Demonstration Report

Next Generation Data Collection System for One-Pass Detection and Discrimination

ESTCP Project MR-200908

December 2011

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ESTCP

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
DEC 2011	**N/A**	**-**

4. TITLE AND SUBTITLE
Next Generation Data Collection System for One-Pass Detection and Discrimination

5a. CONTRACT NUMBER
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER
5e. TASK NUMBER
5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Sky Research, Inc.

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR’S ACRONYM(S)

11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**43**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

AOL	Advanced Ordnance Locater
BUD	Berkeley UXO Discriminator
cm	Centimeter
EMI	Electromagnetic Induction
FLBGR	Former Lowry Bombing and Gunnery Range
GPS	Global Positioning System
Hz	Hertz
IDA	Institute for Defense Analyses
INS	Inertial Navigation System
m	Meter
ms	Microsecond
m/s	Meters per second
N_{fa}	Number of False Alarms
OPTEMA	One-Pass Time-domain ElectroMagnetic Induction Array
P_{class}	Probability of Correct Classification
RTK	Real-Time-Kinematic
SKYDAQ	Sky Research Data Acquisition System
SLO	San Luis Obispo
SNR	Signal-to-noise Ratio
SPAN	Synchronized Position Attitude and Navigation
TEM	Time-domain ElectroMagnetic
TEMTADS	Time-domain ElectroMagnetic Towed Array Detection System
TOI	Targets of Interest
UXO	Unexploded Ordnance
YPG	Yuma Proving Grounds

1.0 INTRODUCTION

1.1 BACKGROUND

The prohibitive costs of excavating all geophysical anomalies are well known and are one of the greatest impediments to efficient clean-up of UXO contaminated sites. Effective discrimination between hazardous UXO and non-hazardous munitions and cultural related debris has the potential to significantly reduce remediation costs. A few years ago it was found that discrimination performance using single-component electromagnetic induction (EMI) sensors in the field had been uniformly poor relative to expectations: predominantly due to stringent requirements on positional accuracy and signal-to-noise ratio (e.g. Bell, 2005). This led to the development of a number of multi-transmitter, multi-receiver EMI sensors (e.g. Berkeley UXO Discriminator, TEMTADS, MetalMapper) that could be deployed in a cued-interrogation mode so that data could be collected without moving the platform. Initials tests with these systems have shown excellent discrimination potential. However, the need to deploy the systems in a cued-mode can significantly increase the time and costs of the geophysical survey. At many sites, we believe that the most cost-effective discrimination strategy will be to deploy a time-domain EMI one-pass detection and discrimination system where positional and orientation accuracy, data-density and SNR are maximized.

The One-Pass Time-domain ElectroMagnetic Induction Array (OPTEMA) is a system derived from the Advanced Ordnance Locator (AOL) that was developed with US Navy funding. It comprises three 1 m x 1 m orthogonal transmitter coils that are rotated 45 degrees to the direction of travel, and nine three component receiver cubes distributed within the footprint of the transmitters. The sensor collects data while continuously moving and cycling through each of the three transmitters. Highly accurate sensor positions and orientations are obtained through the use of the Novatel SPAN which comprises a high end Global Positioning System (GPS) and a precision tactical grade Inertial Navigation System (INS). Position and orientation estimates are optimized by collecting all required data for post-processing in a Kalman filter formulation through Novatel Inertial Explorer software.

1.2 OBJECTIVE OF THE DEMONSTRATION

The objective of this demonstration was to deploy the OPTEMA system to the Yuma Proving Grounds to quantify its expected detection and discrimination performance. As far as we are aware, OPTEMA represents the only advanced EMI sensor technology with the objective of achieving both the detection and discrimination tasks in a single pass of the sensor system[1]. In principal there will be sites where this approach is more cost effective than the two-pass approach that has been adopted by the existing advanced sensor technologies (MetalMapper, TEMTADS, BUD).

[1] The BUD sensor was deployed at Camp Sibert in a hybrid mode that involved switching to cued-interrogation mode each time an item was detected in survey mode.

2.0 TECHNOLOGY

2.1 TECHNOLOGY DESCRIPTION

The original intention of ESTCP MM-0908 was to develop a dynamic deployment mode for the Time-domain Electromagnetic Towed Array Detection System (TEMTADS) sensor which had previously been deployed in a cued-interrogation mode. This was to be achieved by: (i) designing and constructing additional transmitters optimized (as much as possible) for application in a dynamic mode; and (ii) integrating the TEMTADS with the Novatel SPAN using the Sky Research Data Acquisition System (SKYDAQ) for precise time synchronization of all data-streams. During the course of the project we changed the underlying system to one adapted from the Advanced Ordnance Location (AOL) hardware, which includes three-component receiver cubes in place of the single component receiver coils used in TEMTADS. We also eliminated the SKYDAQ from the system and instead adapted the existing AOL DAQ for precise time-synchronization of the electromagnetic and positional data.

In September 2010 the modified system, the OPTEMA, underwent a successful shakedown test at the Former Lowry Bombing and Gunnery Range (FLBGR). For that deployment, the AOL hardware was installed on a sled in front of a Kubota tractor (Figure 1). A key-feature of the new system was the use of transmitters rotated 45 degrees to the direction of travel. This ensures that good horizontal excitation in two orthogonal directions can be achieved for any object that passes underneath the sensor footprint (in particular the object does not have to be directly under the center of the array). Initial processing results from that shakedown test indicated that the system had good discrimination potential (see the supporting technical data). In particular there was generally very good agreement between the polarizabilities obtained for passes over an object at different lateral offsets, indicating that we met our goal of producing a one-pass system that can accurately characterize objects across the full sensor swath.

Front-mounting an EMI sensor on a tractor is a good way to optimize cued-interrogation surveys. However, for dynamic surveying, a lot of engine vibration is transmitted to the sensor system, effectively increasing the noise experienced by the receivers. Engine (and other sources of) vibration can be reduced significantly by mounting the system on a towed-array. Before deployment to YPG, a custom designed towed-array was built for the system (Figure 1c). This sled was designed to be very low to the ground, with minimal vibration transmitted to it either from the ground or the tow-vehicle.

We deployed to YPG with the system as described above even though there were some concerns about the ruggedness of the AOL electronics. To produce a system better suited to wide-scale use in a production environment, two improvements would need to be made:

(1) Wider swath width: The existing horizontal axis transmitters are 1.0 meter (m) wide but are turned by 45 degrees so that they only cover a 70 centimeter (cm) wide swath. In addition, the transmitters sit on top of the Z-axis transmitter raising them by about 8 cm. A significant improvement in production could be achieved by increasing the transmitter lengths to 2.0 m (1.4 m swath), with signal-to-noise ratio (SNR) improved by lowering the horizontal axis transmitters by 8 cm (there are some small construction challenges that arise as the wires for different transmitters almost intersect).

(2) Commercially available electronics: The system is currently based on the electronics from the AOL sensor which was the precursor to the commercially available MetalMapper sensor. The AOL can only support nine receiver cubes, whereas the current design calls for ten receiver cubes. For a production system, the DAQ and, receiver boards and cubes should be replaced with commercially available MetalMapper components.

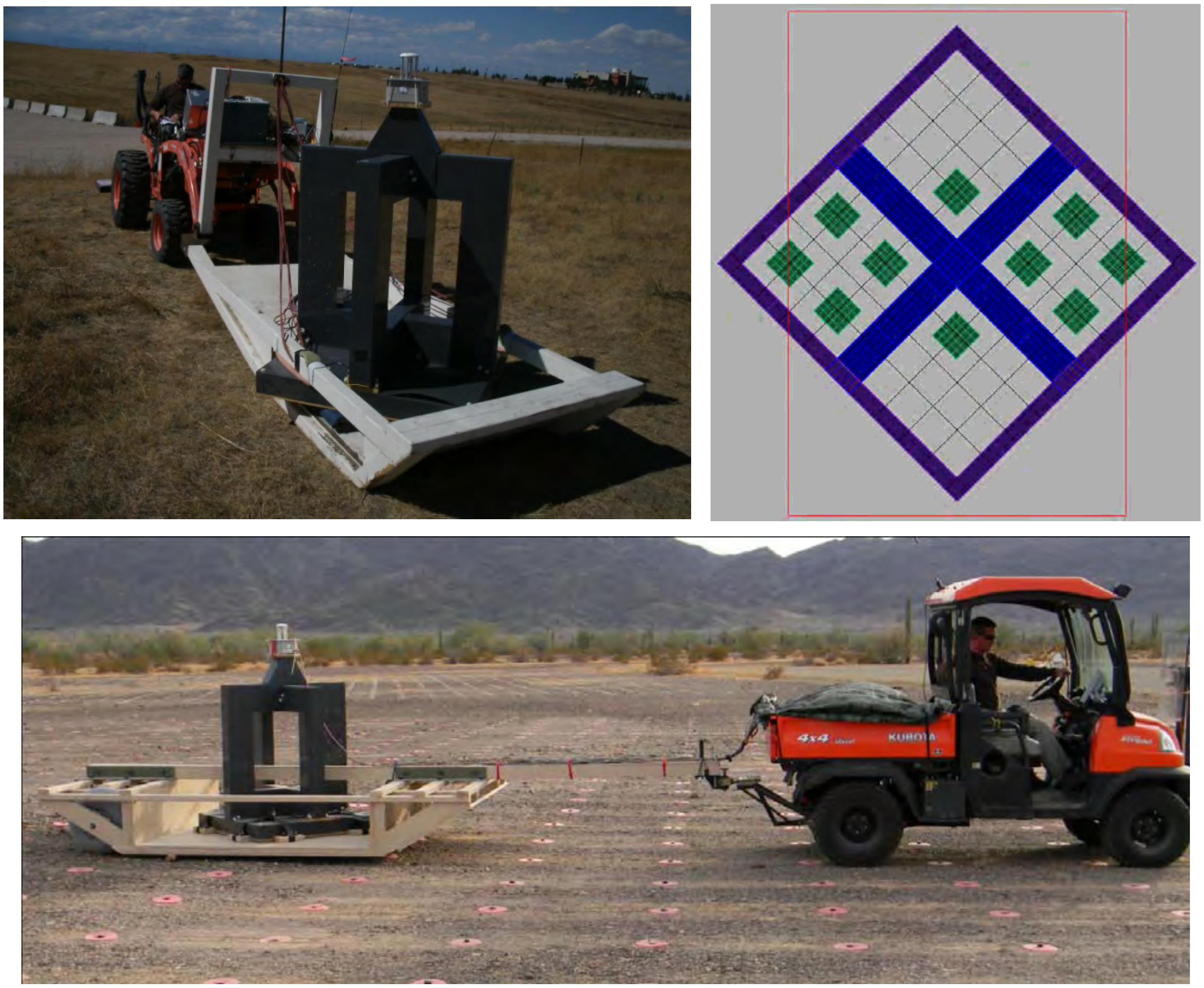


Figure 1: Top left: OPTEMA system undergoing preliminary tests at the Former Lowry Bombing and Gunnery Range. Top right: Plan view of the existing OPTEMA system showing the vertical axis transmitter (purple), two horizontal axis transmitters (blue) and 10 receiver cubes (green). The far right receiver cube position is currently unpopulated. Bottom: System as deployed at YPG in December 2010.

