RAPID RESPONSE SURVEYS OF MOBILITY, BURIAL AND RE-EXPOSURE OF UNDERWATER MUNITIONS IN ENERGETIC SURF-ZONE ENVIRONMENTS AND OBJECT MONITORING TECHNOLOGY DEVELOPMENT

Project Number: 2729

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Woods Hole Oceanographic Institution

In-Progress Review Meeting
May 15, 2018

SERDP
DOD ▪ EPA ▪ DOE

MR-2729: Surf-Zone Mobility and Burial of UXO

Performers:

- Peter Traykovski & Fred Jaffre

Technology Focus

- *Tracking of UXO surrogate mobility in energetic environments, Environmental Forcing Measurements and Predictive/Hindcast Modelling*

Research Objectives

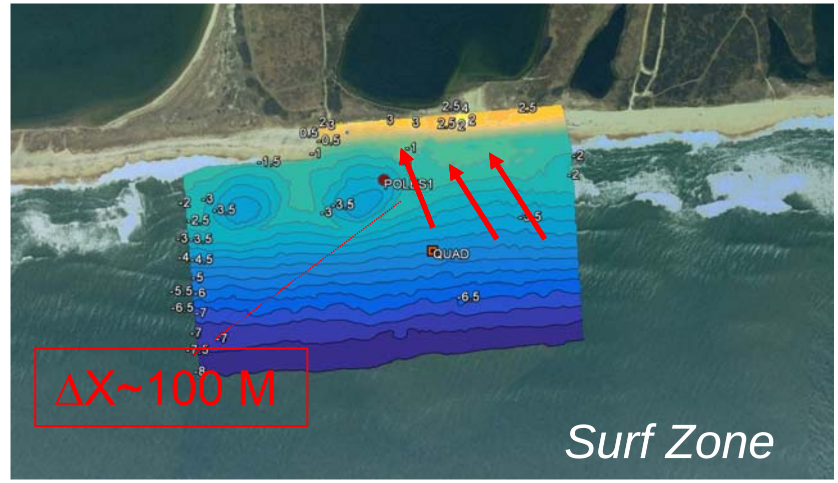
- *Develop "minimal-infrastructure" methods to track UXO mobility and burial in energetic surf-zone environments*
- *Collect and analyze measurements of UXO migration and burial.*
- *Develop deterministic models for environmental forcing and UXO response.*

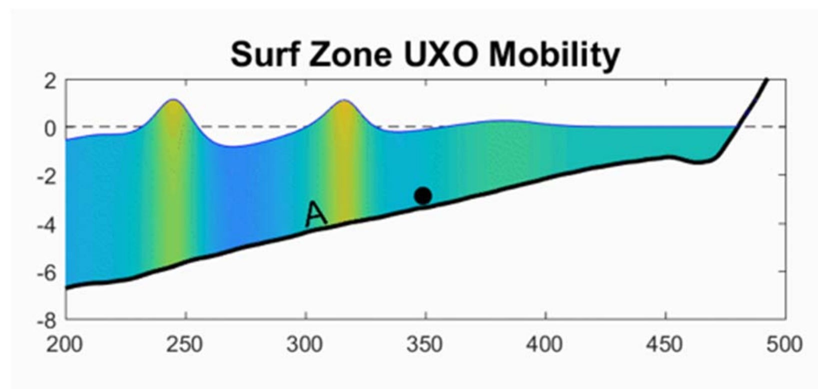
Project Progress and Results

- *UXO Tracking and Environmental Monitoring technology is under development*
- *Predictive modelling upgrade to include migration is underway with promising initial results*

Technology Transition

- *Collaborate with statistical modelling efforts, and direct involvement with remediation contractors*





Social Media Content

- **Technology development efforts related to this project featured on social media often through WHOI outreach**
  - *Jetyak Autonomous surface vessel*
    - *NSF360 Video*
    - *WHOI Videos 1,2*
- **Personal Facebook and YouTube posts on Coastal Erosion and Ice Dynamics filmed from UAS (Drone) platforms.**
  - **Sometimes picked up by local news networks.**

Project Team

Dr. Peter Traykovski

Associate Scientist, Coastal Ocean Fluid Dynamics Laboratory, AOP&E Dept., WHOI

Sediment Transport and Coastal Morphodynamics

- Bedforms, Fluid Mud Flows, Coastal Processes and Morphology
- Instrumentation to measure sediment transport and boundary layer processes

Robotic Platforms for Coastal Morphodynamics

- Unmanned Aerial Systems and Unmanned Surface Vessels

Fredric Jaffre

Research Engineer- REMUS AUV Group, AOP&E Dept., WHOI

Underwater acoustics instrumentation design

remotely operated vehicle electrical design

Problem Statement

- Migration and Burial of munitions is a challenge for remediation efforts and site management.
  - Field and Laboratory Measurements are required to test and develop models.
- Significant progress has been made on both UXO migration/burial measurement techniques and empirical/theoretical modeling.
- Excellent Measurements in a variety of Environments: Surf, Swash, Tidal Shoals/Estuaries
  - Measurements techniques require significant amounts of infrastructure deployed in the energetic environments. Difficult for rapid response.
  - Large Instrumented Seafloor Frames (Tripods), Complex Acoustic Tracking Systems.
- Modeling and analysis has effectively examined transition from burial to mobility but simple parametric models for migration rates and distances have not been developed and tested.
  - Lack of progress in migration modelling is partially due to lack of migration measurements.

Technical Objective

- Develop “minimal-infrastructure” methods to track UXO mobility and burial in energetic surf-zone environments.

  1) Develop UXO tracking methods compatible with COTS acoustic pingers

  2) Develop UXO surrogates with internal environmental forcing sensors (e.g. pressure sensor), or easy to deploy external sensors

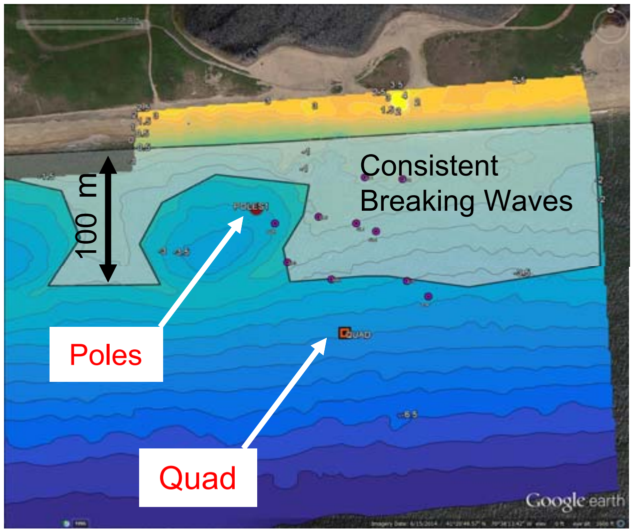
- Collect and analyze measurements of UXO migration and burial in a energetic surf zone environment.
  - ♦ Focus on density parameter space where mobility is likely S ~ 2.0 to 3.5
- Use measurements to develop deterministic models for environmental forcing and UXO response.

