# Unexploded Ordnance Characterization and Detection in Muddy Estuarine Environments

**Art Trembanis and Carter DuVal**

**MR-2730**

Other significant contributors:

Dana Allen & Martin Blostein (Vemco)

Delaware State Police Scuba Unit (Cpl. Brian Green)

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2018 | Enhancing DoD's Mission Effectiveness

# Underwater UXO – Burial and Mobility

*Munitions Response – Site Management*

*Bryan Harre - Keynote*

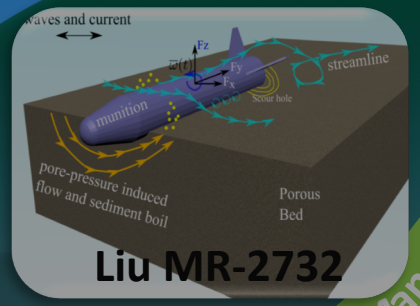
Munitions Mobility

Management Needs

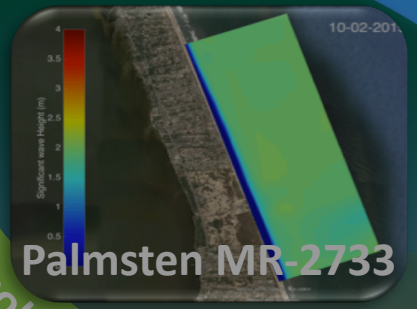
Management Needs

Management Tools

Management Tools



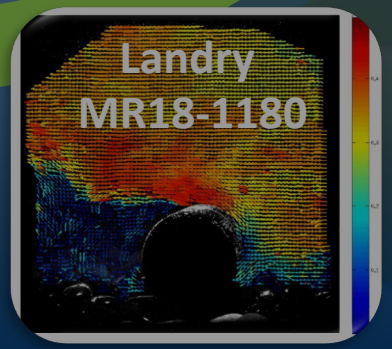

Liu MR-2732



Palmsten MR-2733

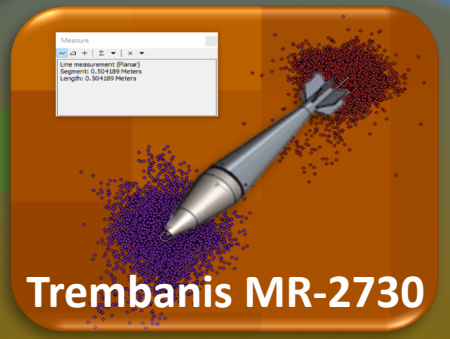
*Simulation & Prediction*

*Laboratory Measurements*



Landry
MR18-1180

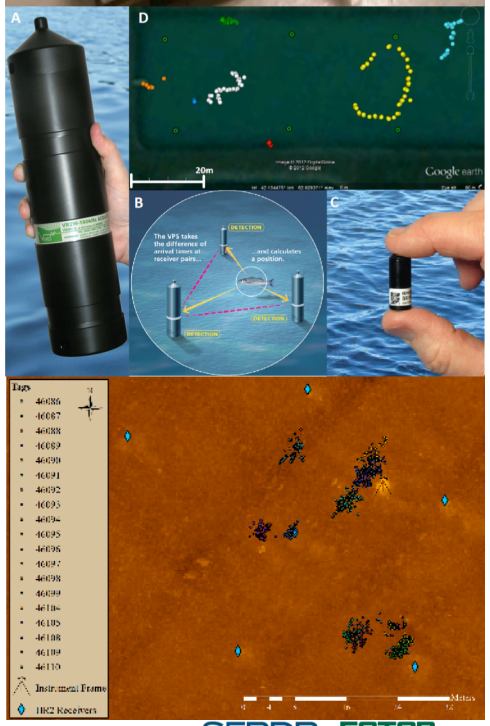
Puleo MR-2503



Trembanis MR-2730

*Field Observations*

# MR-2730: Project Overview




## 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*
- *Four 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 Prepare documentation on surrogate munitions development and VPS system specifications, deployment methods and results*

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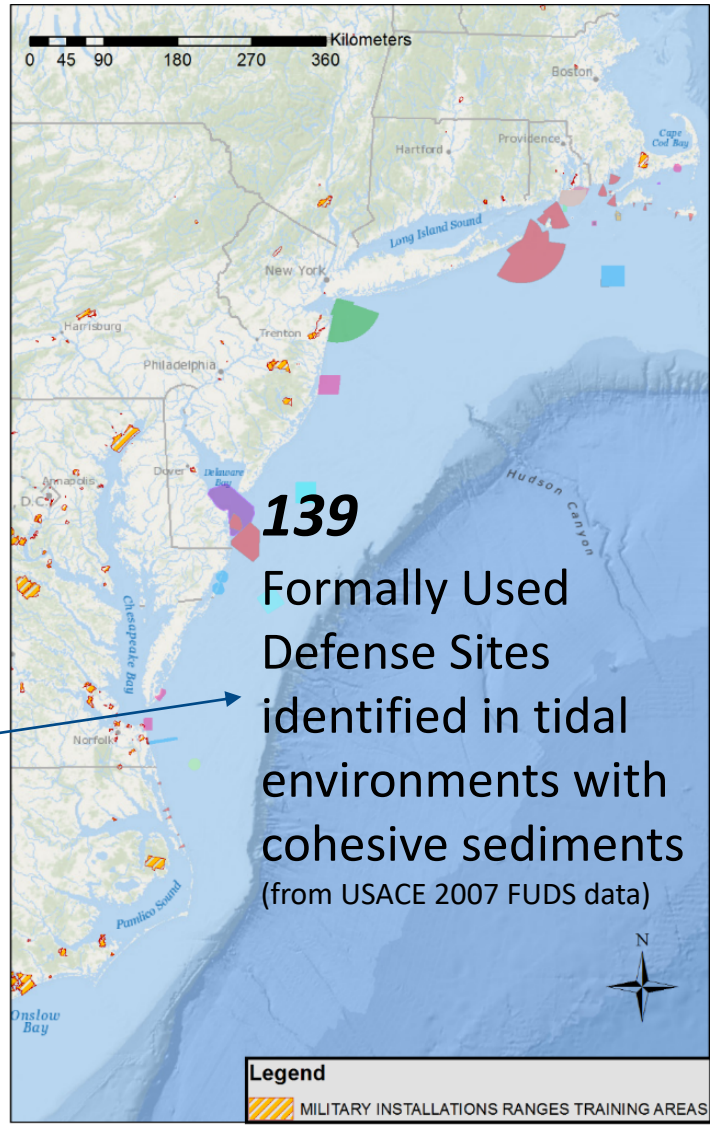
# Problem Statement

- 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).




***139***

Formally Used Defense Sites identified in tidal environments with cohesive sediments

(from USACE 2007 FUDS data)



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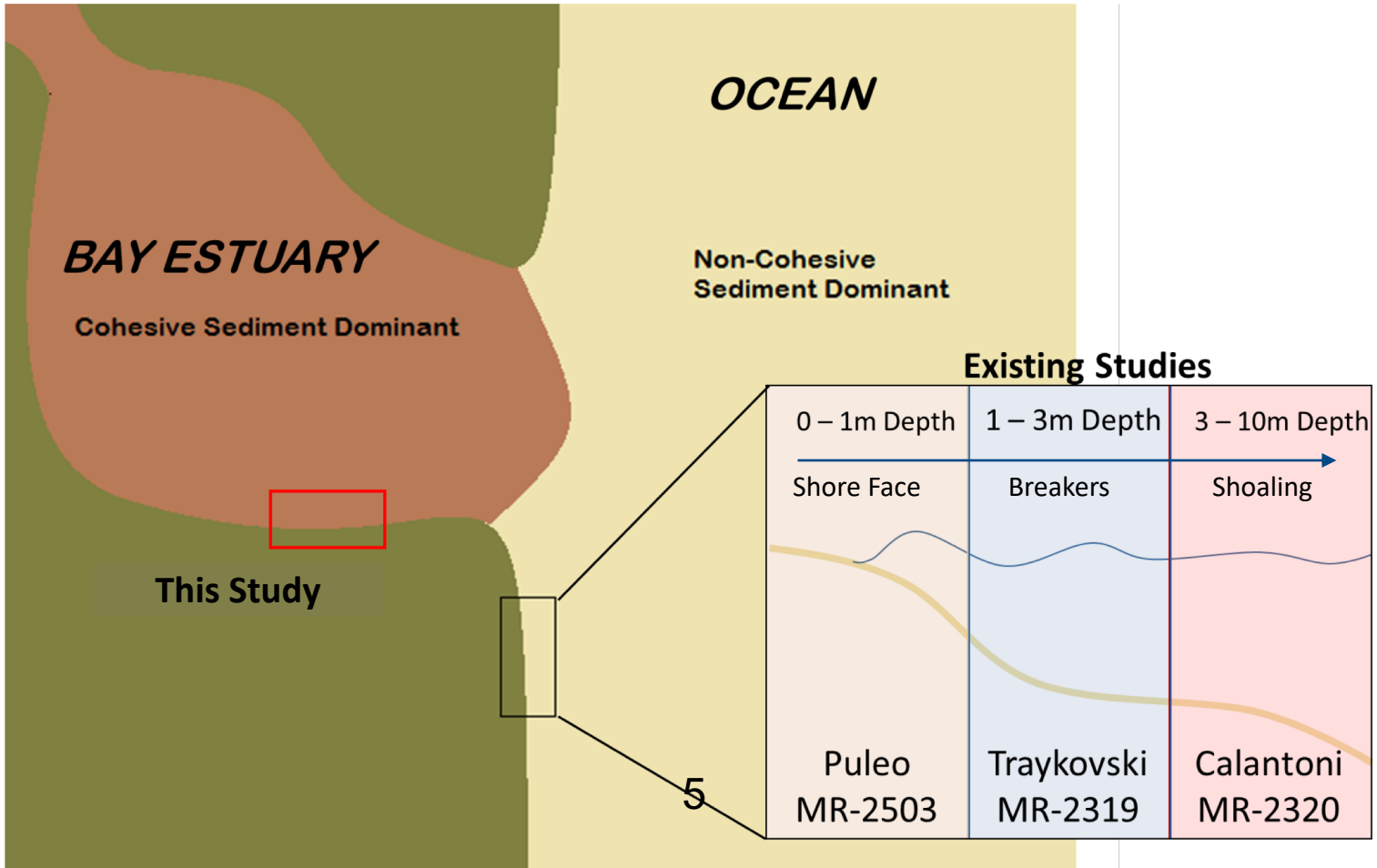
# Problem Statement

## Existing *in situ* data for munitions mobility

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



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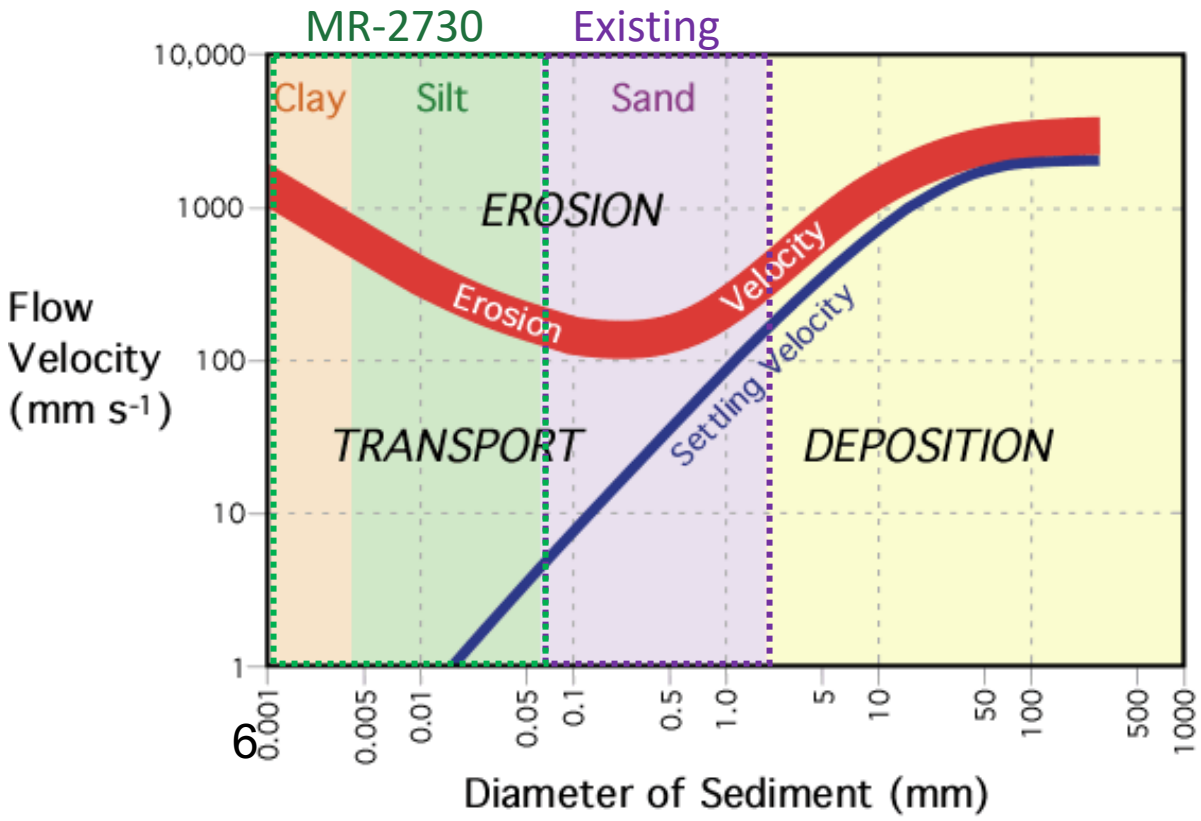
# MEC in Cohesive Sediments

- 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)



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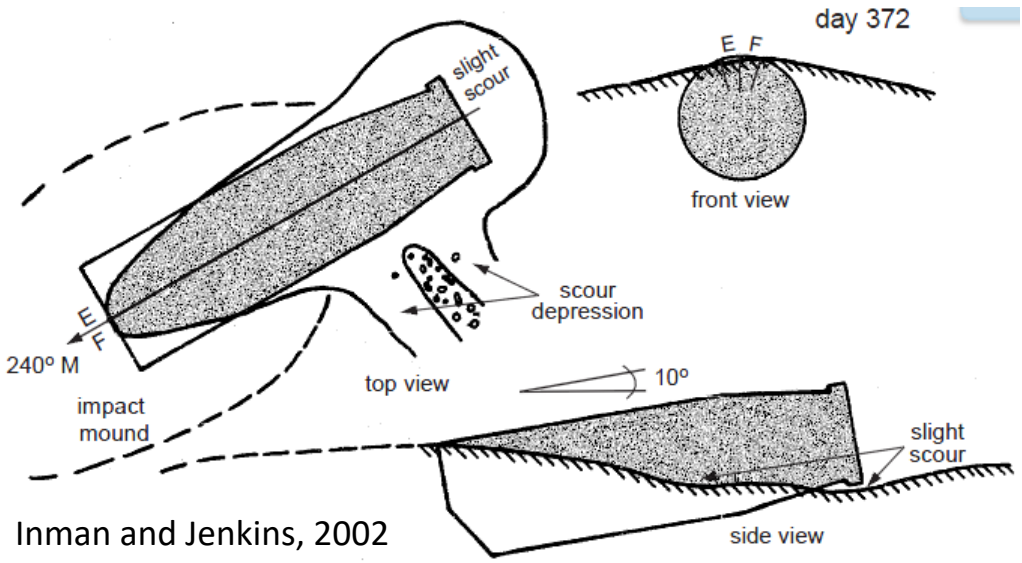
# MEC in Cohesive Sediments

- 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

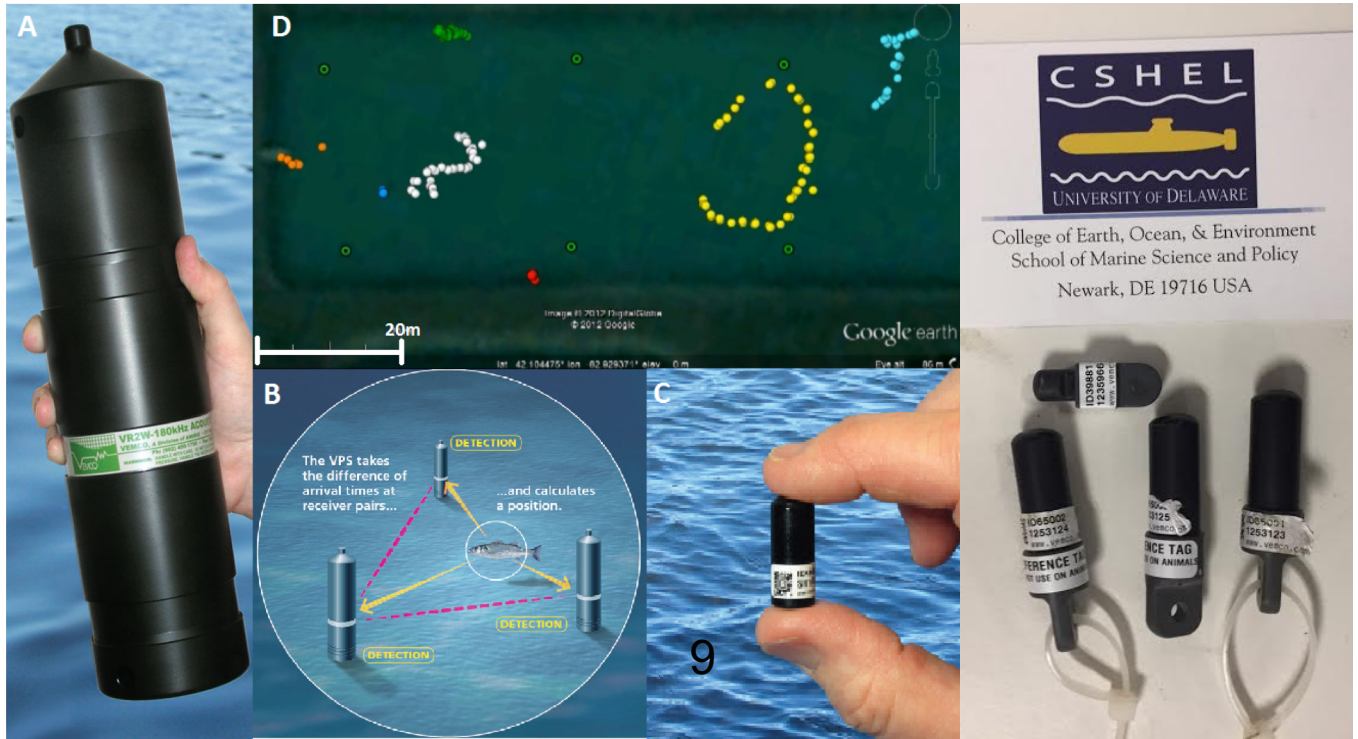
- In stiff muds, mines were found to only undergo slight scour and partial burial (Inman and Jenkins, 2002)
  - Impact burial is largest contributor to mine burial in stiff muds, not subsequent hydrodynamics.