Summarizing the components of the OPTEMA system:

1) Excitation of multiple axes: To be able to discriminate using feature vectors from all three polarizations, the object must be excited from a wide-range of different angles. In cued-mode advanced sensors such as TEMTADS and MetalMapper achieve this by cycling through a number of transmitters. For TEMTADS this involves firing each of the 25 transmitters one at a time while for MetalMapper three orthogonal transmitters are fired one at a time. Achieving something equivalent when attempting mobile discrimination is more challenging. A key innovation of the OPTEMA system is the use

of three orthogonal transmitters that are turned 45^o to the direction of travel. The field directly under each horizontal axis transmitter is at 45^o to the direction of travel (under one transmitter it is 45^o clockwise, under the other it is 45^o anti-clockwise). The field away from the edges of the vertical axis transmitter is either vertical or near vertical. By cycling through each of the three transmitters in rapid succession, the OPTEMA system can generate excitation fields in (approximately) three orthogonal directions across the full swath width of the array.

2) Characterization of scattered field: When a metallic object is beneath the array, it scatters the primary field generated by the transmitter. The OPTEMA system uses nine (and will eventually use ten) three-component receiver coils that measure all three components of the scattered magnetic field (actually the time-rate of change of the scattered field). The scattered field can be approximately modeled as a dipole and the receivers have been positioned to provide near optimal constraints on the dipole location and time-varying moment.
3) Positional and orientation accuracy: In a dynamic mode, discrimination relies on accurate relative positions between successive measurements. The OPTEMA system uses the Novatel SPAN which comprises a global positioning system (GPS) and a high-end inertial navigation system (INS) and which has produced positions accurate to around 1-2 cm in field-tests (see Figure 2) when the data are post-processed using a Kalman filter formulation. The Novatel SPAN outputs Real-Time-Kinematic (RTK) positions and attitude information at a 1 Hertz (Hz) rate over a serial port and this information is used to control the pilot navigation display that guides the driver along parallel transects. GPS and INS messages designed for post-processing are logged at their maximum rates (20 and 100 Hz) on the SPAN system itself. The Inertial Explorer package is then used to post-process the position data within a Kalman filter formulation: this produces maximum position and orientation accuracy.
4) Timing accuracy: The accurate and stable synchronization of the different sensor components is a critical requirement for successful discrimination based on dynamically collected data. Synchronization with GPS time is achieved by outputting a hardware pulse at the start of each data-block to the COM port on the Novatel SPAN where a MARKTIME message is generated with a timing accuracy of better than 1 microsecond (ms).
5) Measurement time and data-density: The longer the time-range measured, the further the array will move during a single measurement, the lower the density of the measurements and the lower the SNR at the later time-channels. Results at Camp Sibert and San Luis Obispo (SLO) have demonstrated the effectiveness of late-time information in distinguishing targets of interest (TOI) from non-TOI. For the OPTEMA system we have settled on a goal of 2.7 ms time-decays, which appears to provide a good compromise between data-density and time-decay range.
6) Signal to noise ratio: In cued-mode, the data are stacked to improve signal-to-noise ratio. In dynamic mode, the choice of the number of stacks involves a compromise between improving SNR and blurring of spatial detail. The lower the number of stacks, the less movement that occurs during each measurement. For the OPTEMA system we have decided to aim for a 0.1 second acquisition time for each individual transmitter cycle, which allows 9 measurements (each one involving a positive and negative transmitter excitation) to be stacked.

The OPTEMA system effectively creates a series of cued-interrogation surveys, with one full cycle through the three transmitters requiring 0.3 seconds. At our target speed of 0.5 meters/second (m/s) this results in 5 cm of movement during each individual transmitter cycle and one complete set of measurements (involving all three transmitters) every 15 cm. The intention is that the lower SNR of the one-pass mode is compensated by an increased number of observation locations. We feel that this characteristic would be particularly useful when dealing with multiple objects. Note that we are currently investigating whether it's necessary to account for the 5 cm of movement during each transmitter cycle when attempting to fit a polarization tensor model to the data.

OPTEMA has the ability to characterize the parameters of a buried object across the swath of the array, including objects that lie towards the edge of the sensor (but still inside the transmitter footprint). We thus only need to use a single pass of the system to characterize the underlying polarization tensor parameters, and hence can avoid stitching together data from adjacent passes. The relative positional and orientation error of adjacent observations in a single pass are smaller than the error between observations collected during different passes. Hence, positional and orientation errors have a smaller impact on the final outcome.

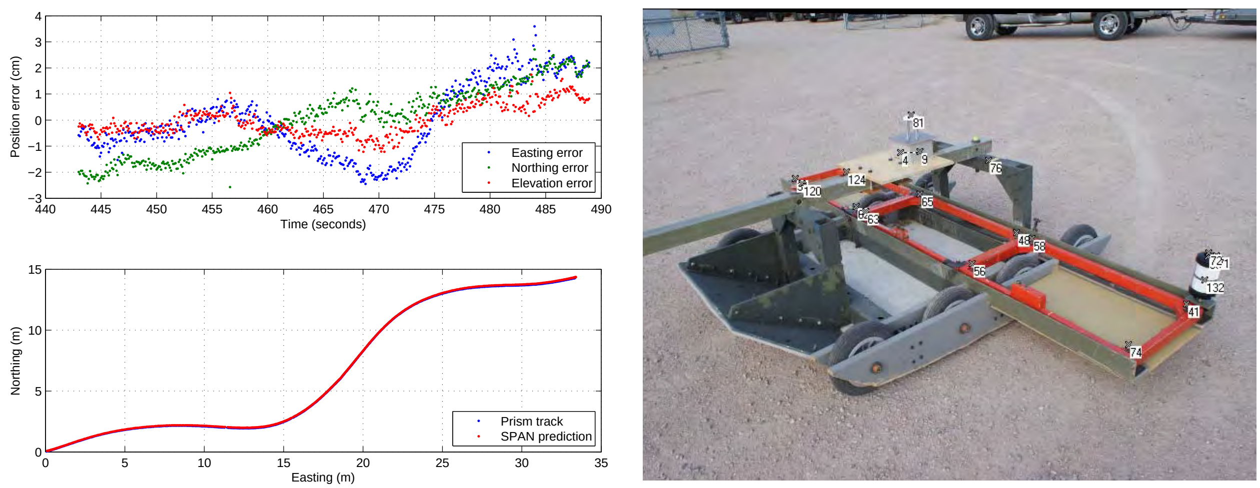
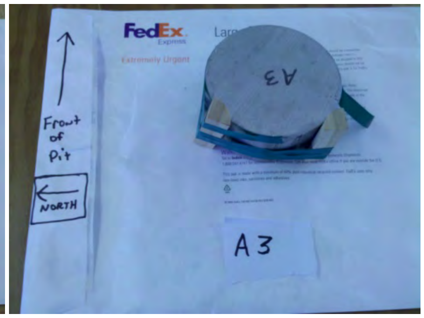


Figure 2: Test of the position accuracy of the SPAN when mounted on the Sky Research EM-61 towed-array. The objective was to use the SPAN positions (point 81) and orientations to predict the position of the Trimble prism (point 132) on the left-rear corner of the array. The Trimble SCS930 positions are accurate to around 0.5 cm. The top panel shows the difference between the SPAN and SCS930 positions as the towed-array traversed the curved path in the middle panel. Most of the SPAN predictions are within 2.5 cm of the prism position with a total mean-squared error of 2.0 cm. The lever-arm between the SPAN and the prism is 158 cm, so a 1 degree error in orientation would translate to a 2.75 cm error in position. We conclude that the SPAN positions are orientations are better than 2 cm and 1 degree.

2.1.1 Preliminary Deployment at FLBGR

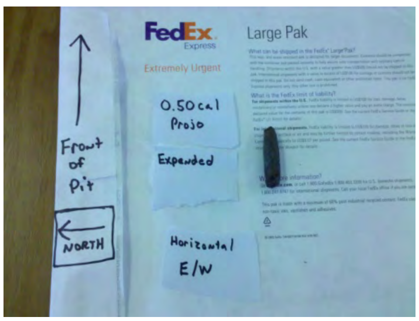
A shakedown test of the OPTEMA system mounted on the front of a Kubota tractor was conducted at the Former Lowry Bombing and Gunnery Range in Colorado between September 20-24, 2010. Data were collected over a Geophysical Prove Out at FLBGR as well as over a number of calibration items (five of them are shown in Figure 3). Each calibration item was placed at the bottom of a shallow test-pit at a depth of 25 cm from the surface. For each item three different transects were collected. In the first transect, the item passed under and along the left edge of the sensor array. For the second transect the item passed directly under the center of the array, while for the third transect it passed under the right edge of the array.

Iron disc



Aluminum disc

Aluminum Rod



50 cal projectile

Fragmentation

Figure 3: Five of the test-objects measured with the OPTEMA system at the FLBGR site.

For each calibration item, a polarization tensor model was fit to each transect to test the ability of the system to characterize items across the 1 m sensor swath. Figure 4 shows the observed and modeled data and residuals from the Z-axis and X-axis transmitters for the central transect over the aluminum disc shown in Figure 3 . Figure 5 shows the observed and modeled soundings when the array is approximately centered over the aluminum disc. In general, there was excellent agreement between observed and modeled data. Note that these results were obtained using the real-time positions from the SPAN and were achieved using default UXOLab inversion settings. We anticipate even better agreement between observed and modeled data when the real-time positions are replaced with post-processed positions and after optimizing inversion settings.

Figure 6 shows the recovered polarizations for each of the three transects over each of the five different items. For this example, all data from all transmitters and receivers were utilized. There is generally very good agreement between the polarizabilities for the three different transects, indicating that we met our goal of producing a one-pass system that can accurately characterize objects across the full sensor swath.

