In-Field Applications of an Autonomous Underwater Vehicle Magnetometer for Munitions and Explosives of Concern Detection

Carter DuVal and Arthur C. Trembanis

University of Delaware, School of Marine Science and Policy, Newark, DE, United States

SAGEEP
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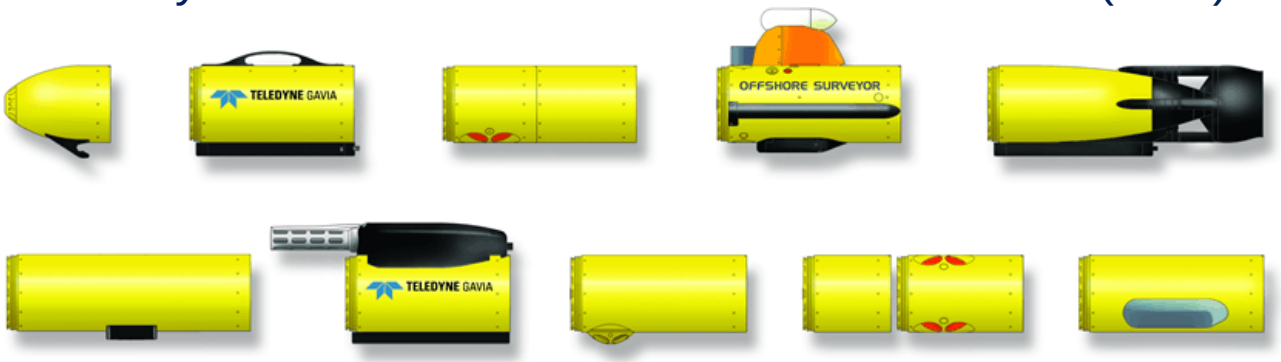
https://www.boem.gov/Munitions-and-Explosives-of-Concern-Survey-Methodology-and-In-field-Testing-for-Wind-Energy-Areas-on-the-Atlantic-Outer-Continental-Shelf/

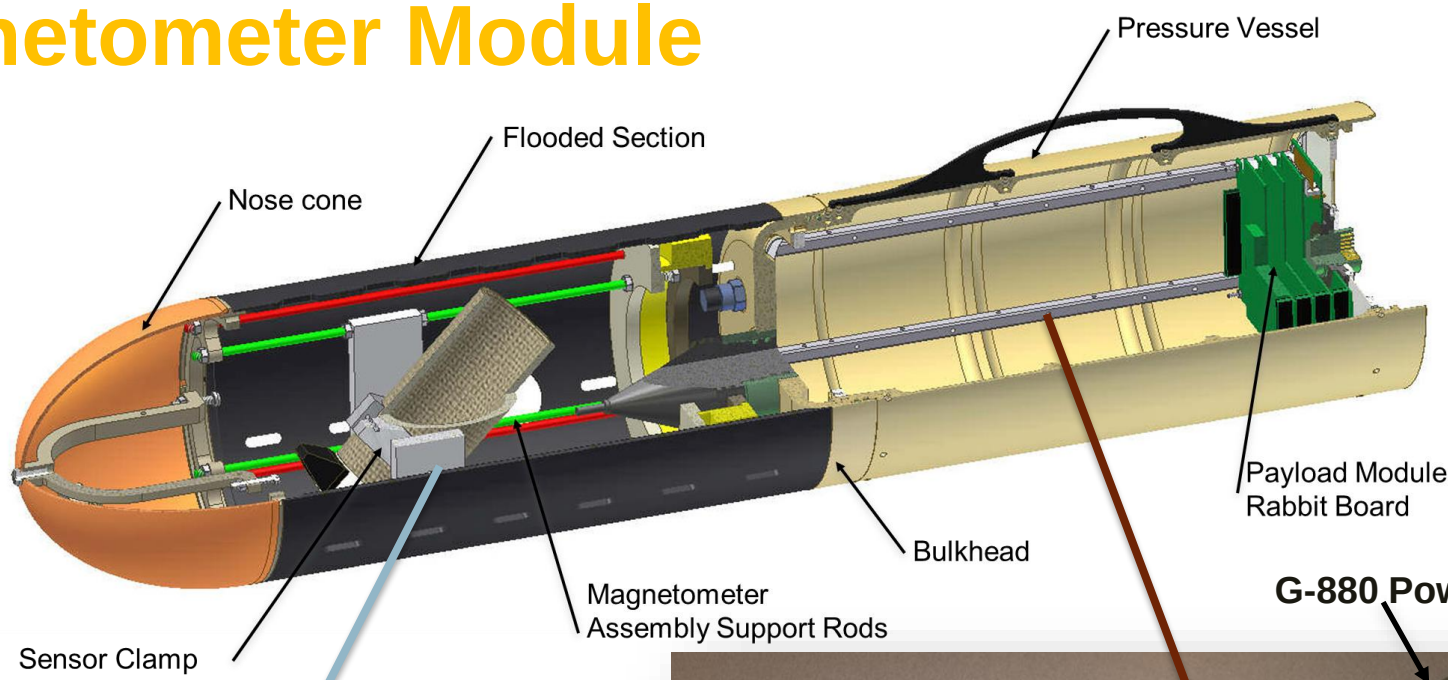
ESTCP: AUV MEC Detection System

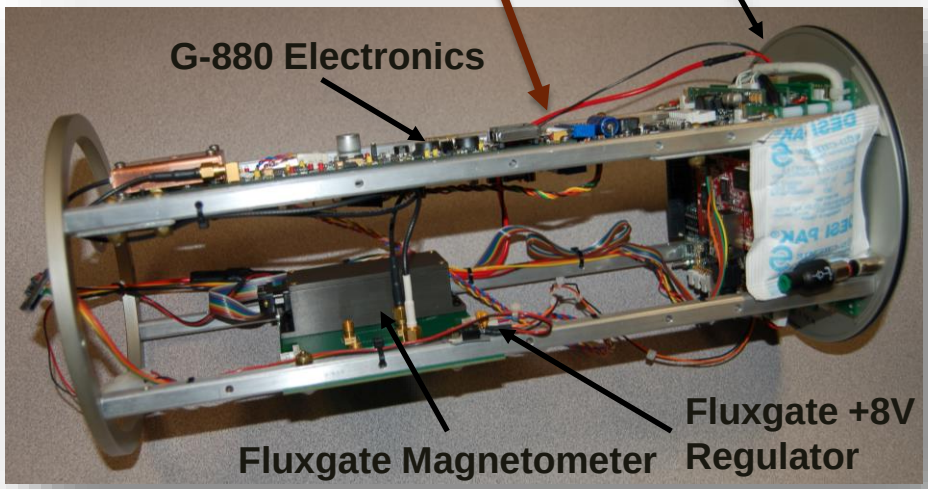
- Integrate a commercially available modular AUV with a sensitive total field magnetometer for MEC detection
  - Perform magnetic noise compensation to remove AUV platform and electrical current interference
  - Deploy and evaluate the system at a demonstration site
- Platform - Teledyne Gavia autonomous underwater vehicle (AUV)



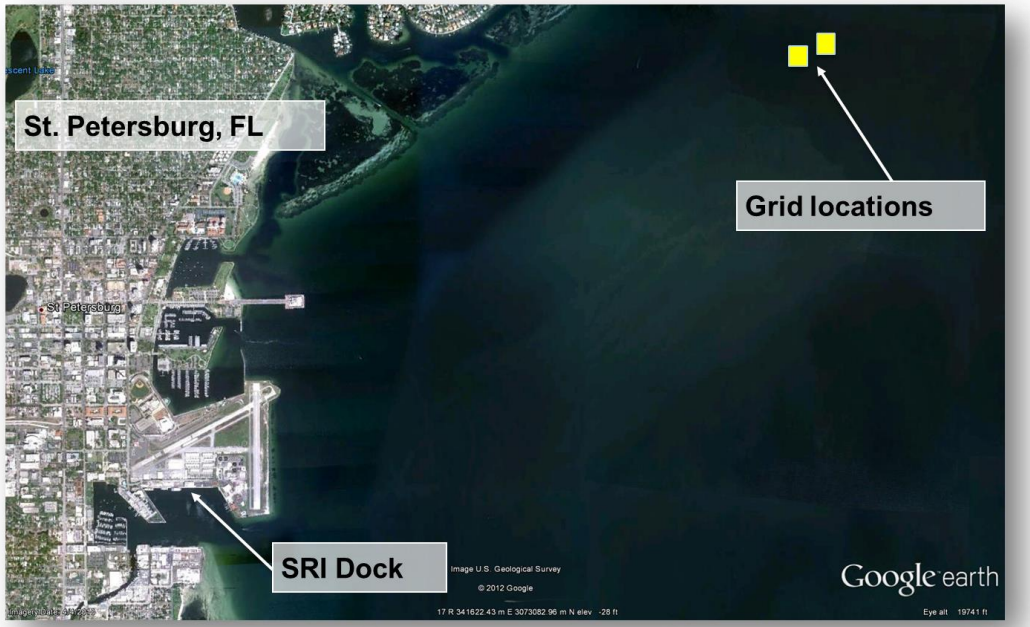
- Magnetometer – Geometrics G880 Self-oscillating split-beam Cesium Vapor
  - 10 Hz sampling
  - Noise: 0.004 nT per √Hz
  - Range: 17,000 nT to 100,000 nT

