MIGRATION AND BURIAL OF VARIABLE DENSITY MUNITIONS IN THE SURF AND SWASH ZONES

MR20-1094

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University of Delaware

In-Progress Review Meeting – FINAL PRESENTATION

August 12, 2025

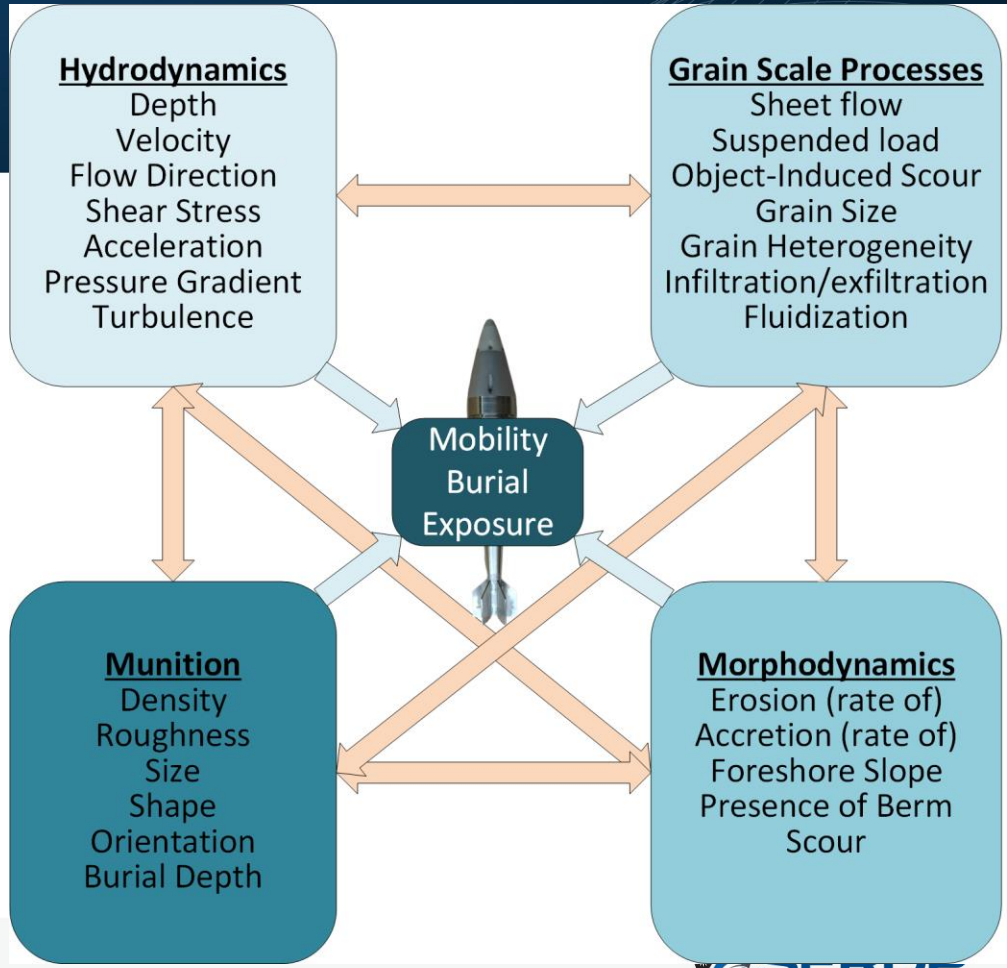
Project Team

Jack A. Puleo
University of Delaware

- Dr. Manoj Gangadharan: Post Doc (WSP)
- Dr. Zaid Alhusban: Post Doc (UD)
- Mr. Temitope Idowu: PhD Student (ODU)
- Ms. Sahar Asrari: PhD Student (UD)
- Ms. Emily Chapman: MCE student (Stantec)
- Ms. Mackenzie Hammel: UG Researcher
- Ms. Lillian Gilardi: UG Researcher
- Mr. David Bogart: UG Researcher
- 25+ volunteers

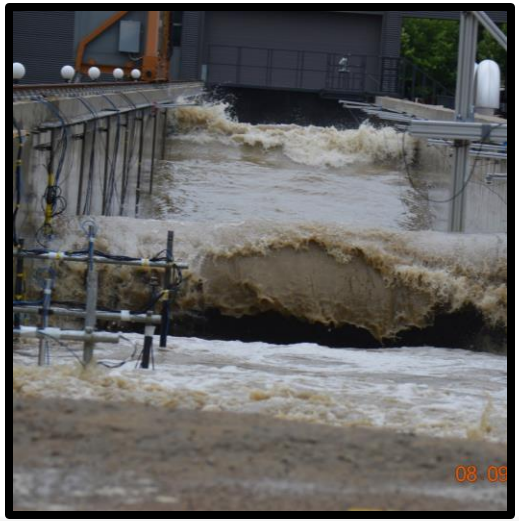
Bottom Line Up Front

- Using munitions of varying density to determine behavior in the nearshore
- Specific gravity important
- Beach slope important
- Cross-shore location important
- Intermittent motion
- Stochastic process!

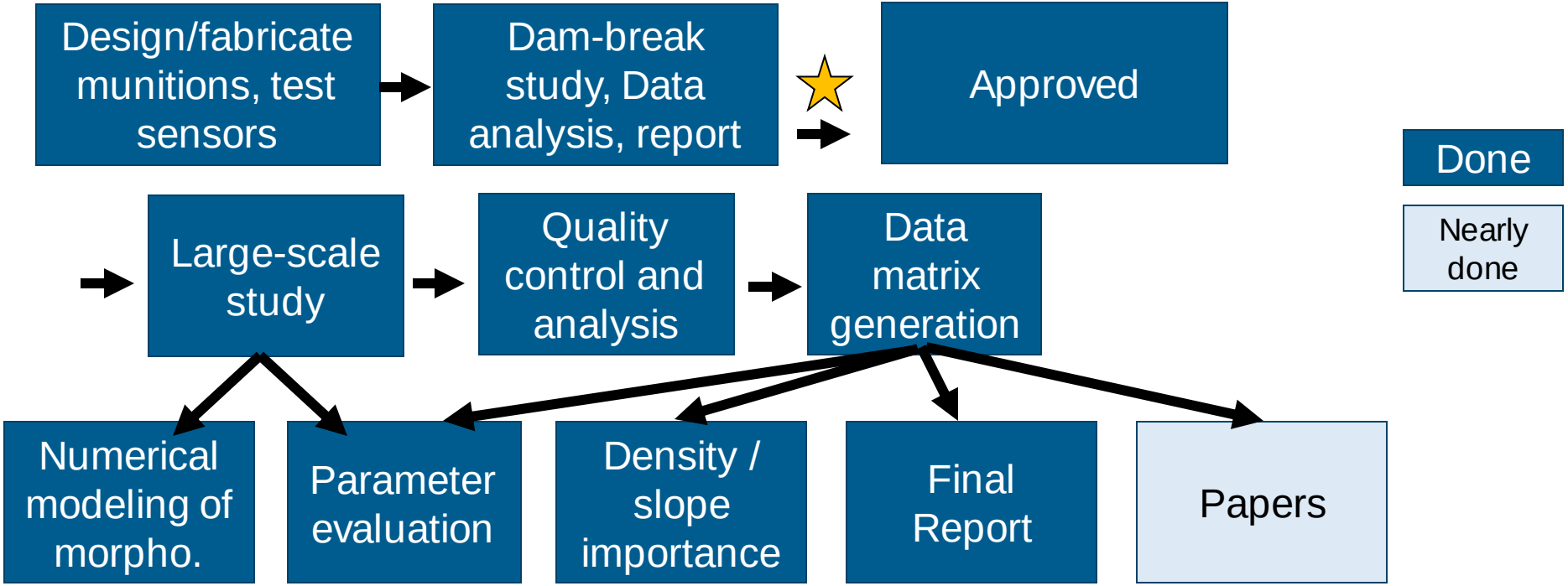


Technical Objective

Relate scaled event forcing of hydrodynamics and morphodynamics to munitions **mobility**, burial, and exposure within the surf zone



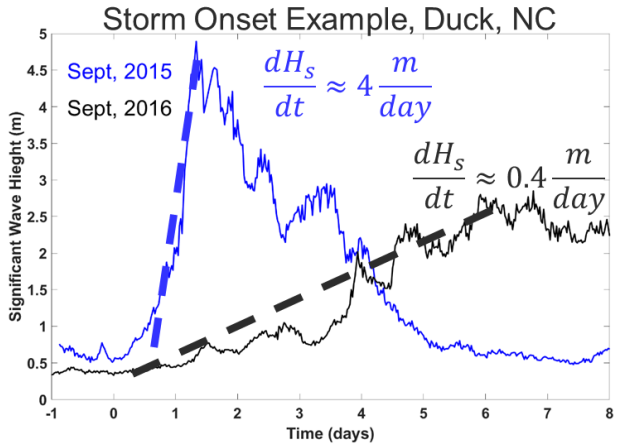
Technical Approach



SERDP

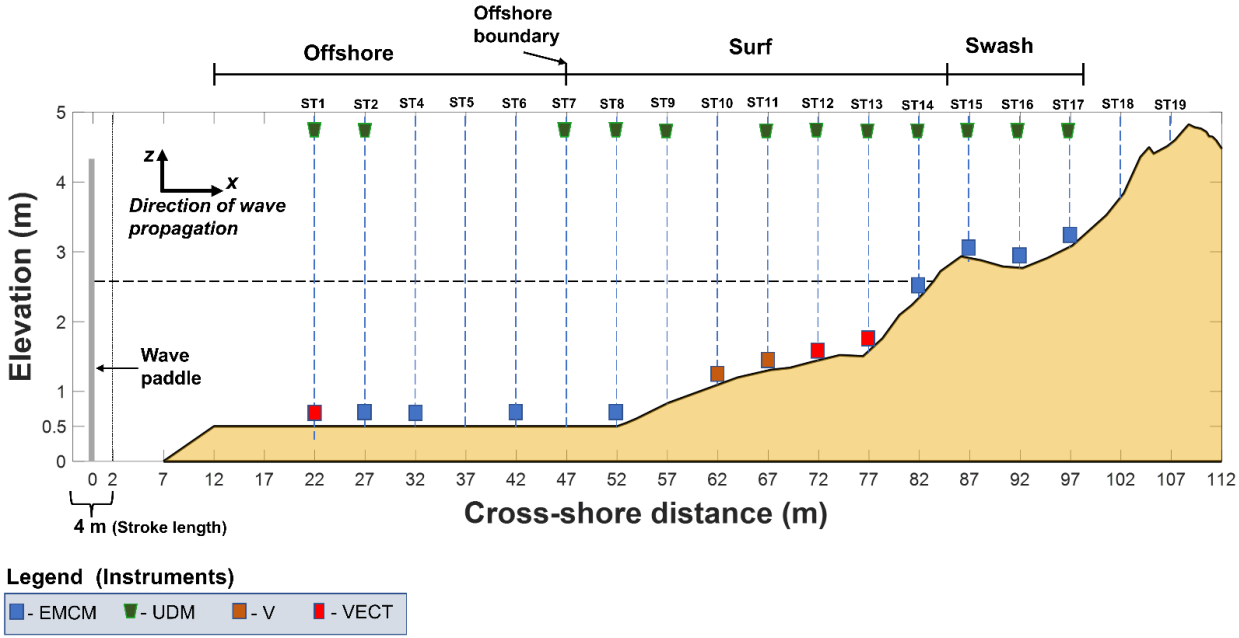
Technical Approach

1) How do surrogates of different density respond to the same forcing conditions?
2) Will exposed munitions migrate onshore?
3) Does the storm onset intensity affect munitions **mobility** and burial