# Technical 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.

# 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



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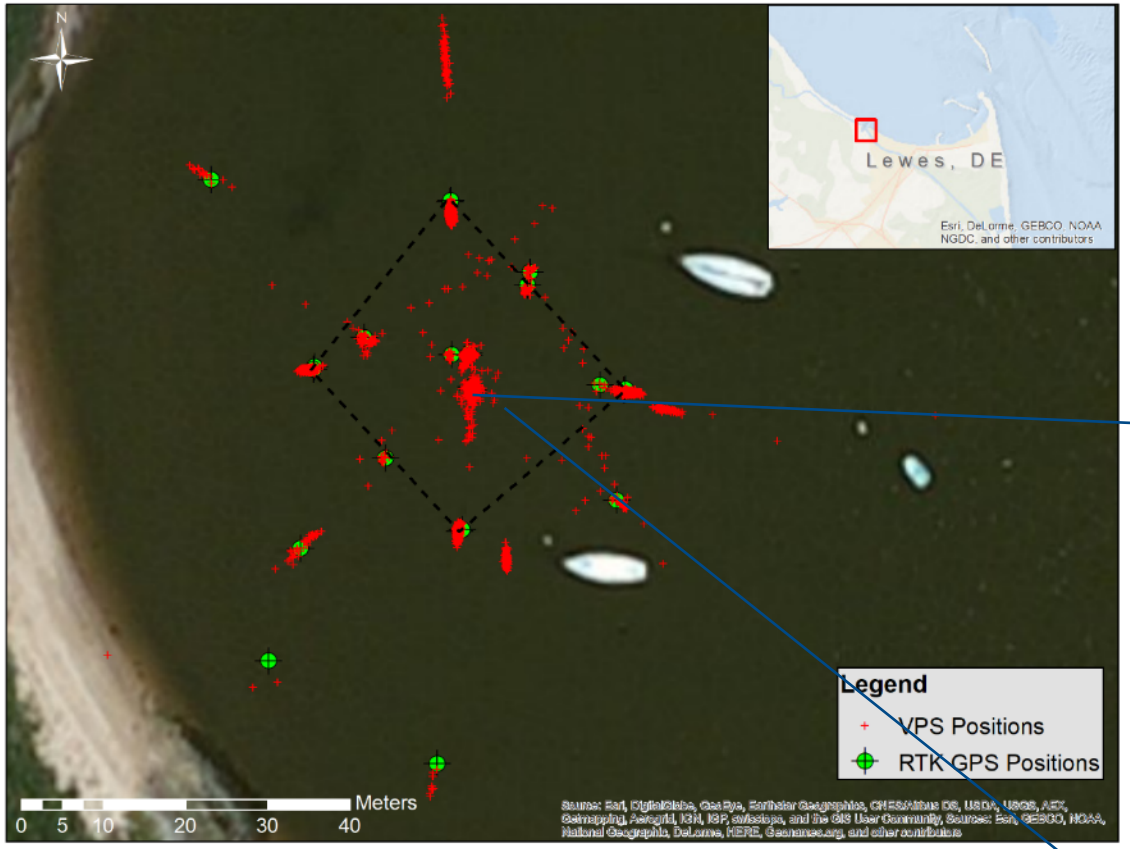
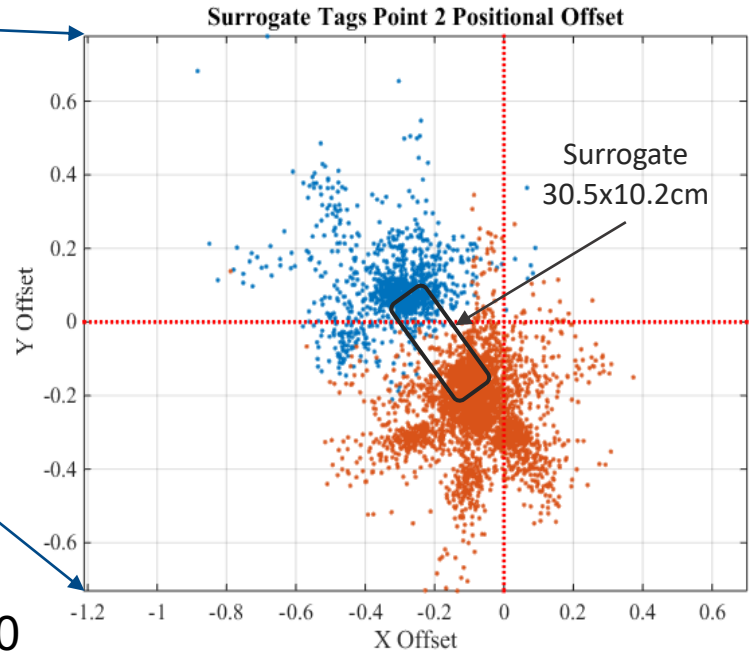
# VPS Field Test: Sept. 26-27, 2016




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



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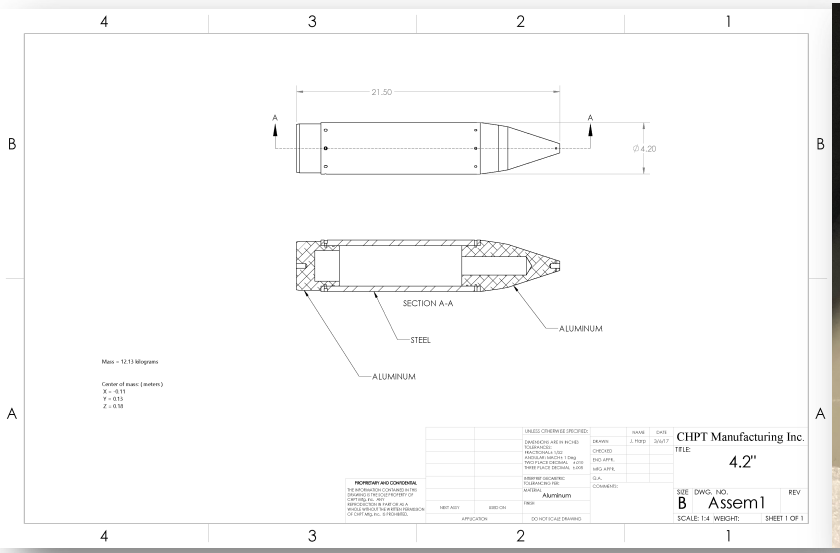
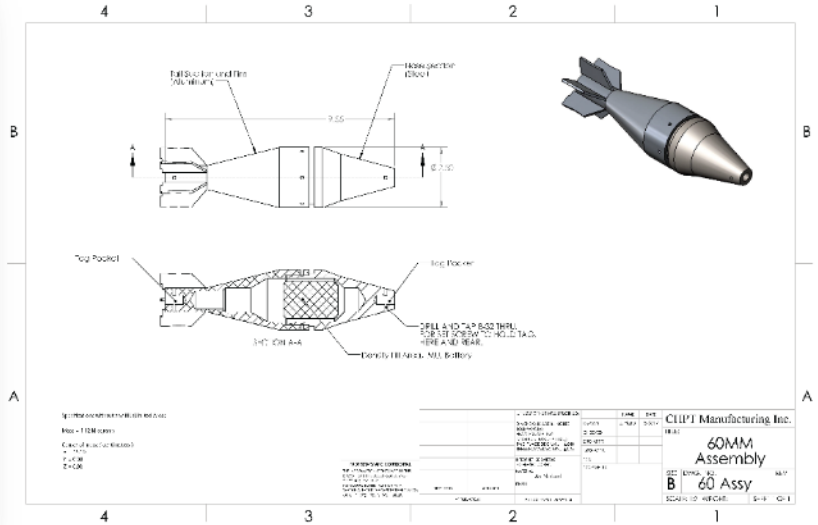
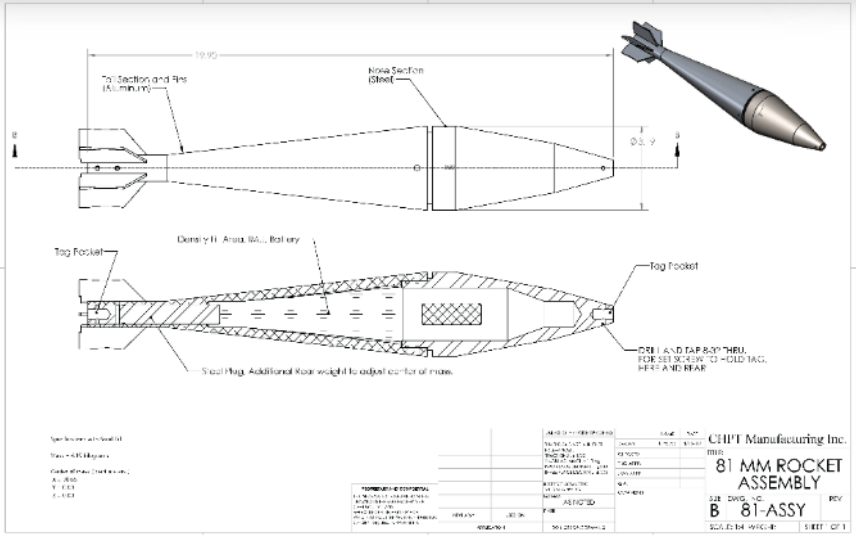
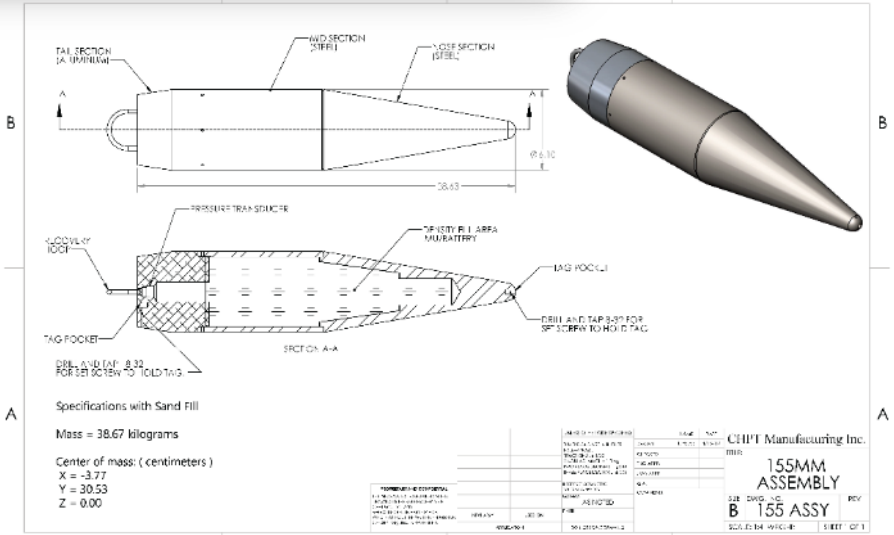
# Task 1: Tracking and Motion Sensor Design



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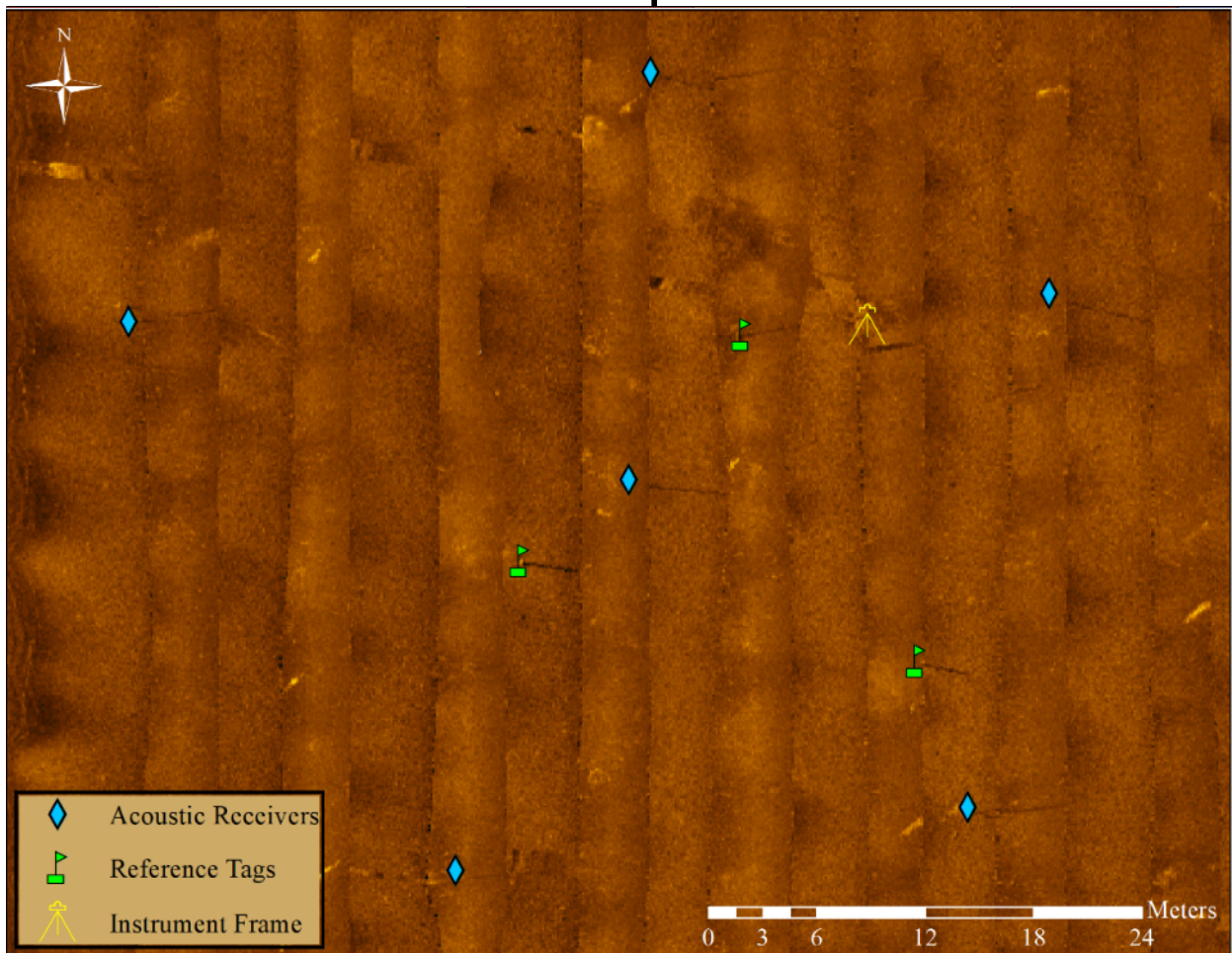
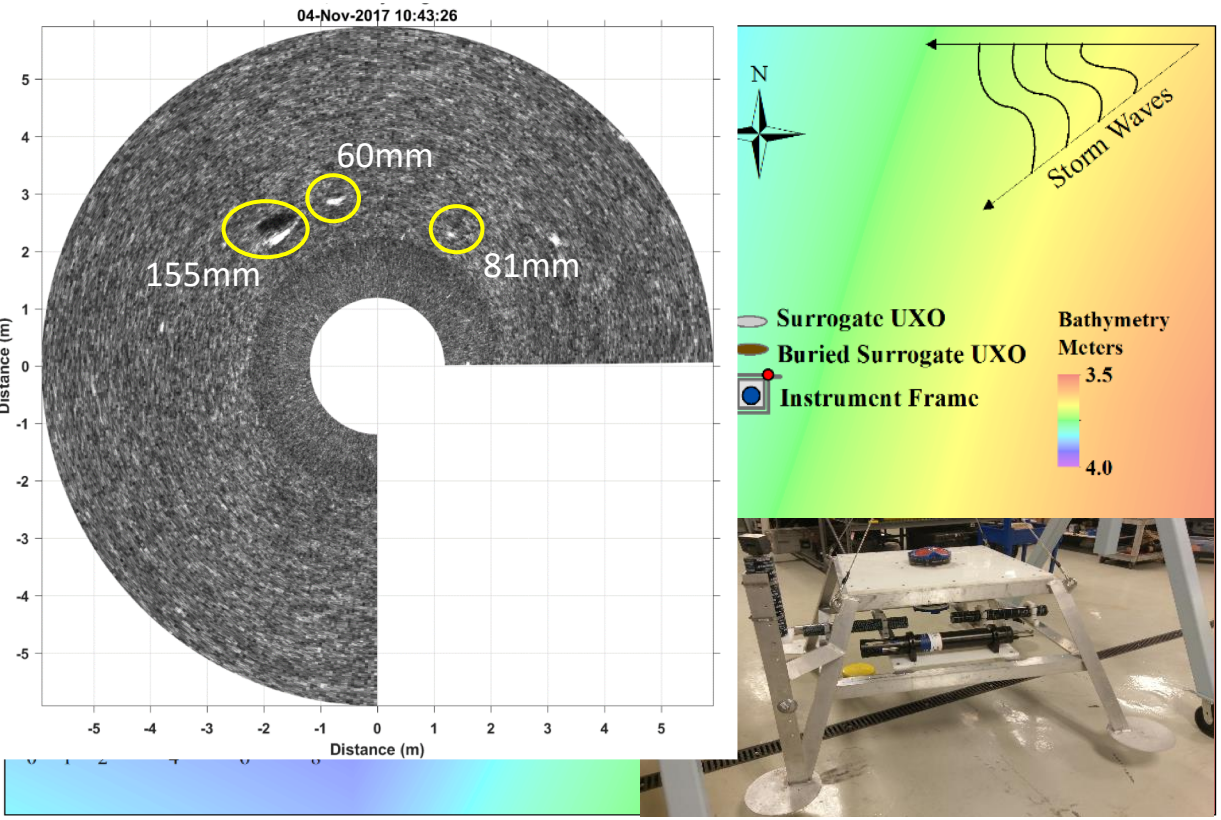
# Task 2: Field Implementation

- 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
    - Recorded multiple detections per minute per tag

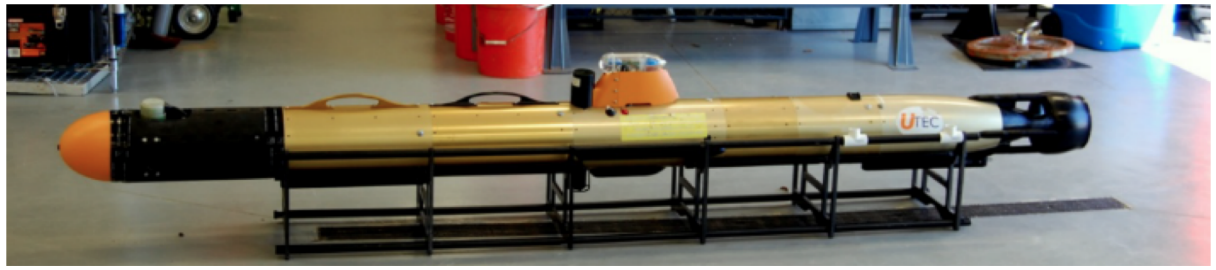


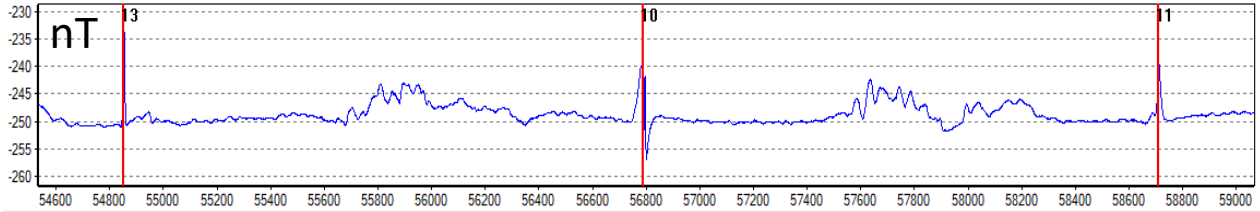
# Task 2: Field Implementation

- Instrument Frame to collect in-situ hydro-dynamics and time-lapse imagery of seabed morphology and surrogates