Magnetometer Module





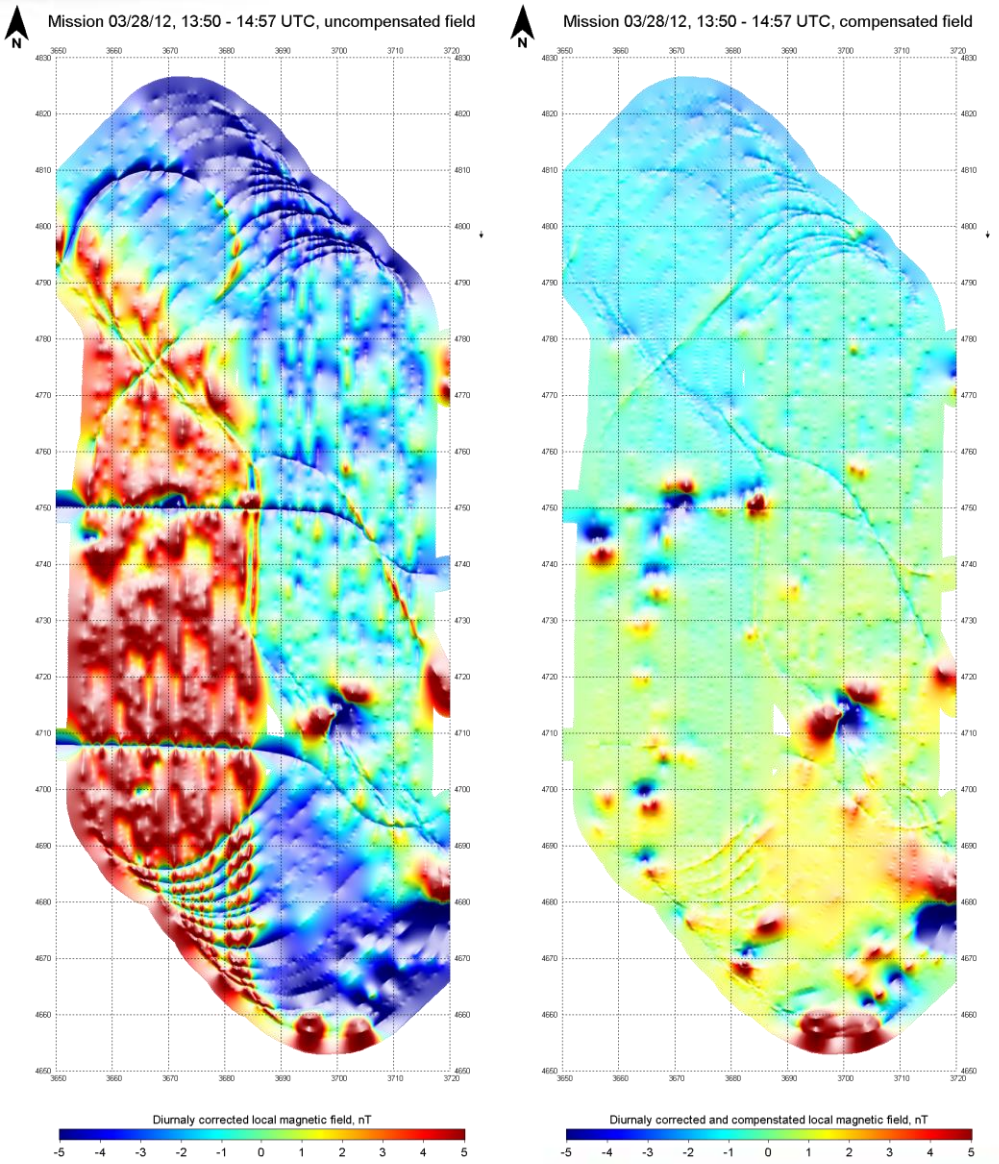
Demonstration Site: Tampa Bay



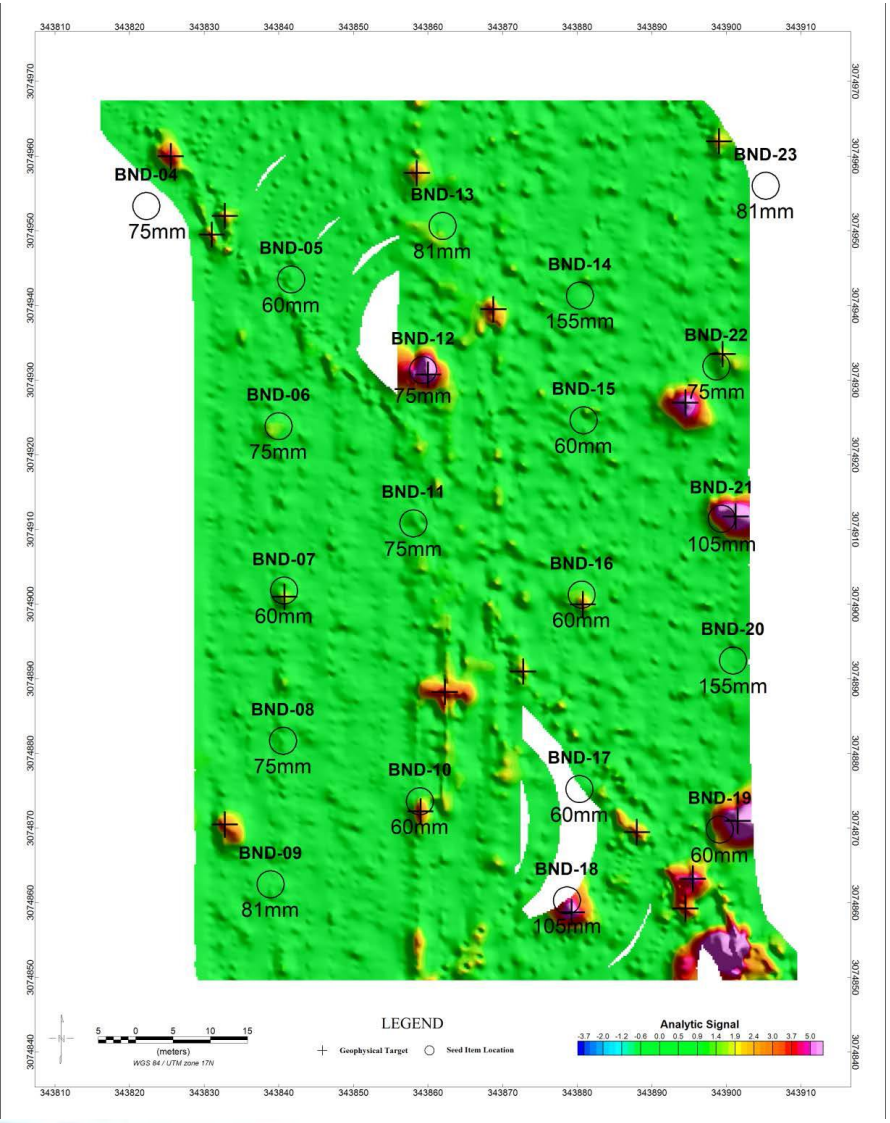
- Flat mud bottom
- Established two 100m x 100m underwater test sites using inert munitions (60mm mortar – 155mm shell)
  - 1 calibration grid (known)
  - 1 blind grid (unknown)
- Demonstrate system and evaluate performance against pre-determined quantitative and qualitative metrics
  - MR201002-DR

Compensation Missions

- Improvement ratios (IRs) ranged from 5.1 to 7.6 (cal grid) and 11 to 12.4 (blind grid)
- Largest magnetic distortions correlated with vehicle pitch and heading
- Current flow contributes to long term and immediate (battery switch) changes in the magnetic signature of the vehicle
  - Compensate for individual battery modules



