# Underwater Munitions Expert System for Remediation Guidance

**MR-2645**

**Sarah Rennie,  Alan Brandt, Jon Ligo**
**The Johns Hopkins University Applied Physics Laboratory**

**In-Progress Review Meeting**

**15 May 2018**

# MR-2645: Underwater Munitions Expert System for Remediation Guidance

**Performers: S. Rennie, A. Brandt, J. Ligo**

## Technology Focus

- Effective management of underwater Munitions Response Sites require prediction of UXO location, movement, and depth of burial

## Research Objectives

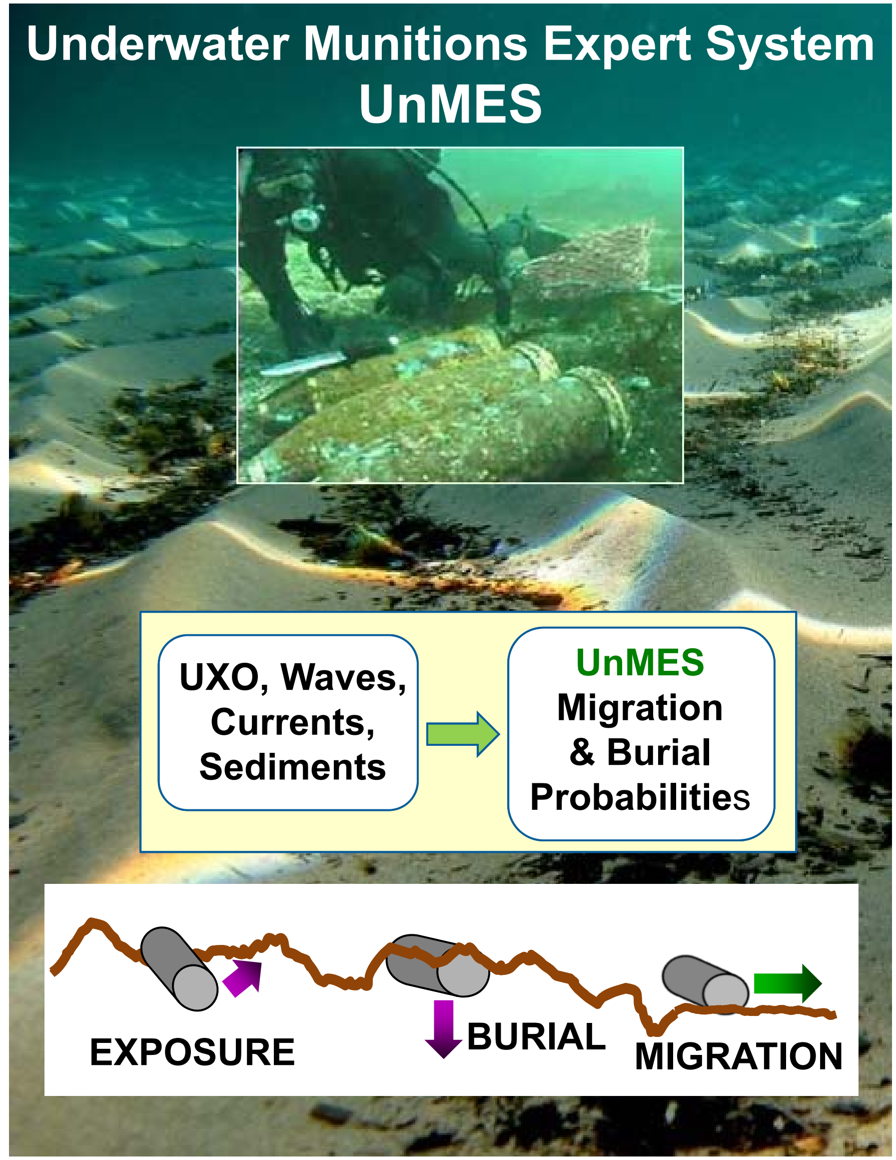
- Synthesis of multiple processes

## Project Progress and Results

- Physics-based process models
- Bayesian network updates
    - Spatial
    - Temporal

## Technology Transition

- Practical applied tool for use by site managers



# Project Team

**The Johns Hopkins University Applied Physics Laboratory**

**Sarah E. Rennie, Alan Brandt, Jonathan Ligo**

Oceanic, Atmospheric & Remote Sensing Sciences Group

## Collaboration with

| | | |
|---|---|---|
| **Carl Friedrichs** | **VIMS** | **SERDP MR-2224/MR-2647** |
| **Joe Calantoni & Blake Landry** | **NRL Stennis** | **SERDP MR-2320** |
| **Peter Traykovski** | **WHOI** | **SERDP MR-2319/MR-2729** |
| **Jack Puleo** | **Univ. of Delaware** | **SERDP MR-2503** |
| **Meg Palmsten & Allison Penko** | **NRL Stennis** | **SERDP MR-2733** |
| **Art Trembanis & Carter Duvall** | **Univ. of Delaware** | **SERDP MR-2730** |
| **Diane Foster** | **Univ. of New Hampshire** | **SERDP MR-2647** |

# Problem Statement

- Guide sustainable management of contaminated sites by predicting times and areas of enhanced burial, mobility and aggregation.

  Challenge: inexact knowledge of
  - initial deployment
  - environmental conditions
  - response to forcing for varying UXO characteristics

  Approach : probabilistic prediction of UXO behavior
  - Physics-based process models only capture part of observed variability
  - Model as Bayesian network:
    - retain knowledge about uncertainty
    - inputs and predictions in form of probability distribution (PDF)

- Best estimate in face of inherent uncertainties

# Technical Objective

**Develop a computer-based probabilistic expert system for predicting UXO location and burial.**

1) **Synthesize and improve basic knowledge of underwater UXO scour, migration, burial, re-exposure, and re-burial**

2) **Address knowledge gaps using laboratory experiments and in-depth literature review**

3) **Develop a probabilistic expert system to predict areas of munitions concentration, exposure and stability:**
   - **Compilation of important environmental factors**
   - **Physics-based modeling of burial and mobility processes**
   - **Validation by extant field & laboratory data**

4) **Build prototype software tool demonstrating methodology:**

**Underwater Munitions Expert System (UnMES)**

# Technical Approach Topics

1) Updated UnMES

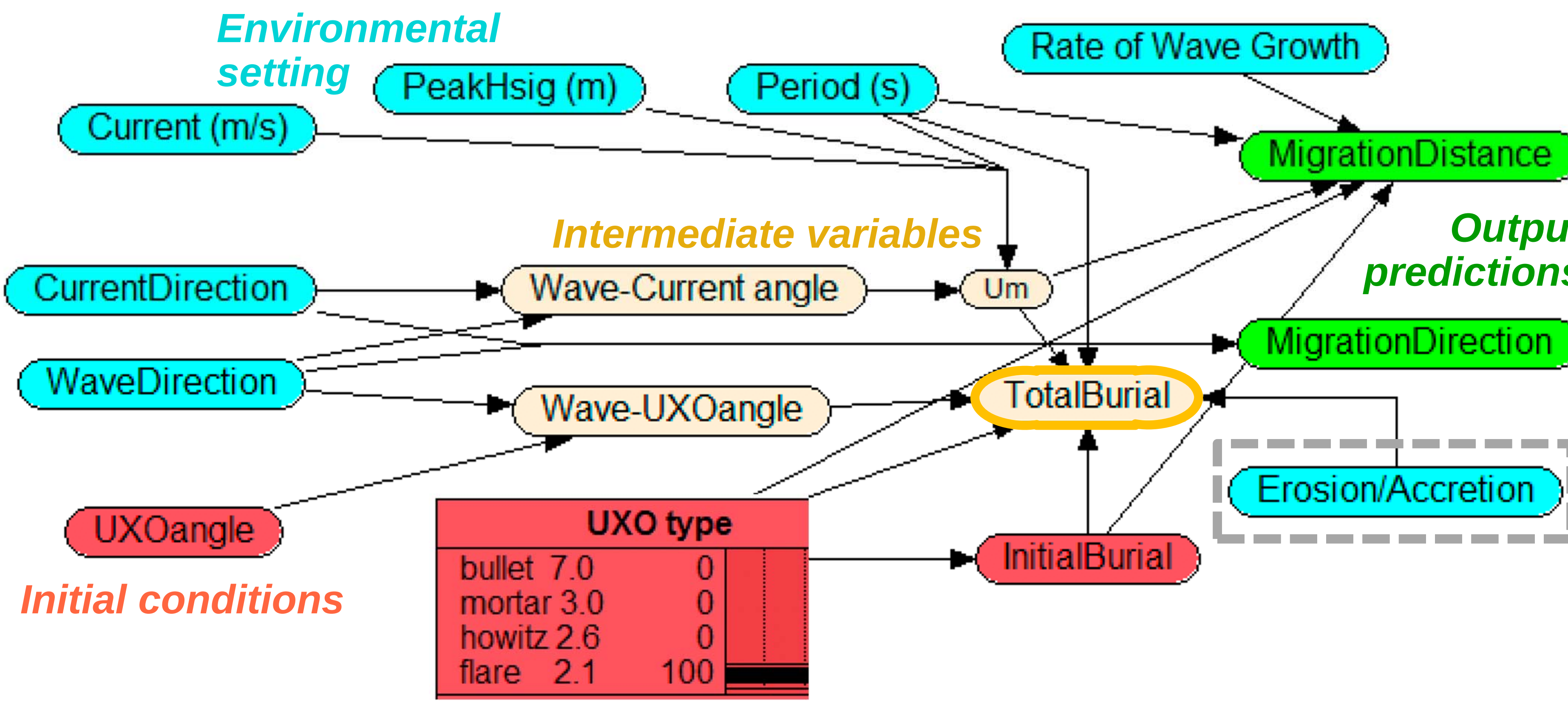
2) Impact penetration

3) “Light” UXO (low specific gravity $\gamma$)

