Environmental Security Technology Certification Program

(ESTCP)

WAA Pilot Project Data Report

Wide Area UXO Contamination Evaluation by Transect Magnetometer Surveys

Pueblo Precision Bombing and Pattern Gunnery Range #2

ESTCP Project # UX-0533

La Junta, CO

28 August - 24 October, 2005

Distribution Statement A: Approved for Public Release, Distribution is Unlimited

Contents

ACKNOWLEDGEMENTS viii

ABSTRACT viii

1. Introduction 1

1.1 Background 1

1.2 Objective of the Demonstration 1

2. Technology Description 2

2.1 Technology Development and Application 2

2.1.1 Vehicular Magnetometer System 2

2.1.2 Data Analysis Methodology 4

2.2 Previous Testing of the Technology 5

2.3 Advantages and Limitations of the Technology 6

3. Demonstration Design 7

3.1 Testing and Evaluation Plan 7

3.1.1 Demonstration Set-Up and Start-Up 7

3.1.2 Period of Operation 11

3.1.3 Operational Parameters for the Technology 12

3.1.4 Transect Magnetometer Survey Results 13

3.1.5 Total Coverage Magnetometer Survey Results 17

3.1.6 Anomaly Density Falloff Analysis for Targets 3 and 4 32

3.1.7 Section 9 Farm House Area of Interest 35

3.1.8 Calibration Items 36

3.1.9 Demobilization 48

4. References 49

5. Points of Contact 50

Appendix A. Analytical Methods to Support the Experimental Design 51

Appendix B. Data Storage and Archiving Procedures 57

B.1 Data Formats 57

Figures

Figure 1 – MTADS Magnetometer system 3

Figure 2 – Screenshot of MTADS Pilot Guidance Display 3

Figure 3 – Working screen in Oasis montaj™ of data preprocessing work flow 4

Figure 4 – Automatic anomaly detection scheme. Example data is from the MTADS Test Field at Blossom Point, MD. Magnetometer data is shown on a ±30 nT vertical scale. Analytic signal data is shown on a ±100 nT/m vertical scale. 5

Figure 5 – Photograph of the WAA Base Camp at the Pueblo PBR#2 WAA demonstration site showing the relative locations of the trailers, etc. 8

Figure 6 – Photograph of the Auxiliary Base Camp at Pueblo PBR#2 WAA demonstration site . 9

Figure 7 – Effect of increasing number of passes of smoothing filter on the 05242006 data set results. The red line indicates the result for the final parameter value. 13

Figure 8 – Effect of increasing peak anomaly cut-off threshold value on the 05242006 data set results. The red line indicates the result for the final parameter value. 13

Figure 9 – Map showing a) North / South Transect Plan (sparse shown in red, additional transects for conservative shown in green). b) Transect plan with actual survey for Julian date (05248, September 5) shown. 15

Figure 10 – Map showing the transect survey results for the Pueblo PBR#2 demonstration. Transect COGs are shown as green lines and individual detected anomalies are shown as filled circles. 16

Figure 11 – Pueblo PBR#2 Total Coverage Survey Results 20

Figure 12 – Magnetometer Anomaly Map of the Simmons Area 21

Figure 13 – Magnetometer Anomaly Map of Area 1C 22

Figure 14 – Magnetometer Anomaly Map of Area 1B 23

Figure 15 – Magnetometer Anomaly Map of Area 1A 24

Figure 16 – Magnetometer Anomaly Map of Area BT4 Center 25

Figure 17 – Magnetometer Anomaly Map of Area 3A 26

Figure 18 – Magnetometer Anomaly Map of Area 3B 27

Figure 19 – Magnetometer Anomaly Map of Area 3C 28

Figure 20 – Magnetometer Anomaly Map of Area 2A 30

Figure 21 – Magnetometer Anomaly Map of Area 2B 31

Figure 22 – Total Coverage Plan for Area 3 (Target 3). The planned total coverage survey areas are shown in blue, the Target 3 target circle from CSM v0 is shown in dark purple and the ASR target outlines are shown in pink. The red diamond indicates the center of the Target 3 target circle. The red line indicates the swath selected for the radial analysis. 32

Figure 23 – Number of anomalies per 30m x 30m cell as a function of radial distance from the CSM v0 T3 target circle center. The solid line is the results of a fit to a normal distribution with a persistent background value of 1.8 anomalies / cell. 33

Figure 24 – Total Coverage Plan for Target 4. The planned total coverage survey areas are shown in blue, the Target 4 target circle from CSM v0 and the ASR target outline are shown in dark brown. The red diamond indicates the center of Target 3 as reported from the AMTADS magnetometer data collected by Sky Research. The red line indicates the swath selected for the radial analysis..... 34

Figure 25 – Number of anomalies per 30m x 30m cell as a function of radial distance from the AMTADS T4 center. The solid line is the results of a fit to a normal distribution with a persistent background value of 1.4 anomalies / cell. 35

Figure 26 – Magnetometer Anomaly Map of Section 9 Farm House Area of Interest 36

Figure 27 – Magnetometer anomaly map of the calibration strip emplaced between the WAA Base Camp and the WAA Demonstration site at Pueblo PBR#2 37

Figure 28 – Magnetometer anomaly map of the calibration sphere emplaced near the Auxiliary Base Camp located south of the WAA demonstration site at Pueblo PBR#2 38

Figure 29 – SNR data runs for 155mm Projectile #2. The result for each data set is shown in order of acquisition. The horizontal axis is survey file number. The solid line represents the aggregate average SNR and the dashed lines represent a 1σ envelope. 40

Figure 30 – SNR data runs for 60mm Projectile #1. The result for each data set is shown in order of acquisition. The horizontal axis is survey file number. The solid line represents the aggregate average SNR and the dashed lines represent a 1σ envelope..... 40

Figure 31 – Analytic signal data runs for 155mm Projectile #2. The result for each data set is shown in order of acquisition. The horizontal axis is survey file number. The solid line represents the aggregate average analytic signal and the dashed lines represent a 1σ envelope.. 42

Figure 32 – Analytic signal data runs for 60mm Mortar #1. The result for each data set is shown in order of acquisition. The horizontal axis is survey file number. The solid line represents the aggregate average analytic signal and the dashed lines represent a 1σ envelope..... 42

Figure 33 – SNR data runs for the metal sphere emplaced near the Auxiliary Base Camp. The result for each data set is shown in order of acquisition. The horizontal axis is survey file number. The solid line represents the aggregate average SNR and the dashed lines represent a 1σ envelope..... 43

Figure 34 – Analytic signal data runs for the metal sphere emplaced near the Auxiliary Base Camp. The result for each data set is shown in order of acquisition. The horizontal axis is survey file number. The solid line represents the aggregate average analytic signal and the dashed lines represent a 1σ envelope..... 44

Figure 35 – Positional variation data runs for static data collected at the calibration strip. The horizontal axis is survey file number. The solid line represents the aggregate average positional variation and the dashed lines represent a 1σ envelope..... 46

Figure 36 – Overall magnetometer (all sensors) variation data runs for static data collected at the calibration strip. The horizontal axis is survey file number. The solid line represents the aggregate average sensor variation and the dashed lines represent a 1σ envelope. 46

Figure 37 – Positional variation data runs for static data collected at the calibration sphere. The horizontal axis is survey file number. The solid line represents the aggregate average positional variation and the dashed lines represent a 1σ envelope..... 47

Figure 38 – Overall magnetometer (all sensors) variation data runs for static data collected at the calibration sphere. The horizontal axis is survey file number. The solid line represents the aggregate average sensor variation and the dashed lines represent a 1σ envelope. 47

Tables

Table 3-1 – Coordinates for the Approximate Corners of the WAA Pilot Project Pueblo PBR #2 demonstration site 7

Table 3-2 – Survey Control Points Installed for the WAA Pilot Project at the Pueblo PBR #2 site 9

Table 3-3 – Schedule of Ground-based System WAA Calibration Items for Pueblo PBR#2.....10

Table 3-4 – Pueblo PBR #2 Survey Demonstration Deployment Schedule.....11

Table 3-5 – Excerpt of Annotated Listing of Transect Surveys Conducted During Pueblo PBR#2 Demonstration.....17

Table 3-6 – Total Coverage Area Result Summary.....18

Table 3-7 – Background Anomaly Densities for Total Coverage Areas 1, 2, 3, and the Simmons Area.....34

Table 3-8 – Boundaries of Background Areas Selected for Noise Calculation.....38

Table 3-9 – Signal to Noise (SNR) Aggregate Values for Calibration Strip Items.....39

Table 3-10 – Signal Aggregate Values for Calibration Strip Items.....41

Table 3-11 – Static Test Data Results.....45

Table A-1 – Results for emplaced targets at Blossom Point for various parameters 54

Abbreviations Used

Abbreviation	Definition
AMTADS	Airborne Multi-sensor Towed Array Detection System
AS	Analytic Signal (nT/m)
ATC	Aberdeen Test Center
BP	Blossom Point
CD-R	Compact Disk - Recordable
COG	course-over-ground
CSM	Conceptual Site Model
DAQ	Data Acqusition (System)
DAS	Data Analysis System
DoD	Department of Defense
DSB	Defense Science Board
DVD-R	Writable digital versatile disc
ESTCP	Environmental Security Technology Certification Program
FA	False Alarm
FAR	False Alarm Rate
FFT	Fast Fourier Transform
GPS	Global Positioning System
Hz	Hertz
IDA	Institute for Defense Analyses
MTADS	Multi-sensor Towed Array Detection System
NRL	Naval Research Laboratory
nT	nanoTesla
PBR #2	Peublo Precision Bombing and Pattern Gunnery Range #2
Pd	Probability of Detection
PNNL	Pacific Northwest National Laboratory
POC	Point of Contact
RMS	Root-Mean-Squared
ROC	Reciever Operating Characteristic
RTK	Real Time Kinematic
SNL	Sandia National Laboratories
SNR	Signal to Noise Ratio
TBD	To Be Determined
UTC	Universial Coordinated Time
UXO	Unexploded Ordnance
WAA	Wide Area Assessment
YTC	Yuma Test Center
ZIP (250)	Iomega ZIP disk (250 MB version)

ACKNOWLEDGEMENTS

Glenn Harbaugh and Daniel Steinhurst (P.I.) of Nova Research, Inc. and Nagi Khadr of AETC, Inc. comprised the field team responsible for the collection and processing of all data. Nagi Khadr also assisted the P.I. in the analysis of the results presented in this report. This work was supported by ESTCP under project UX-0533.

The P.I. would like to thank the Russell, Rounds, and Simmons families as land owners / lessees / permit holders of the land involved in the demonstration site and Kurt Staton of the Comanche Nation Grasslands (U.S. Forest Service) for their cooperation and assistance in conducting this demonstration.

ABSTRACT

As part of the Environmental Security Technology Certification Program (ESTCP) Wide Area Assessment (WAA) Pilot Project conducted during the second half of calendar 2005, Nova Research, Inc. conducted a series of magnetometer surveys at the Pueblo Precision Bombing and Pattern Gunnery Range #2 (Pueblo PBR#2), south of La Junta, CO using the Naval Research Laboratory (NRL) Multi-sensor Towed Array System (MTADS). Two types of surveys were conducted. First, 143 acres of transect surveys were conducted based on survey design plans generated by Pacific Northwest National Laboratory and Sandia National Laboratory. These plans were designed to allow the tow vehicle to efficiently sample the entire demonstration site while maintaining a statistically defensible probability of traversing areas of interest within the demonstration site that matched the criteria developed from the available archive data and collected in the Conceptual Site Model (CSM) version 0. Secondly, 379 acres of total coverage surveys were conducted in small areas (30-85 acres per area) to better characterize the overall site. The goals of the total coverage surveys were a) to characterize background anomaly densities in areas found to be quiet (low anomaly density) in the transect survey results, b) to characterize the falloff behavior of the anomaly density as a function of distance from the two known Targets (3 and 4) within the demonstration site, and c) to gather further information on the Suspected 75mm Range area of interest. This data report serves to document the data collected during the demonstration in preparation for the validation phase of the program and further analysis.

Wide Area UXO Contamination Evaluation by Transect Magnetometer Surveys

Pueblo Precision Bombing and Pattern Gunnery Range #2

La Junta, CO

28 August - 24 October, 2005

1. Introduction

1.1 Background

The location and cleanup of buried unexploded ordnance (UXO) has been identified as a high priority mission-related environmental requirement of the Department of Defense (DoD). The DoD UXO Response Technology Investment Strategy [1] has identified wide area assessment as one of six technology objectives, with a goal of developing capabilities to perform rapid initial assessment of large areas. The benefit, reiterated by the recent Defense Science Board (DSB) Task Force on UXO [2] is that the identification of lands where UXO is not present may substantially reduce the total area subjected to detailed site characterization and may allow for more rapid release of these lands to reuse functions.

To date, a great deal of effort in the UXO research community has been focused on previously identified sites that are known or suspected of being contaminated with UXO. Total-coverage investigations typically involve conducting a geophysical survey of some kind (magnetometer, for example) with sufficient measurement density to insure that measurements are taken over the entire site. The results are then analyzed in a data-appropriate manner and anomalies are selected and prioritized. Recommendations for remediation are made based on the results. Based on these recommendations, remediation may or may not be required prior to land reuse.

The broader problem posed by the DSB and the subject of the ESTCP Wide Area Assessment (WAA) Pilot Program is how to handle large areas that may or may not have isolated areas of UXO contamination within them. Techniques for efficiently surveying a large area to locate concentrations of UXO contamination without requiring the time-consuming total-coverage type of survey are needed to address this problem. We have demonstrated one such technique using a ground-based magnetometer array system.

1.2 Objective of the Demonstration

A comprehensive WAA program has the possibility of making an immediate impact on the scope of the UXO problem currently facing the DoD. The Defense Science Board recently estimated that there are 1400 sites suspected of containing UXO contamination covering approximately 10 million acres in the continental US. By some estimates, as much as 80% of this acreage is quite

likely not contaminated with UXO at all. A suite of technologies that can accurately and rapidly delineate the areas on each site that are contaminated from those that are not contaminated would lead to an immediate payback in terms of reducing the acreage that must be carefully examined and potentially cleaned.

We have demonstration a data collection and analysis methodology to support the rapid delineation of UXO contamination within a suspect site. Full-field magnetometer data was collected over the demonstration site along planned transects provided by Pacific Northwest National Laboratories (PNNL) and Sandia National Laboratory (SNL) in cooperation with the ESTCP Program Office. These transects were designed based on available archive information and sound statistical sampling methodologies. Anomaly location and a measure of anomaly magnitude were extracted from these data using an automated anomaly detection methodology. This information was provided to PNNL / SNL for analysis to rapidly delineate UXO contamination sites such as impact areas and bombing targets. With the rapid pace of the automated routines, it was possible to interactively plan and execute additional transects to further resolve features of interest while the survey team was still deployed in the field.

2. Technology Description

2.1 Technology Development and Application

2.1.1 Vehicular Magnetometer System

The demonstration was conducted using the Naval Research Laboratory (NRL) Multi-sensor Towed Array Detection System (MTADS). The MTADS was developed with support from the Environmental Security Technology Certification Program (ESTCP). The MTADS hardware consists of a low-magnetic-signature vehicle that is used to tow a linear array of eight magnetometer sensors over large areas (25 acres / day) to detect buried UXO, Figure 1. The sensors are sampled at 50 Hz and typical surveys are conducted at 6 mph; this results in a sampling density of ~6 cm along track with a horizontal sensor spacing of 25 cm. Each magnetometer measures the local magnetic field of the earth at the sensor.

The sensor positions are measured in real-time (5 Hz) with position accuracies of ~5 cm using high performance Real Time Kinematic (RTK) Global Positioning System (GPS) receivers. All navigation and sensor data are time-stamped with Universal Coordinated Time (UTC) derived from the satellite clocks and recorded by the data acquisition computer (DAQ) in the tow vehicle. The positioning technology requires the availability of one or more known first-order survey control points. The sensor, position, and timing files are downloaded periodically throughout a survey onto magnetic disks and transferred to the data analyst for analysis.

The GPS positioning information used for data collection is shared with an onboard navigation guidance display and provides real-time navigational information to the operator. The guidance display was originally developed for the airborne adjunct of the MTADS system (AMTADS) [3] and is installed in the vehicle and available for operator use. Figure 2 shows a screenshot of the guidance display configured for vehicular use. An integral part of the guidance display is the ability to import a series of planned survey lines (or transects) and to guide the operator to follow

these transects. The display provides left-right course correction indicators, an optional altitude indicator, and color-coded flight swath overlays where the current transect is displayed in red and the other transects are displayed in black for operator reference. The survey course-over-ground (COG) is plotted for the pilot in real time on the display in green. If a GPS outage occurs during the survey, the COG changes color to warn the operator and allow for on-the-fly reacquisition of the affected area. Figure 2 shows the operator lining up to survey line 30 of a transect plan.

Figure 1 – MTADS Magnetometer system

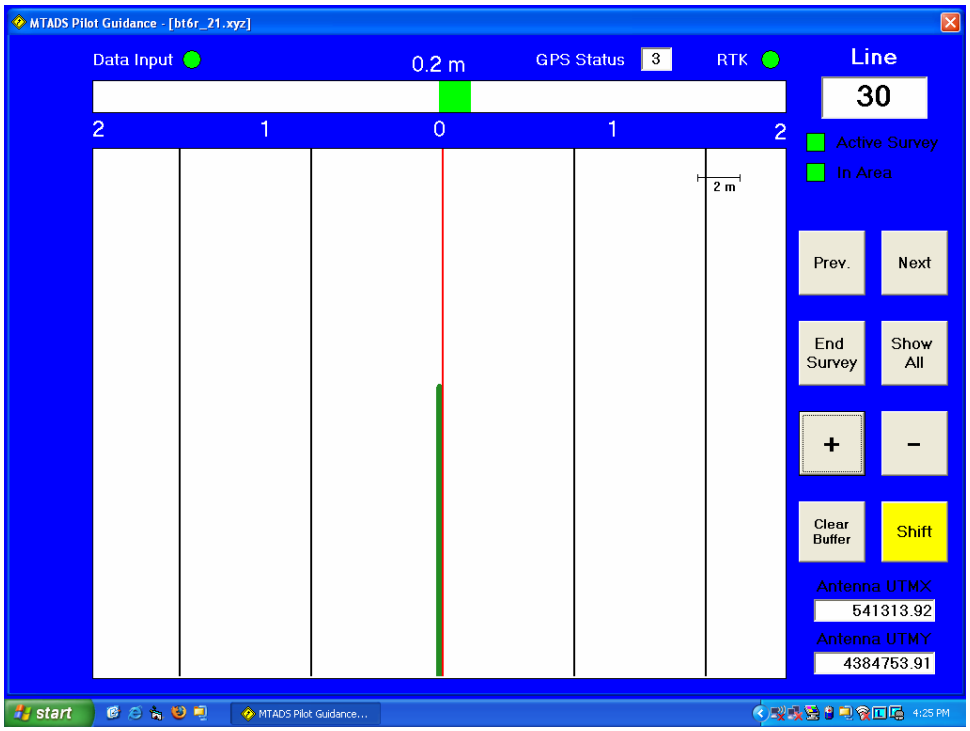


Figure 2 – Screenshot of MTADS Pilot Guidance Display

2.1.2 Data Analysis Methodology

Each data set is collected using the MagLogNT software package (v2.921b, Geometrics, Inc.). The collected raw data is preprocessed on site for quality assurance purposes using standard MTADS procedures and checks. The data set is comprised of ten separate files, each containing the data from a single system device. See appendix B for further details about file contents and formats. Each device has a unique data rate. A software package written by NRL examines each file and compares the number entries to the product (total survey time * data rate). Any discrepancies are flagged for the Data Analyst to address. Next, the data is merged and imported into a single Oasis montaj (Geosoft, Inc.) database using custom scripts developed from the original MTADS DAS routines which have been extensively validated. An example of a working screen from Oasis montaj is shown in Figure 3. As part of the import process any data corresponding to a magnetometer outage, a GPS outage, or a vehicle stop / reverse, is defaulted or marked to not be further processed. Defaulted data is not deleted and can be recovered at a later time if so desired. Any long wavelength features such as the diurnal variation of the earth's magnetic field and large scale geology are filtered from the data (demedianed).

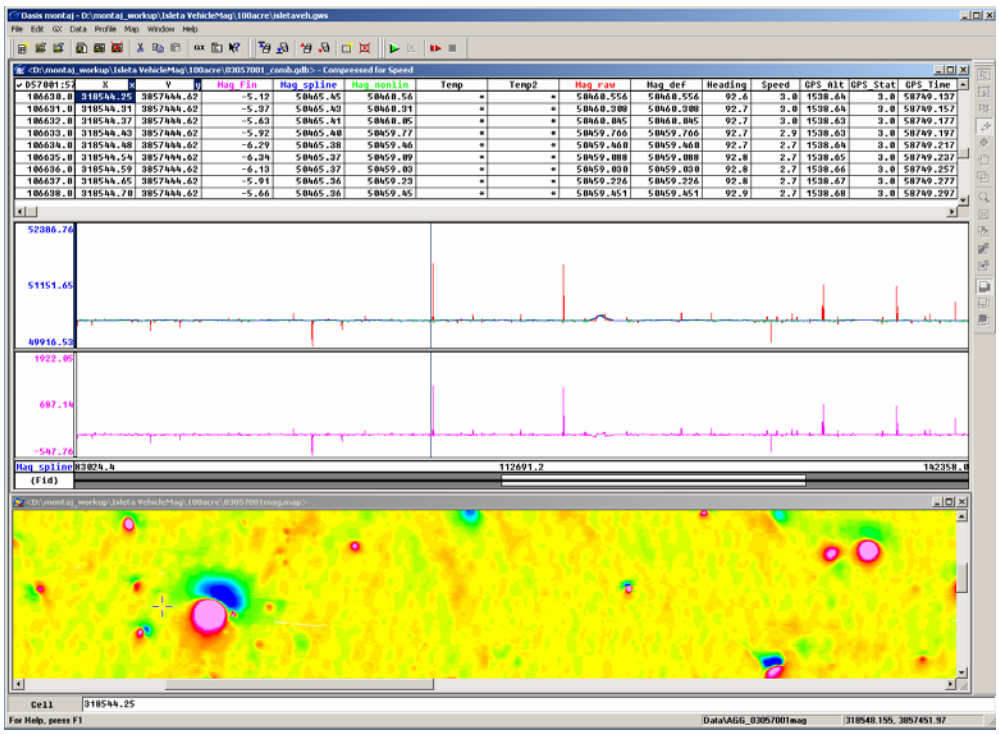


Figure 3 – Working screen in Oasis montaj™ of data preprocessing work flow

For the transect surveys, the demedianed magnetometer data are converted to analytic signal. A built-in feature of Oasis montaj is used to extract peaks above a given threshold from a grid like that of the analytic signal. The analytic signal is used because anomaly features which are dipolar (having both positive and negative components) in the demedianed magnetometer data are monopolar in the analytic signal. The detected anomaly locations along with the analytic signal strength at the peak of the anomaly were provided daily to the ESTCP Program Office, PNNL, and SNL for the previous day's survey results. The down-sampled transect COG (6 – 10

m spacing) was also provided at the request of PNNL / SNL. The data analysis work flow is shown pictorially in Figure 4. Additional details on the methodology and its development are available in Appendix A.

