Underwater targets detection and classification Using Enhanced EMI models

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Problem Statement

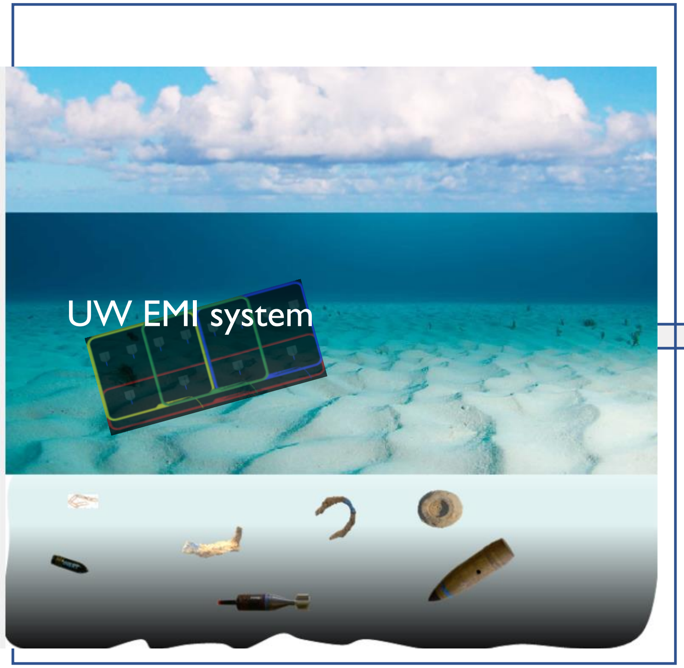
- Remediation and Detection of underwater UXO targets are more expensive than excavating the same targets on land
- Advanced EMI sensors and models have provided excellent classification performance for detecting and classifying subsurface metallic targets on land

There are needs to develop better EMI models and systems to:

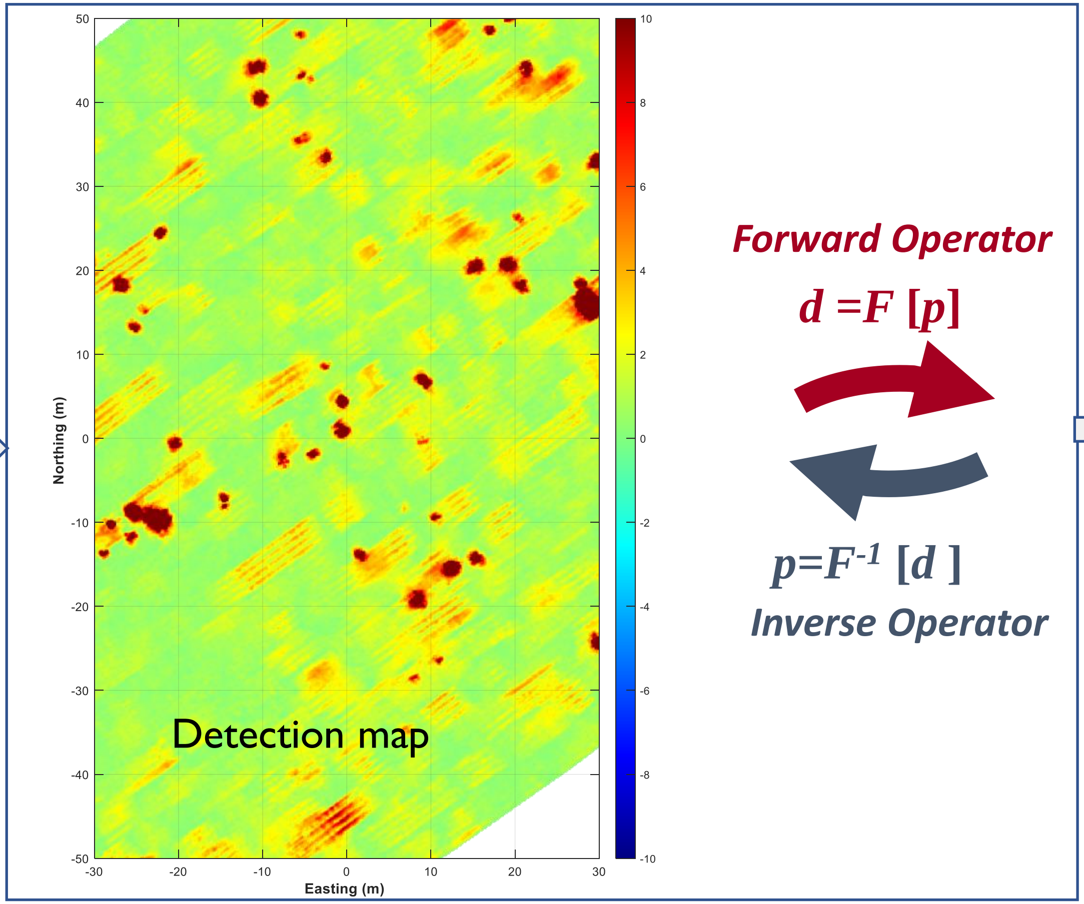
➢ Ehnance EMI systems and signal processing approaches for UW targets detection and classification