4) Speed of storm arrival

# Technical Approach: Bayesian Network

## Updated "event" version of UnMES




1) "Flare" UXO to represent light ( low $\gamma$ ) munitions
2) Initial burial: impact penetration or burial from previous events
3) Lagged time-dependent burial & rate of storm increase
4) Total burial = Initial + Scour + Liquefaction

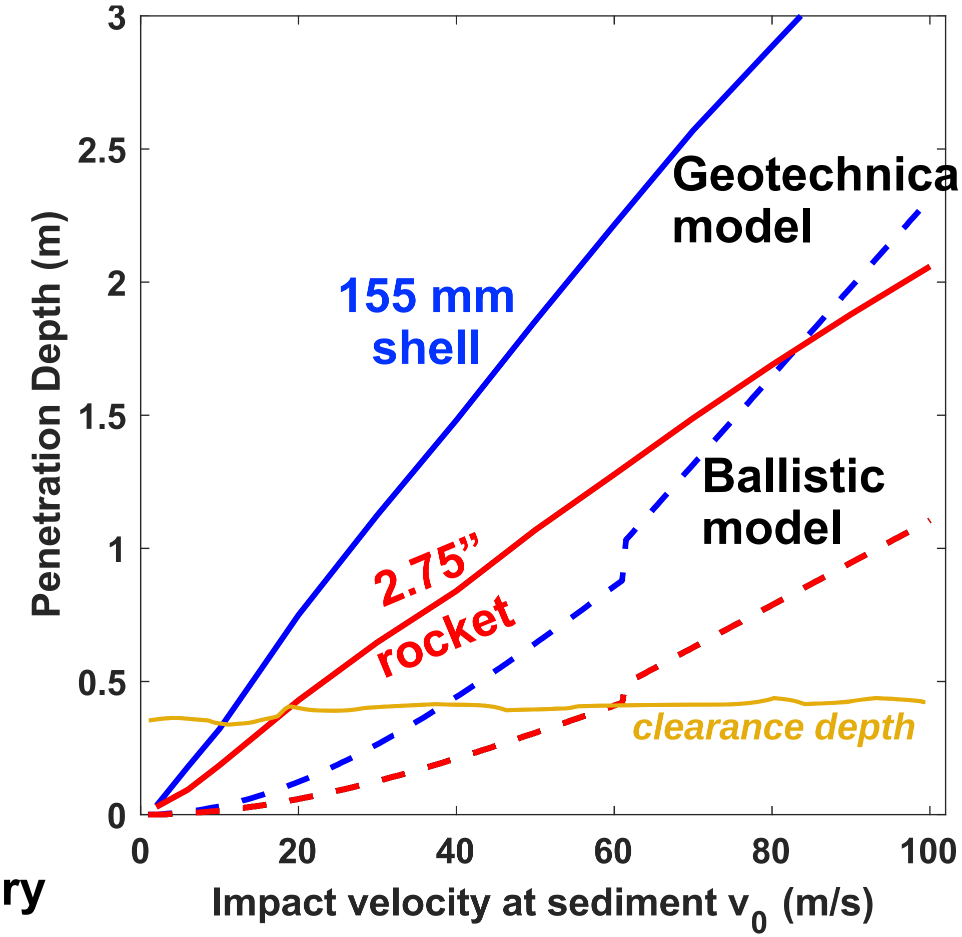
# Approach : Model High-Speed Impact Penetration

### IDA Report
- Concern: mobility potential
- Focus on shallow burial

### JHU/APL Report
- Concern: UXO exposed following significant erosion
- Focus on deep burial

### High-speed impact at sediment
- Consider shallow water (< 10m)
- Depends on tail and fin breakage
  - ➢ Treat probabilistically
- Predictions from existing models vary

**Nose-down penetration into sediment**




**High speed impact burial in sandy sediments**
*(20 kPa or S-num = 7)*

**Concerted science effort needed to understand impact burial in saturated non-cohesive sediment**

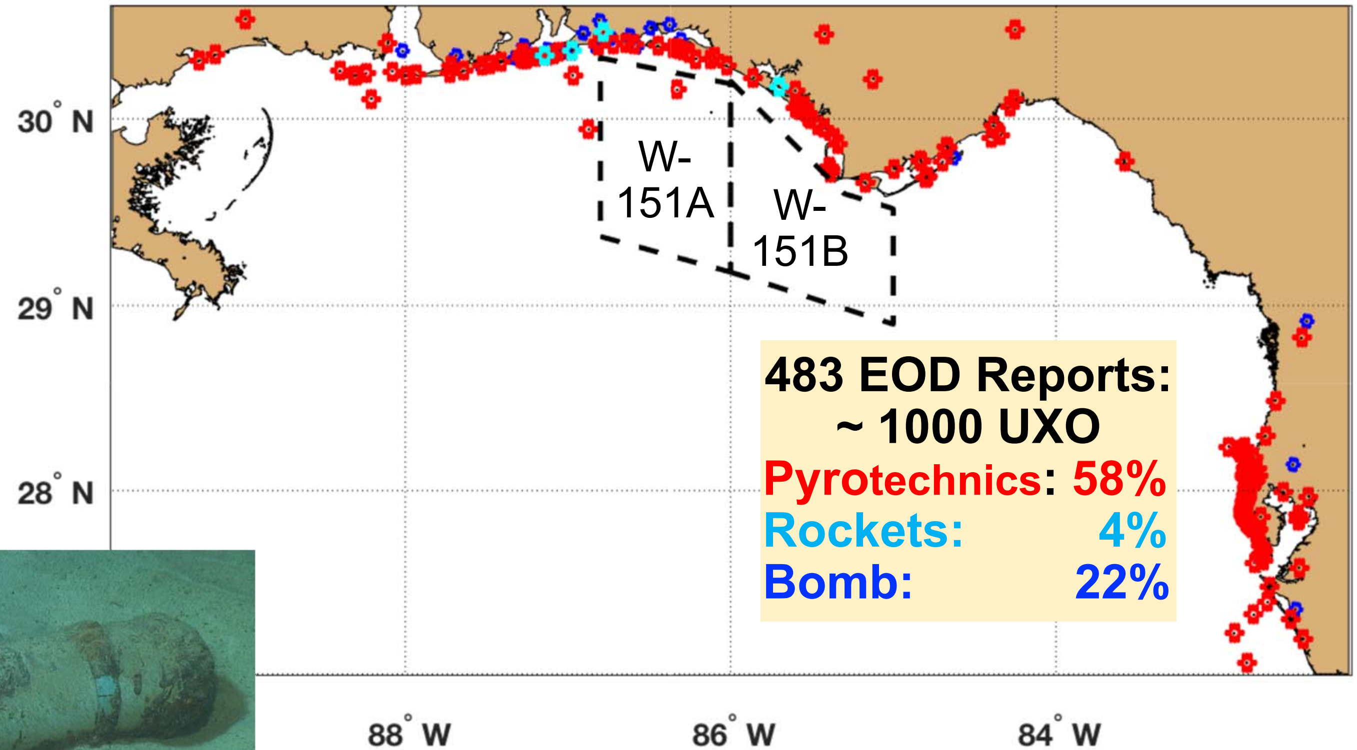
# Approach: Explore Range of UXO Specific Gravity $\gamma$