Flume Study – INRS – Quebec City, CA

- Numerous sensors – A lot of data
- 7 cases
  - Water level
  - Wave height
  - Wave period
- Multiple trials per case



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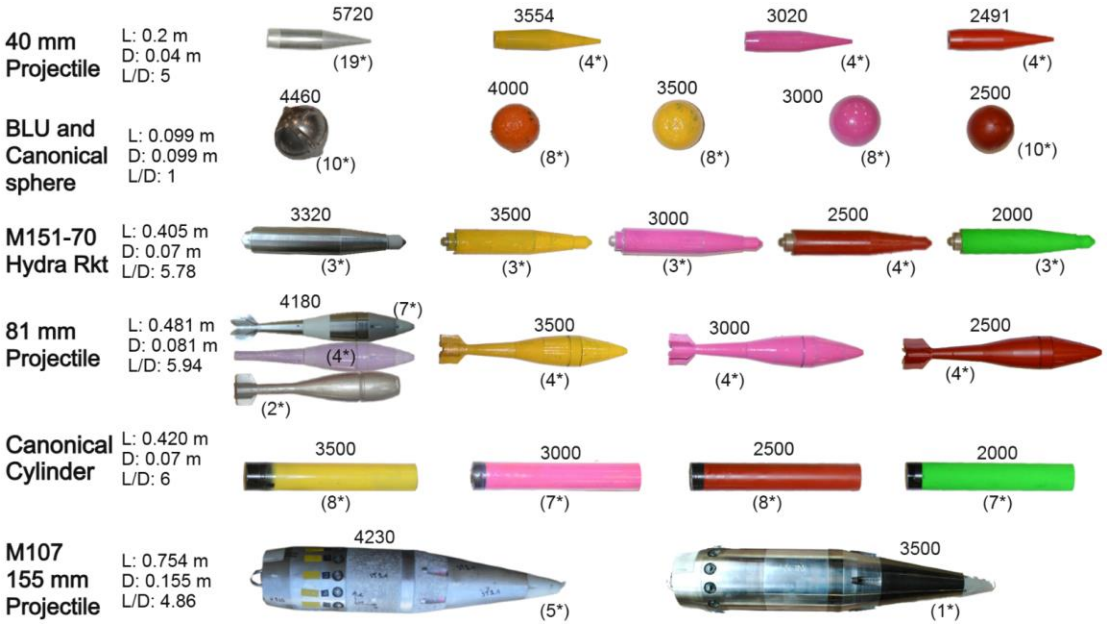
Technical Approach



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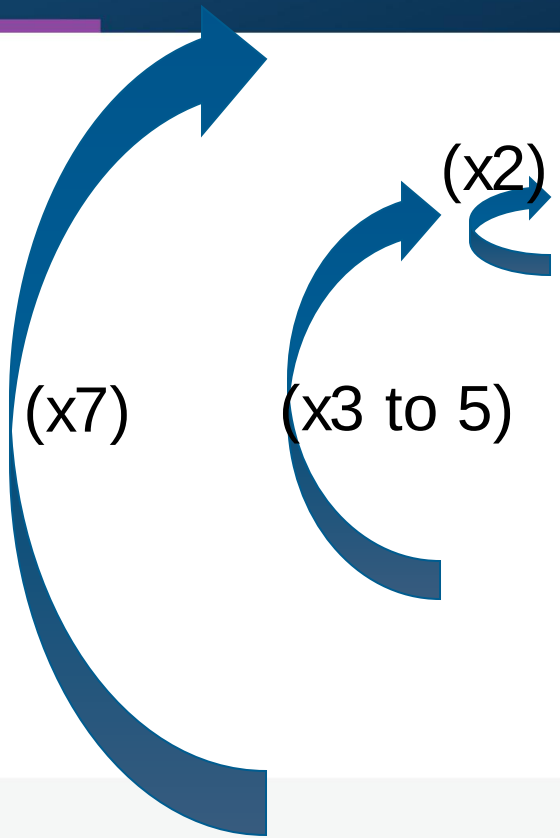
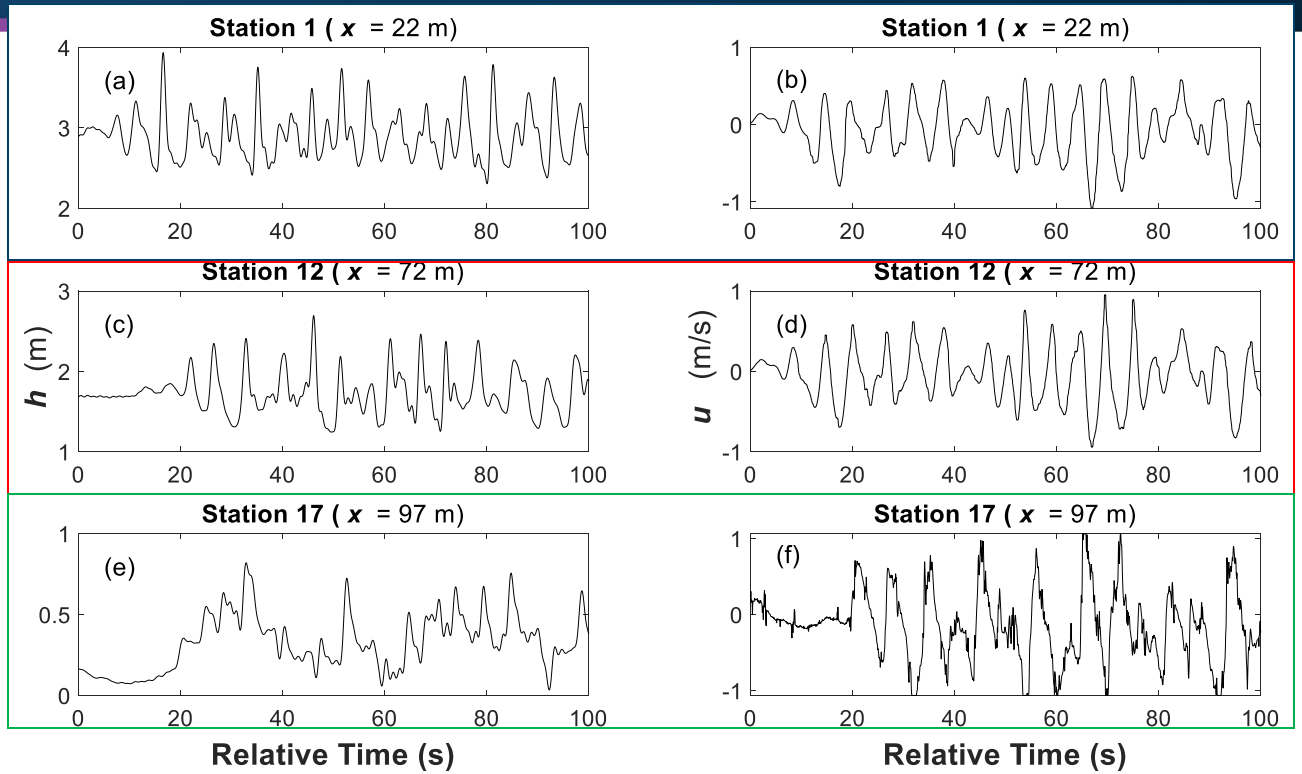
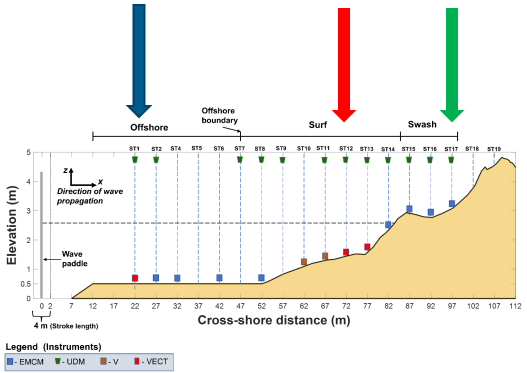
Flume Protocol → Effort (Much Effort)



- Install frames
- Install sensors, orient cameras and lidars
- Run trial
- Survey beach profile
- Drain flume
- Survey profile
- Metal detect, survey munitions
- Fill flume
- Finish Case
- Remove frames and sensors
- Reshape beach

