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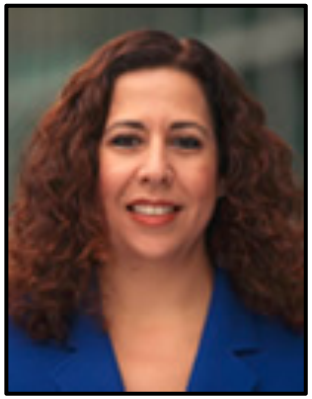
Understanding Underwater Munitions Mobility and Behavior on the Beach Face and in Shallow Muddy Environments

July 25, 2019

Welcome and Introductions

Rula A. Deeb, Ph.D.
Webinar Coordinator



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Webinar Agenda

- **Webinar Logistics** (5 minutes)
  Dr. Rula Deeb, Geosyntec Consultants
- **Overview of SERDP and ESTCP** (5 minutes)
  Dr. Herb Nelson, SERDP and ESTCP
- **Mobility of Instrumented Unexploded Ordnance in the Nearshore Environment** (25 minutes + Q&A)
  Dr. Jack Puleo, University of Delaware
- **Unexploded Ordnance Characterization and Detection in Muddy Estuarine Environments** (25 minutes + Q&A)
  Dr. Arthur Trembanis and Dr. Carter DuVal, University of Delaware
- **Final Q&A session**

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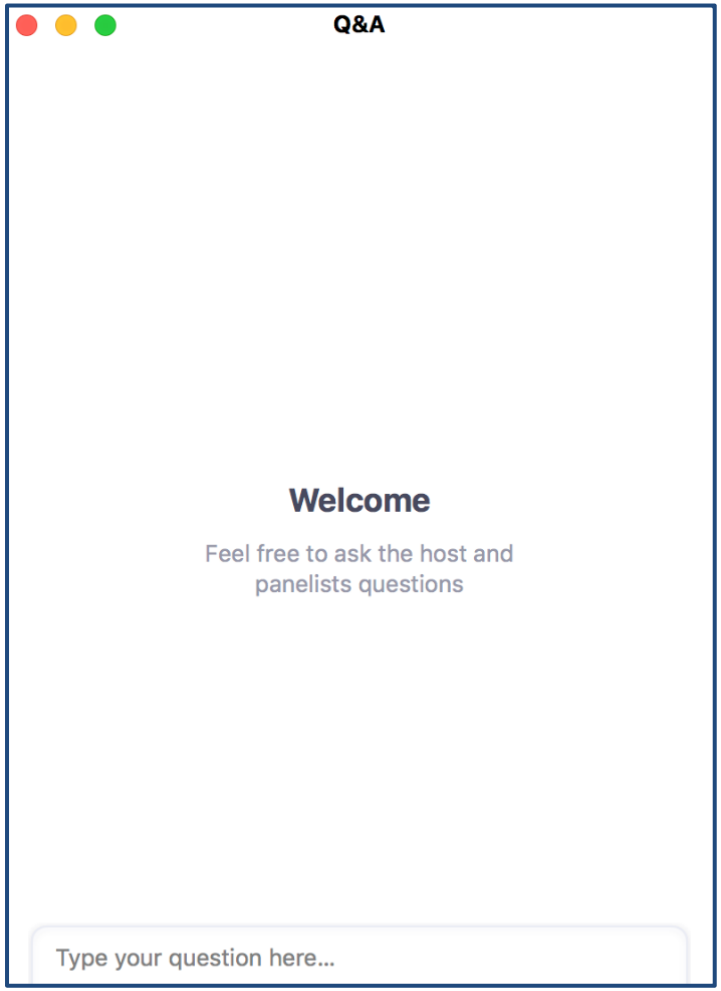
- Make sure to add your organization name at the end of your question so that we can identify you during the Q&A sessions



SERDP and ESTCP Overview

Herb Nelson, Ph.D.
SERDP and ESTCP

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SERDP

- Strategic Environmental Research and Development Program
- Established by Congress in FY 1991
  - DoD, DOE and EPA partnership
- SERDP is a requirements driven program which identifies high-priority environmental science and technology investment opportunities that address DoD requirements
  - Advanced technology development to address near term needs
  - Fundamental research to impact real world environmental management

ESTCP

- Environmental Security Technology Certification Program
- Demonstrate innovative cost-effective environmental and energy technologies
  - Capitalize on past investments
  - Transition technology out of the lab
- Promote implementation
  - Facilitate regulatory acceptance

Program Areas

- Environmental Restoration
- Installation Energy and Water
- Munitions Response
- Resource Conservation and Resiliency
- Weapons Systems and Platforms

Munitions Response

- Munitions on land
  - Classification
- Munitions underwater
  - Wide area and detailed surveys
  - Cost-effective recovery and disposal
  - Characteristics of munitions underwater, their environment and mobility

SERDP and ESTCP Webinar Series

Date	Topic
August 8, 2019	Building Energy and Water Efficiency Solutions
August 22, 2019	Pacific Island Ecology and Management: Recovery of Native Plant Communities Following Removal of Non-Native Species
September 5, 2019	The Use of Advanced Molecular Biological Tools in Groundwater Contaminated with Chlorinated Solvents
September 19, 2019	Life Cycle Assessment and Developmental Environment Safety and Occupational Health Evaluation: Tools for Sustainment and Health
October 3, 2019	Variation in Phenological Shifts: How do Annual Cycles and Genetic Diversity Constrain or Enable Responses to Climate Change?

For upcoming webinars, please visit

http://serdp-estcp.org/Tools-and-Training/Webinar-Series

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Save the Date!

SERDP • ESTCP
SYMPOSIUM

A three-day symposium showcasing the latest technologies that enhance DoD's mission through improved environmental and energy performance

December 3-5, 2019

Washington Marriott Wardman Park

Registration is open

Munitions Mobility on the Beach Face

Jack A. Puleo, Ph.D.
University of Delaware

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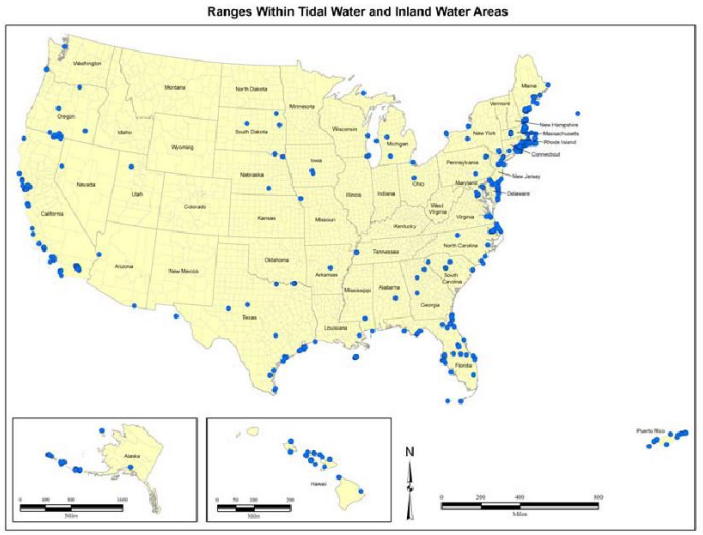
Agenda

- Overview of problem
- Making surrogate munitions
- Data collection procedures
- Migration results
- Burial results
- Summary

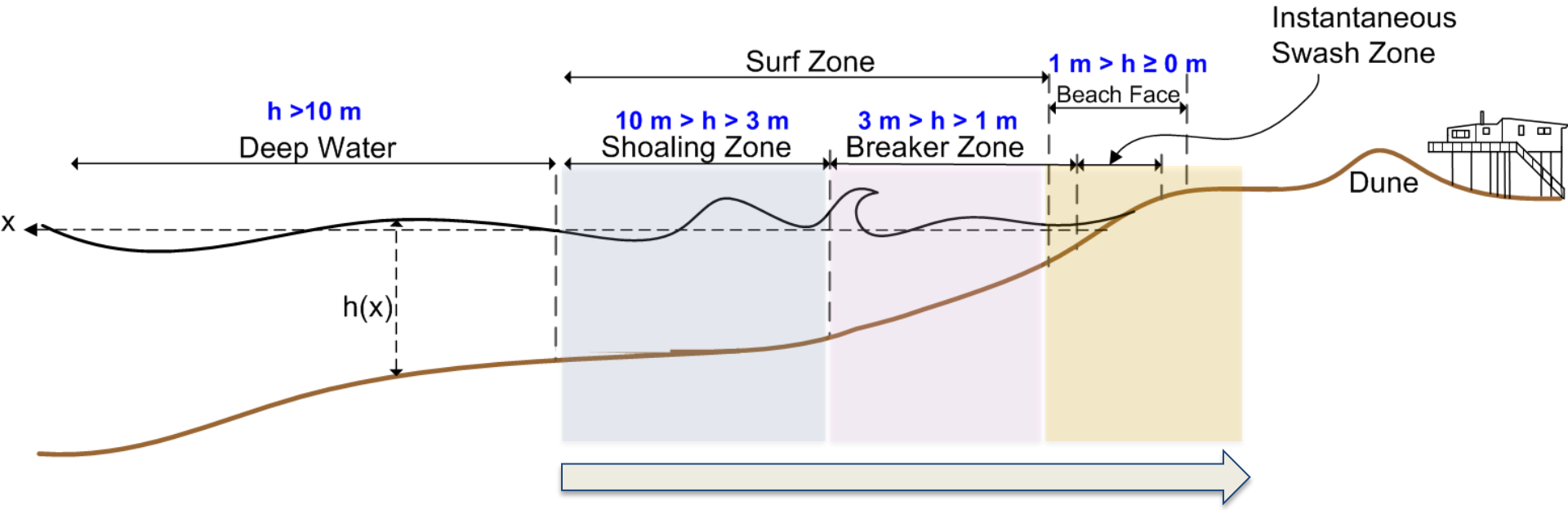
Problem Overview

- Majority of FUDS sites contain shoreline
- 39% of coastal sites → non-cohesive
- Coastal UXO studies focused on offshore
- Importance of beach face → receptor contact



The Beach Problem

- Physical processes differ across profile
- Large forcing in the swash zone



Near bed hydrodynamic forcing increases

Mobility and Burial Questions

1. Will buried munitions on the beach face be exhumed under wave action?
2. Will swash zone munitions transport onshore, offshore, alongshore, or bury?
3. Will munitions just outside the swash zone transport offshore, enter the swash zone, or bury?