- **Include Light (low specific gravity) munitions in UnMES**

***Flares and marine markers are dominant problem for EOD at Eglin AirBase.***

***Estimate of Missile densities range from***

***$\gamma$ = 1.8 to 2.2***





HAWAI'I UNDERSEA MILITARY MUNITIONS ASSESSMENT (HUMMA) 2015

***80% of beach sighting in OSPAR dataset are pyrotechnics and missiles***

**Liquefaction and mobility models sensitive to $\gamma$ → include full range**

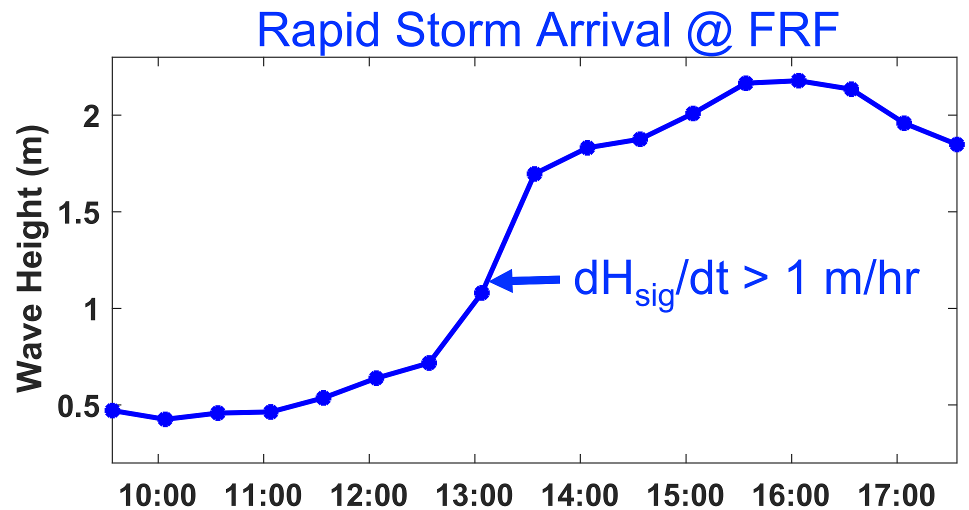
# Approach: Rate of Wave Growth

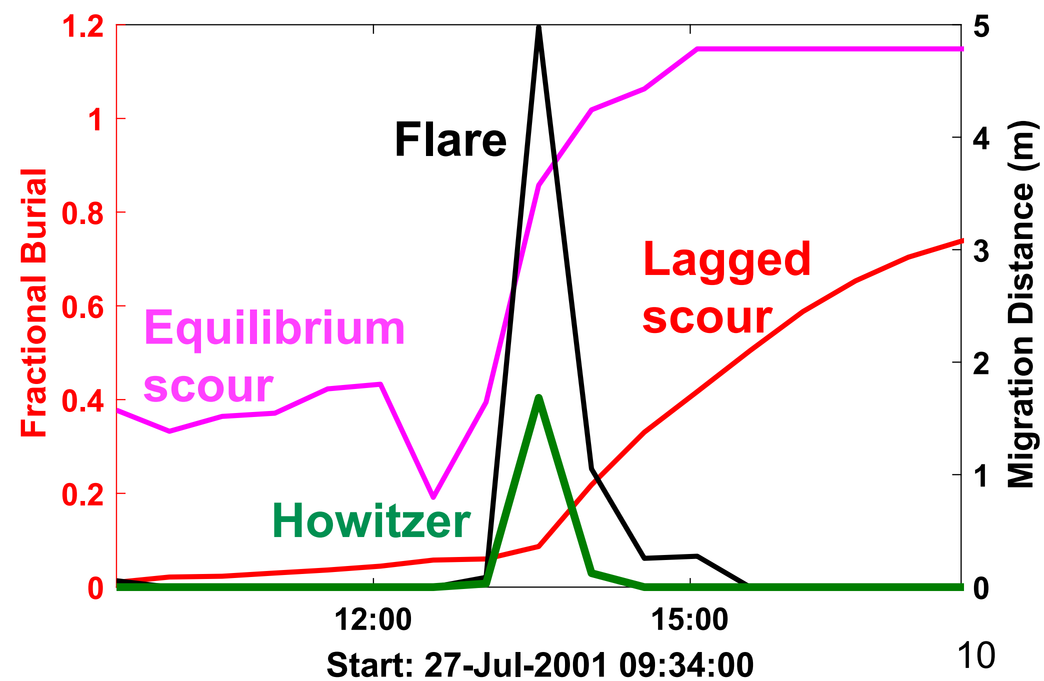
**Burial ⟷ Mobility**

- **Characterize storm by how fast waves increase: $dH_{sig}/dt$**
- **Impose increased time scale (10X) for scour burial**

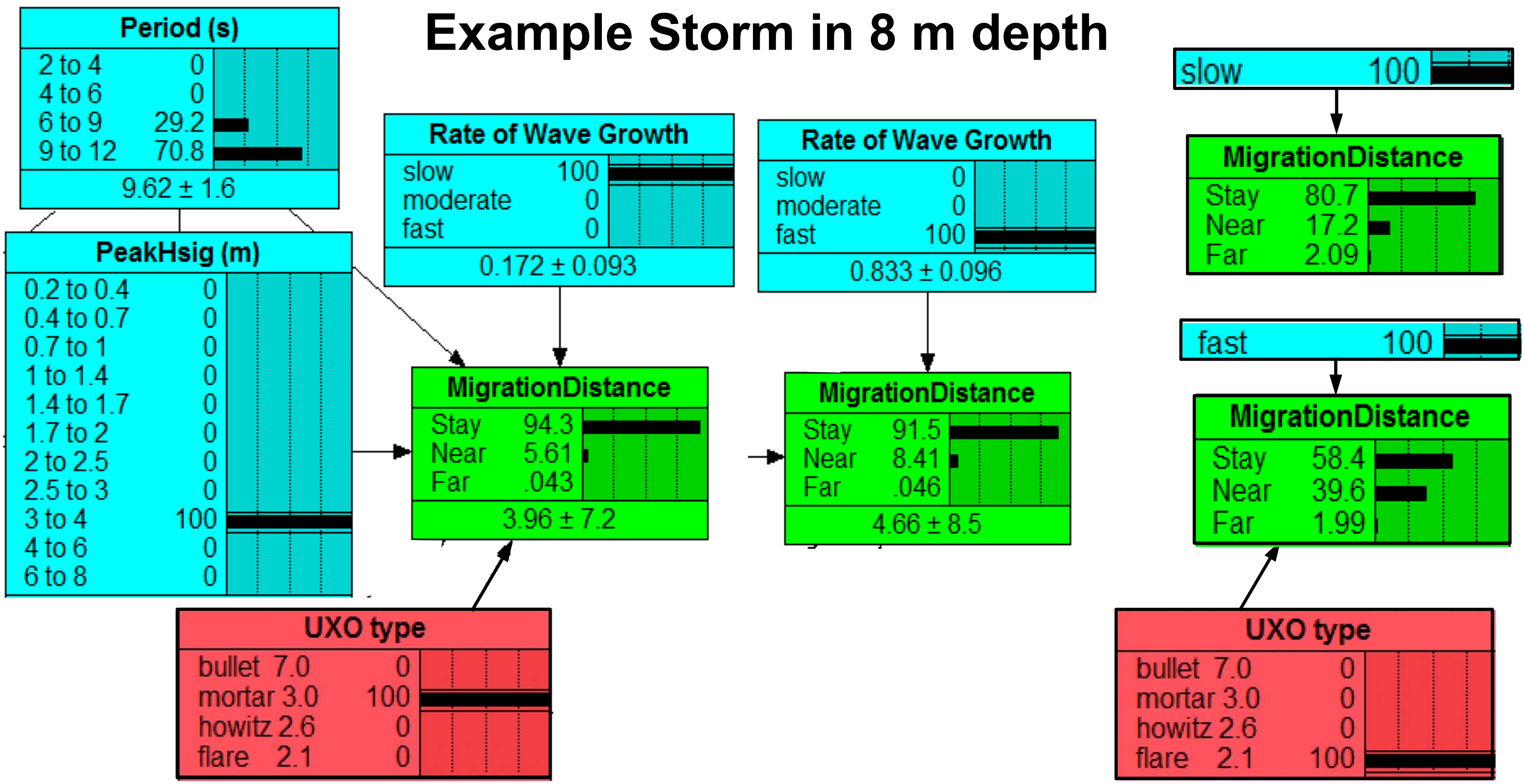
| | Rate of Wave Growth | |
|---|---|---|
| < 0.3 m/hr | slow | 96.0 |
| 0.3 to 0.6 | moderate | 3.00 |
| > 0.6 m/hr | fast | 1.0 |

> ➢ **High rate of wave growth is unusual occurrence**



# Approach: Rate of Wave Growth




- ➢ **For heavy UXO, mobility likely only if scour burial is slow or suppressed**