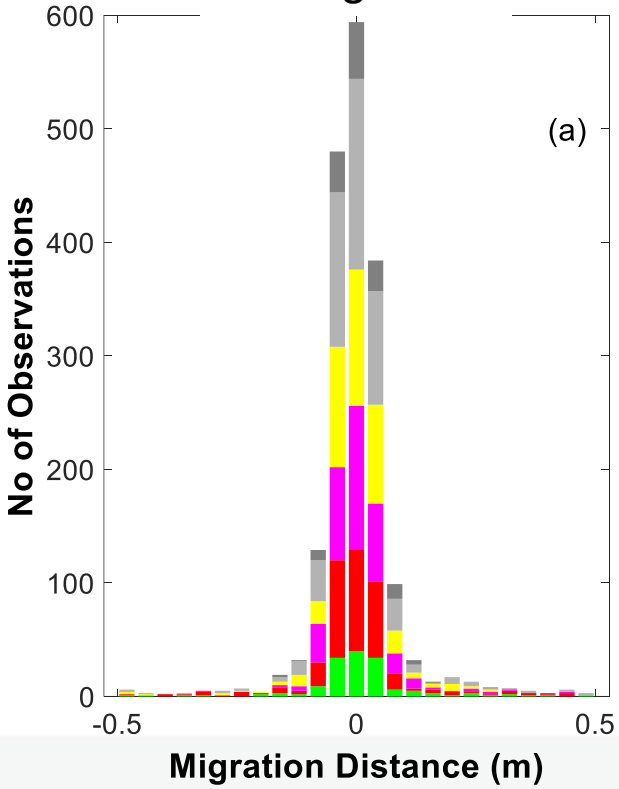
Depth and Velocity Data



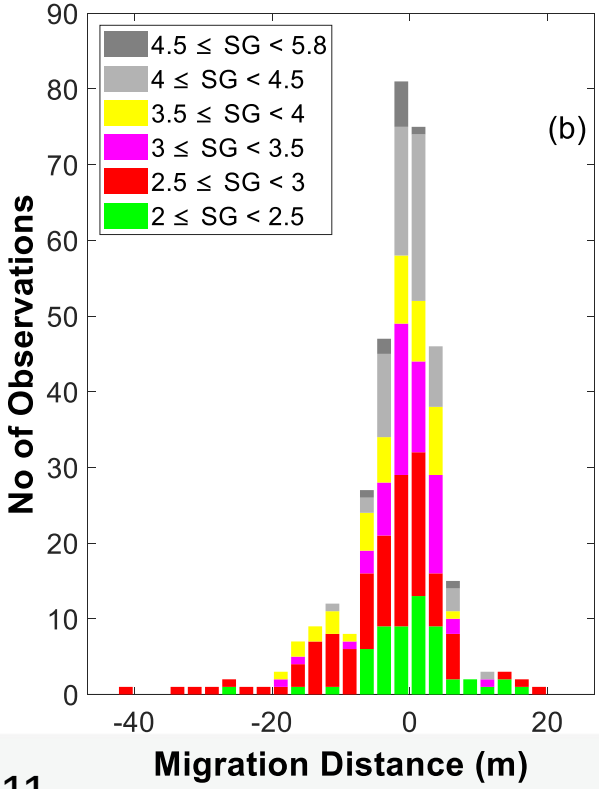


Migration

No Migration



Migration



- Trends based on SG
- No cross-shore fidelity

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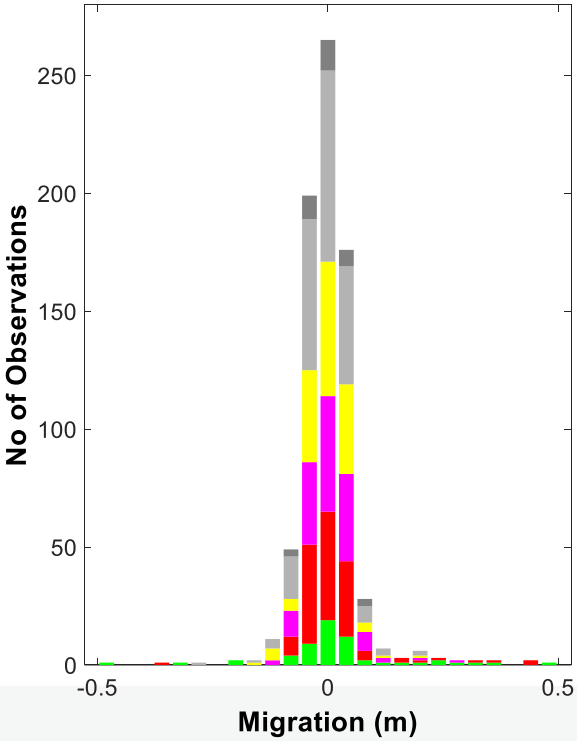
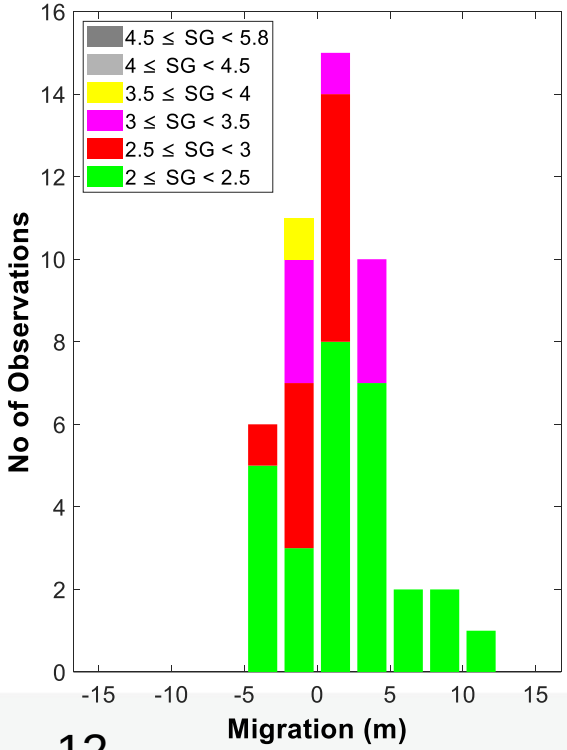
Migration - Offshore

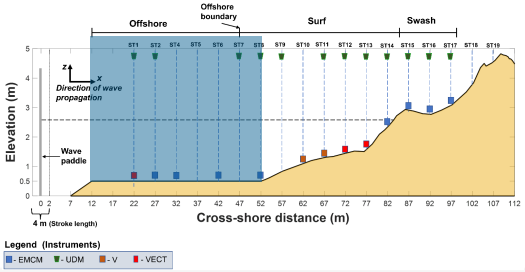
No Migration



Migration



- "Flat"
- No wave breaking
- Only low density munitions move



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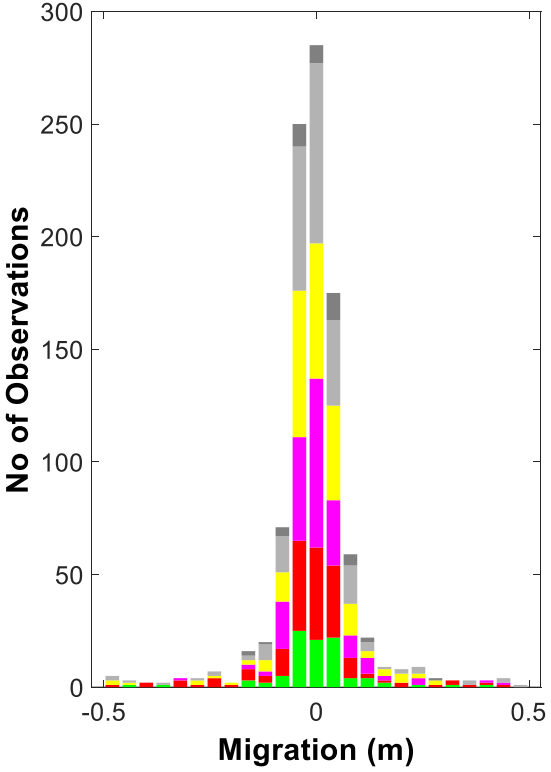
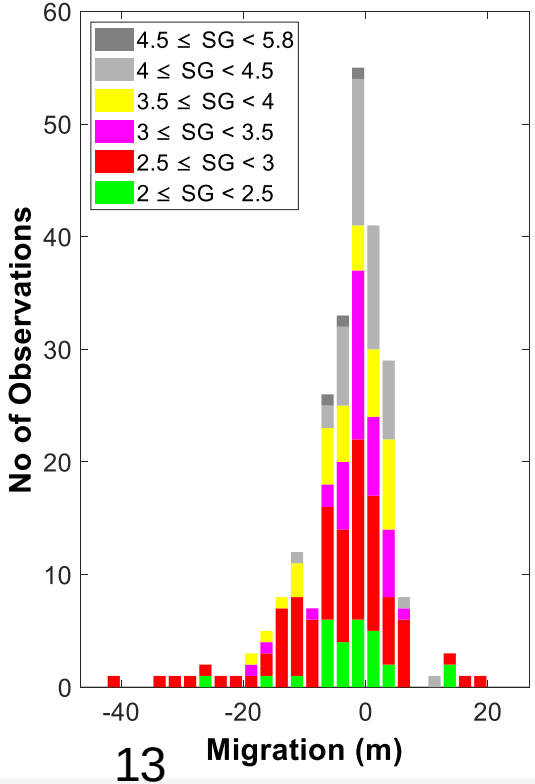
Migration – Surf Zone

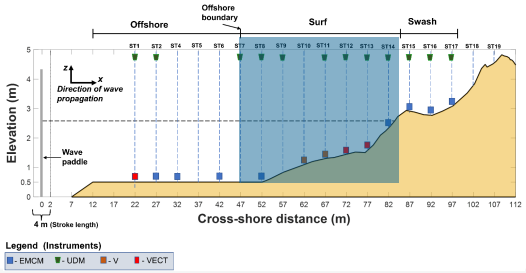
No Migration



Migration

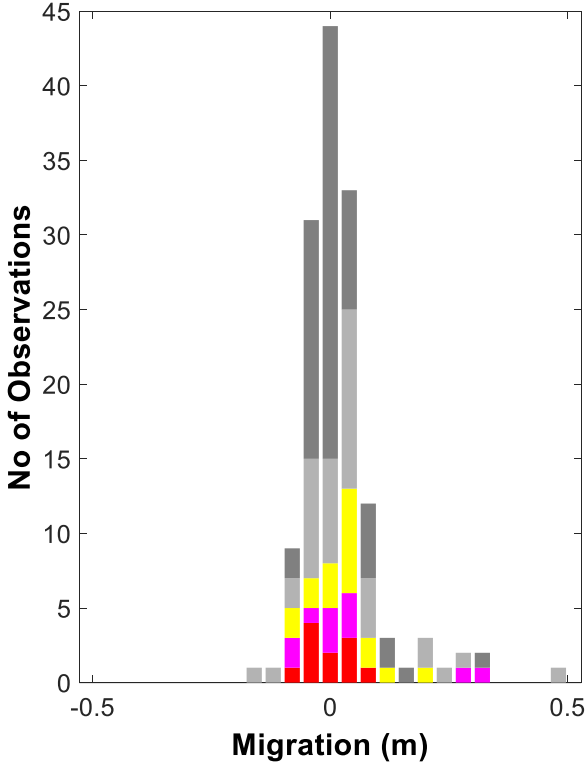


- Less “flat”
- Some more dense munitions migrate…
- ...but less distance
- Picture not clear

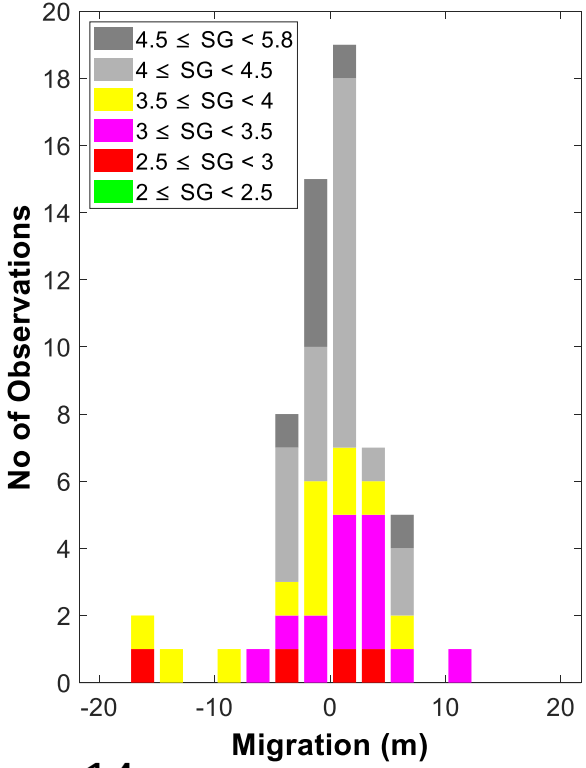


Migration – Swash Zone

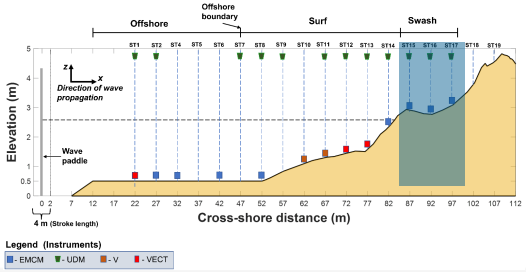
No Migration



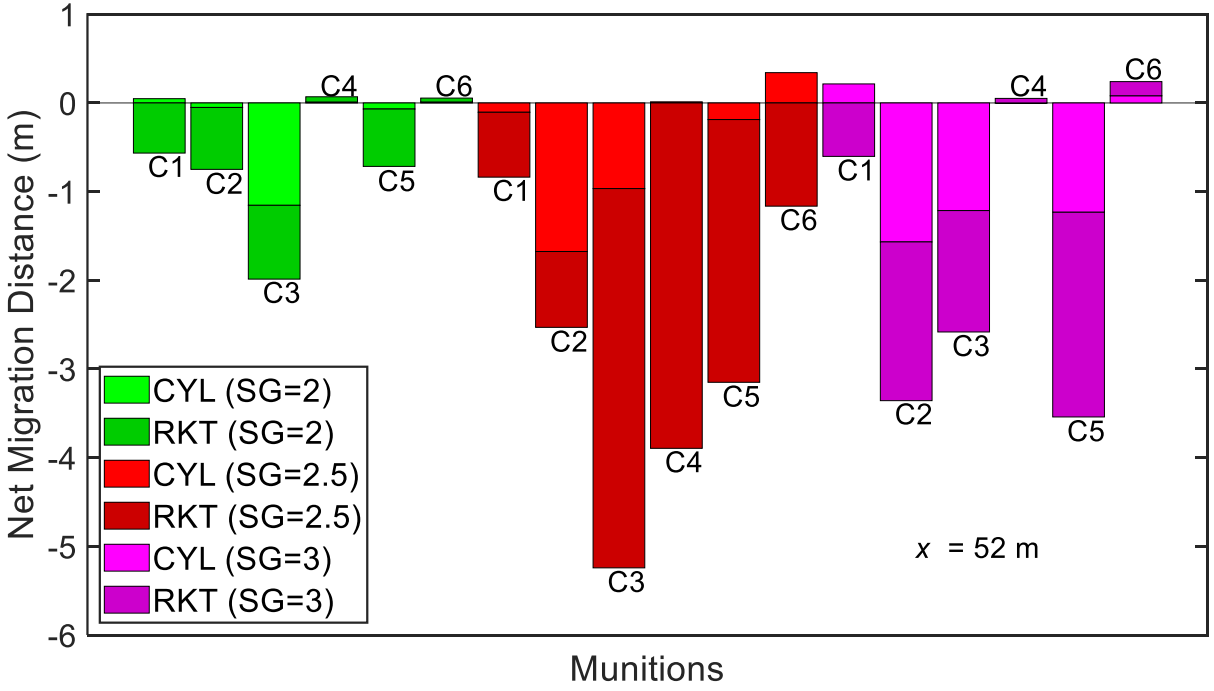
Migration

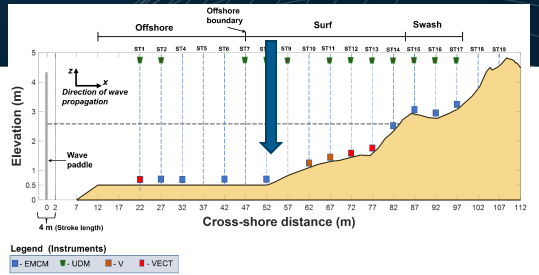


- "Steep"
- More dense munitions
- Less direction preference
- Onshore motion is over berm; then "stuck"



