Unexploded Ordnance Characterization and Detection in Muddy Estuarine Environments

MR-2730
Art Trembanis and Carter DuVal
University of Delaware
In-Progress Review Meeting
May 16, 2018

SERDP
DOD ▪ EPA ▪ DOE

MR-2730: UXO in Muddy Environments

Performers:

- *University of Delaware – Art Trembanis and Carter DuVal*

Technology Focus

- *Evaluating an acoustic positioning system (Vemco VPS) to monitor munitions mobility and scour/burial through the use of instrumented "smart surrogate munitions" through long-term deployments*

Research Objectives

- *Provide long-term observations of surrogate munitions in muddy environments through the use of an in-situ acoustic positing system, periodic geophysical surveys, and in-situ time-series hydrodynamics*

Project Progress and Results

- *Development and testing of 10 "smart surrogate" munitions*
- *Two field deployments of Vemco VPS acoustic positioning system with smart surrogate munitions and hydrodynamic sensor suite*
- *Time-series acoustic tracking and IMU measurements of surrogates during 4 nor'easter storm events in the Delaware Bay*

Technology Transition

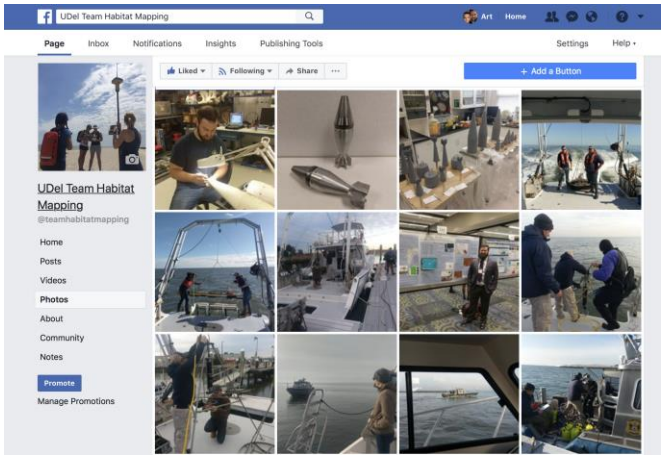
- *Distribute data collected on munition mobility/scour/burial for incorporation into expert system model (in progress)*
- *Prepare documentation on surrogate munitions development and VPS system specifications, deployment methods and results*

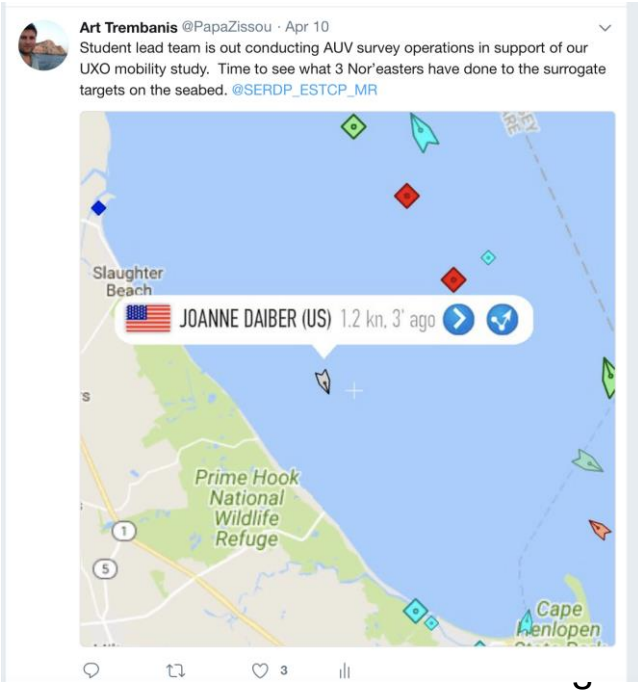
Social Media Content

- **Project outreach through multiple social media platforms**
  - *Twitter, Facebook, and Google+*
- **Outreach highlights:**
  - *Project development and field highlights shared through FaceBook Teampage- UDel Team Habitat Mappings*

https://www.facebook.com/media/set/?set=a.211571635204328 8.1073741833.143997761961716 8&type=1&l=db37da86d6

  - *Twitter feeds- @PapaZissou*
  - *Public Google Photo Page https://photos.app.goo.gl/HYdZ69ManvZHuzB96*





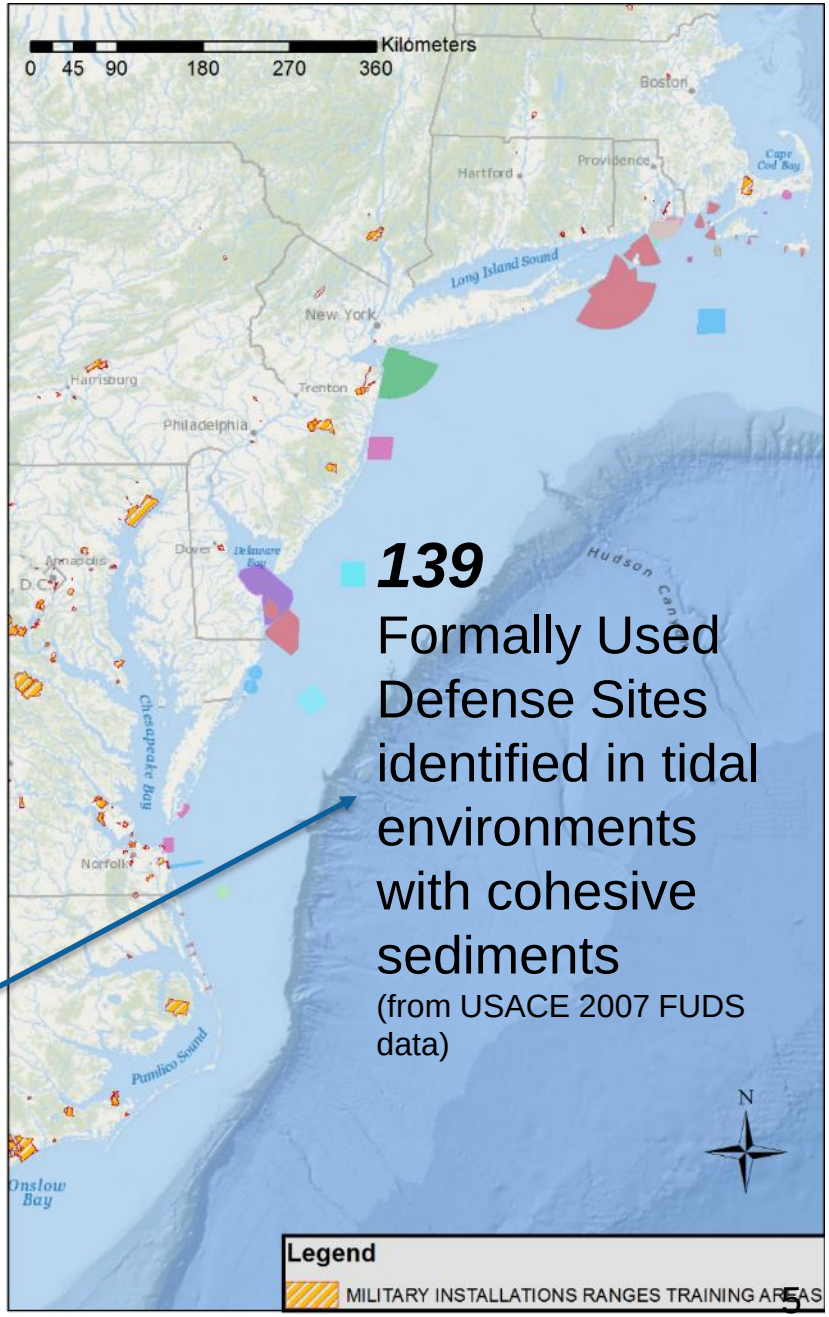
Project Team

- P.I., Art Trembanis (University of Delaware)
- Co-P.I., Carter DuVal (University of Delaware)

- Other significant contributors:
  - Dana Allen & Martin Blostein (Vemco)
  - Delaware State Police Scuba Unit (Cpl. Brian Green)
  - Maria Spadaro (UD)
  - Kenny Haulsee (UTEC)

Problem Statement

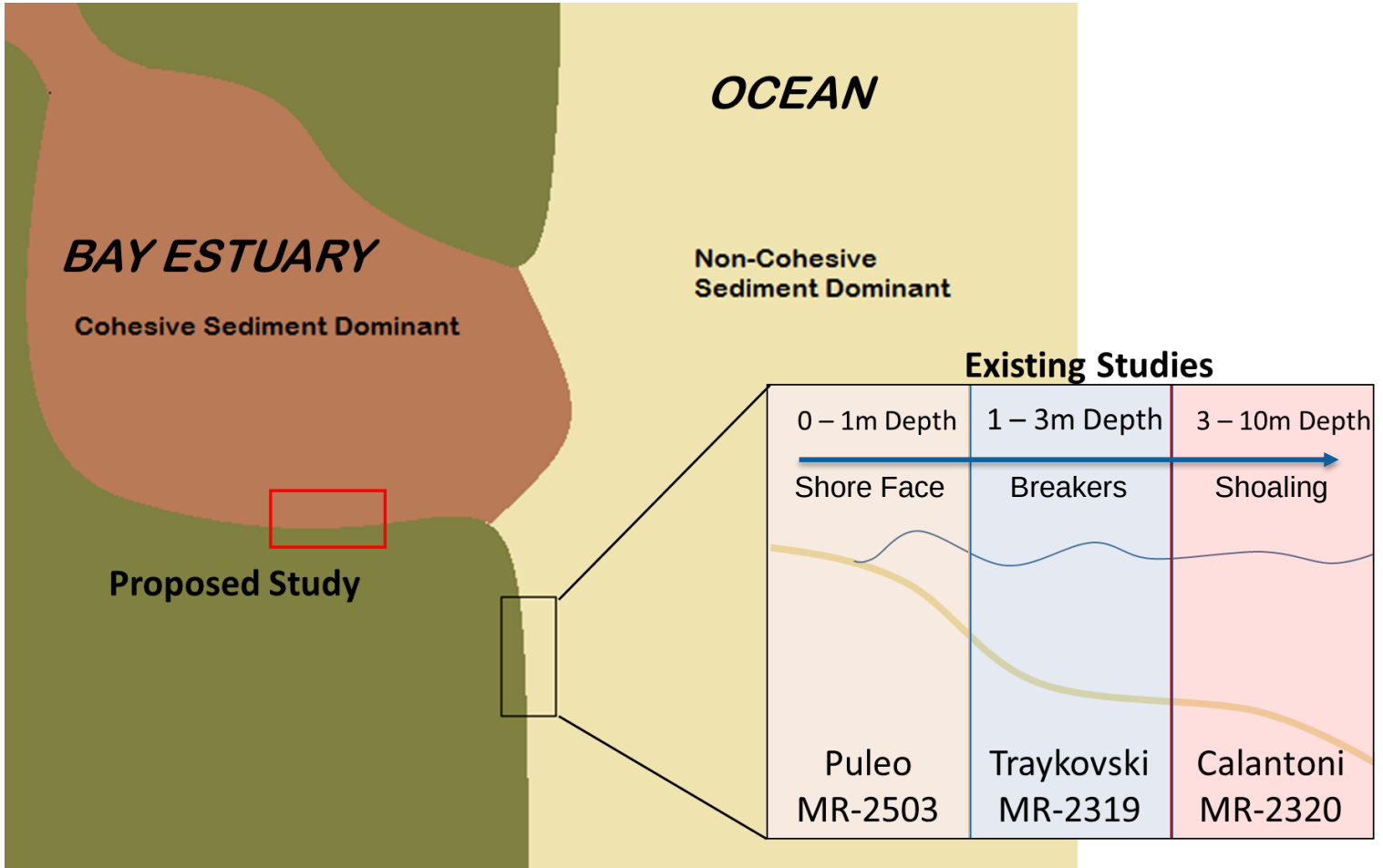
- Need for better quantitative understanding of the impact of coastal environments on UXO mobility and behavior (MRSON-17-01).
  - ♦ Concern by Military Services over near-shore UXO and potential for harmful human interaction
  - ♦ Current studies addressing the mobility and detection of UXO in sandy coastal areas (e.g. Calantoni SERDP MR-2320, Traykovski MR-2319, Puleo MR-2503)
- A significant data gap has been identified regarding UXO in shallow, muddy environments (2nd SERDP Munitions Mobility and Modeling Workshop, Dec. 8-9, 2015).



Problem Statement

Existing *in situ* data for munitions mobility

- Field experiments conducted in environments characterized by non-cohesive sediment



Technical Objective

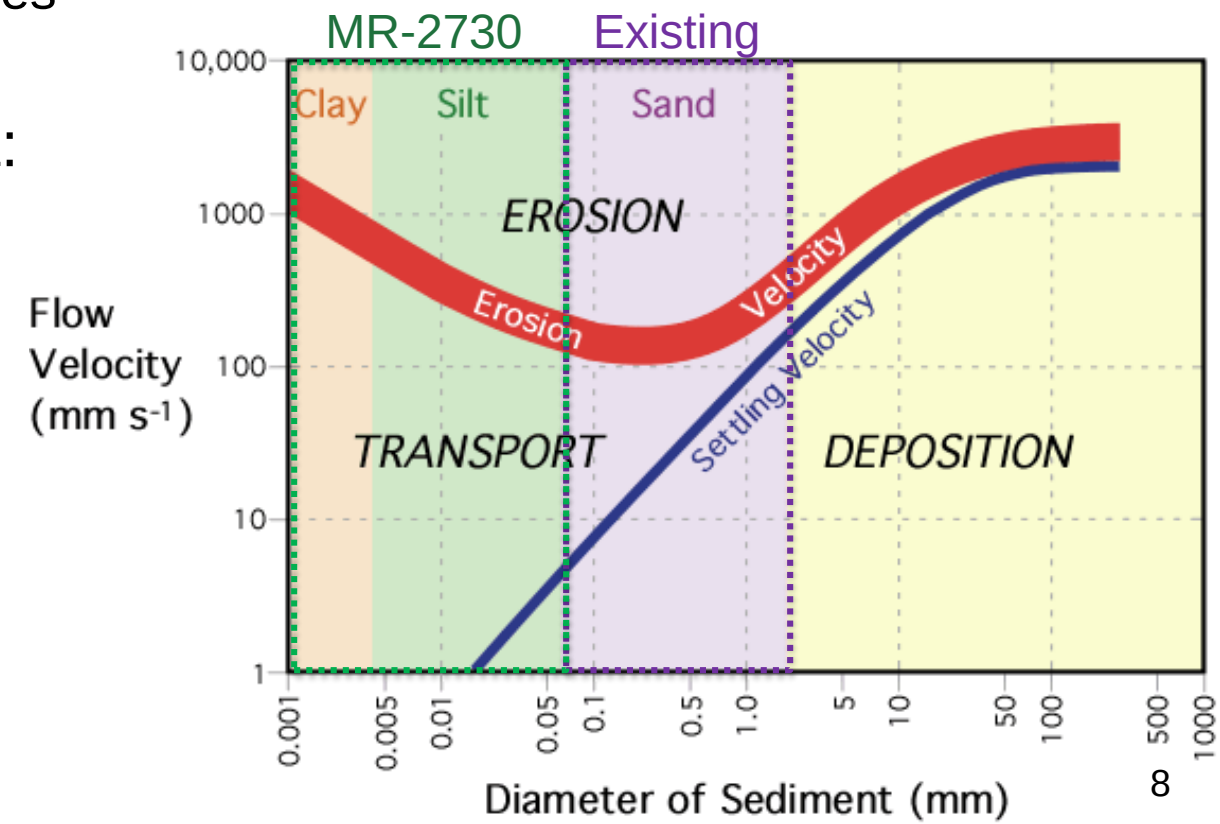
- The goal of this proposed study is to test and characterize munition mobility, behavior, and detection in shallow, muddy environments. Using a shallow estuarine site in the Delaware Bay, this study proposes to:

  - Monitor the mobility and behavior of sensor-integrated surrogate munitions high-accuracy acoustic positioning system
  - Directly observe surrogate munition response to hydrodynamic forcing through instrumented bottom frame time-lapse hydrodynamic data and sonar imagery
  - Monitor site changes and test an AUV-borne magnetometer through repetitive site surveying.

Technical Background

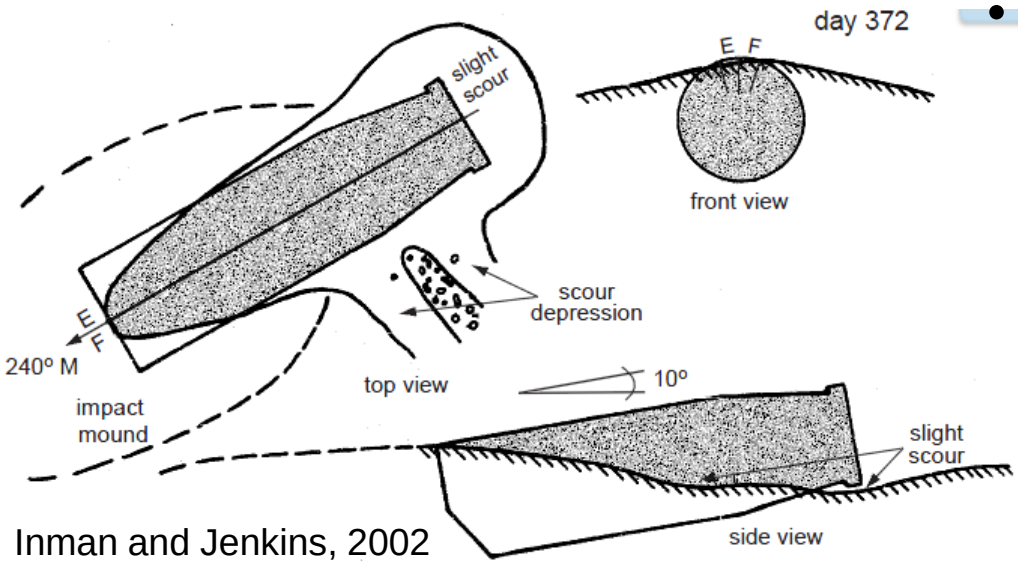
- How are the mobility and burial characteristics of munitions effected in cohesive sediments?
  - ♦ Cohesive sediments conform to different transport regimes than non-cohesive particles

- Cohesive Transport:
  - May occur as flocculate particles (Letter and Mehta, 2011)
  - May even travel as fluidized mobile mud beds (Inman and Jenkins, 2002)



Technical Background

- Mobility and Burial
  - ♦ In fluidized muds, UXO may scour and bury in similar fashion as in non-cohesive sediments
    - ▪ *However, objects may also travel within mobile fluid mud beds during storms (Inman and Jenkins, 2002)*

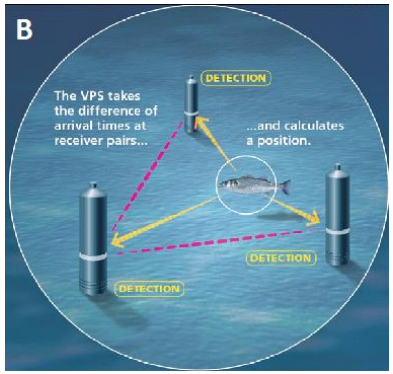


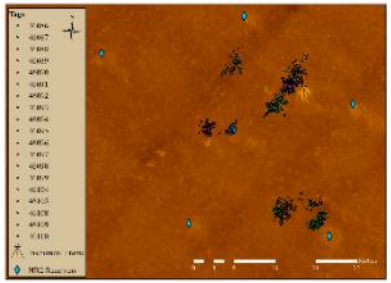
Inman and Jenkins, 2002

- In stiff muds, mines were found to only undergo slight scour and partial burial (Inman and Jenkins, 2002)
  - Impact burial is largest contributor to mine burial in stiff muds, not subsequent hydrodynamics.

