



UltraTEM UXO Technical Memorandum

1. Introduction

Gap Explosive Ordnance Detection Pty Ltd (GapEOD) is an Australian company that specialises in the detection and characterisation of near-surface metallic items both on land and underwater. GapEOD's goal is to provide clients with high-quality, cost effective digital geophysical data with superior performance to conventional instruments and techniques. Our services are based on innovative technologies that have proven their success in a range of conditions.

GapEOD have developed the multi-component multi-sensor UltraTEM system for deployment in both terrestrial and marine environments. In partnership with Black Tusk Geophysics (BTG), the UltraTEM has been officially validated through the DoD Advanced Geophysical Classification Accreditation program (DAGCAP). The UltraTEM is capable of distinguishing closely spaced individual targets with precision, providing accurate estimates of object position, depth, size, and shape. Additionally, it produces comprehensive, auditable digital records of all collected data. By utilizing proprietary high-powered transmitters, the UltraTEM system achieves greater imaging depths and remains effective in magnetic geology environments where passive magnetometers and standard electromagnetic (EM) systems are typically ineffective.



FIGURE 1. ULTRATEM CLASSIFIER TOWED-ARRAY (TNB MODEL).

2. System Components

2.1. Summary

The electronic components of the UltraTEM are interchangeable between different survey platforms, allowing for flexible deployment optimized to site conditions. All UltraTEM system components are synchronized with the 1PPS signal from internal GNSS receiver modules which allows precise time-alignment of all data streams. An UltraTEM system is assembled using the following base components:

- i. Geophysical receiver system, either the UltraTEM-IV or UltraTEM-V Receiver Bank (Figure 3) containing six 3-component receiver cards.
- ii. Multiple 3-component receiver cubes (up to six per UltraTEM receiver bank). Receiver cubes consist of three orthogonal coils with dimensions of 8 cm or 15 cm per side depending on the platform configuration.
- iii. High current geophysical transmitter, either the EODTx50 series (Figure 3) which is capable of powering 1-5 transmitters coils or the UltraTEM-V integrated transmitter capable of powering 1-3 transmitters coils.
- iv. A Real-Time-Kinematic Global Navigation Satellite System (RTK-GNSS) and Attitude Heading and Reference System (AHRS) for position and orientation of the sensor frame. This may be substituted for Stencil/Topaz Simultaneous Localisation and Mapping (SLAM) positioning or Robotic Total Station (RTS).
- v. A Windows data acquisition computer system running BTField software developed by BTG. BTField is connected to an UltraTEM receiver via ethernet and is loaded with TeamViewer for remote troubleshooting.



FIGURE 2 ULTRATEM SCREENER TOWED ARRAY (TPC MODEL).



FIGURE 3 ULTRATEM-IV RECEIVER BANK AND EODTx50-2 TRANSMITTER (LEFT) COMPARED TO AN ULTRATEM-V RECEIVER BANK (RIGHT).

3. UltraTEM Systems

3.1. Introduction

The components and geometry of the UltraTEM are not fixed and the system geometry and survey parameters can be optimised for Advanced Geophysical Classification (AGC) or Screening of metallic clutter in a range of environments.

When configured for AGC, the system operates in a one-pass detection and classification mode rather than the two-pass mode previously used for AGC in the USA. The one-pass approach has the potential to significantly reduce the costs and financial risks of UXO remediation as survey costs are only weakly dependent on the number of anomalies per area. This system has slower survey speed (Table 1) but with significantly improved screening of metallic clutter and an ability to target specific calibre UXO through library matching.

When rapid coverage of large areas is prioritized, or when detailed classification is not essential, the UltraTEM can be optimised for screening of metallic clutter to reduce remediation effort. In this mode, the survey speed is increased (Table 1) making the system effective for broad-area clearance projects. Despite the streamlined approach, the system retains advanced capabilities such as filtering and target identification, as well as the ability to invert signals from single or multiple objects and perform Informed Source Selection (ISS).

GapEOD's transmitters can operate at a range of base frequencies: slow - 8.33 and 10 Hz, medium - 25 and 30 Hz and fast - 75 and 90 Hz (first number is for 50 Hz and second for 60 Hz powerline frequency). Long time-decays can be measured for static cued interrogation and fast, short decays for rapid dynamic data acquisition.

TABLE 1 ULTRATEM SURVEY SPEEDS FOR CLASSIFICATION AND SCREENING.