# Results: Topics

1) Erosion/Accretion: burial and re-exposure by geomorphological processes
2) Spatial Implementation of UnMES
3) Characterizing Extreme Storms
4) Temporal Implementation

# Results: Re-exposure / Burial Processes

## Time-varying Geomorphology

1) Ripples
2) Dune migration
3) Seasonal shore adjustment
4) Shoreline erosion

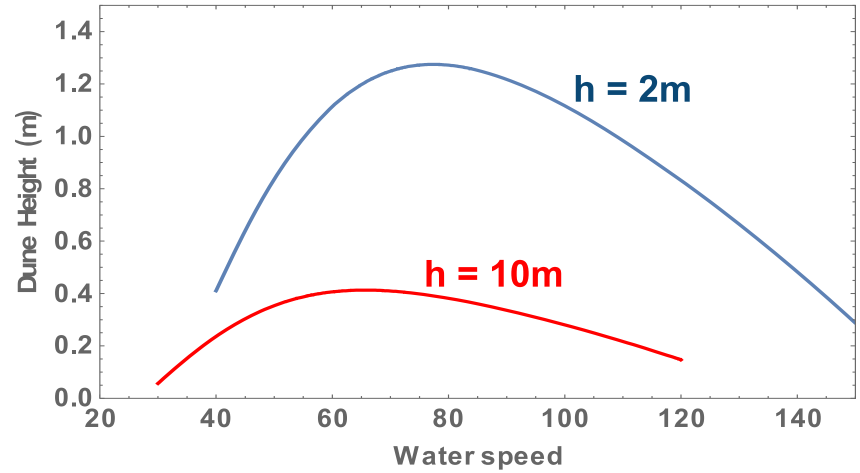
size & timescale

Erosion/Accretion

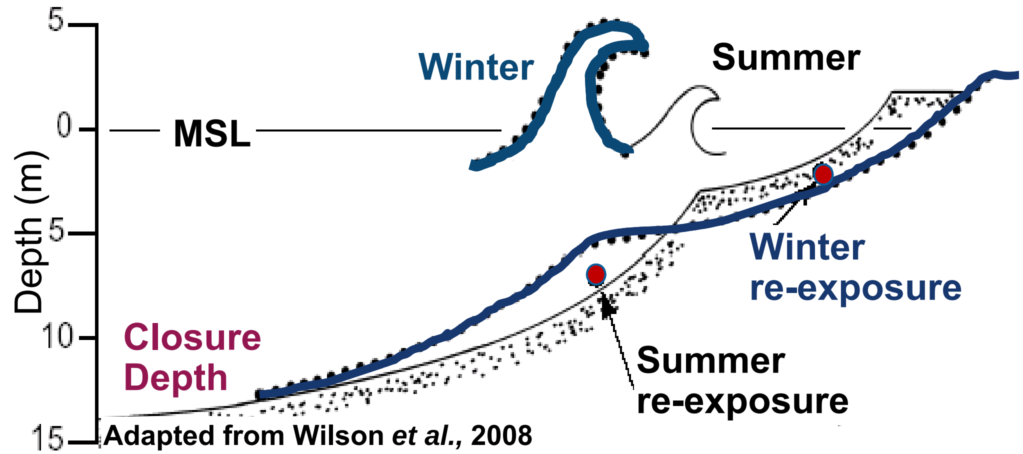
1) Manmade disturbance:
   1) cable laying
   2) pipeline activity
   3) bottom-trawling

HumanActivity

## Bedform Models




## Seasonal Shoreline Adjustment



Adapted from Wilson *et al.*, 2008

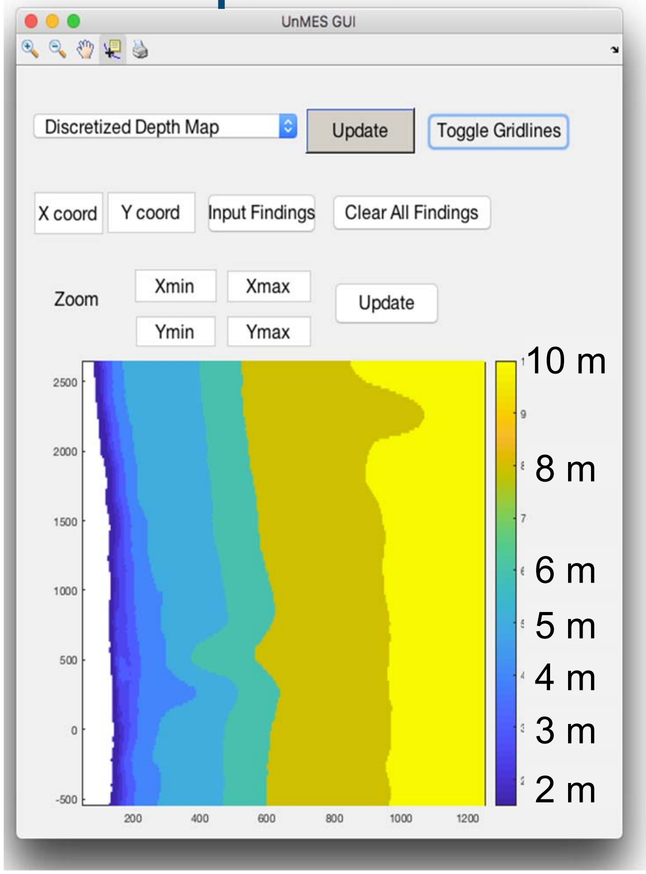
***Engineering models implemented but require location-specific tuning***

# Results: Spatial Implementation

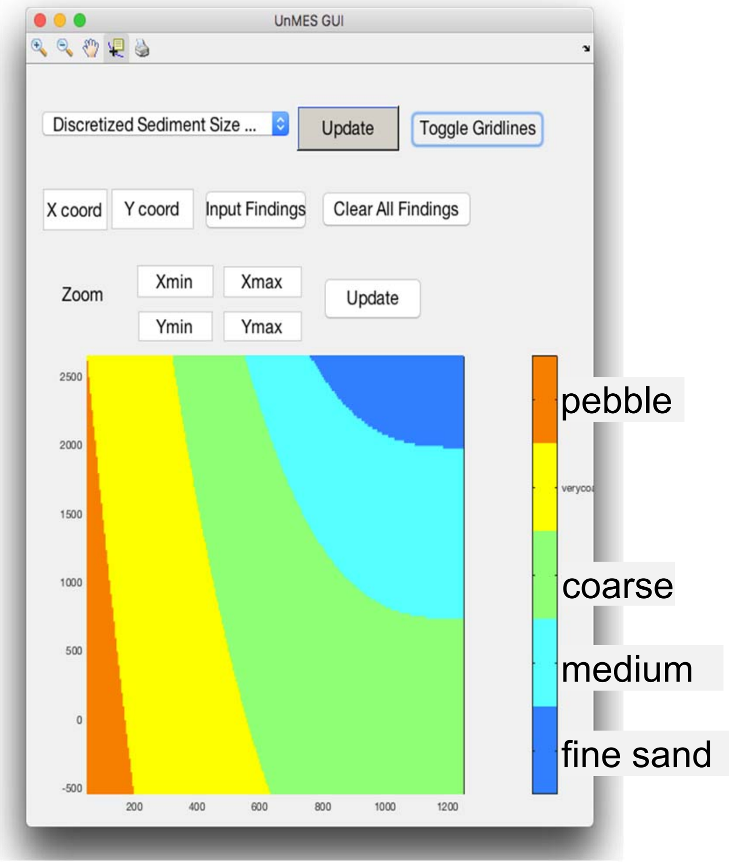
**Replicate "event" UnMES Bayes Net at multiple spatial locations**