Technical Approach

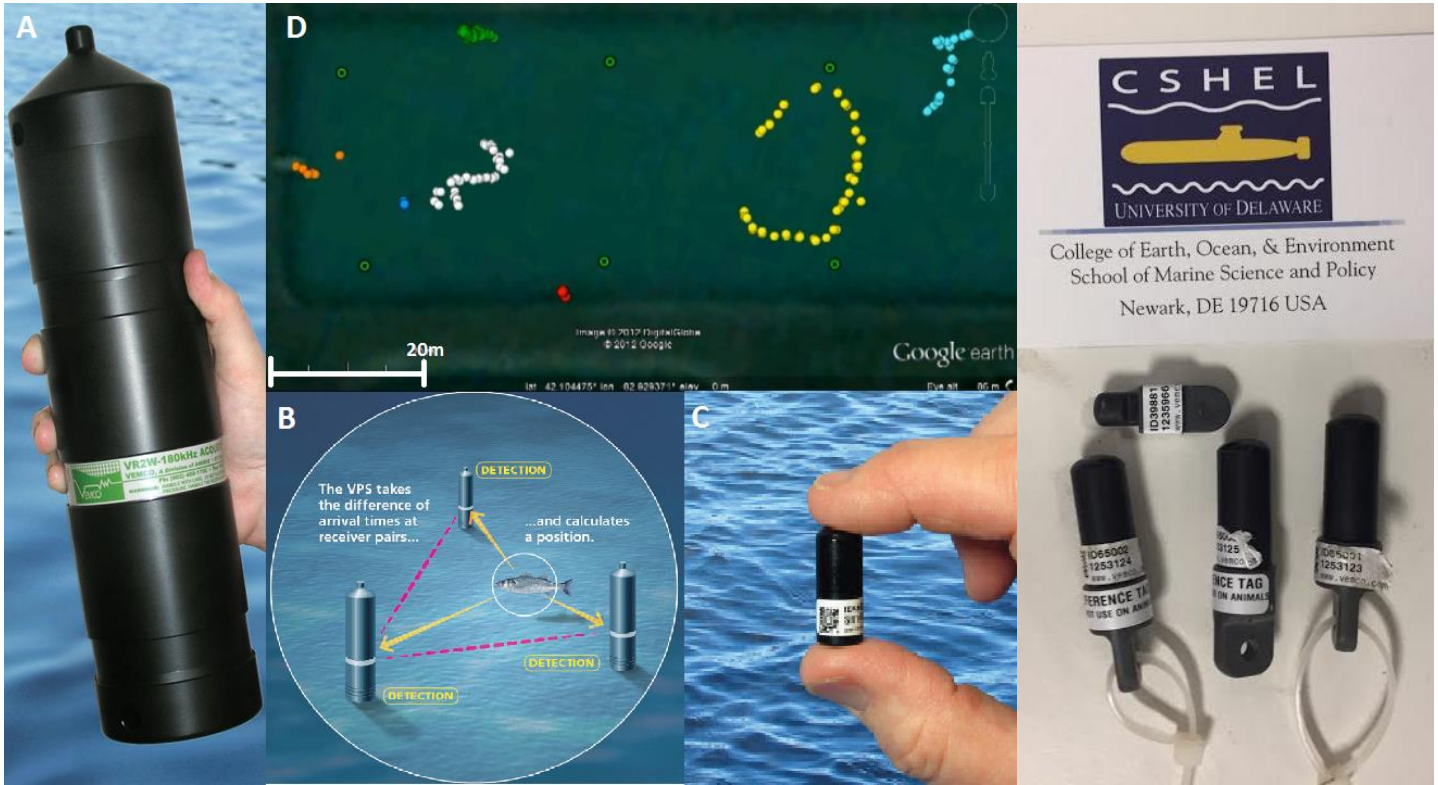
- Task 1: Tracking and Motion Sensor Design
  - ♦ Acoustic tracking technology selection and testing
    - ▪ Vemco Positioning System (VPS)
  - ♦ Surrogate UXO fabrication and instrumentation
- Task 2: Field Implementation
  - ♦ Two deployments: Fall 2017 & Spring 2018
  - ♦ Preliminary data analysis
- Task 3: Advanced Data Analysis and Reporting
  - ♦ Integration of IMU data with VPS tracking data and related to hydrodynamic data
- Task 4: Additional Deployments



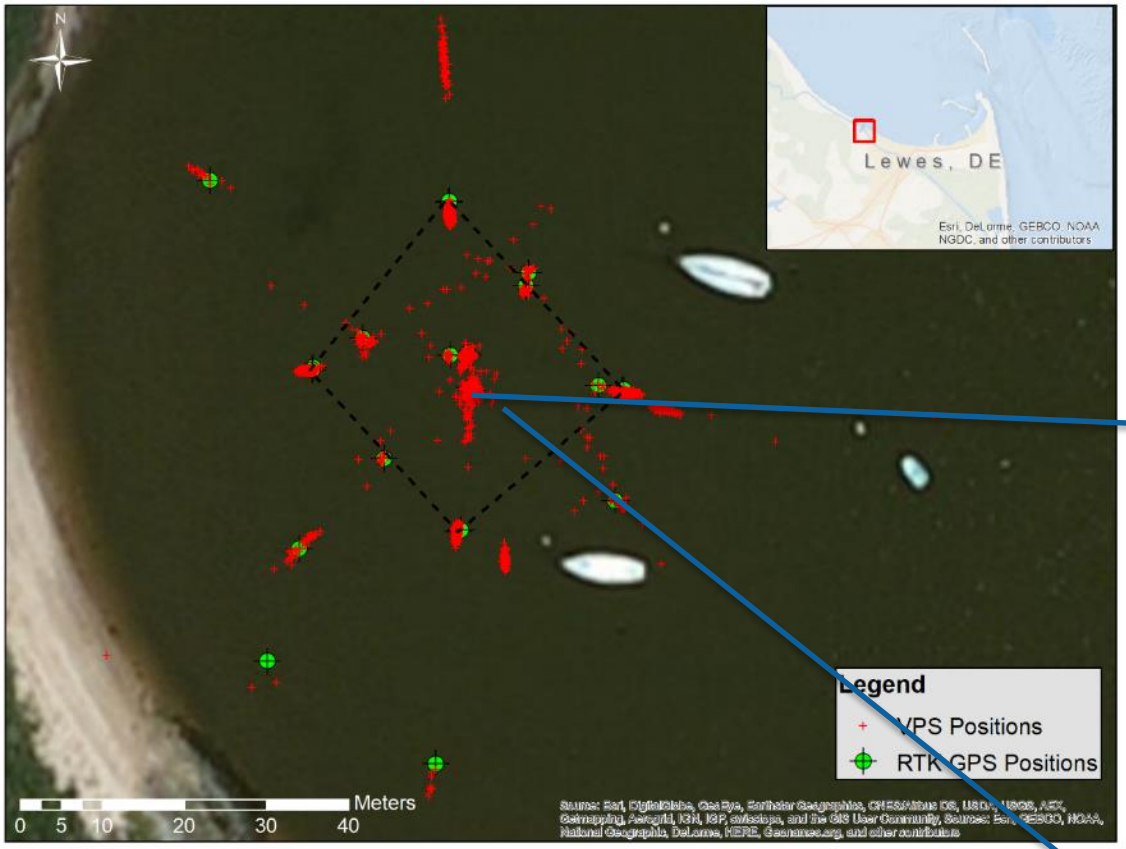


Task 1: Tracking and Motion Sensor Design

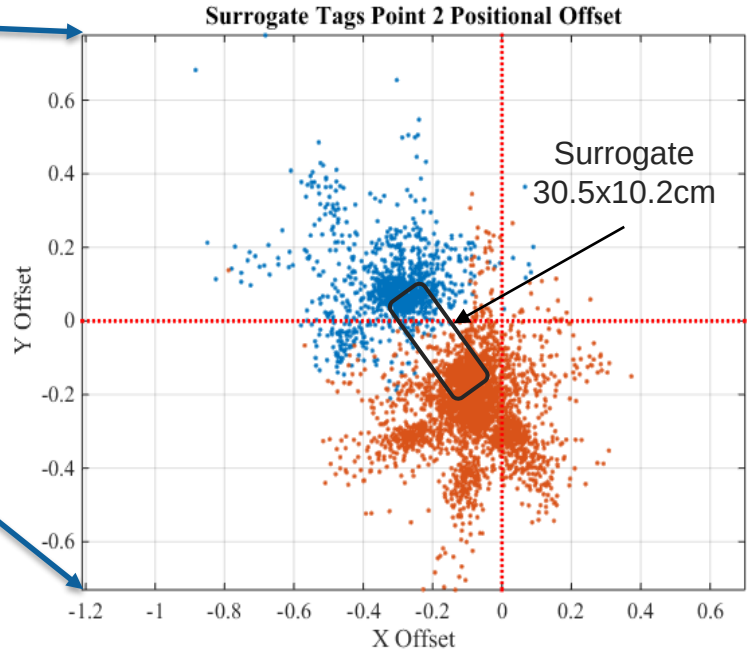
- Vemco Positioning System (VEMCO) Testing
  - Designed to track biology acoustically – small acoustic tags
  - 180 kHz system – positional accuracies down to 10cm
  - Easily deployable and customizable system
- Vemco provides both raw and processed data products



VPS Field Test: Sept. 26-27, 2016

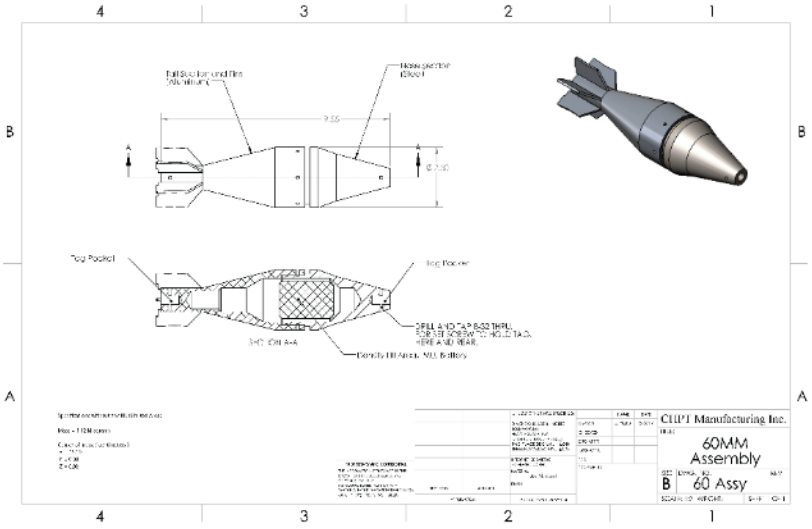


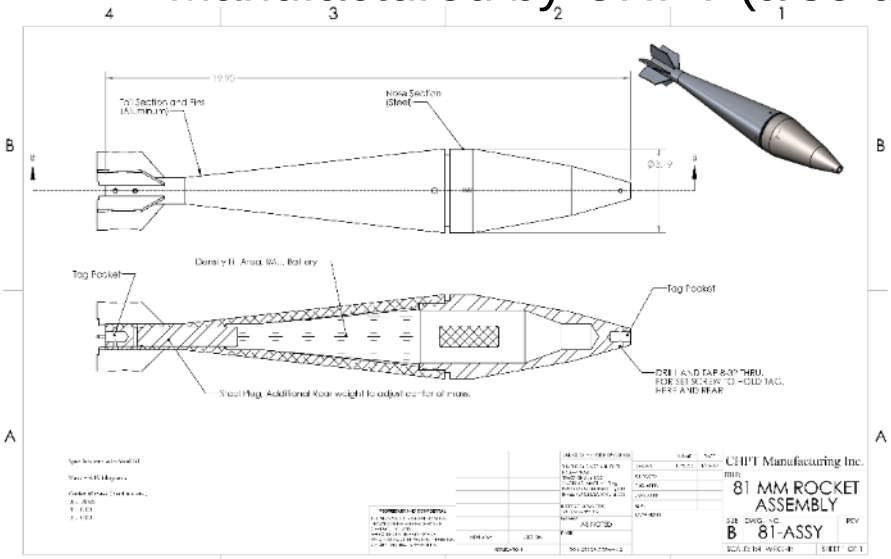
- Surrogate GPS to VPS positional offset < 20cm
  - VEMCO estimated surrogate size at 13” from data alone (surrogate 12” long)

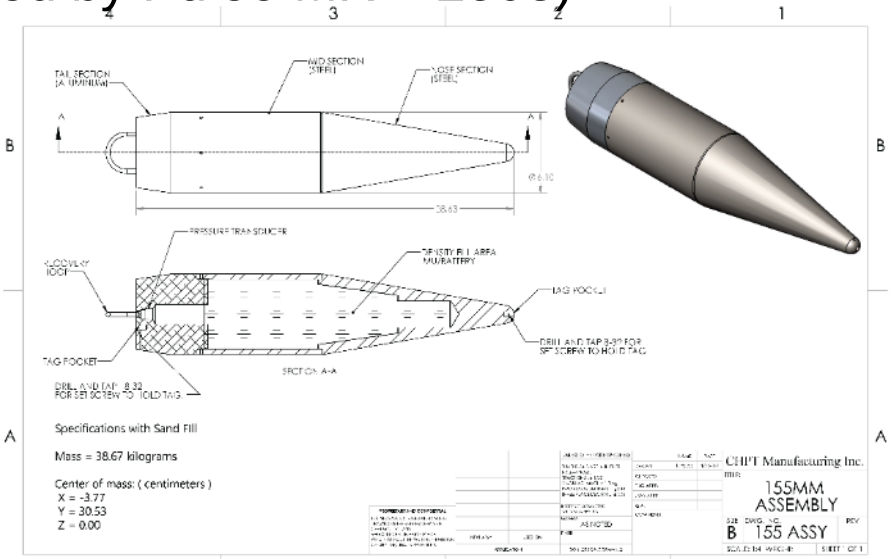


Task 1: Tracking and Motion Sensor Design

- Surrogate Munition Development
  - Instrumented steel surrogates in 155mm artillery, and 81mm and 60mm mortar
    - Equipped with IMU (X-io NGIMU)
    - Fitted with 2 Vemco acoustic tags for tracking
    - 155mm pressure sensor
  - Manufactured by CHPT (also used by Puleo MR – 2503)

