The Johns Hopkins University
APPLIED PHYSICS LABORATORY

Advanced Capabilities in the Underwater Munitions Expert System

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Applied Physics Laboratory

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SERDP • ESTCP SYMPOSIUM
25 YEARS OF ESTCP
2019 | Enhancing DoD's Mission Effectiveness

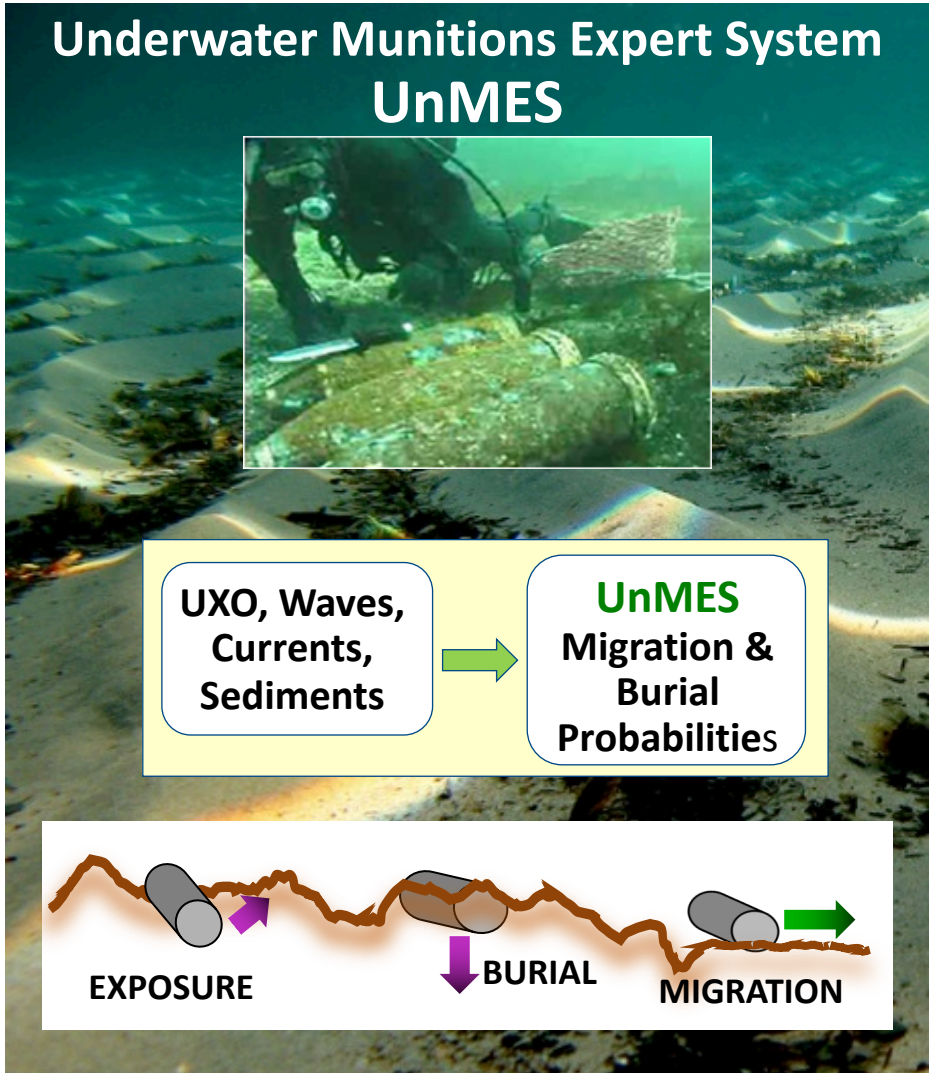
OUTLINE

- **Expert System Motivation and Approach**
- Improvements in Process Models
- UnMES Validation
- Interaction with Site Managers

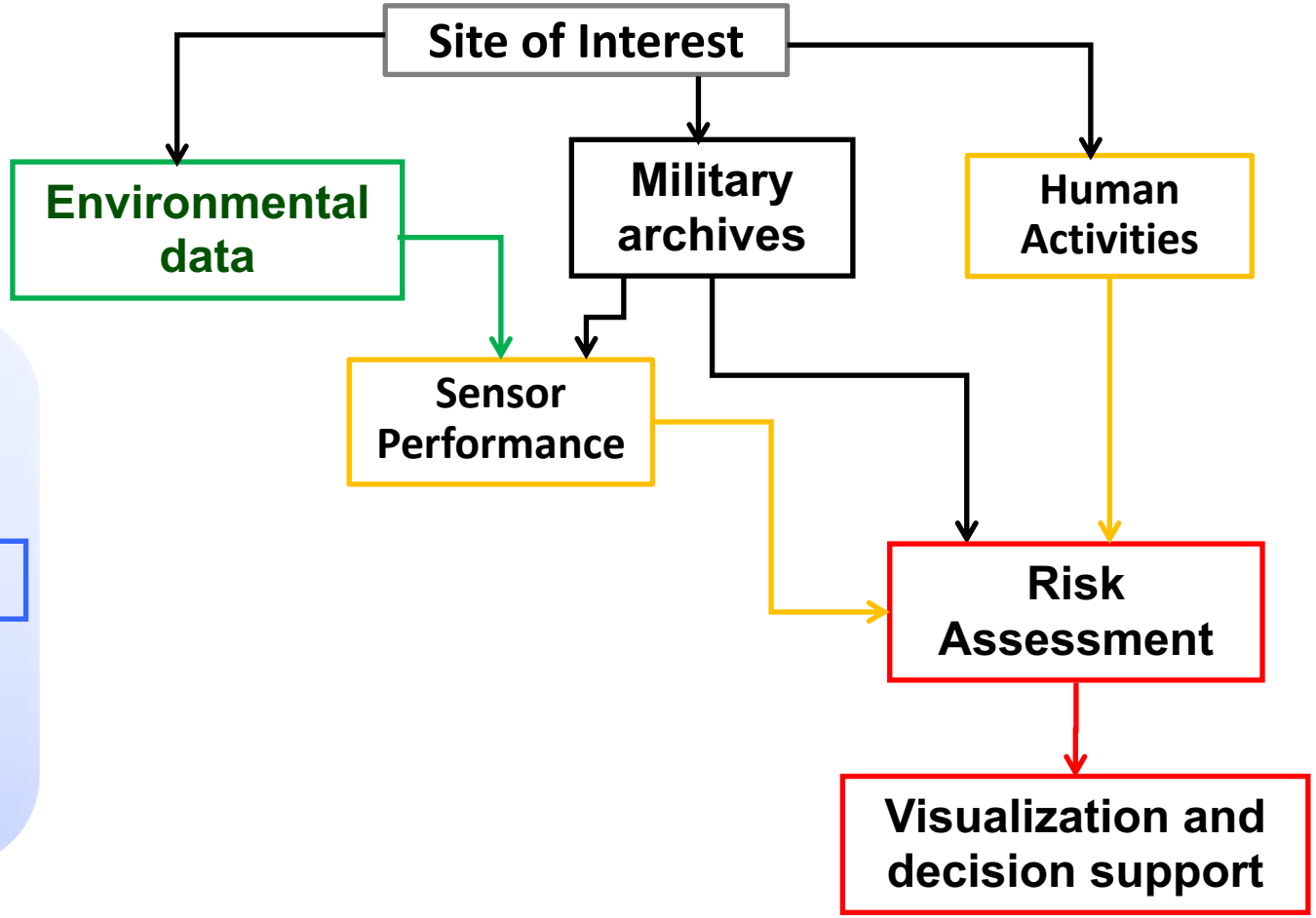
MR19-1126: Advanced Capabilities in the Underwater Munitions Expert System (UnMES)