Blind Survey Results



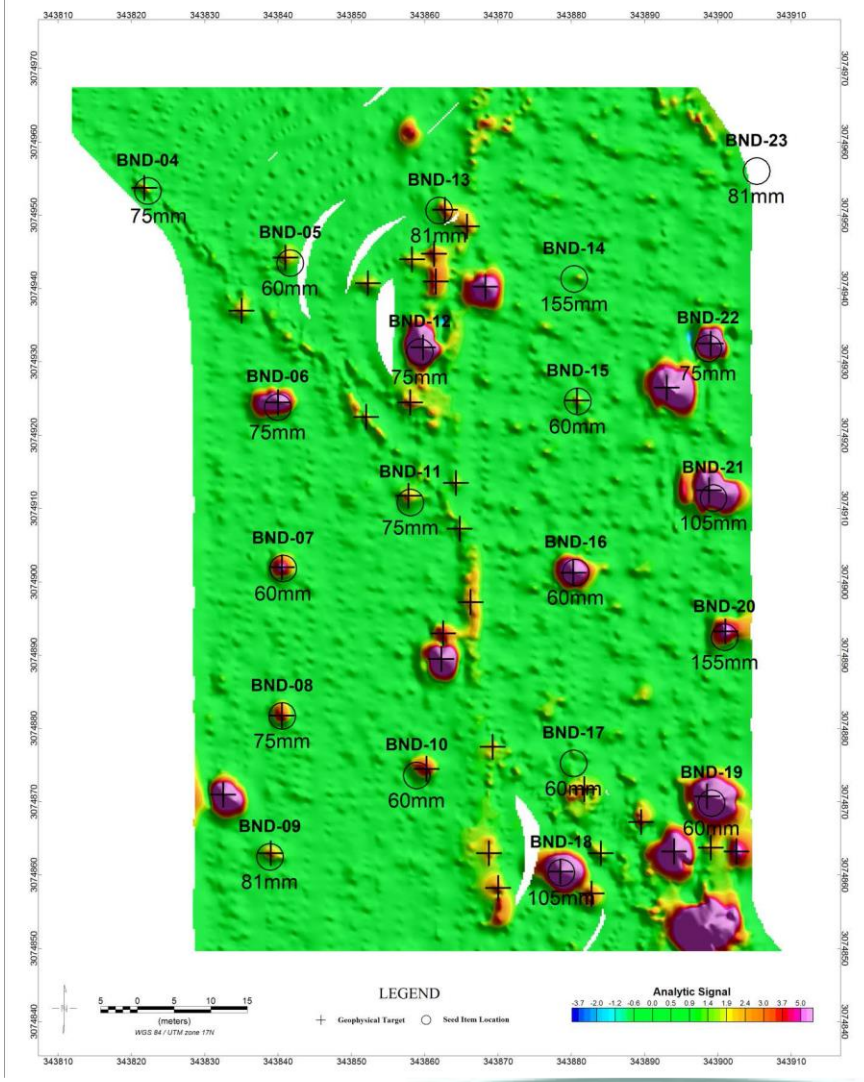
- Mission Design
  - 2m altitude, 2m line spacing*
  - 19 seed items (60mm, 81mm mortar, 75 and 155 shell)
- Two missions
  - 8/19 and 11/19 detections
- Navigation - seed offsets –
    - Mission 1 – 1.57m avg., <2.66m overall
    - Mission 2 – 1.32m avg., <2.61m overall

*Vehicle transect spacing limitations

Blind Survey Results

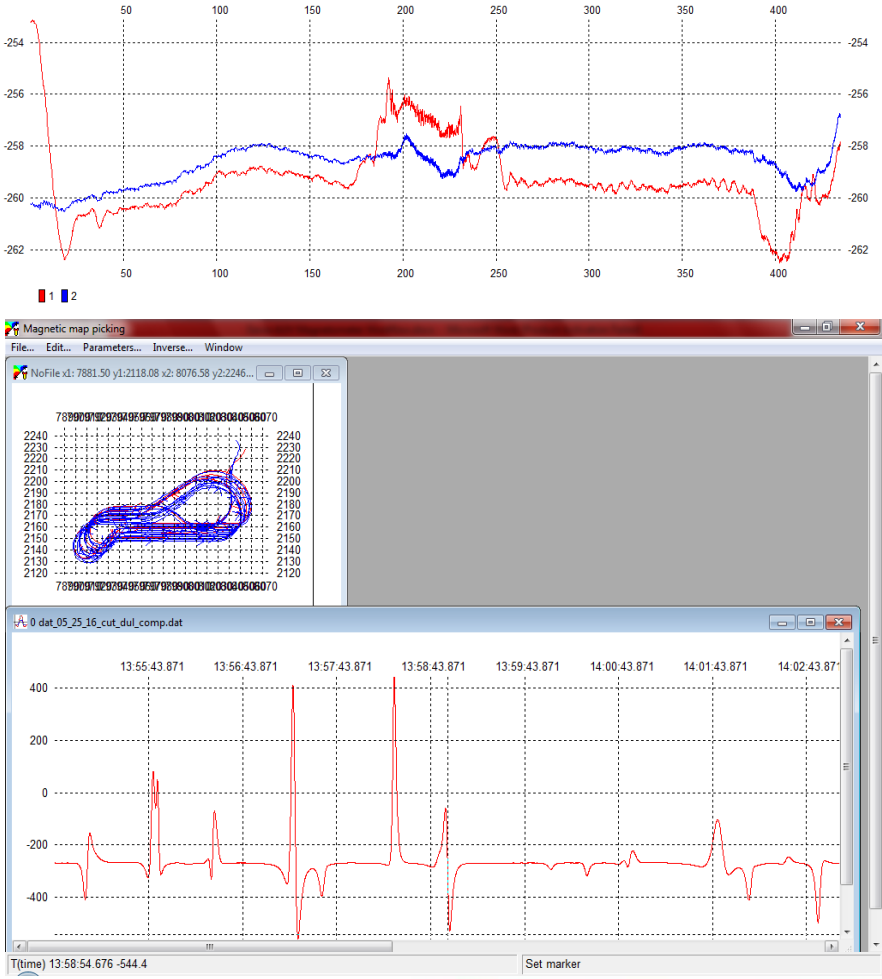
- Mission Design
  - 1.5m altitude, 2m line spacing*
  - 19 seed items (60mm, 81mm mortar, 75 and 155 shell)
- Two missions
  - 17/19 and 14/19 detections
- Navigation - seed offsets –
    - Mission 1 – 0.7m avg., <1.61m overall
    - Mission 2 – 1.65m avg., <2.72m overall

*Vehicle transect spacing limitations



Improvements Resulting from ESTCP

- Software update to allow for finer line spacing (<2m)
  - Surrogate position offsets attributed to line spacing
- GPS upgrade for better initial and post-mission vehicle positioning
  - L1/L2 GPS receiver
- Magnetometer module material refit
  - Better IR for compensation
- New batteries
  - Less noise and longer duration
- Data processing pipeline established to improve user “friendliness”



BOEM MEC Study 2016

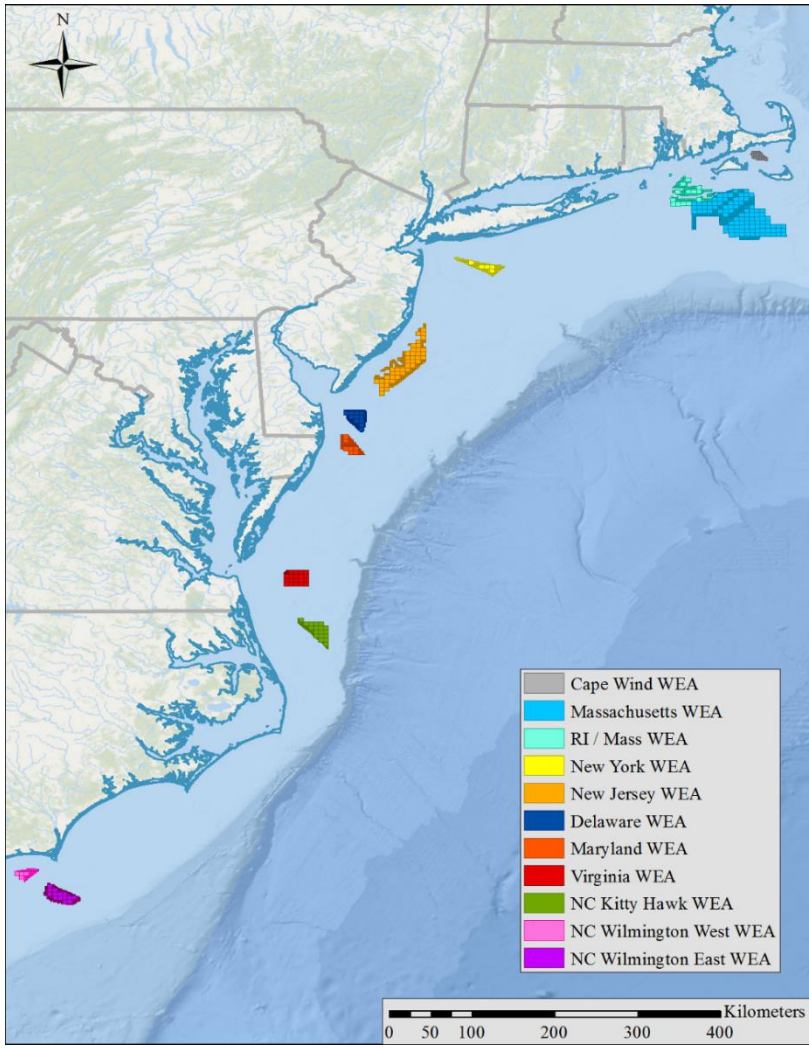
- **Support the Bureau of Ocean Energy Management (BOEM) to develop guidance:**

Identifying potential MEC type and distribution in Atlantic OCS Wind Energy Areas (WEA)

