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AUV-Based Structural Acoustic SONARS For Underwater Buried UXO Detection and Classification

MR-201714

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

Presentation Outline

- ❑ Sonar methodology, program objectives and performance goals
- ❑ Demonstration site and establishment of proud / buried target training fields
- ❑ Shakedown exercises and collection of training data
- ❑ Blind target demonstration status
- ❑ Skyfish Video

Background

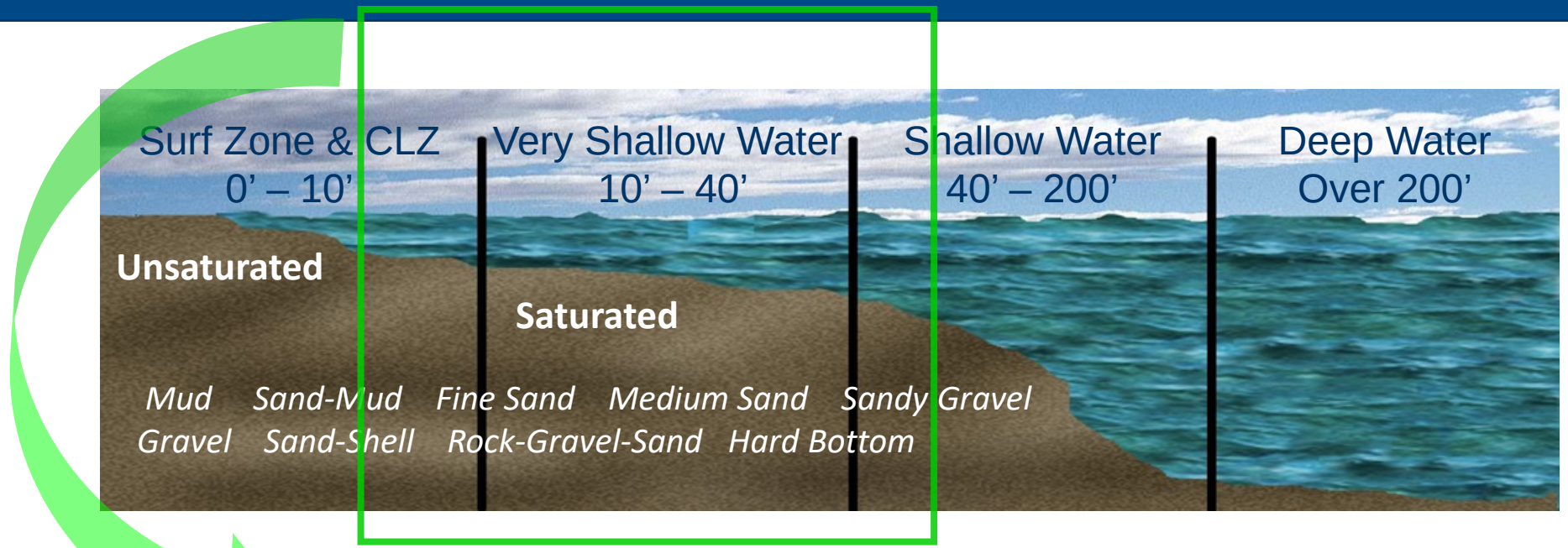
Many military installations have adjacent water environments with UXO (from wartime activities, dumping, & accidents) requiring cleanup.

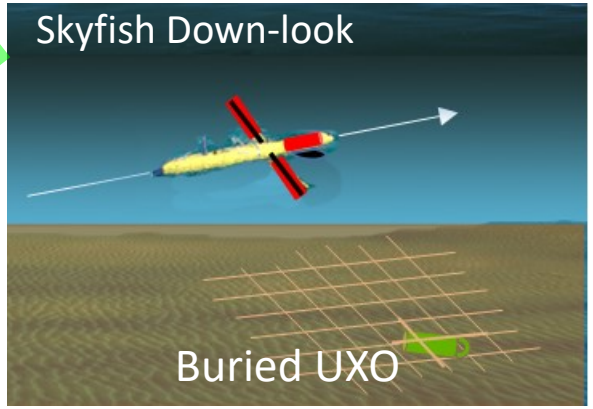
SERDP/ESTCP goals require technologies able to detect/classify proud and buried UXO with

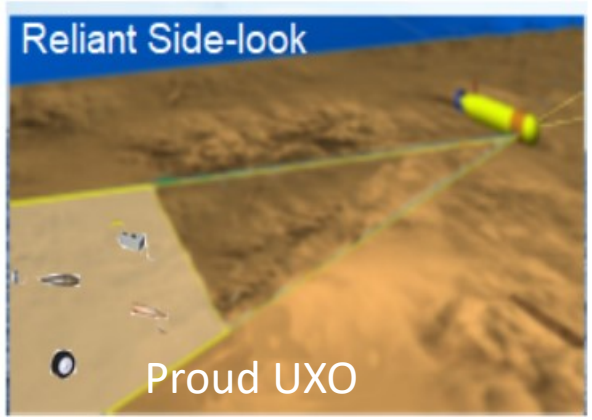
- ✓ high $P_{D,C}$
- ✓ low P_{FA}
- ✓ moderate to high coverage rates

Can this technology meet these goals?

Environment / Technology Focus





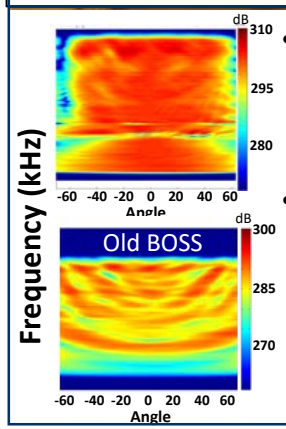


ESTCP Demonstration: *Two interchangeable AUV- based SA sonars scanning blind target fields outside Boston Harbor*

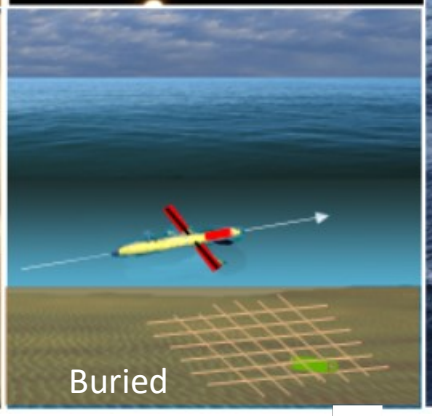
New Skyfish Down-Look SA Sonar

Buried and proud targets

- 32 – low-noise piezo-ceramic receivers per retractable wing
- 3.75cm spacing pushing Nyquist frequency to 20kHz @ 2kn

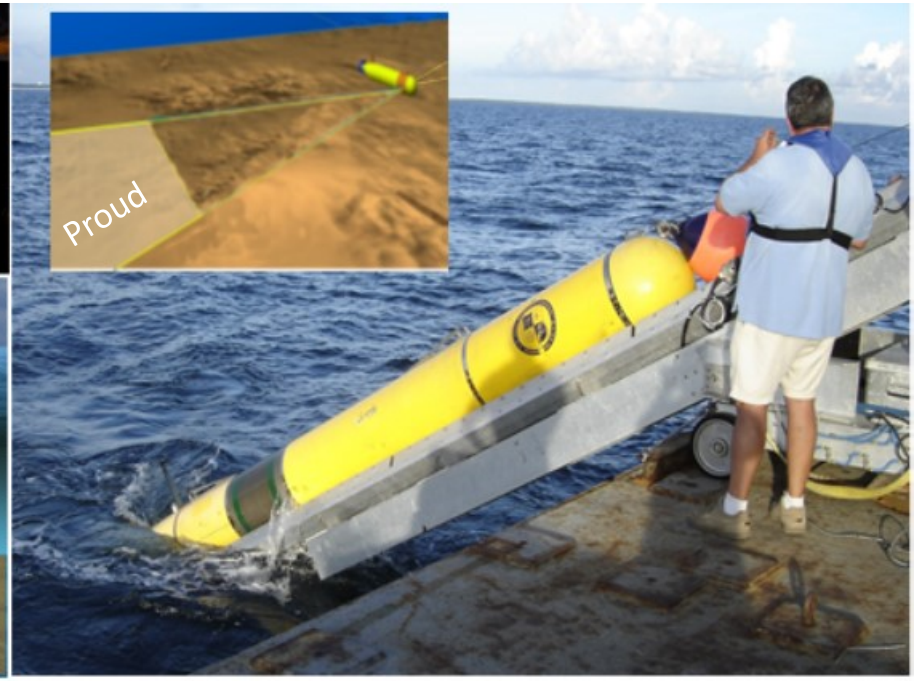


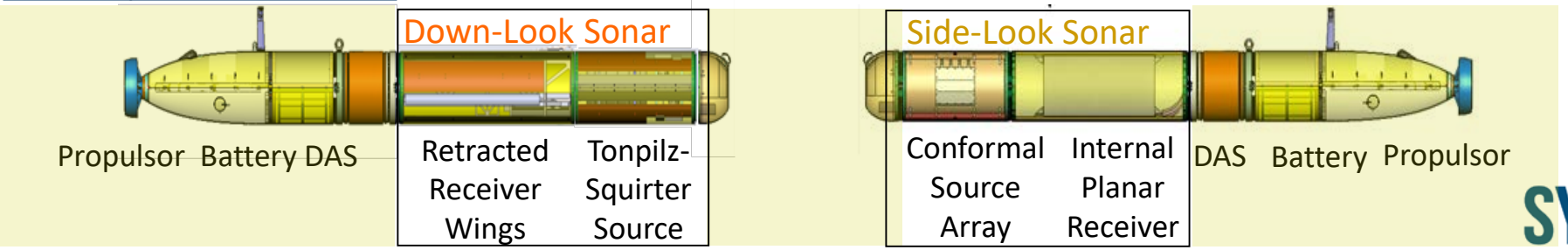
- Stronger source for deeper burial
- More uniform spatial/ spectral source response



Existing NRL Side-Look SA Sonar

High coverage rate on proud targets





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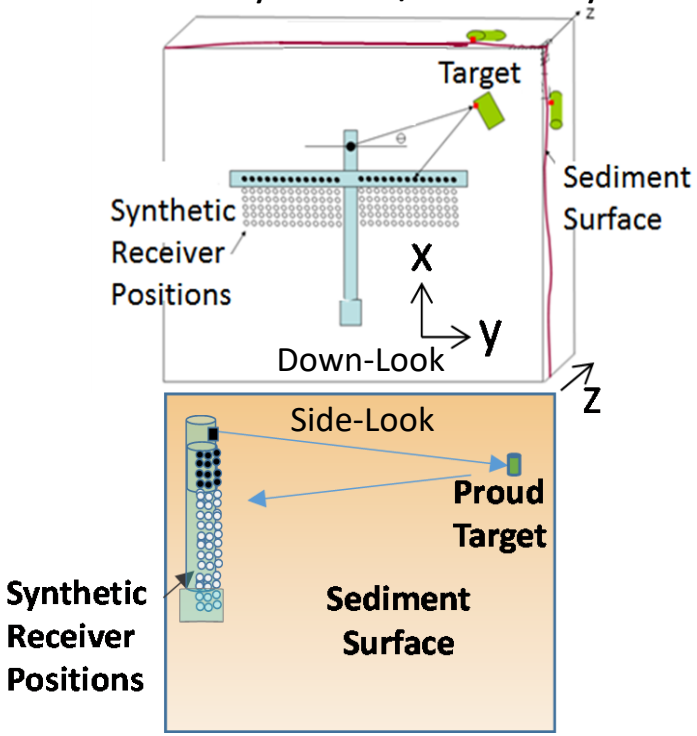
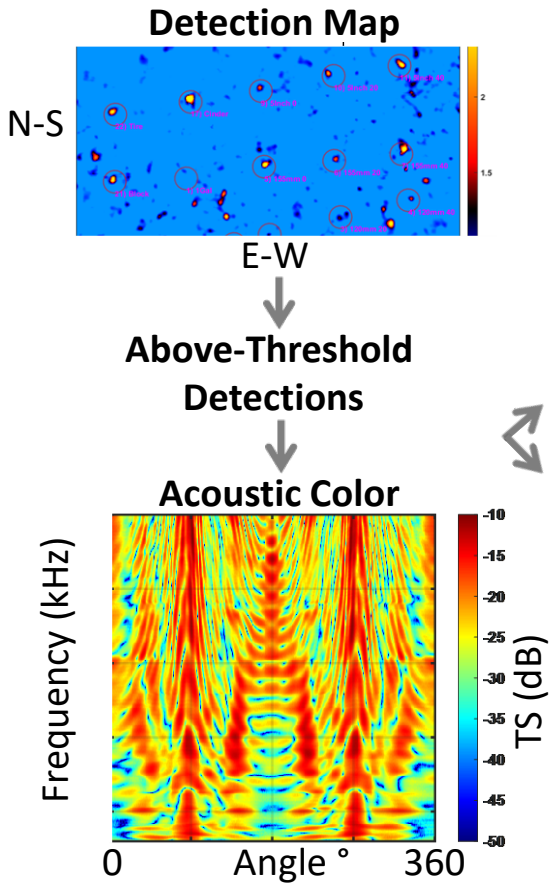
Overall Schematic of the Methodology