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

- **Synthesize basic knowledge of underwater UXO burial, migration, re-exposure**
- **Address knowledge gaps**
- **Predict areas of UXO concentration, exposure, stability**
  - Important environmental factors
  - Physics-based modeling of processes
  - Validation by recent field & laboratory data



UnMES: Module in Decision Support System

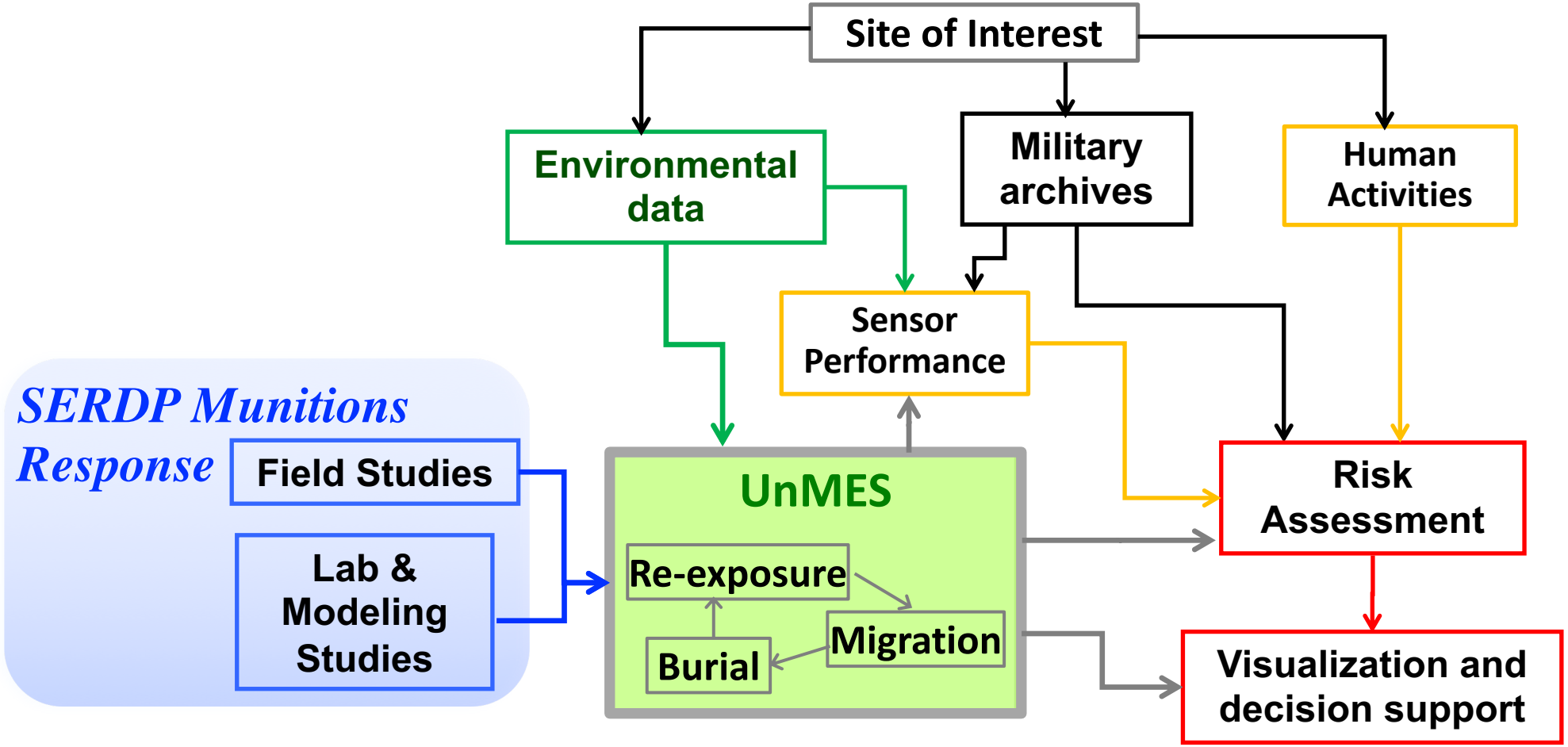


SERDP Munitions Response

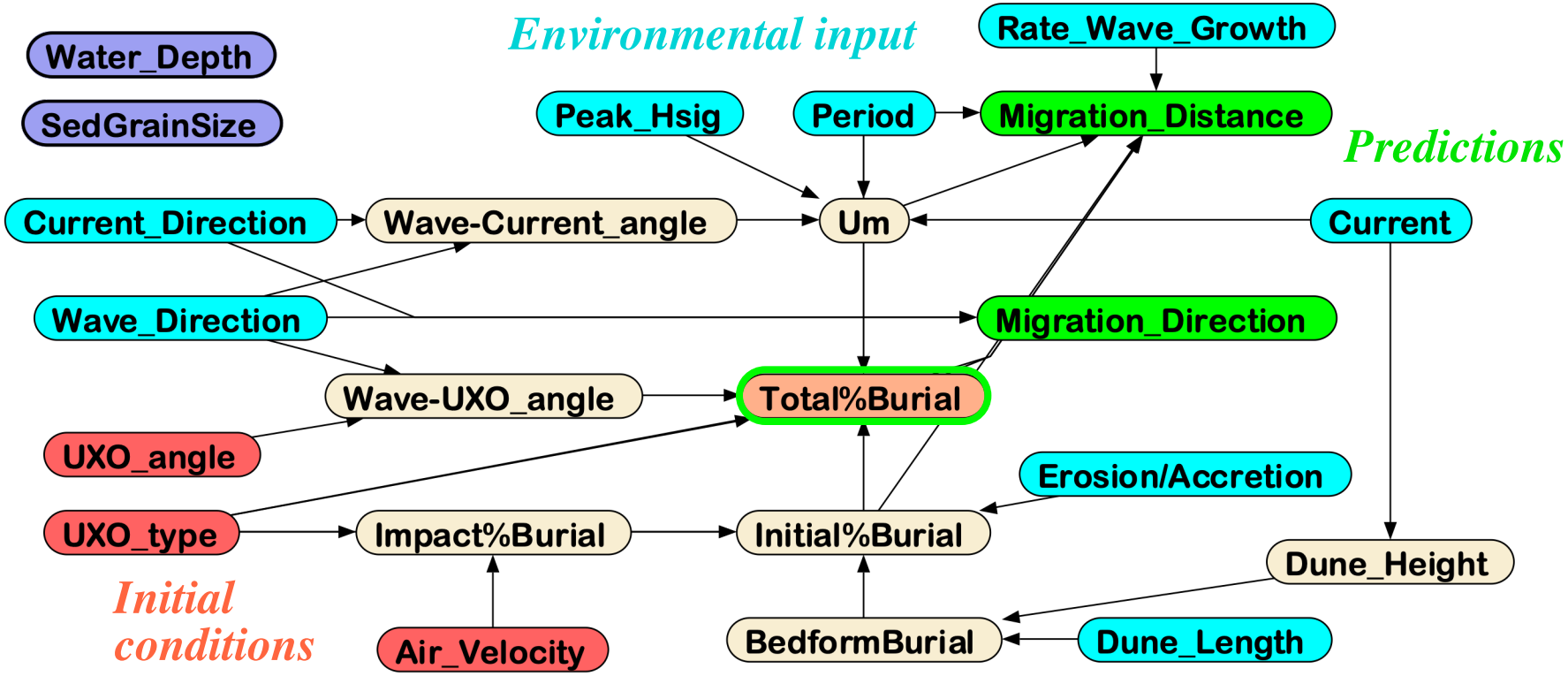
Field Studies

Lab & Modeling Studies

UnMES: Module in Decision Support System