For the more typical total (100%) coverage surveys, the located demedianed magnetometer data were imported into the MTADS Data Analysis System (DAS) software for individual anomaly selection and analysis. In the case of isolated munitions in the far field (i.e. farther from the sensors than their characteristic dimension) the DAS employs resident physics-based models to determine target size, position, and depth. A spreadsheet containing details of the anomaly location and fit parameters is provided along with the locations of anomalies above background which are identified by the operator but for which the dipole model do not give a reasonable fit. The located demedianed magnetometer data are also provided for archival purposes.

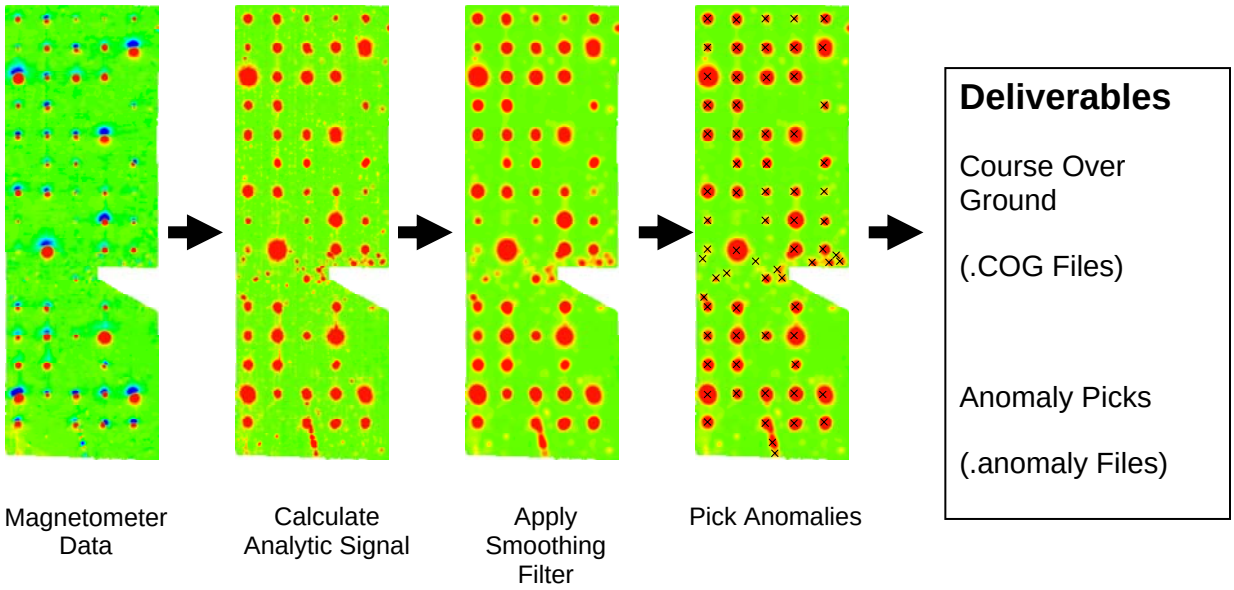


Figure 4 – Automatic anomaly detection scheme. Example data is from the MTADS Test Field at Blossom Point, MD. Magnetometer data is shown on a ±30 nT vertical scale. Analytic signal data is shown on a ±100 nT/m vertical scale.

2.2 Previous Testing of the Technology

The performance of the vehicular MTADS has been demonstrated at several seeded and live ranges sites over the last decade [4-9]. The MTADS has demonstrated probabilities of detection of 95 to 97% and location accuracies of better than 15 cm with the magnetometer system [7]. The vehicular MTADS has been selected to serve as the ground truth for several ESTCP-supported demonstrations of potential wide area survey systems [3,10,11].

As an example of the performance of the MTADS, the results from the survey of the Target S1 at Isleta Pueblo, NM [11] are discussed here briefly. For the Isleta demonstration, a portion of the site was blind seeded by the ESTCP Program Office with a variety of inert munitions. A total coverage survey was conducted over the site. The anomaly list generated by the MTADS was then submitted to a neutral third party for independent evaluation. The results were

representative of the past performance of the MTADS system. Analyzed anomalies were classified into 6 priority categories where 1 is likely UXO, 3 is unlikely UXO, 4 is unlikely a clutter item, and 6 is likely a clutter item. The probability of detection, P_d, and the cumulative alarm rate were determined for including each successive category (from 1 to 6). P_d is the fraction of emplaced items detected and the false alarm rate is given as picks per hectare not corresponding to an emplaced item. For the emplaced items at this demonstration, 89% of the emplaced items ($P_d = 0.89$) were detected and placed in the first three categories with a False Alarm Rate (FAR) of 7 / hectare. The locational performance metrics were mean errors of -1 and 4 cm for easting and northing, respectively, with a standard deviation of 12 and 13 cm for the same. As demonstrated previously, there was no improvement in detection by widening the detection radius from 1.0 to 1.5 m. The detection radius defines how large an error in reported position can still be considered a detection of the emplaced item.

Several hundred detected anomalies were selected for remediation to determine the performance of the systems involved in the overall demonstration. The evaluation metric used was the location difference between the reported location of the anomaly by the MTADS and the actual location reported by the remediation contractor. As was seen for the emplaced items, a large majority of the anomaly picks fall well within the more restrictive 1.0-m halo. The detailed location performance was a mean miss distance of 35 cm. 90% of the anomaly picks were within 59 cm and 95% were within 77 cm of actual remediated location of the anomaly. As was seen for the emplaced items, a large fraction of the remediated anomalies corresponding to munitions or munitions-related fragments were categorized in the first three priority groups with 95% being captured in the first two priority groups.

2.3 Advantages and Limitations of the Technology

On large open ranges the vehicular MTADS provides an efficient survey technology. Surveys with the magnetometer array often exceed production rates of 20 acres per day. UXO items with gauges of 20mm or larger are typically detected to their self-burial depths. This process has to date involved a human operator manually selected the data corresponding to individual anomalies. Each data segment is then processed by a physics-based algorithm incorporated into the MTADS DAS software.

While this methodology has proven highly successful in the past, it is not fast enough to support the rapid data requirements for the transect surveys to be conducted as part of the WAA pilot project. A faster, more automated method was developed and demonstrated. The location and amplitude of anomalies with an amplitude above an empirically-determined threshold were reported to the ESTCP Program Office, PNNL, and SNL along with the survey COG for reference. This rapid feedback of information allowed for an interactive planning and execution of additional transects while the demonstration was ongoing.

The presence of certain terrain features such as deep ravines without good crossing points and thick clusters of trees limited the areas that could be surveyed somewhat. One example is the “bowl” feature on the north face of the plateau (south of Target 3, Sections 3 and 4). This area was so broken with ravines without good crossing points and bound by the plateau on the south side that it was not possible to reach with the tow vehicle. In other cases, the presence of long

barbed-wire fences without gates and deep ravines / plateau faces without good access points slowed survey operations by reducing survey line length and increasing travel time to go around these obstacles.

3. Demonstration Design

3.1 Testing and Evaluation Plan

3.1.1 Demonstration Set-Up and Start-Up

The former Pueblo Precision Bombing and Pattern Gunnery Range #2 (Pueblo PBR#2) is located in Otero County, Colorado, approximately 20 miles south of the town of La Junta [12]. The training range encompasses approximately 68,000 acres. The demonstration area encompasses approximately 7,400 acres of the overall Pueblo PBR #2 site and includes Targets 3 and 4 along with the Suspected 75mm Range area of interest. See Reference 12 for additional discussion. The coordinates for the Pueblo PBR#2 demonstration site are given in Table 3-1.

Table 3-1 – Coordinates for the Approximate Corners of the WAA Pilot Project Pueblo PBR #2 demonstration site

Point	Latitude	Longitude	Northing (m)	Easting (m)
			UTM Zone 13N, NAD 83	
SW	37° 39' 52.662290656" N	103° 42' 02.32095666" W	4,169,400.00	614,600.00
MW1	37° 42' 02.421430304" N	103° 42' 00.05663171" W	4,173,400.00	614,600.00
MW2	37° 42' 01.969283698" N	103° 41' 19.22920282" W	4,173,400.00	615,600.00
NW	37° 44' 44.166511803" N	103° 41' 16.36838703" W	4,178,400.00	615,600.00
NE	37° 44' 42.784290086" N	103° 39' 13.81346694" W	4,178,400.00	618,600.00
ME1	37° 43' 05.249205491" N	103° 39' 15.57919156" W	4,175,393.27	618,600.00
ME2	37° 43' 05.360723355" N	103° 39' 25.35768396" W	4,175,393.27	618,360.54
SE	37° 39' 50.892927079" N	103° 39' 24.40635276" W	4,169,400.00	618,469.76

The MTADS vehicular system mobilized to the Pueblo PBR#2 site in a U.S. Navy-owned 53-ft trailer. The tow vehicle, the magnetometer trailer, notebook computers for the analysis team, GPS equipment, batteries and chargers, office equipment, radios and chargers, tools, equipment spares, and maintenance items, and magnetometers were transported in the trailer. Harris Transportation Company, a government contract transportation firm transported the trailer to the site.

Due to the remoteness of the survey site, no essential support services were available on-site. Accordingly, Nova Research made provisions to acquire all of the requisite supplies, materials, and facilities from local rental firms to establish the Pueblo PBR#2 WAA Base Camp. For this operation an office trailer was used for data processing and analysis, as a communications center, for battery storage and charging stations, electronics repair station, and as storage for spares and

supplies. This trailer was supplied with AC power, heating, and cooling. A 8' x 40' trailer, which could be fully opened from either end (for drive-through access), was provided to garage and for secure storage of the MTADS vehicle and sensor platform. Power to the trailers was provided by a diesel field generator (65 kW range) that was also used to recharge the vehicle, radios, and GPS batteries overnight. Communications among on-site personnel was provided by hand-held VHF radios, with a base station located in the office trailer. Radios were provided to all field and office personnel. The availability of cellular phone communications on site was limited but was available at the higher elevation areas of the site, especially in the general vicinity of GPS control points Sky CP5 and Sky CP6 and at the U.S. Forest Service corral at the corner of CR 25 and CR B. Fuel storage was provided for the generator with refueling as necessary and a portable toilet was provided to support all field and office crews with weekly servicing. Figure 5 shows the arrangement of this logistics support at a recent survey. Due to the distance from the WAA Base Camp to the survey areas at the southern end of the site, an additional limited-scope Auxiliary Base Camp was established at the intersection of Roads B and 23, shown in Figure 6. A second 8' x 40' trailer was provided to garage and for secure storage of the MTADS vehicle and sensor platform along with a 5 kW generator for battery charging.

Upon arrival at the WAA Base Camp on August 28, the team personnel unpack the 53' trailer and prepared the MTADS vehicle and support equipment for survey. Another performer within the WAA Pilot Project, Sky Research, Inc. has established eight geodetic survey points in the general area of the demonstration site. The coordinates of all eight points are given in Table 3-2 (horizontal datum: North American Datum of 1983, 1992 Adjustment (NAD83/92); vertical datum: North American Vertical Datum of 1988 (NAVD88); geoid model: National Geodetic Survey Geoid03).

Figure 5 – Photograph of the WAA Base Camp at the Pueblo PBR#2 WAA demonstration site showing the relative locations of the trailers, etc.

Figure 6 – Photograph of the Auxiliary Base Camp at Pueblo PBR#2 WAA demonstration site

Table 3-2 – Survey Control Points Installed for the WAA Pilot Project at the Pueblo PBR #2 site

Point Name	Latitude	Longitude	Ellipsoid Height (m)	Northing (m)	Easting (m)	Elevation (m)
	WGS84			UTM Zone 13N, NAD 83		NAVD88
Sky CP1	37° 39' 31.00828" N	103° 39' 23.98352" W	1397.643	4168787.291	618488.902	1418.797
Sky CP2	37° 39' 31.81861" N	103° 38' 50.55881" W	1393.904	4168824.039	619307.531	1415.076
Sky CP3	37° 38' 38.47452" N	103° 39' 56.81331" W	1401.753	4167156.697	617707.526	1422.860
Sky CP4	37° 39' 57.22970" N	103° 39' 23.93856" W	1396.392	4169595.462	618478.424	1417.560
Sky CP5	37° 44' 38.76102" N	103° 40' 42.21410" W	1439.133	4178245.156	616438.238	1460.417
Sky CP6	37° 44' 16.35566" N	103° 39' 18.00019" W	1453.184	4177583.970	618509.241	1474.494
Sky CP7	37° 42' 07.59478" N	103° 38' 13.14673"W	1365.804	4173638.425	620154.391	1387.077
Sky CP8	37° 43' 01.02076" N	103° 42' 11.45205" W	1468.740	4175202.188	614295.936	1489.925

On August 29, the RTK GPS base station receiver and radio link were established on one of the available established control points (initially Sky CP6, Sky CP5 and Sky CP1 were used as required during the demonstration). The magnetometer trailer was connected to the tow vehicle and the system was powered up. The connectivity of the magnetometers to the DAQ computer and the establishment of normal SNR performance were verified along with the operational state of the vehicle RTK GPS system. A period (5-6 minutes) of quiet, static data was collected and submitted to the Data Analyst for validation. This same static test was repeated throughout the survey campaign each morning prior to surveying the calibration items.

A lane of emplaced calibrations items was emplaced by the demonstration team and representatives of the ESTCP Program Office south of the WAA Base Camp between the WAA Base Camp and the WAA demonstration area. The schedule of ground based system calibration items emplaced for the Pueblo PBR#2 site is given in Table 3-3. A multi-pass magnetometer survey of the proposed calibration strip was conducted prior to emplacement and the quietest

area in terms of geology was selected for the calibration items. The composition of the ground in the selected area was approximately 0.5 m of soil and broken rock on top of a hard rock layer. Consequently, emplacement depths were limited to 60 cm. Once the items were emplaced and photographed, the positions of each item's nose and tail were recording using RTK GPS. The digital photographs of the emplaced items are available on the attached DVD. The holes were refilled with the removed material and leveled. A single pass magnetometer survey was conducted over the emplaced items. Additional surveys of the calibration items were conducted at the beginning and end of each work day. On a few occasions it was not possible to collect the end-of-day calibration data due to range closure due to weather or equipment malfunction bringing about an abrupt end to the day's efforts. Prior to operating out of the Auxiliary Base Camp, Sphere #1 was relocated to near the Auxiliary Base Camp for calibration purposes. The new location of the sphere is also given in Table 3-3.

Table 3-3 – Schedule of Ground-based System WAA Calibration Items for Pueblo PBR#2

ID	**UTM Zone 13N**		**Actual**	
	Easting (m)	**Northing (m)**	**Depth (cm)**	**Grid Azimuth (deg)**
North Calibration Lane				
Sphere #1 (Driver Side)	616434.500	4178732.403	0	N/A
Sphere #2 (Passenger Side)	616435.459	4178732.109	0	N/A
155mm Projectile #2	616441.180	4178749.703	35	35
60 mm Mortar #2	616447.267	4178768.742	30	46
105mm Projectile #2	616453.828	4178787.621	60	44
105mm Projectile #1	616459.639	4178806.967	45	178
81mm Mortar #2	616465.341	4178825.771	43	69
81mm Mortar #1	616469.792	4178839.941	25	20
155mm Projectile #1	616474.350	4178854.198	50	46
60 mm Mortar #1	616478.260	4178868.186	10	148
37mm Sim #2	616481.220	4178877.825	10	57
37mm Sim #1	616484.096	4178887.419	5	160
South Calibration Sphere				
Sphere #1 (Driver Side)	618349.507	4168713.105	0	N/A

The Site Safety Officer conducted a 'tail-gate' safety meeting prior to beginning the day's efforts and again each day that personnel were on site. The topic(s) for each day's meeting were at the discretion of the Site Safety Officer and focused on safety issues relating to the day's planned work.

Preventative maintenance inspections were conducted at least once a day by all team members, focusing particularly on the tow vehicle and sensor trailer. Any deficiencies were addressed according to the severity of the deficiency. Parts, tools, and materials for many maintenance scenarios are available in the system spares inventory located on site. Routine tools and supplies, for example spare tires for the tow vehicle and sensor trailer, were carried in the chase vehicle which accompanied the tow vehicle onto the site. Status on break-downs / failures that resulted in long-term delays in surveying was reported to the WAA Project Manager as appropriate.

3.1.2 Period of Operation

The main portion of the demonstration was accomplished from Tuesday, August 30th through Saturday, October 22nd. Operations were conducted in three portions as detailed in tabular form in Table 3-4. The originally scheduled second survey portion was broken into two due to unscheduled maintenance required on the tow vehicle.

Table 3-4 – Pueblo PBR #2 Survey Demonstration Deployment Schedule

Date	**Planned Action**
Week of August 15th	Pack trailer at Blossom Point.
Friday, August 19th	Trailer leaves Blossom Point for Pueblo PBR #2.
Tuesday, August 23th	Trailer arrives Pueblo PBR #2.
Sun, August 28th	Personnel arrive La Junta; unpack trailer, assemble MTADS system.
Mon, Aug 29th	Scout demonstration area, emplace and survey calibration items.
Tue, Aug 30th	Begin ground surveys.
Fri, Sep 16th	Pause ground surveys. Personnel departs site.
Sun, Oct 2th	Personnel return to La Junta.
Mon, Oct 3rd	Resume ground surveys.
Fri, Oct 7th	Pause ground surveys, arrange for vehicle maintenance.
Sat, Oct 8th – Tue, Oct 11th	Personnel depart La Junta.
Mon, Oct 17th	Personnel return to La Junta, reassemble vehicle.
Tue, Oct 18th	Resume ground surveys.
Sat, Oct 22th	Complete ground surveys.
Sun, Oct 23th	Pack trailer.
Mon, Oct 24th	Personnel depart La Junta.
Thu, Nov 10th	Trailer departed Pueblo PBR #2.
Mon, Nov 14th	Trailer arrives at Blossom Point, MD.
Week of Nov 28th	Submit Data Report to ESTCP.

3.1.3 Operational Parameters for the Technology

The precision collection of high SNR magnetometer data using the MTADS platform is a mature technology. The rapid and accurate extraction of anomaly location and a measure of anomaly amplitude (peak analytic signal) from high-volume transect data collection is the novel component of this demonstration. To accomplish this task an automated method of extracting the anomaly locations from the survey data was required. One such method has been developed and is discussed in detail in Appendix A. Briefly, the located magnetic field data (nT) are collected as normal for an MTADS survey. The demedianed total field data are converted to analytic signal (AS, nT/m) where the analytic signal is calculated from the squares of the derivatives in the x, y, and z directions:

$$AS = \sqrt{\left(\frac{d}{dx}\right)^2 + \left(\frac{d}{dy}\right)^2 + \left(\frac{d}{dz}\right)^2}$$

This process involves a gridding step, where real-world data is interpolated onto a fine-scale mesh with a defined grid cell size. The use of a regular grid reduces the complexity of the calculations required for the following steps. The utility of the analytic signal is that anomaly features which are dipolar (have both positive and negative components) in the total field are monopolar in the analytic signal. This facilitates the detection of anomalies.

One can then define the peak cut-off threshold, grid smoothing parameters required to eliminate multiple picks per target, and grid cell size to be used for the analysis. Initial analysis (See Appendix A) has shown that these parameters may be similar for several sites with diverse geology and have the potential to be applied more generally. This assertion was evaluated during the early data collection stages by optimizing two parameters (# of smoothing passes, and peak threshold cut-off value) against the incoming data. The grid cell size parameter was not varied as initial testing indicated that processing times become prohibitive at grid cell sizes smaller than 0.25m for transects of any length. When the survey results from the calibration strip and several transect data sets from the first day of data collection were available, the data was used to evaluate the extraction parameters for the Pueblo PBR#2 site. At a fixed cut-off threshold of 25 nT/m, the effect of the number of passes of the smoothing filter was evaluated and the initial result of 6 passes was found appropriate. Such an evaluation on an early data set (05242006) from August 30th is shown in Figure 7. The RMS variation in the analytic signal from quiet portions of the data was evaluated and found to be on the order of 2.5 nT/m. Starting with this level and increasing the cut-off threshold in increments of 2.5 nT/m, the anomaly extraction results were determined and a peak anomaly cut-off value of 20-25 nT/ was found to be necessary to avoid extracting spurious anomalies from the incoming data. The results for an early data set (05242006) from August 30th are shown in Figure 8. A threshold of 25 nT/m was used for the remainder of the demonstration transect results.

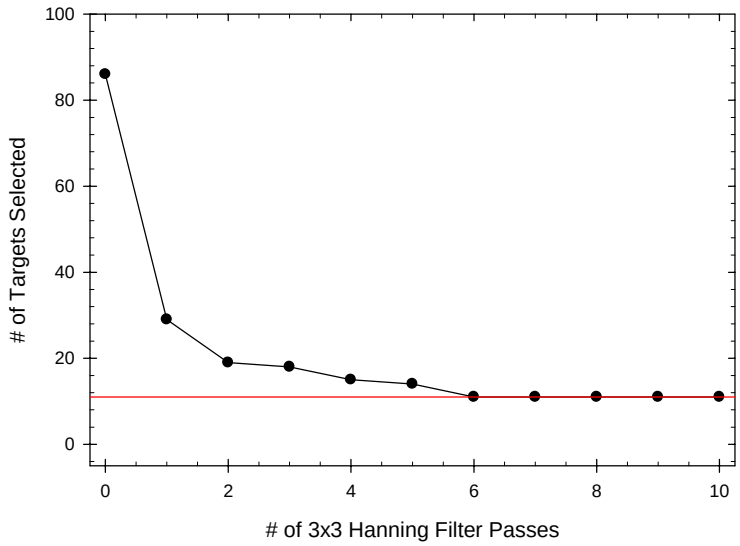


Figure 7 – Effect of increasing number of passes of smoothing filter on the 05242006 data set results. The red line indicates the result for the final parameter value.

