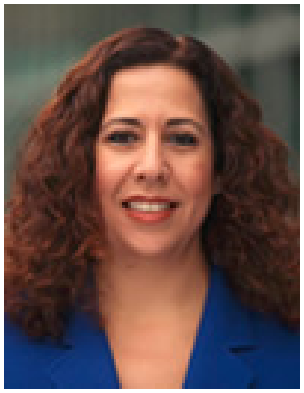
Acoustic Methods for Underwater Munitions

February 5, 2015

Welcome and Introductions

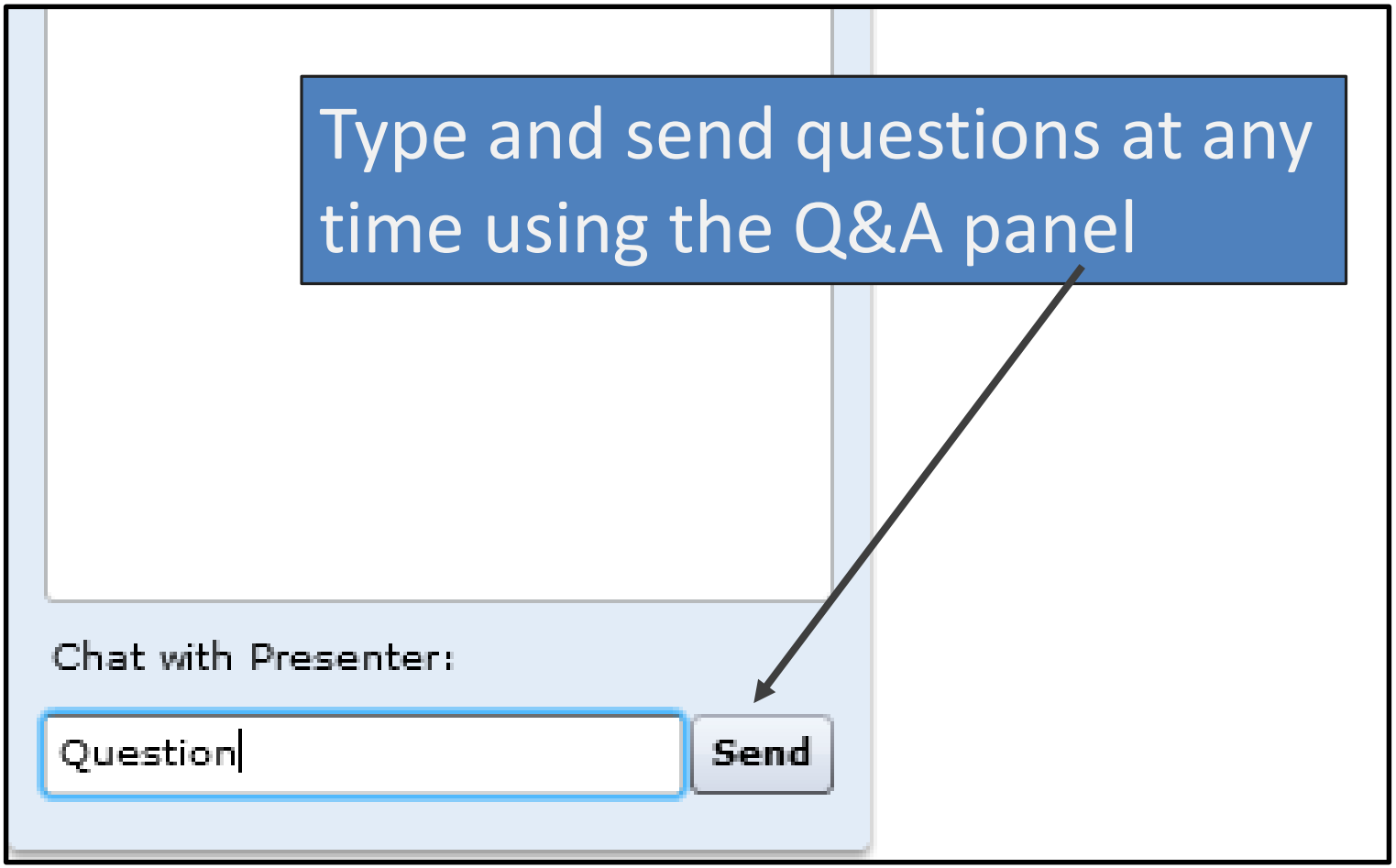
Rula Deeb, Ph.D.
Webinar Coordinator



Webinar Agenda

- Webinar Overview and ReadyTalk Instructions
  Dr. Rula Deeb, Geosyntec (5 minutes)
- Overview of SERDP and ESTCP, and webinar series goals
  Dr. Herb Nelson, SERDP and ESTCP (5 minutes)
- Structural Acoustic Sonars: Searching for Buried Underwater Unexploded Ordnance (UXO)
  Dr. Joseph Bucaro, Excet, Inc. and the Naval Research Laboratory (25 minutes + Q&A)
- Low Frequency Acoustic Scattering by Underwater UXO and its Use in Classification
  Dr. Kevin Williams, University of Washington (25 minutes + Q&A)
- Final Q&A session

How to Ask Questions



SERDP and ESTCP Overview

Herb Nelson, Ph.D.
Munitions Response
Program Manager

SERDP DOD • EPA • DOE | ESTCP

SERDP

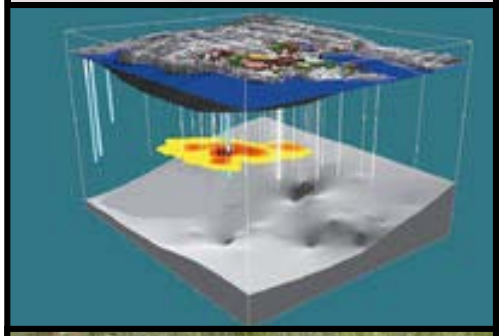
- Strategic Environmental Research and Development Program
- Established by Congress in FY 1991
  - DoD, DOE and EPA partnership
- SERDP is a requirements driven program which identifies high-priority environmental science and technology investment opportunities that address DoD requirements
  - Advanced technology development to address near term needs
  - Fundamental research to impact real world environmental management

ESTCP

- Environmental Security Technology Certification Program
- Demonstrate innovative cost-effective environmental and energy technologies
  - Capitalize on past investments
  - Transition technology out of the lab
- Promote implementation
  - Facilitate regulatory acceptance

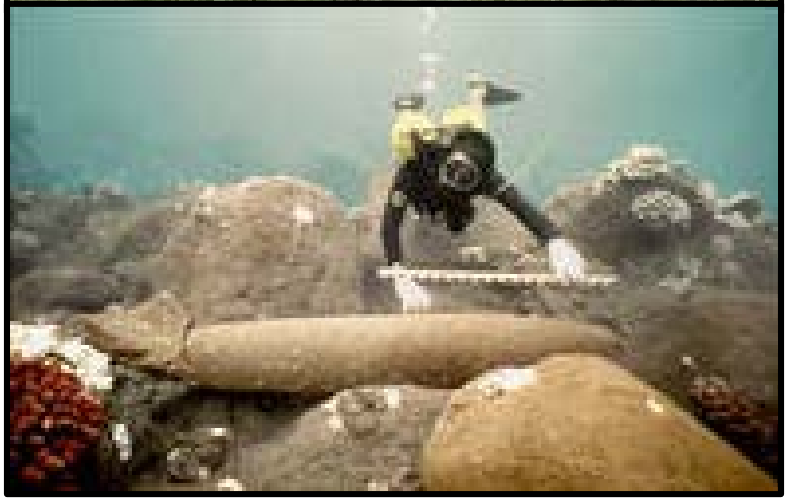
Program Areas

1. Energy and Water
2. Environmental Restoration
3. Munitions Response
4. Resource Conservation and Climate Change
5. Weapons Systems and Platforms



Munition Response

- Munitions on land
  - Classification
- Munitions underwater
  - Wide area and detailed surveys
  - Cost-effective recovery and disposal
  - Characteristics of munitions underwater, their environment and mobility



SERDP and ESTCP Webinar Series

DATE	WEBINARS AND PRESENTERS
February 19, 2015	**Raise the Roof: Increased Rooftop Solar Efficiency Beyond Flat Panel PV** • Ms. Deborah Jelen, Electricore • Mr. John Archibald, American Solar
March 5, 2015	**Lead Free Electronics** • Dr. Peter Borgesen (Binghamton University, The State University of New York • Dr. Stephan Meschter (BAE Systems)
March 19, 2015	**Quantitative Framework and Management Expectation Tool for the Selection of Bioremediation Approaches at Chlorinated Solvent Sites** • Dr. John Wilson, Scissor Tail Environmental • Carmen LeBron, Independent Consultant
March 26, 2015	**Environmental DNA: A New Tool for Species Inventory, Monitoring and Management** • Dr. Lisette Waits, University of Idaho • Dr. Alexander Fremier, Washington State University

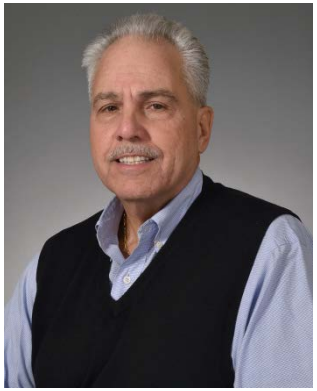
http://serdp-estcp.org/Tools-and-Training/Webinar-Series

SERDP
DOD • EPA • DOE

ESTCP

Structural Acoustic Sonars: Searching for Buried Underwater Unexploded Ordnance

Dr. Joseph Bucaro,
Excet, Inc. and the Naval Research Laboratory



SERDP DOD • EPA • DOE | ESTCP

Structural Acoustic Sonars: Searching for Buried Underwater Unexploded Ordnance (UXO)

SERDP MR-2103
J.A. Bucaro, Excet, Inc., Springfield, VA
Naval Research Laboratory Contract # N00173-14-D-2012

Agenda

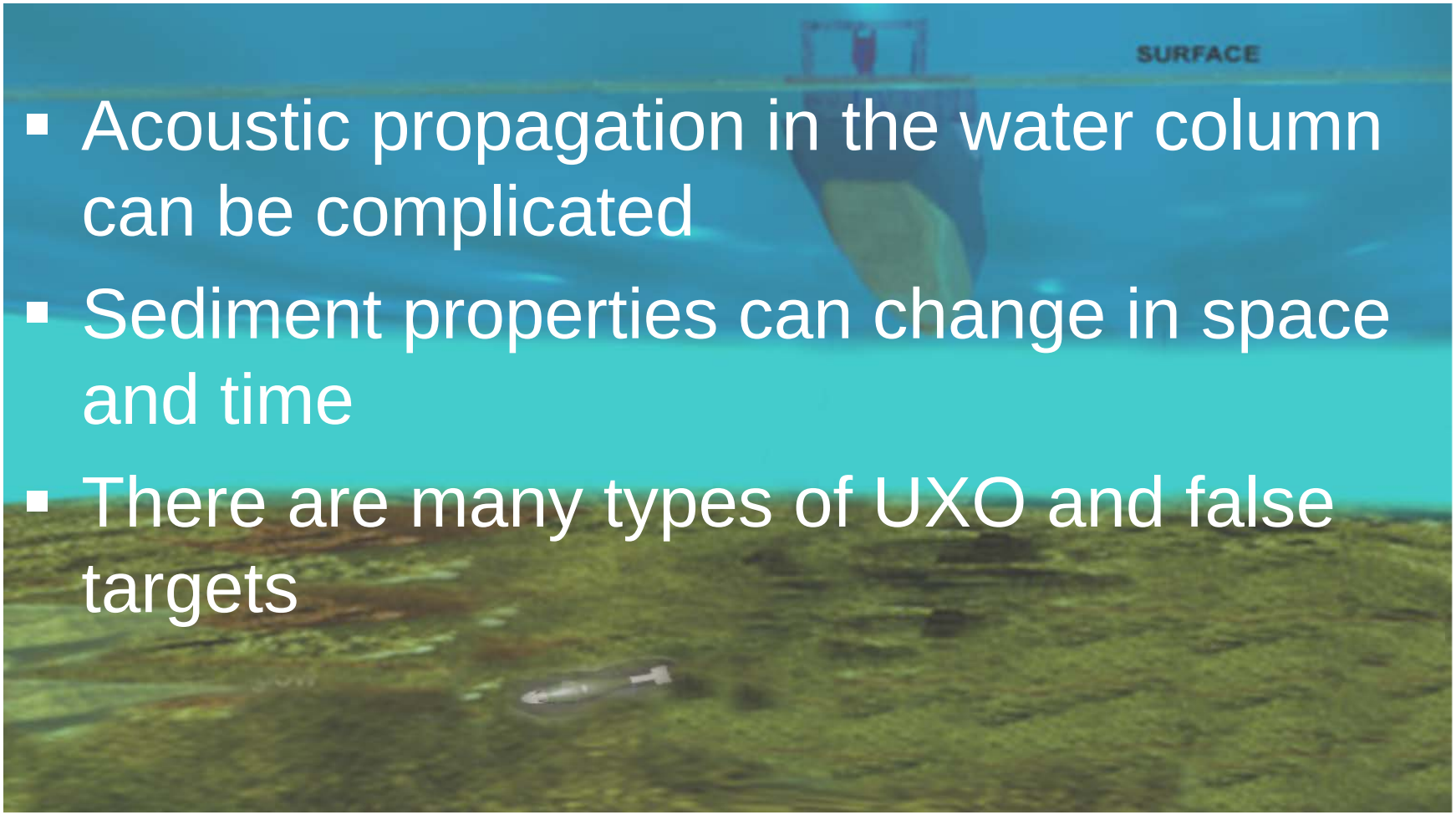
- Background: Need – Difficulties – Focus
- UXO echo spectral levels
- High resolution imagers for proud UXO
- Why structural acoustics (SA) for buried UXO
- SA images: St. Andrews Bay, Gulf of Mexico
- SA color: Gulf of Mexico
- Conclusions

The Need

- Many active/former military sites have ordnance ranges/ training areas with adjacent water environments where UXO now exists due to wartime activities, dumping and accidents

- SERDP munitions response program goals require the development of underwater sonar technology that can:
  - Detect buried and proud targets and
  - Separate the detections into UXO versus non-UXO

Underwater UXO Sonar Detection and Classification is Difficult



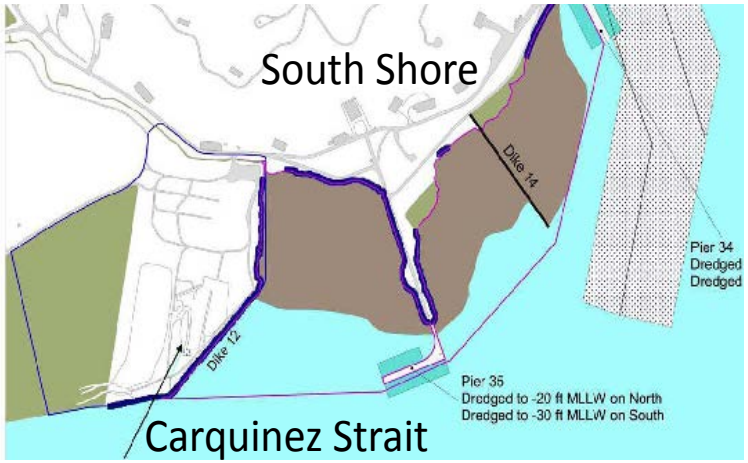
- Acoustic propagation in the water column can be complicated
- Sediment properties can change in space and time
- There are many types of UXO and false targets

There are Hundreds of Potential UXO Types

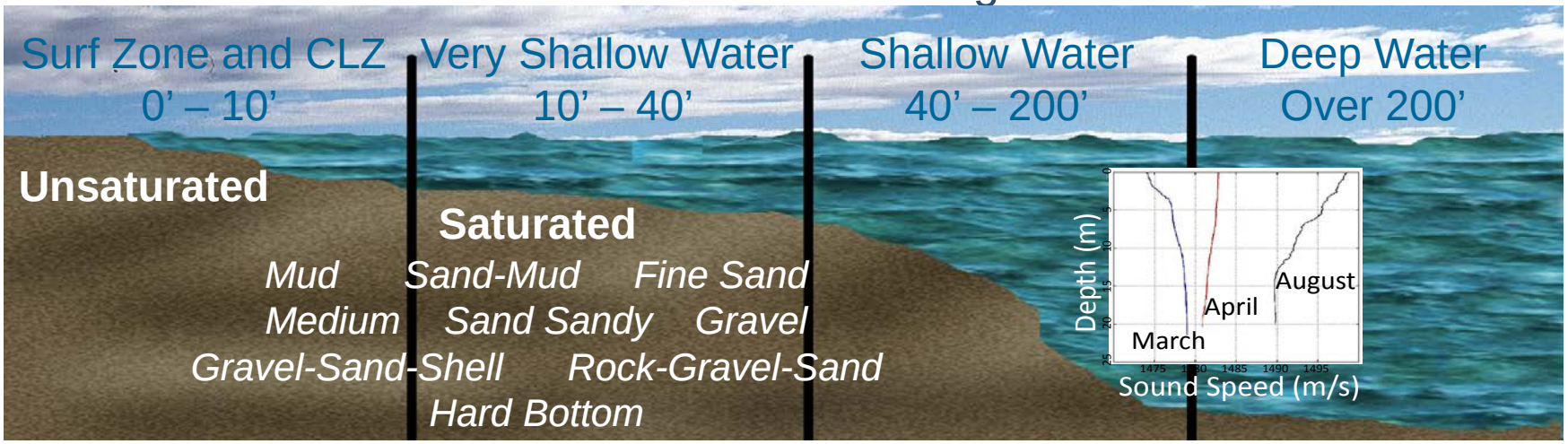
Few Examples of the Almost Unlimited Variety of Natural and Man-made Clutter