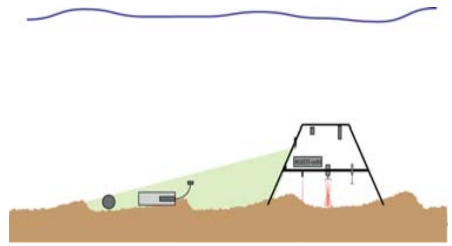
  3) Modelling effort will focus on hindcasting / predicating migrations rates and distances

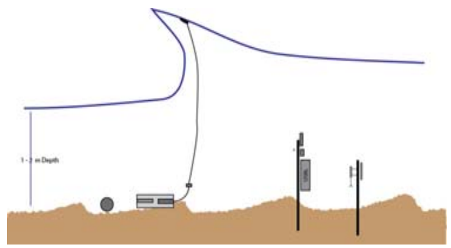
For rest of talk will focus on Items 1, 2 and 3. Will combine approach with some some results for each item

Technical Approach: 1) Tracking Technology

Previous: In-Situ USBL Acoustic Tracking Arrays and UXO mounted transponders And Frame Mounted Instruments for Hydro Forcing







Previously:

- Two way travel time (Ping-Respond)
- USBL Bearing
- In-Situ System was difficult to deploy and maintain
- Could only track sUXO before and after storms
- Limited to Large sUXO (14 cm OD)

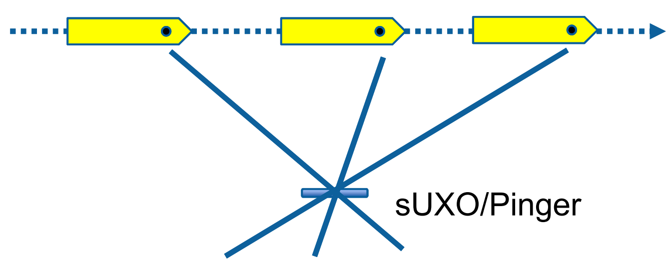
New Technical Approach:

USV/ USBL Based Surveys of UXO with COTS pingers, No Travel Time. Bearing Only System deployed on Jetyak ASV

New:

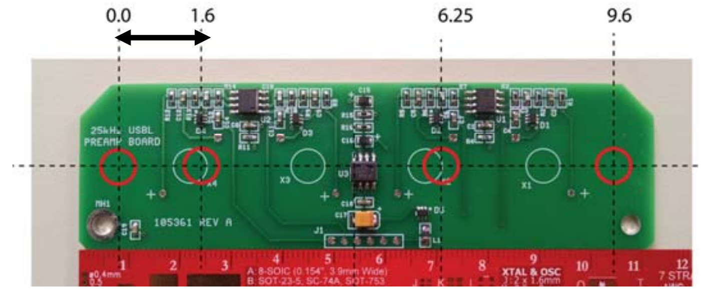
- COTS Pingers are small and low cost, can be adapted to small sUXO
- Discrete transmission freqs (32-40 kHz) allows 8 or 16 targets

USV/USBL
(Position, Heading, USBL Bearing)



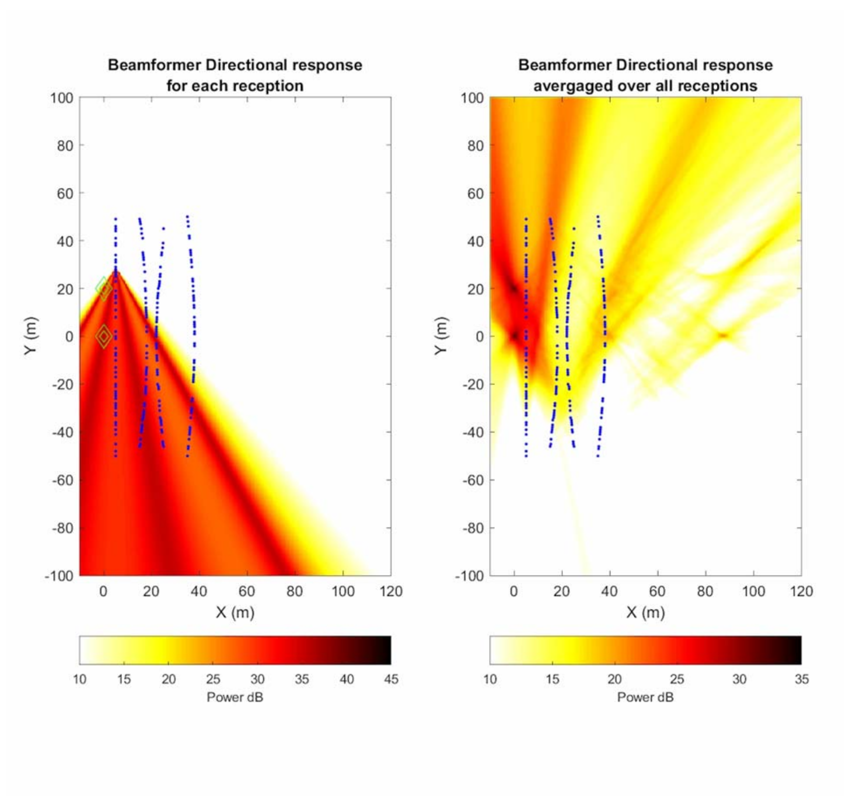
Technical Approach: 1) Tracking Technology