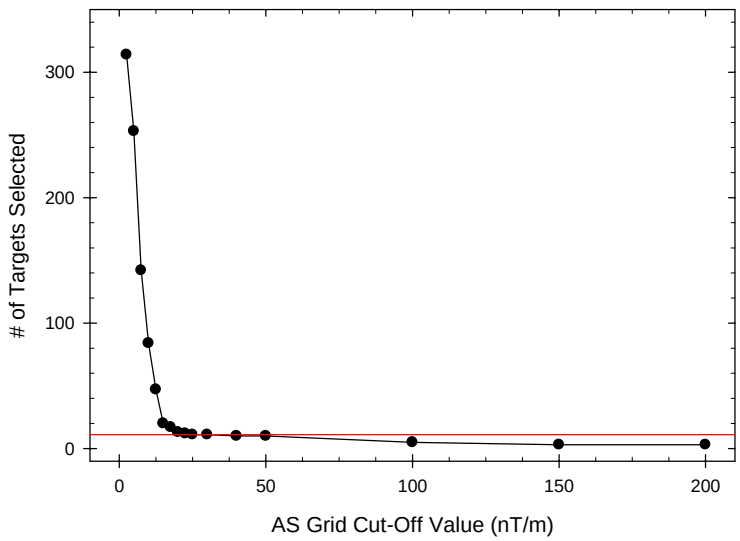


Figure 8 – Effect of increasing peak anomaly cut-off threshold value on the 05242006 data set results. The red line indicates the result for the final parameter value.

3.1.4 Transect Magnetometer Survey Results

The major focus of the data collection effort for the first three weeks of the demonstration was the collection of transect magnetometer data following the transect plans provided by PNNL / SNL based on archive data (CSM v0) and WAA Pilot Project goals. The transect plans were divided into three categories: 1) Transects to interrogate the entire WAA Demonstration site for the actual positions and footprints of Targets 3 and 4 as noted in CSM v0 and any additional similar features of interest, 2) East / West Transects to interrogate the Suspected 75mm Range

area of interest for possible features of interest, and 3) Any additional transects requested by PNNL / SNL / ESTCP Program Office based on the results of items 1 & 2 or other data.

For the first category, N/S transects covering the entire WAA demonstration area, two transect designs were prepared by PNNL/SNL. The first, sparse design was based on traversing 100-lb practice bomb targets and features of interest with a 99% probability of traversing a 1000 ft circular target or feature of interest. The transects were oriented N/S with a 308 m spacing. The second, conservative design was based on finding 500-ft diameter, circular 100-lb practice bomb targets with a 99% probability of traversing the target or feature of interest. The transects were oriented N/S with a 154 m spacing. This design leverages the data already collected as part of the sparse design and adds an addition transect equally spaced between each pair of sparse transects.

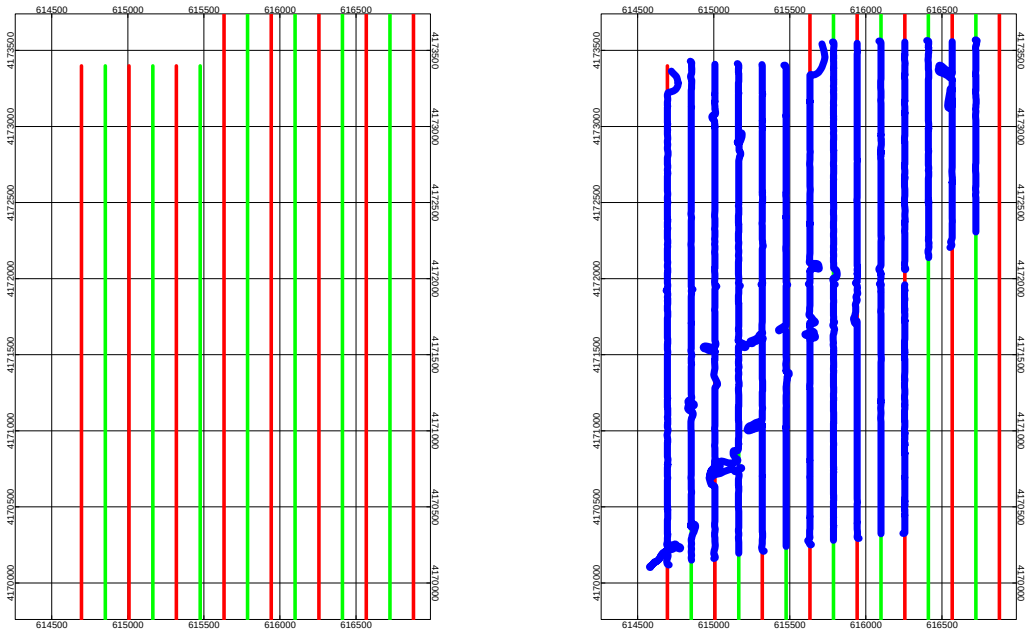
For the second category, E/W transects covering the suspected 75mm range, two designs were prepared by PNNL/SNL. The first, sparse design was based on a 99% probability of traversing a 100 m x 400 m elliptical target or feature of interest. The transects were oriented E/W with 400 m spacing and leveraging the N/S transects already recorded. The second, conservative design was based on a 99% probability of traversing a 100 m diameter, circular feature of interest. The transects were oriented E/W with 100 m spacing and leveraging the N/S transects already recorded. This design leverages the data already collected as part of the sparse design and adds three additional transect equally spaced between each pair of sparse E/W transects.

For the third category, 17 100-m spacing E/W transects starting from 50m north of the southern boundary of the WAA demonstration site were surveyed to further define the footprint of Target 4. Four additional areas of interest were also identified from the N/S transect data by PNNL / SNL, labeled Areas 23, 25, 26, 27. Based on CSM v1, four additional areas of interest were identified. In these additional areas of interest, transect plans of 4 – 10 transects were designed and surveyed. Oasis montaj .XYZ files of all planned transects are included on the attached DVD. As an example, a portion of the N/S transect plan shown in Figure 9 along with the COG of the transect data collected on September 5, 2005.

The position (easting, northing) and signal strength (peak analytic signal) were extracted for each anomaly above an empirically determined threshold for all transect data. Data collection began with transects that did not included identified targets to allow for the establishment of the cut-off threshold based on the determined noise floor. Figure 10 shows the results of all transect data collected in course of this demonstration. The COGs are shown as green lines and each detected anomaly is shown as a filled circle.

The total acreage covered by transect surveys was 143 acres, or approximately 2% of the total 7,400 acres site. Natural topology (ravines, plateau faces, trees, etc.) and man-made obstructions (e.g. fences) made it difficult and impractical to complete each transect in a single survey. Therefore each transect was broken into one or more segments in the field. The flexibility of the MTADS Pilot Guidance software allows for this to be done easily and on the fly. The exact details of the area covered by each survey file are given in an Excel spreadsheet on the attached DVD (Transects_Summary.xls). An excerpt of the annotated listing is given in Table 3-5. The corresponding demedianed magnetometer data, the analytic signal data, the anomaly list, and the

COG files for each transect survey are also supplied on the attached DVD in the “Transect Surveys” subdirectory.



a) b)

Figure 9 – Map showing a) North / South Transect Plan (sparse shown in red, additional transects for conservative shown in green). b) Transect plan with actual survey for Julian date (05248, September 5) shown.

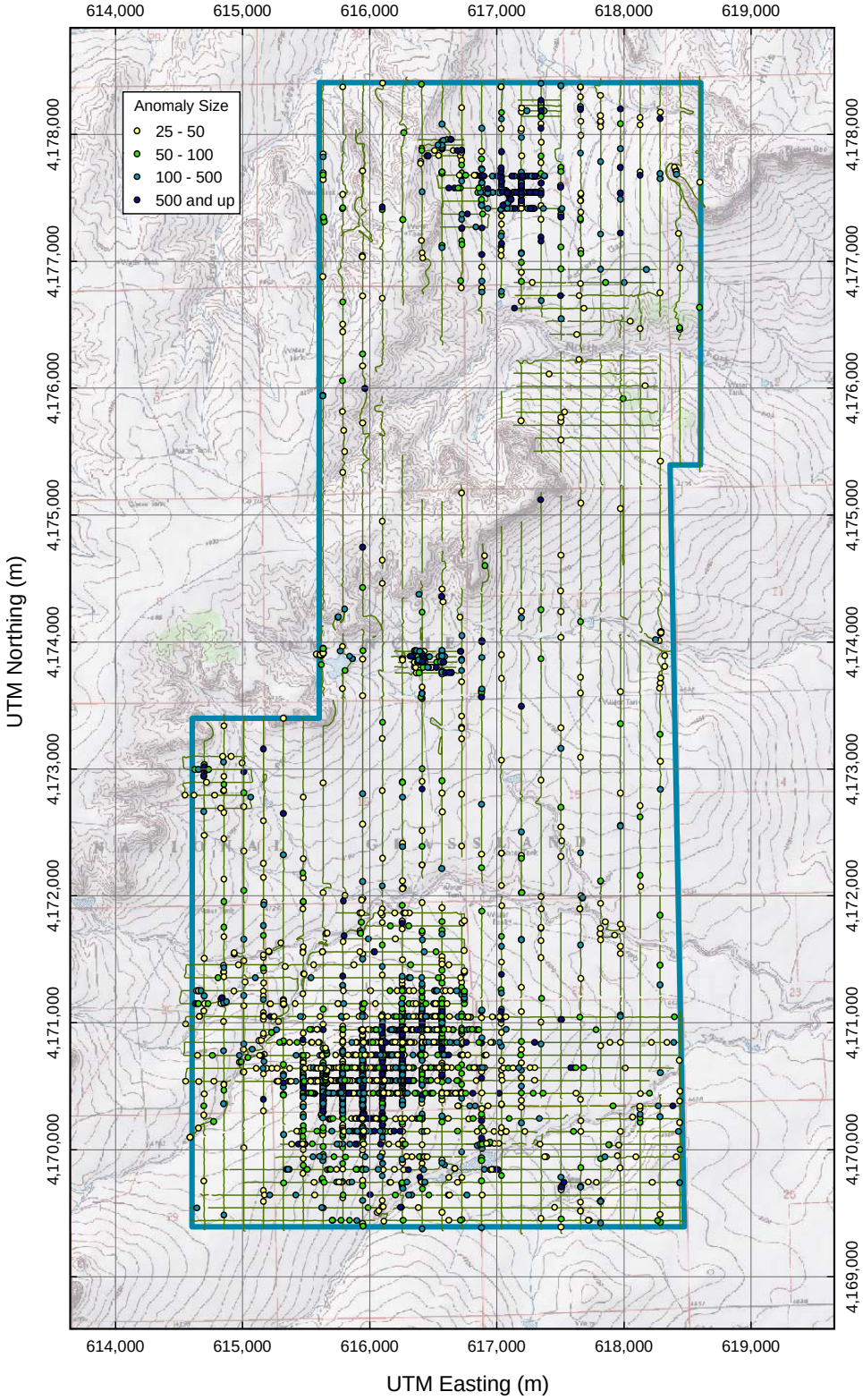


Figure 10 – Map showing the transect survey results for the Pueblo PBR#2 demonstration. Transect COGs are shown as green lines and individual detected anomalies are shown as filled circles.

Table 3-5 – Excerpt of Annotated Listing of Transect Surveys Conducted During Pueblo PBR#2 Demonstration.

Day 1 Deliverables	
05242004	Northern-most portion of NS Line 21
05242006	Northern-most portion of NS Line 19
05242007	Northern-most portion of NS Line 17
05242008	Northern-most portion of NS Line 15
05242010	Northern-most portion of NS Line 11
05242011	Northern-most portion of NS Line 9
05242012	Northern-most portion of NS Line 7
05242013	Northern-most portion of NS Line 12
05242014	Northern-most portion of NS Line 14
05242015	Northern-most portion of NS Line 16
05242016	Northern-most portion of NS Line 18
Day 2 Deliverables	
05243003	Northern-most portion of NS Line 8
05243004	Northern-most portion of NS Line 10
05243005	Northern-most portion of NS Line 13
05243006	Northern-most portion of NS Line 20
05243007	Northern-most portion of NS Line 22
05243008	Northern-most portion of NS Line 24
05243009	Northern-most portion of NS Line 26
Day 3 Deliverables	
05244004	Northern-most portion of NS Line 23
05244005	Northern-most portion of NS Line 27
05244006	NS Line 7 (Plateau in Section 8)
05244007	NS Line 8 (Plateau in Section 8)
05244008	NS Line 9 (Plateau in Section 8)
05244009	NS Line 27 (South of ravine in Section 2)
05244010	NS Line 26 (South of ravine in Section 2)
05244011	NS Line 24 (South of ravine in Section 3)
05244012	NS Line 23 (South of ravine in Section 3)
05244013	NS Line 22 (South of ravine in Section 3)
05244014	NS Line 21 (South of ravine in Section 3)
05244015	NS Line 20 (South of ravine in Section 3)
05244017	NS Line 23 (Simmons half-section)
05244018	NS Line 22 (Simmons half-section)
05244019	NS Line 21 (Simmons half-section)
…	…

3.1.5 Total Coverage Magnetometer Survey Results

In addition to the transect surveys covering the breadth of the WAA demonstration area, several small areas (30 – 85 acres) were selected for total coverage surveys. Areas were selected in cooperation with the ESTCP Program Office to achieve three objectives: 1) Collect data in areas identified by the transect surveys as “quiet” to determine what the background anomaly density

for the WAA demonstration site, 2) Collect data near Targets 3 and 4 to evaluate the anomaly density. By starting near the target and moving away in several steps, it is possible to map the anomaly density falloff as one moves away from the Target, and 3) Collect addition data on the Suspected 75mm Range area of interest in support of the transect survey results. These surveys were conducted as typical MTADS magnetometer surveys with a line spacing of 2.0 m (tire next to tire spacing). Collected and processed magnetometer data were exported from the Oasis montaj environment and loaded into the MTADS DAS software for individual anomaly analysis. Detailed target lists for each area are provided on the attached DVD along with the magnetometer data archives. See Appendix B for the file format details.

Figure 11 shows the total coverage area anomaly maps superimposed on the WAA demonstration site topographical map. Table 3-6 contains a summary of the total coverage survey results. Column three lists the number of anomalies extracted by the operator in the DAS in each area and column five lists the number of those anomalies which could be fit using the resident dipole model to a coherence value of 0.85 or better.

Table 3-6 – Total Coverage Area Result Summary

Target	**Area**	**Number of Anomalies**	**Anomalies / Acres**	**Number of Dipole Fits**	**Acres**
Target 4	BT4 Center	938	85	873	11.0
	1C	1095	28	938	38.8
	1B	245	7	242	33.9
	1A	169	5	168	33.6
Target 3	3A	2112	60	1830	35.4
	3B	520	14	519	36.3
	3C	207	6	206	35.7
Simmons Area		72	1	72	85.0
Suspected 75mm Range	2A	148	5	148	31.0
	2B	83	2	83	36.8

An 85 acre area was selected in the northern portion of Section 10, referred to as the Simmons Area in reference to the ranchers who currently lease the area (Brian and Janet Simmons), as a "quiet" area for determining the background anomaly level. The transect survey results indicated that this area had very few anomalies with only a single anomaly detected by the transect surveys within the Simmons Area total coverage area. Figure 12 presents the magnetometer data anomaly map for the Simmons Area.

Four total coverage areas were surveyed in the vicinity of Target 4, located in the southern part of the WAA demonstration site. The three main total coverage areas are labeled Area 1A, 1B, and 1C with Area 1C being the closest to Target 4 and Area 1A being the furthest east. The area BT4 Center was part of an earlier survey scheme developed to map the anomaly density falloff from Target 4 which was altered to the Area 1A – 1C plan at the request of the landowners involved (Ralph and Russell Rounds). The BT4 Center data consists of 4 acres and is presented

for completeness. Figure 13, Figure 14, Figure 15, and Figure 16 present the magnetometer data anomaly maps for Areas 1C, 1B, 1A, and BT4 Center respectively.

The data shown in the magnetometer anomaly maps shown for the total coverage areas have been masked by the final perimeters of the areas. The archive data sets are also bounded by these perimeters. Oasis montaj polygon files (.ply) of each perimeter are provided on the attached DVD. Data outside the perimeters (turn arounds, etc.) is generally unreliable for dipole analysis because of severely non-parallel directions but alternative data sets with all data are also provided on the attached DVD. These data should be used with caution.

