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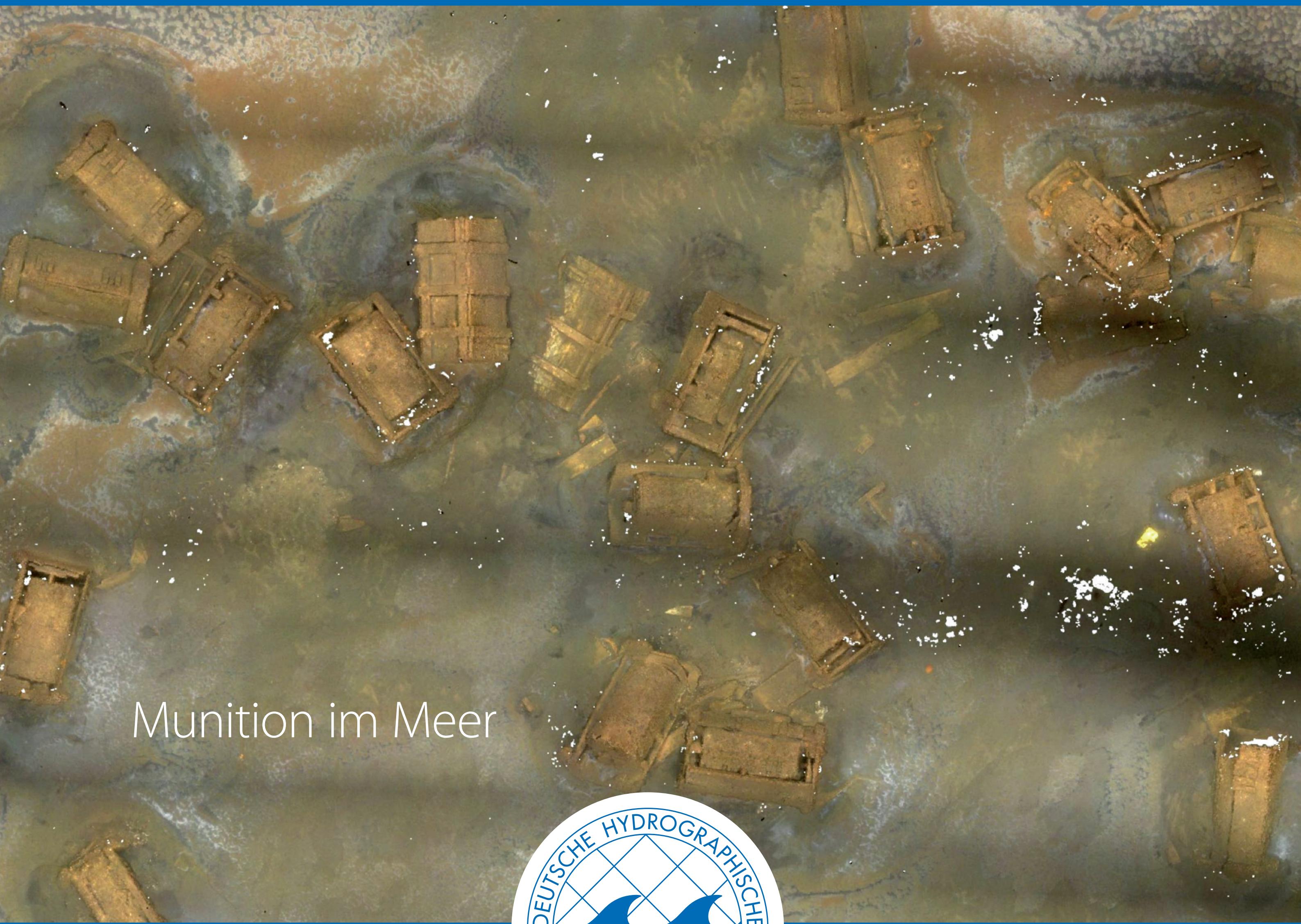

Munition im Meer

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Magnetic data optimisation for advanced UXO interpretation

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Collaborative industry research was undertaken to provide insight into survey planning, processing and modelling of magnetic data for UXO mitigation. The outcomes should help to increase understanding factors relevant if advanced interpretation is desired, which could then be used to improve accuracy and reduce false positives during target discrimination. Current industry methods are explored to provide practicable insight for developers, UXO consultants and survey companies. The data sets comprised magnetic data from 220 found munitions, a controlled drone test over an inert munition, a vertical gradient test series over a surrogate item and synthetic data. Significant research was undertaken on a variety of topics, however, here we have confined the discussion to just the key results regarding altitude correction, munition response, synthetic items, modelling and acquisition sampling. This document closes with a summary of a potential workflow for advanced interpretation as supported by the research.

UXO | magnetic data | advanced processing and modelling | synthetic data | industry research
UXO | Magnetikdaten | fortgeschrittene Verarbeitung und Modellierung | synthetische Daten | Industrieforschung

In Zusammenarbeit mit der Industrie wurden Forschungsarbeiten durchgeführt, um einen Einblick in die Planung, Verarbeitung und Modellierung von magnetischen Daten zur Entschärfung von Blindgängern zu gewinnen. Die Ergebnisse sollten zu einem besseren Verständnis der Faktoren beitragen, die relevant sind, wenn eine erweiterte Interpretation erwünscht ist, die dann zur Verbesserung der Genauigkeit und zur Verringerung falsch positiver Ergebnisse bei der Zielunterscheidung genutzt werden könnte. Die aktuellen Methoden der Industrie werden untersucht, um Entwicklern, UXO-Beratern und Vermessungsunternehmen einen praktikablen Einblick zu geben. Die Datensätze umfassten magnetische Daten von 220 Munitionsfunden, einen kontrollierten Drohnentest über einer inerten Munition, eine vertikale Gradiententestserie über einem Ersatzobjekt und synthetische Daten. Es wurden umfangreiche Forschungsarbeiten zu einer Vielzahl von Themen durchgeführt, doch beschränken wir uns hier auf die wichtigsten Ergebnisse in Bezug auf die Höhenkorrektur, die Reaktion der Munition, die synthetischen Elemente, die Modellierung und die Erfassungsproben. Dieses Dokument schließt mit einer Zusammenfassung eines potenziellen Arbeitsablaufs für eine erweiterte Interpretation, wie sie durch die Forschung unterstützt wird.