	Classification	Screening
Target Survey Speed	< 0.8 m/s	< 1.5 m/s
Max Survey Speed	1.25 m/s	2.25 m/s

3.2. UltraTEM Sensor Platforms

GapEOD sensor platform serial numbers have a specific format: three letters or Roman numerals, followed by the year and unit number in the format YY####. In the next section, platforms will be referred to by their general name (e.g. Towed-Array Classifier) followed by the serial number in brackets (e.g. TNB). This corresponds with summary in Table 2.

3.2.1. Towed-Array Classifier (TNB)

The UltraTEM Towed-Array Classifier (TNB) is GapEOD's most advanced system and was the first system validated through DAGCAP in 2019. The towed-array system features 11 receiver cubes and 5 transmitter coils (Figure 4). The system features suspension to reduce motion noise in the data and can be configured at 3 ride heights to suit site terrain. See Table 2 for additional system specifications.



FIGURE 4. TOWED-ARRAY CLASSIFIER (TNB).

3.2.2. Towed-Array Screener (TPC)

The UltraTEM Towed-Array Screener (TPC) is optimized for rapid area search and features 6 receiver cubes and 2 transmitter coils (Figure 5). An additional 3rd large transmitter loop can be added to increase depth of detection. See Table 2 for additional system specifications.



FIGURE 5 TOWED-ARRAY SCREENER (TPC) CONFIGURATIONS. STANDARD (TOP) & 3RD TX LOOP (BOTTOM).

3.2.3. Pedestrian Classifier (TNC)

The UltraTEM Pedestrian (TNC) system can operate as either a Classifier or Screener system depending on survey speed (Table 1). The system utilises 6 receiver cubes and 2 transmitter coils (Figure 6). The system is versatile and can be configured as a single-person push-cart, a two-person carried array, or a hybrid push-carry setup. Switching between configurations is quick and straightforward, allowing operators to adapt the platform to site conditions throughout a project. See Table 2 for additional system specifications.



FIGURE 6 PEDESTRIAN CLASSIFIER (TNC) SYSTEM CONFIGURATIONS. PUSH-CART (TOP), HYBRID (BOTTOM).

3.2.4. XC Classifier (TND)

The UltraTEM XC Classifier (TND) is designed to survey small and inaccessible areas and features 6 receiver cubes and 2 transmitter coils (Figure 7). An additional 3rd transmitter loop can be added for static or dynamic cued surveys. See Table 2 for additional system specifications.



FIGURE 7 XC CLASSIFIER (TND).

3.2.5. Summary

Table 1 summarises the specifics of the four sensor platforms discussed in this section.

TABLE 2 SUMMARY OF ULTRATEM SENSOR PLATFORMS.

Specifications	Sensor Platform			
	Towed-Array TNB	Towed-Array TPC	Pedestrian TNC	Classifier XC TND
Classification	✓		✓	✓
Screening	✓	✓	✓	✓
Dynamic + Static Cueing				✓
Receiver Cubes	11	6	6	6
Receiver Cube Dimensions	15 x 15 x 15 cm	15 x 15 x 15 cm	15 x 15 x 15 cm	8 x 8 x 8 cm
Transmitter Coils	5	2-3	2	2-3
Transmitter Coil Dimensions	1.0 x 0.9 m 2.4 x 1.0 m	1.3 x 0.9 2.1 x 3.8	1.2 x 0.8	0.5 x 0.6 0.9 x 0.4
Production Rates	2 ha / 5 ac	4-8 ha / 10-20 ac	1-1.5 ha / 2.5-3.7 ac	0.5 ha / 1 ac
Indicative Cube Overlap	2	1	2	1
Target Line Spacing	2.0 m	1.8 m	1.6 m	0.6 m
Max Line Spacing	2.4 m	2.0 m	1.8 m	0.8 m

3.3. UltraTEM Deep Search

The UltraTEM Deep Search configuration is deployed when deep ordnance detection is the overriding priority. In this configuration a large loop of copper wire is laid around the survey area and the field crew survey inside the wire loop using an UltraTEM receiver system. The loop configuration can be dictated by terrain and space limitations of the survey area within certain constraints imposed by the desired detection depth. Loops are typically larger than 10 by 10 meters but can be rectangular with side length up to 100 m.