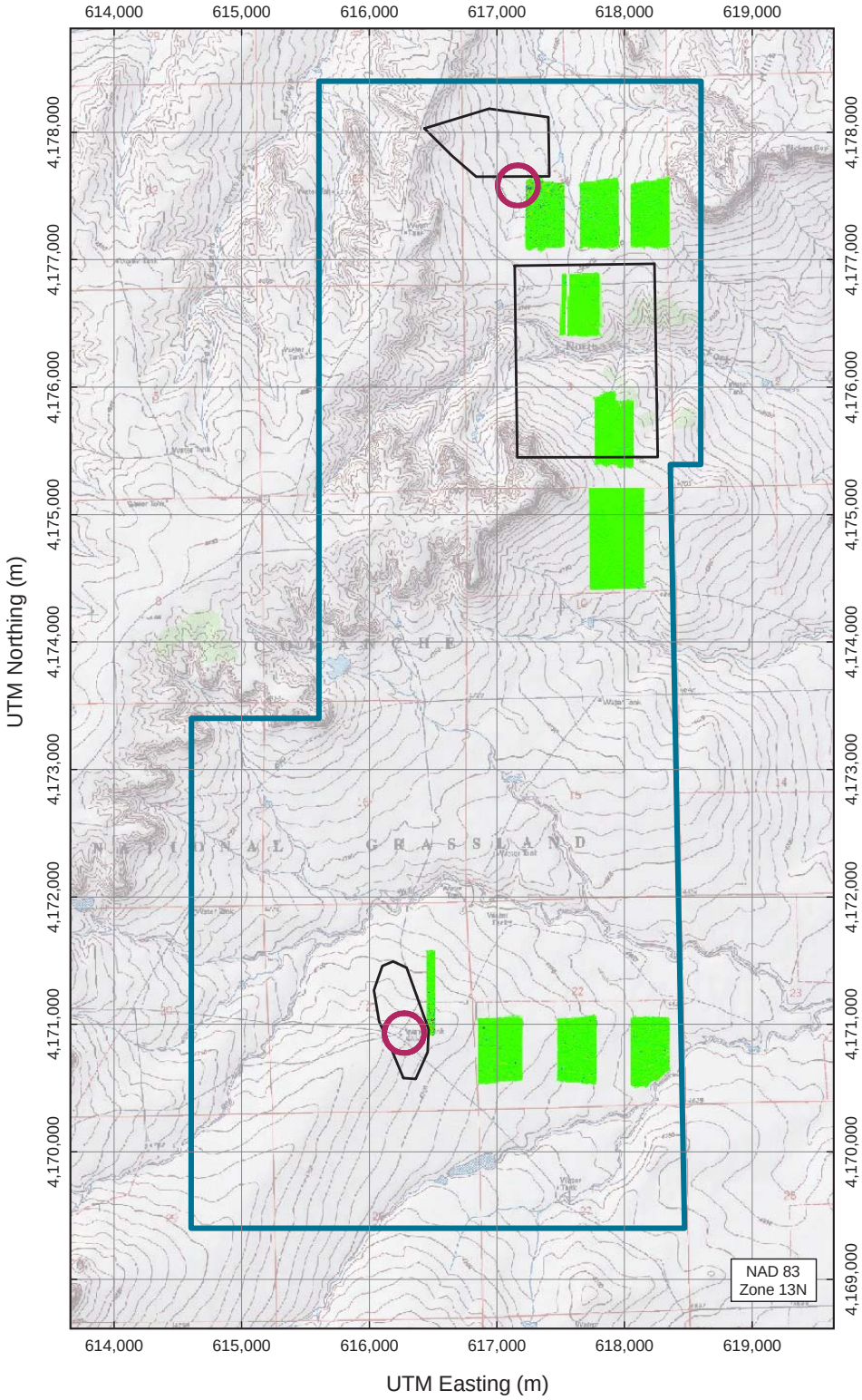


Figure 11 – Pueblo PBR#2 Total Coverage Survey Results

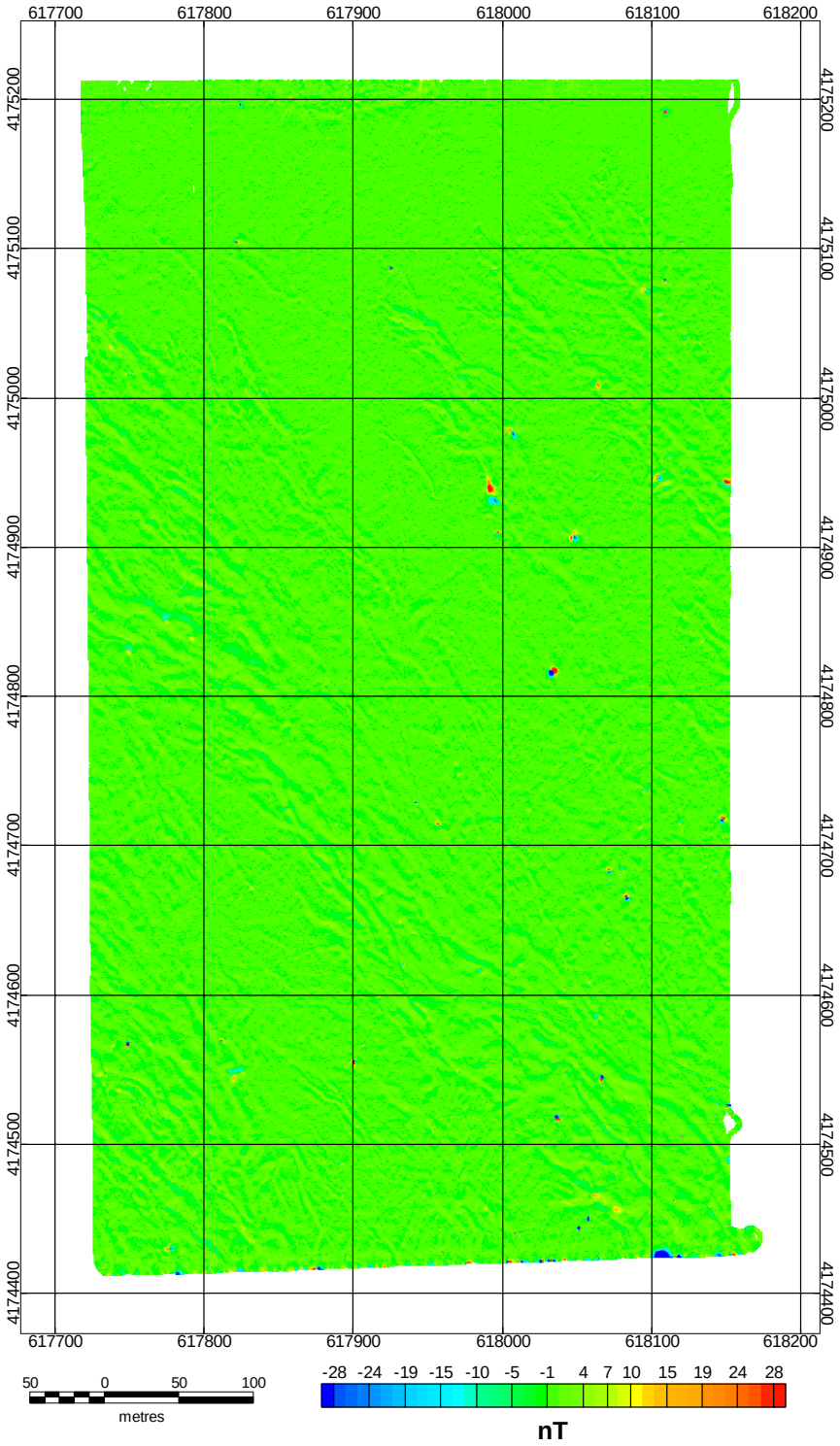


Figure 12 – Magnetometer Anomaly Map of the Simmons Area

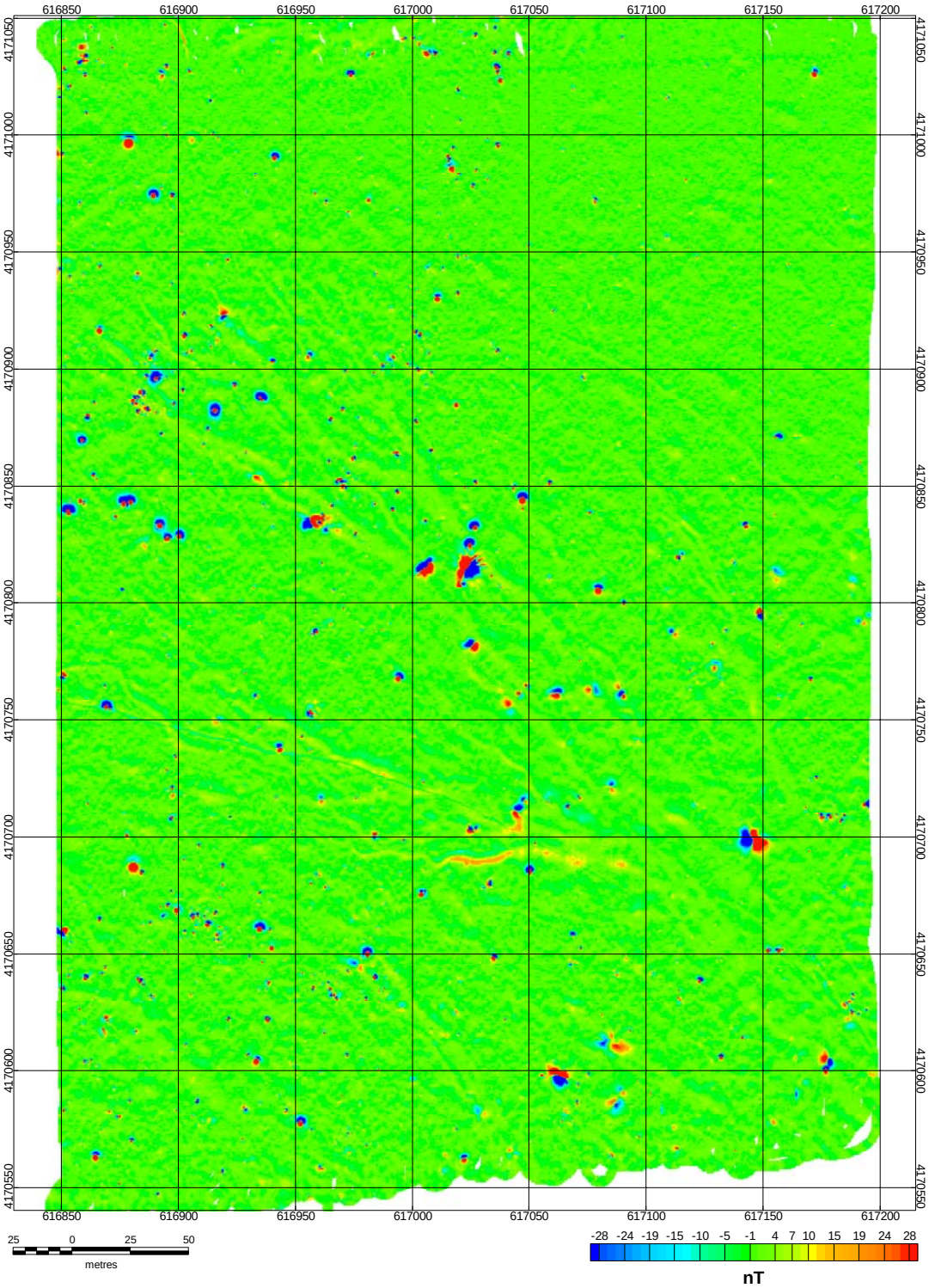


Figure 13 – Magnetometer Anomaly Map of Area 1C

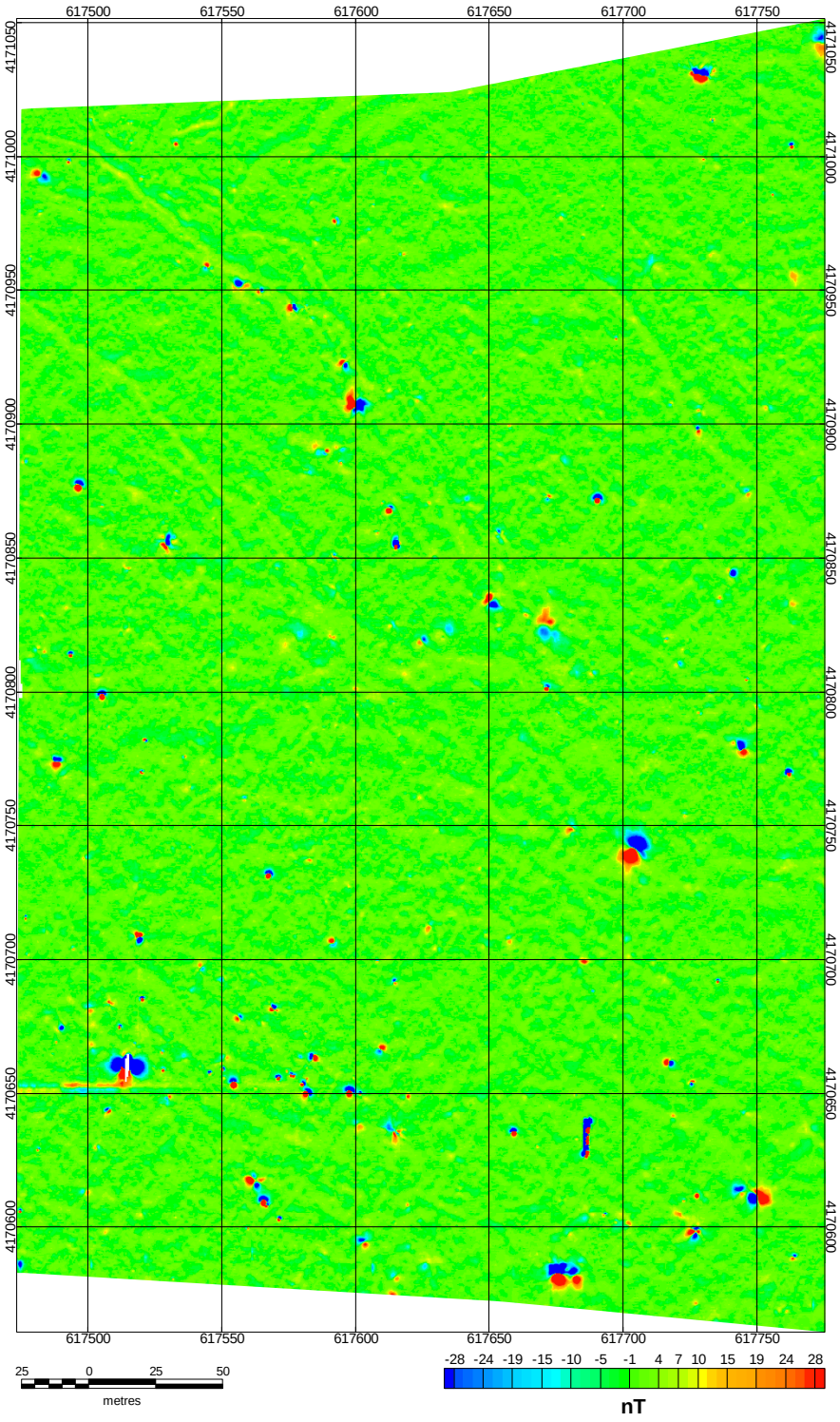


Figure 14 – Magnetometer Anomaly Map of Area 1B

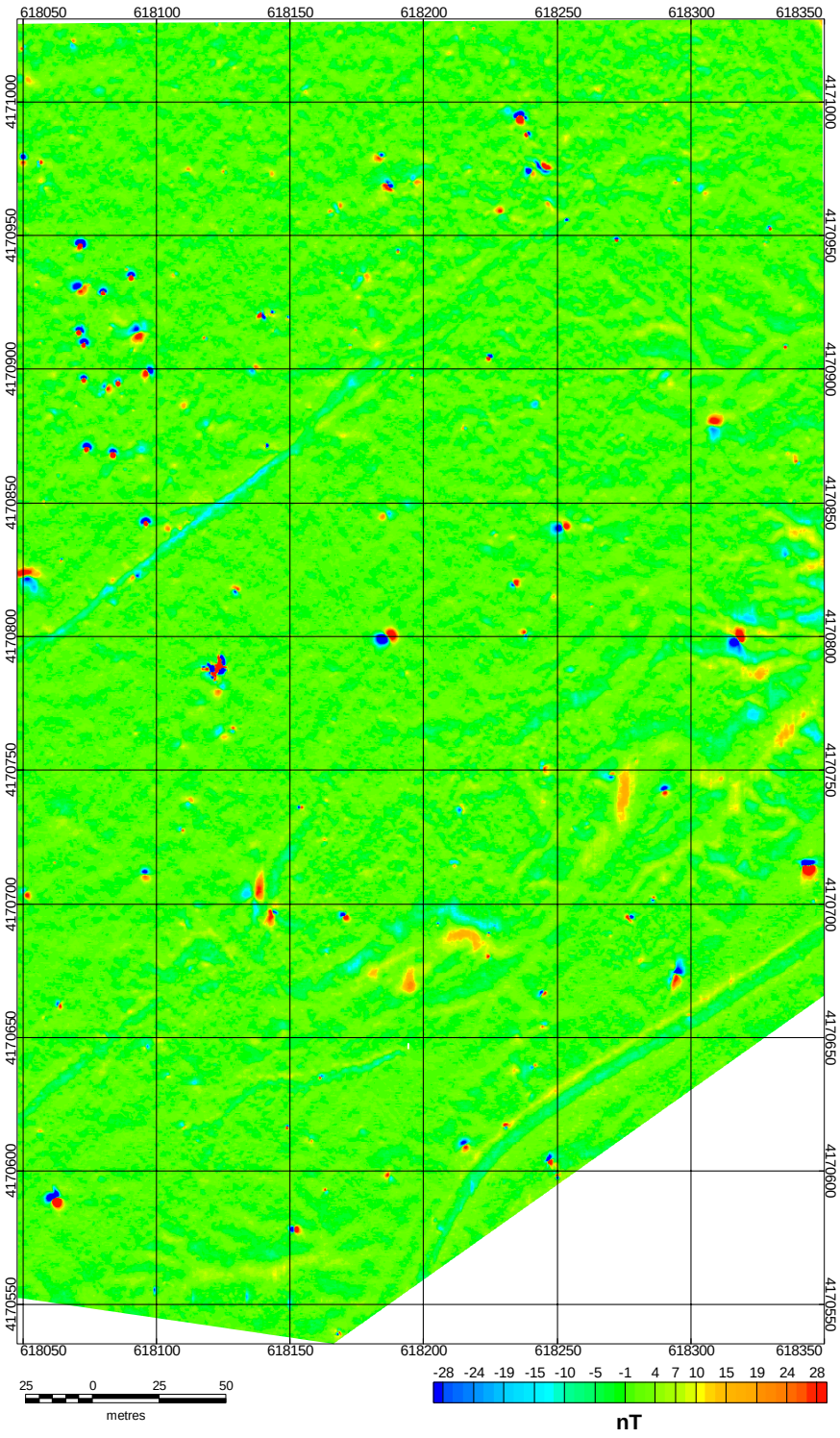


Figure 15 – Magnetometer Anomaly Map of Area 1A

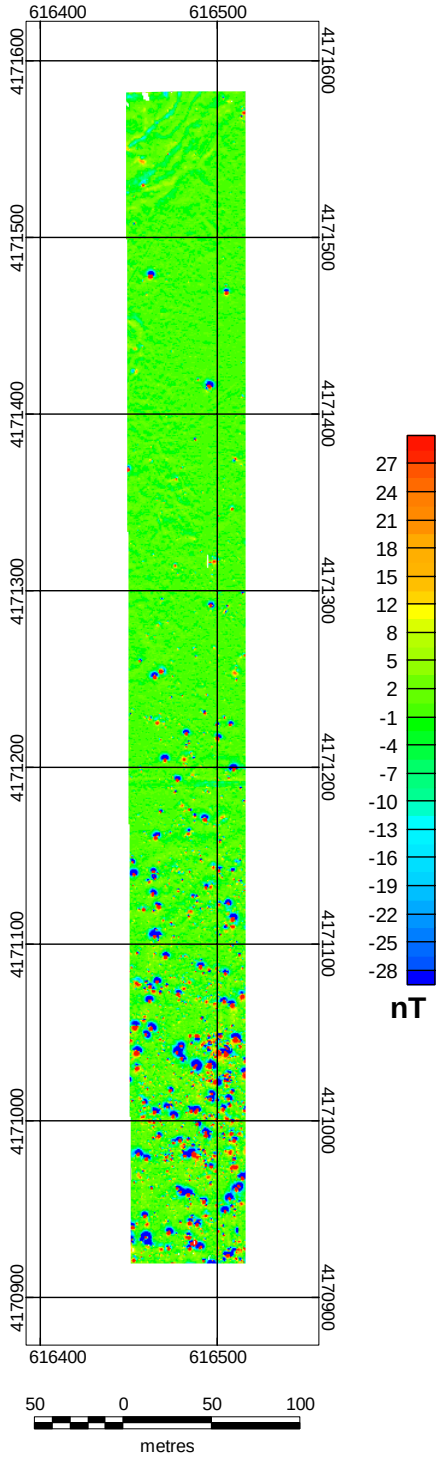


Figure 16 – Magnetometer Anomaly Map of Area BT4 Center

Three total coverage areas were surveyed in the vicinity of Target 3, located in the northern part of the WAA demonstration site. The three total coverage areas are labeled Area 3A, 3B, and 3C

with Area 3A being the closest to Target 3. Figure 17, Figure 18, and Figure 19 present the magnetometer data anomaly maps for Areas 3A, 3B, 3C respectively.

