Underwater UXO: EMI Detection and Classification

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2018 | Enhancing DoD's Mission Effectiveness

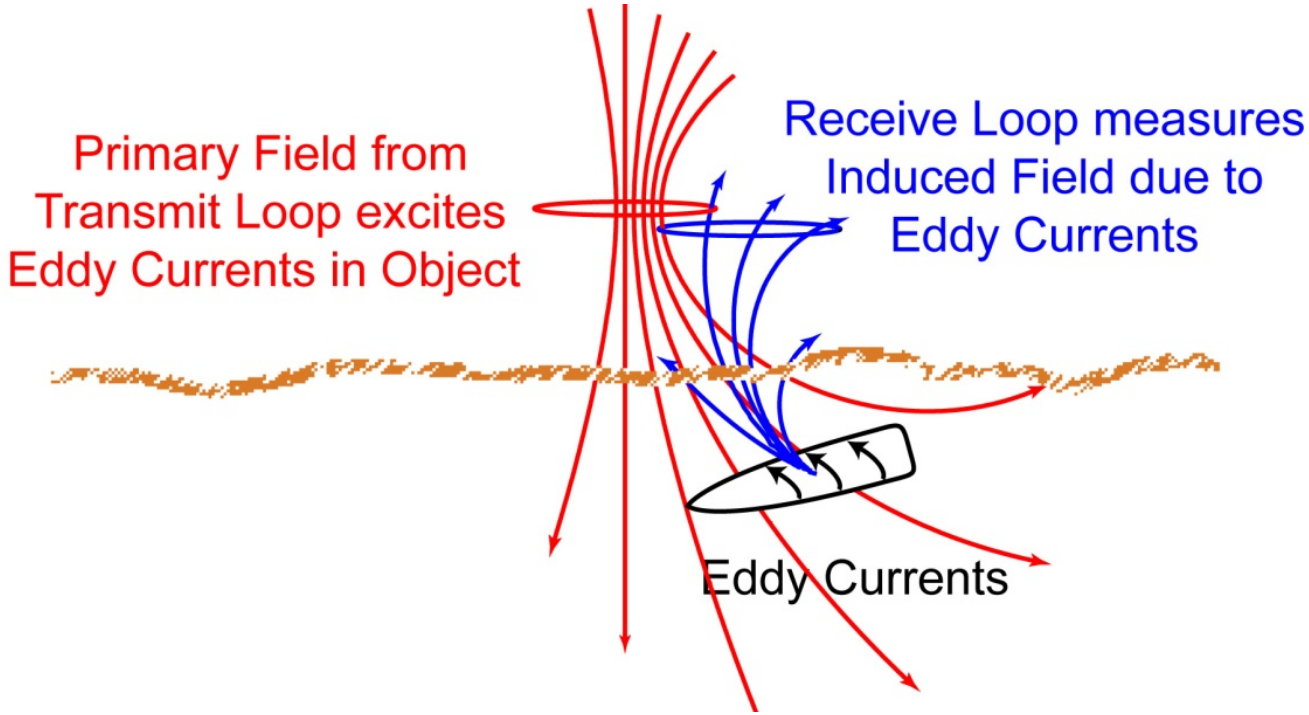
Agenda

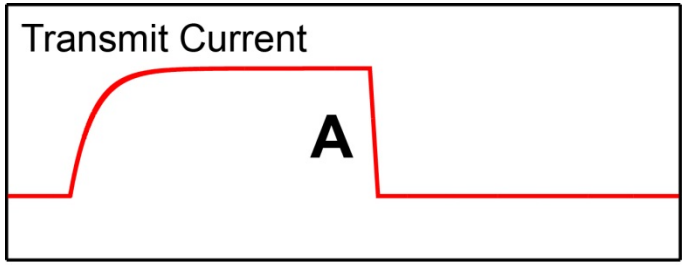
- Background: EMI sensors for munitions detection and classification
- EMI in marine environments
  - SERDP project MR-2409
- Underwater cued array for target classification
  - ESTCP project MR-201313
- Marine towed array for detection and classification
  - ESTCP project MR-201610

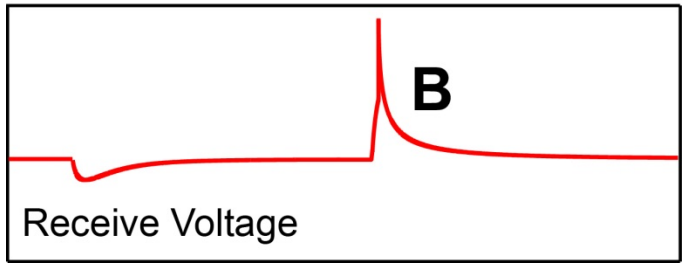
Munitions Detection & Classification on Land

- SERDP/ESTCP-developed advanced electromagnetic induction (EMI) sensor arrays can reliably detect and classify buried munitions on land under operational conditions
- Dual mode:
  - Dynamic survey mode for detection with limited classification
  - Static cued mode with sensors parked over detected object for target identification

EMI Sensors







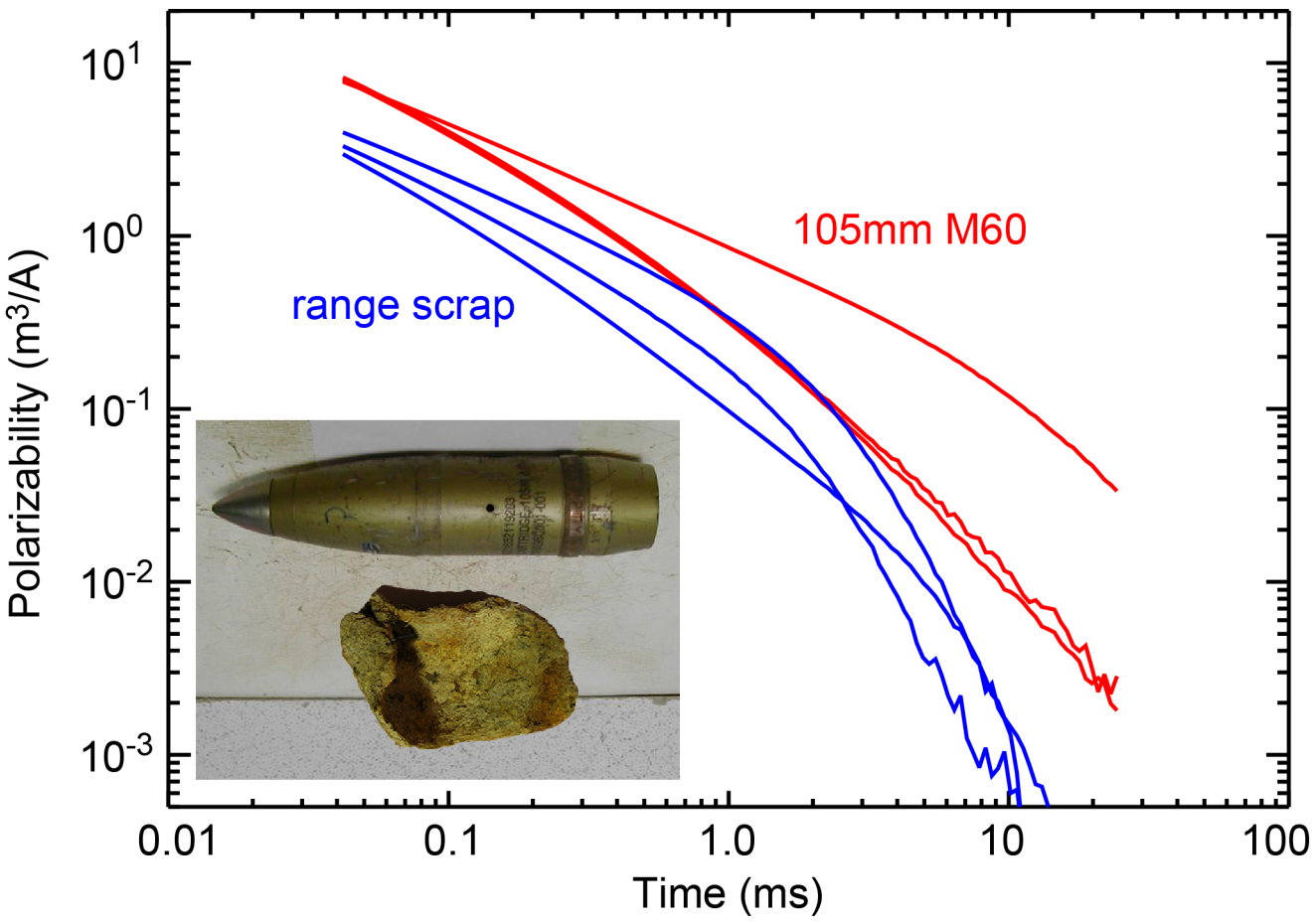
A Abrupt change in primary field excites eddy currents in buried object