- 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





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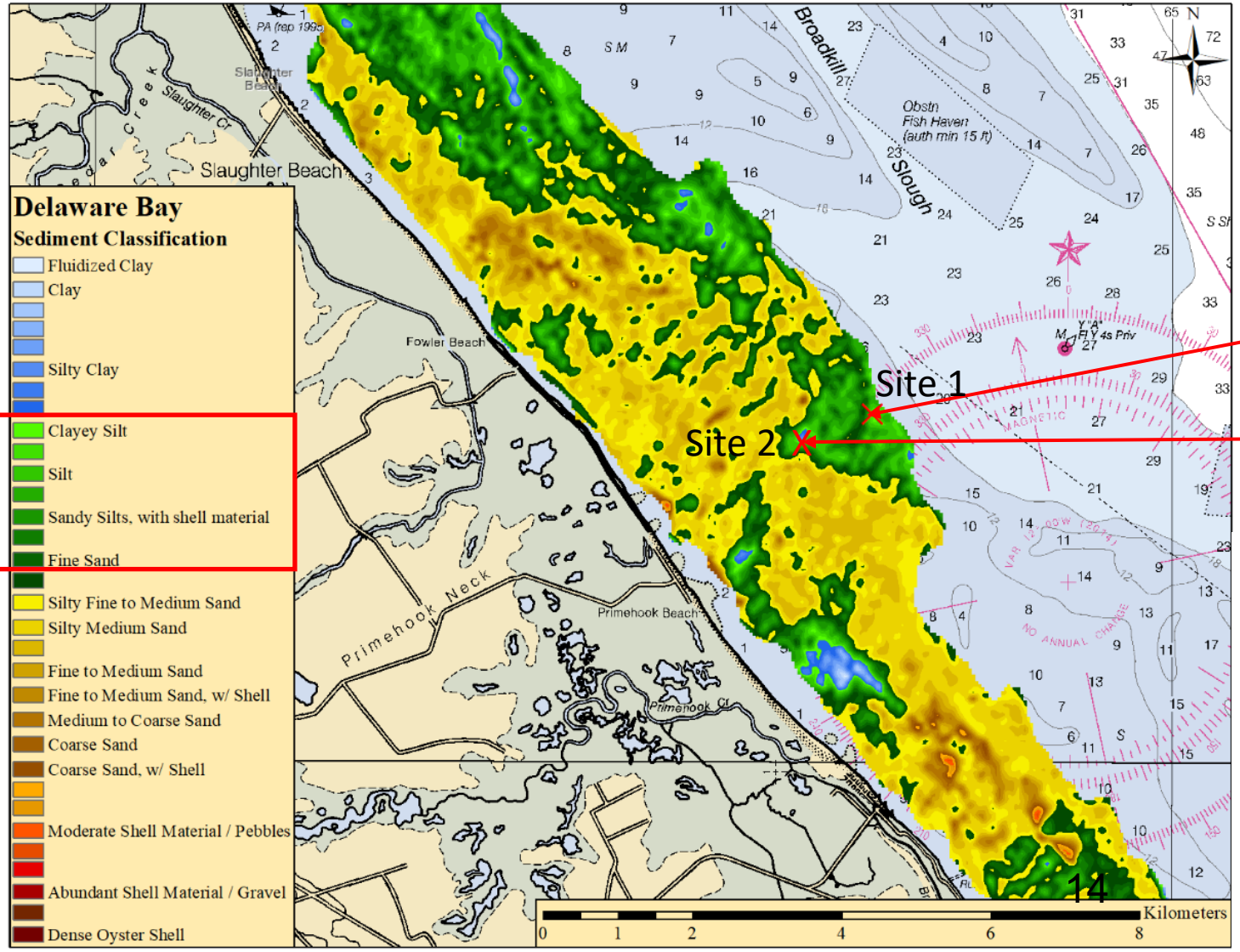
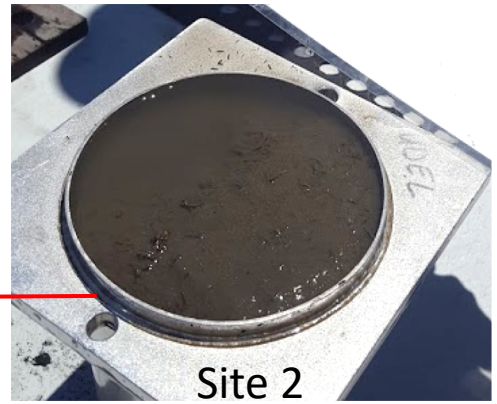
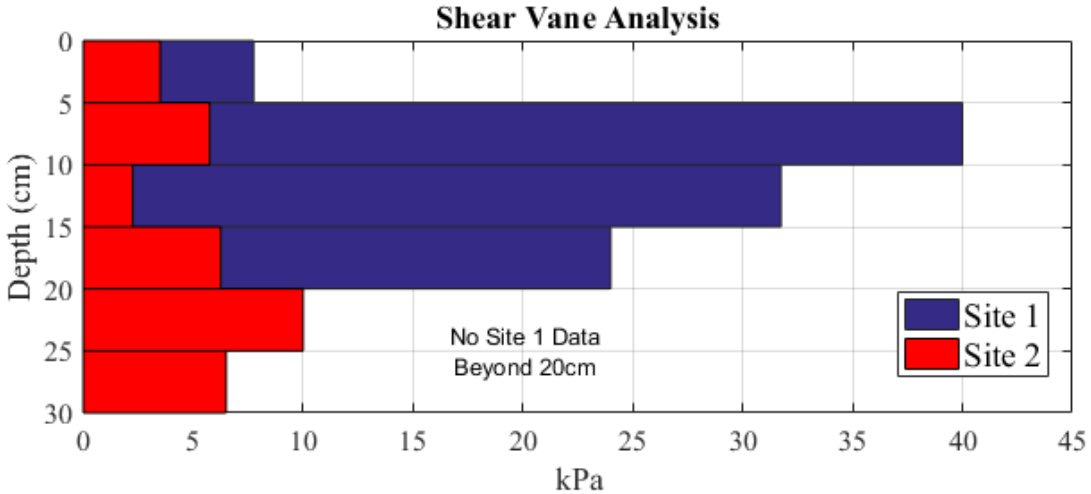
# Site Selection



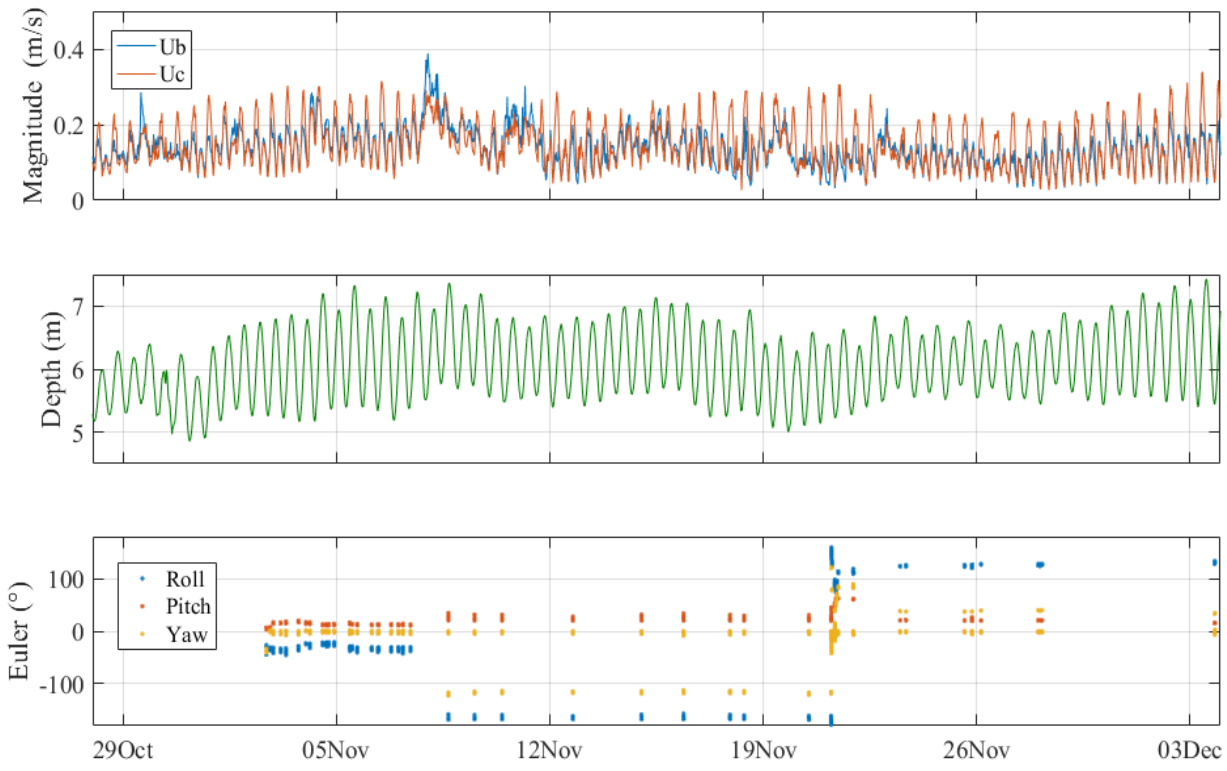

- Field sites within Roxann context
  - Site 1 samples: silty, clayey sand
  - Site 2 samples: sandy silt with clay



# Field Deployment Summary Slide

- Fall 2017: Nov. 02 - Dec. 4 (32 Days)
  - Location – Site 1 (muddy sands)
  - Activities
    - 4 Surveys (10/20, 11/02, 11/09, 12/02) – side-scan, bathymetry, sub-bottom, magnetometry, and/or sediment sampling
  - 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



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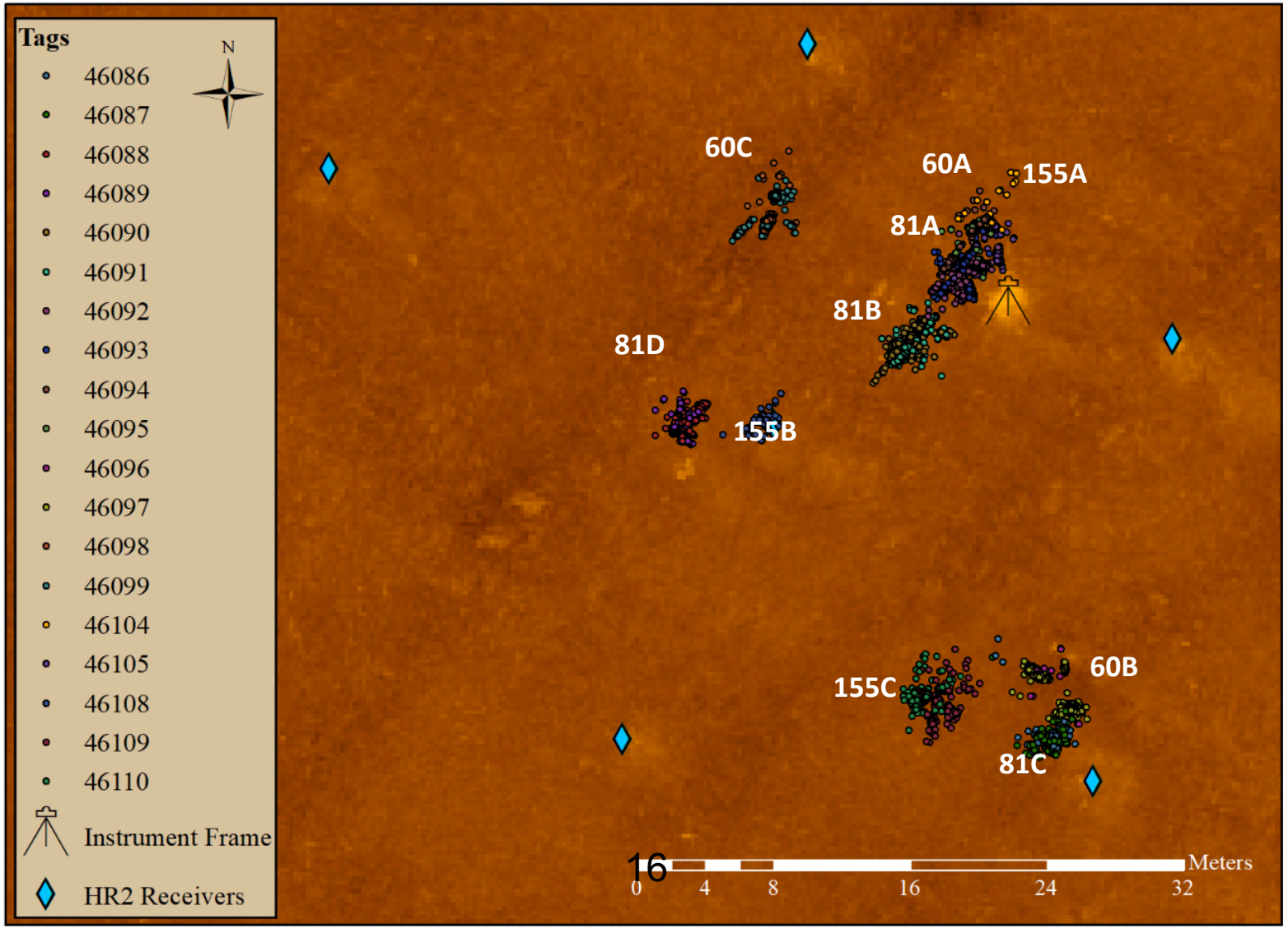
# Fall 2017 Field Deployment



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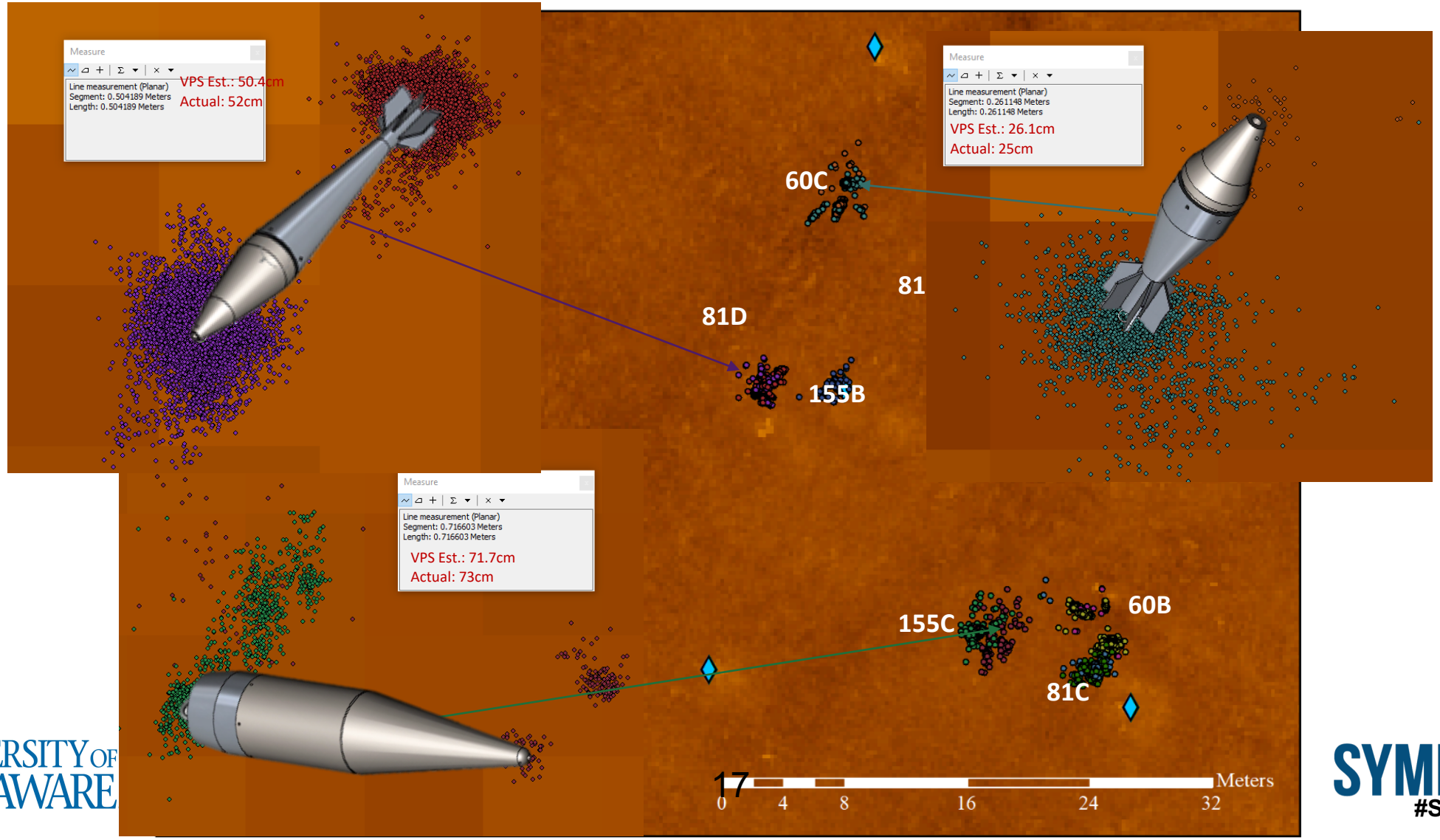
# Fall 2017 Field Deployment