Investigating and recommending methods/technologies for MEC detection in OCS WEA

In-field verification of recommended methods/technologies

Investigation of munitions mobility / burial following storm activity on the OCS



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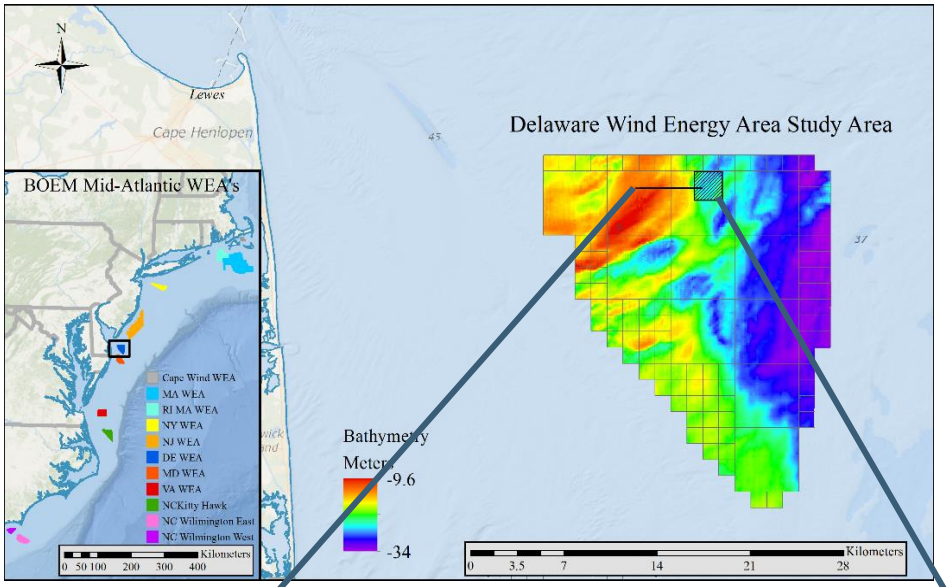
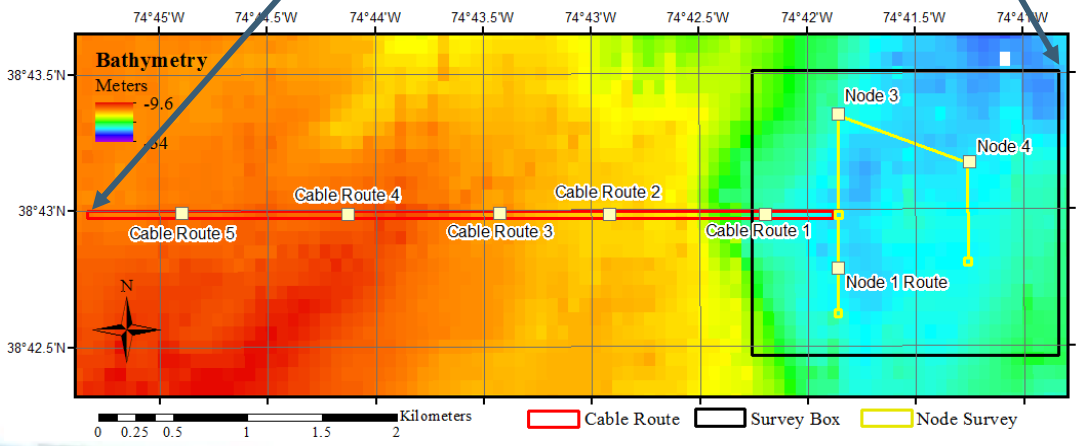
Study Area

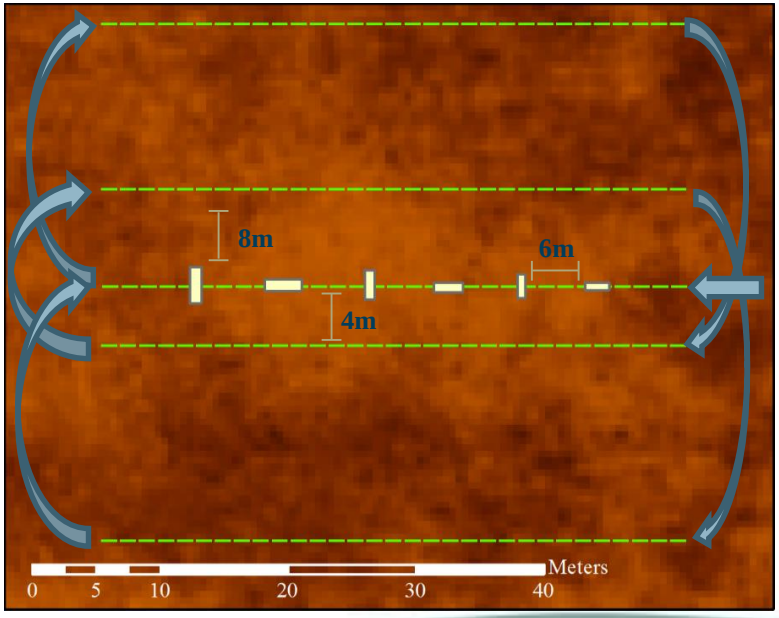




- Located within two lease blocks of DE WEA
  - Water depth of 13-25 m
  - Variety of sediment types, depth, and slope
- Search area
  - Replicates offshore wind farm
  - 2 x 2km survey area composed of five wind turbine "node" sites
  - 5 km cable route simulating landfall cable from WEA

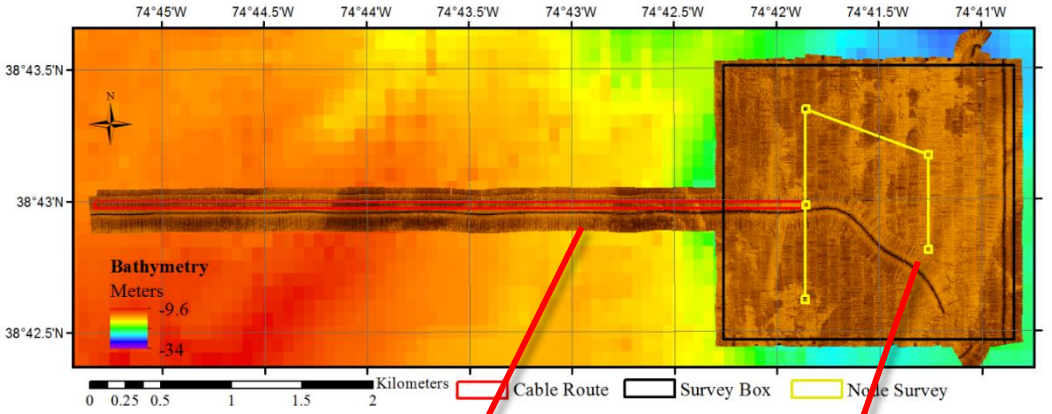
Surrogates and Seeding

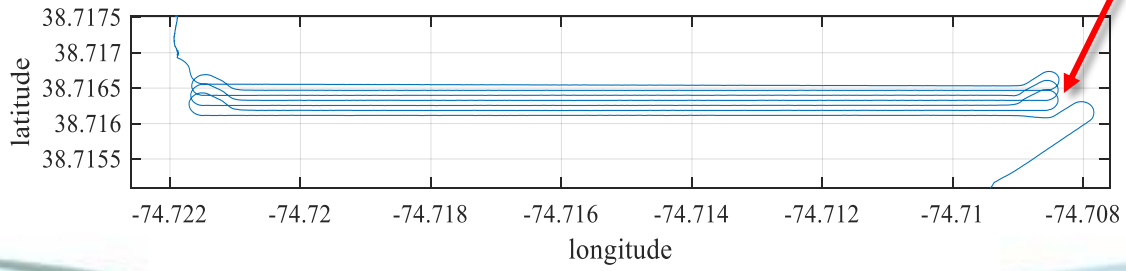
- Industry Standard Objects (ISO) – objects the present similar acoustic/magnetic signature to munitions
  - Composed of four surrogate sizes
    - 8- x 36-inch pipe (8-inch artillery shell)
    - 6- x 24-inch pipe (155 mm artillery shell)
    - 4- x 12-inch pipe (105 mm artillery shell)
    - 2- x 8-inch pipe (60 mm mortar)
  - Established instrument verification strip (IVS) for daily instrument tests
- 62 total surrogates at 8 sites