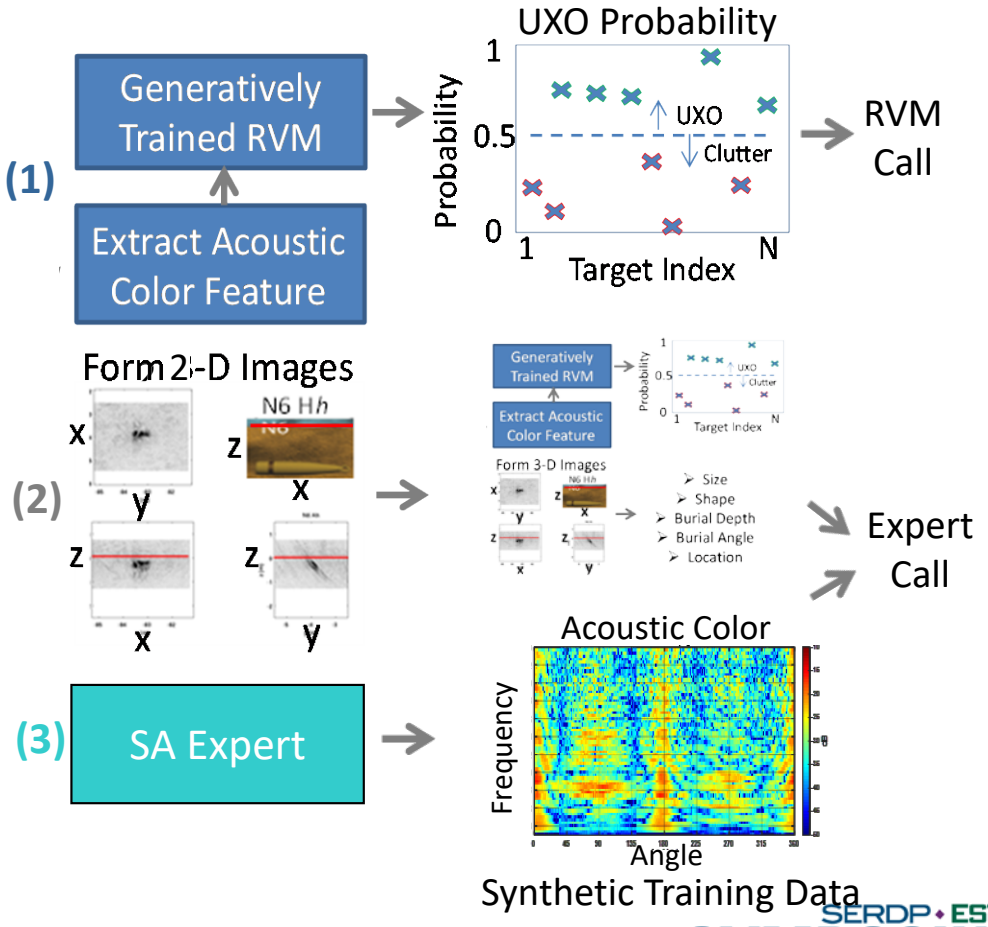
At Contaminated Site

Collecting Data Scattered from the Sediment Bottom with Synthetic/Real Array



Off-Line





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ESTCP Demonstration Program Objectives

Objective: to demonstrate this technology in a “blind test” in a shallow water region which can act as a surrogate for locations in which the DoD holds environmental responsibility.

Performance Goals:

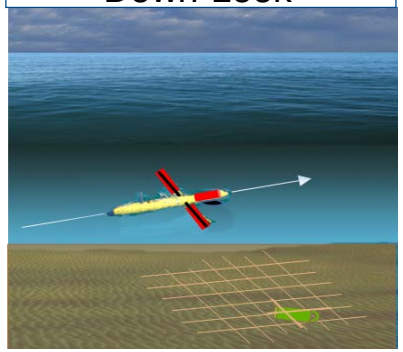
(1) *Buried UXO:*

$P_D = 1$, $P_C \geq 0.9$, $P_{FA} \leq 0.25$

$\Delta N, \Delta E \leq 0.5m$

Coverage Rate 10 acres/hr

Down-Look



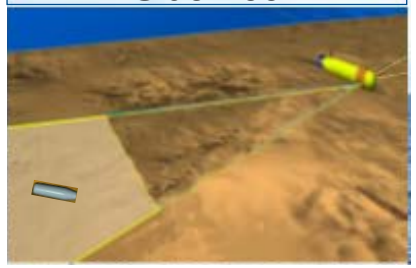
(2) *Proud UXO:*

$P_D = 1$, $P_C \geq 0.9$, $P_{FA} \leq 0.25$

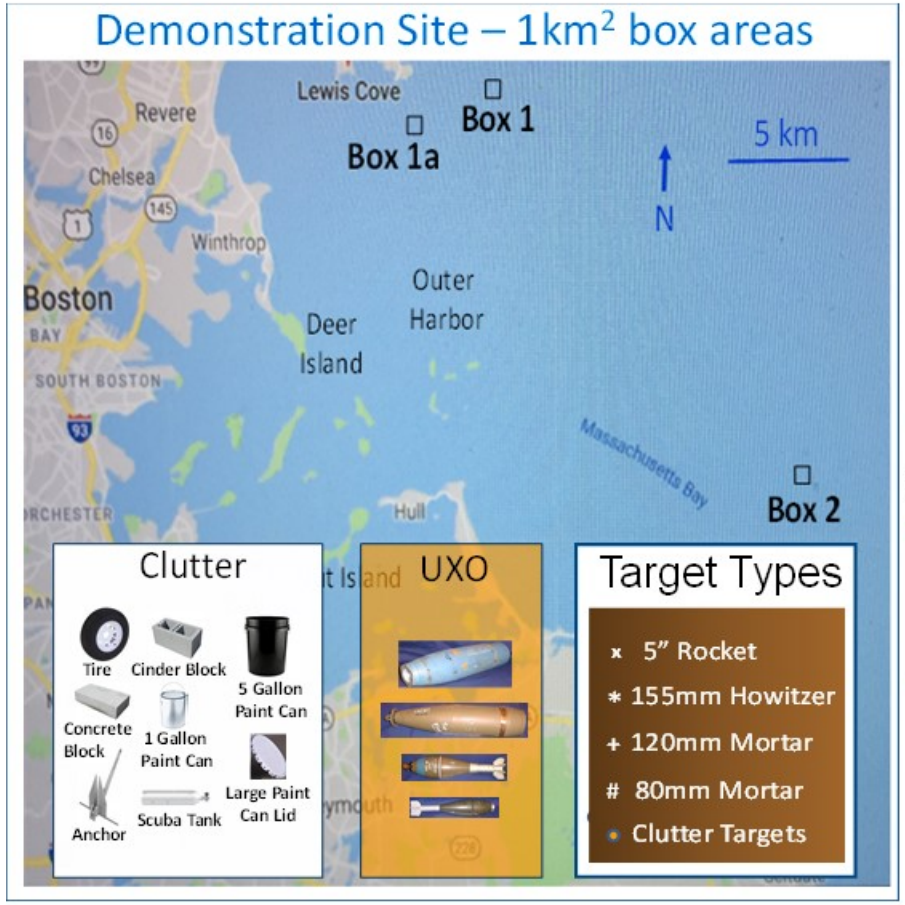
$\Delta N, \Delta E \leq 0.5m$

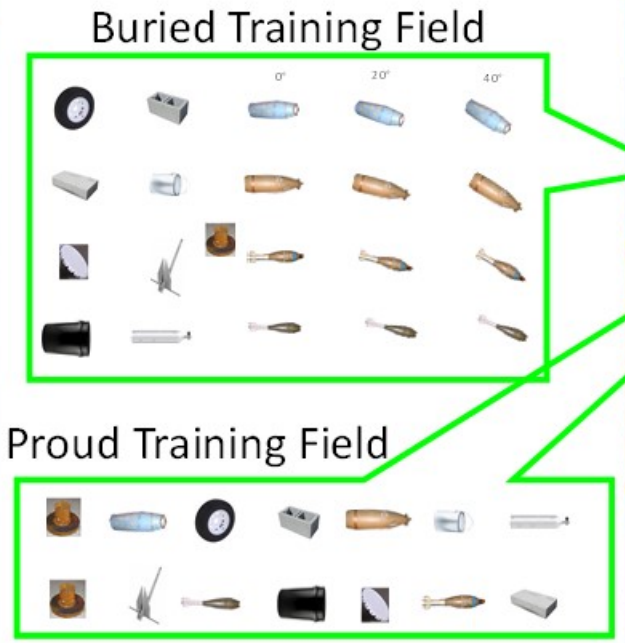
Coverage Rate 130 acres/hr

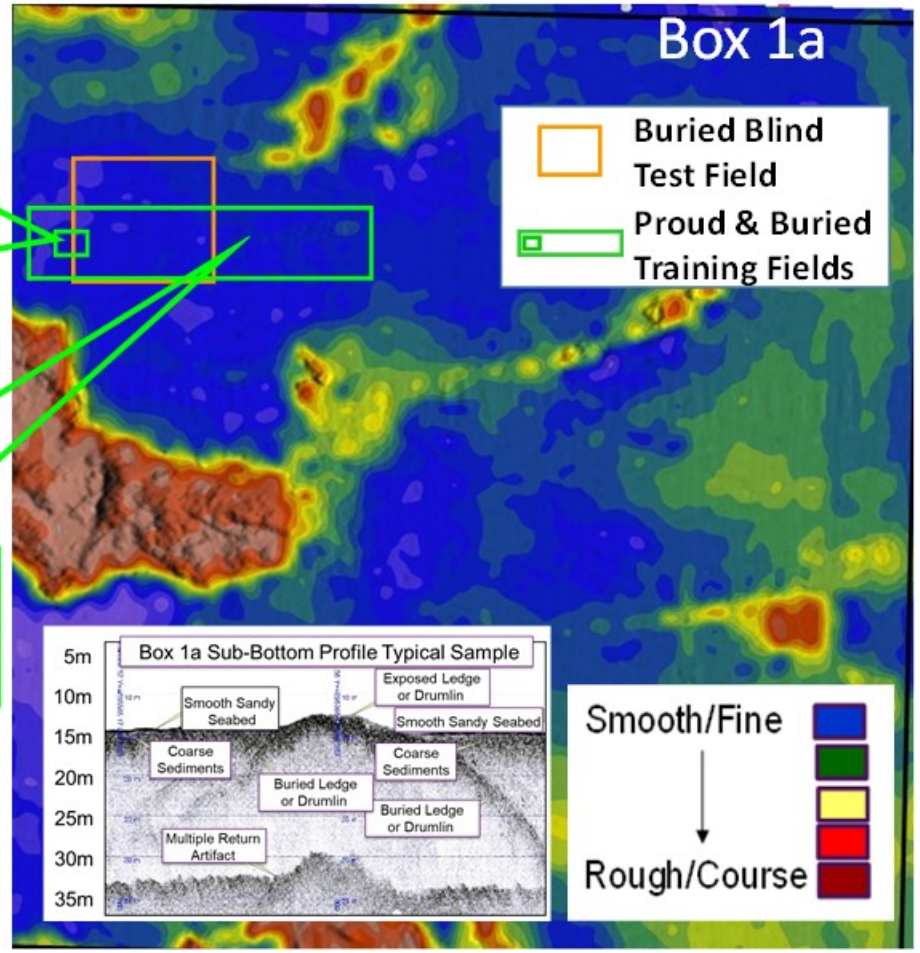
Side-Look



Demonstration Site: *1 km² areas in the Approaches to Boston Harbor*







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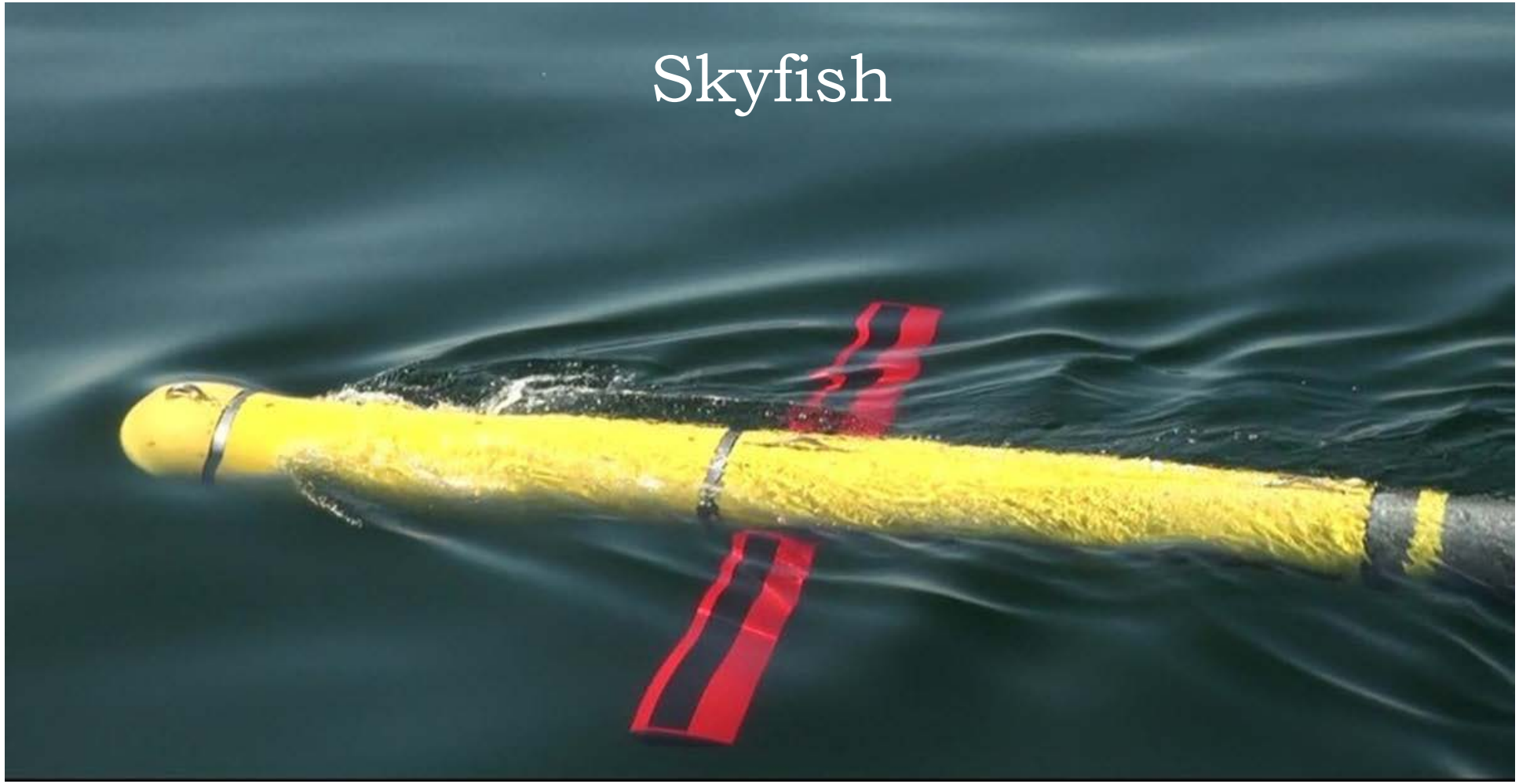
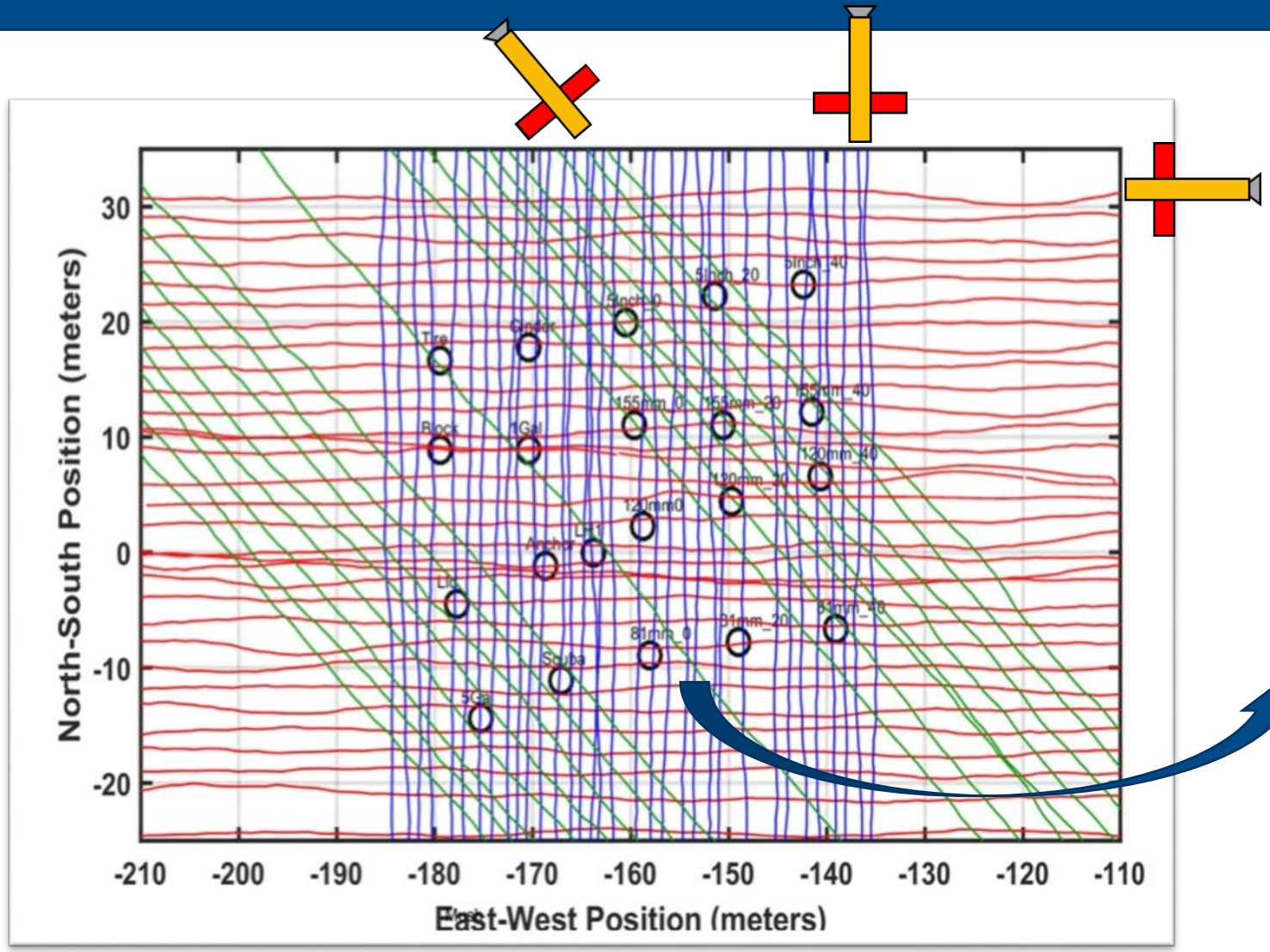
Buried Target Demonstration Status

