



Improving Advanced Geophysical Classification performance in the marine environment

MR24-4262

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Black Tusk Geophysics Inc

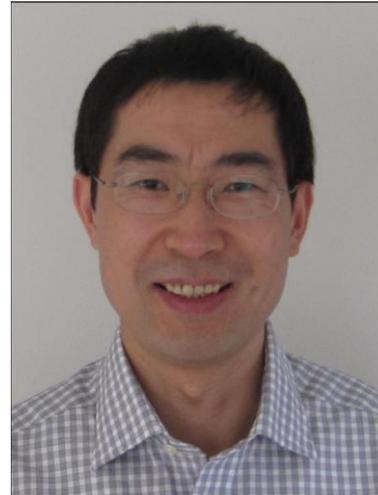
In-Progress Review Meeting

13-Jan-2026

Project Team



Dr Stephen Billings
BTG



Dr Lin-Ping Song
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Bottom Line Up Front

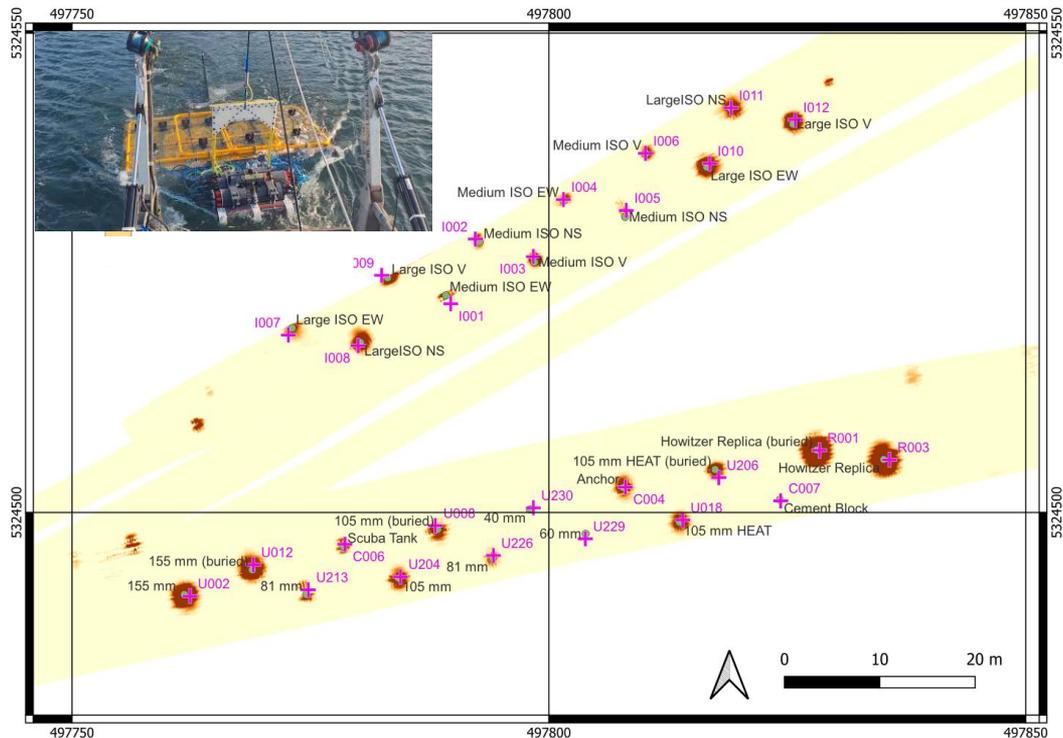
This project aims to quantify and address the challenges of marine detection and classification of munitions in the underwater environment.

- 1) Improving signal-to-noise ratio of measured target responses;
- 2) Exploring methods for predictive estimation of sensor positions;
- 3) Developing alternative methods for dealing with sensor positional uncertainty.

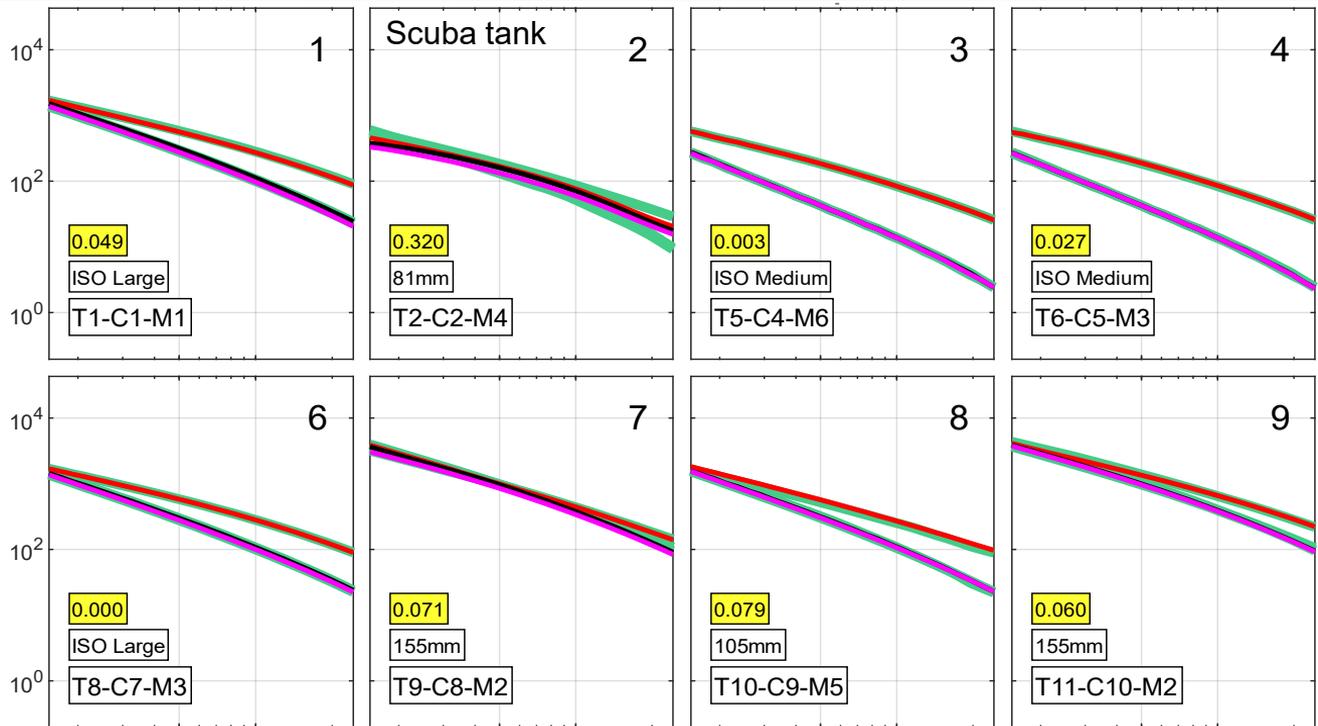
This project is going well and we have a wealth of underwater data from production projects that present different challenges.

ESTCP Demonstration at Sequim Bay

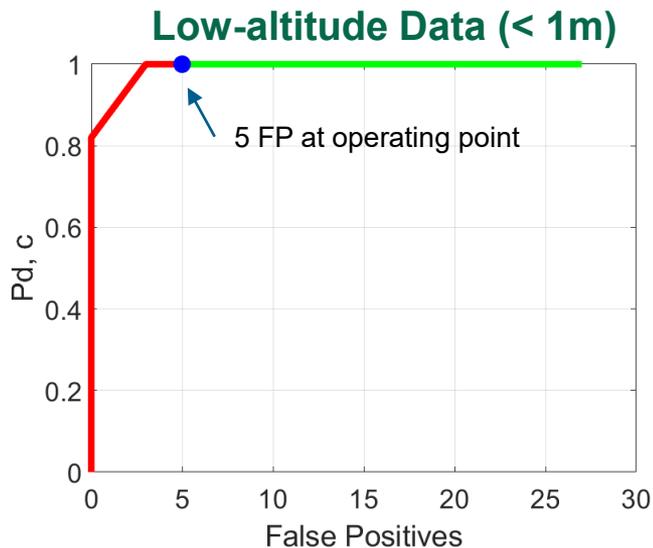
Calibration Lane



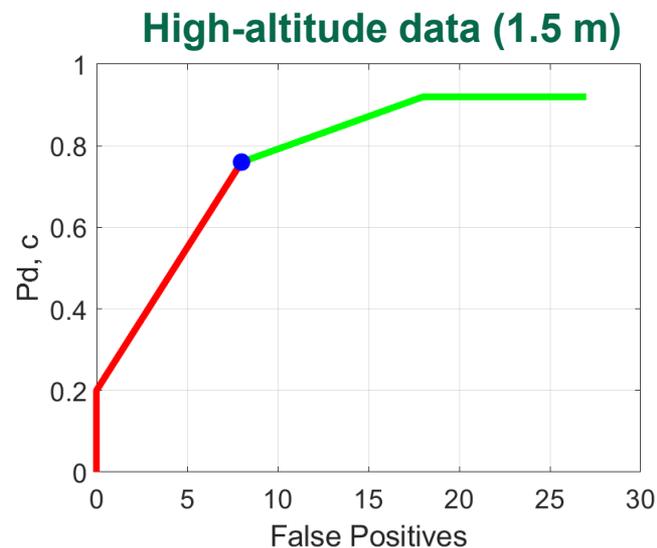
Polarizabilities: Low altitude



Performance on Blind Grid



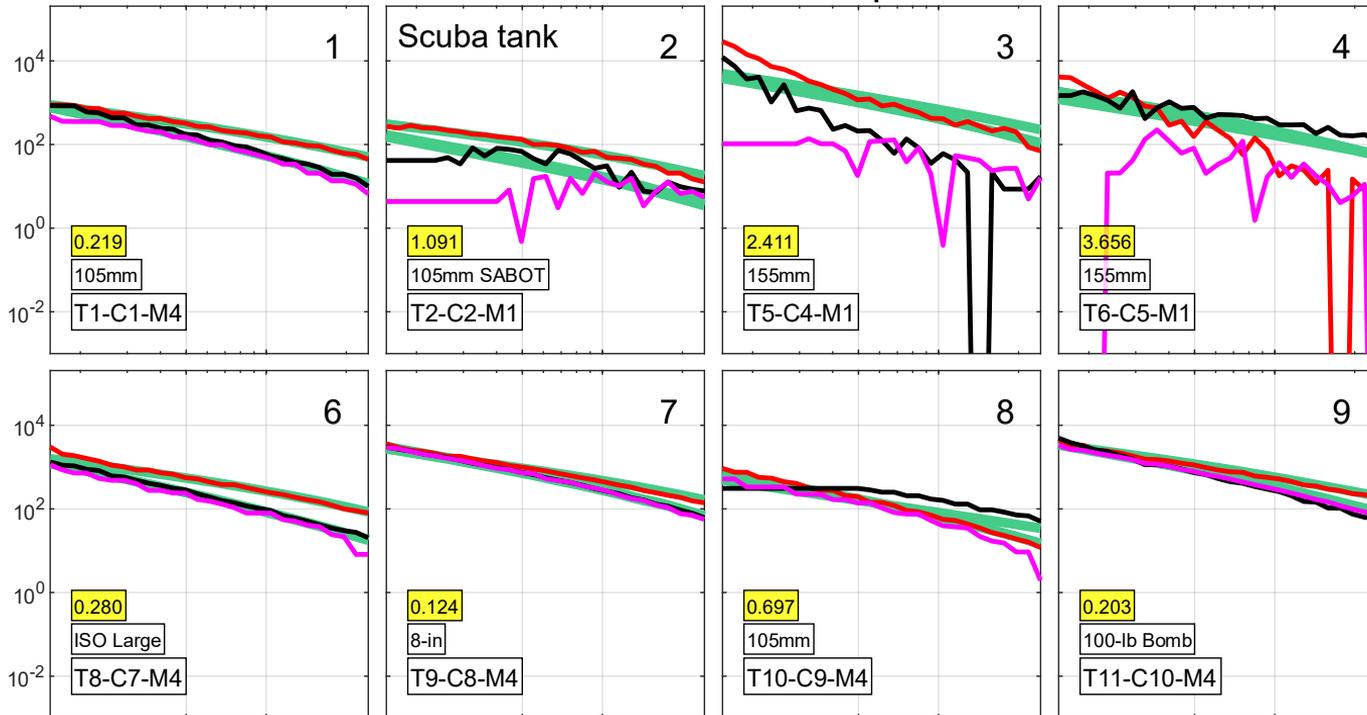
Detected and correctly classified all UXO items