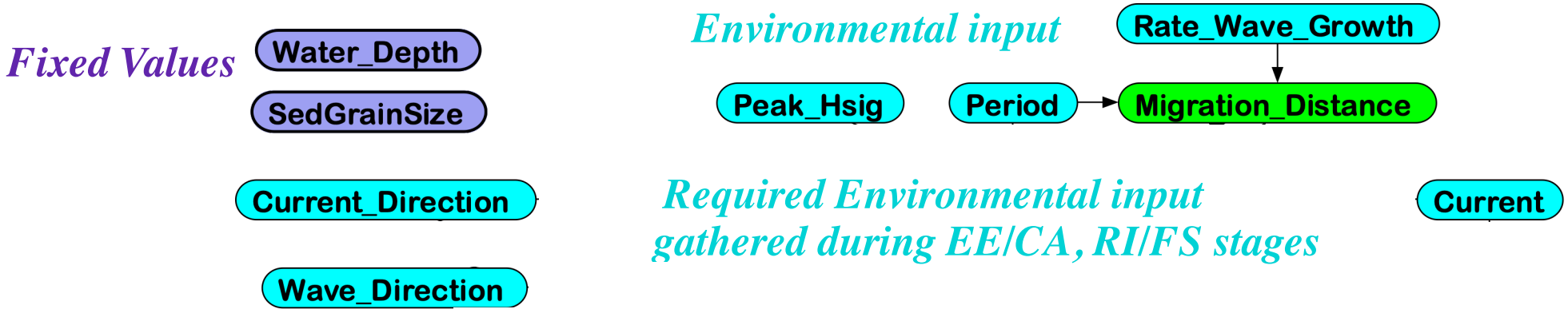


UnMES Implementation: Probabilistic Bayesian Network



- *Implemented as Bayesian Network in* Netica™ *software*
- *Arrows indicate causal relationships between forcing and UXO behavior*

UnMES Implementation: Probabilistic Bayesian Network



Environment may be poorly known –

- low cost, minimal investment: inputs may be broad distributions

→ spread in output distributions represent large uncertainty

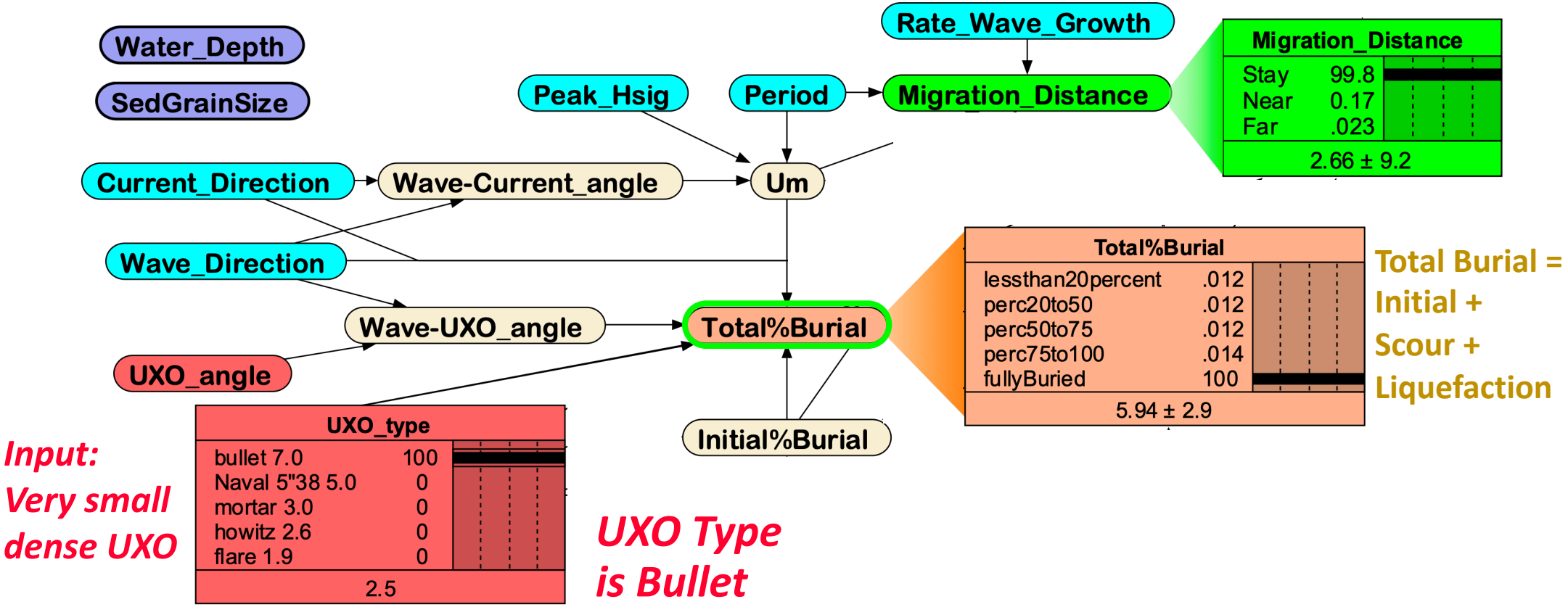
or Environment represented by high-fidelity model

- e.g. DELFT3D implementation (Palmsten & Penko)