Migration in Surf Zone – More Detailed Look





- Station 8
- Rockets migrated farther than cylinders
- SG = 2.5 had greatest migration distance

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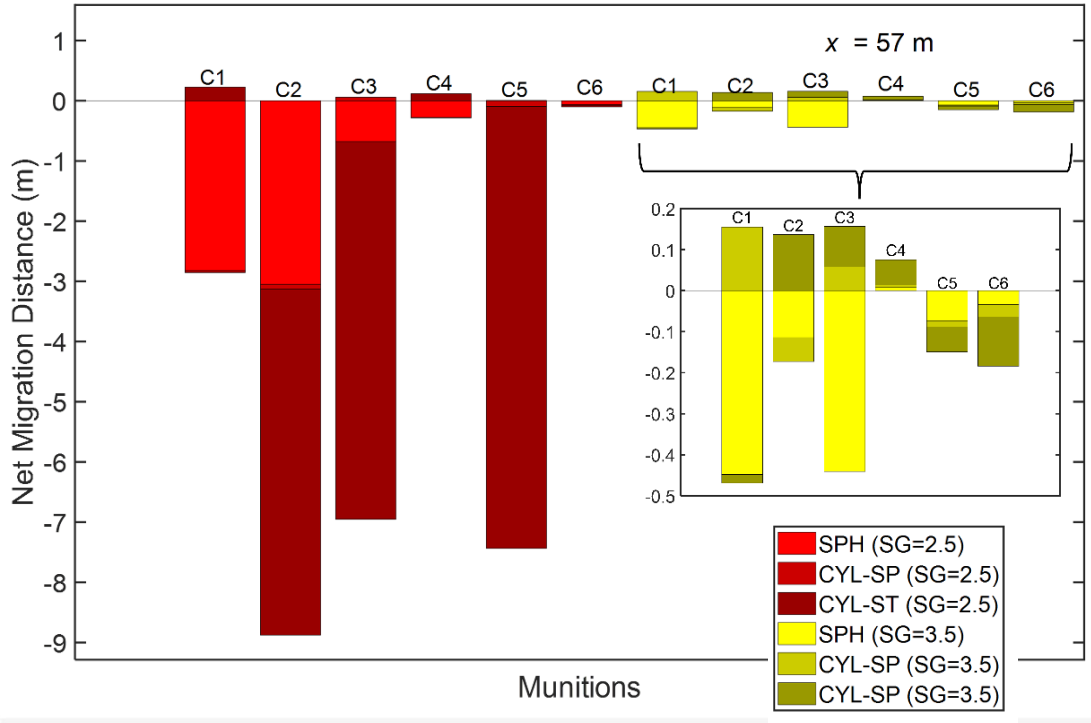
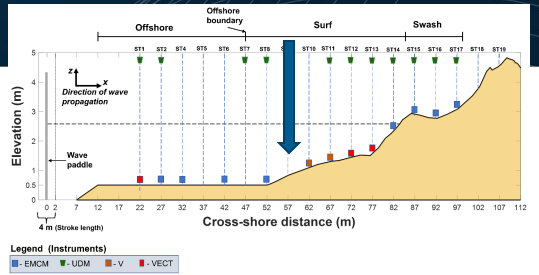
Migration in Surf Zone – More Detailed Look





- Station 9
- Spheres vs Cylinders
- Cylinders seem to migrate more
- Density differences

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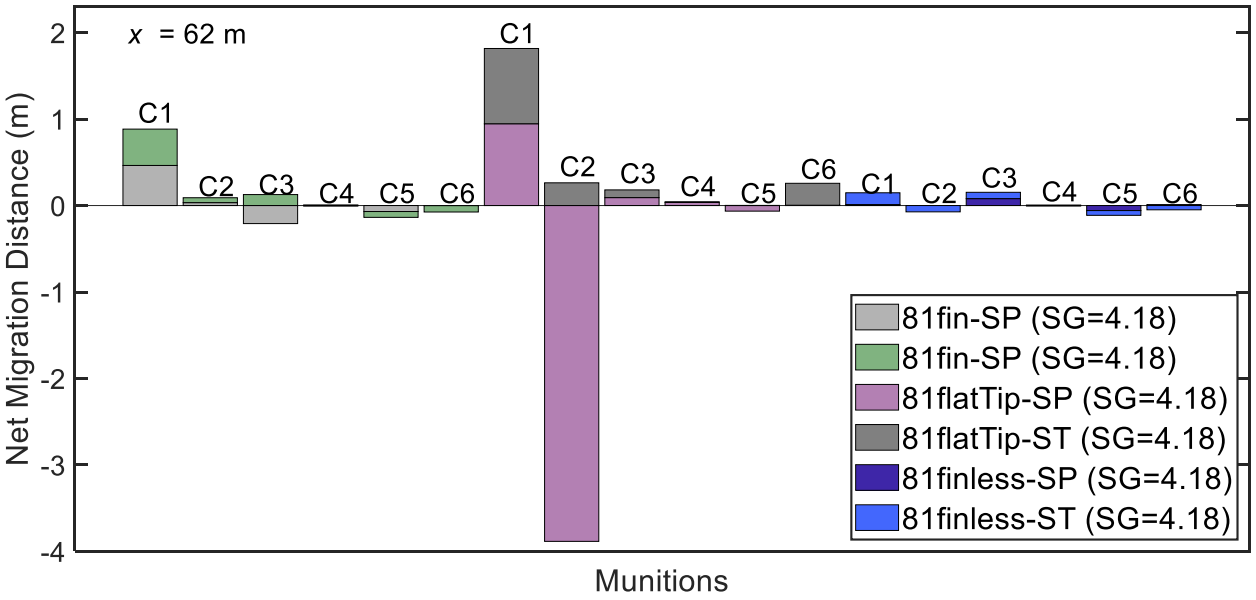
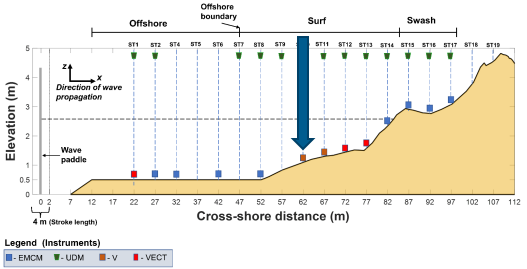
Migration in Surf Zone – More Detailed Look





- Station 10
- More dense munitions
- Moderate migration onshore

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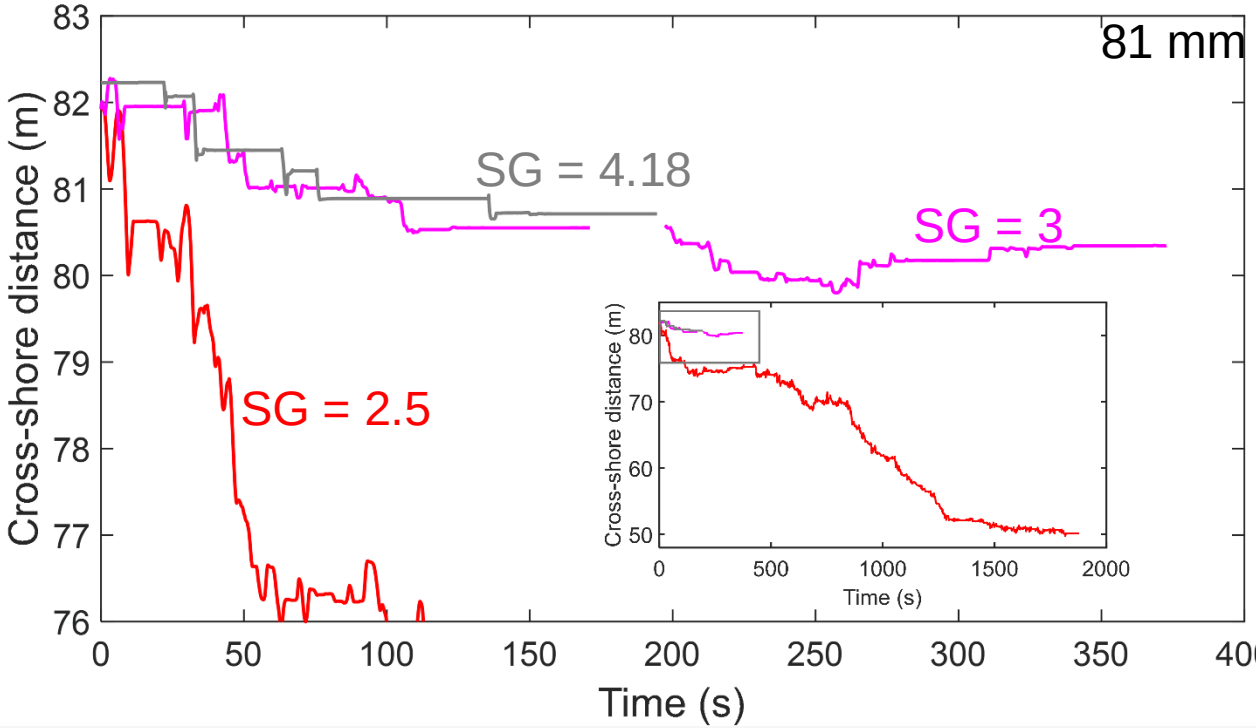
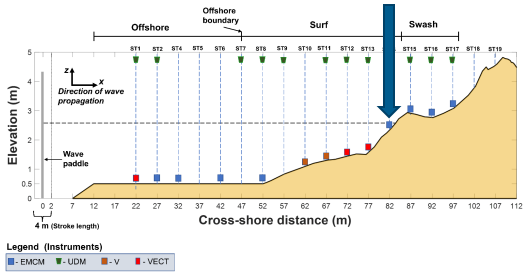
Surf Zone Migration – Time Dependent – Intermittent!





