Coupled Ensemble Sea-floor Environment and 6-DOF (CESE6D) Model

Peter C Chu
Naval Postgraduate School
FY19-FY22

SERDP

Continuation of ONR/NAVO Mine Burial Prediction Project (1999-2011) Theses

- (1) Taber, Victoria L., "Environmental Sensitivity Studies on Mine Impact Burial Prediction Model" MS in Meteorology and Oceanography, March 1999.
- (2) Smith, Timothy, "Validation of the Mine Impact Burial Model Using Experiment Data". MS in Meteorology and Oceanography, September 2000.
- (3) Cintron, Carlos, "Environmental Impact on Mine Hunting in the Yellow Using the CASS-GRAB Model". MS in Physical Oceanography, March 2001.
- (4) Anthony Gilles, "Mine Drop Experiments". MS in Meteorology and Oceanography, September 2001.
- (5) Ashely Evans, "Hydrodynamics of Mine Impact Burial". MS in Meteorology and Oceanography, September 2002.
- (6) Michael Cornelius, "Effect of a Suspended Sediment Layer on Acoustic Imagery", MS in Meteorology and Oceanography, June 2004.
- (7) Greg Ray, "Bomb strike experiment for mine countermeasure." MS in Meteorology and Oceanography, March 2006.
- (8) Charles Allen, "Mine drop experiments with operational mine shapes". MS in Meteorology and Oceanography, March 2006.
- (9) Travis Clem, "Oceanographic Effects on Maritime Threats: Mines and Oil Spills in the Strait of Hormuz," MS in Meteorology and Oceanography, March 2007.
- (10) David Hudson, "Similarity Analysis of Littoral Environments between Korean and U.S. Coasts for Mine Warfare,." (Secret) MS in Physical Oceanography, September 2008.

Continuation of ONR/NAVO Mine Burial Prediction Project (1999-2011) Theses

- (11) Hartwell Coke, "Route Survey Periodicity for Mine Warfare," MS in Meteorology and Oceanography, September 2009..
- (12) John P. Garstka, "Optimizing U.S. Navy Mine Warfare and Department of Homeland Security Maritime Security Requirements: A Quantitative Analysis of Bottom Sediments to Determine Analogous Areas in the Strait of Hormuz and Continental United States." (Secret) MS in Physical Oceanography, September 2009.
- (13) Jillene Bushnell, "Prediction of Bomb Trajectory for Mine Breaching", MS in Meteorology and Oceanography, December 2009.
- (14) Samantha Poteete, "Navy's N-Layer Magnetic Model with Application to Naval Magnetic Demining", MS in Meteorology and Oceanography, September 2010.
- (15) Christopher Beuligman, "Expert System for Mine Burial Prediction," MS in Physical Oceanography, September 2011.
- (16) Jason Gipson, "Application of Mine Burial Expert System to Mine Warfare Doctrine," MS in Meteorology and Oceanography, June 2012 [co-advisers: Ronald E. Bestch, Pete Fleischer (NAVO)].
- (17) Kristi Colpo, "Joint Sensing/Sampling optimization for Surface Drifting Mine Detection with High-resolution NCOM Drift Model," MS in Meteorology and Oceanography, September 2012 [co-advisers: Thomas Wettergren(NUWC-NPT), Ronald E. Bestch (NAVO)] .
- (18) Patrick Earls, "Effect of Bottom Roughness on Acoustic Scattering for Mine Warfare from Multibeam Echo Sounders," MS in Physical Oceanography, September 2012

Continuation of ONR/NAVO Mine Burial Prediction Project (1999-2011) Journal Articles

- (1) Chu, P.C., A.F. Gilles, C.W. Fan, and P. Fleischer, 2002: Hydrodynamical characteristics of falling cylinder in water column. Advances in Fluid Mechanics, 4, 163-181.
- (2) Chu, P.C., C.W. Fan, A. D. Evans, and A. Gilles, 2004: Triple coordinate transforms for prediction of falling cylinder through the water column. *ASME Journal of Applied Mechanics*, **71**, 292-298.
- (3) Chu, P.C., and C.W. Fan, 2004: 3D rigid body impact burial prediction model. Advances in Mechanics, 5, 43-52.
- (4) Chu, P.C., A. Gilles, and C.W. Fan, 2005: Experiment of falling cylinder through the water column. *Experimental and Thermal Fluid Sciences*, **29**, 555-568.
- (5) Chu, P.C., and C.W. Fan, 2005: Pseudo-cylinder parameterization for mine impact burial prediction. *ASME Journal of Fluids Engineering*, **127**, 1515-1520.
- (6) Chu, P.C., and C.W. Fan, 2006: Prediction of falling cylinder through air-water-sediment columns. *ASME Journal of Applied Mechanics*, **73**, 300-314.
- (7) Chu, P.C., and G. Ray, 2006: Prediction of High Speed Rigid Body Maneuvering in Air-Water-Sediment Columns, Advances in Fluid Mechanics, **6**, 123-132.