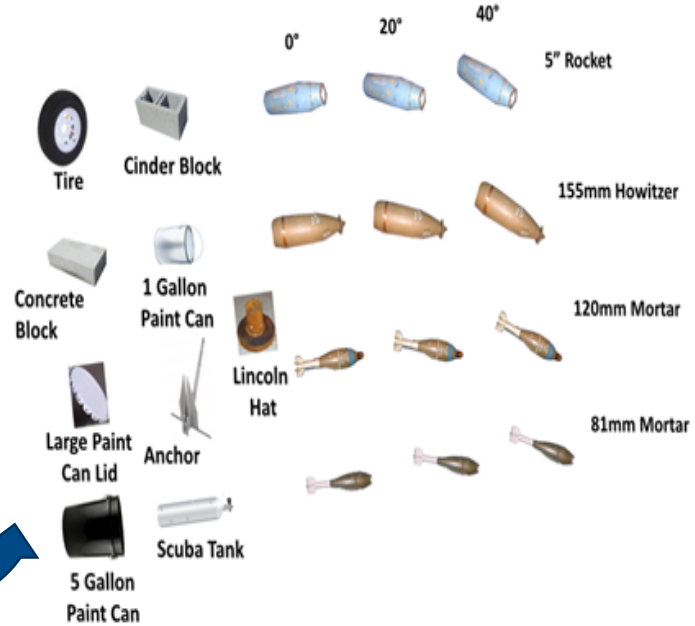


Down-look Training Data Collected over Buried Target Field in Box 1A

x.y positions during E/W, N/S, & diagonal flight paths

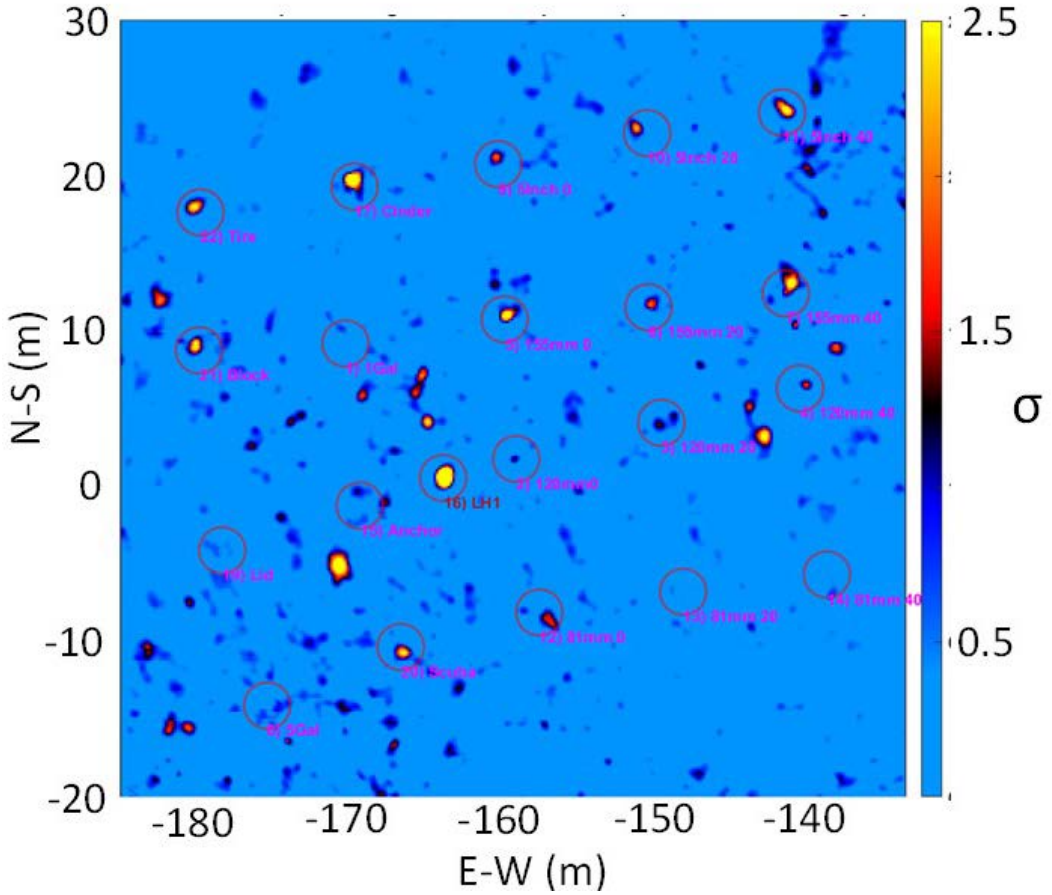


Buried Target Field

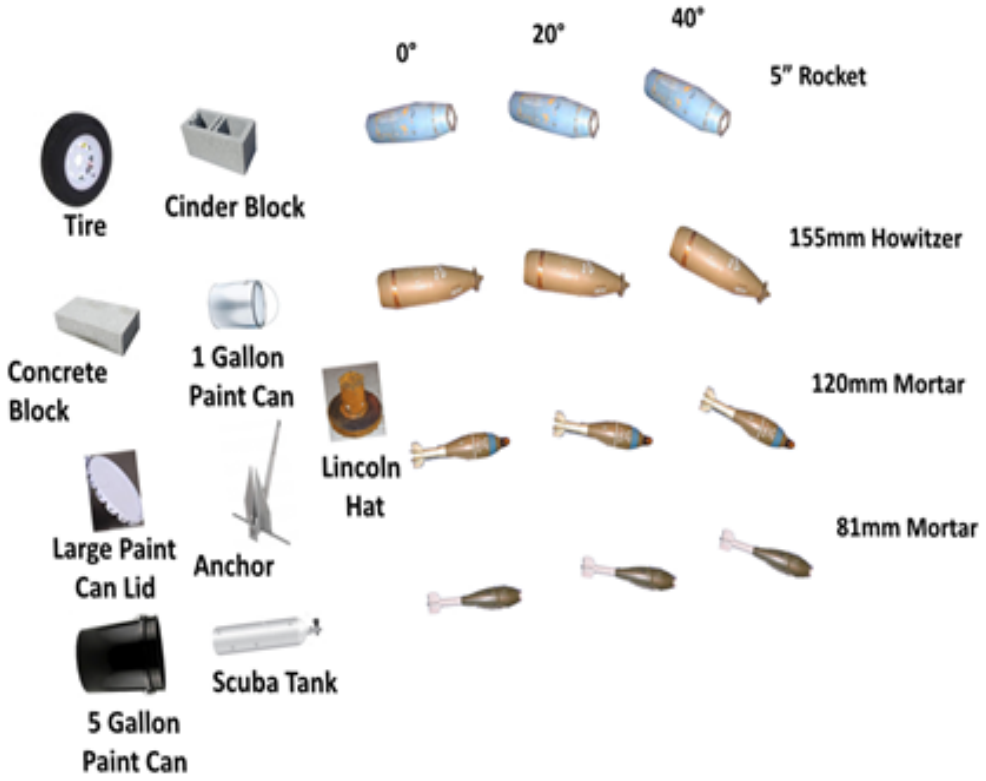


Multi-Line Composite Detection Map over Buried Target Training Field

Forty Line Composite Detection Map



Buried Target Field



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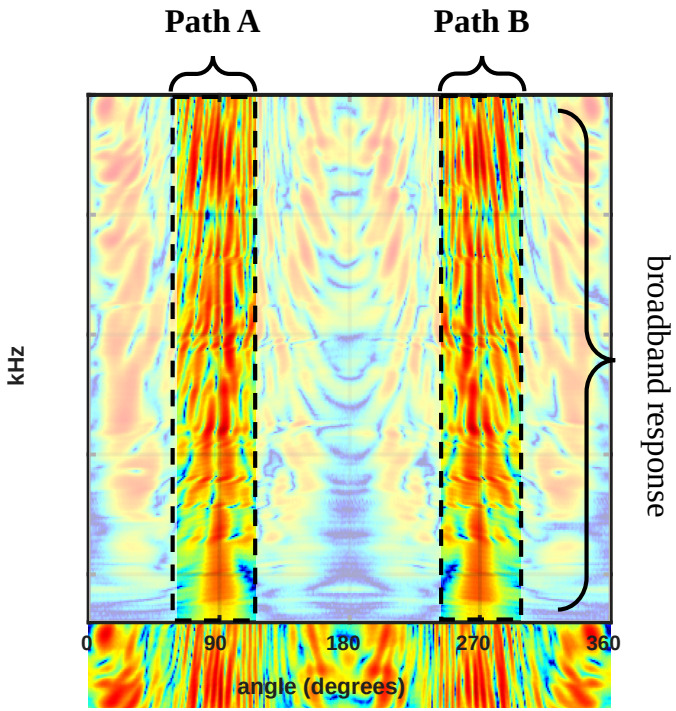
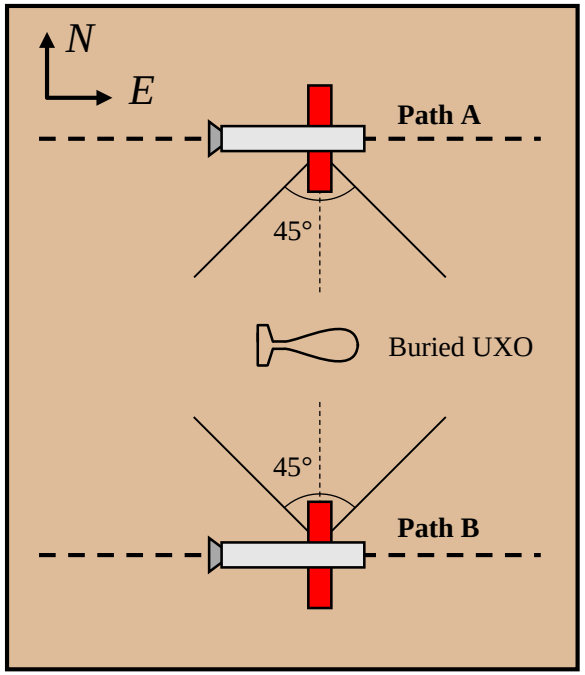
TS Extraction for Beam Aspect

- **Beam aspect response important for classification**
  - large dBs across broadband frequencies (easily detectable)
  - exploit symmetry to discriminate cylindrical targets from asymmetric clutter

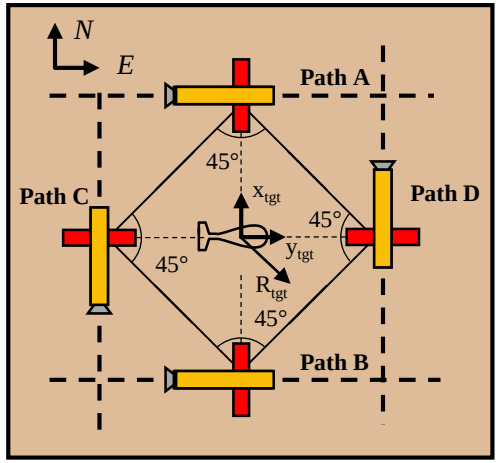
Extracting beam aspect TS from horizontally buried UXOs using two parallel flight paths

free-field response for 120 mm mortar



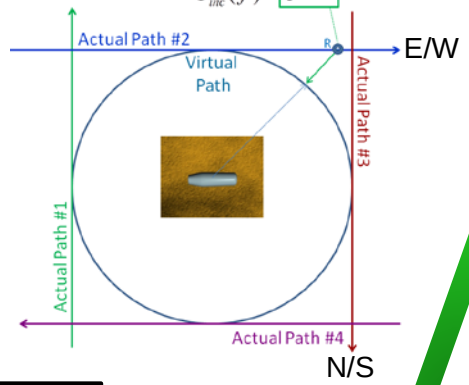


Composite 360 Degree TS Map: 155mm Shell

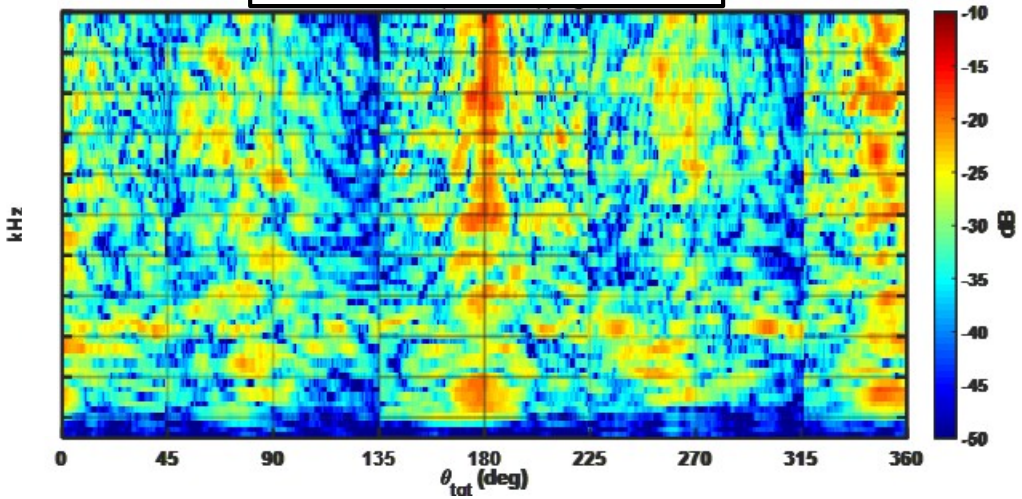


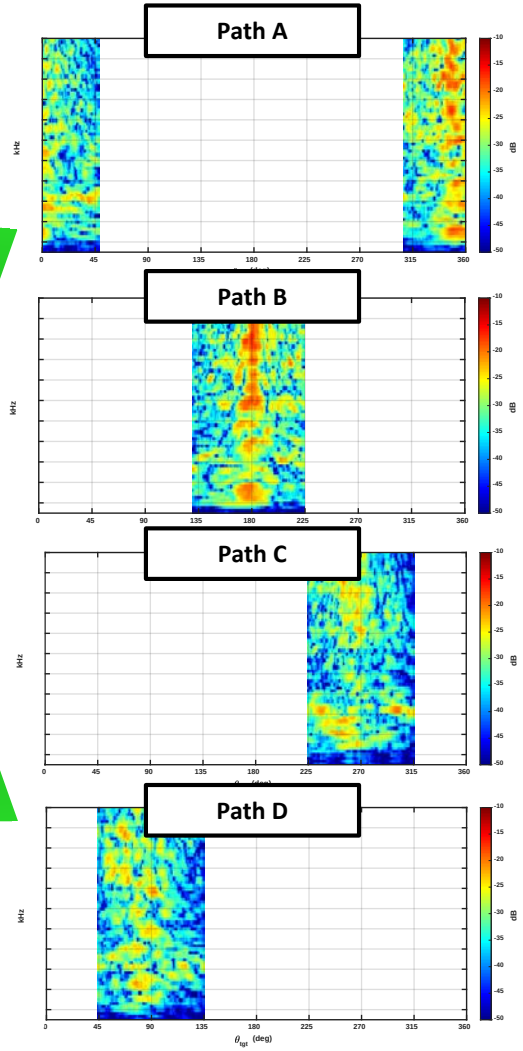
Synthesizing circular path

$$X(f,\theta) = \frac{P_{scat}(f,\theta)}{P_{inc}(f)} \frac{r_{scat}}{e^{ikr_{scat}}}$$



Composite TS 155mm shell





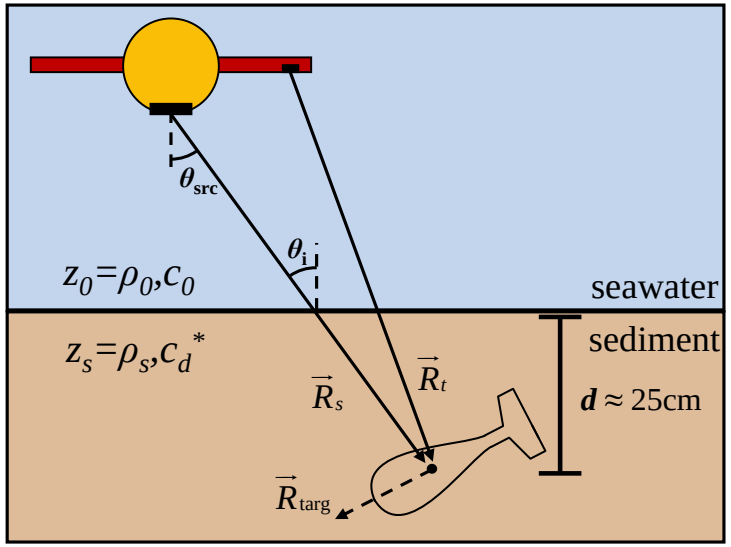
Environmentally Realistic Synthetic Echo Generator

Scattered Echo Spectrum

$$P_s(\omega) = D(\omega,\theta_{\text{src}})T(z_0 \mid z_s)T(z_s \mid z_0)e^{2\gamma_{imag}d}\frac{e^{ik(R_s+R_r)}}{R_s R_r}P_{\text{targ}}(\omega,\theta_{\text{targ}})$$

Echo time response for each ping and receiver

$$p_t(t) = p_s(t) + p_{reverb}(t)$$



I) Free-Field Target Scattering (Pool)

$$P_{\text{targ}}(\omega,\theta_{\text{targ}})$$

II) Source Directivity (Pool Calibration)

$$D(\omega,\theta_{\text{src}})$$

III) First-Order Sediment Coupling

- both into and out of sediment

$$T(z_0 \mid z_s)T(z_s \mid z_0)e^{2\gamma_{imag}d}$$

IV) Beamforming Delay and Spreading

$$e^{ik(R_s+R_r)} / R_s R_r$$

V) Reverb Noise Profile (Boston Harbor)

$$p_{reverb}(t)$$

- Average $p_t(t)$ from each receiver over many pings - removes targets, clutter, etc. and extracts line-specific Green's Function for $p_{reverb}(t)$
- Convolve with bandlimited white noise to generate unique profile for each ping and receiver

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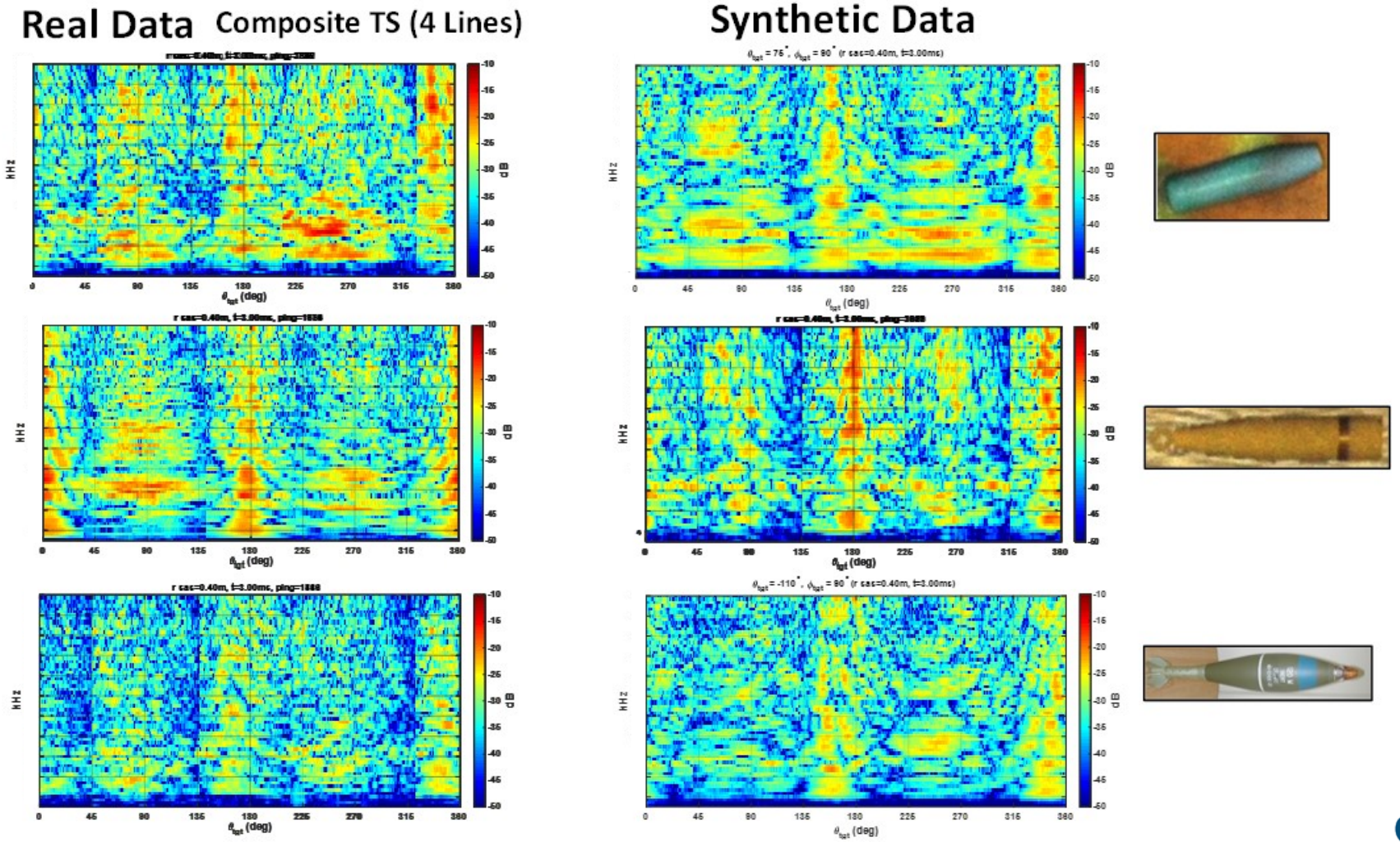
Synthetic / Real Data Comparison