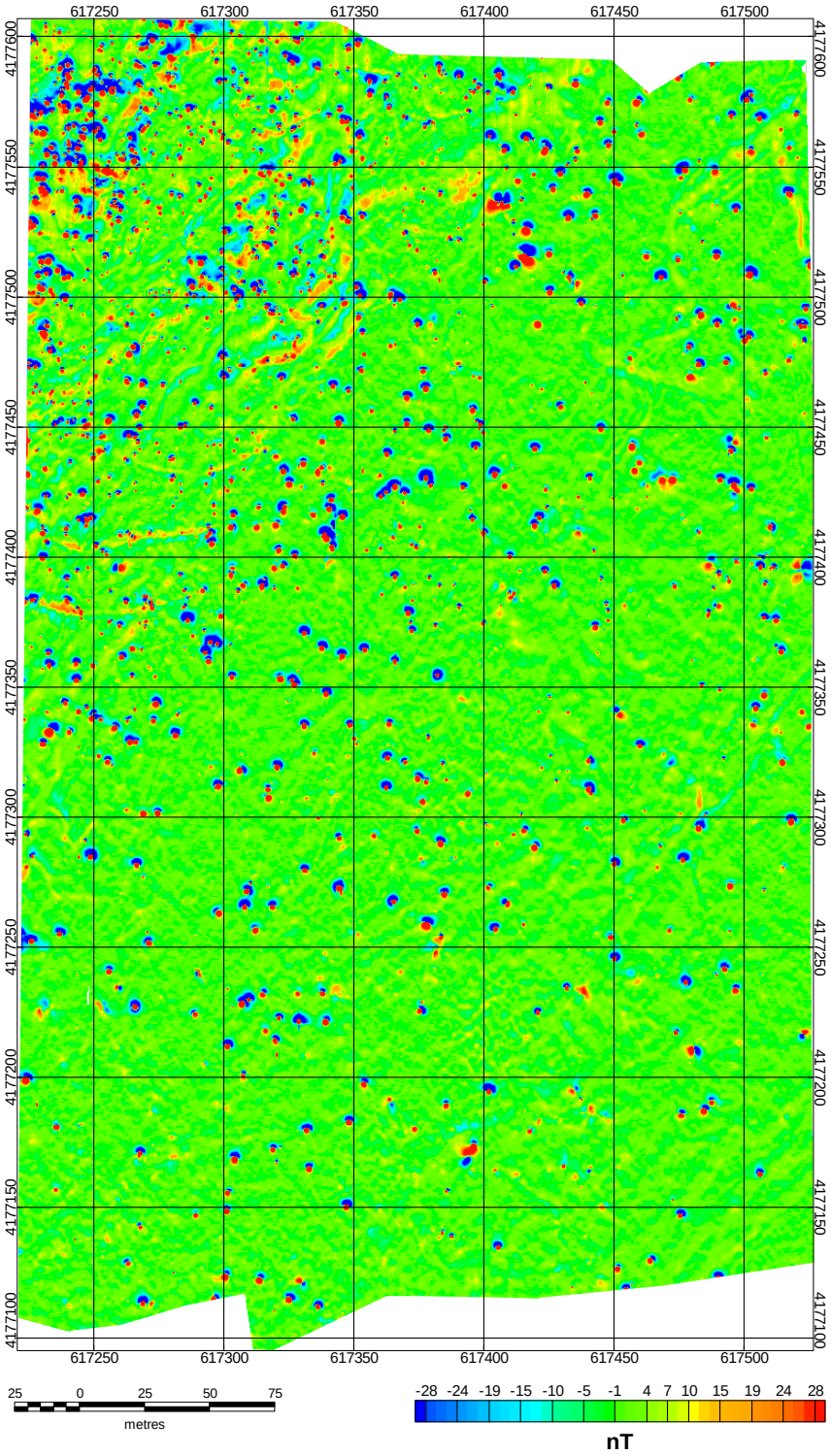


Figure 17 – Magnetometer Anomaly Map of Area 3A

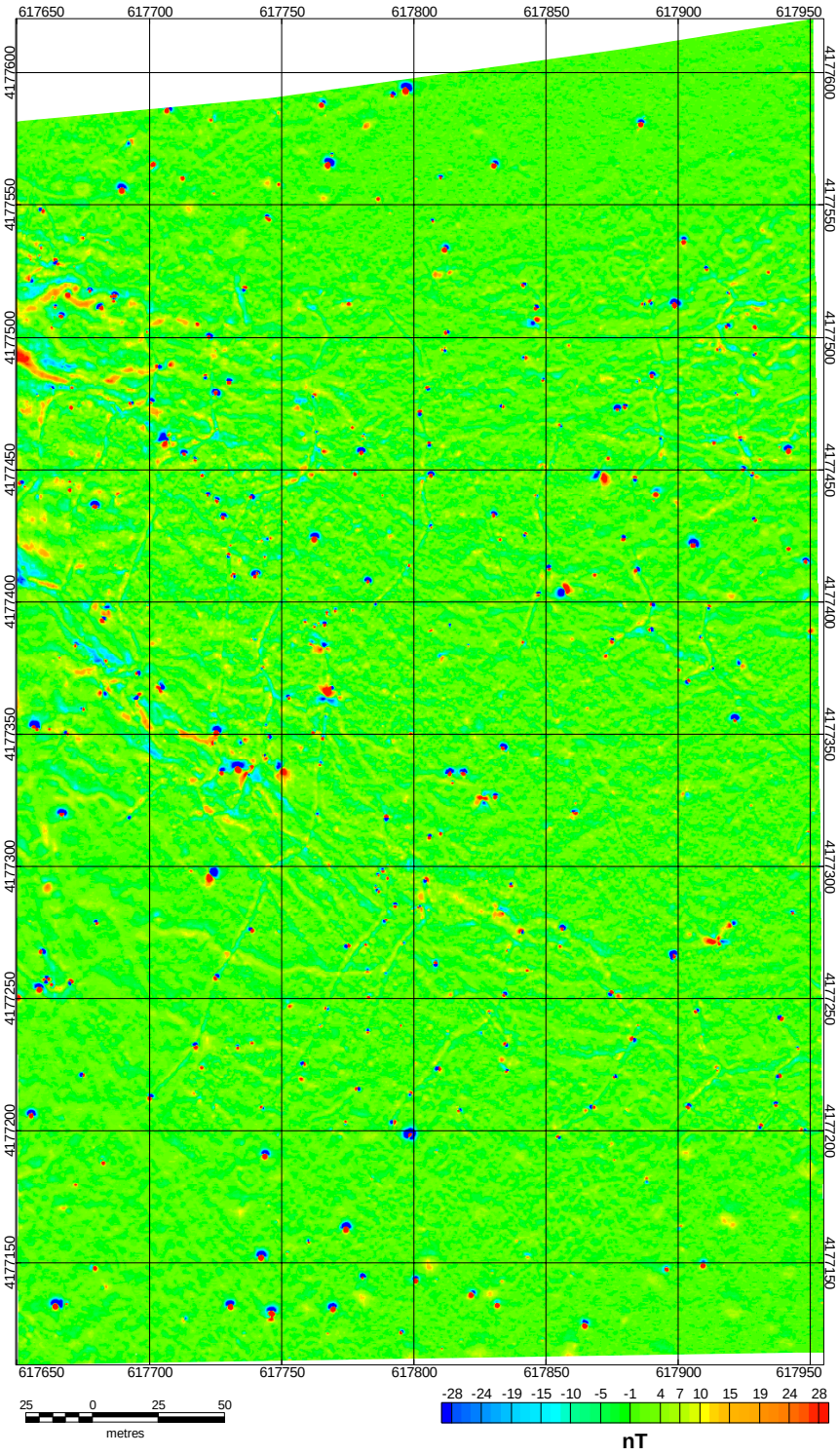


Figure 18 – Magnetometer Anomaly Map of Area 3B

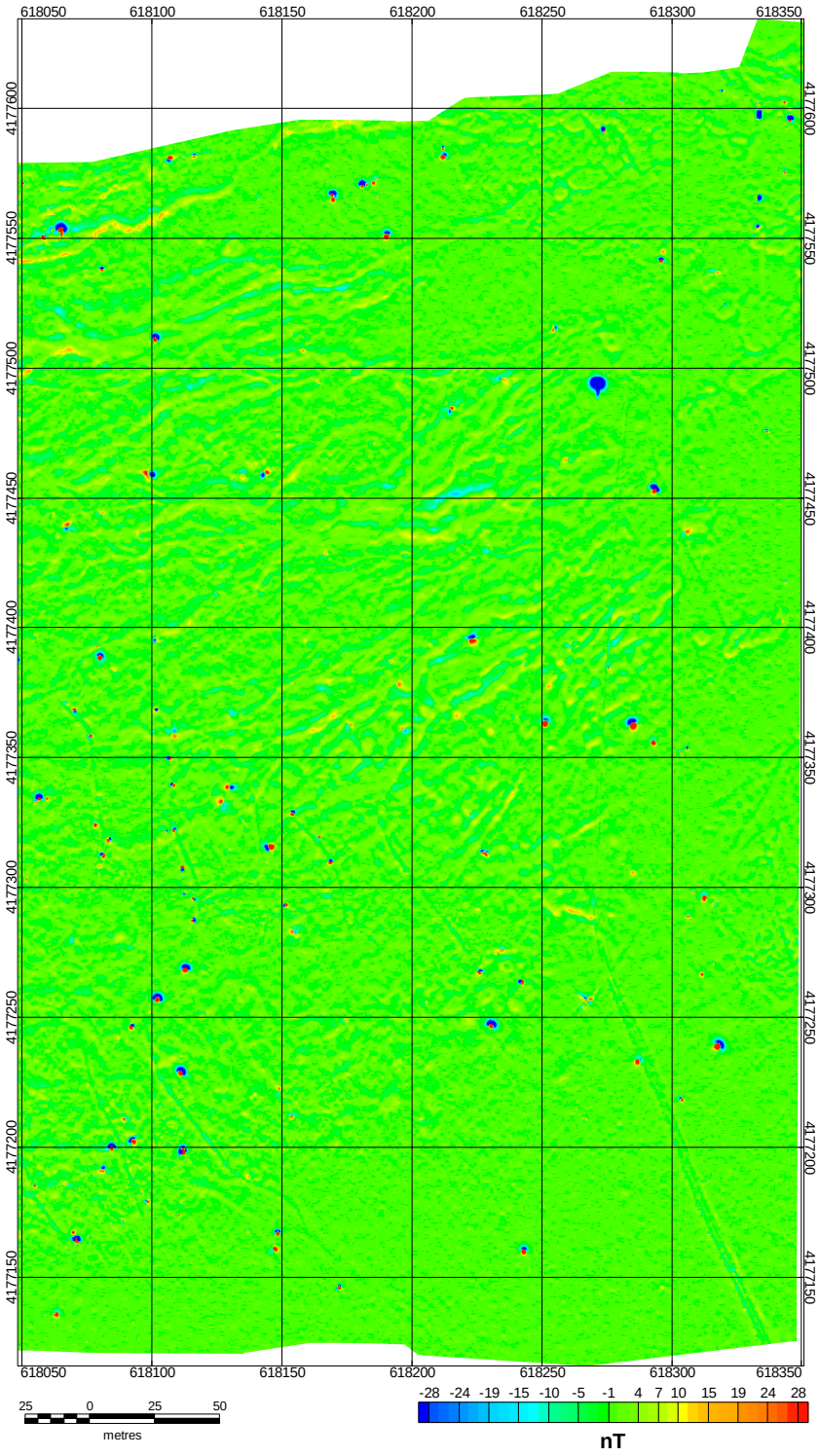


Figure 19 – Magnetometer Anomaly Map of Area 3C

Two total coverage areas were surveyed in the vicinity of the Suspected 75mm Range area of interest, located in the northeastern portion of the WAA demonstration site. The two total

coverage areas are labeled Area 2A and 2B with Area 2A located in the northwestern corner of the Suspected 75mm Range area of interest and Area 2B located in the southeastern corner. Figure 20 and Figure 21 present the magnetometer data anomaly maps for Areas 2A and 2B respectively. Area 2A is split vertically on the western side by a barbed wire fence and cattle guard on the road. The survey was stopped several swath widths on either side of the fence to limit the impact of the fence on the data collected. The southeastern portion of Area 2A also had a large number of small trees and cactus which resulted in small areas where data could not be collected.

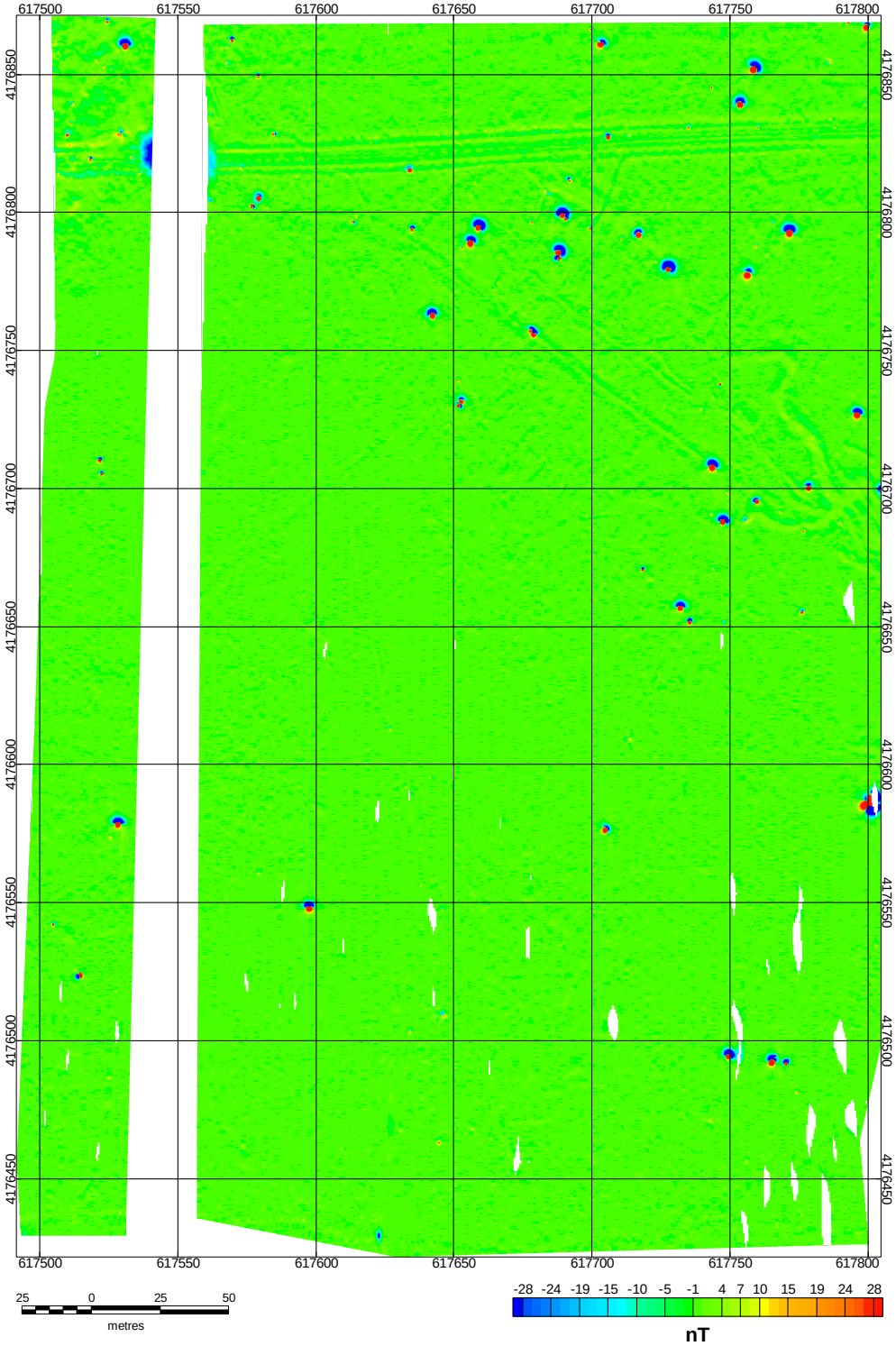


Figure 20 – Magnetometer Anomaly Map of Area 2A

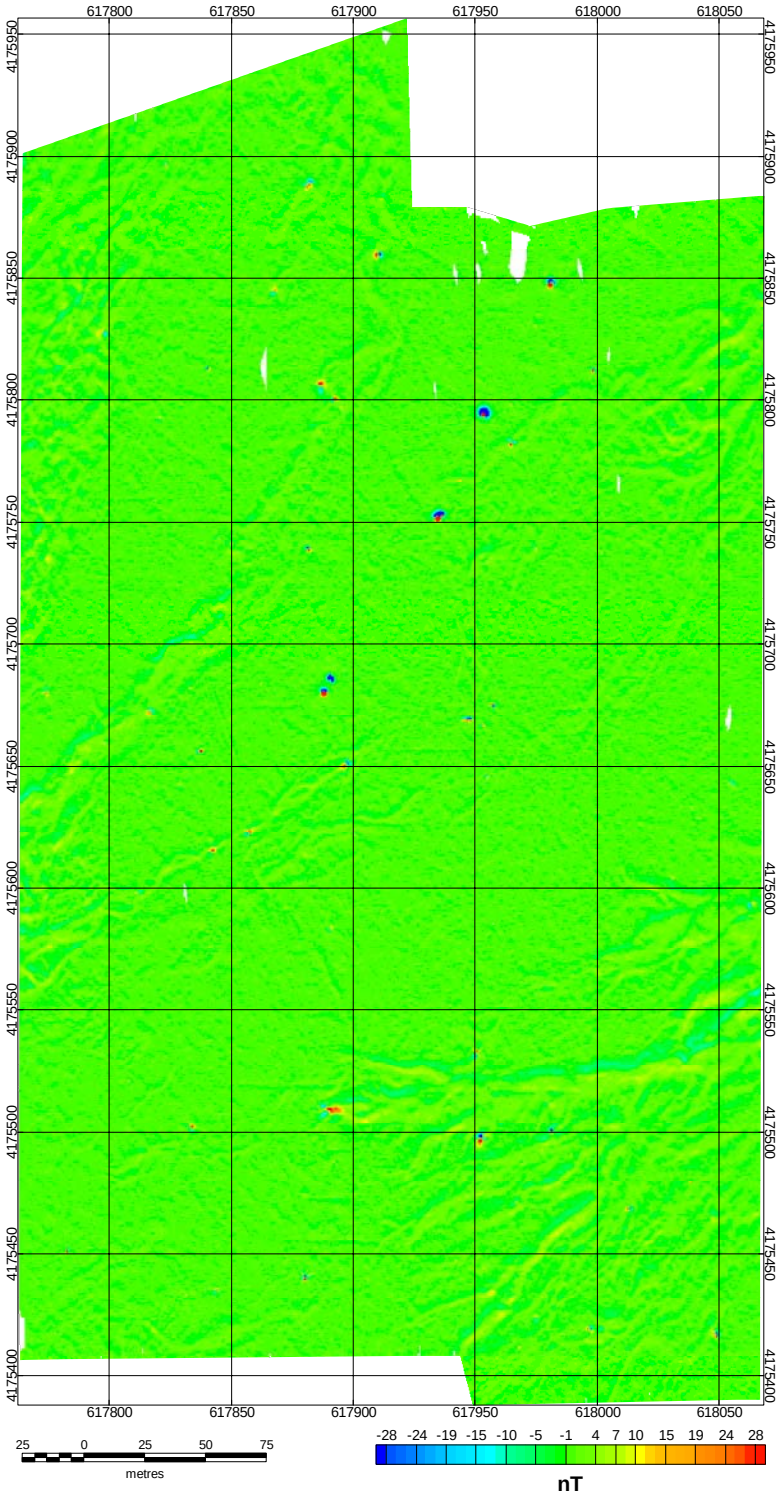


Figure 21 – Magnetometer Anomaly Map of Area 2B

3.1.6 Anomaly Density Falloff Analysis for Targets 3 and 4

One intention of the total coverage surveys conducted in Areas 1 (Target 4) and 3 (Target 3) was to map the anomaly density falloff as a function of distance from the target. Once the total coverage data had been collected and analyzed in the MTADS DAS, the data was divided into 30m x 30m cells in an East / West radial leading from the center of each target in an easterly direction. Figure 22 depicts the total coverage plan for Area 3 (Target 3). The red diamond indicates the CSM v0 center of the Target 3 target circle. The red line indicates the path of the 30m x 30m cells. The blue rectangles represent the planned locations of the total coverage areas. Some modification to the area locations were made in the field and the small mismatch between the red line and blue rectangles reflects this. The number of anomalies in each cell was counted and is shown in Figure 23. Assuming that the anomaly density around a target falls off according to a normal distribution, the results can be fit to a normal distribution with a persistent background value. Such a fit is shown in Figure 23 as a solid line. If the center of the distribution is fixed at the center of the CSM v0 target circle, the resulting background value is 1.8 anomalies per cell. Allowing the center to float yields the same background value and displaces the center position to -38m along the radial.

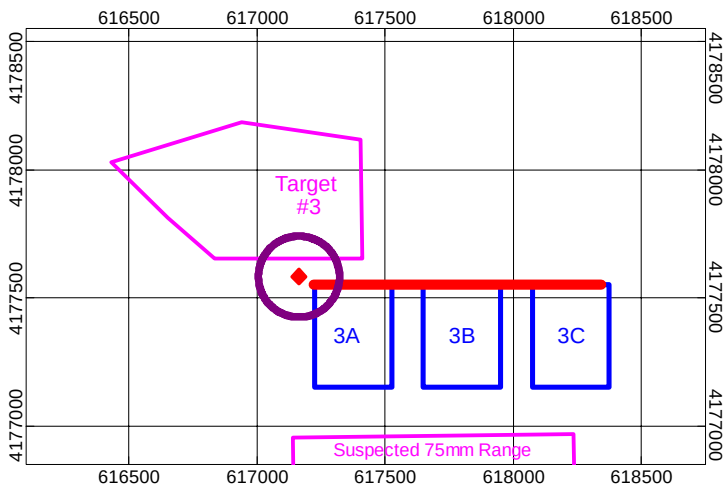


Figure 22 – Total Coverage Plan for Area 3 (Target 3). The planned total coverage survey areas are shown in blue, the Target 3 target circle from CSM v0 is shown in dark purple and the ASR target outlines are shown in pink. The red diamond indicates the center of the Target 3 target circle. The red line indicates the swath selected for the radial analysis.

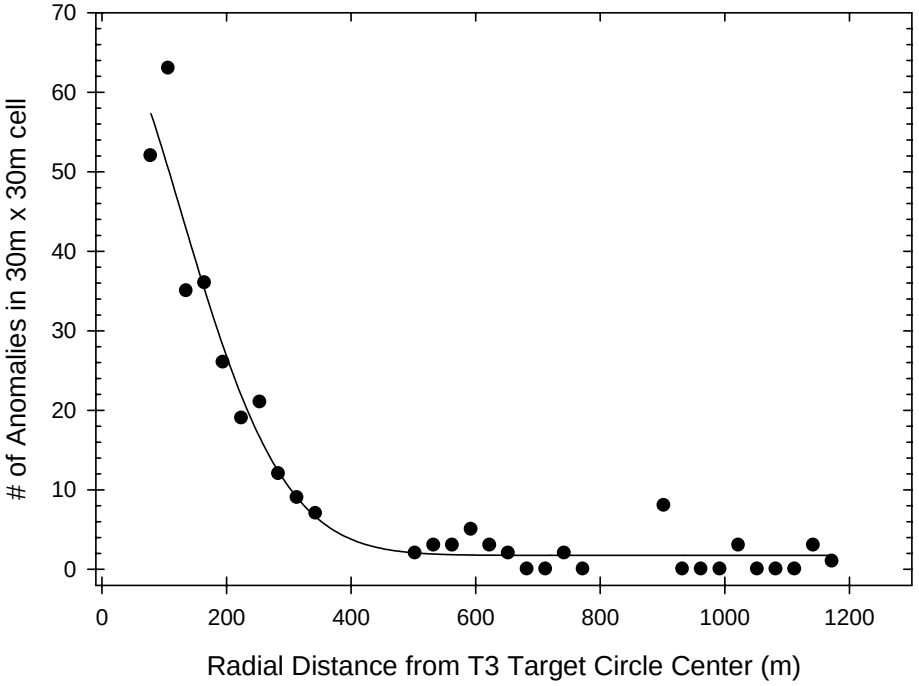


Figure 23 – Number of anomalies per 30m x 30m cell as a function of radial distance from the CSM v0 T3 target circle center. The solid line is the results of a fit to a normal distribution with a persistent background value of 1.8 anomalies / cell.

Figure 24 depicts the total coverage plan for Area 1 (Target 4). The red diamond indicates the AMTADS magnetometer survey center of Target 4. The red line indicates the swath of the 30m x 30m cells. The blue rectangles represent the planned locations of the total coverage areas. Some modification to the area locations were made in the field and the small mismatch between the red line and blue rectangles reflects this. The number of anomalies in each cell was counted and is shown in Figure 25. Assuming that the anomaly density around a target falls off according to a normal distribution, the results can be fit to a normal distribution with a persistent background value. Such a fit is shown in Figure 25. If the center of the distribution is fixed at the center of the AMTADS survey, the resulting background value is 1.4 anomalies per cell. Table 3-7 tabulates these results along with the overall anomaly densities for the Area 2 (Suspected 75mm Range) and the Simmons Area for comparison. The background anomaly density 1200 – 2000 m from the center of the two Targets remains higher than any other area subjected to a total coverage survey.

Table 3-7 – Background Anomaly Densities for Total Coverage Areas 1, 2, 3, and the Simmons Area

Area	Anomalies / 30m x 30m cell
Area 1 (Target 4)	1.4
Area 2A (Suspected 75mm Range)	1.1
Area 2B (Suspected 75mm Range)	0.5
Area 3 (Target 3)	1.8
Simmons Area	0.1

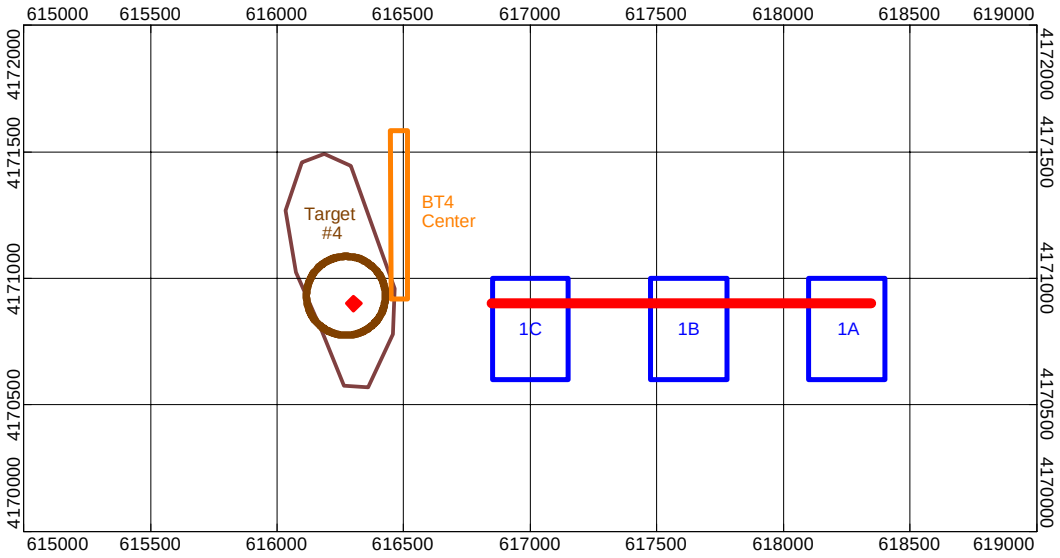


Figure 24 – Total Coverage Plan for Target 4. The planned total coverage survey areas are shown in blue, the Target 4 target circle from CSM v0 and the ASR target outline are shown in dark brown. The red diamond indicates the center of Target 3 as reported from the AMTADS magnetometer data collected by Sky Research. The red line indicates the swath selected for the radial analysis.

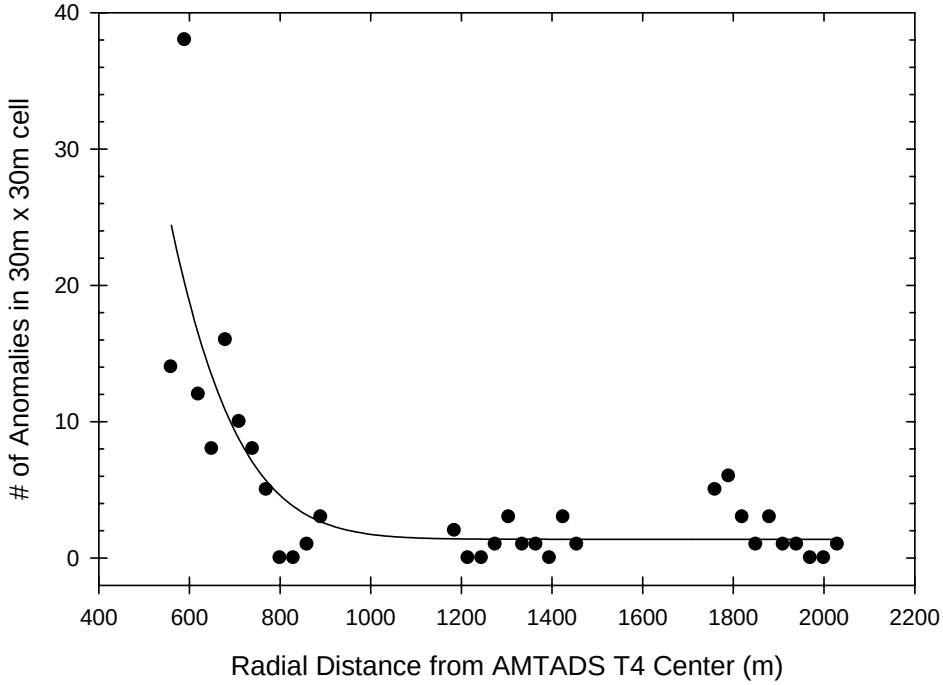


Figure 25 – Number of anomalies per 30m x 30m cell as a function of radial distance from the AMTADS T4 center. The solid line is the results of a fit to a normal distribution with a persistent background value of 1.4 anomalies / cell.