Munitions of Interest

81 mm mortar

Mass: 4.58 kg Density: 4260 kg/m^3

155 mm HE

Mass: 43.00 kg Density: 4400 kg/m^3

BLU 61 Cluster Bomb

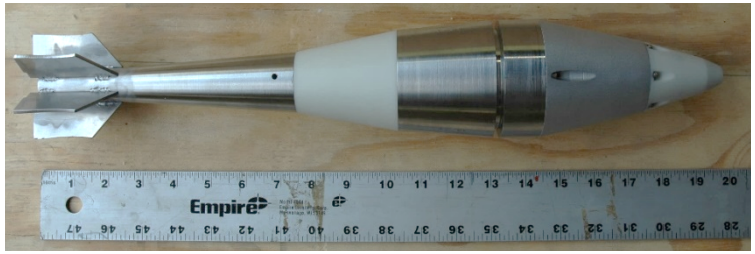
Mass: 1.47 kg Density: 4940 kg/m^3

Hydra-70 rocket

Mass: 4.22 kg Density: 3440 kg/m^3

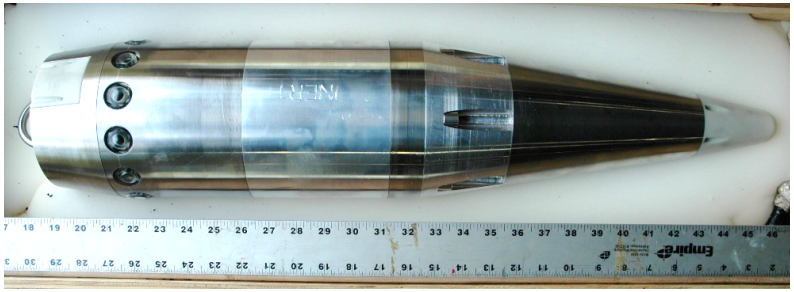
Surrogate Munitions

81 mm mortar



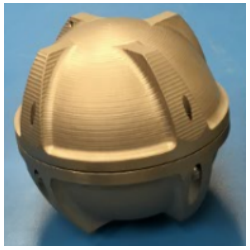
Mass: 4.50 kg Density: 4180 kg/m^3

155 mm HE



Mass: 41.29 kg Density: 4230 kg/m^3

BLU 61 Cluster Bomb



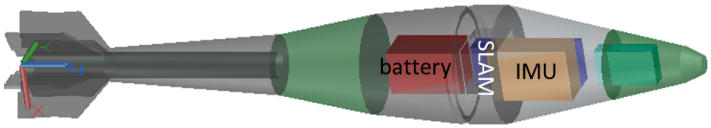
Mass: 1.39 kg Density: 4460 kg/m^3

Hydra-70 rocket

Mass: 4.06 kg Density: 3320 kg/m^3

“Smart” Surrogate Munitions

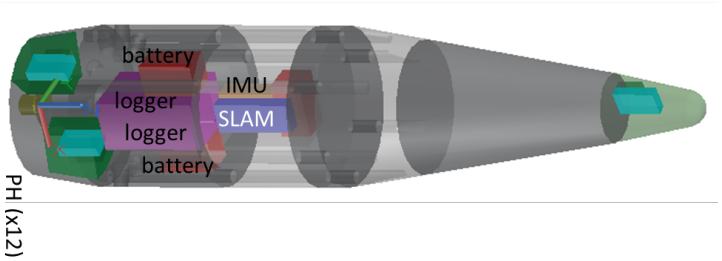
81 mm mortar



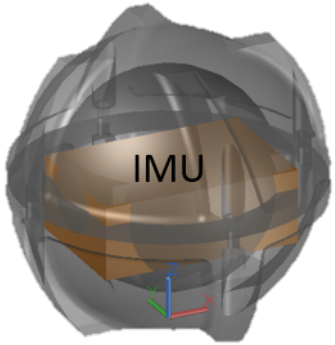
Measurements
- Position
- Wave impact

155 mm HE

Measurements
- Position
- Wave impact
- Water depth
- Rolling/buria



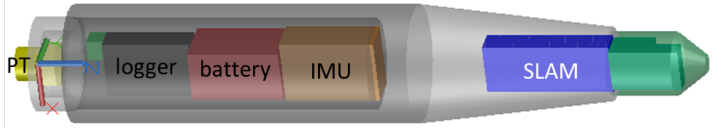
BLU 61 Cluster Bomb



Measurements
- Position

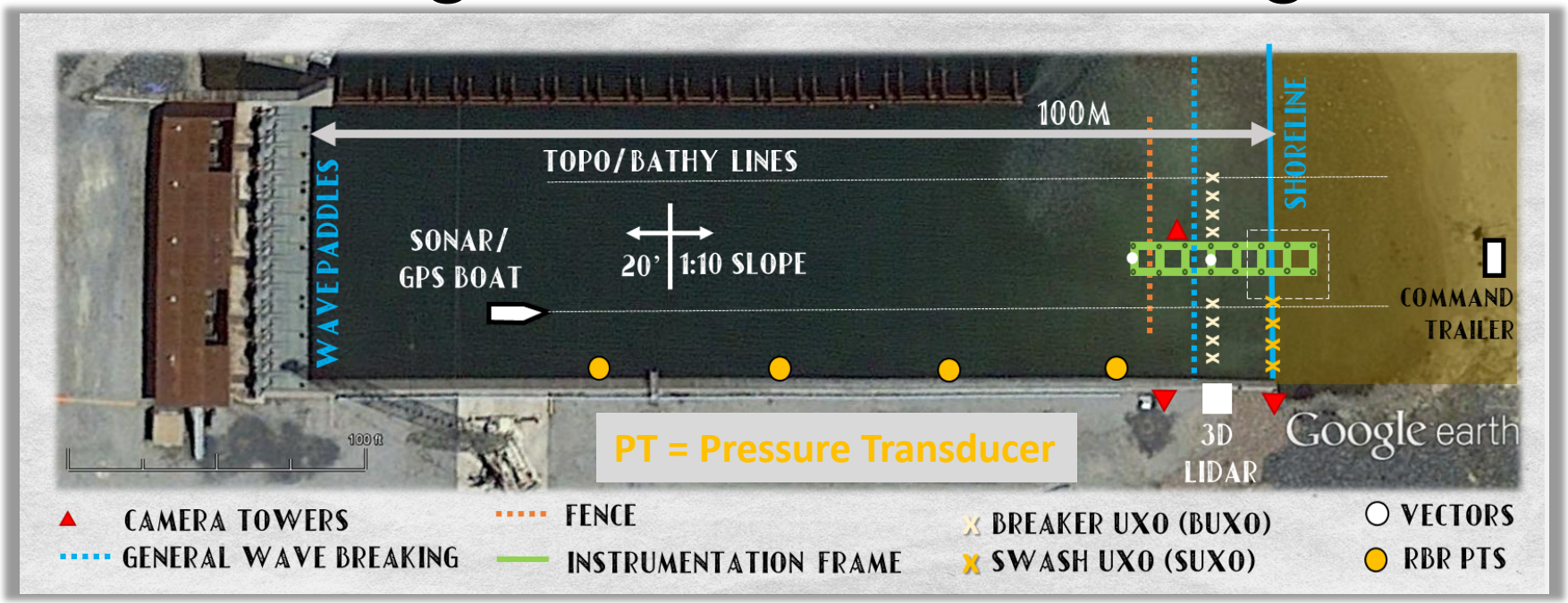
Hydra-70 rocket

Measurements
- Position
- Wave impact
- Water depth



IMU = Inertial Motion Unit **PT = Pressure Transducer**
SLAM = Shock sensor

Large-Scale Lab Testing

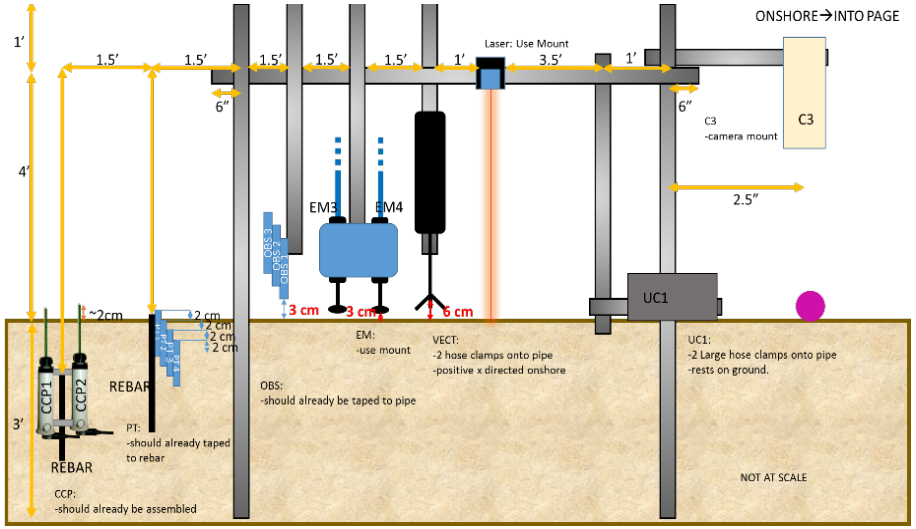


- Littoral Warfare Environment (LWE) at Aberdeen Test Center (ATC)
- 100 m long, up to 1.8 m high waves, 7 s period, reconfigurable beach
- Side-by-side comparison of inert and surrogate munitions (ATC priority study area)
- Jun 23-29; Nov 29-Dec 6, 2016

Small-Scale Lab Testing

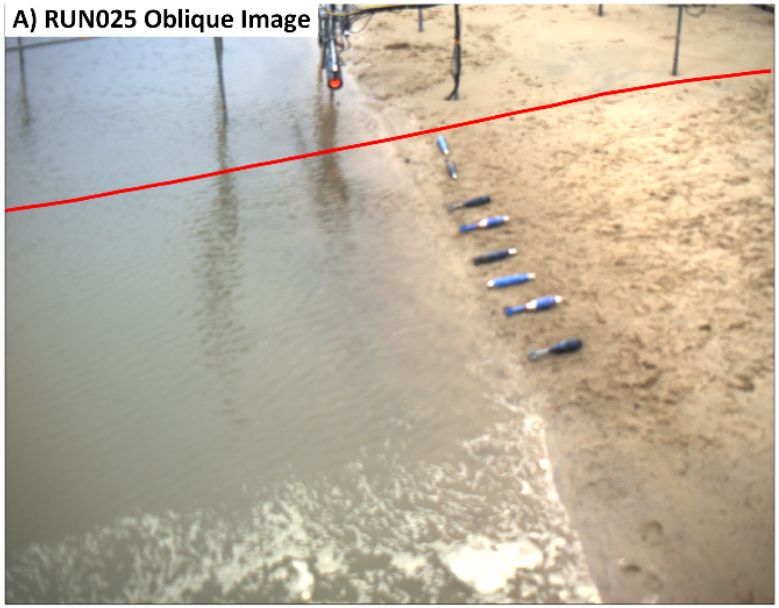
- Dam break
  - Repeatable forcing, same beach slope, single event
- 165 runs with multiple BLU-61 surrogates
- Alter
  - Cross-shore position
  - Initial burial depth
  - Surrogate density
    - SG = 1.8 to 7.7

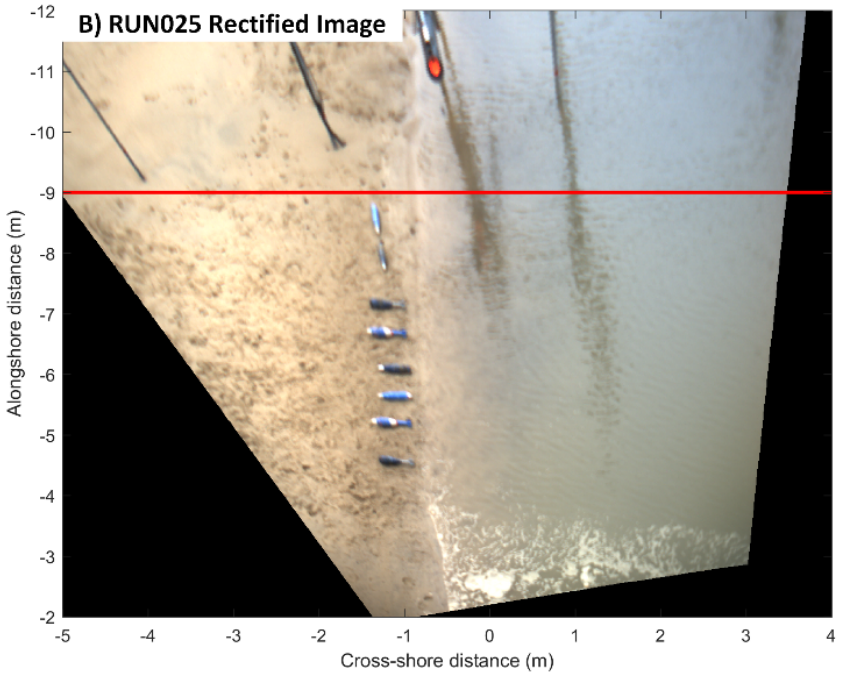
Sensor and Imagers



- Over 20 sensors
- ~60 data runs at Aberdeen
- GPS and sonar surveying → bathymetry

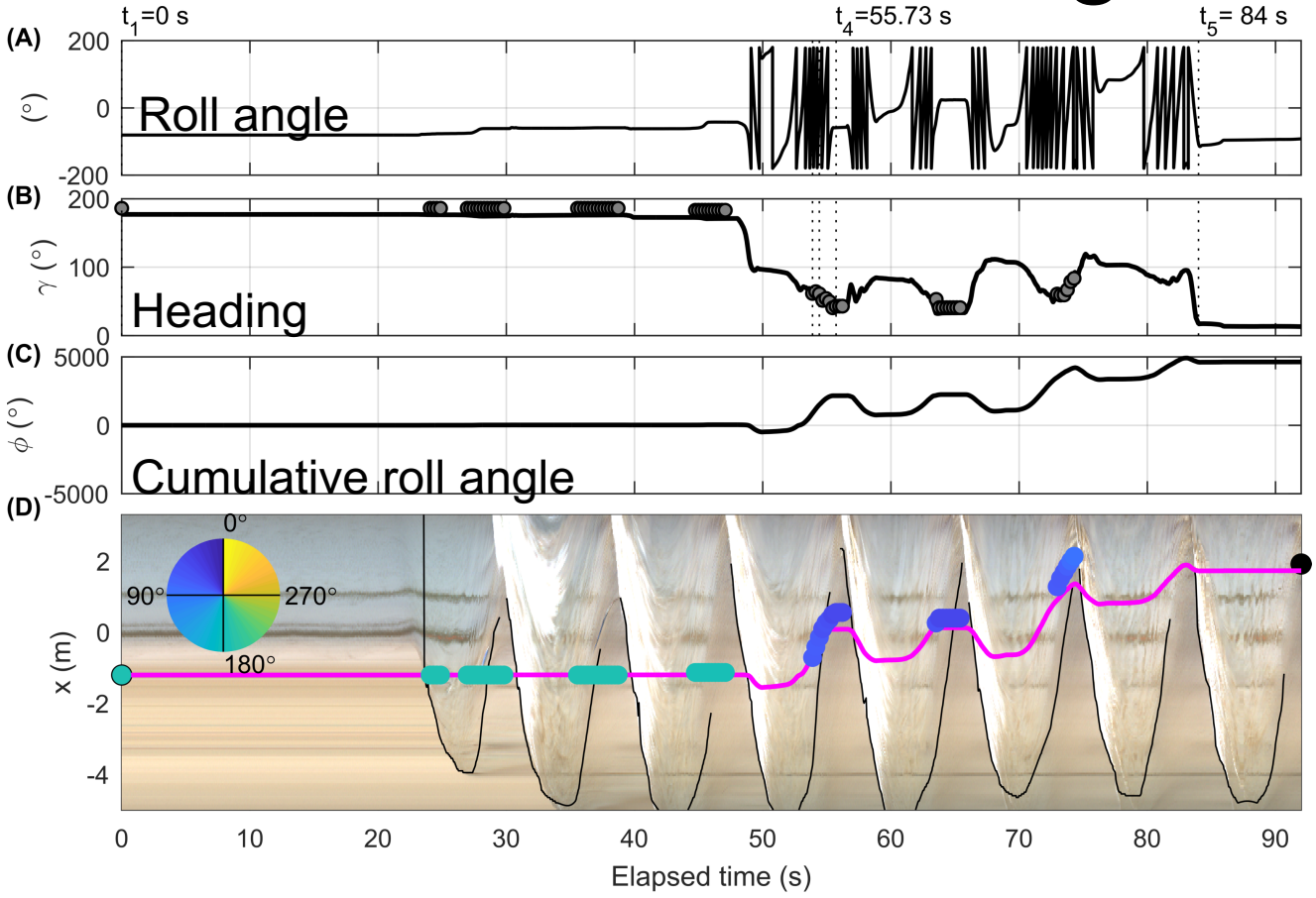
Image Rectification

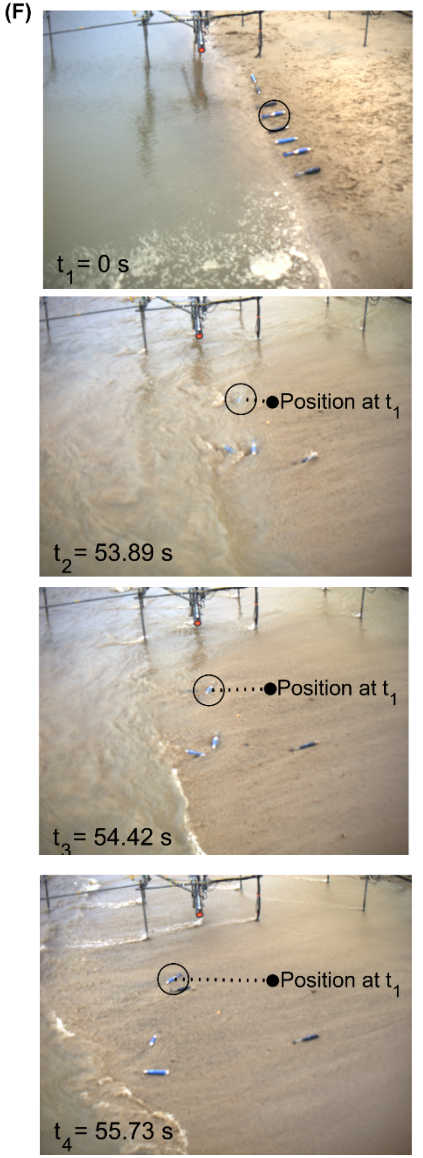




- Camera model → image to real world
- Quantify surrogate location/trajectory
- Quantify wave runup