- **varying bathymetry and sediment across model region**

## Depth Bins




## Sediment Bins




***Bathymetry and Sediment fixed within each UnMES replicate***

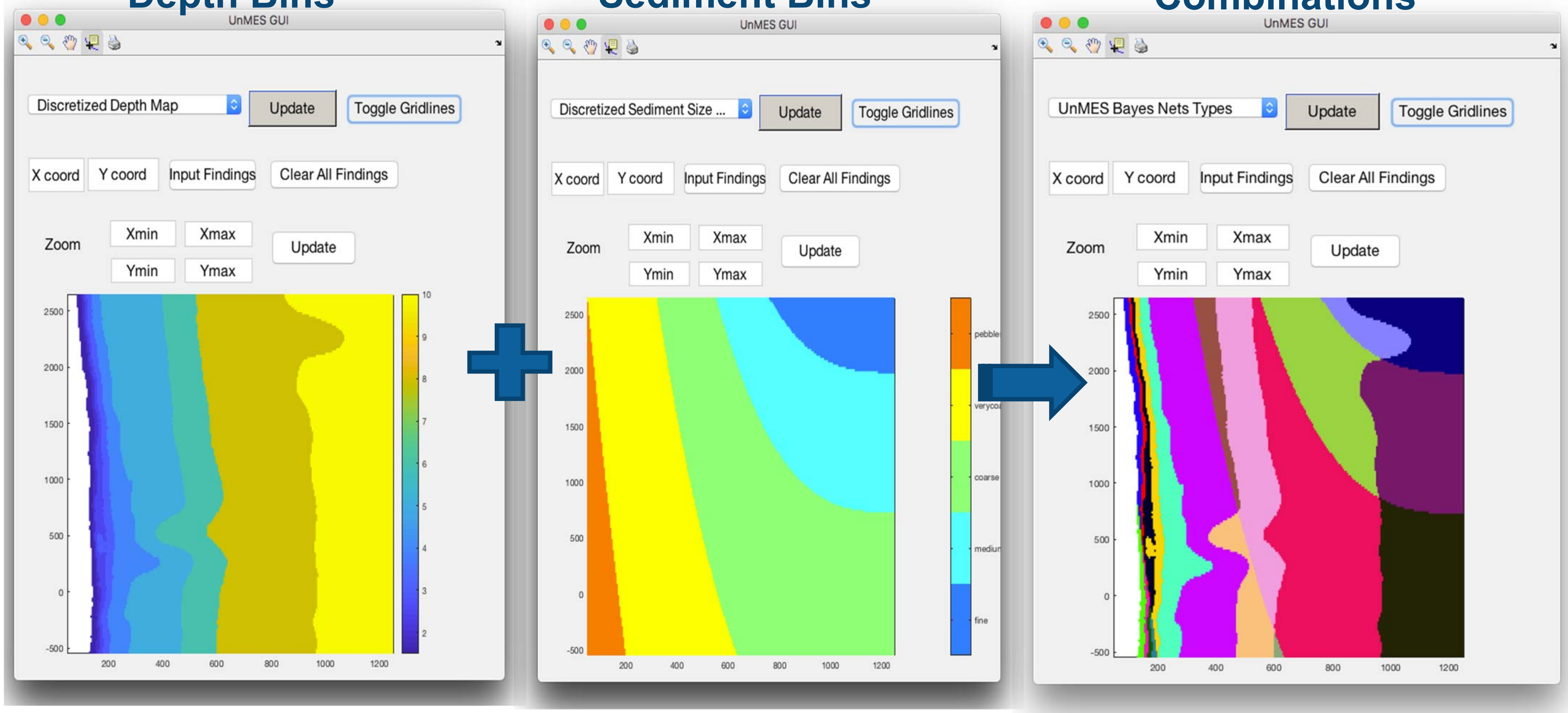
# Results: Spatial Implementation

**Example based on MR-2733 DELFT3D bathymetry: total of 16 unique provinces**

## Depth Bins

## Sediment Bins

## Depth+Sediment Combinations




***Auto-generate custom BN replicate for each Depth + Sediment province***

# Results: Characterize Storm Events

## Example query: What size storm could cause full burial in 8 m depth?

**Probabilistic inference can be either predictive or diagnostic**

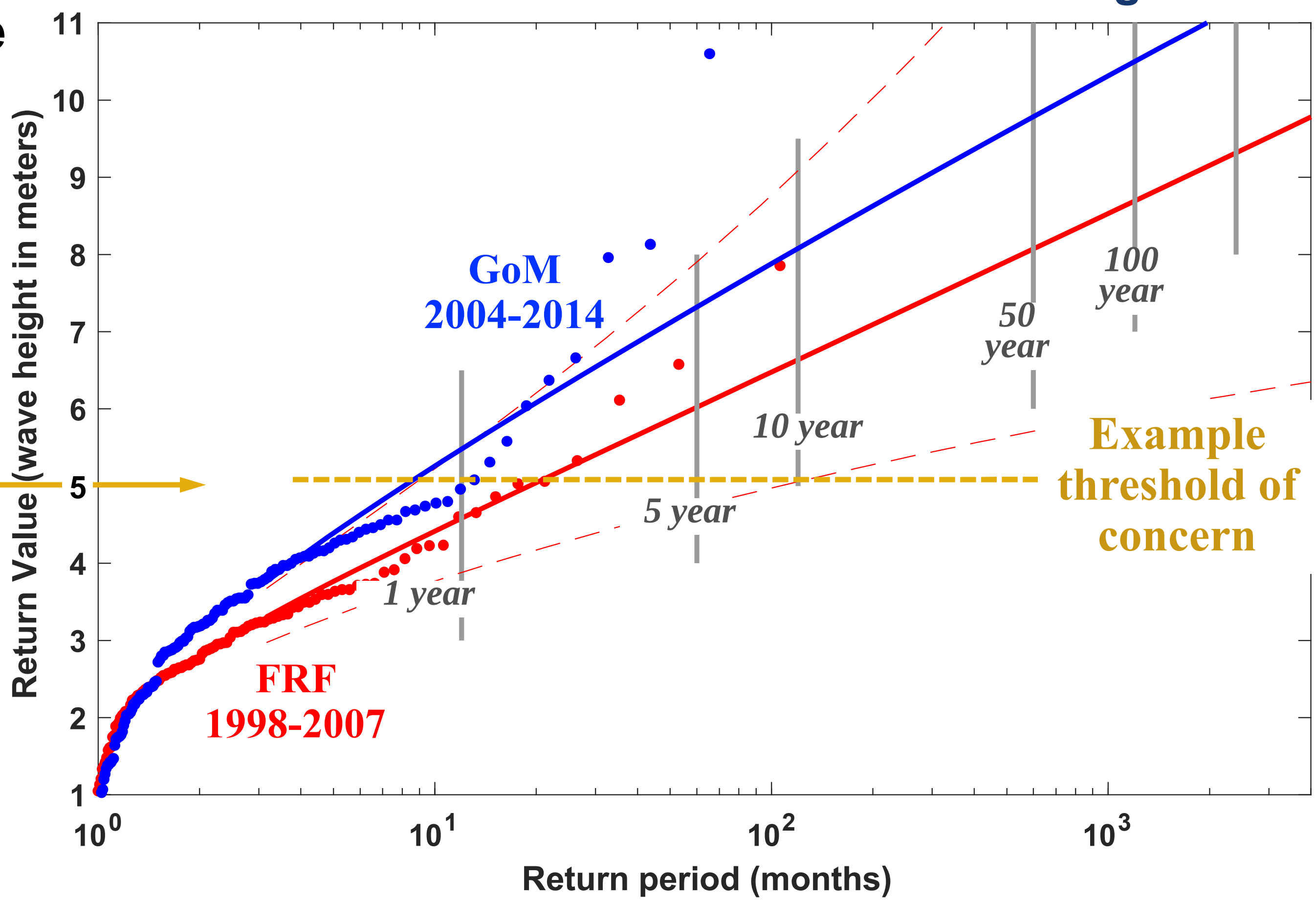
| PeakHsig (m) | |
|---|---|
| 0.2 to 0.4 | .088 |
| 0.4 to 0.7 | .050 |
| 0.7 to 1 | .041 |
| 1 to 1.4 | .040 |
| 1.4 to 1.7 | .055 |
| 1.7 to 2 | .077 |
| 2 to 2.5 | .091 |
| 2.5 to 3 | 0.69 |
| 3 to 4 | 9.24 |
| 4 to 6 | 39.7 |
| 6 to 8 | 49.9 |

*diagnostic query*

| TotalBurial | |
|---|---|
| lessthan20percent | 0 |
| perc20to50 | 0 |
| perc50to75 | 0 |
| perc75to100 | 0 |
| fullyBuried | 100 |