The transmitter system consists of an EODTx200 fast-switching transmitter and a PS10LV power supply powered by a diesel three-phase generator (Figure 8). This system can transmit up to 200 A with a maximum output of less than 120 V. The EODTx200 has an inbuilt timing controller and can transmit at a range of base-frequency and duty cycles to suit survey requirements.

In June 2013 GapEOD conducted a series of tests of the UltraTEM Large Loop system at the LXML copper mine in Sepon, Laos, which is located on the former Ho Chi Minh Trail. The site is contaminated with large, unexploded bombs (50 kg and larger). During the trial, the UltraTEM detected all 28 MK81 and MK82 bombs buried to depths of 5 m. The system consistently detects smaller MK81 air-dropped bombs at depths of up to 3.5 m across all site conditions—including beneath safety bunds at the edges of fitches.

Following these trials, LXML entered into a long-term lease of an UltraTEM Fixed Loop system, which was continuously operated at the site from 2015 to 2021 (Figure 9). LXML has since transitioned to an UltraTEM Screener system for shallower, faster surveys that align with the site's production methodology



FIGURE 8. FIXED LOOP TRANSMITTER SYSTEM. EODTX200 TRANSMITTER POWERED BY PS10LV AND 3-PHASE GENERATOR.



FIGURE 9. ULTRATEM DEEP SEARCH SYSTEM IN OPERATION IN LAOS.

4. Data Analysis

4.1. Data Acquisition

UltraTEM data are acquired using the BTFIELD software package. During data acquisition BTFIELD displays gridded raw data, GPS quality, data profiles, transmitter information and raw EM decays in real time (Figure 10). This allows the user to achieve 100% coverage of the survey area on the first pass, removing the need to return to the survey area to fill gaps.

BTFIELD is a real-time data acquisition, classification and processing system for UXO detection developed and maintained by Black Tusk Geophysics. It has been designed to meet the needs of both data collection crews and geophysicists by allowing processing and inversions to run simultaneously as data is being collected.

BTFIELD can be used with a variety of systems and platform configurations. A detailed guide and introduction to BTFIELD can be found at <https://btfield.btgeophysics.com/BTProduct.aspx>

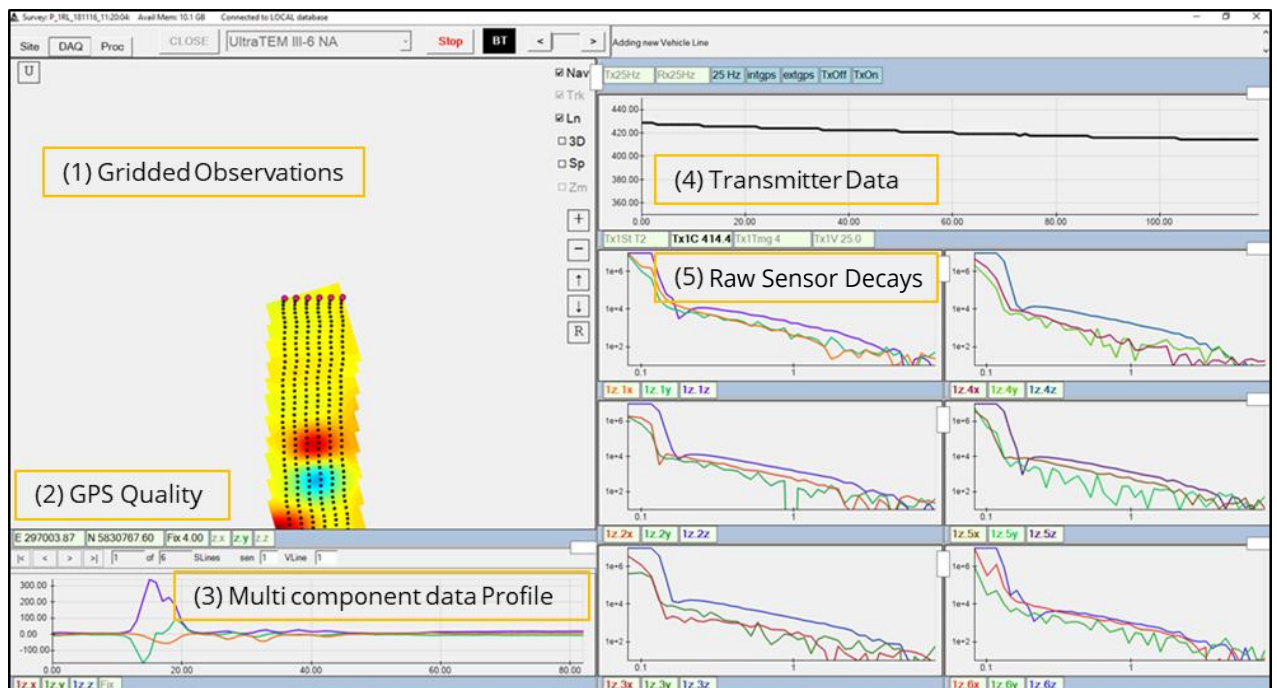


FIGURE 10. BTFIELD DATA ACQUISITION SOFTWARE.