Some of the Environments of Interest

Interior waters are acoustically challenging



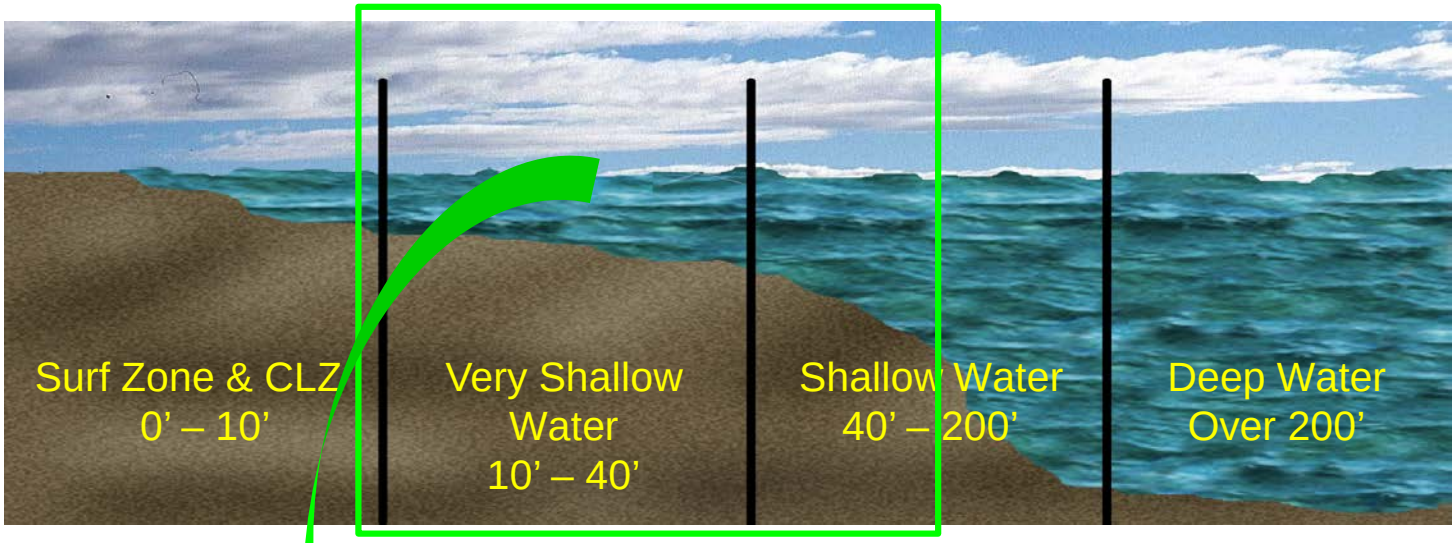
Coastal environments have a range of conditions



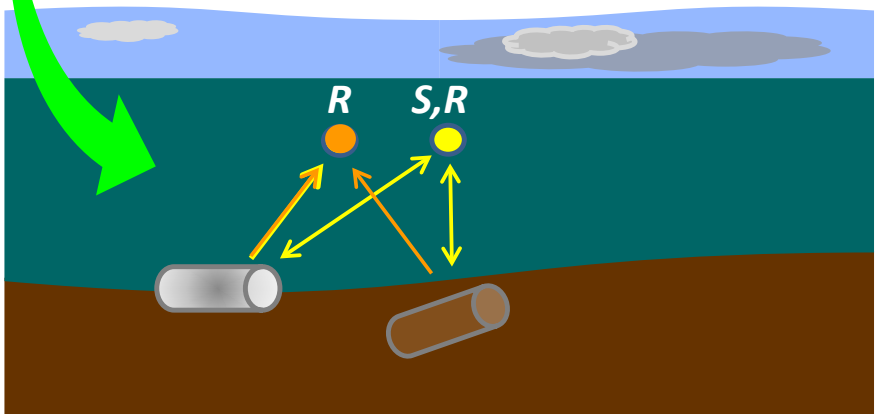
Navy's Munitions Response Program (MRP)

- Focused on shallow water areas where munitions releases are known or suspected to have occurred and where:
  - Munitions are covered by water no deeper than 120 feet
  - Munitions located in waters between high and low tides are considered terrestrial

Focus of Presentation



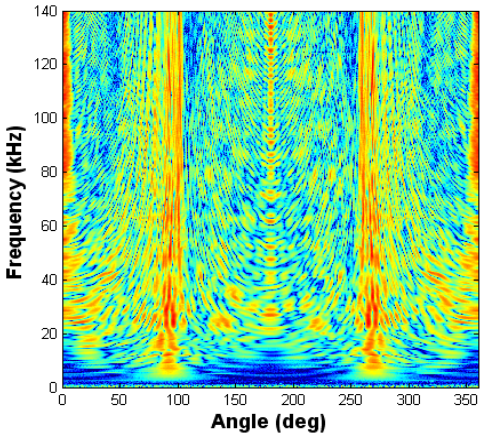
Down-Looking, Short Range Sonars

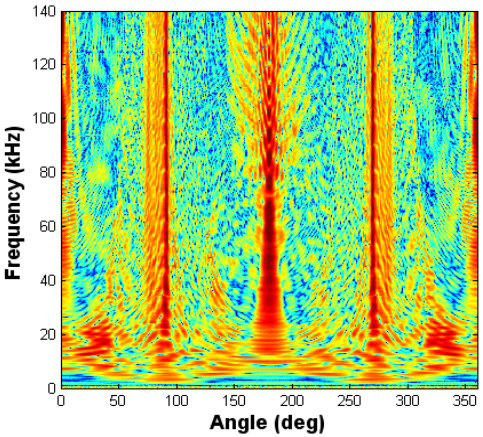


UXO Acoustic Signals

$$TS = 20\log_{10}\frac{P_{scat}(f,\theta)}{P_{inc}(f)}\frac{r_{scat}}{e^{ikr_{scat}}}$$

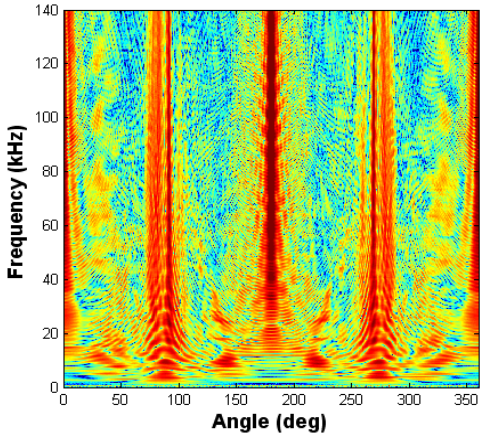
80 mm Mortar

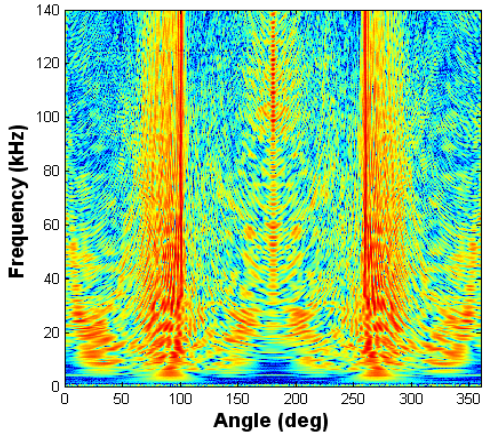




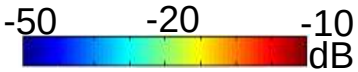
5 inch Rocket

155 mm Shell



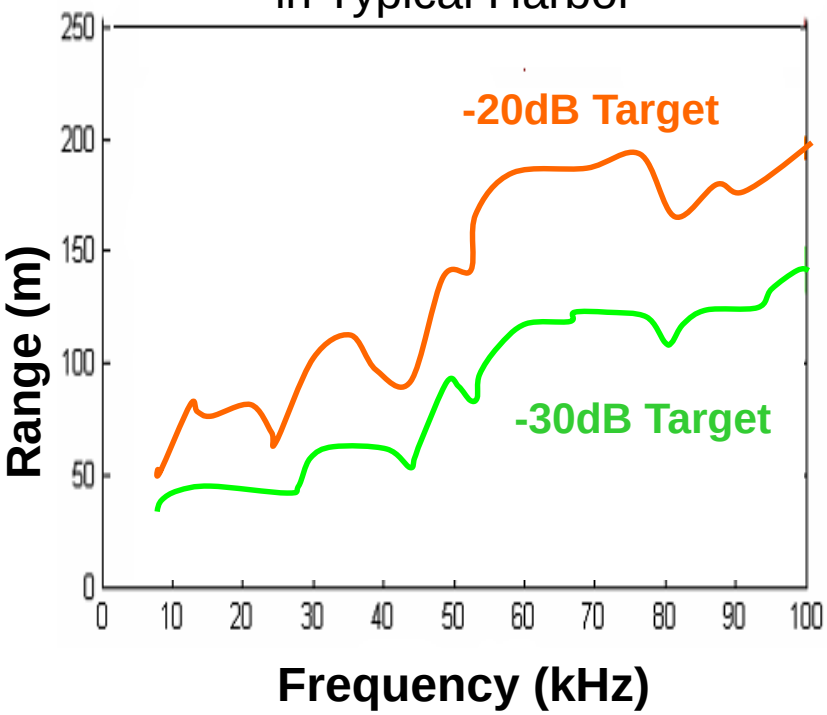


120 mm Mortar



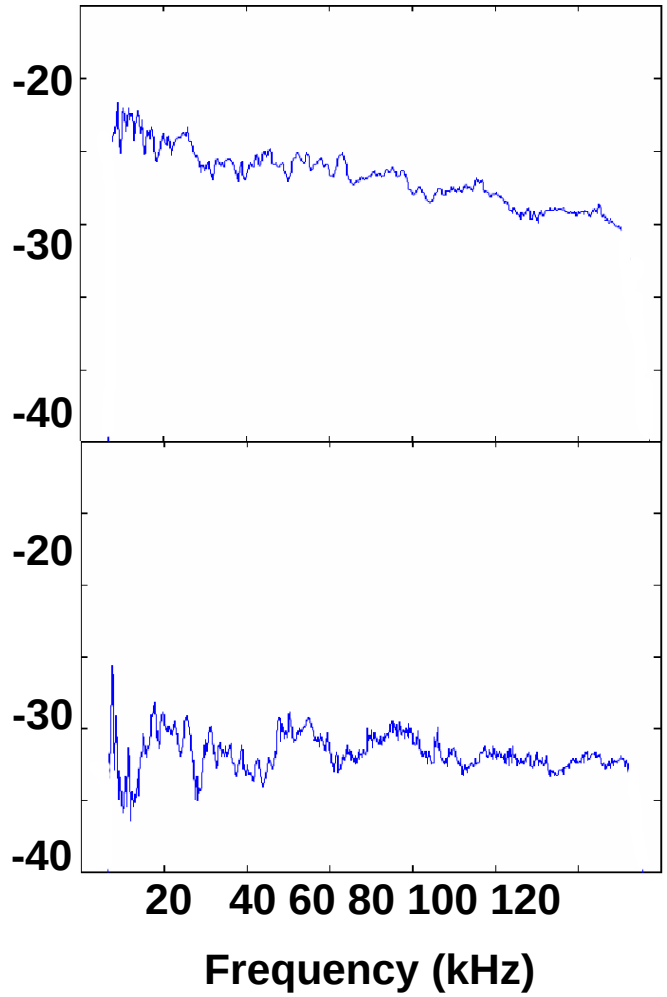
Detection Range versus Frequency

Detection Range (*S/N* = 10)
in Typical Harbor



- No boundaries
- 170 dB re:µPa source level
- San Diego Harbor noise
- No acoustic absorption

Random Aspect TS (dB)



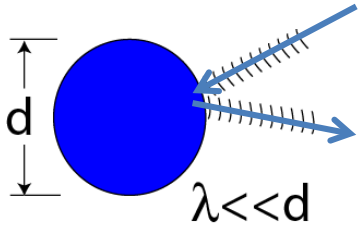
155 mm

25 mm

High Resolution Imaging versus Structural Acoustics

HF Imaging Sonars

Commercially available

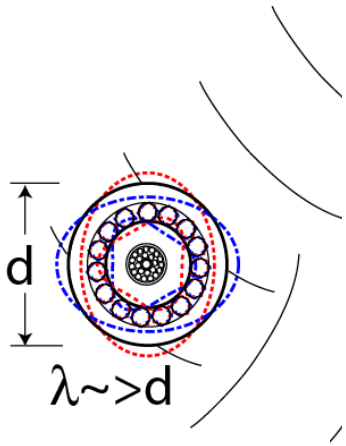


Acoustic Imaging Regime

"Specular" echo tracks external target shape

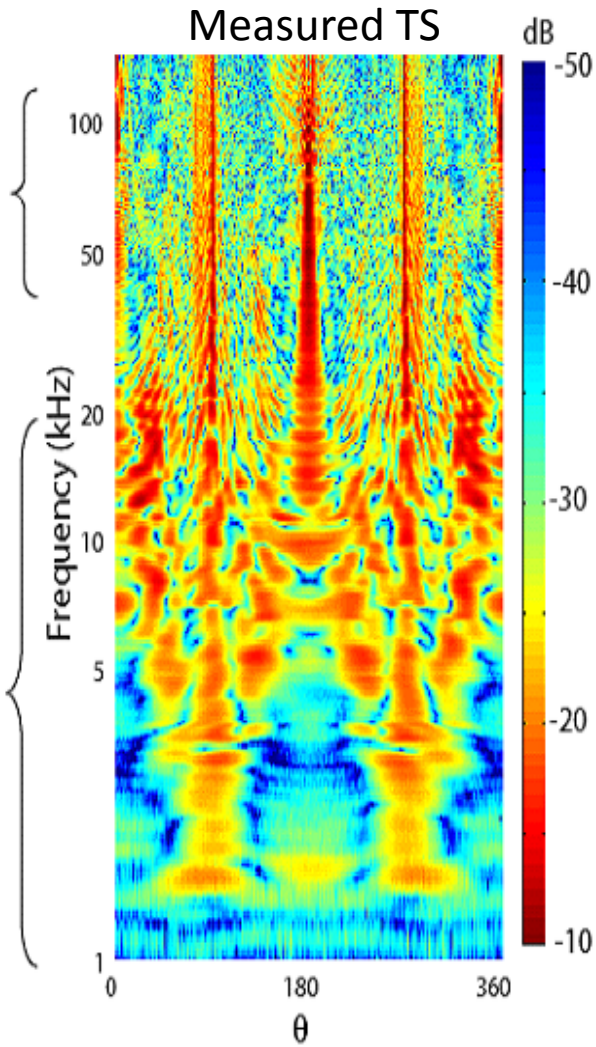
SA Sonars

Under development

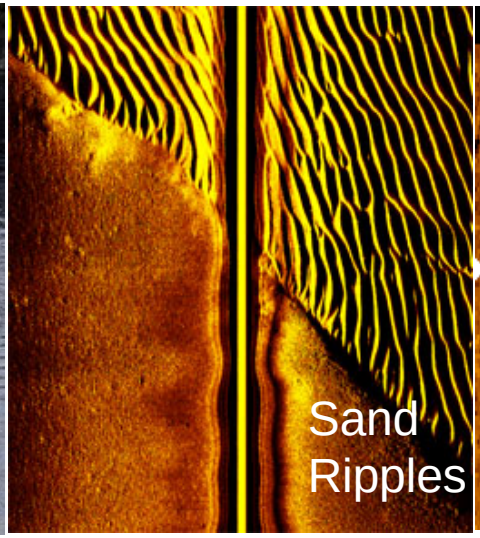


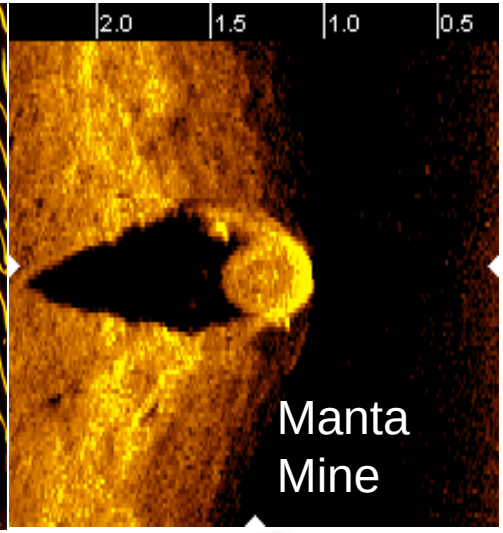
Structural Acoustic Regime

Echo related to vibrational dynamics-both whole-body and internal structure

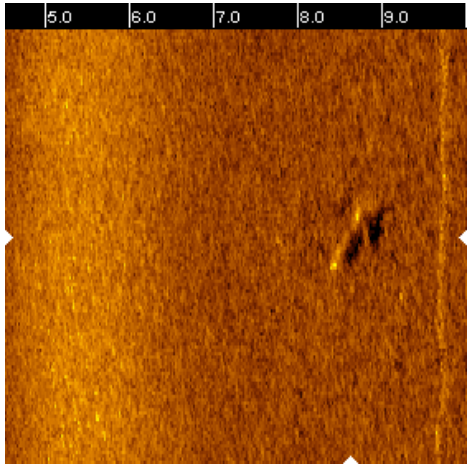


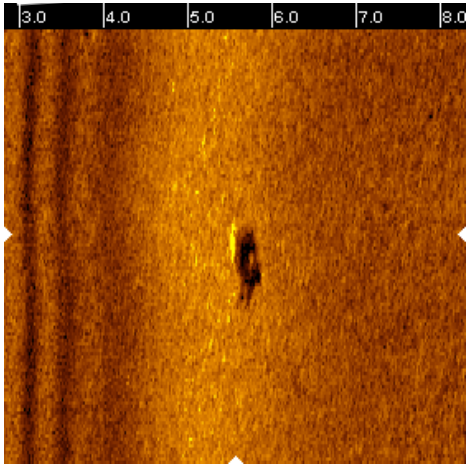
High Frequency Marine Sonic Side Scan Sonar





