Sediment Volume Search Sonar: Automated Detection and Classification Algorithms

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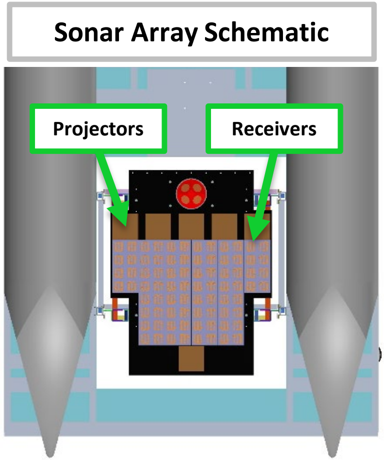
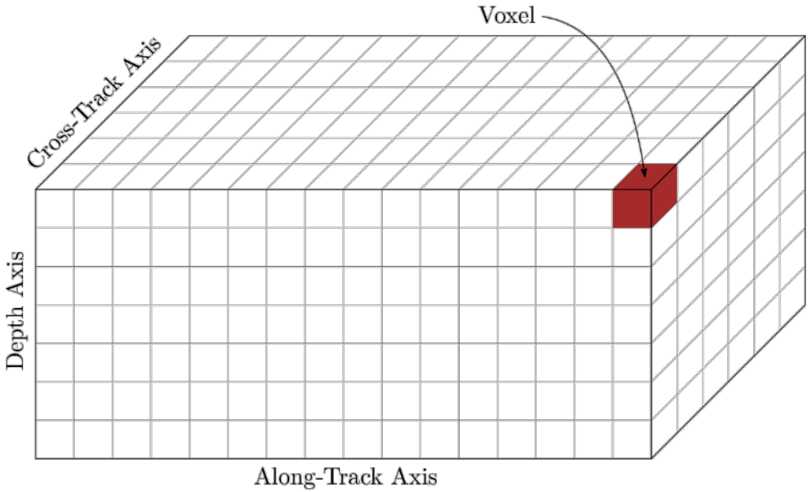
Sediment Volume Search Sonar (SVSS)

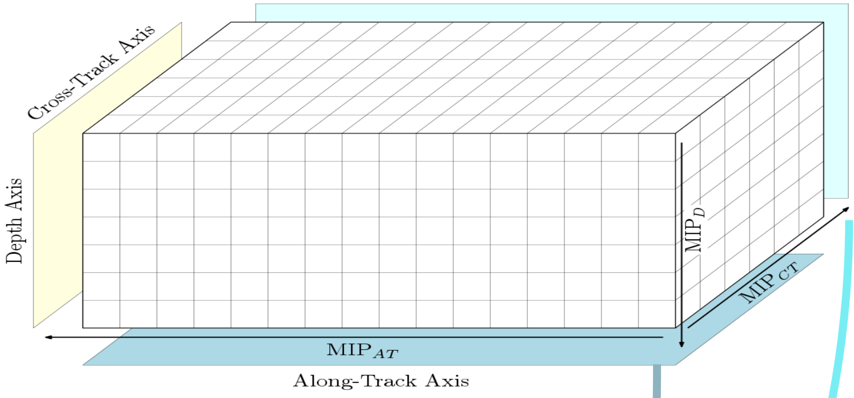
- Detect proud and buried unexploded ordnance (UXO) in shallow water

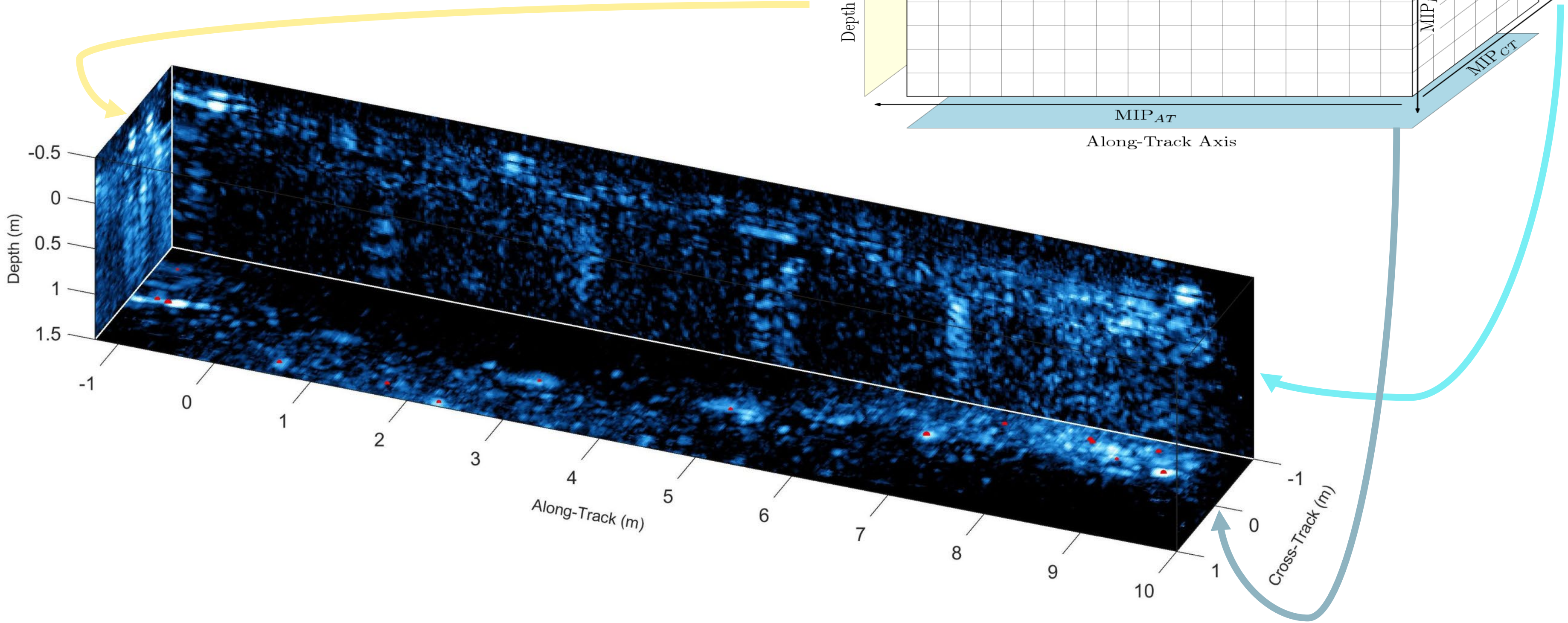




Data Cube Visualization

- Maximum intensity projection (MIP)



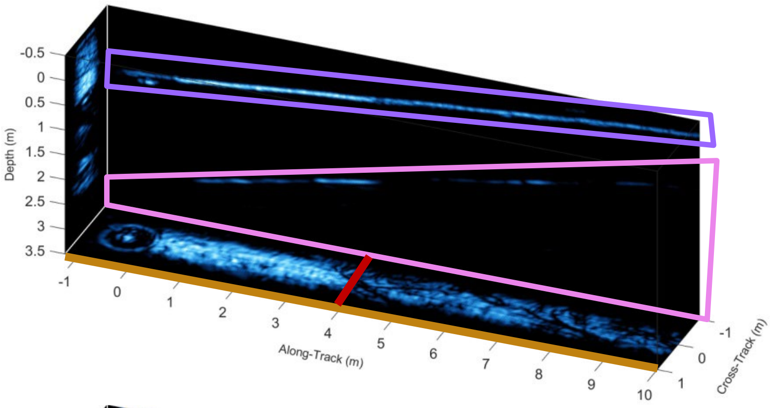


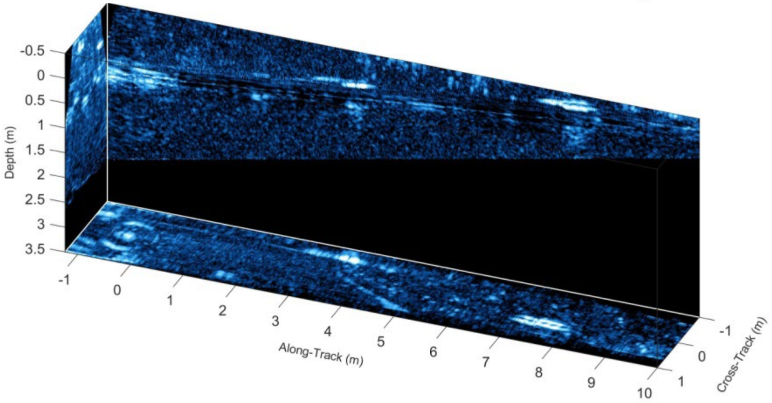
ATR Approach

- Two-stage ATR approach
  - Fast, simple, general-purpose MondrianB detector
    - Generate set of alarms to classify
    - Reduces amount of data to process
  - Follow-on, more sophisticated convolutional neural network (CNN) classifiers
    - Ensemble of tiny CNNs using different architectures and also different input representations
    - Leverage all available information in robust manner