λ/2 @ 40 kHz

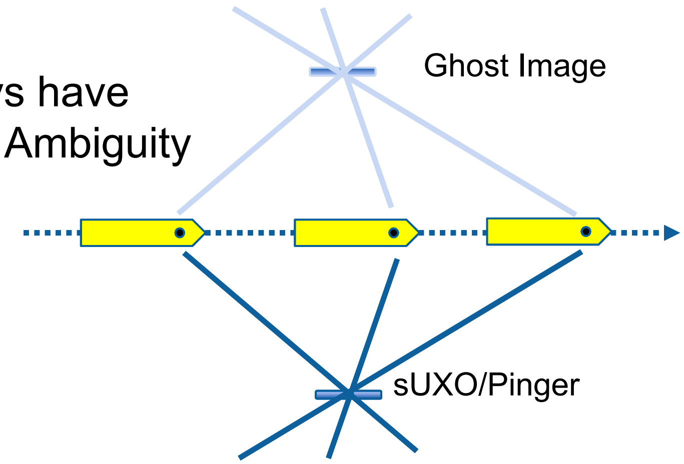


Acoustic array design analysis

- Previous ULA array spacing was designed for 25 khz. Modify for 40 Khz
- New design will use irregularly spaced elements for optimum resolution and sidelobe rejection.
  - MRLA from Van Trees 2002 Textbook and MVDR high resolution beamforming methods
- In manufacturing stage now



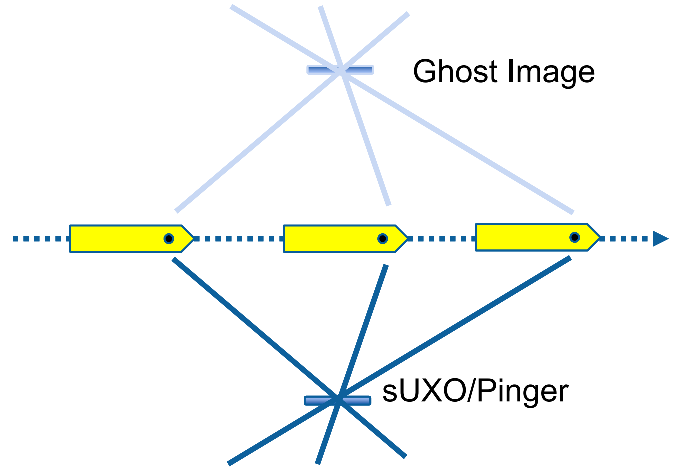
Line Arrays have Left/Right Ambiguity



Tracking filter required for localization in a bearing only system

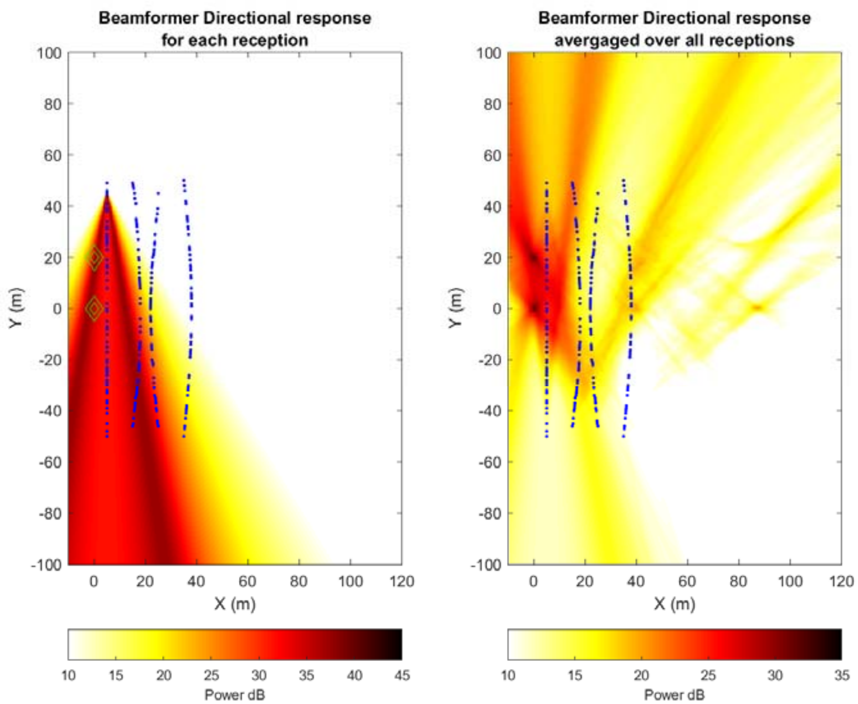
- Breaks L/R ambiguity
- Separate multiple targets at same frequency
- Requires tight coupling of Jetyak ASV AHRS and array
  - In progress

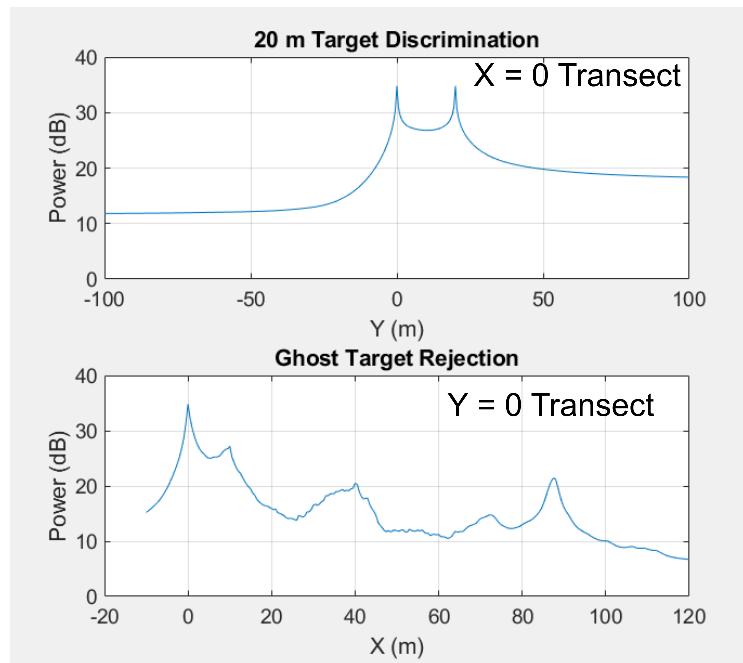
Technical Approach: 1) Tracking Technology