4.2. Data Processing

UltraTEM processing and interpretation can be performed in a variety of software packages including both BTFIELD and UXOLab from Black Tusk Geophysics (BTG). UXOLab is built on Matlab and is not available for sale or lease, whereas BTFIELD is written in .NET and C++ and is available for lease.

Processing of the UltraTEM data first involves manipulation and quality control of the GPS data. The array azimuth is then calculated and the GPS and sensor data are merged and any GPS antenna to receiver position offsets are applied. A high pass demedian filter is then used to remove offsets or long wavelength features in the UltraTEM data.

A “heat map” or gridded image of the UltraTEM data is created by interpolating the amplitudes of an early time-channel to a regular grid with 10 cm pixel size. An example heat-map is shown in Figure 11. Any anomalies that exceed the target detection threshold for the survey area are then selected for further analysis. The detection threshold can be set to find the smallest item of concern to the deepest depth. If that information is unavailable, then the threshold is set at 5 times the sensor noise-floor.

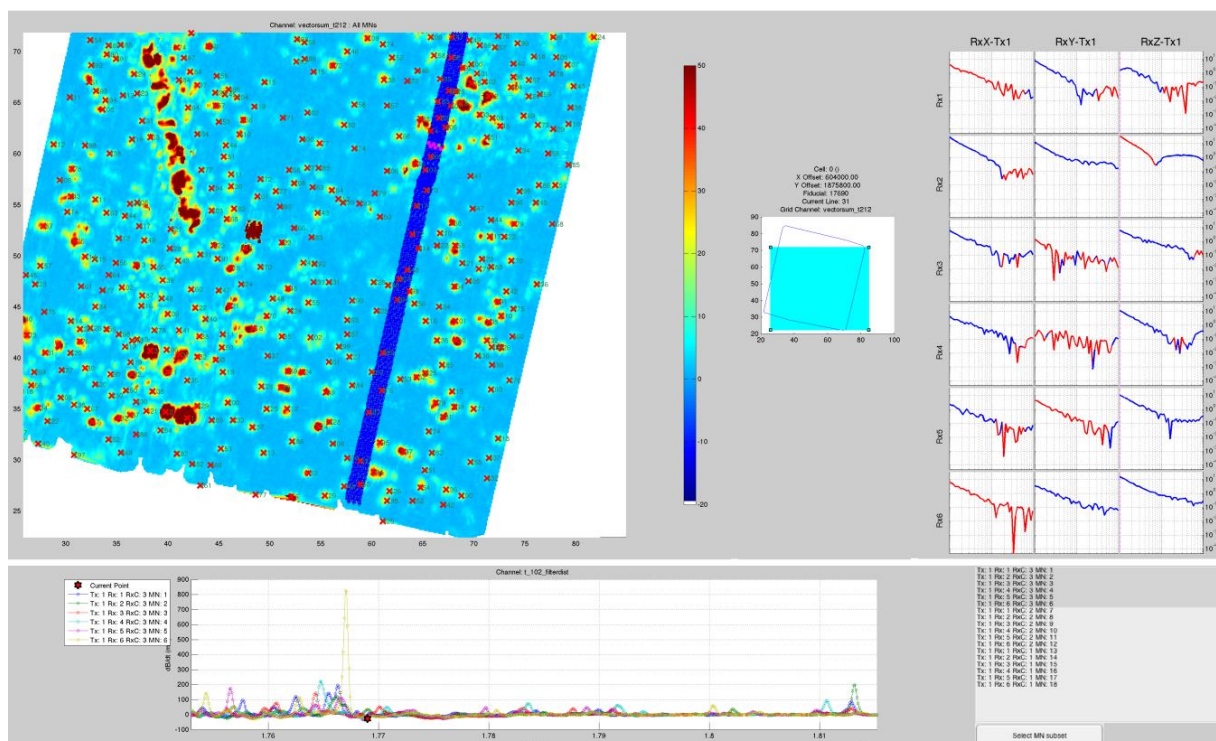


FIGURE 11. ONE OF THE INTERFACES IN THE UXOLAB SOFTWARE USED FOR DATA ANALYSIS AND INTERPRETATION.