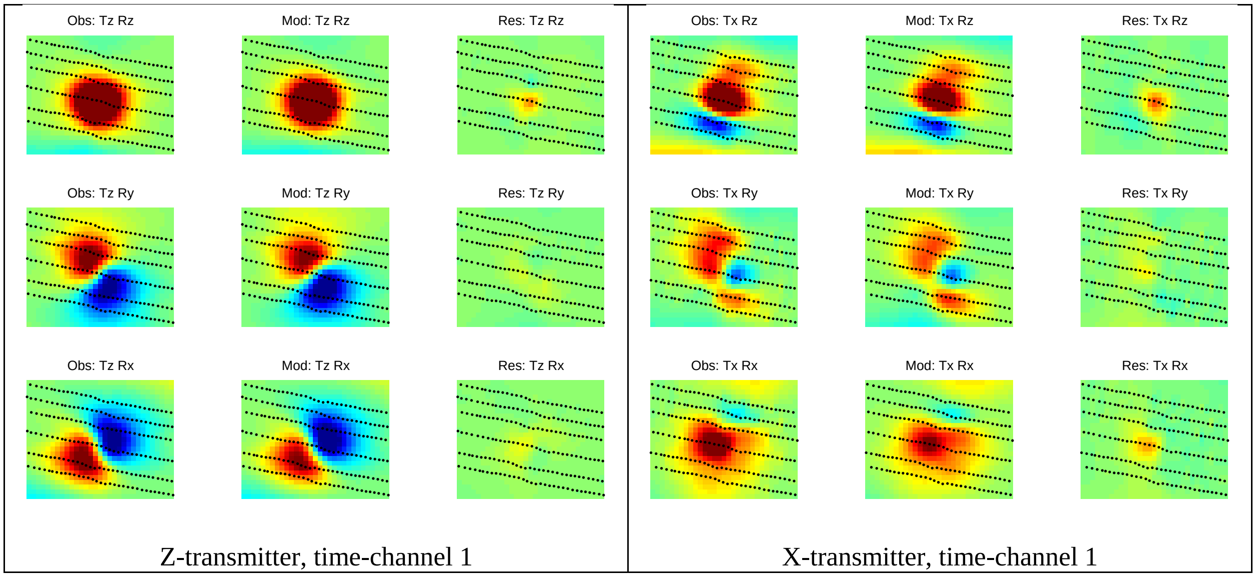


Figure 4: Example match between data and model for the Al-disc: results are shown for time-channel 1. Sensor measurement locations are shown as black dots.

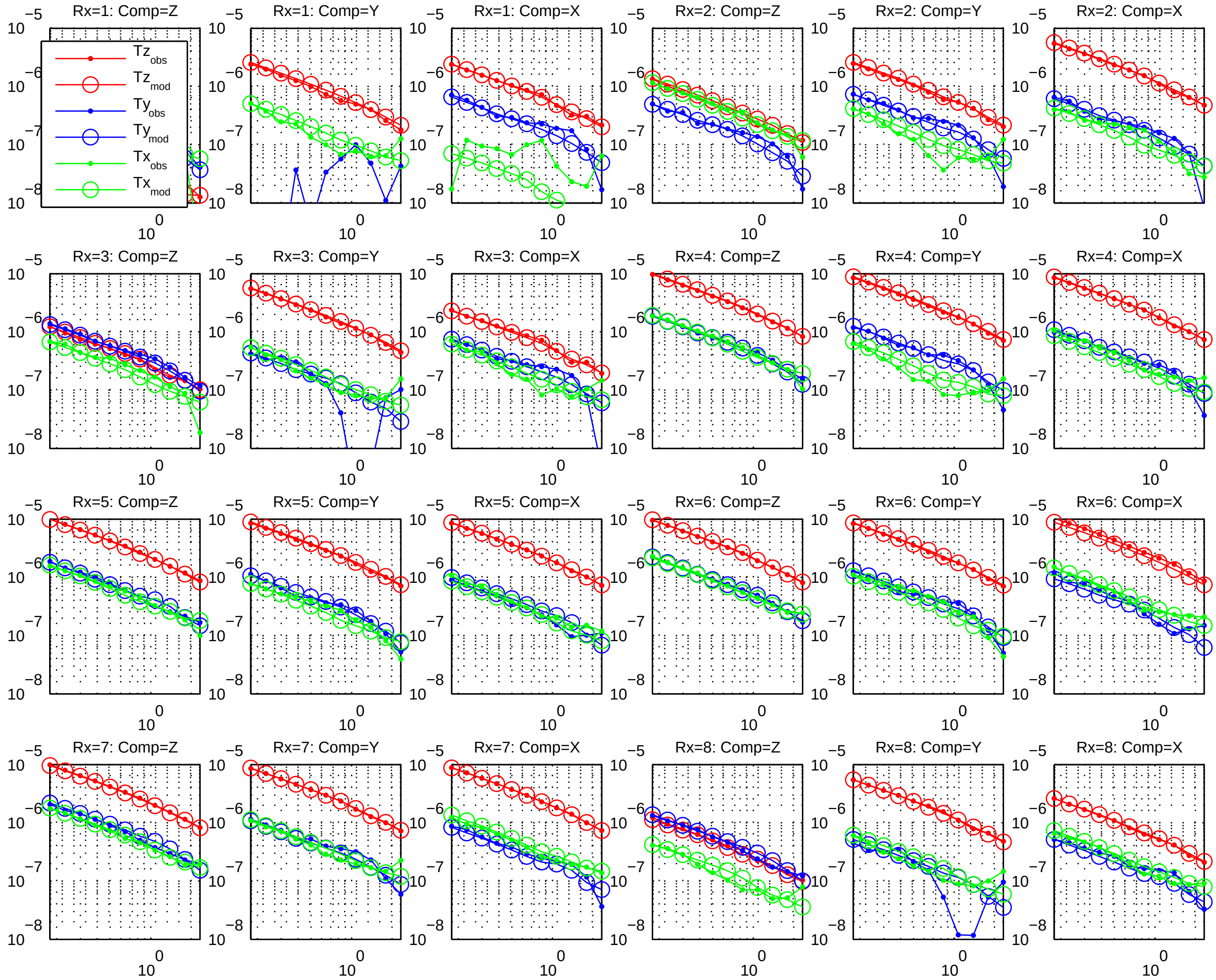


Figure 5: Example match between data and model for 8 of 9 receivers for the sensor position closest to the buried object, in this case an Aluminum disc.

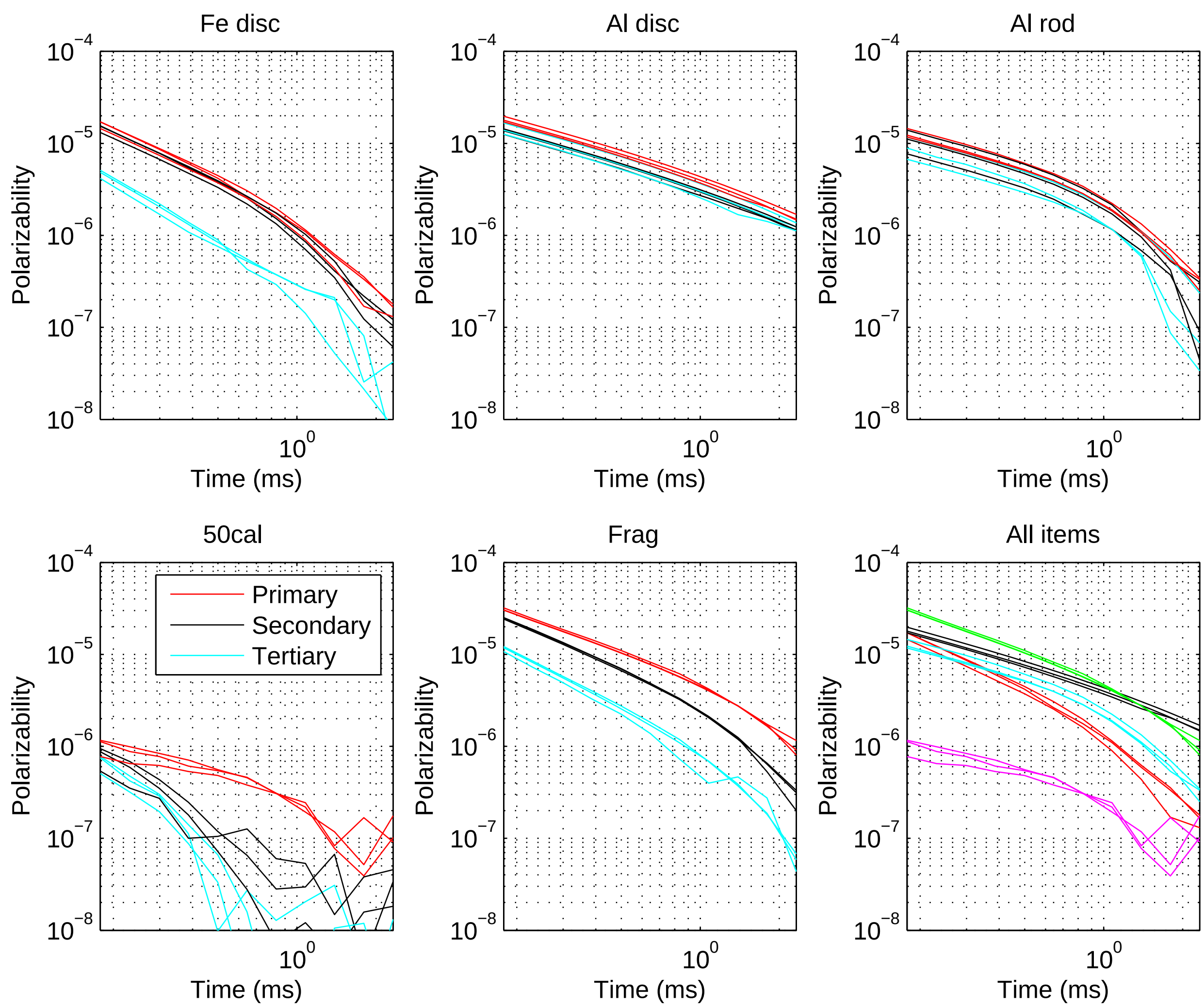


Figure 6: Recovered polarizations using all receivers and transmitters. Each panel (expect the last) contains three models corresponding to different lateral positions of the object relative to the sensor array (left edge, center, right edge). The last panel shows the primary polarizability for all three models for all 5 items in the previous panels.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The main advantage of the OPTEMA system is the ability to collect data for the dual purposes of detection and discrimination in a single pass, as opposed to the two pass approach currently used with TEMTADS, MetalMapper and Berkeley UXO Discriminator (BUD) sensors. The main limitation is that the system can only be deployed in areas that are trafficable by a vehicle towed system. We don't yet know if the discrimination ability of the system will be better or worse than the cued-interrogation sensor. This will likely depend on the nature of the targets of interest, the clutter and any physical features of the site (e.g. surface roughness, effect of soil on sensors).

3.0 PERFORMANCE OBJECTIVES

The performance objectives for this demonstration are summarized in Table 1. Note that to preserve the integrity of ground-truth information that IDA rounds the numbers related to detection and discrimination performance to within 5%.

Table 1: Performance Objectives for This Demonstration.

				Performance metric achieved?	
Performance Objective	**Metric**	**Data Required**	**Success Criteria**	**Blind-Grid**	**Open-Field**
Detection of all munitions of interest	Probability of detection (Pd) of seeded items at different depth	• Detection map • List of potential targets • Rate of detection of seeded munitions	Pd=0.98 for all munitions within top 0.75 m depth	Yes 1.0	Yes 0.98
Maximize correct classification of munitions	Number of targets-of-interest retained	• Prioritized anomaly lists • Scoring reports from Institute for Defense Analyses (IDA)	Pdisc=0.98 for all munitions within top 0.75 m depth	Yes 1.0	No >=0.95
Maximize correct classification of non-munitions	Number of false alarms eliminated	• Prioritized anomaly lists • Scoring reports from IDA	Reduction of false alarms by > 30% while retaining all targets of interest	Yes 60% reduction	No 28% reduction
Minimize number of false detections that are classified as munitions	Number of items on the dig-list that do not correspond to either ordnance or clutter that are classified as ordnance	• List of detections • Scoring reports from IDA	Pfa < 0.05 (less than 5% of targets don't correspond to locations of seeded ordnance or clutter)	Not reported	Not fully reported Pfa < 0.1
Correct estimation of target locations	Accuracy of estimated target locations	• Demonstrator target parameters • Scoring reports from IDA	X, Y < 15 cm (1σ) Z < 10 cm (1σ)	Yes 9.3, 9.6 cm for X,Y Unknown for Z	Yes 9.1 cm for X,Y No 15 cm for Z

3.1 OBJECTIVE: DETECTION OF ALL MUNITIONS OF INTEREST

All munitions of interest need to be successfully detected for this technology to be a success.