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Key findings

- There is extreme variation in the anomaly amplitude of previously found munitions. For example, standard deviations of over 100 nT for 30 1000-lb bombs.
- Therefore, anomaly amplitude should not be used as the sole discrimination method within the target list.
- The practice of using a single instance of an inert munition, or a surrogate item to determine the response at various altitudes is inconsistent between equivalent items and so should not be used to define survey specification. Synthetic data is a recommended alternative to determine the possible detection distance of a munition for a given geographic location.
- The altitude correction performed better when the correction distance was less than 25 % of the total altitude. Ideally, a survey would have a tighter range of altitude requirements with a minimum altitude requirement as well as a maximum.
- It is recommended to use Batch fit modelling within Oasis montaj to refine initial target positions, estimate depth, and calculate the magnetic moment and a modelled diameter.
- Apparent weight performed poorly, is based on outdated science and should not be used.
- Anomaly amplitude and the accuracy of modelled values (depth, position and magnetic moment) are strongly influenced by sensor spacing and gap sizes.
- Data accuracy improved when the maximum sampling frequency in the data set was less than ½ (though ideally to ⅓ or ⅕) the maximum source-sensor separation. This sampling

Fact Box 1

Measured response amplitude of found UXO

Profiles were extracted over the peak positive and negative responses of 30 1000-lb bombs, 24 500-lb bombs, 18 projectiles, 25 sea mines and 4 fabricated sea mine items. The data was collected in the North Sea and has been corrected to 2.75 m above each item using the altitude correction in Brighouse et al. (2024). The 1000-lb bomb and 500-lb bomb graphs also show the synthetic response produced using the McFee (1990) method presented here at an equivalent 2.75 m height above the item. The synthetic responses are shown at the most favourable (north-south, 66°) and least favourable (east-west, 0°) orientations and dip angle for amplitude size.

There are multiple reasons why the amplitude of a found UXO response could be smaller than the smallest synthetic response, including item degradation, missing tail fins, high amount of remanent magnetism and non-horizontal item alignment. However, we consider the most likely cause to be the large sensor spacing and resulting lower data density over some of the included UXO.

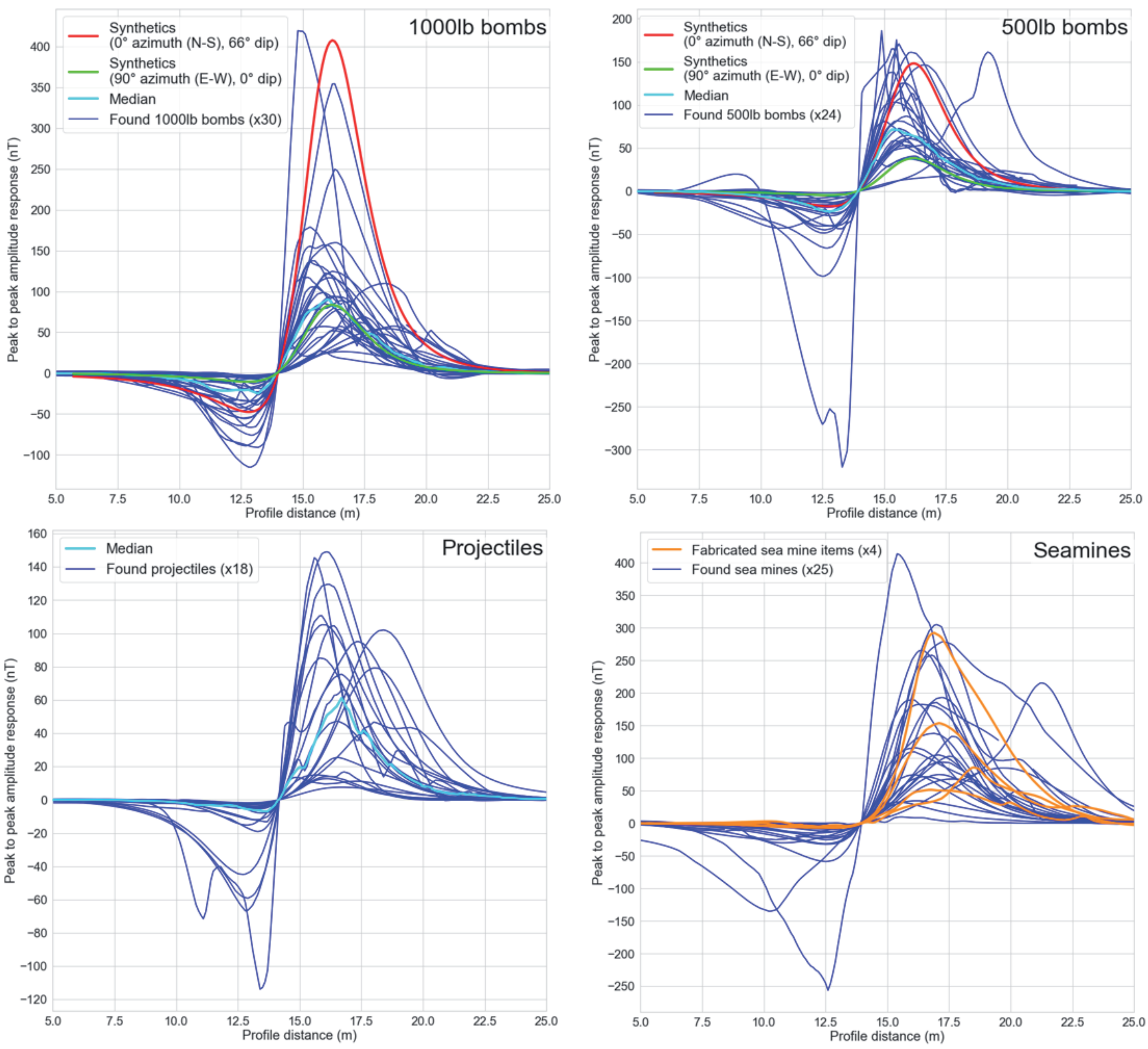

Fig.: Amplitude ranges for 1000-lb bombs, 500-lb bombs, projectiles and sea mines from the magnetic data included in the research compared to synthetic data in two directions and responses from fabricated items frequency includes the (fixed frame) sensor spacing and any allowance for along track and across track gaps.