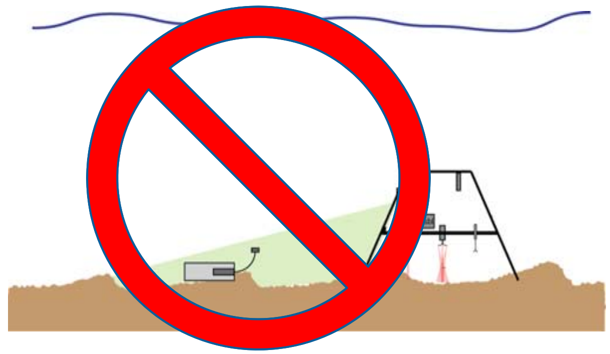
Tracking filter required for localization in a bearing only system

- Can discriminate targets 10 m apart
- At least 10 dB rejection of ghost targets with typical ASV trajectories

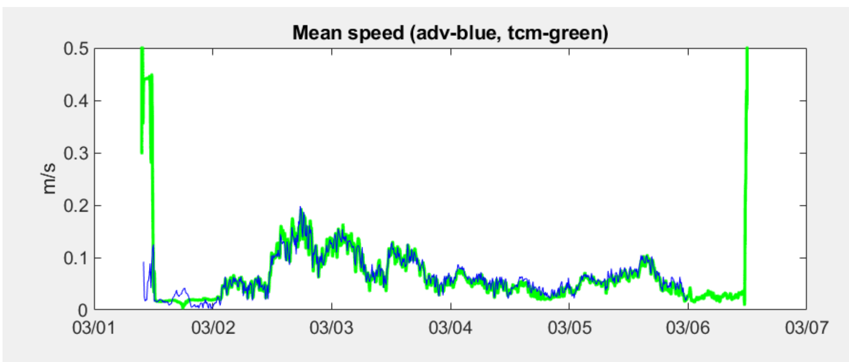




Technical Approach: 2) Environmental Forcing Sensors



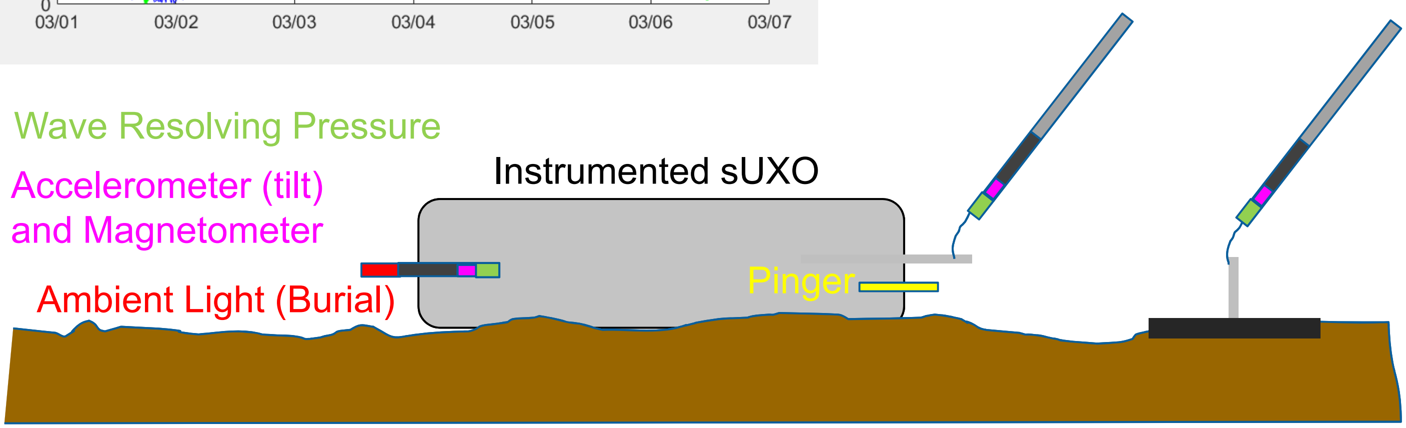
- Worked with Lowell to develop sensor package suited for our purposes.
    - Commercially available for others
    - Up to 6 month endurance
- Testing in combined wave and current forcing and pure tidal forcing.
    - Compared to Acoustic Doppler Velocimeter “state of art” research reference sensor
    - Pressure is the same
    - Means currents in presence of 1.5 m/s waves are good.
    - Spectra has a linear decay above 0.1 Hz
    - Seems OK for UXO mobility studies
    - 1/7 the cost and much simpler to deploy, so samples spatial variability much better.