Continuation of ONR Mine Burial Prediction Project (2003-2011) Journal Articles

- (8) Chu, P.C., and C.W. Fan, 2007: Mine impact burial model (IMPACT35) verification and improvement using sediment bearing factor method. *IEEE Journal of Oceanic Engineering*, **32** (1), 34-48.
- (9) Chu, P.C., and C.W. Fan, 2008: Semi-empirical formulas of drag/lift coefficients for high speed rigid body maneuvering in water column, Advances in Fluid Mechanics, 7, 163-172
- (10) Chu, P.C., 2009a: Mine impact burial prediction from one to three dimensions. *ASME Applied Mechanics Reviews*, 62 (1), 010802 (25 pages), DOI: 1115/1.3013823.
- (11) Chu, P.C., C.W. Fan, and P. R. Gefken, 2010: Diagnostic-photographic determination of drag/lift/torque coefficients of high speed rigid body in water column. *ASME Journal of Applied Mechanics*, **77**, 011015-1.
- (12) Chu, P.C., J.M. Bushnell, C.W. Fan, and K.P. Watson, 2011: Modeling of underwater bomb trajectory for mine clearance. *Journal of Defense Modeling and Simulation,* **8** (1), 25-36.
- (13) Chu, P.C., and C.W. Fan, 2011: Probability density function of underwater bomb trajectory deviation due to stochastic ocean surface slope. *Journal of Dynamic Systems, Measurement and Control*, **133**, 031002.

Problem Statement

- DoD needs capabilities to detect, classify, and remediate military munitions found at underwater sites such as ponds, lakes, rivers, estuaries, and coastal and open ocean areas.
- There is a need to improve our current and historical understanding of environmental conditions of underwater sites that impact the performance of sensors and systems used to detect and classify buried and proud munitions.
- Coupled Ensemble Sea-floor Environment and 6-DOF (CESE6D) Model will provide timely prediction of environment and munition 's mobility and burial.

Project Objective

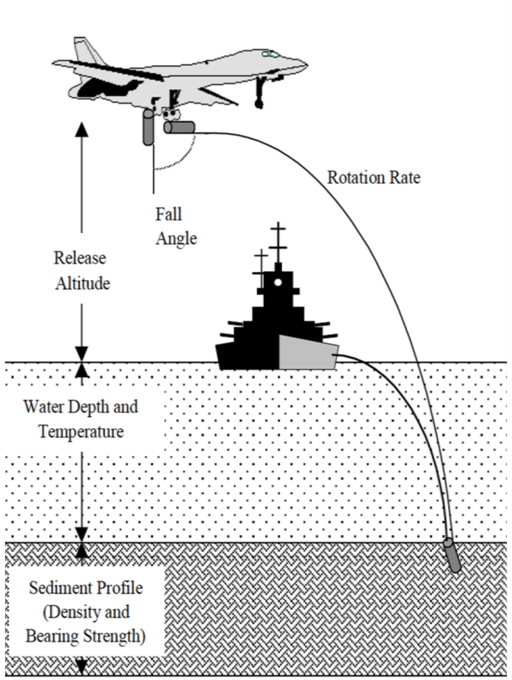
To build a coupled ensemble seabed environment and 6 degree-of-freedom (DoF) model for assessing characteristics of munitions underwater and their environment.

Fundamental questions:

- How to combine IMPACT35 and VORTEX-LATTICE into one burial model?
- How to calculate the seabed environmental variables from Delft3D such as shear strength for impact burial (initial burial), pore pressure change (consolidation), stress relieve (creep) for subsequent burial in mud bed, critical mass envelop for farfield and horseshoe vortices for nearfield for scour burial in the non-mud beds?
- How to quantify the effects of munition density, size, geometric shapes?
- How to determine drag and lift force coefficients applicable to munition 's 6-DoF mode?
- How to determine farfield parameters (K_C, ψ) and nearfield parameters (ε_S ε_b, C_D) in scour burial?
- What are the underwater munition 's characteristics during consolidation and creep of the mud bed?

Technical Background

Coupled ensemble system: flow, waves, sediment bed, and munition

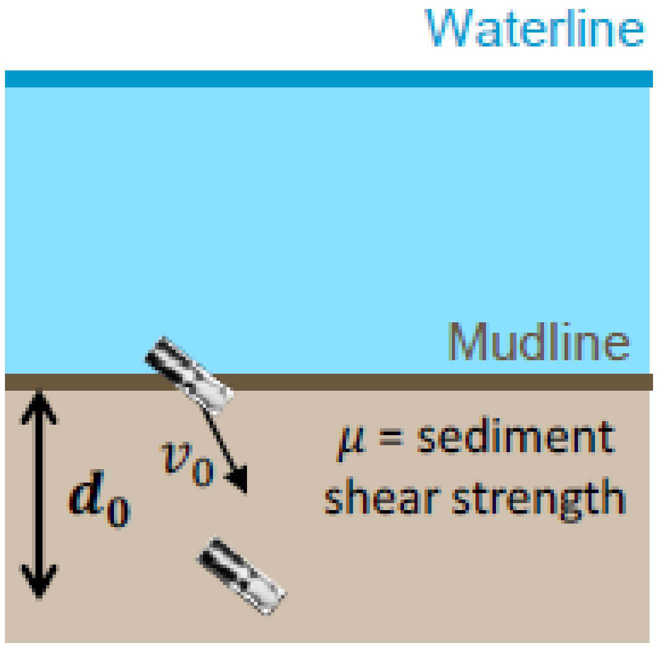


Key Physical Processes

- 6 degree of freedom (DoF) rigid body (munition) motion
  - ♦ Initial burial (Impact)
  - ♦ Subsequent burial (Mud and Non-Mud)
- Currents
- Waves
- Sediment dynamics
  - ♦ Liquefaction (pore-pressure build-up)
  - ♦ Scour and erosion)
  - ♦ Granular sediment movement