Misclassified several items and can't detect any small items

Polarizabilities: High altitude

Performance OK on large but not on small ordnance



Key remaining challenges

Rapid signal fall-off with distance

Methods to remove noise and enhance signals will increase the operational envelop of the technology

Better background removal

Signals from ordnance are highest at early time but so is the background from the sea-water

Tolerant of positional errors

Positional accuracy won't always be as good as at Sequim Bay so need methods that are tolerant of errors

Operation in dynamic environments

Understand and address challenges operating in dynamic environments (e.g. surf-zone or off-shore with swell)

Technical Objective Focus of year 1

1.1. Data-driven decomposition methods

- Singular spectrum analysis and dynamic mode techniques and testing
- Objective is to optimise the signal-to-ratio of the data

1.2 Autoencoder method

- Theory, method and testing
- Objective is to optimise the signal-to-ratio of the data

2. Positional offset prediction

- Fusion of GPS and inertial measurements via Kalman filter applications
- Objective is to improve the positional accuracy of marine data

Technical Approach



Theoretically rigorous method



Apply on test datasets



Site specific challenge



Theory / Modelling



Improve and implement method



Standard Methods



ESTCP/
production
pathway

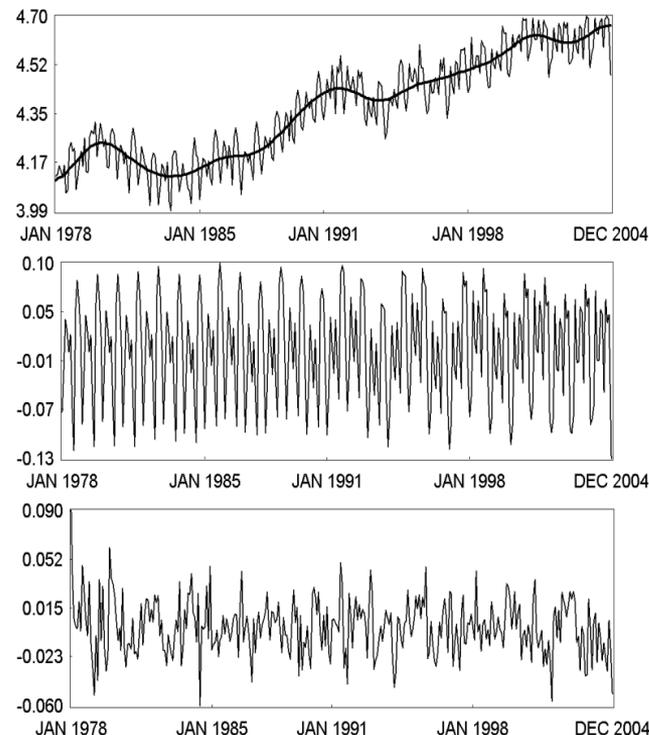


Performance on blind-test

Singular spectrum analysis (SSA)

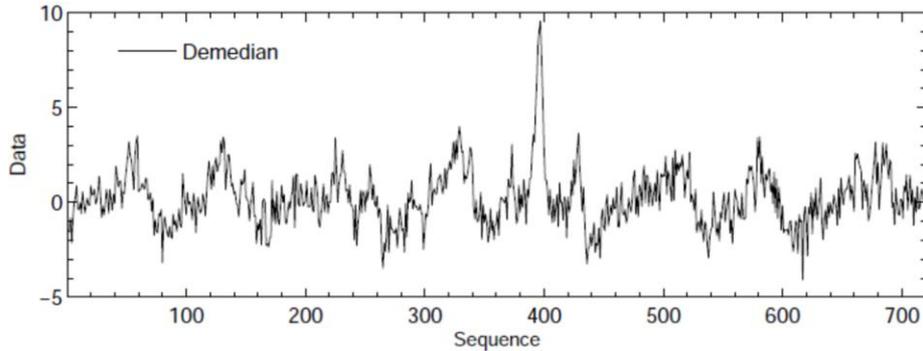
SSA is a non-parametric method that has been applied to time-series data:

- Decompose signal into components
 - Trend
 - Discrete signals from object
 - Noise
- Reconstruct signal after removing noise and trend

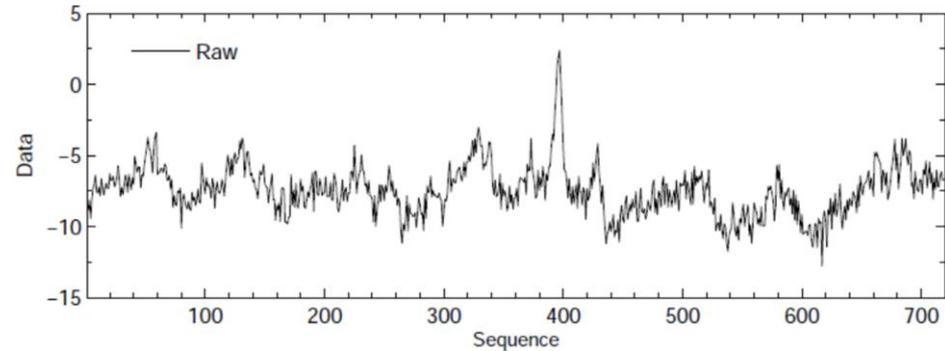


Application of SSA to noisy marine data

Filtered data

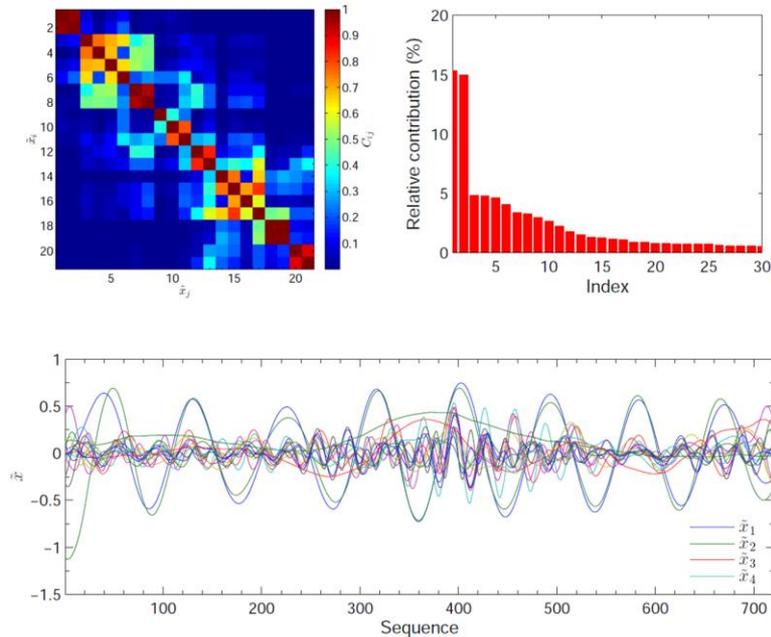


Raw data

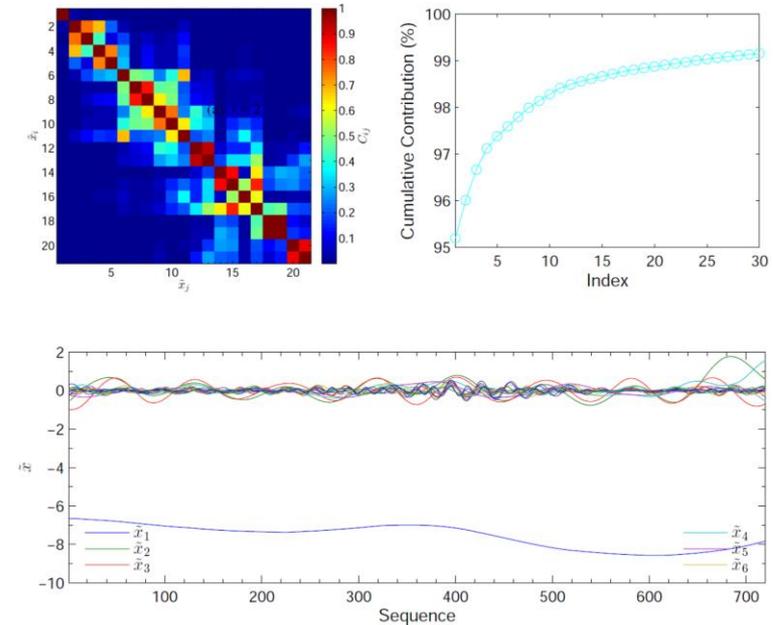


Application of SSA to noisy marine data

Filtered data: SSA

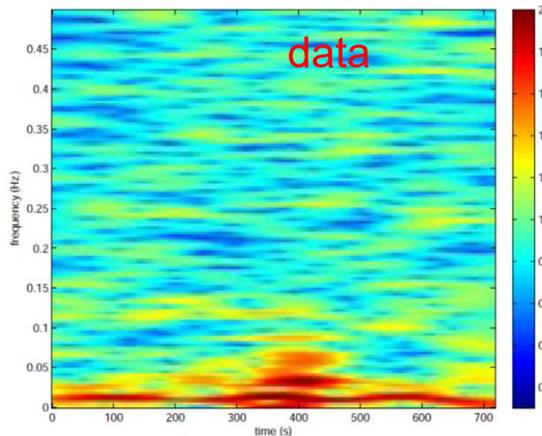


Raw data: SSA



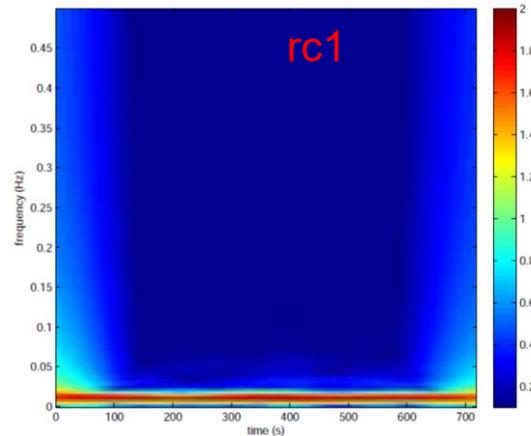
Application of SSA to noisy marine data

Filtered data

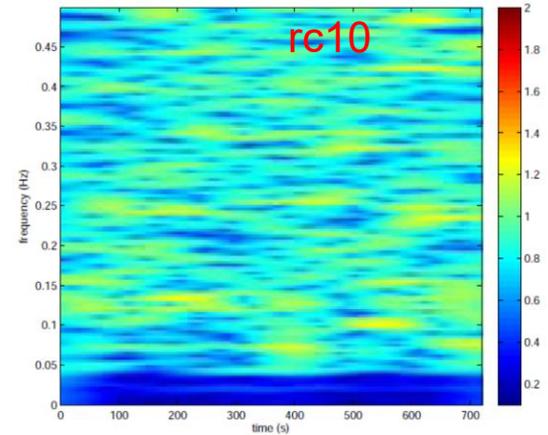


Strong signals and low frequency and rapid variations of energy.