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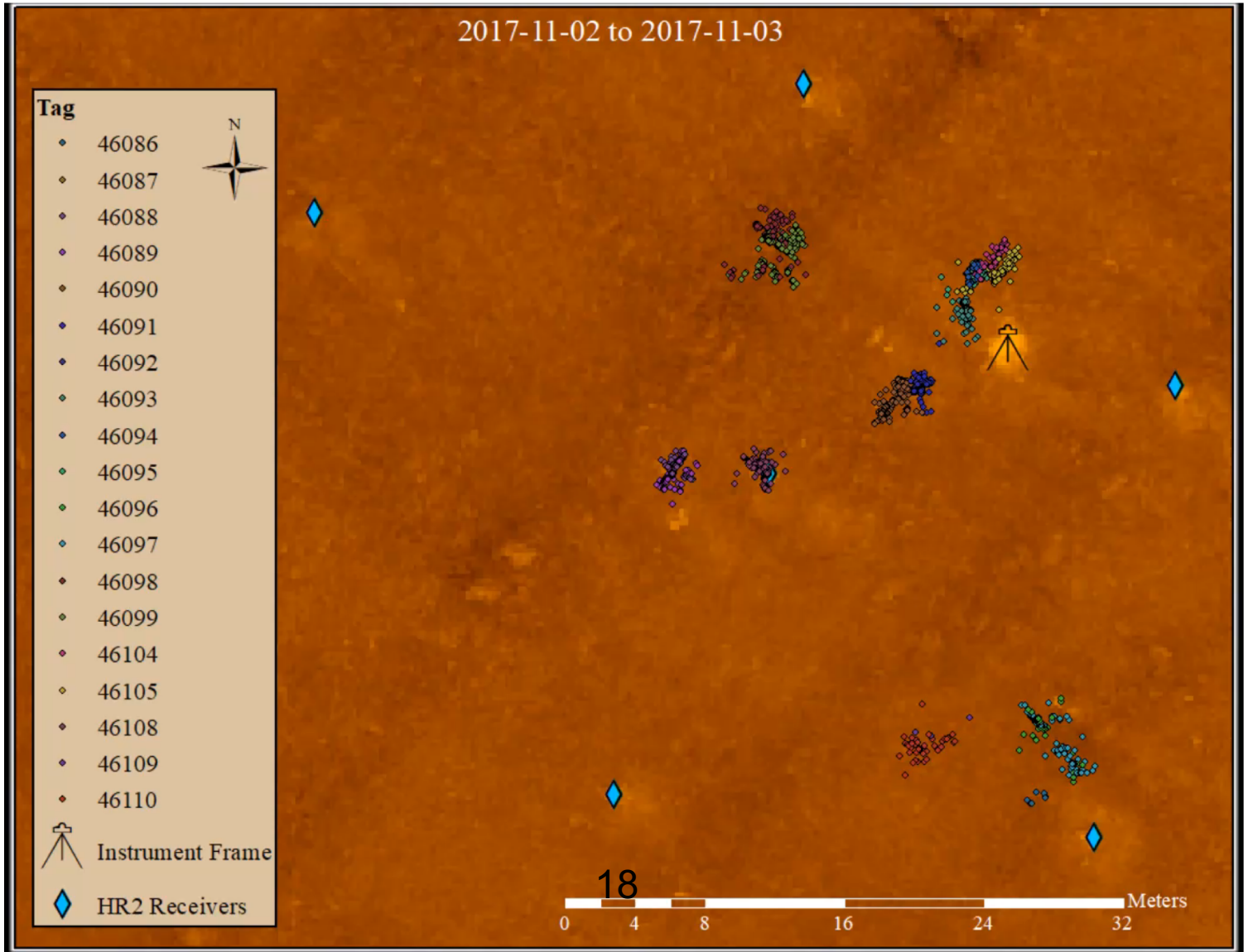
# Fall 2017 Animation



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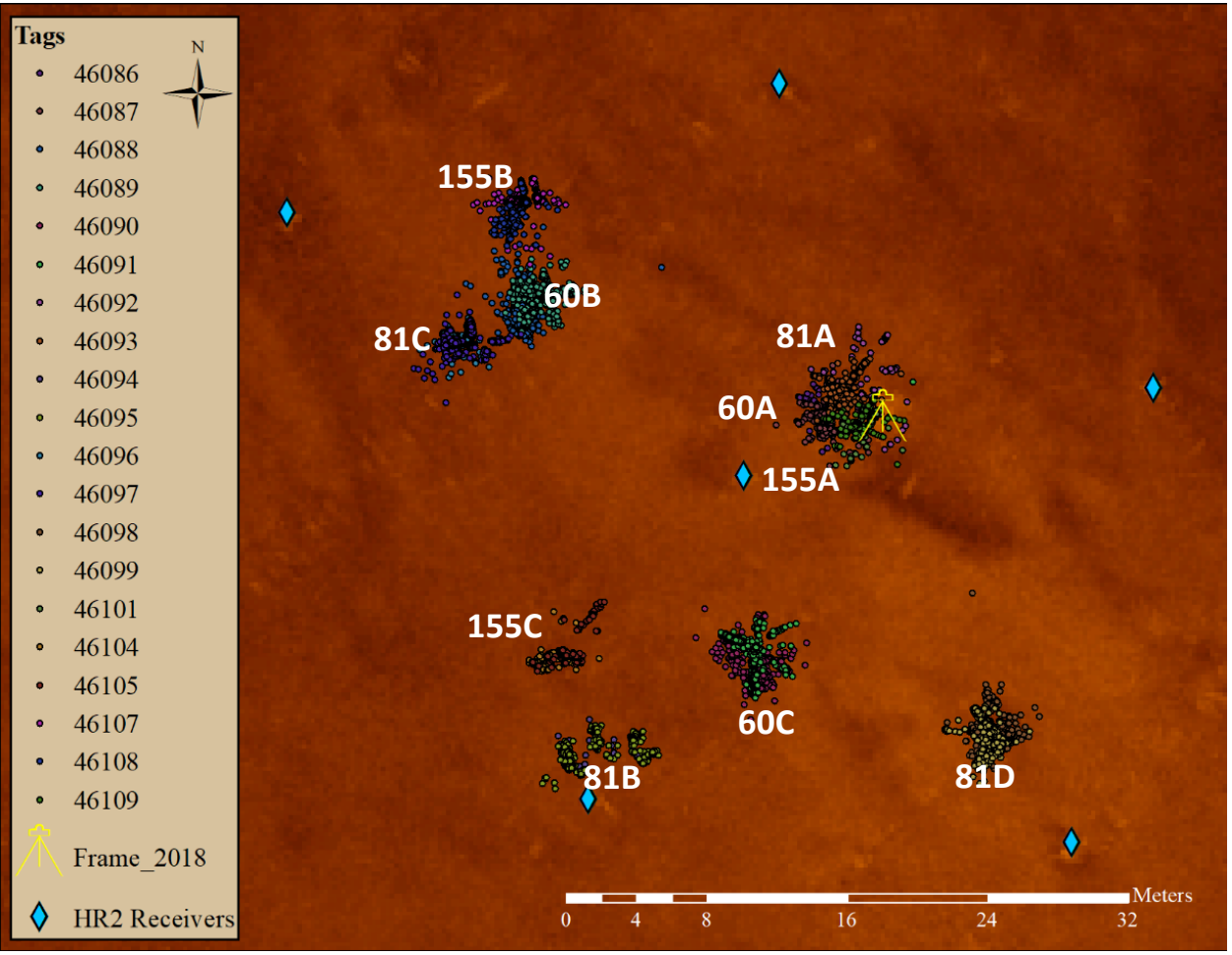
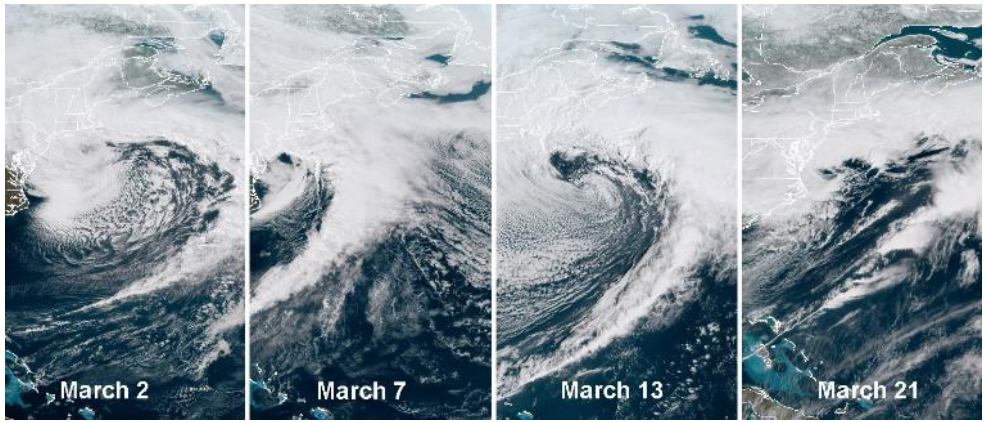
# Field Deployment Summary Slide



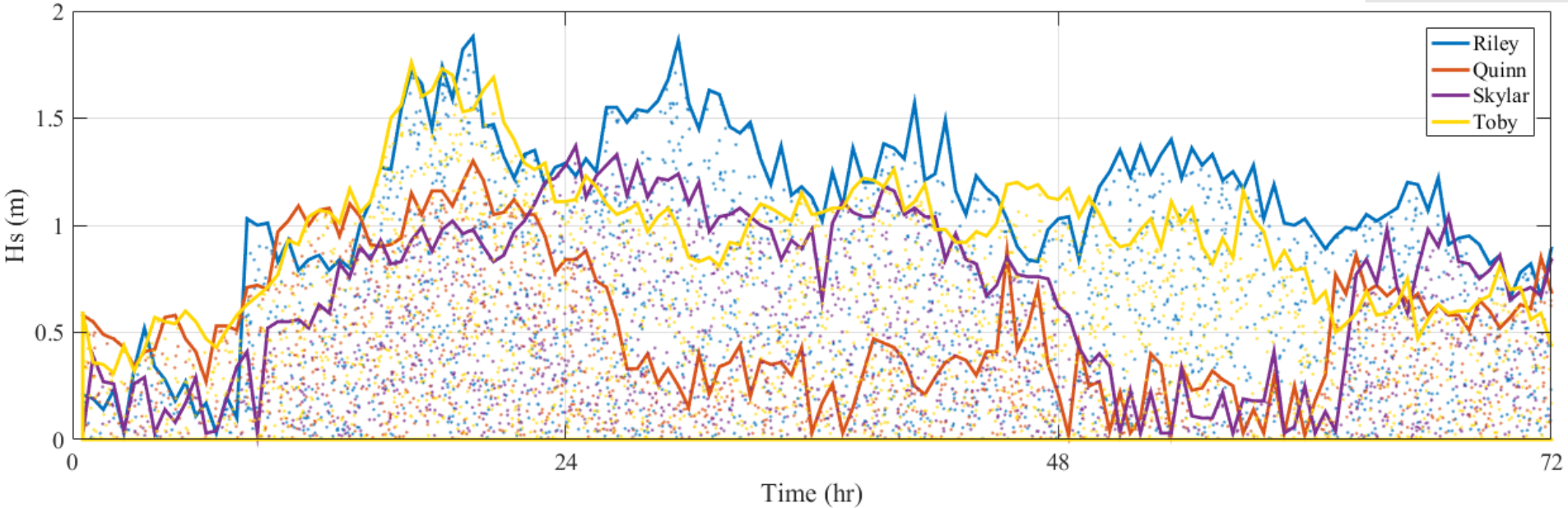

- Spring 2018: Feb. 09 - Apr. 11 (61 Days)
  - Location – Site 1 (muddy sands)
  - Activities
    - 3 Surveys (03/06, 04/10, 04/12) – side-scan, bathymetry, sub-bottom, magnetometry, and/or sediment sampling
  - Surrogates – equipped with IMU's and 2 acoustic tags
    - 3 – 60mm mortars
    - 4 – 81mm mortars
    - 3 – 155mm artillery (equipped with pressure sensors)
  - Highlights
    - 4 nor'easter events

# “Four’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 |



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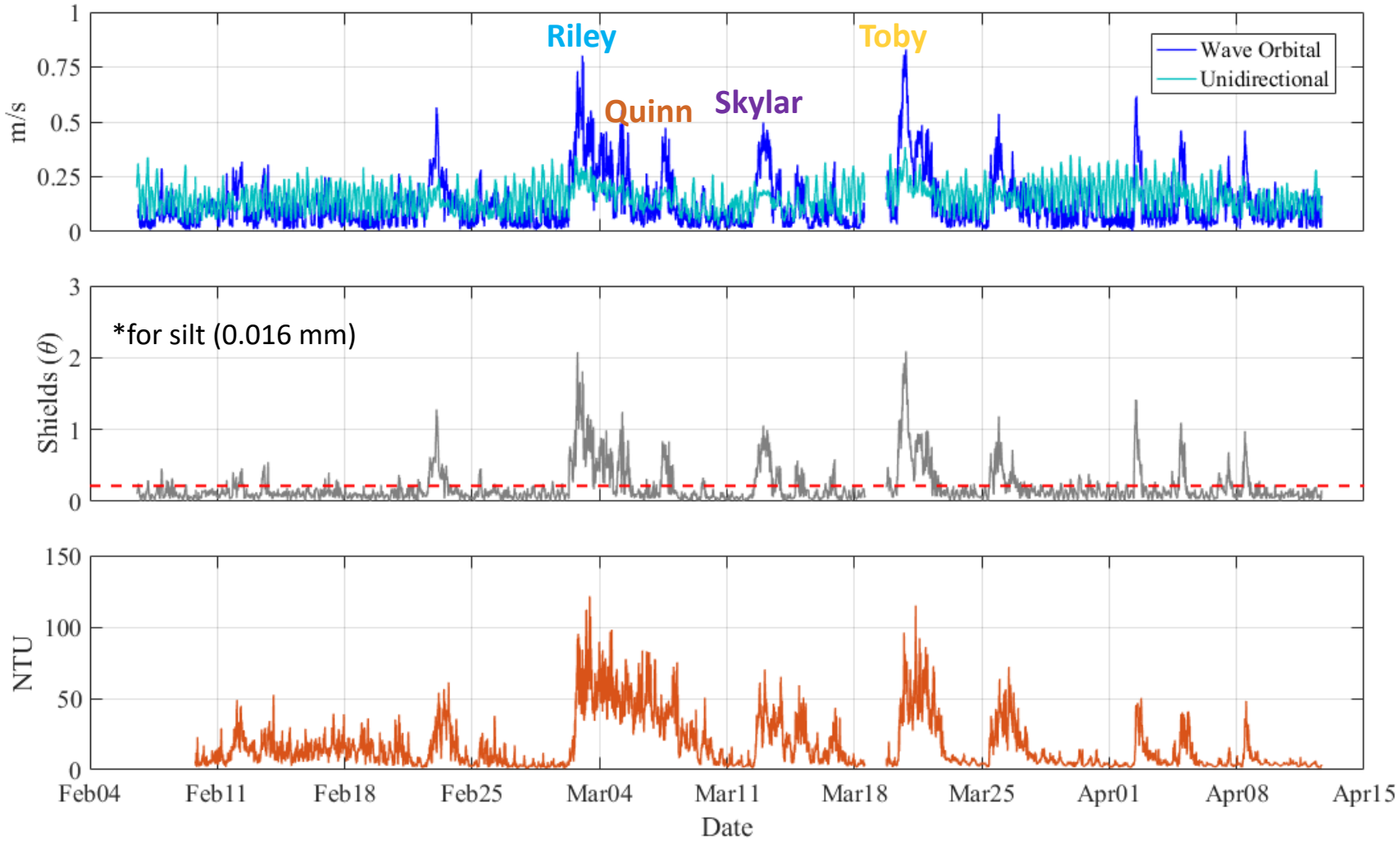
# Spring 2018 Field Deployment



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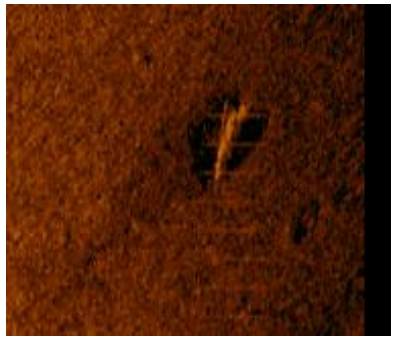
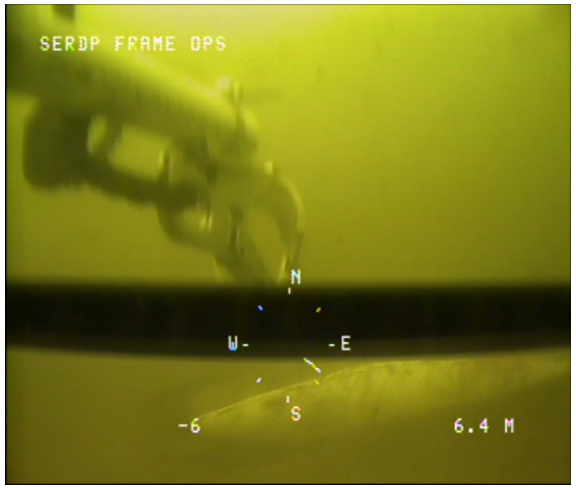
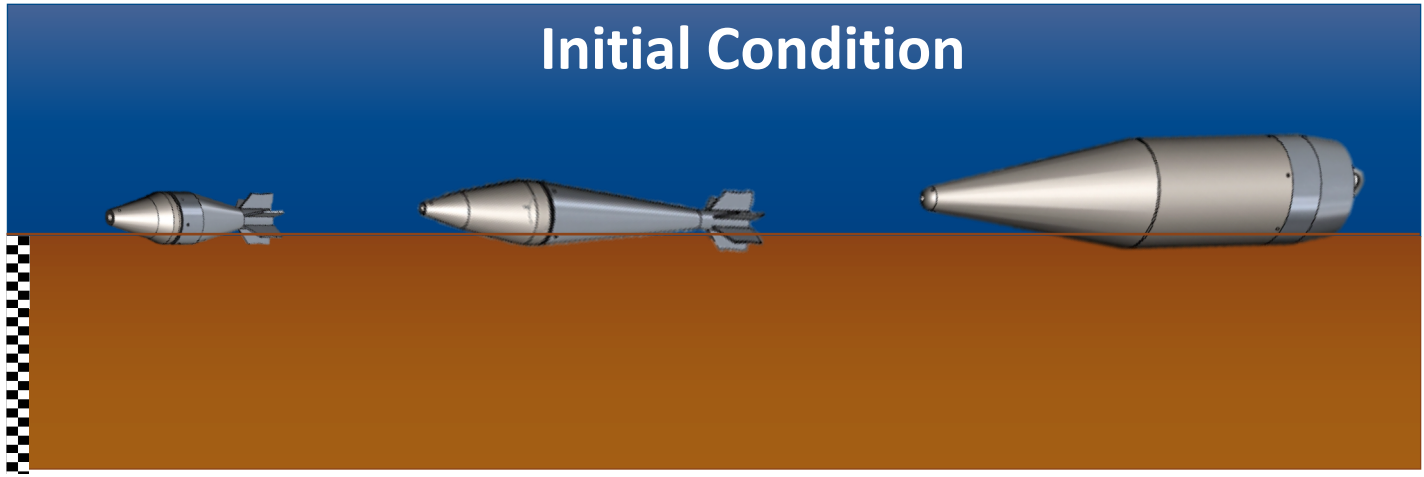
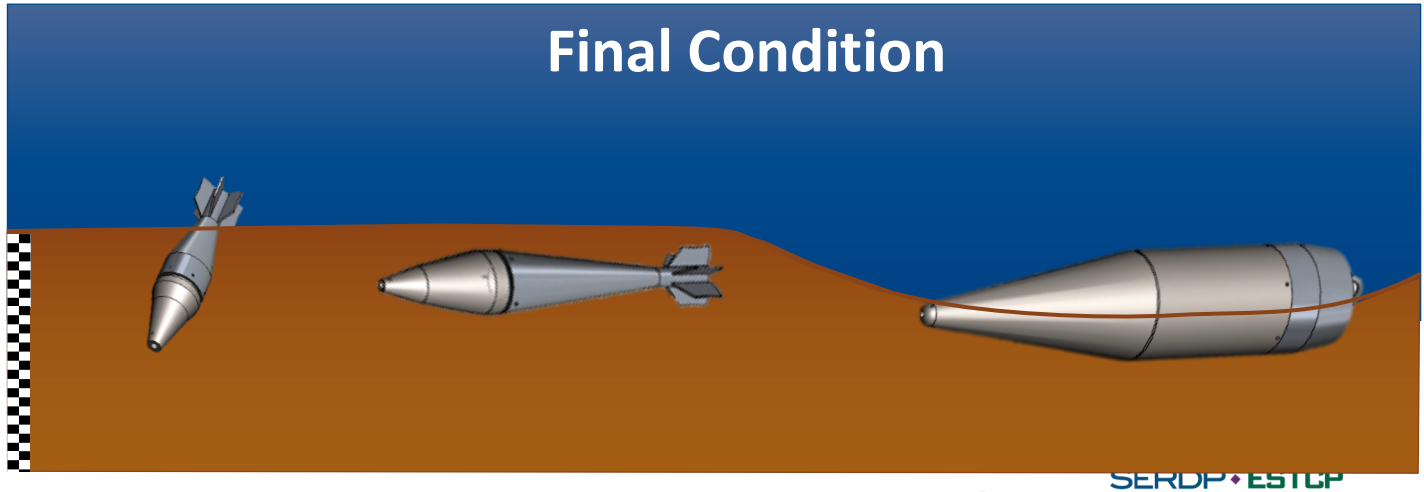
# Scour / Burial