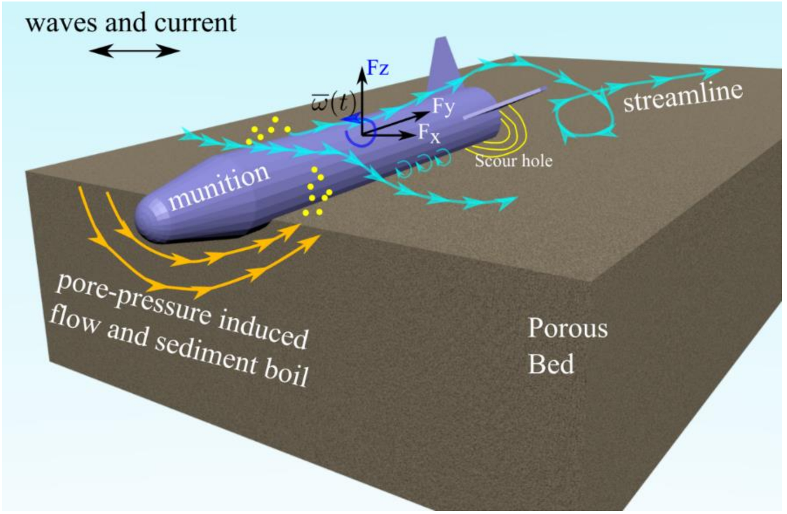
Technical Background

Munition movement - impact burial, subsequent burial



From Teichman et al. (2017)

Seabed environmental processes near munition



From Liu and Qiu, MR-2732,
SERDP Munition Response Workshop, 20 June 2017

Technical Background

- What are the phenomena or processes involved?
  Impact burial; subsequent burial in non-mud bed due to scour and liquefaction; seabed, subsequent burial in mud bed due to consolidation and creep; environmental processes such as currents, waves, sediment transport.
- What prior work has been done?
  Munition impact burial through air, water, and sediment (IMPACT35, STRIKE35)
  Munition scour burial (VORTEX-LATTICE by Jenkins et al, 2007)
- What is known; what is not known?
  Known – basic physics and model framework for initial impact and scour burials
  Unknown – Scour burial model parameters such as (Kc, ψ) for far-field, (ε_s, ε_b, C_D) for near-field; consolidation and creep for subsequent burial in mud sediment
- Is the science ready for exploitation? Yes.

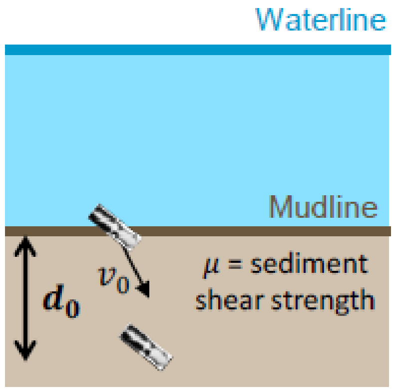
Technical Background

Munition Impact and Scour Burials

Mud - IMPACT35 (Chu 's Group)

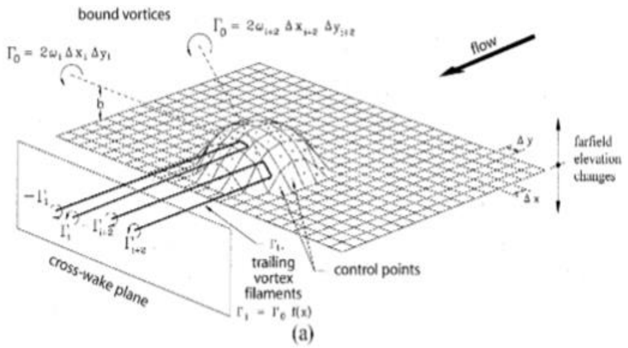
Sand, Gravel, Rock

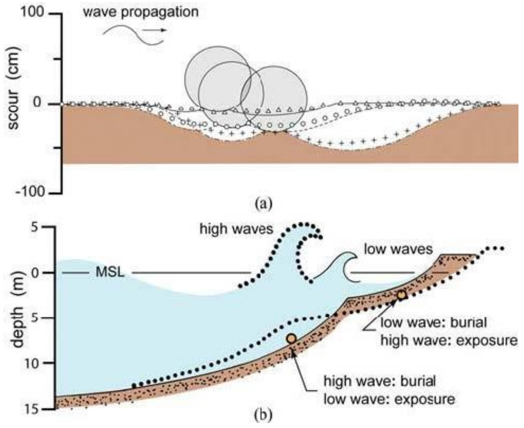
Scour Burial (Jenkins et al. 2007; Friedrichs et al, 2016)

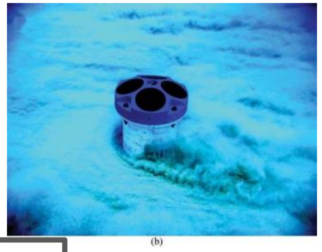


Bearing Factor Method

Initial Burial







Pore Pressure Change

Stress Relieve

Unknown

Consolidation

Creep

(Teichman et al. 2017)