Normalization Algorithm

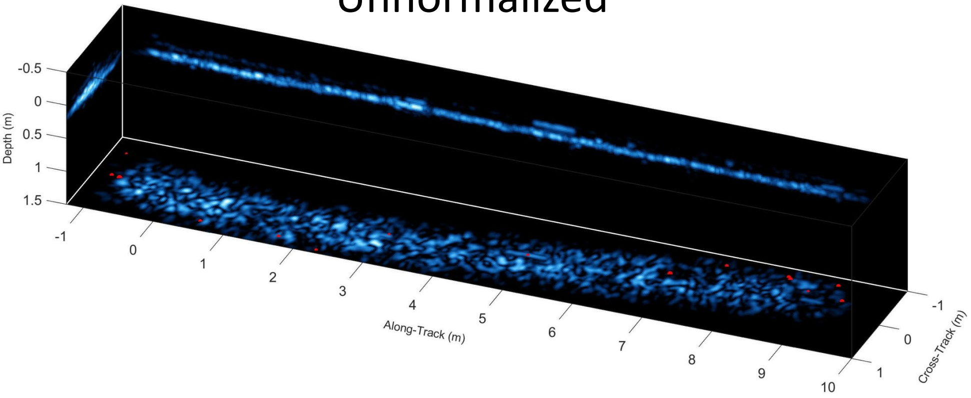
1. Determine dominant interface
2. Determine multipath region
3. For each cross-track position *x*, compute median of depth slice
4. For each along-track position *y*, compute median of depth slice
5. Convert to logarithmic scale



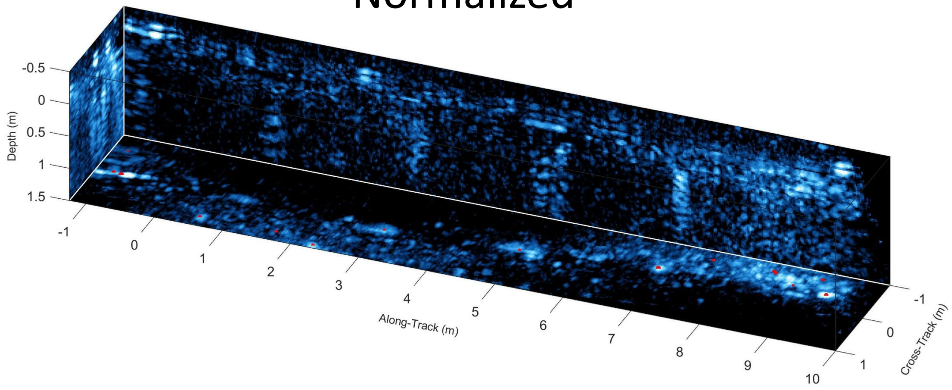


Impact of Normalization

Unnormalized

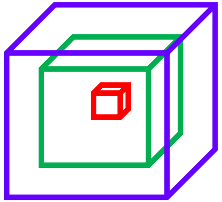


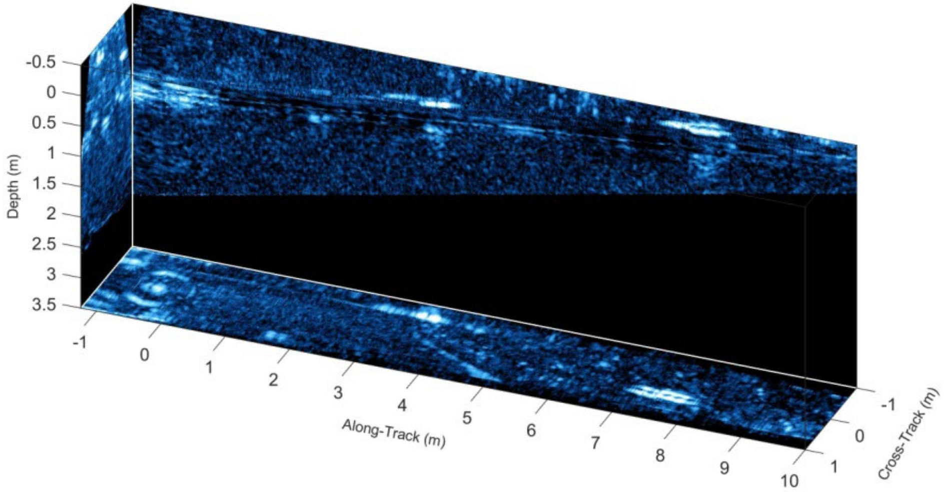
Normalized



Detection Algorithm: MondrianB

- Compute summed intensity in three concentric volumes
  - Target
  - Guard
  - Background





- Target-to-background ratio test

$$\left(\frac{n_B - n_G}{n_T}\right)\left(\frac{T(x,y,z)}{B(x,y,z) - G(x,y,z)}\right) \geq \tau_s$$

Integral Images

- A: Image (data)
- W: Integral image
- U: Summed intensity in a block

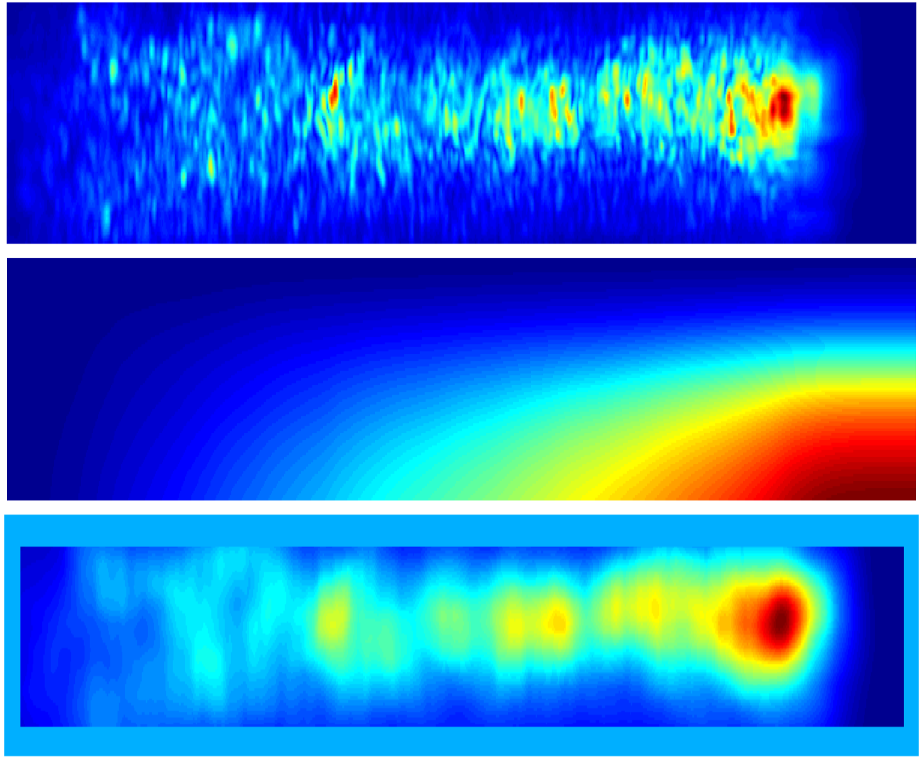
$$W(x, y, z) = \Sigma_{x' \leq x} \Sigma_{y' \leq y} \Sigma_{z' \leq z} A(x, y, z)$$