3.1.7 Section 9 Farm House Area of Interest

At the request of the ESTCP Program Office, the transect survey data from an identified area of interest in the central region of the WAA demonstration site was loaded into the MTADS DAS software and analyzed. The permit holders were queried about this area of interest and reported that it the location of an old homestead with a remaining structure. The tow vehicle operator reported a large quantity of surface barb-wire in the area of the structure. The data from Section 9, N/S transects 11-14 and Area 27, E/W transects 1-5, also located in Section 9 were analyzed and a composite magnetometer anomaly map is shown in Figure 26. For the purposes of this report the area will be referred to as the Section 9 Farm House area of interest. 188 anomalies were identified and 76 of those anomalies were reasonably fit to the resident dipole model (coherence > 0.85). The anomalies which could be fit using the dipole model are reported with all parameters in the anomaly list on the attached DVD. The remaining anomalies did not fit well enough to the dipole model and only positions and often a comment are reported.

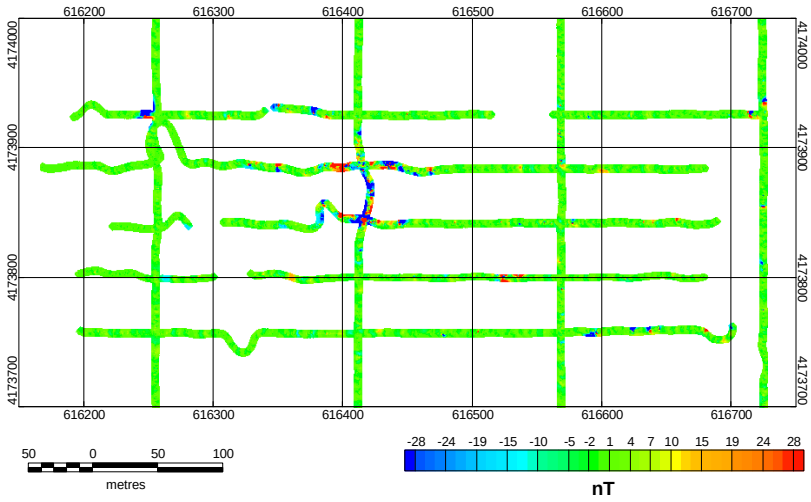


Figure 26 – Magnetometer Anomaly Map of Section 9 Farm House Area of Interest

3.1.8 Calibration Items

As mentioned in Section 3.1.1, a calibration strip of munitions and munitions stimulants were emplaced between the WAA Base Camp and the northern boundary of the WAA Demonstration site. Additionally a 16-lb shotput was emplaced near the Auxiliary Base Camp during use. Table 3-3 gives a schedule of the emplaced items and parameters (i.e. depth and orientation). Figure 27 shows a magnetometer anomaly map of the calibration strip. Figure 28 shows a magnetometer anomaly map of the calibration sphere emplaced near the Auxiliary Base Camp. For both figures, the midpoint positions of the emplaced items, as determined by RTK GPS waypointing, are shown as open circles.

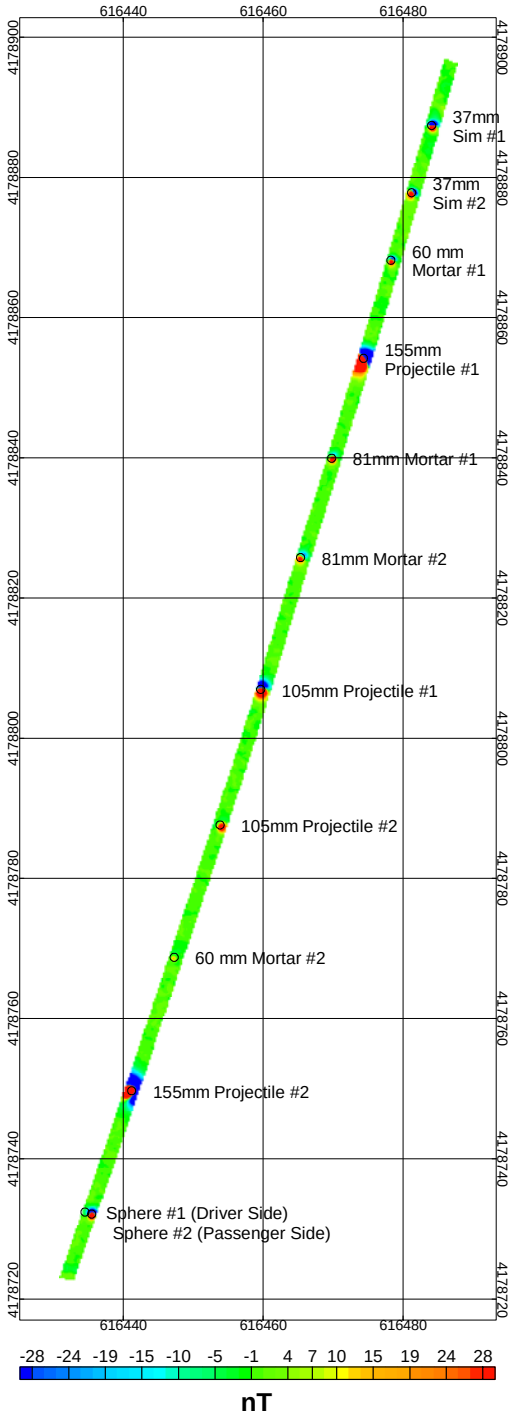


Figure 27 – Magnetometer anomaly map of the calibration strip emplaced between the WAA Base Camp and the WAA Demonstration site at Pueblo PBR#2

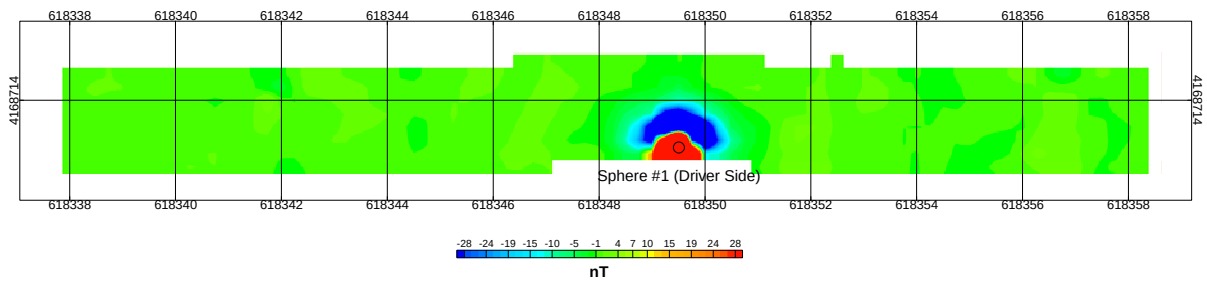


Figure 28 – Magnetometer anomaly map of the calibration sphere emplaced near the Auxiliary Base Camp located south of the WAA demonstration site at Pueblo PBR#2

Each survey day commenced with collection of a 5-6 minute static survey after the sensors had been warmed up and RTK GPS was established. After the static survey, the calibration items were surveyed, the calibration strip when operations were being conducted out of the WAA Base Camp and the calibration sphere when operations were being conducted out of the Auxiliary Base Camp. At the end of the survey day, the appropriate calibration area was surveyed again. In some cases the survey day would begin at one base camp and end at the other. In this situation, the nearest calibration area was surveyed. To evaluate the data from the calibration items, the signal to noise ratio (SNR) was determined. The peak amplitude (analytic signal) of each calibration item emplaced in the calibration strip was determined for each data set using the automated anomaly picking routines to determine a Signal value for each item. A sub-area within the bounds of all surveys, identified to be relatively free of anomalies, was used for each data set to extract a small area of the magnetometer data and convert it to analytic signal. The analytic signal standard deviation (1σ) was then calculated for the sub-area and that value was used as the Noise value for each survey. The bounds of the background areas for the calibration strip and calibration sphere are given in Table 3-8.

Table 3-8 – Boundaries of Background Areas Selected for Noise Calculation

Boundary	**Easting (UTM,m)**	**Northing (UTM, m)**
Calibration Strip		
Minimum	618,445	4,178,771
Maximum	618,457	4,178,785
Calibration Sphere		
Minimum	618,353	4,168,710
Maximum	618,360	4,168,717

The aggregate values of the SNR for all data sets for the calibration strip items (average and standard deviation (1σ) are tabulated in Table 3-9.

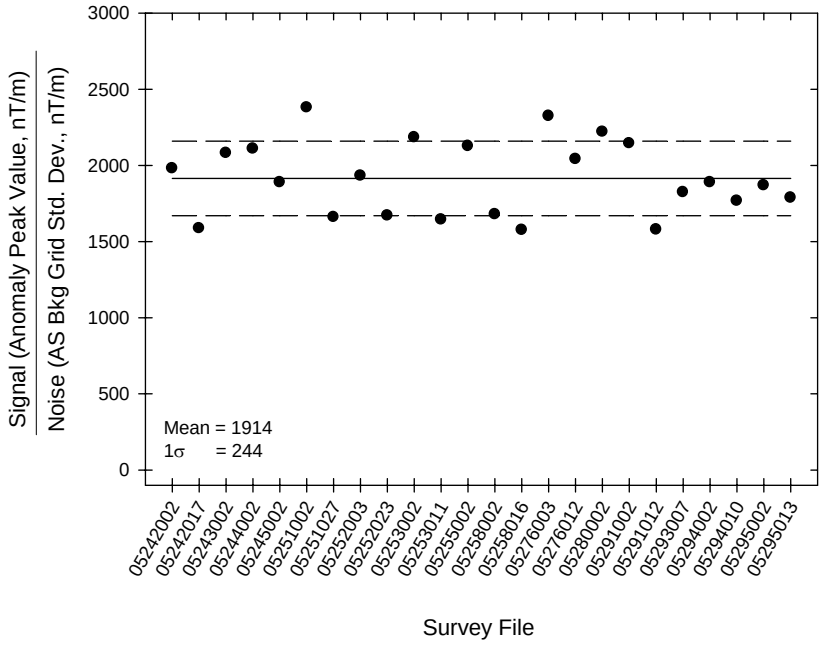


Figure 29 and Figure 30 plot the SNR values for the 155mm Projectile #2 and the 60mm Mortar #1 for all data sets in a pseudo-time series as examples. The 155mm Projectile #2 had the largest SNR (and analytic signal) values. The 60mm Mortar #1 values were approximately 1/10 the 155mm values and represent the smaller values measured. The solid line indicates the aggregate average and the dashed lines indicate a 1σ envelope.

Table 3-9 – Signal to Noise (SNR) Aggregate Values for Calibration Strip Items

ID	Easting (UTM, m)	Northing (UTM,m)	Depth (cm)	Orientation (deg., from North)	Avg. SNR	SNR SD (1σ)
Sphere #1 (Driver Side)	616434.500	4178732.403	0	N/A	623.09	135.43
Sphere #2 (Passenger Side)	616435.459	4178732.109	0	N/A	356.24	48.86
155mm Projectile #2	616441.180	4178749.703	35	35	1914.52	244.19
60 mm Mortar #2	616447.267	4178768.742	30	46	18.19	2.35
105mm Projectile #2	616453.828	4178787.621	60	44	66.26	7.62
105mm Projectile #1	616459.639	4178806.967	45	178	231.75	31.08
81mm Mortar #2	616465.341	4178825.771	43	69	53.03	6.47
81mm Mortar #1	616469.792	4178839.941	25	20	90.97	9.72
155mm Projectile #1	616474.350	4178854.198	50	46	536.95	61.99
60 mm Mortar #1	616478.260	4178868.186	10	148	107.68	14.20
37mm Sim #2	616481.220	4178877.825	10	57	139.69	18.25
37mm Sim #1	616484.096	4178887.419	5	160	255.47	37.02

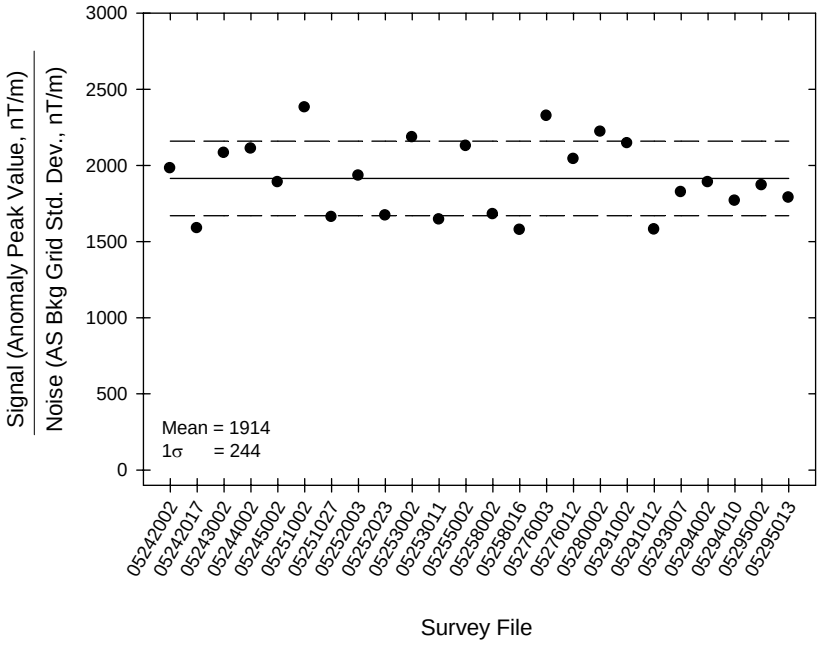


Figure 29 – SNR data runs for 155mm Projectile #2. The result for each data set is shown in order of acquisition. The horizontal axis is survey file number. The solid line represents the aggregate average SNR and the dashed lines represent a 1σ envelope.

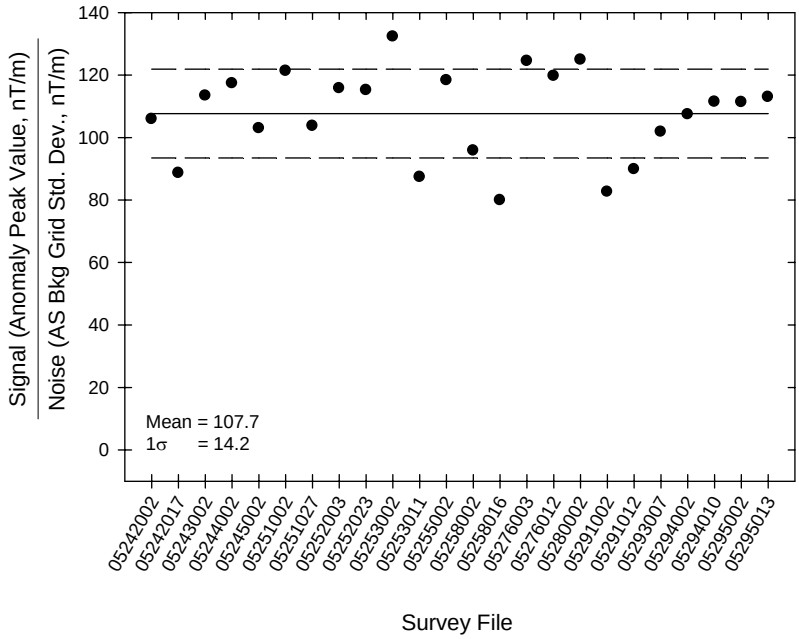


Figure 30 – SNR data runs for 60mm Projectile #1. The result for each data set is shown in order of acquisition. The horizontal axis is survey file number. The solid line represents the aggregate average SNR and the dashed lines represent a 1σ envelope.

The aggregate values of the analytic signal alone for all data sets for the calibration strip items (average and standard deviation (1σ) are tabulated in Table 3-10. Figure 31 and Figure 32 plot the Signal values for the 155mm Projectile #2 and the 60mm Mortar #1 for all data sets in a pseudo-time series as examples. The 155mm Projectile #2 had the largest signal values. The 60mm Mortar #1 values were approximately 1/10 the 155mm values and represent the smaller values measured. The solid line indicates the aggregate average and the dashed lines indicate a 1σ envelope. Comparing the SNR and analytic signal values indicates that the analytic signal values are approximately twice that of the SNR (typical Pueblo PBR#2 Noise values being on the order of 2 nT/m) and have a standard deviation that is one half the SNR value. This indicates that measuring the peak amplitude of the item analytic signal is not the limiting factor in the SNR calculation in this case.

Table 3-10 – Signal Aggregate Values for Calibration Strip Items

ID	Easting (UTM, m)	Northing (UTM,m)	Depth (cm)	Orientation (deg., from North)	Avg. Signal (nT/m)	Signal SD (1σ, nT/m)
Sphere #1 (Driver Side)	616434.500	4178732.403	0	N/A	1064.56	203.42
Sphere #2 (Passenger Side)	616435.459	4178732.109	0	N/A	645.75	47.30
155mm Projectile #2	616441.180	4178749.703	35	35	3461.28	153.18
60 mm Mortar #2	616447.267	4178768.742	30	46	32.90	1.96
105mm Projectile #2	616453.828	4178787.621	60	44	119.92	4.38
105mm Projectile #1	616459.639	4178806.967	45	178	418.80	21.70
81mm Mortar #2	616465.341	4178825.771	43	69	95.98	5.02
81mm Mortar #1	616469.792	4178839.941	25	20	165.35	14.69
155mm Projectile #1	616474.350	4178854.198	50	46	971.91	37.72
60 mm Mortar #1	616478.260	4178868.186	10	148	195.48	20.91
37mm Sim #2	616481.220	4178877.825	10	57	253.46	24.75
37mm Sim #1	616484.096	4178887.419	5	160	463.54	53.27

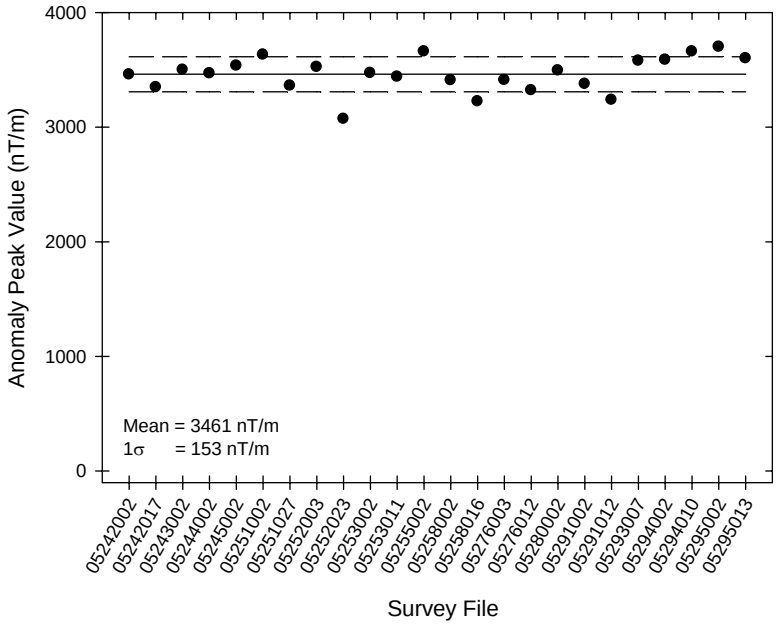


Figure 31 – Analytic signal data runs for 155mm Projectile #2. The result for each data set is shown in order of acquisition. The horizontal axis is survey file number. The solid line represents the aggregate average analytic signal and the dashed lines represent a 1σ envelope.

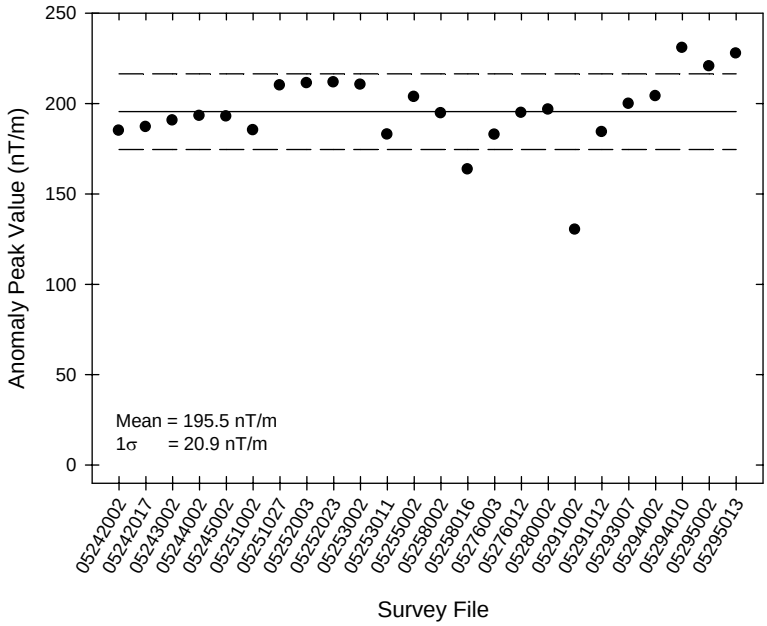


Figure 32 – Analytic signal data runs for 60mm Mortar #1. The result for each data set is shown in order of acquisition. The horizontal axis is survey file number. The solid line represents the aggregate average analytic signal and the dashed lines represent a 1σ envelope.

A similar analysis was conducted for the metal sphere emplaced near the Auxiliary Base Camp. The results and the aggregate values of the SNR and the analytic signal for all data sets for the calibration sphere (average and standard deviation (1σ) are shown in Figure 33 and Figure 34. The aggregate values for the metal sphere were an SNR of 191.9 ± 79.1 and a peak analytic signal amplitude of 857.7 ± 235.9 nT/m. If the analysis is restricted to the morning calibration runs only, the standard deviation reduces by approximately one-half to values of 185.6 ± 44.5 for the SNR and 919.6 ± 121.5 nT/m for the analytic signal. The tow vehicle batteries were charged by a 5 kW rather than a 65 kW-range generator at the Auxiliary Base Camp. This may show a limit of the system's daily operational endurance when charging the batteries overnight using the smaller generator since this phenomenon was not observed in the data collect when operating out of the WAA Base Camp.