Spectrogram



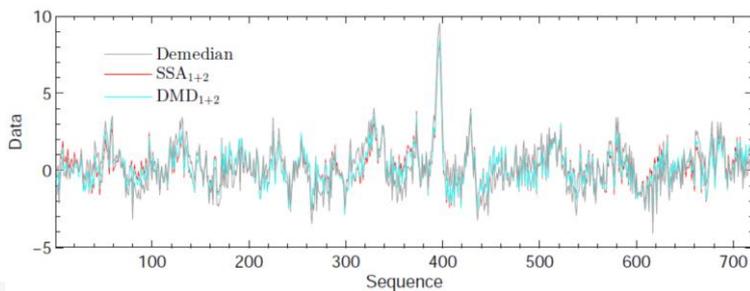
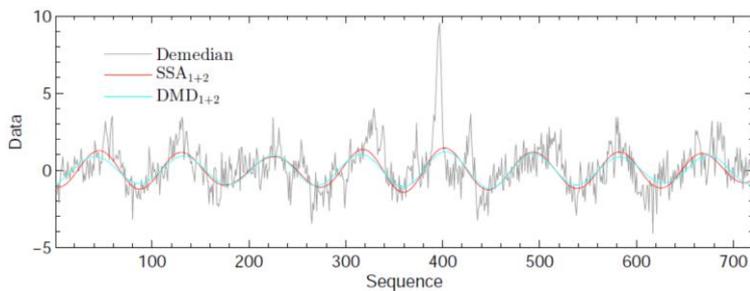
A signal around frequency of 0.015 Hz



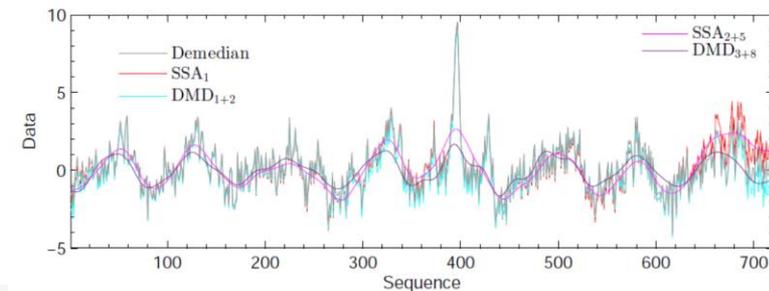
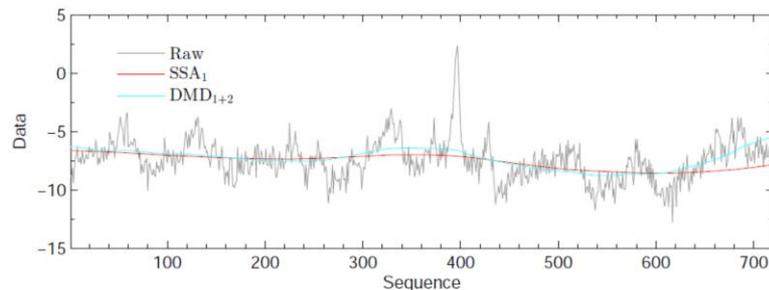
Noise-like energy spreading across the whole frequency range

Application to noisy marine data

Filtered data: Synthesis and Subtraction



Raw data: Synthesis and Subtraction



Also worked on a Domain Mode Decomposition method (DMD)

SSA

- Modes based on variance and smoothness in a sliding time-window.
- Modes ordered by energy content
- Best for trend extraction and noise reduction

DMD

- Modes based on how signal patterns evolve with time (e.g. trend, oscillation, decay)
- Explicitly reveals temporal behavior for each mode.
- Best for identifying physically meaningful or dynamically coherent processes

Technical Objective

- Technical focus of the current year

1.1. Data-driven decomposition methods

- Singular spectrum analysis and dynamic mode techniques and testing
- Objective is to optimise the signal-to-ratio of the data

1.2 Autoencoder method

- Theory, method and testing
- Objective is to optimise the signal-to-ratio of the data

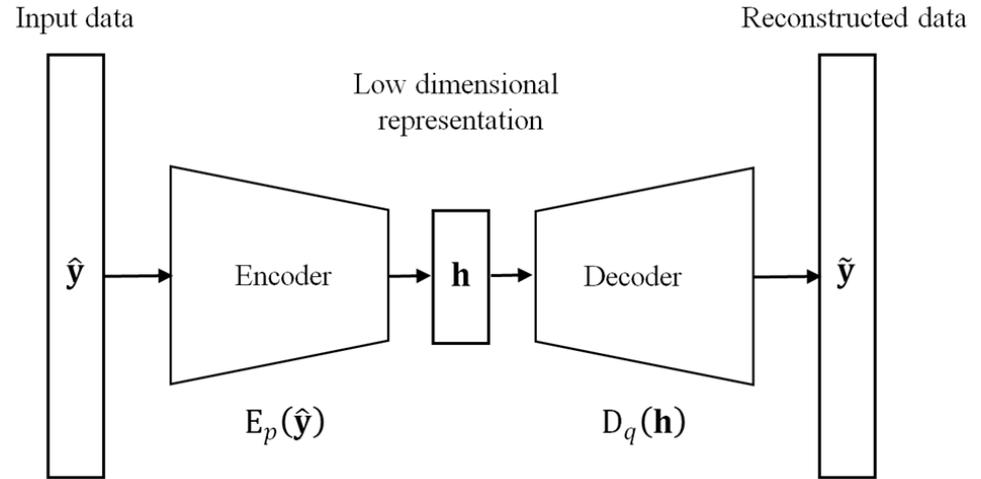
2. Positional offset prediction

- Fusion of GPS and inertial measurements via Kalman filter applications
- Objective is to improve the positional accuracy of marine data

Autoencoder method

Architecture

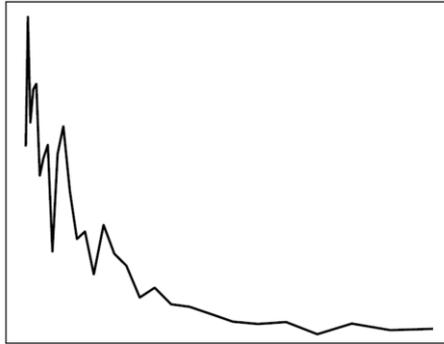
- Dimensionality reduction to recover signals from noisy data
- Neural network based approach (FNN, CNN or LSTM)
- Learn the statistics of signal and noise from training data



p : Encoder parameters
 q : Decoder parameters

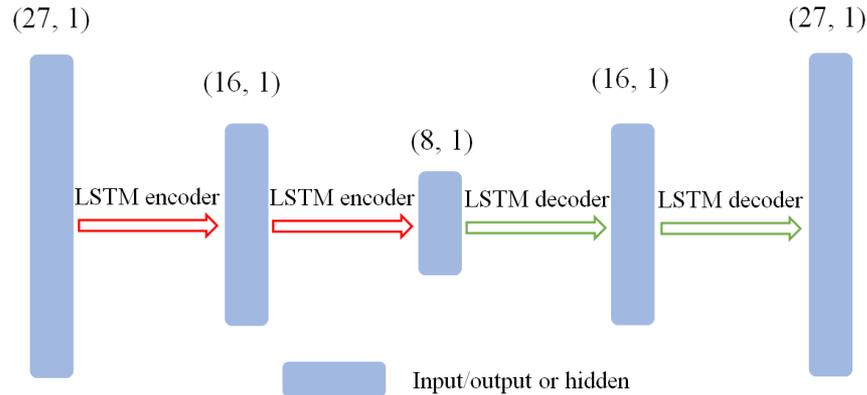
Autoencoder method

Input



TEM decay with 27 sampling points

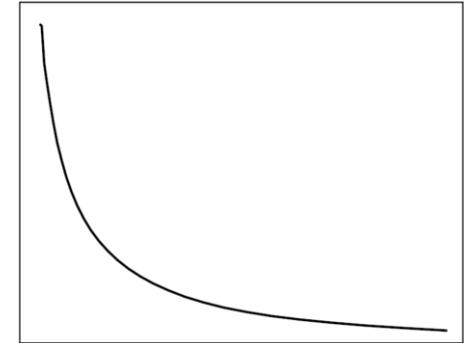
LSTM AE



Encoders convert input into latent variable

Decoders convert latent variable into output

Output

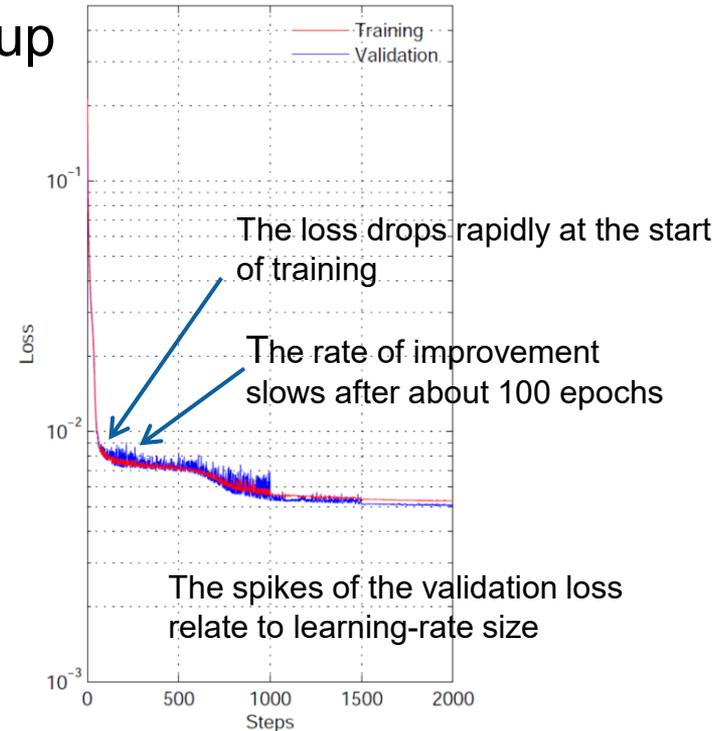


De-noised TEM decay with 27 sampling points

Autoencoder method

Training setup

- Use ~ 3000 UltraTEM decay pairs: Observed responses and corresponding inversion-predicted responses
- Split 80/20 into training/validation subsets
- The LSTM-AE was trained on decays with 27-sample points (0.15–2.6 ms)

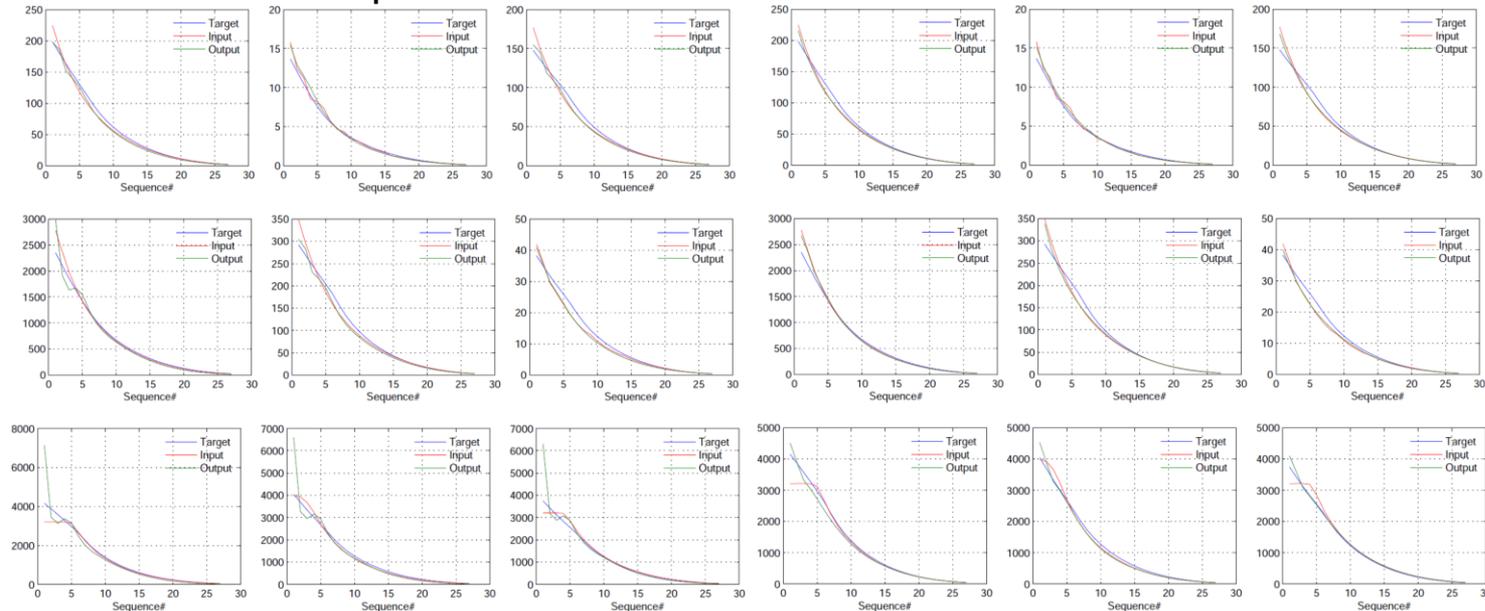


Autoencoder method

Training results: The input, target and the reconstructed decay curves

100 epochs

2000 epochs



- The model learned most of each input curve.
- Noticeable kinks remain at early time.
- As training proceeds, these kinks diminish.
- The outputs match the targets more closely at late time.

