INTERPRETING MIXED SIGNALS: THE IMPACT OF INTERFERENCE ON CLASSIFICATION PERFORMANCE AT CAMP SAN LUIS OBISPO

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Abstract

Data quality and signal interpretability for advanced geophysical classification data collected in support of the remedial action at Munitions Response Site (MRS) 07, Camp San Luis Obispo, San Luis Obispo County, California, were complicated by two key sources of signal interference: geological noise and high-density metallic clutter. Blind and non-blind seed data were used to identify and quantify interfering signals, enhancing the reliability and accuracy of detection and classification.

Geological noise at MRS 07 was characterized by the pervasive presence of small, scattered pockets of ferromagnesian minerals and rocks, which introduced significant subsurface heterogeneity across the MRS. This interference degraded the signal-to-noise ratio, particularly for smaller and deeper targets, and produced false positive signals with polarizabilities that closely resembled those of the targets of interest (TOI) in the site library. Ultimately, this geologic noise presented challenges to the classification process by masking legitimate targets, leading to misclassification, and increasing the number of false detections that required investigation. Additionally, a 0.2-acre area of anomalous terrain, characterized by non-native fill material elevated up to 1.5 meters above the native substrate, introduced significant topographical variability. This variability altered the sensor's standoff distance, which, in turn, amplified soil response sensitivity and generated a high volume of false-positive detections. A key challenge was the inability to isolate the signals of discrete geologic pockets, which often closely mimicked the polarizabilities of the specific TOI in the site library. Furthermore, unlike regions such as Hawaii or the southeastern U.S., where broad, low-frequency responses are characteristic, alternative filtering parameters failed to effectively and reliably enhance the target signals. Mitigating these issues required adjustments to the classification process. Seed data were successfully used to establish a set of discriminatory characteristics for potential TOI affected by extraneous geologic noise signals. These characteristics were then quantitatively parameterized and used to re-evaluate the classification data using a standardized set of criteria. However, the introduction of an interfering geologic signal led the classification model's feature extraction process to overestimate the size of buried items at increased depths relative to the ground truth.

In a 0.24-acre area identified as a former grenade target area, high-density fragmentation debris from historical training operations resulted in a saturated response area with an anomaly density exceeding 10,000 per acre. Following analog-based subsurface reduction, the anomaly density within a 0.18-acre area remained above 4,000 per acre. The initial reduction resulted in the removal of over 218 pounds of metallic debris, including grenade fragmentation as small as 1 by 1.5 centimeters, down to 0.30 meter. Following review of non-blind seed data, adjustments were made to the detection parameters to mitigate interference from the remaining high anomaly density. The tile detection offset parameter was modified from 0.65 to 0.45 meter. This modification improved detection results for both non-blind and blind seeds, which were subsequently classified as TOIs. Performance was notably improved under conditions of high anomaly density and for seeds placed at depths approaching the maximum reliable detection depth. As with the examples of geologic noise interference, the classification prediction for seeds in areas of high anomaly density was overestimated in terms of size and depth.

These findings possess significant technical implications for the munitions response community, intersecting with several key operational and methodological challenges. These challenges are as follows:

•**Site Characterization:** The need for enhanced methodologies during the Remedial Investigation phase to improve estimates of data density, usability, and reliability for developing the conceptual site model

•**Blind Seed Protocols:** The need to define and standardize protocols regarding the location and burial depth of quality control, validation, and non-blind/data usability seeds

•**Environmental Factors:** The persistent difficulties encountered due to challenging terrain, geology, which complicates geophysical surveys and can impact the reliability of the classification including size and depth predictions

•**Prediction Measurement Quality Objectives (MQOs):** The need to improve MQOs related to classification parameter predictions, especially as related to size and depth estimations

Environmental Factors

Data Quality: Degraded the signal to noise ratio, specifically impacting classification of smaller/deeper targets.

Survey Effectiveness: Masked legitimate targets, caused misclassification errors, and increased the number of false detections requiring investigation.

Target Classification: Led to several classification MQO failures related to size, depth, or library match for 4 blind QC seeds placed at the anticipated maximum classification depth (30 cm) (Figure 1). Adjustments to leveling process did not result in an overall performance improvement.

Geologic Noise: Pervasive, scattered pockets of ferromagnesian material introduced significant subsurface heterogeneity (Figure 2).