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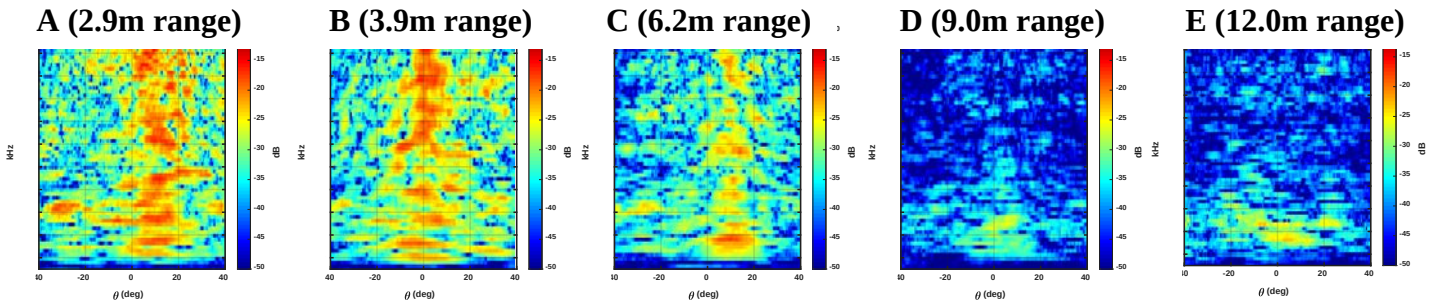
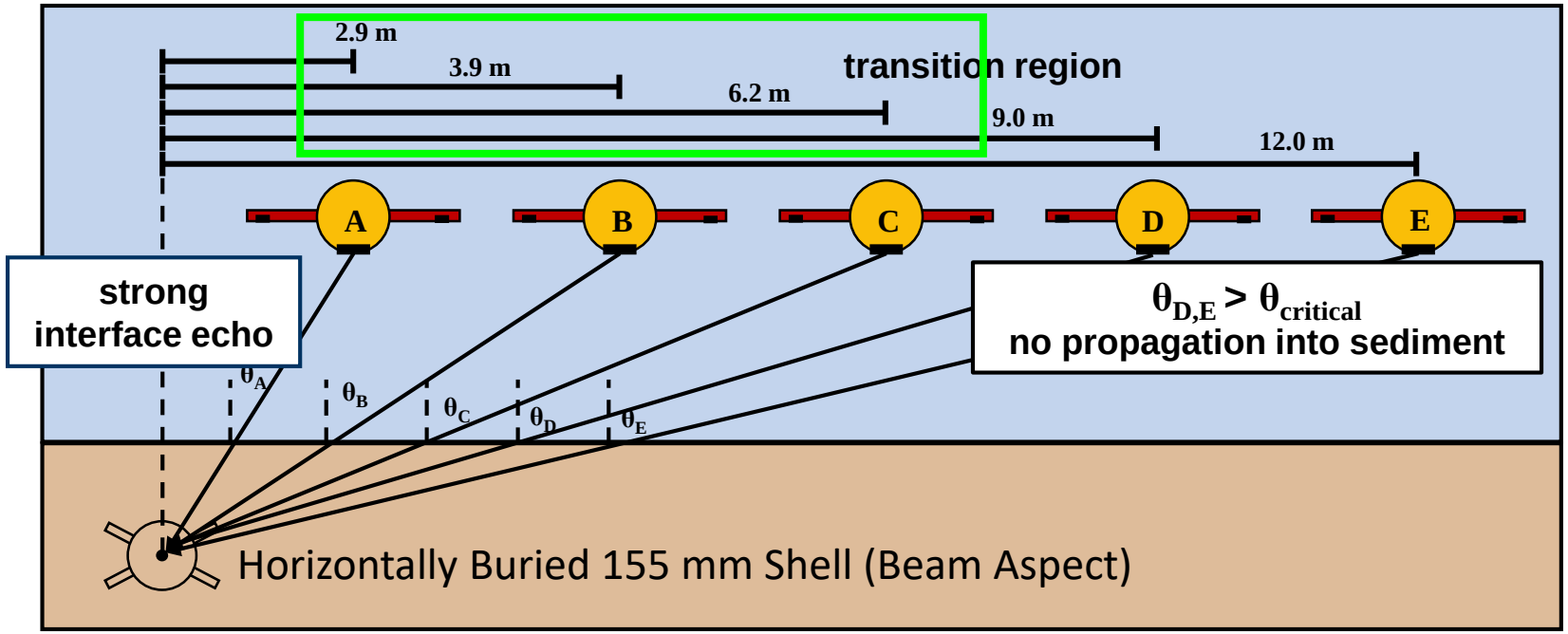
TS Range Dependence for Buried Target
- Finding the "Sweet Spot" -

Sweet spot for buried UXO @ 4m altitude





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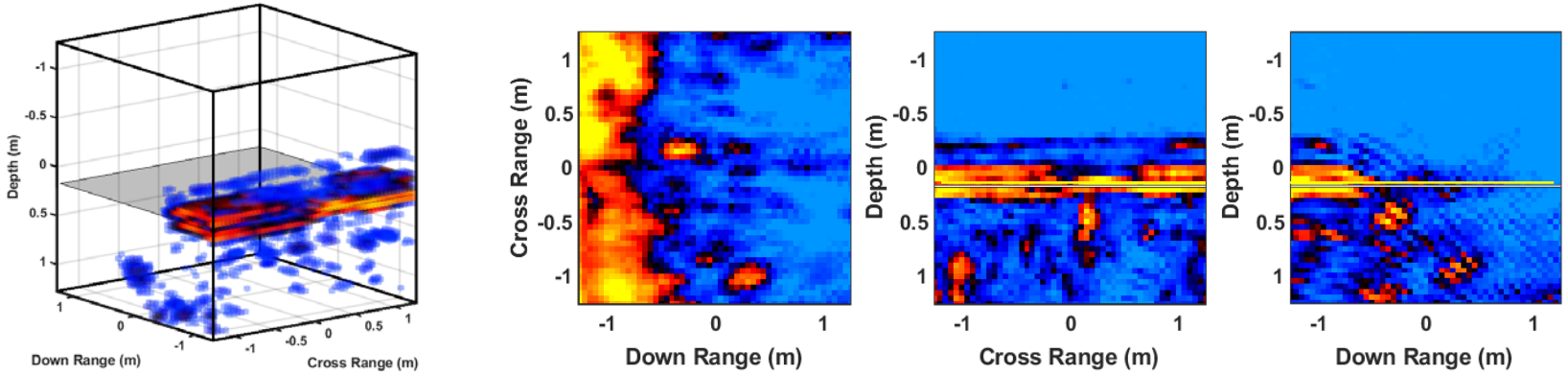
Element Level Filtering
Results: Three 2D Images of Buried Target

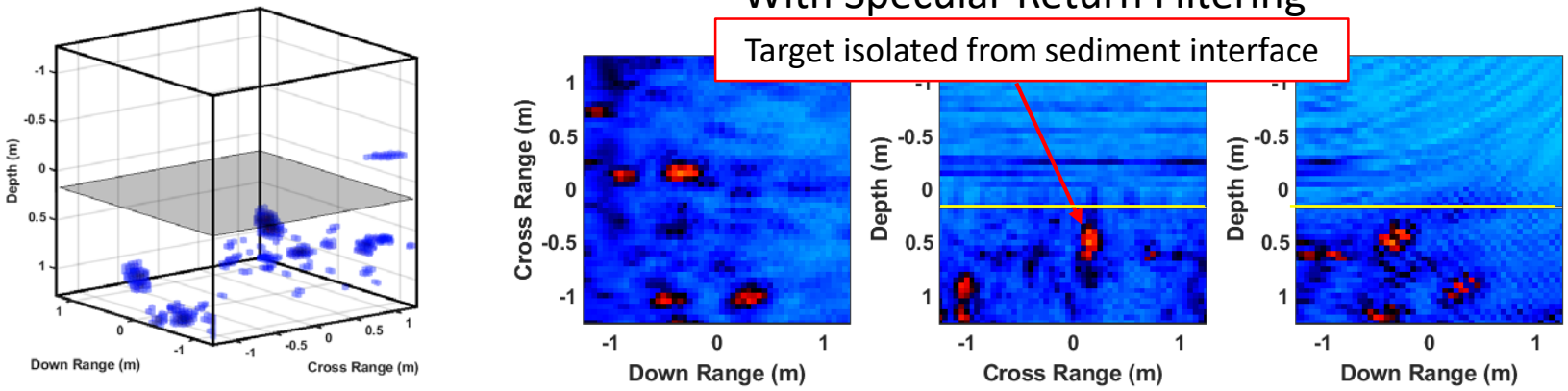
5 inch Buried Rocket

Unfiltered



With Specular Return Filtering

Target isolated from sediment interface



More Detailed Skyfish Detection / RVM Classification

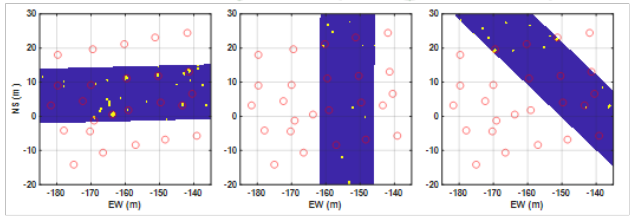
Acoustic Data
Signal Processing

Generate 2D single line detection surfaces

Re-navigate using monuments accuracy

~ 2m to < 1m accuracy

Local Objects (Single-Pass)



Single Pass Classification

Generate binary detection display & local objects

~ 4000 local objects

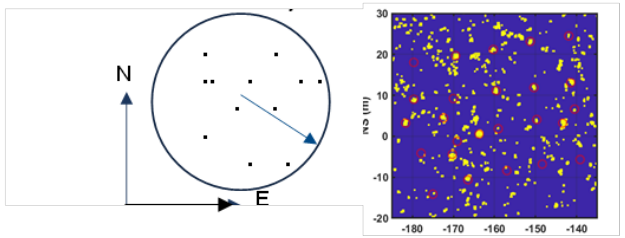
Extract TS for each local object

Apply single-pass thresholds

Extract single-pass local object feature vectors

Feed feature vectors into RVM & produce call list

Global Objects (Multi-Pass)



~ 10 local objects → 1 global object

Generate 2D composite detection surface

Generate binary composite detection display & global objects

Multi-Pass Classification

Map local objects to global objects

~ 200 global objects

Apply multi/single pass thresholds (proud object, etc.)