B Eddy currents diffuse throughout the object and decay

Details depend on the size, shape and orientation of the object

Target Classification

- Classification exploits target features related to EMI response observed over a complete range of excitation directions
  - Principal axis polarizabilities encode information about an object's size, shape and composition
- Likelihood that target is UXO is determined by comparing its polarizabilities with those of known targets of interest



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Underwater Munitions

- The marine environment introduces complexities in the EMI response
  - Salt water conducting medium complicates the physics
  - Sediment conductivity adds significant background effects
- Underwater operations introduce challenges to the deployment of EMI arrays
  - Getting survey mode systems close to the bottom
  - Delivering cued mode systems to the target location

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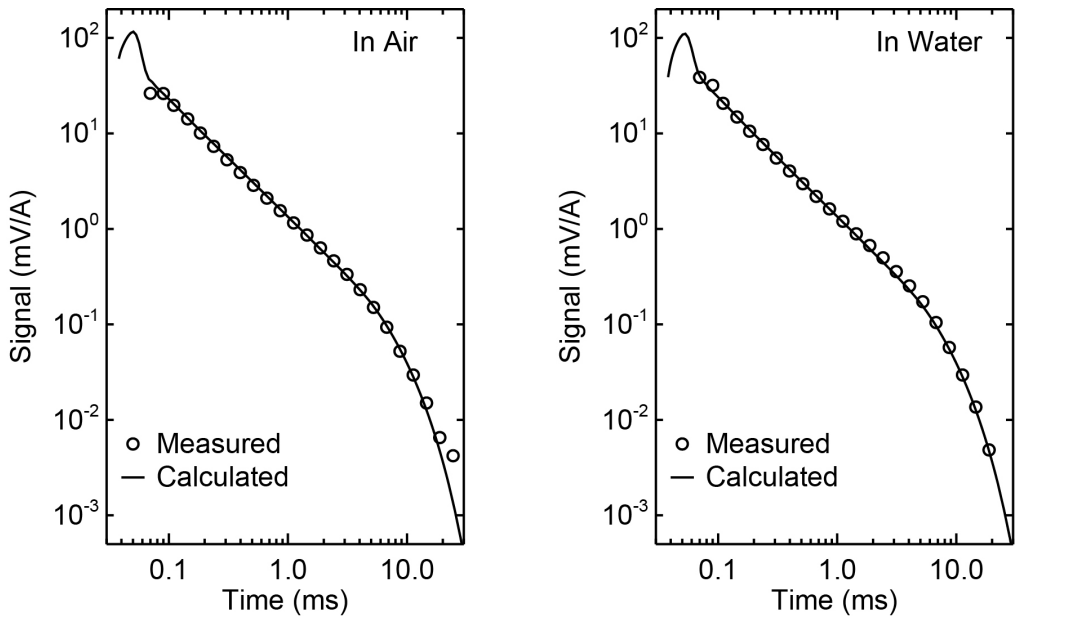
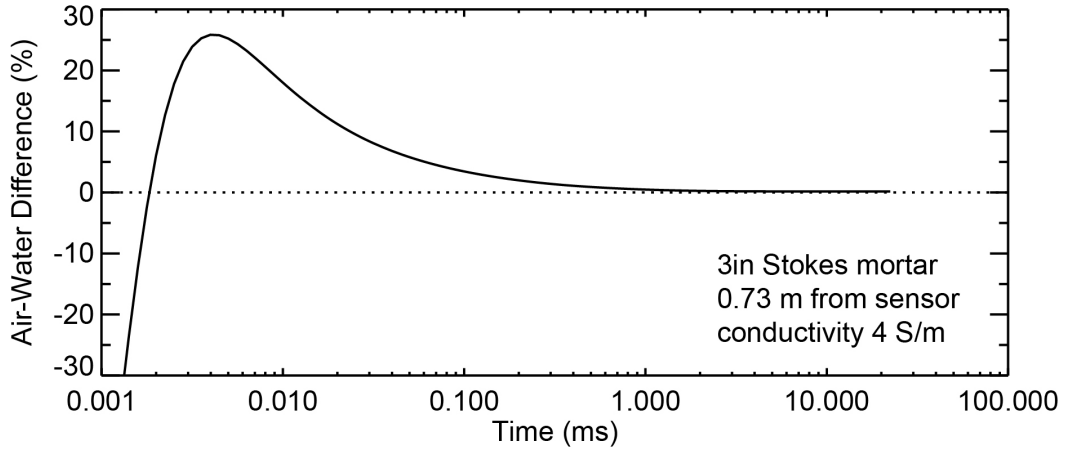
EMI Response in Water

- Extensive modeling, tank tests and field measurements
  - No difference expected or observed between EMI response to munitions in air and in salt water in operationally interesting configurations
- Electric field (current channeling) effects unimportant in operationally interesting situations
  - Strongest for target off to side of sensors
  - Target must make electrical contact with water