3.1.1 Metric

The metric for this objective is the number of seeded items that are detected by the OPTEMA sensor, using a 0.5 m detection halo.

3.1.2 Data Requirements

The YPG scoring submission will be used to calculate detection probability.

3.1.3 Success Criteria

The objective will be considered to be met if at least 98% of the munitions seeded at depths of 75 cm or less are detected.

3.1.4 Results achieved

Scoring information provided by IDA on behalf of the Program Office indicated that:

- On the Blind-Grid all emplaced UXO were detected (performance metric met).
- On the Open-field (performance metric met):
  - > 95% of all emplaced ordnance were detected.
  - UXO types missed included 2.75” rockets, 40mm projectiles, 60 and 81mm mortars and BDU-28 submunitions.
  - The depth distributions of missed detections were as follows: 0-4 diameters=10%, 4-8 diameters=35%, >8 diameters=55%
  - > 98% of UXO buried at less than 75 cm were detected within the specified detection halo (0.5 m radius for targets <0.5 m long and an ellipse with a semi-major axis of L*cos(theta)/2+0.5 m and semi-minor axis=0.5 m, where L is UXO length and theta is dip angle for targets with L>0.5 m).

3.2 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF MUNITIONS

This is one of the two primary measures of the effectiveness of the classification approach. By collecting high quality data and analyzing those data with advanced parameter estimation and classification algorithms we expect to be able to classify the targets with high efficiency. This objective concerns the component of the classification problem that involves correct classification of items-of-interest.

3.2.1 Metric

The metric for this objective is the number of items on the master anomaly list that can be correctly classified as munitions by each classification approach.

3.2.2 Data Requirements

Each demonstrator will prepare a prioritized dig list for the targets on the master anomaly list. IDA personnel will use their scoring algorithms to assess the results.

3.2.3 Success Criteria

The objective will be considered to be met if all of the items of interest are correctly labeled as munitions on the prioritized anomaly list.

3.2.4 Results achieved

Scoring information provided by IDA on behalf of the Program Office indicated that:

- On the Blind-Grid all emplaced UXO were detected and correctly classified as UXO (performance metric met).
- On the Open-field (performance metric not met).
  - Probability of correct classification was > 95%
  - UXO types classified as clutter included 105 and 155mm projectiles, 60 and 81mm mortars, M42 and M75 submunitions.
  - The depth distribution of false negatives was: 0-4 diameters=35%, 4-8 diameters=45%, >8 diameters=20%.
  - The top ~50% of the false negatives (closest to the top of the list) were all 60mm mortars and M42 submunitions
  - The bottom ~50% of the false negatives were dominated by 105mm rounds (projectiles and HEAT)
  - The maximum location error for a false negative was 34 cm, and the average location error for a false negative was 11 cm.

3.3 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF NON-MUNITIONS

This is the second of the two primary measures of the effectiveness of the classification approach. By collecting high-quality data and analyzing those data with advanced parameter estimation and classification algorithms we expect to be able to classify the targets with high efficiency. This objective concerns the component of the classification problem that involves false alarm reduction.

3.3.1 Metric

The metric for this objective is the number of items-of-interest in the YPG scoring submission that can be correctly classified as clutter.

3.3.2 Data Requirements

Prioritized dig-lists in the standard scoring format required by YPG.

3.3.3 Success Criteria

The objective will be considered to be met if more than 30% of the non-munitions items can be correctly labeled as non-munitions while retaining all of the targets-of-interest on the dig list.

3.3.4 Results achieved

Scoring information provided by IDA on behalf of the Program Office indicated that:

- On the Blind-Grid (performance metric met):

  - Probability of False Alarm was 40% (60% unneccesary digs saved) for the classifier with 100% probability correct classification (Pcc) of UXO.
  - Probability of False Alarm was 20% for a more aggressive classifier that reduced the probability of correct classification to 95%.
- On the Open-Field (performance metric not met):
  - At P_{class} = 100%, 28% of the unnecessary digs would have been saved.
  - At P_{class} = 99%, 56% of the unnecessary digs would have been saved.
  - At P_{class} = 95%, 81% of the unnecessary digs would have been saved.

3.4 OBJECTIVE: MINIMIZE NUMBER OF FALSE DETECTIONS THAT ARE CLASSIFIED AS MUNITIONS

Digging up anomalies that don't have a metallic source (e.g. geological false-alarms, or noise events that trigger a detection) can be expensive because the source of the anomaly is never conclusively determined.

3.4.1 Metric

The metric for this objective is the number of items classified as munitions that don't correspond to the location of either a munition or non-munition item (this is a different metric than the one in 3.3 which concerns the number of non-munitions that are incorrectly classified as munition).

3.4.2 Data Requirements

Prioritized dig-lists in the standard scoring format required by YPG.

3.4.3 Success Criteria

The objective will be considered to be met if no more that 5% of the targets classified as munition don't correspond to the location of a munition or non-munition item (using a detection halo of 0.5 m).

3.4.4 Results achieved

No information on detection stage false-alarm rates were reported on the Blind-Grid. For the Open-Field only limited information was provided in the form of a statement that less than 10% of declared anomalies fell outside the detection halo for munitions and clutter items.

3.5 OBJECTIVE: CORRECT ESTIMATION OF TARGET LOCATIONS

This objective is intended involves the accuracy of the target locations that are estimated in the parameter extraction process. Successful classification is only possible if the input features are internally consistent, and one indirect measure of this attribute is the positional accuracy of the recovered dipole models.

3.5.1 Metric

Accuracy of estimation of target locations is the metric for this objective.

3.5.2 Data Requirements

Position and depth of detected items.

3.5.3 Success Criteria

The objective will be considered to be met if the estimated X, Y locations are within 15 cm (1σ), and the estimated depths are within 10 cm (1σ).

3.5.4 Results achieved

Mislocation errors on the Blind-Grid can be obtained by calculating the mismatch between the cell center and the recovered dipole location. This analysis revealed root-mean-square location errors of 9.3 and 9.6 cm in Easting and Northing respectively.

For the Open-field, IDA provided location error statistics using isolated true positives that were within the detection halo of OPTEMA detections (Table II). These revealed that the performance metric for horizontal location error was met, but that the performance metric regarding error in estimated depth was not met.

Table 2. Statistics of location error from the Open-Field on isolated true positives within the detection halo.

Miss Distance	Maximum negative (cm)	Maximum Positive (cm)	Median Error (cm)	Mean Error (cm)	Standard deviation of error (cm)
East	-42.6	54.7	-0.4	-0. 6	9.9
North	-50.0	38.3	-0.3	0	8.5
Horizontal Radius	0.5	74.1	6.4	9.4	9.1
Depth	-95.6	39.2	12.7	9.7	15.4

4.0 SITE DESCRIPTION

The demonstration was conducted at the Unexploded Ordnance (UXO) Standardized Test Site at Yuma Proving Grounds in Arizona. We surveyed the Calibration and Blind Grids as well as a large portion of the the Open Field Area. Information on YPG can be found at:

http://aec.army.mil/usaec/technology/uxo01c02.html.

5.0 TEST DESIGN

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

During the course of the demonstration we surveyed the Calibration and Blind Test Grids as well as the Open Field Area. All relevant data collection parameters (see section 5.5) except the time-decay range were selected through previous testing and analysis. We selected 2.7 ms as the time-decay range to use, but also collected data with shorter time-decay (0.9 ms) and longer decay (8.1 ms) on the Calibration and Blind-Test Grids.

5.2 SITE PREPARATION

No site preparation work was required.

5.3 SYSTEM SPECIFICATION

The OPTEMA comprises three transmitter (Tx) coils in the X, Y and Z planes with overall dimensions of 1.0 x 1.0 x 1.0 meters. Each inductive Tx coil draws ~5 Amps from the Tx Driver electronics. The Receiver system consists of nine strategically placed 3 axis receiver (Rx) coils. Transmitter pulse duration is user selectable from 300 μs to 225 ms, with a target time-decay range of 2.77ms (2.77ms Tx On, 2.66ms Tx Off). Tx repetition is in the order of TxOn+, TxOff, TxOn-, and last TxOff. The Tx cycle then repeats until altered. All Rx channels and coils were utilized along with all three Tx coils.

Data logging is integrated into and performed by the custom designed Electronics Console. Synchronization of EM data with GPS positional data was achieved via trigger pulses sent to the GPS from the EMI sensor at the same time as an EMI data acquisition event commenced. This provided a common signal channel between the EMI sensor and GPS and provided the necessary synchronization.

Positional data was acquired by a NovAtel DL-4 GPS receiver in Real Time Kinematic (RTK) mode that utilized real time corrections transmitted by a local base-station. The DL-4 receiver was interfaced to a Honeywell IMU-HG tactical grade inertial measurement unit. Together these two sensors comprise the NovAtel Synchronized Position, Attitude and Navigation (SPAN) system. The SPAN outputs highly accurate position and attitude measurements at up to 100 Hz rates. This allowed very tight integration between physical coil orientations, location and EM data enhancing the overall system capabilities.

5.4 CALIBRATION ACTIVITIES

Periodically throughout the day (and at least twice) an Instrument Validation Survey (IVS) was conducted by collecting data along Lane L of the Calibration Grid (Figure 7). Polarization tensor models were fit to each of the 15 items that the array passes directly over and the locations and polarizability parameters were compared across days. The equipment was assumed to be functioning correctly if predicted locations and depths were within 10 cm of the expected values and the polarizabilities varied by less than 25% (compared to the average value computed from all the previous IVS instances).

5.5 DATA COLLECTION PROCEDURES

For the OPTEMA system we recorded 2.7 ms time-decays with a 0.1 second acquisition time for each individual transmitter cycle. This allowed 9 measurements (each one involving a positive and negative transmitter excitation) to be stacked. On the Calibration and Blind-Test Grids we also collected data with both shorter (0.9 ms) and longer (8.1 ms) decay transients, but keep the stack-time fixed at 0.1 seconds. This resulted in either 27 stacks (for 0.9 ms) or 3 stacks (for 8.1 ms).

The OPTEMA system effectively created a series of cued-interrogation surveys, with one full cycle through the three transmitters requiring 0.3 seconds. At our target speed of 0.5 meters/second (m/s) this resulted in 5 cm of movement during each individual transmitter cycle and one complete set of measurements (involving all three transmitters) every 15 cm.