Subsequent Burial

Given Boundary Layer Waves/Currents

Horseshoe Vortices

Nearfield Parameters

Nearfield

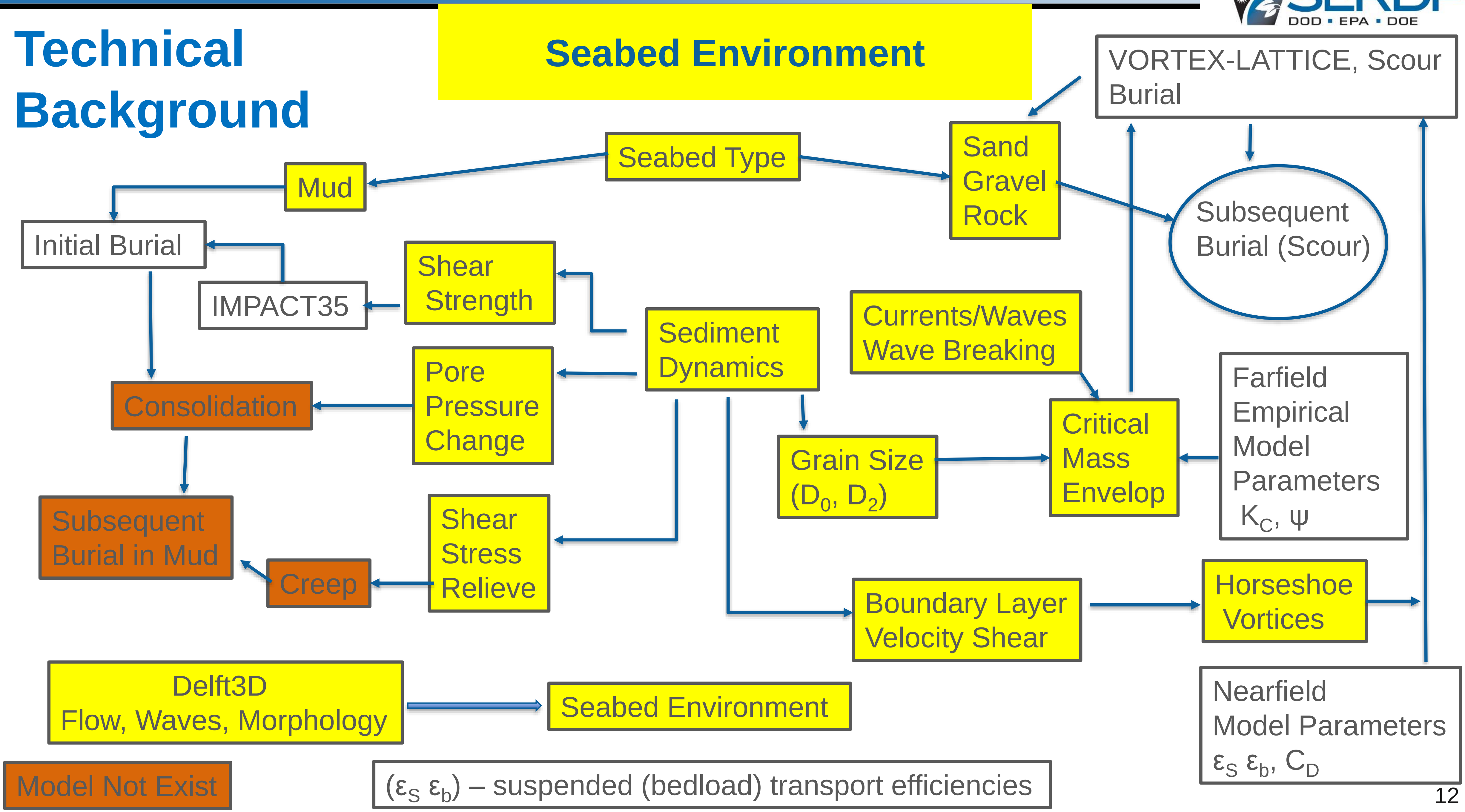
Farfield Parameters

Given Waves, Grain Size Wave-Breaking

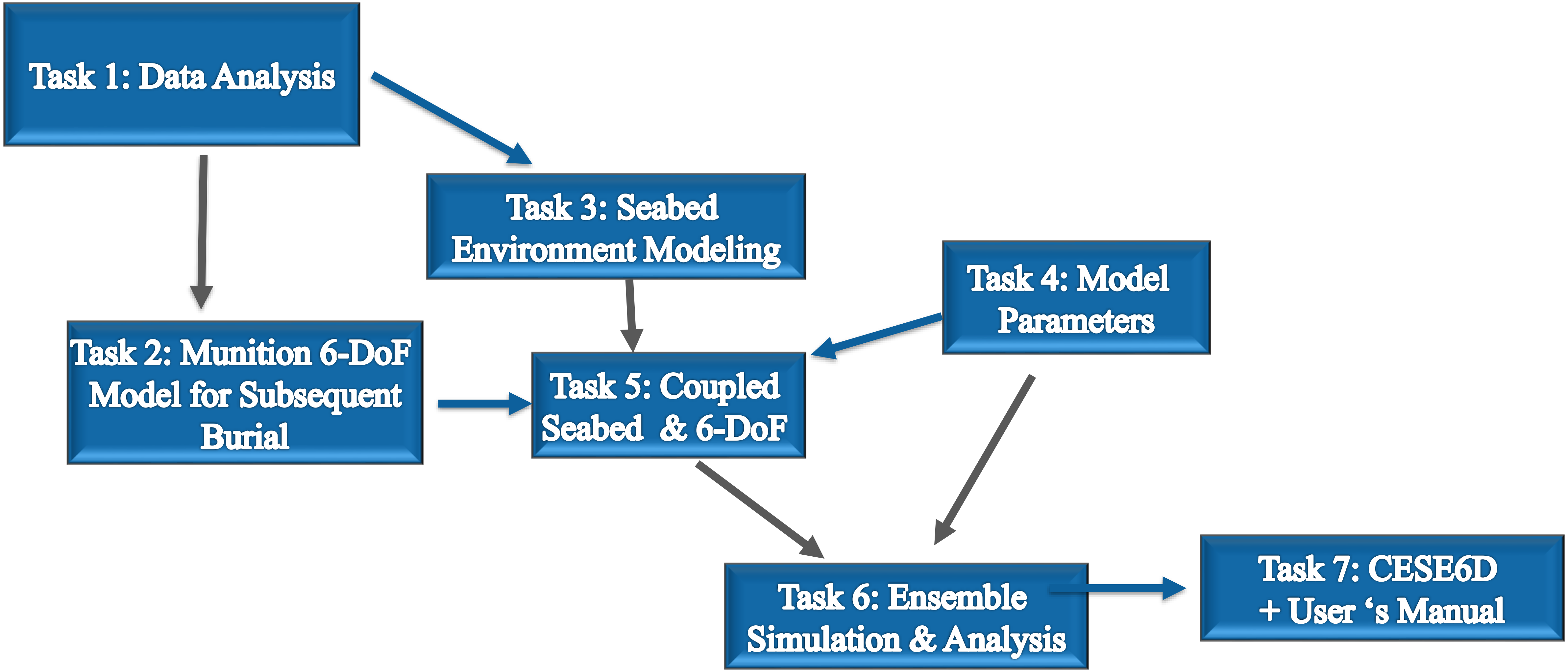
Critical Mass Envelop

Farfield

Technical Background



Technical Approach

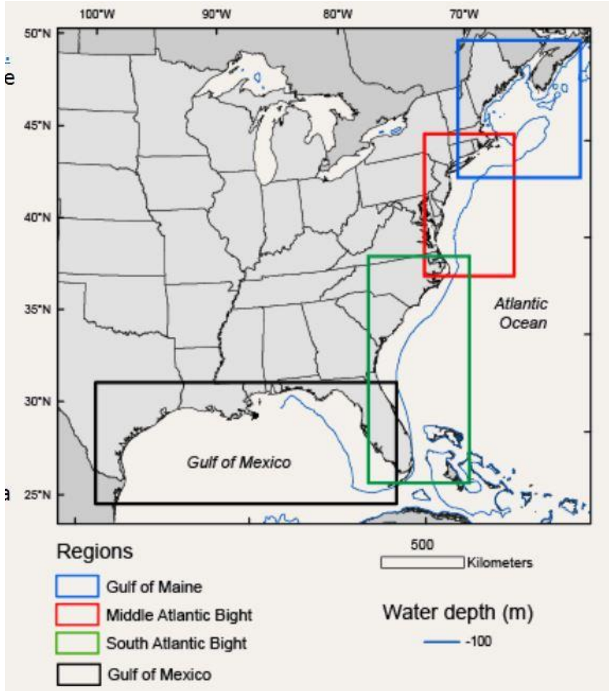


Task 1: Data Analysis

Objective:

Analyze observational data for the underwater munition sites from all available sources to get comprehensive information about the seabed environment, as well as the munition burial and mobility.

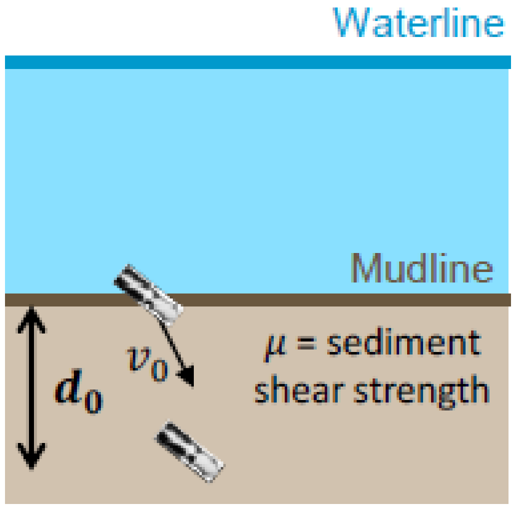
U.S. Geological Survey Sea Floor Stress and Sediment Mobility Database

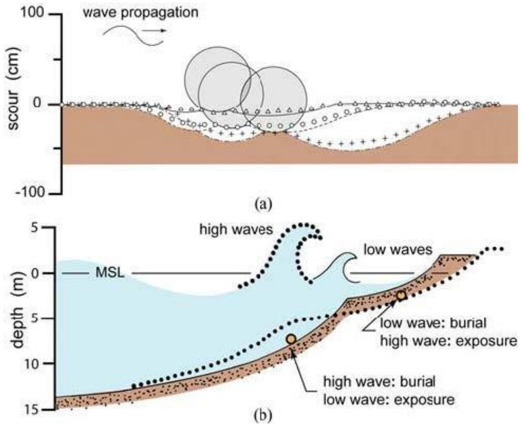


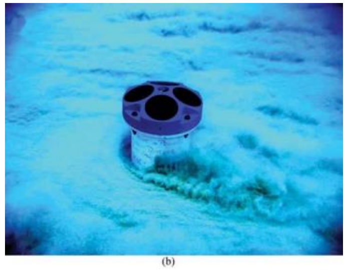
Task 2: Munition ‘s 6-DoF Model for Subsequent Burial