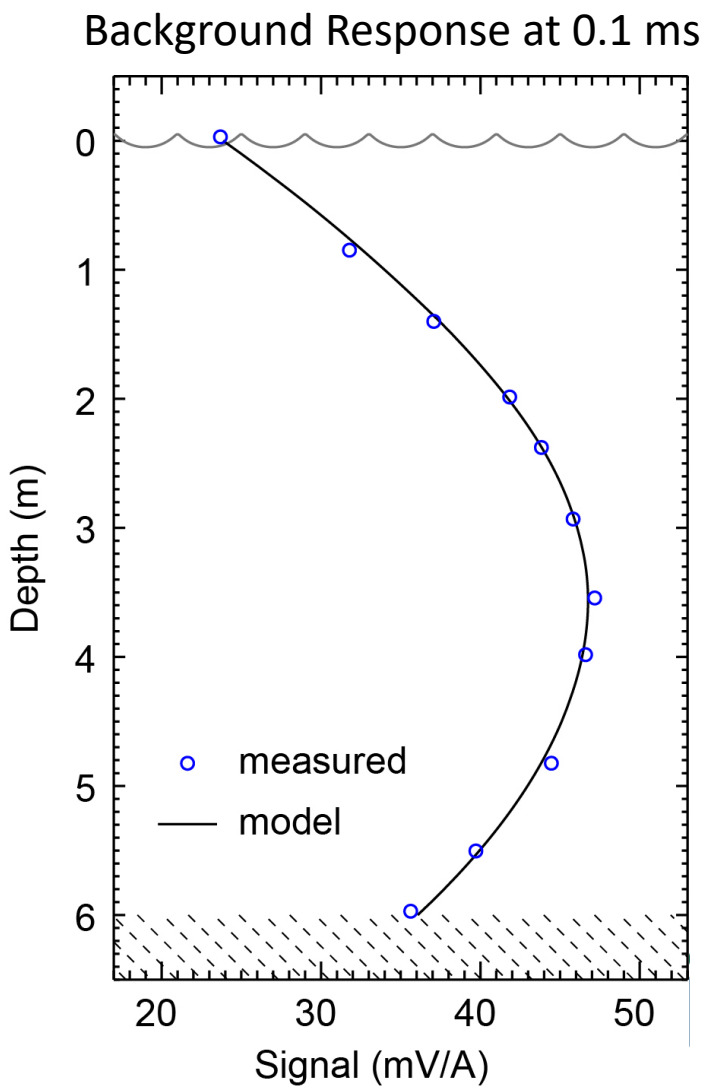


Background Response

- Background response determined by
  - Water depth & electrical conductivity
  - Conductivity of underlying sediment layers
  - Sensor depth
- Stronger than early time response from 105mm projectile at 1m range in seawater
  - Decays rapidly in time (~t^{-3})

e.g. York River estuary, 10 km upriver from Chesapeake Bay

- Temperature 26C, Salinity 23‰
- 6m depth, muddy bottom



EMI Arrays for Underwater Applications

Underwater Cued Array (ESTCP project MR-201313)

Marine Towed Array (ESTCP project MR-201610)

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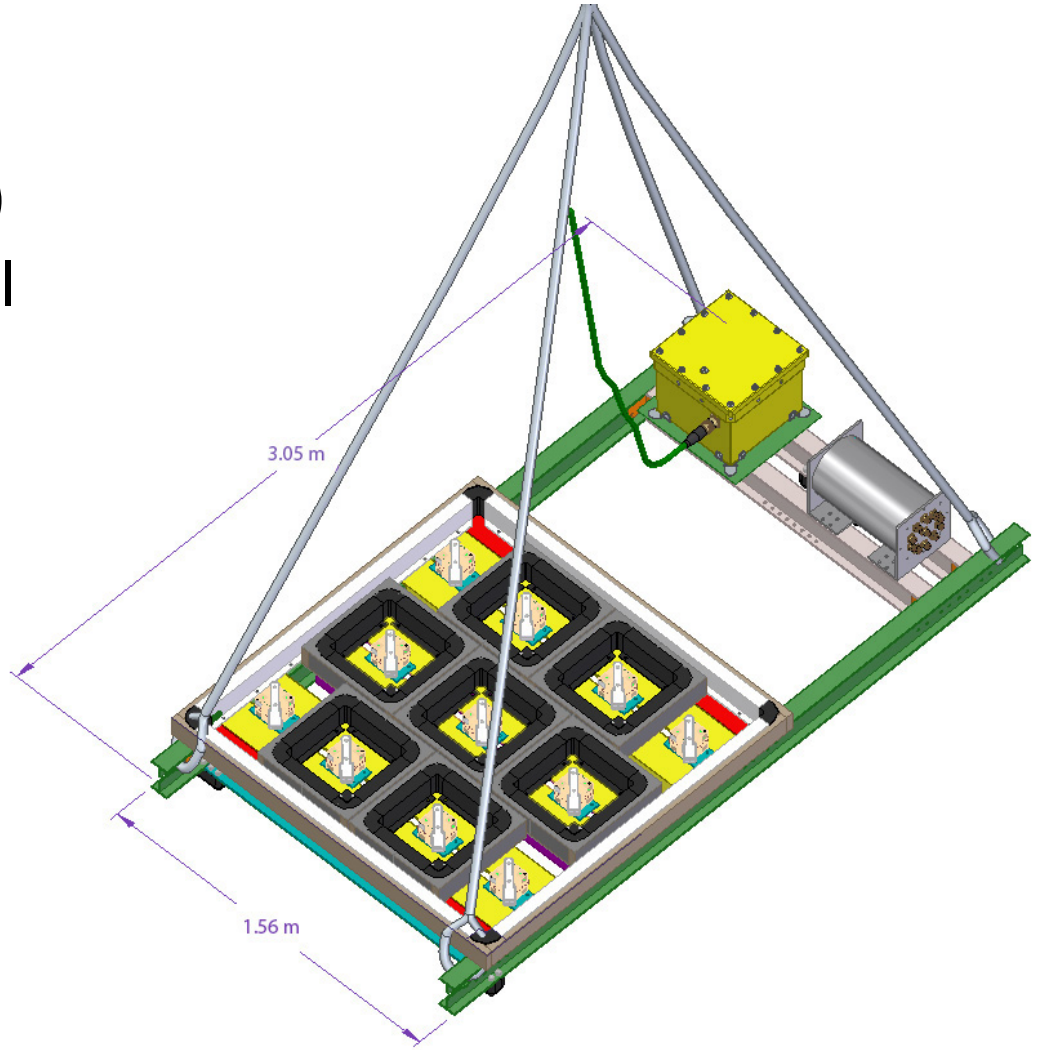
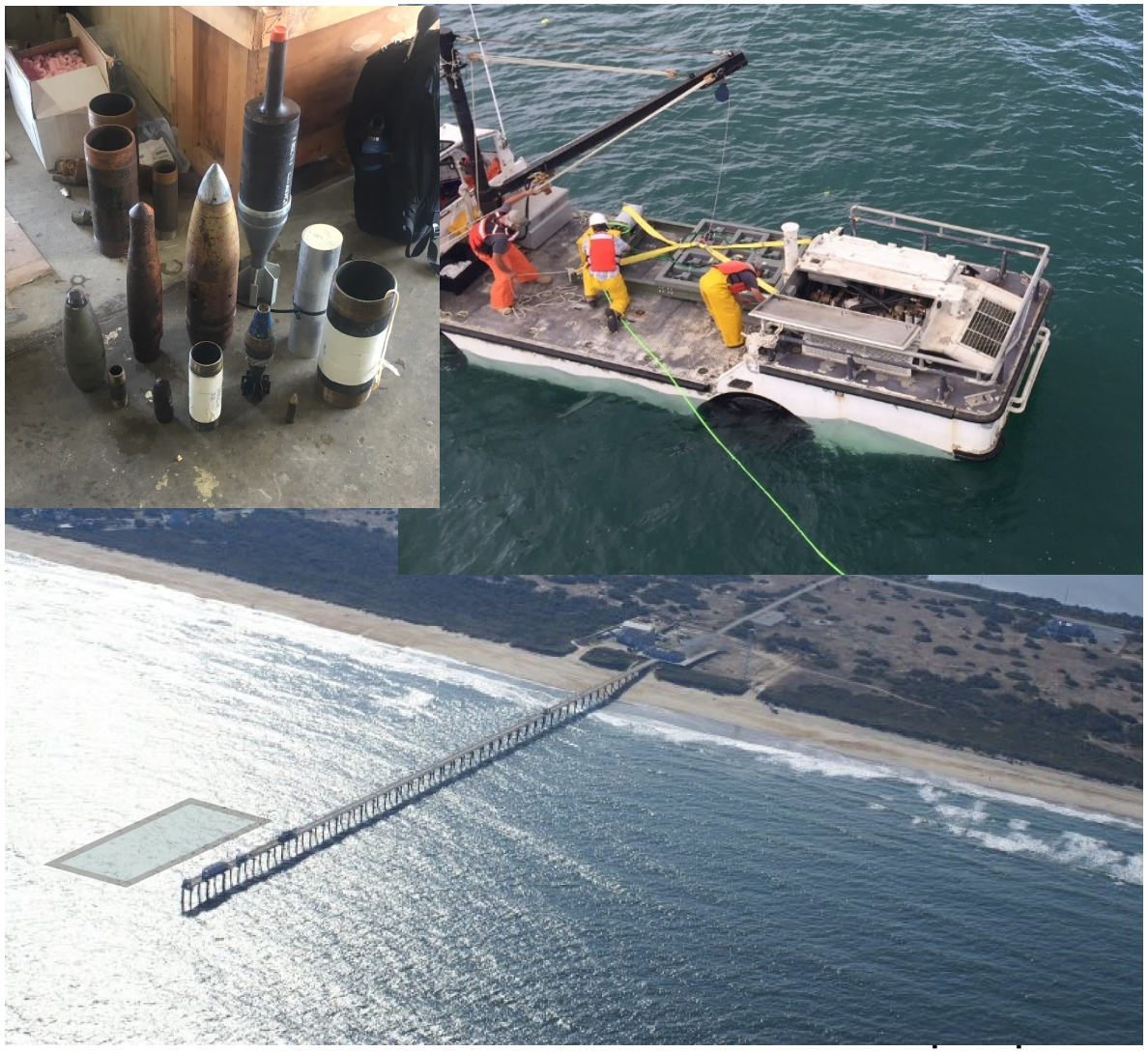
Underwater Cued Array