UXO classification workflow

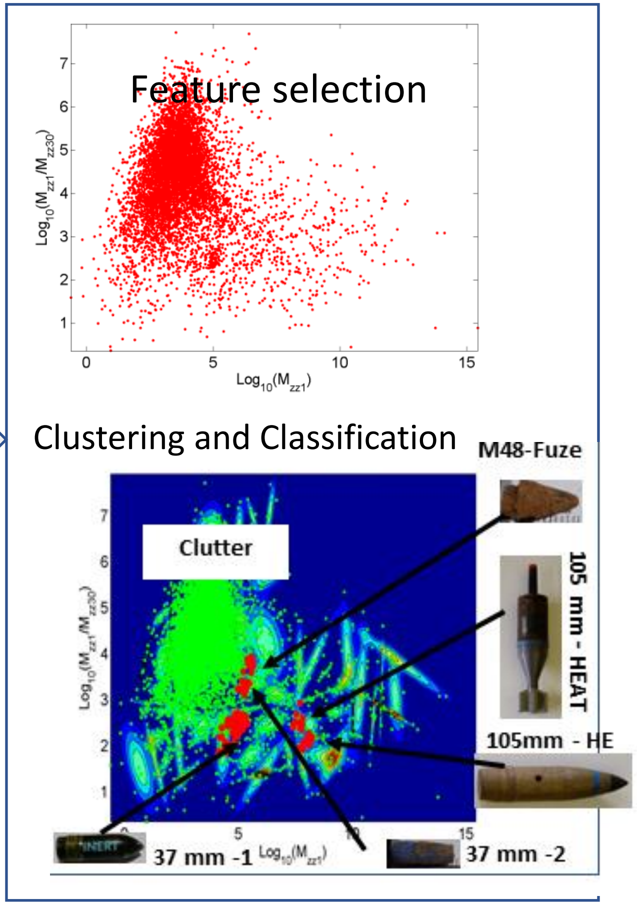
1. Data Acquisition



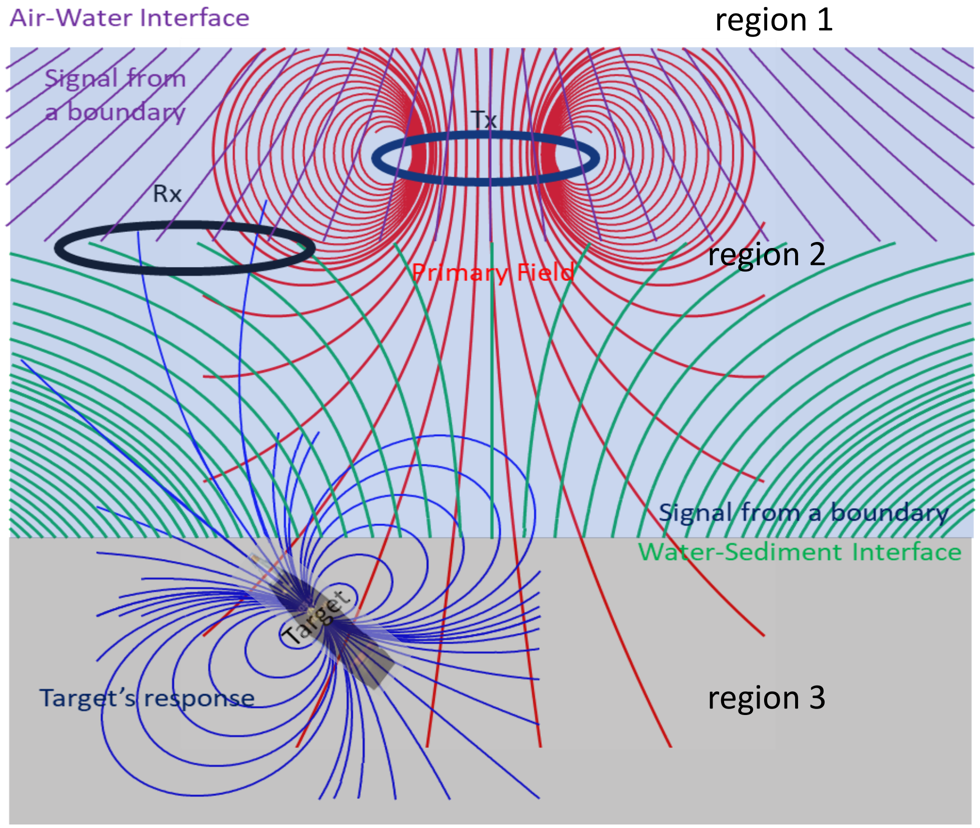
2. Data Inversion



3. Decision

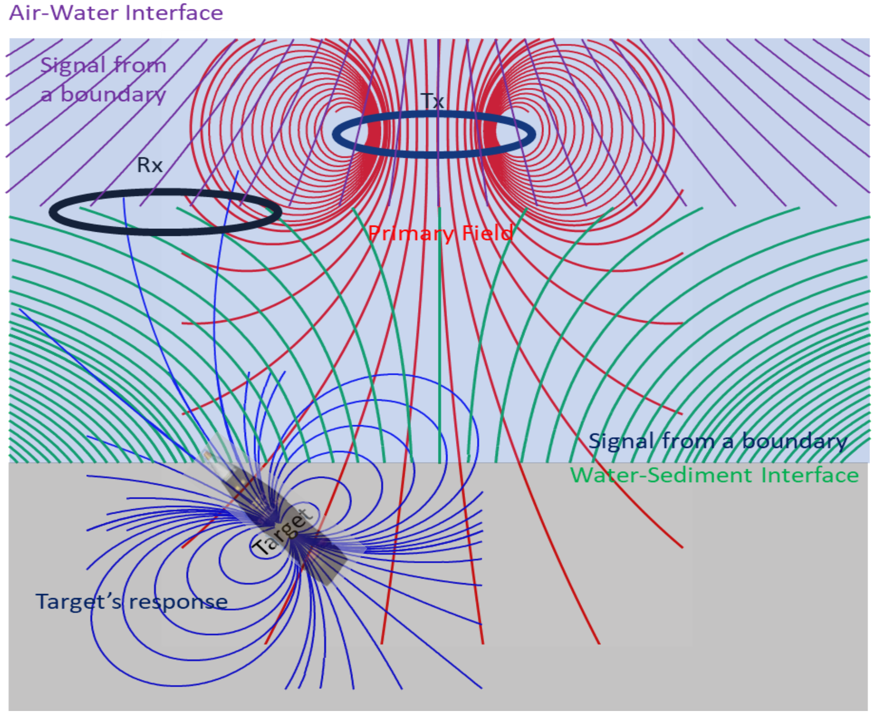


UW EMI sensing



- The primary electromagnetic fields induce currents in conducting media
- The total field in region 2 is sum of fields produced by a Tx coil (response from water), reflected fields from Boundaries and fields from a target
- The fields in region 1 are transmitted fields
- The total field in region 3 is sum of transmitted fields and response from a target

Enhanced models



Time harmonic response

$$\mathbf{B} = \mu_o \frac{e^{-ikR}}{4\pi R^3}\left[\left(\frac{3\mathbf{R}(\mathbf{R}\cdot\mathbf{m})}{R^2} - \mathbf{m}\right)(1+ikR) - k^2\left(\mathbf{R}\times(\mathbf{R}\times\mathbf{m})\right)\right];$$

$k = \sqrt{\omega^2 \mu_o \varepsilon_o \varepsilon \mu + i\sigma\omega\mu\mu_o}$; for low frequency induction $k = \sqrt{i\sigma\omega\mu\mu_o}$

Using the inverse Laplace Transform

$$\mathbf{B}(t) = L^{-1}\left[\frac{\mathbf{B}(s)}{s}\right]; \quad s = i\omega$$

Transient responses

The magnetic field in marine environment

$$\mathbf{B}(\mathbf{r},\mathbf{r}',t) = \int_0^t \bar{\bar{\mathbf{G}}}_{step}(\mathbf{r},\mathbf{r}',t-\tau)\cdot\ \mathbf{m}(\tau)\, d\tau$$

The magnetic field in terrestrial environment

$$\mathbf{B}(\mathbf{r},\mathbf{r}',t) = \bar{\bar{\mathbf{G}}}(\mathbf{r},\mathbf{r}',t=0)\cdot\ \mathbf{m}(\mathrm{t})$$

Induced *emf* (voltage) in the receiver coil is the time derivative of the magnetic field

$$V(t) = \frac{\partial \mathbf{H}(\mathbf{r},\mathbf{r}',t)}{\partial t} \approx \sum \bar{\bar{\mathbf{G}}}(\mathbf{r},\mathbf{r}',t=0)\cdot \frac{\partial \mathbf{m}(\mathrm{t})}{\partial t} + \frac{\partial \bar{\bar{\mathbf{G}}}(\mathbf{r},\mathbf{r}',t)}{\partial t}\cdot\ \mathbf{m}(\mathrm{t{=}0})$$

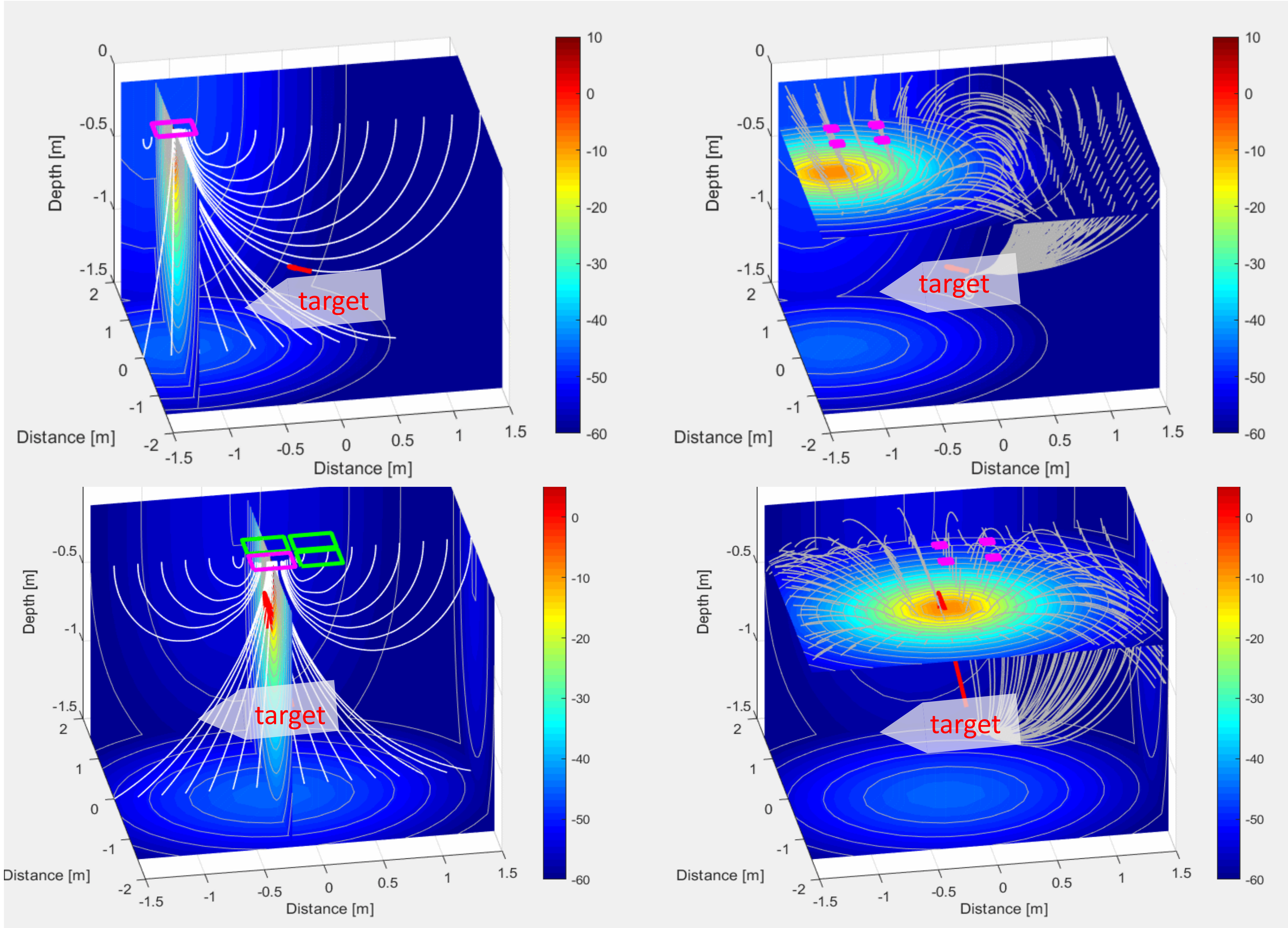
Old model:
Voltage due to the time derivative of magnetic dipole

Complete model:
Voltage due to both the magnetic dipole and its time derivative

Dynamic and Cued Data Collection

Dynamic data collection

Cued data collection



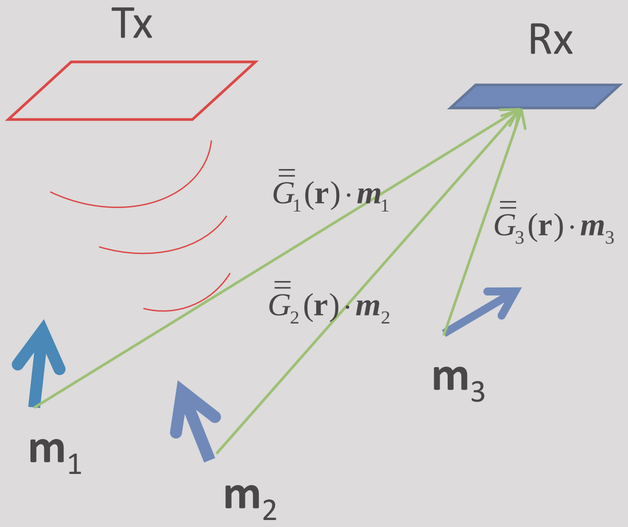
- Covers large areas;
- Provides very dense data;
- Illuminates targets from multiple points.
- Data are NOT stacked