Target Identification: Produced false positive signals with polarizabilities closely resembling TOI in the site library (Figure 3).

Dirt Mounds: Variable terrain height (up to 1.5 m above native ground) and responsive soil across the 0.2-acre area of off-site fill, combined with the higher field strength of the APEX-Mini coils, resulted in amplified soil response sensitivity and a high number of false-positives (Figure 4).

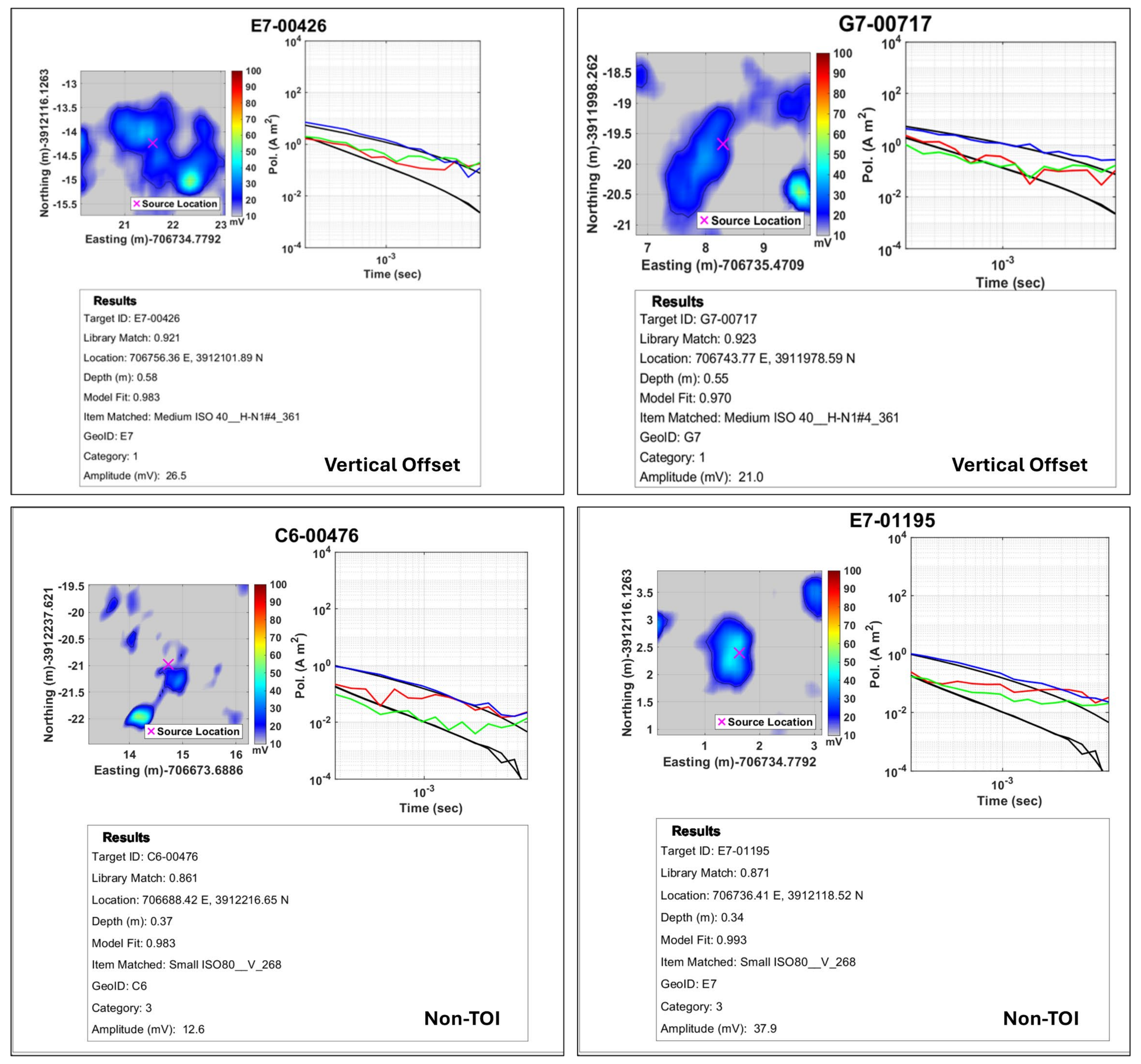

Figure 1. Classification Results for Failed QC Seeds

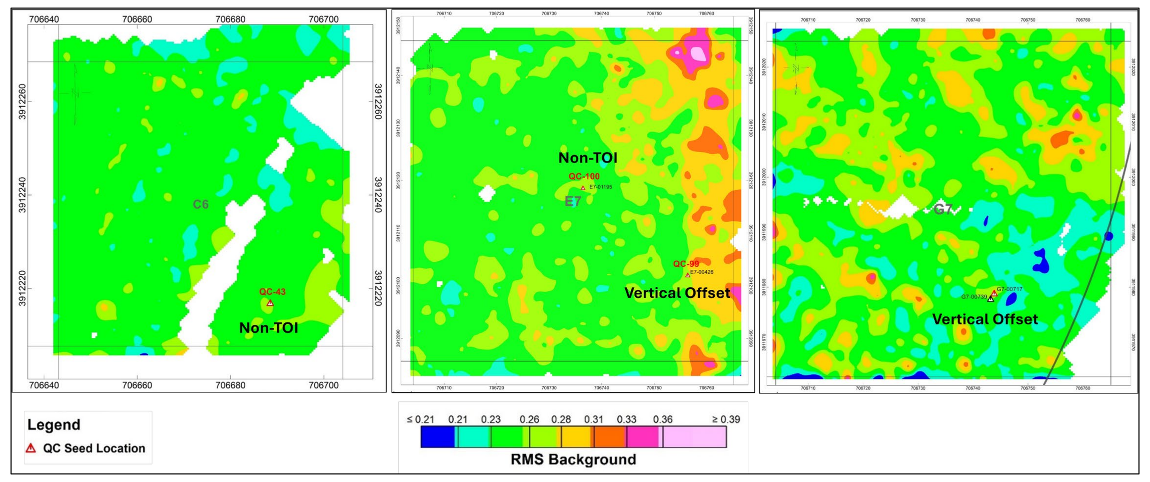

Figure 2. Noise Analysis for Failed QC Seeds

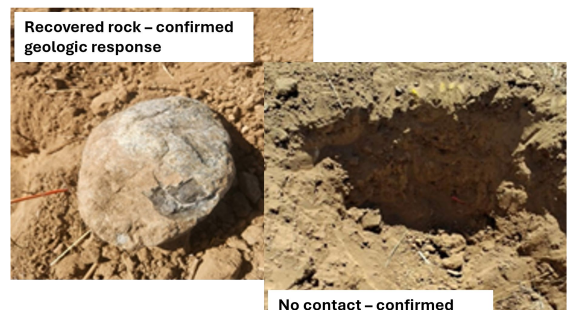

Figure 3. Examples of Digs with Geologic Response

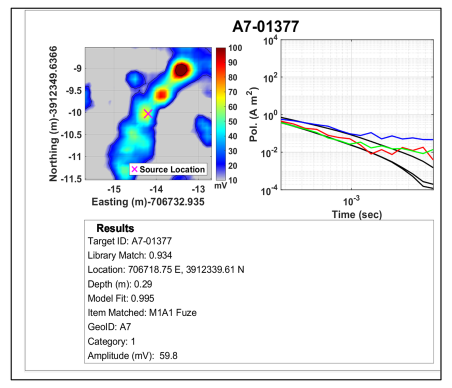

Figure 4. Soil Sensitivity False Positive

Prediction MQOs (Confirm Derived Features)

The data demonstrate that inherent physical and environmental factors make the current MQOs related to confirm derived features match ground truth unattainable with the site having a 62% failure rate (Figure 4):

- **Environmental/Subsurface Variables**: Geologic response, site specific subsurface conditions, and variations in target orientation (Figure 5), size, and depth introduce variability that AGC sensors cannot entirely overcome.
- **Physical and Resolution Limits**: AGC sensors have resolution limits that prevent the precise characterization of every item.
- **Non-Unique Interpretations**: A variety of subsurface conditions can yield similar signatures, leading to non-unique interpretations.
- **Library Constraints**: The quality of library entries used for comparison, a critical part of the classification process, also imposes limitations (Figure 6).