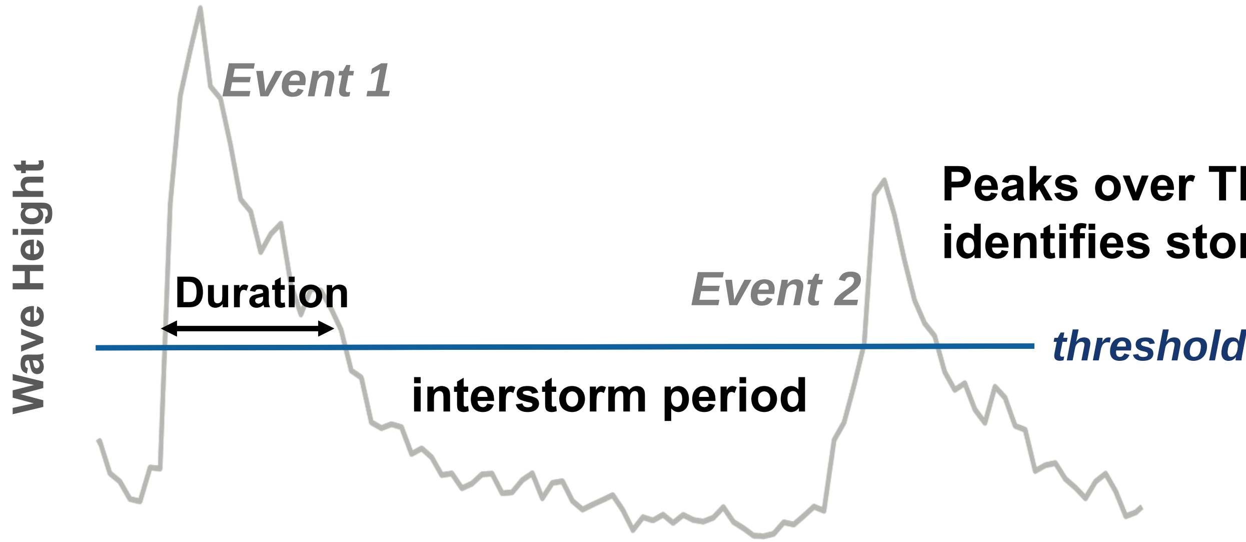
| | |
|---|---|
| howitz 2.6 | 100 |

**Related Question: How often do storms that big occur?**




*Advise managers on likelihood of extreme events*

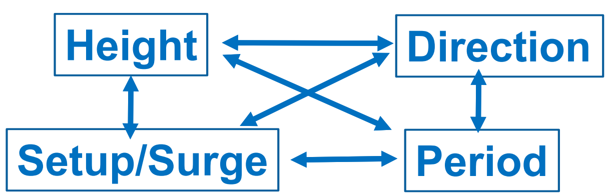
# Results: Characterize Storm Events



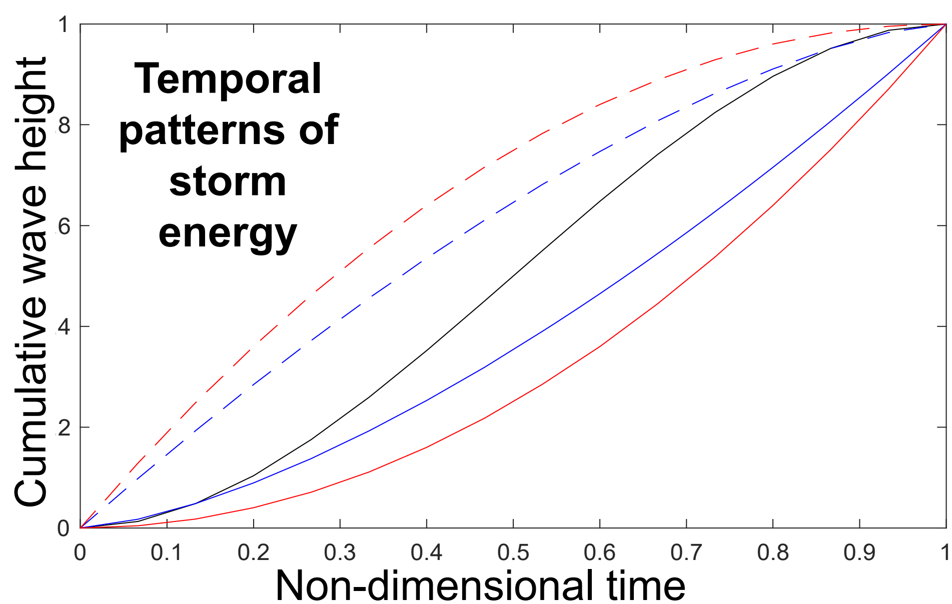

**Peaks over Threshold identifies storms**

**Characterize → Synthesize**

- **Limited data time series length → poor statistics of extreme events**
- **Capture joint distributions**