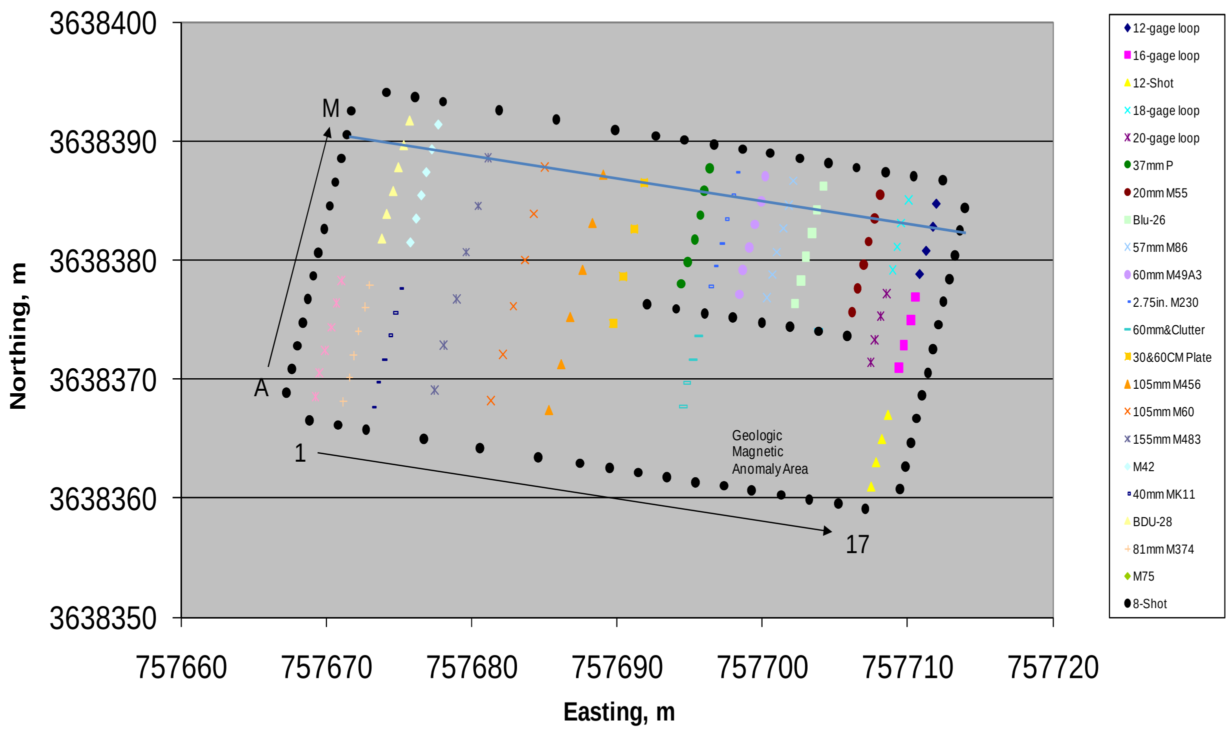


Figure 7. YPG calibration grid showing the layout of buried items. The blue-line shows the IVS that will be collected twice each day (along lane L).

Operation of the Novatel SPAN in RTK mode (for navigation) required the establishment of a GPS base-station that transmitted real-time corrections to the rover unit. For post-processing, the following logs were enabled on the base-station:

- RANGECMPB ONTIME 1
- RAWEPHEMB ONNEW

On the rover unit the following logs were collected:

- RANGECMPB ONTIME 1
- RAWEPHEMB ONNEW
- RAWIMUSB ONNEW

For optimal position and orientation accuracy, two minutes of static data collection were required for the Novatel SPAN to initialize and align the IMU. The alignment routine started soon after the SPAN was switched on (status INS_ALIGNING) and the SPAN was kept stationary (with the Kubota engine off) until the status changed to INS_ALIGNMENT_COMPLETE. At that point, not enough vehicle dynamics occurred for the INS solution to be accurate. The field operator then executed a figure 8 maneuver at which point the status would change to INS_SOLUTION_GOOD. The operator monitored the GPS status throughout the survey and would stop and rectify any issues if the status changed (e.g. if the RTK radio link dropped out, or not enough satellites were in the field of view). To optimize post-processing accuracy, 2 minutes of static data were collected at the end of the survey.

All EMI data and RTK estimates of position and platform orientation were stored in 0.3 second data blocks on the National Instruments computer that forms the backbone of the AOL DAQ. The position and orientation corresponded precisely (to within 0.1 ms or better) to the time at the start of a transmitter firing sequence (where each sequence comprises excitations from all three orthogonal transmitters). GPS and INS data, including RTK corrected and raw, were stored directly on the flash-card within the Novatel SPAN at rates of either 20 Hz (GPS messages) or 100 Hz (INS messages). The RTK position and orientation estimates were later replaced by their post-processed equivalents.

5.6 VALIDATION

Response and discrimination stage analysis of the Blind Test Grid and Open Field surveys were submitted in the standard YPG formats (see http://aec.army.mil/usaec/technology/uxo01b.html). The dig predicted were then scored by IDA for the Program Office.

6.0 DATA ANALYSIS PLAN

6.1 PREPROCESSING

The “raw” data collected as part of an OPTEMA survey comprises the following:

- EMI data in *.TEM files with one TEM file per line of data collected. Each line comprises a collection of data blocks with each block corresponding to 0.3 seconds of data collection that comprises
  - Precise (to within < 1μs) GPS time at the start of the data-block;
  - Estimated position (of the center of the IMU) and orientation of the platform at the start of the data-block (along with a number of GPS and INS quality factors and auxiliary data);
  - Decay transients of the X-, Y-, and Z-components of the nine different receivers corresponding the firing of the Z-transmitter along with the current in the Z-transmitter (times 0 to 0.1 seconds from start of data block)
  - Decay transients of the X-, Y-, and Z-components of the nine different receivers corresponding the firing of the Y-transmitter along with the current in the Y-transmitter (times 0.1 to 0.2 seconds from start of data block)
  - Decay transients of the X-, Y-, and Z-components of the nine different receivers corresponding the firing of the X-transmitter along with the current in the X-transmitter (times 0.2 to 0.3 seconds from start of data block)
- Raw and RTK GPS/INS data in Novatel *.PDC files, with one file per “survey event” (contiguous survey period). This file contains the following
  - RANGECMPB at 1 second increments
  - RAWEPHEMB at typically 1 second increments
  - RAWIMUSB at 100 Hz
  - INSPVAS at 100 Hz (RTK corrected position, velocity and attitude estimates)
- Base-station ephemeris data in Trimble *t00 format files (as we use a Trimble base-station). This file contains the equivalent of the following messages:
  - RANGECMPB at 1 second increments
  - RAWEPHEMB at typically 1 second increments

The following data processing steps are executed on the raw data:

(1) Post-process the Novatel SPAN data using the following procedure:
   a. Import raw SPAN and base-station files into Inertial Explorer;
   b. Select appropriate SPAN error model (for AG58 IMU);
   c. Process GPS data using default Inertial Explorer parameters;
   d. Check the estimated GPS position accuracies and flag locations where horizontal error exceeds 1.5 cm (these locations may need to be recollected);
   e. Set the GPS to IMU lever arm (for OPTEMA there is no horizontal offset just a 16.7 cm vertical offset of the GPS antenna from the IMU center);
   f. Smooth IMU data using the Rauch, Tung, and Striebel (RTS) smoother in both directions (forwards and reverse);
   g. Process the GPS/IMU data using the “loosely coupled” method and the Inertial Explorer default parameters;

   h. Check the estimated attitude and positional accuracies and flag any points with orientation errors exceeding 1 degree or horizontal position errors exceeding 1.5 cm.

(2) Estimate the positions and orientations of the centers of each of the nine receiver cubes at times of 0.05, 0.15 and 0.25 seconds after the start of a data-block (the mid-point of the transmit cycle for the Z-, Y- and X-axis transmitters respectively). This step requires the known offsets of each receiver relative to the center of the IMU;

(3) Import the *.TEM files into Matlab and extract the three components decay transients for each of the nine receiver cubes. This requires the following substeps:
   a. Convert raw TEM format files to ASCII format;
   b. Import ASCII format data into Matlab;
   c. Extract three-component decay transients from individual transmitter/receiver combinations and assign appropriate GPS times to each combination (e.g. for each Z-component transmitter block add 0.05 seconds to the GPS time at the start of the data block).

(4) Merge the decay transients calculated in (3) with the position/orientation estimates computed in (2).

(5) Estimate a background value for each receiver/transmitter/component/time-channel and remove that from the data. This was achieved by selecting a quiet region within the dataset, and calculating and then removing an average time-decay transient for each receiver/transmitter/component combination. This was done once for each day;

(6) Create spatial representations of the data by gridding the Z-transmit/Z-receive data combination (along with several others).

6.2 TARGET SELECTION FOR DETECTION

All targets above the sensor noise floor (found to be about 0.5 mV on the Z-transmit/Z-receive combination) were selected as potential UXO or clutter using an automated target detection routine based on the Blakely and Simpson (1985) method. An analyst inspected the data picks along with various other transmit/reciver combinations (e.g. Y-transmit/Y-receive) and added or rejected targets as appropriate.

6.3 PARAMETER ESTIMATION

A polarization tensor model was extracted for each detected targets as follows:

- Region definition: The sensor data within a 1.5 m diameter circle of the picked target position was submitted to the inversion routine. Only a single transect of data (9 receivers x 3 transmitters at multiple position) was used to constrain the polarization tensor parameters. The data transect whose center-point passed closest to the picked anomaly location was used. Where necessary, the region of data selected and/or the transect used was manually altered by the analyst. This proved to only be necessary in less than 2% of instances
- Single object inversion: An instantaneous polarization model was fit to each selected anomaly assuming there is one object in the field of the view of the sensor;
- Two object inversion: In about 2% of cases it was necessary to fit a two-object, instantaneous polarization tensor model;