- ESTCP Project MR-201313
  - PI Steve Saville (Jacobs)
- 1.6 m square array (built by Geometrics)
  - 7 40 cm Tx coils enclosed by a 1.6 m Tx coil
  - 11 Rx cubes
- 716 lb in air, ~30 lb in seawater
  - Maneuvered over targets by divers
- Demonstrations
  - NSWC Panama City (FL) freshwater pond
  - USACE Duck (NC) Field Research Facility



Salt Water Test

- USACE Field Research Facility
  - Duck (NC), May 2018
- Array deployed from LARC (Lighter, Amphibious Resupply, Cargo)
  - Maneuvered by divers over targets
- Water depth 7 m, Sandy Bottom
  - Temp ~15C, Conductivity 4 S/m
- Shallow buried (~20cm) targets
  - 20mm – 105mm inert munitions
  - Small, medium & large pipe sections
  - aluminum rod

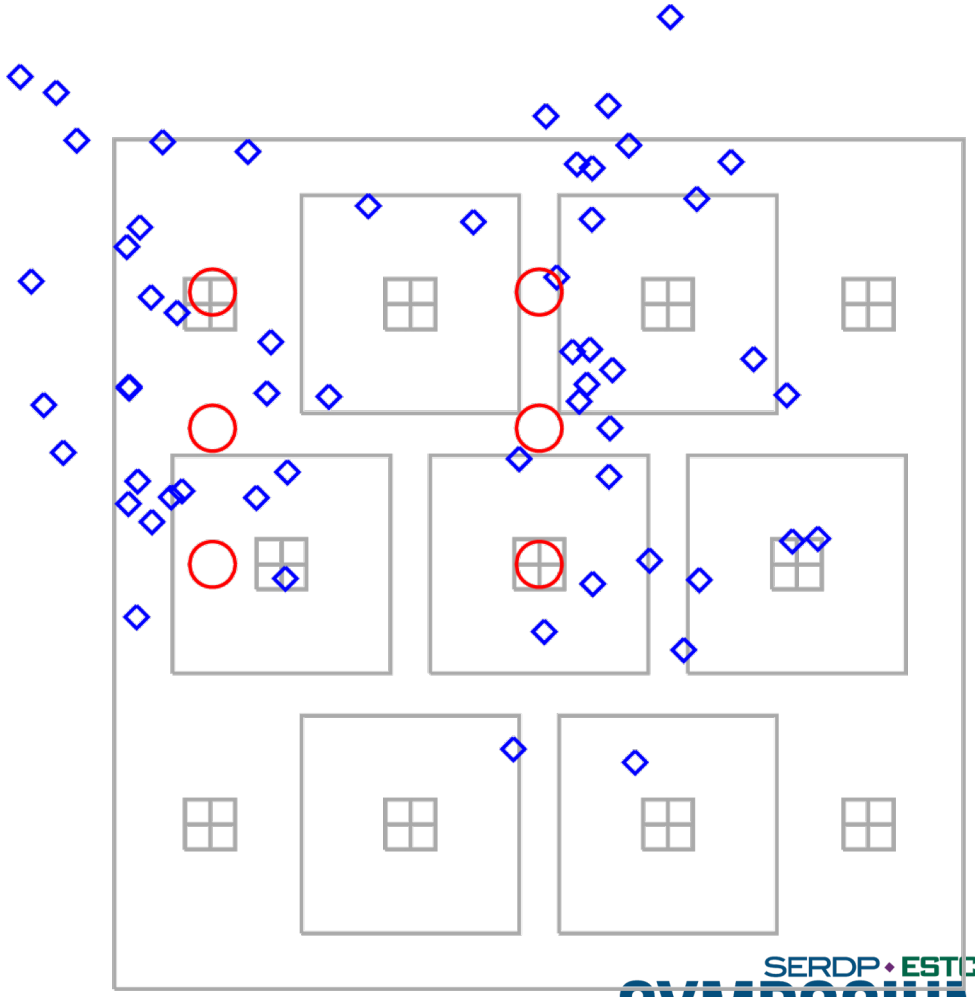


Operational Performance Criteria & Results

Performance Objective	Success Criteria	Results
Sensor can be sufficiently maneuvered in dynamic underwater environment by divers such that the divers' safety is not compromised.	Divers indicate they are comfortable that their safety is not compromised.	The system was lowered 7m to the Test Area using the LARC-mounted davit. Two divers safely moved system over test area without aid of weights or lift bags.
Sensor can be sufficiently maneuvered in dynamic underwater environment by divers such that the system can be placed satisfactorily on the desired cue location to collect classification data.	Divers indicate they are able to effectively and efficiently maneuver the system. Time required to move system between cue locations is less than 10 minutes.	Divers effectively and efficiently maneuvered system through Test Area. Divers moved system between Test Area cued locations in an average of 1 minute each.