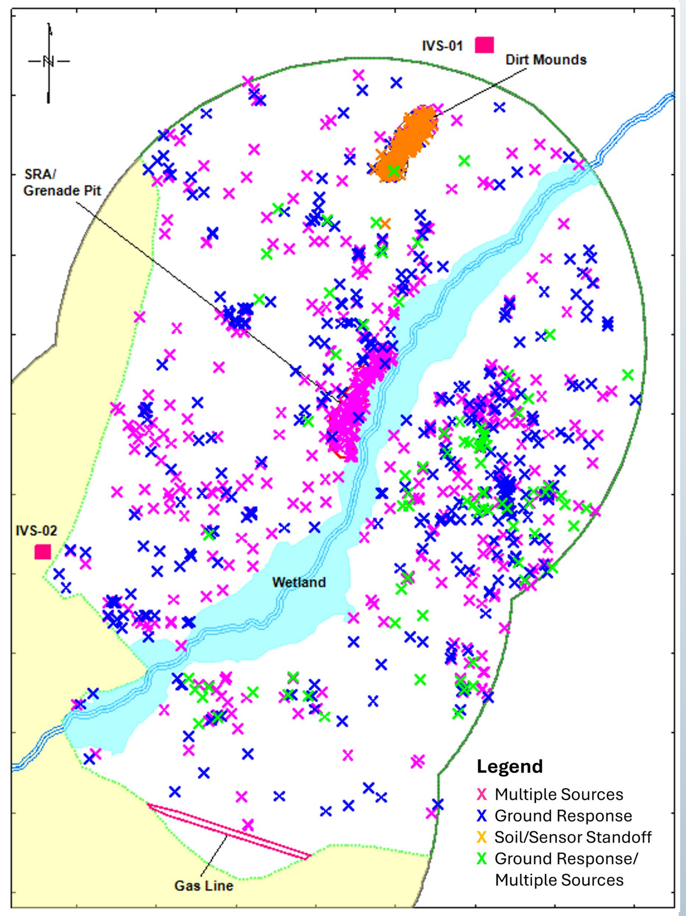

Figure 5. Prediction MQO Failures

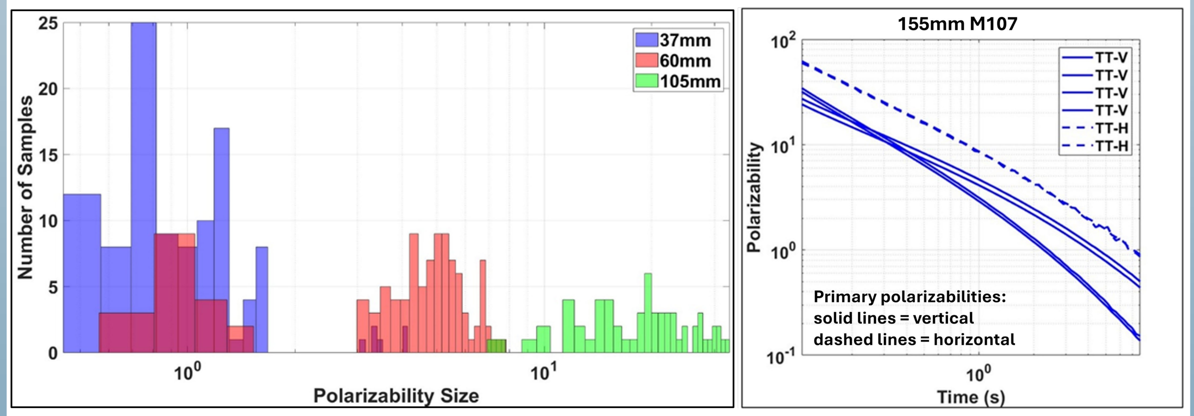

Figure 6. Polarizability Uncertainties – DoD Library and Orientations

Library-based size estimates can lead to size prediction MQO failures due to the variability in the size of library entries. This uncertainty was compounded by challenging site conditions including high anomaly density and geology.

Blind Seeding

Validation Seeds (Figure 7):

- Provided assurance of AGC and intrusive processes across diverse, noise/density environments, including the grenade target area (SRA).
- Depths align with NAOC recommendations of seed placement at 50–30% of required detection depth for small ISO at 30 cm.

QC Seeds (Figure 7):

- Emphasize need for strategic placement to gain data usability insights not apparent in initial project planning.
- Allowed development of quantitative CAs.