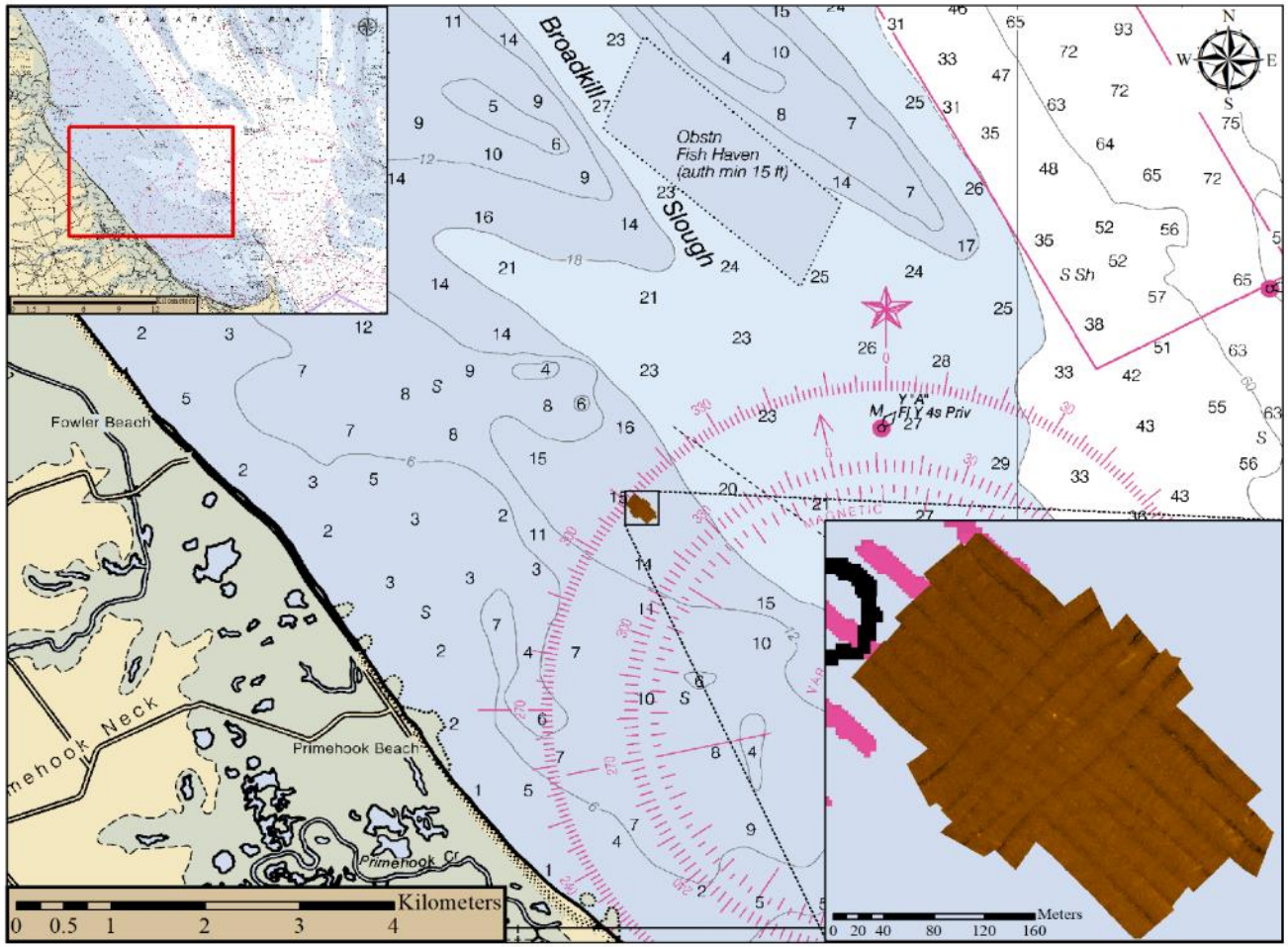






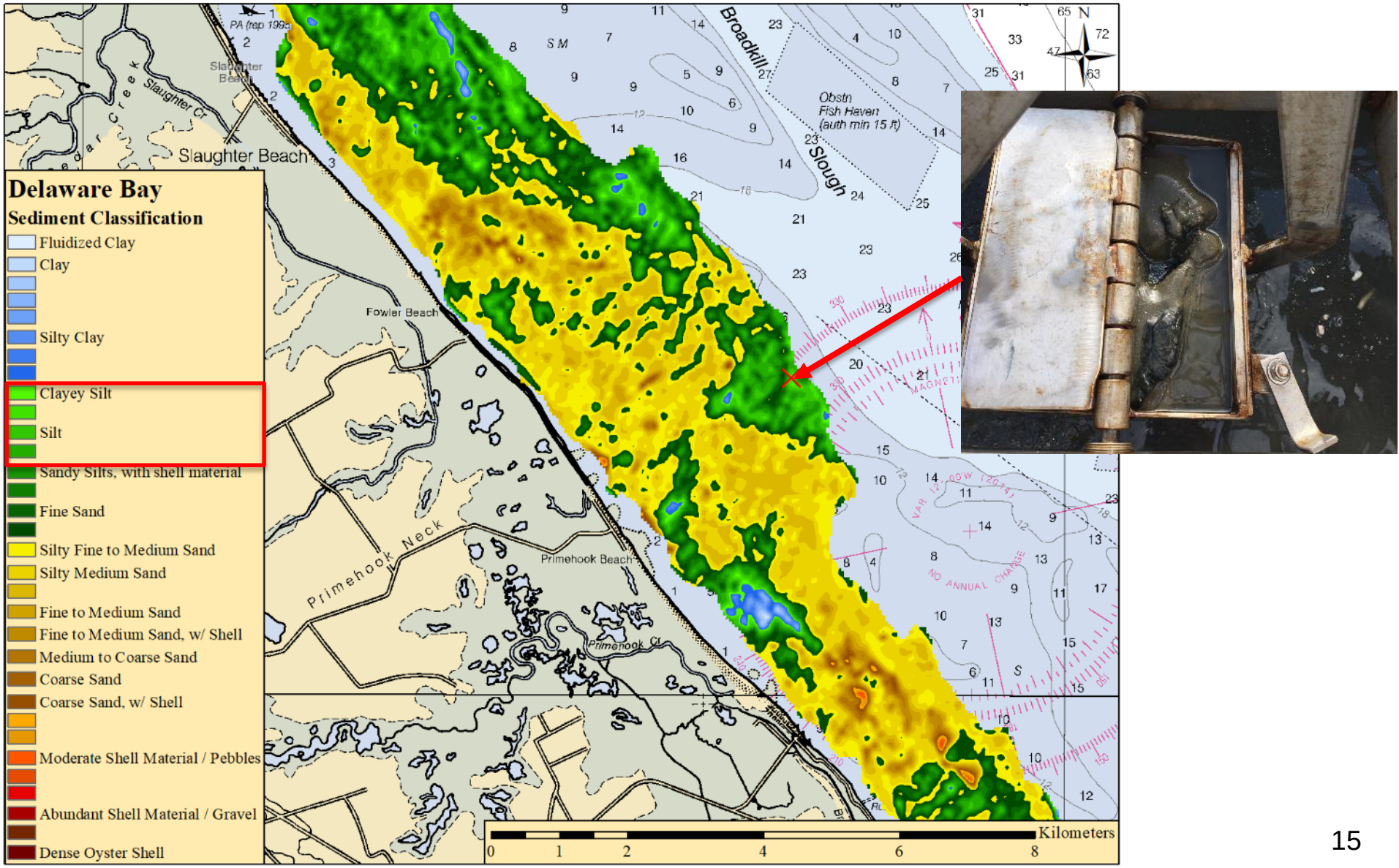
Task 2: Field Implementation

- VPS Grid and Surrogate Tracking
  - Deployed in pre-determined shallow, muddy site in DE, Bay



- Complete bathymetric, magnetometer, sub-bottom, and side-scan surveys
- Sediment grab samples and shallow cores
- In-situ hydrodynamic sensors

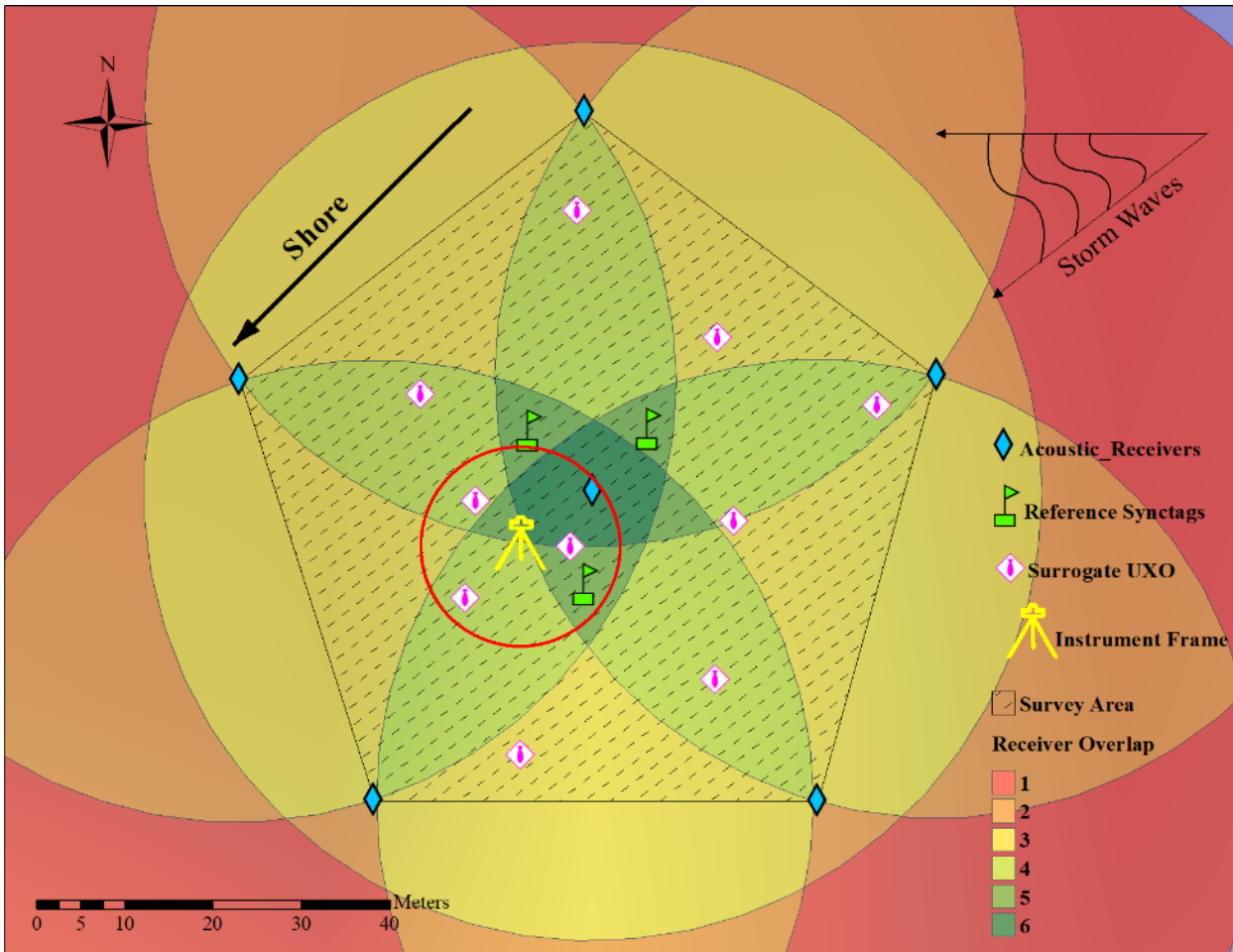
Task 2: Field Implementation



Task 2: Field Implementation

- VPS Grid and Surrogate Tracking
  - ♦ 6 receiver system in pentagonal grid allows for maximum overlap in shallow water (suggested by Vemco)

- 10 instrumented surrogates deployed and monitored by VPS tracking
  - Capable of multiple detections per minute



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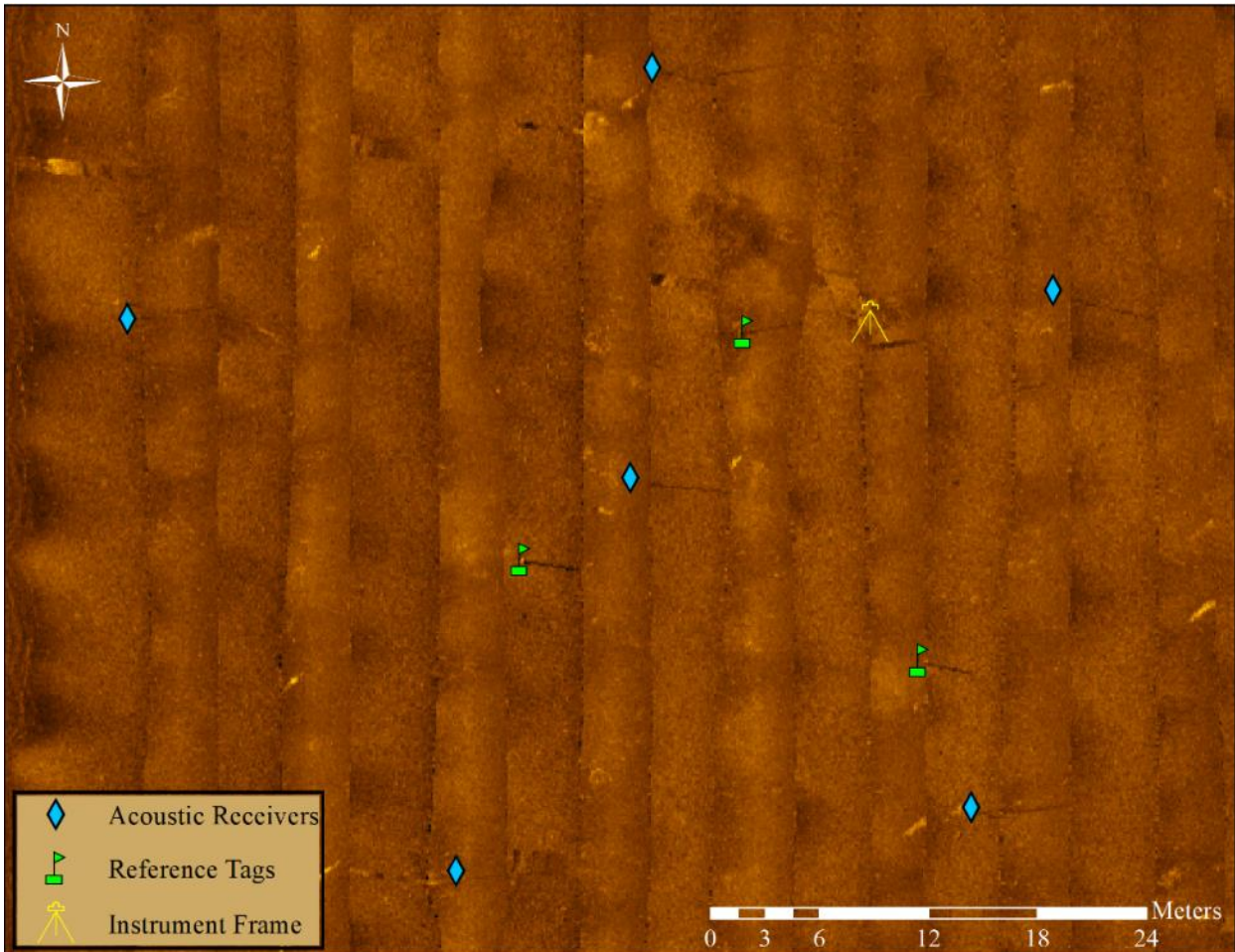
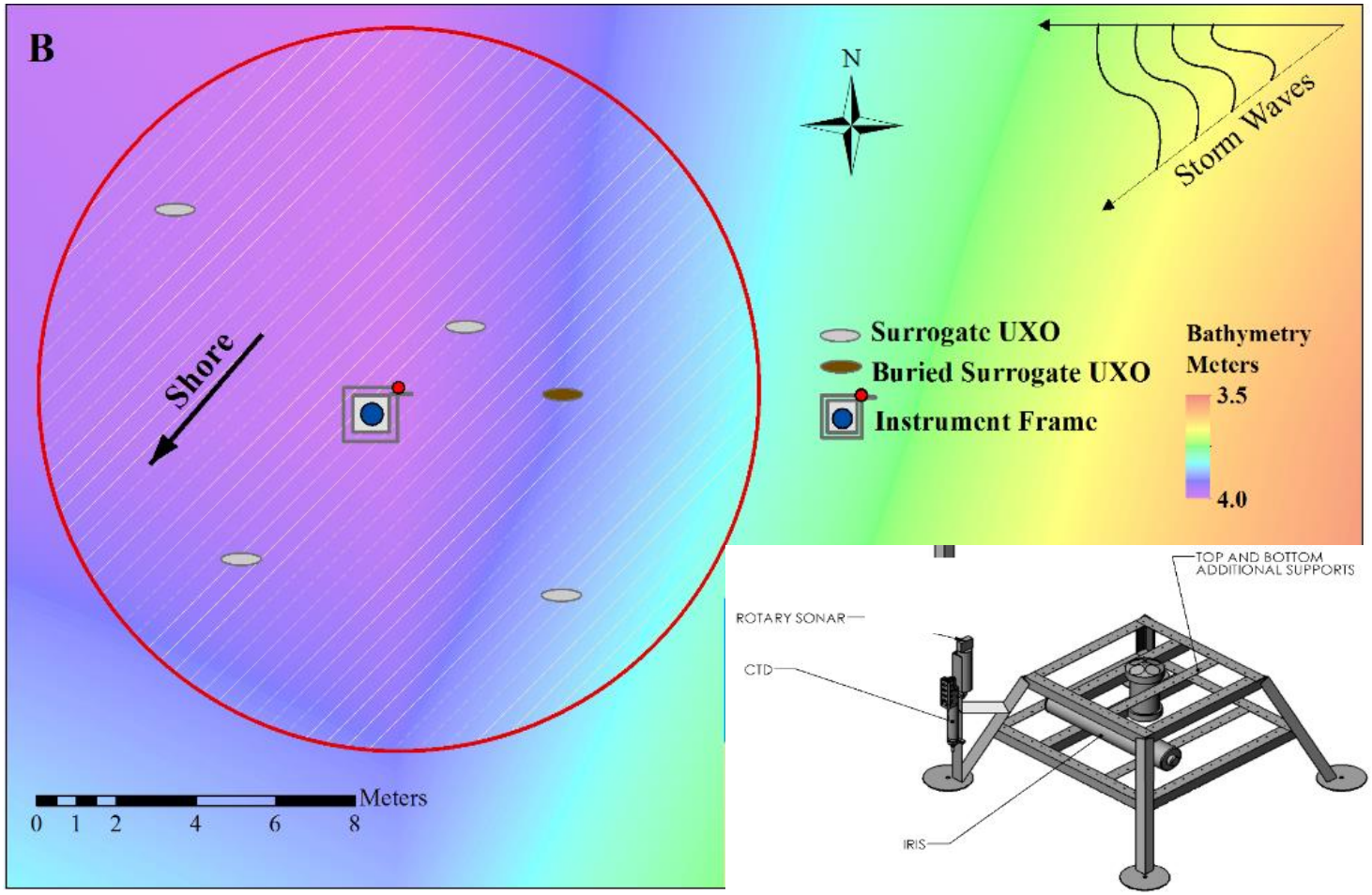


Task 2: Field Implementation

- Instrument Frame
  - ADCP, PC-ADCP, CTD and Rotary Sonar collect in-situ hydro-dynamics and time-lapse imagery of seabed morphology and objects