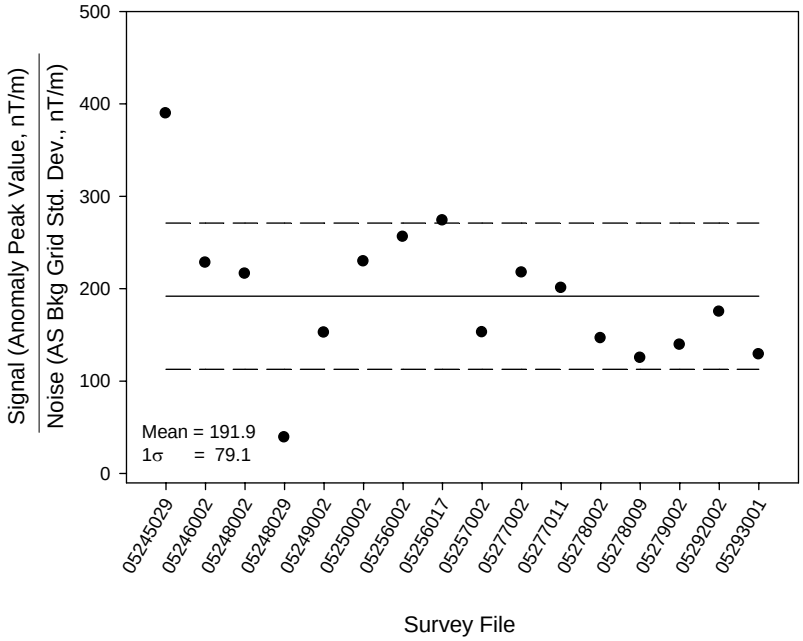


Figure 33 – SNR data runs for the metal sphere emplaced near the Auxiliary Base Camp. The result for each data set is shown in order of acquisition. The horizontal axis is survey file number. The solid line represents the aggregate average SNR and the dashed lines represent a 1σ envelope.

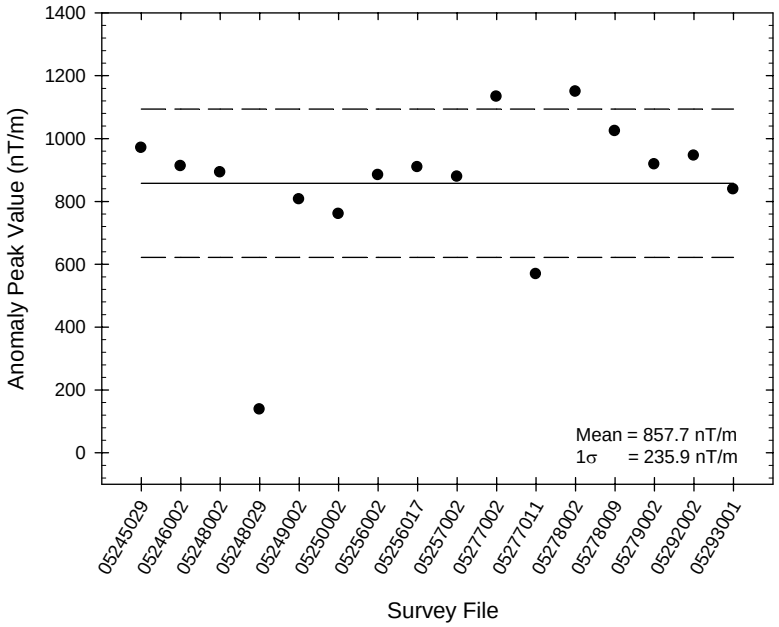


Figure 34 – Analytic signal data runs for the metal sphere emplaced near the Auxiliary Base Camp. The result for each data set is shown in order of acquisition. The horizontal axis is survey file number. The solid line represents the aggregate average analytic signal and the dashed lines represent a 1σ envelope.

As stated above, static tests of the sensor platform were conducted at the beginning of each survey day. After a period for system warm up (approximately 15 minutes), walk-around preventative maintenance inspections, and the establishment of RTK GPS, the tow vehicle was driven to the appropriate calibration area. A data set was collected for at least 5-6 minutes while the vehicle was kept stationary. The 2-D positioning variation was evaluated by computing the standard deviation of both the northing and easting components of the position data for the entire period and combining them as the square root of the sum of the squares. The standard deviation for the demedianed magnetometer data from each sensor was computed and the arithmetic mean computed was for the data set. In occasional cases, an obvious artifact was present in the data (e.g. a vehicle pulls up along side the tow vehicle unannounced) and distorts a portion of the static run. In these cases, only the unperturbed data was used with a minimum of 3 minutes total data. The standard deviation of both the positioning and sensor data for all data sets was computed. The results are shown in the follow pseudo-time series figures. Figure 35 and Figure 36 show the positioning and magnetometer variations for the static tests conducted at the southern end of the calibration strip. Figure 37 and Figure 38 display the results of a similar analysis for the data sets collected at the western edge of the survey path used for the calibration sphere located near the Auxiliary Base Camp.

The magnetometer values shown in Figure 38 indicate a significant increase in the overall average magnetometer sensor noise level for Julian dates 05277 and later. The first three-week portion of the demonstration depleted the reserve of spare magnetometers. The manufacturer had promised to deliver the repaired spares prior to the commencement of the second portion of

the survey. The return of the sensors was delayed due to difficulties in tuning the sensors at the factory. The repaired sensors arrived after the survey was stopped on October 7 for unscheduled repairs to the vehicle tow vehicle engine. A consequence was that the surveys were conducted with one sensor operating at a noise level approximately 10 times the norm. The data from this sensor was only used for further analysis when the SNR was 10 or greater. For the third portion of the survey the spare sensors were deployed as required. An intermittent problem with the counter board for one outboard sensor developed during the third portion of the survey. A part was required to troubleshoot / repair this issue that is not typically kept in the spares collection. The data from this sensor was not used for further analyses for data sets when the problem manifest itself while the part was being delivered. The part arrived on October 21 and the problem did not manifest itself again. The combination of these issues results in the increase sensor measurement variation indicated in Figure 38. In the cases where all sensors appeared to be working within limits and yet the static variation is higher than expected, a long wavelength variation in the sensors could be observed in the data but not by the operator in the field. It is possible that the source of this issue was insufficient warm up time in the morning but the issue is still under investigation and only occurred during operations out of the Auxiliary Base Camp with the smaller generator. Table 3-11 summarizes the static test data results.

Table 3-11 – Static Test Data Results

Calibration Area	Result Type	Value
North	2-D Position	0.42 ± 0.14 cm
	Magnetometer	0.89 ± 0.97 nT
South	2-D Position	0.44 ± 0.10 cm
	Magnetometer	0.67 ± 0.72 nT

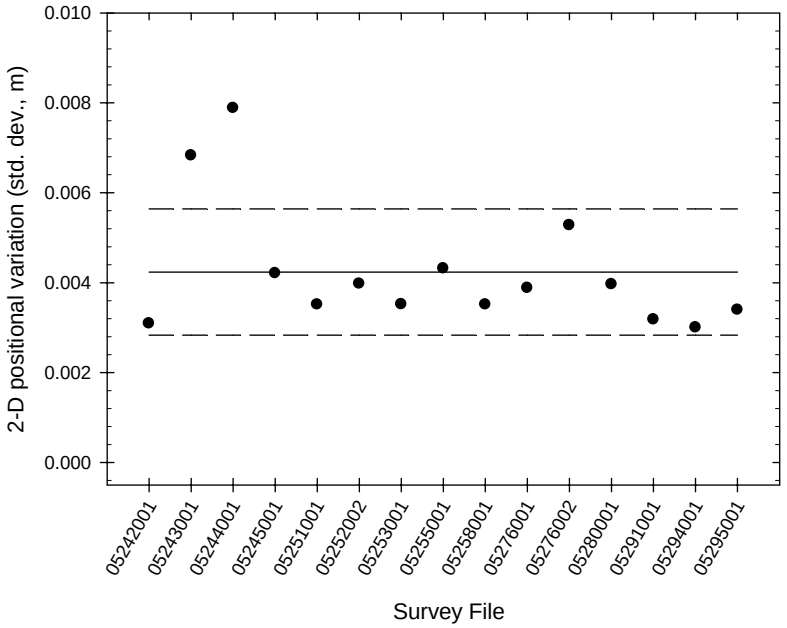


Figure 35 – Positional variation data runs for static data collected at the calibration strip. The horizontal axis is survey file number. The solid line represents the aggregate average positional variation and the dashed lines represent a 1σ envelope.

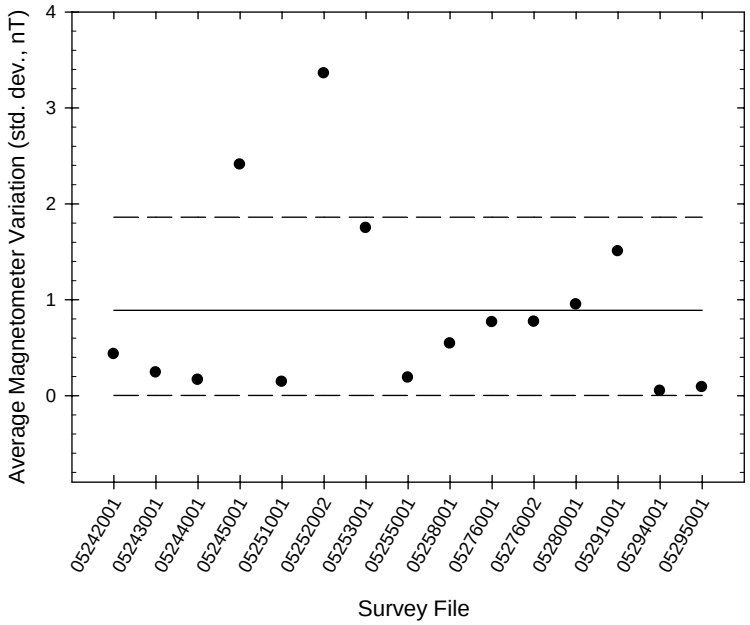


Figure 36 – Overall magnetometer (all sensors) variation data runs for static data collected at the calibration strip. The horizontal axis is survey file number. The solid line represents the aggregate average sensor variation and the dashed lines represent a 1σ envelope.

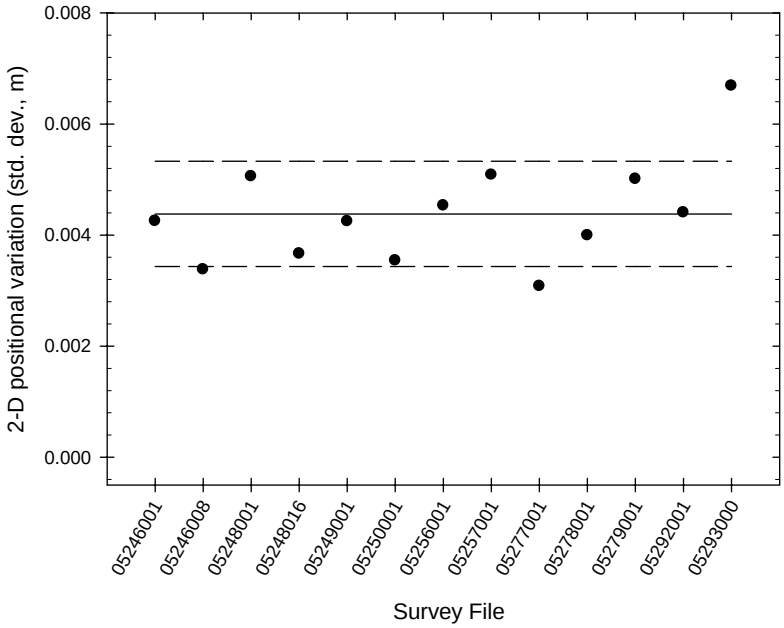


Figure 37 – Positional variation data runs for static data collected at the calibration sphere. The horizontal axis is survey file number. The solid line represents the aggregate average positional variation and the dashed lines represent a 1σ envelope.

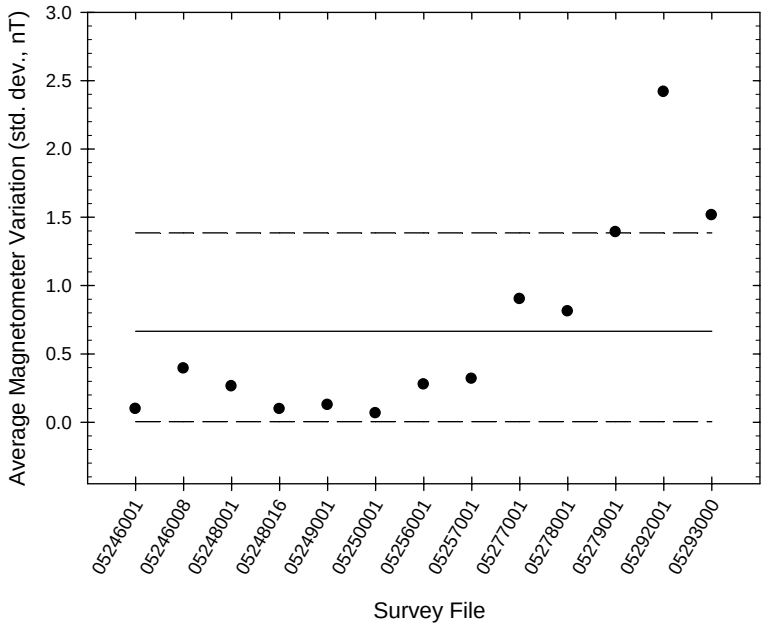


Figure 38 – Overall magnetometer (all sensors) variation data runs for static data collected at the calibration sphere. The horizontal axis is survey file number. The solid line represents the aggregate average sensor variation and the dashed lines represent a 1σ envelope.

3.1.9 Demobilization

At the end of field operations, all equipment, materials, and supplies were repacked on the 53' trailer and secured. Harris Transportation Company, a government contract transportation firm transported the trailer from the site to the MTADS home base at ARL Blossom Point, Welcome, MD. Once all personnel had departed the site the local vendors were contacted to arrange for the generator and fuel storage to be removed. In cooperation with the land owner, Tead Russell, the office and garage trailers and the portable toilet at the WAA Base Camp are being left in place for the validation effort currently being planned for Spring, 2006 by the WAA Pilot Project. The second garage trailer, located at the south end of the site, was also removed from its location on U.S. Forest Service land.

4. References

1. "Department of Defense Unexploded Ordnance Response: Estimated Costs and Technology Investments," Report to the Congressional Defense Committees, March 2001.
2. Report of the Defense Science Board Task Group on Unexploded Ordnance, Office of the Under Secretary of Defense For Acquisition, Technology, and Logistics, Washington, D. C., Nov. 2003.
3. "Airborne MTADS Demonstration at the Badlands Bombing Range, September, 2001," J.R. McDonald, D.J. Wright, N. Khadr, H.H. Nelson, NRL/PU/6110—02-453.
4. "MTADS TECHEVAL Demonstration, October 1996," H. H. Nelson, J. R. McDonald, and Richard Robertson, NRL/PU/6110--97-348.
5. "Results of the MTADS Technology Demonstration #2, Magnetic Test Range, Marine Corps Air Ground Combat Center, Twentynine Palms, CA, December, 1996," J.R. McDonald, H.H. Nelson, R.A. Jeffries, and Richard Robertson, NRL/PU/6110—97-349.
6. "Results of the MTADS Technology Demonstration #3," Jefferson Proving Ground, Madison, IN, January 13-24, 1997," H.H. Nelson, J.R. McDonald, R.A. Jeffries, and Richard Robertson, NRL/PU/6110—99-375.
7. "MTADS Unexploded Ordnance Operations at the Badlands Bombing Range, Pine Ridge Reservation, Cuny Table, SD, July 1997," J.R. McDonald, H.H. Nelson, J. Neece, R. Robertson, R.A. Jeffries, NRL/PU/6110—98-353.
8. "MTADS Live Site Survey, Bombing Target #2 at the Former Buckley Field, Arapahoe County, CO," J. R. McDonald, H. H. Nelson, and R. Robertson, NRL/PU/6110--99-379.
9. "MTADS Unexploded Ordnance Operations at the Badlands Bombing Range Air Force Retained Area, Pine Ridge Reservation, SD, September, 1999," J. R. McDonald, H. H. Nelson, R. Robertson, and R. A. Jeffries, NRL/PU/6110--00-424.
10. "MTADS Magnetometer Survey of the Badlands Bombing Range, SD Impact Area, Combined Airborne, Vehicular, and Man-portable Survey, September 2002," H.H. Nelson, D.A. Steinhurst, D. Wright, T. Furuya, J.R. McDonald, B. Barrow, N. Khadr, and J. Haliscak, NRL/MR-MM/6110—03-8666.
11. "MTADS Airborne and Vehicular Survey of Target S1 at Isleta Pueblo, Albuquerque, NM, 17 February – 2 March 2003," H.H. Nelson, D. Wright, T. Furuya, J.R. McDonald, N. Khadr, D.A. Steinhurst, NRL/MR/6110—04-8764.
12. "Conceptual Site Models to Support ESTCP Wide Area Assessment Demonstration Project – Final Version 0, July, 2005," Versar, Inc., July, 2005.

5. Points of Contact

ESTCP		
Anne Andrews	Program Manager, UXO	Tel: 703-696-3826 Fax: 703-696-2114 anne.andrews@osd.mil
Jeffrey Fairbanks	Program Assistant, UXO	Tel: 703-736-4514 Fax: 703-471-4180 jef@hgl.com
NRL		
H. H. Nelson	Project Manager, WAA	Tel: 202-767-3686 Fax: 202-404-8119 Cell: 202-215-4844 herb.nelson@nrl.navy.mil
Nova Research, Inc.		
Dan Steinhurst	Principle Investigator	Tel: 202-767-3556 Fax: 202-404-8119 Cell: 703-850-5217 dan.steinhurst@nrl.navy.mil
Glenn Harbaugh	Site Safety Officer	Tel: 301-392-1702 Fax: 301-392-1702 Cell: 804-761-5904 roo749@yahoo.com
Russell Jeffries	Logistics Support	Tel: 703-360-3900 Fax: 703-360-3911 Cell: 703-244-1245 rjeffr@erols.com
AETC		
Nagi Khadr	Data Analyst	Tel: 703-413-0500 Fax: 703-413-0505 nagi@va.aetc.com
Hotel Accomodations		
Holiday Inn Express	27994 US Highway 50 Frontage Road, La Junta, CO 81050	Tel: 719-384-2900

Appendix A. Analytical Methods to Support the Experimental Design

To facilitate the scope and tempo of the WAA pilot project, the typical MTADS man-in-the-loop analysis of total field magnetometer data was not going to fit the bill. The process is too time consuming and provides far richer results than is initially required by the planning elements of the project on a daily time scale. An alternate approach was required. Briefly, the located total magnetic field data (nT) are collected as normal for an MTADS survey. The total field data are converted to analytic signal (AS, nT/m) where the analytic signal is calculated from the squares of the derivatives in the x, y, and z directions:

$$AS = \sqrt{\left(\frac{d}{dx}\right)^2 + \left(\frac{d}{dy}\right)^2 + \left(\frac{d}{dz}\right)^2}$$

The z derivatives can be estimated from the total field 2-D data using either FFT or convolution methods. For this work, the FFT method was used. All processing work was done in the commercial geophysics software package, Oasis montaj and requires the advanced 1-D filters available as part of the Geophysics add-on package (and others). A data grid is calculated for the total field data and this involves interpolating the actual data to a regularly spaced grid of a given cell size. The algorithms which compute the AS require a regularly spaced input data grid to work efficiently and output an AS data grid. The GRIDPEAK GX is then used to extract all peaks in the AS grid which are above a given threshold. This Appendix describes initial evaluation work done on existing data sets to validate this method and provide initial estimates of the optimized parameters required.

Total field magnetometer and AS grids were calculated from an existing data set collected using the MTADS platform at our home base in Blossom Point, MD at 0.125, 0.25, 0.50, and 1.00 m grid cell sizes. The GRIDPEAK.GX was then run using a set of Cut-Off threshold values (required peak amplitude to be counted as a peak) and a fixed number of smoothing filter passes (six) on each AS grid. Six passes was found to be the minimum to get reasonable results. Using fewer passes result in multiple picks for the same actual peak in the grid. The following four graphs (Figures A1 – A4) show the # of peaks picked for a given Cut-Off value for each AS grid cell size. The red line indicates the number of emplaced targets (all types) in the BP test field (61).

Each curve shows a 'knee', below which one picks up non-emplaced targets faster than emplaced targets. The 0.25m studies captured 51 to 57 of the 61 emplaced targets with a range of non-emplaced targets picked. A majority of the undetected emplaced targets were in the Clutter category and the exclusion of these objects is not necessarily a failing of the method.