- Diver and remote observations
  - 155mm sitting exposed in large scour pits
  - 81mm mortars partially or fully buried
  - 60mm partially buried
    - In 2 cases (60mm B,C), oriented nearly vertical with only fins exposed





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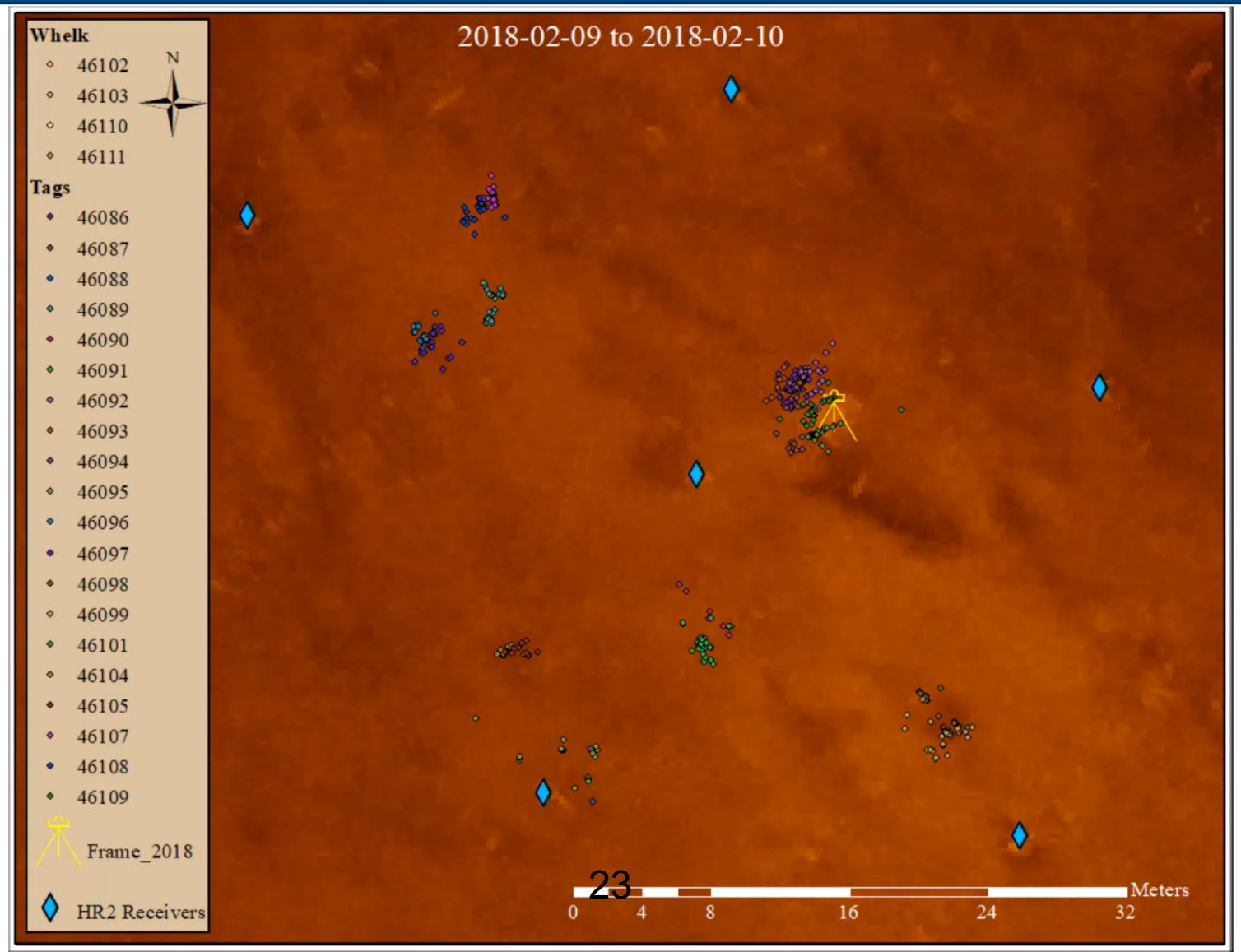
# Spring 2018 Animation



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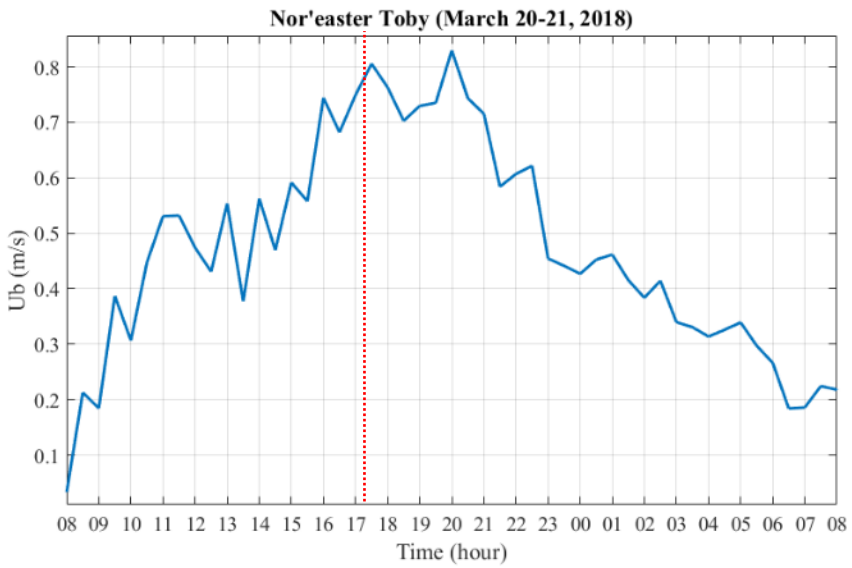
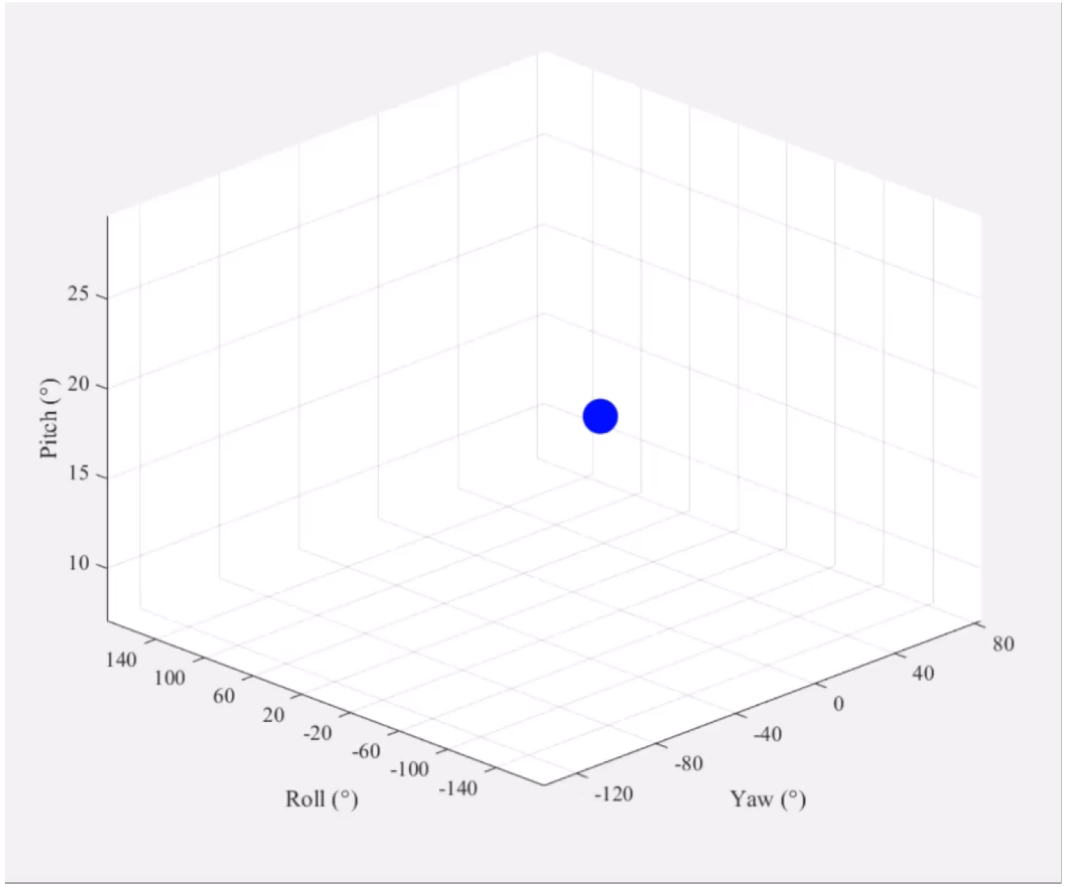
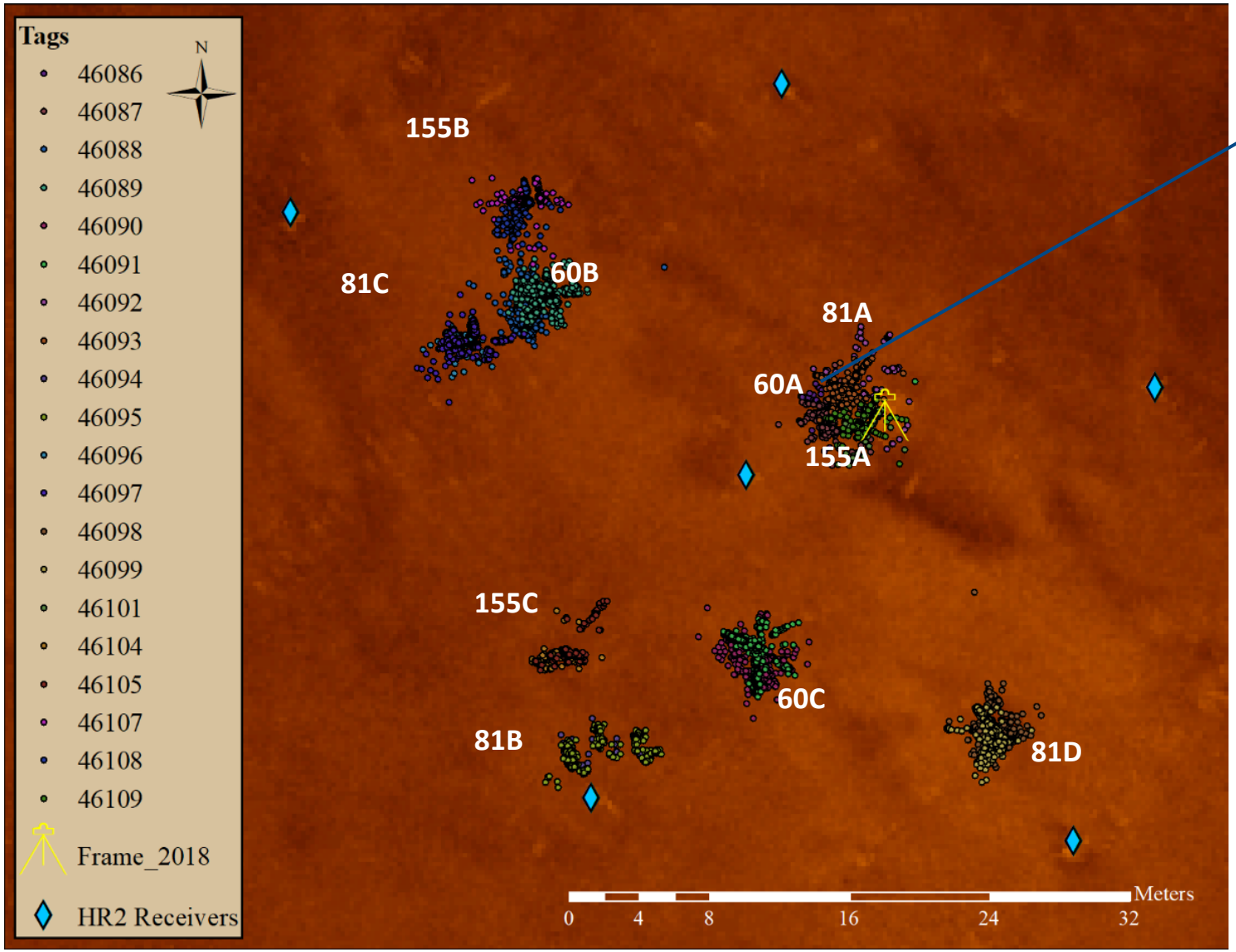
# 60mm Mortar (IMU animation)

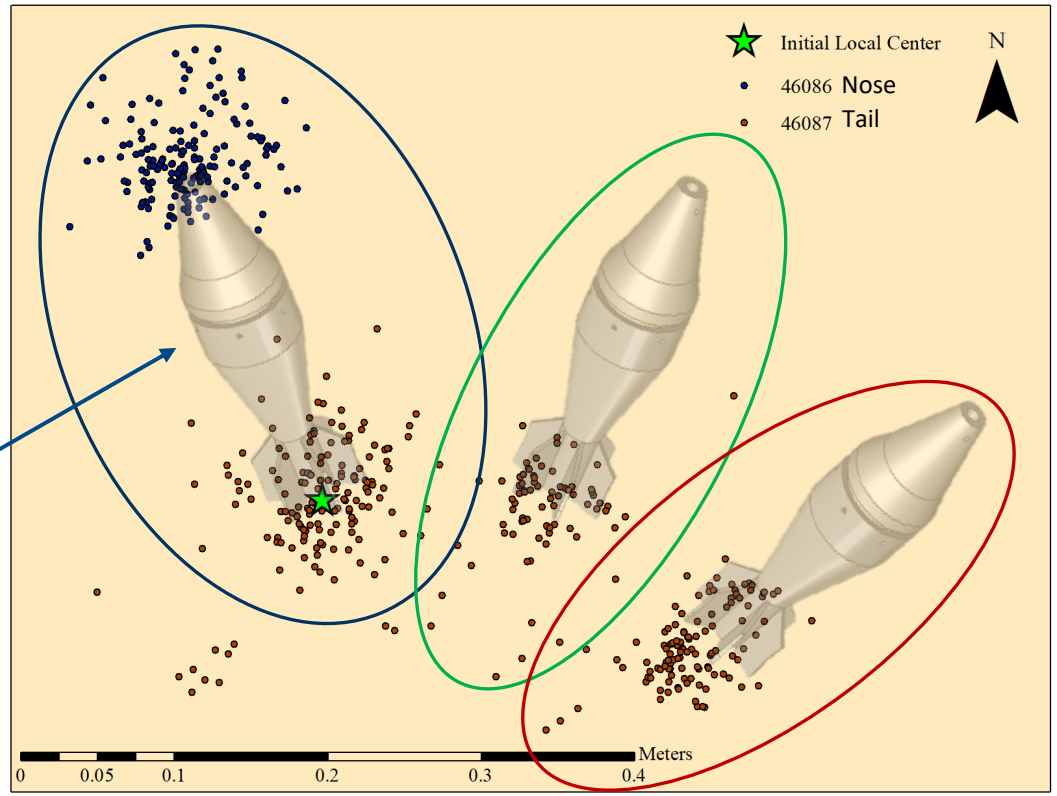
- Nor'easter Toby – March 20, 2018
  - Episodic rolling between 1700 and 2100 UTC