$$U = \Sigma_{j \in \{0,1\}^3} (-1)^{3-||j||_1} W(\alpha^j)$$

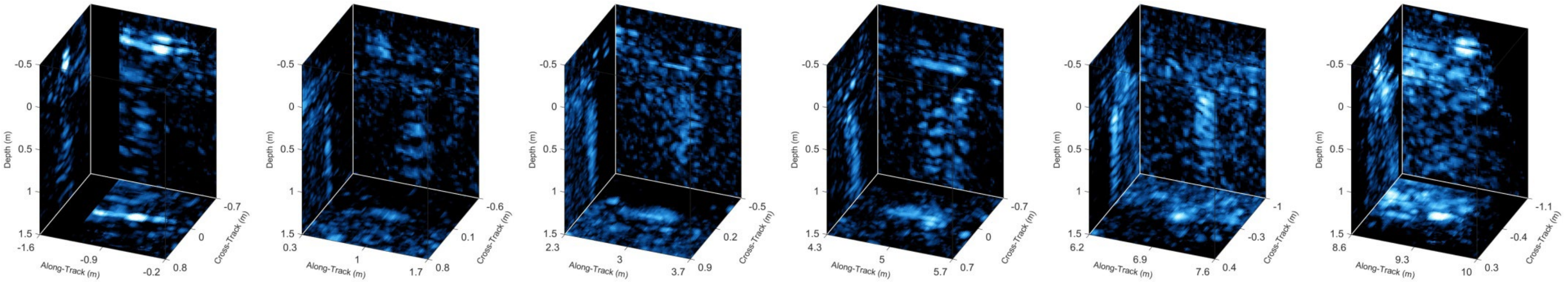
A

W

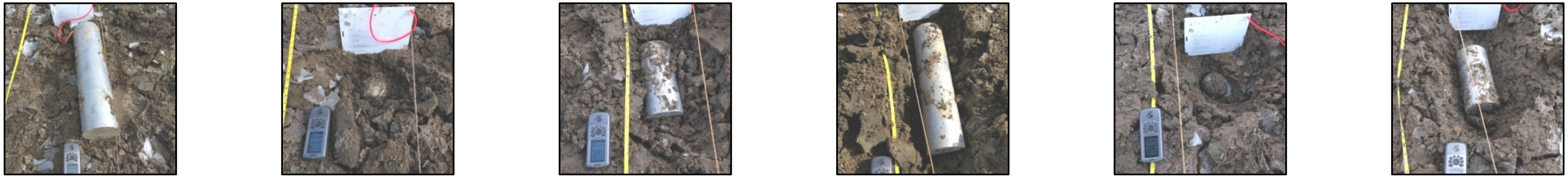
U



Example Target Alarms



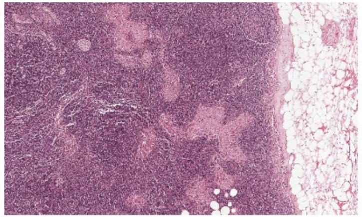
A **B** **C** **D** **E** **F**

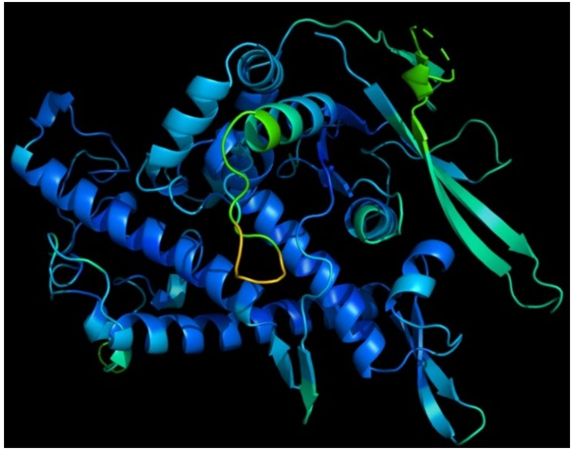


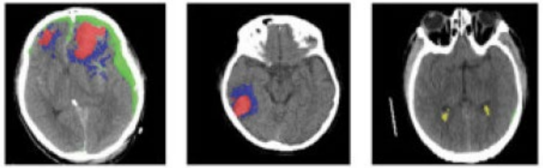
Classification

- Take alarms generated by MondrianB detector and make predictions with classifier(s)
- CNN-based approach
  - 8 new basic CNN architectures designed
    - Different architectures uncover/exploit different clues
    - “Vanilla” architecture: alternating convolutional blocks and pooling layers
  - Ensemble approach in terms of architectures and also in terms of input data representations
  - Tiny CNNs to balance network complexity with amount of labeled data available
    - Avoid overfitting