Tilting current meter

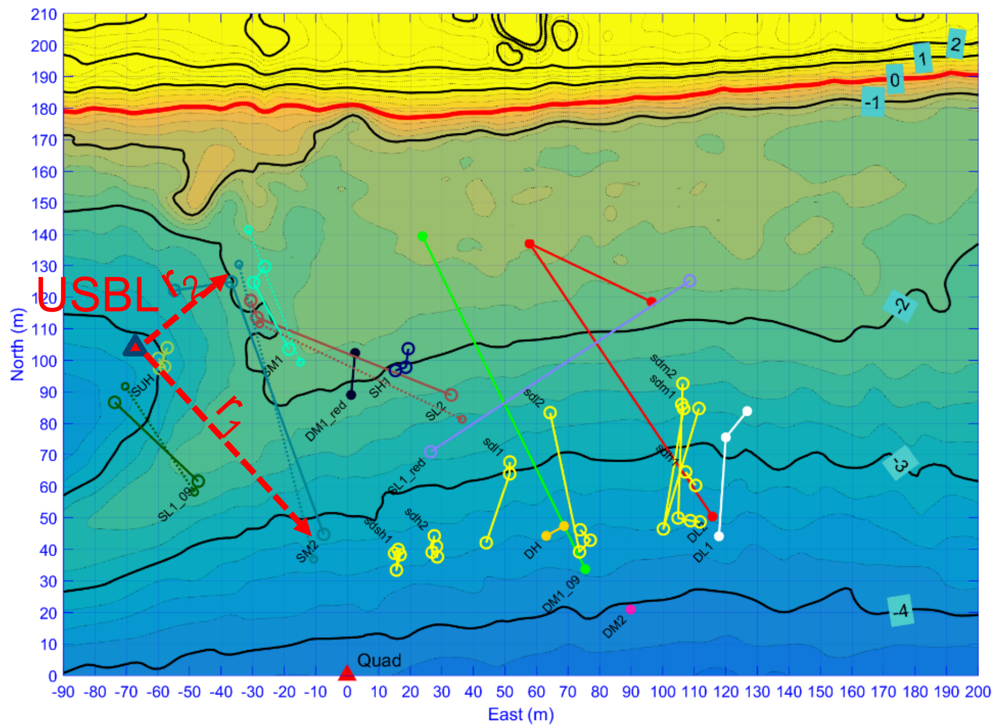
Same data logger as instrumented sUXO

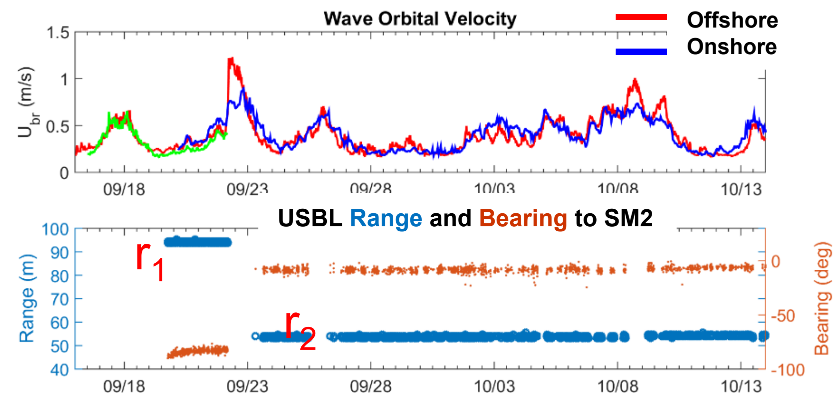
Rod provides buoyancy and drag

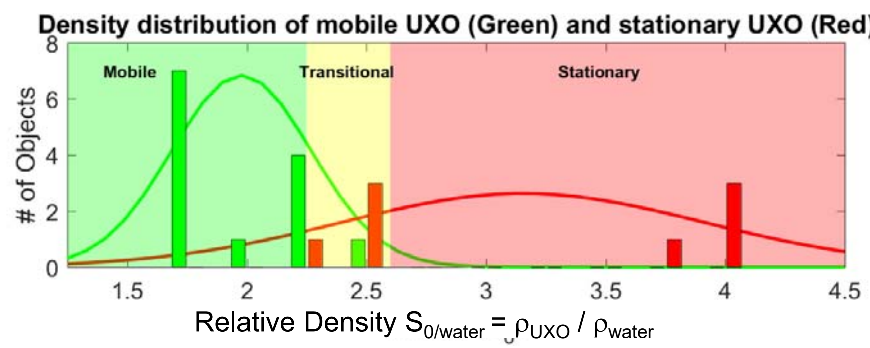


Technical Approach: 3) Migration Modelling
MR-2319 Measured Migration Trajectories (2014 - 2015)

(no new measurements yet)



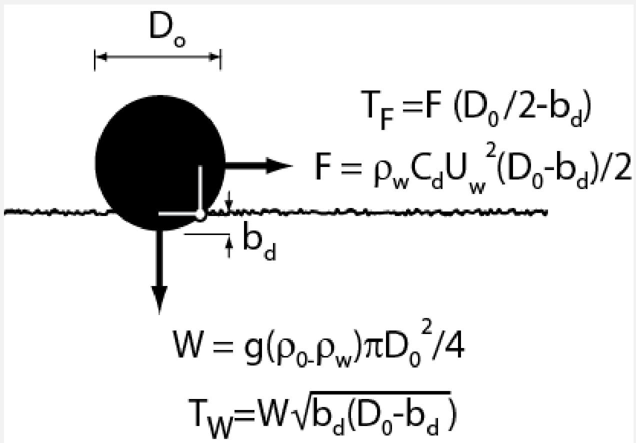


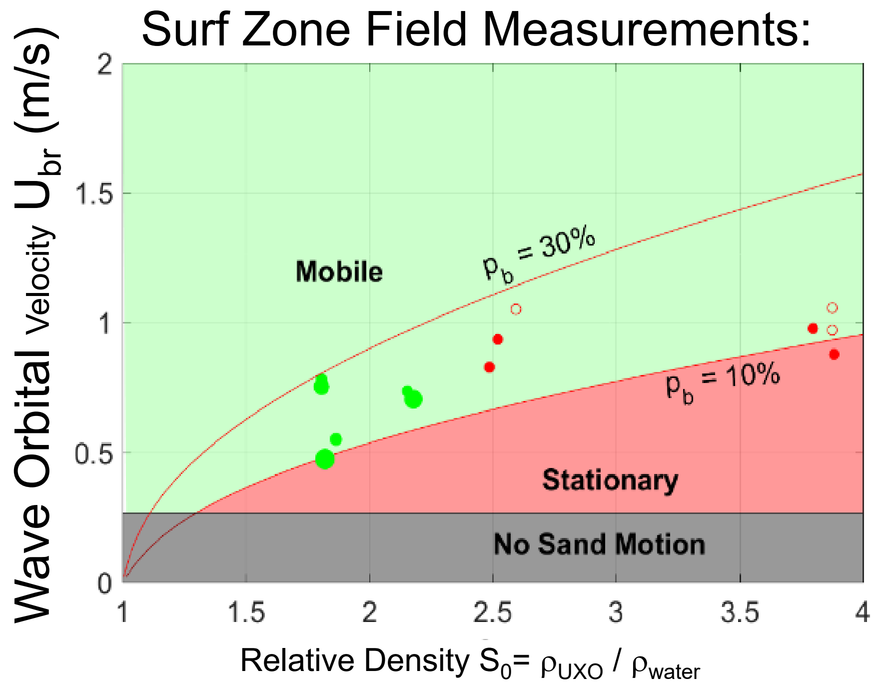


- Migration vs Burial Strongly Dependent on Relative Density
- Less Dense Objects Migrated Across Surf-zone
- Acoustic USBL Tracking provided location data before and after storms