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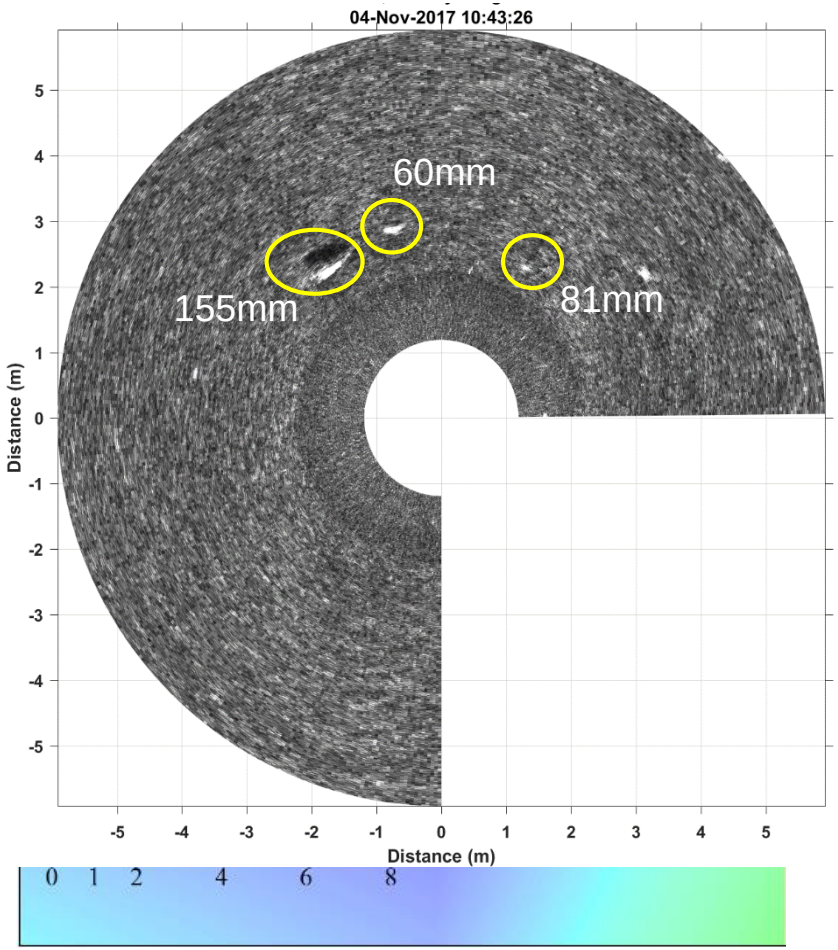
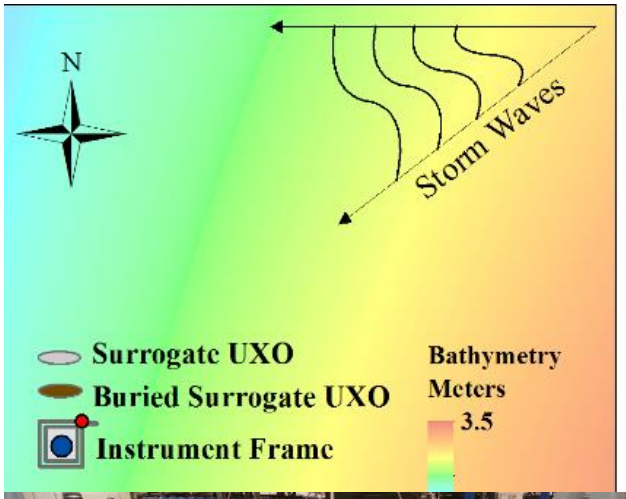
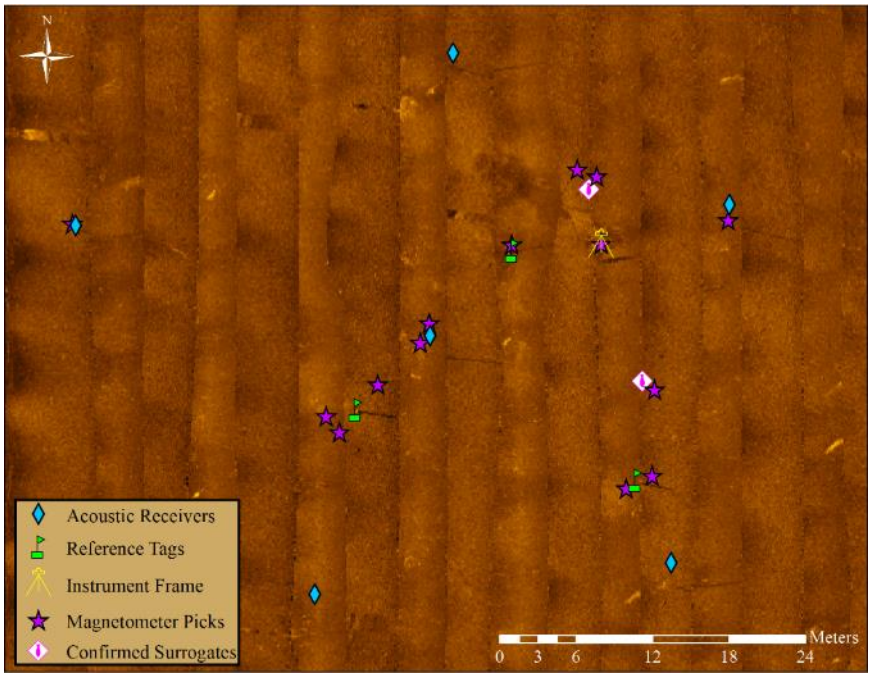


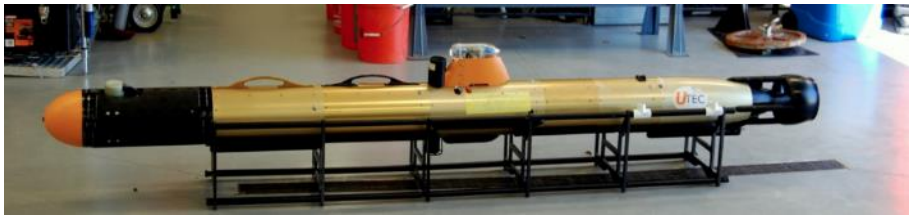


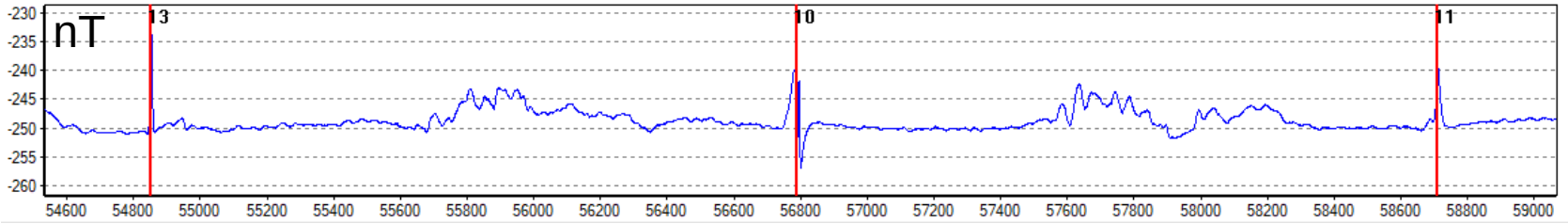
Task 2: Field Implementation

- Autonomous Underwater Vehicle 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



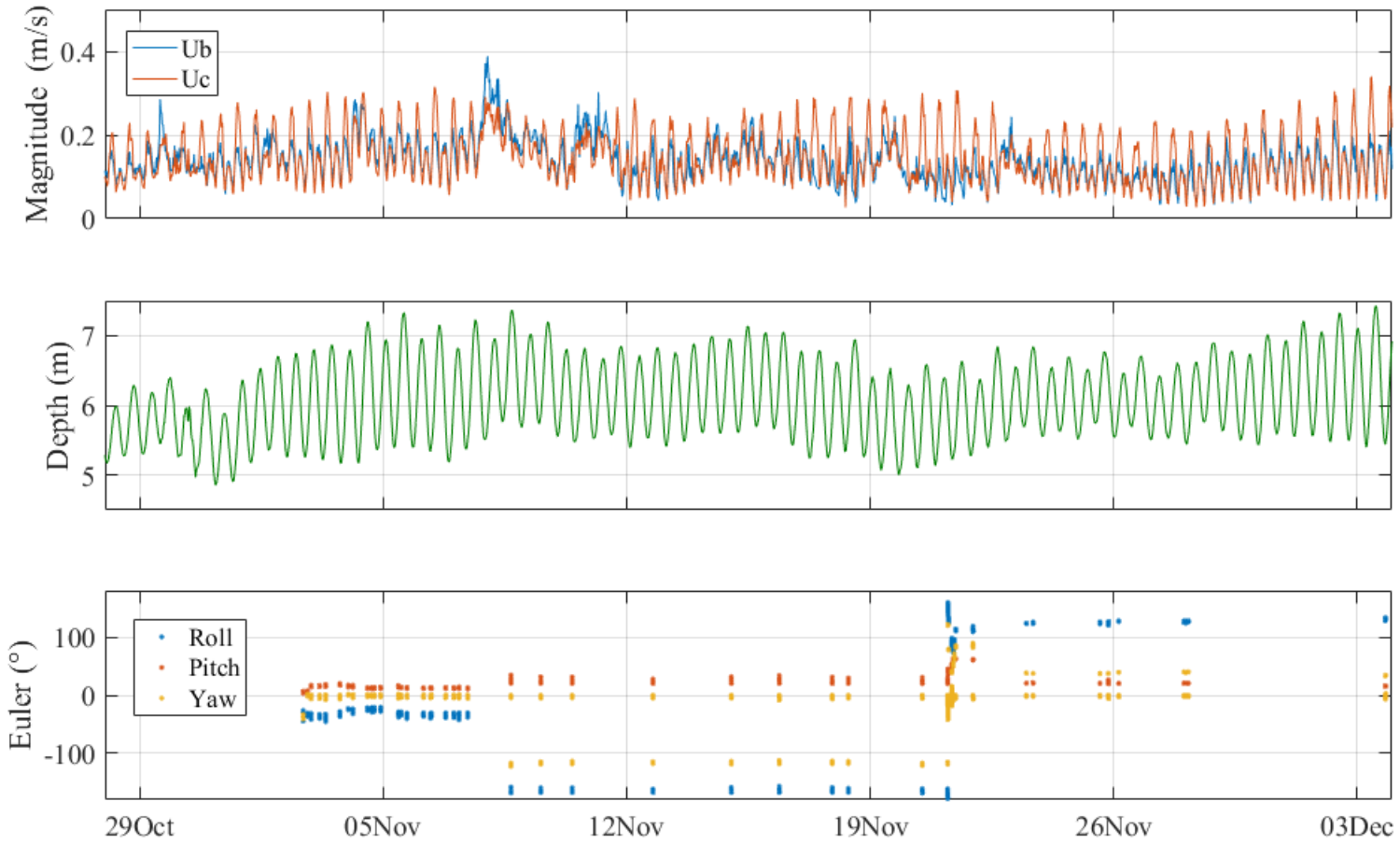


Field Deployment Summary Slide

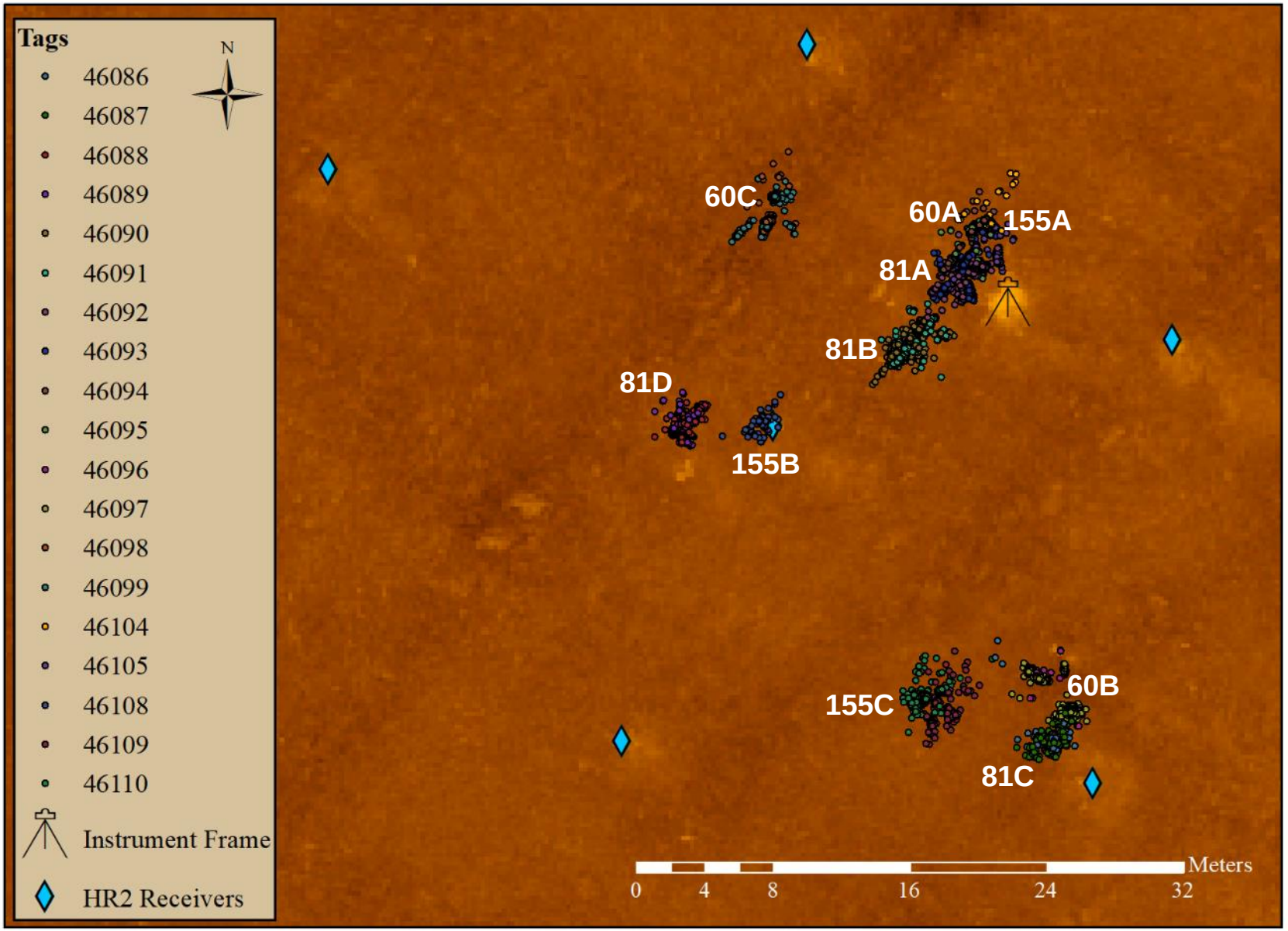
- Fall 2017 – Nov. 02 - Dec. 4 (32 Days)
  - Activities
    - 4 Surveys (10/20, 11/02, 11/09, 12/02) – side-scan, bathymetry, sub-bottom, magnetometry, and/or sediment sampling
  - Instruments
    - Vemco Positioning System (VPS); ADCP (waves/currents), PC-ADCP (bottom currents), CTD, and rotary sonar
  - Surrogates – equipped with IMU's and 2 acoustic tags
    - 3 – 60mm mortars
    - 4 – 81mm mortars
    - 3 – 155mm artillery
  - Highlights
    - No storm events
    - Episodic 'rocking' recorded in all 60mm and one 81mm mortar

Fall 2017 Field Deployment

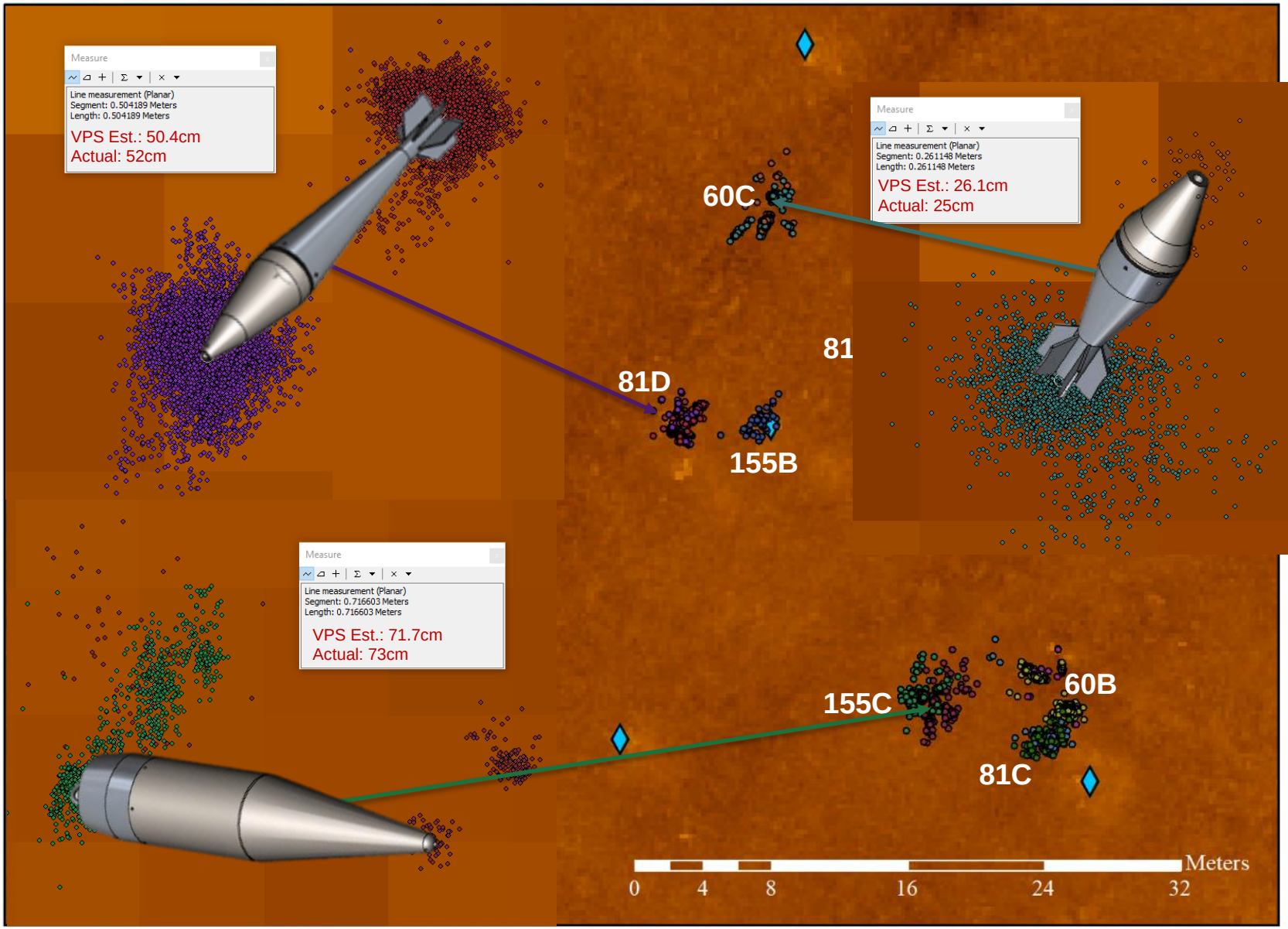
- No storm events recorded
  - ♦ Moments of minimal “rocking” recorded in IMU of 60mm
    - ▪ Not associated with strongest wave orbital velocity