4.3. Inversion method for analysing detected anomalies

Each detected anomaly is then analysed further by the following inversion method. The UltraTEM system uses a time varying field, illuminating buried, conductive targets. Currents induced in the target then produce a secondary field that is measured at the surface. EM data inversion involves using the secondary field generated by the target for recovery of the position, orientation, and parameters related to the target's material properties and shape. In the UXO community, the inverse problem is simplified by assuming that the secondary field can be accurately approximated as a dipole and the intrinsic object properties by an orthogonal set of principal axis polarizabilities.

4.4. Making dig or no dig decisions

Following inversion of a physics-based model of the data, the polarization tensor parameters are used to make dig or no-dig decisions (Figure 12). Dig or no-dig decisions can be made using a wide variety of criteria dictated by project requirements. For instance, all items that exceed a certain size could be excavated, or only those objects displaying characteristics of UXO (axial symmetry), or only those items within a user specified depth range.

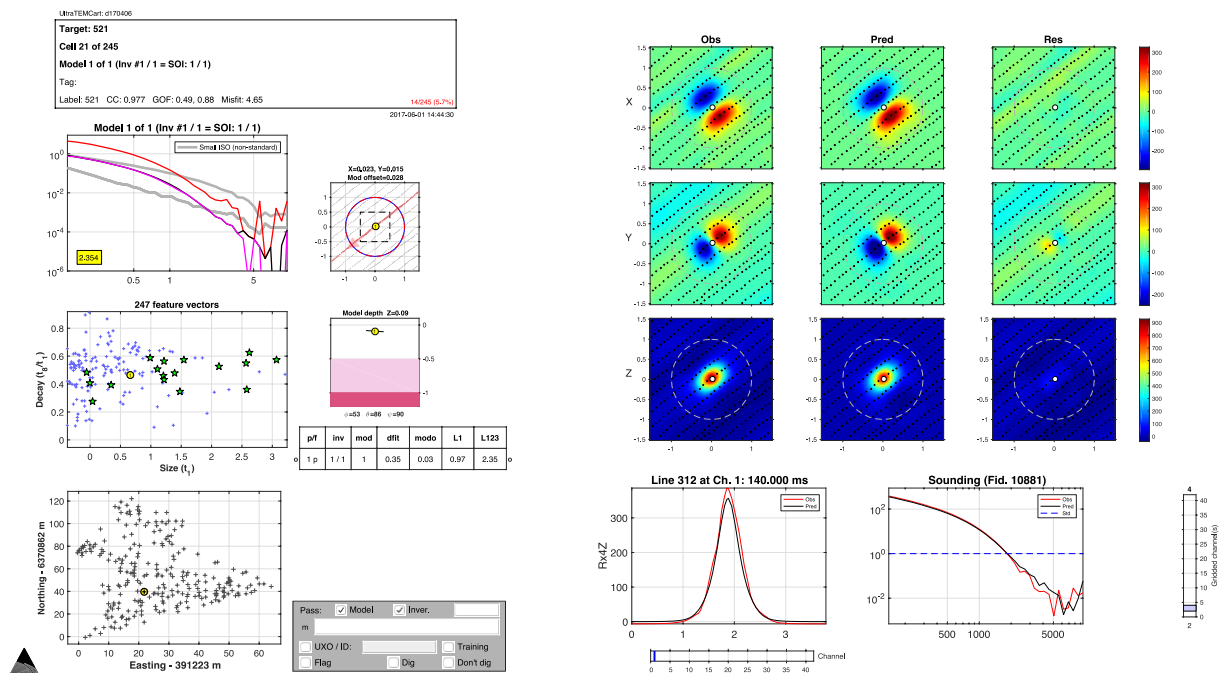


FIGURE 12. UXOLAB INVERSION REVIEW INTERFACE. THE OBJECT MODELLED HERE DISPLAYS AXIAL SYMMETRY (HENCE HAS A UXO-LIKE SHAPE) AND IS SLIGHTLY LARGER THAN A 8 CM LONG PIPE PIECE (SMALL ISO).