Technical Approach: 3) Migration Modelling Results from MR-2319

Initiation of Motion Torque Balance





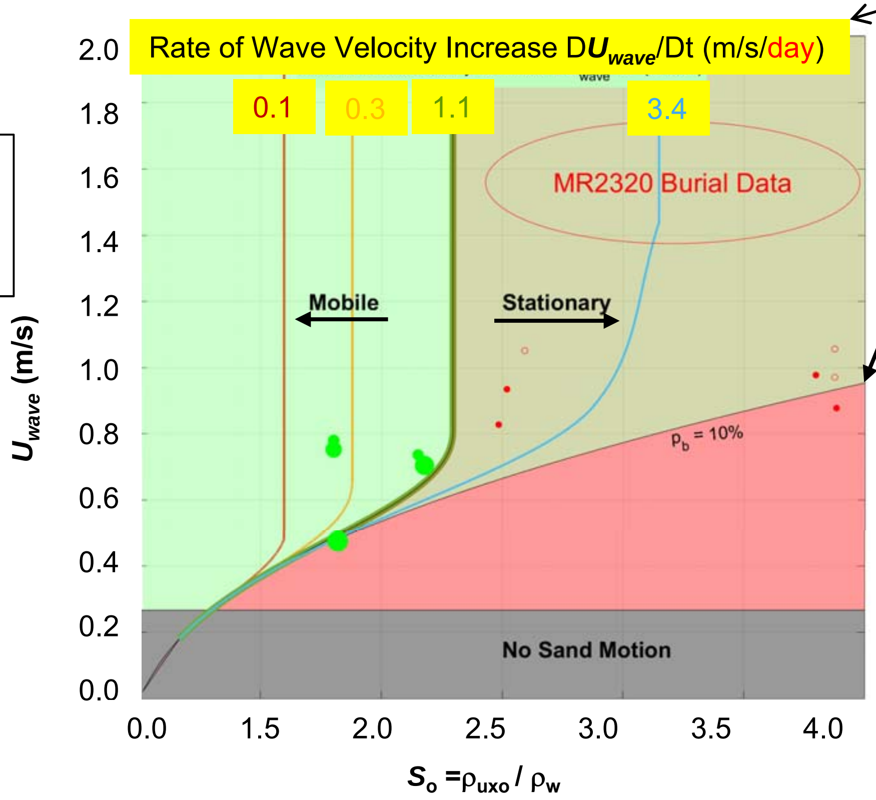
- ***Previous theory could not classify measurements based on a constant initial percent burial***
- ***A time-dependent parametrized numerical model that accounts for slow burial of UXO was developed***
- ***Introduces a new parameter: The rate of hydrodynamic energy change:***
- ***Slowly increasing moderate waves sufficient for scour, but not object mobility -> BURIAL***
- ***With waves increasing rapidly from a calm state, object is subjected to large waves before partial burial, -> MOBILITY***

Technical Approach: 3) Migration Modelling

Time Dependent Mobility Model Results

Units error in previous presentations (hours)!

Slow DU_{wave}/Dt
All but least dense objects bury



Fast DU_{wave}/Dt converges to previous "instantaneous forcing" model,
Incorrectly predicts dense objects are mobile for U_{wave} > 0.6 to 0.8

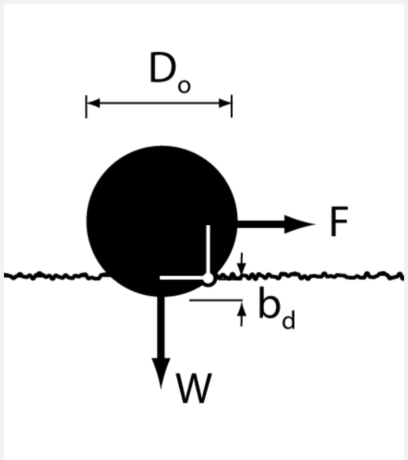
- *The time dependent relation between U_{wave} and S for U increasing with realistic rates successfully classifies burial and mobility data.*
- *Produces the same qualitative structure of a sharp transition w.r.t to S_0 as measurements.*

● S, $U_{wave\ initial\ motion}$ for mobile objects
● S, $U_{wave\ maximum}$ for non-mobile buried objects

Technical Approach: 3) Migration Modelling

Expand previous model for Mobile UXO

Dynamic Force Balance:



Fluid Drag — Inertial “Added Mass” — Pressure Gradient

$$F_b = 0.5\,C_d\,\rho_w(D_o - b_d)(U_w - U_o)|U - U_o| + C_m\rho_w\frac{\pi(D_o - b_d)^2}{4}(\dot{U}_w - \dot{U}_o) - \rho_w\frac{\pi(D_o - b_d)^2}{4}\dot{U}_w$$

$$F_d = g\,\rho_O\pi\frac{D_o^2}{4}\sqrt{b/(0.5D_0 - b_d)}$$

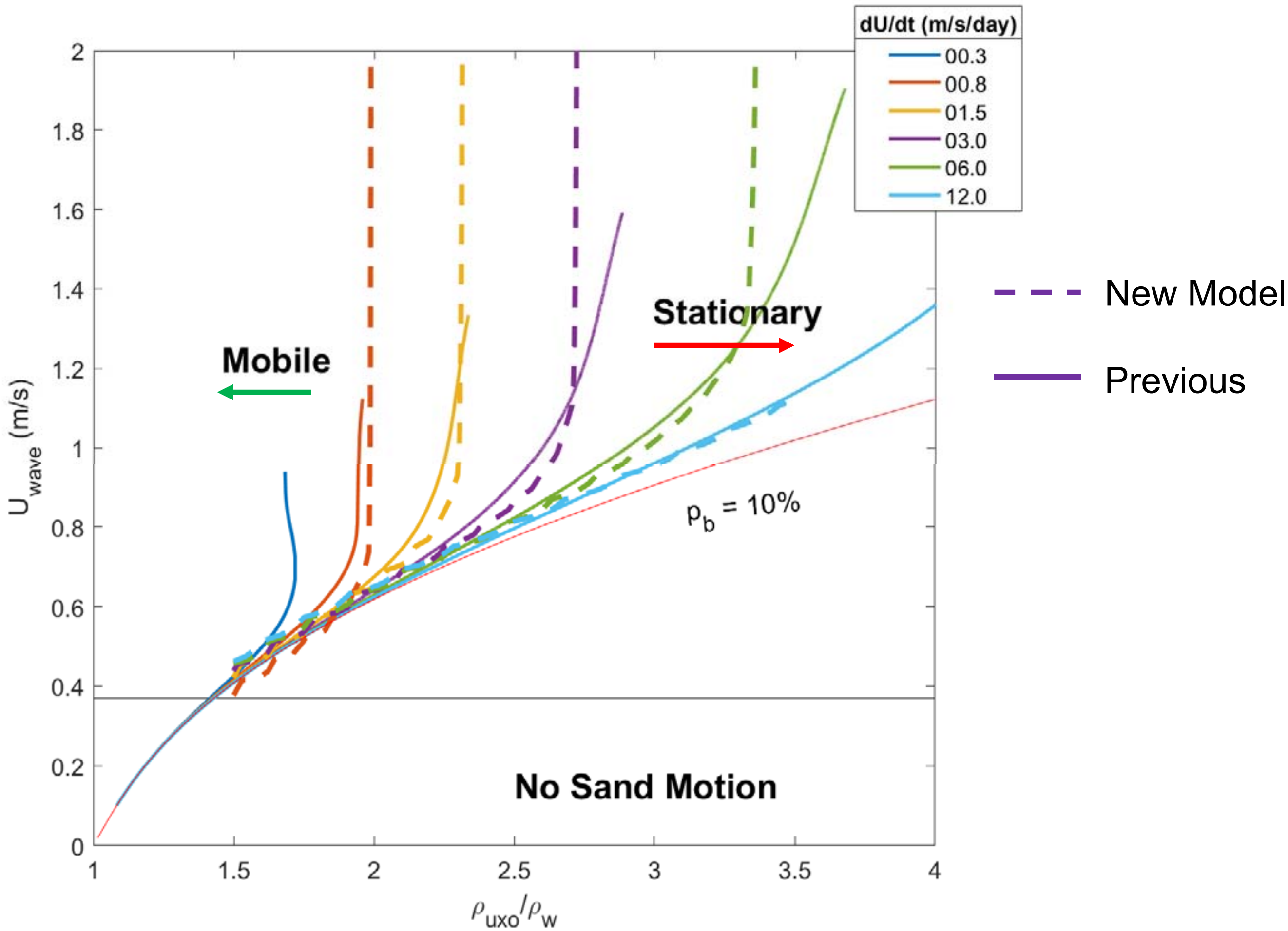
Rigid Object rolling on deformable bed friction