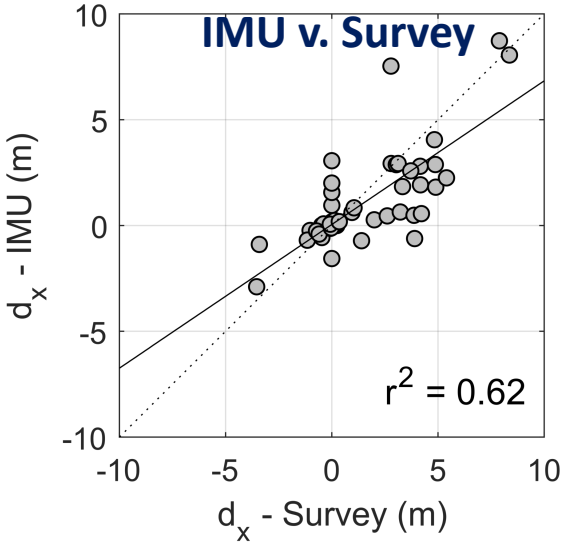
Results – Migration

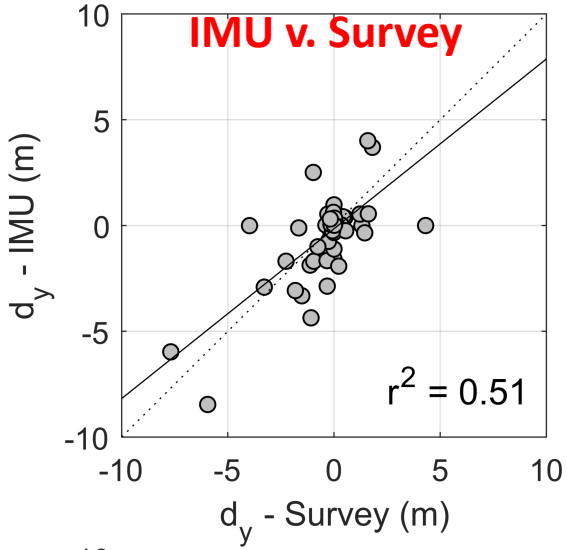


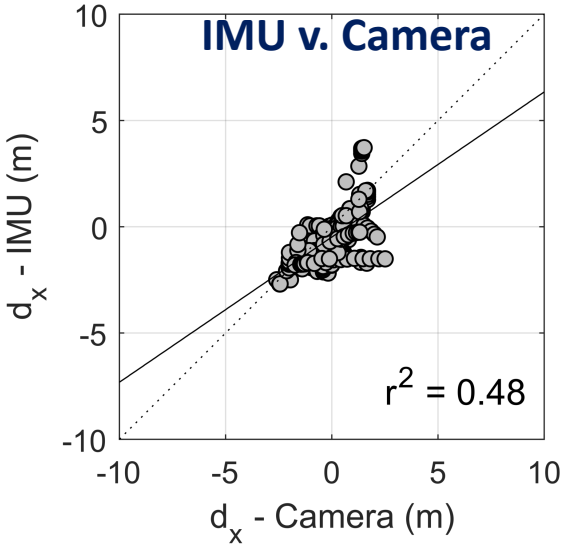


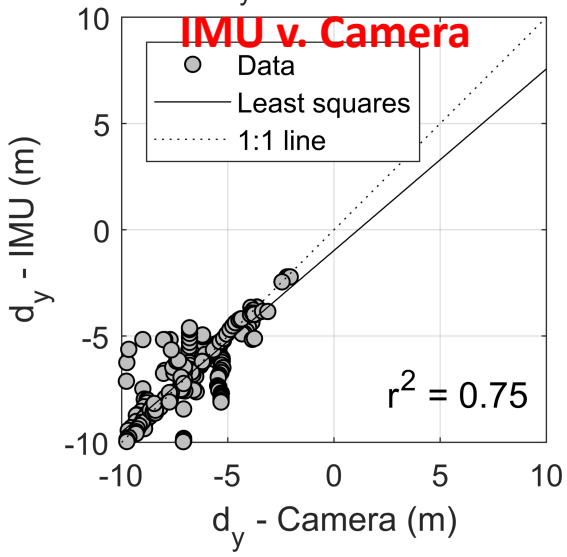
- Symbols → imagery
- Curves → IMU

Results – Migration







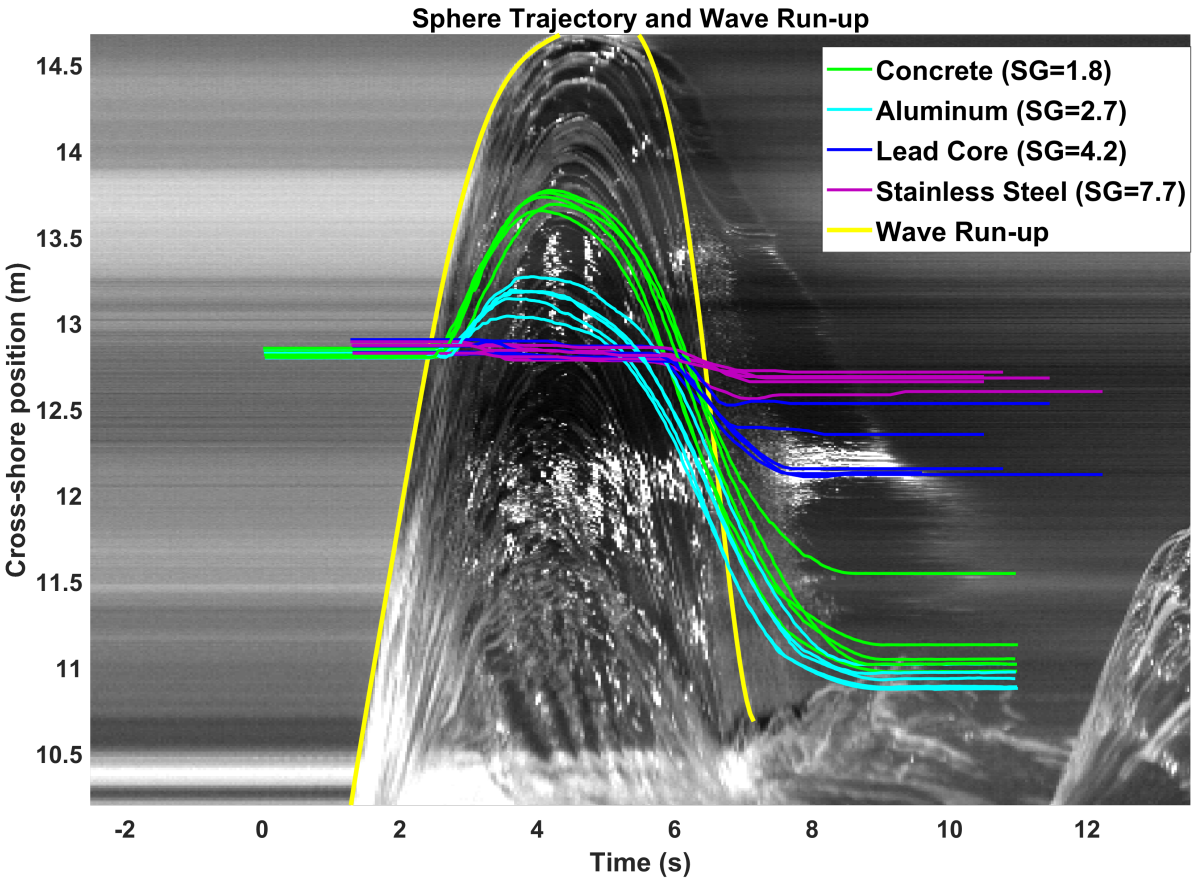


- Moderate correlation
- Low-cost IMU and simple algorithm

Cross-shore

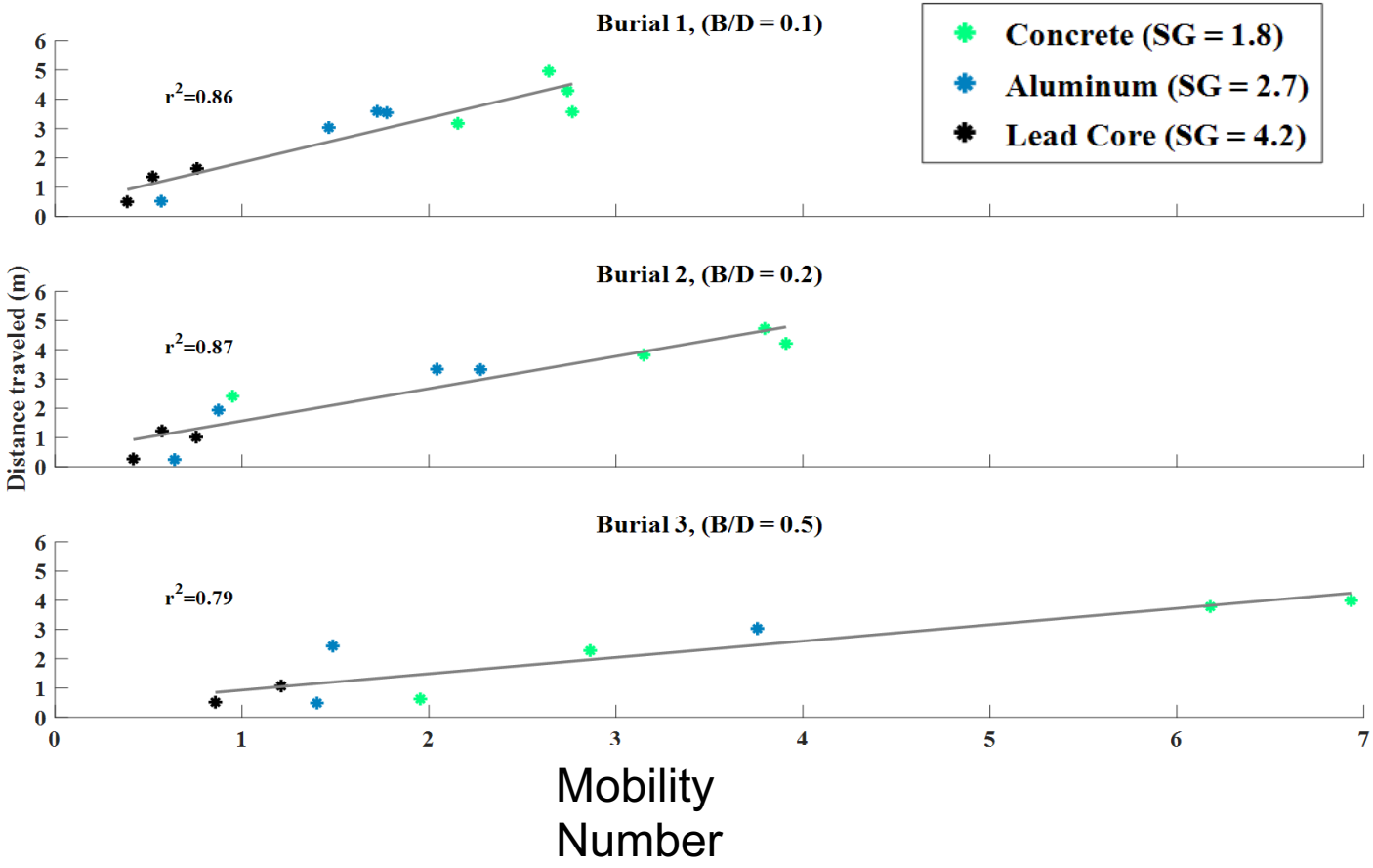
Alongshore

Results – Migration



- Motion governed by density
- "Light" spheres move onshore and offshore
- "Heavy" spheres offshore only
- "Heavy" spheres → less migration

Results – Migration

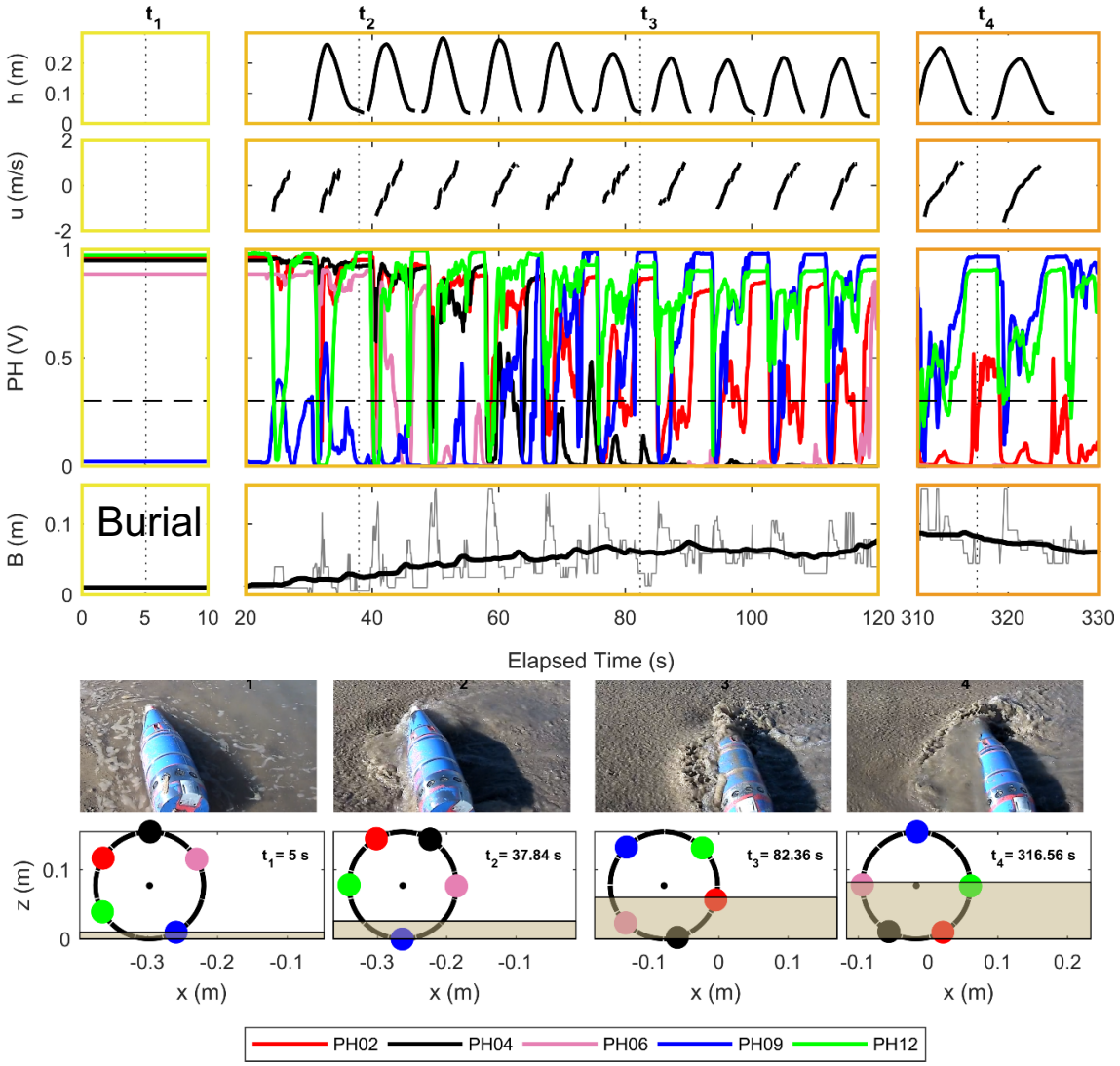


Mobility Number

$$\frac{U^2 \frac{h}{D-B}}{gD\left(\frac{\rho_{obj}}{\rho_w}-1\right)}$$

Travel distance increases with increasing mobility number and decreasing density

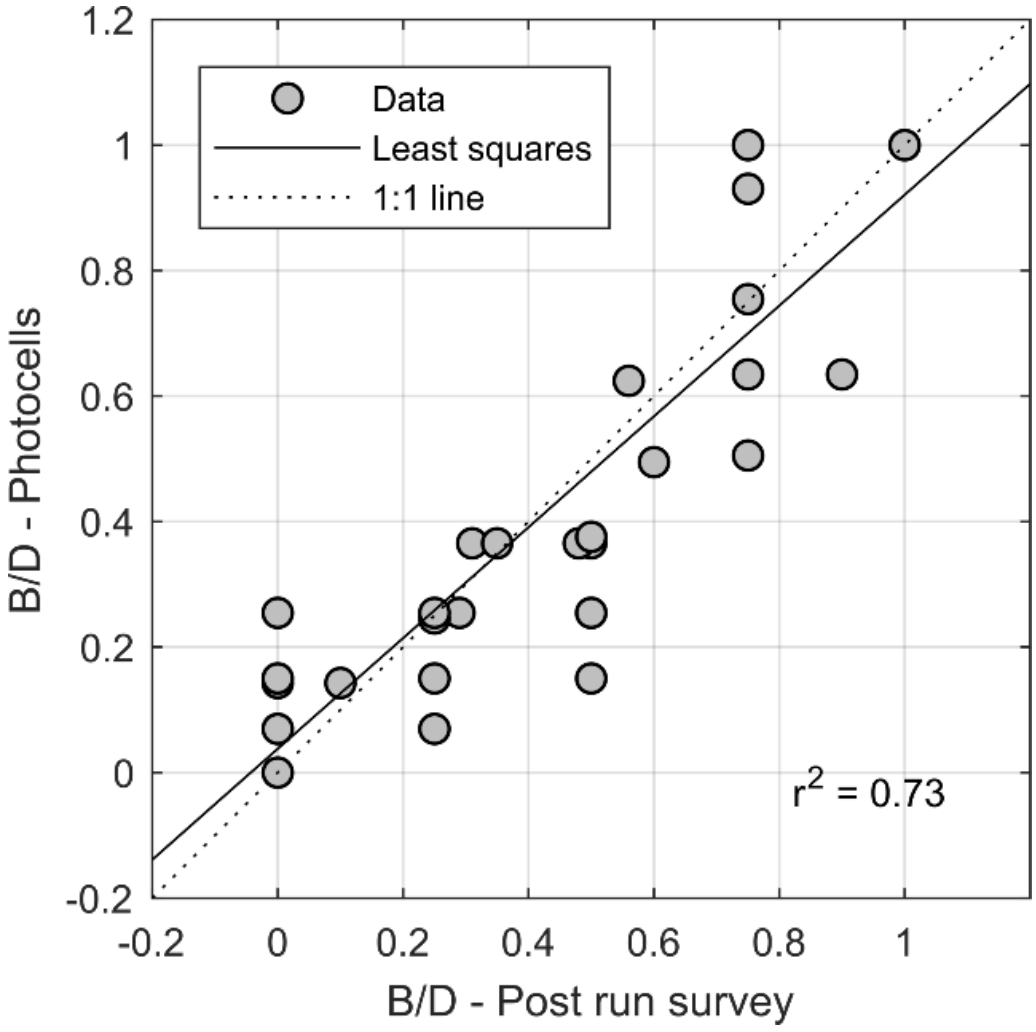
Results – Burial



- Slow burial over time
- Offshore migration
- "Falls" into scour pit

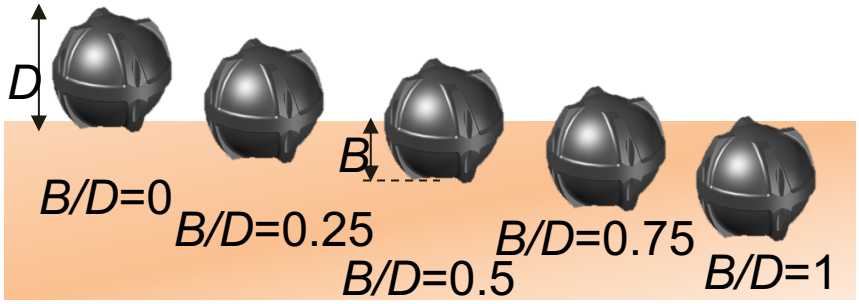
PH = Photocell

Results – Burial



- B/D = Relative burial depth
- Photocells vs. manual
- High correlation
- Manual → difficult in murky/turbid water