5. Summary

The UltraTEM system has been deployed at a wide range of sites since 2014. GapEOD can provide project references on request.

In Summary key benefits of the UltraTEM are:

- i. It collects a much richer set of data including the full three-dimensional EMI field over a wide time-range, which results in much more accurate localization and characterization of the size, shape and wall-thickness of buried items; Deep detection with high current transmitters;
- ii. Flexible multi-static transmitter and receiver geometry;
- iii. Precise time synchronisation of all sensor streams;
- iv. Real-time data visualisation in BTField;
- v. Validated by DAGCAP for Advanced Geophysical Classification (AGC) and proven One-pass classification capability;
- vi. The system is largely immune to ferromagnetic minerals in soils and rocks that can render magnetometers virtually unusable;
- vii. It has a much higher spatial resolution and more concentrated response than competing technologies, allowing individual items to be distinguished in cluttered areas and detection performance to be maintained in proximity to cultural features;
- viii. It can detect both ferrous and non-ferrous items; and
- ix. Dig decisions are based on objective criteria and all stages of the decision-making process are supported by a digital audit trail.



FIGURE 13 ORDNANCE FROM ULTRATEM SURVEY.

6. UltraTEM Marine

6.1. Summary

In 2016, GapEOD together with BTG, commissioned the first UltraTEM Marine system for Boskalis who market the system as the SubTEM. The system comprises 5 transmitter loops that are each 1.8 m x 1.8 m in size and 28 three-component receiver cubes. The transmitters fire sequentially while the system moves over the seafloor. The five transmitters provide distinct signal perspectives, and when combined with the dense array of three-component receivers, enable the UltraTEM Marine to both detect and characterize buried metal. The system has a swath width of over 5.5 m and can detect both ferrous and non-ferrous ordnance items to depths of over three meters below the sea-bottom. Of particular concern in European waters are large German ground mines that are made of aluminium and are undetectable by the magnetometers typically employed for marine surveys.

In 2016 and early 2017 the UltraTEM Marine system was used to survey over 500 Ha at Portsmouth Harbor and 20 Ha in Dover Harbor in the United Kingdom. Both operations were performed to support Harbor dredging operations. These harbors have been used for centuries and, particularly for Portsmouth, contain large amounts of buried subsurface metal (Figure 14) including cables, unexploded bombs, torpedoes and sea-mines. Recovery of metal items in the marine environment is extremely expensive, hence it is important to minimise the number of non-hazardous items that are excavated. The UltraTEM Marine was designed with subsurface characterization in mind (Figure 15) so that digging operations could focus on the removal of dredging hazards including large pieces of metal, cables, unexploded bombs and sea-mines. With this approach less than 5% of the more than 22,000 pieces of metal detected required excavation.

In January 2018, GapEOD commenced the commissioning of an ROV-based version of the SubTEM system for Boskalis (Figure 16). The system has the same physical footprint as the sled system but can be deployed in water depths of 70 m and more and can be flown at a constant 0.5 m above sea-bottom.

In 2022, GapEOD partnered with Tetra Tech to carry out ESTCP project MR19-5073. The project aimed to design a marine Advanced Geophysical Classification system that integrates GapEOD's UltraTEM sensors with Tetra Tech's TEMA platform and Black Tusk Geophysics' BField software. Design objectives were to detect and classify medium-sized ordnance with a single-pass towed platform at minimal standoff distances in water depths between 5 and 150 feet. Successful marine trials were completed at Sequim Bay, WA, USA, in 2022 (Figure 17).