Array Positioning

- Six measurements per target, array repositioned by divers for each measurement
- Nominal locations (red circles) chosen to avoid malfunctioning data channels
- Actual locations (blue diamonds) determined by dipole fit location
- Array positioned within 40 cm of desired location 80% of time
  - Median offset 25 cm



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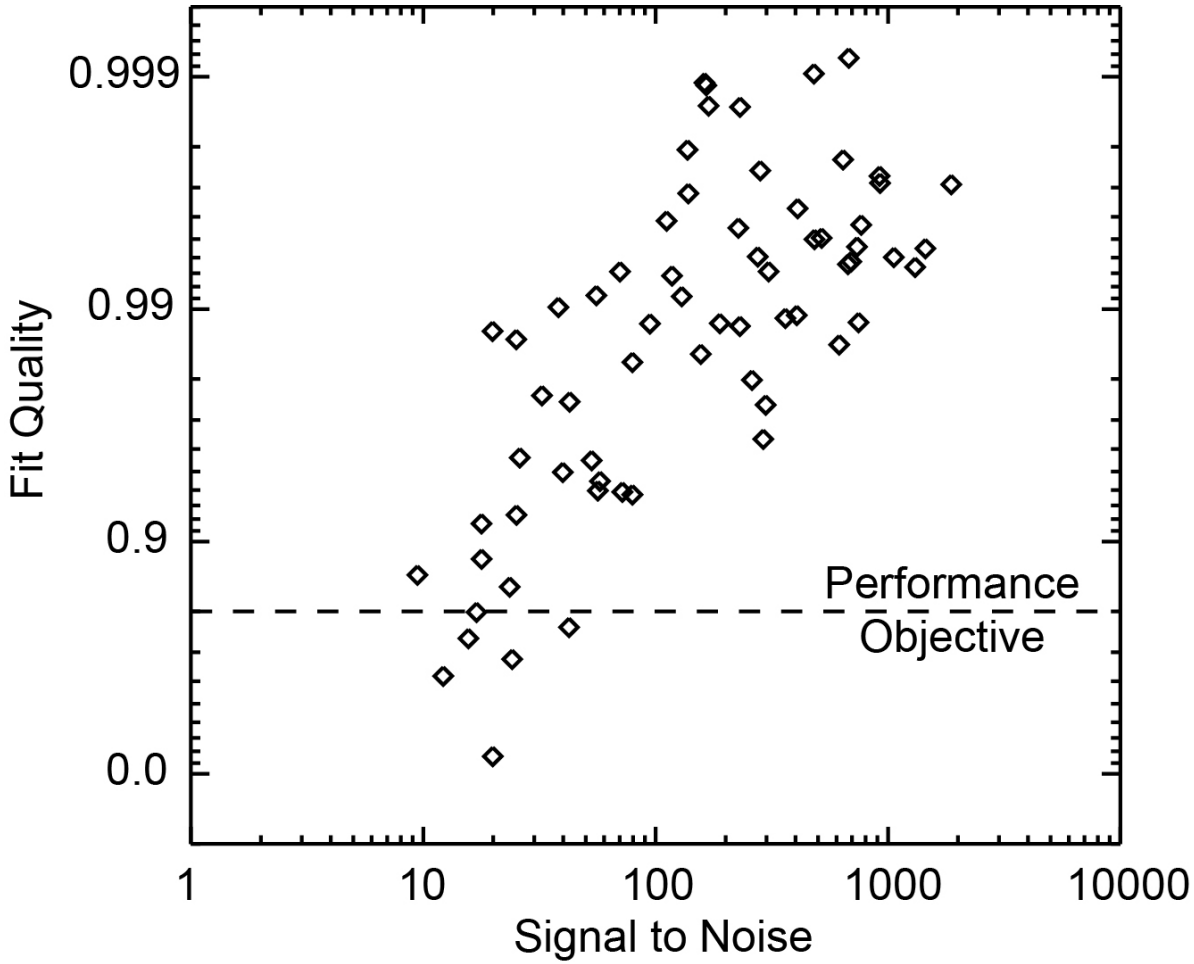
Array Performance

- Performance objective: Data quality supports inversion to determine target parameters.
  - Metric: Dipole fit quality (how well model represents data) > 0.8
- 60 of 66 target measurements met performance objective
  - Fit quality generally increases with target signal to noise ratio
  - Failures: 20mm (5), Al rod (1)



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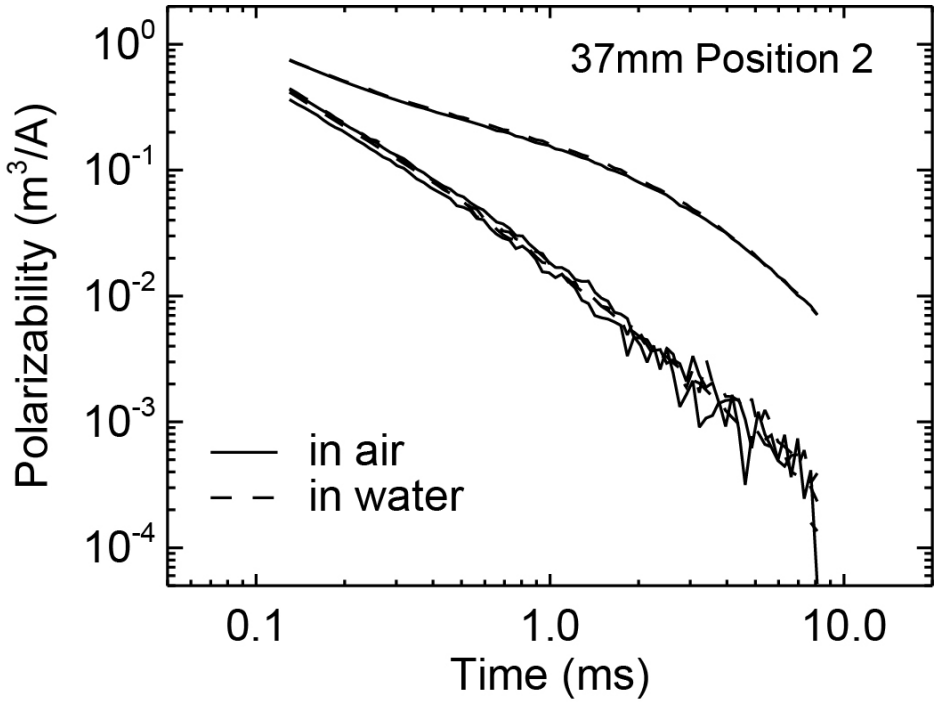
Classification Performance