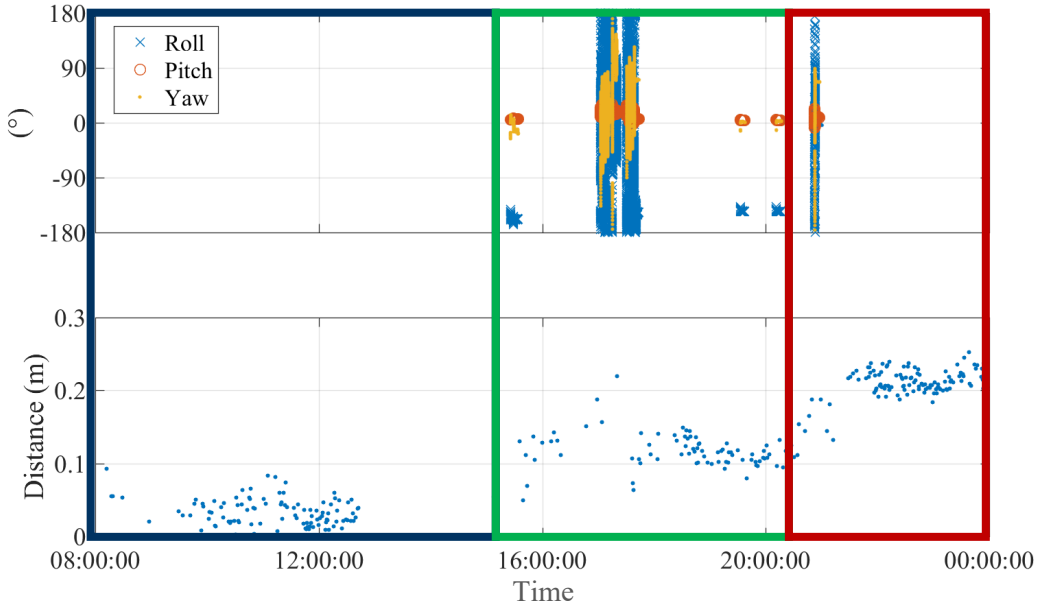


# 60mm Mortar – March 20, 2018

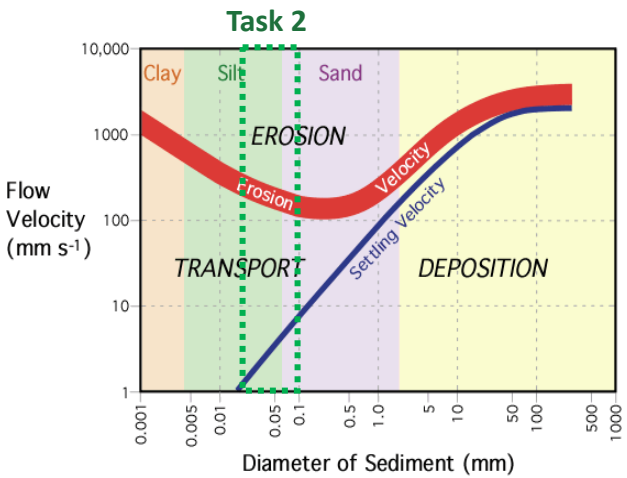


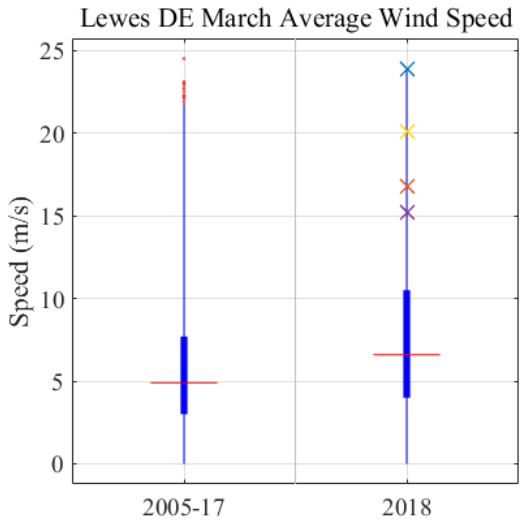



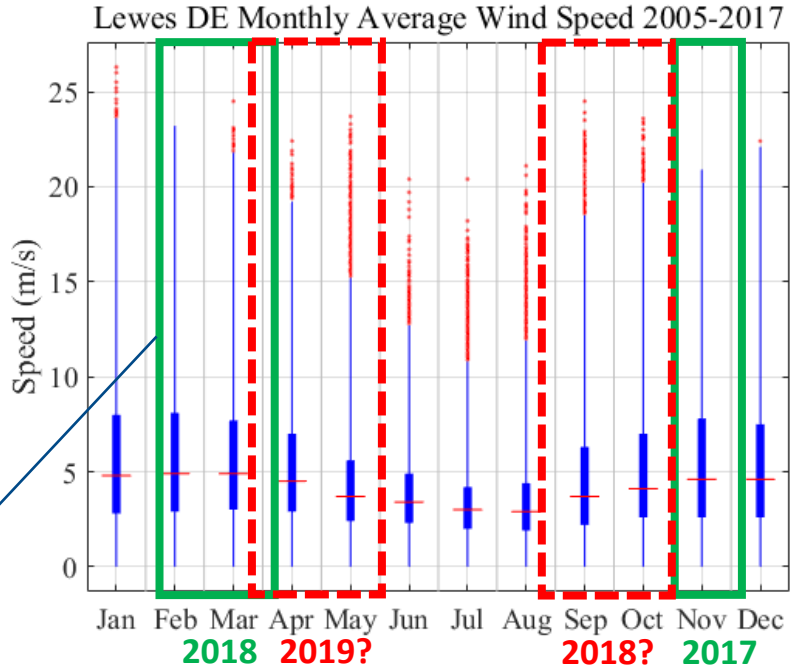



# Task 4 - Filling in the Parameter Space

- 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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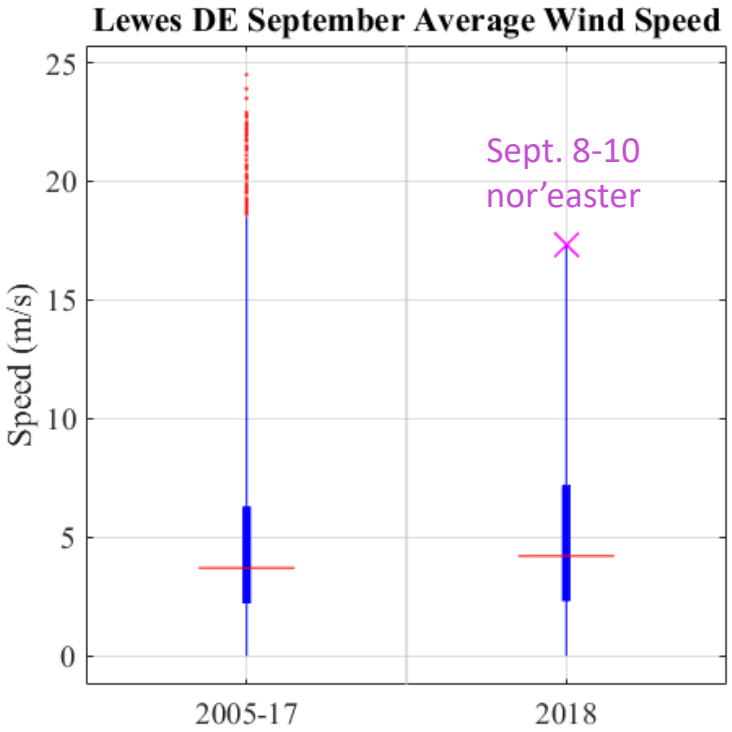
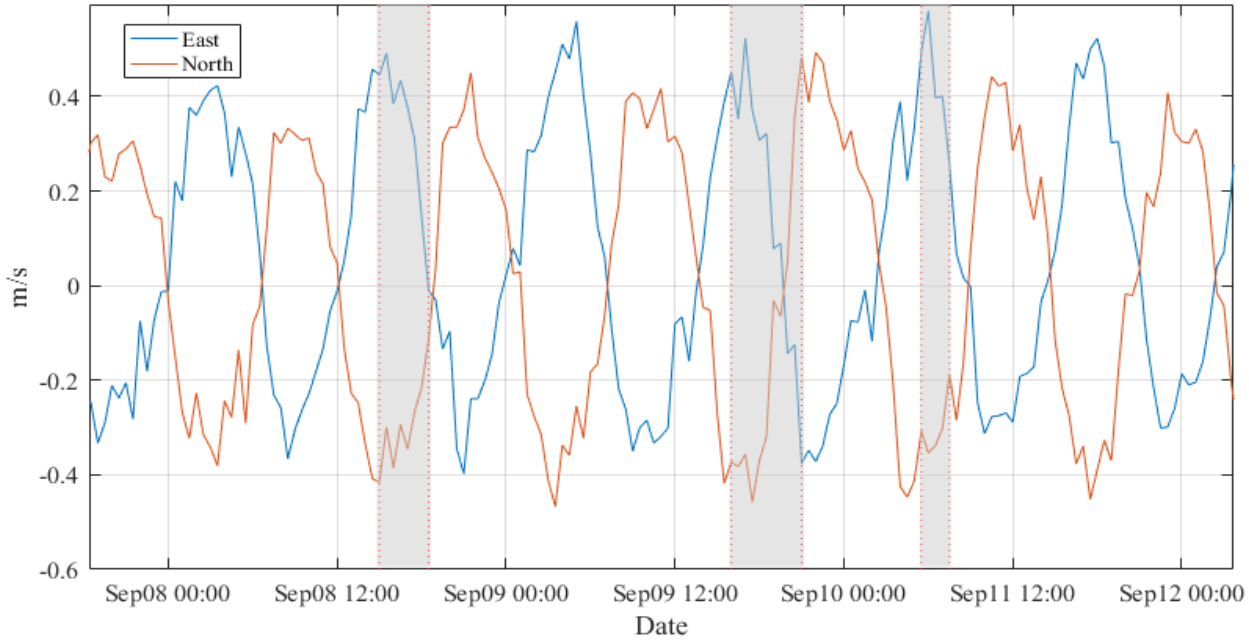
# Fall 2018 Deployment

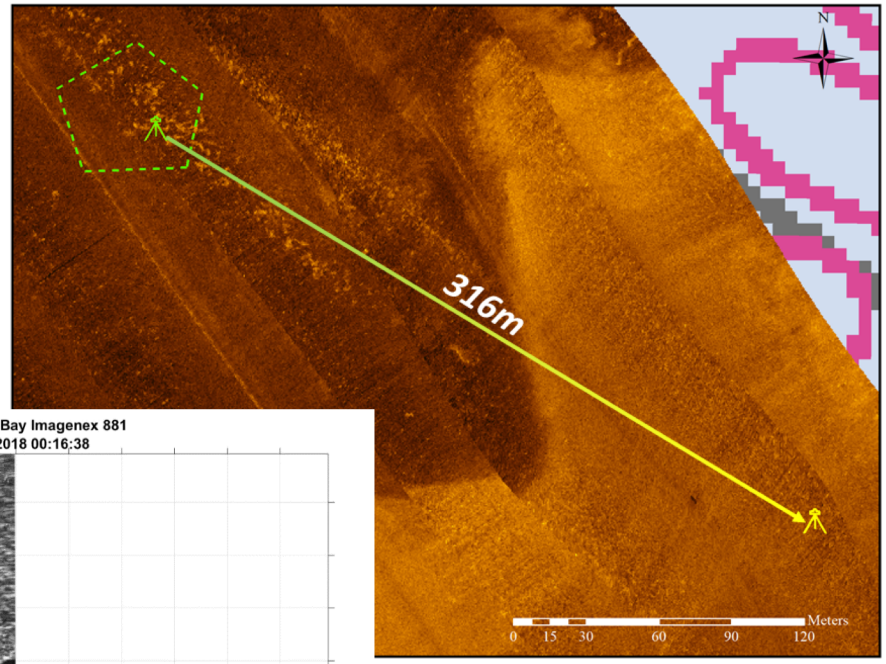
- Fall 2018: Aug. 28 – Nov. 19 (83 Days*)
  - Location: Site 2 (sandy mud)
  - Activities
    - Surveys (Aug. 27, Sep. 17, 23, Oct. 03, 22, Nov. 07) – side-scan, bathymetry, magnetometry, and/or sediment sampling
  - Surrogates – equipped with IMU's and 2 acoustic tags
    - 3 – 60mm mortars
    - 4 – 81mm mortars
    - 3 – 155mm artillery (equipped with pressure sensors)
  - Highlights
    - 2 Nor'easters (Sept 8-10, Oct. 27)
    - Instrument frame moved out of study area

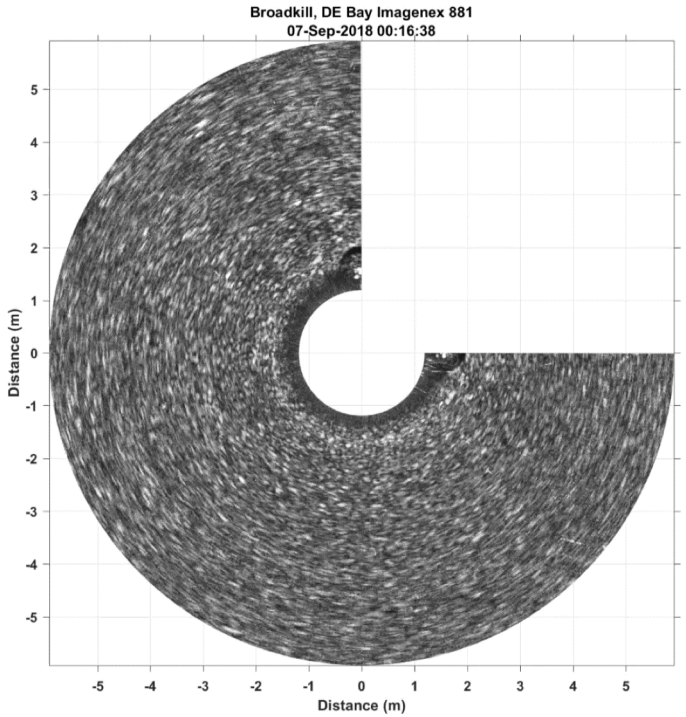


# The Case of the Missing Frame…

- Frame displaced 316m to the SE after Sept. 8-10 storm
  - Occurred over 3 phases in storm, initiated by peak ebb tide
  - Water level 0.6m higher than average



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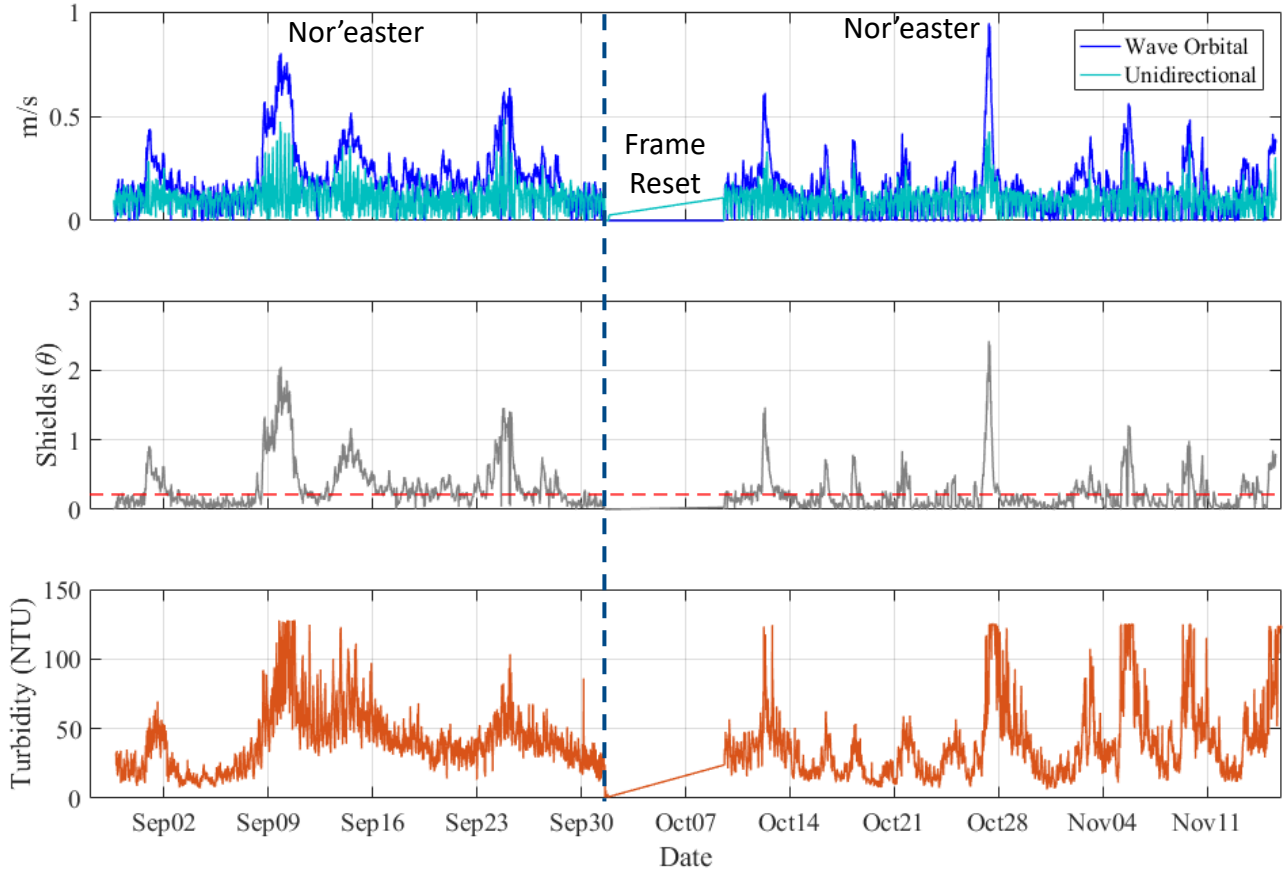
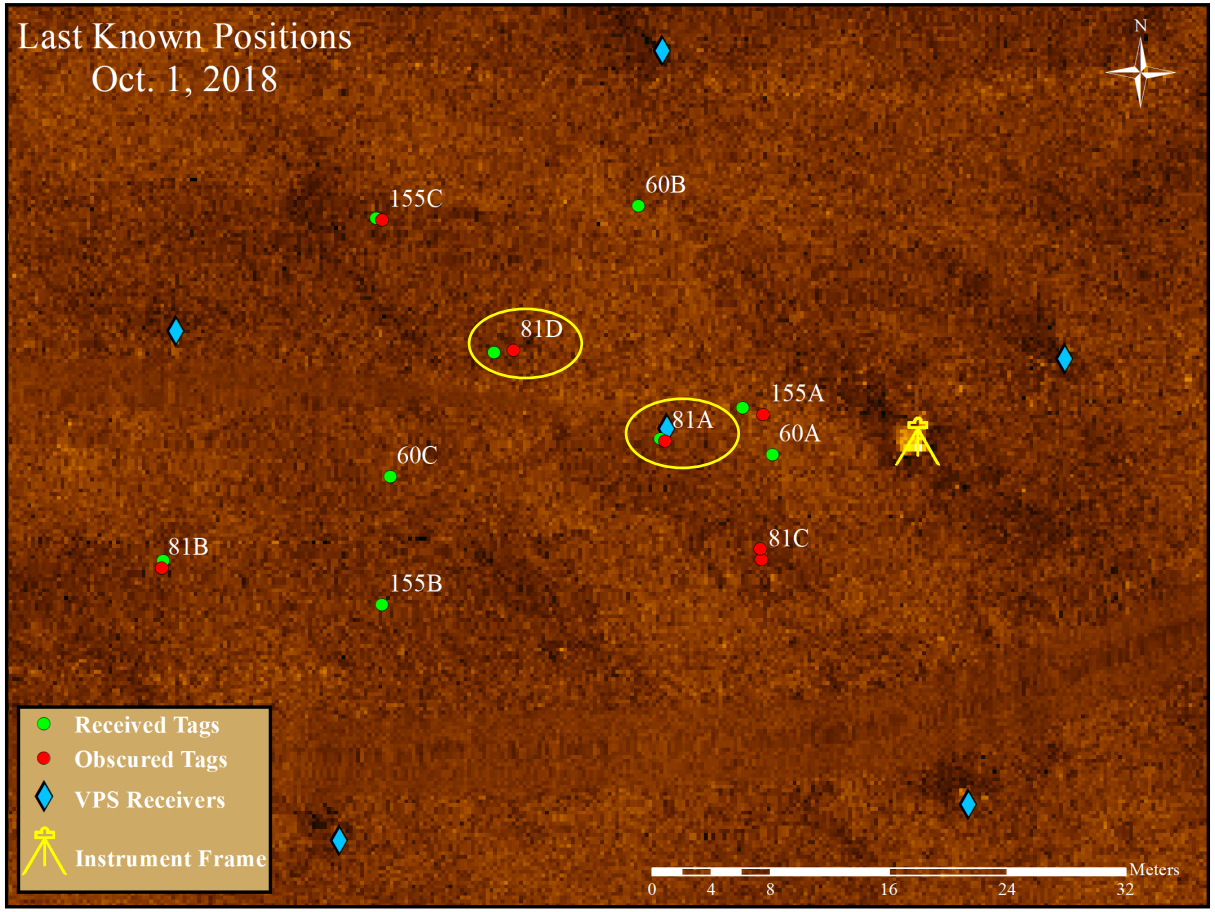
# Fall 2018 Deployment