→ narrow output distributions represents higher certainty

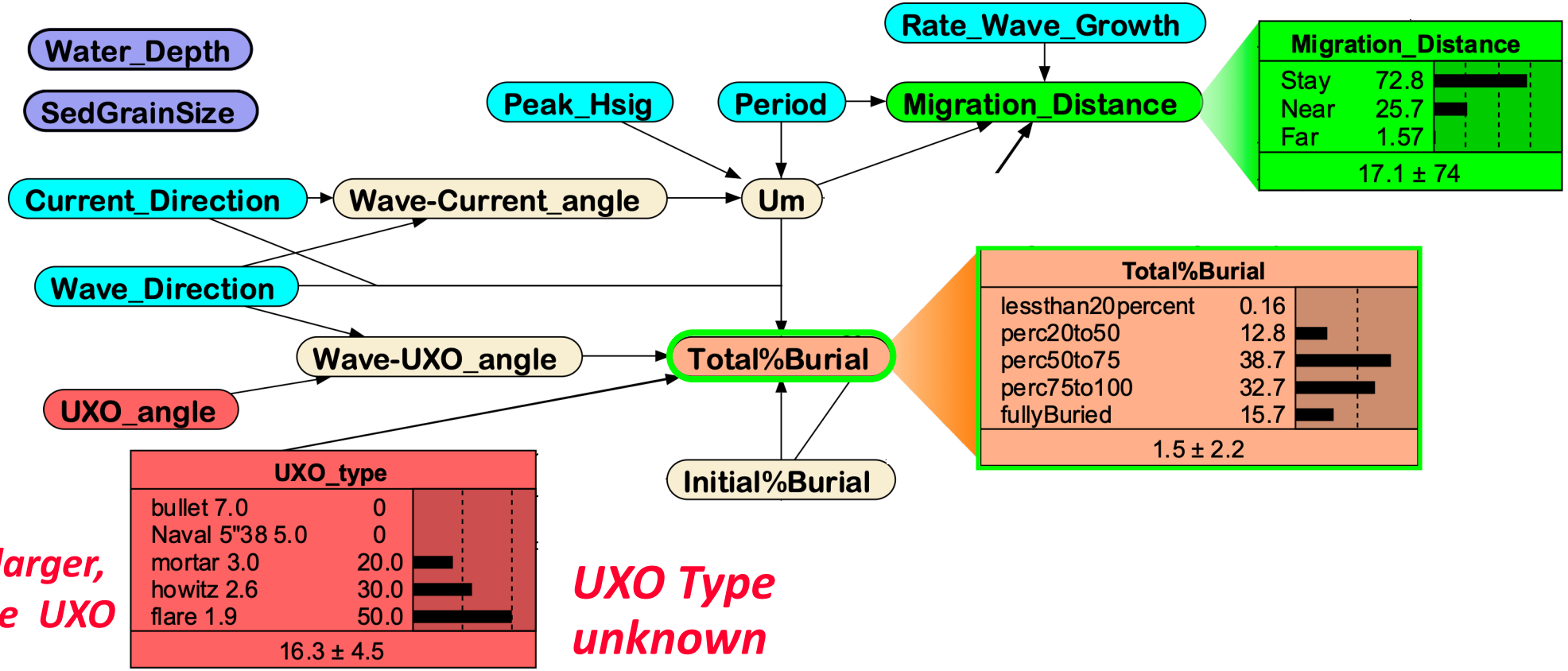
- *Variables (nodes) represented by Probability Distributions*
  - *Probability structure accounts for uncertainty*

UnMES Implementation: Probabilistic Bayesian Network



- ***Relationships quantified by Conditional Probability Tables***
  - ***extreme inputs result in highly certain CPT***

UnMES Implementation: Probabilistic Bayesian Network



a mix of larger, less dense UXO

UXO Type unknown

- ***Uncertain, mixed, or moderate inputs produce uncertain outputs***

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Improved Implemented Process Models for UnMES

Recent Updates to UnMES:

Improved Physics with additional factors:

- **Lagged scour burial**
  - **Rate of Wave Growth**
  - ➢ **fast storm arrival increases migration probability**
- **Liquefaction burial :**
  - **Duration of storm based on wave height**

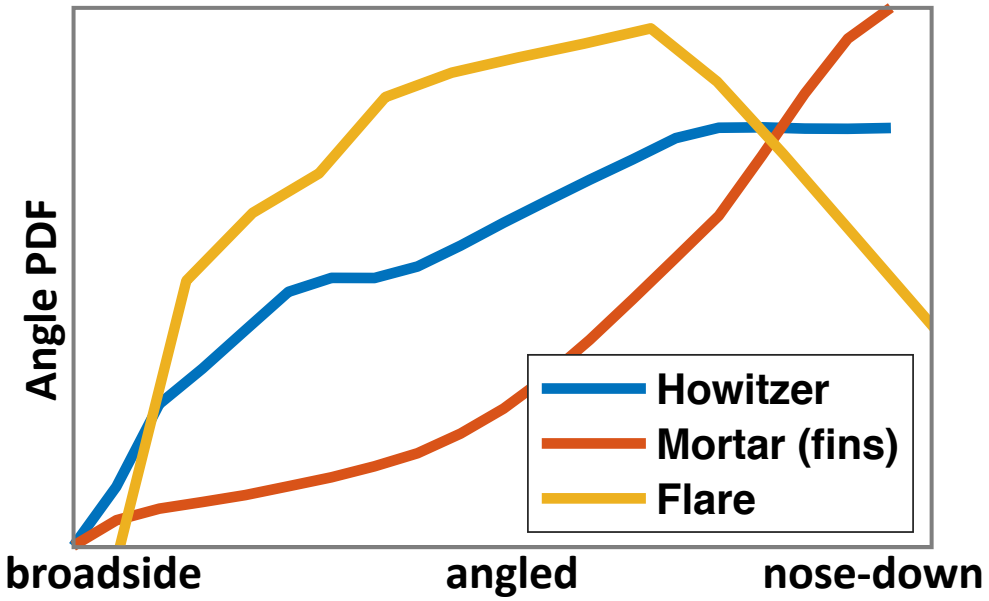
  [Dolan and Davis, 1992]

Implemented:

- **Impact Burial**
- **Burial & Exposure by Dune Migration**

Impact Penetration

- provisional model
- terminal velocity approached exponentially
- drag of coefficient based on Angle of Attack
- assign Angle of Attack thru water trajectory
  - based on empirical PDF



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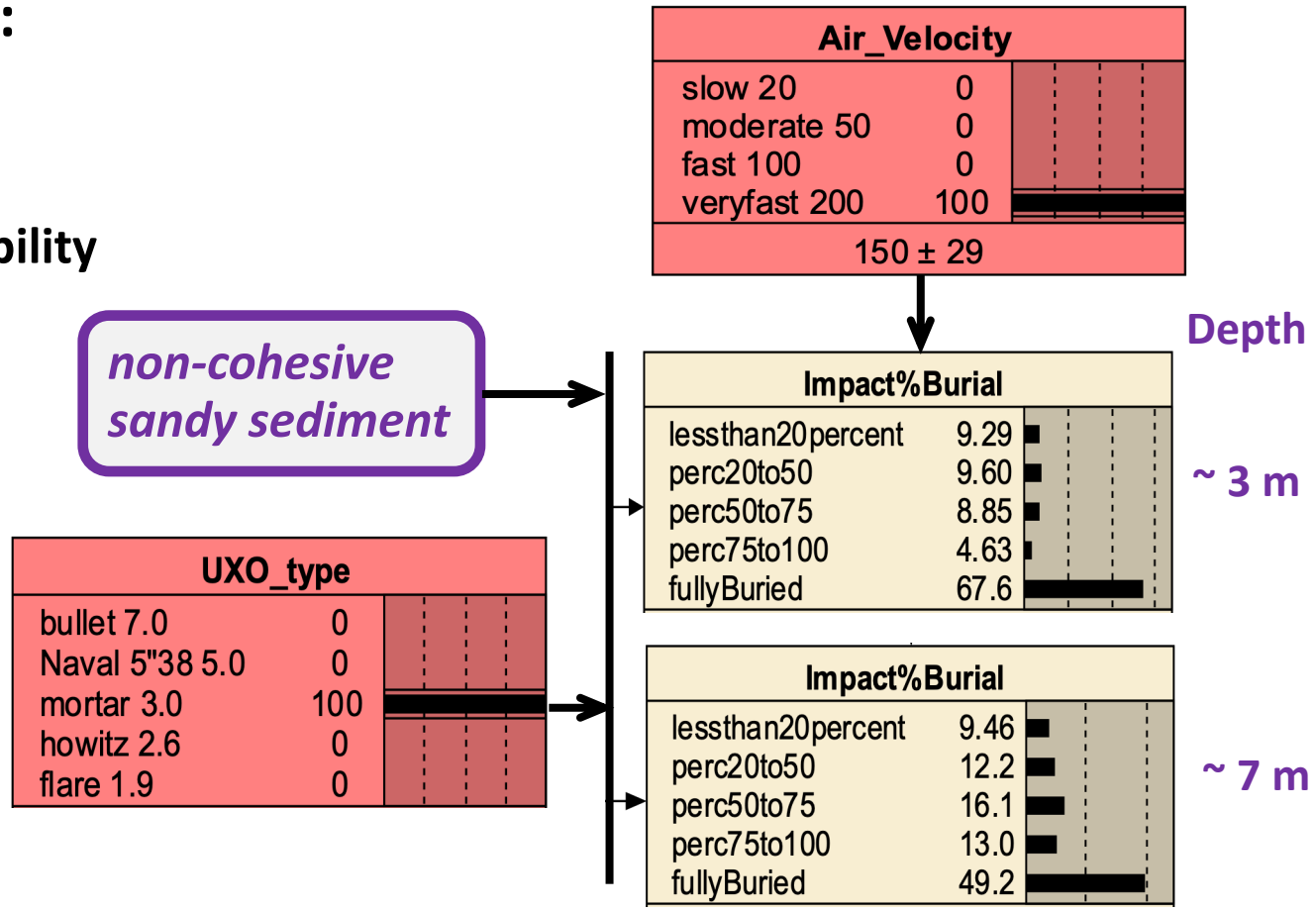