Most results found here can be implemented by changes in the scope of work for future offshore survey campaigns. These changes will primarily comprise tailored survey specifications fitting the threat level on the site and intended interpretation level for the data set. A benefit of an improved magnetic data set and the potential for advanced interpretation is a reduction in false positive investigations and more efficient investigation campaigns.

Disclaimer: All information contained in this document has been researched, calculated and compiled to the best of our knowledge and belief. Nevertheless, no guarantee can be given for the accuracy of the information. No liability is assumed for the assessment of anomalies based on this document.

Munition response

Profiles were extracted over the peak positive and negative responses of 1000-lb bombs, 500-lb bombs, projectiles and sea mines (see Fact Box 1 for cross sections). The data was collected in the North Sea and has been corrected to 2.75 m above each item using the altitude correction approach introduced in Brighouse et al. (2024). Synthetics were modelled for the 1000-lb bomb oriented horizontally with the long axis east-west (lower response) and north-south (higher response) for comparison against the measured response (more details on synthetics in the next section and in Fact Box 2 and Fact Box 3).

Fact Box 2

Synthetic modelling theory and validation

Magnetic modelling theory for munitions

The synthetic magnetic response for this project was created using a forward model for a uniformly magnetised solid spheroid implemented in Python 3.9 using the multipole expansion method detailed in McFee and Das (1990) and further explained in Butler (1998). The algorithm is based on a solid spheroid with the length along the major axis of symmetry, a diameter across the minor axis, a relative magnetic permeability (1000) and an orientation (azimuth and dip). The International Geomagnetic Reference Field (IGRF) acts as the inducing field and the output is a 2D array representing a horizontal plane of the Total Magnetic Field magnitude (McFee and Das 1990). Cross sections, amplitudes and other metrics are extracted from this 2D array.

The elongated shape and the high magnetic permeability of the steel in the casing for many munitions is important to account for in a synthetic model as it creates an internal magnetic field that opposes the inducing field, effectively reducing the object's magnetisation. This phenomenon is referred to as self-demagnetisation and is a function of the relative permeability and the object's shape and orientation within the inducing magnetic field (McFee and Das 1990). The demagnetisation effects are amplified with elongation, and spheroids with aspect ratios greater than 1 will experience significantly different magnetisations along their major and minor axes. When magnetised along its long axis, increasing aspect ratio will result in significantly increased magnetisation (Butler 2001). When magnetised along its short axis, increasing aspect ratio can result in decreased magnetisation. For example, in the North Sea, this means that when the long axis of the munition is aligned with the IGRF (north-south, with a dip of around 66°), the magnetic response will be considerably stronger than when it is perpendicular (east-west and laying horizontal).

Though relative magnetic permeability can have a significant effect on the magnetisation of spheroids (especially with larger aspect ratios), it is not considered a critical parameter as the magnetisation tends to saturate quickly above 150-250 (unitless) and increase only by about 10 % up to 1000 (Butler 2001). Most modelling studies fix the relative magnetic permeability at 1000. Shell thickness does not have a significant effect on the magnetisation, unless it is very thin (Altshluer 1996). The algorithm assumes that the magnetisation is wholly induced.

Synthetic model validation

Validation of the presented algorithm was performed against published data from previous implementations of the maths and of measured data. The figure shows the following validation comparisons: Panel A: Magnetic anomaly of a 20-mm projectile at 0.5 m altitude and measured with a north-south profile directly over the munition and at a 0.5 m offset (Butler et al. 2012). Panel B: Magnetic anomaly maximum of a modelled 20-mm projectile (Butler et al. 2012). Panel C: Magnetic anomaly of a 175-mm projectile pointing north at dips of 0° (horizontal), 45° and 90° (vertical) (Simms et al. 2004). Panel D: Magnetic anomaly of a horizontal 105-mm projectile at azimuths of 0° (north), 45° and 90° (east) (Butler et al. 1998). Panel E: Magnetic anomaly of a horizontal 105-mm projectile pointing north. Both modelled and measured data are presented (Butler et al. 1998).

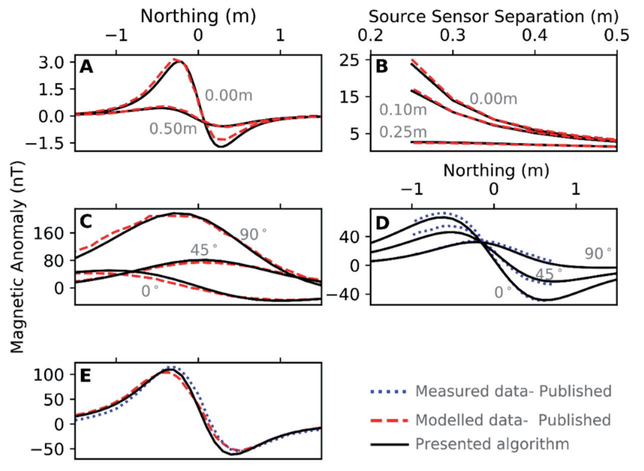

Fig.: As demonstrated in Fact Box 1, in practice it is possible for UXO to have lower responses than the synthetics, with munition degradation and lower sampling of responses not considered in the synthetics

The absolute difference in the ranges of amplitudes is greater than 500 nT for the sea mines and 1000-lb bombs, highlighting the response variability that can be found within a single munition type. Note, there is variation in ferrous content between the different types of 1000-lb bombs (e.g. GP, SAP and MC) and also size variation within the sea mines plotted in Fact Box 1. The sea mine plot also displays the response of four fabricated surrogate items with the same dimensions and weight, showing that there is a significant variation in response within these items, as well as between the real munitions and the surrogates.