- Provides high quality data for classification
- Very slow process ~1.5 min/per anomaly
- Data stacked

Forward Models

Standard model

Magnetic dipole model



The scattered EMI field is approximated as superposition of magnetic fields from each individual dipole, using the dyadic Green's function:

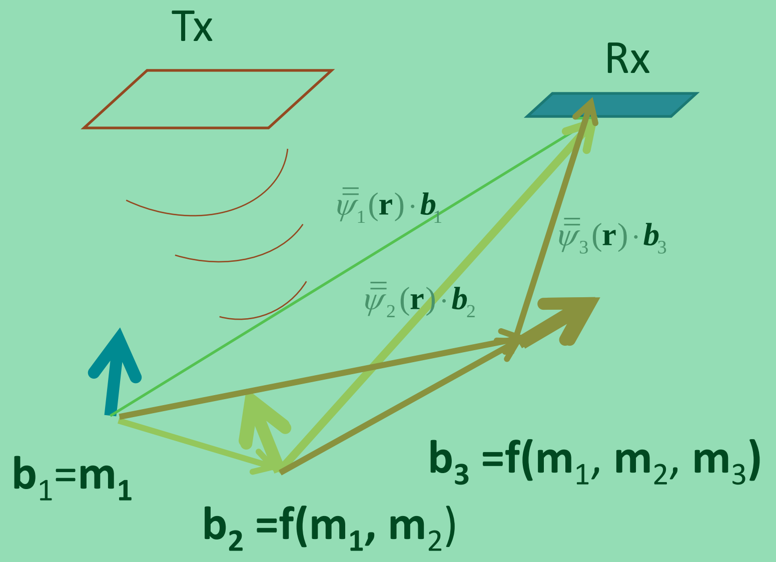
$$\mathbf{H}(\mathbf{r}) = \sum_{i=1}^{N_v} \bar{\bar{G}}_i(\mathbf{r})\cdot \boldsymbol{m}_i$$

where

$$\bar{\bar{G}}_i(\mathbf{r}) = \frac{1}{4\pi R_i^3}\left(3\vec{R}_i\,\vec{R}_i - \bar{\bar{I}}\right)\;;\;\; \vec{R}_i = \mathbf{r}_i - \mathbf{r}$$

Advanced model

Orthonormalized Volume Magnetic Source (ONVMS) model



The scattered EMI field is approximated as magnetic field from **groups of interacting dipoles** using an ortho-normalized function expansion:

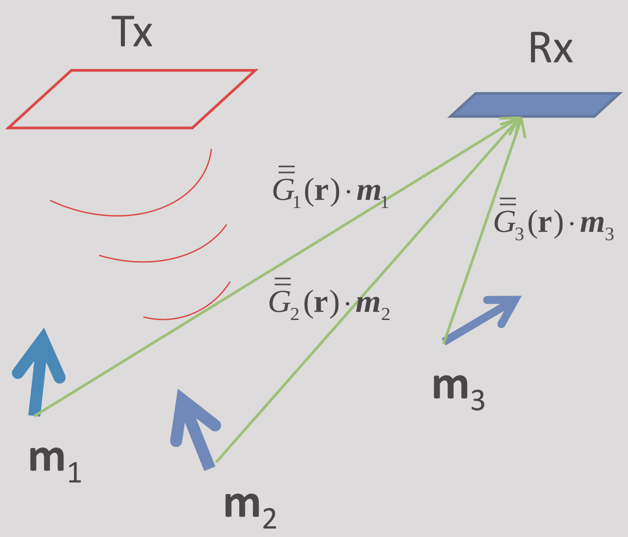
$$\mathbf{H}(\mathbf{r}) = \sum_{q=1}^{Q} \bar{\bar{\psi}}_q(\mathbf{r})\cdot \boldsymbol{b}_q,$$

where $\bar{\bar{\psi}}_q(\mathbf{r}) = \bar{\bar{G}}_q(\mathbf{r}) - \sum_{k=1}^{q-1} \bar{\bar{\psi}}_k(\mathbf{r})\cdot \bar{\bar{A}}_{qk};$

Forward Models

Standard model

Magnetic dipole mode

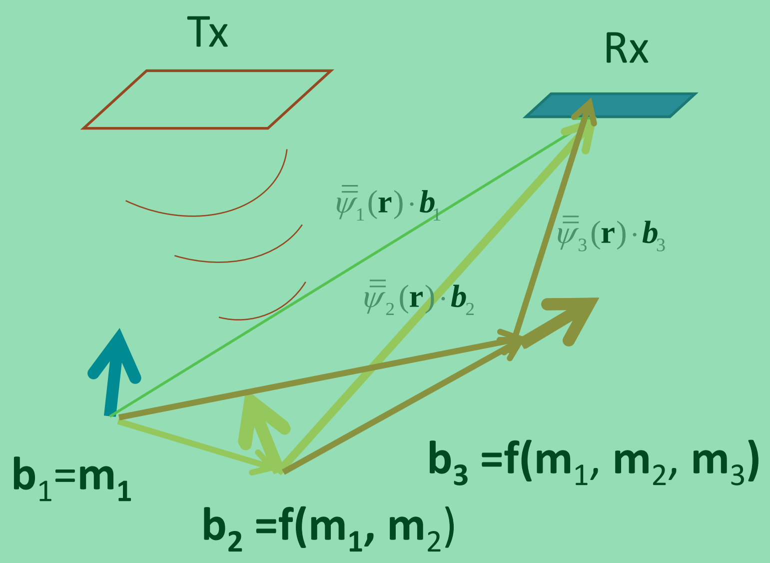


- $\mathbf{m}_i$ are determine from the measured data **by solving** a linear system of equations.

- Uses **individual dipole polarizabilities** for classification

Advanced model

Orthonormalized Volume Magnetic Source (ONVMS) model



- First it determines b_q from the measured data **without solving** a linear system of equations, then it backs out $\mathbf{m}_i$

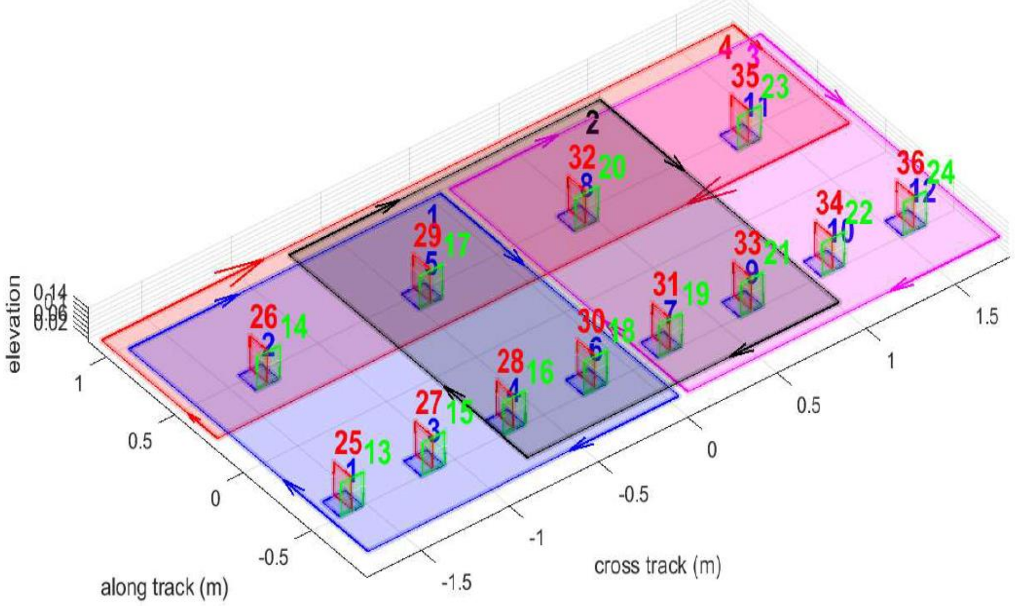
- Uses **total ONVMS/effective polarizabilities** for classification

UW ULTRATEMA

System has:

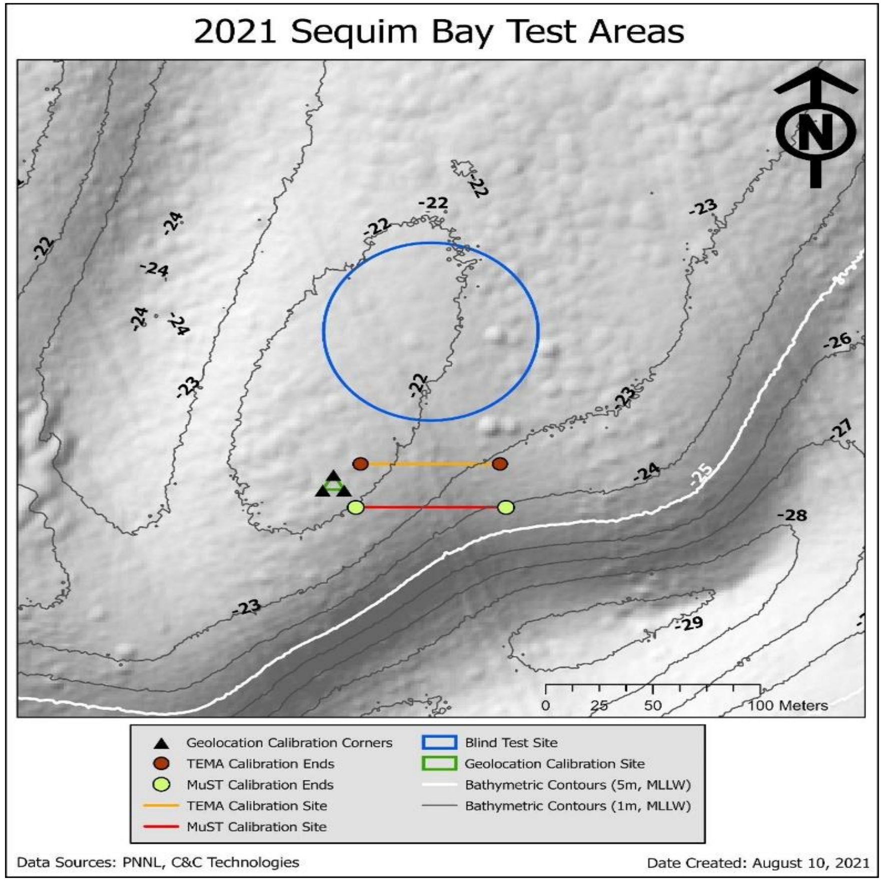
- Four (4) Tx coils
- Twelve (12) vector receivers

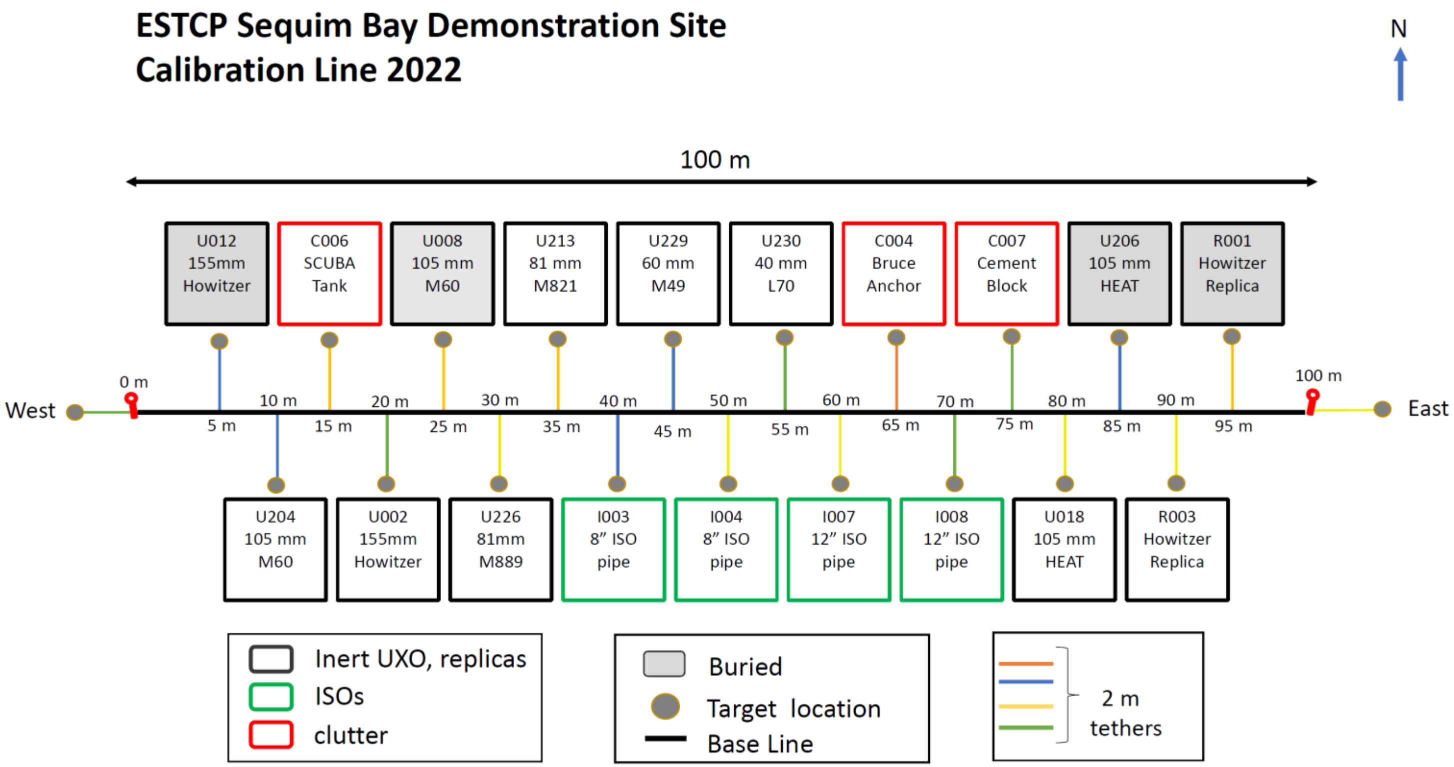
And operates in dynamic model and measures targets transient responses .



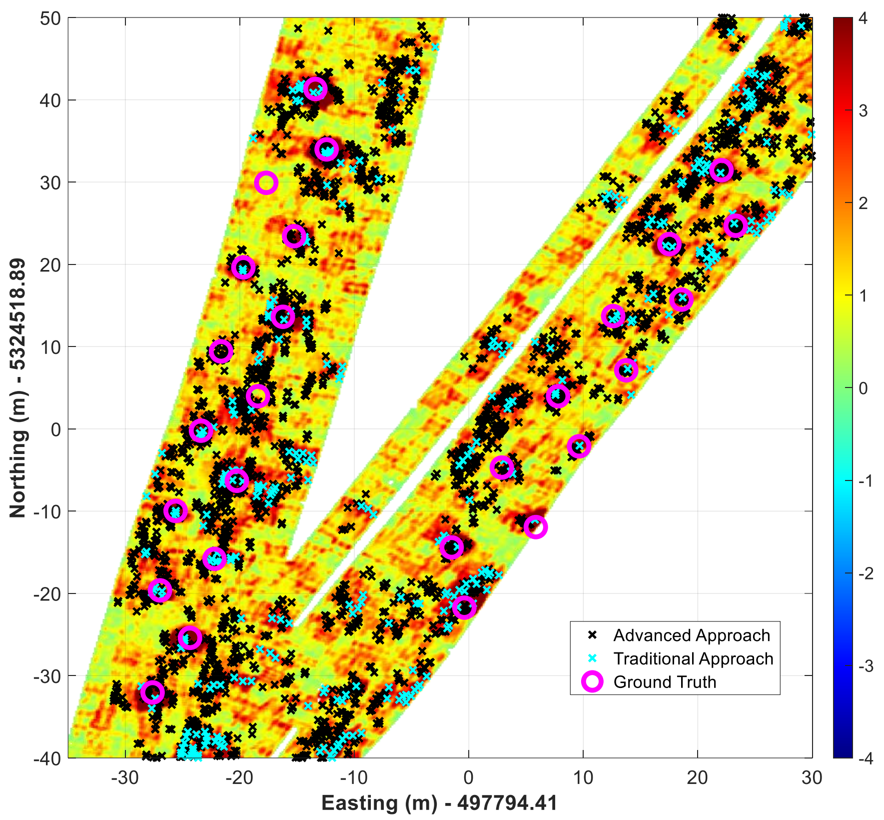
Combine enhanced forward and inverse EMI models for UW data processing