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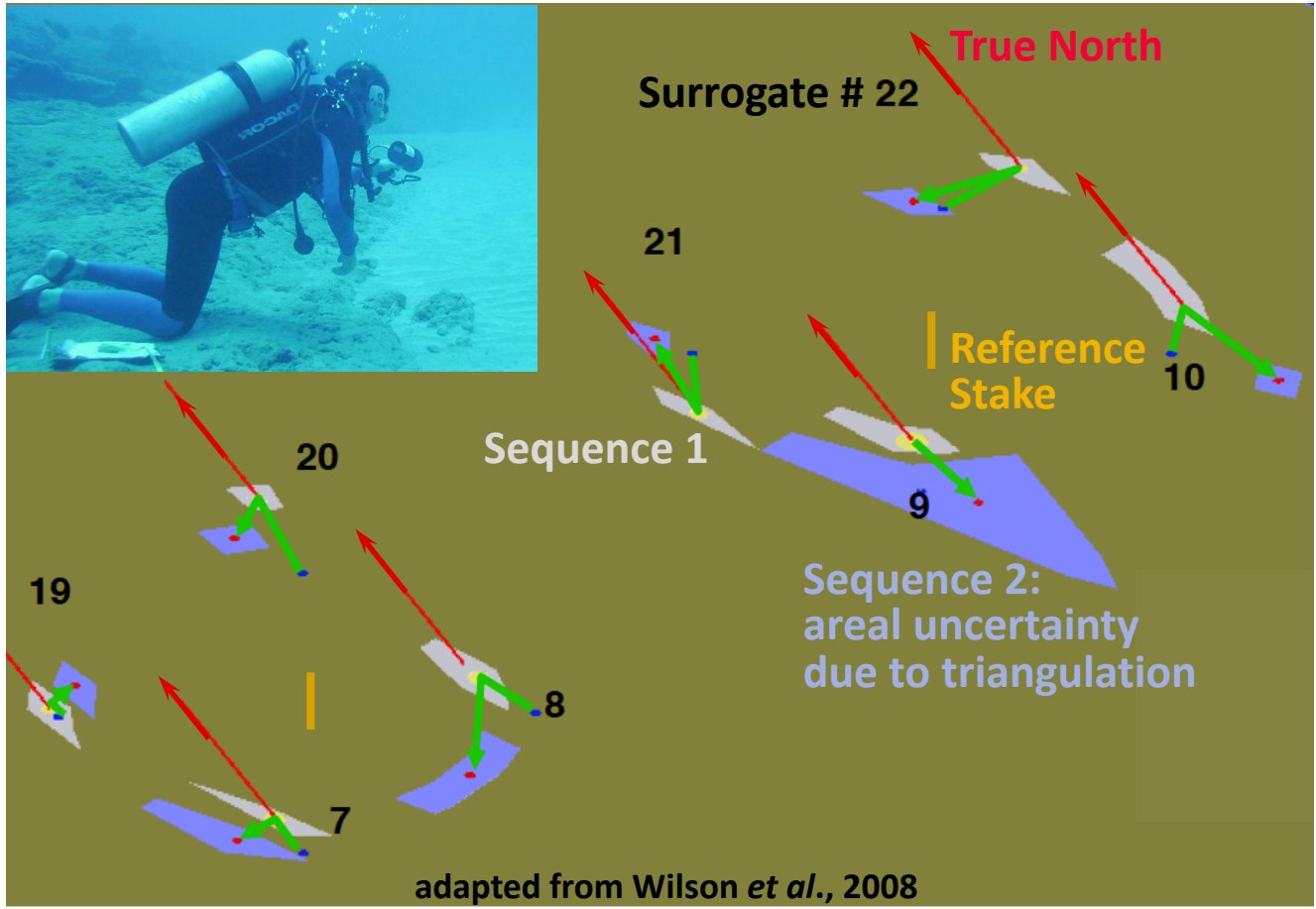
Field Validation of UnMES Predictions

Applying new factors in UnMES for Scour, Liquefaction, and Mobility processes

UnMES predictions compared to SERDP-ESTCP 2005-2006 field test at Duck FRF

[Wilson et al., 2008]

- **4 sequences of 24 surrogate UXO**
- **5”/38 Naval rounds; density $S_g = 5$**
- **2 water depths: $h \cong 3$ m and $h \cong 7$ m**
  - ➢ **diver surveys measure burial & movement**
  - ➢ **small migration distances observed**
    - **(mean distance = 4.6 m)**
  - ➢ **almost complete burial observed**



adapted from Wilson *et al.*, 2008

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Field Validation of UnMES Predictions

Observations

Combined Locations

Observed Burial

lessthan20percent	1.0
perc20to50	0
perc50to75	0
perc75to100	0
fullyBuried	99.0

Observed Migration

Stay	71.0
Near	29.0
Far	0

mean = 4.6 m

UnMES Predictions

Shallow Location

TotalBurial

lessthan20percent	0 +
perc20to50	.002
perc50to75	1.89
perc75to100	12.9
fullyBuried	85.2

MigrationDistance

Stay	100
Near	.003
Far	.003

2.5 ± 1.6

Deeper Location

TotalBurial

lessthan20percent	.011
perc20to50	2.12
perc50to75	8.68
perc75to100	13.0
fullyBuried	76.2