Results – Burial

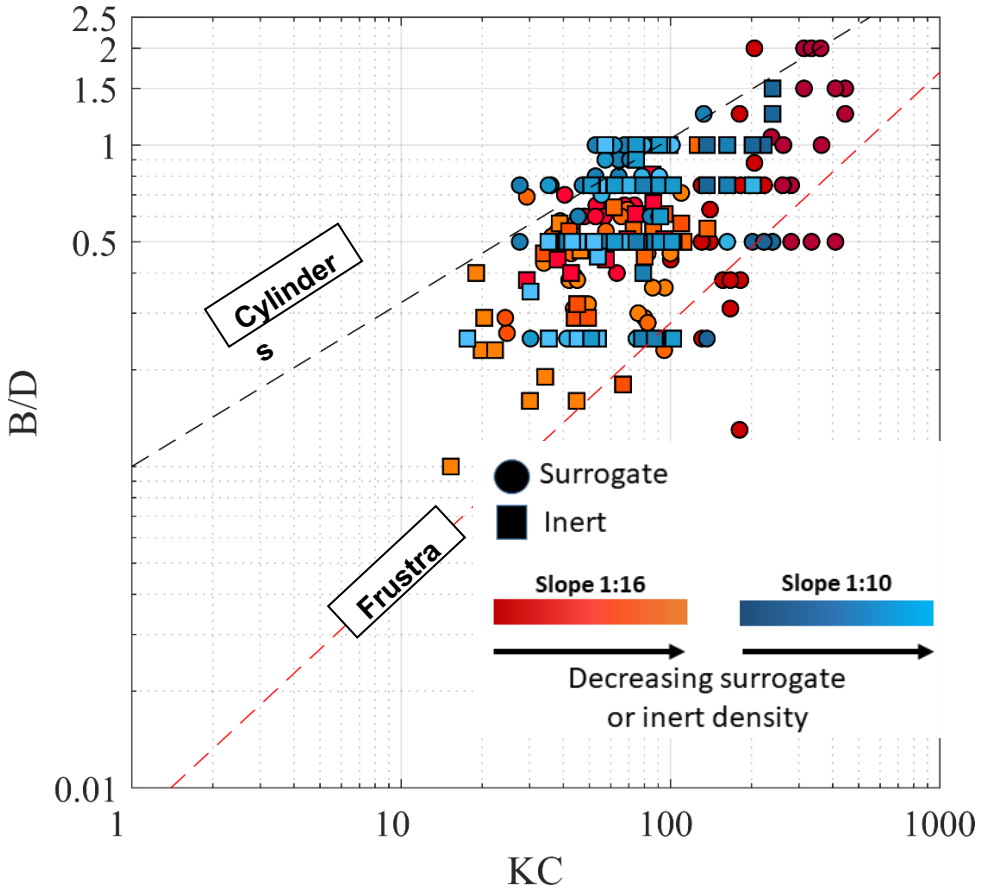


KEULEGAN-CARPENTER NUMBER

$$KC = \frac{U\,T}{D} = \frac{drag}{inertia}$$

U : flow velocity
T : duration of swash event
D: surrogate diameter

Data cluster within empirical relationships



Empirical relationship, Friedrichs et al., 2016

Conclusions

- Munitions migration → tracked with imagery and IMU
- Munitions can migrate onshore and offshore
- Munitions tend to bury over time (density-dependent)
- Burial trends bounded by existing empirical relationships

Benefits to DoD

- Site managers require knowledge of likelihood of migration/exhumation
- Reduce efforts of an already cleared area
- Predictive and probabilistic models require validation data
- Goal
  - Reduce cost of remediation through munitions processes understanding

For additional information, please visit

https://www.serdp-estcp.org/Program-Areas/Munitions-Response/Munitions-Underwater/MR-2503

Speaker Contact Information

jpuleo@udel.edu; 302-831-2440

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Q&A Session 1

Unexploded Ordnance Characterization and Detection in Muddy Estuarine Environments

Art Trembanis, Ph.D.
University of Delaware

Carter DuVal, Ph.D.
University of Delaware

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Part 1: Munitions Mobility and Designing/Tracking Surrogate Munitions

Art Trembanis, Ph.D.
University of Delaware

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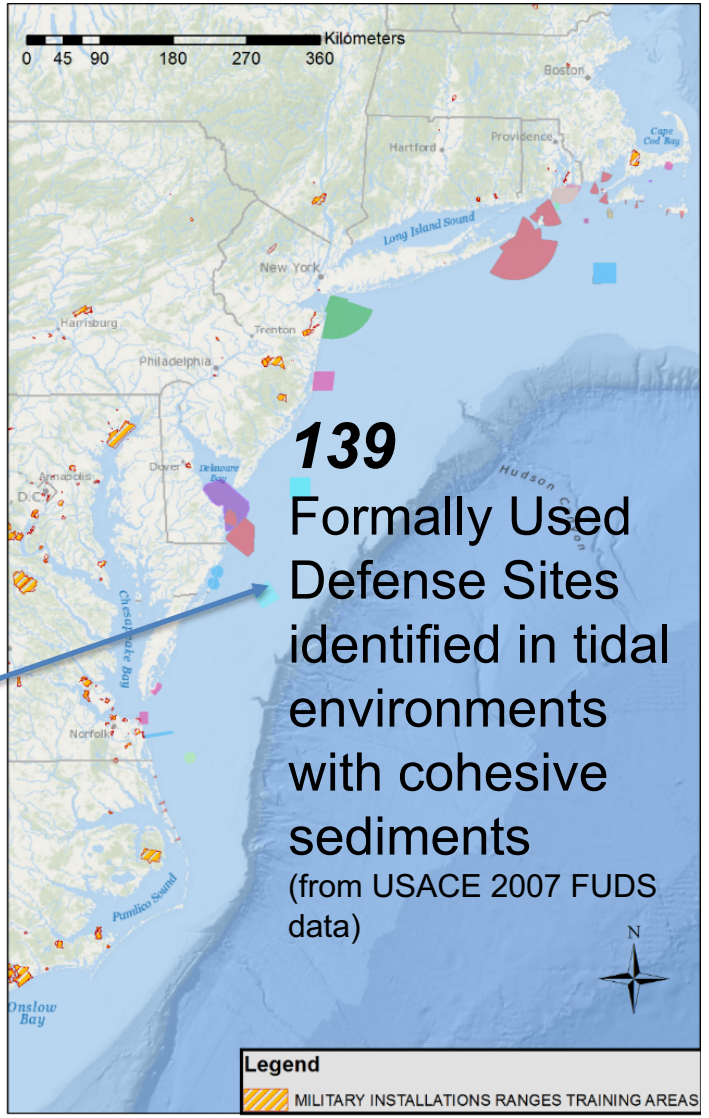
Agenda

- Munitions mobility
  - Cohesive sediments
- Designing and tracking surrogate munitions
- Field deployments
  - Filling in the parameter space
- Linking cohesive sediment properties to munitions mobility

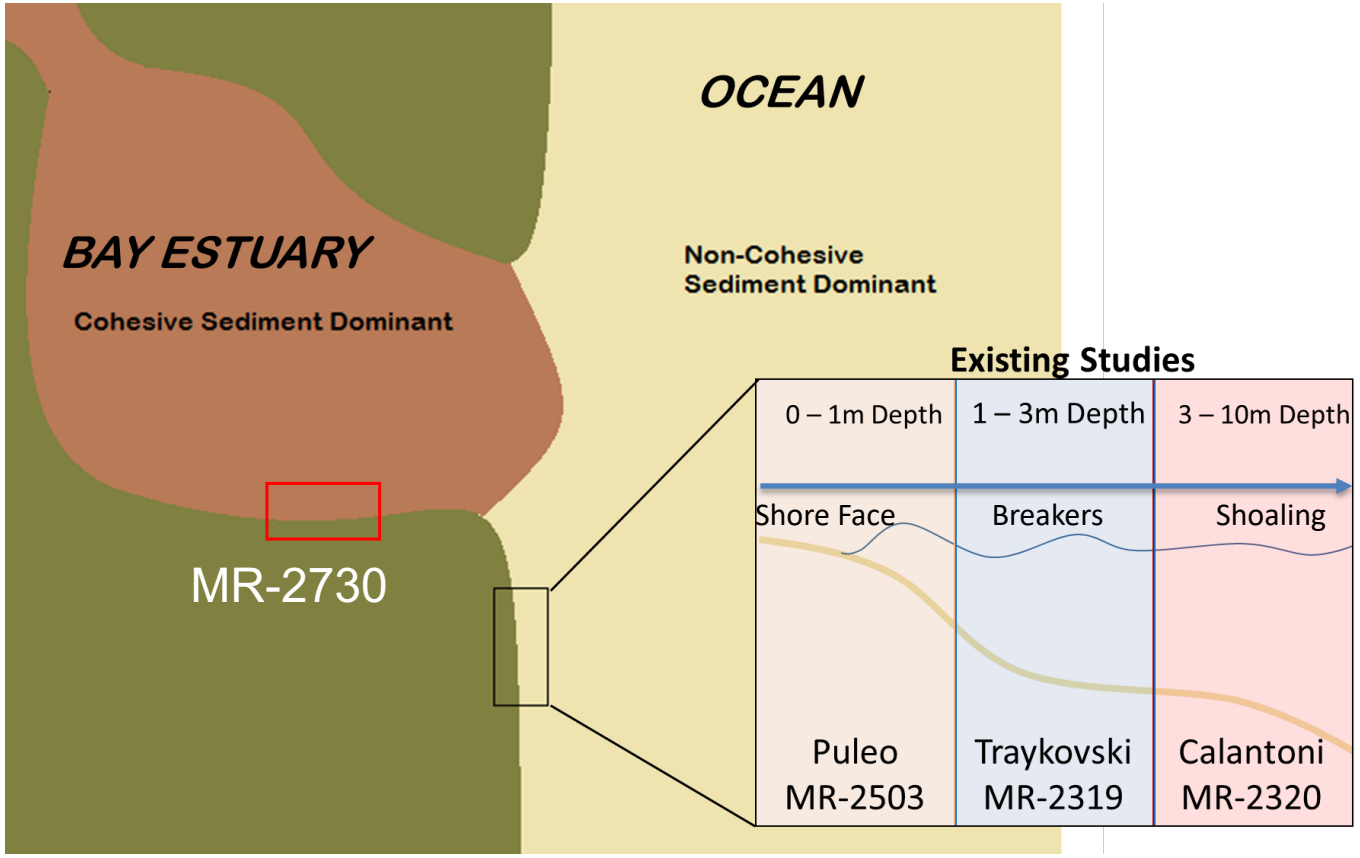
Problem Statement

- Need for better quantitative understanding of the impact of coastal environments on UXO mobility and behavior (MRSON-17-01)
- A significant data gap regarding UXO in shallow, muddy environments



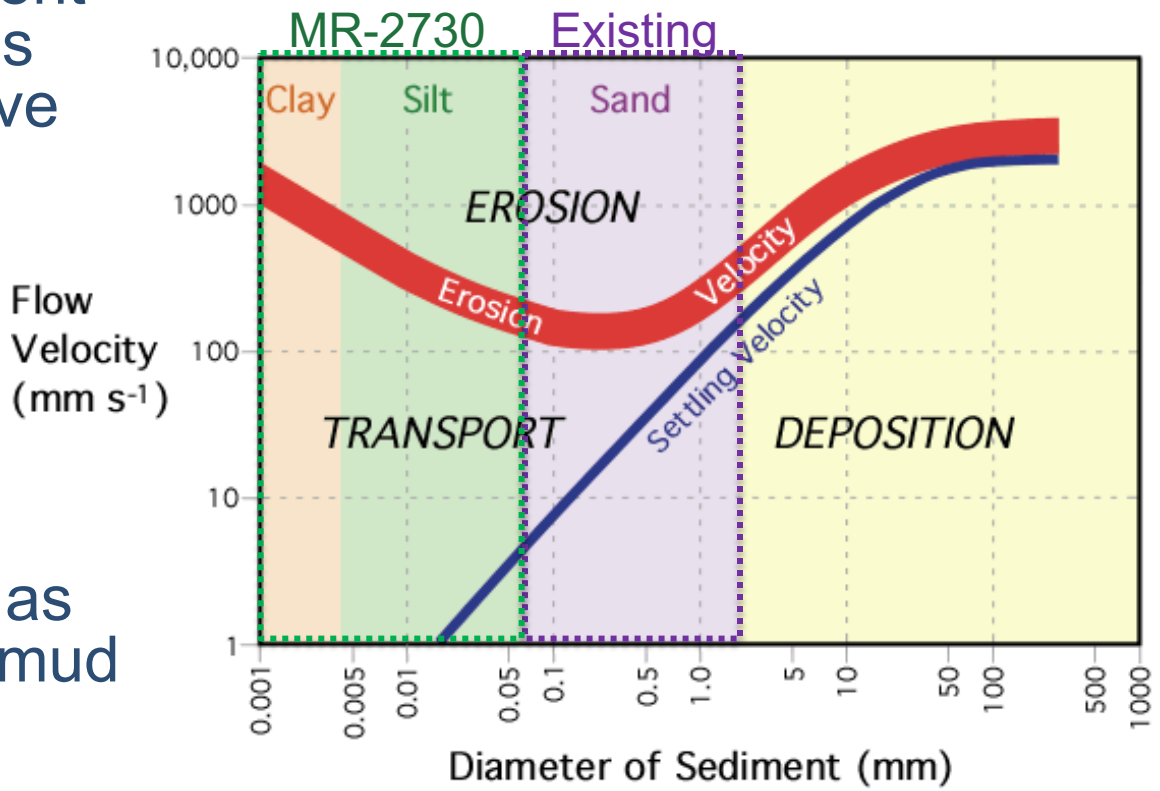
Existing in situ Data for Munitions Mobility

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



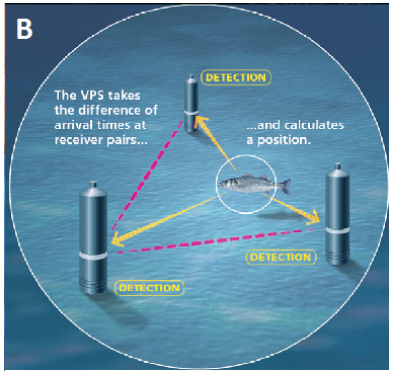
Cohesive Sediments

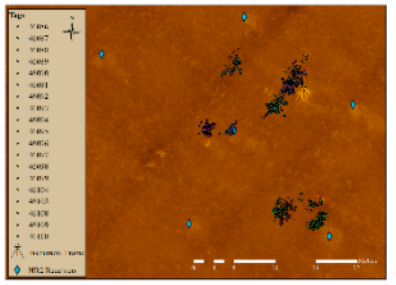
- How are the mobility and burial characteristics of munitions effected in cohesive sediments?
  - Cohesive sediments conform to different transport regimes than non-cohesive particles
- Cohesive transport
  - May occur as flocculate particles
  - May even travel as fluidized mobile mud beds



Technical Approach

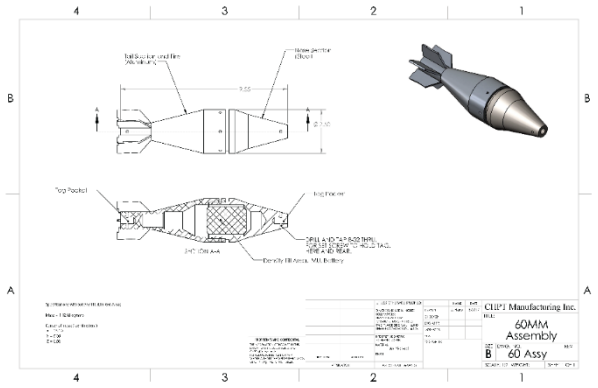
- Tracking and motion sensor design
  - Acoustic tracking technology selection and testing
  - Surrogate UXO fabrication and instrumentation
- Field implementation
  - Deployments of tracking suite in the Delaware Bay Estuary
- Geotechnical characterization
  - Relating munitions mobility to sediment properties

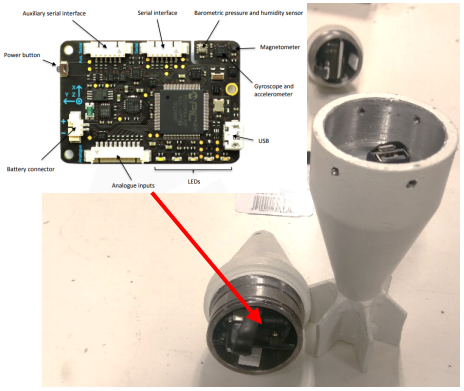




Surrogate Munitions

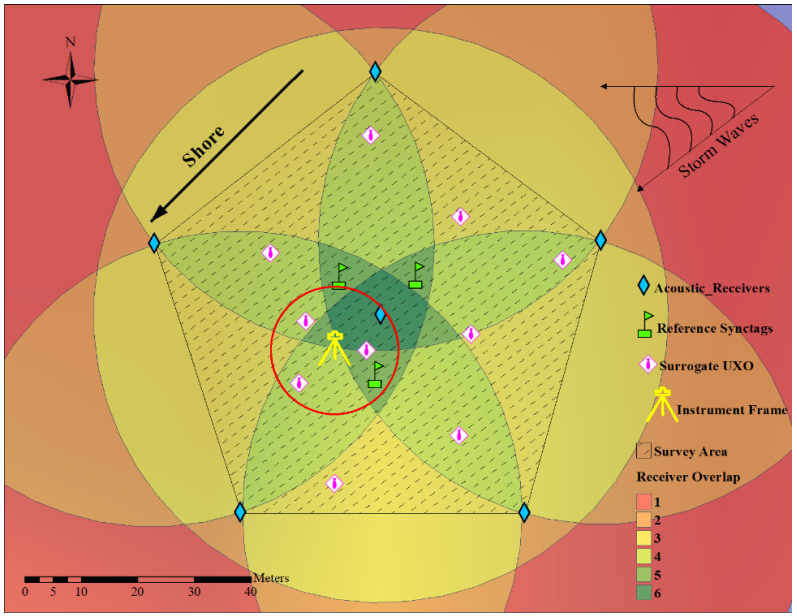
- Instrumented steel surrogates in 155mm artillery, and 81mm and 60mm mortar
  - Equipped with Inertial Measurement Units (IMU)
  - Fitted with 2 Vemco acoustic tags for underwater tracking
  - 155mm shells additional pressure sensor