Extract multi/single pass features for each global object using local object TS

Feed feature Vectors into RVM & produce call list

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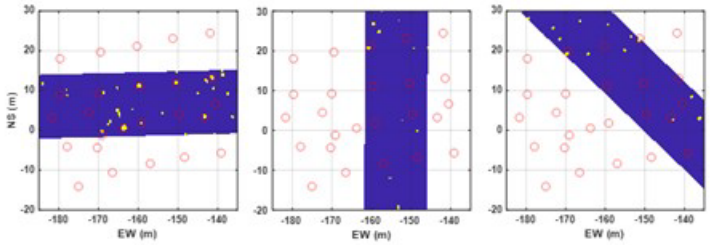
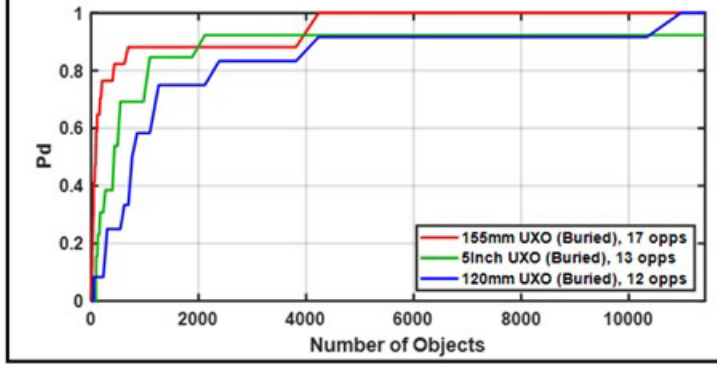
P_D ROC Curves for Buried UXOs

Single Pass Approach

- classical approach for sidelook
- 86 lines x ~25 objs/line = **2000-3000 objects**
- multiple opportunities per target
- only single pass features

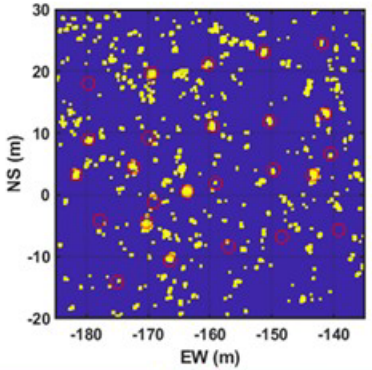


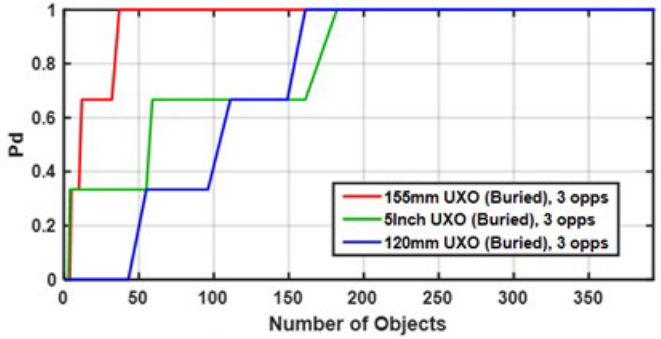


compile using max at each grid point

Multi Pass Approach

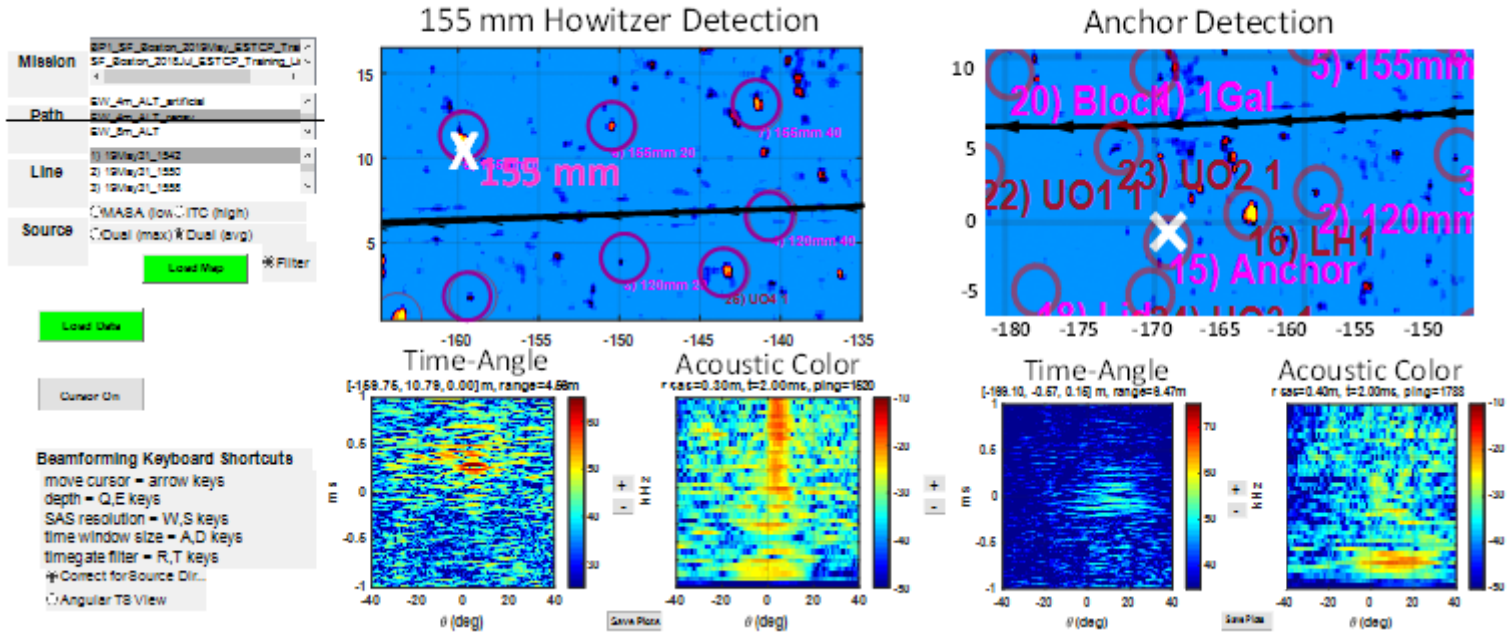
- new innovative approach for Skyfish
- single composite map = **200 objects**
- one opportunity per target
- single and multi pass features
- requires precise AUV re-navigation





Down-Look Pre-Test Classifier Sanity Check

"Expert" MatLab-based *single-path* classifier tool
- two examples -



"Expert" Sanity Check Summary

- Using six E-W paths, all twelve UXOs were detected
- Acoustic color spectra allowed "expert" classifier to correctly call all UXO
- Of the eight false targets, three were false positives
- For the NRL targets the performance is:

  $P_D = P_C = 1$

  $P_{FA} = 3/(12 + 8) = 0.15$
- Considering all "targets":

  $P_{FA} = (3 + 30) / (12 + 8 + 91) = 0.30$

  indigenous false calls — indigenous detections

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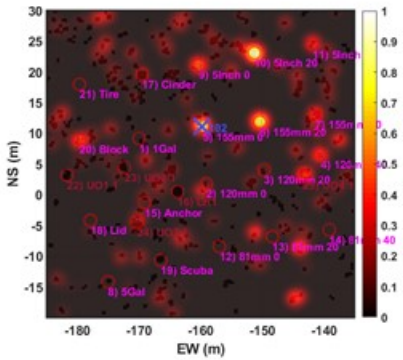
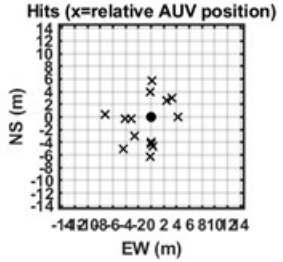
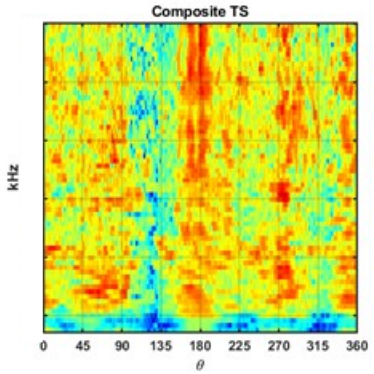
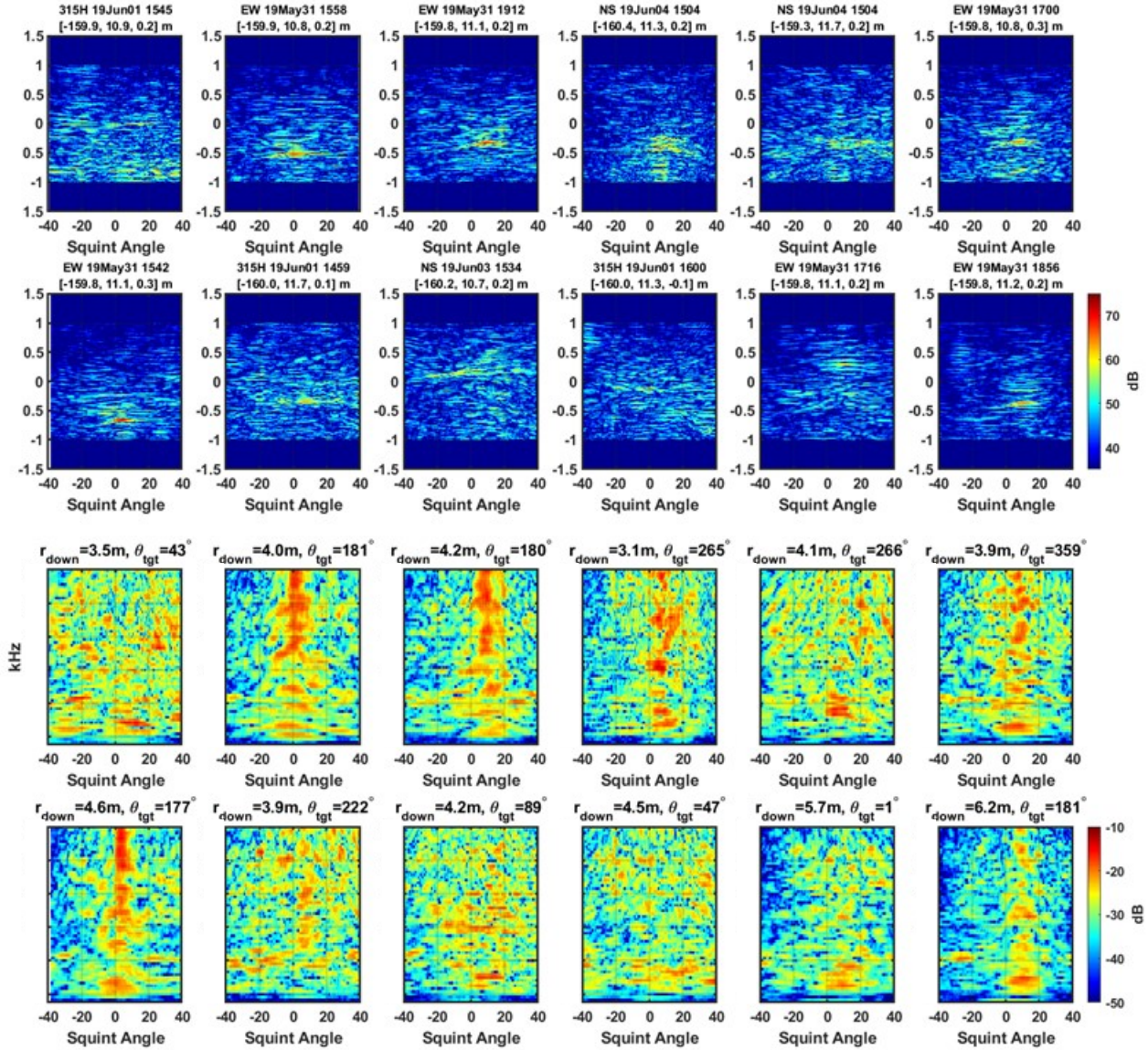
Multi-Path Detection: 155mm Howitzer @ 0 Degree Burial Angle

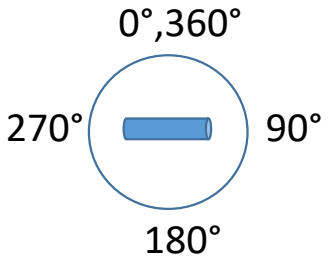
Global Objects
14 hits











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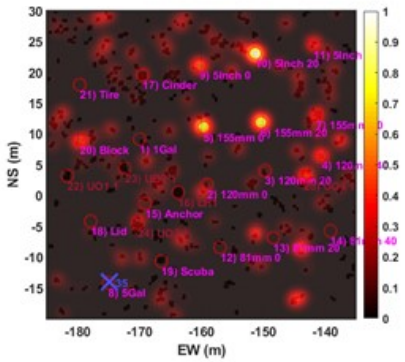
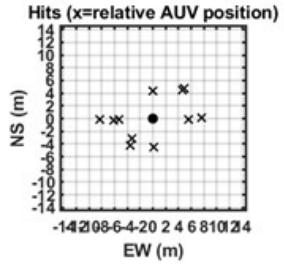
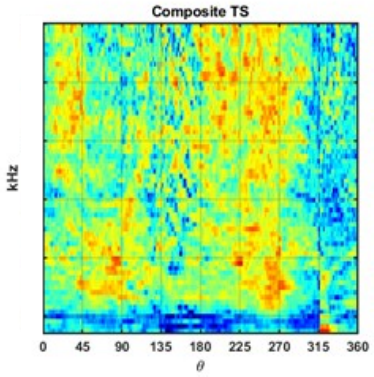
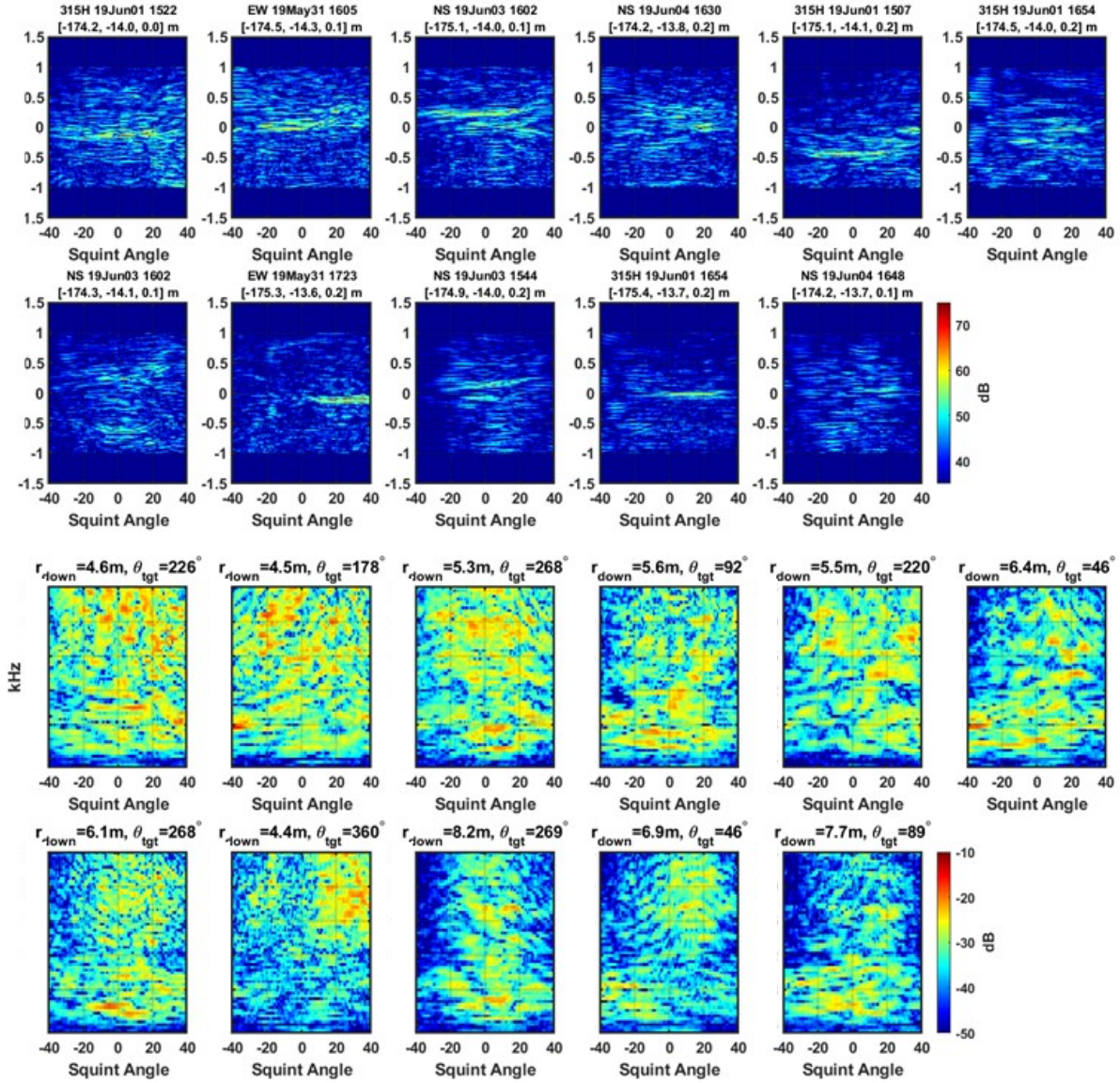
Multi-Path Detection: 5 Gallon Paint Can