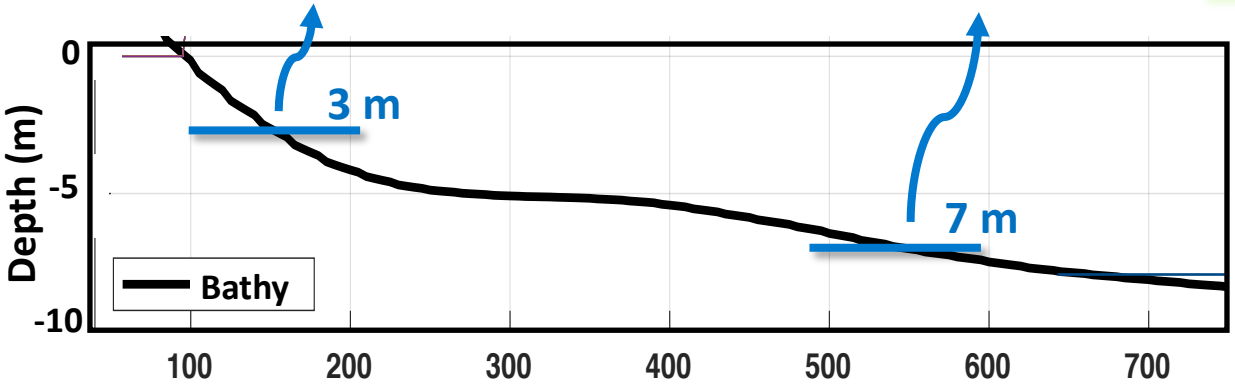
MigrationDistance

Stay	100
Near	.002
Far	.002

2.5 ± 1.5

Migration Distance PDT

Stay	0 – 5 m
Near	5 – 50 m
Far	> 50 meters

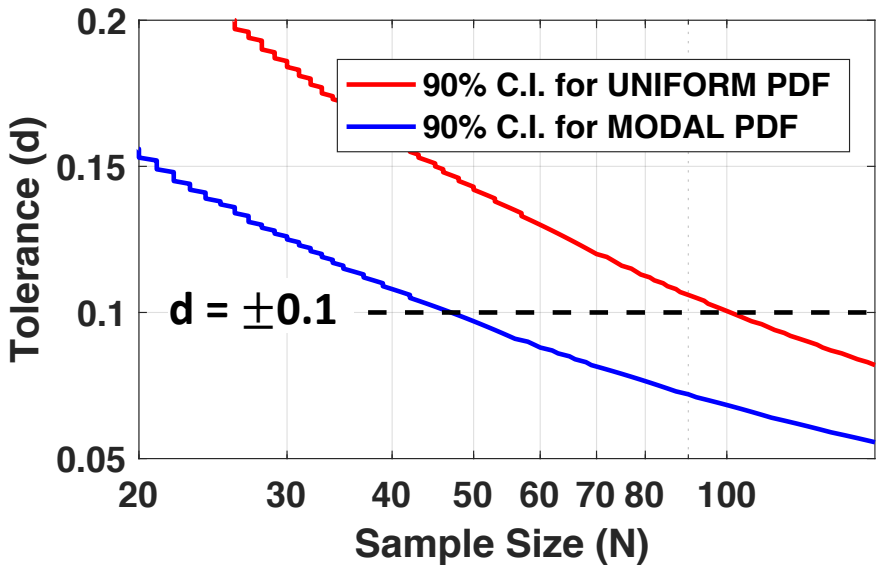


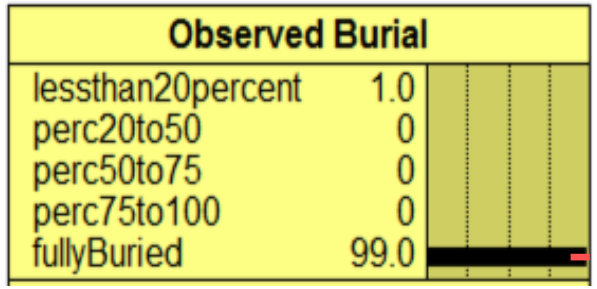
Cross Shore Bathymetry at FRF, Duck NC

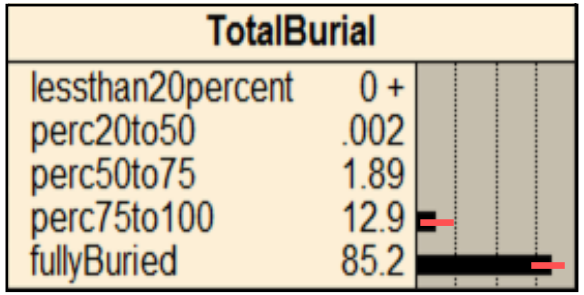
Field Validation of UnMES Predictions

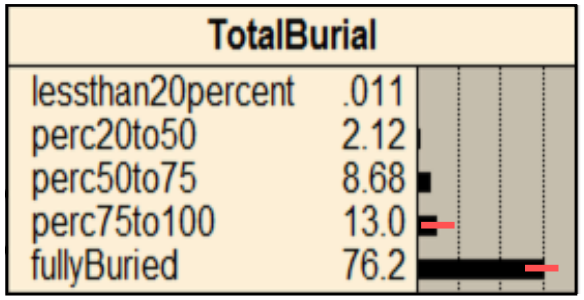
Statistical Accuracy based on <u>Observation Sample Size</u>:
for N = 48, at 90% confidence level a tolerance of d = ±10% is achieved for strongly peaked distributions

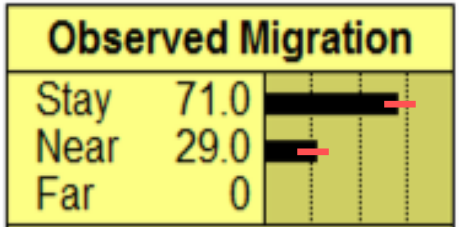
[Thompson, 1987]

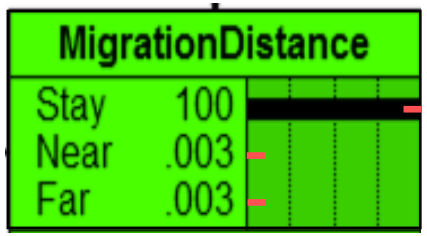


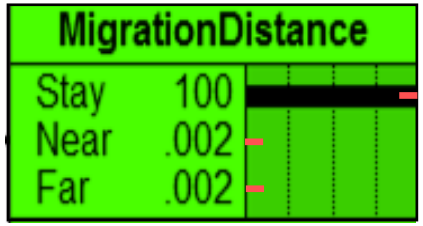












Observations

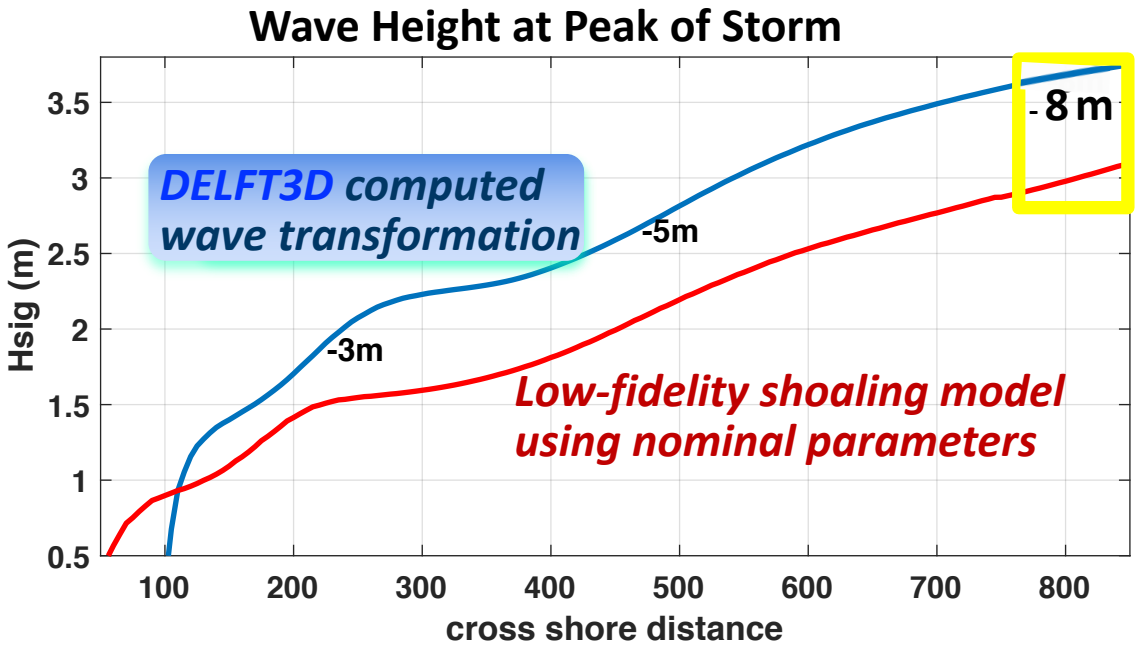
UnMES Predictions

Low *vs* High Investment in UnMES Input

Application Example: Duck15 Field Test (Calantoni, MR-2320)