The variation in response may be attributed to factors intrinsic to the munition (physical properties) and its unique relationship with the Earth's magnetic field. In 1996, Altshuler showed that the orientation of a munition can change the shape and amplitude of the response, with greater variation among elongated items, and less with more spherical items. Other unknown magnetisation factors, such as remanence or demagnetisation may be contributing to the variation. Differences in the degradation and rusting of the munitions may also be considered a significant influence on response amplitude.

Also, extrinsic factors (determined by the acquisition and processing) must be considered. Variation in sampling such as sensor or line spacing and the presence of gaps within the data sets can have a large effect on the shape and amplitude of the signal (see »Sensor spacing and coverage« section). Additionally, the exponential relationship between changes in source-sensor distance and changes in amplitude must be considered. In this case the application of an altitude correction to account for this

Fact Box 3

Synthetic munition response – detection range

The figure shows examples of detection curves for four munitions, modelled using synthetic data. The magnetic anomaly amplitudes are shown against source-sensor distance from an induced spheroid oriented perpendicular (dip 0°, azimuth 90°) and parallel (dip 66°, azimuth 0°) to the IGRF, producing the lowest (red) and highest (blue) responses respectively. An additional detection curve is shown on the 250-lb and SC50 bombs as an example of a response that could occur with a slight variation in object orientation (dip 20°, azimuth 90°).

Detection ranges using the lowest response of a munition can be helpful in determining the maximum source-sensor distance and therefore sensor altitude and sampling requirements for advanced interpretation. If achieving the desired altitudes proves challenging in practice due to seabed characteristics, it may be necessary to use a higher detection threshold.

The detection ranges assume a wholly induced response of a solid prolate spheroid and do not account for remanence or demagnetisation. Relative magnetic permeability was set to 1000 (unitless). The data was modelled onto a grid with 0.2 m cell size and the amplitude sampled as the maximum and minimum of the modelled area. All object dimensions were extracted from Zetica Ordnance Data Sheets, and the ferrous dimensions were used and do not include tail fins.

Please note that these values should be used for guidance only, and each survey should model their own munition response with local parameters.

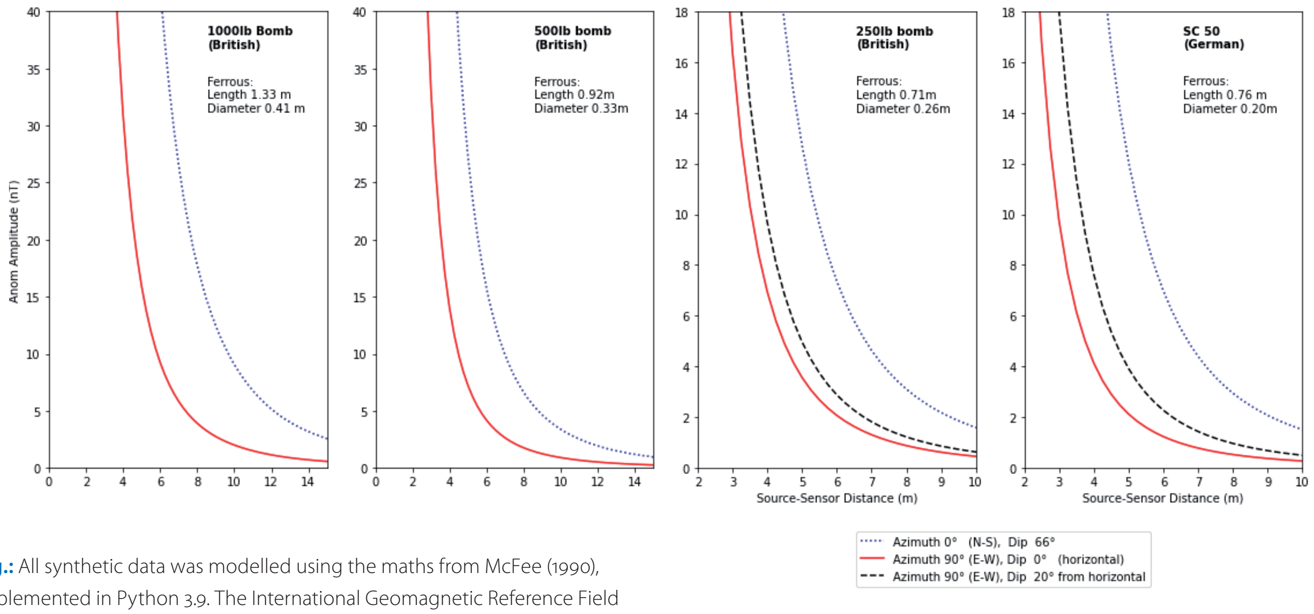

Fig.: All synthetic data was modelled using the maths from McFee (1990), implemented in Python 3.9. The International Geomagnetic Reference Field (IGRF) was modelled, with reference to London, January 1st 2024 with a magnitude of 48912.29 nT, an inclination of 66.38° and a declination of 0.63°

may have contributed some error, though likely less than approximately 20 % of the amplitude variation (see »Altitude correction« section). It is possible to control for the extrinsic factors with acquisition and processing practices and reduce the variability to those intrinsic to the munition type.

The variation in the responses from the real munitions and surrogate item responses demonstrate that the practice of using a single instance of an item to determine the response at various altitudes is unreliable and should not be undertaken.

Determining target thresholds: surrogates and synthetic data

The previous section highlights the variation in response from real UXO, synthetics and fabricated items which raises the question – what should we base UXO project thresholds on if we shouldn't use surrogates? Synthetic data could be the answer, with the ability to provide the expected response for any item at any detection range for any part of the world. Here we compare the response range from different synthetic munitions to previously found UXO and fabricated items.