155mm Projectile

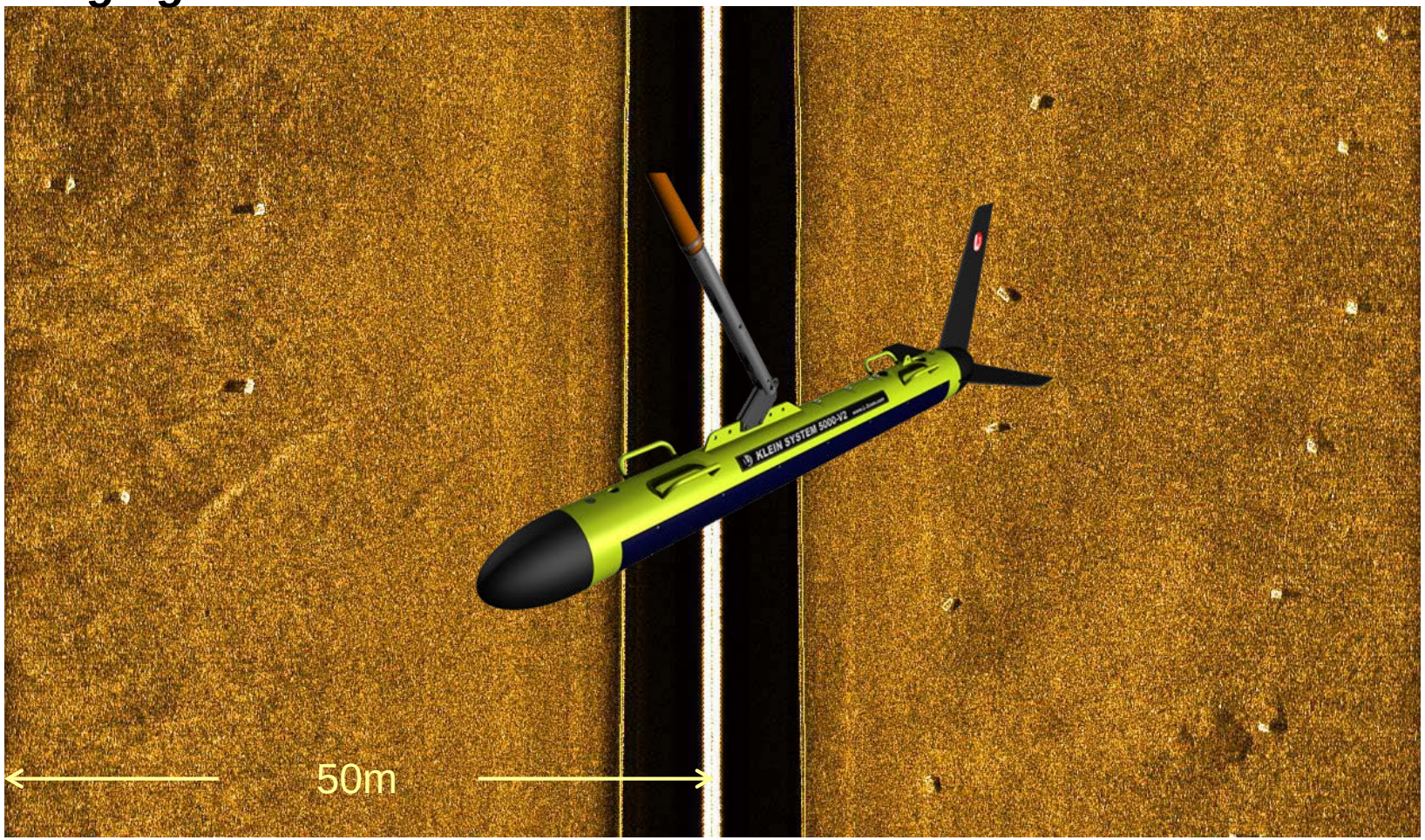




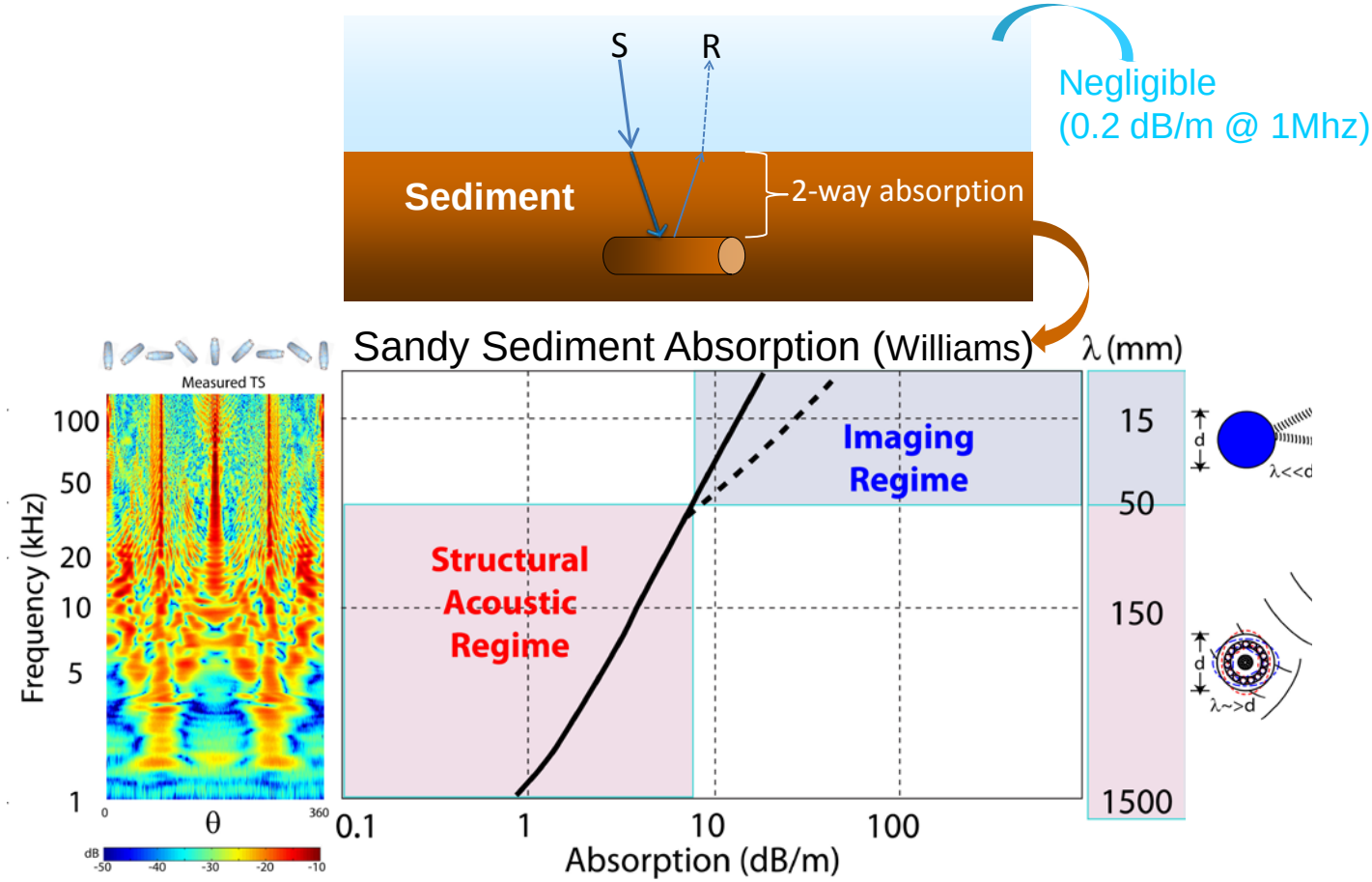
Marine Sonic Technology, Ltd.

Klein 5000: 455 kHz Sidescan Sonar

Imaging of Lobster Pots



How Important is Acoustic Absorption?



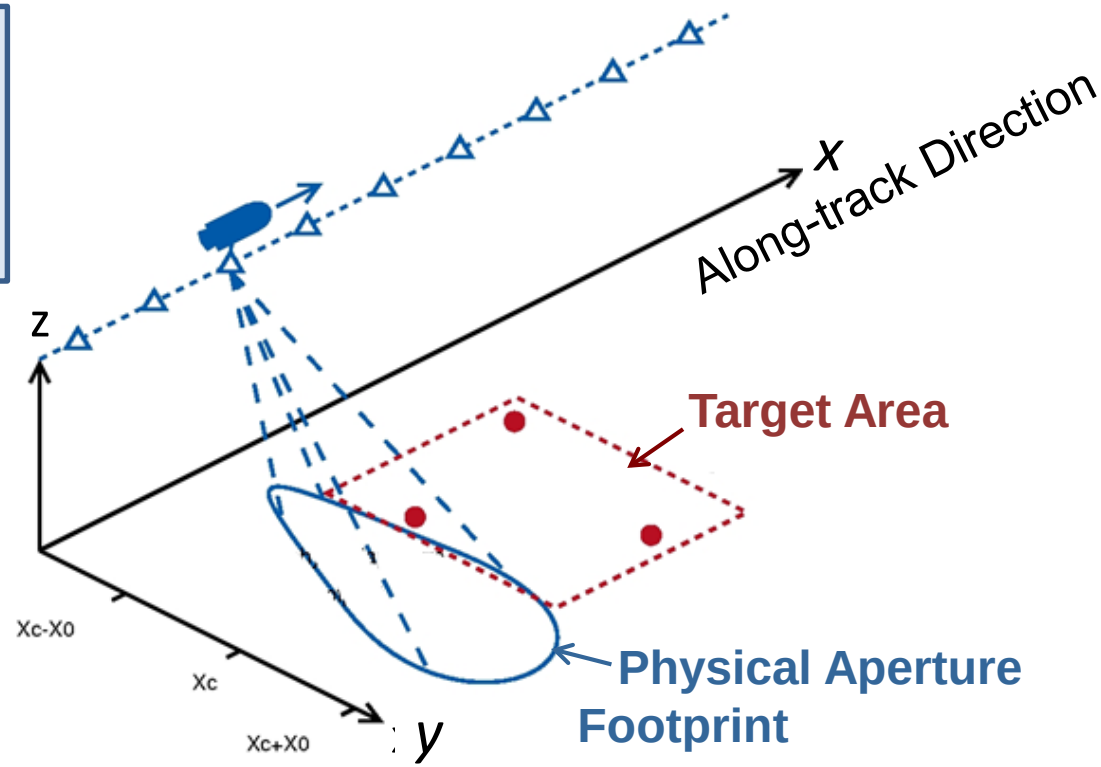
- High resolution imaging sonars will not see most buried targets
- Structural acoustic sonars can detect buried targets *and* obtain SA fingerprints

Adding Imaging Capability to the Structural Acoustic Sonar

- By adding SAS processing, the structural acoustic sonar can provide modest resolution images even at the low frequencies and long acoustic wavelengths (10 cm to 50 cm) characteristic of this regime

Typical Resolution

Along-Track: ~ 10 cm
Cross-Track: ~ 25 cm

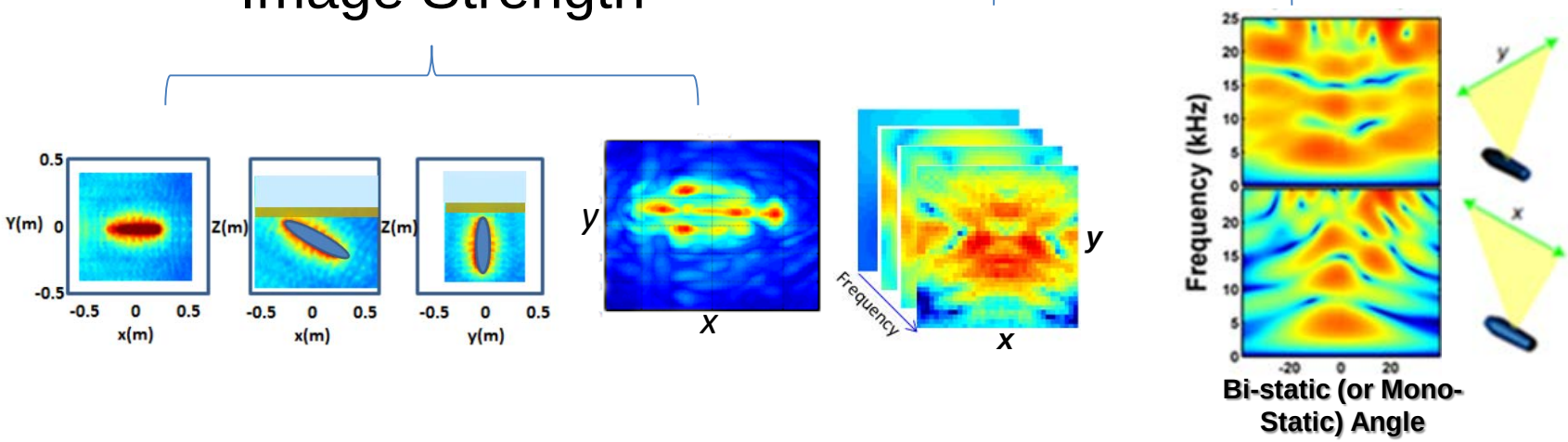


SA Band

Image, strength and target strength provide constructs for generating classifying features

Target Strength

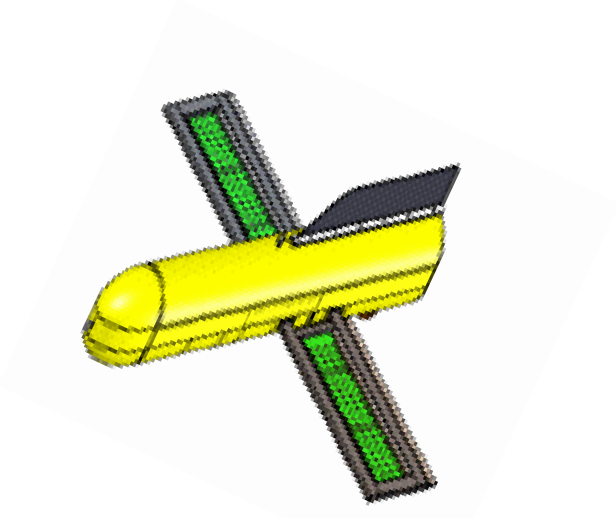
Image Strength



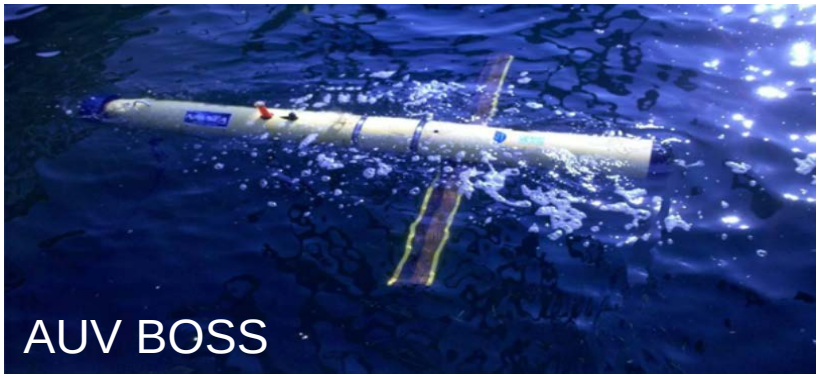
(a) Specular Plan View and Depth Images	(b) Elastic Plan View	(c) 2-D Target Strength	(d) Target Strength vs θ,ω (Acoustic Color)

Buried Object Scanning Sonar (BOSS)

- Structural acoustic sonar consisting of sound source and wing-based hydrophones mounted on an AUV or tow body developed over ten years ago by Steven Schock of Florida Atlantic University



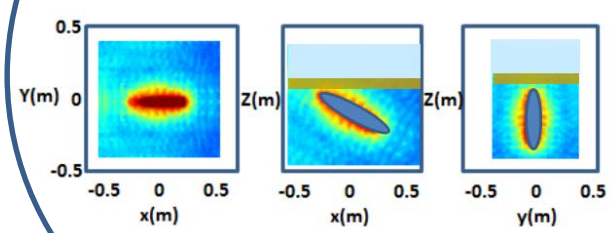
Tow Body BOSS

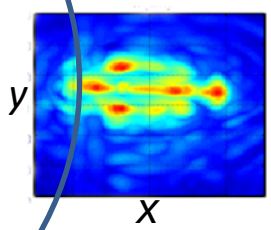


SA Band

Specular images provide size, shape and orientation classification features

Image Strength

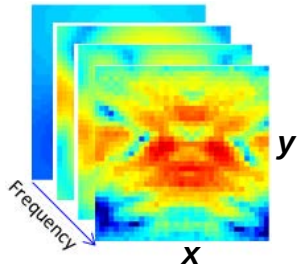


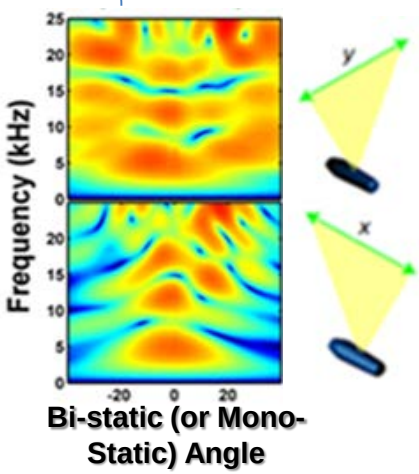


(a)
Specular Plan View
and Depth Images

Target size, shape, orientation

Target Strength

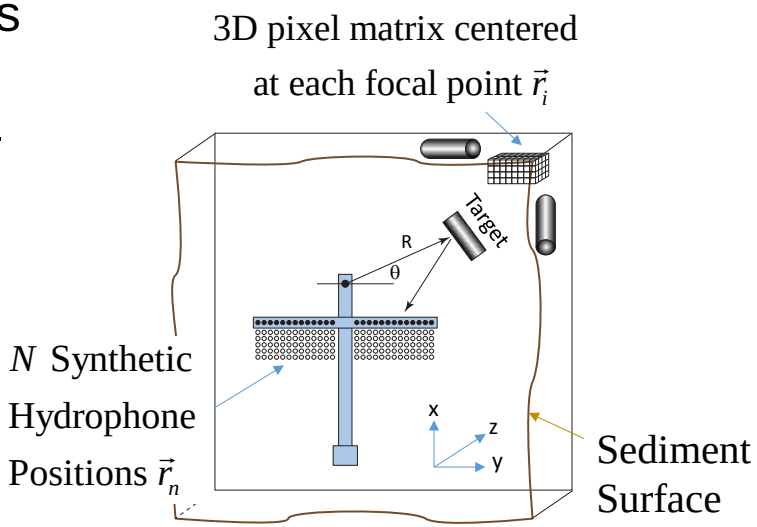




Sources: Carroll et al.; Leasko et al.