- Station 14
- Offshore migration
- Density dependence

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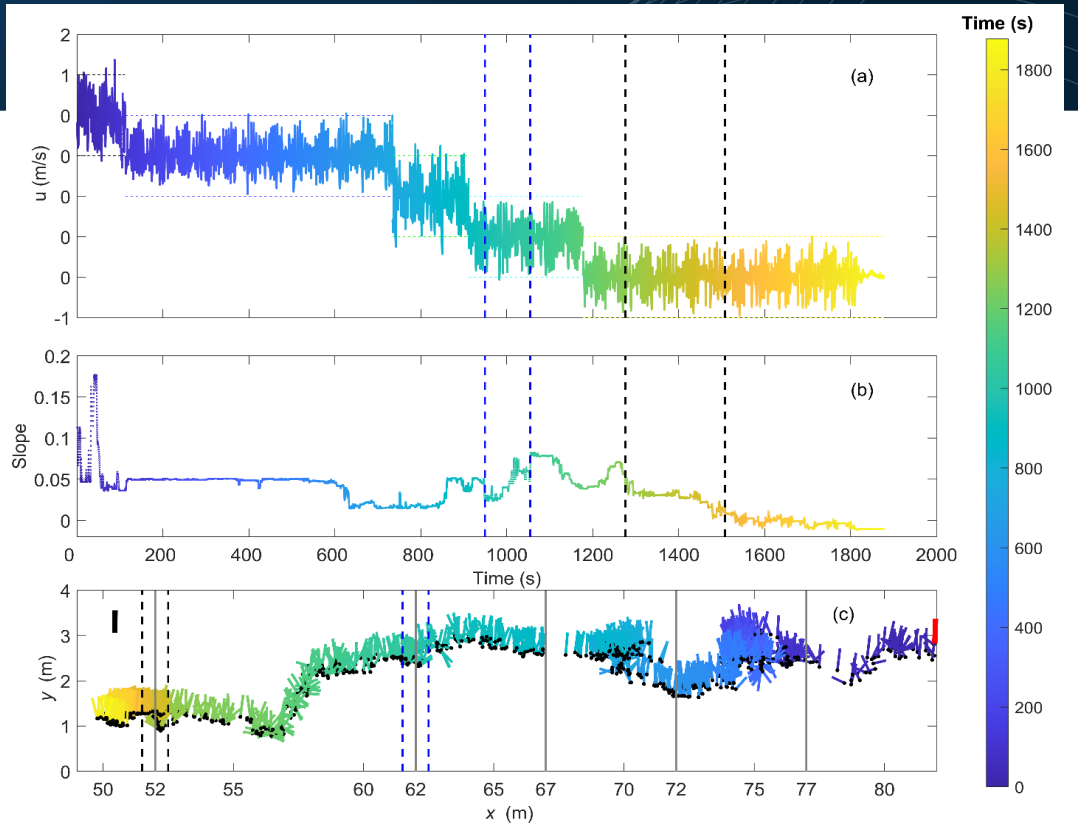
Migration and Orientation – Time Dependent

- Station 14, 81 mm, SG = 2.5
- Intermittent motion
- Migration related to slope
- No obvious relation to forcing
- Fairly constant orientation



Migration Summary

How do surrogates of different density respond to the same forcing conditions?

- Less dense munitions tend to migrate more but not always
- More dense munitions tend to bury
- SG “sweet spot” was near 2.5-3 (density of dry sand)

Migration Summary

Will exposed munitions migrate onshore?

- Only 17% of “migration” events classified as motion (out of >2000)
- Offshore → 7% migration (tended to be onshore-directed)
- Surf zone → 20% migration (tended to be offshore)
- Swash zone → 29% migration (no preferred direction)

Conclusion: Most munitions do not migrate
Initial condition unknown, but likely (partially) buried

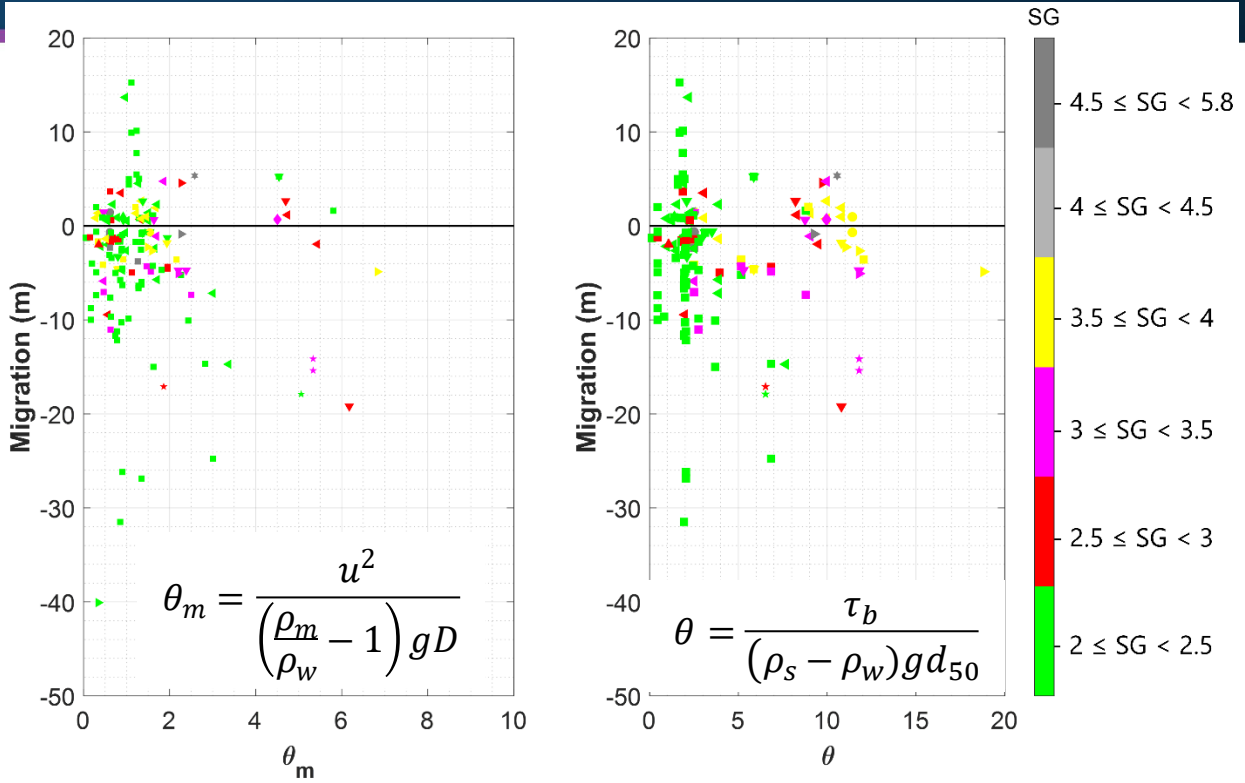
Migration Summary

Does the storm onset intensity affect munitions mobility and burial?

- Less dense munitions respond faster to applied forcing
- No major difference observed for the different onsets
- Overall forcing magnitude likely more important

This finding is unlikely to be similar in the field
→ the default condition is assumed to be at least partially buried
→ need to unbury first

Migration – Dimensionless Parameters



- Some relation between forcing and migration
- Much scatter
- Stochastic

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Next Steps

- Project complete
- Second paper on density and orientation under review
- Finalize the data matrix and description for project web page and partners

Technology Transfer

- Numerous presentations given at local and international conferences
- Created an archived data set
- Will be available for all SERDP and other researchers
  - Already posted to the project web site
- Data provided to NRL to train UnMES
- Data provided to Peter Chu
- Data collection and analysis used to assist Wengrove during lab study at UD

BACKUP MATERIAL

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

MR20-1094: MUNITIONS AND BURIAL OF VARIABLE DENSITY MUNITIONS IN THE SURF AND SWASH ZONES

Performers: Puleo, Gangadharan, Alhusban, Idowu, Chapman, Asrari; Stolle (INRS), Pham Van Bang (INRS), Mulligan (QU)

Technology Focus

- *Using surrogate munitions, in situ data, and remote sensing for mobility and burial studies*

Research Objectives

- *Determine the importance of munitions bulk density on mobility, transport, and exposure under varied forcing*

Project Progress and Results

- *Extensive large-scale laboratory study completed end of September, 2022*

Technology Transition

- *Prior data provided to Chu (MR19-1073) and Rennie (MR19-1126); Summer lab access and effort provided to Wengrove (MR21-1333), new data provided to NRL and on the project webpage*

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Plain Language Summary

Past military activity and discarding has left a large (unknown) quantity of UXO in the underwater environment

UXO mobility and burial processes are poorly understood especially in the surf zone

Quantify munitions processes over a range of forcing and munitions characteristics

Determine importance of different parameters for future modeling efforts

Impact to DoD Mission

- Analyzed a large data set of munitions migration and burial
- Showed that there is a preference for less dense munitions (near the density of dry sand to migrate)
- More dense munitions tend to remain in place
- Offshore munitions migrated onshore, surf zone munitions migrated offshore
- Burial was highly controlled by far-field processes
- Varying migration and burial response indicates a deterministic model may be impossible
- Effort should continue to focus on probabilistic approaches

Action Items

- There are no SERDP Technical Committee/Program Office action items assigned over the past year, nor any open action items from earlier years.

Publications - Papers

- Rodriguez-Burgette, J., C. Olney, A. Torres-Freyermuth, and **J.A. Puleo**. Accepted. Numerical modeling or pressure gradients and bed shear stress in swash-swash interactions drive by double dam-break, *Coastal Engineering*
- Idowu, T. and **J.A. Puleo**. In Revision. Laboratory observations of object migration in the surf zone, *Applied Ocean Research*.
- Idowu, T., and **J.A. Puleo**. 2024. Nearshore migration of munitions and canonical objects under large-scale laboratory forcing, *Journal of Marine Science and Engineering*, https://doi.org/10.3390/jmse12112103

Publications – Invited Presentations

- **Puleo, J.A.** 2024. Munitions mobility and burial in the nearshore, Coastal and Hydraulics Lab, Engineering Research and Development Center, USACE, Vicksburg, MS. (INVITED)
- **Puleo, J.A.** 2024. Mobility and burial of unexploded ordnance in the surf zone. Key note lecture at the 8th International Conference on Estuaries and Coasts, Quebec, Canada. (INVITED)
- **Puleo, J.A.** 2024. Munitions burial processes in the nearshore. SERDP/ESTCP Symposium, Washington, DC, USA (NVITED)
- Idowu, T. and **J.A. Puleo**. 2024. Behavior of variable density munitions in the nearshore under scaled storm onsets. Invited for "Earth and Planetary Surface Processes General Contributions" session. 2024 Fall Meeting, American Geophysical Union, Washington, DC, USA (INVITED)

Publications – Presentations

- Idowu, T. and **J.A. Puleo**. 2025. Near-instantaneous observations of various density munitions in the surf zone, Young Coastal Scientists and Engineers Conference - Americas (YCSECA), University North Carolina – Wilmington
- Asrari, S. and **J.A. Puleo**. 2025. Near-real time coastal hazard modeling with XBeach: An automated framework for the Delaware Coast, Young Coastal Scientists and Engineers Conference - Americas (YCSECA), University North Carolina – Wilmington
- Asrari, S. and **J.A. Puleo**. 2025. Optimizing XBeach modeling parameters for coastal change, Seventh Annual Mid-Atlantic Ocean Forum, Baltimore, MD.
- **Puleo, J.A.** 2024. Munitions burial processes in the nearshore. SERDP/ESTCP Symposium, Washington, DC, USA
- Idowu, T. and **J.A. Puleo**. 2024. Behavior of variable density munitions in the nearshore under scaled storm onsets. Invited for "Earth and Planetary Surface Processes General Contributions" session. 2024 Fall Meeting, American Geophysical Union, Washington, DC, USA
- **Puleo, J.A.**, T. Idowu, E. Chapman. 2024. *Mobility and burial of variable density munitions in the surf zone*, 38th International Conference on Coastal Engineering, Rome, Italy.
- Idowu, T., M. Gangadharan, E. Chapman, J. Stolle, D. Pham Van Bang, and **J.A. Puleo**. 2024. Behavior of variable density munitions in the nearshore under scaled storm onsets, 8th International Conference on Estuaries and Coasts, Quebec City, Quebec, CA.
- Idowu, T., M. Gangadharan, E. Chapman, J. Stolle, D. Pham Van Bang, and **J.A. Puleo**. 2024. Migration and burial of variable density munitions under scaled storm events, Young Coastal Scientists and Engineers Conference - Americas (YCSEC-A), Quebec City, Quebec, CA.