Fig. 1 shows the range in response amplitude and magnetic moments that can be explained by orientation (horizontal to the seabed) of the item. However, we see the measured responses still extend outside of the expected synthetic range. Potential causes for this additional variation in the real UXO are likely attributed to the intrinsic and extrinsic causes noted in the previous section (such as variation in sampling gaps in the data, altitude variation or altitude correction errors, as well as possible degradation of the items, missing parts of the item and vertical orientation variation). Additionally, the synthetic data was modelled off the dimensions of one item, and then rotated to provide the possible range. The accuracy of the dimension values as well as the variations in retrieved measurements of other munitions may explain some of the response variation.

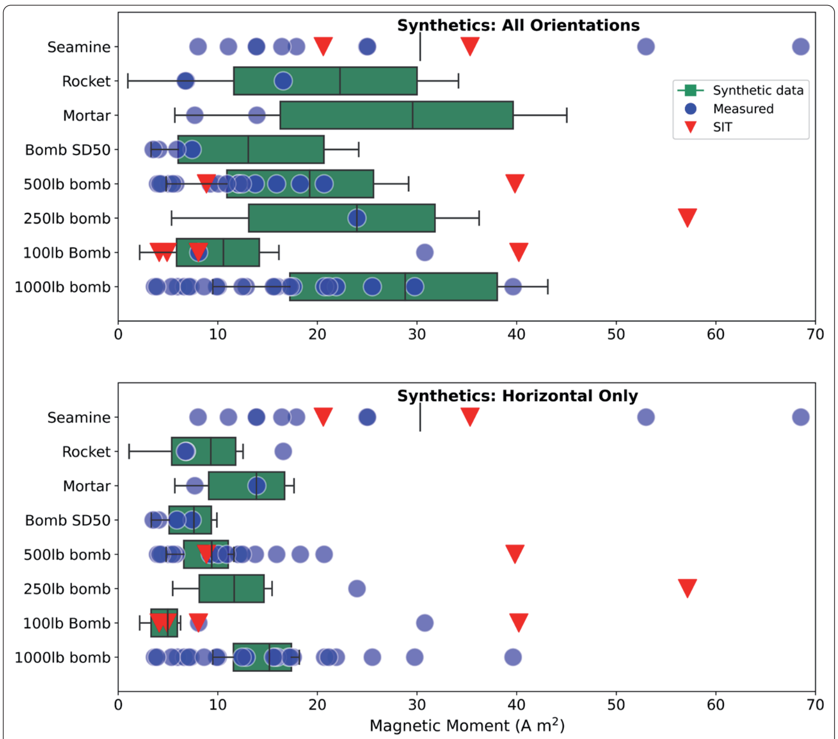

Fig. 1: All data has been normalised to 2.75 m above the item and the synthetic data is created assuming the item is orientated horizontal to the seabed

There are multiple methods to create synthetic data. Caution must therefore be used to ensure that at minimum, the model is based on the ferrous dimensions, accounts for self-demagnetisation effects of the item orientation, and uses the project location and date to determine the inducing Earth's magnetic field.

To ensure the lowest response of an item, the orientation of the long axis should be perpendicular to the Earth's magnetic field at the project location. In northern Europe this would be approximately horizontal and with the long axis-oriented east-west.

In a project scenario where synthetics are used, the mathematical model should be shared in the report, with literature references.

This report provides the synthetic cross-sectional responses of the 1000-lb and 500-lb bombs for comparison against measured responses in Fact Box 1. Additionally, in Fact Box 3 the amplitude detection is modelled for the 1000-lb, 500-lb, 250-lb British bombs and a German SC50 bomb.

Though synthetic data is highly recommended, if real items are to be used, then it is important that the dimensions (length, diameter and general shape) match the ferrous dimensions of the minimum threat item. Additionally, it should be ensured that the objects are oriented perpendicular to the Earth's magnetic field to provide the lowest response.

Altitude correction

Deep's vertical gradient Iron Lady configuration was used to run a surrogate item test at various altitudes over a fabricated 50-kg item. The fixed frame array had eight sensors (four top and four bottom), with a 0.5 m vertical separation between sensors. This was an optimal set-up to test the altitude correction, as it allowed for tests of both upward and downward continuation, and then comparison against the measured values. The Oasis Montaj altitude correction (green square in Fig. 2) was compared to inverse cube root scaling and the sensor-source scaling method described in Brighouse et al. (2024), using different structural indices. Fig. 2 shows the upward continuation results:

There are errors and uncertainties present in both applying and not applying an altitude correction. This research highlights some guidance for both scenarios:

- If no altitude correction is performed, there may still be an error in the data from inconsist-