How are the SA Images Formed?

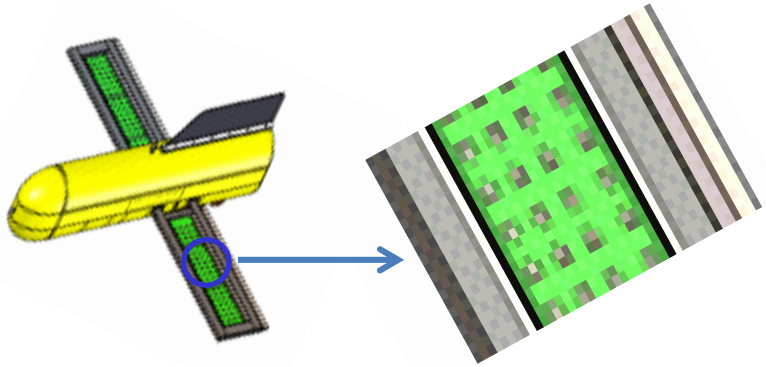
- Using the signals on the 40 (160) receivers from 40 pings (40 vehicle x positions), the image (x,y,z) is produced over the band 3-20kHz using time-delay beam-forming (algorithm on the lower right)
- Images at the same (x,y,z) locations are produced from the next set of i=6 to i=45 pings. This is repeated to produce 33 images at every (x,y,z) location
- The maximum image value in the 33 images (x,y,z) becomes the final image (x,y,z). (Resulting multi-static aperture is 10m or 90°)
- 2-D images are obtained by taking the maximum image value along the third co-ordinate



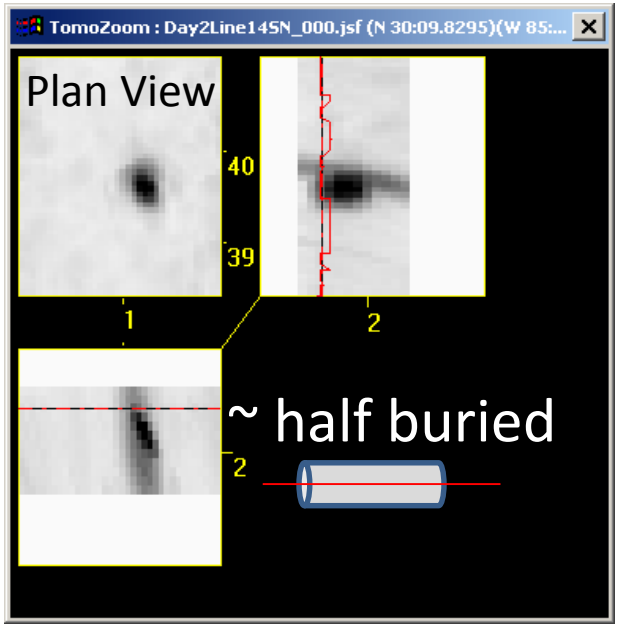
$$\text{Image Strength at } \vec{r}_i \equiv \sigma_i\left(\vec{r}_i\right) = \frac{1}{N}\sum_{n=1}^{N} 4\pi\left|\vec{r}_n - \vec{r}_i\right| d_n\left(\vec{r}_n \middle| \vec{r}_i, \frac{\left|\vec{r}_n - \vec{r}_i\right|}{c}\right)$$

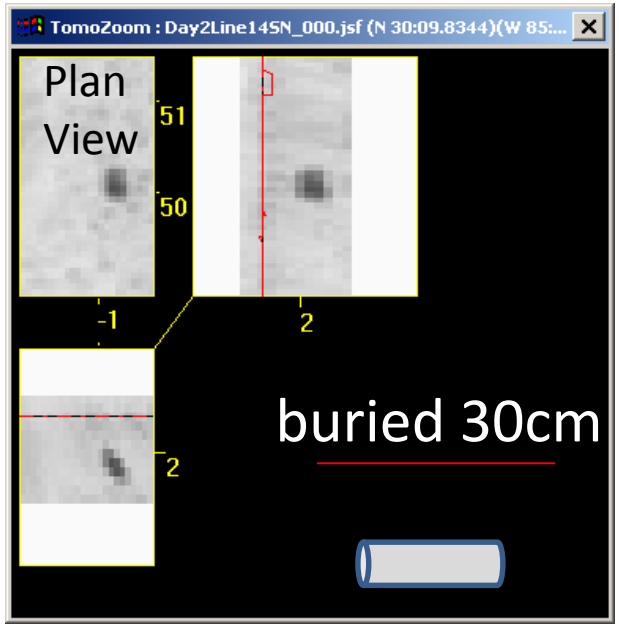
SA BOSS-160 Tow-Body Data Collection-St. Andrews Bay (~39' water depths)

Source:
SERDP MM-1507
(2009) by Paul Carroll



Images of cylinder (3"diameter x 14" length)





SA BOSS-40 AUV Studies in the Gulf (2013)

BOSS exercises off the Panama City, FL coast were a success due to the following efforts:

BOSS Preparation and Flights

Richard Holtzapple, Joe Lopes, and Nick Pineda NSWC Panama City

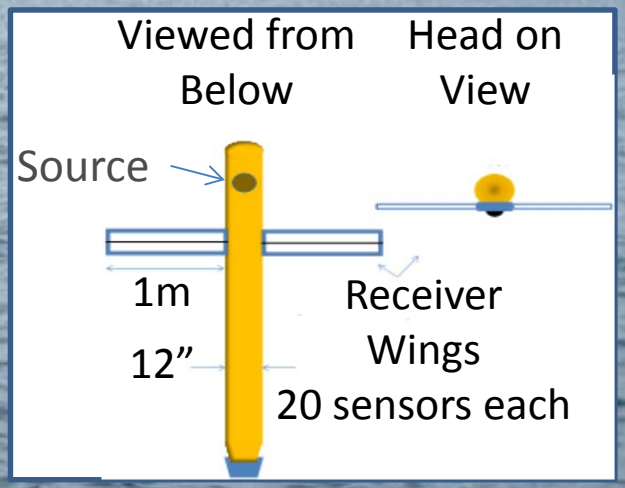
Harvey Duplantis, Bluefin Robotics

Daniel Amon, NRL

Target Burial

Kevin Williams and his diving team, APL-UW

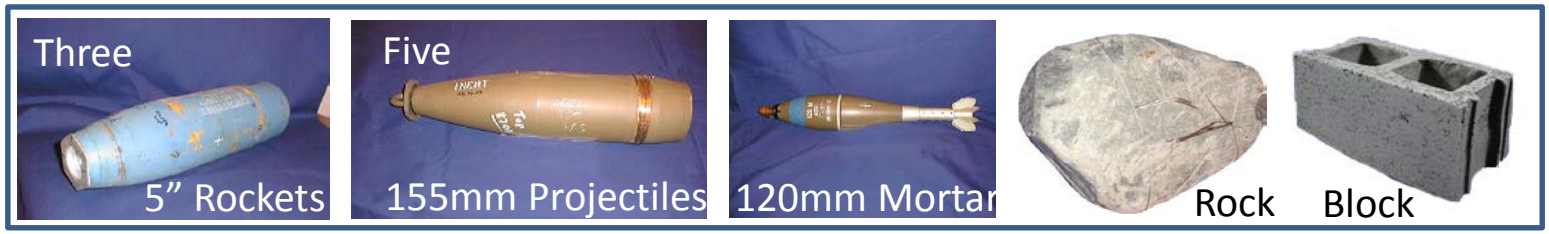
Mike Richardson, SERDP

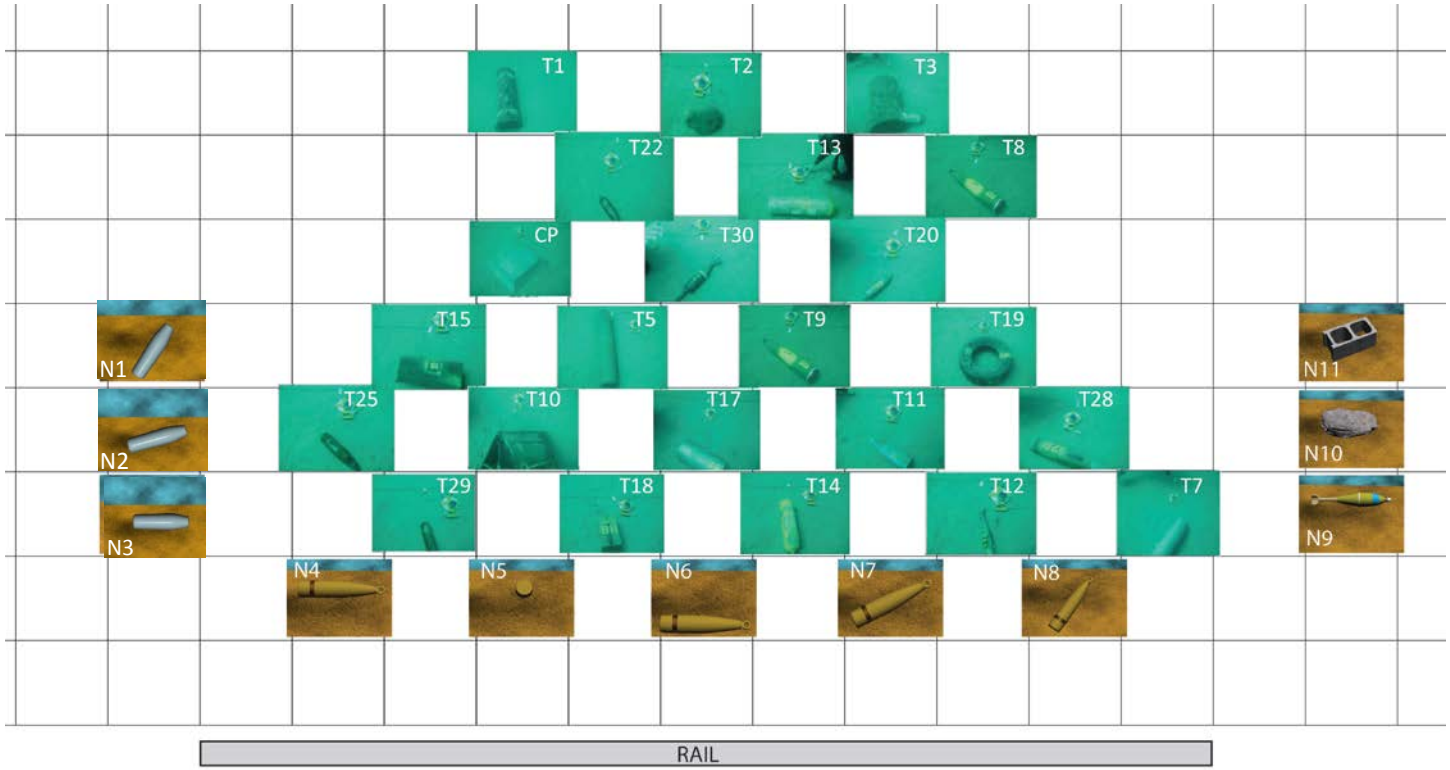


60’ water depths

Planned Placement of the Targets

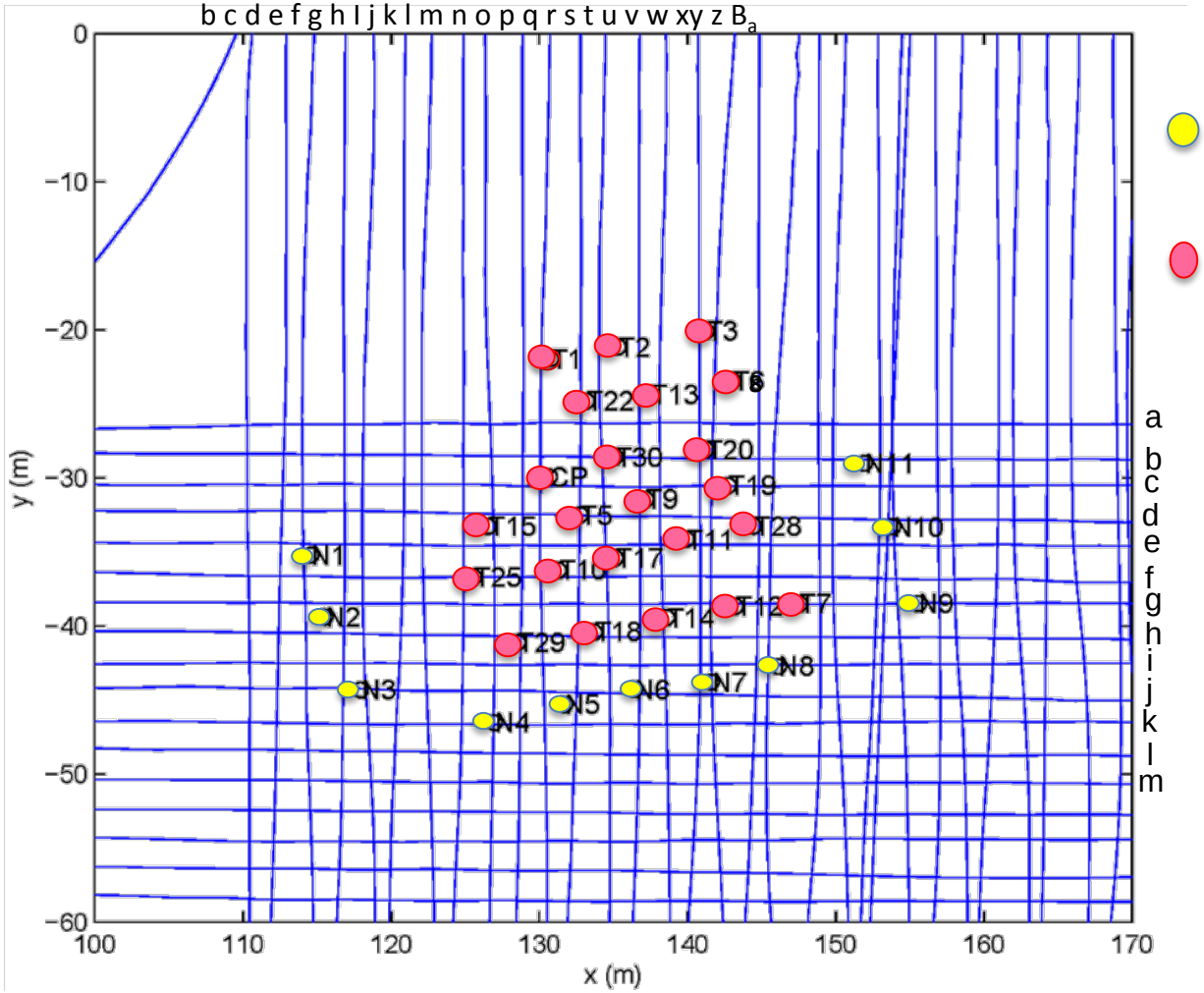
Buried Targets





Targets are separated by approximately 5 meters (5 meter grid).