Publications – Presentations

- Asrari, S. and **J.A. Puleo**. 2024. Optimizing cross-shore hydrodynamic modeling parameters using XBeach-Surfbeat. 2024 Fall Meeting, American Geophysical Union, Washington DC, USA.
- Idowu, T. and **J.A. Puleo**. 2024. Impact of shape and orientation on munitions migration in the surf zone under scaled forcing. 2024 Fall Meeting, American Geophysical Union, Washington DC, USA
- Asrari, S. and **J.A. Puleo**. 2024. XBeach modeling of cross-shore hydrodynamics: Optimizing modeling parameters. ASBPA National Conference, New Orleans, LA.
- **Puleo, J.A.** 2024. Mobility in the swash and inner surf zones: From grains to munitions. University of Georgia
- **Puleo, J.A.**, T. Idowu, E. Chapman. 2024. *Mobility and burial of variable density munitions in the surf zone*, 38th International Conference on Coastal Engineering, Rome, Italy.
- **Puleo, J.A.** and J. Calantoni. 2023. SERDP Workshop on UXO Mobility, Burial, and Exposure Processes - Discussion for a Demonstration Project, SERDP.
- Idowu, T., E. Chapman, M. Gangadharan, J. Stolle, D. Pham van Bang, and **J.A. Puleo**. 2023. Experimental observations of swash morphodynamic response to a storm onset. American Shore and Beach Preservation Association, Providence, Rhode Island, USA.
- Idowu, T. and **J.A. Puleo**. 2023. Swash Morphodynamic Response to Storm Onset in a Near-prototype Experiment. 2023 Fall Meeting, American Geophysical Union, San Francisco, CA, USA.
- Idowu, T., E. Chapman, M. Gangadharan, J. Stolle, D. Pham van Bang, R. Mulligan and **J.A. Puleo**. 2023. Migration and burial of variable density munitions in the nearshore under scaled events, Young Coastal Scientists and Engineers Conference - Americas (YCSEC-A), Madison, WI.

Publications – Presentations

- Idowu, T., E. Chapman, M. Gangadharan, J. Stolle, D. Pham van Bang, and **J.A. Puleo**. 2023. Experimental observations of swash morphodynamic response to a storm onset. American Shore and Beach Preservation Association, Providence, Rhode Island, USA
- Idowu, T. and **J.A. Puleo**. 2023. Swash Morphodynamic Response to Storm Onset in a Near-prototype Experiment. 2023 Fall Meeting, American Geophysical Union, San Francisco, CA, USA
- **Puleo, J.A.**, M.K. Gangadharan, T. Idowu, E. Chapman, J. Stolle, D. Pham Van Bang, R. Mulligan. 2022. Mobility and Burial of Variable Density Munitions in the Inner Surf and Swash Zones during Controlled Extreme Forcing**,** SERDP/ESTCP Symposium, Washington, DC
- **Puleo, J.A.** 2022. White Paper: Understanding the Swash Zone Environment and Impact on UXO Mobility, Burial, and Exposure Processes, SERDP.
- Gangadharan, M K., T. Idowu, E. Chapman., **J.A. Puleo**, J. Stolle, D. Pham Van Bang. 2022. Migration and burial tendencies of variable density munitions: initial results from a large-scale study, 37th International Conference on Coastal Engineering 2022 in Sydney, Australia
- Gangadharan, M K., J.K. Paskoski, T. Idowu, E. Chapman, **J.A. Puleo**. 2022. Assessment of wave characteristics and morphodynamics using lidars in a large-scale wave flume, SERDP/ESTCP Symposium, Washington, DC
- Gangadharan, M K., E. Chapman, T. Idowu, **J.A. Puleo**, J. Stolle, D. Pham Van Bang. 2022. Migration and burial of unexploded ordnances under the influence of solitary waves., Young Coastal Scientists and Engineers Conference–Americas, Pensacola Beach, Florida
- Idowu, T. E., M.K. Gangadharan, E. Chapman, **J.A. Puleo**, J. Stolle, D. Pham Van Bang. 2022. Behavior of variable density munitions under dam break forcing, 37th International Conference on Coastal Engineering, Sydney Australia

Publications – Presentations

- Idowu, T. E., M.K. Gangadharan, E. Chapman, **J.A. Puleo**, J. Stolle, D. Pham Van Bang. 2022. Cross-shore migration of variable density munitions under scaled storm conditions, SERDP and ESTCP Symposium, Arlington, VA
- Chapman, E., M.K. Gangadharan, T. Idowu, **J.A. Puleo**. 2022. Berm migration under scaled storm events, 37th International Conference on Coastal Engineering, Sydney Australia
- Chapman, E., T. Idowu, M.K. Gangadharan, **J.A. Puleo**, J. Stolle, D. Pham van Bang, R. Mulligan. 2022. Berm migration and munitions motion under scaled storm events, 2022 SERDP and ESTCP Symposium, Arlington, VA
- Chapman, E., T. Idowu, M.K. Gangadharan, **J.A. Puleo**. 2022. Wave Runup and Munitions Motion Forced by Scaled Storm Events, 2022 Young Coastal Scientists and Engineers Conference - Americas (YCSEC-A), Pensacola, FL
- Gangadharan, M K., C. Olney, and **J.A. Puleo**. 2022. Simulating a controlled swash-swash interaction (double dam break) using DualSPHysics, DualSPHysics Workshop, Universitat Politècnica de Catalunya - BarcelonaTech, in Barcelona, Spain
- Chapman, E., T.E. Idowu, M. Gangadharan, and **J.A. Puleo**. 2022. Migration and burial of variable density munitions in the nearshore, AGU Ocean Sciences Meeting, Honolulu, HI
- Idowu, T., M. Gangadharan, E. Chapman, and **J.A. Puleo**. 2022. Quantification of the mobility and burial of variable density munitions under single event forcing, AGU Ocean Sciences Meeting, Honolulu, HI
- Gangadharan, M.K., J.K. Paskoski, W.E. Wengrove and **J.A. Puleo**. 2022. Comparative analysis of three LiDAR systems for estimating wave transformation and morphodynamics under the influence of a double dam break, AGU Ocean Sciences Meeting, Honolulu, HI
- Horney, B., M. Gangadharan, T. Idowu, E. Chapman, **J.A. Puleo**, and R. Mieras. 2021. Comparing a low-cost 2D LIDAR to solid-state lidar by scanning bed evolution under double dam break driven swash, 7th Young Coastal Scientists and Engineers Conference Americas, Myrtle Beach, South Carolina

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- Idowu, T., M. Gangadharan, E. Chapman, **J.A. Puleo**, J. Stolle, D. Pham van Bang, and R. Mulligan, 2021. Impact of varying bulk densities on munitions mobility, burial and exposure under single event forcing in nearshore environments, SERDP/ESTCP Symposium, Washington, DC
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- **Puleo, J.A.**, T. Idowu, M. Gangadharan, E. Chapman, J. Stolle, D. Pham van Bang, and R. Mulligan. 2021. Mobility and Burial of Variable Density Munitions in the Inner Surf and Swash Zones during Controlled Extreme Forcing, SERDP/ESTCP Symposium, Washington, DC
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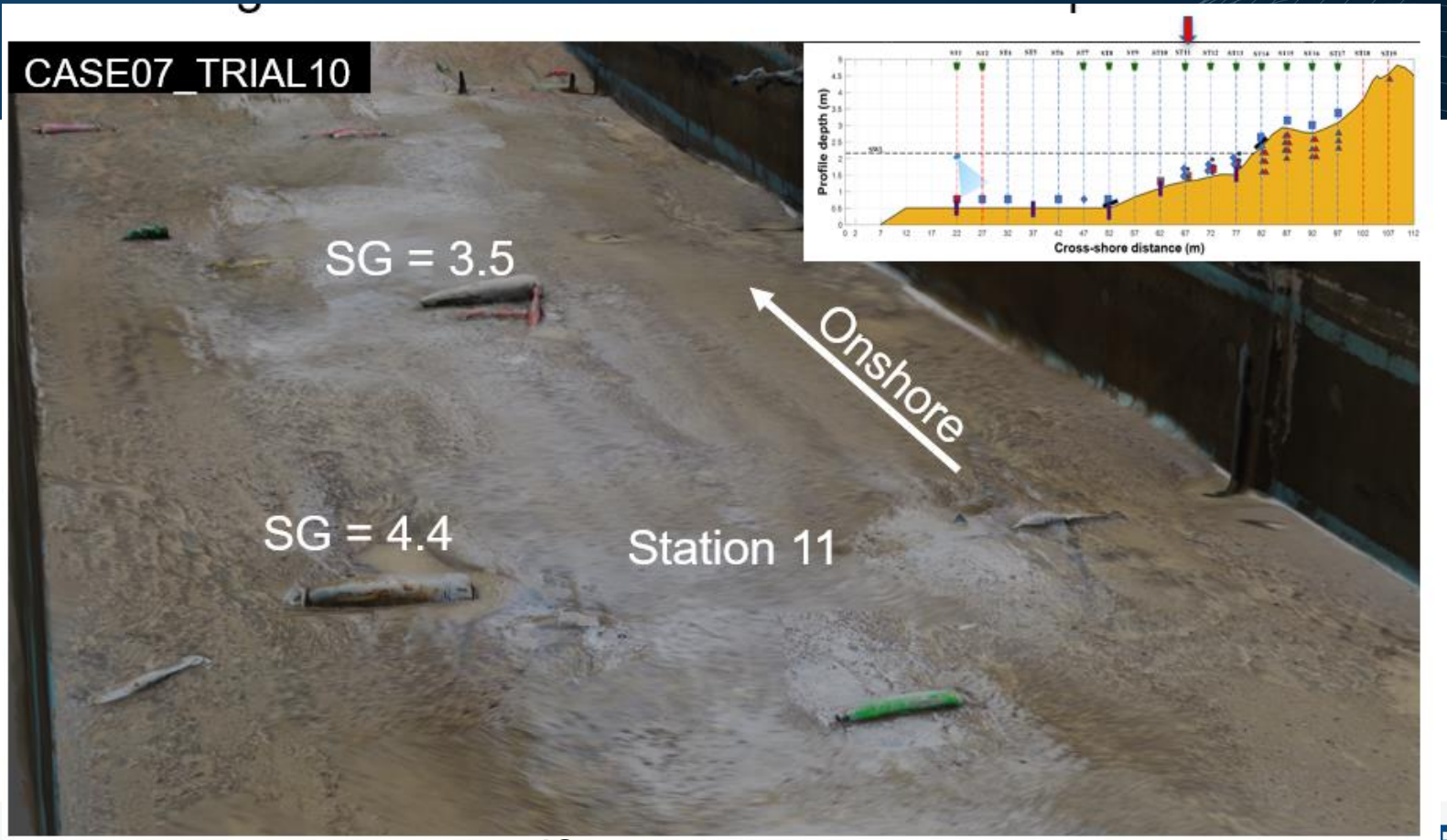
- Chapman, E., T. Idowu, M. Gangadharan, and **J.A. Puleo**. 2021. Variable density munitions motion in the swash zone, 7th Young Coastal Scientists and Engineers Conference Americas, Myrtle Beach, South Carolina
- Gangadharan, M., and **J.A. Puleo**. 2021. Dual Physics as a tool for simulating swash zone dynamics under the influence of a double dam break, ASBPA National Conference, New Orleans, LA
- Idowu, T., M. Gangadharan, E. Chapman, **J.A. Puleo**, J. Stolle, D. Pham van Bang, and R. Mulligan. 2021. Experimental framework for observing the physical behavior of variable density munitions in swash and inner surf zones under extreme storm events, ASBPA National Conference, New Orleans, LA