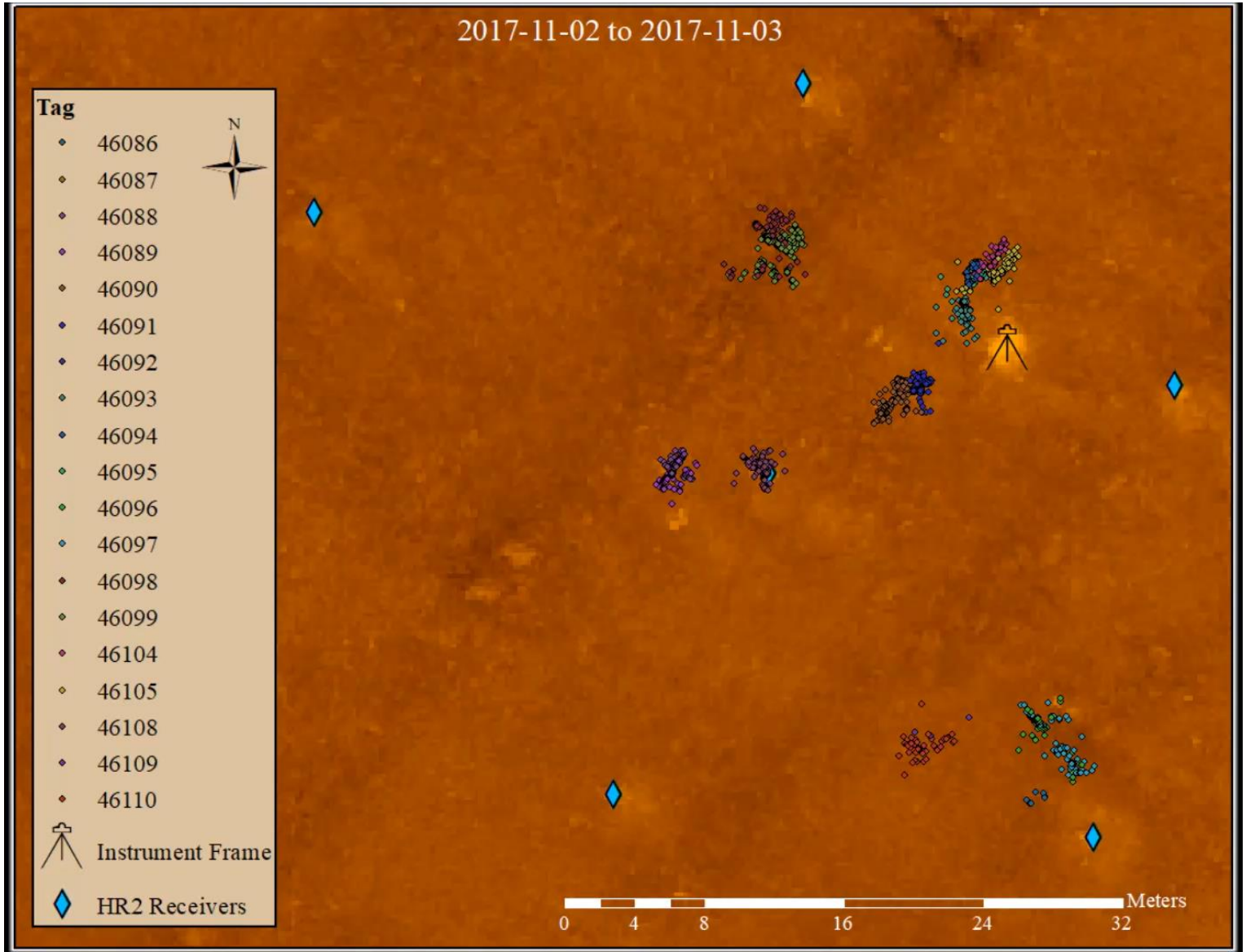
Fall 2017 Field Deployment



Fall 2017 Field Deployment



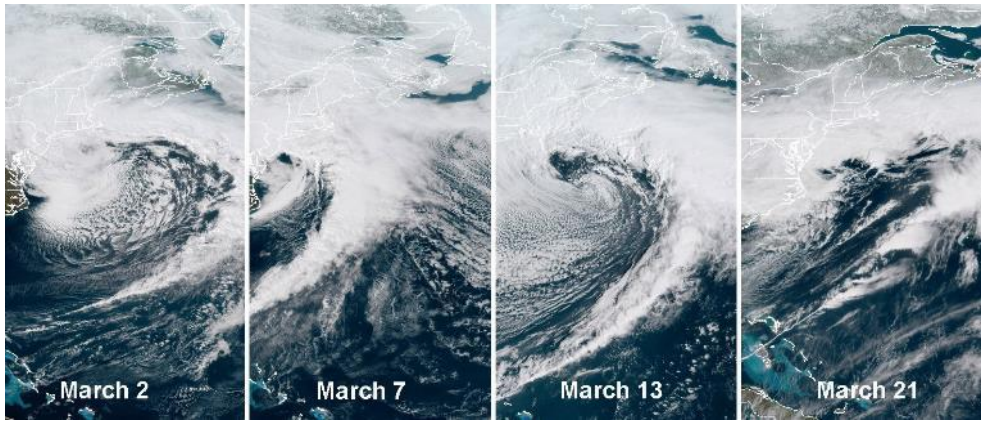
Fall 2017 Animation



Field Deployment Summary Slide

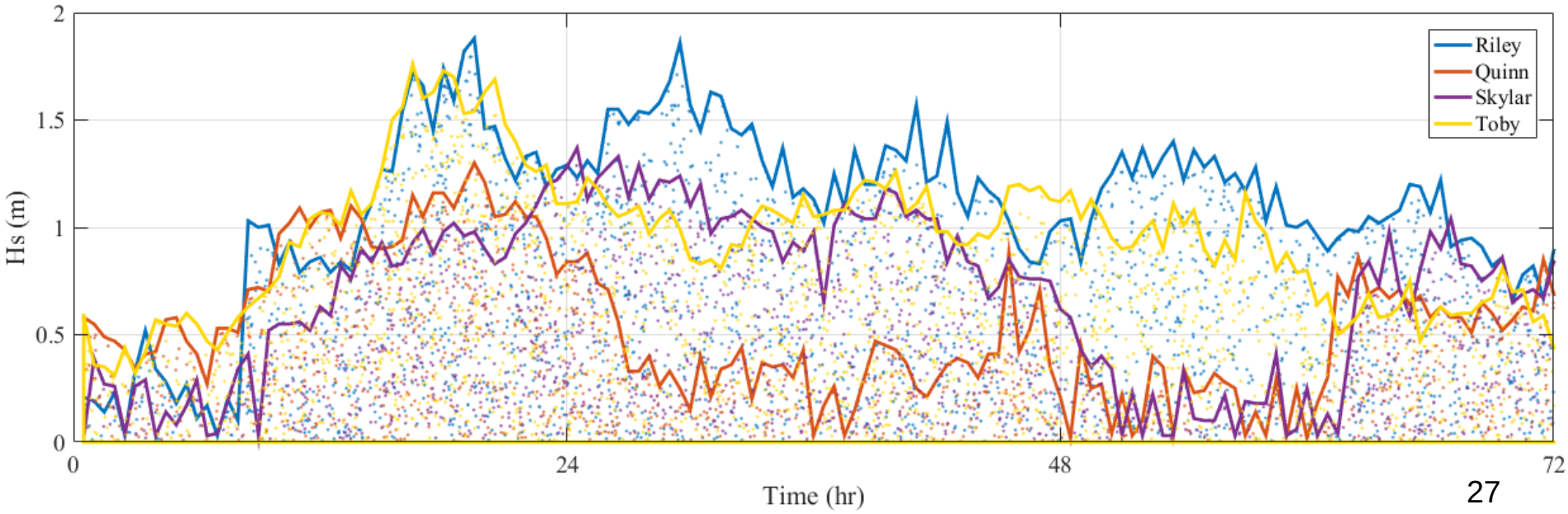
- Spring 2018 – Feb. 09 - Apr. 11 (61 Days)
  - Activities
    - 3 Surveys (03/06, 04/10, 04/12) – side-scan, bathymetry, sub-bottom, magnetometry, and/or sediment sampling
  - Instruments
    - Vemco Positioning System (VPS); ADCP (waves/currents), PC-ADCP (bottom currents), CTD, and rotary sonar
  - Surrogates – equipped with IMU's and 2 acoustic tags
    - 3 – 60mm mortars
    - 4 – 81mm mortars
    - 3 – 155mm artillery (equipped with pressure sensors)
  - Highlights
    - 4 nor'easter events

Nor’easters

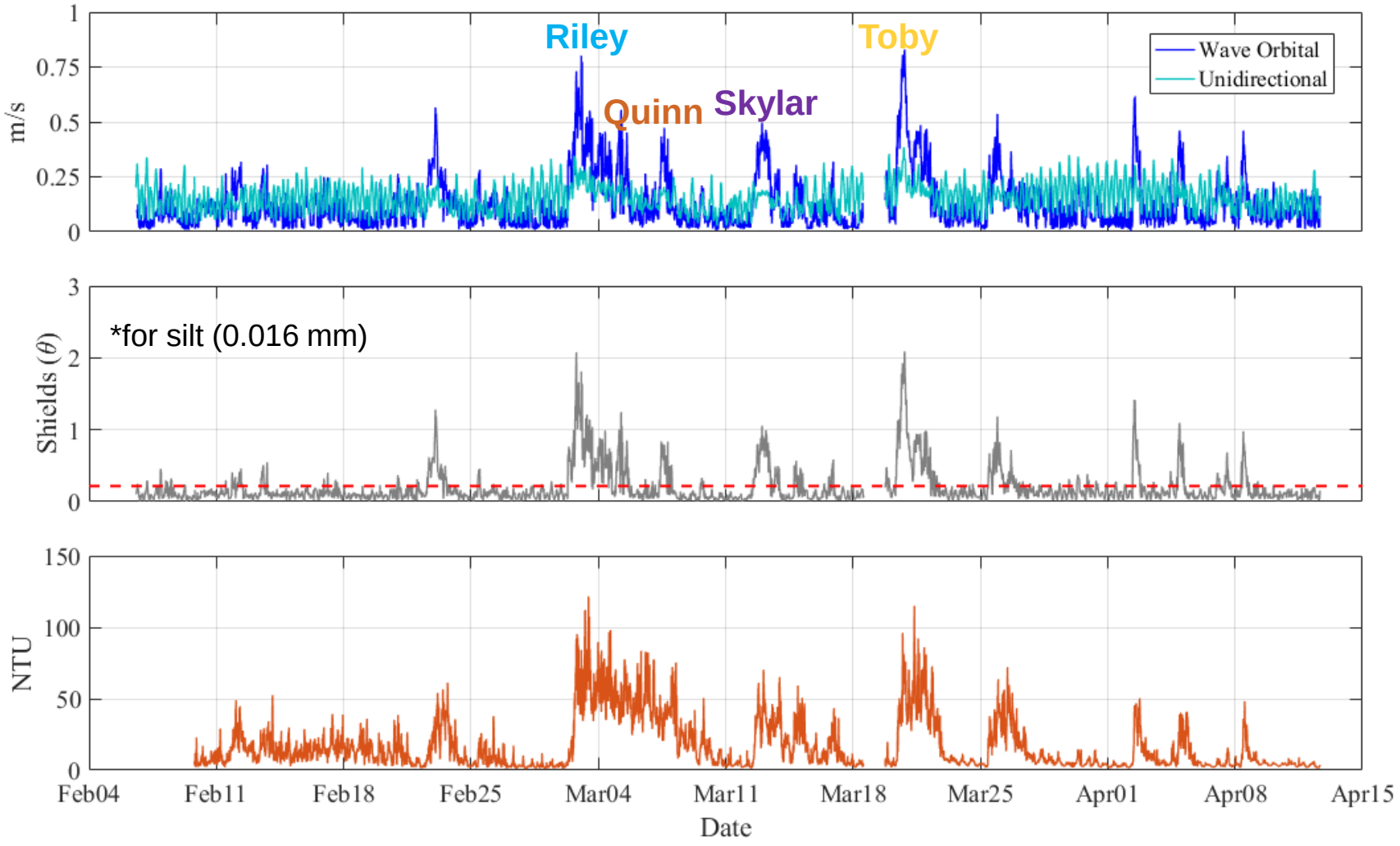


Riley Quinn Skylar Toby

	Riley	Quinn	Skylar	Toby
Duration (hr)	50	10	17	35
dHs/dt (m/hr)	0.56	0.54	0.46	0.46
Hs (m)	1.88	1.3	1.37	1.76
Dp (º)	336	334	41	48
Ub (m/s)	0.8	0.47	0.5	0.83
Uc (m/s)	0.35	0.25	0.23	0.39

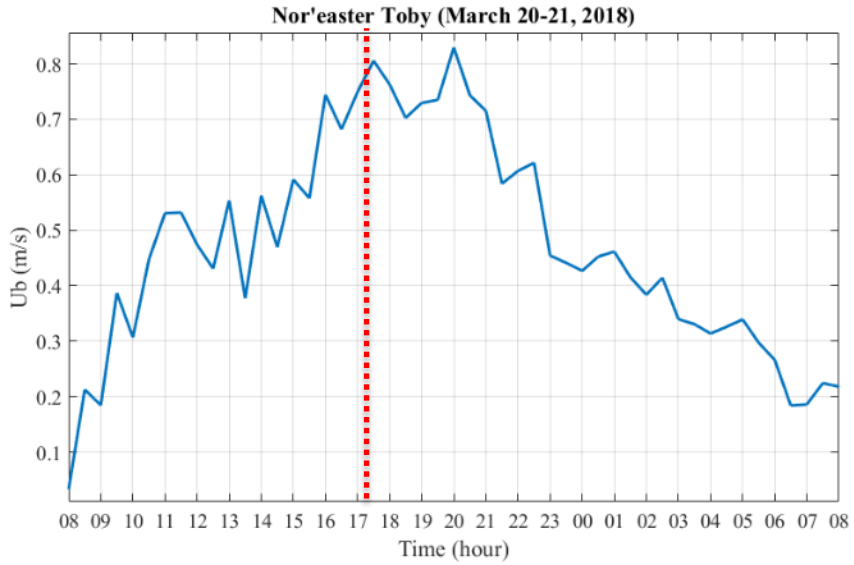


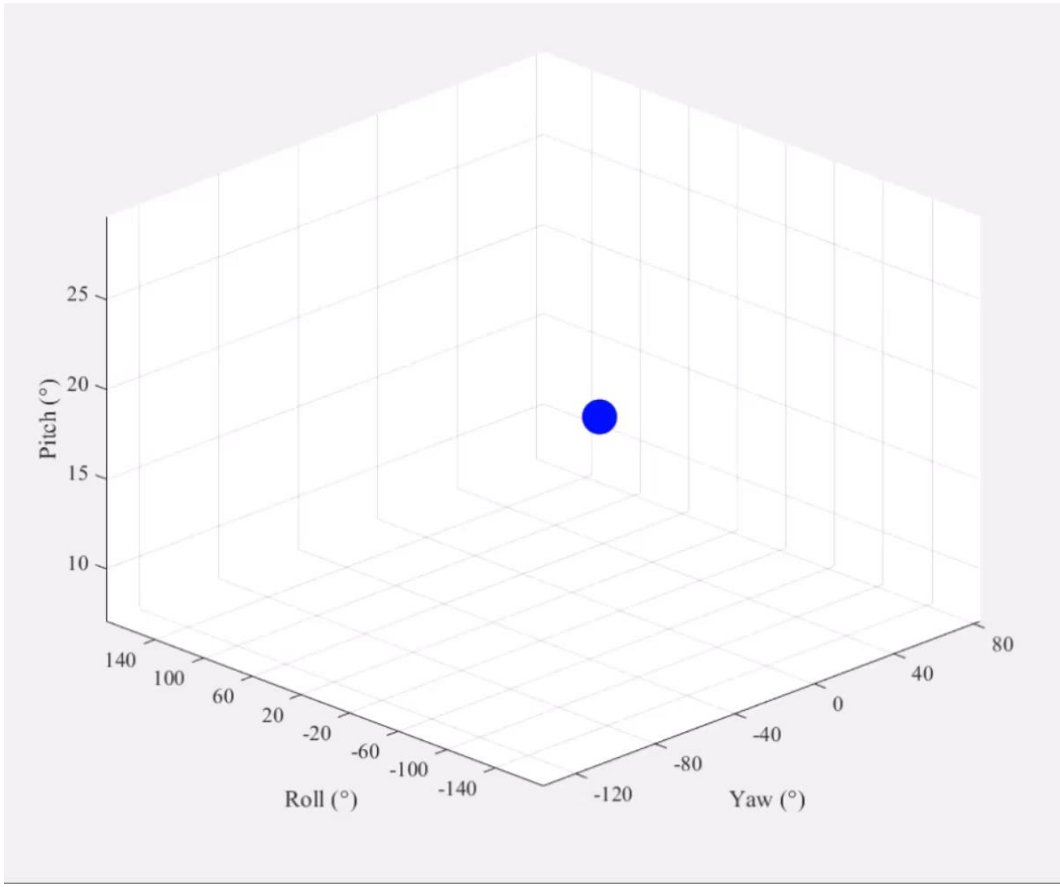
Spring 2018 Field Deployment



60mm Mortar (IMU animation)

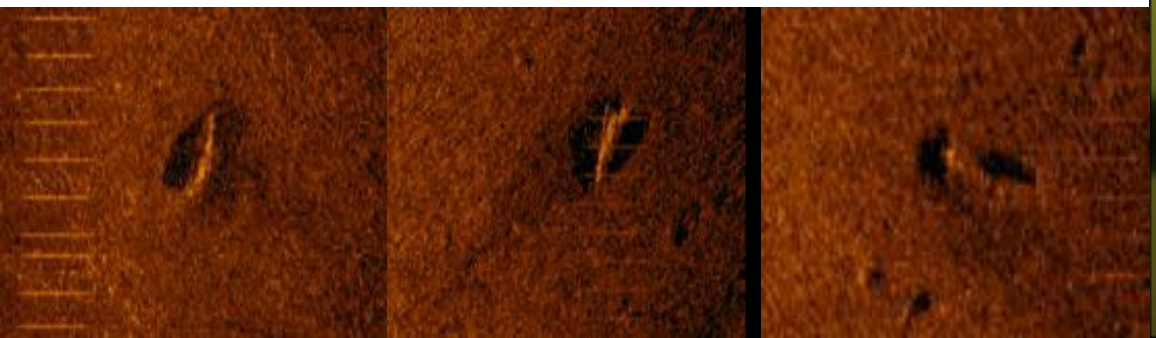
- Nor'easter Toby – March 20, 2018
  - Episodic rolling between 1700 and 2100 UTC