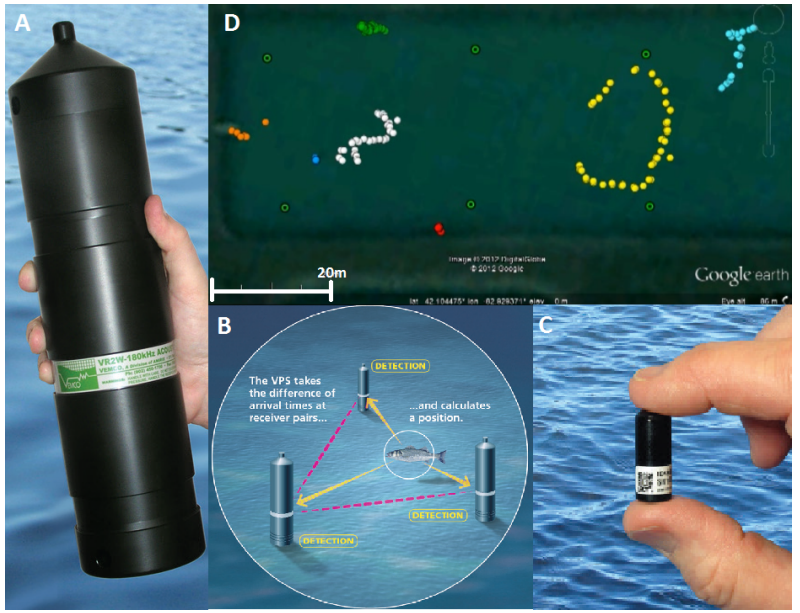




Surrogate Tracking Network

- Vemco positioning system
  - Designed to track biology acoustically
  - < 20cm positional accuracies (field tested)

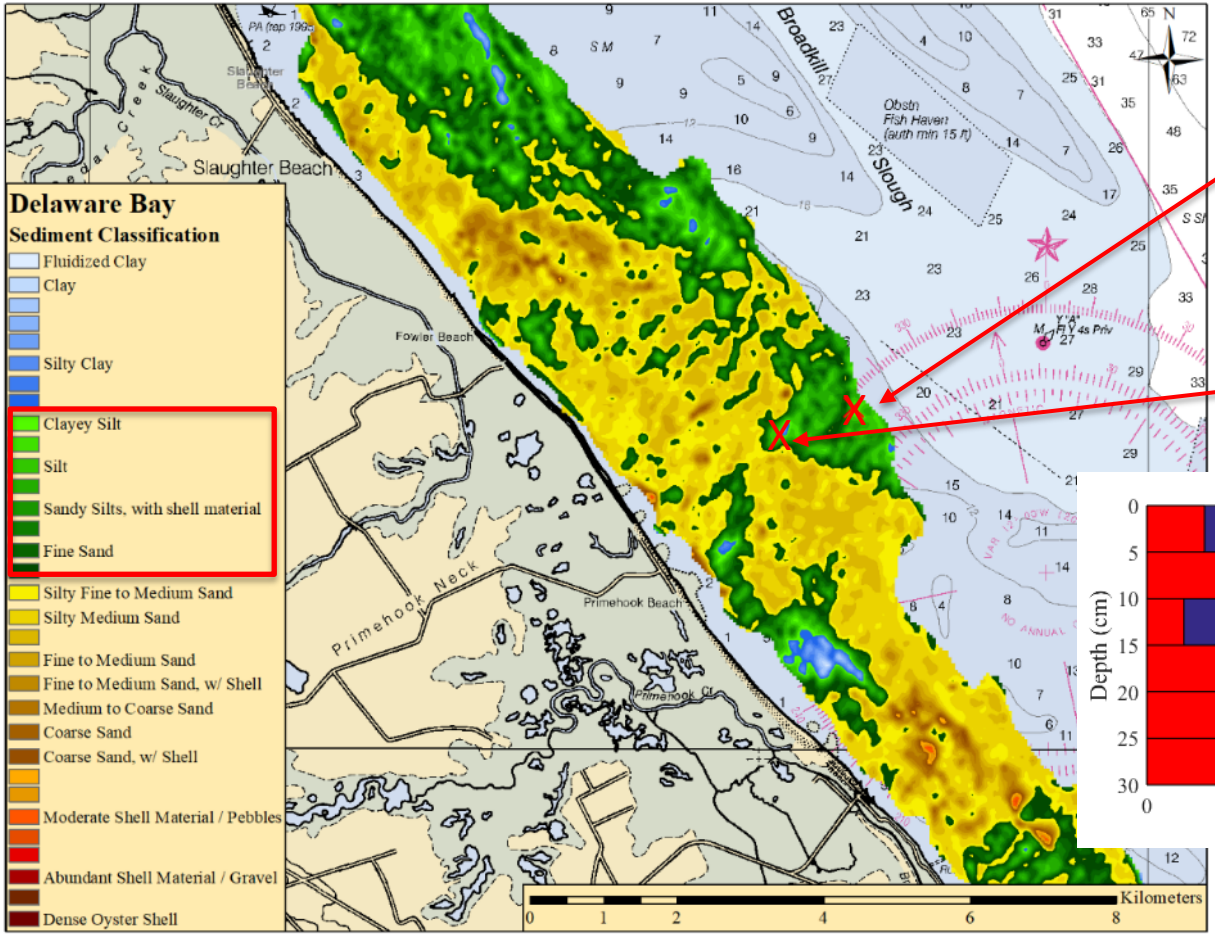


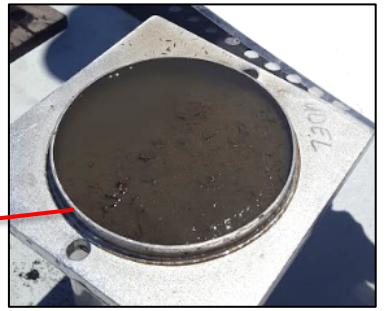


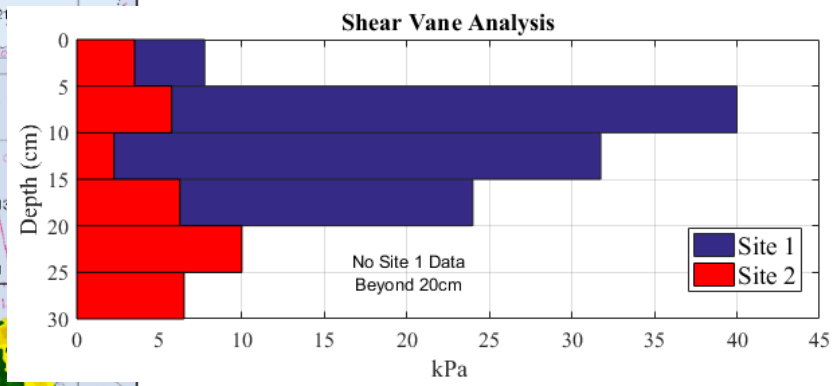
- Field design
  - 6 receiver system in pentagonal grid
  - Multiples detection per minute

Field Sites

Site 1 samples: silty, clayey sand; Site 2 samples: sandy silt with clay

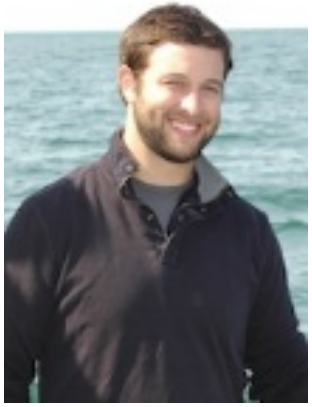






Part 2: Field Deployments and Linking Cohesive Sediment Properties to Munitions Mobility

Carter DuVal, Ph.D.
University of Delaware



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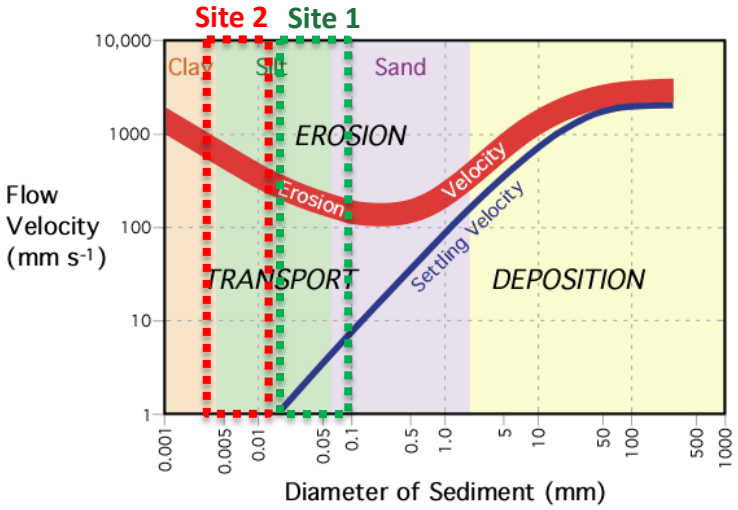
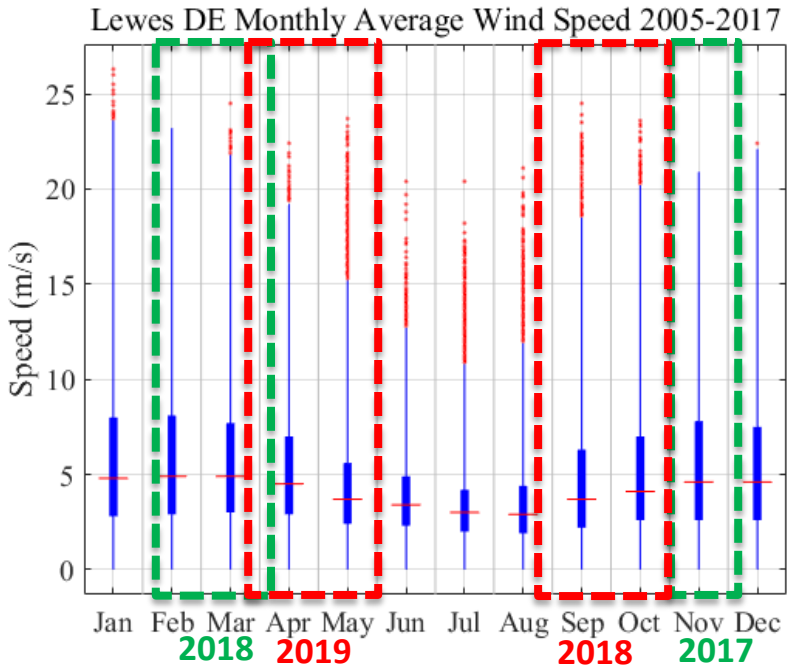
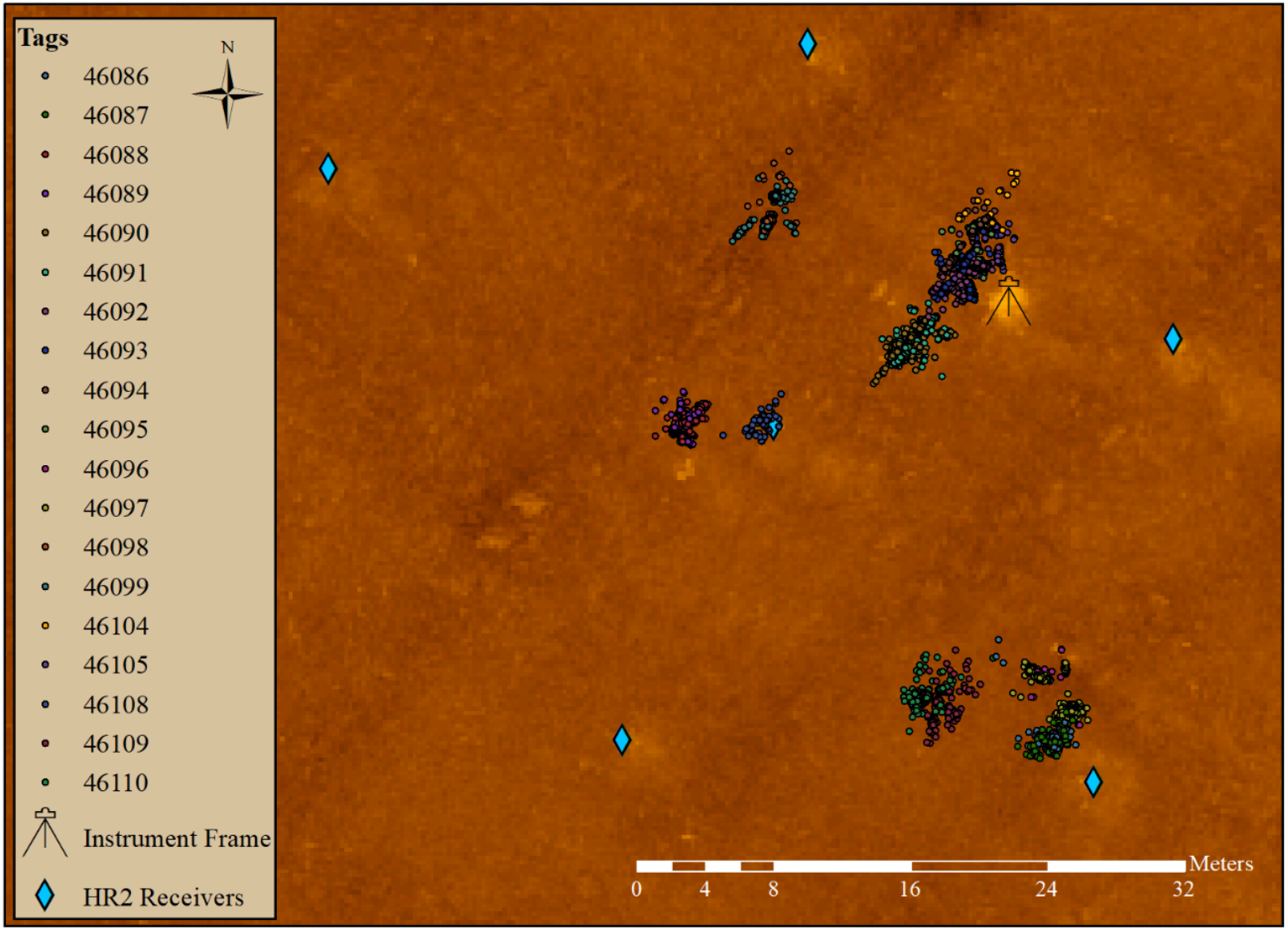
Field Deployments

- Fill in the parameter space for the modeling
- Four deployments at 2 sites
  - Site 1 – muddy sand
  - Site 2 – sandy, clayey silt
- Deployment window
  - Based on local wind record
    - Fall Hurricane / nor'easter season
    - Late winter – Spring nor'easter season