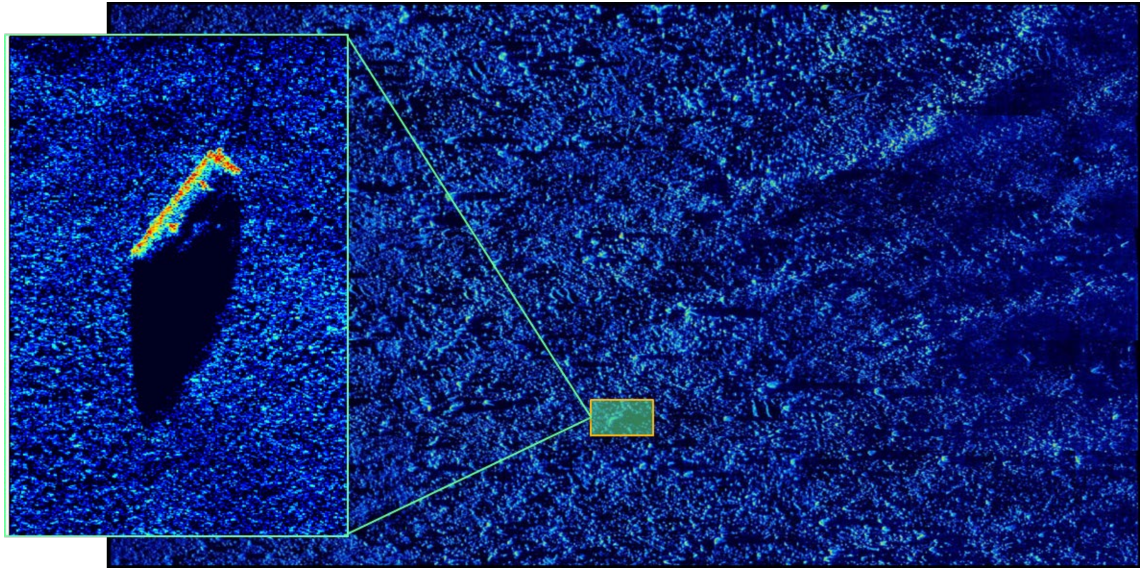
Era of Deep Learning



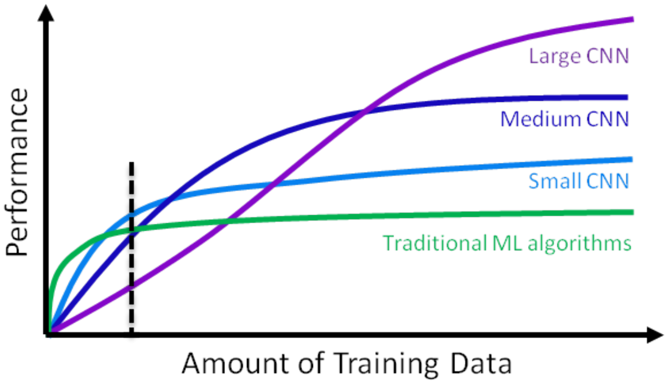


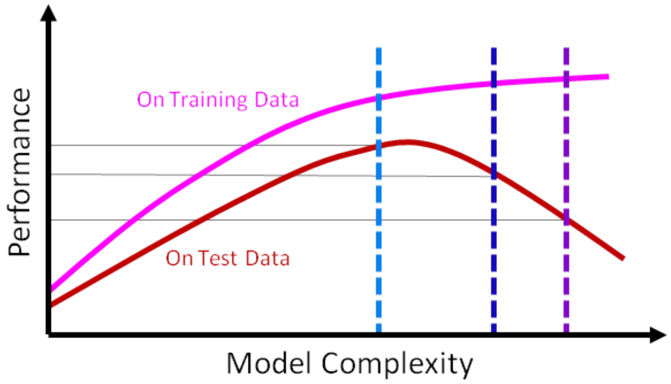


UXO Classification with Sonar Data



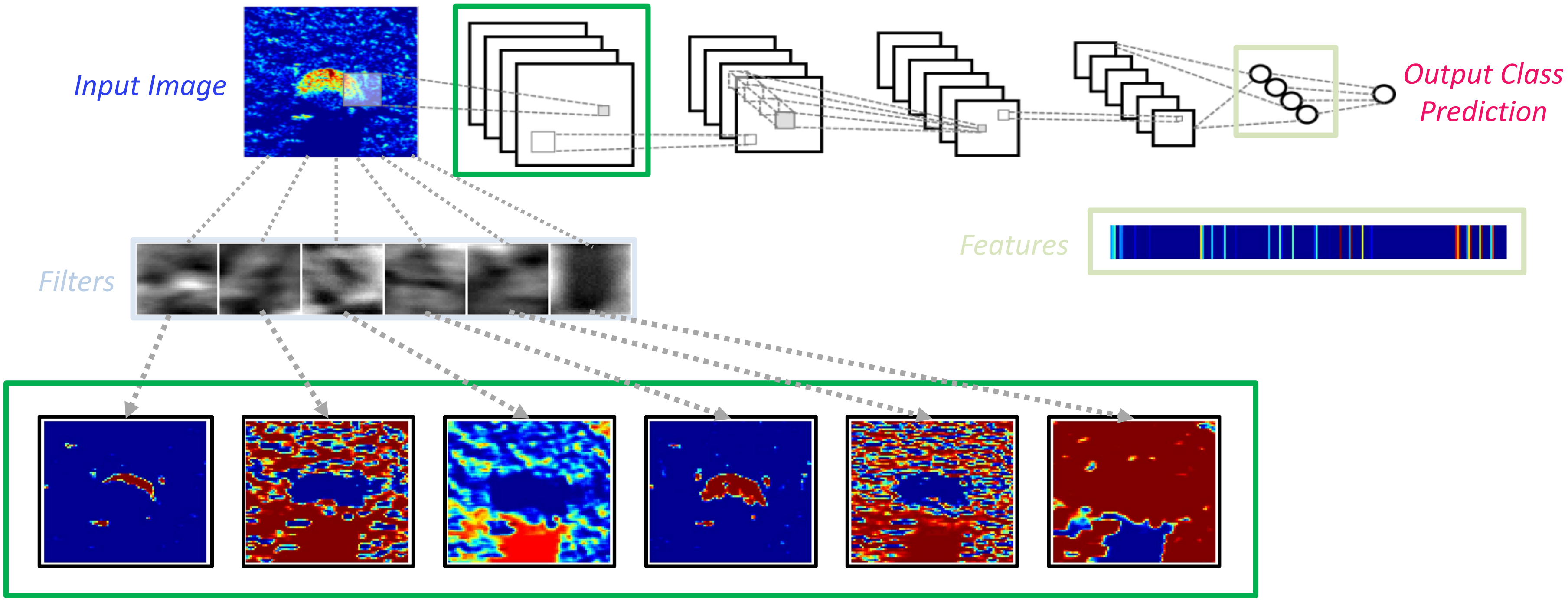
Deep Learning





- Key Ratio: Model Complexity / Training Data

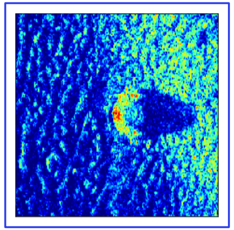
Convolutional Neural Networks (CNNs)

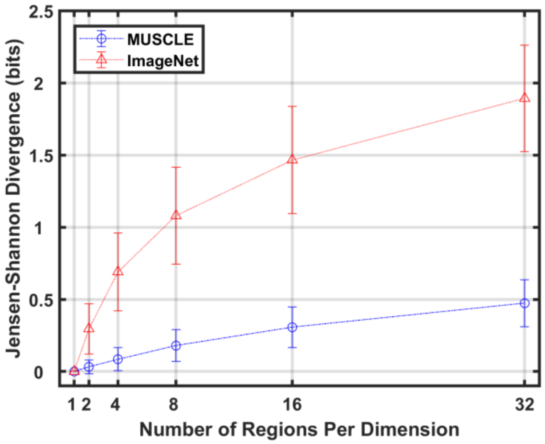


CNNs for SAS Data

- Simpler task
  - Number of classes, image complexity
- Resource constraints
  - Data, computing power