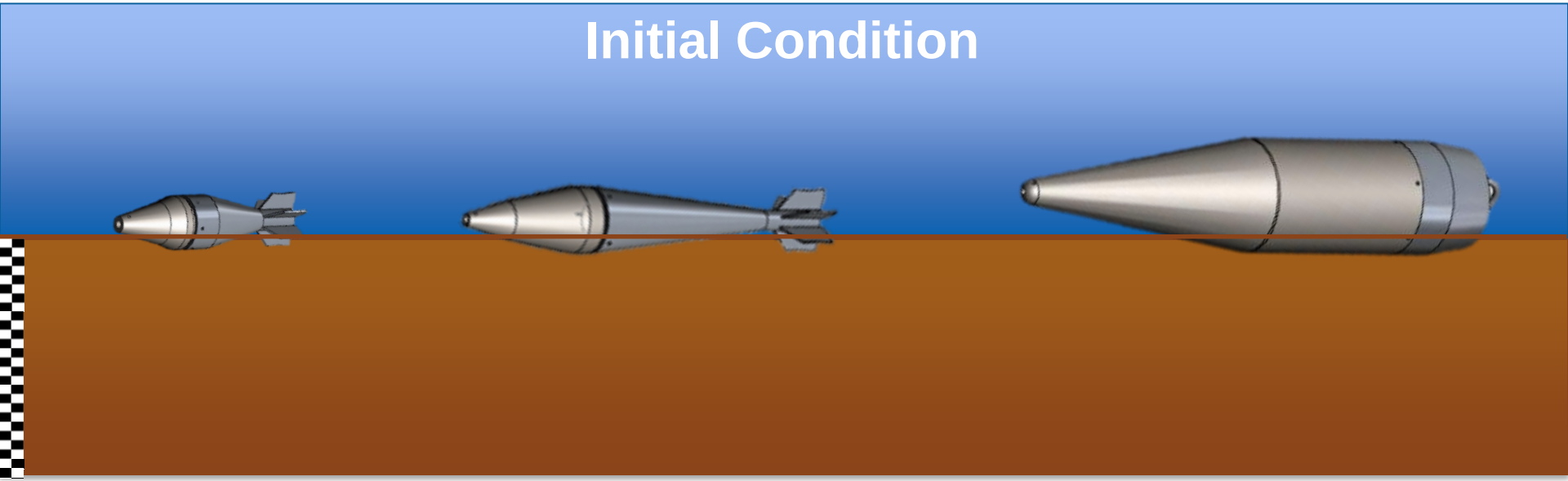


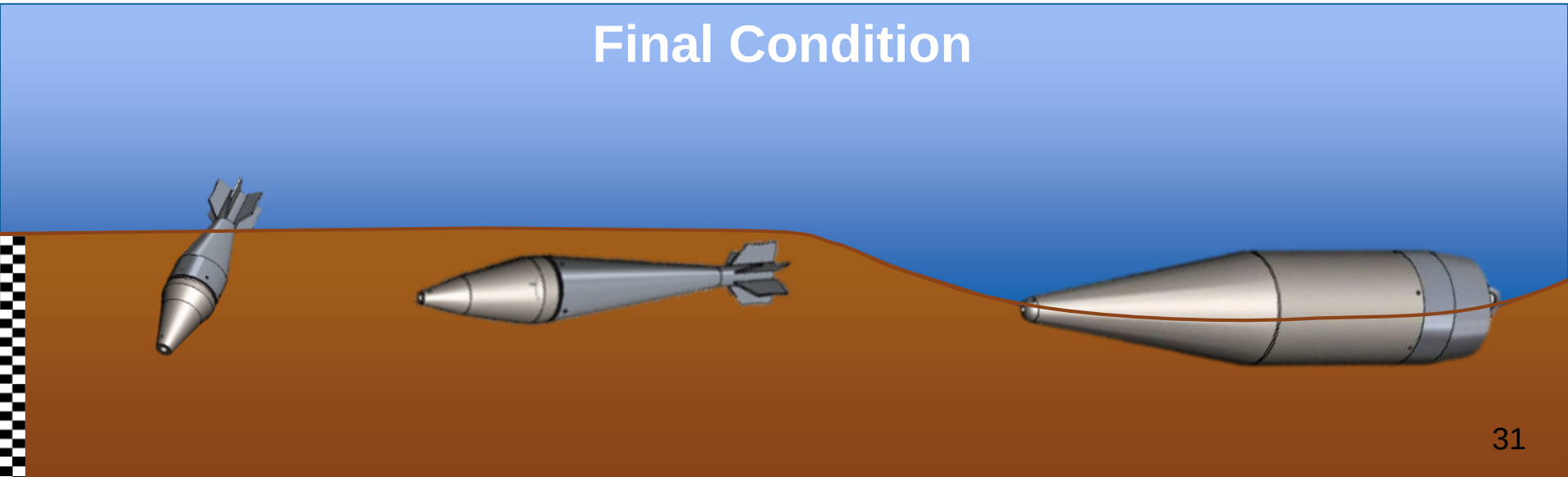
Scour / Burial

- Diver and remote observations
  - ♦ 155mm sitting exposed in large scour pits
    - Side-scan sonar supports this observation
  - ♦ 81mm mortars partially or fully buried
    - Two 81mm(B, C) noted as buried 1” below surface
    - One 81mm(D) buried with only 2 fin blades exposed
    - One 81mm(A) observed by ROV prior to Toby– partially buried
  - ♦ 60mm partially buried
    - In 2 cases (60mm B,C), oriented nearly vertical with only fins exposed



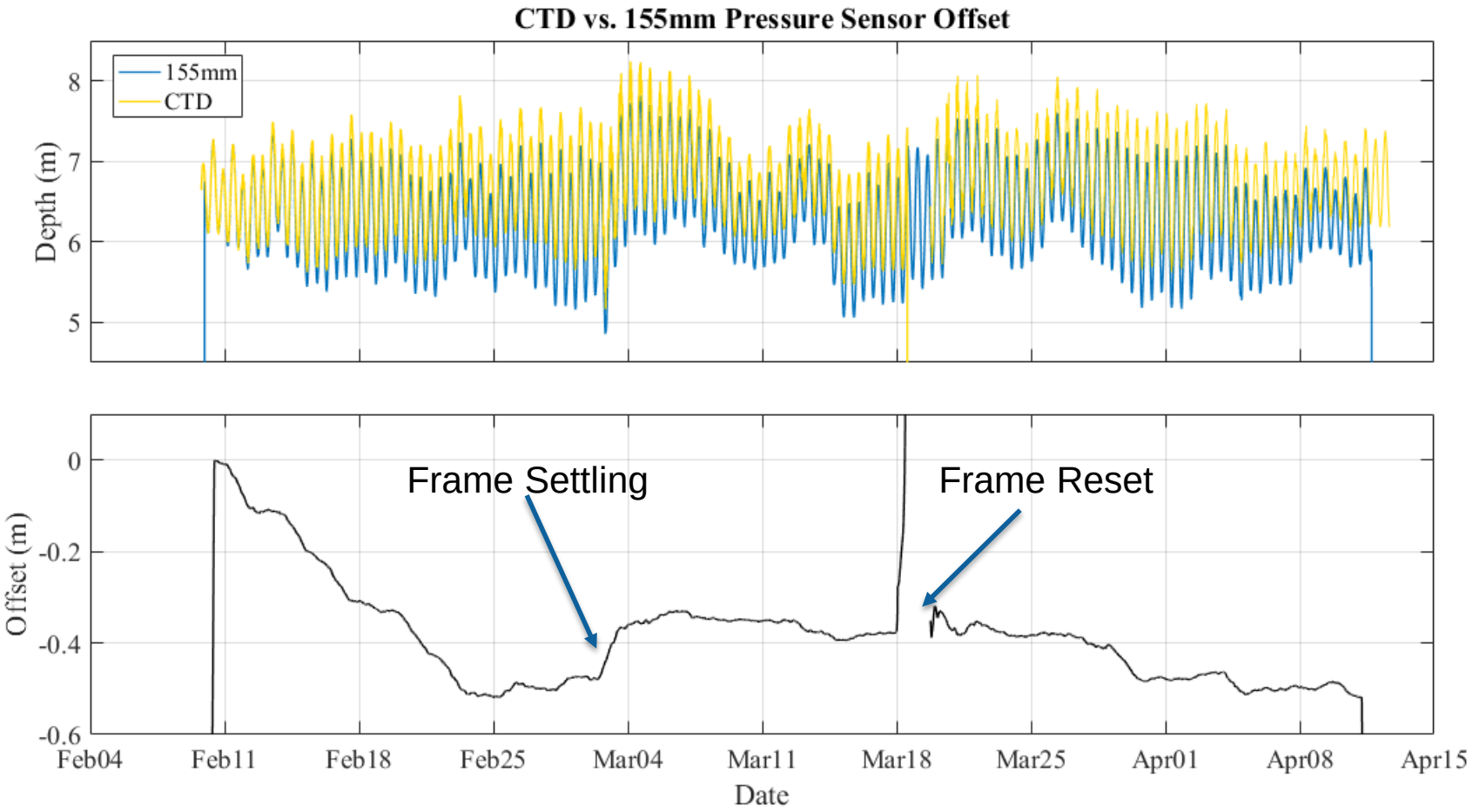
Diver Observations





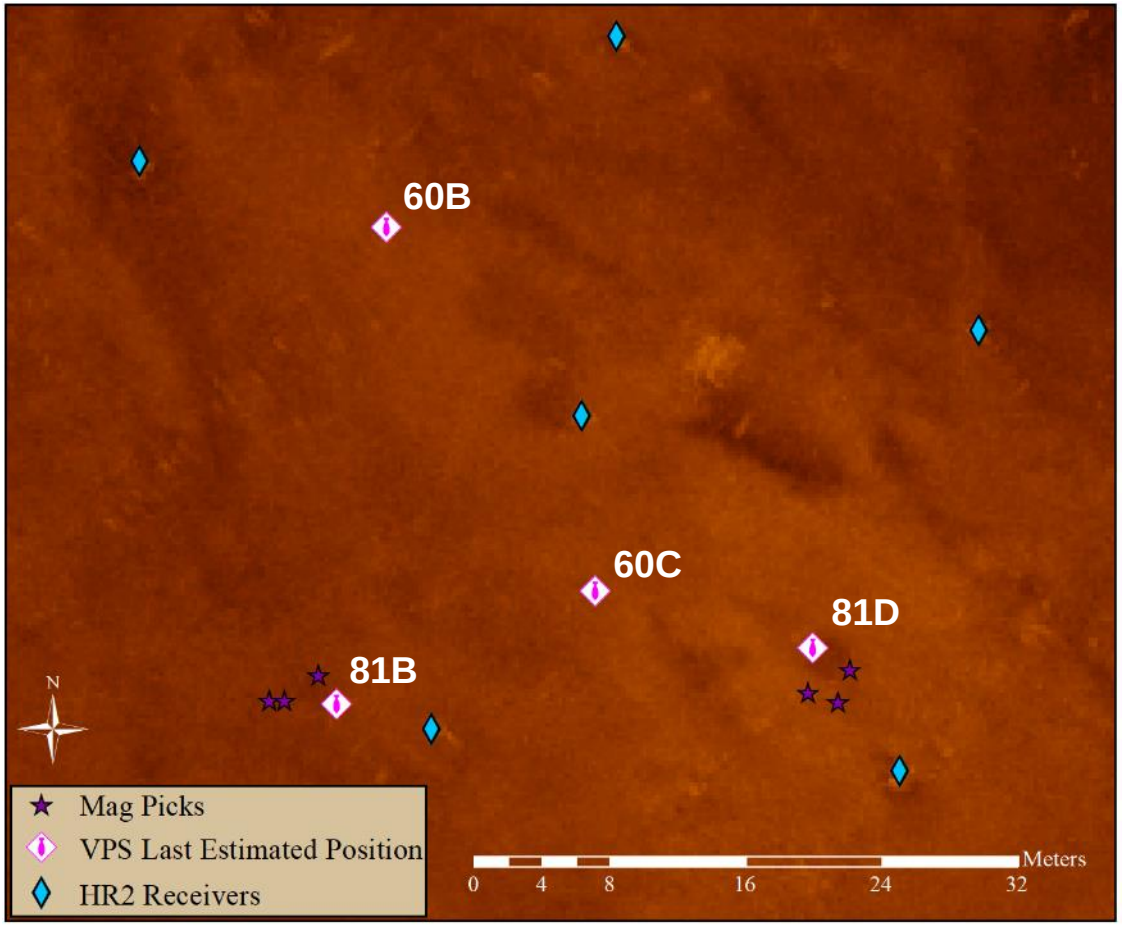
Scour / Burial

- Offset in pressure between CTD and 155mm supports scour observations
  - Offset suggests burial in excess of surrogate diameter – why?

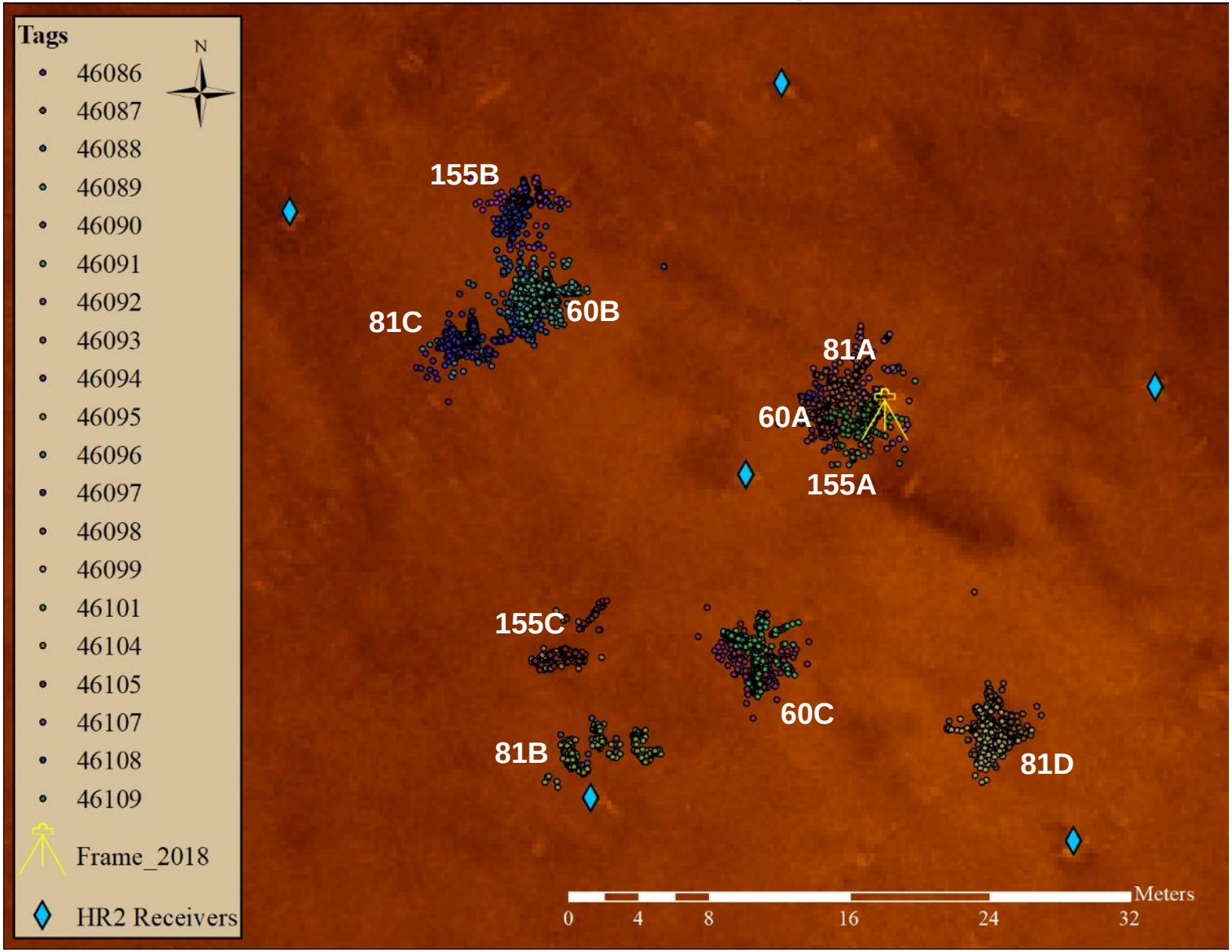


Unrecovered Surrogate Search

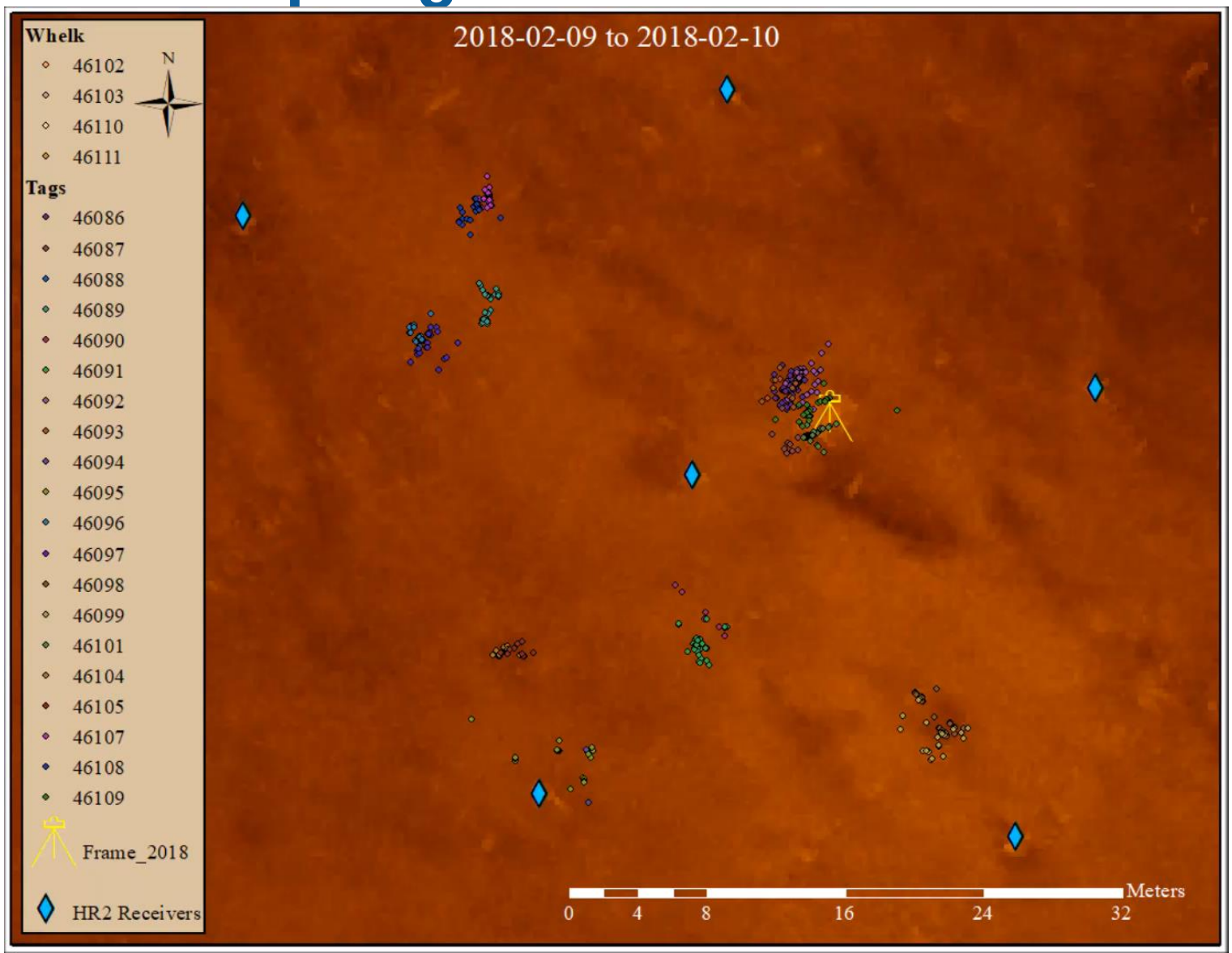
- Only 6 of 10 surrogates were located during initial recovery on Apr. 11, 2018
  - VPS data sent to Vemco to obtain “last known position estimates” for remaining surrogates
  - Magnetometer survey conducted Apr. 12, 2018
    - Magnetic picks identified in near VPS estimates
  - All four surrogates successfully recovered (Apr. 26 & May 7, 2018)
    - Mostly to completely buried