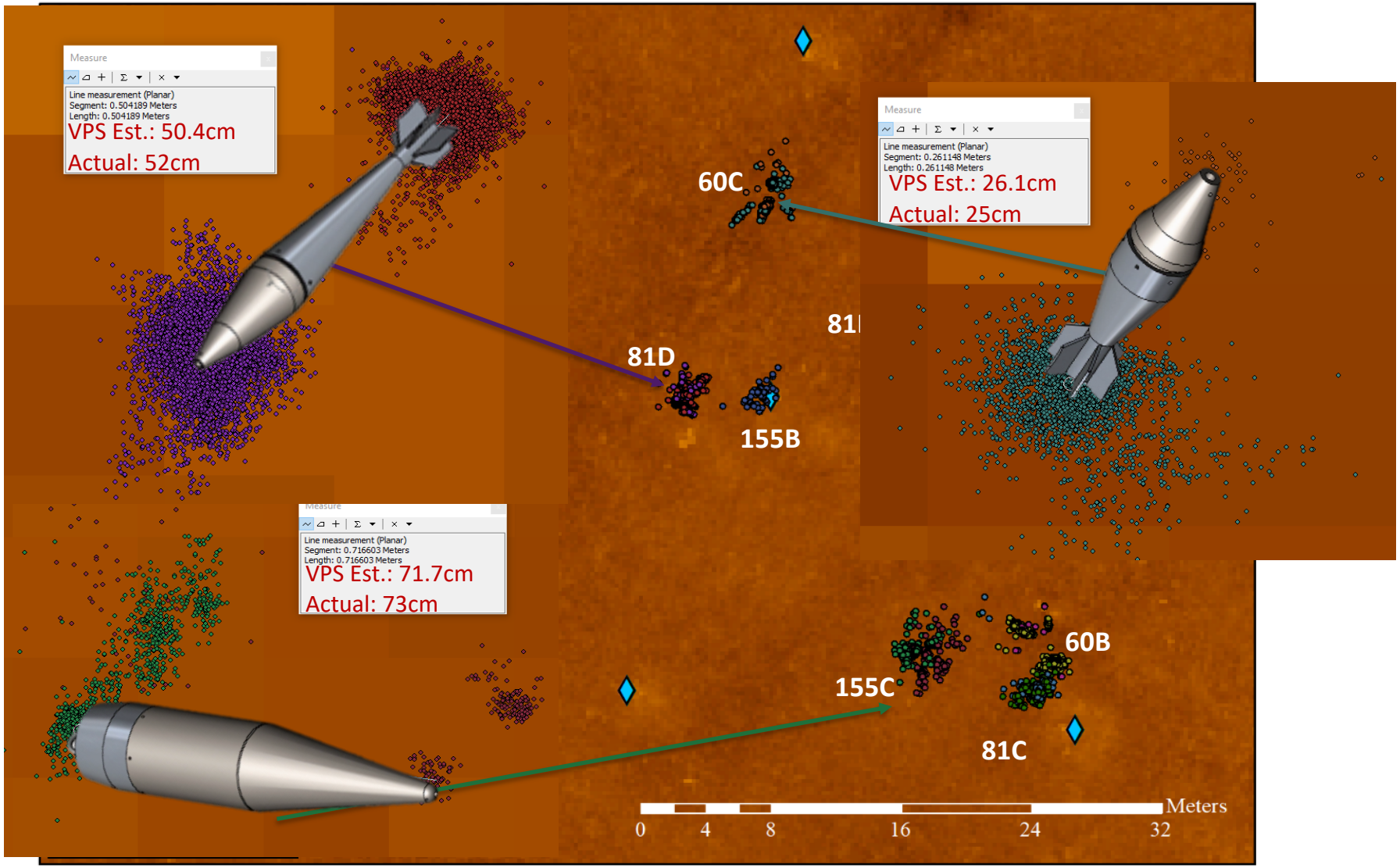




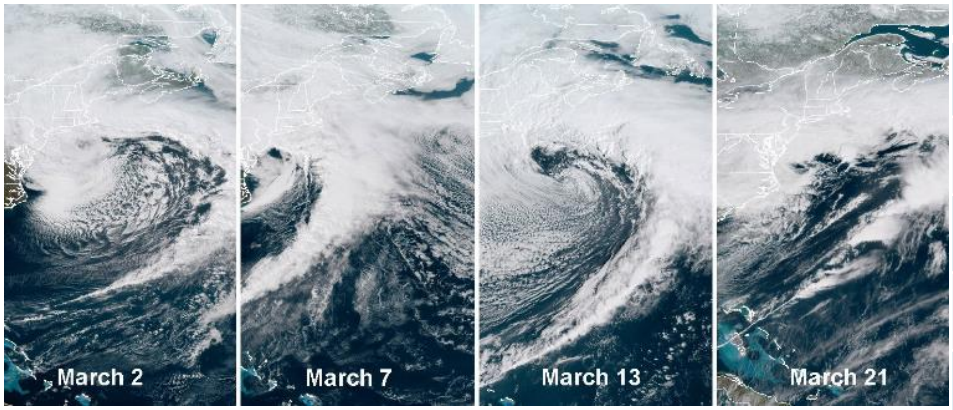
Example: Fall 2017 Field Deployment



Example: Fall 2017 Field Deployment

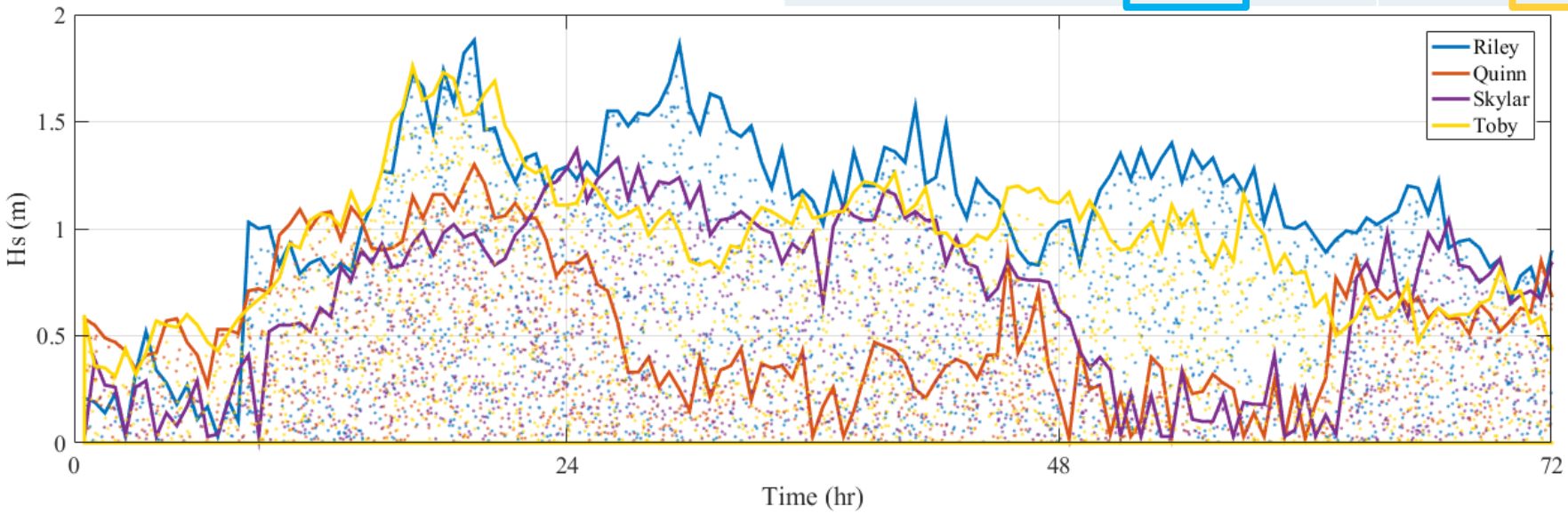


March 2018 Nor'easters



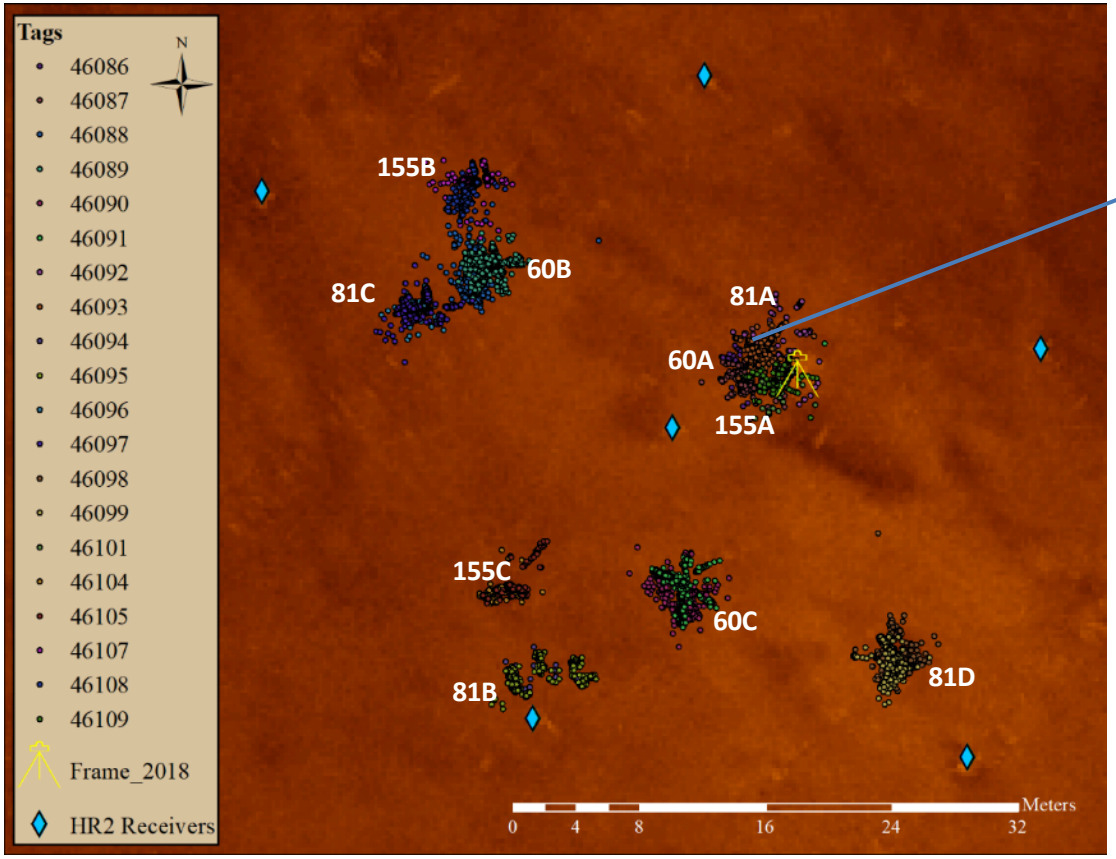
Riley Quinn Skylar Toby

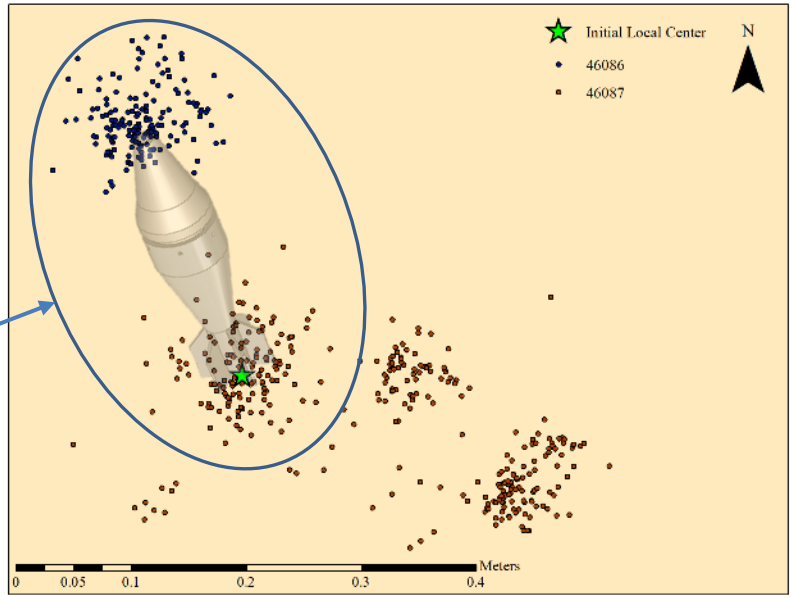
	Riley	Quinn	Skylar	Toby
Duration (hr)	50	10	17	35
dHs/dt (m/hr)	0.56	0.54	0.46	0.46
Wave Height (m)	1.88	1.3	1.37	1.76
Wave Direction (º)	336	334	41	48
Orbital Current (m/s)	0.8	0.47	0.5	0.83
Mean Current (m/s)	0.35	0.25	0.23	0.39