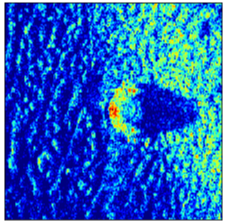
➢ Solution: Tiny networks

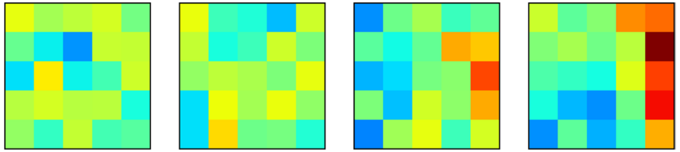




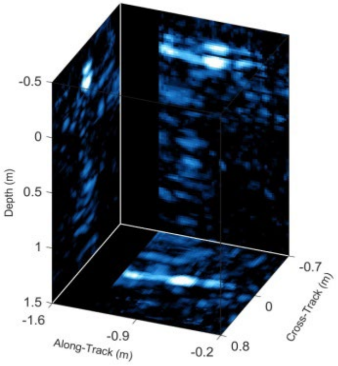
3-d CNNs

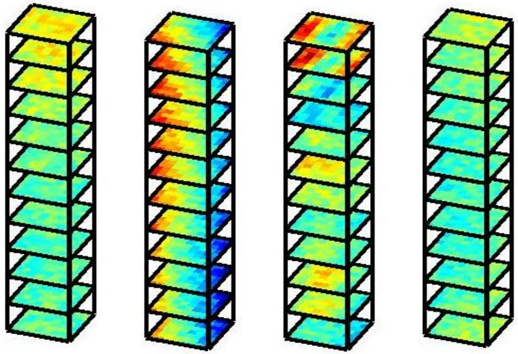
2-d inputs



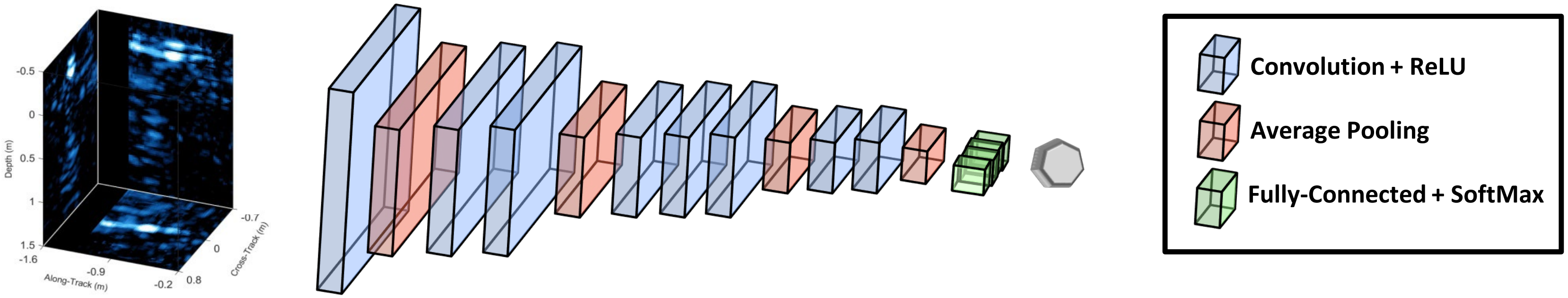


3-d inputs



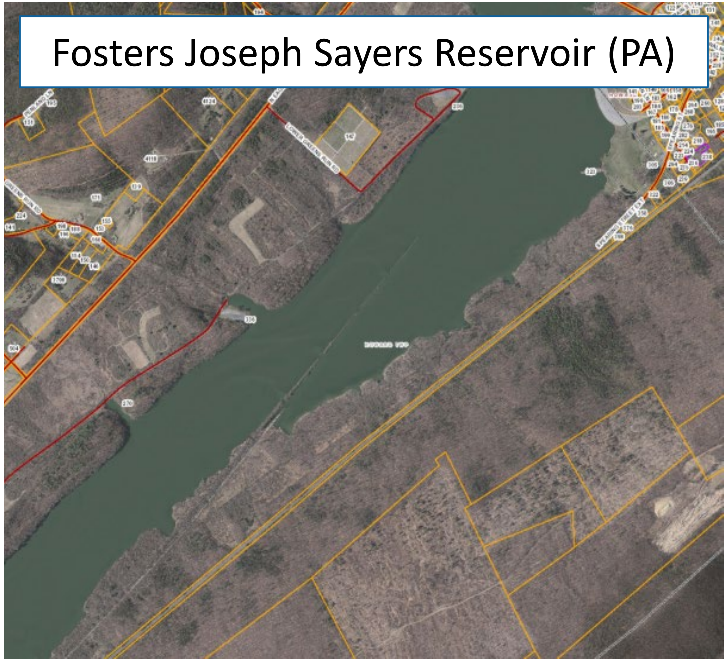


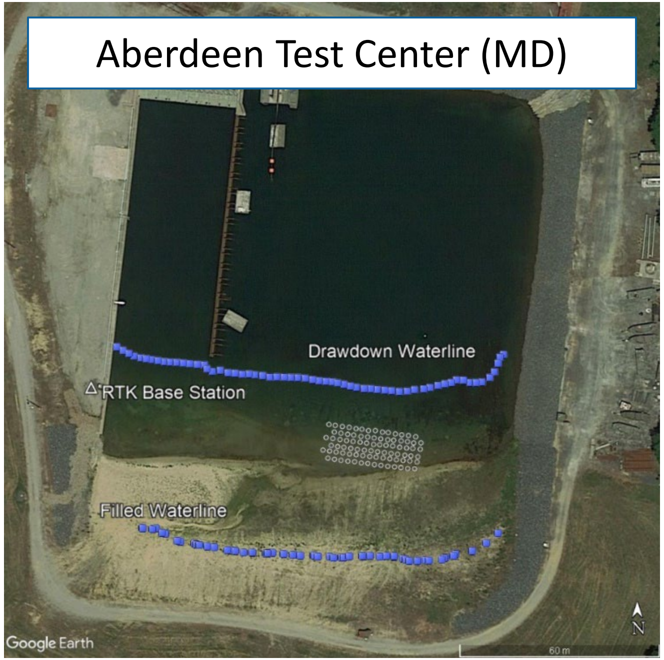
3-d CNN Architectures



CNN Label	CNN Depth	Conv. Blocks	Conv. Layers Per Conv. Block	Filters Per Conv. Layer	Filter Sizes (Voxels) $[x \times y \times z]$	Pooling Factors $[x \times y \times z]$	Number of Parameters
A	2	2	1	4	$[6 \times 6 \times 6]$ $[4 \times 4 \times 5]$	$[8 \times 8 \times 12]$ $[4 \times 4 \times 4]$	2157
B	2	2	1	4	$[8 \times 8 \times 12]$ $[6 \times 6 \times 7]$	$[6 \times 6 \times 9]$ $[4 \times 4 \times 4]$	7117
C	3	3	1	4	$[6 \times 6 \times 6]$ $[5 \times 5 \times 5]$ $[4 \times 4 \times 5]$	$[4 \times 4 \times 6]$ $[2 \times 2 \times 2]$ $[2 \times 2 \times 2]$	4161
D	3	3	1	4	$[11 \times 11 \times 12]$ $[8 \times 8 \times 7]$ $[4 \times 4 \times 5]$	$[3 \times 3 \times 5]$ $[2 \times 2 \times 2]$ $[2 \times 2 \times 2]$	14273
E	6	3	2	4	$\begin{bmatrix} 5 \times 5 \times 6 \\ 4 \times 4 \times 5 \end{bmatrix} \begin{bmatrix} 5 \times 5 \times 6 \\ 4 \times 4 \times 5 \end{bmatrix} \begin{bmatrix} 5 \times 5 \times 3 \\ 4 \times 4 \times 3 \end{bmatrix}$	$[2 \times 2 \times 4]$ $[2 \times 2 \times 2]$ $[3 \times 3 \times 3]$	7557
F	6	3	2	4	$\begin{bmatrix} 7 \times 7 \times 12 \\ 5 \times 5 \times 7 \end{bmatrix} \begin{bmatrix} 5 \times 5 \times 8 \\ 4 \times 4 \times 5 \end{bmatrix} \begin{bmatrix} 3 \times 3 \times 3 \\ 3 \times 3 \times 3 \end{bmatrix}$	$[3 \times 3 \times 4]$ $[2 \times 2 \times 2]$ $[1 \times 1 \times 1]$	10525
G	9	3	3	4	$\begin{bmatrix} 4 \times 4 \times 5 \\ 3 \times 3 \times 5 \\ 3 \times 3 \times 4 \end{bmatrix} \begin{bmatrix} 4 \times 4 \times 4 \\ 3 \times 3 \times 4 \\ 3 \times 3 \times 3 \end{bmatrix} \begin{bmatrix} 4 \times 4 \times 4 \\ 4 \times 4 \times 4 \\ 3 \times 3 \times 4 \end{bmatrix}$	$[2 \times 2 \times 3]$ $[2 \times 2 \times 2]$ $[2 \times 2 \times 2]$	6313
H	12	3	4	4	$\begin{bmatrix} 4 \times 4 \times 3 \\ 3 \times 3 \times 3 \\ 3 \times 3 \times 3 \\ 3 \times 3 \times 3 \end{bmatrix} \begin{bmatrix} 3 \times 3 \times 4 \\ 3 \times 3 \times 3 \\ 3 \times 3 \times 3 \\ 3 \times 3 \times 3 \end{bmatrix} \begin{bmatrix} 3 \times 3 \times 3 \\ 3 \times 3 \times 3 \\ 3 \times 3 \times 3 \\ 3 \times 3 \times 3 \end{bmatrix}$	$[2 \times 2 \times 3]$ $[2 \times 2 \times 2]$ $[1 \times 1 \times 3]$	5141