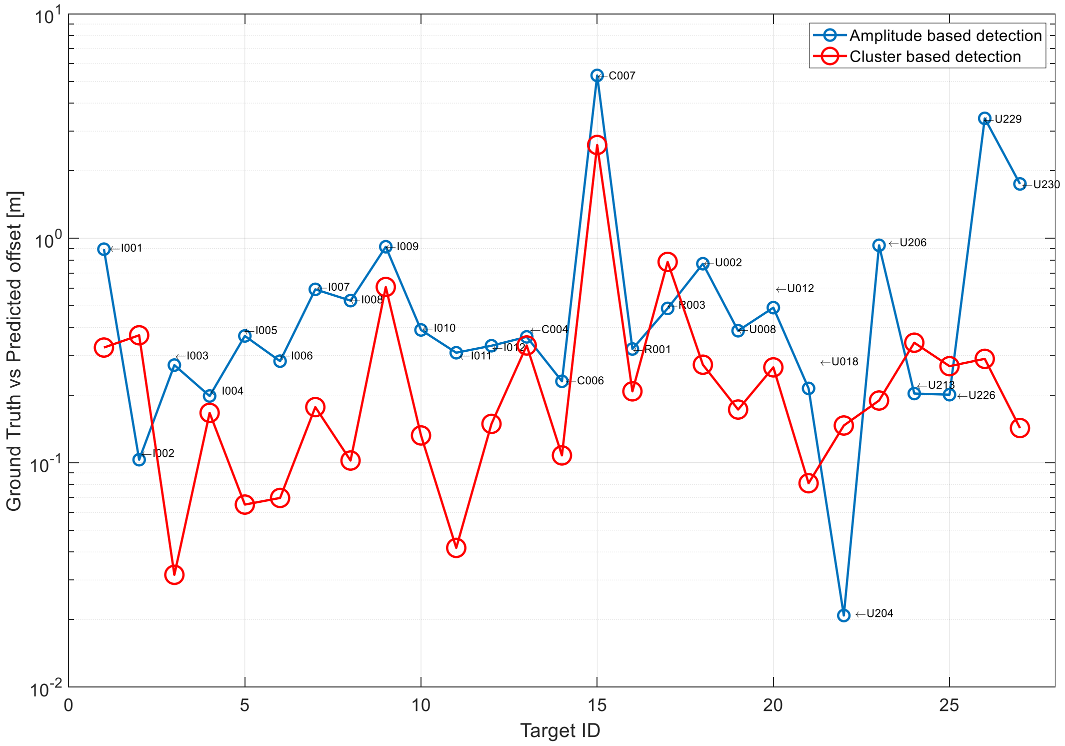
2021 Sequim Bay



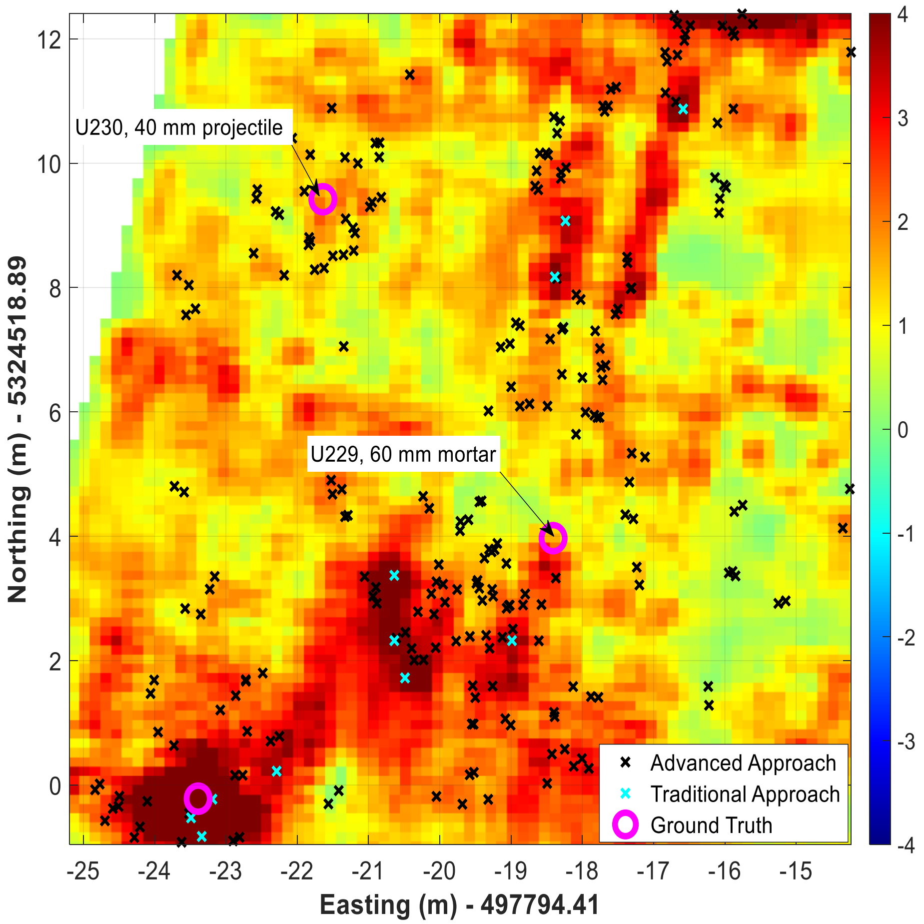


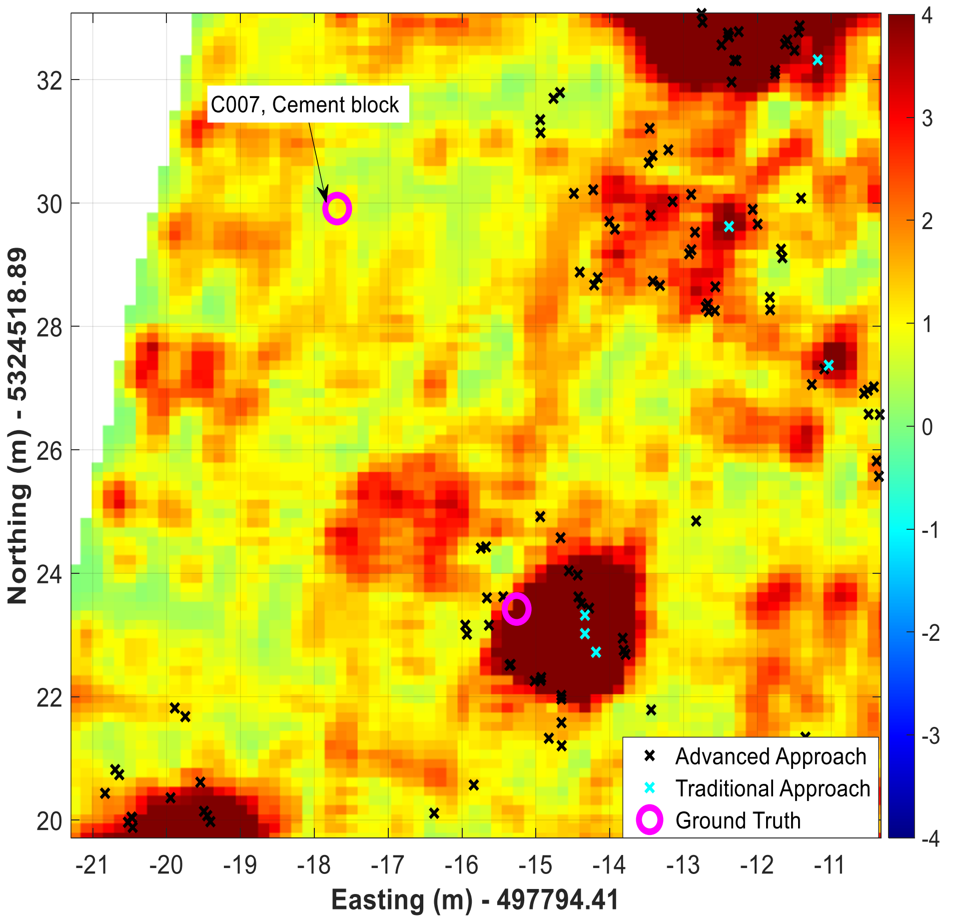
Detection map: calibration grid



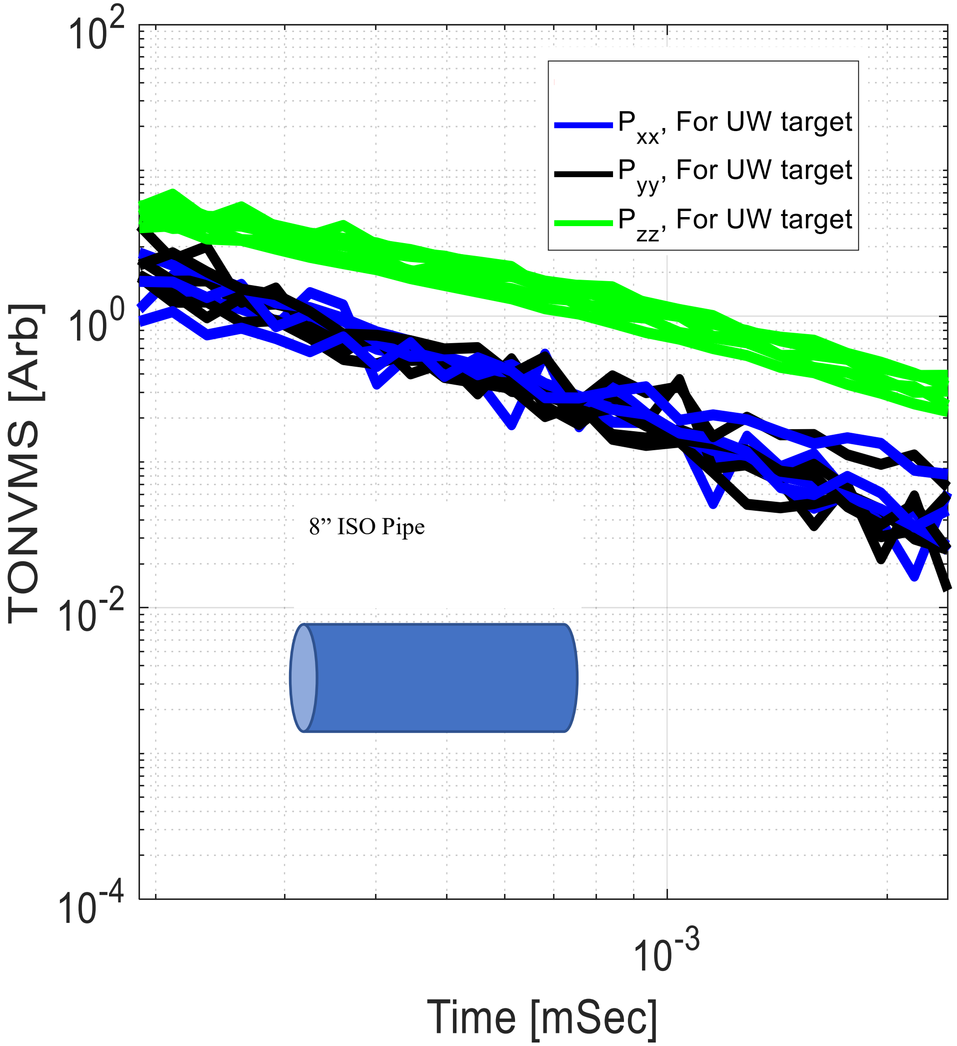


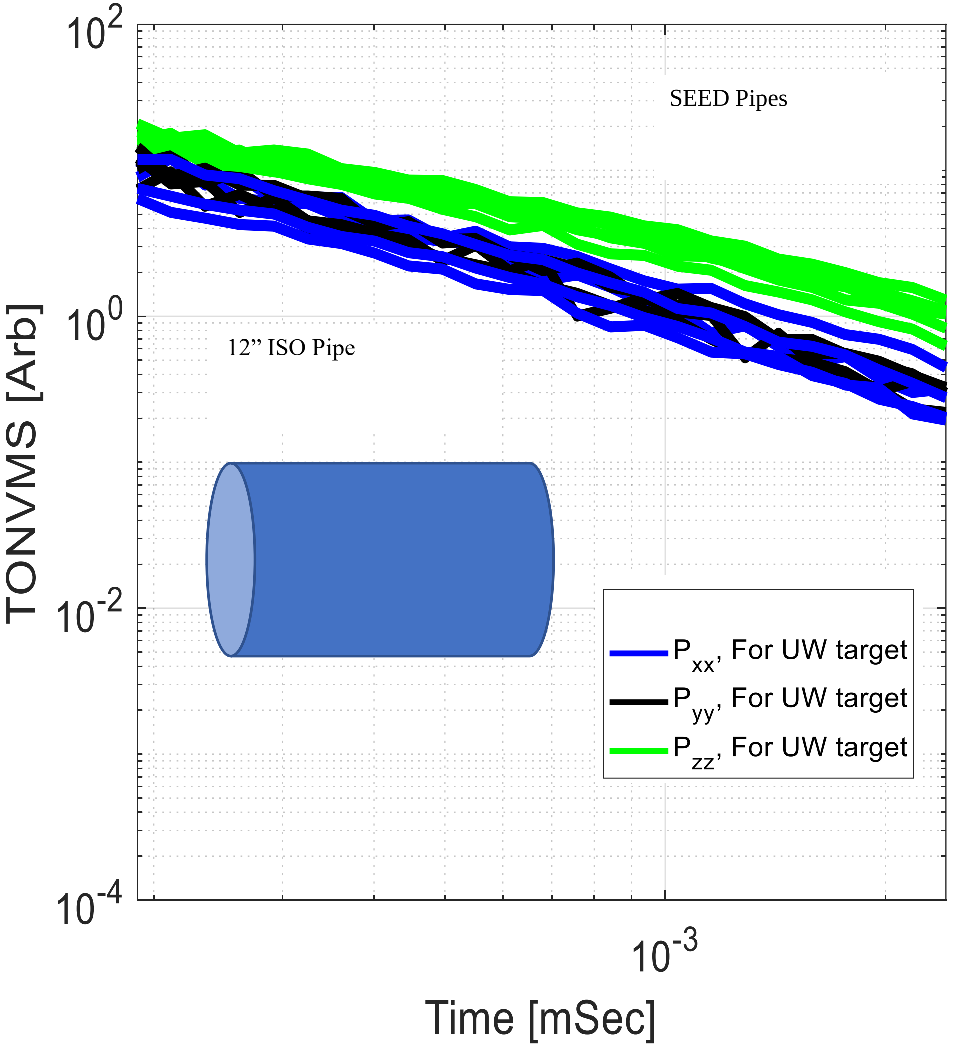
Detection map: calibration grid



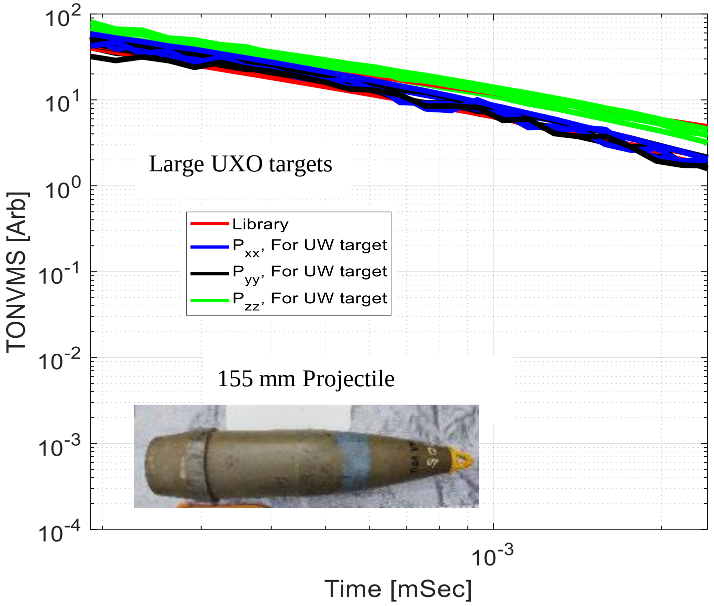


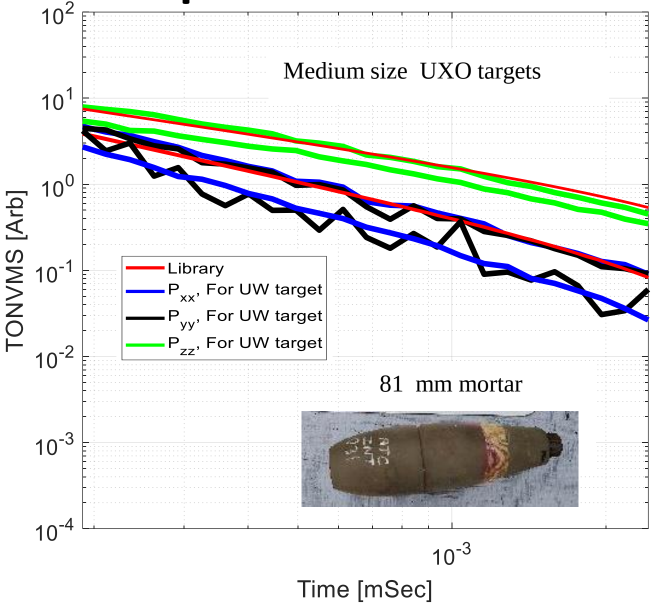