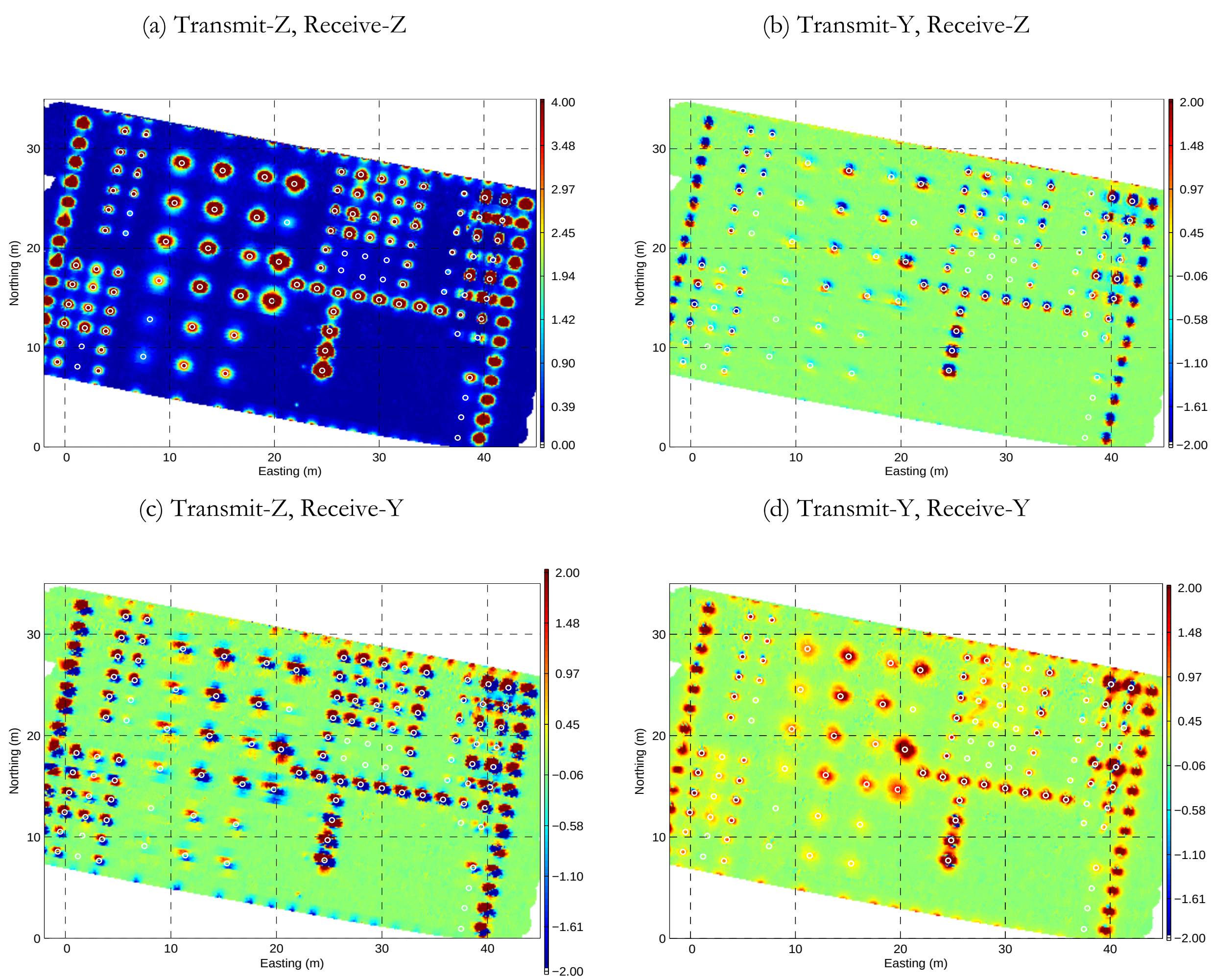


Figure 8. Maps of four of the nine transmit and receive combinations of the OPTEMA data from the Calibration Grid at YPG.

6.4 TRAINING

Training data were obtained from the Calibration Grid from the shallow, high SNR specimens of each of the targets of interest.

6.5 CLASSIFICATION

Items in the Blind Grid and Open-Field were classified as either UXO or non-UXO by an experienced analyst. The analyst reviewed the inversion results and the extracted polarization tensor model using the data QC tool illustrated in Figure 10 and developed a manual ranking scheme as follows:

- -3 high-probability clutter
- -2 medium probability clutter
- -1 low-probability clutter
- 1 low probability of UXO or fit too poor to reliably classify as clutter
- 2 medium probability to be UXO
- 3 high probability UXO

Anomalies with poor fits or overlap with adjacent anomalies were reinverted using a 2 object inversion code, sometimes after modifying the mask.

The polarization tensor models were also compared to each library polarization obtained from the calibration grid and an automated item match metric was computed as the norm of the difference between polarizabilities. This automated ranking scheme was used to sort the anomalies within each category of the manual ranking scheme.

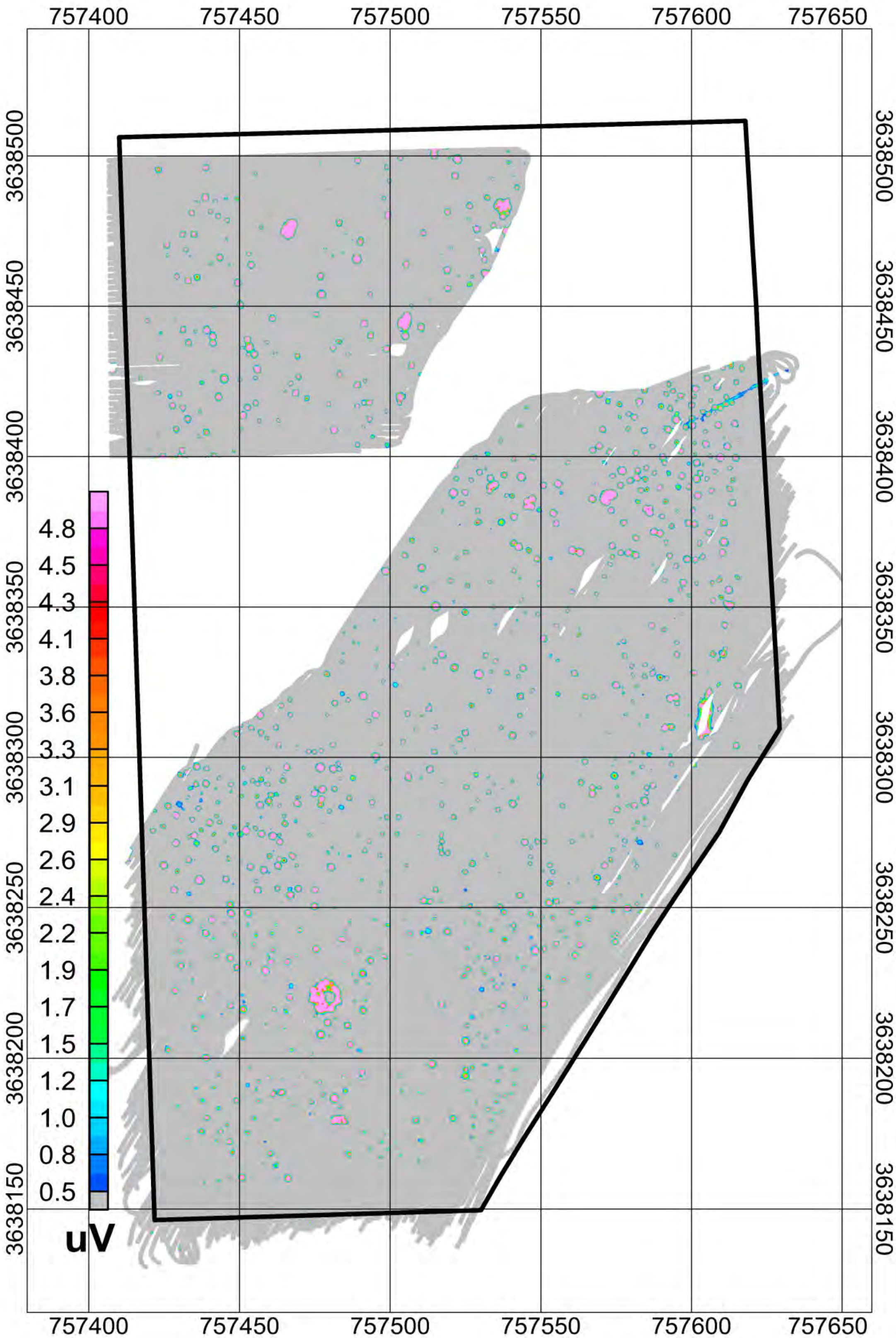


Figure 9. Map of open-field TxZRxZ data.

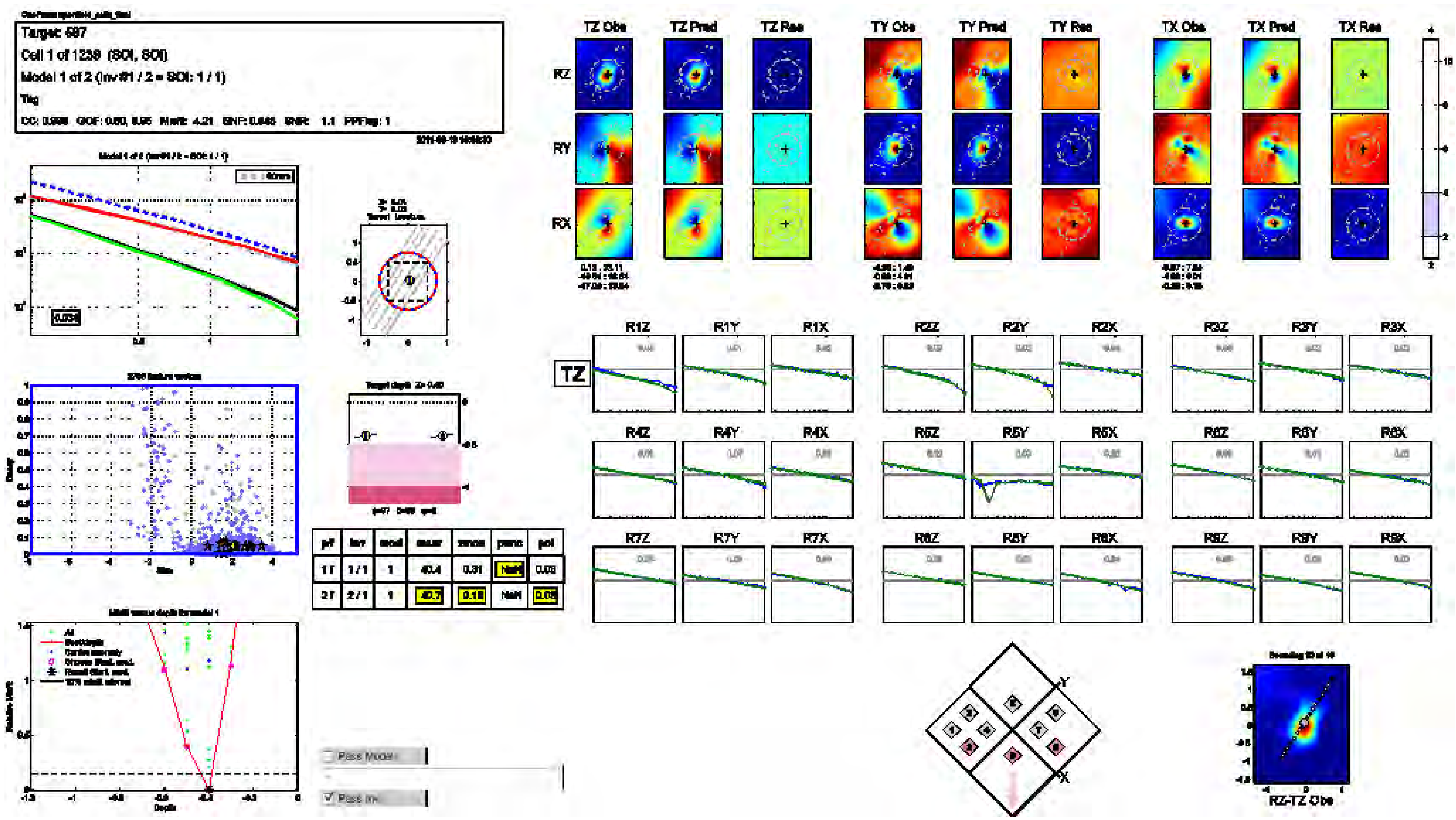


Figure 10. Data QC and classification tool used for developing UXO/non-UXO rankings

6.6 DATA PRODUCT SPECIFICATION

Response and discrimination stage analysis of the Blind Test Grid and Open Field surveys were submitted in the standard required formats. Two separate dig-sheets were submitted for the Blind-Grid (original and aggressive approach) and one dig-sheet for the Open-field.