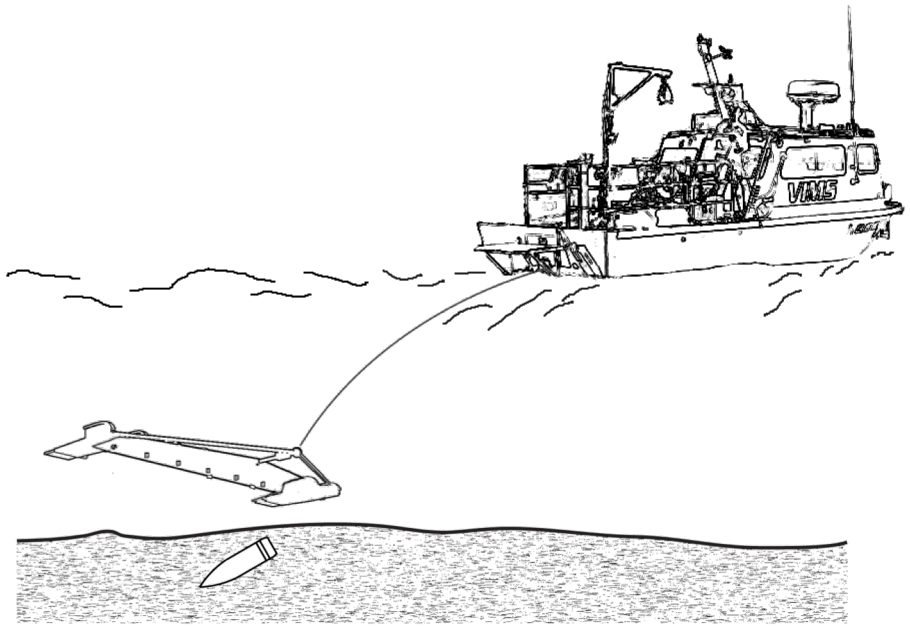
Polarizabilities calculated from in-water data match in-air library polarizabilities



Target	Depth (cm)	Fit Quality	Class. Metric
20mm	-	-	-
37mm	11	0.988	0.97
Small ISO	21	0.955	0.89
60mm	10	0.999	0.95
Med. ISO	8	0.999	0.95
81mm	19	0.998	0.96
2.75in	16	0.994	0.95
Large ISO	21	0.993	0.96
105mm	16	0.994	0.97
105 HEAT	16	0.997	0.98

Marine Towed Array

- Towed array of magnetic and electro-magnetic sensors
  - Originally developed and demonstrated in SERDP project MR-1322 & ESTCP project MR-200324
- ESTCP demonstrations of magnetic detection of underwater munitions at five sites during 2005-2007
  - EMI sensors failed during first test
- San Diego Harbor magnetometer surveys in 2010-2012



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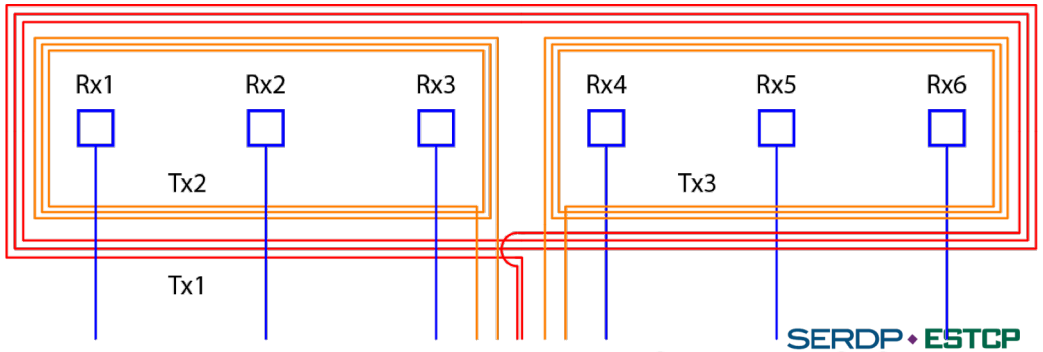
MTA Upgrade

- ESTCP project MR-201610
  - PI Dan Steinhurst (Nova Research)
- Refurbish tow body and magnetometers
- Install and demonstrate purpose-built EMI array
  - Original EMI array based on older analog technology
- 2019 demonstration at original Blossom Point, MD 2007 MTA survey site



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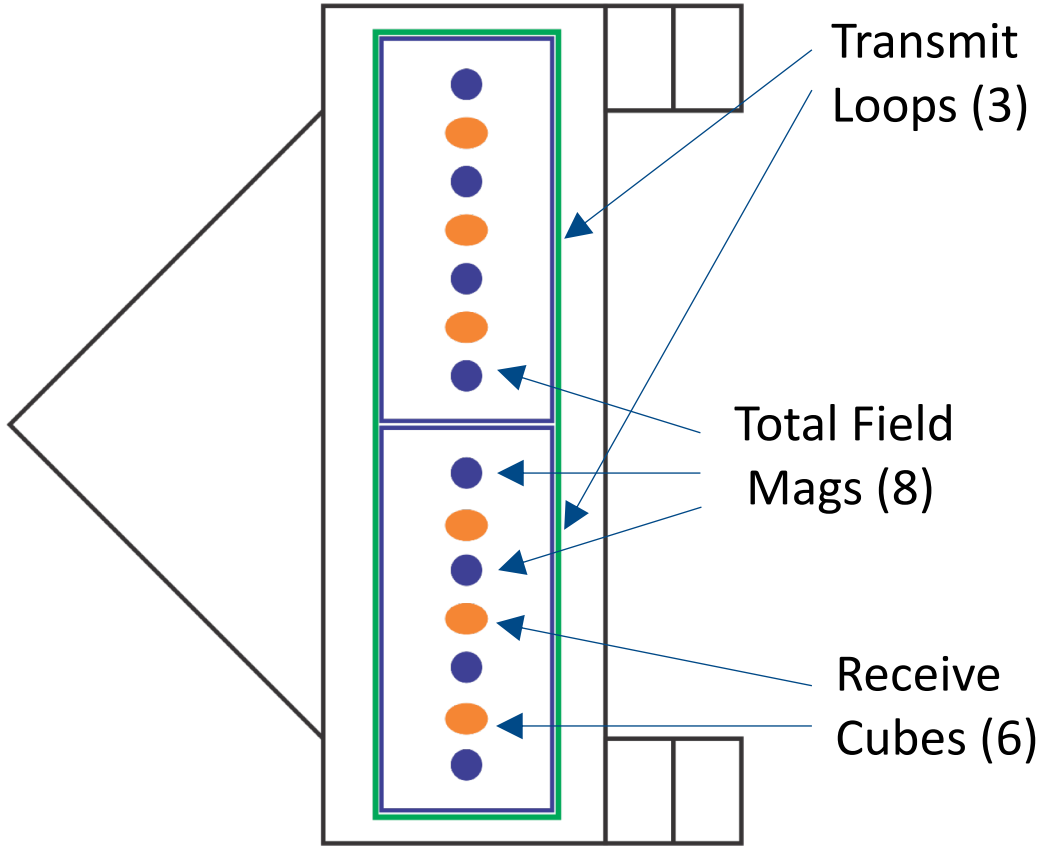
Array Configuration

- Wing-shaped tow body with active depth control
  - Imaging sonar on tow vessel for obstacle avoidance
- Three transmit coils
  - Two side-by-side 1x2.3 m inner coils
  - 1.1x4.7 m outer coil surrounds inner coils
  - 24 turns, 20 A
- Six three-axis receive cubes
- Eight total field magnetometers