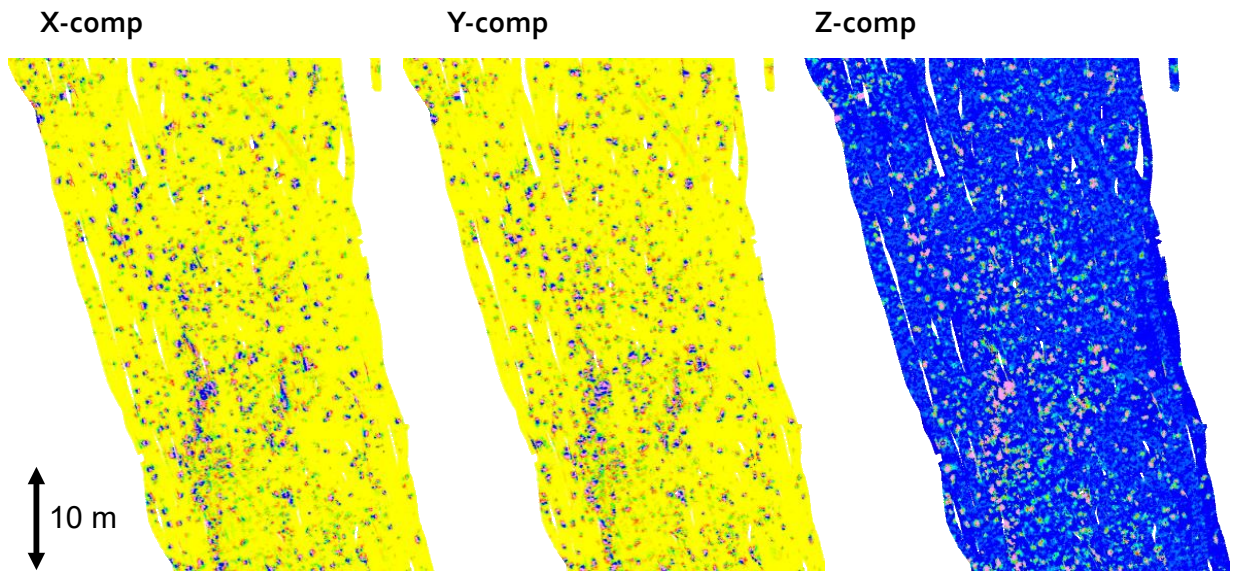


FIGURE 14. SAMPLE SUBTEM DATA SHOWING A LARGE NUMBER OF BURIED METALLIC ITEMS.