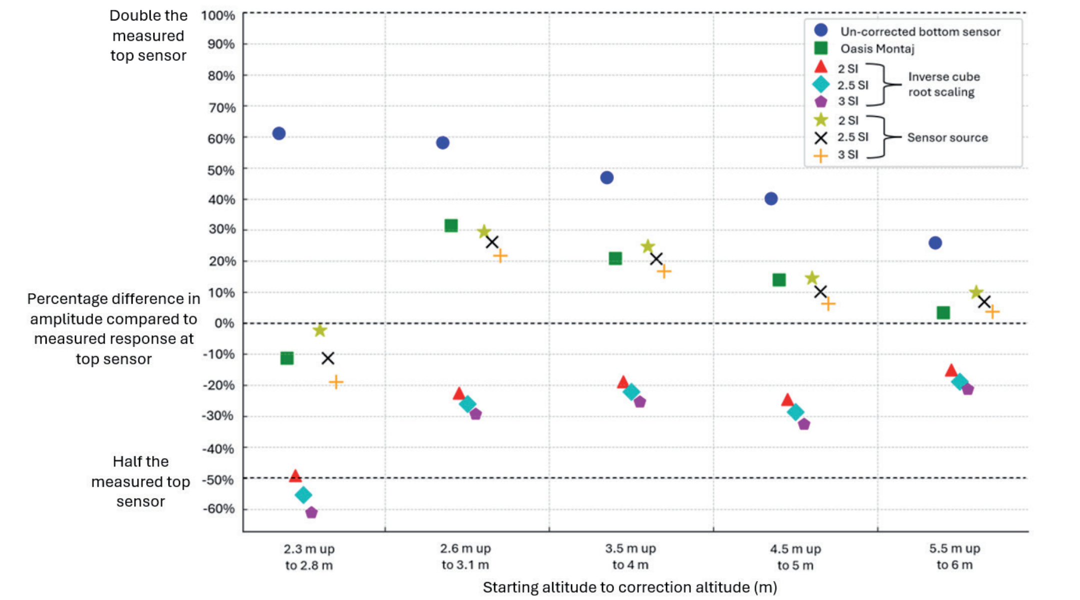

Fig. 2: Mean values for the percentage difference in amplitude between the measured response of the top sensor and the response of seven upward continuation altitude correction methods performed on the bottom sensor. The results are shown for different altitudes as detailed on the x-axis. Also shown is the uncorrected bottom sensor, which shows the percentage difference in amplitude of the uncorrected bottom and top sensors for comparison

ent altitudes and extra care must be taken during background removal, target picking and modelling. Fig. 2 highlights that the error when not correcting is greater than all the tested altitude correction approaches.

- The altitude correction performed better when the correction distance was less than 25 % of the total altitude.
- In other tests which were part of the research, there were no significant differences between altitude correction applied on the total field (pre-processing) or residual (post-processing).
- If an altitude correction is used, the software or method (including version) should be noted in the report with the number of continuation levels and the low pass factor used.
- The altitude of each target should be reported in all further outputs, regardless of whether an altitude correction is performed.

Modelling: magnetic moment and apparent weight

The apparent weight, as an output from Euler Deconvolution, and the magnetic moment as an output from Batch fit, both from Oasis Montaj, are explored as size proxies for the recovered munitions (note: size may mean mass, volume or object dimensions depending on context). The apparent weight values were compared against the measured weights, though the magnetic moment did not have a direct value to compare against.

- Apparent weight values are based on outdated science which supposes that the magnetic response is related to the mass of a ferrous object. Instead, it was found, by multiple authors that it is in fact the volume and the aspect ratio (length/diameter) which are the controlling factors for the magnetic response and which can vary significantly with object orientation (McFee 1990; Altshuler 1996; Billings 2002).
- Many munitions modelled here (Fig. 3) have apparent weights which ranged from almost zero to several hundred kilograms and which were highly dependent on the structural index and the window size for Euler Deconvolution.
- There was only a 14 % mean variation in the magnetic moments calculated from un-altitude corrected data and data altitude corrected using Oasis Montaj, a notably lower variation

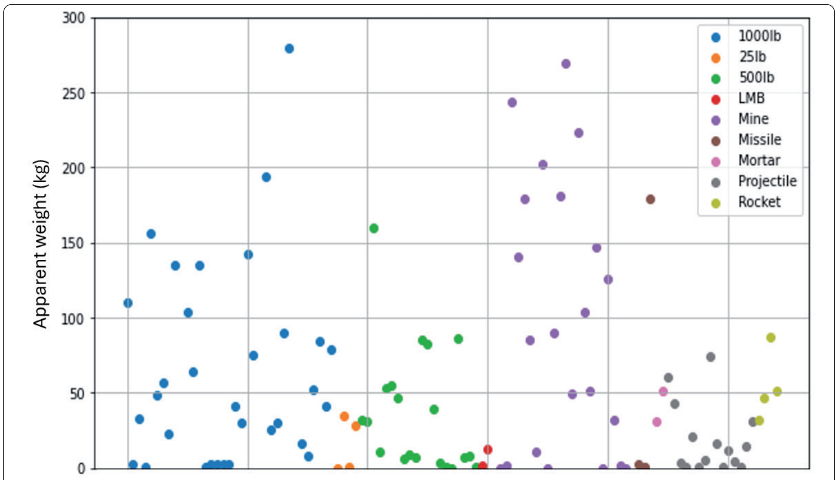

Fig. 3: This graph shows the variation in modelled weights as calculated in Oasis Montaj. It is recommended to use Batch fit to model the magnetic moment, and not to use apparent weight for size proxies

Munition type	Items measured	Magnetic moment Am^2	
		Lowest	Mean
Mine	24	8.0	41.0
1000 lb	35	3.6	15.8
500 lb	20	4.0	11.0
Projectile	15	2.0	10.3

Table 1: Mean and lowest magnetic moments for previously found items measured on un-altitude corrected data using Oasis Montaj Batch fit inversion in the UXO marine module, version 2022.2

than seen in the response amplitude. However, the range of magnetic moments was often larger within a munition type than across munition types and therefore it cannot be used to discriminate between munitions. The lowest magnetic moments from Table 1 are higher than the magnetic moments for many debris currently on target lists (Brighouse et al. 2024).

- The confidence coefficient (Fit_coh) within Batch fit was useful to determine the data quality, with values above approximately 0.8 generally providing more repeatable results. Note that this value does not determine the validity of the interpretation only that the input data allowed for a mathematical fit.
- Batch fit produced more accurate results than Euler Deconvolution for depth modelling and positioning estimates.

Sensor spacing and coverage

A high-resolution drone data set over an inert SC50 bomb and a fabricated 250-lb bomb was used to explore the impact of different sensor spacing on modelling results. The initial data set was acquired with 1-m sensor spacing and at 1-m altitude intervals. Sensor tracks were progressively removed from the data set to artificially create larger sensor spacings. At the larger sensor spacings, different combinations of lines were chosen to demonstrate the variability of responses depending on where the lines sampled the anomaly. Munitions had depths of 0.0 m and were oriented with their long axis east-west.

The graphs in Fig. 4 show reduced precision in the modelled results due to aliasing caused by scarce sampling in large sensor spacing, especially at lower amplitudes, such as for the SC50. The magnetic moment of the SC50 was almost 15× larger in the wider sensor spacings at 4-m altitude than with a 2-m sensor spacing.