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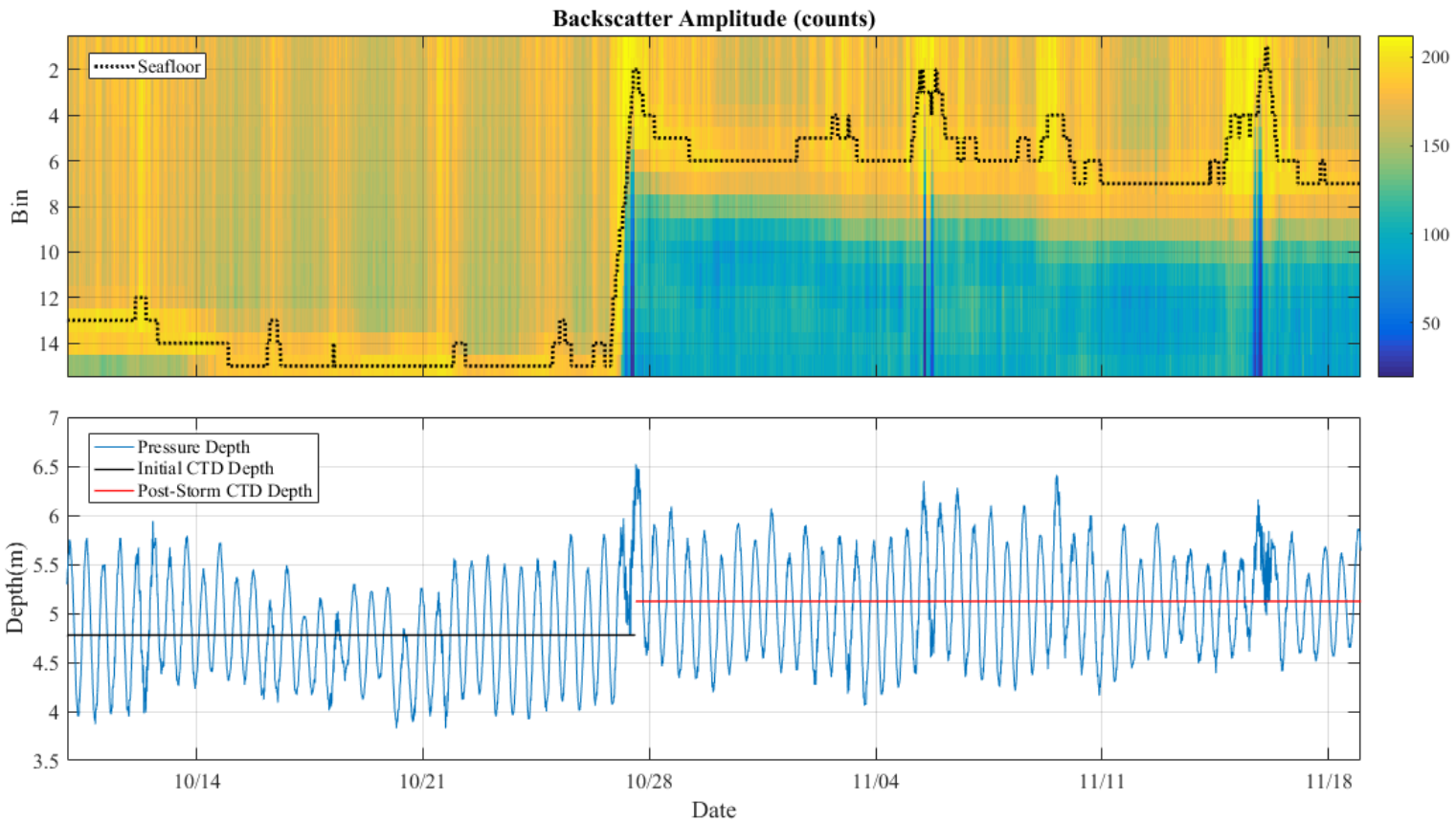
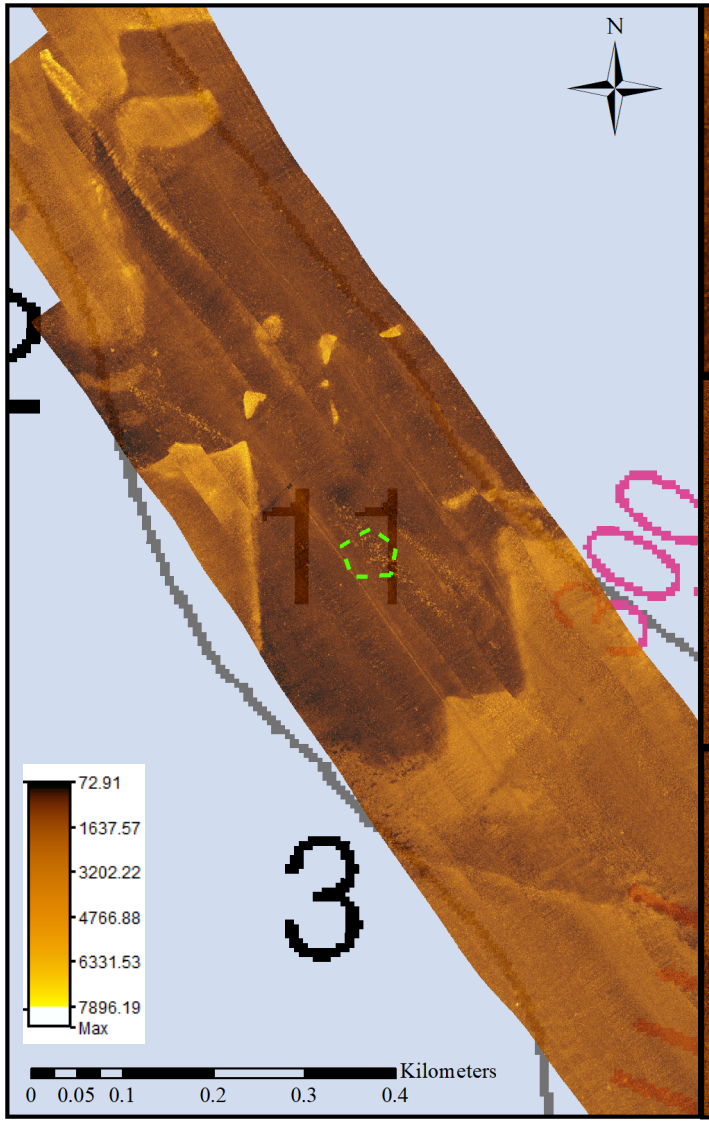
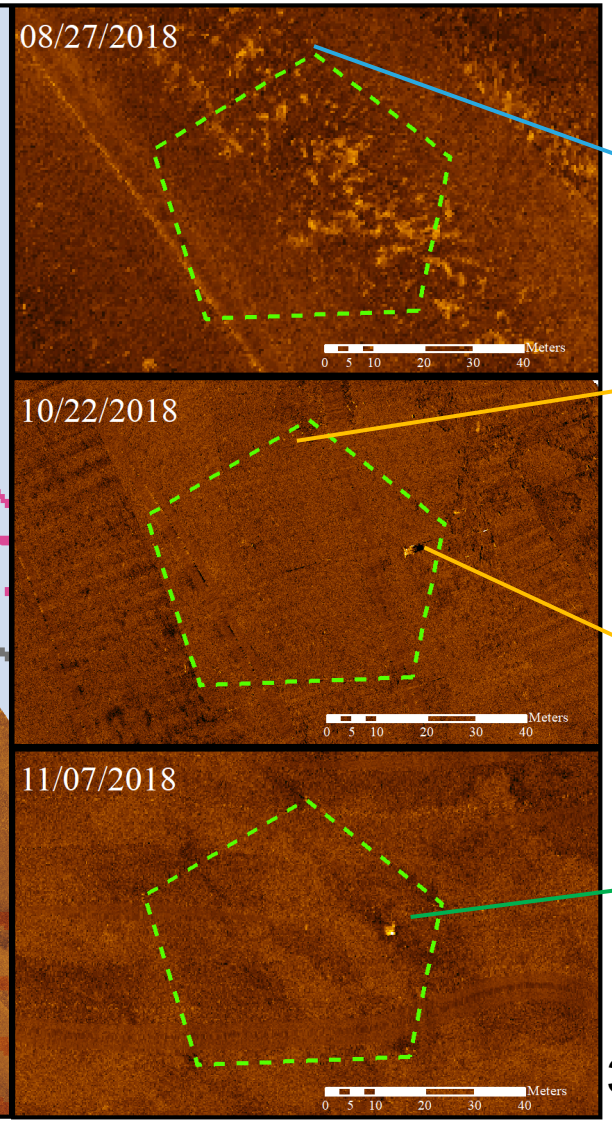
# Scour & Burial

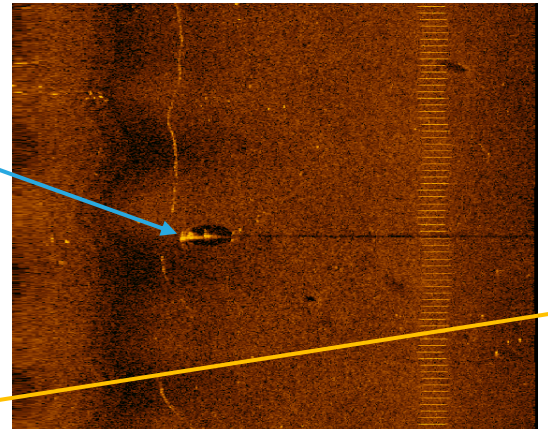


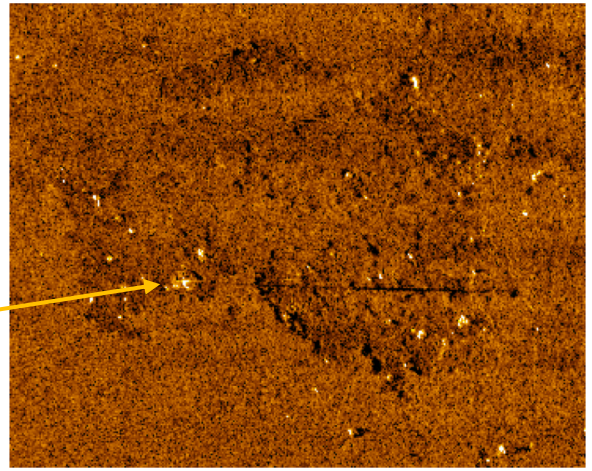

- Several surrogate tags were still detected by Oct. 1, suggesting only partial burial
- By Nov. 19, divers recovered two 81mm buried under ~20cm of mud
  - Failed to locate several other munitions suggesting total burial
- Instrument frame was recovered with feet showing similar burial depth
  - Backscatter from Aquadopp indicates rapid and significant burial Oct. 27-28
  - Pressure record shows 34cm shift in frame depth before and after storm

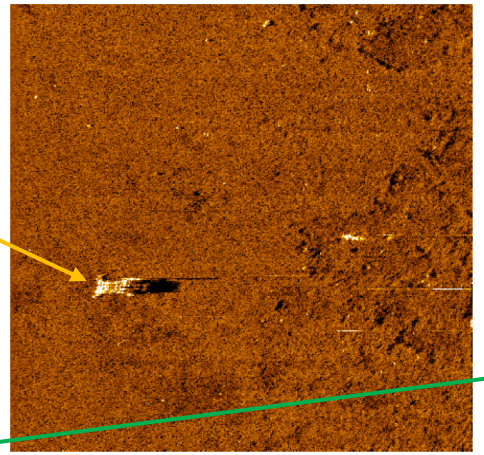
# Geomorphology

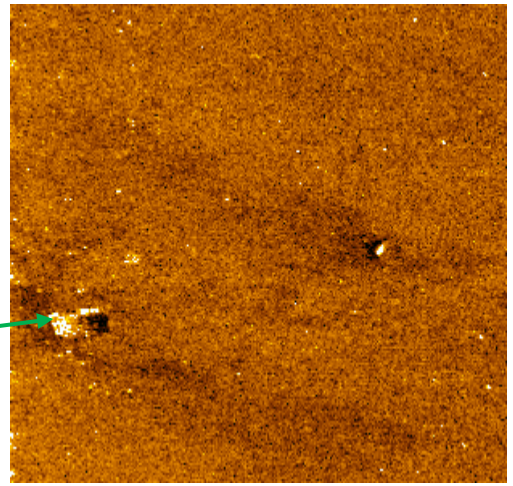










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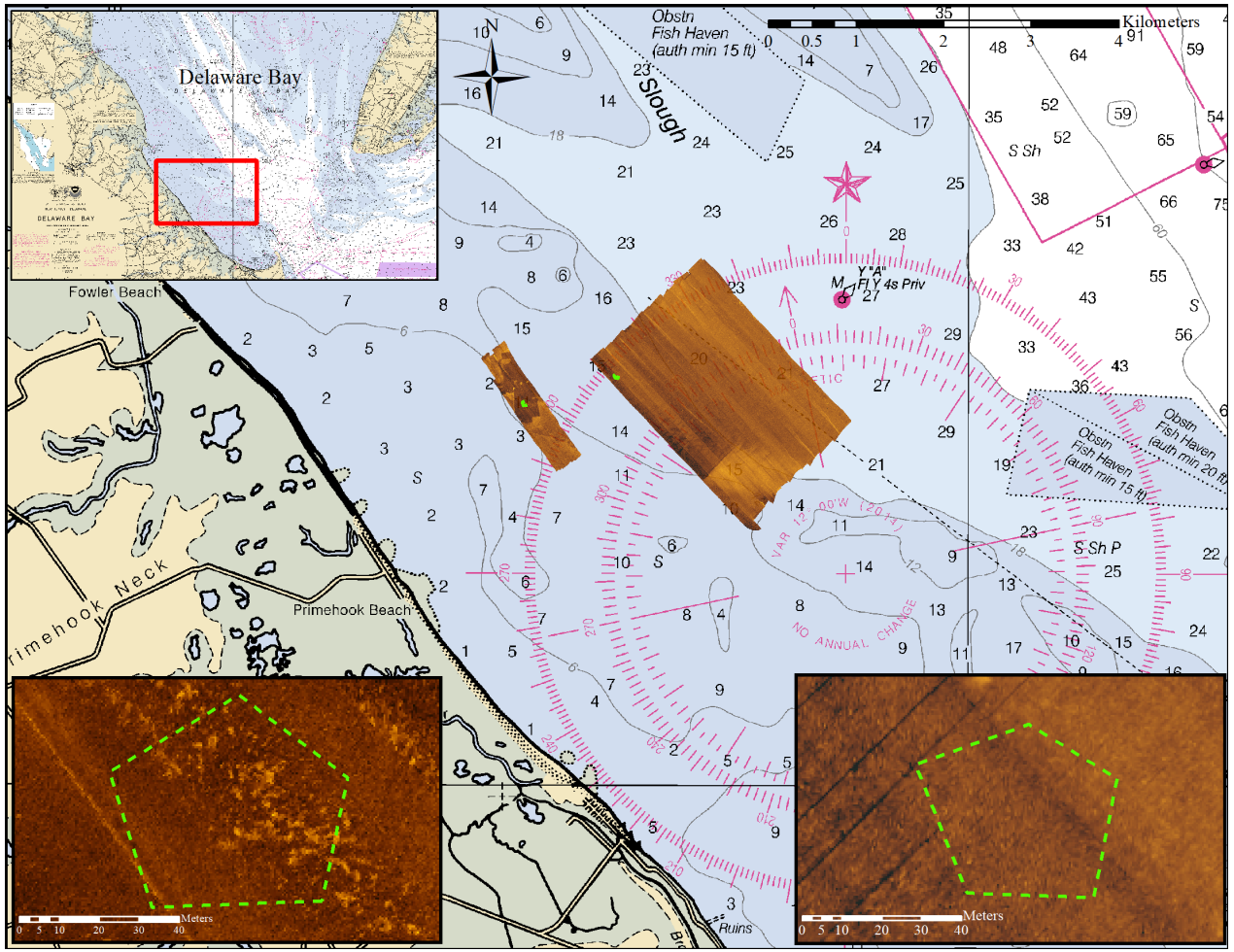
# Conclusion

- Novel combined acoustic tracking / IMU (3 deployments)
  - VPS capable of tracking sub-meter movement during storms
- Field deployments have included both fair-weather and storm events
  - 6 storm events in 2018
- Estuarine sediment dynamics – transition from mud to mixed sediments during storm conditions
- Surrogate burial observed in both deployments featuring storm events
- Next Steps:
  - 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