6.7 SCORING RESULTS FROM PROGRAM OFFICE

Table 2 below summarizes the scoring results on the Blind-Grid. All UXO were detected and correctly classified as UXO with a false-alarm rate of 40%. After submitting a more aggressive dig-list the false alarm rate was reduced to 20% but the True Positive fraction dropped to 95%. All of these numbers have been rounded by IDA to prevent full-disclosure of the ground-truth. The location accuracy of the polarizabilities can be inferred from the deviation of the location of the recovered polarizability from the center of the Blind-Grid cells. Standard deviations of the position estimates were 9.3 and 9.6 cm in Easting and Northing, respectively.

Table 2. Results from the Blind-Grid.

Depth range	Original submission		Aggressive submission	
	True Positives	False positives	True Positives	False positives
All depths	1.0	0.4	0.95	0.2
< 0.3 m	1.0	0.35		
0.3 to 1.0 m	1.0	0.5		
> 1.0 m	1.0	N/A		

For the Open-field the response stage True-Positive fraction was 95% or greater with at least one each of the following munitions missed: 2.75” rockets, 40mm projectiles, 60 and 81mm mortars and BDU-28 submunitions. Depth distributions of missed detections were as follows: 0-4 diameters=10%, 4-8 diameters=35%, >8 diameters=55%.

For the classification stage, the True Positive fraction was 95% or greater with at least one of each of these UXO types classified as clutter: 105 and 155mm projectiles, 60 and 81mm mortars, M42 and M75 submunitions. The depth distribution of false negatives was: 0-4 diameters=35%, 4-8 diameters=45%, >8 diameters=20%.

At Pcc=100%, 28% of the unnecessary digs would have been saved.
At Pcc=99%, 56% of the unnecessary digs would have been saved.
At Pcc=95%, 81% of the unnecessary digs would have been saved.

Most problematic UXO: The top ~50% of the false negatives (closest to the top of the list) were all 60mm mortars and M42 submunitions. The bottom ~50% of the false negatives were dominated by 105mm rounds (projectiles and HEAT).

The maximum location error for a false negative was 34 cm, and the average location error for a false negative was 11 cm.

7.0 COST ASSESSMENT

The deployment at YPG was not representative of an actual field deployment of the OPTEMA system. Hence the costs incurred to conduct the YPG demonstration are not indicative of the costs to deploy the technology. We will defer development of a cost-assessment until the system has been deployed to a live-site.

8.0 SCHEDULE OF ACTIVITIES

Table 2 summarizes the activities conducted during the December 6 to 17 deployment of the system, with a detailed field notes provided in the appendix.

Table 3: Main project activities at YPG (R indicates a repeat survey).

	December 6 to 10					**December 13 to 17**				
Activity	**M**	**T**	**W**	**T**	**F**	**M**	**T**	**W**	**T**	**F**
Unpack and set-up										
Calibration grid surveys										
2.7 ms time-decays										
0.9 ms time-decays										
8.1 ms time-decays										
Blind Test Grid surveys										
2.7 ms time-decays			R							
0.9 ms time-decays										
8.1 ms time-decays										
Days with significant downtime										
Open Field surveys										
Pack up and depart.										

9.0 MANAGEMENT AND STAFFING

Dr Stephen Billings was the PI on this project and oversaw the data collection, processing and analysis tasks. He was on-site at YPG for the first week of the project.

Dr. Dan Steinhurst (Nova/Naval Research Laboratory) assisted with the data collection and the assessment of the appropriate data collection parameters to be used. He was at YPG for the first week of the demonstration.

Mr Kevin Kingdon was the on-site geophysicist for the second week of the demonstration and supervised the data collection tasks as well as conducting initial processing and QC of the data.

Mr Cameron Pond will be the field technician responsible for operating the OPTEMA system at the site.

Mr Glenn Harbaugh (Nova/Naval Research Laboratory) assisted with the data during the second week of the demonstration.

Data processing and interpretation was conducted by Dr Stephen Billings with support from Drs Laurens Beran (Sky Research) and Lin-Ping Song (University of British Columbia).

Joy Rogalla was the project manager and provided project coordination.

The project Organization chart is shown in Figure 7.

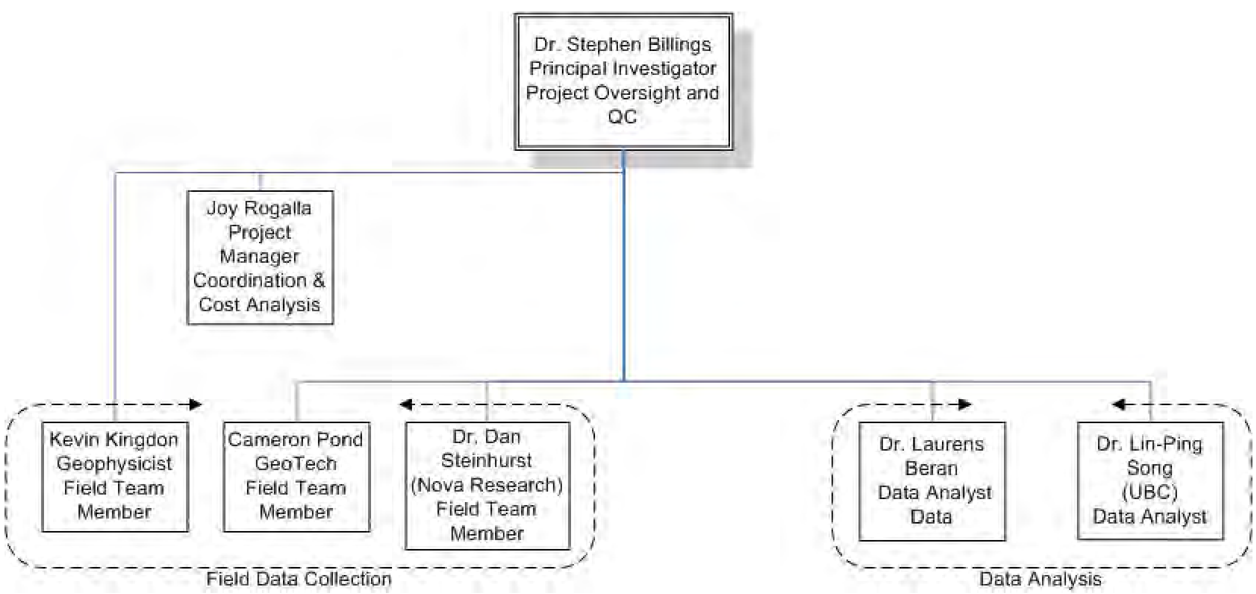


Figure 11: Project Organization Chart

10.0 REFERENCES

Blakely, R. J. and Simpson, R. W., 1986, Approximating edges of source bodies from magnetic or gravity anomalies: Geophysics, v.51, p. 1494-1498.

APPENDICES

Appendix A: Health and Safety Plan (HASP)

The YPG Standardized UXO test-site Health and Safety Plan will be used for this demonstration. The plan can be found at:

(http://aec.army.mil/usaec/technology/uxo-workplan.pdf)

Appendix B: Points of Contact

POINT OF CONTACT Name	ORGANIZATION Name Address	Phone Fax E-mail	Role in Project
Stephen Billings	Sky Research Inc. Suite 112A, 2386 East Mall Vancouver, BC V6T 1Z3 Canada	541.552.5185 542.488.4606 Steve.billings@skyresearch.com	PI On site lead in week 1 Data processing and QC
Kevin Kingdon	Sky Research Inc. Suite 112A, 2386 East Mall Vancouver, BC V6T 1Z3 Canada	541.552.5188 604.827.3221 Kevin.kingdon@skyresearch.com	Data processing and QC On site lead in week 2
Daniel Steinhurst	Nova Research, Inc./ Naval Research Laboratory 1900 Elkin Street, Suite 230 Alexandria, VA, 22308		Data processing and field data collection assistance
Cameron Pond	Sky Research Inc. 12850 East Control Tower Road Hangar 14 Centennial, CO 80112	541.552.5158 303-925-1067 cameron.pond@skyresearch.com	Field technician, on-site data collection
Laurens Beran	Sky Research, Inc. Suite 112A, 2386 East Mall Vancouver, BC V6T 1Z3 Canada	541.552.5188 604.827.3221 laurens.beran@skyresearch.com	Data analyst Review collected data to evaluate discrimination performance
Lin Ping Song	UBC-GIF The University of British Columbia 6339 Stores Road Vancouver BC V6T 1Z4 Canada	604.822.1819 604.822.6088 lpsong@eos.ubc.ca	Data analyst Fit polarization tensor models to the data
Joy Rogalla	Sky Research, Inc. 445 Dead Indian Memorial Road Ashland, OR 97520	541.552.5104 541.488.4606 joy.rogalla@skyresearch.com	Project coordination and cost analysis
Dr. Herb Nelson	ESTCP Program Office ESTCP Office 901 North Stuart Street, Suite 303 Arlington, VA 22203-1821		ESTCP Munitions Management Program Manager

Appendix C: Data processing considerations

Some basic information and notes on data processing:

- Offset from IMU to GPS antenna is 16.7 cm.
- Offset from IMU to center of receiver cubes is 132.9 cm
- Y-component data had the wrong sign so needed to be reversed (Figure C-2).