Extracted effective polarizabilities



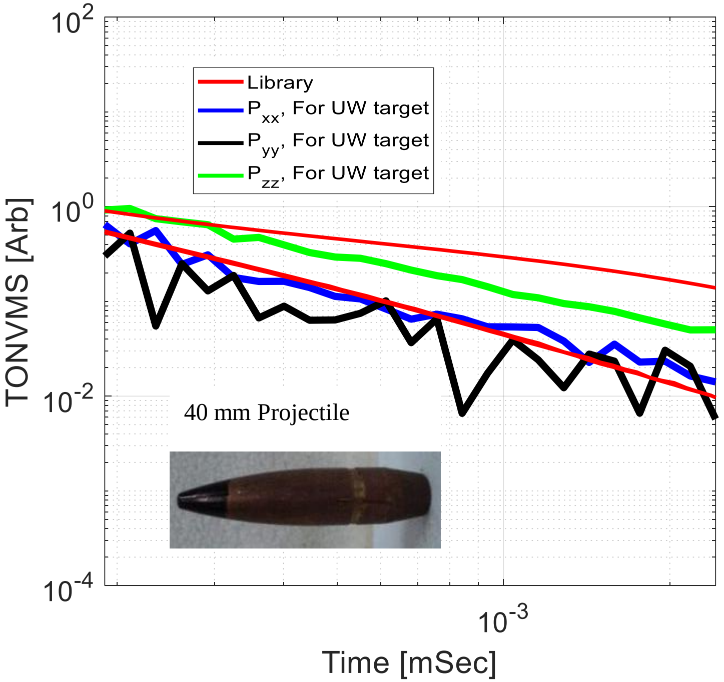


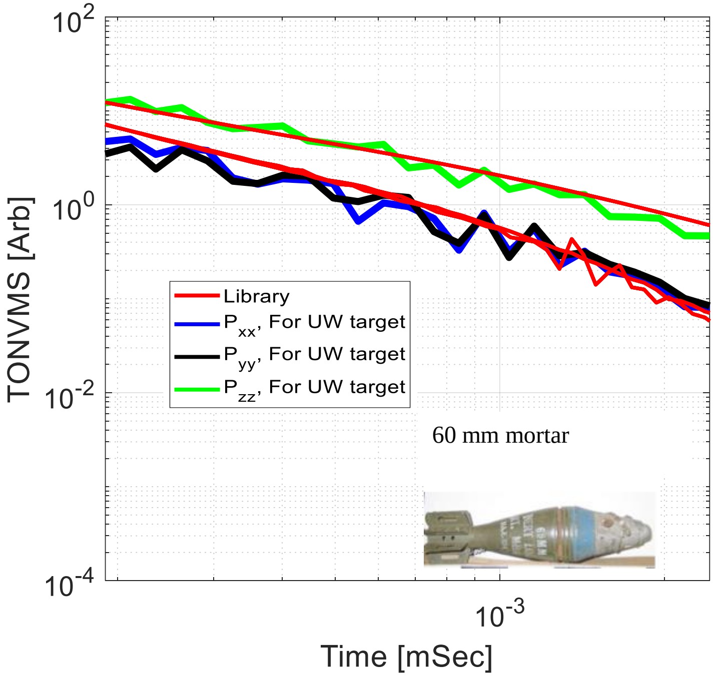
Extracted effective polarizabilities



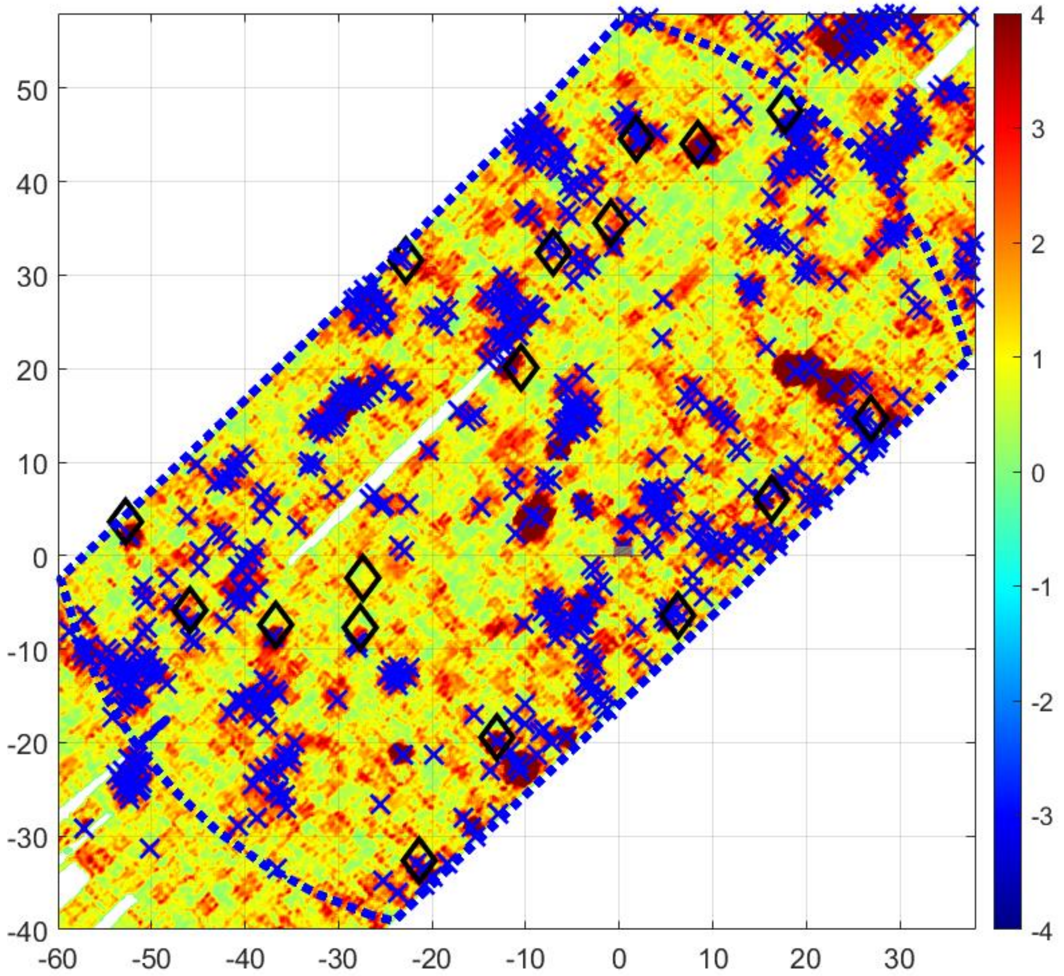


Small UXO targets

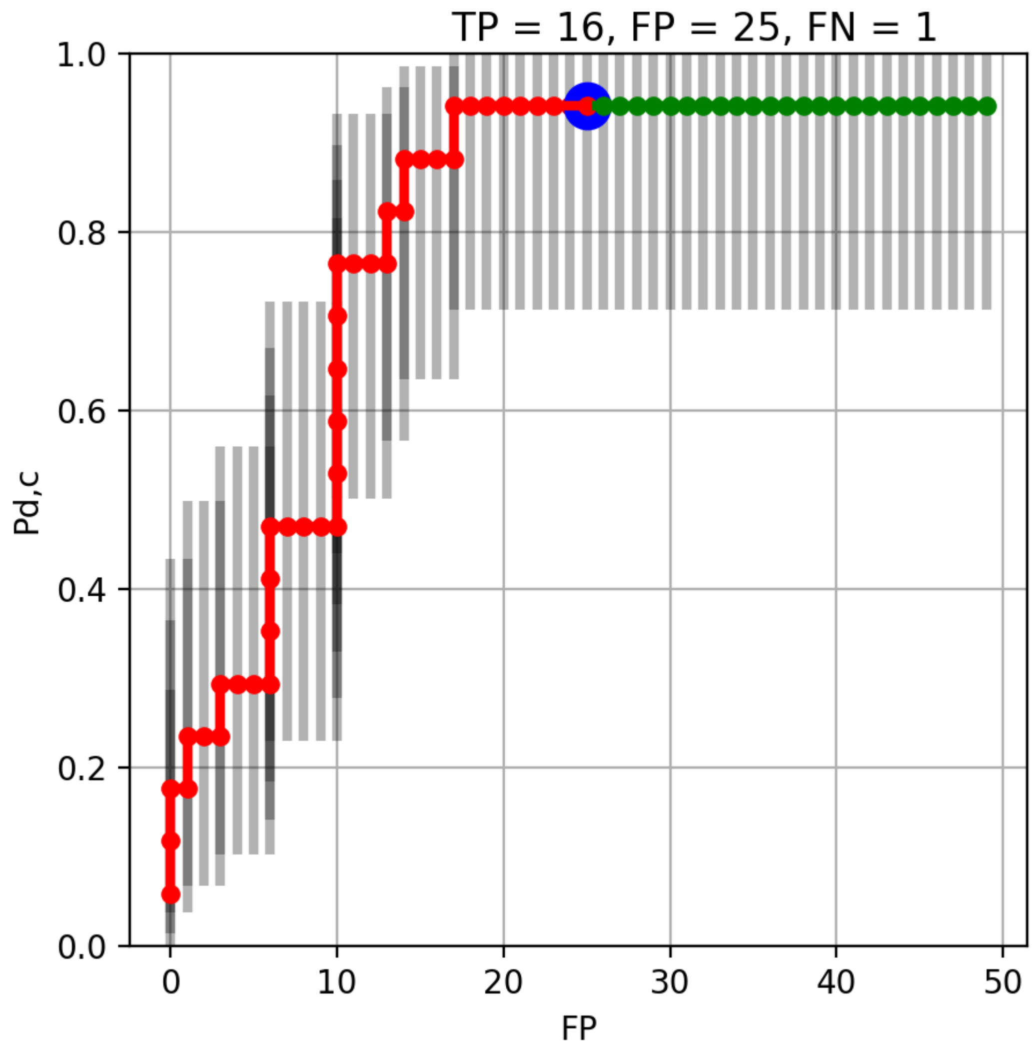




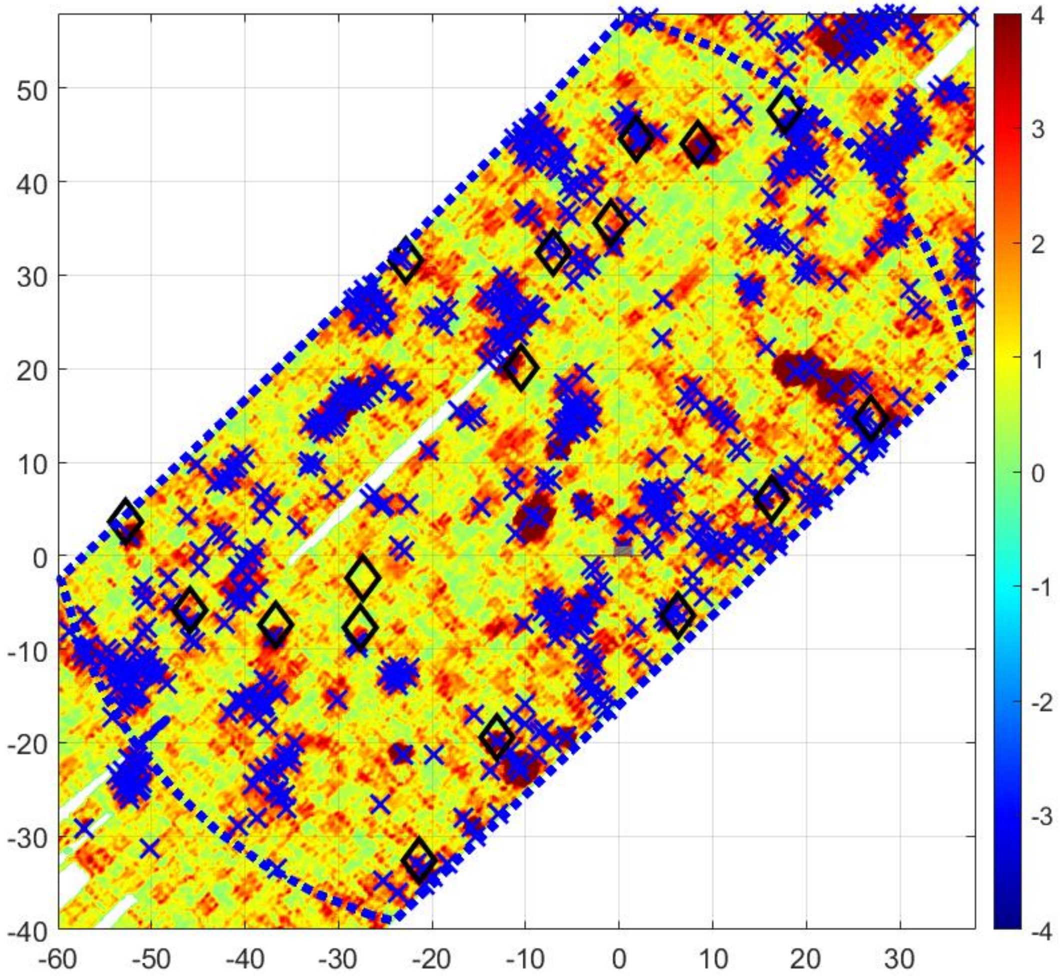
Detection map using standard approach