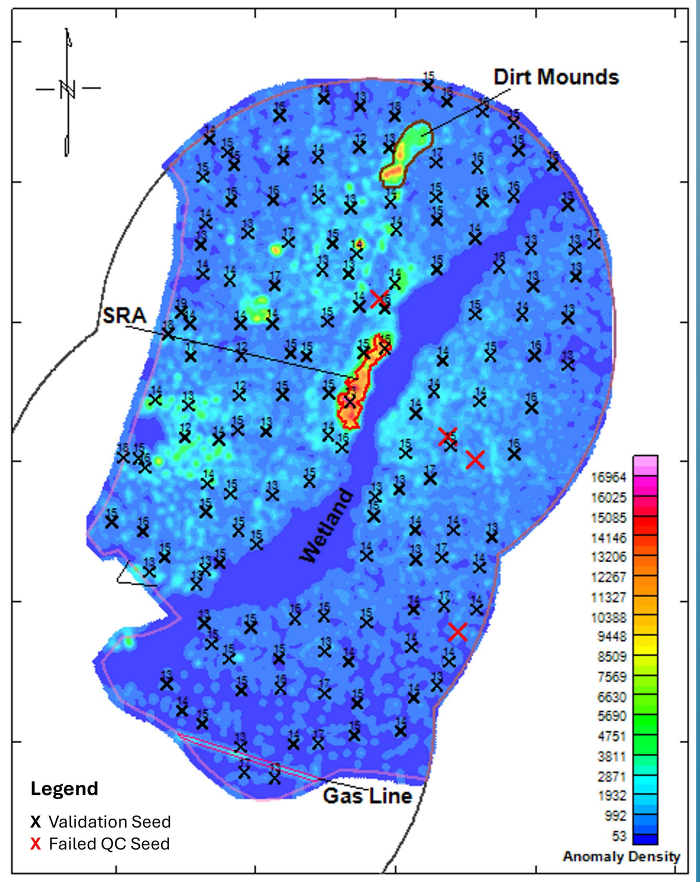

Figure 7. Density/Seeding Map

Site Characterization

Limited characterization of the site during the RI included:

- Incomplete identification of the grenade target area.
- Shortage of CSM documentation regarding munitions potentially present.
- Inadequate identification of geologic noise conditions.
- Non-identification of mounds of off-site fill.
- A remediation depth greater than the capability of the electromagnetic induction sensing technology.

Successes

Despite the challenges presented the RA was ultimately successful:

- 98% of QC seeds and 100% of validation seeds met classification MQOs
- Grenade target area identified and delineated
- 4 MEC items (max depth 38 cm) and over 1,300 MPPEH items (max depth 95 cm) recovered
- Significant reduction in unnecessary excavations: approximately 90% based on detections and 92% based on classified sources

Conclusions/Recommendations

Environmental Factors: A key challenge was the inability to isolate the signals of discrete geologic pockets, which often closely mimicked the polarizabilities of the specific TOI in the site library. Furthermore, unlike regions such as Hawaii or the southeastern U.S., where broad, low-frequency responses are characteristic, alternative filtering parameters failed to effectively and reliably enhance the target signals. Mitigating these issues required adjustments to the classification process.

Prediction MQOs: The MQOs requiring confirmation that derived features perfectly match ground truth must be revisited due to inherent technical limitations. While AGC remains highly valuable for making informed, risk-based decisions on anomaly excavations, the precision needed for a 100% confidence match between a target's exact features and ground truth is technically unachievable for every buried item. The MQOs therefore need urgent revision to reflect these realities.

Blind Seed Protocols: The data support NAOC recommendations to standardize protocols regarding validation seed burial depth. It additionally demonstrates the importance of placing QC seeds in a manner that informs potentially unknown data usability limitations.

Site Characterization: Robust site characterization during the RI phase is essential for developing accurate RAOs and ensuring successful project outcomes. The issues encountered underscore the importance of employing robust methodologies during the RI to improve data density estimates, improve understanding of data usability issues, and the reliability of the CSM. Effective characterization ensures that:

- RAOs accurately defined: A full understanding of the scope and nature of contamination, driven by clear, data-rich objectives, allows for the establishment of achievable goals.
- Appropriate technologies/depths : Understanding the physical reality of the site - such as fill height, geologic conditions, and contamination depth -enables the establishment of feasible and effective remediation depths for the specific munition types and the selection of suitable technology.
- Efficiency: A comprehensive CSM derived from a robust data set prevents costly surprises and operational failures during remediation, ultimately leading to a more efficient, successful, and cost-effective project.

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