Technical Objective

First year

1.1. Data-driven decomposition methods

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1.2 Autoencoder method

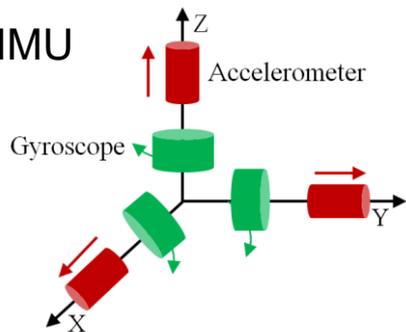
- Theory, method and testing
- Objective is to optimise the signal-to-ratio of the data

2. Positional offset prediction

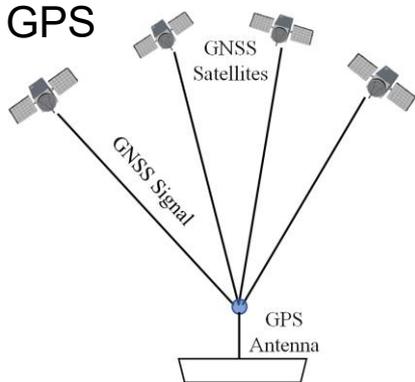
- Fusion of GPS and inertial measurements via Kalman filter applications
- Objective is to improve the positional accuracy of marine data

Fusion of GPS and inertial measurements

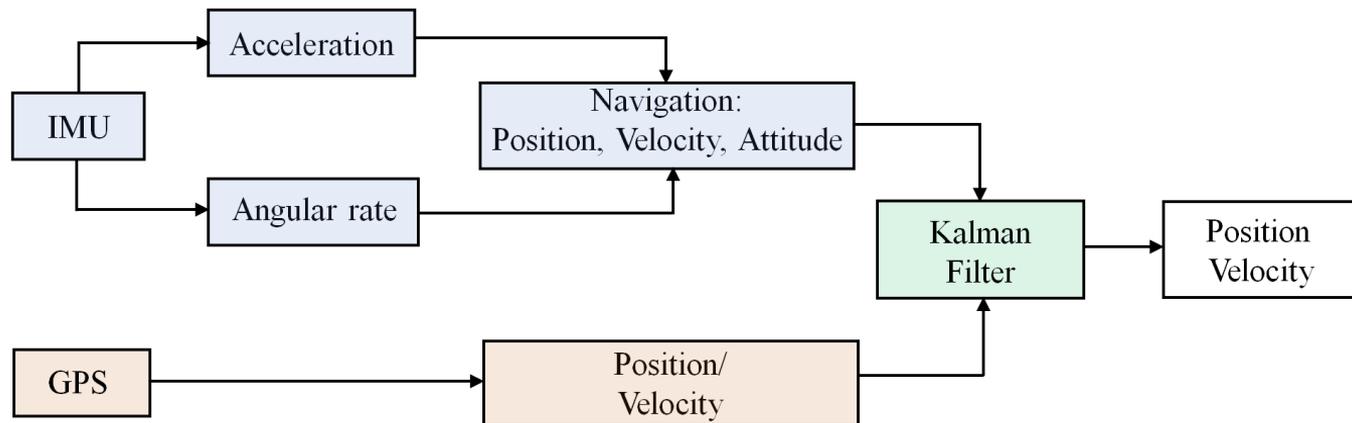
- IMU



- GPS

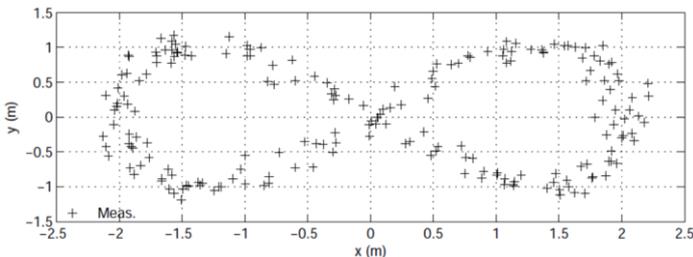


Sensor-fusion



Fusion of GPS and inertial measurements

Positions

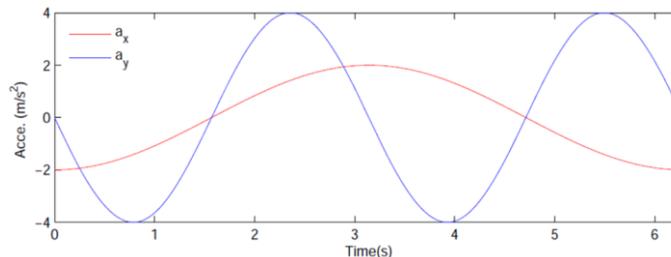


$$x = 2\cos(t) + n_x$$

$$y = \sin(2t) + n_y$$

figure-eight path:

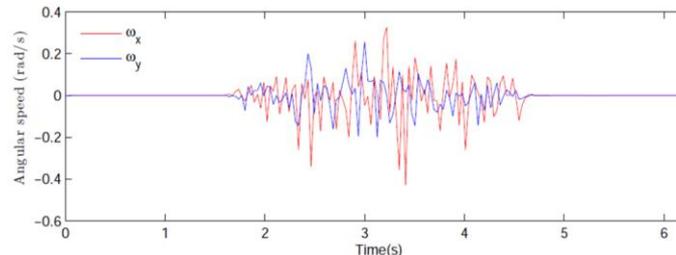
Acceleration



$$a_x = -2\cos(t)$$

$$a_y = -4\sin(2t)$$

Angular speeds



Rotation speeds are modeled as sine function modulated with random amplitudes.

$$\omega_x = \left[\mathbf{0} \frac{10\pi}{180} \sin(t(51:150)) * \text{randn} \mathbf{0} \right]$$

$$\omega_y = \left[\mathbf{0} \frac{7\pi}{180} \sin(t(51:150)) * \text{randn} \mathbf{0} \right]$$

Fusion of GPS and inertial measurements

Position

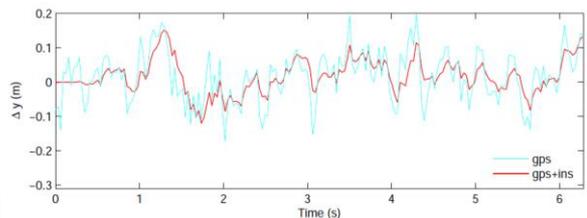
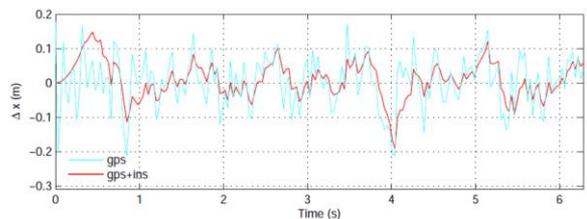
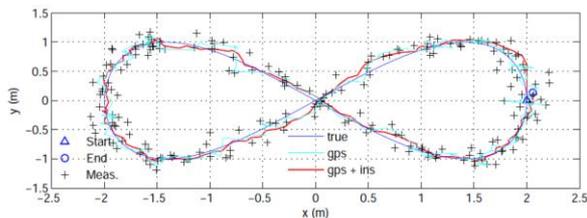
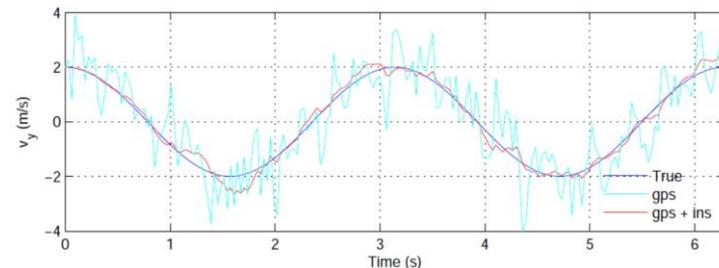
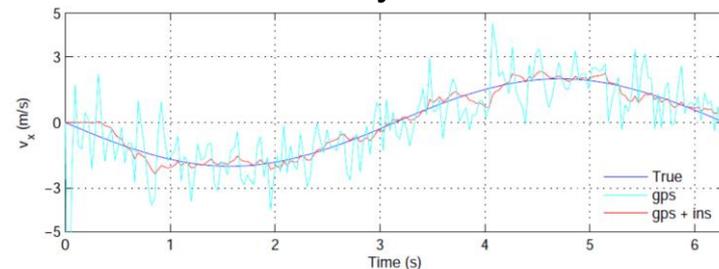


Figure-eight path:

- GPS-only: Large zigzag excursions
- Fused: a smooth trajectory and closely tracks the truth.
- GPS-only: the velocity fluctuates widely
- Fused: a smooth estimate that closely matches the true velocity.

Velocity



Data driven problems and research

Requirements for Advanced Geophysical Classification

- How many receiver components need to be functional for UltraTEM Marine data to be used for AGC

Dealing with EMI and motion generated noise

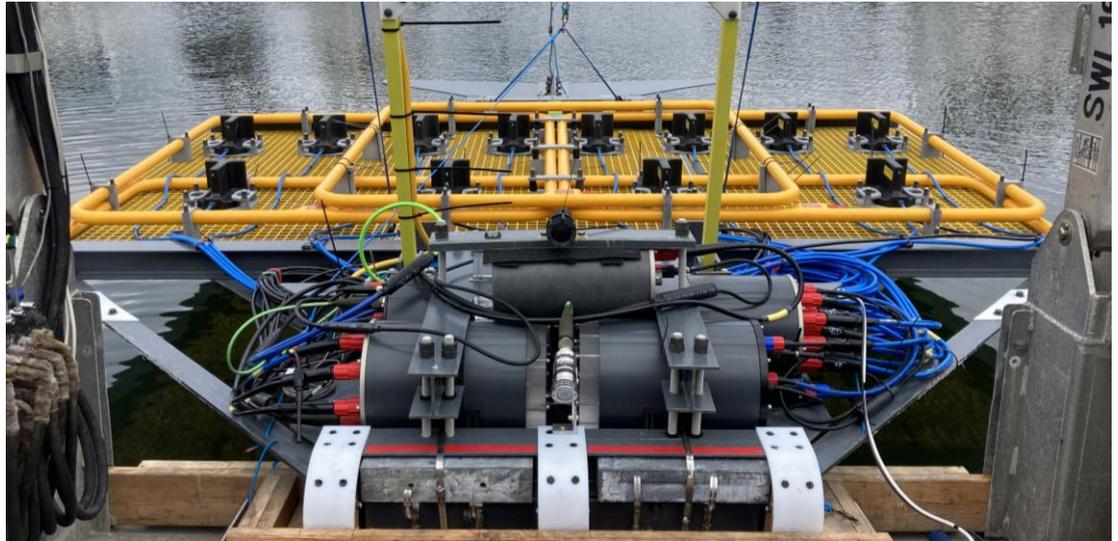
- Damaged thrusters generated strong noise in a production project
- Can those noise sources be mitigated

Detection of large objects at significant standoff distances

- Optimal transmitter parameters and receiver time channels
- Potential role for B-Field sensors

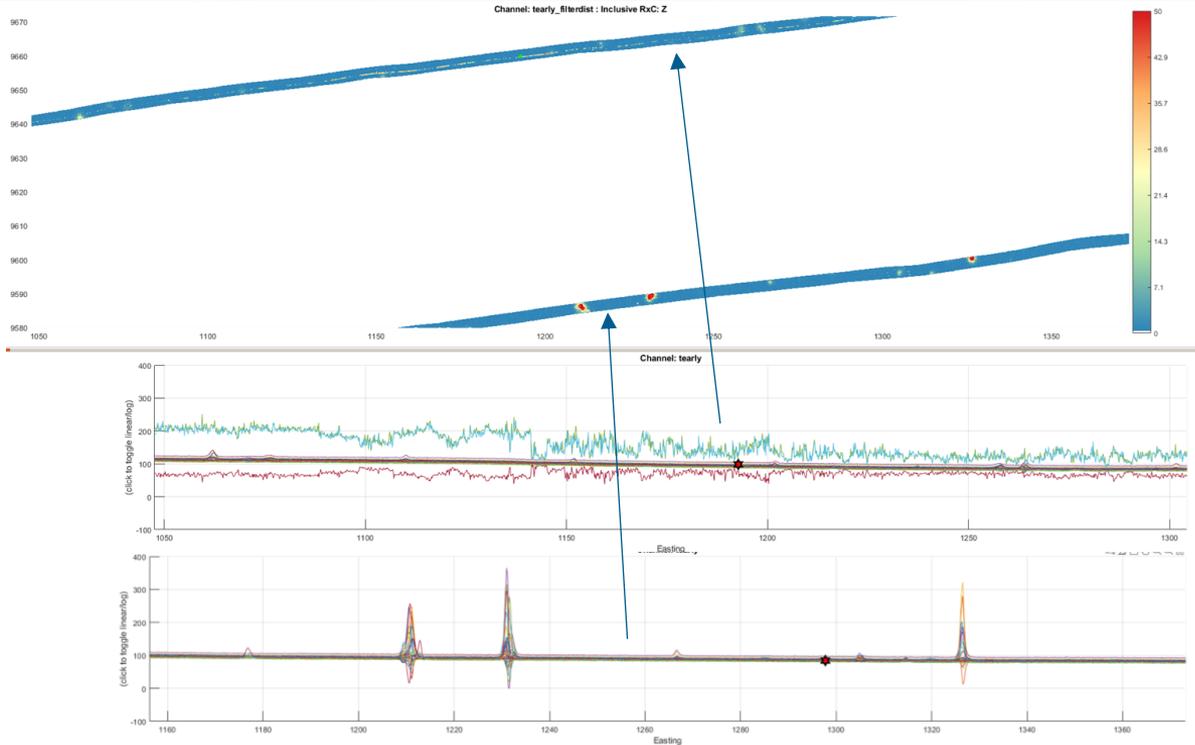
UltraTEM Marine: Redundancy

- System has significant redundancy
- Receivers
 - 12 Receiver cubes
 - 3 components each
 - Total of 36 coils
- Transmitters
 - Either 3 or 4 transmitter loops