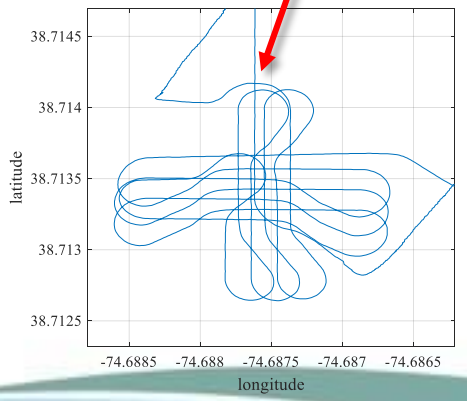


Survey Methodology

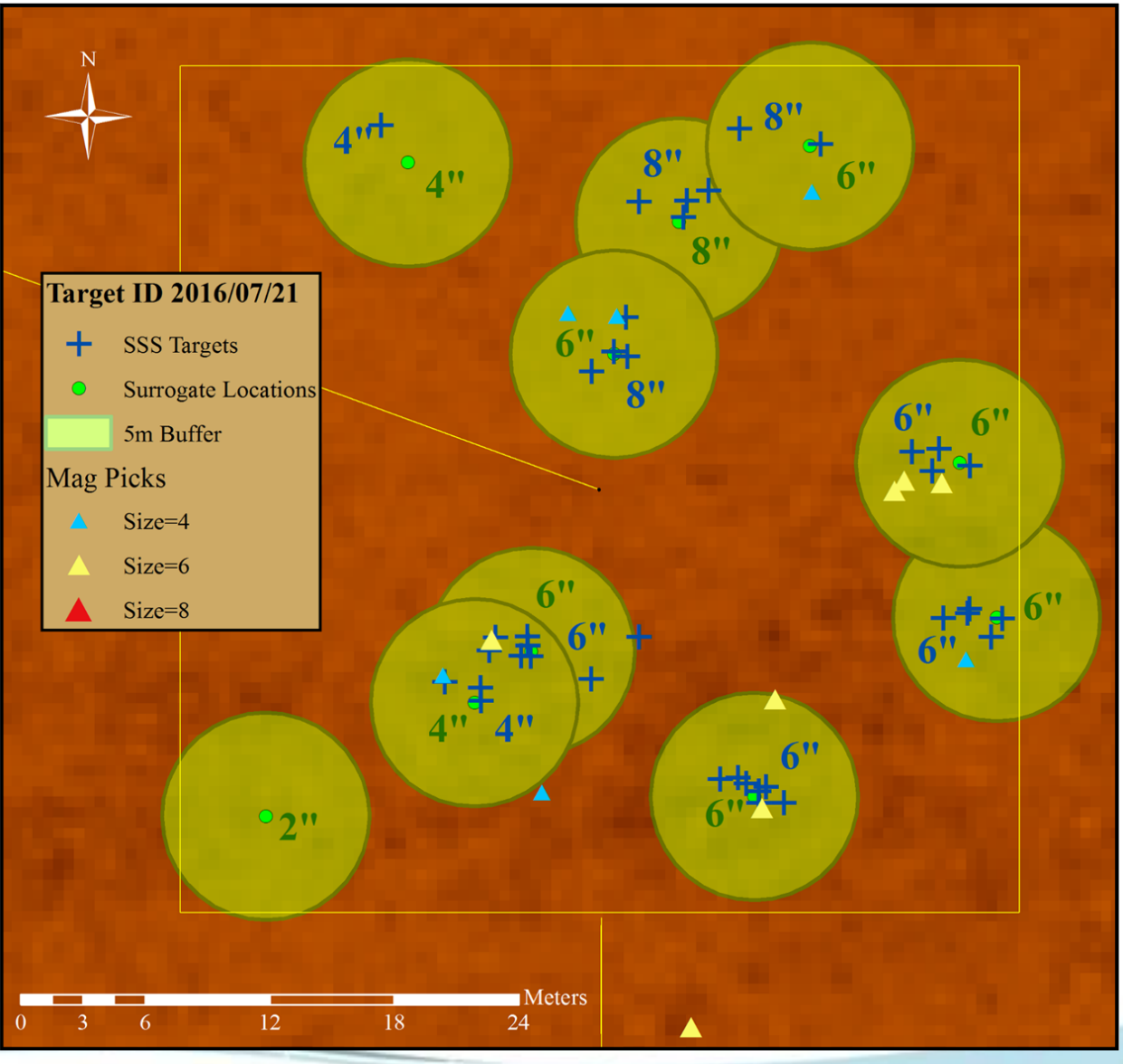
- Wide Area Assessment (WAA) – >100% coverage
  - Provides contextual information on bathymetry, seabed texture / sediment distribution
  - Identify obstructions to AUV operations
  - Identify ISOs?
- Detailed AUV Sonar / Magnetometer Survey
  - Node Route Missions (40x40m)
    - 2 m altitude, 8 m spacing
    - Transects run N-S, and E-W
  - Cable Route Missions (1 x 0.05 km corridor)
    - 2 m altitude, 8 m spacing, transects run E-W only







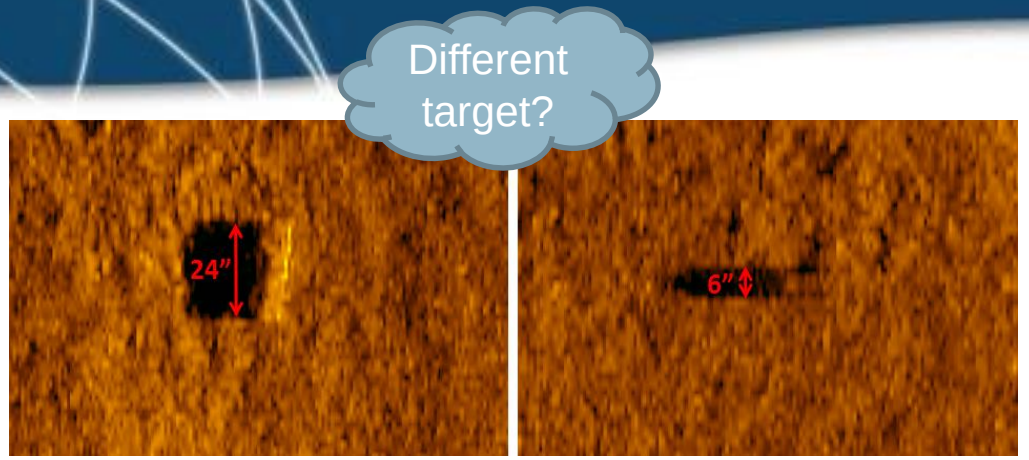
AUV Survey Results

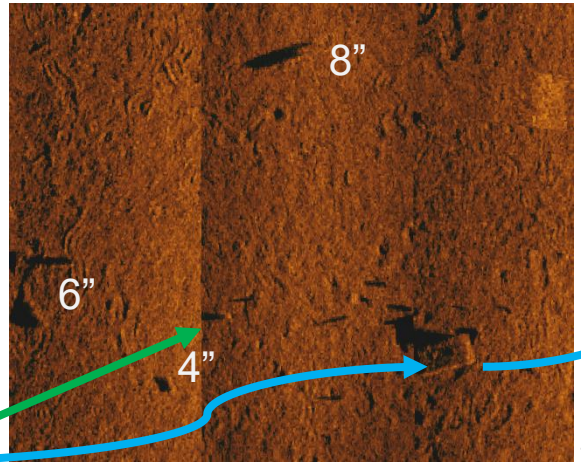


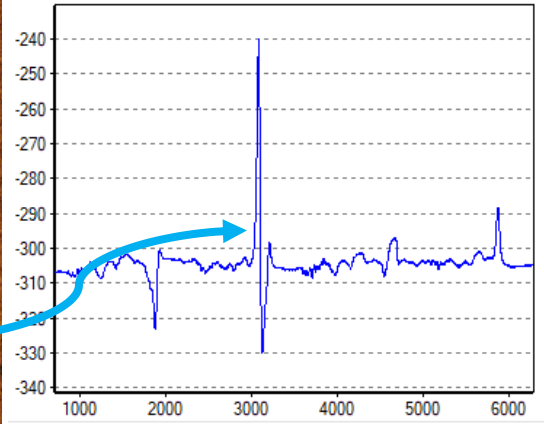
- Better performance of target detection of ISO in side-scan sonar (SSS)
  - All 6 inch (155mm) or larger ISO detected SSS
  - Detection rate by magnetometer < 50%
- SSS also proved better for target size estimation
  - Tendency to under-estimate target size in magnetometer

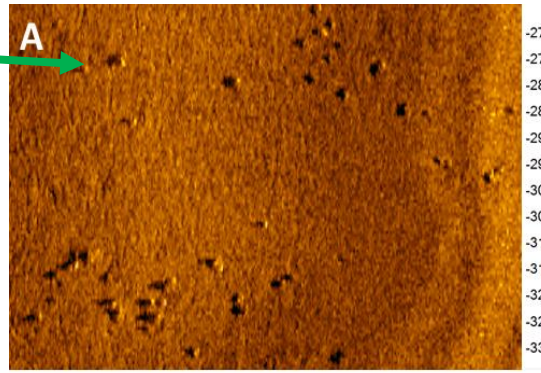
Complications

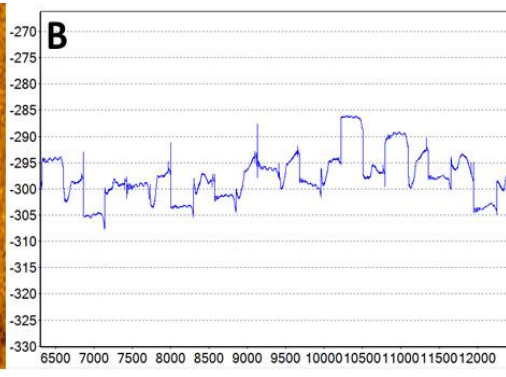
- Target size estimation
  - Orientation of ISO relative to sonar
  - Distance between ISO and magnetometer
- "Noise"
  - Non-ISO targets on the seafloor
    - Fishing gear (Mag)
    - Biology (SSS)
  - Vehicle navigation issues
    - Issue settling into constant altitude (B)