2018 VPS Preliminary Results



Spring 2018 Animation

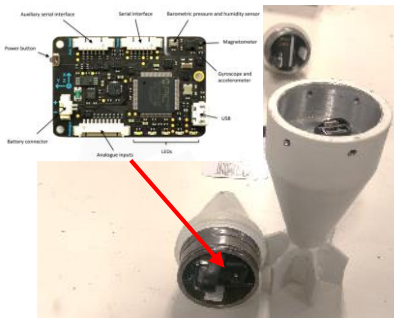


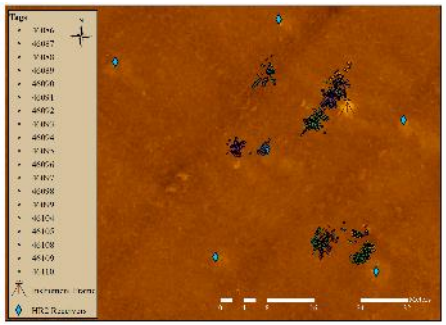
Research Questions Moving Forward

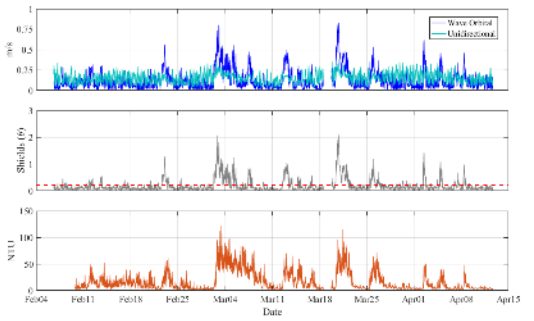
- What is the primary characteristic / feature predictive of scour/burial/mobility in cohesive sediments?
  - Most movement recorded in the most dense, but smallest surrogates (60mm)
  - No movement recorded in the least dense, but largest surrogates (155mm)
- How do the field observations relate to the Friedrichs et al. 2016 munition threshold for motion?
  - Developed for non-cohesive sediment
- How do the field observations relate to Inman and Jenkins (2002) mine burial research?

Task 3 Moving Forward

- Continuation of VPS data processing / analysis
  - ♦ Filtering, refinement, statistics, etc.
- Continuation of IMU data processing / analysis
- Sediment sample processing / analysis
  - ♦ Size, classification, shear vane analysis
- Integration of IMU data with VPS tracking data and related to hydrodynamic data
- Data preparation / transfer for distribution
- Reporting / publishing

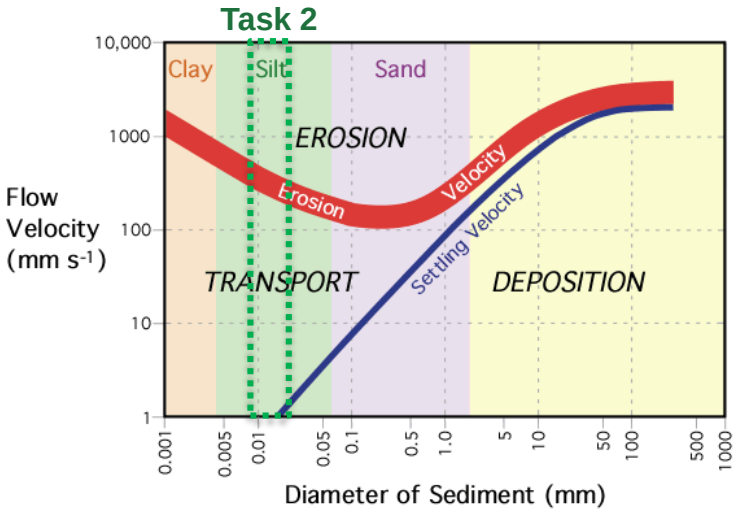


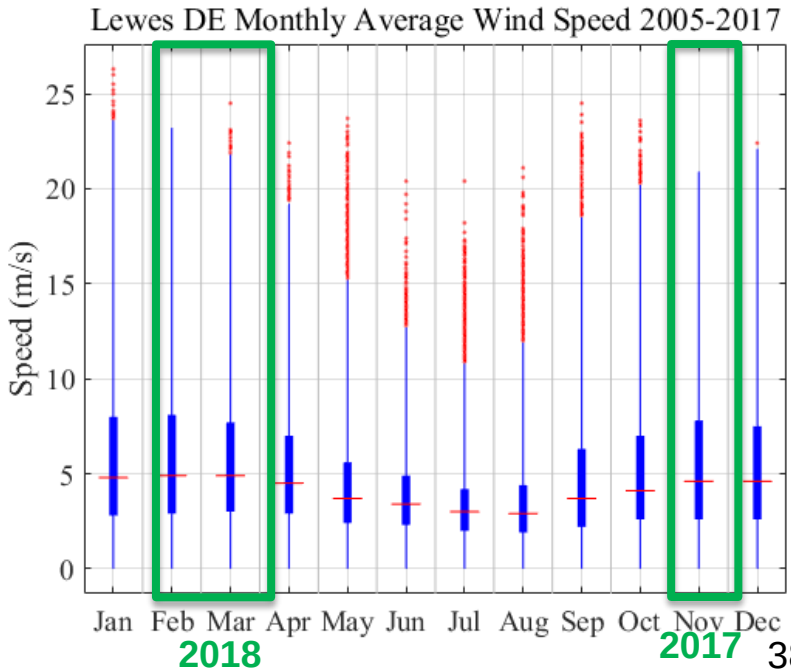




Task 4

- Option to conduct two additional deployments (Fall 2018 / Spring 2019)
  - ♦ Task 2 conducted in silty cohesive sediments, what about in more fluidized or clayey sediments
    - Shallower / deeper
    - In another bay / estuary
- Expanding grid size / surrogate type
  - ♦ Corrosion / Growth
- Deployment window
  - ♦ Task 2 capture nor'easter season
  - ♦ Hurricane season
- Continue to fill in the parameter space for the Expert System





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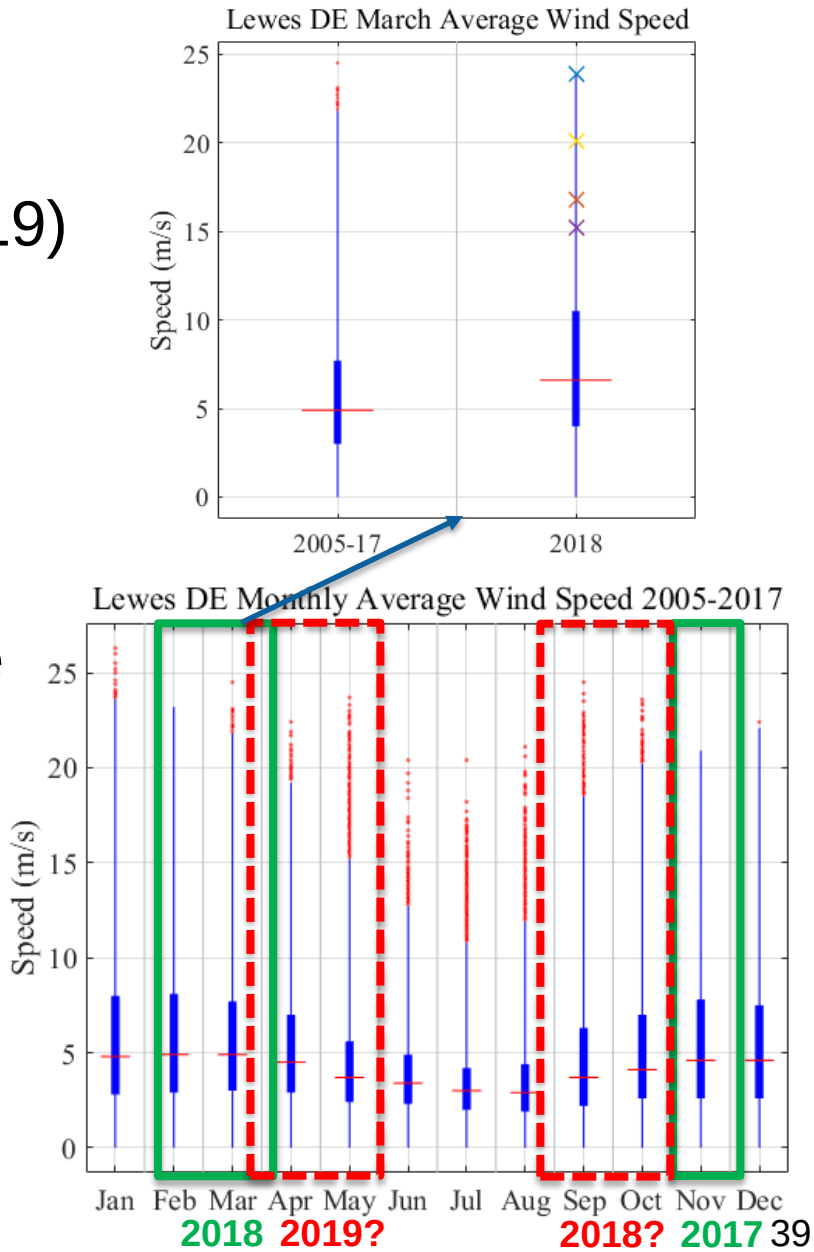


Transition Plan

- Surrogate mobility behavior and site characteristics will be provided (*have initiated data transferring*) to the SERDP Munitions Mobility studies for use in the developing Underwater Munitions Expert System (Rennie MR-2227).
- The Vemco VPS and smart surrogates development and methods in this study can easily be transitioned into future studies in various environments and conditions.
    - The proposed technologies for this study were chosen based on robustness and design for wider applications than this proposed effort.
- This study could focus at a known UXO site for demonstration or confirmation of the methodology.

Publications / Presentations

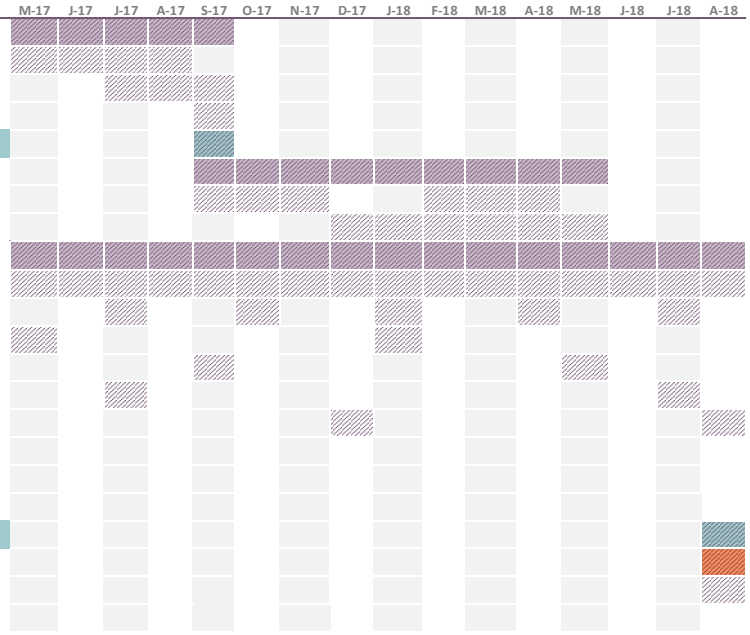
- Trembanis, A.C., and C. DuVal. Unexploded Ordnance Characterization and Detection in Muddy Estuarine Environments. (Poster). SERDP/ESTCP 2017 Symposium, Washigton D.C.
- Trembanis, A.C., and C. DuVal. Unexploded Ordnance Characterization and Detection in Muddy Estuarine Environments. (Poster). American Geophysical Union Fall 2017 Meeting, New Orleans, LA.
- DuVal, C. and A.C. Trembanis. In-Field Applications of an Autonomous Underwater Vehicle for Munitions and Explosives of Concern Detection. SAGEEP 2018, Nashville, TN.

BACKUP MATERIAL

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

Milestones

		(weeks)	
Task 1: Tracking and Motion Sensor Technology Design	**M-17**	**20**	**S-17**
Surrogate Fabrication and Sensor Design	M-17	16	A-17
VEMCO VPS System Configuration	J-17	12	A-17
Preliminary Technology Testing	S-17	2	S-17
Interim Milestone 1: Go / No-Go Decision	S/17	1	S-17
Task 2: Field Implementation	**S-17**	**38**	**M-18**
Surrogate Tracking and Mapping Field Work	S-17	24	N-17
Preliminary Data Analysis	D-17	24	M-18
Task 3: Data Analysis, Project Review and Reporting	**M-17**	**84**	**J-19**
Monthly Finance Report	M-17	84	J-19
Quarterly Progress Report	J-17	7	J-19
Execution Plan	M-17	2	J-18
Interim Technial Report	S-17	2	M-18
In-Progress Review	J-17	2	J-18
Advanced Data Analysis, Archiving and Distribution Formatting	A-18	17	N-18
Final Technical Report	N-18	12	J-19
End-of-Project Presentation	J-19	1	J-19
Project Publications	N-19	12	J-19
Interim Milestone 2: Go / No-Go Decision	A-18	1	A-18
Task 4: Optional Field Effort	A-18	40	M-19
Surrogate Tracking and Mapping Field Work	S-17	28	M-19
Preliminary Data Analysis	D-17	24	M-18



Continued Below

ACTIVITY	START	DURATION (weeks)	FINISH
Task 1: Tracking and Motion Sensor Technology Design	**M-17**	**20**	**S-17**
Surrogate Fabrication and Sensor Design	M-17	16	A-17
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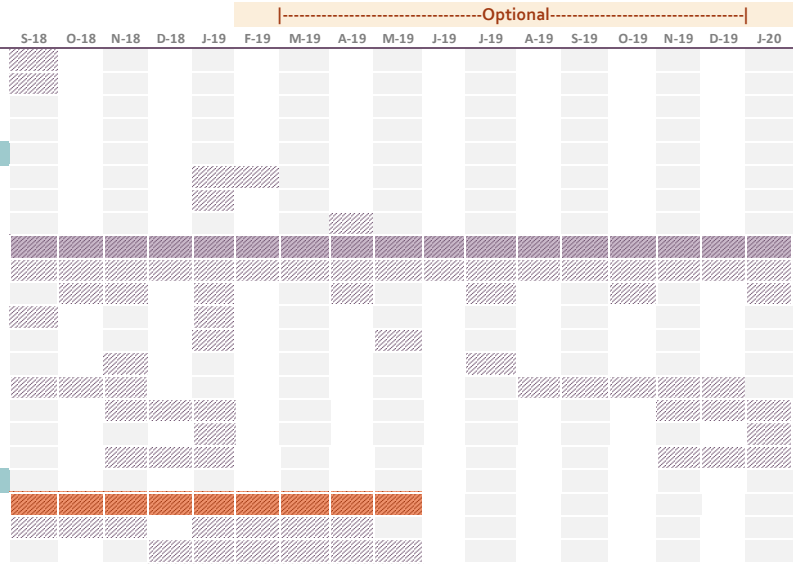
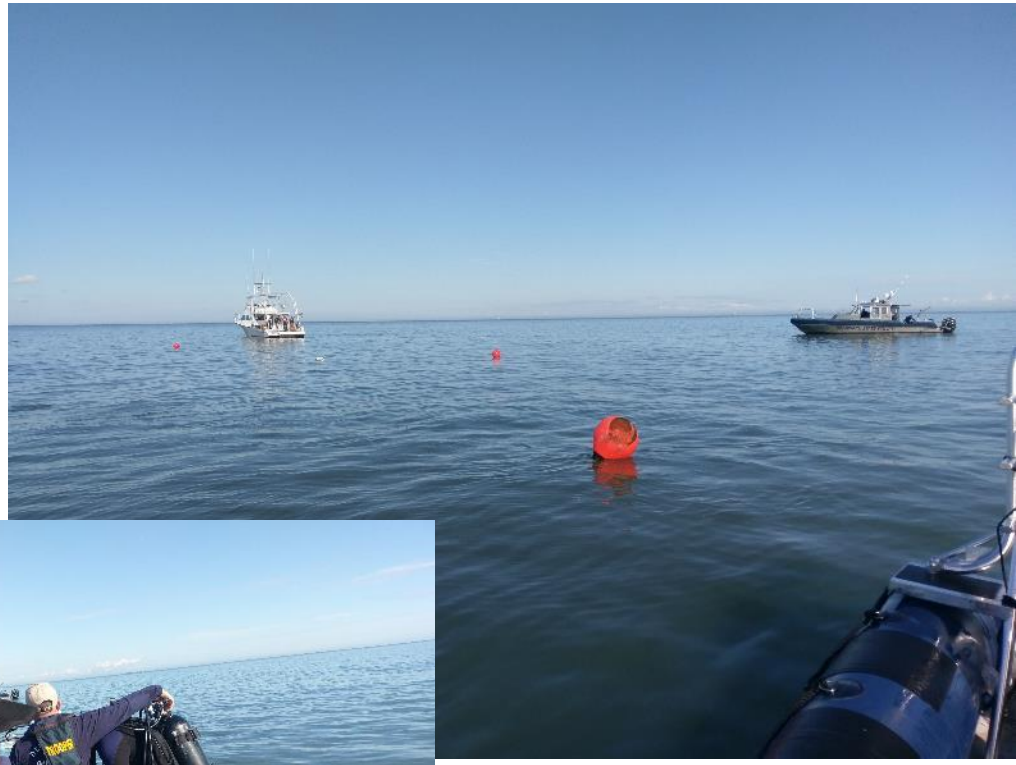
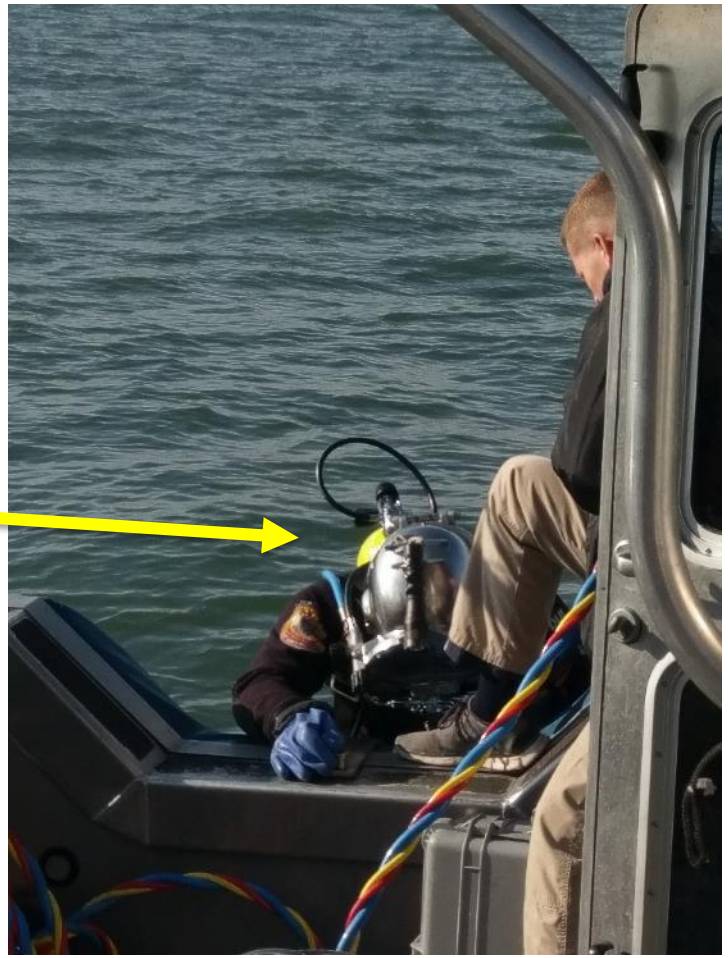