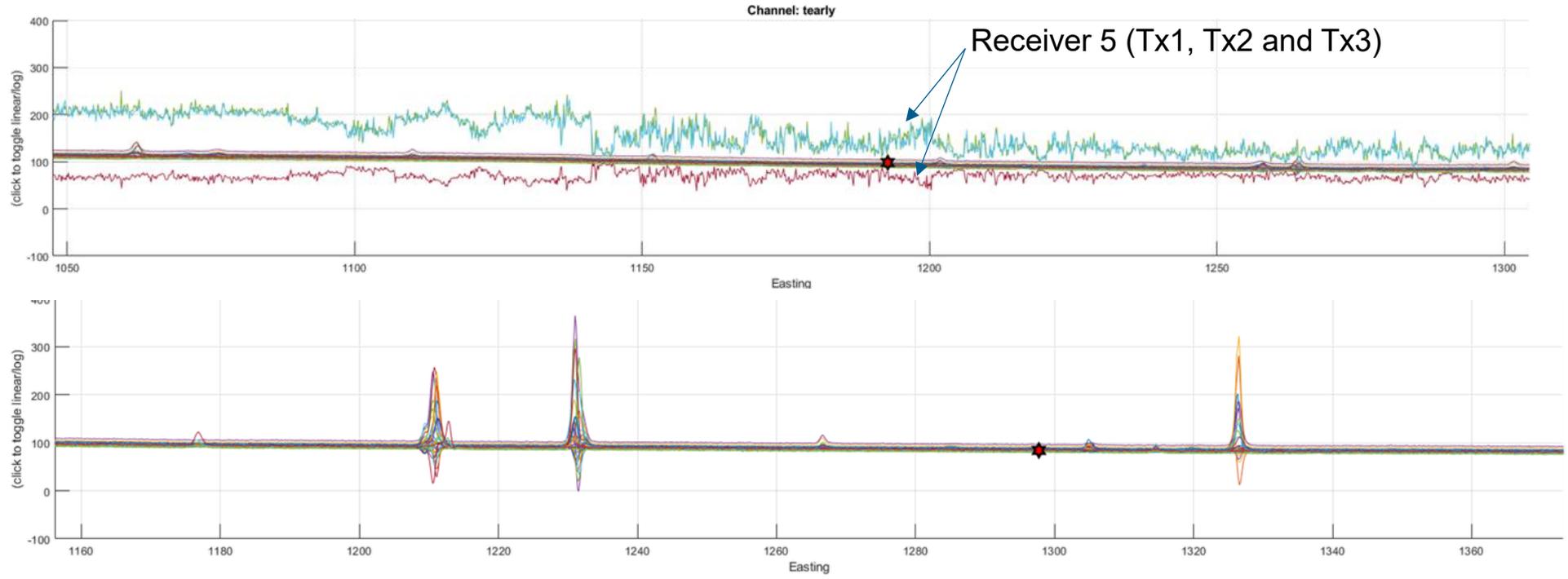
Do all components have to be functional for the data to be used for Advanced Geophysical Classification?

Real-world data issues

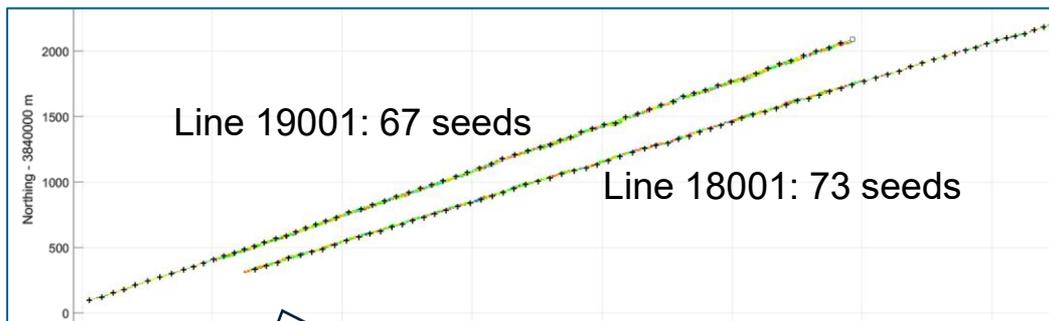


Real-world data issues

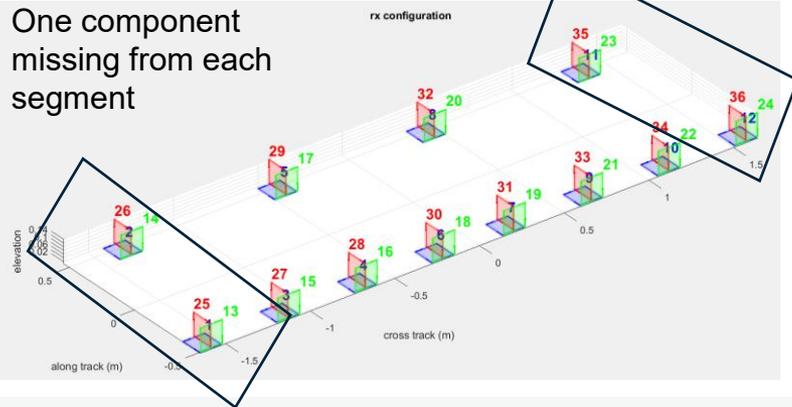
Close up of profiles



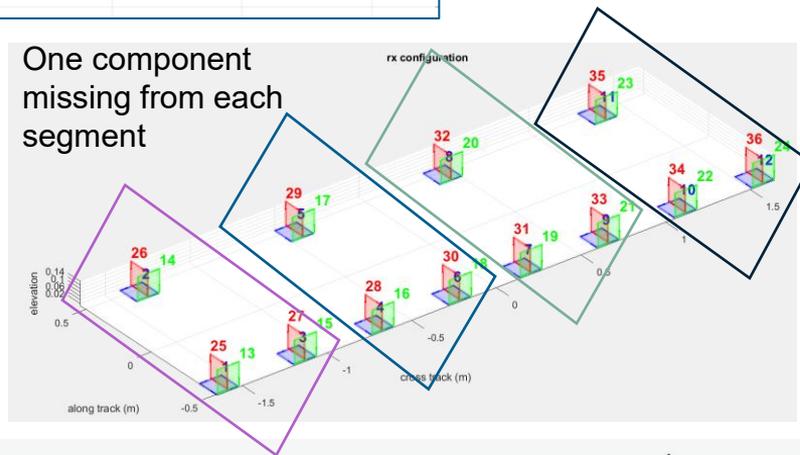
Synthetic seeding: small ISO at 60 cm standoff



One component
missing from each
segment



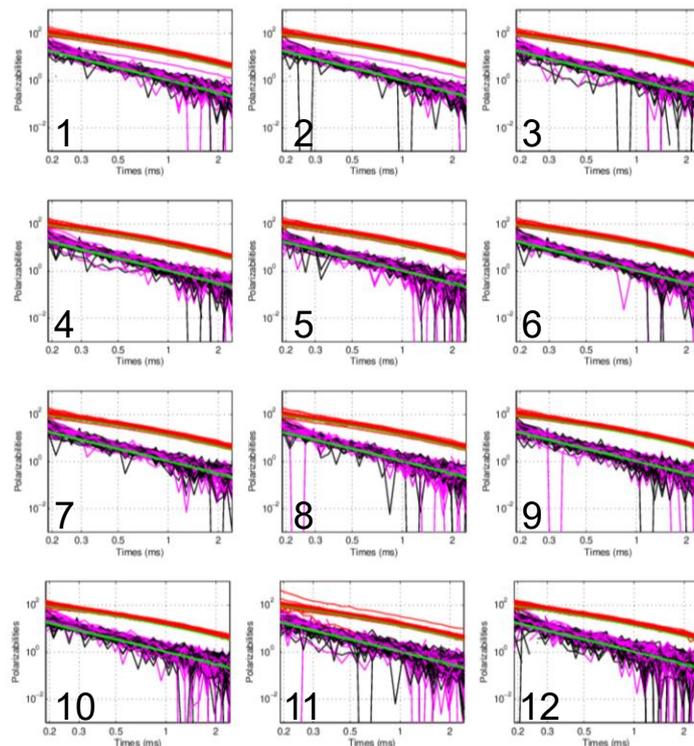
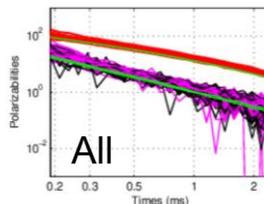
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Synthetic seeding: small ISO at 60 cm standoff

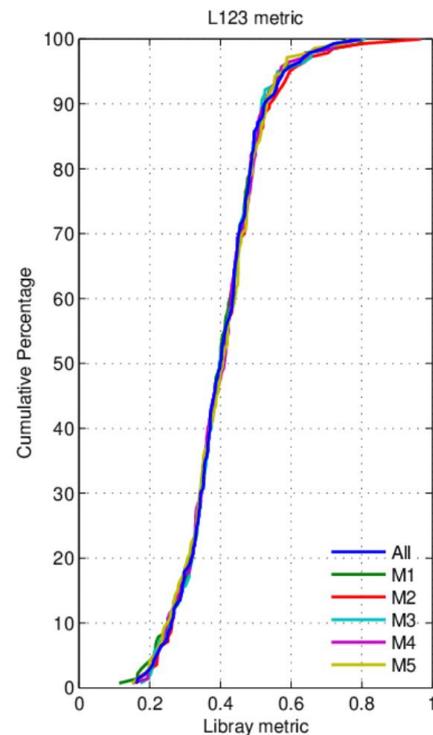
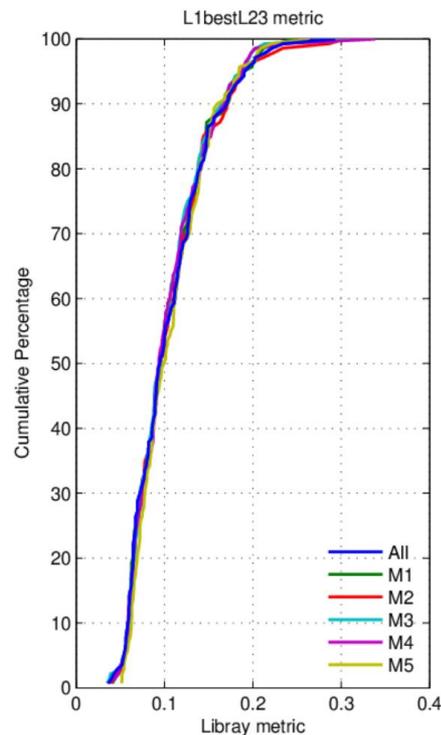
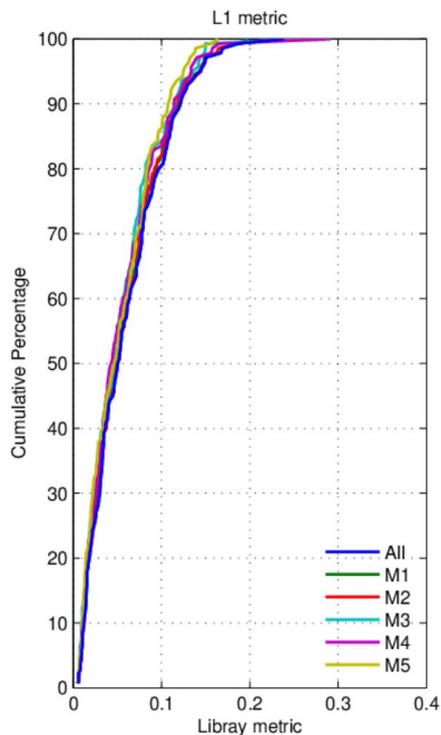
Experiments of missing data at random

- (1) One random component missing;
- (2) Two random components missing (one on the left & right side of the array);
- (3) One random cube completely missing;
- (4) Four random components missing (1 component per quarter across the array);
- (5) One entire x- or y- or z-component missing
- (6)-(12) Dropout 10%, 20%, 30%, 40%, 50%, 60%,70% of MNs.