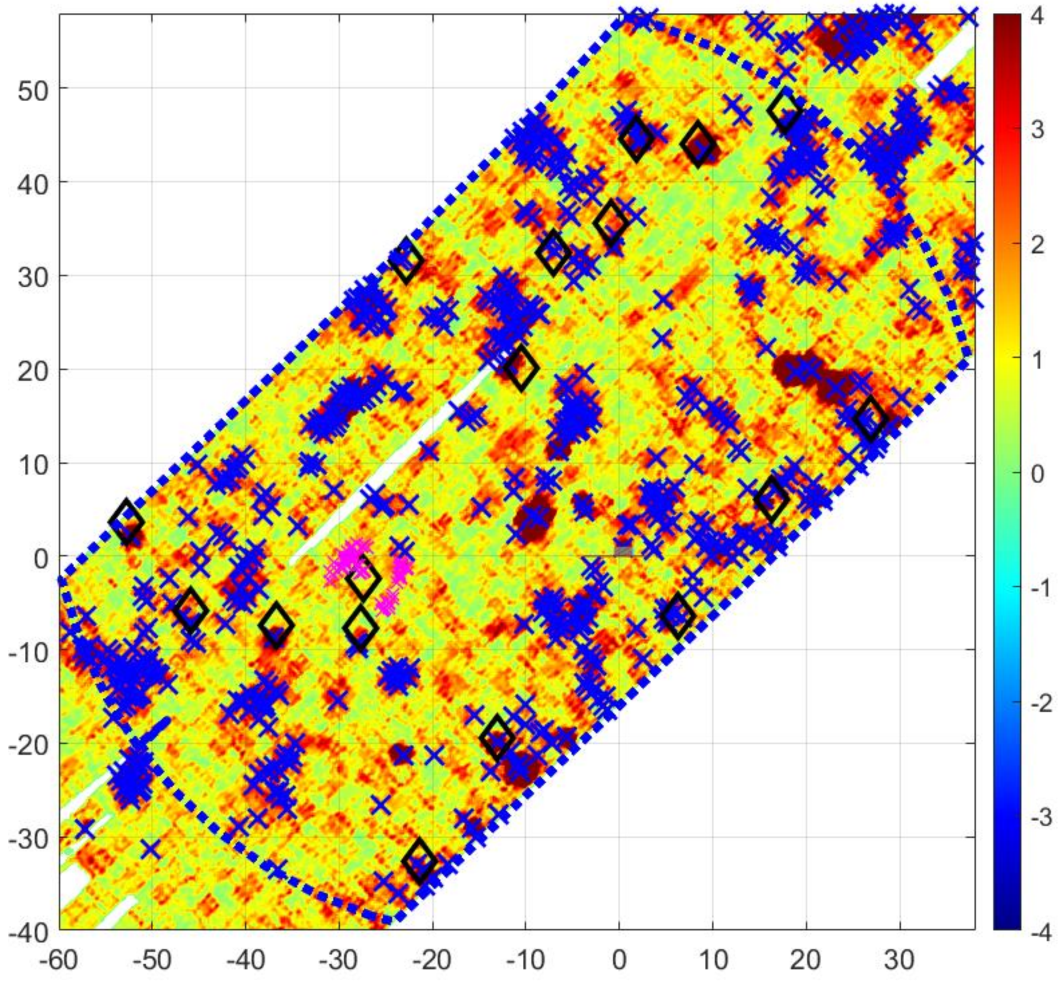
Independently scored results:



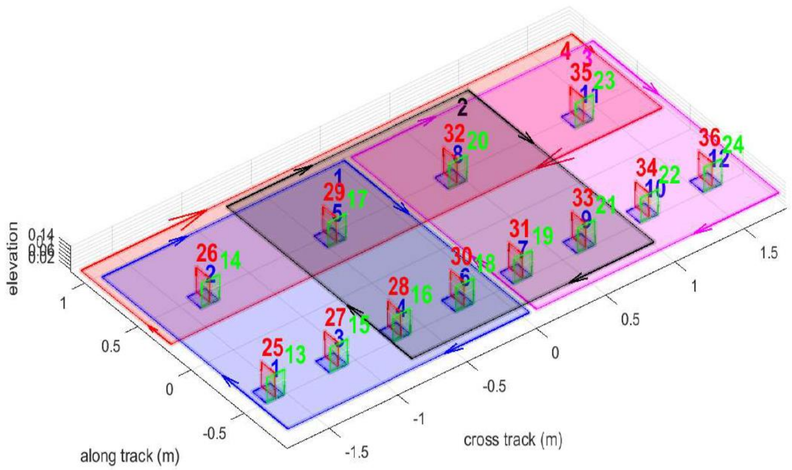
Detection map using standard approach



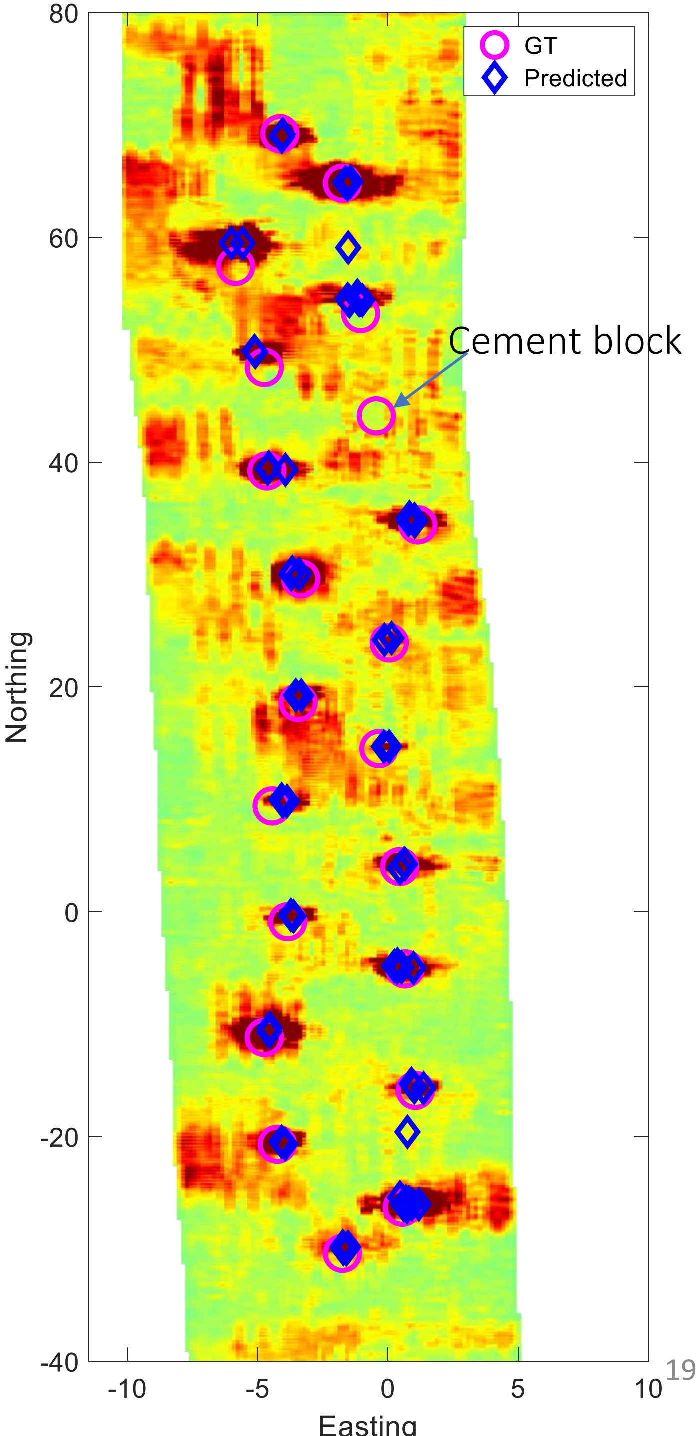
Detection map using advanced approach



2022 Sequim Bay



Detection map: calibration grid



Conclusions:

- Enhanced EMI models account accurately transient responses from: UW targets, layer boundaries and transmitters/receivers surrounding medium

- The voltage due to direct coupling from Tx to Rx is much higher than signals due to air-water and water-sediment boundaries

- Enhanced EMI provided excellent classification results when applied to UW UltraTEMA data sets.

Acknowledgments:

This work was supported by the SERDP Project # MR-2728.