SERDP: 2017 Field Test

- Assisted by the DE State Police Scuba Unit

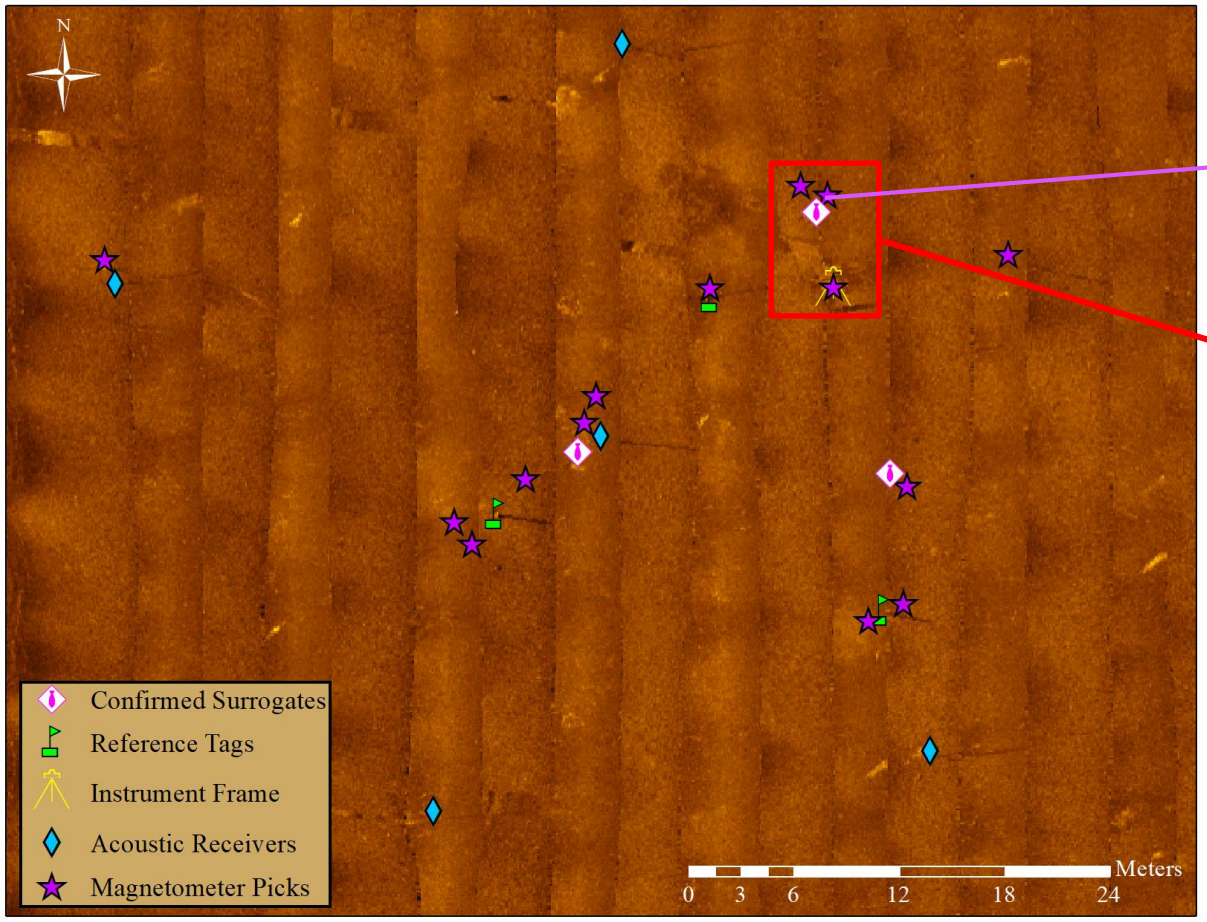


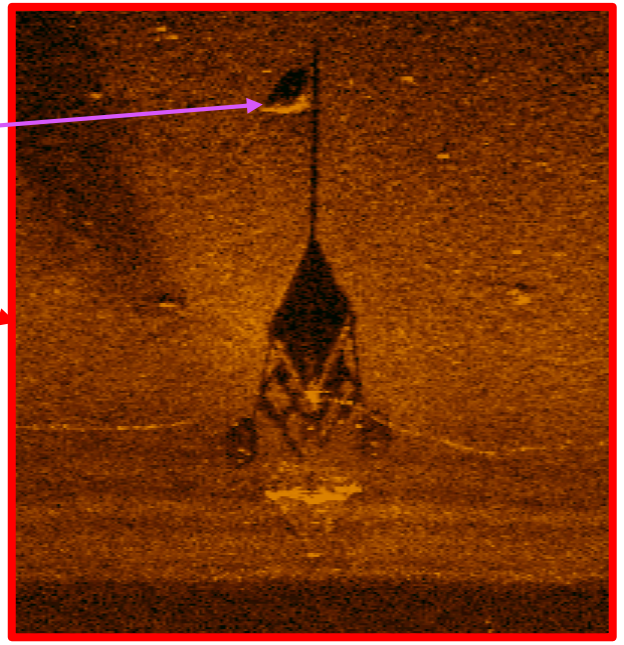
SERDP 2017 – Search and Recovery



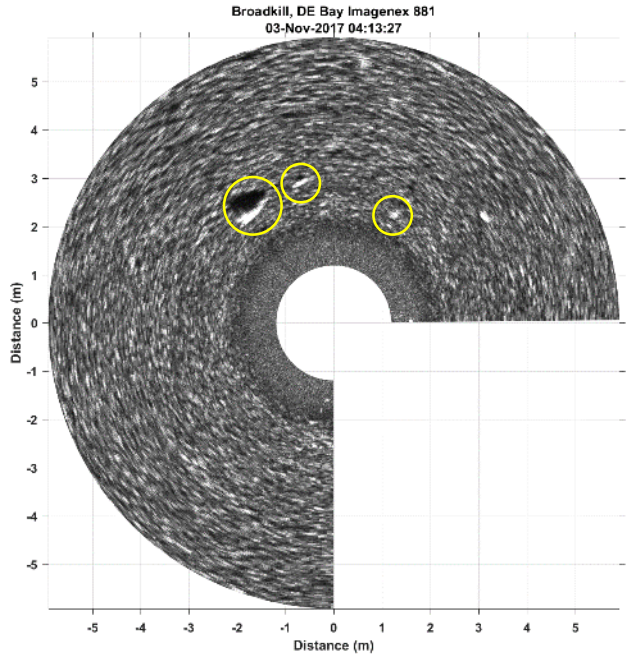
SERDP: 2017 Field Test

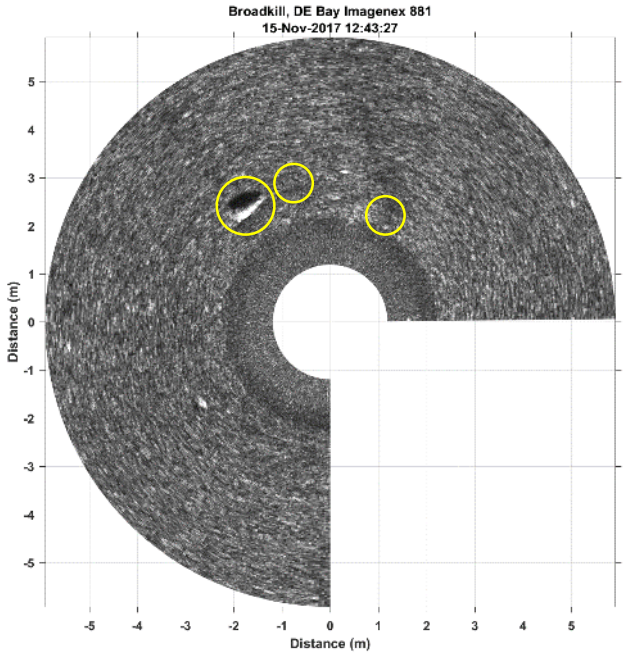
- Sonar and magnetometer targets from AUV

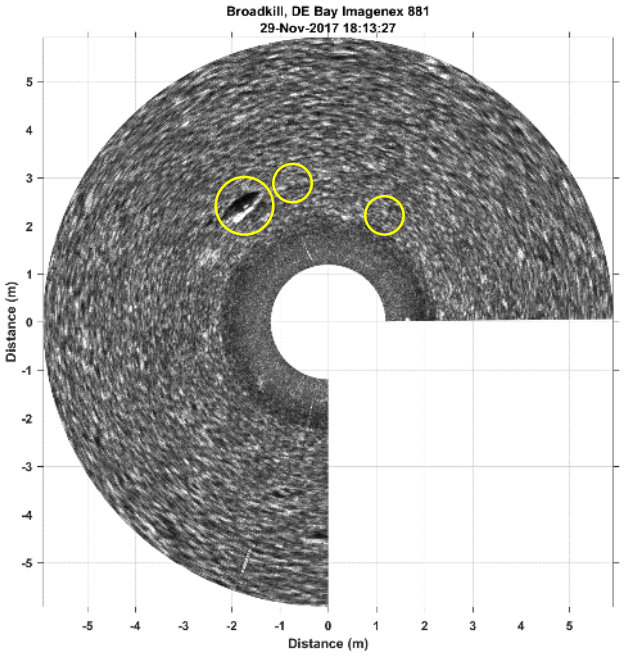




2017 Rotary Sonar Imagery

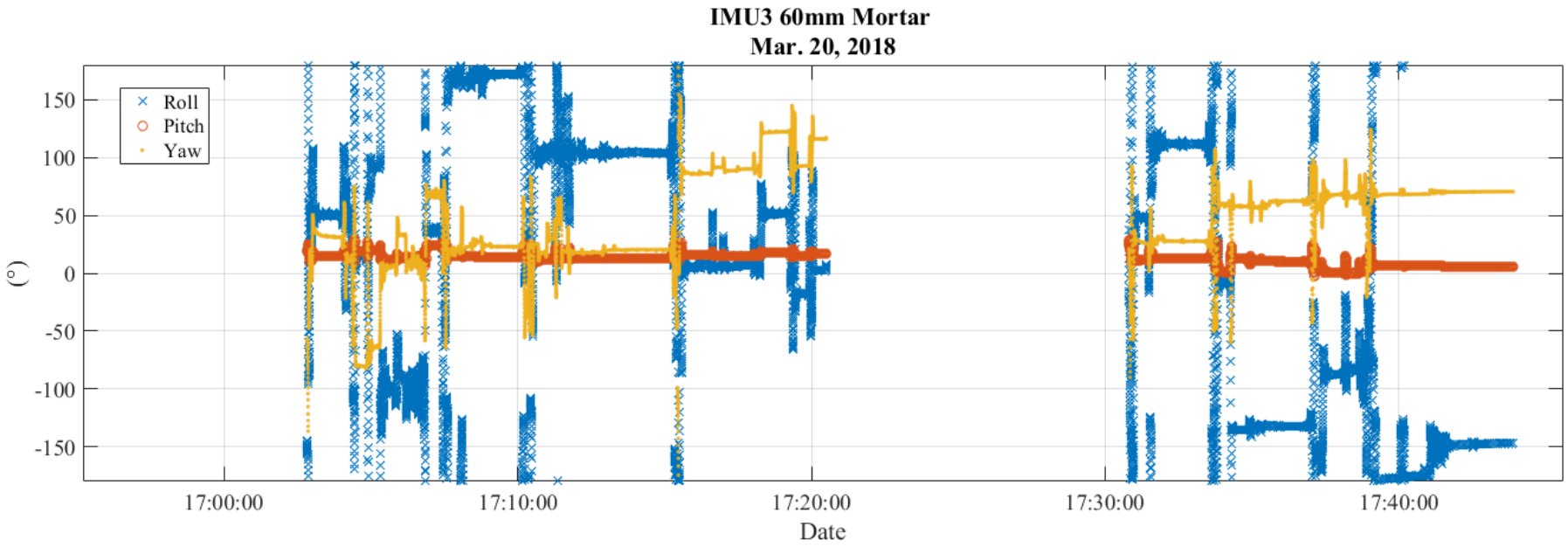






- Notable scour of all three surrogates
  - 81mm and 60mm become obscured in sonar imagery within 5 days of deployment

60mm Mortar Time-Series



Data

- Munitions Tracking Data
  - Vemco VPS data – .csv/kmz locations
    - Currently raw data with Vemco HPE error (nondimensional) – working with Vemco to convert into HPEm (in meters) to additionally filter data
  - IMU data - Matlab (.mat)
    - Working with Joe Calantoni to get scripts to convert IMU data into 3D motion
    - Working on visualization of IMU time series
  - Pressure sensor (155mm only) - .csv/matlab
    - Differencing from in situ AML CTD to estimate scour depth for 155
      - Scour pits noted in SSS and by divers retrieving munitions

Data

- Hydrodynamic data
  - ADCP (TRDI) - .mat/csv
    - Waves and water column currents during deployment duration
  - PC-ADCP (Aquadopp HR) - .mat/csv
    - Near bed currents, turbulence estimates, qualitative backscatter (suspended sediment)
  - Rotary Sonar (Imagenex) - .png
    - Time-series data of munitions monitoring / sediment morphology
      - Incomplete
  - CTD (AML) - .csv
    - CTD, sound speed, turbidity during deployment duration

Data

- Geophysical Data
  - Side-scan sonar – geotiff/kmz
    - Monitor locations of munitions and surficial sediment / morphology pre-post storms
  - Bathymetric data - .asc/geotiff/kmz
    - Monitor bathymetric changes to the site
  - Magnetometer - .csv
    - Monitor munition locations and detection if buried (2018)

Action Items

Action Item	Status	Deliverable	Action Type	Due Date
Surrogate Fabrication and Sensor Design	Submitted	None	Subtask	8/28/2017
Data import MFR for FY17 funds	Submitted	None	MFR	9/15/2017
Preliminary Technology Testing	Submitted	None	Subtask	9/28/2017
Vemco VPS System Configuration	Submitted	None	Subtask	9/28/2017
FY17 Expenditure Plan	Submitted	None	Expenditure Plan	10/11/2017
Unexploded Ordnance Characterization And Detection In Muddy Estuarine Environments	Submitted	None	Project Overview	10/11/2017
September MFR for FY17 funds	Submitted	None	MFR	10/15/2017
October 2017 Quarterly Progress Report	Submitted	None	QPR	10/15/2017
October MFR for FY17 funds	Submitted	None	MFR	11/15/2017
November MFR for FY17 funds	Submitted	None	MFR	12/15/2017
December MFR for FY17 funds	Submitted	None	MFR	1/15/2018
January 2018 Quarterly Progress Report	Submitted	None	QPR	1/15/2018
January MFR for FY17 funds	Submitted	None	MFR	2/15/2018
February MFR for FY17 funds	Submitted	None	MFR	3/15/2018
March MFR for FY17 funds	Submitted	None	MFR	4/15/2018
April 2018 Quarterly Progress Report	Submitted	None	QPR	4/15/2018
FY18 Expenditure Plan	Submitted	None	Expenditure Plan	4/25/2018
Surrogate Tracking and Mapping Field Work	Submitted	None	Subtask	4/28/2018
April MFR for FY17 funds	Pending	None	MFR	5/15/2018
Interim Report (v1)	Pending	Interim Report	Subtask	5/28/2018
Preliminary Data Analysis	Pending	None	Subtask	5/28/2018
Final Report (v1)	Pending	Final Report	Subtask	11/28/2018
Advanced Data Analysis, Archiving and Distribution	Pending	None	Subtask	1/28/2019