Equation of motion: $$\rho_O\pi\frac{D_o^2}{4}\dot{U}_o = F_b + F_d$$

Numerically solve the equation of motion along with the time dependent burial model developed previously

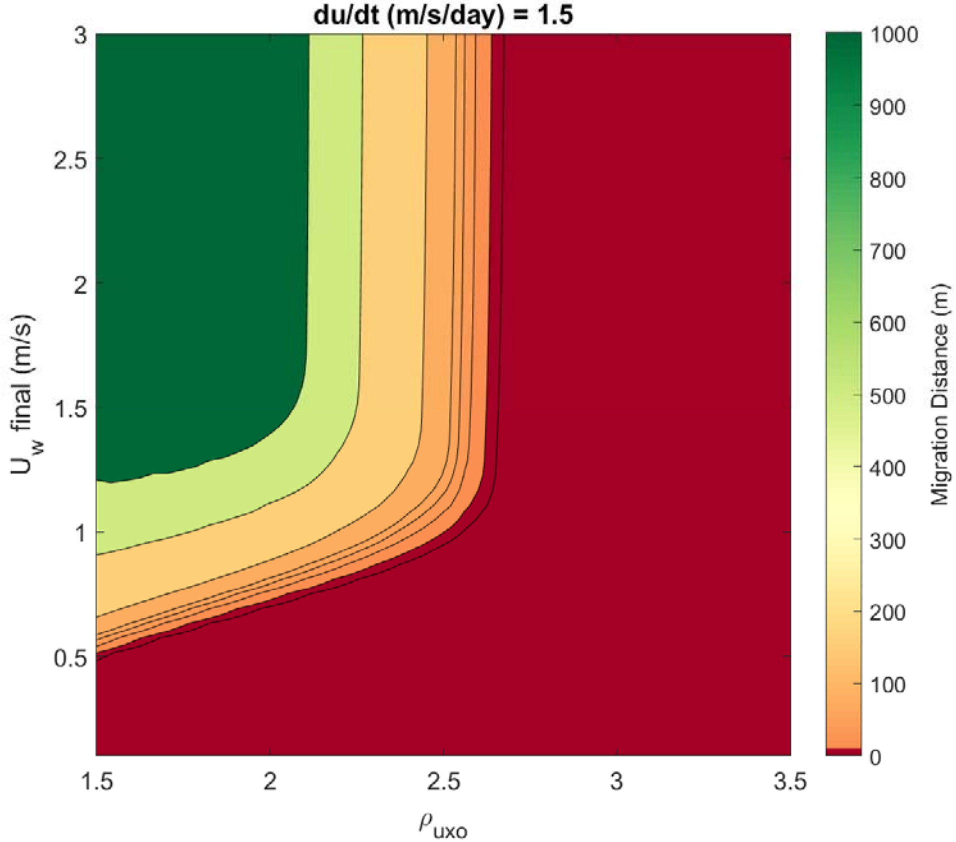
Technical Approach: 3) Migration Modelling