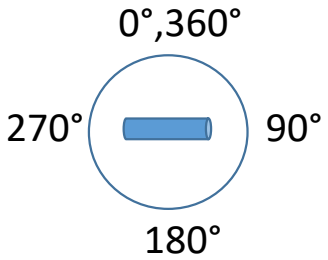
Global Objects
11 hits











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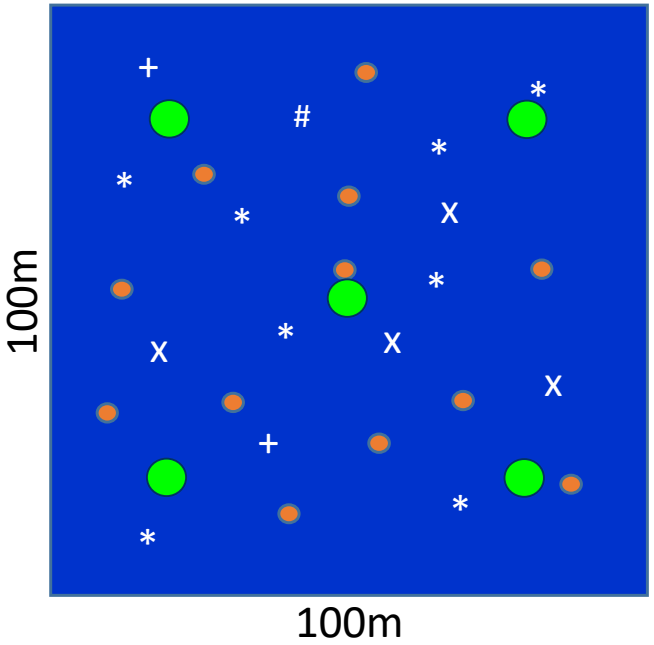
Upcoming Blind Buried Target Demonstration

Buried UXO & False Target Blind Field Established

EPS Corporation & the diving team established the buried blind test field, localized the placement of these targets *wrt* the Lincoln hat monuments, and reported this information to the ESTCP Program Office.



15 UXO

4 x's: 5 inch rocket

8 *'s: 155 mm shell

2 +'s: 120 mm mortar

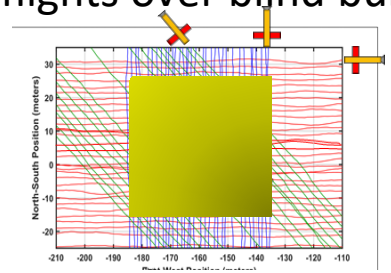
1 # : 81 mm mortar

5 LH Monuments

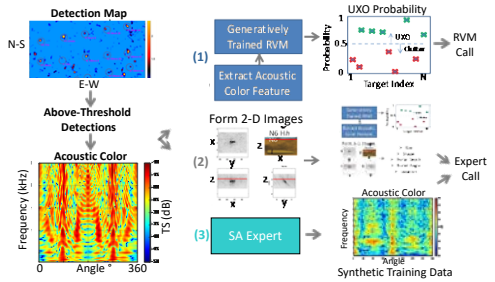
12 NRL false targets (anchors, tires, 5-gal cans, concrete blocks, cinder blocks,1-gal can)

What's Next

- Skyfish flights over blind buried field



- Generate detection maps & classify



- Report classification/ localization calls to ESTCP

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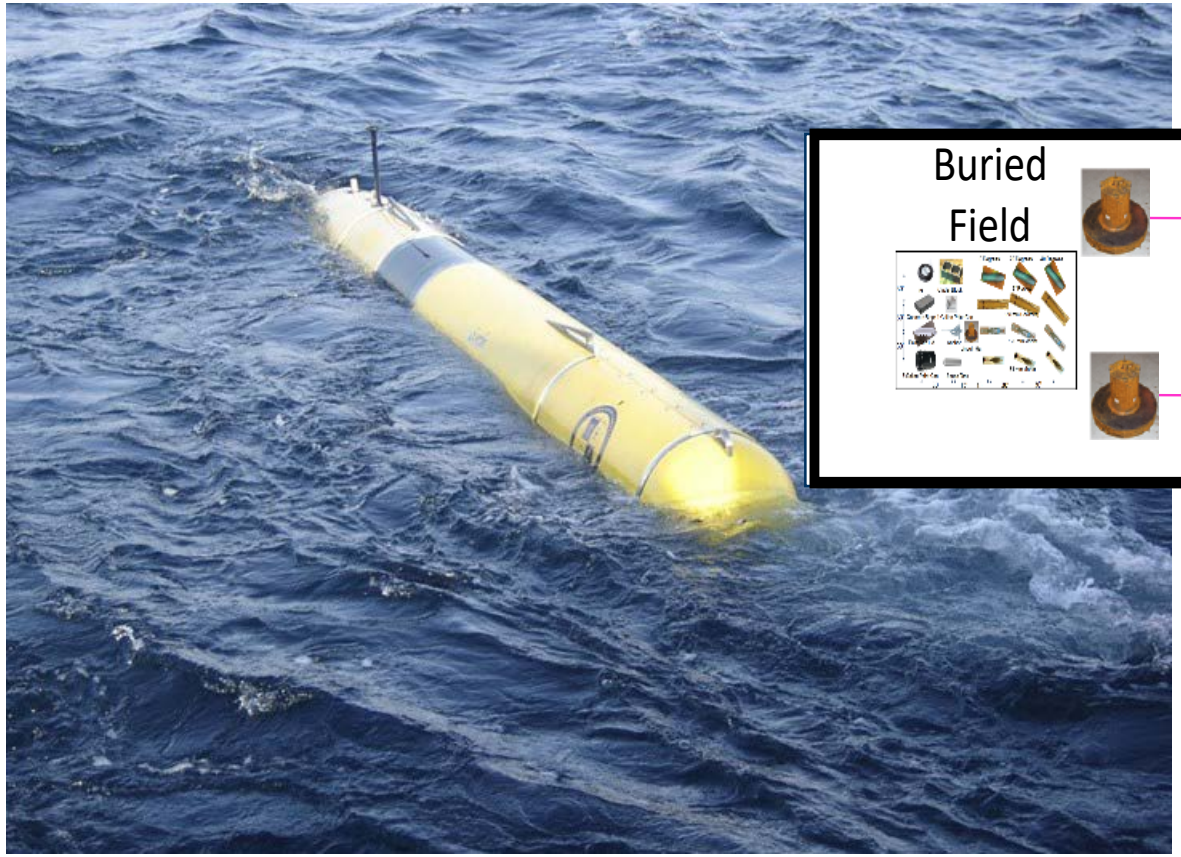
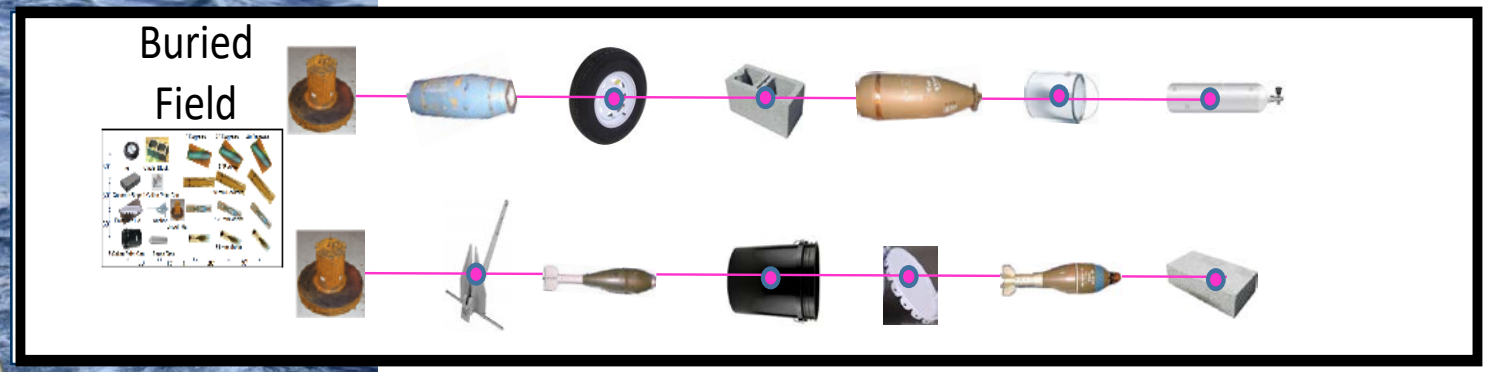
Side-Look Proud Target Demonstration Status

Training Surveys over Proud Target Field: *Post-Processing and Analysis*



Proud Target Lines

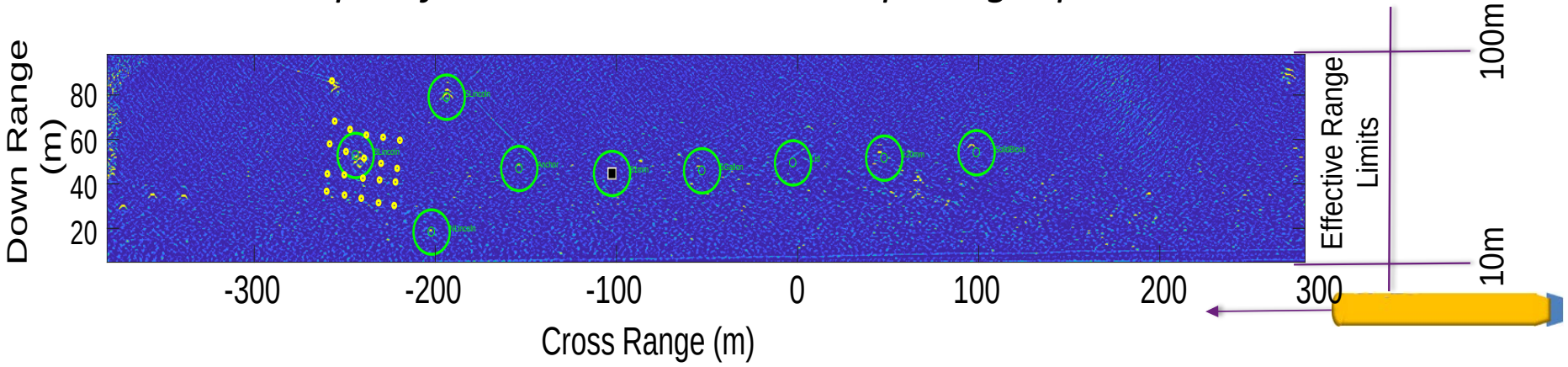


Monument Proud North: 42°23.830'N 070°55.680W
Monument Proud South: 42°23.800'N 070°55.680W
Monument Buried Field: 42°23.812'N 070°55.720W

Side-Look Detection Displays using Training Field Data

Detection map with the Side-scan interrogating area
about 100m by 700m in size swept out using east-west flight path

One example of the eleven detection maps: Flight path 1518



What determines range limits?