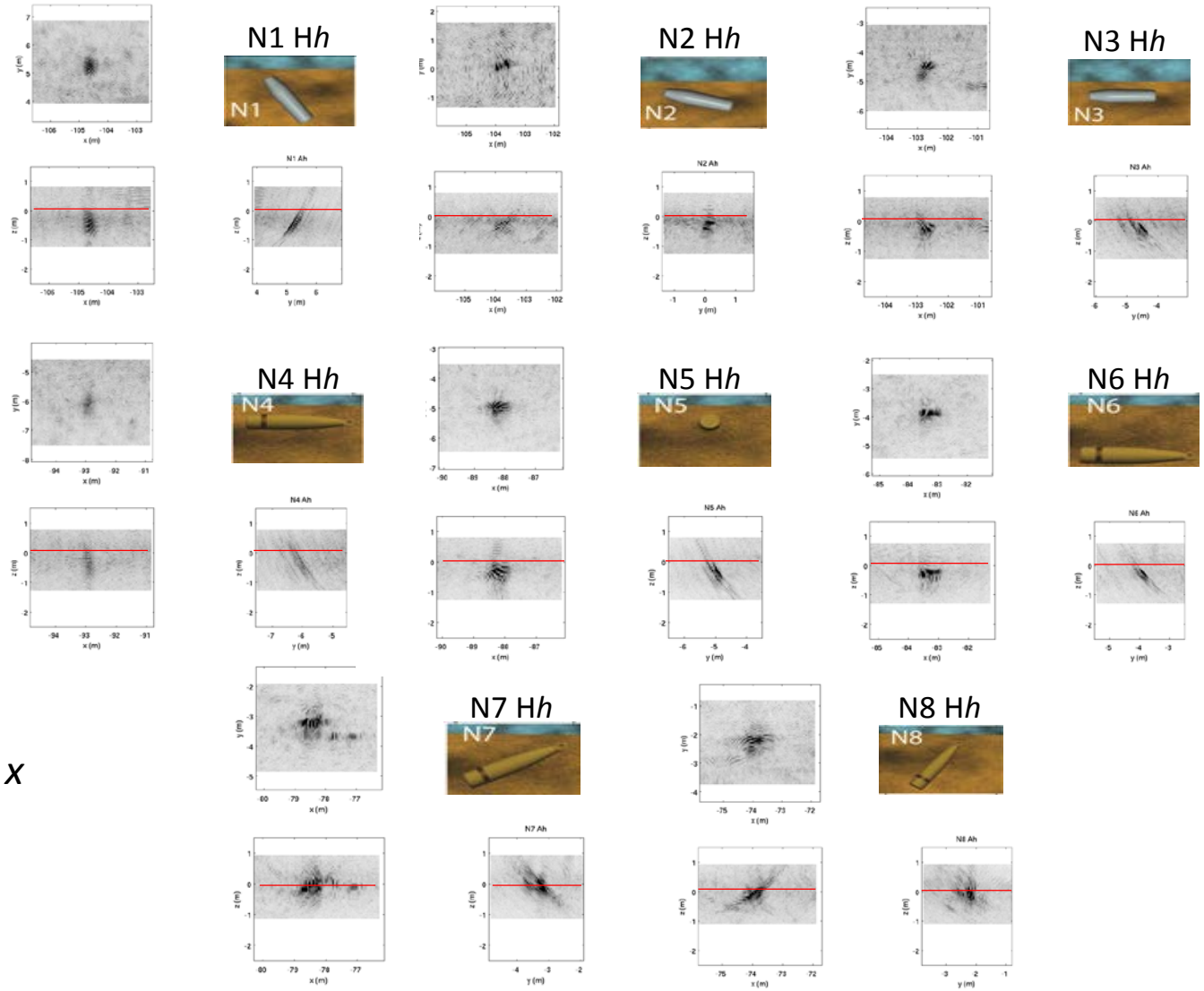
Target Locations Relative to the East-West and North-South AUV Flight Paths

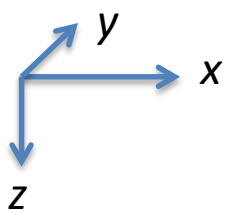


NRL Buried Targets

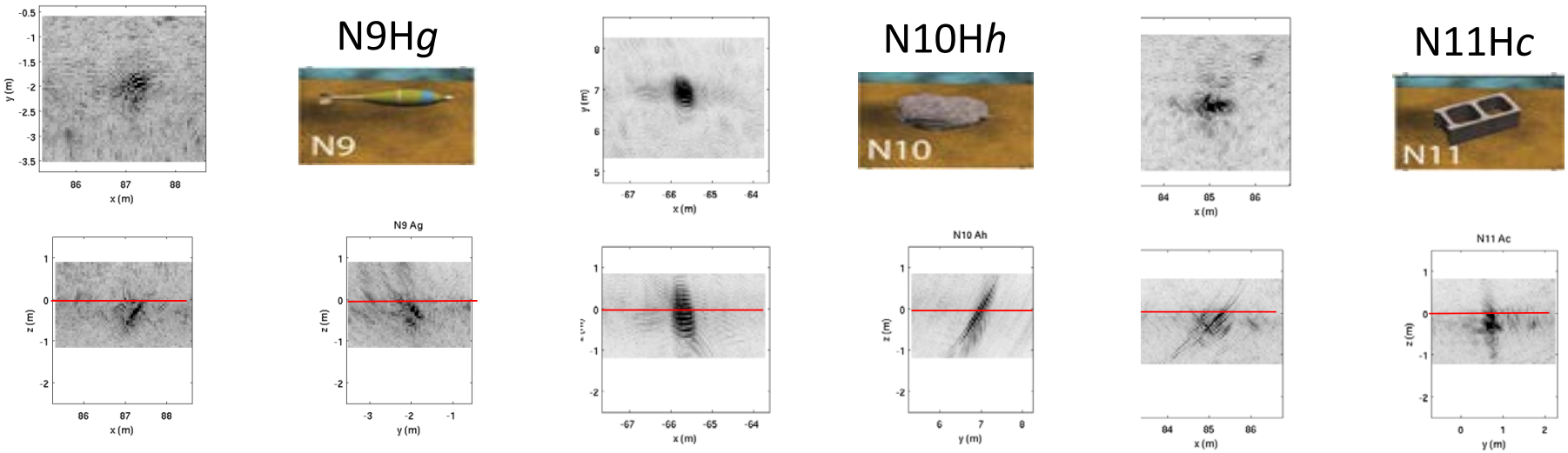
Gulfex13 Proud Targets

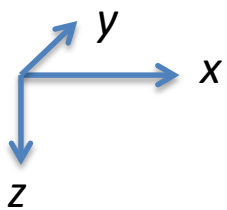
2-D Images Extracted from the Measured Data





2-D Images Extracted from the Measured Data



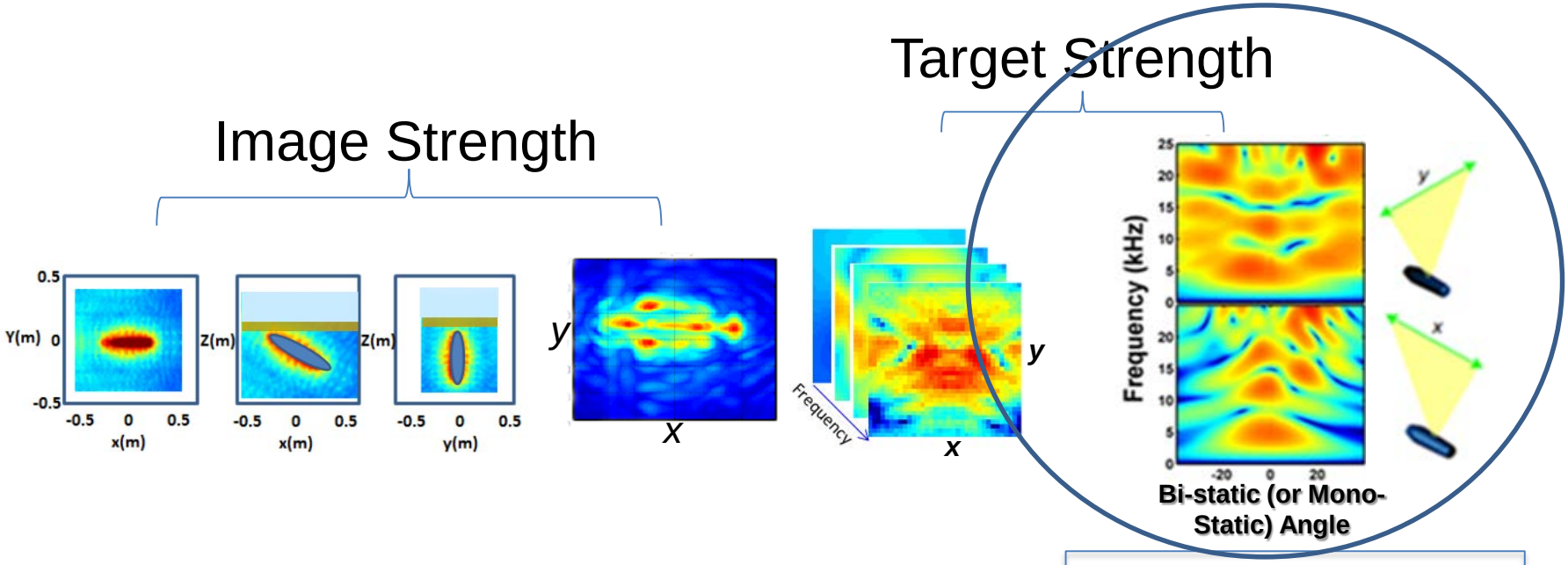


Summarizing the BOSS Gulf and St. Andrews Bay Images

- A few images incorrectly show a partially buried target
  - Sediment sloping introduces this ambiguity at longer ranges
- Several horizontal target depth images deviate from intended burial angle
  - Shift in burial orientation with time?
- Image target lengths correct but widths doubled
  - Resolution limit for our imaging process (data collection, aperture and imaging algorithm) ~ 0.1 - 0.25 m

SA Band

- Target strength (Acoustic Color) provides multi-dimensional classifying features

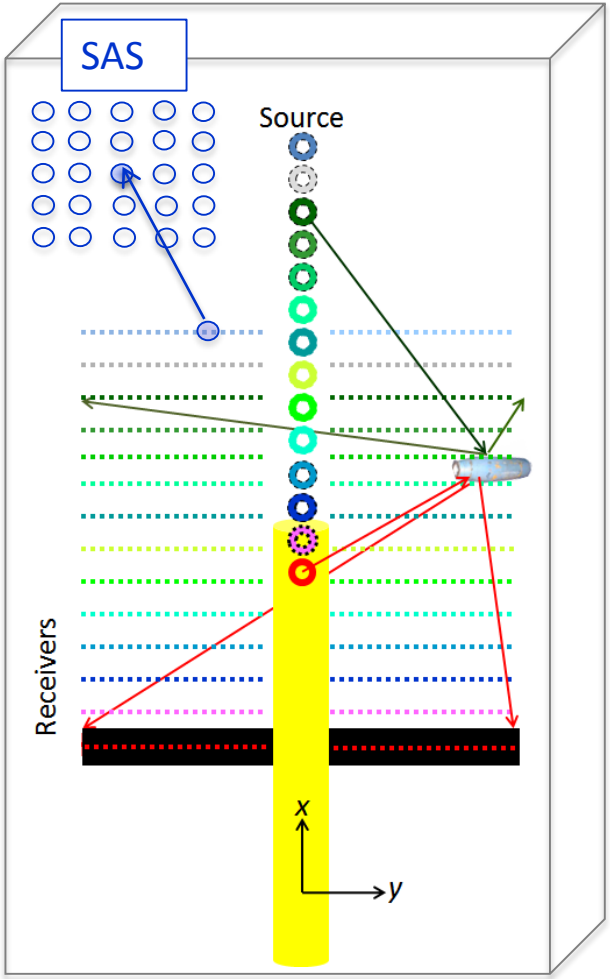


(d)
Target Strength
vs θ,ω
(Acoustic Color)

Source: Bucaro et al.

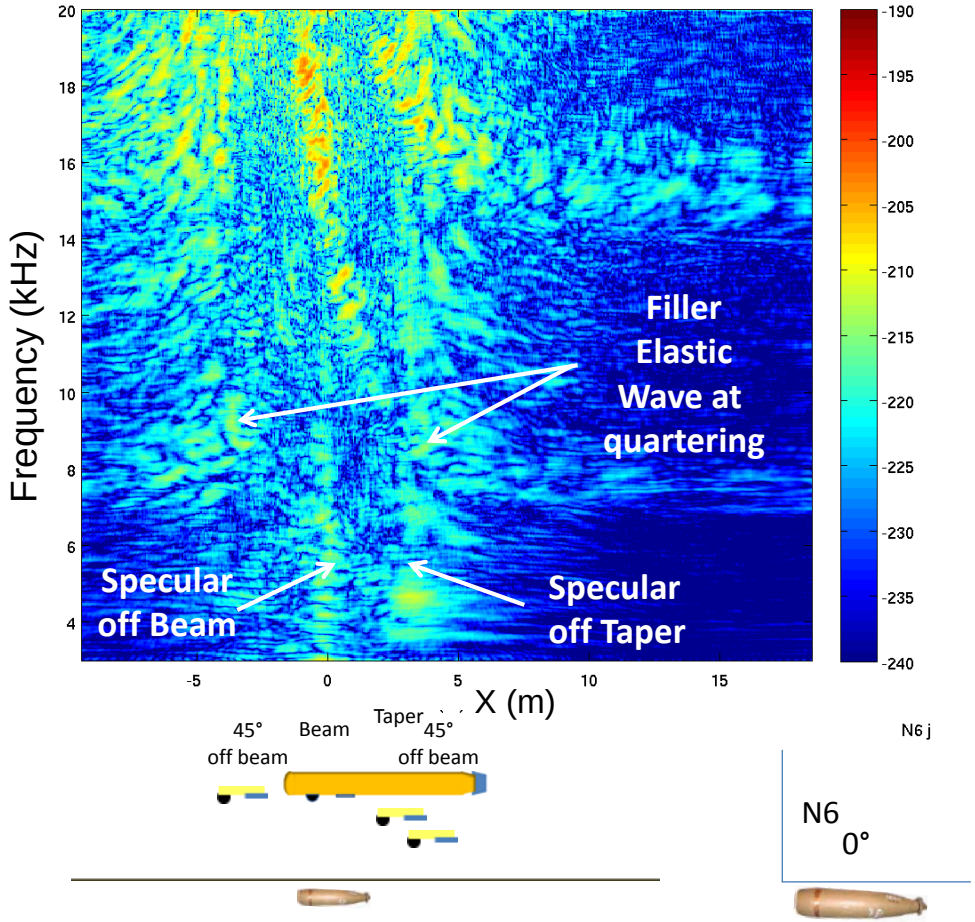
How is Target Strength (Acoustic Color) Obtained?

- Target center coordinates are determined from the image
- At that target location, SAS processing is performed. For each receiver (x,y), signals at neighboring receiver locations are time-aligned and their mean computed. The result, $p(x,y,\omega)$, becomes the SAS processed pressure value at that receiver location for the particular target
- Acoustic color is $20\log|p_y(x,\omega)|$ for a particular wing receiver



Acoustic Color (Arbitrary dB Units)

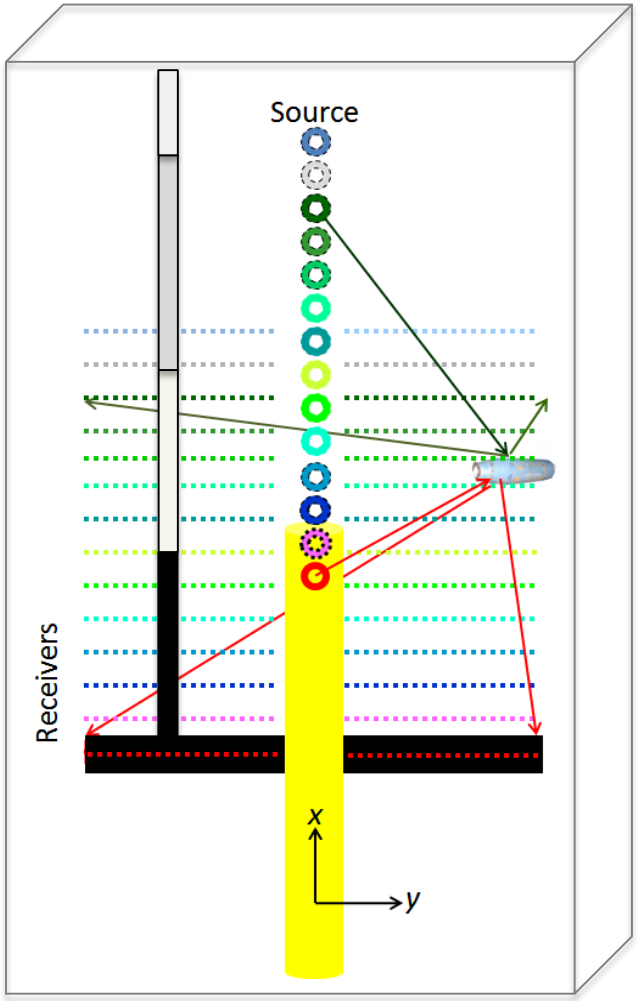
Scattering Levels Versus Frequency and x Position of the Receiver for Target N6



The several source (black sphere) and receiver (blue bar) locations shown help visualize the source/receiver angles along the x co-ordinate of the color plots

How are Acoustic Color Features Extracted from Scattering Data?