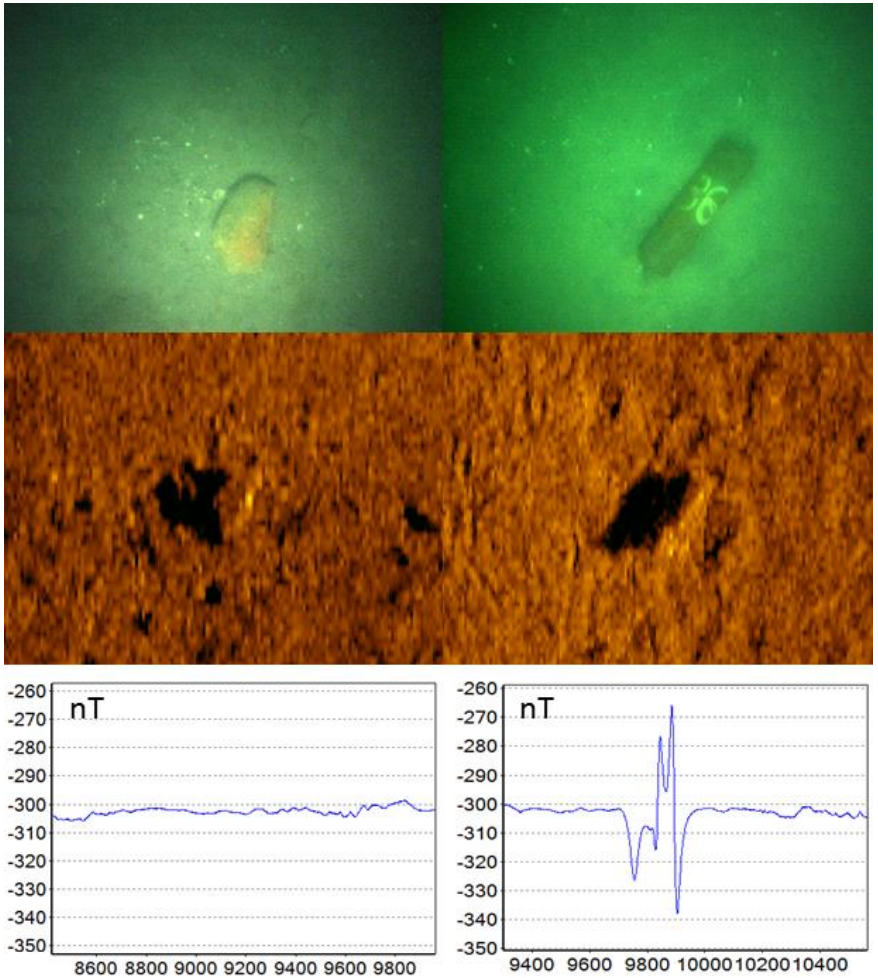








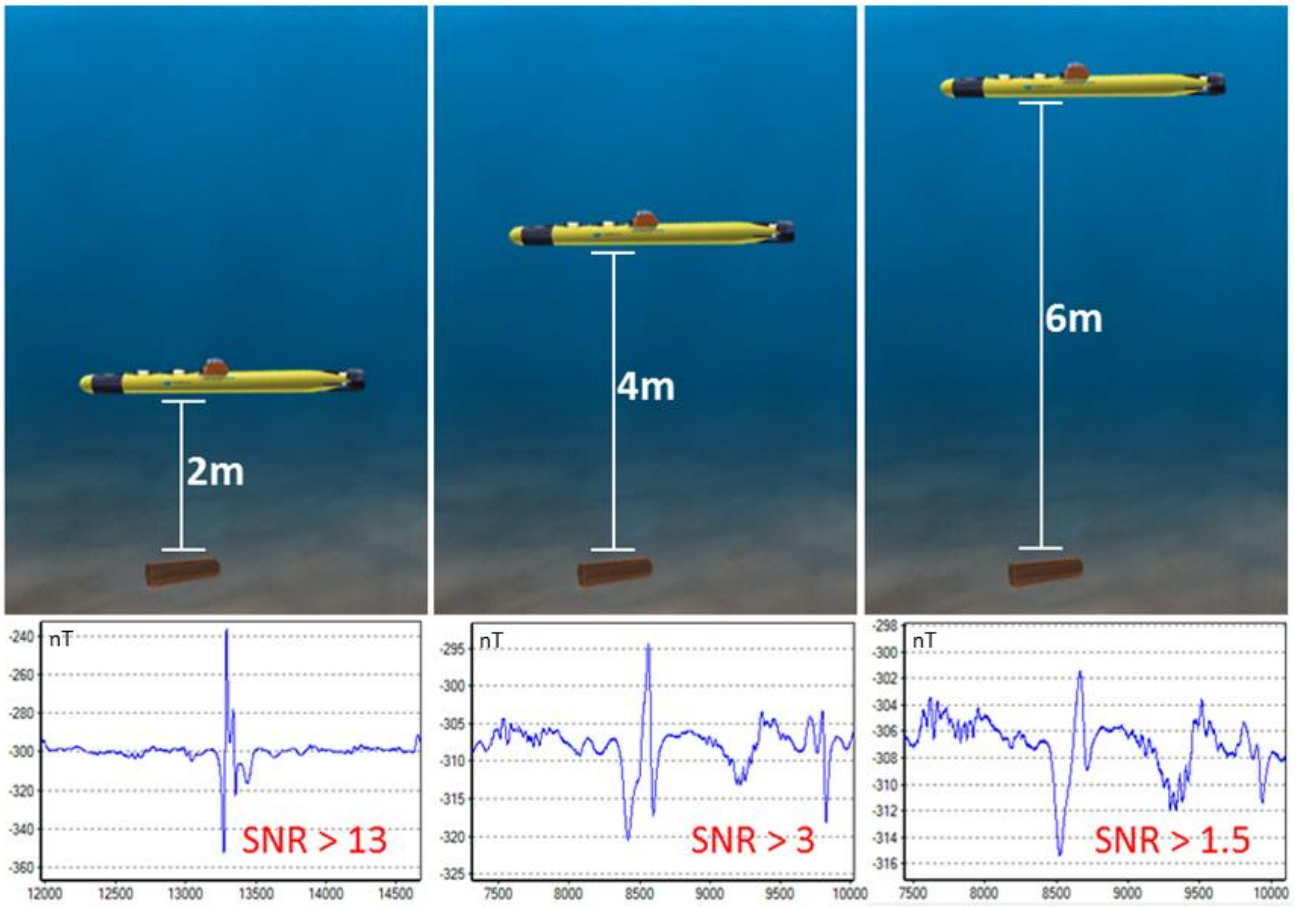
Combined Sensors



- Individual sensors not as effective as combined
- Magnetometer can discern ISO from debris / geology in side-scan data
- Reanalysis of data
  - Combination of side-scan and magnetometer data
  - Improved target size estimation

Region	Side-scan Sonar Alone	Magnetometer Alone	Combined Reanalysis
Node 1 Route	10	1	14
Node 3	18	3	23
Node 4	19	6	27
Total	**47**	**10**	**64**

Simulated Burial



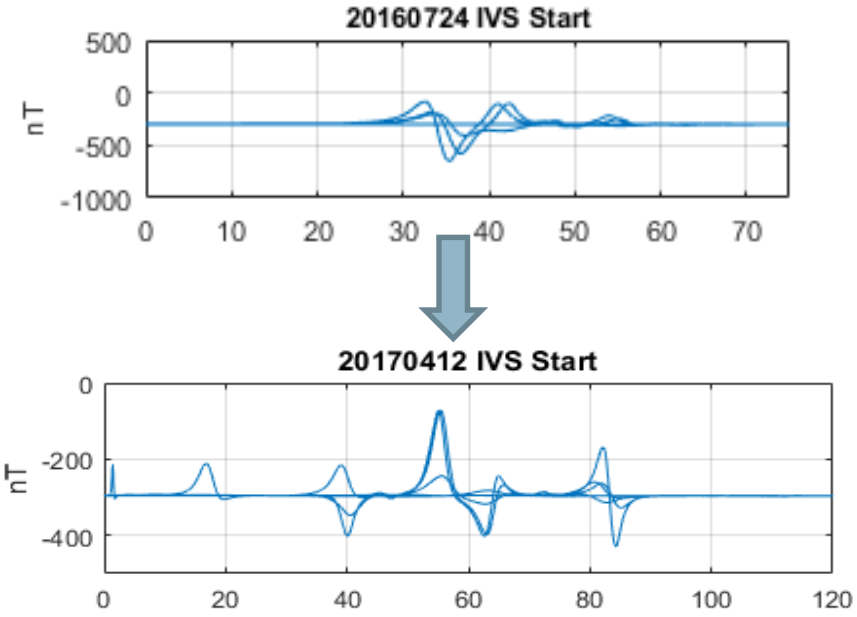
- Simulated burial at Node 3
  - 4 m altitude (2m burial)
  - 6 m altitude (4m burial)
- Able to detect 155 mm ISO at all altitudes
- Increase in altitude significantly reduced signal to noise
  - Magnetic signal drop ~ cube of distance between sensor and object