Max Range – Target echo levels and spreading loss
Min Range – Projector beam width

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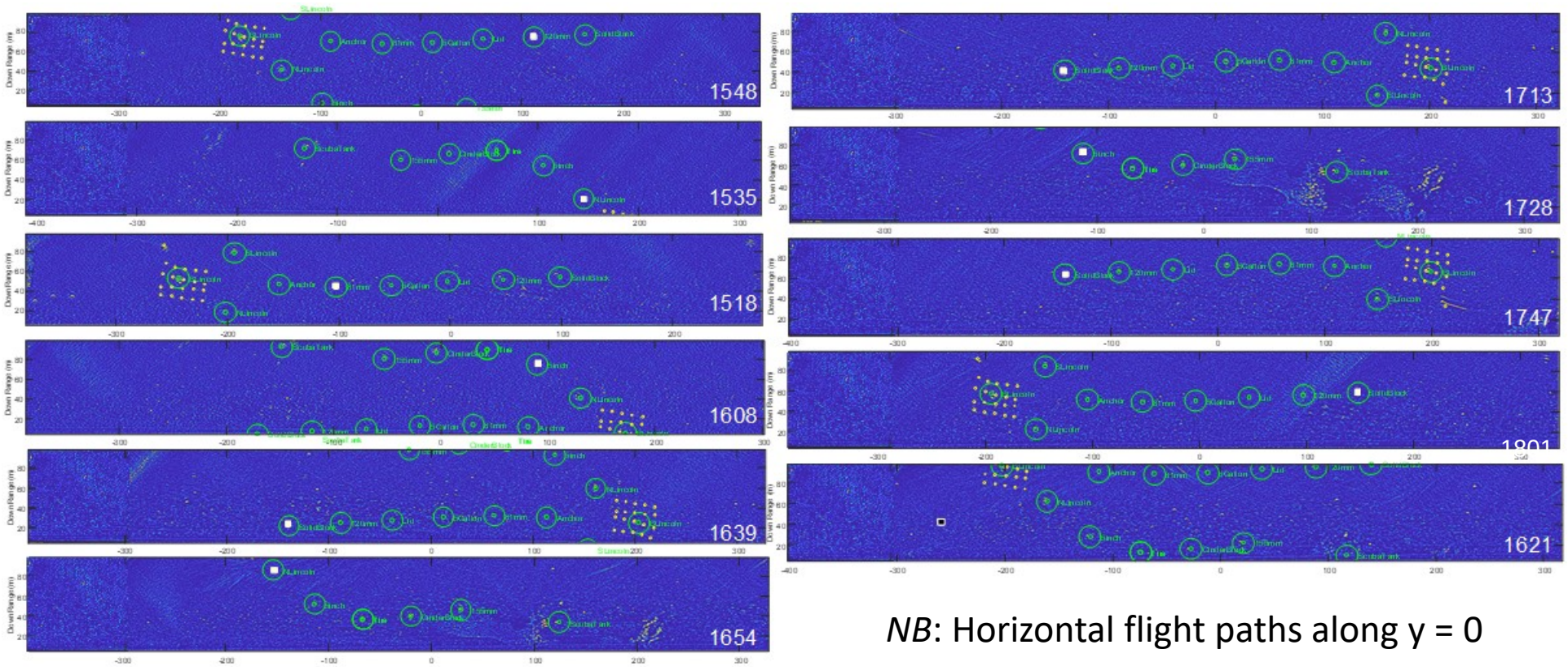
Side-Look Multi-path Detection Maps for Training Field

The eleven Side-Look flight paths

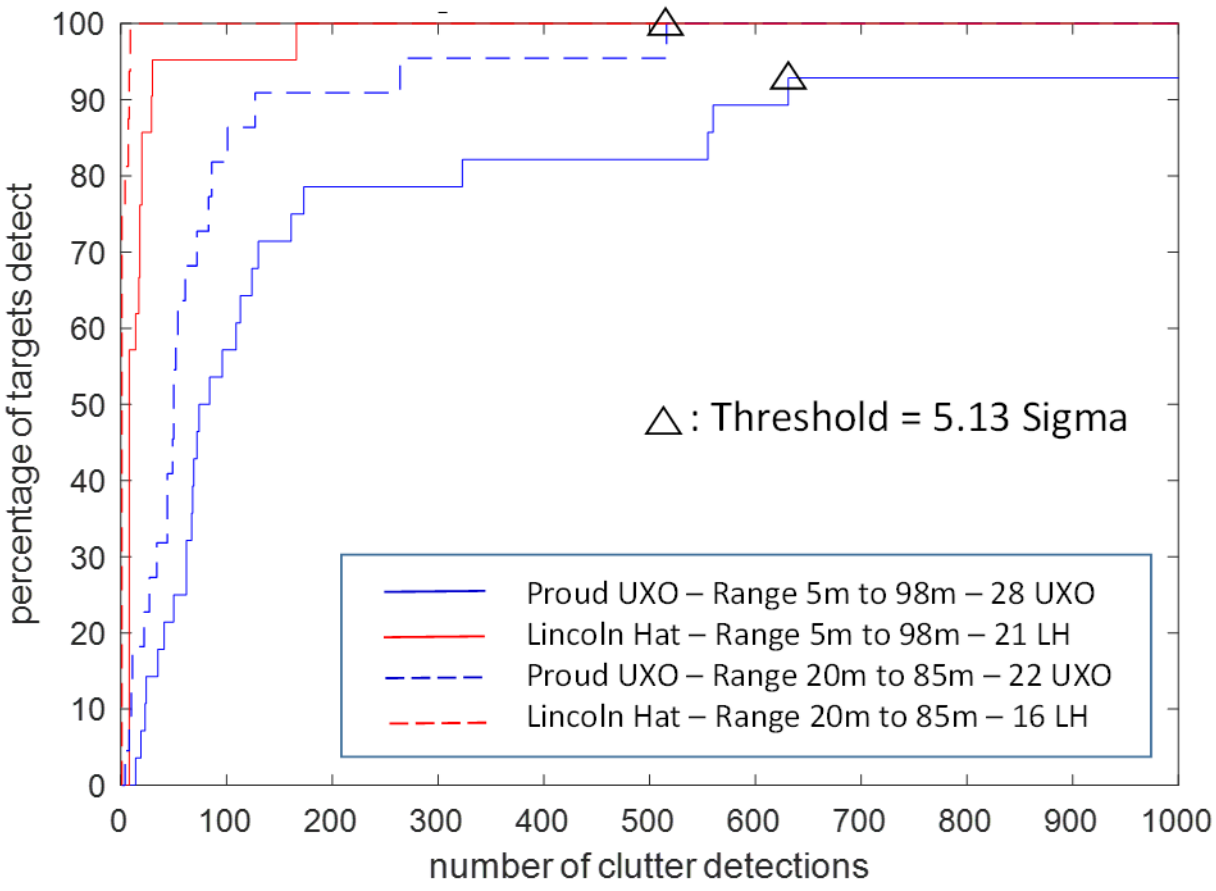


NB: Horizontal flight paths along y = 0

Side-Look Pre-Test Detections

Automated detection ROC curves generated using the eleven paths

E-W Flight Paths @ 8m Altitude over the Proud Training Field
Frequency Band = 4kHz – 24.5 kHz



— (5m to 98m)

P_D = 26/28 = 0.93

28 UXO in full swath
Detections 26

- - (20m to 85m)

P_D = 22/22 =1.0

22 UXO in "sweet spot"
Detections 22

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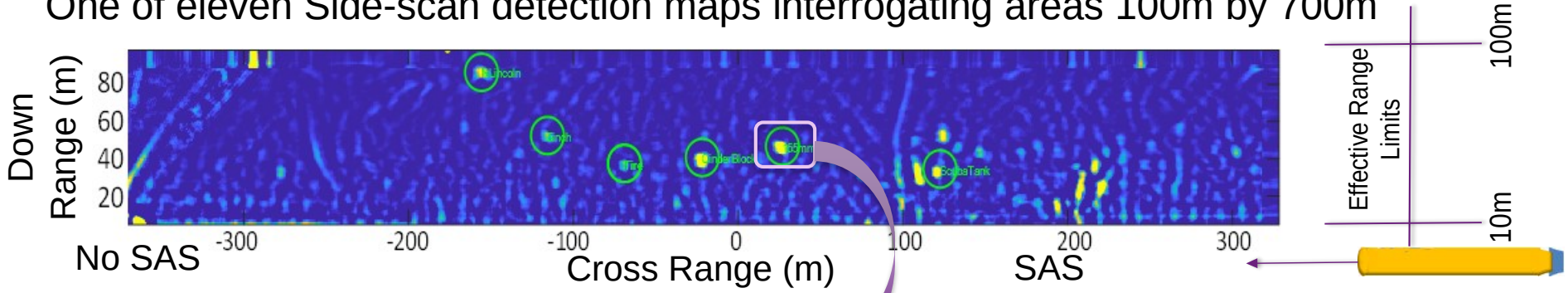
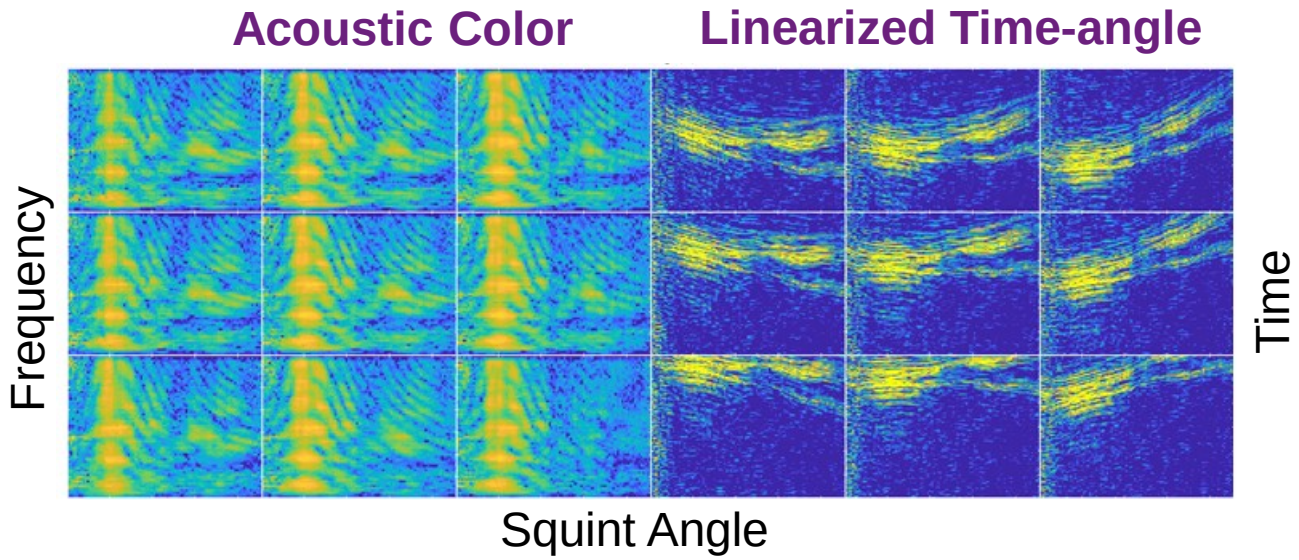
Side-Look Pre-Test Acoustic Color Example

One of eleven Side-scan detection maps interrogating areas 100m by 700m



155mm Howitzer@ 45m; 9 adjacent locations separated by 0.5m



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Side-Look Pre-Test Classifier Results

Results of Expert Classification "Calls" for 400-plus Detections

	P_C*	1548	1535	1518	1608	1621	1639	1654	1713	1728	1747	1801	P_{FA}*
S. Lincoln Hat				★					★		★	★	0.00
N Lincoln Hat		★	★	★	★	★	★	★	★			★	0.00
Lincoln Hat Buried Field		★		★		★	★		★		★	★	0.00
120mm UXO	0.94	✪		✪	●	✪	✪		✪		✪	✪	
155mm UXO	0.9		✪		●	✪		✪		✪			
81mm UXO	0.86	●		✪	●		✪		✪		✪	✪	
5" Rocket	0.5		●		●	●	●	●		●			
Tire			★		★			★		★			0.00
Cinder Block			★		★	★		★		★			0.00
Anchor		★		★			★		★		★	★	0.00
5 Gal Pt Can		★		★	★	★	●		★		★	★	0.06
Solid Block		●		●			★		★		★	★	0.17
Scuba Tank			●		●	●		★		●			0.4
Can Lid				★									0.00
Paint Can													0.00
Unknown		**25**	**22**	**39**	**17**	**29**	**30**	**16–1**	**29**	**57–1**	**52-1**	**37-1**	0.01

(4/353)

LEGEND

- Range < 5 m
- Range < 10 m
- Range > 100 m
- ✪ UXO Color
- ★ Non-UXO Color
- ● Ambiguous Color
- # of UXOs
- # of Non-UXO
- *within Range

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Side-Look Technology Conclusions

The Positive Results:

- UXO targets detected beyond 100m ranges
- Automated detector exhibits high detection probabilities
- “Expert” classification sanity check results encouraging
- Proud blind target demonstration soon

Project Team

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SKYFISH Video