- The features are obtained from the narrowband complex scattered pressure values for a fixed y co-ordinate (a particular receiver on the BOSS wing) at 21 equally spaced x co-ordinates (the flight path direction) centered on the target CPA as the AUV flies by
- These 21 complex echo level values are determined for each of the 383 frequencies in the 3 to 13.3 kHz band giving a ~16,000 dimensional feature for each of the 40 receivers



Proud and Buried Target List

Proud Targets

T1	DEU Trainer
T2	Rock
T3	55 Gallon Filled Drum
T5	5:1 Aspect Phone Pole Section
T7	3ft Aluminum Cylinder
T8	155mm Projectile w/o collar
T9	155mm Projectile w/ collar
CP	Panel Target
T11	152 mm TP-T
T12	81mm Mortar
T13	Scuba Tank w/water w/o stem
T14	Scuba Tank w/water w stem
T15	2:1 Aspect Phone Pole Section
T17	2 ft Aluminum Cylinder
T18	Cement Block
T19	Tire
T20	Aluminum UXO Replica
T22	Original Material UXO
T25	Bullet #1
T28	155mm Projectile w/collar
T29	Bullet #2
T30	Finned Shell #1

NRL Simulant–Filled Buried Targets

N1	5inch Rocket nose-up 60°
N2	5inch Rocket nose-up 30°
N3	5inch Rocket horizontal
N4	155mm Projectile horizontal
N5	155mm Projectile horizontal 90°
N6	155mm Projectile horizontal 20cm
N7	155mm Projectile nose-up 30°
N8	155mm Projectile nose-up 60°
N9	120mm Mortar horizontal
N10	Large Rock (no simulant)
N11	Cinder Block (no simulant)

For this study:

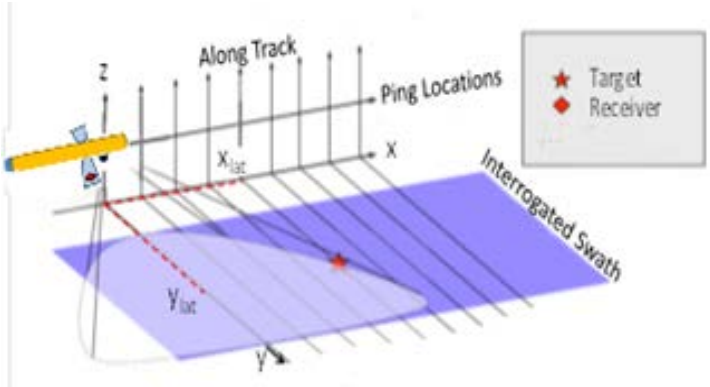
N1 – N9: 9 Buried UXOs *w/epoxy filler*

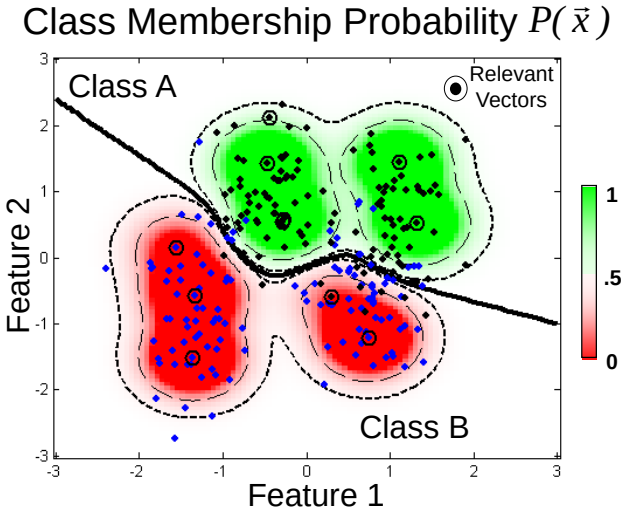
◯: 9 False Targets (7 Proud – 2 Buried)

Target Separation Using RVM Classifier

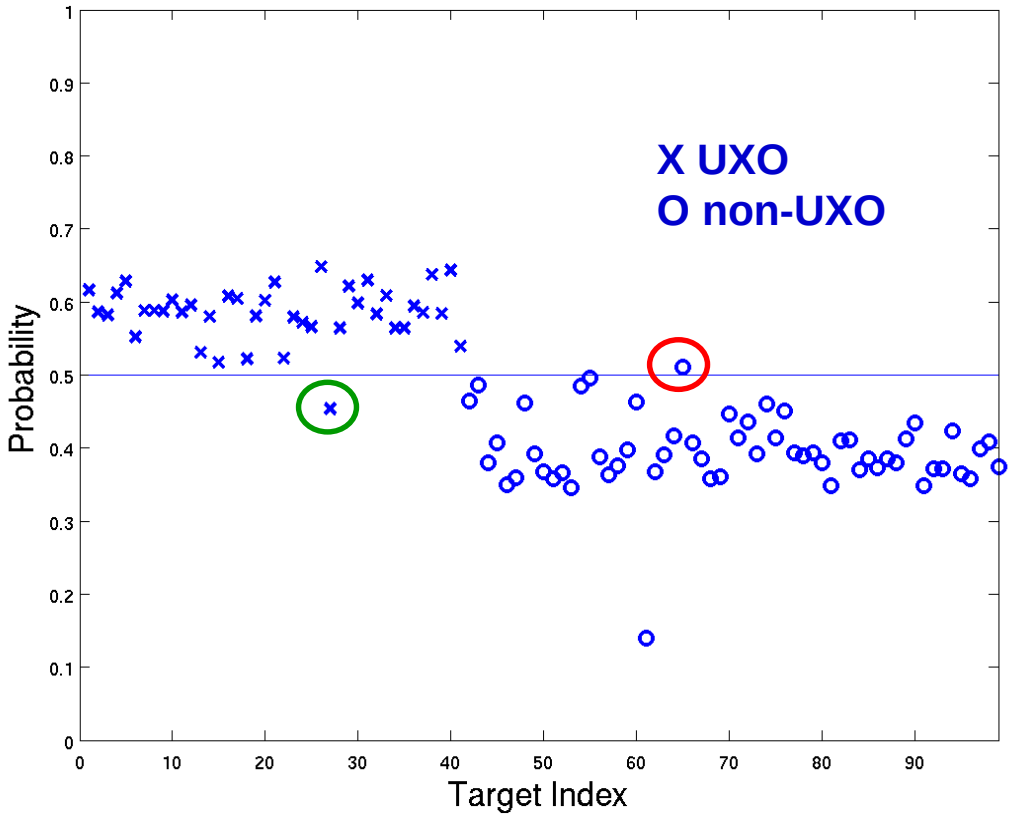
How well can this multi-dimensional feature separate UXO from false targets?

- RVM classifier trained discriminatively using signals from even numbered source pings and tested using odd numbered source pings
- We combine the probabilities over the 40 y positions (receivers) by taking the product of the probabilities at each receiver (y) raised to the 1/40 power
- Vertical paths having good target images (~ 5 paths/target) are used
- Training/testing on ~90 realizations (5 paths for each of the 18 targets)

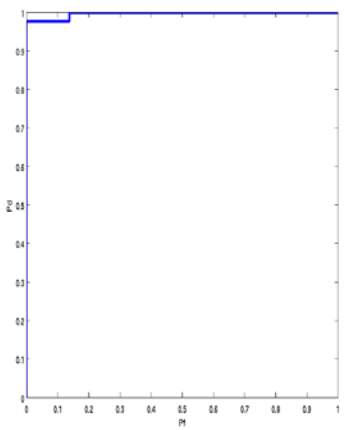




Probability that a Detected Target is a UXO Using the Combinatorial Probability Alternating Pings - North/South Paths



ROC Curve

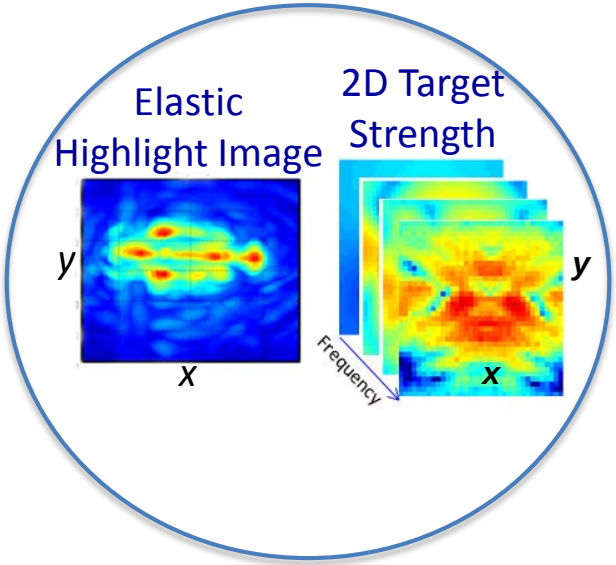


False negative: N7 path *n*

False Positive: T15 path *m*

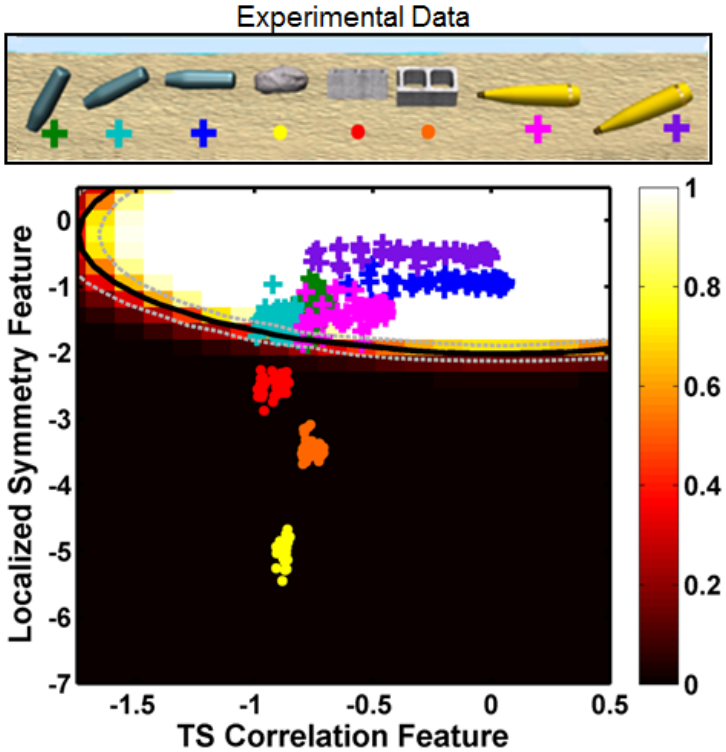
Buried Target Classification using Numerically Trained Classifier

- Numerical model data bases used to train RVM classification algorithm
- Demonstrated buried UXO/false target classification in sediment pool (2 features)



2-D Feature Space

Image Symmetry	TS Correlation Against Template



Summarizing the Acoustic Color Studies

- Accurate echo measurements (including acoustic color) for buried targets are possible using BOSS
- A suitably trained RVM classifier (our next goal) should be able to separate most detections into UXO versus non-UXO for the cylindrically symmetric UXOs and class of false targets studied here
- Methods to incorporate the spatial and temporal behavior of the projector's incident field will lead to improvements in the various constructs

Final Comments

- Commercially available high resolution sonars are very capable of detecting, localizing and identifying proud UXO targets
- Structural acoustic sonars and data processing techniques are under development for detecting, localizing and identifying buried UXO targets

Acknowledgements

- A significant portion of the contents of this webinar has been assembled from my research at NRL as an on-site contractor with my collaborators Dr. Angie Sarkissian, Dr. Brian H. Houston, Dr. Zachary Waters, Dr. Timothy J. Yoder, Dr. Harry Simpson, Mr. Michael Saniga, Dr. Saikat Dey, and Mr. D. Amon, all of whom are with the Physical Acoustics Branch at NRL
- The work was made possible by the long term SERDP program support managed by Dr. Herb Nelson and through complementary NRL and ONR programs

Target Construct and Features References

- Paul J. Carroll, “Underwater (UW) Unexploded Ordnance (UXO) Multi-Sensor Data Base (MSDB) Collection,” Final report SERDP Project MM-1507, July 2009.
- Robert A. Leasko, Charles L. Bernstein, Richard Holtzapple, and Jesse I. Angle, “Munitions Detection using Unmanned Underwater Vehicles Equipped with Advanced Sensors,” Interim Report, ESTCP Project MR-201103, June 29, 2012.
- Z.J. Waters et al. “Bistatic, above critical angle scattering measurements of fully buried unexploded ordnance (UXO) and clutter ,” J. Acoust. Soc. Am., 132, pp. 3076–3085 (2012).
- J.A. Bucaro, Zachary J. Waters, Brian H. Houston, Harry J. Simpson, Angie Sarkissian, Saikat Dey, and Timothy J. Yoder, “Acoustic Identification of Buried Underwater Unexploded Ordnance Using a Numerically Trained Classifier,” J. Acoust. Soc. Am., 132, 3614-3617 (2012).
- J.A. Bucaro, B.H. Houston, M. Saniga, H. Nelson, T. Yoder, L. Kraus, and L. Carin, “Wide Area Detection and Identification of Underwater UXO Using Structural Acoustic Sensors – NRL/MR/7130 -06-9014 Report to SERDP MM-1513,” December 2006.
- J.A. Bucaro, B.H. Houston, H. Simpson, D. Calvo, L. Kraus, T. Yoder, M. Saniga, S. Dey, and A. Sarkissian, “Wide Area Detection and Identification of Underwater UXO Using Structural Acoustic Sensors –Final Report to SERDP MR-1513,” February 2011.

For additional information, please visit
https://www.serdp-estcp.org/Program-Areas/Munitions-Response/Underwater-Environments/MR-2103

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Q&A Session 1

SERDP DOD • EPA • DOE | ESTCP

Low Frequency Acoustic Scattering by Underwater UXO and its Use in Classification

Dr. Kevin Williams,
University of Washington

SERDP DOD • EPA • DOE | ESTCP

Low Frequency Acoustic Scattering by Underwater UXO and its Use in Classification

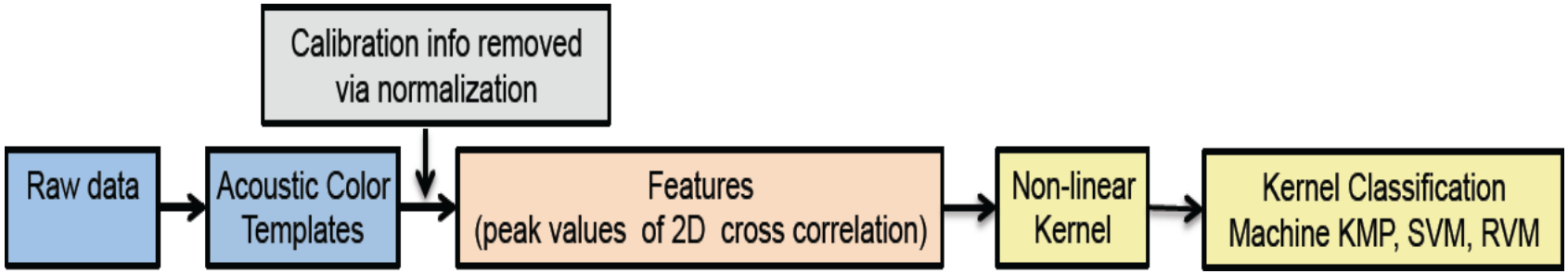
Dr. Kevin Williams
Applied Physics Laboratory, University of Washington

Objective

- Give a perspective on current state of the art of UXO classification via low frequency acoustics
  - Based on a recent Acoustical Society of America (ASA) special session
    - The session brought together many US researchers in MCM/UXO acoustics community
    - Talks spanned the entire “raw data to final classification” processing chain
- Help pose questions, identify needs for those looking to assist in solving the problem

Outline

- Set the context, including the risks and challenges, inherent in underwater UXO remediation
- Discuss some of the current research aimed at addressing the "building blocks" of target classification using Low Frequency (LF) acoustics and indicate some of the United States researchers involved in studying the problem



Disclaimer: *This presentation is one perspective based on current efforts as presented at the Fall 2014 Acoustical Society of America conference. Those presenters (and others in the field) would certainly have different perspectives*

Context

- SERDP Workshop 2007 and 2013 reports (accessible via SERDP website), with the following excerpts from the 2013 report:
  - "Current areal estimates of munitions in underwater environments exceed 10 million acres"
  - "The U.S. Army Corps of Engineers has identified more than 400 underwater Formerly Used Defense Sites that are contaminated with munitions. The Navy Munitions Response Program currently has an additional 57 closed and active sites potentially contaminated with munitions"
  - "Over 70% of UXO are probably buried"

Context (Continued)

- Challenges
  - Low visibility in the water column, limited range of Electro-Magnetic energy
  - Even more severe attenuation of E&M and acoustics in ocean sediments.
  - Expense of remediation as compared to the land case
  - Mobility of UXO due to wave action/currents
  - Making informed decisions on remediation vs. risks of leaving UXO in place
- Risks
  - Harm to recreational users of area due to UXO detonation
  - Harm to the environment due to release of UXO internal material
- Needs
  - Principled methods to assess risks and thus make informed decisions on remediation versus leave-in-place with monitoring to continue to assess risk

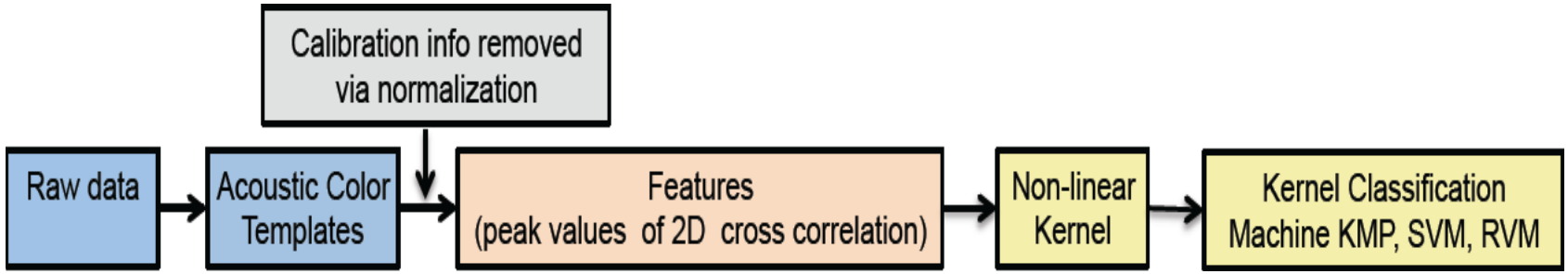
Context (Continued)

- Why acoustics?
  - Much lower attenuation than E&M fields in the water column
- Why low frequency (1-50 kHz) acoustics?
  - Scattering from target includes information on composition
  - Penetration depth into sediments goes up as frequency goes down
  - Example: Attenuation in sand sediments 0.33 dB/m/kHz

1 kHz implies 0.33 dB/m, 10 kHz implies 3.3 dB/m
100 kHz implies 33.3 dB/m
(20 dB is factor of 10 reduction in level,
40 dB a factor of 100)

The UXO LF Acoustics Classification Steps

- Example block diagram



- The talks in ASA special session were associated with work being carried out on one or more of these blocks
- End goal – high probability of correct classification
  - Penalty is VERY large for false positives or false negatives
  - Questions: Which is worse? What is acceptable? How do we achieve desired performance?