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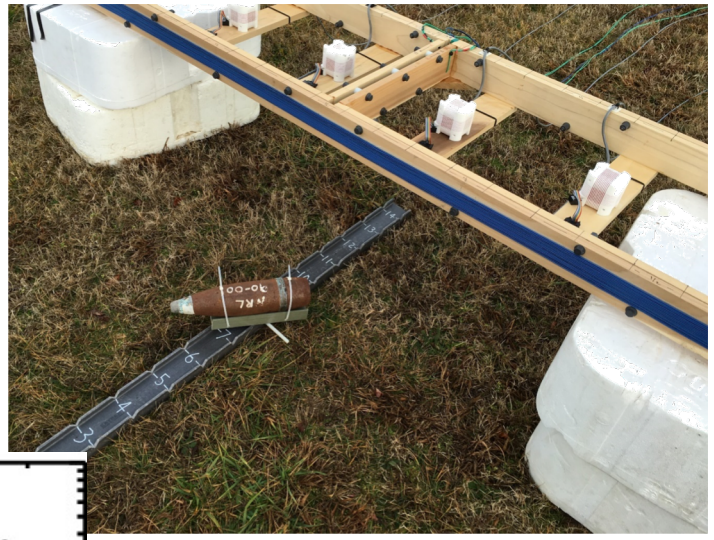
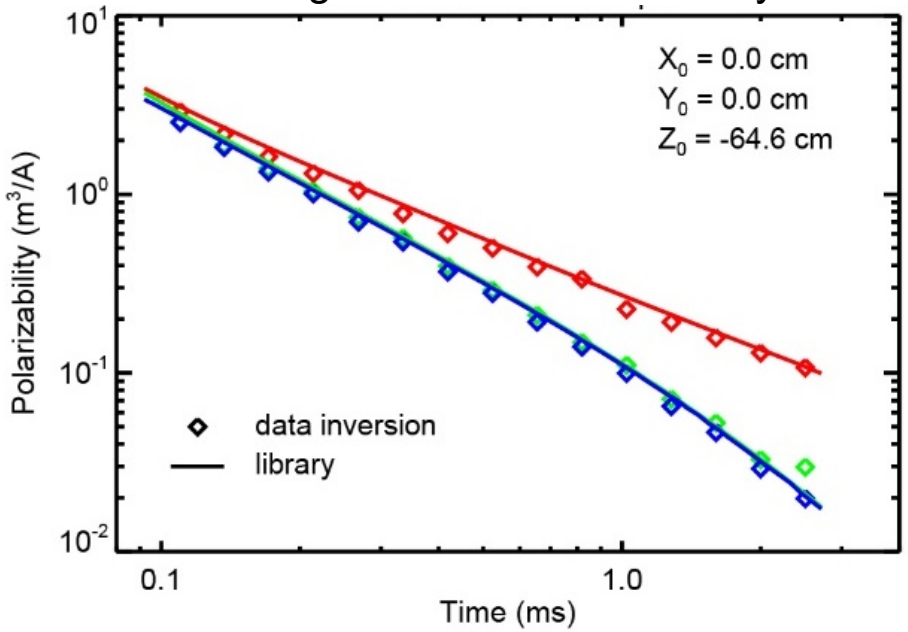
Array Performance

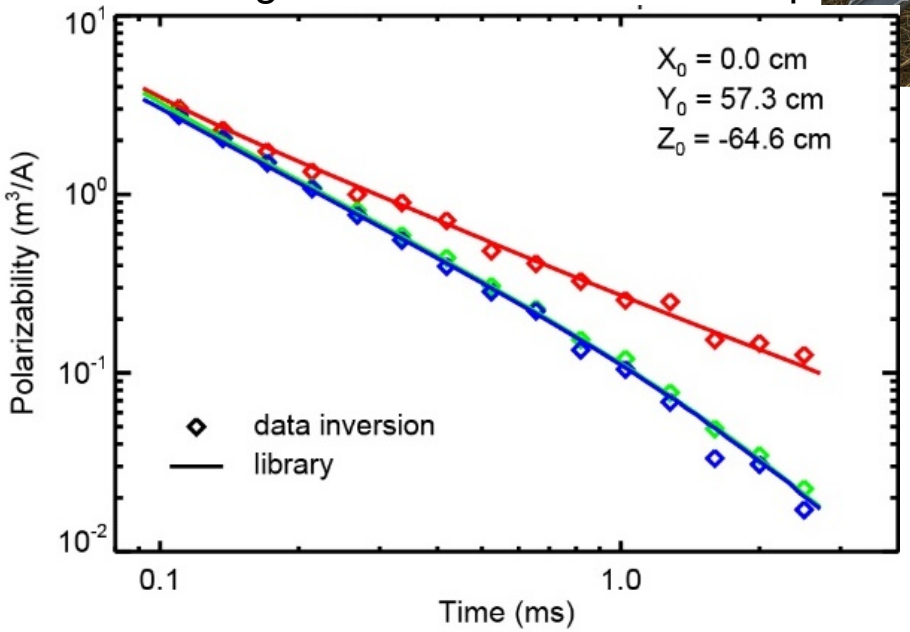
- In-air tests, ½ scale array
  - 57mm projectile
  - 65 cm below array
- Polarizabilities well constrained, match library