To properly characterise an anomaly, at least two points on the signal must be sampled per shortest wavelength (referred to as the Nyquist frequency), though even at this sampling frequency, aliasing can occur (Billings and Richards 2000). The wavelengths of magnetic anomalies have an approximately linearly relationship to source-sensor-separation (in this test, altitude). Though the Nyquist frequency is about ½ of the source-sensor separation, to ensure that the magnetic anomalies can be reliably interpreted, a sampling rate of ⅕ to ⅓ of the source-sensor separation is required (Carbon-Trust 2020; Wehner and Frey 2022). This should refer to sensor spacing, along and across track gaps.

Ensuring that data sampling is optimised for advanced interpretation starts at the survey design phase. Synthetic data can be used to determine the maximum detection distance for a minimum

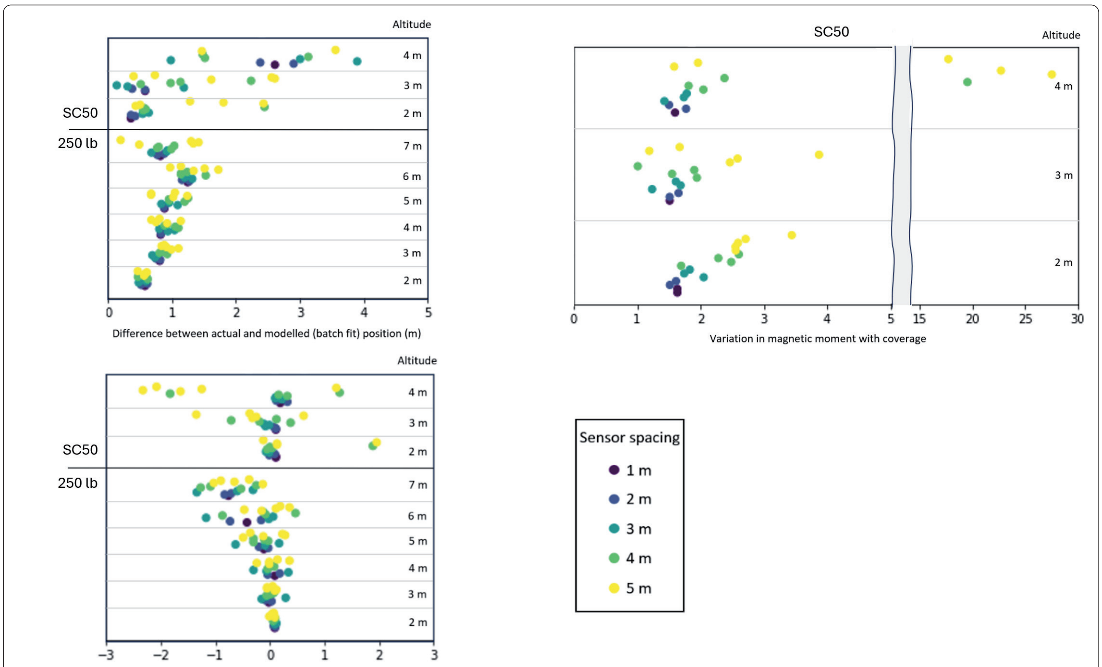

Fig. 4: Top left: Difference in actual altitude and modelled Batch fit position (m). Bottom left: Difference in actual altitude and modelled fit depth (m). Right: Variation in magnetic moment (Am^2) with coverage and altitude

threat item (as detailed in the next section). The sensor spacing and gap tolerance can be determined as noted above, however the balance between ideal data and achievable data must also be considered, with very low maximum sensor spacing not always considered reasonably achievable.

In practice, the tight across track gaps for advanced interpretation can be difficult to achieve, so if it is necessary to have larger gaps between adjacent lines, it was observed that the target interpretations are likely to be aliased resulting in larger amount of false-positives during investigation campaigns.

Proposed workflow for advanced interpretation

Given the findings, a proposed workflow for optimised results of advanced interpretation is described for the pre-survey, acquisition, processing and interpretation stages. These combined steps are intended to improve the survey set-up to detect the minimum threat items whilst reducing false-positives from acquisition and processing artefacts. The quality of the data will also then be sufficient for more advanced discrimination techniques as they become available.

Note that the values used in the following workflow is an example scenario only, and any values should be recalculated for each survey.

The minimum threat item is established at the start of the project in a desktop study. Synthetic data can then be used to model this item's total field response at various source-sensor distances using its ferrous length and diameter, and orienting the synthetic item perpendicular to the Earth's magnetic field, where the response should be at its lowest (approximately horizontal and east-west in the North Sea). The maximum source-sensor distance suitable for advanced interpretation in the project can then be defined. This distance should consider the predicted noise floor of the sensor system, the intended amplitude picking threshold (3-nT amplitude used here for example), the required burial depth and the survey altitude safely achievable by the proposed equipment and the intended maximum accepted across-track sensor spacing.

As an example, Fig. 5 shows that a 500-lb bomb near London, UK, is likely to have an anomaly amplitude response of 3 nT at 6.6 m source-sensor distance when in its worst-case orientation. With low noise in the sensors and the acquisition environment, the amplitude threshold could be lowered, which could increase the maximum detection distance. For this example, we will keep the picking threshold at 3 nT and assume a required burial depth of 2.0 m.