Raw Data – Experimental

Institutions

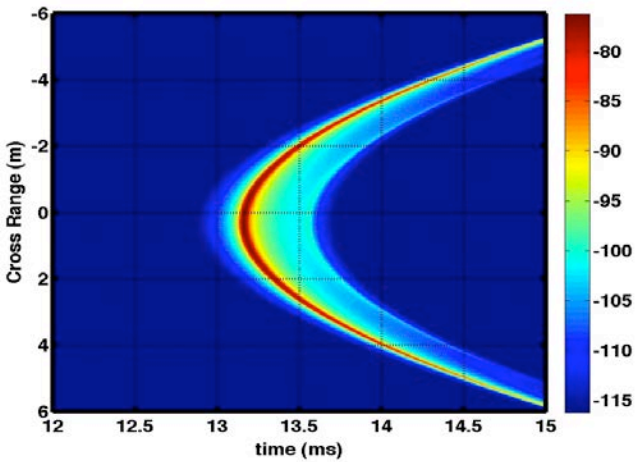
- Applied Physics Lab UW (APL-UW)
- Naval Research Lab (NRL)
- Naval Surface Warfare Center (NSWC-PCD)
- TNO – Netherlands
- Washington State University (WSU)

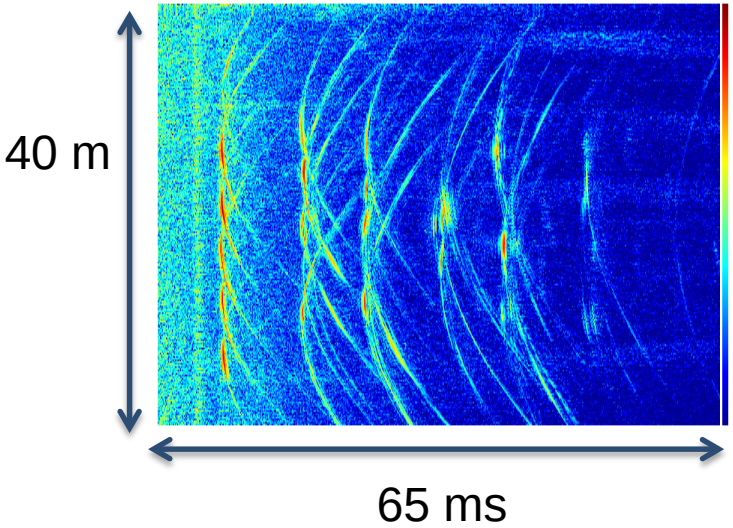
Methods

- Tank experiments
- Rail based ocean experiments
- Ship deployed over-the-side systems
- Autonomous vehicles

Raw Data – Experimental

- Field experiments expensive to carry out
- Limited number of targets
- Limited number of environments/geometries
- Progress to date now allows large number of targets in one experiment
- Raw data sets on multiple targets at multiple ranges available to others – public release and Distribution D (3 -30 kHz)





Raw Data – Model Based

Institutions

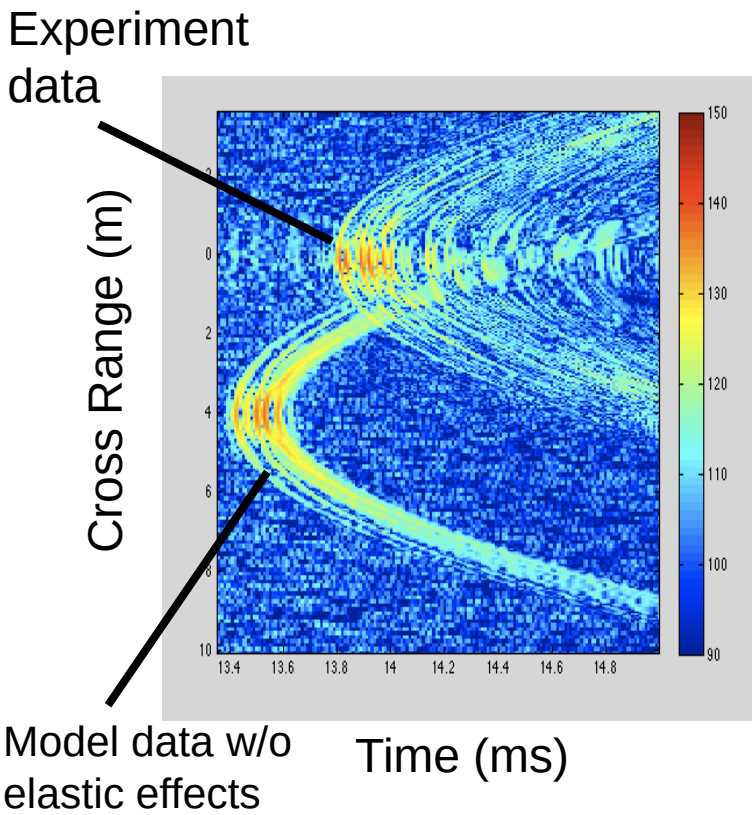
- Applied Physics Lab UW (APL-UW)
- Heat, Light and Sound (HLS)
- Naval Research Lab (NRL)
- Naval Surface Warfare Center (NSWC-PCD)
- TNO – Netherlands
- Washington State University (WSU)

Methods

- Numerical
  - T-matrix
  - 3D finite element
  - Multiple 2D finite element
  - 3D with impedance matrix
  - Helmholtz integral for propagation to the far field
- Analytic
  - Physical acoustics to identify target physics
  - Ray-based propagators for far field calculation

Raw Data – Model Based

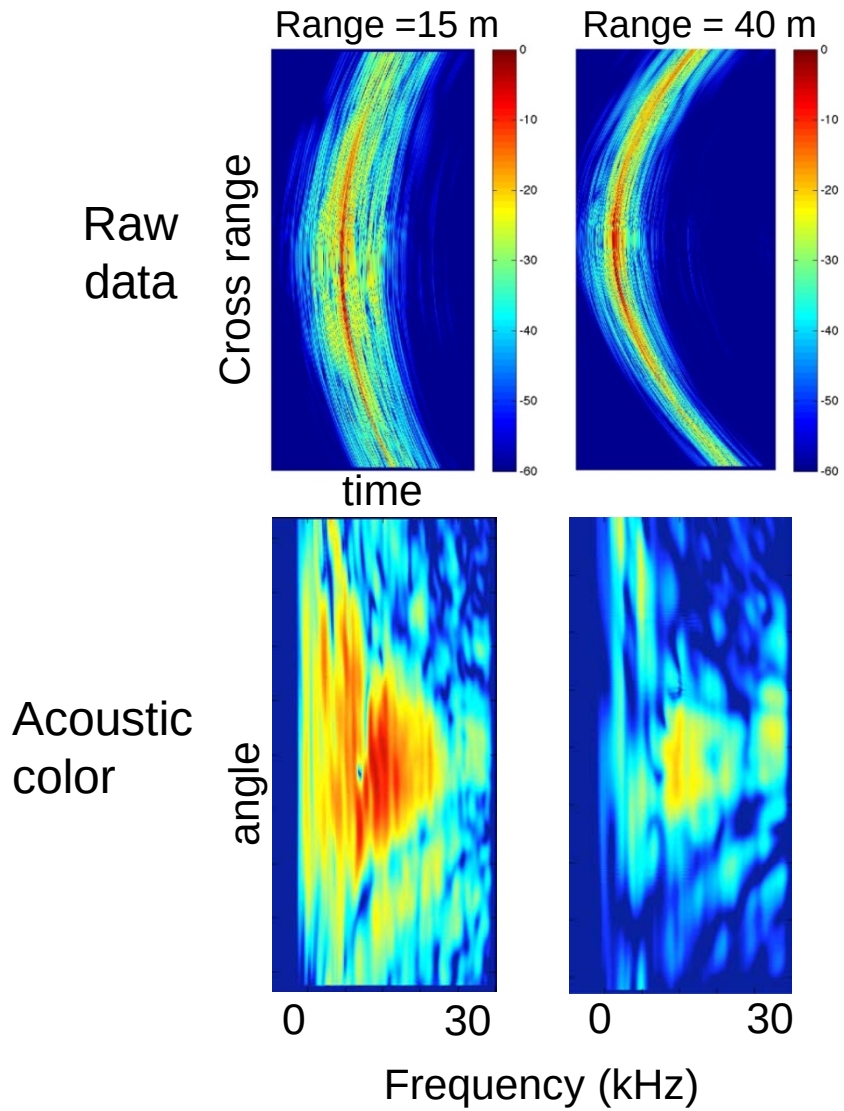
- Reality
  - Target scattering depends on and location in environment
- Goals
  - Produce “stave-level” raw data to augment experiment data for more targets and geometries
  - Understand the scattering physics
  - Identify robust “features”
- Requirements
  - High fidelity – including elastic (composition) effects
  - High speed



High fidelity models now used include target elastic effects as well as propagation environment

Data Products

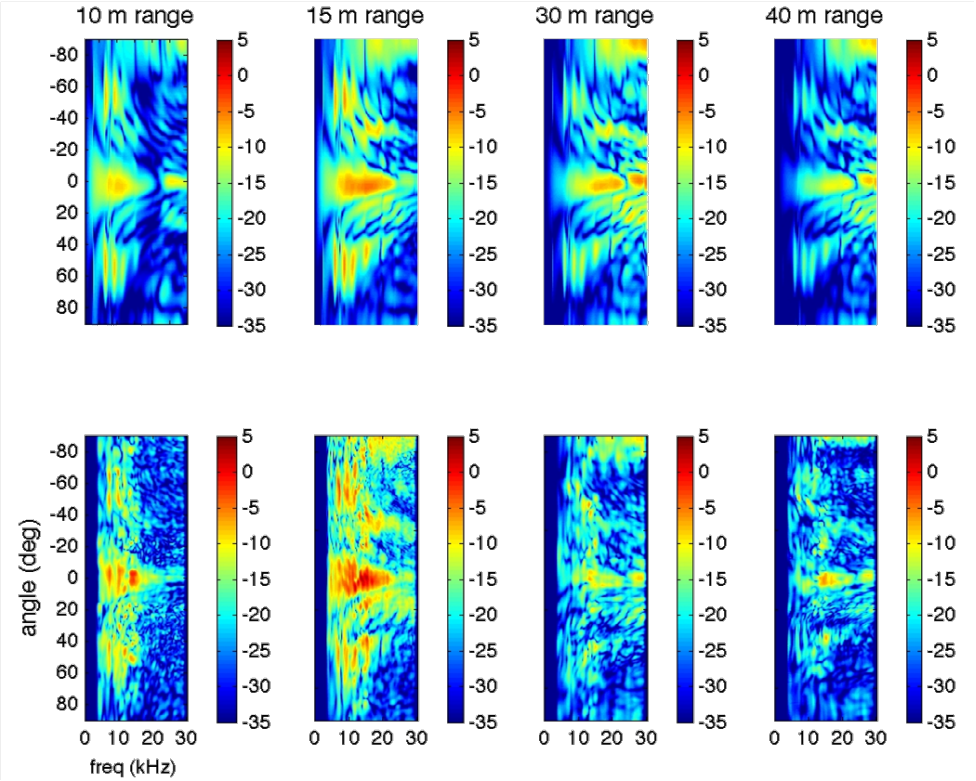
- Processing has been carried out into different spaces
  - (x, y) synthetic aperture
  - (x, t) holographic
  - (angle, frequency) acoustic color
  - ???
- Questions
  - Which spaces allow separation of elastic physics from shape physics?
  - Can combining results from different spaces improve classification?



Data Products

- Acoustic color - sensitivity to environment
- General range dependence predicted by models valid in ocean
- Note an optimal 15 m range (actually grazing angle=14º) for this target

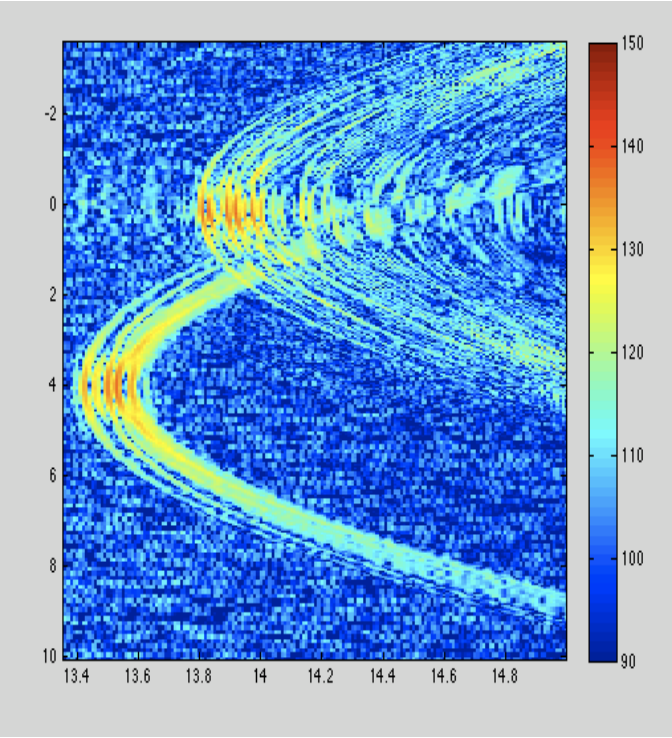
Model



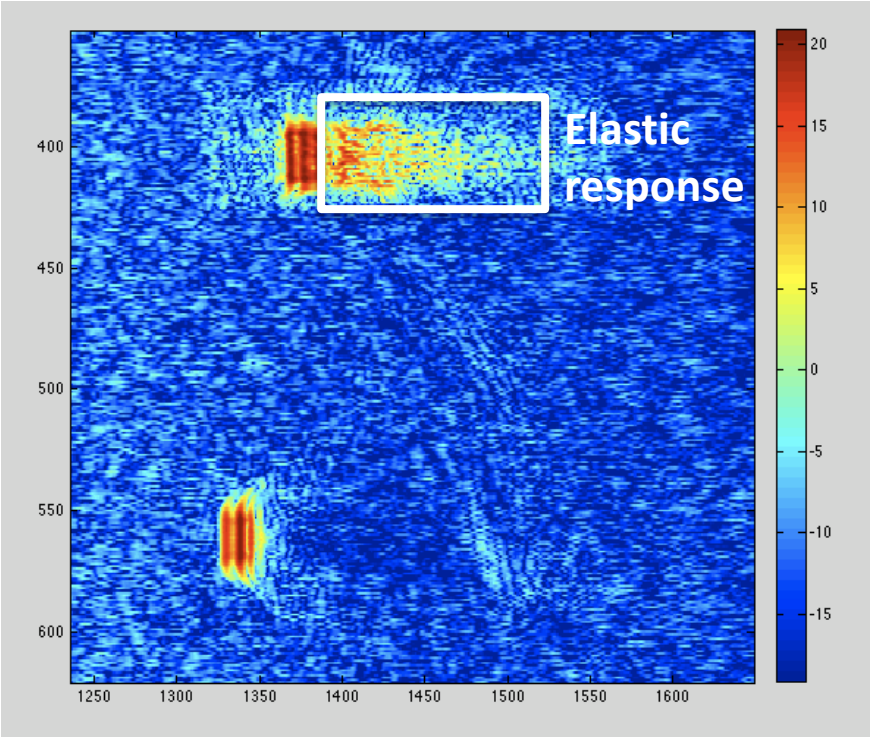
Ocean data

Data Products

- Synthetic Aperture Sonar (SAS) processing



Raw data



SAS Image

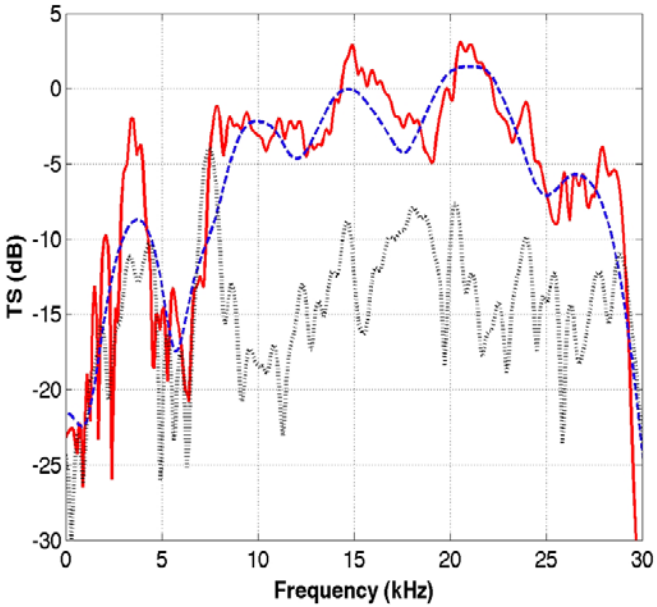
Data Products

Separating elastic physics

Example courtesy of Dr. Philip Marston (WSU)

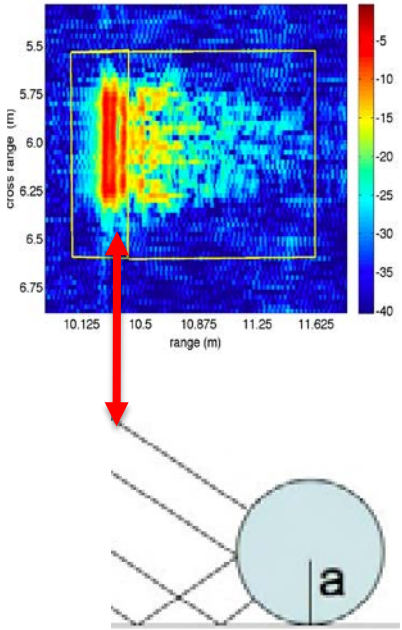
Method developed by Dr. Timothy Marston (NSWC-PCD and APL-UW)

Examples from cylinder proud on sand



Backscattering TS after SAD filtering
Red: Total
Blue dashed: Early triplicate only
Short dashed: Late elastic only

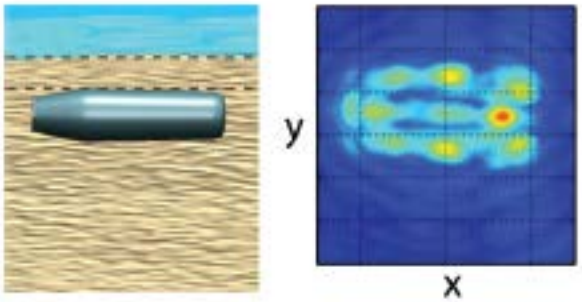
Image of 2:1 Alum cyl



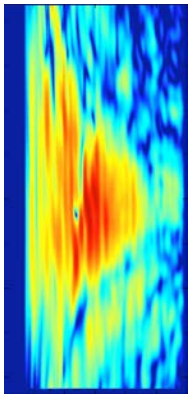
- Williams et al. 2010. JASA
- Baik and Marston. 2008. IEEE JOE

Classification Features

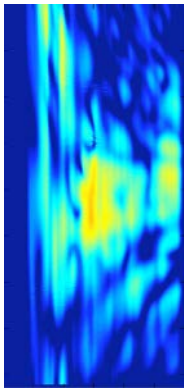
- Goal
  - Features robust to changes in environment and geometry
  - Features sensitive to composition
  - Features that exploit target physics
- Status – examples
  - Image based (e.g., symmetry)
  - Acoustic color based
- Needs
  - Multidimensional feature vectors
  - Insight from other communities
    - Music
    - Speech



Symmetry of image
(J. Acous. Soc. Am., Vol. 132, Bucaro et al.)