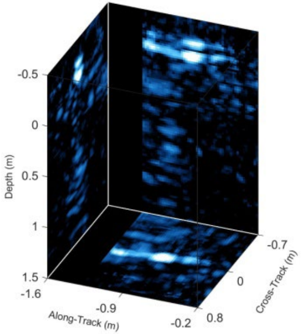
Data Collections



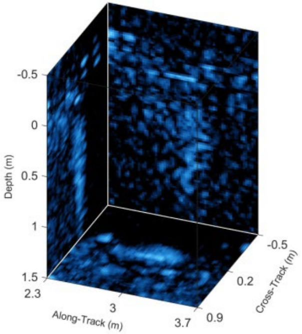


Human Assessment

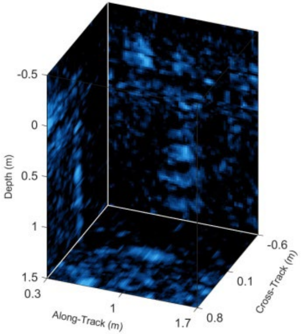
Large / Strong



Small / Strong



Small / Weak

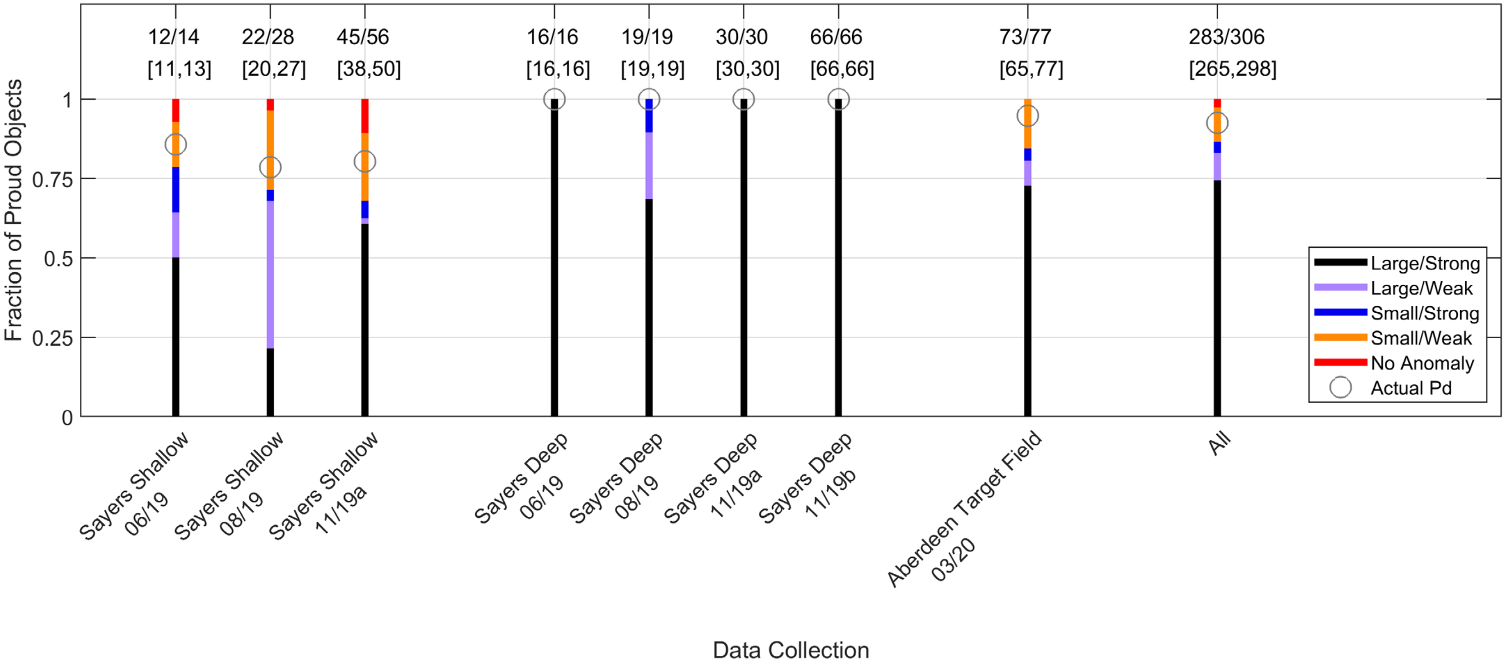


A

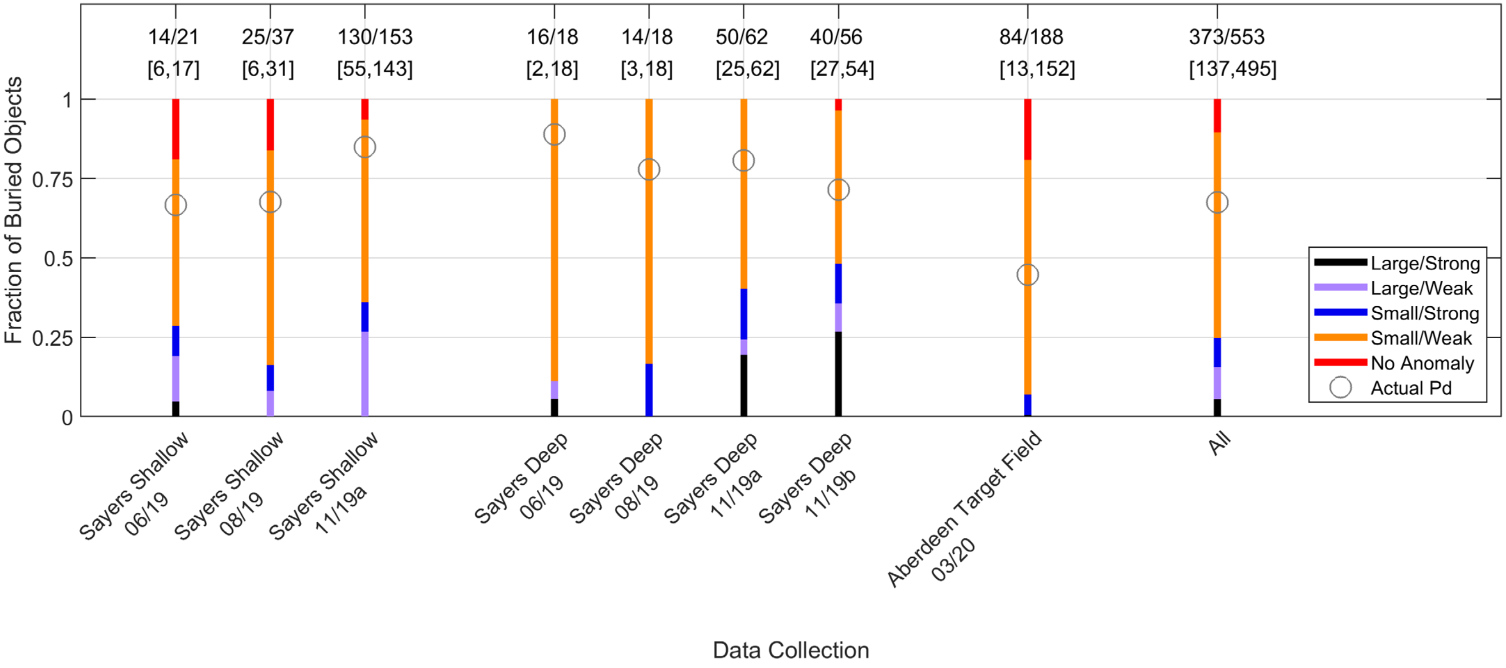
B

C

Performance: Proud Targets



Performance: Buried Targets

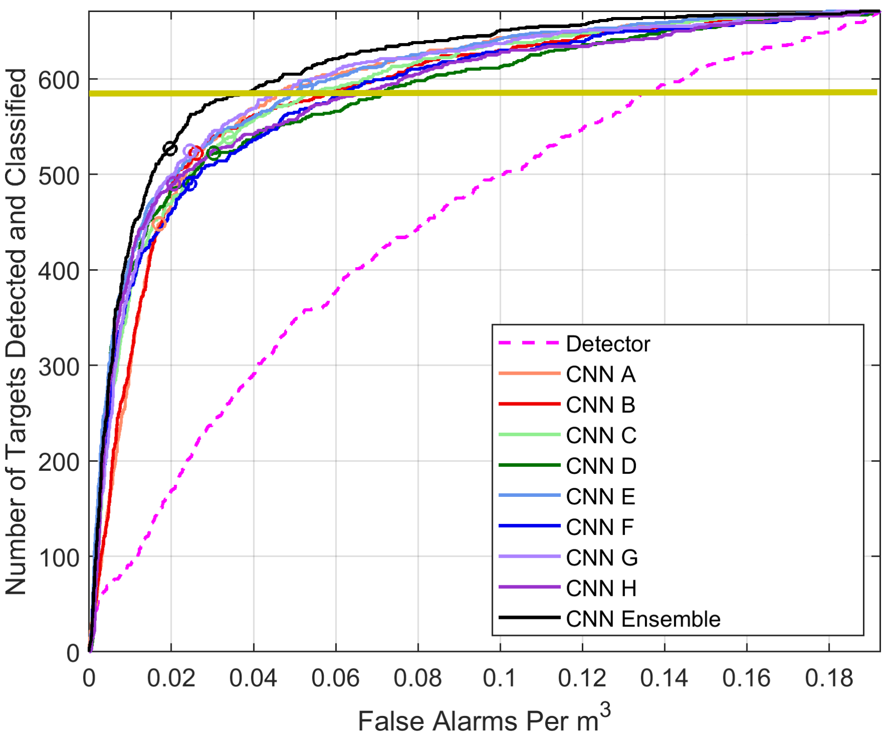


Classification

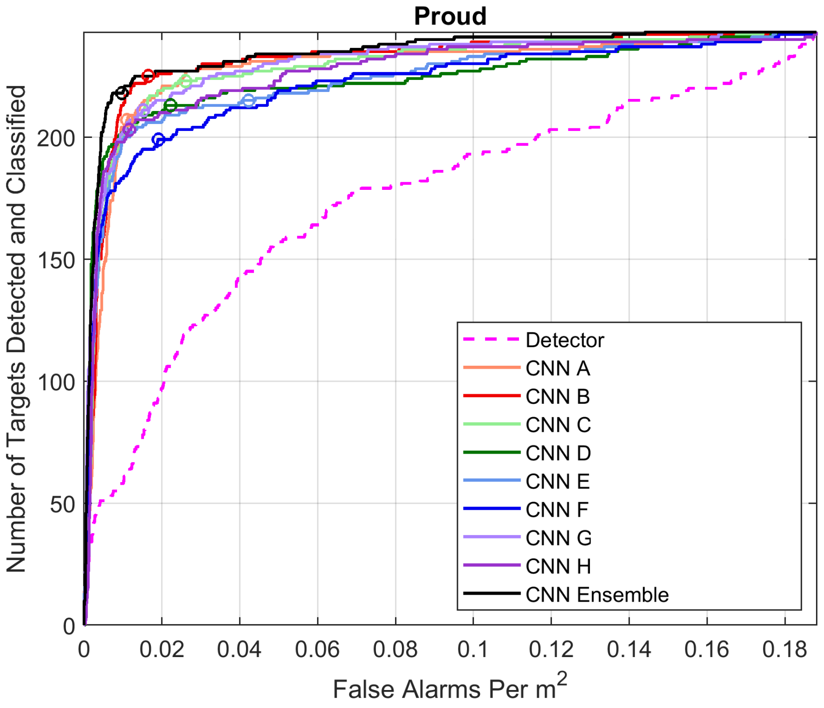