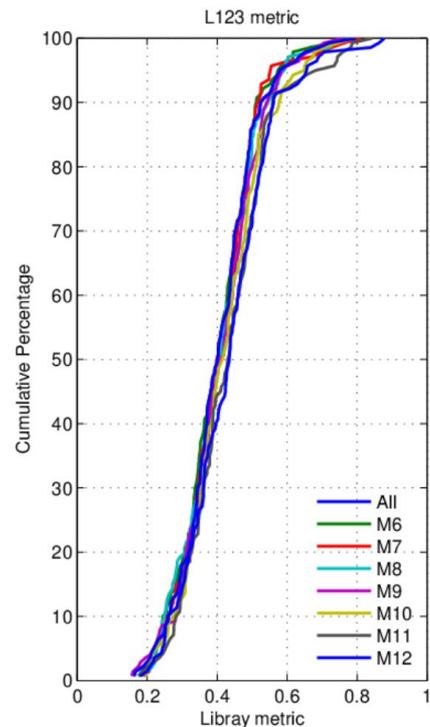
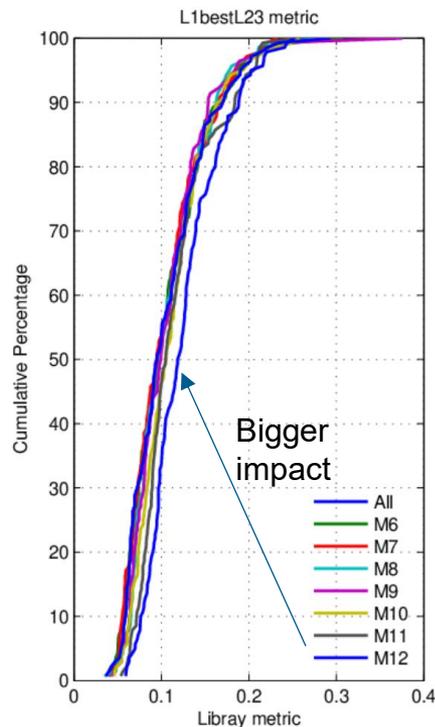
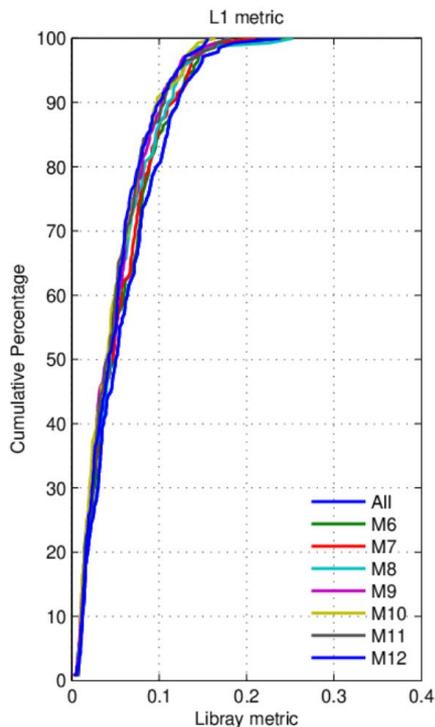
Library metrics: insignificant impact on classification ability

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- (5) One entire x- or y- or z-component missing



Library metrics: insignificant impact on classification ability

- 6) 10% Missing;
- 7) 20% Missing
- 8) 30% Missing
- 9) 40% Missing
- 10) 50% Missing
- 11) 60% Missing
- 12) 70% Missing

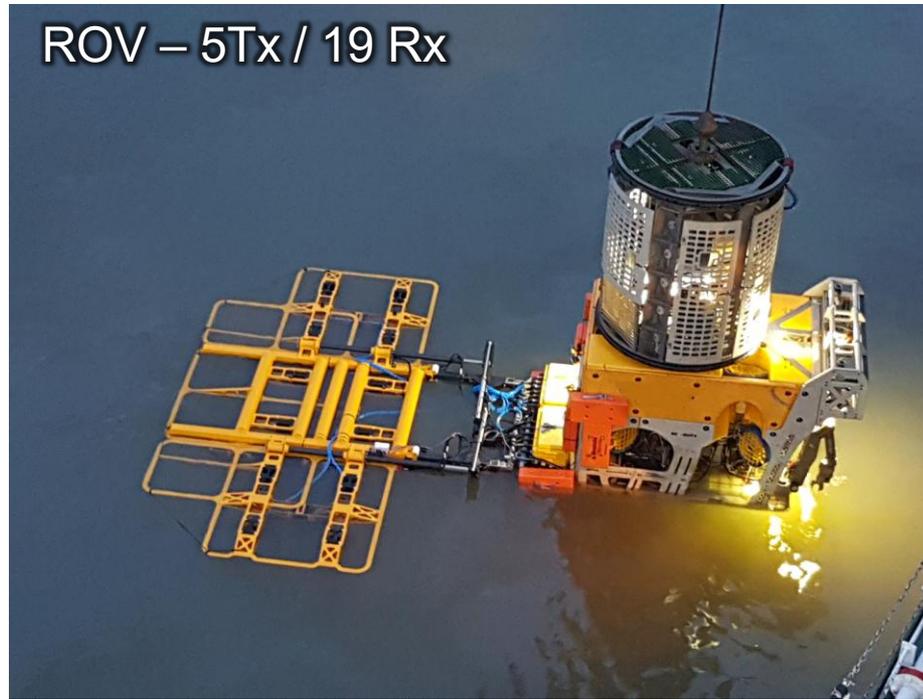


Detecting deeply buried large ordnance North Sea with an ROV

ROV – 1Tx / 6 Rx

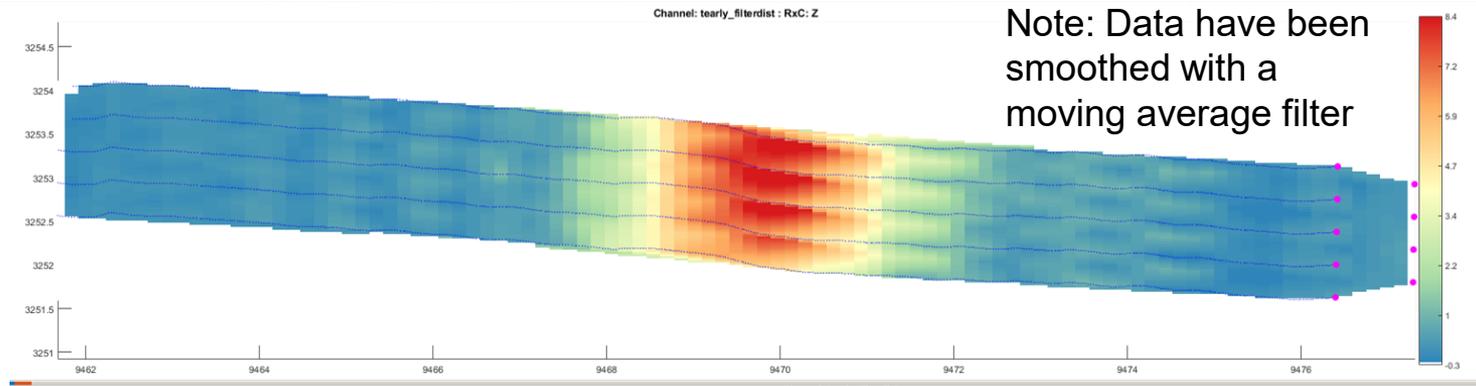


ROV – 5Tx / 19 Rx

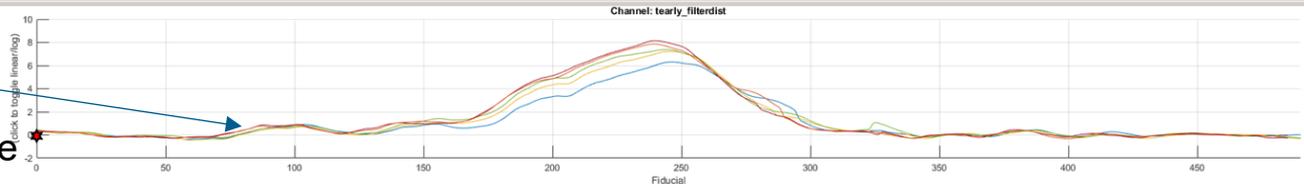


High SNR at all times for modest standoff

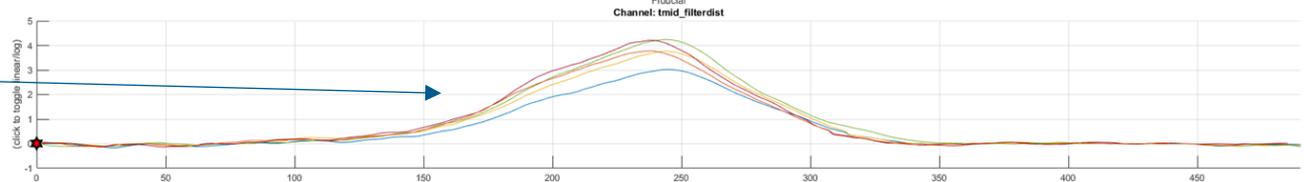
2.5 m standoff to 100 lb bomb



Early times have more maneuverer and sea-water noise



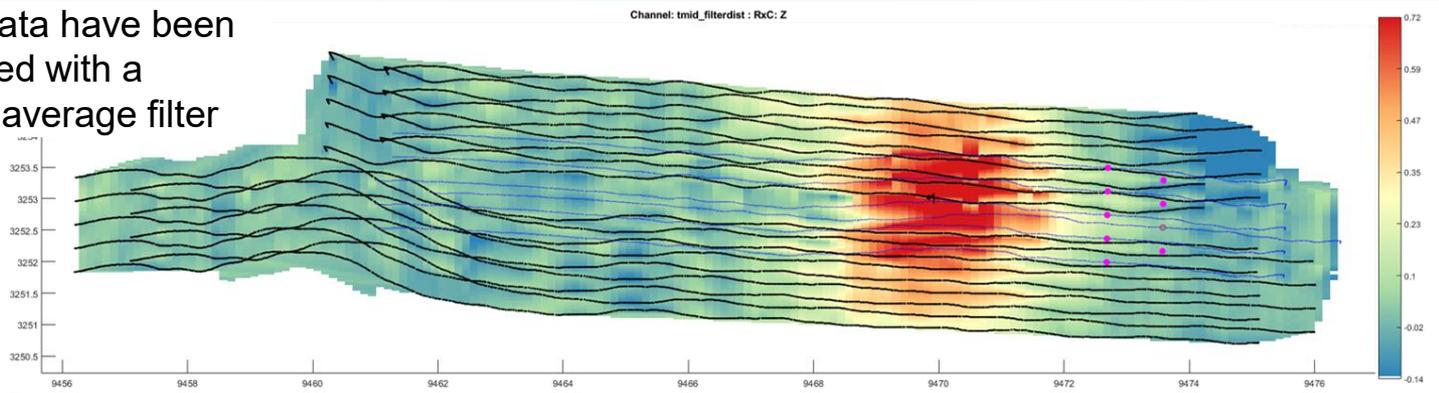
Late times have slightly clearer signal



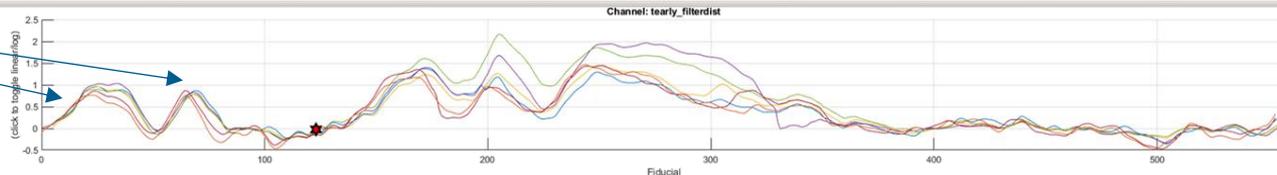
Large standoffs and/or deep burial

Late times are better at 3.5 m standoff

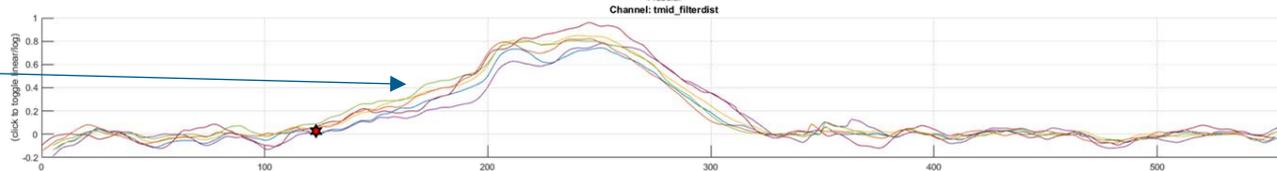
Note: Data have been smoothed with a moving average filter