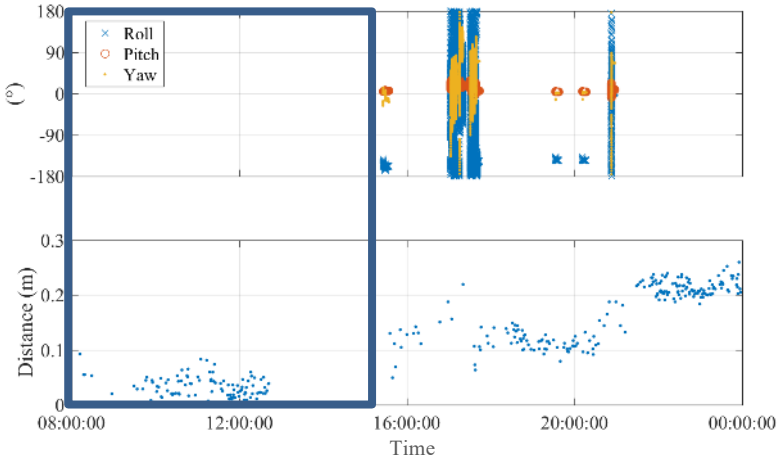


60mm Mortar – March 20, 2018

Initial Position

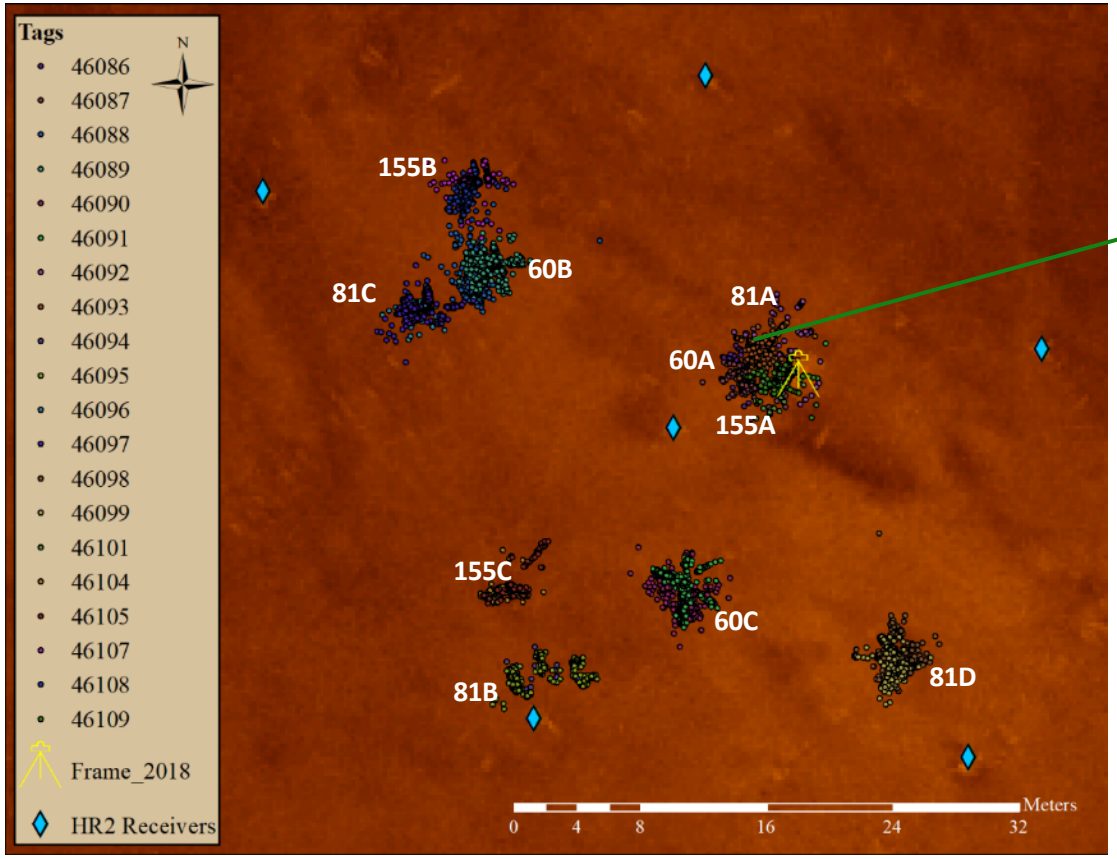


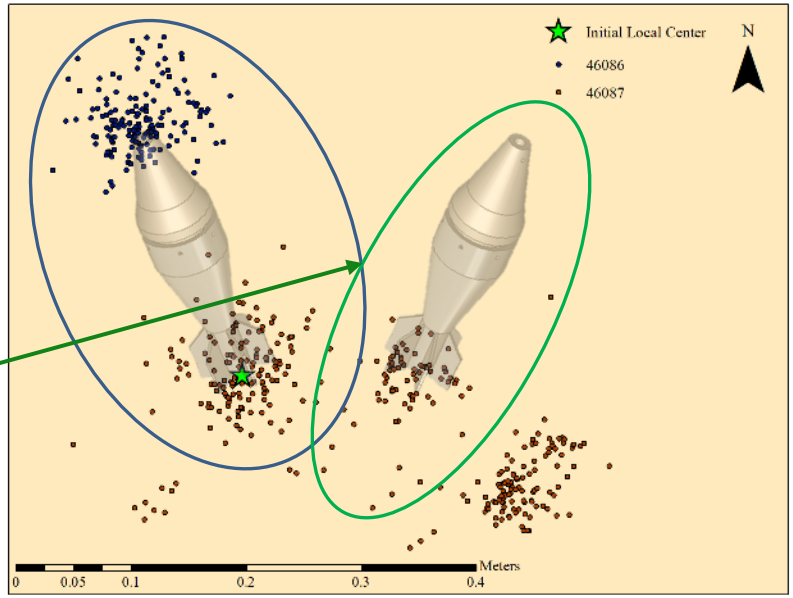


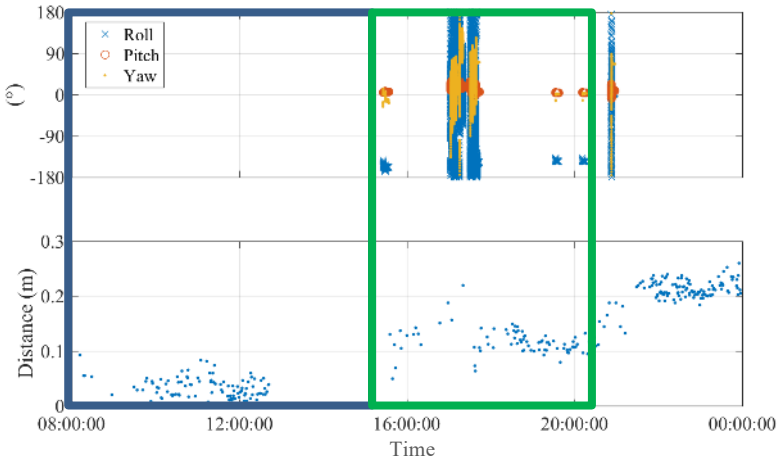


60mm Mortar – March 20, 2018

Second Position

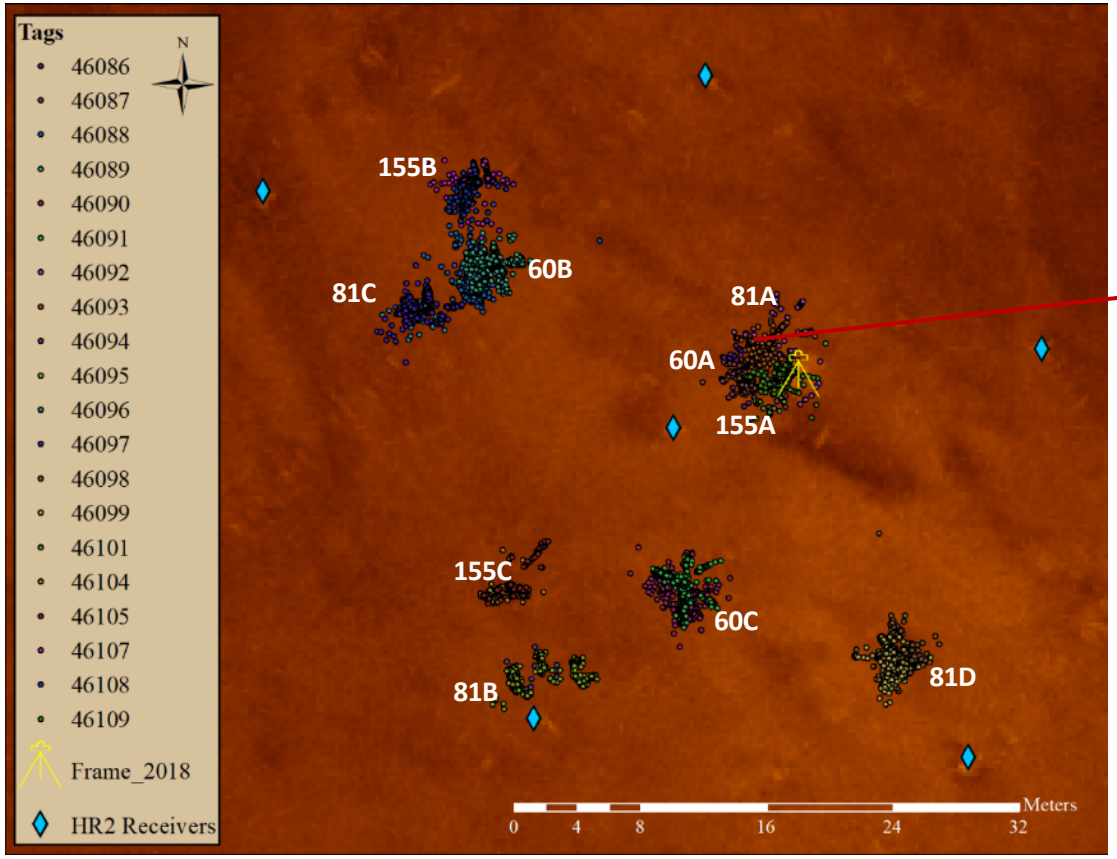


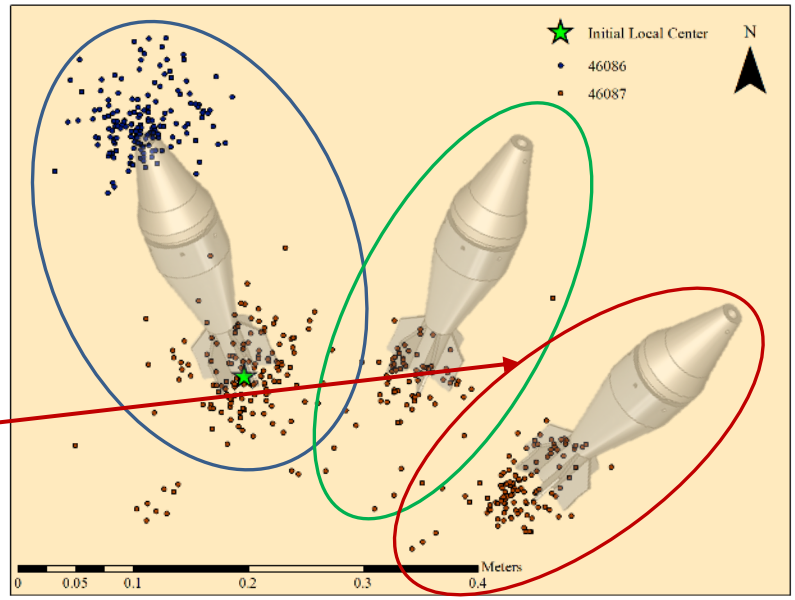


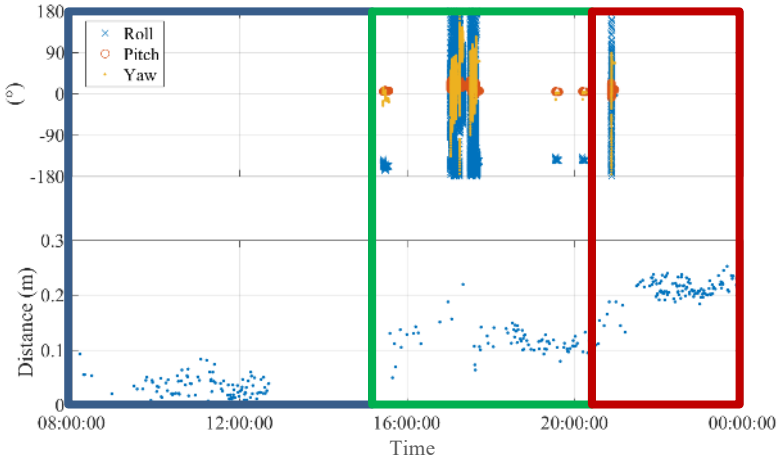


60mm Mortar – March 20, 2018

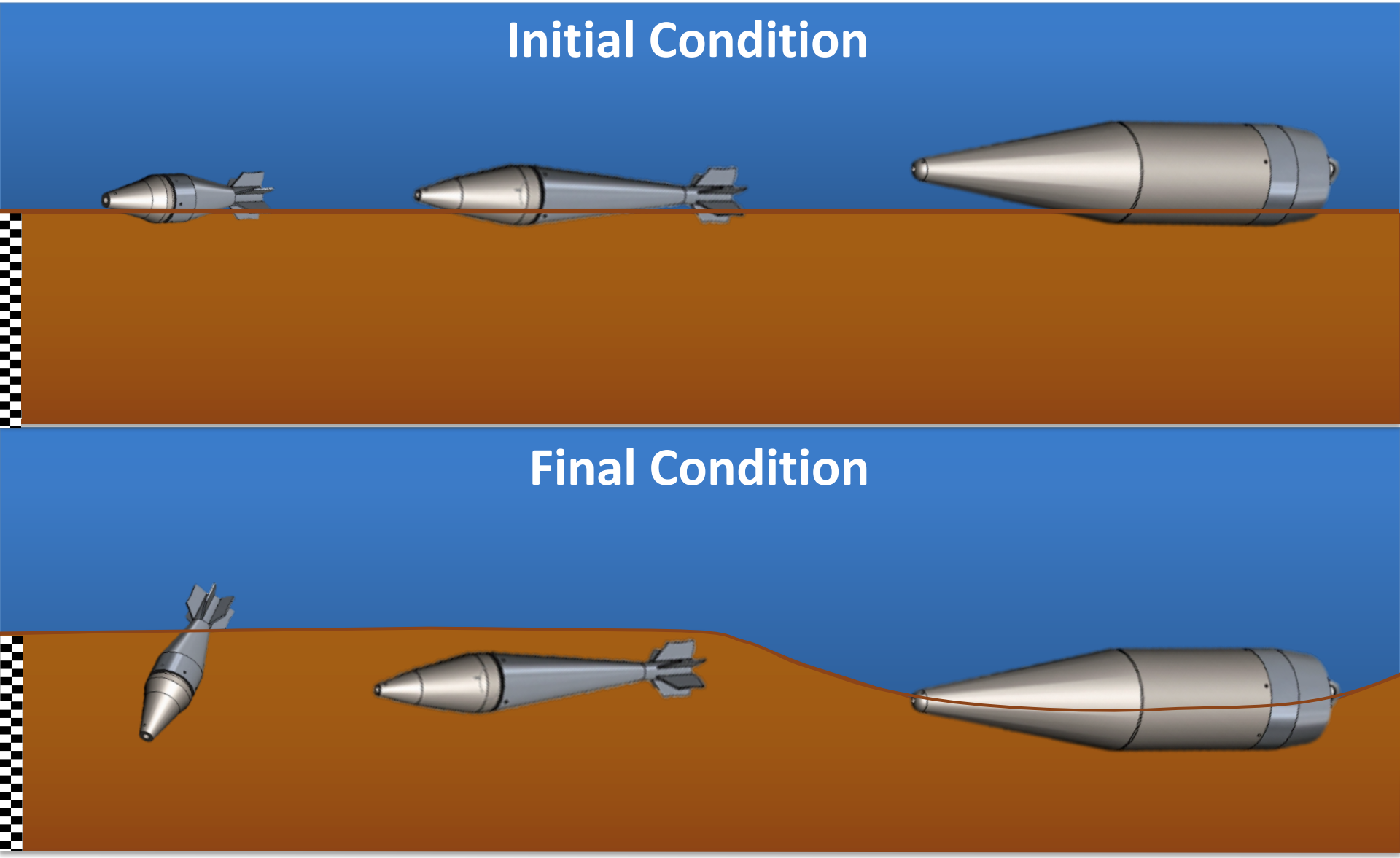
Final Position





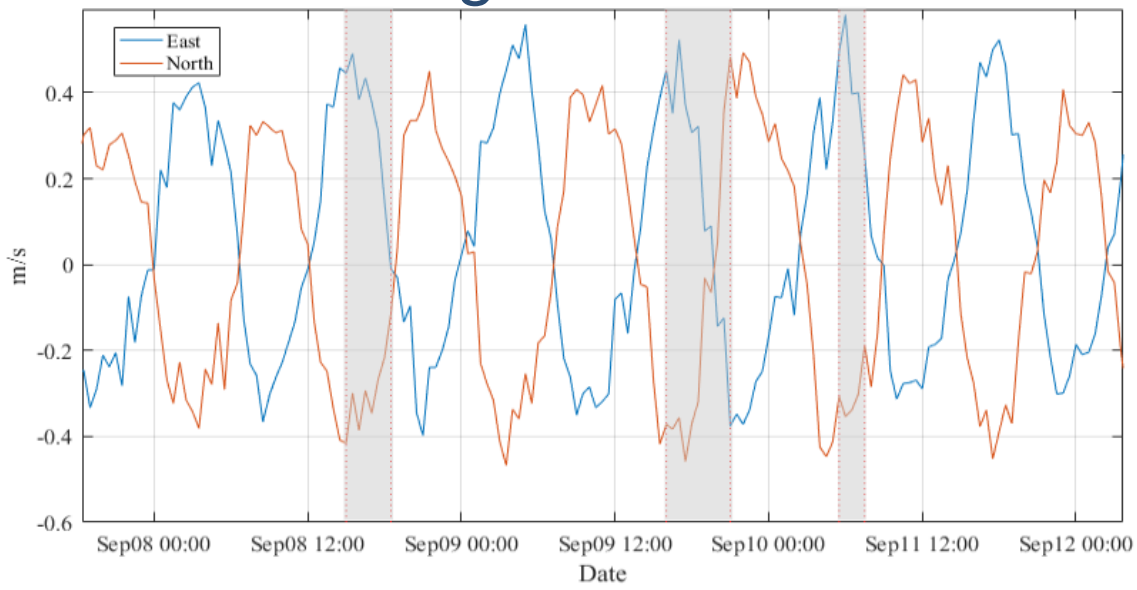


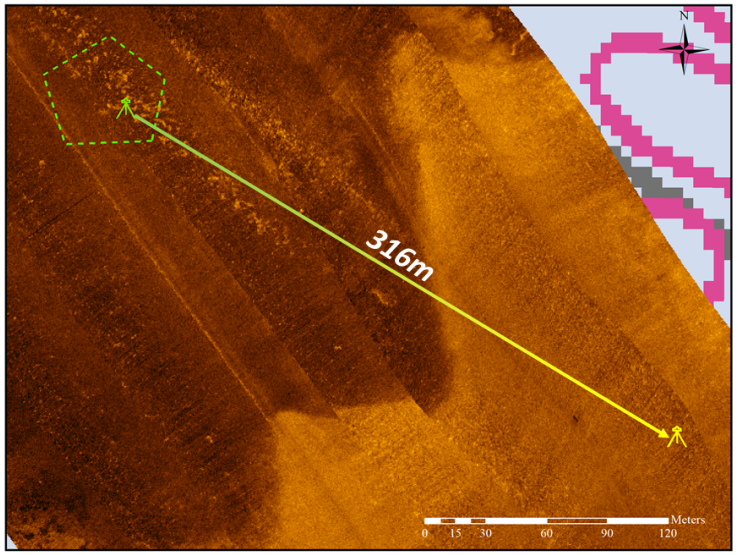
Site 1 (Muddy Sand) Surrogate Results



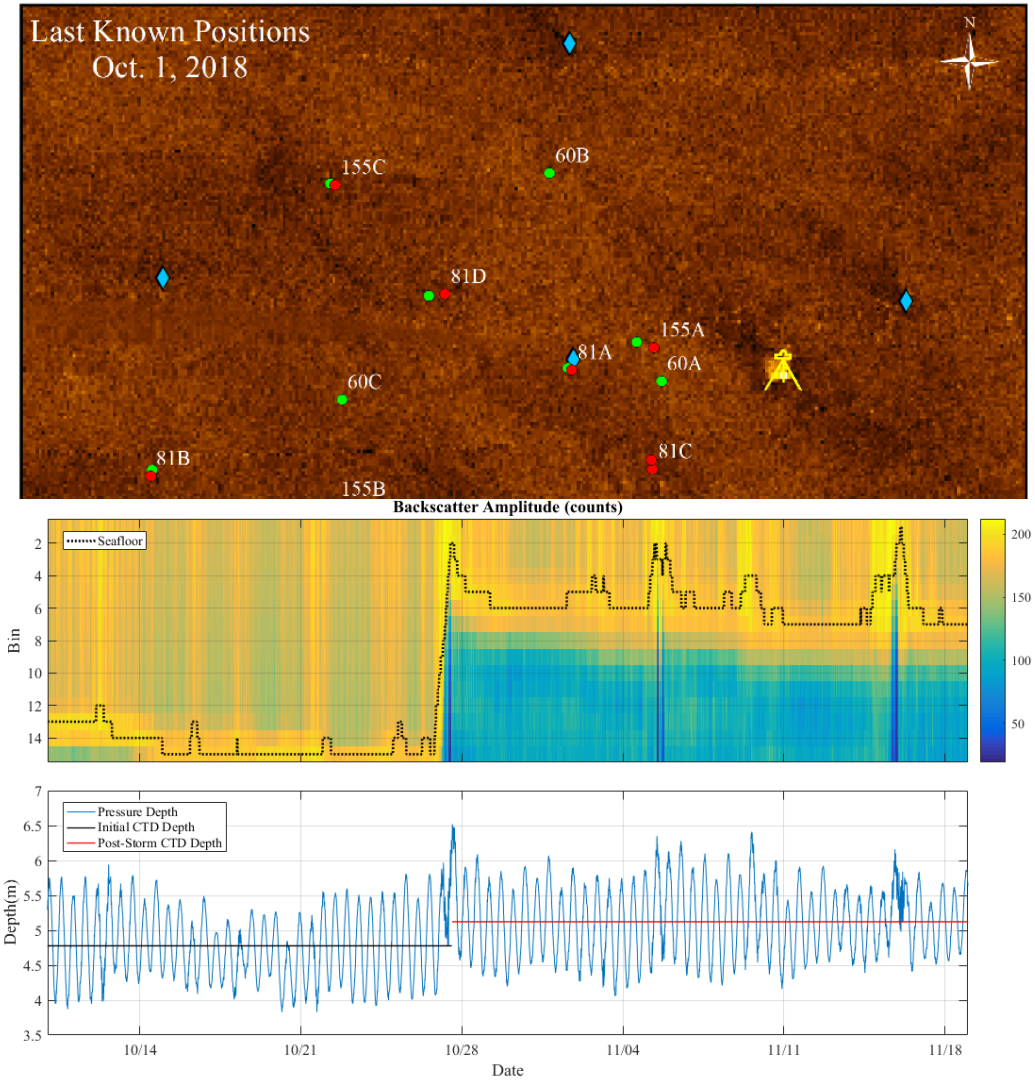
Fall 2018 – Case of the Missing Frame

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



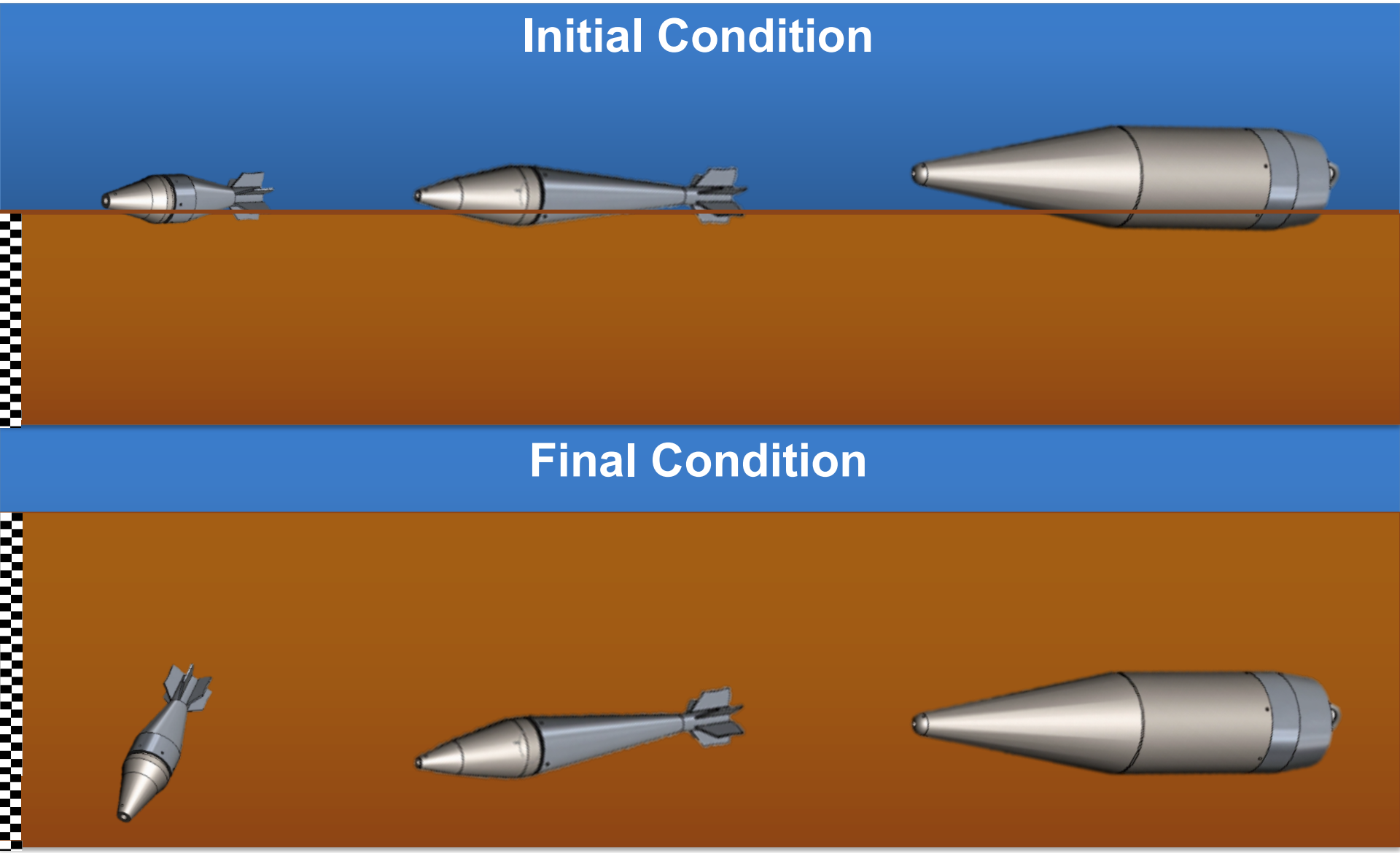


Episodic Burial



- Partial burial observed after 1 month
- After additional month – all surrogates buried to 30cm deep
- Instrument record shows significant burial event in October 27-28 storm
  - Scour or burial by sediment?

Site 2 (Clay/Silt) Surrogate Results

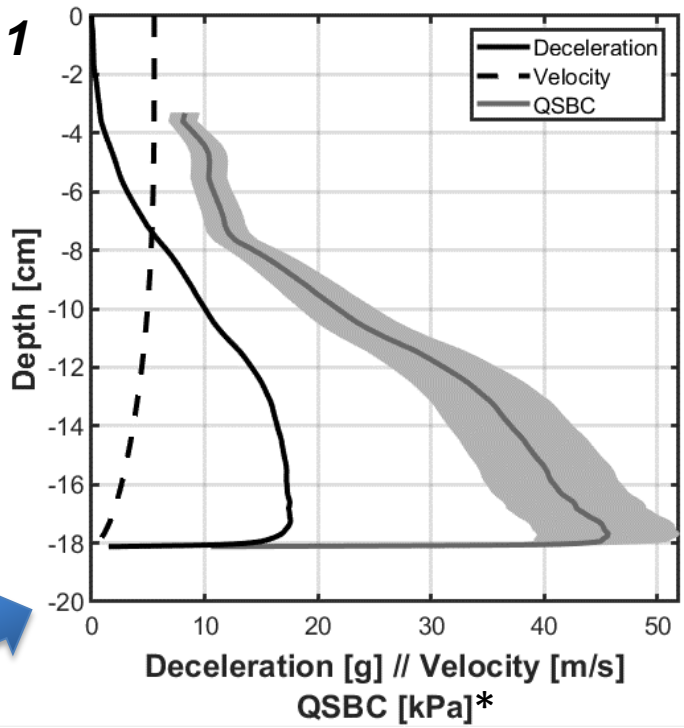


Sediment Characterization

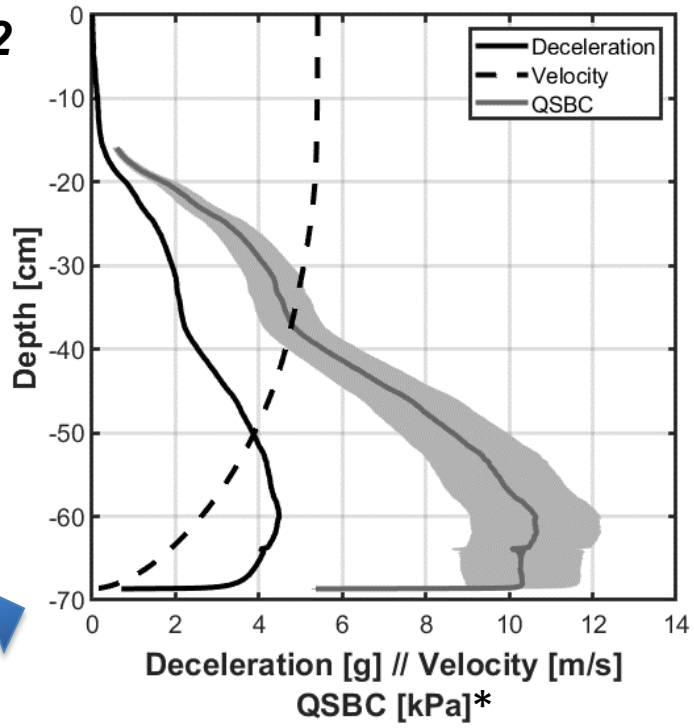
- Penetrometer sampling
  - Dr. Nina Stark, MR18-1233
  - Provide geotechnical sediment characterization
  - Link observed differences in surrogate burial behavior to differences in sediment properties

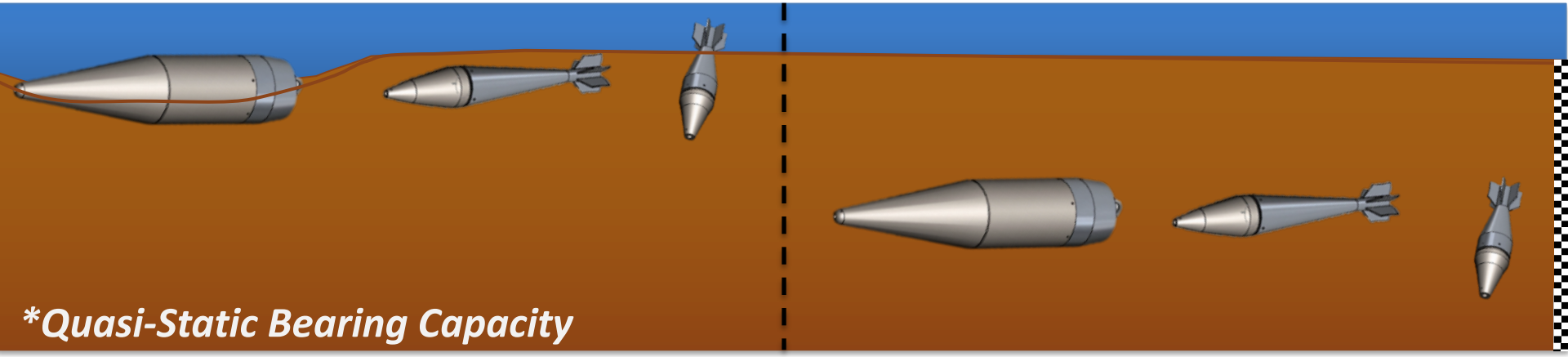
Geotechnical Characterization Results

Site 1



Site 2

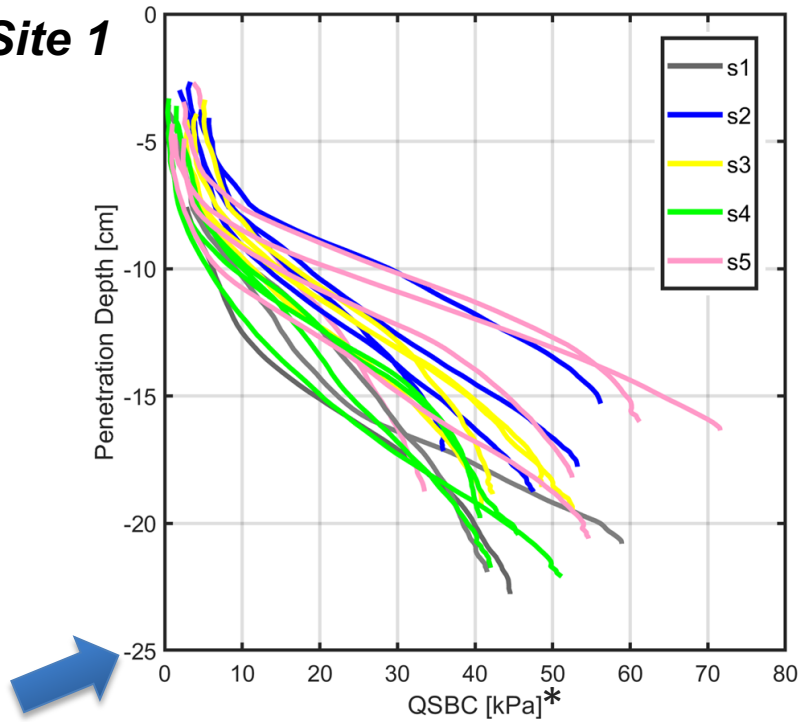




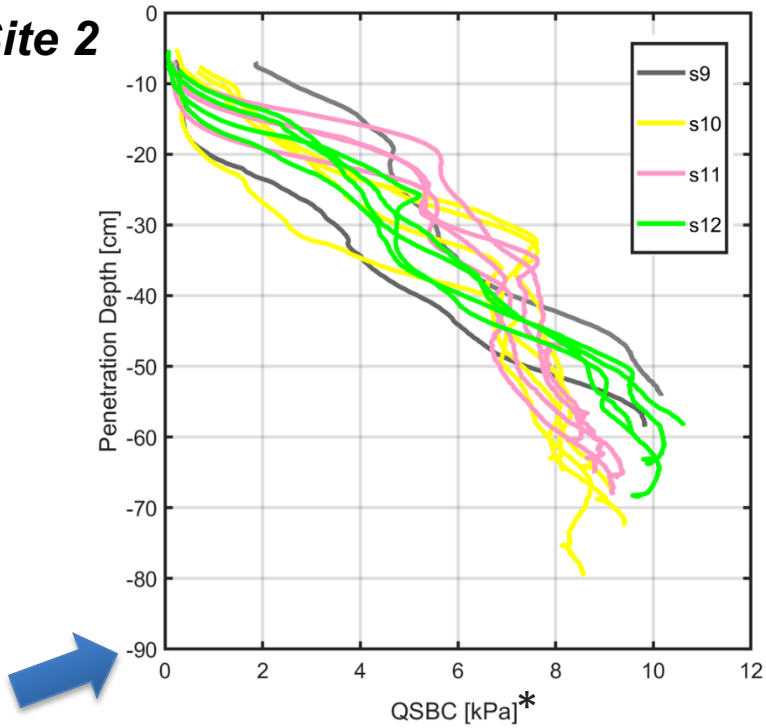