- 3-d CNNs with SVSS data
  - Train: Sayers “Deep” site
  - Test: Sayers “Shallow” site
  - “Target” = man-made object

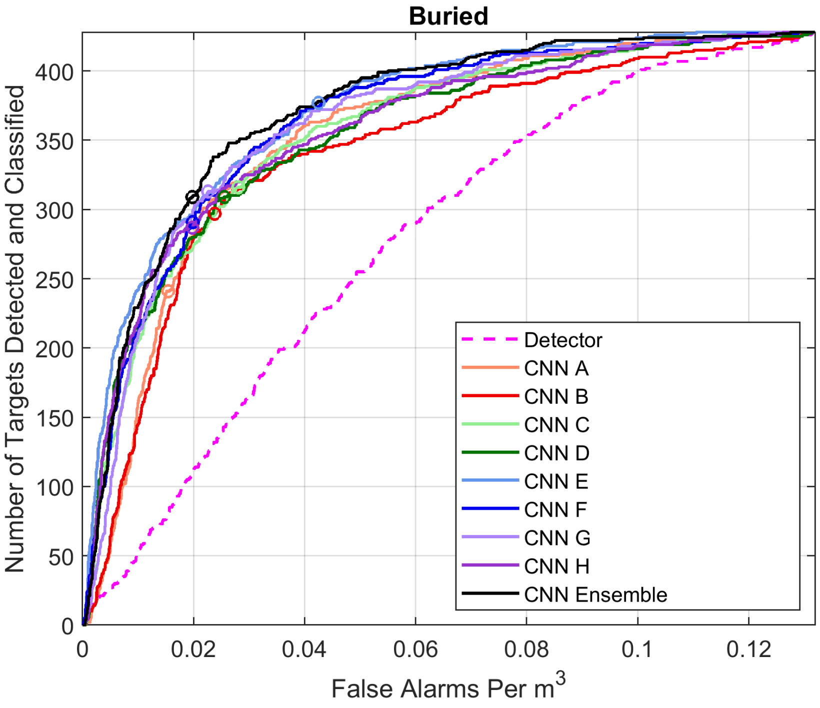
Location	Data Set Usage	Seafloor Area (m^2)	Sediment Volume (m^3)	Number of Clutter	Number of Targets
Site B	Training	15390	23392.8	11029	550
Site A	Test	15630	23757.6	6074	671

- Assessment
  - Asymmetric costs of misclassification
  - False alarm rates at key PdPc values