Results: test mobility threshold consistency with previous model



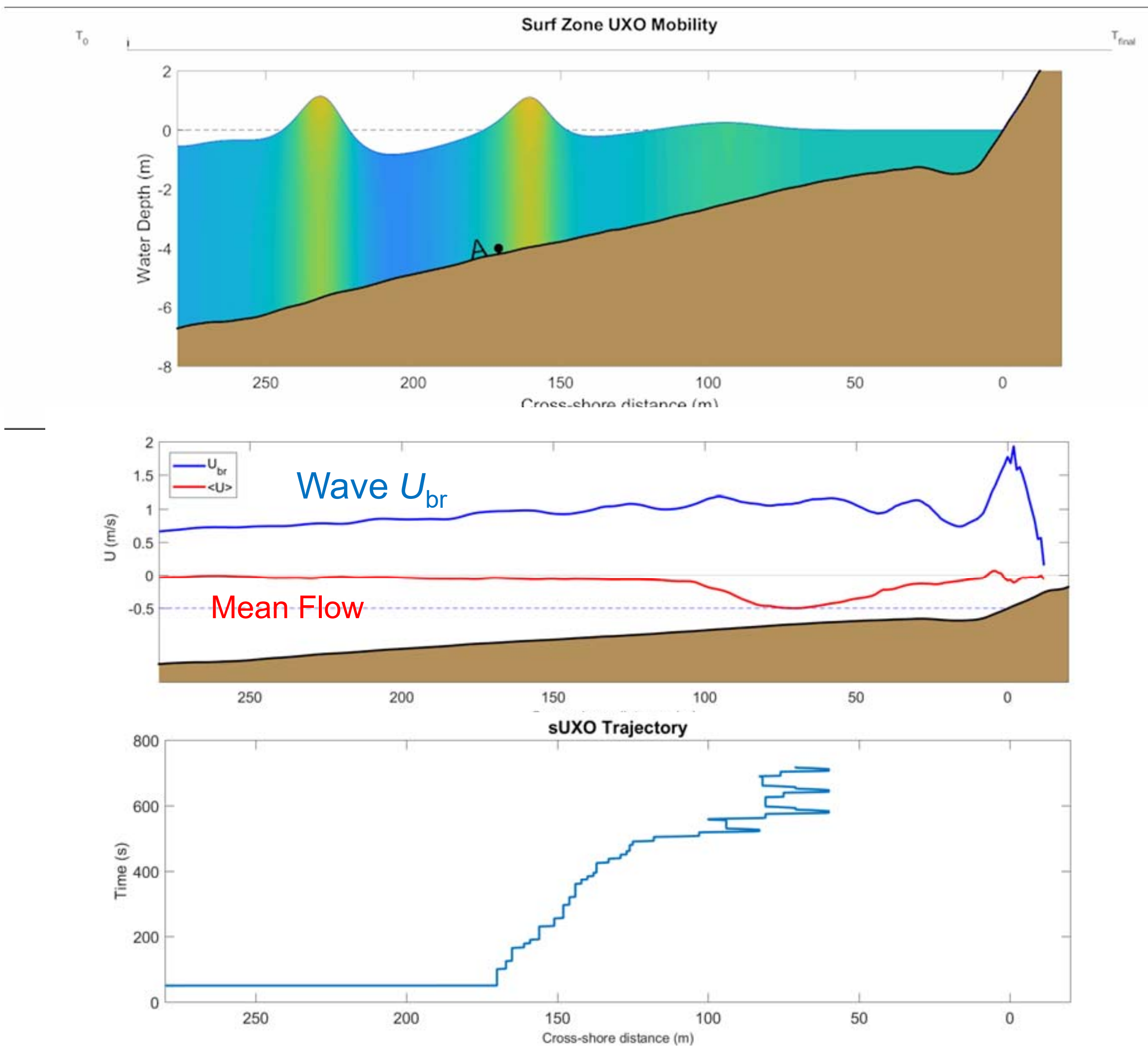
Technical Approach: 3) Migration Modelling

Results: Migration distance on a flat bed with linearly increasing waves



- No realistic spatial variation in wave energy,
  - e.g. breaking and reduced energy near the beach
- Results suggest migration is fast relative to the ~100 m surf zone cross-shore scales and 1-2 day storm time scale
  - Need to check sUXO motion sensor data to see time scales for migration across surf zone

Using the SWASH (Simulating WAves till SHore) Wave Transformation Model to Force sUXO Migration



State of the Art Wave Model:

- Open source model developed at TU Delft
- Non-hydrostatic wave resolving
  - $\Delta x \sim 1m$, #z ~ 3 to 10, $\Delta T \sim 0.02s$
- Captures non-linear wave transformations (Skewness and Asymmetry) and breaking
- Running in 2d mode (X,Z) for now
- Probably the most appropriate available model for this situation

Very Simple Migration Model:

- Mobility thresholds are roughly consistent with the time dependent model
- Simple Migration Velocity ~ $\alpha\ (U - U_{critical})^3$
  - *Implement full migration model next*

Results are consistent with observations indicating migration distance is dominated by wave transformation physics and not a complex migration model

This is supported by the fast migration rate predicted by more complex model

Summary of Results
(work in progress stage)

1. Bearing Only Acoustic Tracking Technology from ASV
   - USBL array design and tracking filter simulations complete
   - Manufacturing in progress, water tests soon
   - Integration of USBL tracking array into open source (ArduPilot) ASV autopilot underway

2. sUXO Integrated motion, burial and environmental forcing sensors
   - Specification, design, production, acquisition with supplier complete
   - Testing and comparison to reference sensors in variety of combined wave and current forcing environments complete with satisfactory results
   - Lower cost and ease of deployment will improve spatial resolution and ability for rapid response to extreme events.

3. Deterministic UXO migration and burial modelling
   - Expanded previous framework for initiation of motion and burial to include migration rate prediction
   - Began work on using SWASH wave model to force sUXO migration rate model

Next Step is to deploy sUXO with new sensors and tracking technology in the surf-zone

Transition Plan

- sUXO Integrated motion and environmental sensor suite.
- Commercialization of Jetyak ASV platform through Integrated Coastal Solutions LLC
- Document survey techniques in technical reports and publications so that others can use them
- Collaborate with other groups who are developing statistical models
  - Limited direct consultation with remediation contractors on Martha's Vineyard

Issues

- Behind schedule on field measurement work
  - ♦ USBL Array Design Delayed
  - ♦ Martha's Vineyard Long Pont had entire dune system removed as part of remediation effort.
  - ♦ Access for research prohibited while work is underway
- Ahead of schedule on modelling work
- Not a critical delay for research goals
  - ♦ led to underspending in year 1

Publications

- Awards:
  - SERDP Munition response Project of year 2015
    - Shared with Calantoni, *Long Time Series Measurements of Munitions Mobility in the Wave-Current Boundary Layer*
- Publications:

1. Traykovski, P. (2017), Continuous Monitoring of Mobility, Burial and Re-Exposure of Underwater Munitions in Energetic Near-Shore Environments, SERDP MR-2319 Final Report. https://www.serdp-estcp.org/content/download/41490/395926/file/MR-2319%20Final%20Report.pdf
2. Jones, K., & Traykovski, P. (2018). A method to quantify bedform height and asymmetry from a low-mounted sidescan sonar. Journal of Atmospheric and Oceanic Technology. https://doi.org/10.1175/JTECH-D-17–0102.1
3. Scully, M. E., Trowbridge, J. H., Sherwood, C. R., Jones, K. R., & Traykovski, P. (2018). Direct measurements of mean reynolds stress and ripple roughness in the presence of energetic forcing by surface waves. Journal of Geophysical Research: Oceans, 123. https://doi.org/10.1002/2017JC013252