Target under center of array

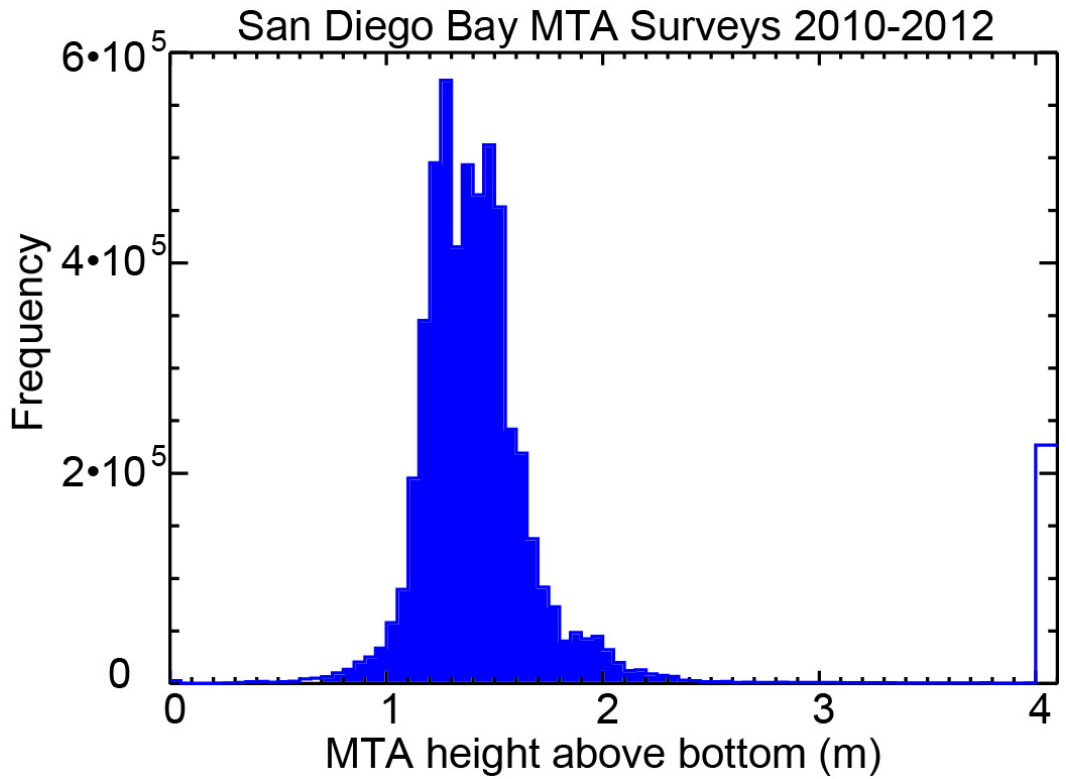


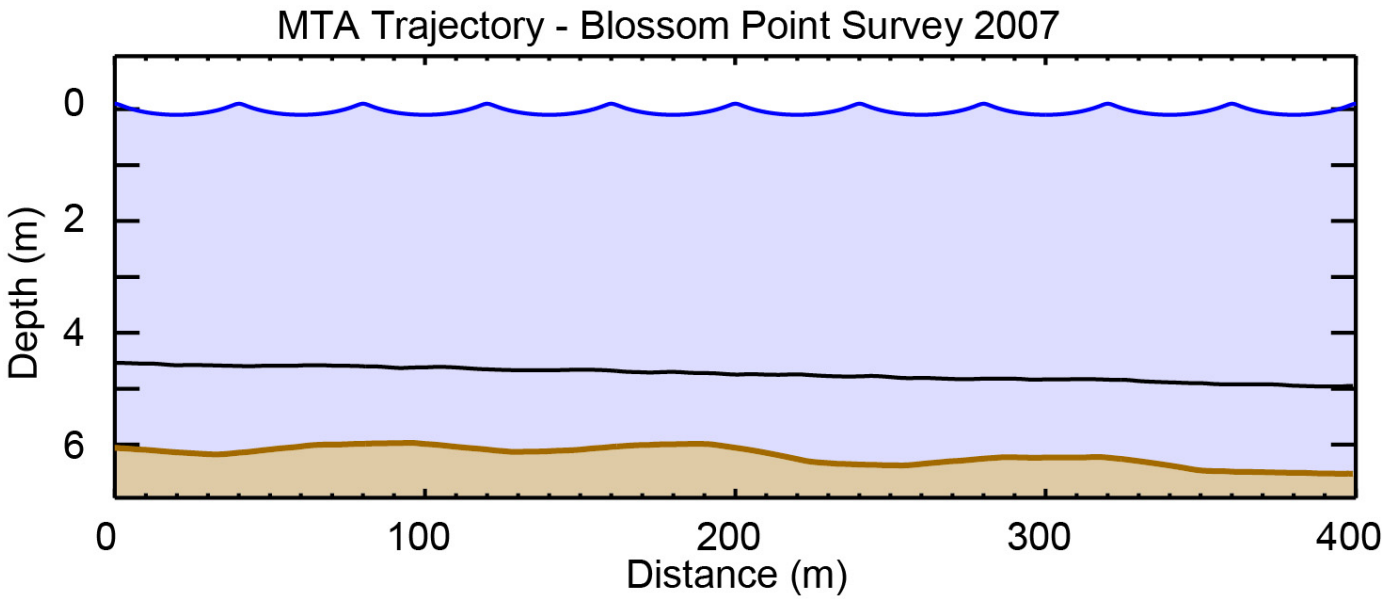
Target under center of inner loop



Tow Characteristics

- Tow speed 2 - 2½ m/s
- Tow depths to ~20 m
- 1-2 m above bottom (active depth control)





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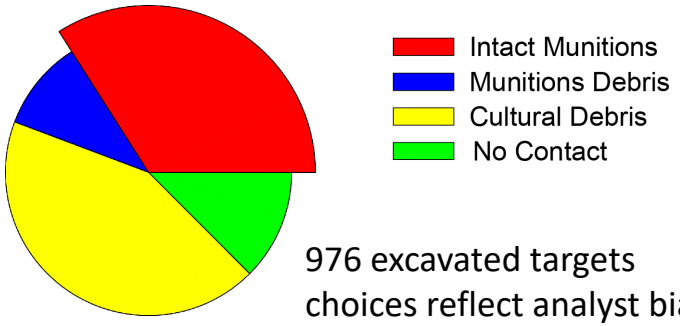
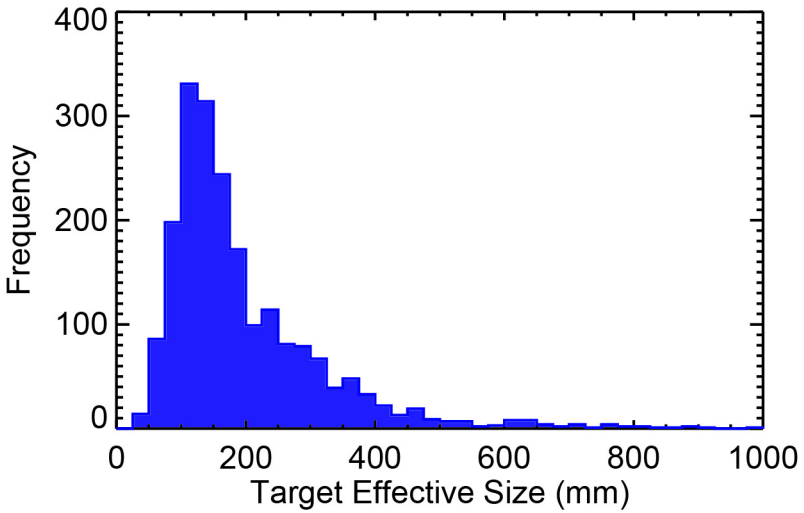
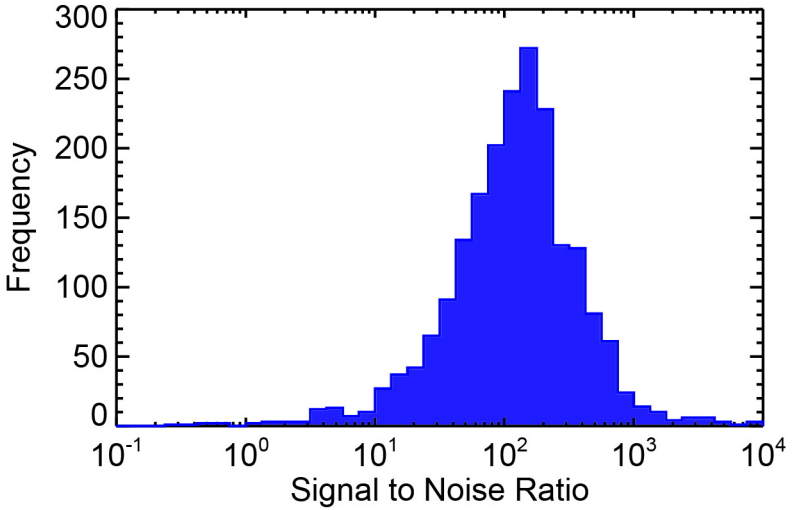
Signal to Noise

- 2042 anomalies selected during magnetometer array demonstrations
  - Effective target size determined from magnetic dipole moment
- Expected MTA EMI signal strength for each target calculated using sphere model
  - Sensor height above bottom 1.5 m
  - Target depth in sediment determined from magnetic dipole fits
  - Noise from 2017 ½ scale model tests
  - No background variation



976 excavated targets
choices reflect analyst bias





Acknowledgements

- SERDP & ESTCP support
  - MR-2409: Empirical Investigation of the Factors Influencing Marine Applications of Electromagnetic Induction
  - MR-201313: Underwater Advanced Time-domain Electromagnetic System
  - MR-201610: Underwater EMI Sensor Platform for Metallic Item Detection

- Nova Research: Dan Steinhurst & Glenn Harbaugh
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- Jacobs: Steve Saville & Stuart Bancroft
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