For the data to be optimally sampled, we would ideally have a 1.3-m to 2.2-m sensor spacing for

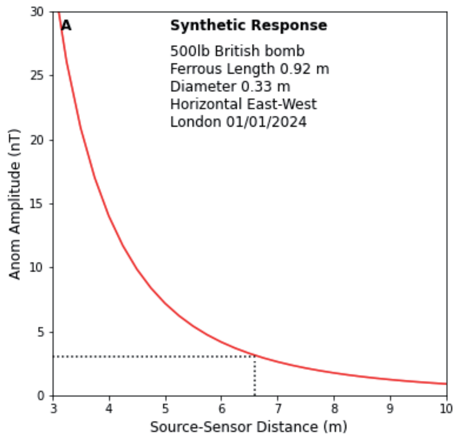

Fig. 5: Synthetic data modelled based on McFee (1990) (permeability 1000), with International Geomagnetic Reference Field (IGRF) modelled from Geomatrix IGRF Calculator. Ferrous dimensions from Zetica UXO Data Sheet and corroborated with recovered munitions

this example (⅕ to ⅓ of the source-sensor separation). In practice a maximum 2.2-m across-track gap is difficult to achieve, so in this example we will use 3.0-m maximum sensor spacing, which still performed reasonably in the coverage section. The maximum altitude in this example would be 4.4 m as detailed in the equation:

$$\text{maximum flying height} = \left(\sqrt{\text{source sensor separation}^2 - \left(\frac{\text{maximum sensor spacing}}{2}\right)^2}\right) - \text{burial depth}$$

To minimise the number of smaller debris items creating large anomalies, to reduce aliasing and to reduce the altitude correction distance, a minimum altitude is recommended. This minimum altitude should be a compromise between the sampling requirements and operational limitations. An upward continued altitude correction to the maximum altitude can then be performed, reducing the impact of amplitude variation.

After careful processing, targets above 3 nT (used as an example threshold only, and should be project dependent) could be picked with an automatic tool, then checked and adjusted by the processor as necessary to ensure a single target per anomaly. The positions could then be refined through inversion in Oasis Montaj Batch fit, where the depth, magnetic moment and fit_coh can also be extracted. Targets with fit_coh values less than approximately 0.8 can be investigated for data quality issues. Magnetic moments may be used with caution to discriminate between particularly small and large objects and comparing the responses to a library of previously found target responses (for example, Brighouse et al. 2024) could be used to further improve the statistical confidence of the target list. //

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Glossary

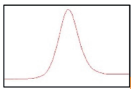
across-track gap lack of acceptable data perpendicular to the direction of acquisition

along-track gap lack of acceptable data parallel to the direction of acquisition

altitude correction [nT] mathematical transformation of the magnetic data ›as if‹ it had been acquired at a different altitude. It is created using upward and downward continuations in the Fourier domain and can be calculated along a survey line (1D) or over a gridded area (2D)

altitude of sensor [m] Vertical distance of the sensor above the seabed

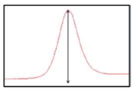
analytic signal (AS) [nT/m] maximum gradient of the magnetic anomaly, and is defined as:



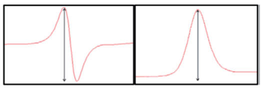
$$\sqrt{\left(\frac{d\|\vec{T}\|}{dx}\right)^2+\left(\frac{d\|\vec{T}\|}{dy}\right)^2+\left(\frac{d\|\vec{T}\|}{dz}\right)^2}$$

where $\vec{T}$ is Total Magnetic Field anomaly and x, y, z are the Cartesian directions. It results in a positive peak, approximately centred over the causative body

analytic signal amplitude [nT/m] analytic signal maximum



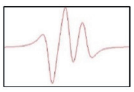
anomaly amplitude (peak to peak, P2P) [nT] the amplitude of an anomaly is defined based on the shape:



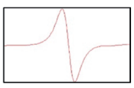
Dipole: Anomaly maximum – Anomaly minimum
Positive monopole: Anomaly maximum
Negative monopole: Anomaly minimum

background removal [nT] a process which removes the longer wavelengths from the signal. These longer wavelengths include the International Geomagnetic Reference Field (IGRF), the diurnal variation and the geology

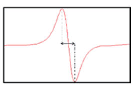
complex anomaly [nT] an anomaly which is neither a monopole nor a dipole. For example, causes for complex anomalies can include (but are not limited to) higher order magnetic moments, multiple ferrous objects clustered together, or shallow geology which was not removed during the background removal



dipole [nT] a magnetic anomaly which has both a positive and a negative pole (peak and trough). The point of maximum gradient is often centred over the causative body



dipole length (peak-to-peak distance) [m] length of a horizontal line connecting the anomaly maximum and minimum



equipment verification test (EVT) pre-survey equipment and detection check to test functionality of all systems within the array which will be used for the planned survey. The test is used to verify the quality of the raw data, confirm positional accuracies and document the capabilities and limitations of each instrument. The test is performed over a known object on a test site close to or within the survey area with all sensors running simultaneously. Lines are usually run in four directions (Cooper et al. 2015)

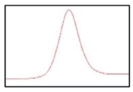
inert munition real munition with explosives removed

International Geomagnetic Reference Field (IGRF) [nT] a mathematical model representing the Earth's magnetic field calculated by the International Association of Geomagnetism and Aeronomy. True measurements and predictions are updated every five years (Thébault et al. 2015)

line spacing [m] lateral spacing between vessel tracks

magnetic moment [Am^2] a vector quantity describing the strength and orientation of the total magnetisation (including induced and remanent components) of a ferrous object

monopole [nT] single peak in the magnetic data. Can be positive or negative. Usually centred approximately over the causative body



nanoTesla [nT] magnetic units

residual [nT] data which remains after the background has been removed from the total magnetic intensity data. This should centre around zero, with dipoles having negative and positive values for their poles

sensor spacing [m] the lateral distance between the individual sensors

source-sensor separation [m] total distance between the sensor and the object of interest. Usually referenced to the centre of the object

surrogate item non-munition object created to mimic the physical properties of the unexploded ordnance of interest

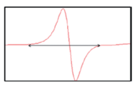
Surrogate Item Trial (SIT) pre-survey equipment and detection check used to prove the capability of the magnetometers to detect potential UXO items within a survey area. The trial has been thought to assist in the determination of the geophysical characteristics of the expected UXO target to aid positive identification and to determine the survey parameters and cut-off values for the survey. The test usually involves multiple short acquisition lines over an object with known ferrous dimensions in various line orientations, lateral offsets and altitudes (Cooper et al. 2015)

synthetic modelling The process of mathematically calculating a geophysical signal

target a magnetic anomaly in the residual data which has the appropriate amplitude above the defined threshold or wavelength

UXO unexploded ordnance

wavelength [m] total horizontal width of the anomaly



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