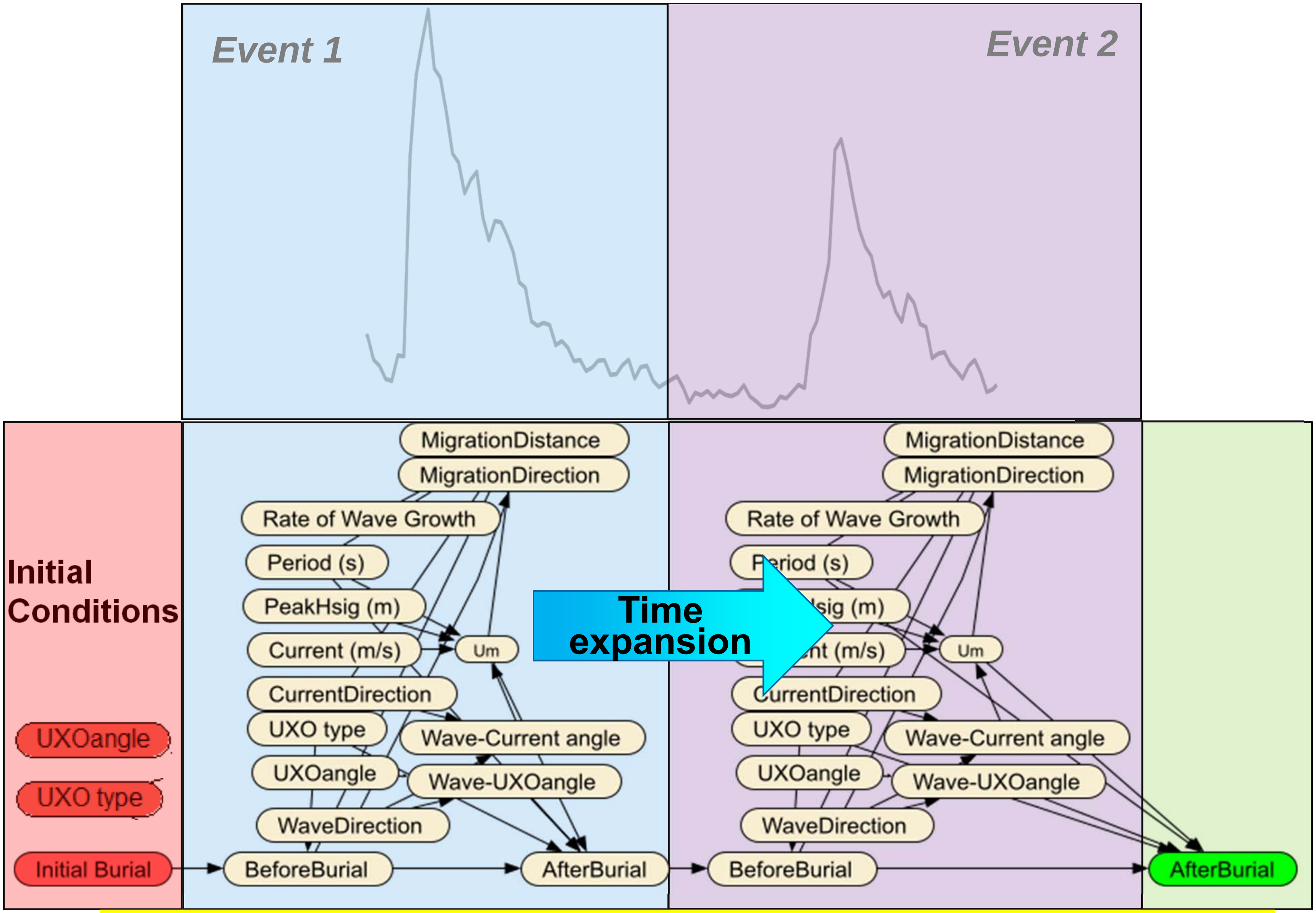



➢ **Copulas: specify marginal univariate PDF of multivariate behavior**



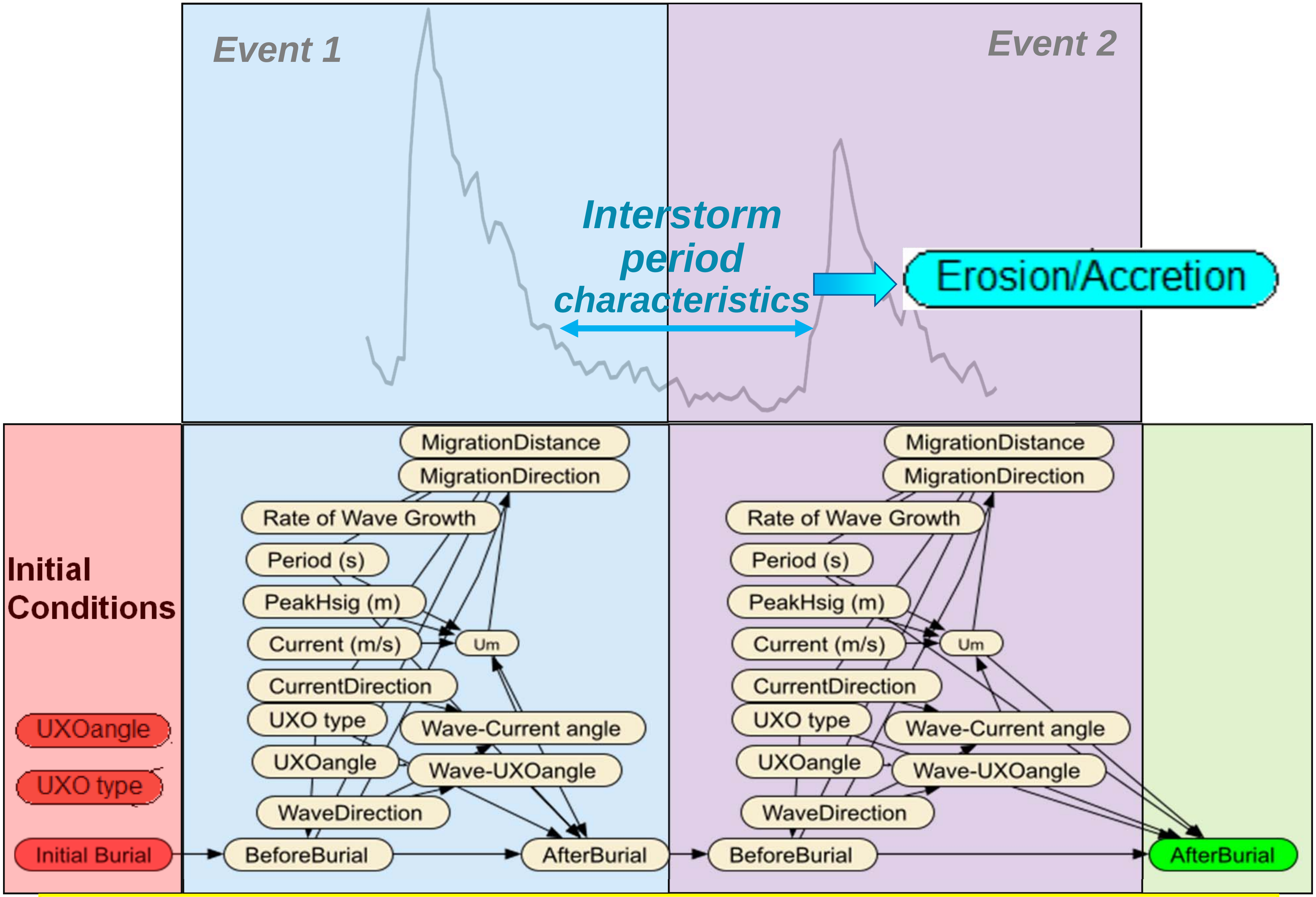

***Use synthetic storm analysis to extend time series for analysis***

# Temporal Extension: Dynamic Bayes Net



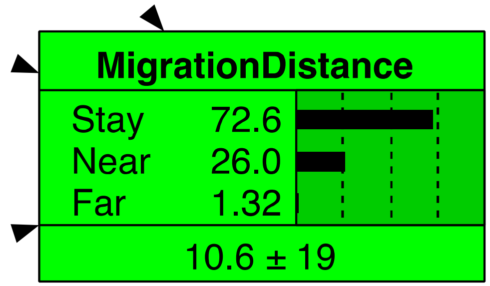

*sequencing UnMES using Dynamic Bayes Network architecture*

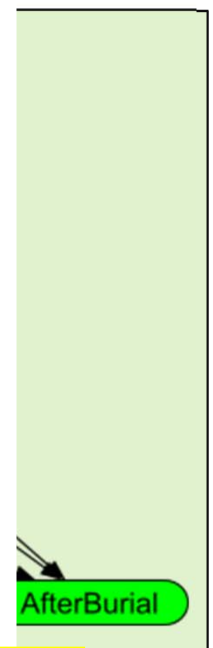
# Temporal Extension: Dynamic Bayes Net




***Characteristics of quiescent interstorm period may dominate accretion***

# Net



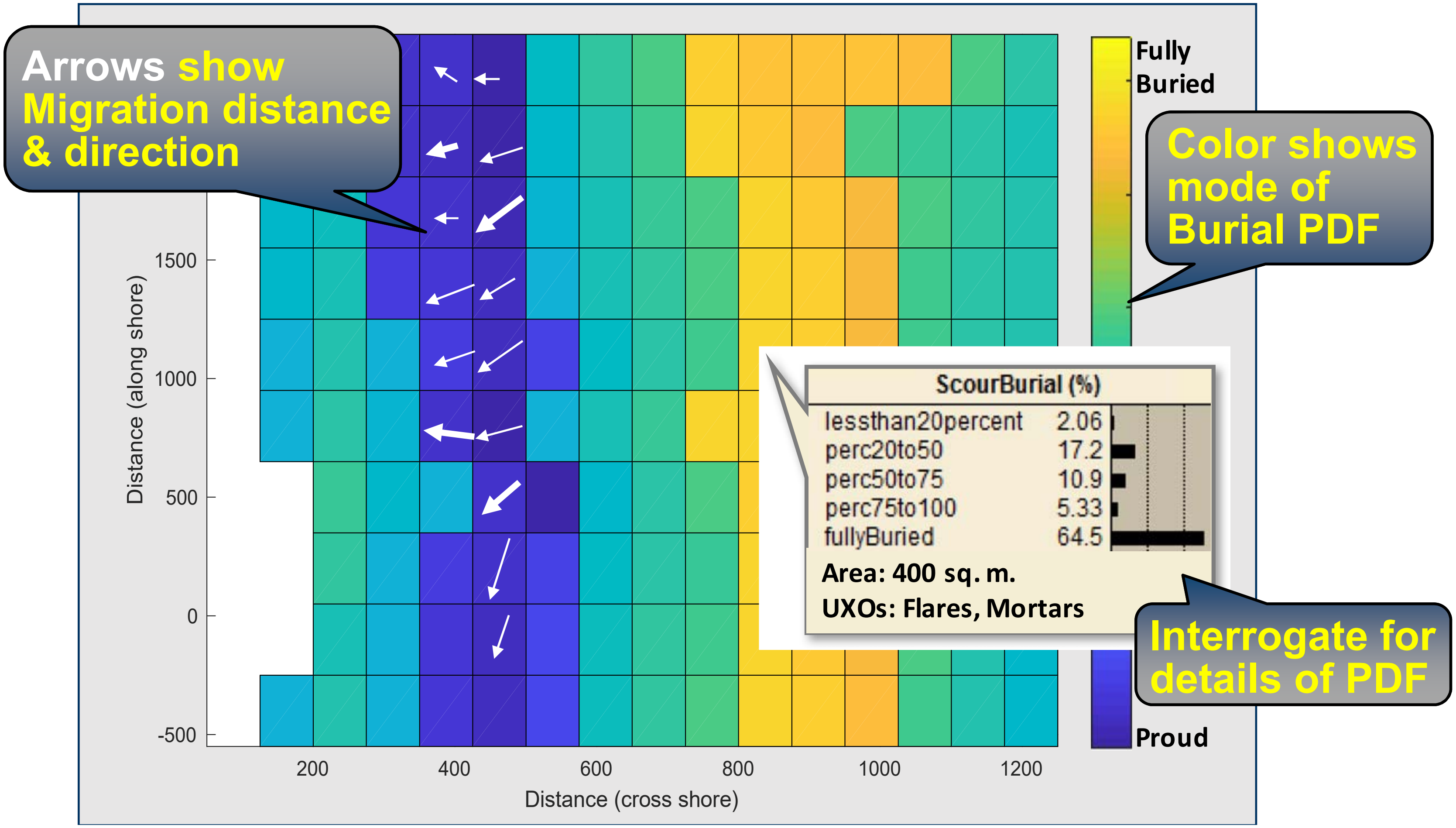

***Temporal results need to interact with spatial implementation***

# Transition Plan

- Collaboration with USACE (A. Schwartz) to solicit feedback from project and technical managers of underwater munitions sites.
  - Prototype questionnaire has been developed:
    - What poses an environmental liability at your site?
      - Identify primary risk factors
      - Characterize munitions types most frequently encountered
    - What types of decisions that are made to manage that liability ?
    - What tools are currently used to address risk?
    - Characteristic time scales of decision making (CERCLA phases)
  - Explore potential for workshop, face-to-face meeting or web conferences with managers.
- Investigating effective visualization tools