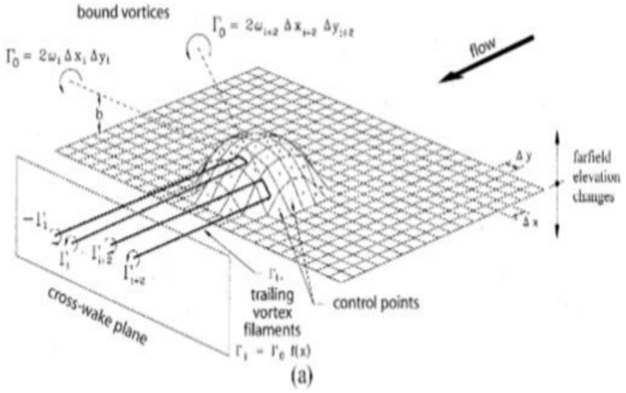
Objective:

Modify, improve and reconstruct the existing impact (IMPACT35), scour (VORTEX-LATTICE), and liquefaction models for munition subsequent burial and mobility including new research on mud bed consolidation and creep (along with the framework of sediment phase of IMPACT35).





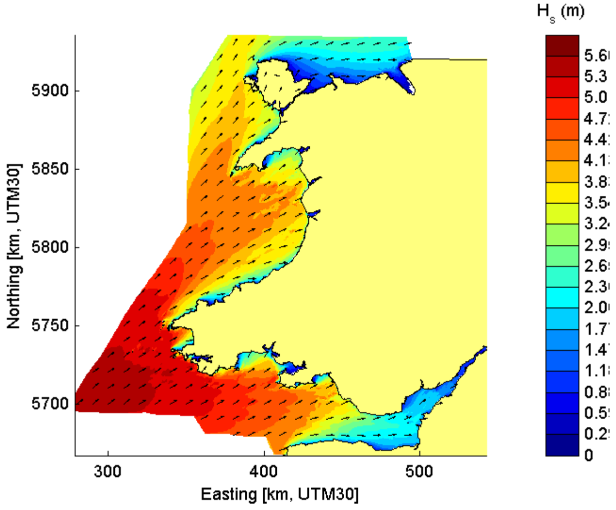


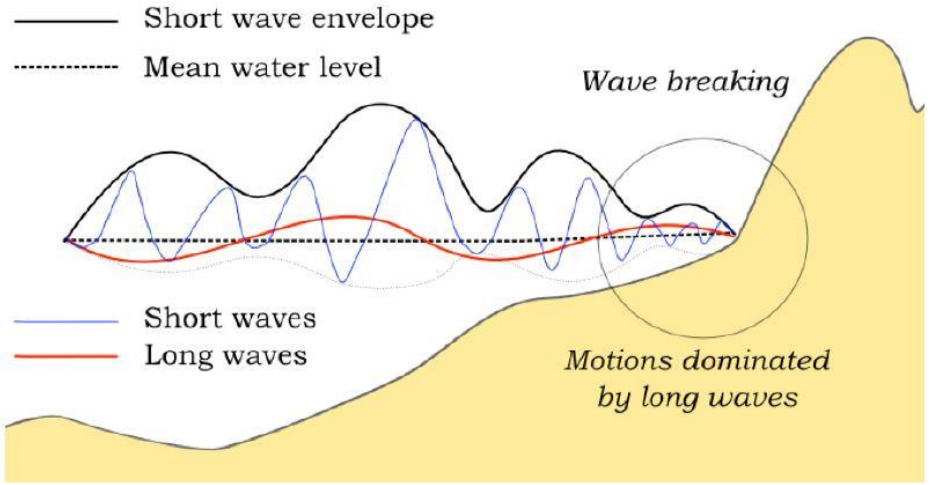


Task 3: Seabed Environment Modeling

Objective:

Simulate three-dimensional flow, wave, and morphologic conditions using the open source Delft3D at underwater remediation sites in order to provide the conditions for the 6DoF munition model for subsequent burial and mobility