**Quasi-Static Bearing Capacity*

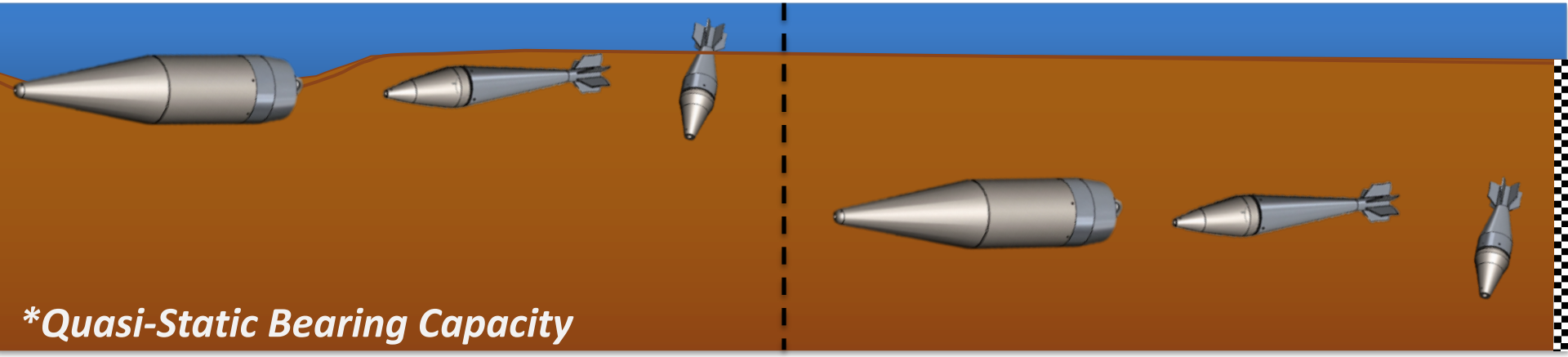
Geotechnical Characterization Results

Site 1



Site 2





**Quasi-Static Bearing Capacity*

Conclusions

- No prior in depth study on munitions mobility in primarily cohesive sediments
- Mobility in cohesive settings unlikely (for surrogates with densities typical of intact UXO)
- Burial behavior consistent throughout all four deployments (Fairweather and Nor'easters)
- Depth of burial influenced by sediment properties (e.g., bulk density)

Benefits to DoD

- Surrogate mobility behavior and site characteristics will be integrated into Underwater Munitions Expert System (Rennie MR-2227)
  - Provide tools for UXO management for site managers of Formerly Used Defense Sites (FUDS)
- The Vemco VPS and smart surrogates development and methods in this study can easily be transitioned into future studies in various environments and conditions
  - Examine potential UXO mobility and burial at FUDS sites

For additional information, please visit

https://www.serdp-estcp.org/Program-Areas/Munitions-Response/Munitions-Underwater/MR-2730

Speaker Contact Information

art@udel.edu; 302-831-2498

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Q&A Session 2

The next webinar is on August 8, 2019

Building Energy and Water Efficiency Solutions

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Survey Reminder

Please take a moment to complete the survey that will pop up on your screen when the webinar ends

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