Early times have more maneuverer and sea-water noise



Late times have clearer signal

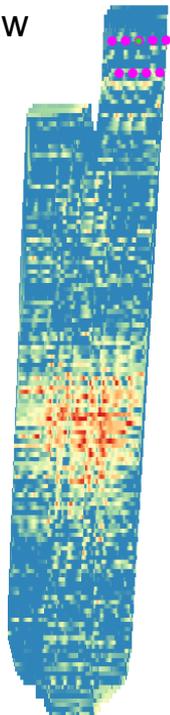


Implications

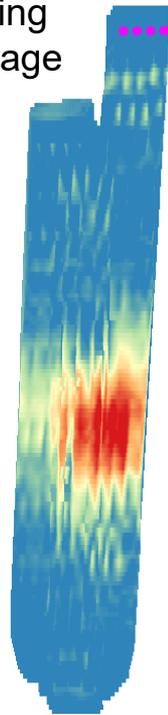
- First, can we use SSA or DMD to extract meaningful signals from the early time-channels?
- Second, the higher SNR at later times may indicate that its worth considering directly measuring the B-field rather than dB/dt

Application of SSA and DMD to early times 3.5 m standoff

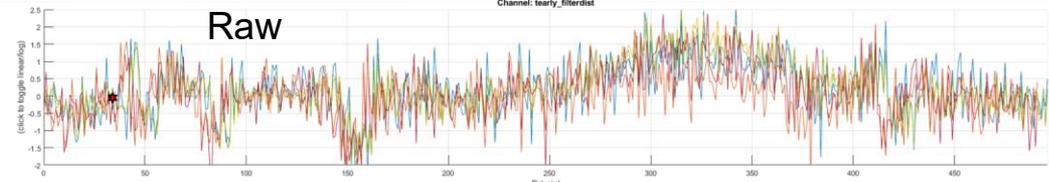
Raw



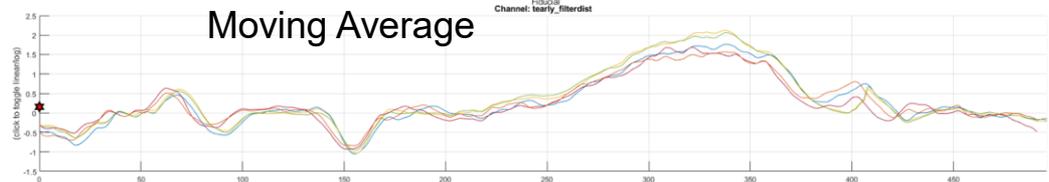
Moving average



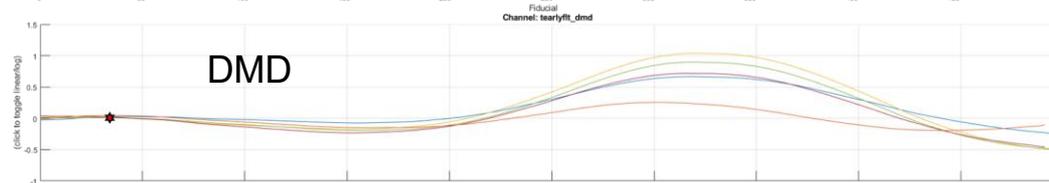
Raw



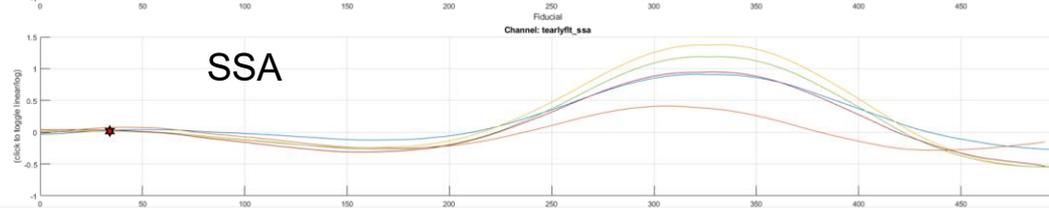
Moving Average



DMD

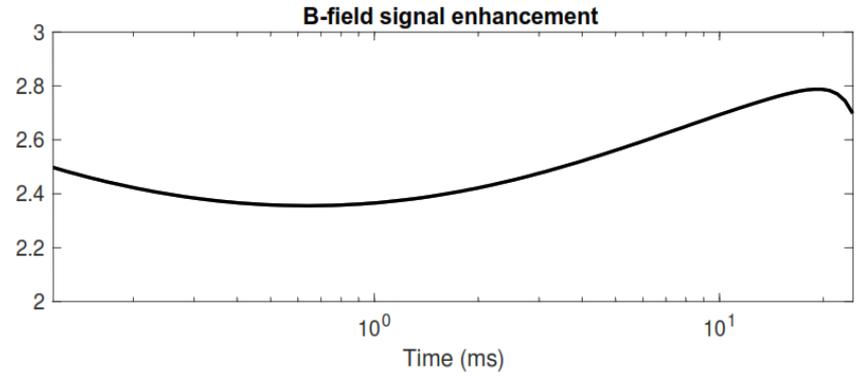
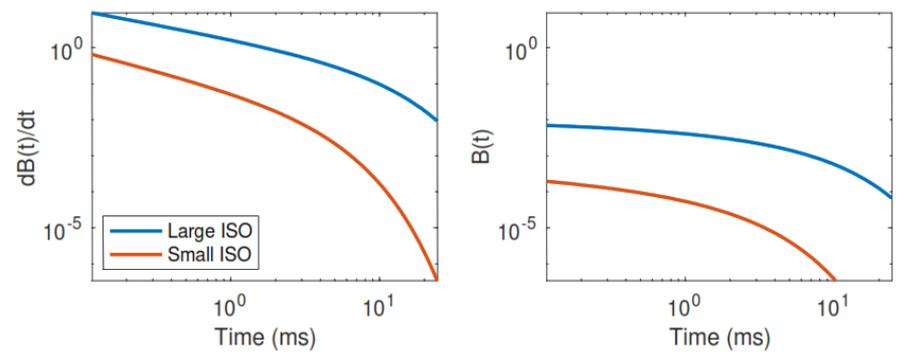


SSA



B-Field sensors

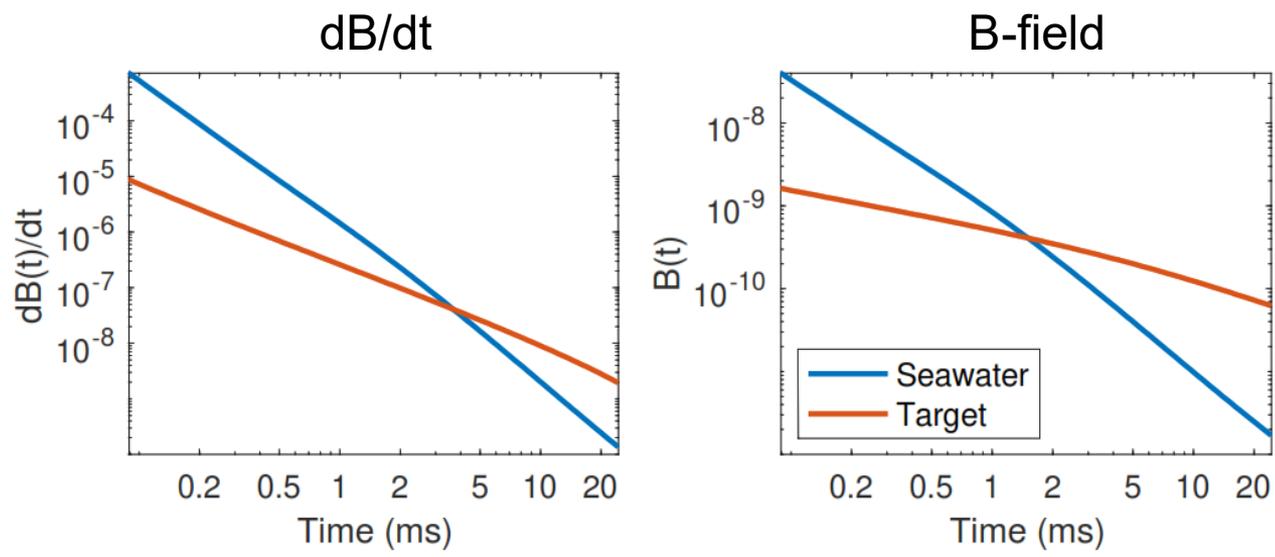
Higher relative signal for larger objects



B-Field sensors

Higher signal relative to sea-water

Medium ISO at 1.25 standoff in 20 m of sea-water

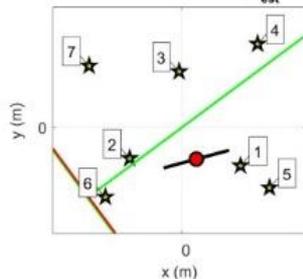


B-Field sensors

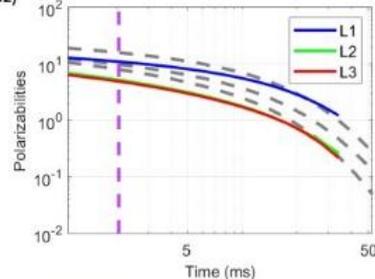
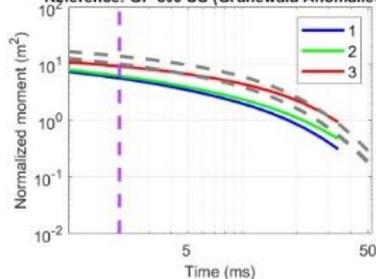
Extensive experience with flux-gates

(3/3) Dipole model
Channel 15 (2.05 ms)

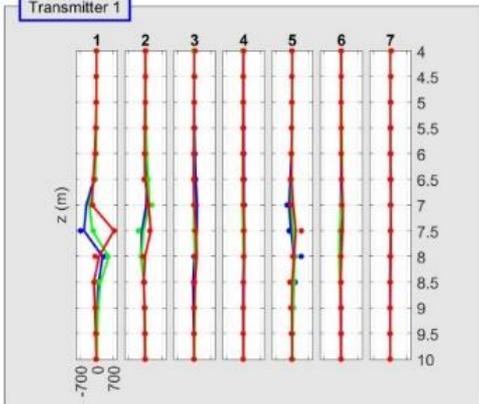
Friedenthaler-Schleuse-A1.dat, $z_{est} = 7.72$ m



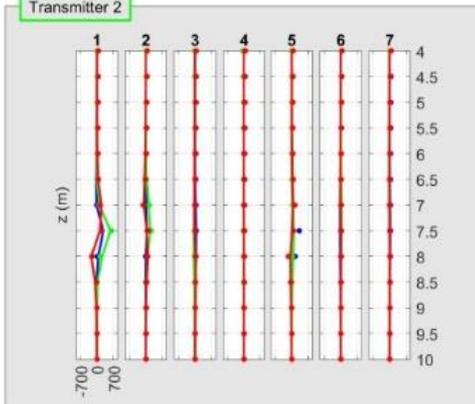
Reference: GP 500 US (Grunewald Anomalie02)