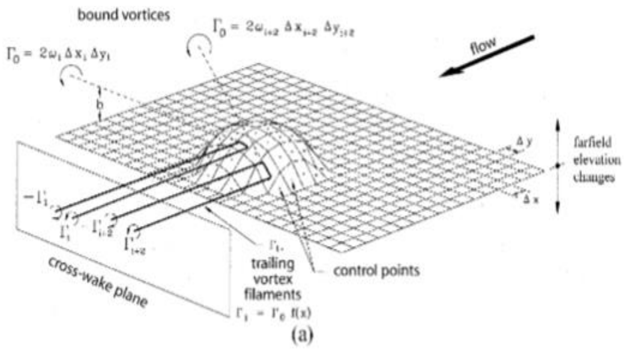


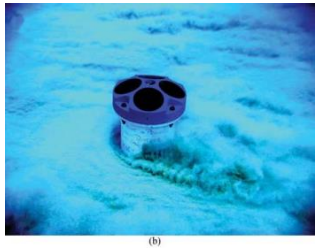


Task 4: Model Parameters

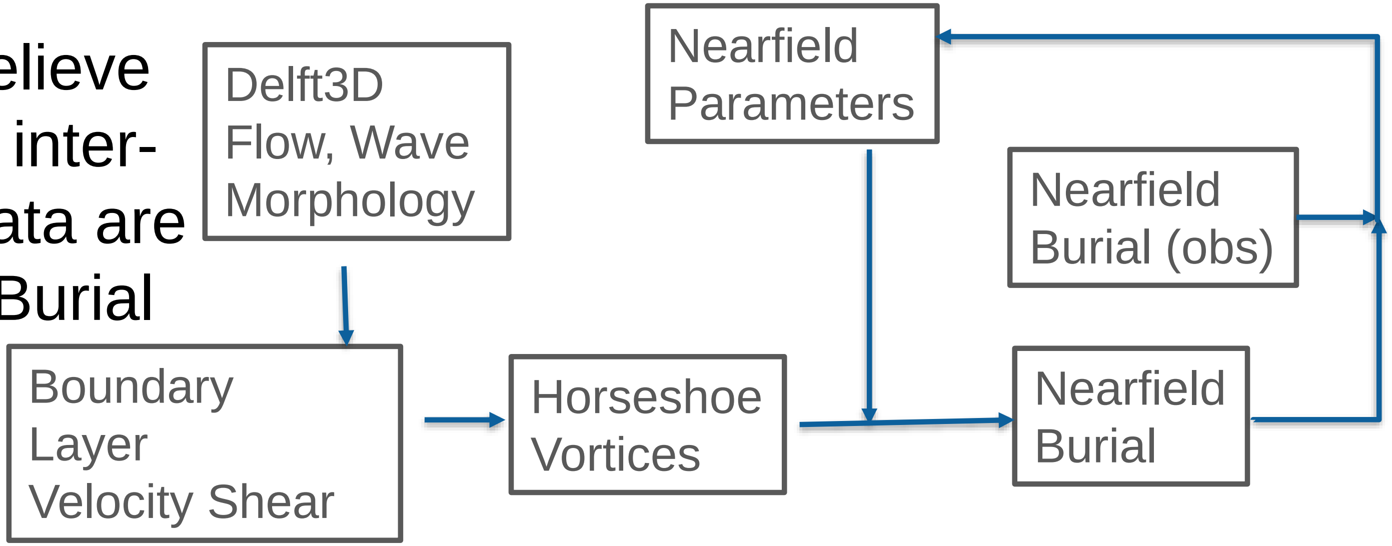
Objective:

Determine the probability distribution functions (PDFs) of drag and lift coefficients (initial burial), farfield parameters (K_C, ψ), nearfield parameters (ε_S ε_b, C_D) (scour burial), and parameters in pore-pressure change (mud consolidation) and shear stress relieve (mud creep) through model-data inter-comparison. The observational data are from the SERDP and ONR Mine Burial Communities.





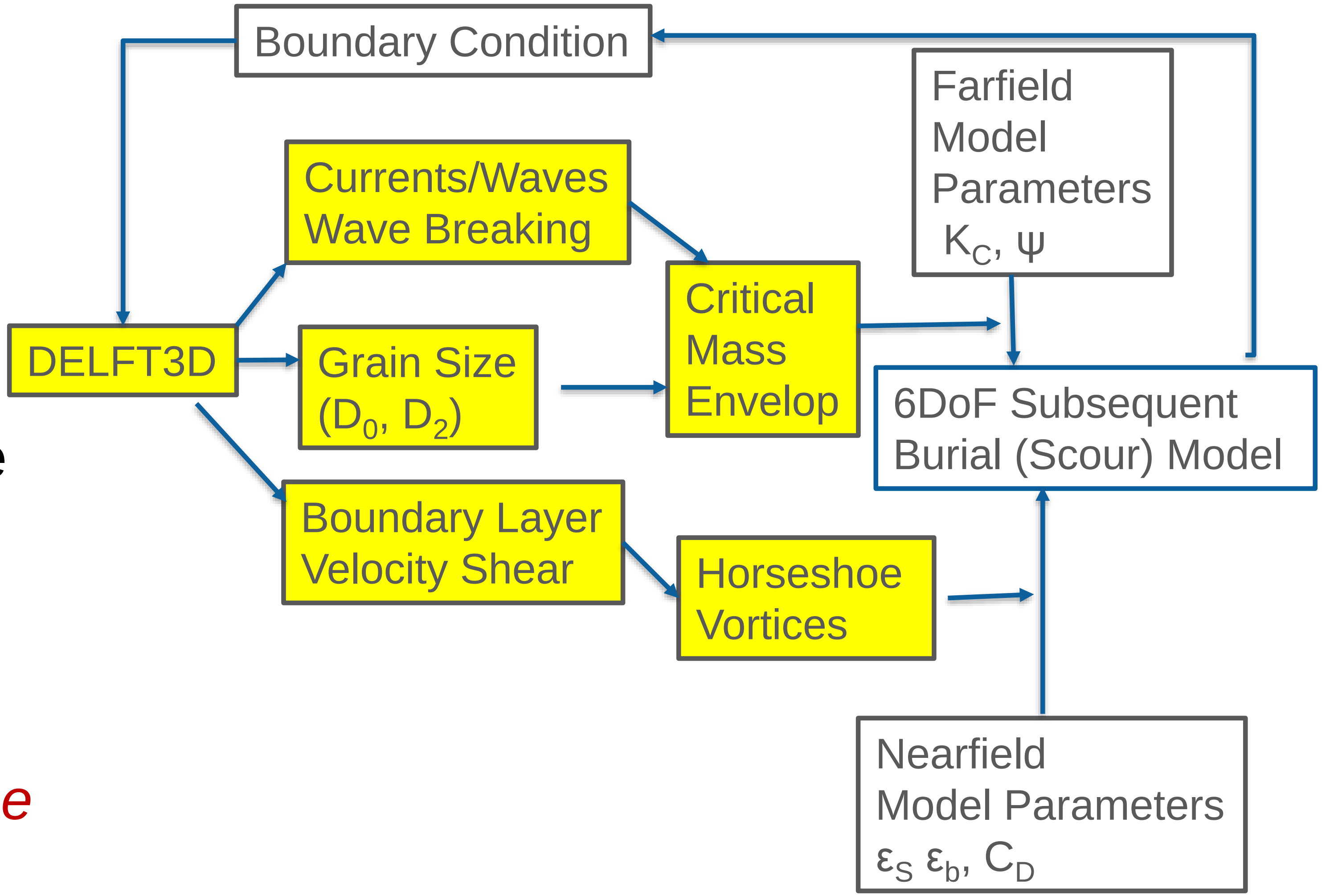
Nearfield Scour Burial as an Example



Task 5: Coupled Seabed Environment and 6DoF Model

Objective:

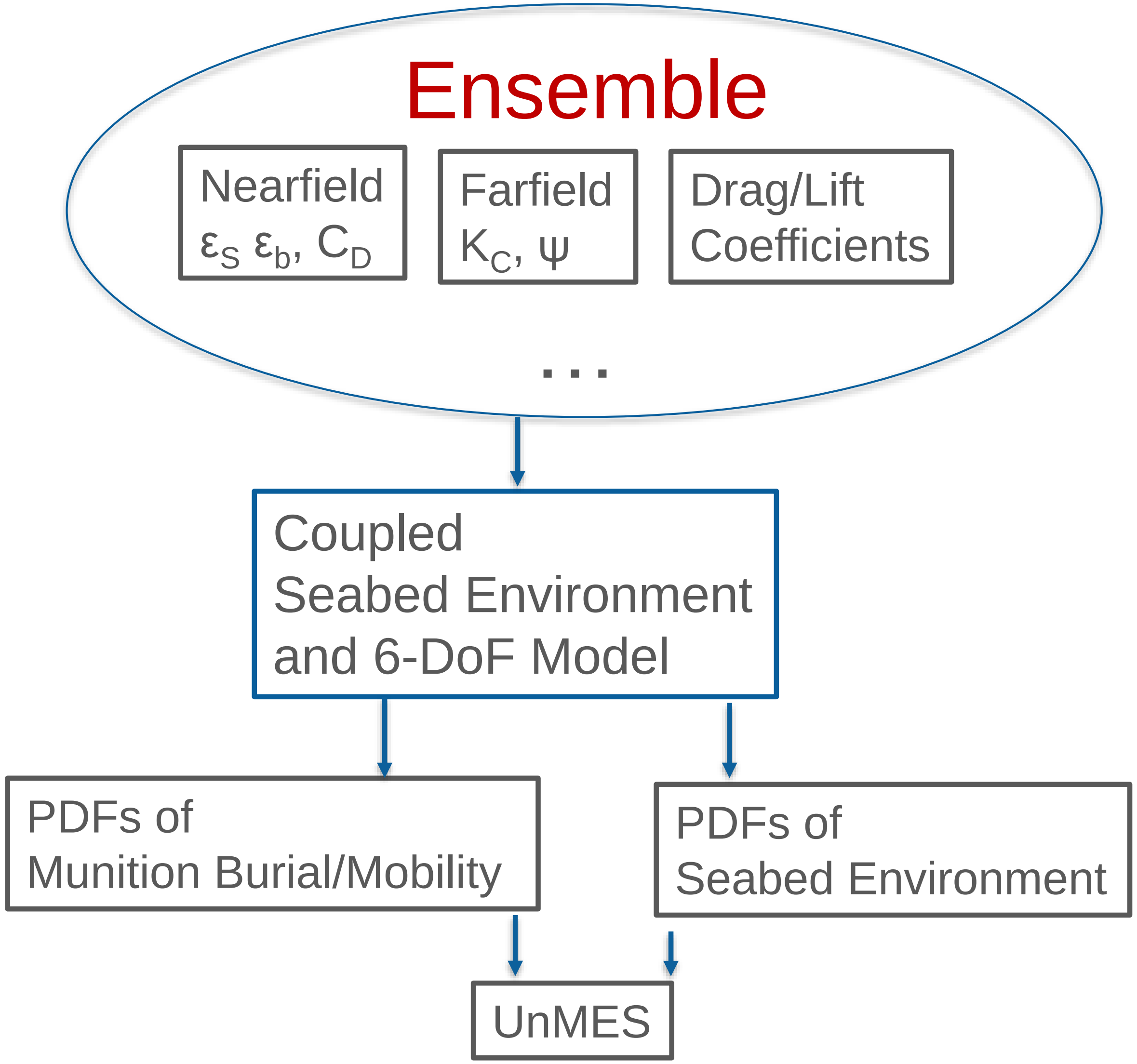
Under initial/boundary conditions DELFT 3D provides seabed environment information such as critical mass envelop, and horseshoe vortices for the 6DoF subsequent burial model. The 6DoF burial model provides the munition ‘s burial and mobility, which is used to update the boundary condition for DELFT3D. *The scheme diagram shows the scour burial as an example.*



Task 6: Ensemble Simulation and Analysis

Objective:

Ensemble simulation is conducted using the PDFs obtained from Task-3. Any realization of model parameters is treated as input to the coupled seabed environment and 6-DoF model (See Task-4). Thus, the output of CESE6D is PDFs of munition's burial, mobility as well parameters of sea floor environment. These PDFs will be ready for the Underwater Munitions Expert System (UnMES) (Rennie et al. 2007, Rennie and Brandt 2017; MR-2645, PIs: Sara Rennie and Alan Brandt).



Task 7: CESE6D Software and User ‘s Manual

Objective:

Provide user-friendly software and write a User ‘s manual to the SERDP community

Thank you!