Cross correlation of acoustic color templates

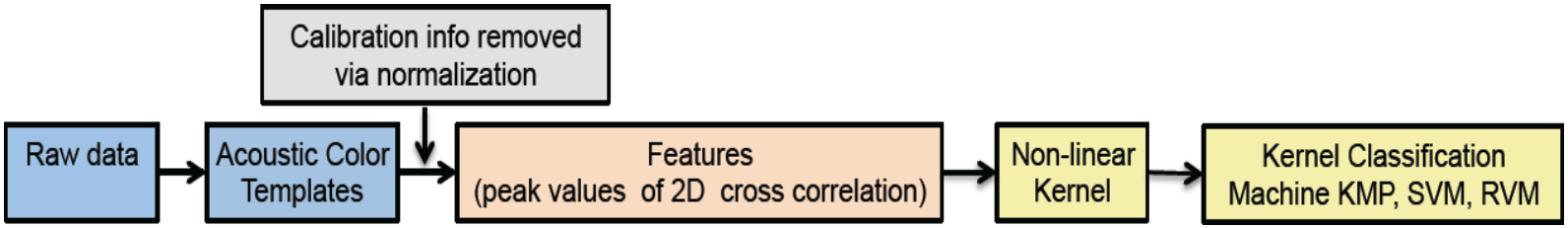


Classification

- Example
  - Use cross correlation of acoustic color template as features
  - Implemented by several groups
  - Inherently incorporates target physics but does not exploit physical understanding of target scattering
  - **Need**: Start at the raw data and develop alternative processing

Classification

- Example: APL-UW implementation

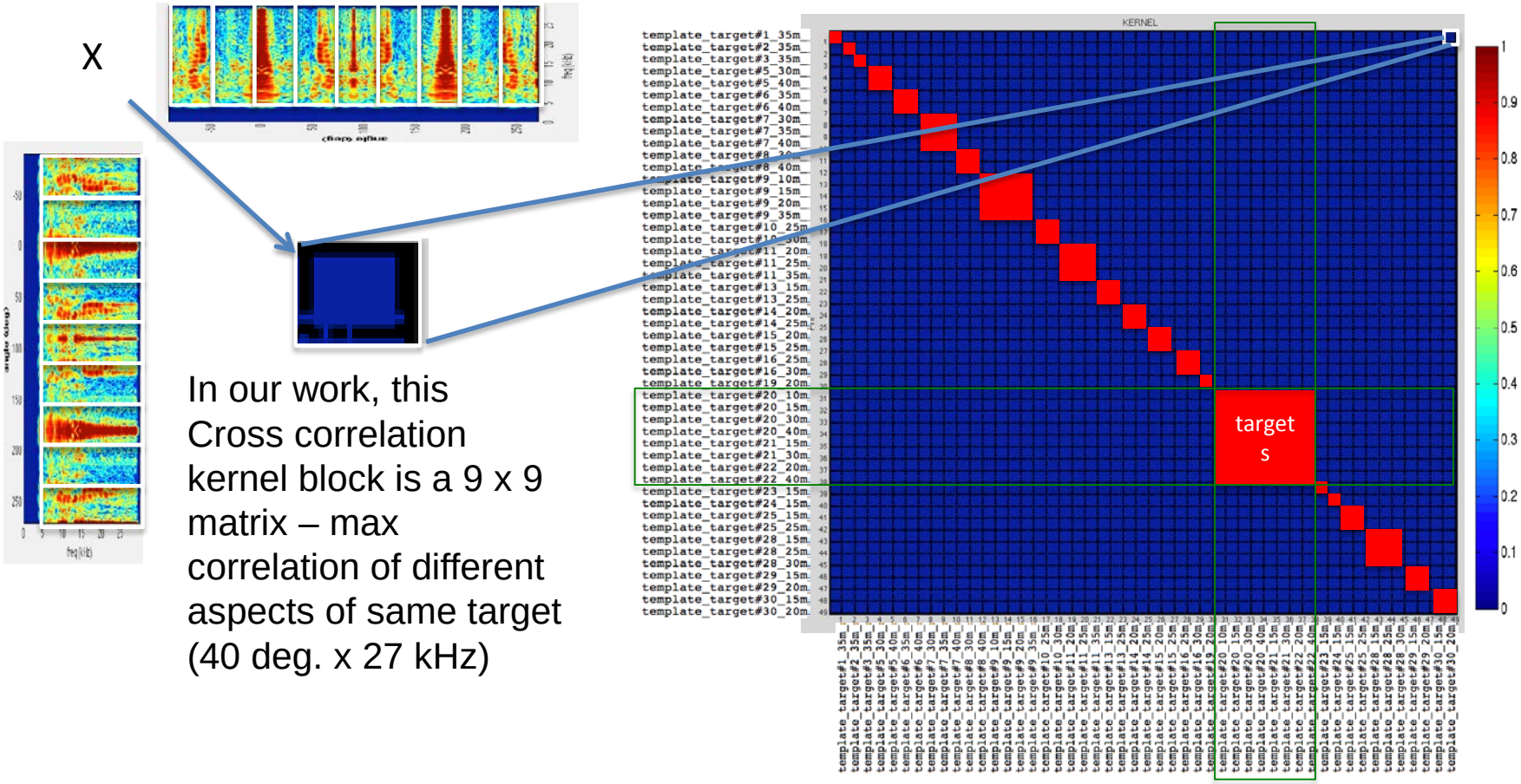


- In a "Perfect Kernel" World
  - All non-targets give perfect correlation with themselves at all aspects and all ranges
  - All targets look exactly alike at all aspects and all ranges
  - Replacing an experiment feature with a model feature would give the same result

Classification

- Pictorial version of a “perfect kernel” world

x

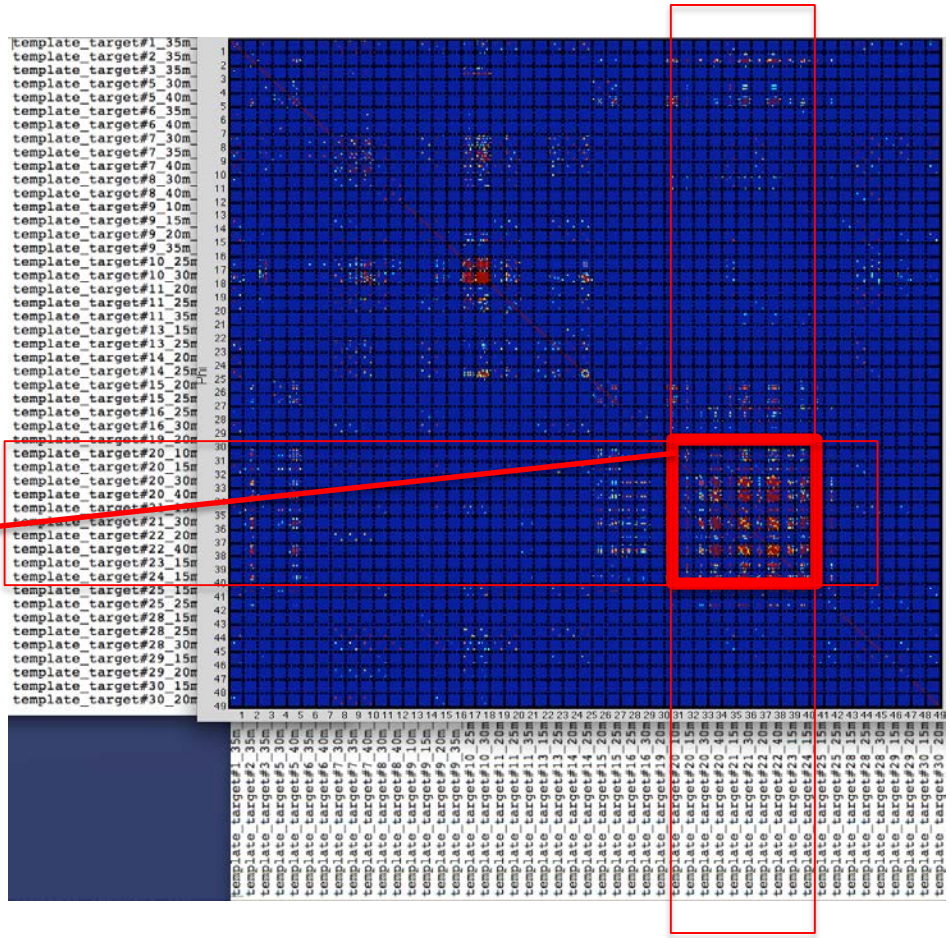


In our work, this Cross correlation kernel block is a 9 x 9 matrix – max correlation of different aspects of same target (40 deg. x 27 kHz)

Classification

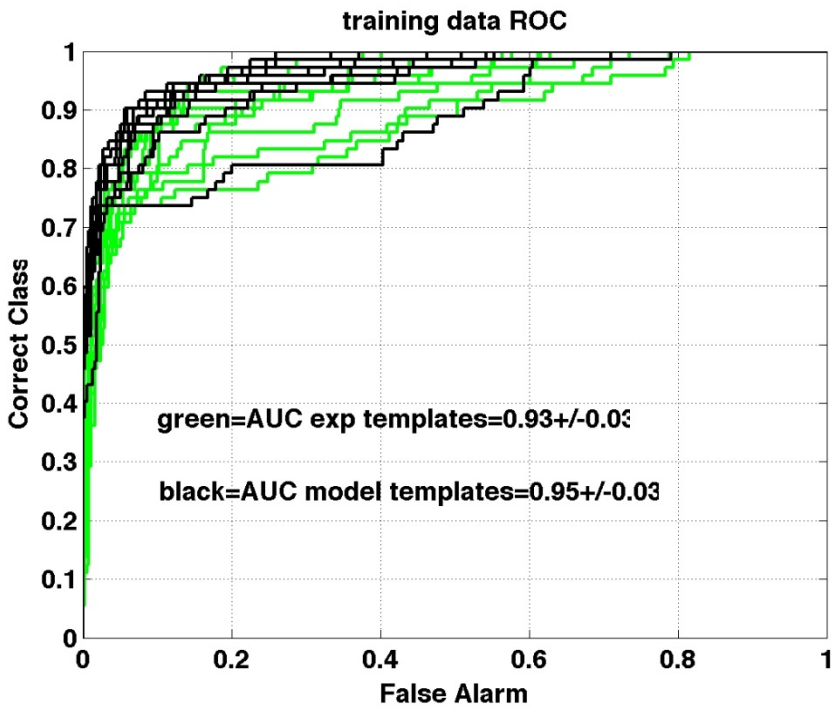
- A Real Kernel from Ocean data

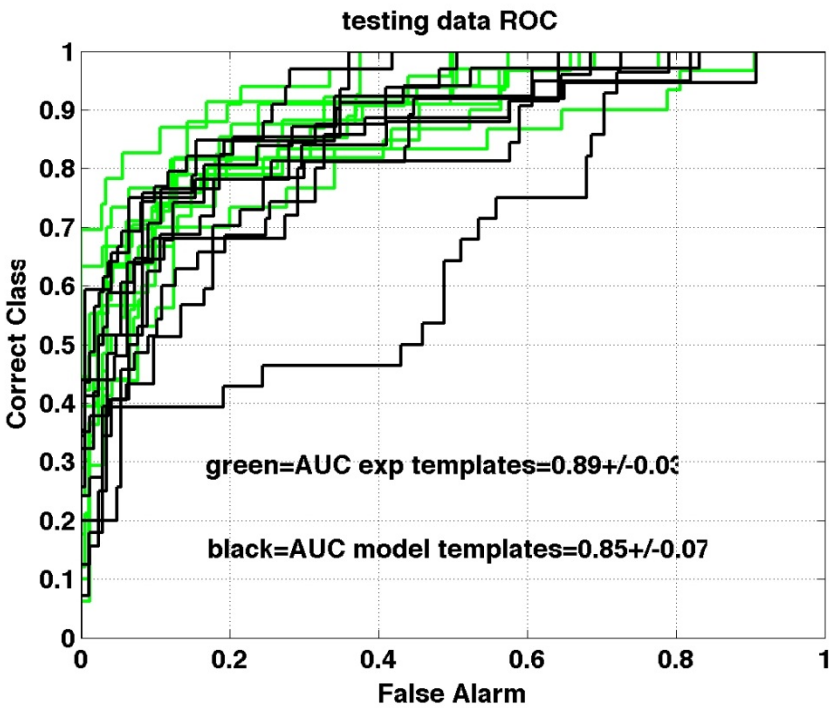
Target #	Target Name
1	DEU trainer
2	Rock
3	55-gallon drum, water filled w/ fixture
4	XXXXXXXXXXXXXXXXXX
5	5:1 aspect telephone pole section
6	55-gallon drum, water-filled
7	3 ft alum cylinder
8	155 mm Howitzer w/o collar
9	155 mm Howitzer w/ collar
10	panel target - Dan Brown
11	152 mm TP-T
12	81 mm mortar
13	Scuba tank, water-filled, w/o stem
14	Scuba tank, water-filled, w/ stem
15	2:1 aspect telephone pole section
16	2 ft alum pipe
17	2 ft alum cylinder
18	Cement block
19	Tire
20	Alum UXO replica
21	Steel UXO replica
22	Original material UXO
23	Solid alum cylinder w/ notch
24	Hollow alum cylinder w/notch
25	Bullet #1
26	XXXXXXXXXXXXXXXXXX
27	XXXXXXXXXXXXXXXXXX
28	155 mm Howitzer w/ collar
29	Bullet #2
30	Finned Shell #1



Classification

- Classification performance with real Kernel used within Relevance Vector Machine (RVM) classifier



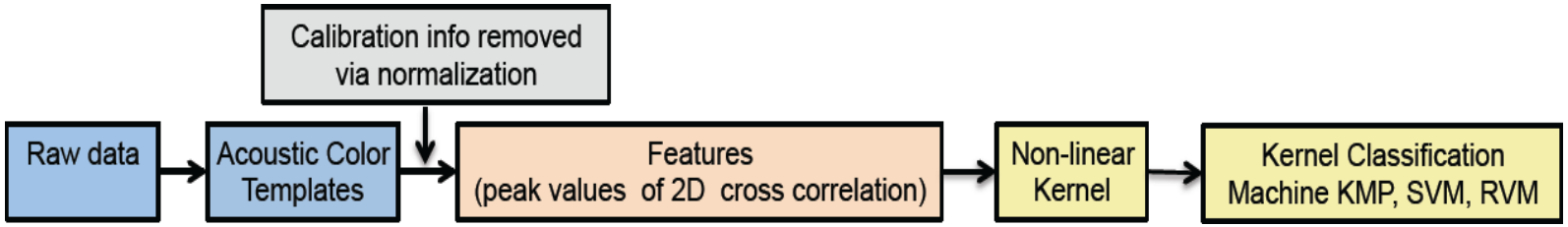


Conclusions

- "Current areal estimates of munitions in underwater environments exceed 10 million acres"
  - We need to detect, classify and remediate where necessary
- LF acoustics is one modality through which to detect/classify
- LF performance may not meet requirements
  - What is an acceptable ROC curve?
  - Where do we need to operate on the Pc/Pfa curve?
- May need other modalities (e.g., HF acoustics, E&M)

Conclusions

- In LF acoustics efforts
  - We are data limited – need models to interpret and augment
  - Our models seem up to the task – for targets modeled to date
  - Our classification feature vectors need to be expanded to better exploit physics
  - Our classification strategies need to include a broader community (e.g., music, speech, bio-sonar)



For additional information, please visit:

https://www.serdp-estcp.org/Featured-Initiatives/Munitions-Response-Initiatives/Munitions-in-the-Underwater-Environment

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Q&A Session 2

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The next webinar is on February 19

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Survey Reminder

Please take a moment to complete the survey that will pop up on your screen when the webinar ends

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