Complete Burial Observed at Depth = 8m

UnMES UXO Type: Mortar Diam = 81 mm Density S_g = 3



Low Effort: Regional Bathymetry & Offshore Wave Data

Total%Burial	
lessthan20percent	.002
perc20to50	.037
perc50to75	3.26
perc75to100	32.8
fullyBuried	63.9

High Effort : DELFT3D

Total%Burial	
lessthan20percent	.002
perc20to50	.004
perc50to75	0.31
perc75to100	13.0
fullyBuried	86.7

More Burial: better match to DUCK15 observations

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- **Interaction with Site Managers**

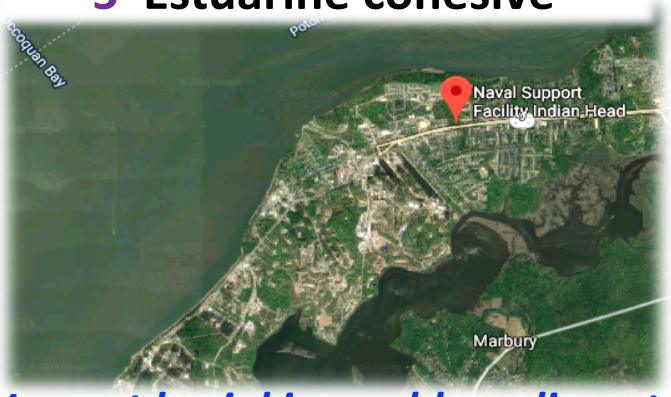
Interaction with Site Managers

- Preliminary questionnaire sent out to NAVFAC and USACE site managers
  - collaboration with Bryan Harre and Andrew Schwartz
    - top stakeholder concerns ; time horizons
    - remedial / monitoring strategies
- ~ dozen respondents
  - various underwater environments – *differing dominant processes*