# Transition Plan: Prototype Visualization Tool

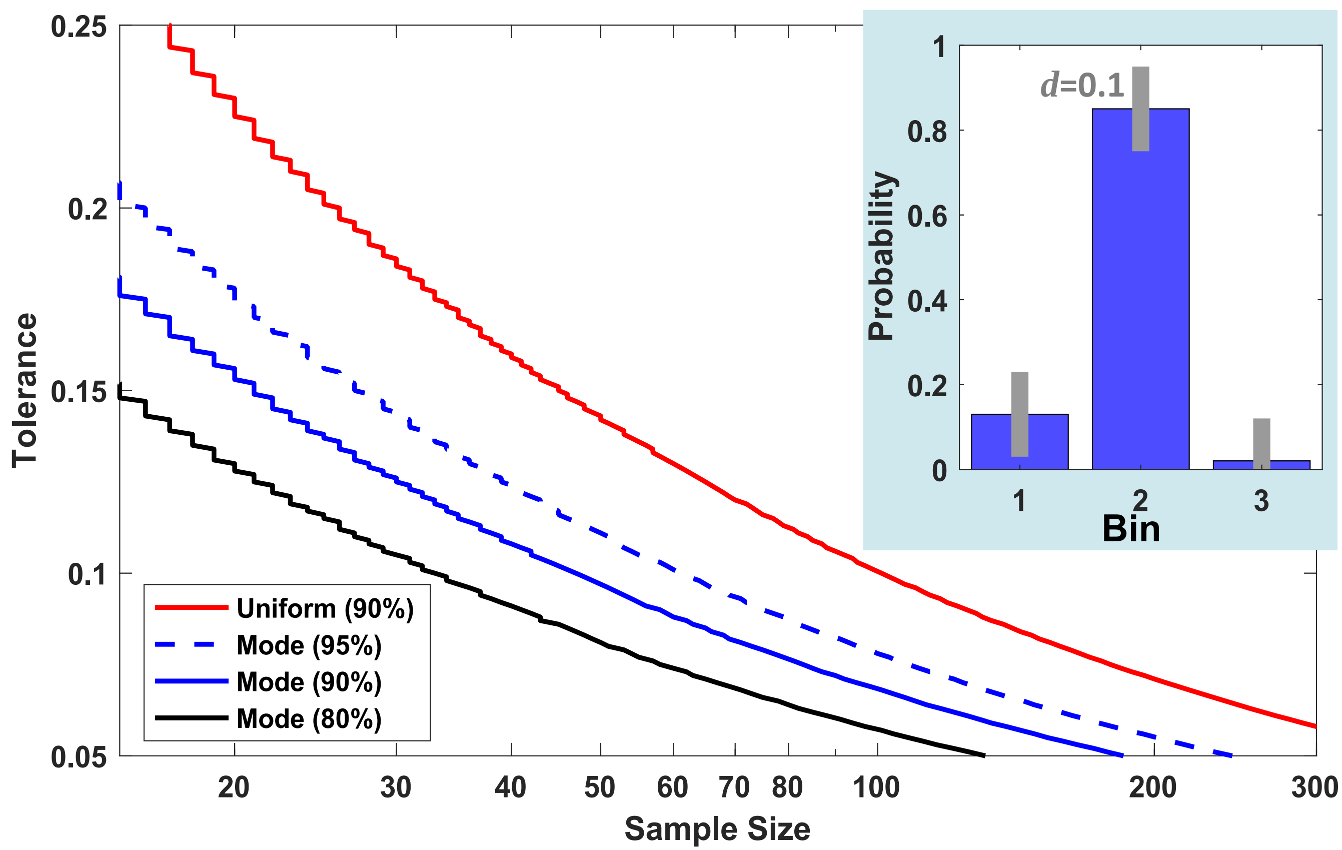
**Example multivariable visualization with GUI for interactive interrogation:**




***Present output in manner readily used by managers: Translate probabilistic result → simple risk metrics***

# Issues

1) Delays in obtaining processed field data from SERDP collaborators
2) Validation challenges: # of observations
   - ➢ Explore use of synthetic data



# BACKUP MATERIAL

# MR-2645 Publications

- **Scientific Literature:**
- Ligo, J., S. Rennie, A. Brandt, "Probabilistic Prediction of the State of Discarded Underwater Munitions," Joint Statistical Meeting, Statistics and the Environment, JSM-329728, July 2018.
- **SERDP Publications:**
- Rennie, S.E., A. Brandt, J.Ligo, "Probabilistic Expert System – Site Guidance for Remediation and Management of Underwater Munitions", SERDP-ESTCP Symposium, November 2017.
- Rennie, S.E., Brandt, A., "Status of Underwater Impact Penetration Modeling for use in the Underwater Munitions Expert System", SERDP Project MR-2645, JHU/APL Technical Report FPS-t_17-0456, November 2017.

# UnMES Approach: Bayesian Network

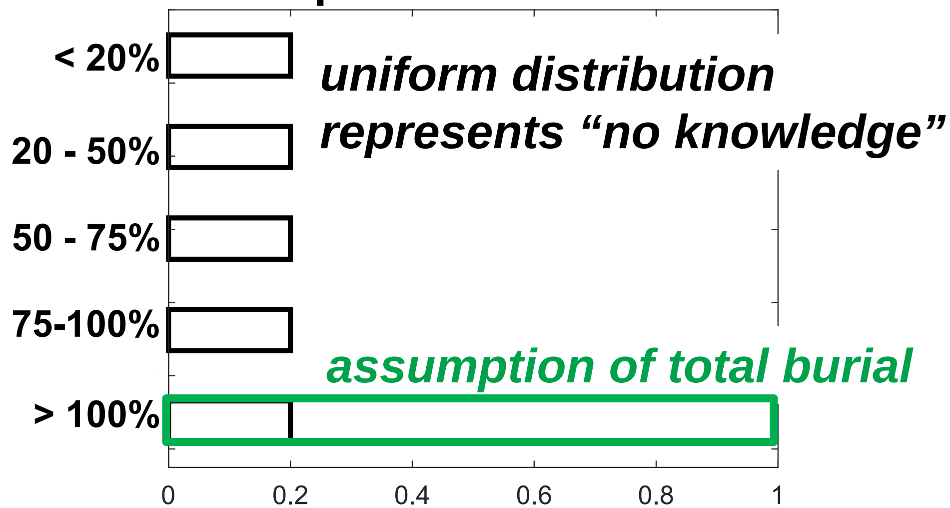
**Bayesian belief network (BN) - a directed acyclic graph**

- nodes are random variables
  - represented by probability distribution
    - records and propagates inherent uncertainty
  - parameter ranges discretized into selected # of states or "bins"
- links (arrows) are directional connections
  - represent statistical dependencies between the nodes
  - relationships quantified as Condition Probability Table (CPT)
- Designed and implemented using Netica™
  - Monte Carlo exploration of process models in Matlab → CPT
  - Input & output connections implemented in Matlab (JAVA API)
  - GIS capability: generate custom BN for fixed water depth and sediment type bins

# Probabilistic Model Skill Assessment

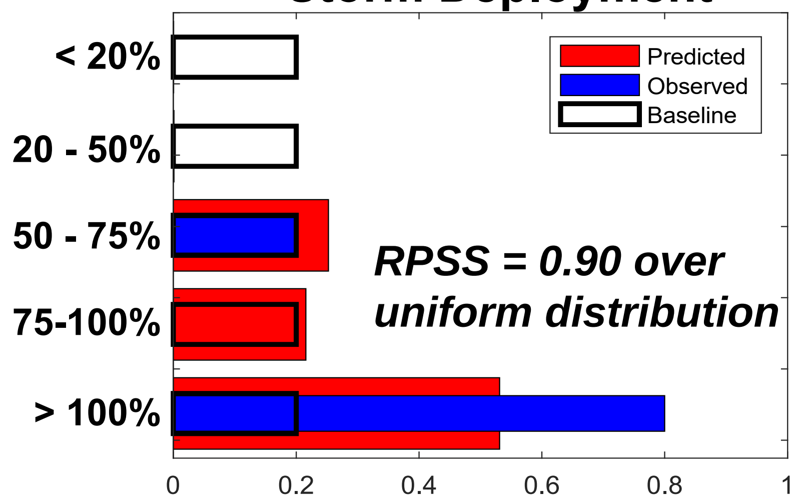
## Ranked Probability Skill Score

### Example Baseline PDFs:




### Example TREX13 Burial Data

### Storm Deployment




### Quiet Deployment