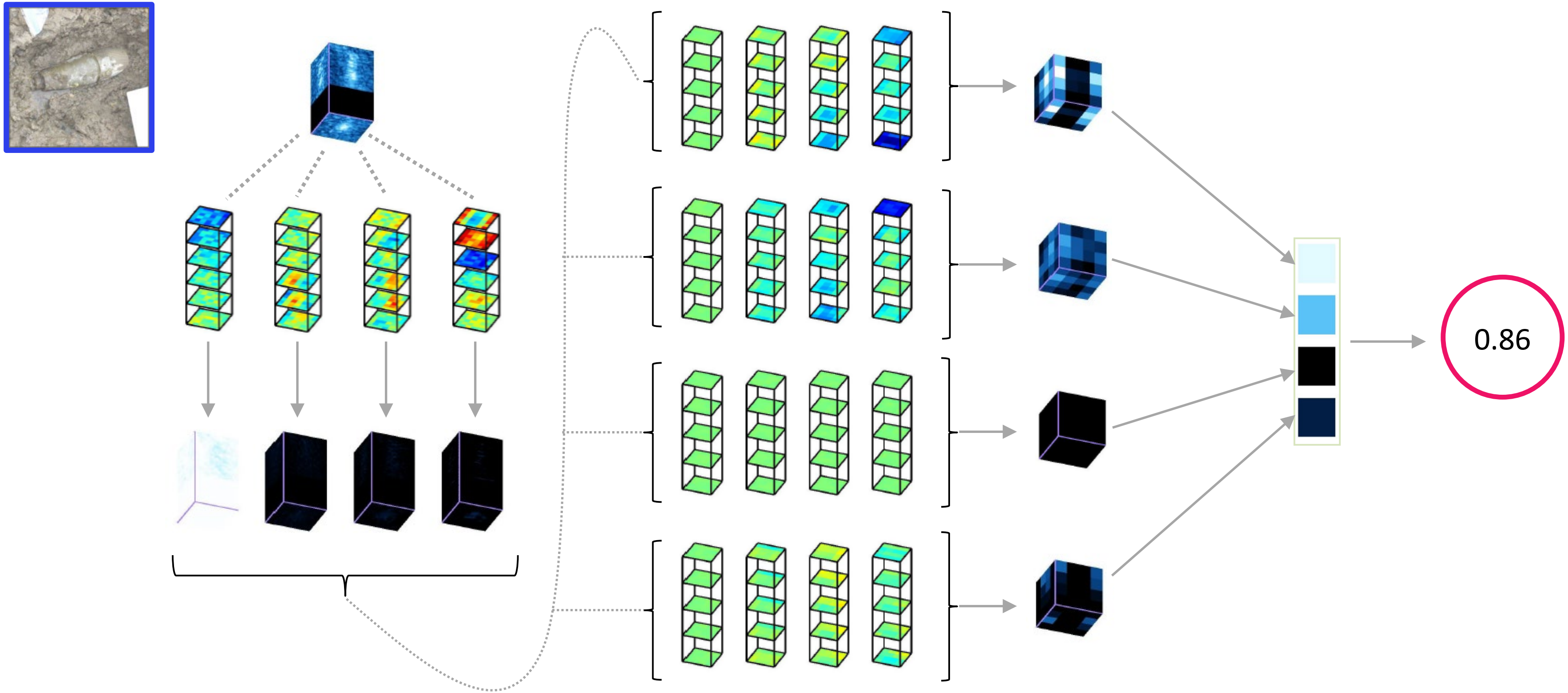


Classification Performance

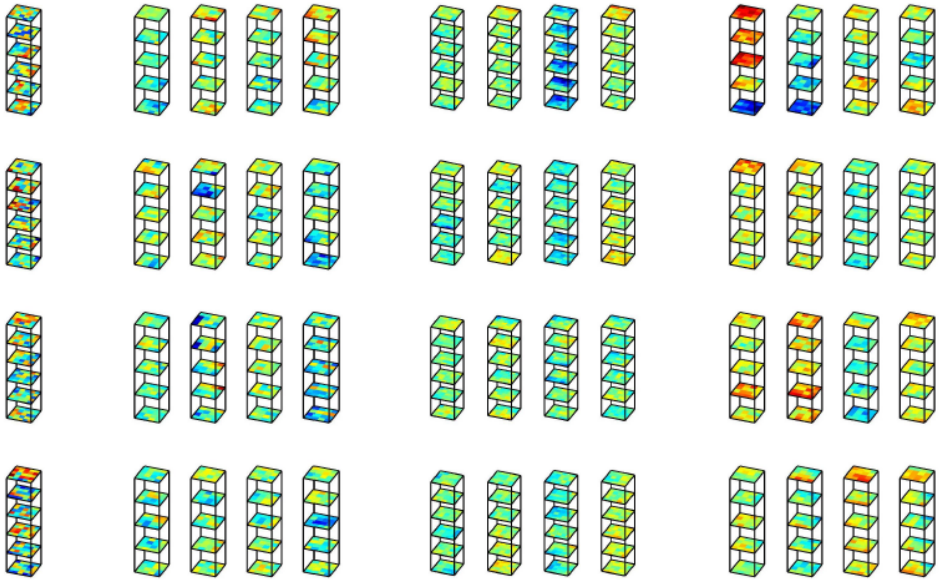




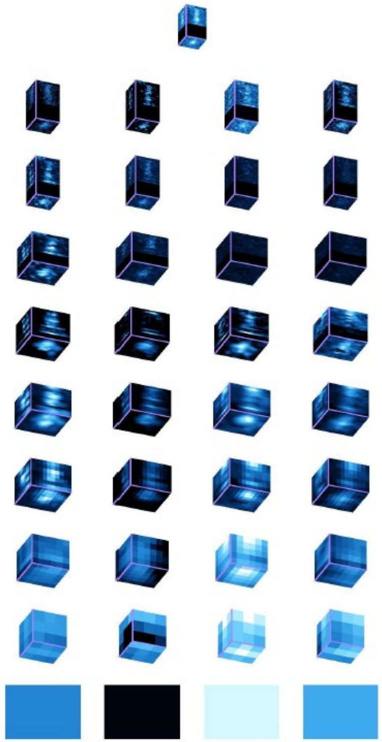
Inside CNN A



CNN E

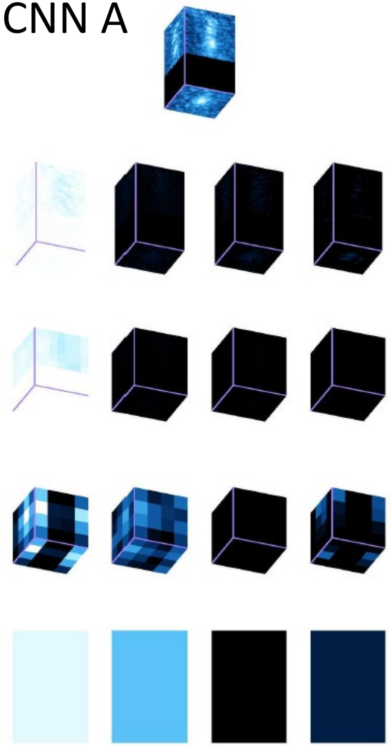


(a) Convo-lutional layer 1 (b) Convolutional layer 2 (c) Convolutional layer 3 (d) Convolutional layer 4

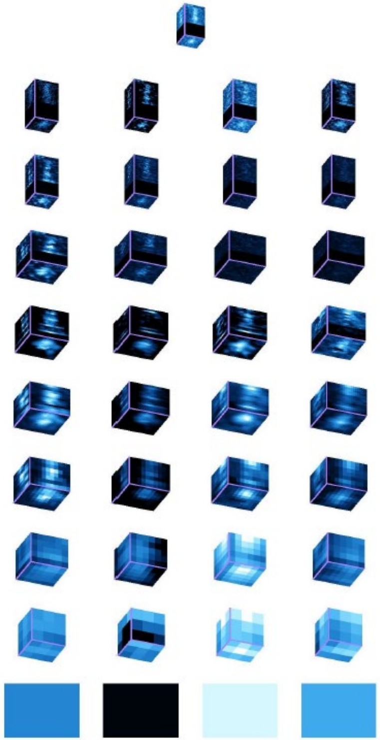


CNN Intermediate Responses

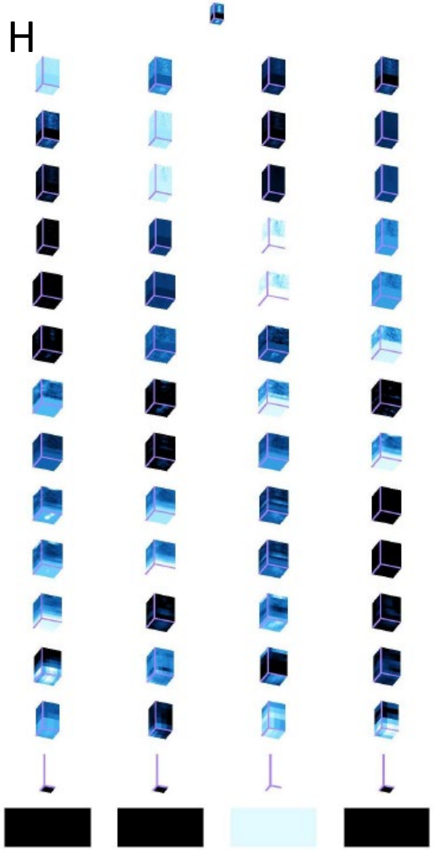
CNN A



CNN E

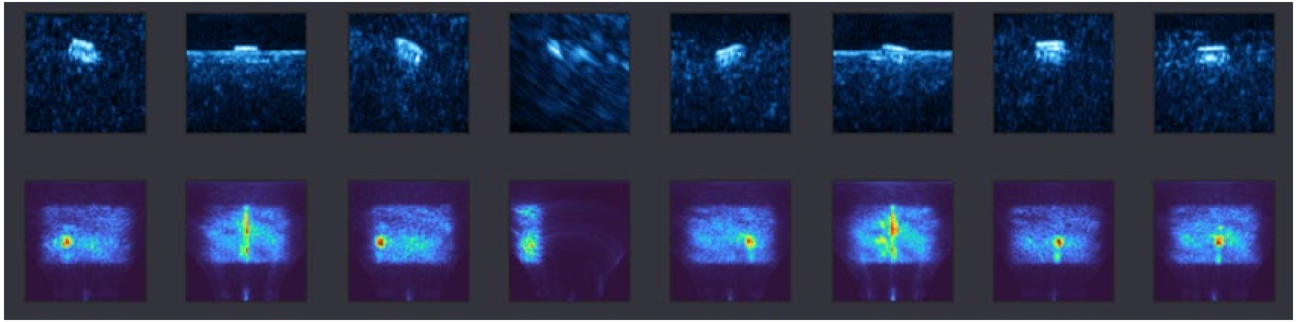


CNN H



Conclusions

- Automated detection and classification algorithms show promise for proud and buried targets in volumetric sonar data
  - Require more extensive field tests (and data!), especially in different environments
- Future/ongoing work: Develop CNNs for alternative data products (e.g., acoustic color)



** Image courtesy of Tim Marston (APL/UW)*