Literature Cited

- No publications were cited

Additional Slide(s) for High-Quality Photos

Additional Slide(s) for High-Quality Photos

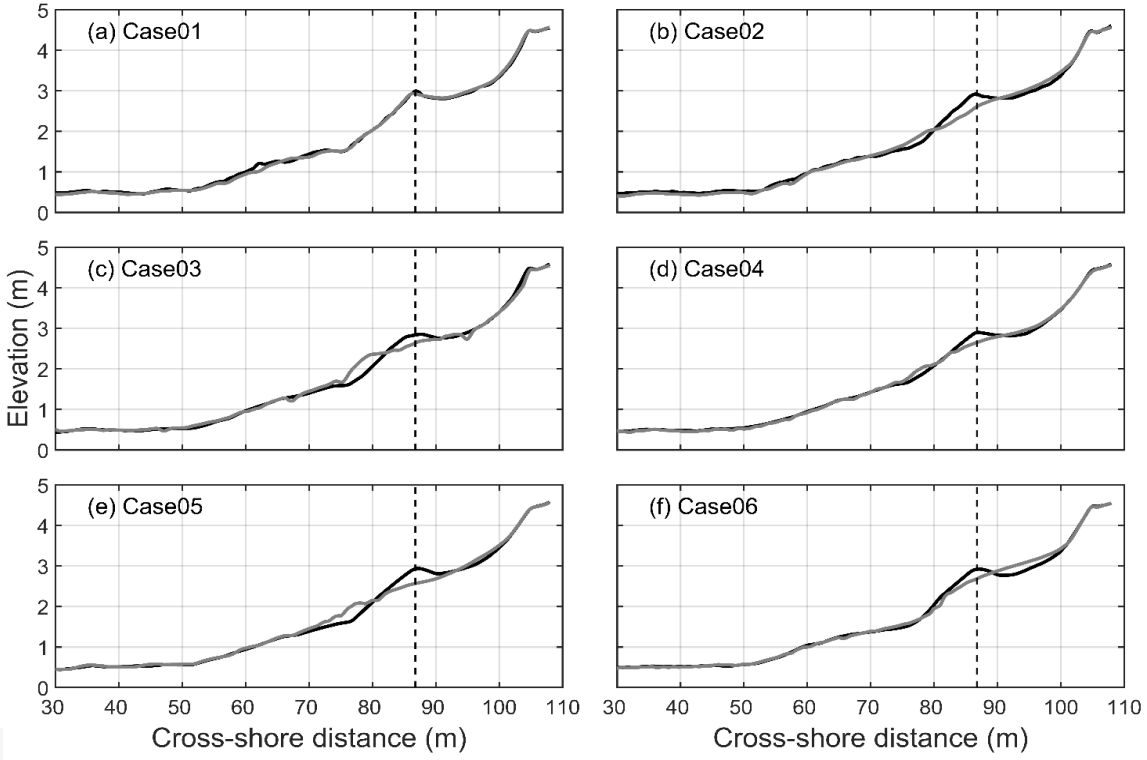

CASE07_TRIAL10
SG = 3.5
SG = 4.4
Station 11
Onshore
Profile depth (m)
Cross-shore distance (m)

Acronym List

NRL – Naval Research Laboratory
SG – Specific Gravity

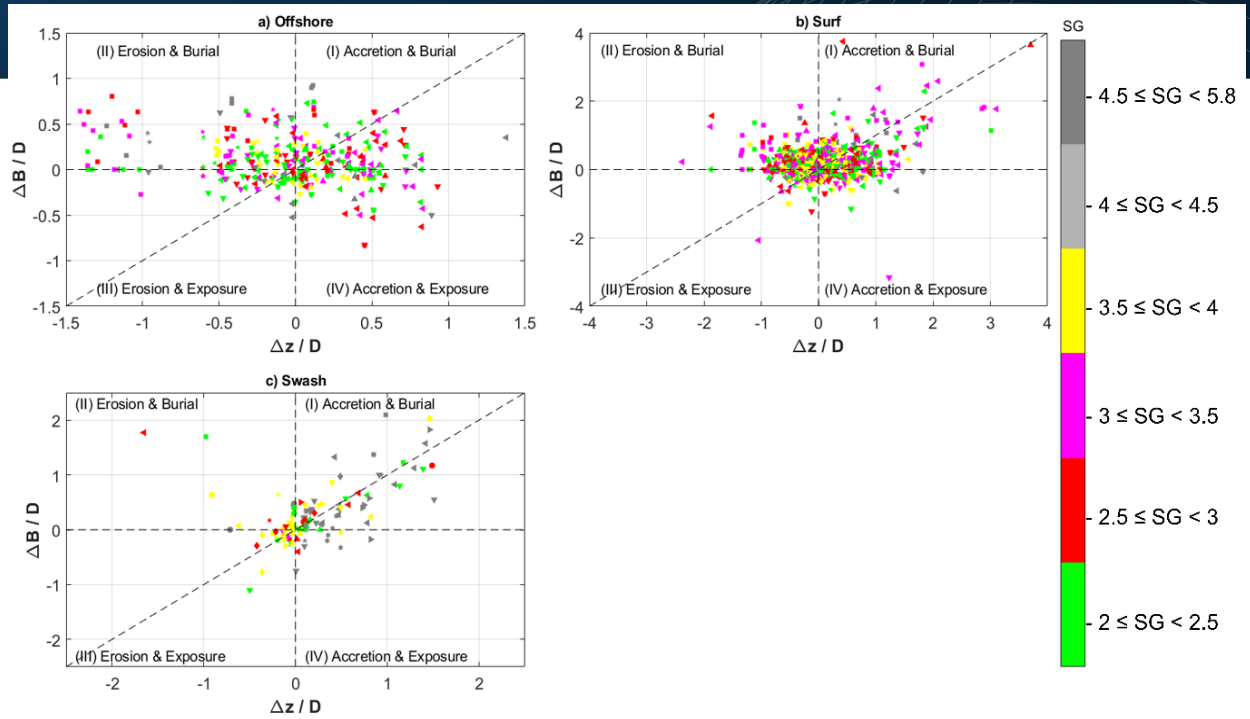
Extra slides

Morphodynamics

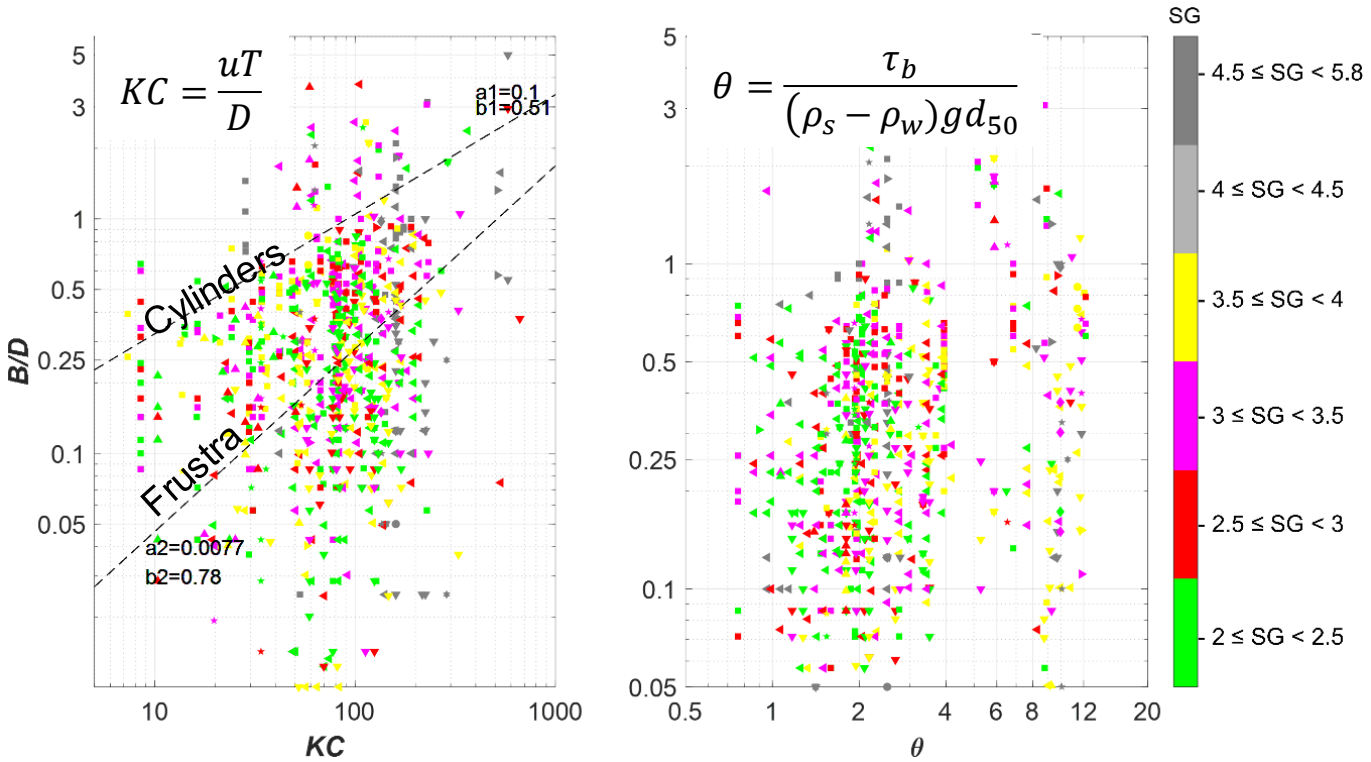


Burial by Location

- **Q1**: offshore: 32%, surf: 39%, swash: 54%
- **Q2**: offshore: 33%, surf: 31%, swash: 19%
- **Q3**: offshore: 14%, surf:15%, swash: 19%
- **Q4**: offshore: 21%, surf: 16%, swash: 9%