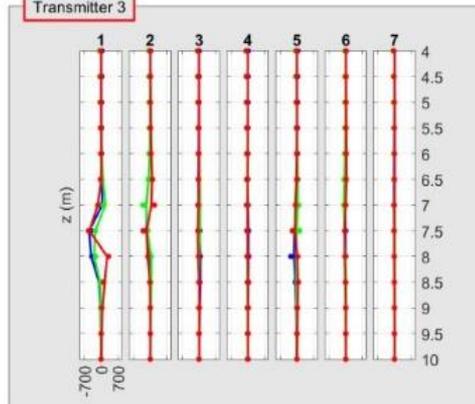
Transmitter 1



Transmitter 2

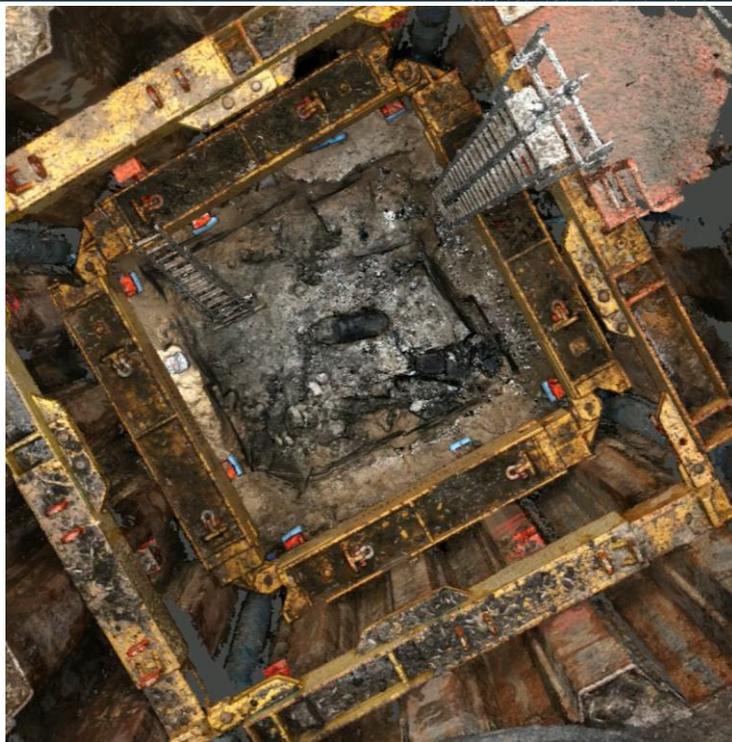


Transmitter 3



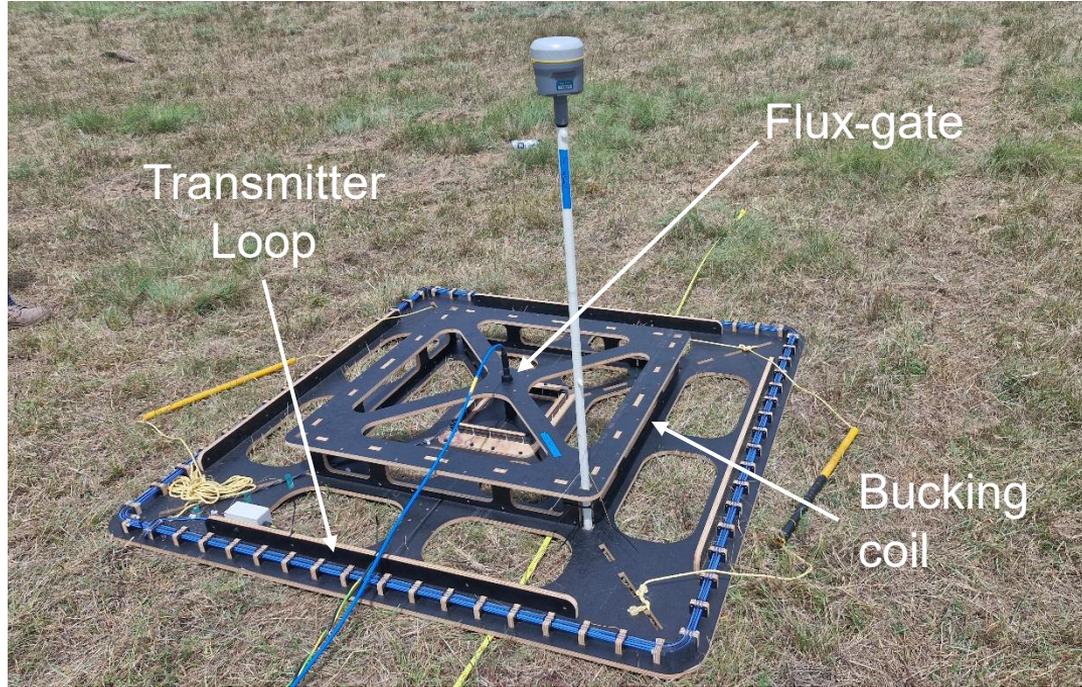
Excavation Revealed an intact 500 lb bomb at 7.5 m depth

One of two identified in the same area



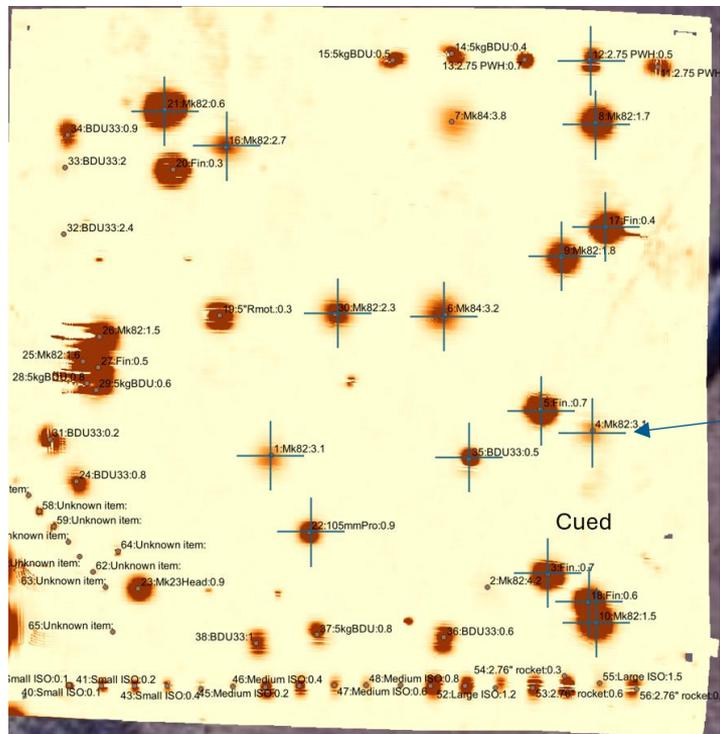
B-Field sensors

Need to buck out the primary field

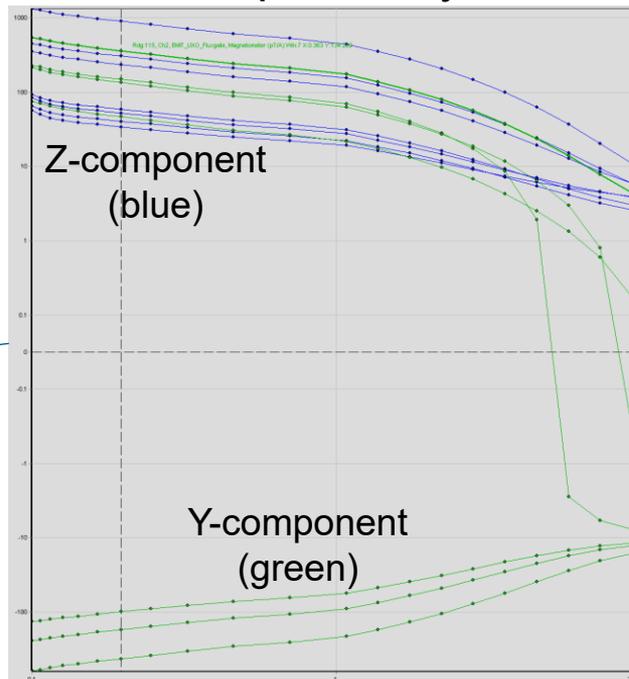


B-Field sensors

Profile data



Sample decays



Challenges with vector B-Field sensors

- Requires static data collection on land due to vibration and sensor movement while surveying
- Damped data collection motions in water may allow dynamic data collection
 - Would require careful design of the sensor platform

Next steps

1.1. Data-driven decomposition methods

- Extend to multi-channel datasets
- Apply and test on real world datasets

1.2 Autoencoder method

- Fine tune on mixed synthetic and real datasets
- Apply and test on real world datasets

2. Positional errors

- Apply Kalman filter algorithm to marine datasets with USBL positioning
- Extend the previously developed IMLI algorithm to deal with along-line errors

3. Real-world datasets

- Shallow water datasets in dynamic surf-zone environments
- Small marine measurement campaign for B-field measurements

Technology Transfer

- The hardware for marine surveying is already very well developed.
- Transition will be through using the developed algorithms and techniques on marine datasets including:
 - ESTCP project MR24-8267 that is extending the operational envelop of the UltraTEM Marine system
 - Numerous production projects
- Presentations at conferences and the symposium

Issues

- There are no issues with the execution of this project

BACKUP MATERIAL

These charts are required, but will only be briefed if questions arise.

MR24-4262: Improving Advanced Geophysical Classification performance in the marine environment

Performers: Dr Stephen Billings, Dr Lin-Ping Song
Black Tusk Geophysics Inc

Technology Focus

- This project is trying to improve the methods used for detection and classification of UXO in underwater environments using Electromagnetic Induction sensing

Research Objectives

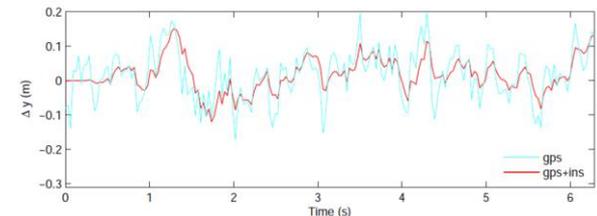
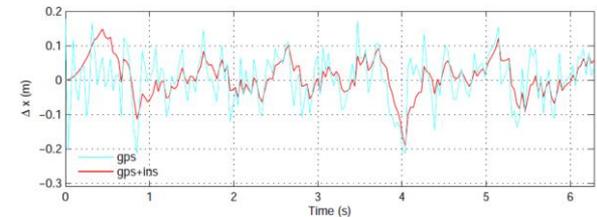
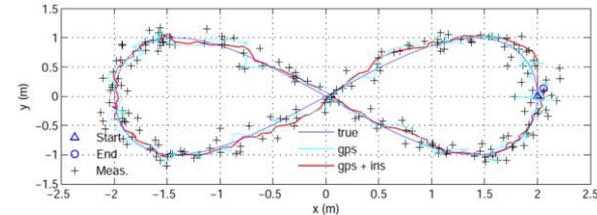
- Develop better tools and algorithms for addressing specific problems encountered in ESTCP and production datasets

Project Progress and Results

- *We have developed improved methods for dealing with noisy underwater data which will increase the detection depth and classification performance of marine EMI*

Technology Transition

- *Implement the developed algorithms into UXOLab and BTField processing softwares*



Plain Language Summary

- This project is trying to improve the methods used for detection and classification of UXO in underwater environments
- This project is focused on developing tools and algorithms for addressing specific problems encountered in ESTCP and production datasets
- The project will result in improved algorithms for detection and characterization of underwater UXO that will be incorporated into software packages

Action Items

- No additional action items have been assigned

Publications

- We have not yet published any results

Literature Cited

- Not applicable

Acronym List

AE	Autoencoder	PCA	Principal Component Analysis
CNN	Convolutional Neural Network	rad	radian
DMD	Dynamic Mode Decomposition	rc	recursive cluster
DVL	Doppler Velocity Log	s	second
EMI	Electromagnetic Induction	SSA	Singular Spectrum Analysis
FNN	Feedforward Neural Network	SVD	Singular Value Decomposition
GPS	Global Positioning System	STFT	Short-Time Fourier Transform
IMU	Inertial Measurement Unit	TEM	Transient Electromagnetic Induction
INS	Inertial Navigation Solution (System)	UXO	Unexploded Ordnance
LSTM	Long Short-Term Memory Network		
m	meter		