sUXO move large (100 m+) distances rarely
- Move small to medium distances frequently
- Have never seen 1 km + movement out of known range boundaries
- High density UXO only move very small (less than 5 m) distances
- Burial and Migration are high coupled to nearshore bathymetric change, with 1 m + burial common by mobile sand bars during storms

Next Steps

- Modelling of 2023 Round1 Complete
  - Have not made good figures
- Modeling of 2025 data
  - In progress
- Modelling skill is generally poor with both data sets due to inability to predict bathymetric change
  - Model was tuned for previous data sets, and that tuning doesn't work for new data
  - Recently discovered I can put measure bathy change data into model with new code
    - This has potential for improved results
- Interim Report on USV Tracking and GPS Buoy Technology
- Final Report Winter 2025

Technology Transfer

- Upcoming Demonstration work at Reid Beach Beach in Maine with USV based sUXO tracker and USV Bathymetry in collaboration with NRL and U Del.
- Commercial availability of Yellowfin Surf Zone Bathymetry USV. USCAE (Duck FRF) and USGS Santa Cruz both have one



Issues

- A bit behind schedule
- Emphasis changed slightly from modelling to refining observational techniques

BACKUP MATERIAL

These charts are required, but will only be briefed if questions arise.

MR22-3303 : Unmanned Surface Vessel Based Munition Detection, Mobility and Burial Monitoring, and Environmental Mapping in Surf Zone Environments and Demonstration of Deterministic Modeling Capabilities

Performers: Peter Traykovski

Technology Focus

- *Measurements of Munition Mobility , Burial and Bathymetric Evolution using Surf-zone Capable Unmanned Surface Vehicles*

Research Objectives

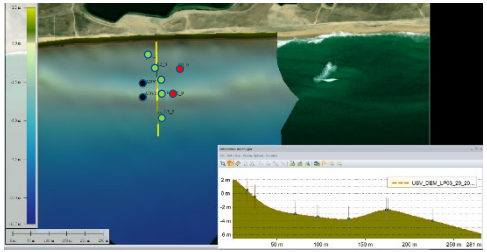
- *Evaluate performance of predictive models for Munition Mobility , Burial and Bathymetric change based on observations*

Project Progress and Results

- *Surf Zone scale numerical models for Munition Mobility , Burial and Bathymetric were refined to include Morphology*
- *Field Measurements underway: 7 surrogates Deployed. 4 surveys conducted*

Technology Transition

- *Present measurement and modelling results at SERDP meeting for transition to integration with more simpler modeling systems*
- *Commercialization of surf –zone USV*



Plain Language Summary

- Munitions are most likely to be encountered by the general public in depths that are suitable for wading, swimming and scuba diving, e.g. the surf zone in open ocean environments
  - Surf zone bathymetric change is an important part of munition mobility and burial predictions
- A model has been developed and tuned with 2014 and 2018 data to predict cross shore movement of munitions and burial.
  - Now Includes Bathymetric Change
  - Needs testing with additional data. This project collects data and tests models
- Also Demonstrate use Unmanned Surf Vessels (USVs) to map bathymetry and survey locations of sUXO.
  - This will be utilized in upcoming collaborative projects.

Impact to DoD Mission

The Program Office wants to convey the significance of your research to DoD leadership, Congress, and the broader community.

- What's the most impactful thing that's happened since the last time you presented your work to us? Probably the Tech Transfer of Surf Zone USVs
- Why is this important? Making this technology available to a larger user group will help with shoreline management and storm response
- How is your project advancing DoD capabilities?
  - Advancing techniques to observe and model sUXO munition processes

Action Items

Actions

View my project actions

MR22-3303 In Progress

▸ Unmanned Surface Vessel Based Munition Detection, Mobility and Burial Monitoring, and Environmental Mapping in Surf Zone Environments and Demonstration of Deterministic Modeling Capabilities

Peter Traykovski, Ph.D. | Woods Hole Oceanographic Institution

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Final reports and publication of results Pending	Deliverable: Final Report	Action Type: Subtask	Due Date: 7/31/2025	Overdue 8 days
UD 4) Interim Report Pending	Deliverable: Interim Report	Action Type: Subtask	Due Date: 9/15/2025	
MB4) Analysis and Modelling with Deployment 1 Data Pending	Deliverable: None	Action Type: Subtask	Due Date: 9/15/2025	
MB 7) Analysis and Modelling with Deployment 2 Data Pending	Deliverable: None	Action Type: Subtask	Due Date: 9/15/2025	
October 2025 Quarterly Progress Report Pending	Deliverable: None	Action Type: QPR	Due Date: 10/15/2025	

1 25 items per page 1 - 5 of 5 items

Publications

- USV based tracking techniques is patented
  - Doppler shift navigation system and method of using same Patent Publication/Patent Number: US11709262B2
  - Publication Date: 2023-07-25
  - Application Number: US17/425,343
  - Filing Date: 2020-10-05
  - Inventor : Fischell, Erin Traykovski, Peter
  - Assignee: WOODS HOLE OCEANOGRAPHIC INSTITUTION
- Publication on that was rejected. Need to resubmit with emphasis on sUXO Tracking
- Surf Zone USV work Published:
  - Francis, Holly, and Peter Traykovski. 2021. “Development of a Highly Portable Unmanned Surface Vehicle for Surf Zone Bathymetric Surveying.” *Journal of Coastal Research*. https://doi.org/10.2112/JCOASTRES-D-20-00143.1.
- Have not published the Munition Mobility and Burial Measurements and models yet other than final reports

Acronym List

GPS	Global Positioning System
IMU	Inertial Motion Unit
MEMS	MicroElectroMechanical Systems
MRSON	Munitions Response Statement Of Need
MVCO	Martha's Vineyard Coastal Observatory
PPK	Post Processing Kinematic
RTK	Real Time Kinematic
SERDP	Strategic Environmental Research and Development Program
sUXO	Surrogate UXO
SWASH	Simulating WAves till SHore
UnMES	Underwater Munitions Expert System
USBL	Ultra-Short Base Line
USV	Unmanned Surface Vessel
UXO	Unexploded Ordinance
WHOI	Woods Hole Oceanographic Institution
3DSS	3-Dimensional Side Scan