Burial

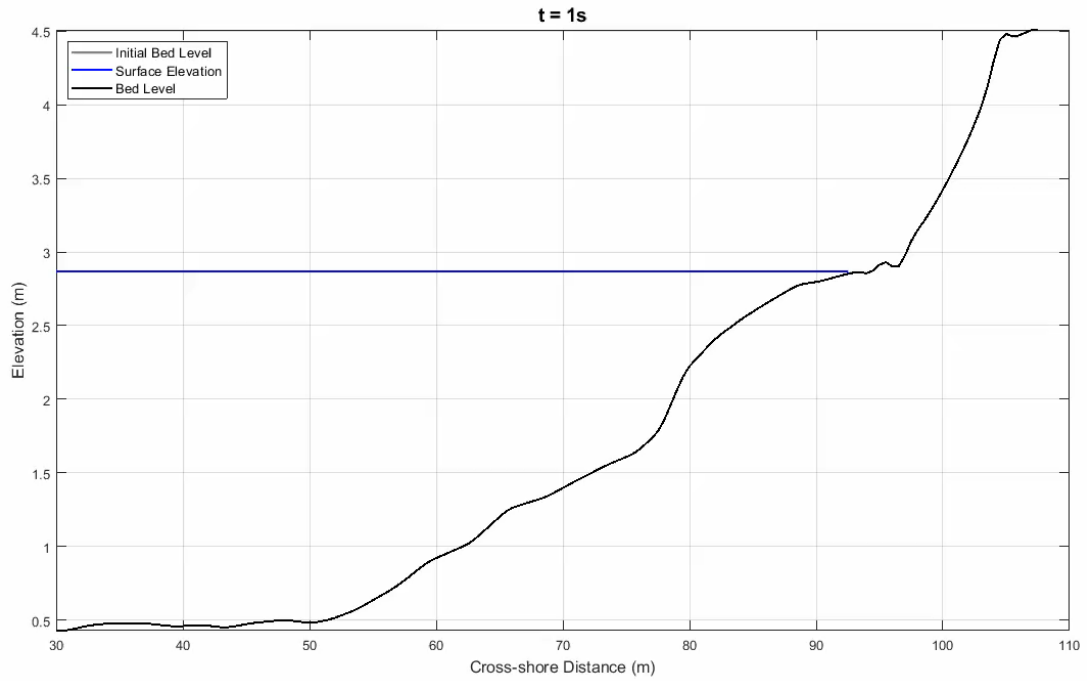


- Related to standard parameters
- No correlation

SERDP

Modeling - XBeach

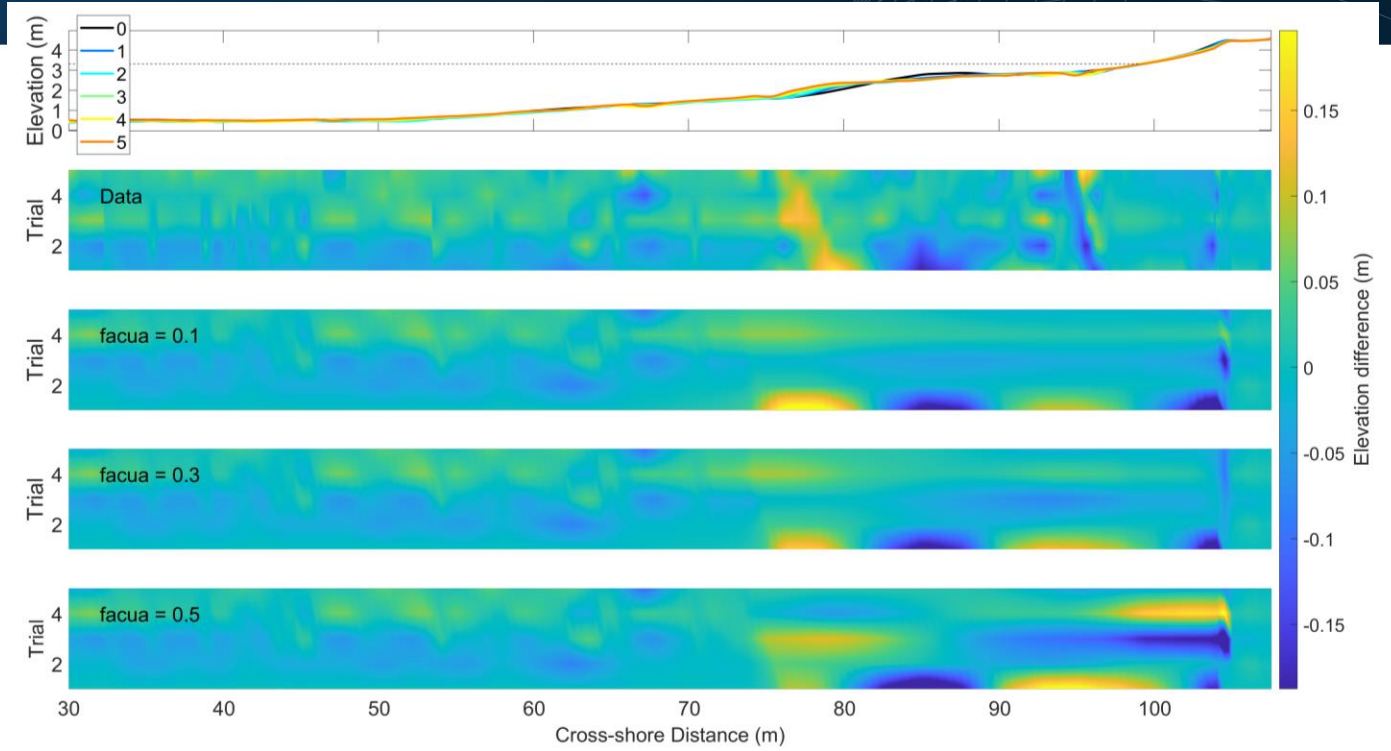
- Surf Beat mode
- Case03 Trial01
- Highest water level
- Hs = 1.4 m, Tp = 6 s
- Numerous parameters to manipulate



SERDP

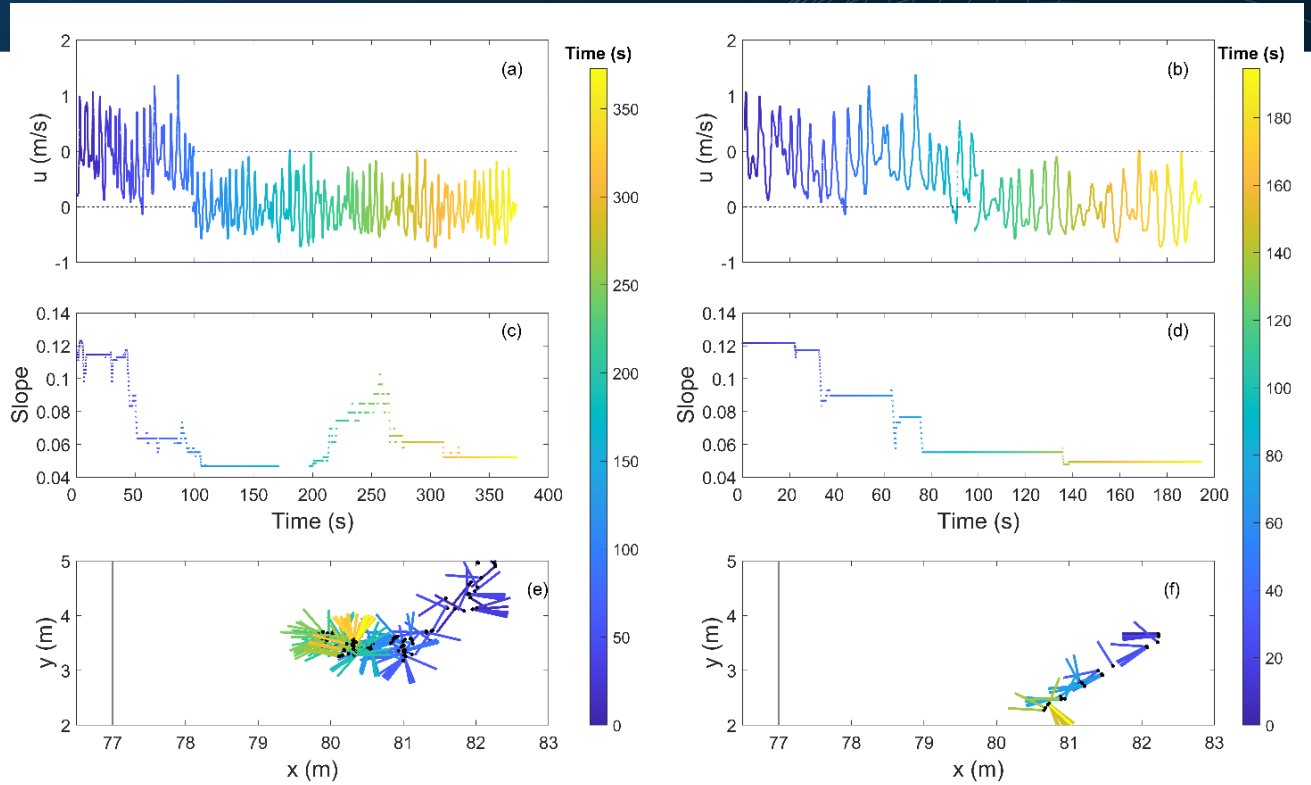
Modeling - Morphodynamics

- facua controls wave skewness – onshore transport
- Recommended 0.3; range 0.1 to 1.
- Parameter space simulations underway

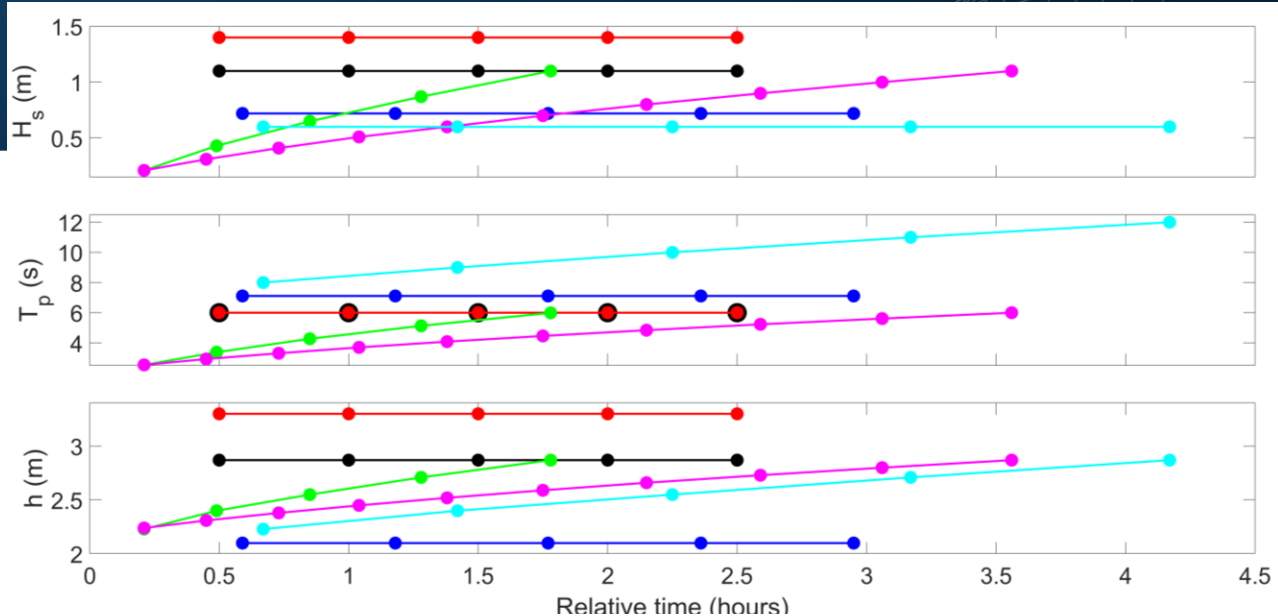


Migration and Orientation – Time Dependent

- Station 14, 81 mm
- Left, SG = 3
- Right SG = 4.18



Technical Approach - Forcing



dH/dt = ∞, low water level, small wave height, long period

dH/dt = ∞, medium water level, medium wave height, medium period

dH/dt = ∞, maximum water level, maximum wave height, medium period

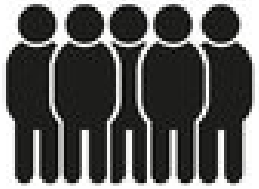
dH/dt = 10, all parameters increasing

dH/dt = 5, all parameters increasing

dH/dt = 5, increasing water level, small wave height, increasing period

By the Numbers

10400 miles driven



>30 people

>18 hours forcing

13 computers

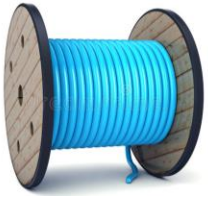
>8000 lbs equipment

~900 m^3 sand

>80 sensors

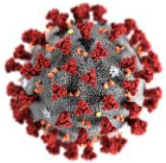
2.5 TB data

>5000 hours



>3 miles cable

>150 surrogates



2 cases

>300

SERDP