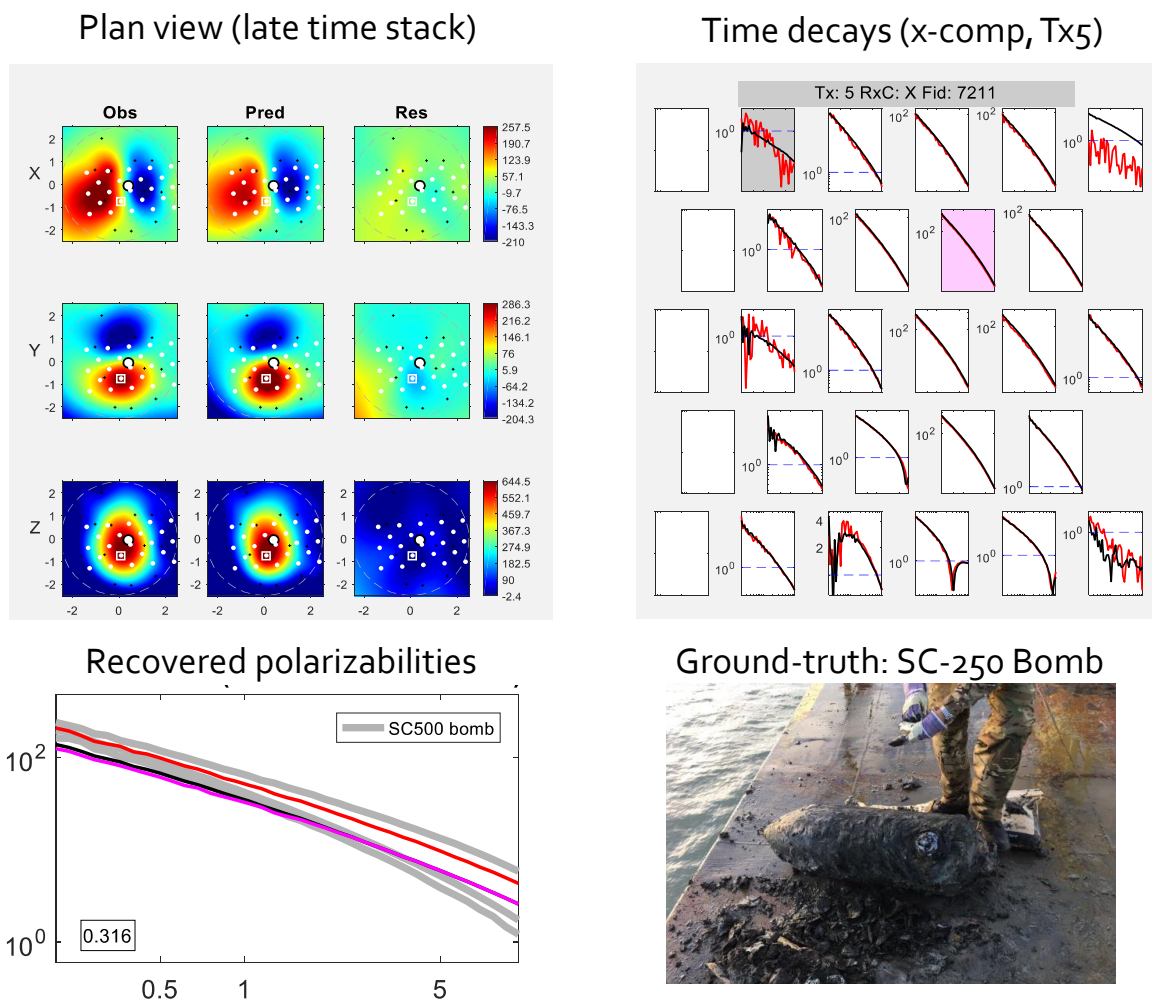


FIGURE 15. INVERSION OF SUBTEM DATA ALLOWS HAZARDOUS ITEMS LIKE THIS SC-250 GERMAN BOMB TO BE DISTINGUISHED FROM NON-HAZARDOUS CONTAMINATION.

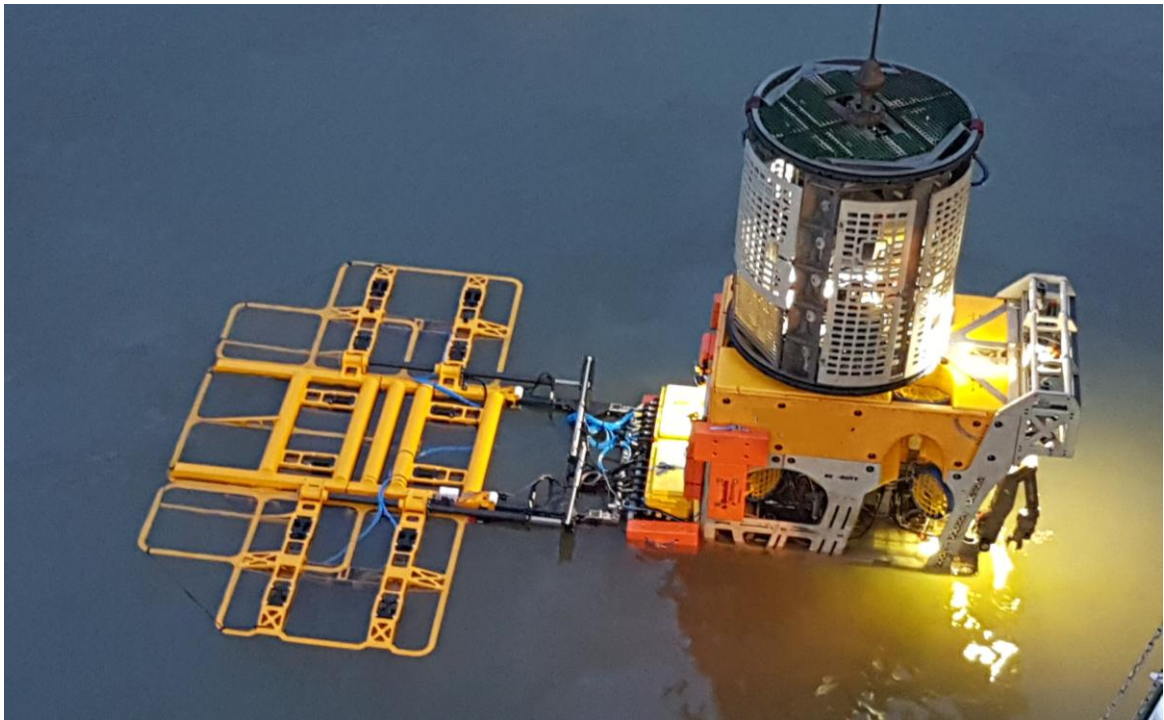


FIGURE 16. ROV-BASED VERSION OF THE ULTRATEM MARINE IN JANUARY 2018



FIGURE 17. THE ULTRATEM MARINE SYSTEM INSTALLED ON A NON-METALLIC SLEDGE TOWED BEHIND A SMALL BOAT.