BOEM 2017

- Following the July 2016 in-field verification, several storm events occurred in the vicinity of the study area
- Additional field effort undertaken to reacquire the surrogates and determine whether:
  - Surrogates became mobile during energetic conditions
  - Surrogates underwent *in situ* scour and burial during energetic conditions, or
  - No surrogate mobility or burial occurred.
- Follow up study also tested several recommendations resulting from the 2016 field effort

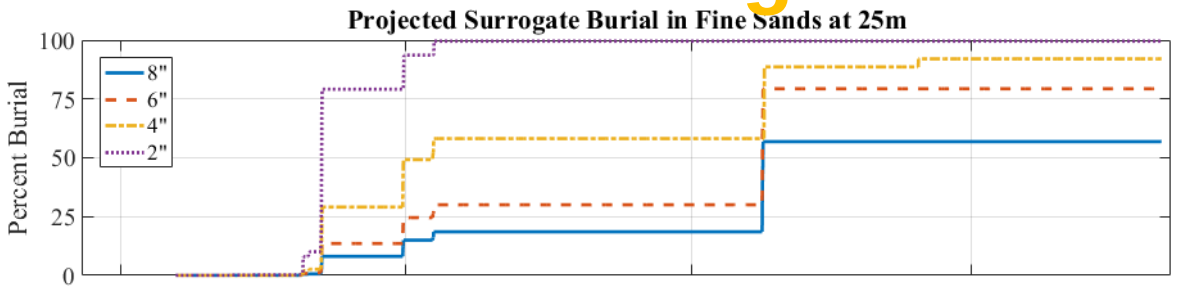
Performance

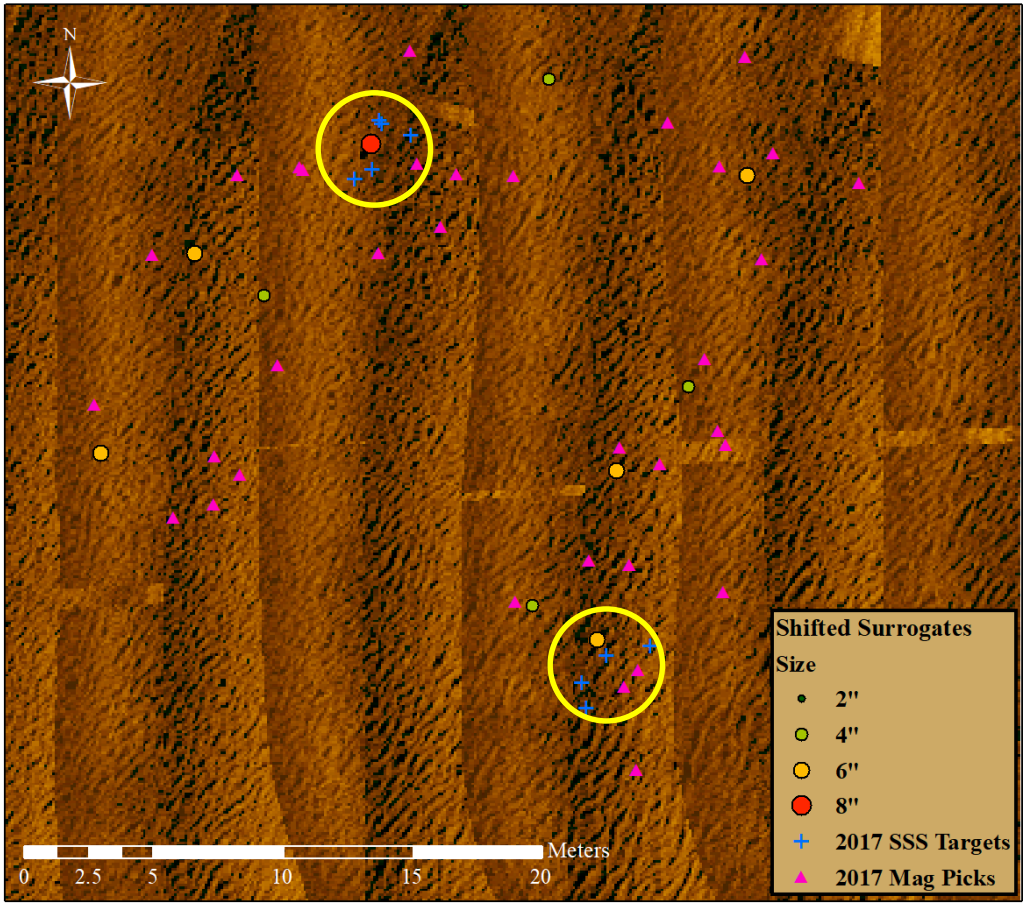
- Based on 2016 recommendations
  - Re-designed IVS to reduce signal overlap by increasing ISO spacing
    - From 6m – 15m
  - Decreased mission spacing from 8m to 4m NS-EW
    - Led to four-fold increase in magnetic picks at 2m altitude



Year	Altitude	Spacing	N-S	E-W	Total Magnetometer Picks
2016	2	8	Yes	Yes	8
2016	2	4	Yes	No	8
2016	4	8	Yes	Yes	7
2016	4	4	Yes	No	7
2016	6	4	Yes	No	7
2017	2	4	Yes	Yes	34
2017	6	4	Yes	Yes	19

Surrogate Burial

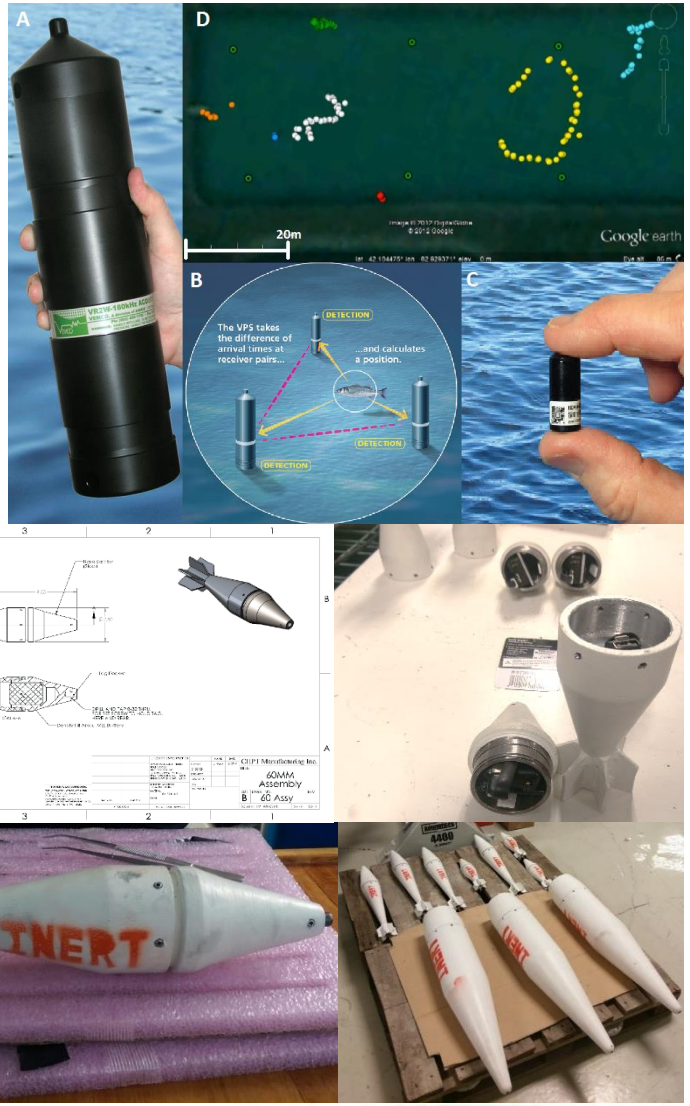




- ONR Mine burial studies provide useful insight into ISO burial
  - Trembanis et al. 2004 model for mine scour / burial
  - Incorporated bedform impedance of burial
- Observations
  - Near total burial of surrogates in fine sands
  - Strong agreement with models
  - Magnetometer able to detect buried / obscured ISO