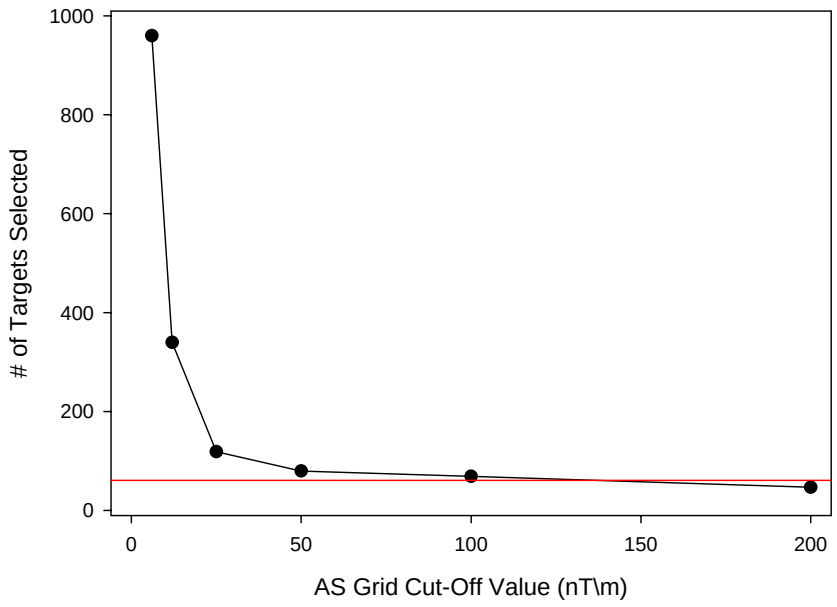


Figure A1 - Blossom Point GRIDPEAK Results for a 0.125m grid cell size

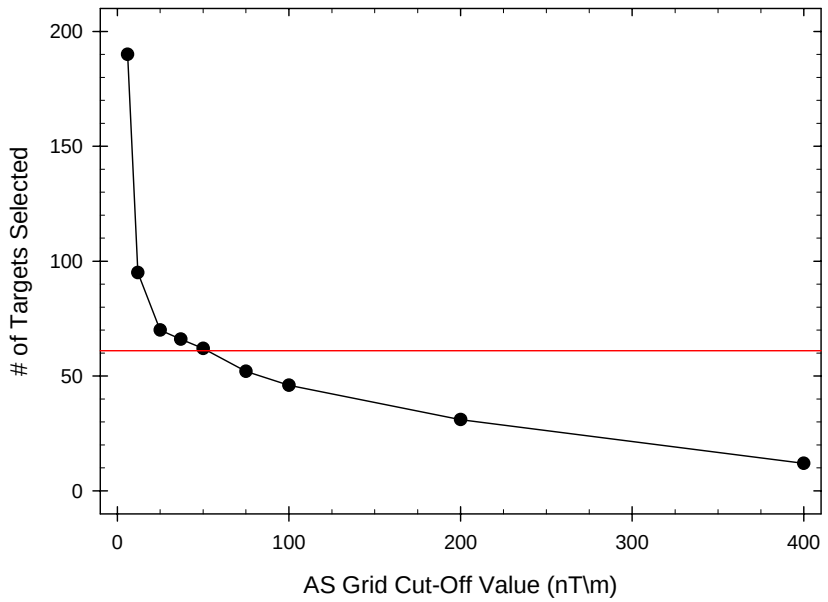


Figure A2 - Blossom Point GRIDPEAK Results for a 0.25m grid cell size

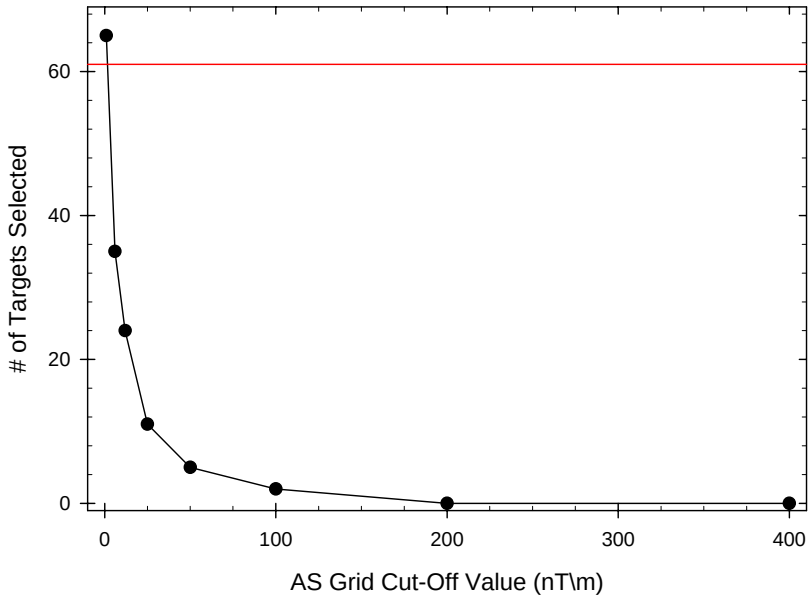


Figure A3 - Blossom Point GRIDPEAK Results for a 0.50m grid cell size

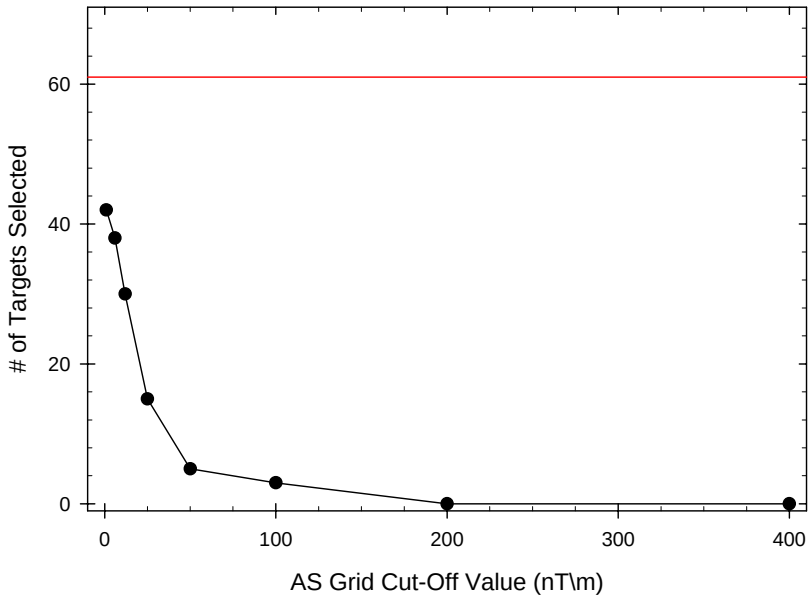


Figure A4 - Blossom Point GRIDPEAK Results for a 1.00m grid cell size

For eight points from the above studies (predominately from the 0.25m grid cell size results), the picked anomalies were matched to an emplaced target. If the pick was not clearly associated with an emplaced target, it was marked as a False Alarm (FA) since the Blossom Point Test Field is relatively clean after repeated clearances and should have no non-emplaced targets. Based on these results, values for probability of detection (P_d), false alarm rate (FAR, FA's / hectare), average miss distance, and the standard deviation of the miss distance were calculated.

Table A-1 gives the results. A ROC curve was constructed and is shown as Figure A5 for all analyzed cases with the 0.25m cases plotted in red.

Table A-1 – Results for emplaced targets at Blossom Point for various parameters

Grid Cell Size (m)	CutOff Threshold (nT\m)	# of Targets Picked	# of Emplaced Targets Picked	Pd	# of Targets Picked Not Emplaced Targets	FAR (# FA/ Hectare)	Average Miss Distance (m)	Std. Dev (1s) (m)
0.125	25	120	57	0.934	63	223	0.119	0.079
0.125	50	80	57	0.934	23	82	0.119	0.079
0.250	25	70	57	0.934	13	46	0.132	0.080
0.250	37	66	56	0.918	10	35	0.133	0.081
0.250	50	62	55	0.902	7	25	0.131	0.080
0.250	75	52	51	0.836	1	4	0.136	0.082
0.500	25	11	11	0.180	0	0	0.419	0.396
0.500	50	5	5	0.080	0	0	0.370	0.289

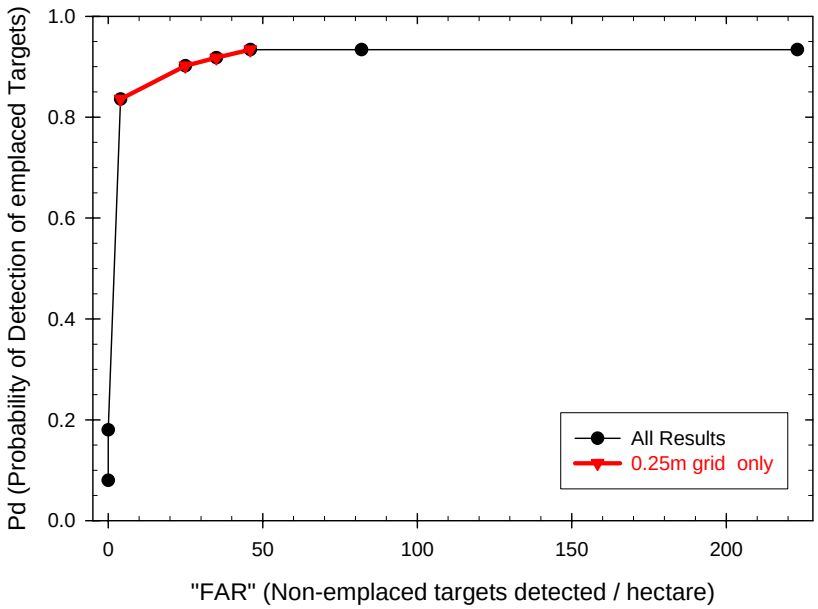


Figure A5 – ROC curve for emplaced target comparisons

As stated above, the BP Test Field is a relatively small site with a limited number of emplaced targets and is relatively clean. To further test the developed method, existing MTADS magnetometer data collected at the Standardized UXO Technology Demonstration Sites located at the Aberdeen and Yuma Proving Grounds was considered. Using 0.25m grid spacing and the same range of Cut-Off threshold values, the # of picks vs. Cut-Off Threshold value for these two sites was determined. Plots are included showing ATC (Figure A6) and YTC (Figure A7) separately and then together with the BP results for 0.25 m (Figure A8) are shown. Notice the strong similarity between the ATC and YTC results. The similarity to the BP is also good considering how much smaller/cleaner the BP field is. These results support the general applicability of the BP analysis to ATC and YTC (if no further). No count of the actual number of emplaced targets is available for these sites, so no reference lines are plotted.

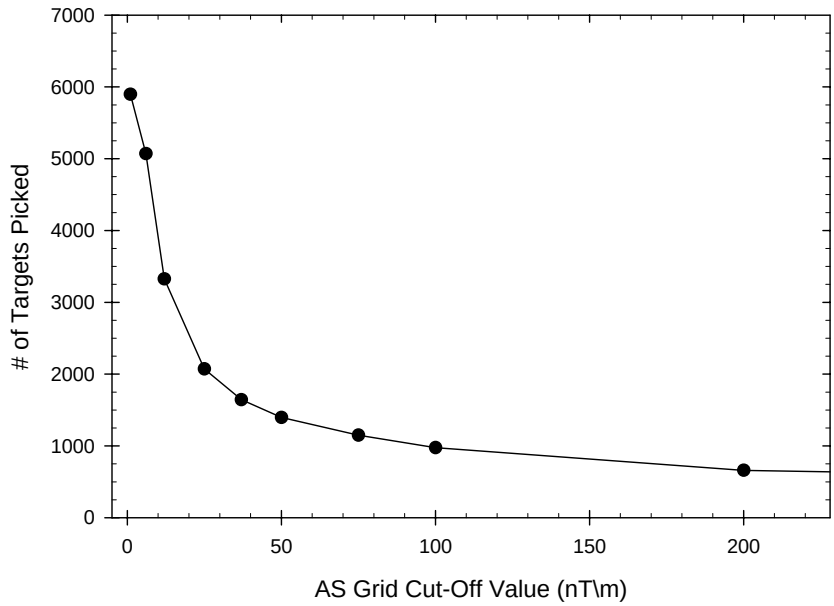


Figure A6 – ATC GRIDPEAK Results for a 0.25m grid cell size

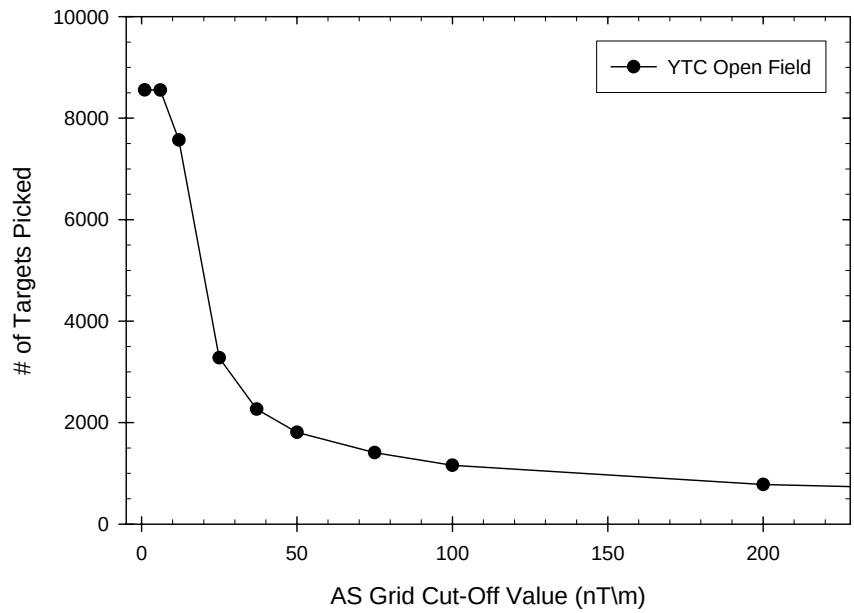


Figure A7 – YTC GRIDPEAK Results for a 0.25m grid cell size

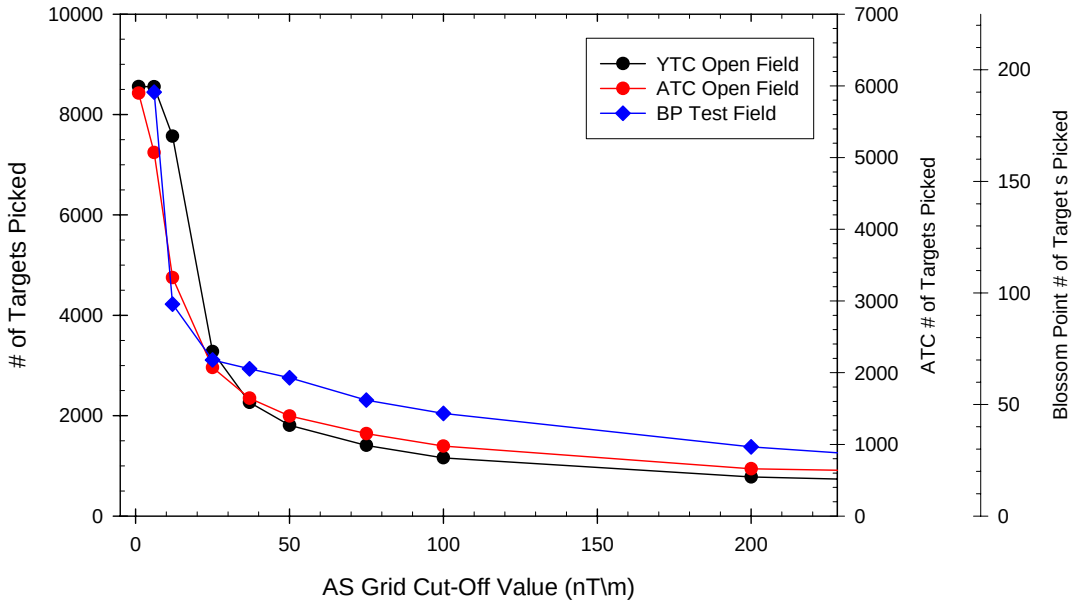


Figure A8 – YTC, ATC, and BP GRIDPEAK Results for a 0.25m grid cell size

The 0.25m grid cell size appears to be a promising combination of sensitivity (from this work) and computational speed. Timed trials conducted on a large data set found that the typical grid cell sized used in total coverage surveys (0.125 m) is computationally impractical for transect style data with long (~6 km) down track distances and narrow cross track width (2 km). If the computations were completed, the time required was on the order of 4 hours per one hour of survey.

In conclusion, the following three points can be drawn:

1) The 0.25m grid cell size appears to be a promising combination of sensitivity and computational speed.

2) A generally applicable guideline of 25 to 100 nT/m for the AS cut-off threshold value is beginning to appear and holds on three sites.

3) The choice of AS cut-off threshold value will be driven by the relative tolerance for detection of smaller clutter items versus desired sensitivity.

Ongoing efforts which will feed directly into this project include the analysis of other data sets and further exploration of the available parameter space. One other data set from the MTADS BBR 2002 vehicular survey exists. This data set represents a plains-like geology which may be relevant to the PBR#2 site. The large positional errors reported for the 0.5 and 1.0 m grid cell sizes leave room for improvement. Alternate smoothing filter settings may prove more effective for the larger grid cell sizes. This will be an area of continued effort.

Appendix B. Data Storage and Archiving Procedures

B.1 Data Formats

Each survey file set contains 10 files which constitute the ‘raw data’. The file name structure is YYDDDFFF.DeviceType.DeviceAlias; where YY is the 2-digit year, DDD is the "Julian" day, or day in the year, and FFF is the flight number starting with 001. In the following example, the data was taken on the 210th day of 2002, flight number 4.

02210004.Survey.822A.822A_1
02210004.Survey.822A. 822A_2
02210004.Survey.GPS.NMEA
02210004.Survey.SerialDevice.UTC
02210004.Survey.PpsDevice.PPS
02210004.Survey.TriggerDevice.Trigger
02210004.Survey.LineNumber
02210004.Survey
02210004.Survey.page
02210004.Survey.loginfo1.txt

Each data line is time stamped with the PC system clock to allow syncronization between files

YYDDDFFF.Survey.LineNumber - start and stop time of each line in survey, typically only one line / file
YYDDDFFF.Survey.822A.822A_1 - Output from Counter 1 (4 magnetometers), in nT x 10^5, 50 Hz.
YYDDDFFF.Survey.822A.822A_2 - Output from Counter 2 (4 magnetometers), in nT x 10^5, 50 Hz.
YYDDDFFF.Survey.PpsDevice.PPS - pulse per second (PPS) from GPS receiver, 1 Hz.
YYDDDFFF.Survey.GPS.NMEA - GPS output, Trimble PTNL,GGK sentence at 5 Hz (position).
YYDDDFFF.Survey.TriggerDevice.Trigger - trigger pulse to magnetometers, 50 Hz.
YYDDDFFF.Survey.SerialDevice.UTC - UTC time tag from GPS receiver, "The time will be" message for next PPS, 1 Hz.

The .Survey, .Survey.page, and .Survey.loginfo*.txt files are setup information recorded by the data collection program and contain no data of use to the user.

.Survey.LineNumber files:

```
START LINE 0  12/21/04 12:45:39.523
STOP  LINE 0   12/21/04 12:59:21.072
```

Magnetometer (.822A) files:

```
d15289543808d25289567673d35289555967d45289802122  10/10/02 14:17:00.508
d15289545560d25289568728d35289557064d45289803821  10/10/02 14:17:00.528
d15289547878d25289569235d35289557743d45289805162  10/10/02 14:17:00.548
d15289547468d25289568538d35289557255d45289804417  10/10/02 14:17:00.568
d15289546204d25289567936d35289556456d45289802950  10/10/02 14:17:00.588
d15289545018d25289566714d35289556217d45289801466  10/10/02 14:17:00.608
```

First line:
d1 - Sensor 1 ok - two characters of status code / marker - other two character codes are possible

to indicate error conditions
`5289543808 - 52895.43808 gamma or nT`
d2 - Sensor 2 ok
`5289567673 - 52895.67673 nT`
d3 - Sensor 2 ok
`5289555967 - 52895.55967 nT`
d4 - Sensor 2 ok
`5289802122 - 52898.02122 nT`

`10/10/02` - computer date stamp for receipt of string at computer.
`14:17:00.508` - computer time stamp for receipt of string at computer.

.Survey.PpsDevice.PPS files:

```
PPS   12/21/04 12:45:40.433
PPS   12/21/04 12:45:41.433
PPS   12/21/04 12:45:42.433
```

.Survey.GPS.NMEA files:

```
$PTNL,GGK,175017.00,122104,3825.06336634,N,07706.26656042,W,3,07,2.8,EHT-
25.694,M*7C  12/21/04 12:45:39.470
```

Table C-1 – PTNL,GGK Message Fields[a]

Field	Meaning
1	UTC of position fix
2	Date
3	Latitude
4	Direction of Latitude (N = North, S = South)
5	Longitude
6	Direction of Longitude (E = East, W = West)
7	GPS Fix Quality (0 = Invalid,1,2,3,4)
8	Number of Satellites in fix
9	DOP of fix
10	Ellipsoidal height of fix
11	M: ellipsoidal height is measured in meters

[a] For further information, refer to the Trimble MS Series Operation Manual

.Survey.SerialDevice.UTC files:

```
UTC 04.12.21 17:50:18 57  12/21/04 12:45:39.645
UTC 04.12.21 17:50:19 57  12/21/04 12:45:40.646
```

Located data archives are ASCII files of the format:

For located, demedianed magnetometer data:

```
X (UTM Zone X, NAD83, m) Easting
Y (UTM Zone X, NAD83, m) Northing
Z Height Above Ellipsoid (HAE, WGS84, m)
S Signal in nT
```
where X is the appropriate UTM zone (13N for PBR#2,CO)

for the analytic signal data, the Signal is reported in nT/m.

Anomaly Report (.Anomaly) Files:
Anomaly Reports from Transect data will be ASCII files of the format:

```
ID Fiducial ID of the anomaly
X  (UTM Zone X, NAD83, m) Easting
Y  (UTM Zone X, NAD83, m) Northing
S  Analytic Signal in nT\m
```
where X is the appropriate UTM zone (13N for PBR#2,CO)

Course over Ground (.COG) files:
Corresponding Course-Over-Ground (COG) Reports for Transect data will be ASCII files of the format:

```
X       (UTM Zone X, NAD83, m) Easting
Y       (UTM Zone X, NAD83, m) Northing
GPSTime UTC Time in seconds past midnight
```
where X is the appropriate UTM zone (13N for PBR#2,CO)

Static Survey Archive (_static.xyz) files:
Daily static calibration run data will be archived as geosoft .XYZ files of the format:

```
X       (UTM Zone X, NAD83, m) Easting for GPS antenna
Y       (UTM Zone X, NAD83, m) Northing for GPS antenna
HAE     (WGS84, m) Height above Ellipsoid for GPS antenna
Mag1    (nT) Demedianed magnetometer data for sensor 1
Mag2    (nT) Demedianed magnetometer data for sensor 2
Mag3    (nT) Demedianed magnetometer data for sensor 3
Mag4    (nT) Demedianed magnetometer data for sensor 4
Mag5    (nT) Demedianed magnetometer data for sensor 5
Mag6    (nT) Demedianed magnetometer data for sensor 6
Mag7    (nT) Demedianed magnetometer data for sensor 7
Mag8    (nT) Demedianed magnetometer data for sensor 8
```
where X is the appropriate UTM zone (13N for PBR#2,CO)

MTADS DAS Target List Example

The example is given in ASCII text file format. Actual delivery will be in Excel Spreadsheet format.

```
MTADS TARGET REPORT
###################
Mon Oct 31 14:00:47 2005
PROJECT: PBR2
SITE: Area_2A
SENSOR: mag
```

```
SURVEY: Survey
PRIMARY COORDINATES: UTM=13, nad83
###################
###################
###################
###################
ID,UTM X (m),UTM Y (m),Depth (m),Size (m),Moment (Amps-
m2),Inclination,Azimuth,Goodness of Fit,Comments
1,617608.50,4176876.99,0.331,0.028,0.0121,26.70,30.32,0.9714,
2,617793.59,4176877.94,0.931,0.168,2.5717,57.71,10.09,0.9362,
3,617799.14,4176867.65,0.844,0.125,1.0476,55.00,24.48,0.9964,
```