4 Wave-driven sandy beach

Burial by scour & liquefaction; bathymetry modulation

5 Estuarine cohesive

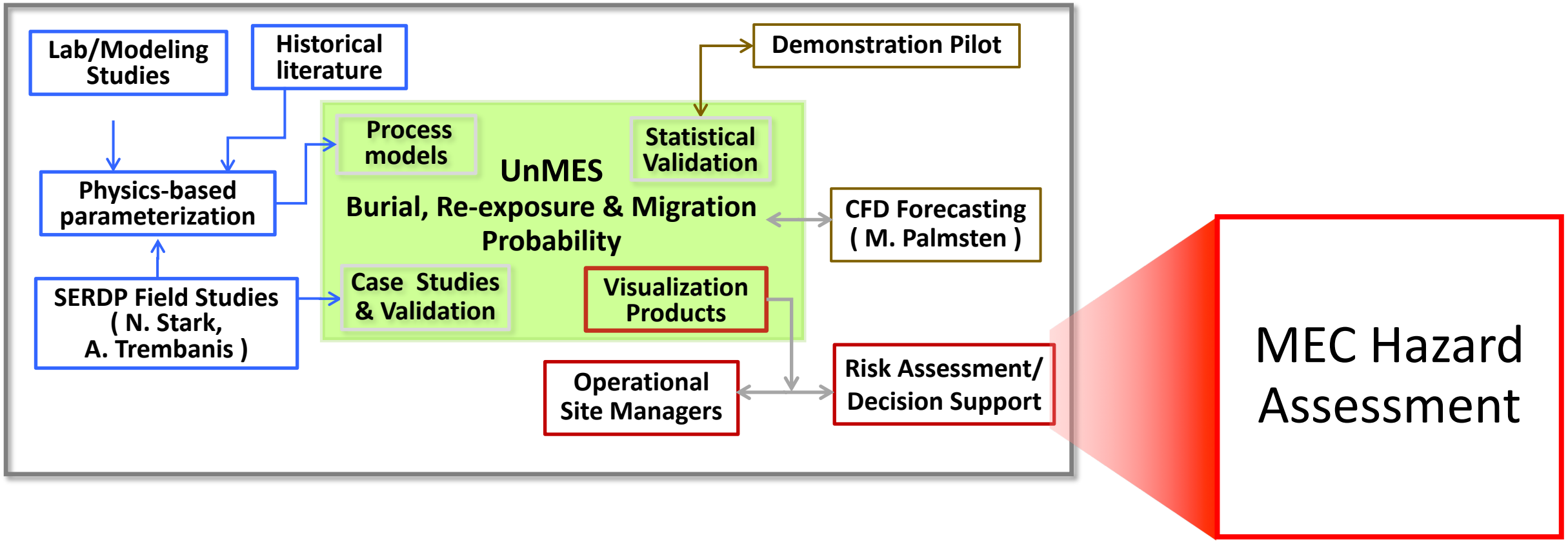


Impact burial in muddy sediments; biogenic changes

2 Wave-driven coral reef

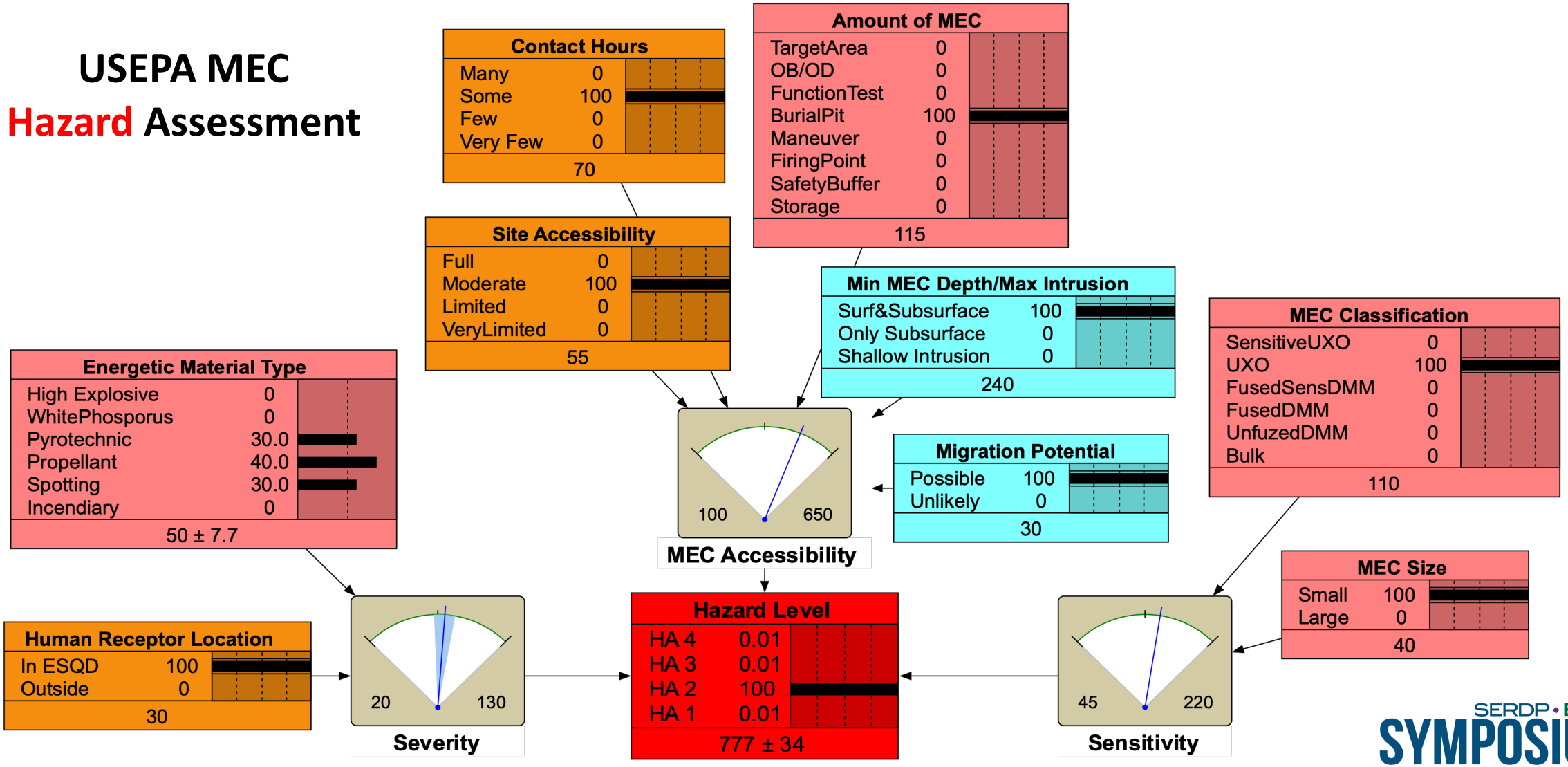
coralline encrustation

UnMES Contribution to Risk Management



UnMES Contribution to Site Management

USEPA MEC Hazard Assessment



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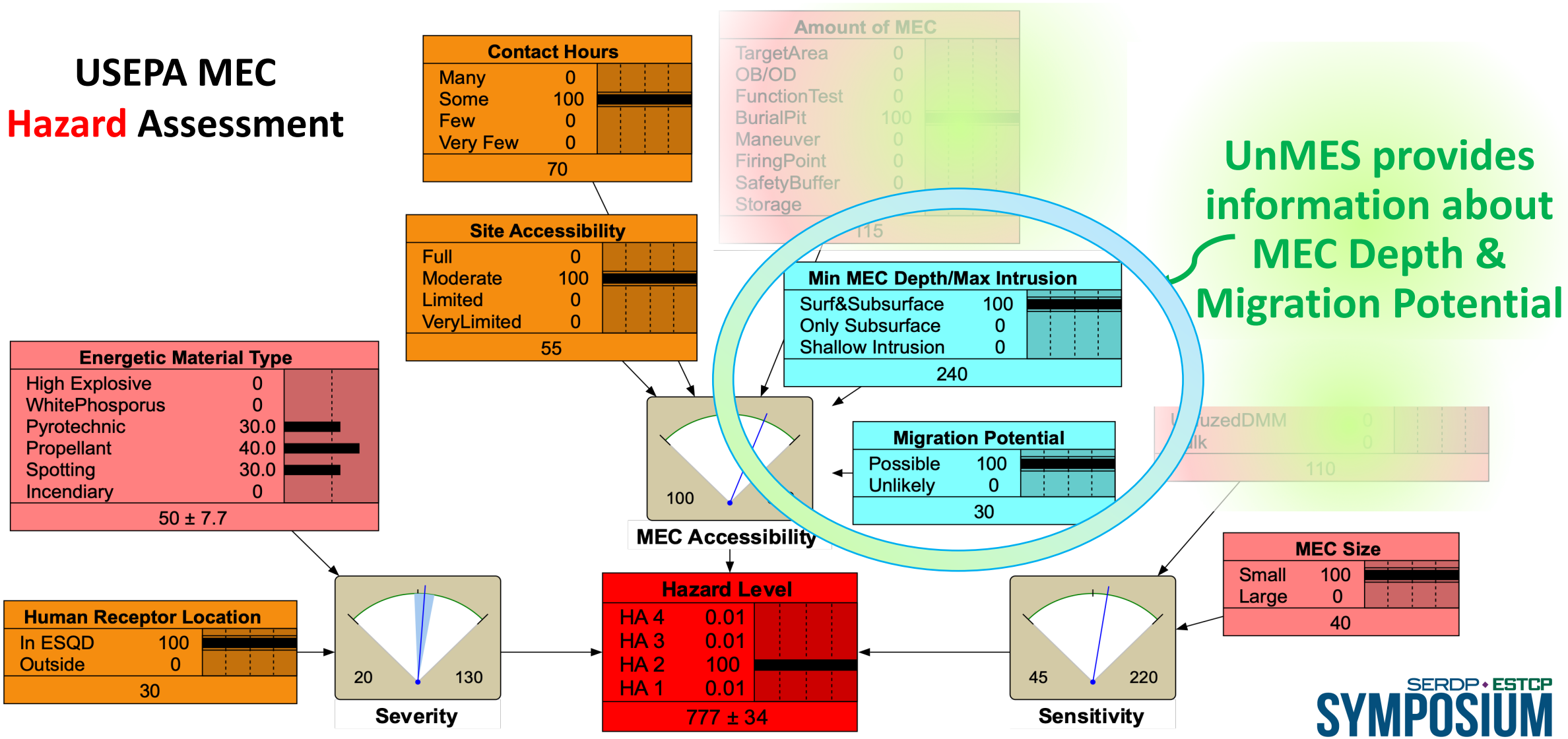
UnMES → MEC Hazard Assessment

USEPA MEC Hazard Assessment



UnMES provides information about MEC Depth & Migration Potential

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UnMES → Cost Analysis

UnMES predictions are only as good as

- the inputs
  - environmental setting and forcings
  - munitions characteristics

  Previous deterministic modeling approach evaluated Low and High Investment inputs:
  - Low required 8 inputs, High required 40
  - Low achieved predictive skill $r^2 < 0.6$
  - High quality input → $r^2 > 0.85$

- the skill of the underlying models

UnMES Sensitivity Analysis

- can indicate which information is most valuable

Total%Burial	Migration_Distance
UXO_type	UXO_type
Peak_Hsig	Peak_Hsig
Wave_UXO_angle	Total%Burial
Current	Rate_Wave_Growth

> 10% variance reduction
1 to 10%
~ 1% variance reduction

UnMES Summary / Future

- Demonstrated probabilistic expert system for burial & mobility
- Validated with SERDP field data

- Future Work
  - Improved and additional process models
  - Statistical design for demonstration experiment
  - Transition to applied decision tool
    - need to collaborate closely with working managers
      - Follow-up questionnaire with phone contact, face-to-face meetings or web conferences.

Questions?