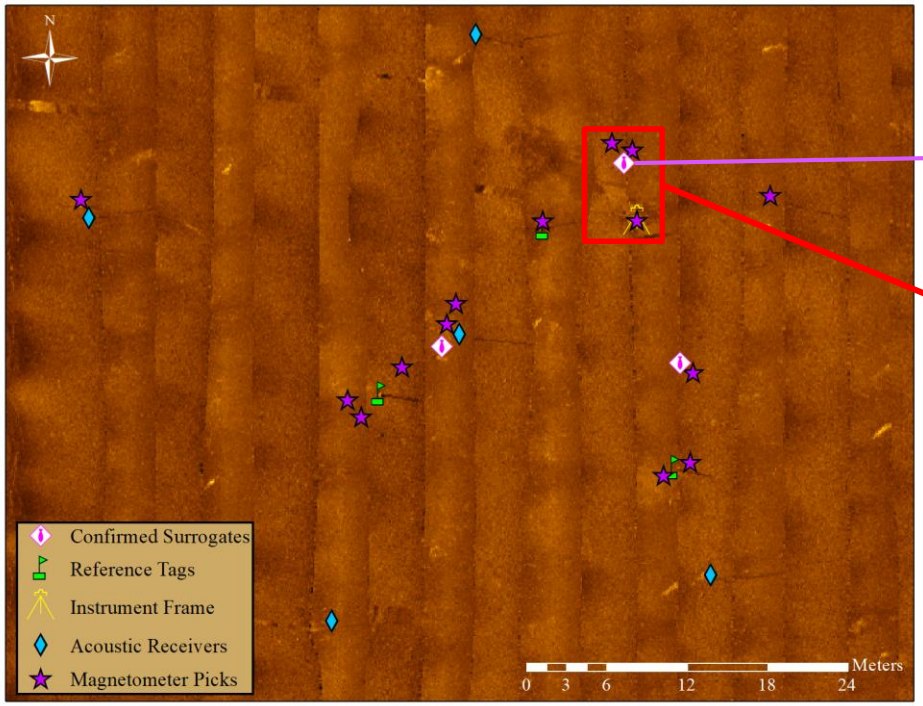
SERDP: Munitions Mobility

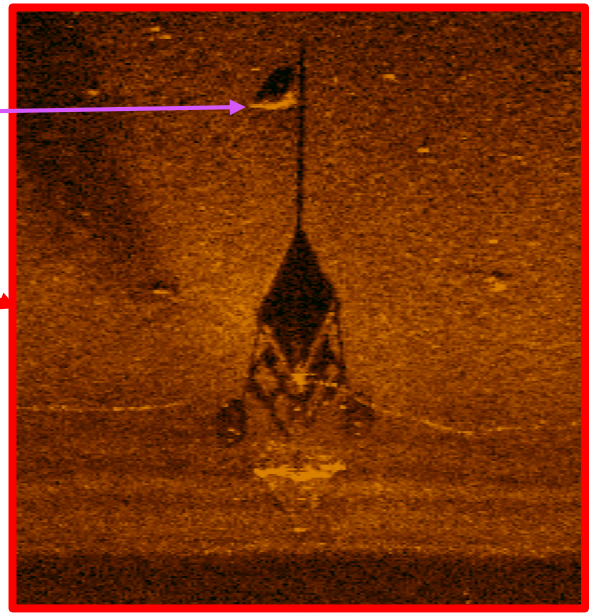
- Using VEMCO acoustic tags to track surrogate munitions in DE Bay
  - Mobility or burial in muds?
- AUV Magnetometer Surveys
  - Repetitive side-scan sonar and magnetometer surveys will be conducted and compared to VPS tracking results.
- Provides extra tracking mechanism should the surrogates become buried too deep for acoustic tracking



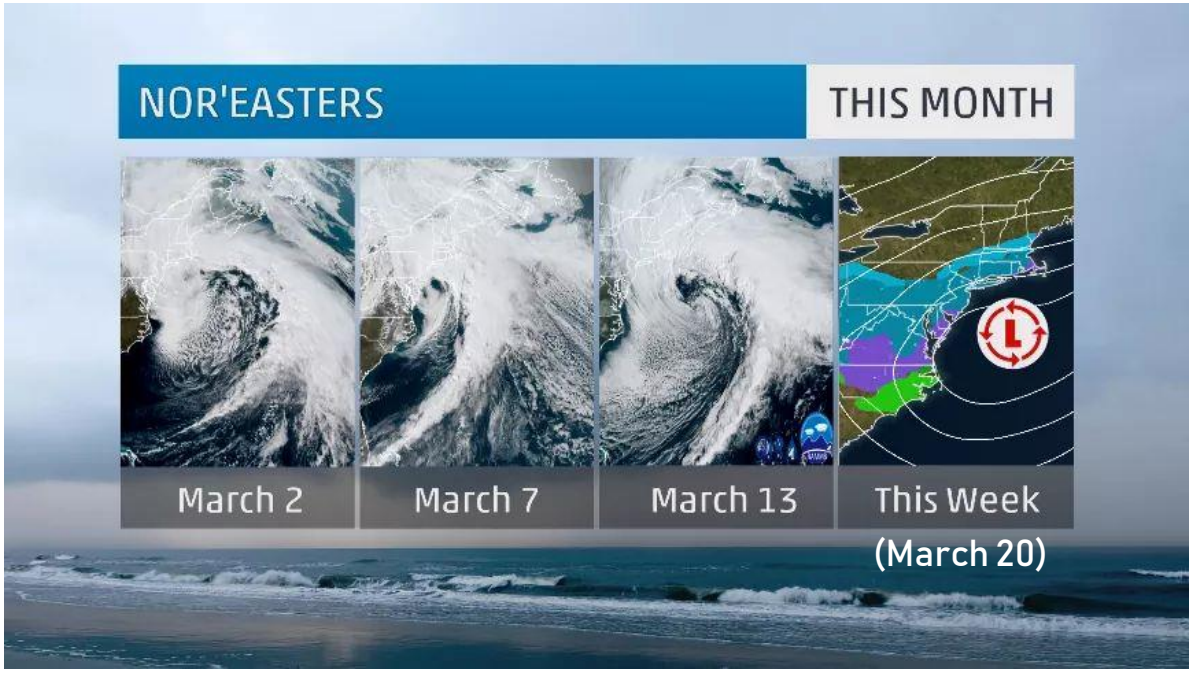
SERDP: 2017 Field Test

- Test mission – 2m Alt, 4m spacing
  - Separate NS, EW missions to improve positioning
  - Difficulty detecting smaller munitions due to “noise” from close proximity of VPS and moored instruments
    - *Currently testing lower altitude mission plans to compensate*





Still to come… 2018 Spring Deployment



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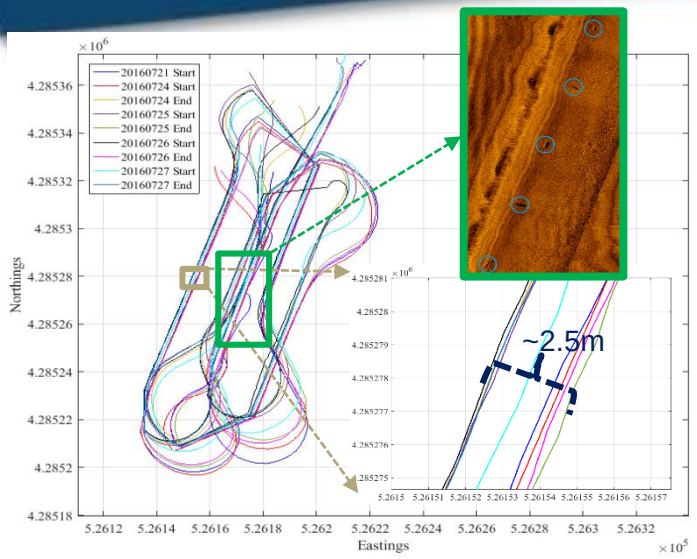
Conclusions

- Mounting magnetometer to AUV allows for near-bed, *repeatable*, high-precision surveying for MEC
  - Continued development has improved performance and "user friendliness"



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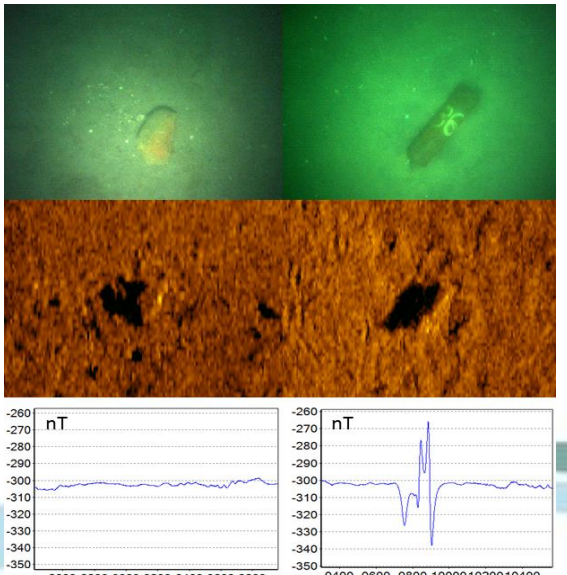
2017	6	4	Yes	Yes	19

- Multi-sensor fusion for MEC detection
  - No one sensor is fully capable of detection in all cases
  - "The whole is greater than the sum of the parts"

- Importance of in-field testing
  - Modify mission design for improved performance based on mission goals



Thank You

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OCS Study
BOEM 2017-063

Munitions and Explosives of Concern Survey Methodology and In-field Testing for Wind Energy Areas on the Atlantic Outer Continental Shelf