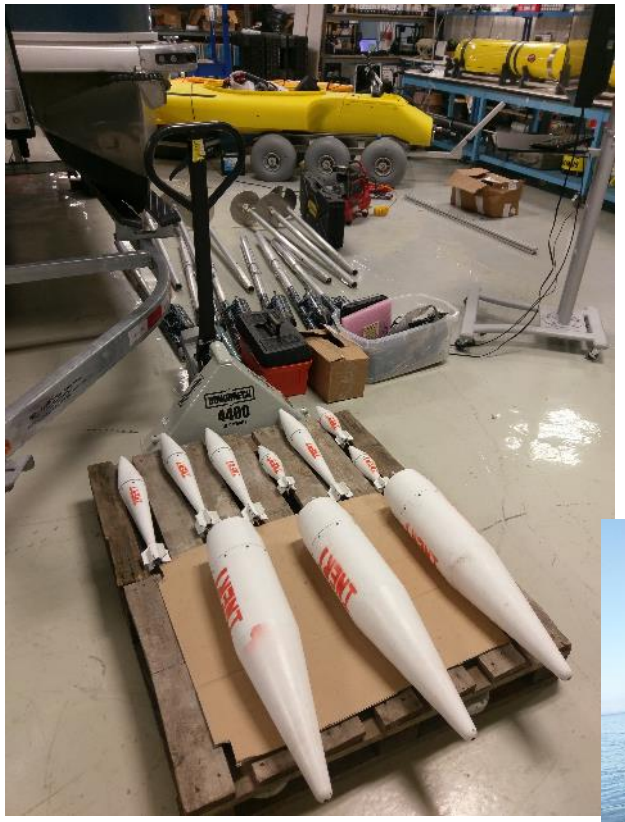
# Task 2: Field Implementation

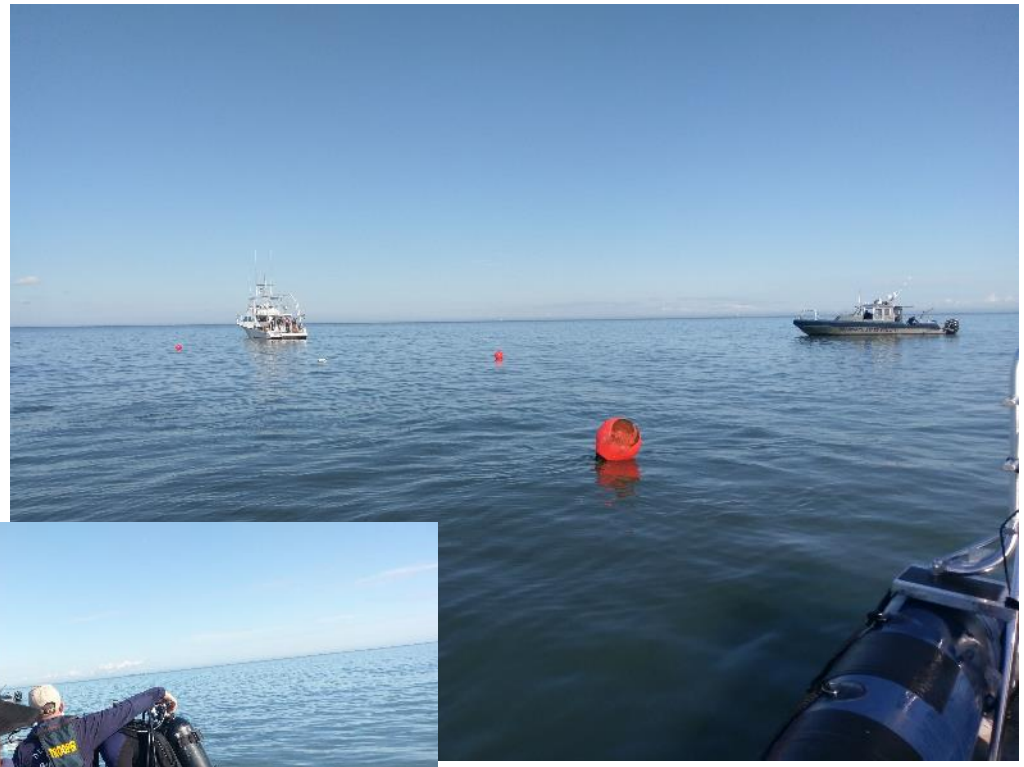


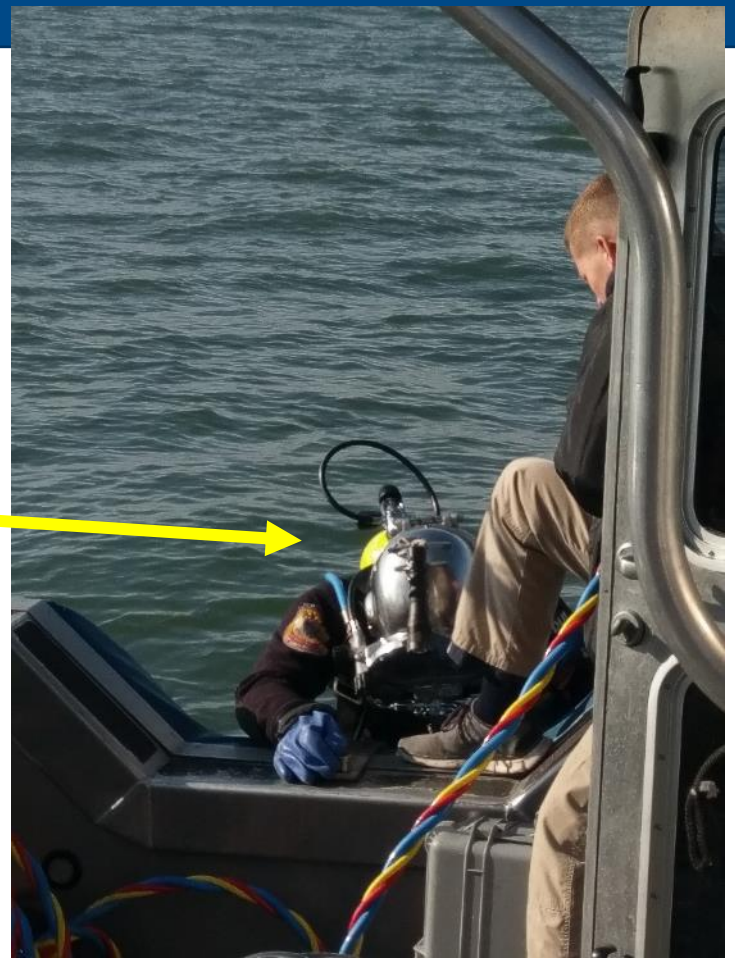

- VPS Grid and Surrogate Tracking
  - Deployed in pre-determined shallow, muddy site in DE, Bay
  - Complete bathymetric, magnetometer, sub-bottom, and side-scan surveys
  - Sediment grab samples and shallow cores
  - In-situ hydrodynamic sensors

# SERDP: 2017 Field Test

- Assisted by the DE State Police Scuba Unit







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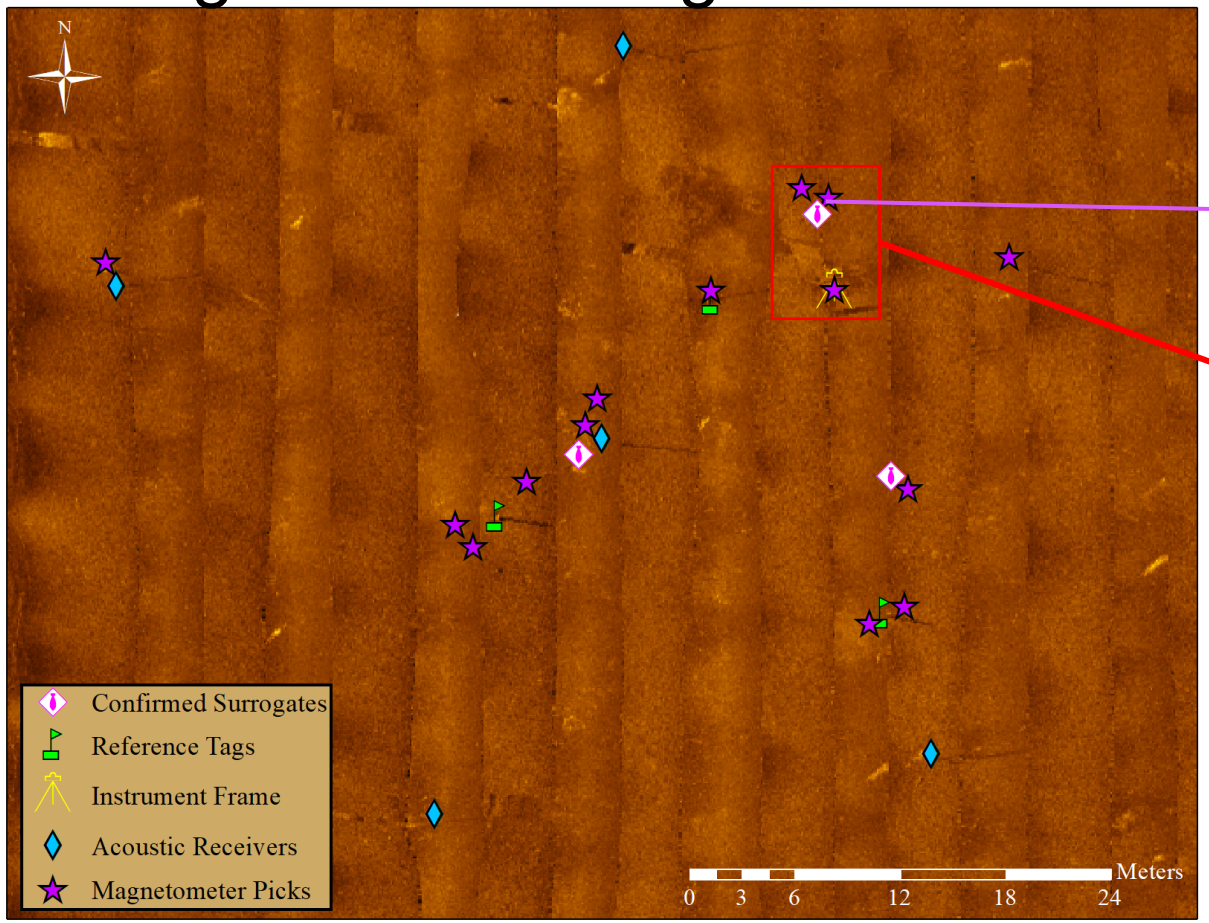
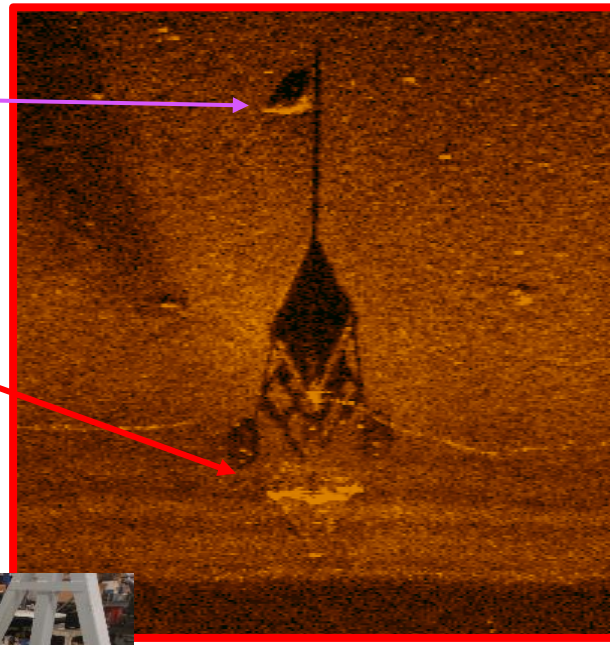
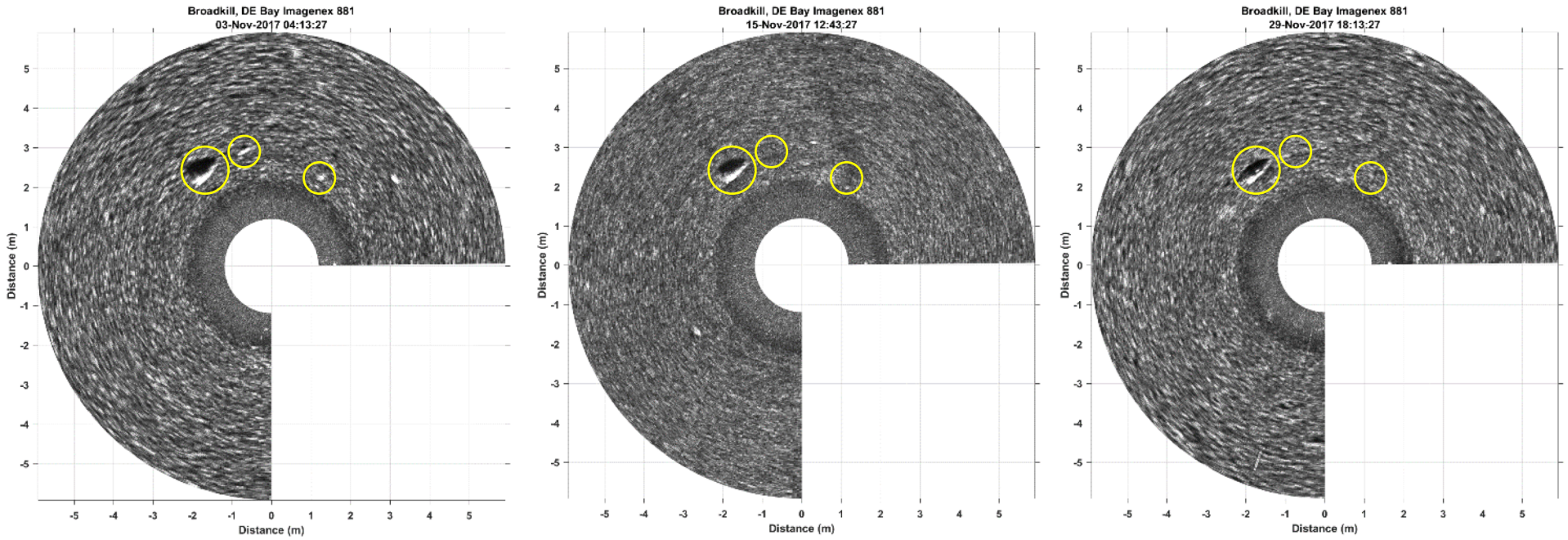
# SERDP: 2017 Field Test

- 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



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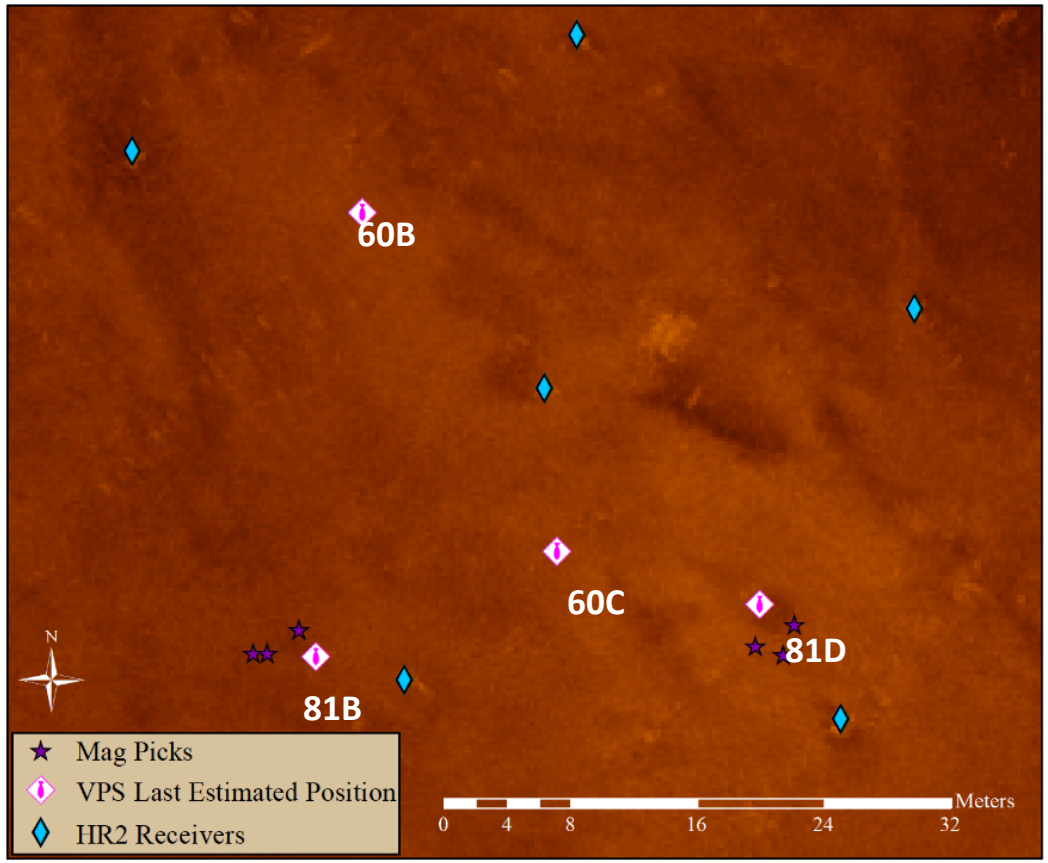
# Unrecovered Surrogate Search

- 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



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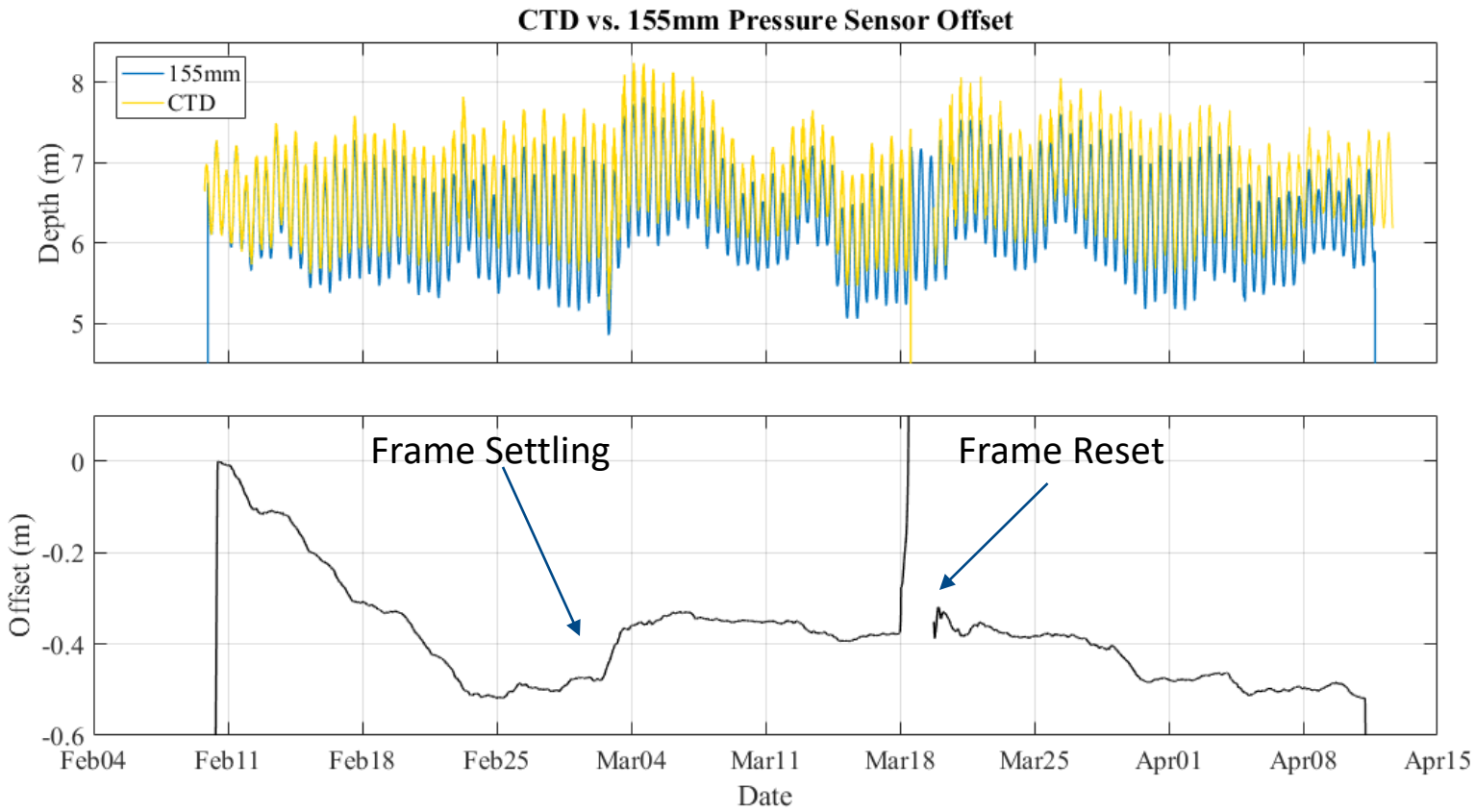
# Scour / Burial

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