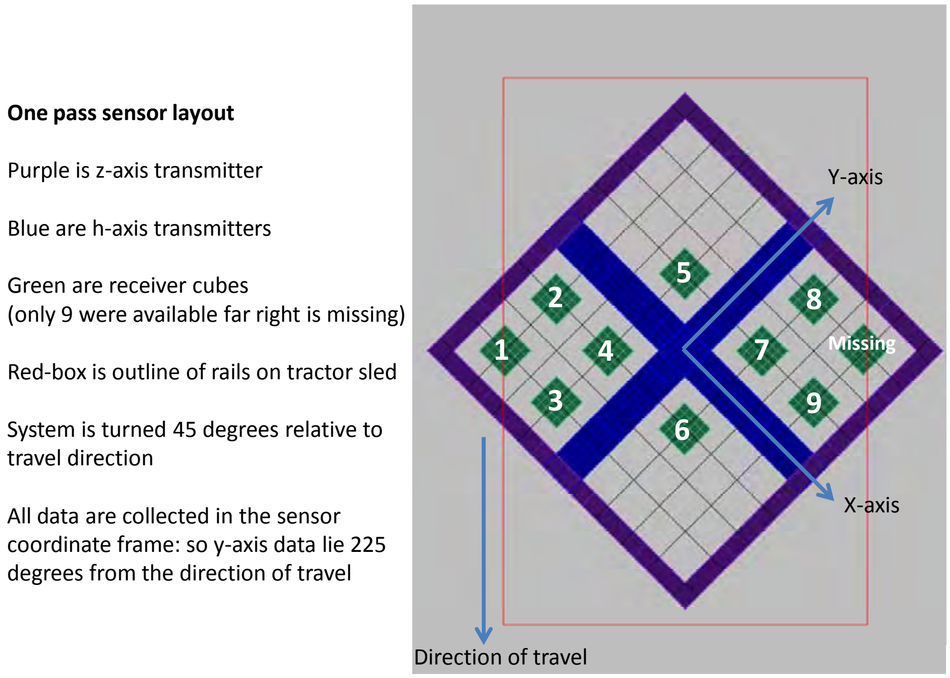
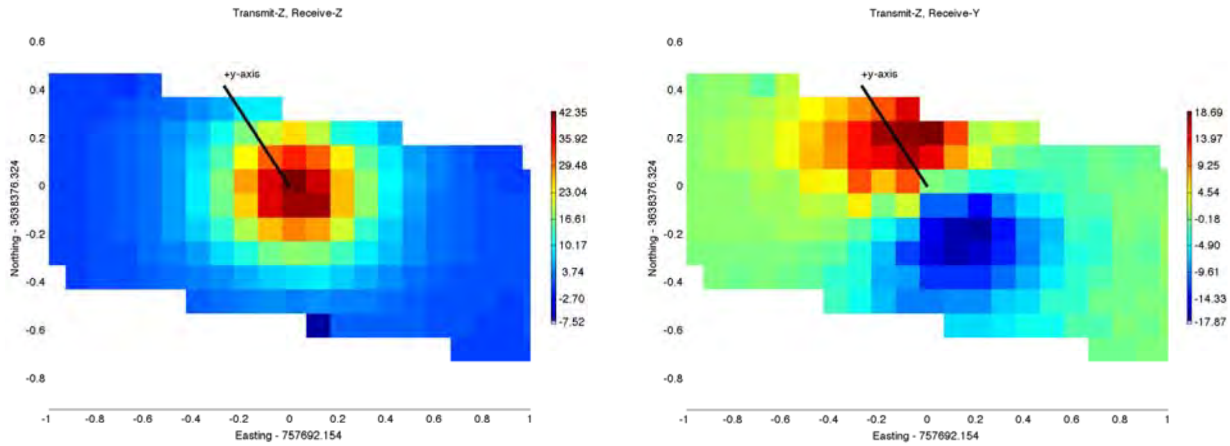


Figure C1: Layout of the OPTEMA system including the positions of the transmitters and receivers.

This is the order and spatial positions of the receivers

Receiver number	X-location	Y-location	Z-location
1	-35	-35	0
2	-35	-15	0
3	-15	-35	0
4	-15	-15	0
5	-15	15	0
6	15	-15	0
7	15	15	0
8	15	35	0
9	35	15	0



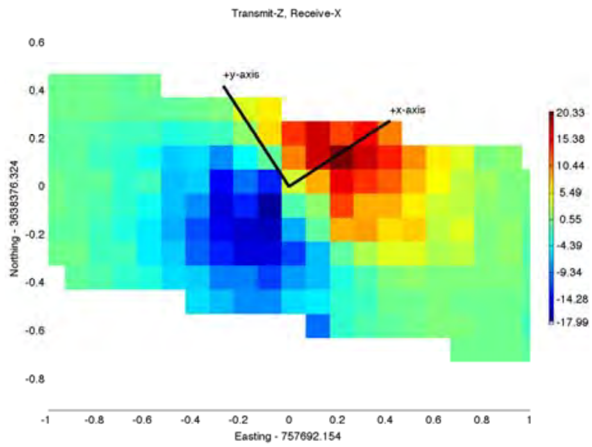


Figure C2: Gridded images of OPTEMA data collected over a #8 shot on the Calibration Grid. The sign of the Y-component receiver data needed to be switched in order for the receiver data to match the sensor coordinate system. X- and Z- receiver component data both appear to have the correct sign. Note that the Y-receiver data in the plot above had their sign changed before plotting.

Appendix D: Field notes

Friday December 3, 2010

Personnel: Cameron Pond, Stephen Billings and Matthew Ragusa

At the FLBGR compound we conducted an initial test of the OPTEMA system to ensure that it was operating correctly. There were some problems with baud-rate inconsistencies between the DAQ and the Novatel SPAN system (SPAN was outputting 39400, EM3DAcquire was expecting 115200), that took a while to track down. A line of data over a test-object was used to ensure that the system was operating correctly.

In the afternoon, Matt, Cameron and Stephen packed the system into a U-Haul truck and a trailer.

Saturday December 4, 2010

Personnel: Cameron Pond, Stephen Billings

Pack remaining equipment during the morning and hook the trailer up to the U-Haul truck. Cameron starts driving to Yuma at about midday.

Sunday December 5, 2010

Personnel: Cameron Pond, Stephen Billings and Daniel Steinhurst (same personnel until Saturday December 11).

Daniel flies into Yuma midafternoon, from DC. Stephen drives in from Phoenix (after a flight from Denver) with arrival late afternoon. Cameron arrives in Yuma with the U-Haul truck and the trailer in the late afternoon.

Monday December 6, 2010

Drive out to security gate arriving around 7:15 AM. Get stuck at the gate for a while as Stephen is a foreign national and requires an escort. Eventually Dan gets in touch with Manny and he comes out to the gate to provide an escort. After getting security passes and watching a safety video we drive to the UXO test-site where Kerry takes over as escort.

Spend morning unpacking the system and getting it ready for survey. We have a small problem with the GPS base-station as we find we are missing the cable from the GPS receiver to the antenna (it's a Trimble R7 system). Fortunately, we have a Trimble R8 rover that we can configure to use as a base-station. There are some issues with the Trimmark3 radio that prevent transmission of the CMR corrections from the base-station. Fortunately we have a spare and are able to use that unit as a replacement. Eventually get data streaming from the SPAN and into the EM3DAcquire program.

Collect data over the calibration grid at 1 m lane-spacing using a 2.7 ms time-decay.

Also collect data over the calibration grid at 1 m lane-spacing with an 8.1 ms time-decay range.

Start data collection over the calibration grid with 0.9 ms time-decay range.

Start to pack up system around 4PM (we put the Kubota into a connex box and the array into our trailer) and demobilize from the UXO test-site around 4:30 PM.

We found that each 12 V battery would only provide < 2 hours of power, and also don't like the alligator clips used to connect the inverter to the car-batteries. On way back to the hotel we buy some cables and connectors from an autoparts store so that we can connect two batteries in parallel.

Tuesday December 7, 2010

Arrive at main-gate at around 7:10AM where Kelly escorts us to the UXO test-site. We spend the first hour unpacking the system and developing a system for powering the DAQ from two batteries connected in parallel.

Start collecting data on Calibration Grid with 0.9 ms time-decay at 8:55AM and complete the remaining 15 lines by 9:45AM.

Switch to the blind-grid where we collect with 1 m transects at 2.7 ms time-decay range. Data collection starts at 9:50AM and we finish by 12:05.

Next repeat blind-grid with 8.1 ms time-decay starting at 12:14 AM and continuing until 1:29 PM when we stop to refuel the Kubota (after the 25th line). Continuing data collection starting at 1:42PM for 10 minutes when the batteries ran out of power. We were down for an hour while we configured some new batteries for first time use with this system. Finish blind-grid using the 8.1 ms time-decay starting at 3:11 and finishing around 3:50.

Start the blind-grid with 0.9 ms decay at 3:55 PM and continue until 4:10 PM with 8 lines collected.

One issue with the data collected today was that the Novatel SPAN was not recording to the flash-drive for the morning and early afternoon.

Wednesday 8 December 2010

Arrive at main-gate at around 7:05AM where Kelly escorts us to the UXO test-site. Unpack the system and commence surveying at 8:15AM. Start with a recollect in the calibration grid with 2.7 ms time-decay range, then continuing surveying the blind-grid with 0.9 ms time-decay range. Part way through we switch to a race-track pattern. Complete survey at 9:41 AM.

After pulling out the compact flash-card from the SPAN we have a lot of trouble getting the system up and functioning again. The TEMAcquire program seems to drop many of the data packets coming through the COM port. After persistence, we finally get the system up and running again.

Survey the blind-grid at 2.7 ms time-decay range (this is a repeat survey required because the last survey occurred when we weren't recording SPAN data). Start at 11:45 AM finish at 1:32 PM.

We decide to switch batteries but this appears to be a mistake as it again takes a long time to get the SPAN streaming data correctly. We manage to collect 10 lines on the open-field, with at least one restart due to the EM3D Acquire program hanging. Surveying commences at 2:46PM and we finish by 4:10 PM.

Thursday 9 December 2010

Arrive at main-gate at around 7:05AM where Kelly escorts us to the UXO test-site. Unpack the system and immediately experience the same SPAN problems that plagued us yesterday. We don't start collecting data on the open-field until 10 AM (starting on line 11). Program crashes half-way through line 11, so start on line 12 and continue to 13. Then do the calibration line which appears to show some timing problems.

Cameron resets the DAQ and we start collecting data, doing the calibration line (00005) after a few lines. Everything looks to be good with that data.

Continue surveying the open-field for the rest of the day until the power runs out during line 42 and we are forced to restart the SPAN. Have the usual communication problems, but then eventually it all starts to work and we continue surveying on line 43. After two lines we re-do the calibration line (00006). We survey till just after 4PM and then recollect the calibration line in both directions (0007 and 0008). During all this time there are multiple SPAN message block errors and I suspect the timing is all screwed up.

We abandon using the track-plot tool and instead use traffic cones and the tire marks to ensure complete coverage.

Friday 10 December 2010

Arrive at main-gate at around 7:00AM where Kelly escorts us to the UXO test-site. Unpack the system and this time manage to start surveying immediately without any SPAN problems. I had issued a SAVECONFIG command yesterday before powering down, and the system came up and immediately started to stream data at 115200 baud rate.

After calibration line (00009) we commence surveying the open-field on line 51 and survey until line 55, when we briefly head over to the calibration grid to do 3 recollects.

We continue surveying the open-field collecting lines 59 (at 9:55 AM) and going to line 73 at 12:24 PM. Then collect another calibration line (00010) before continuing with data collection. Collect from line 74 (at 12:41 PM) up to line 77 (at 1:12 PM), when the SPAN flash card runs out of memory.

Restart the SPAN and continue data collection starting on line 78 (1:36 PM), with a calibration line collected after line 81 (00011). Continue data collection until the DAQ disk runs out of space one of the lines around line 85 (did not obtain a record of that line). Continue surveying until about 4:15 PM with line 101 the last line collected.

After that last restart of the SPAN we get in the habit of always restarting a line if any SPAN or DAQ errors are reported.

Saturday December 11, 2010

Personnel: Cameron Pond, Stephen Billings and Kevin Kingdon

Kevin flies from Vancouver to Phoenix and Steve and Cameron drive from Yuma to Phoenix where everyone meets to transfer data collection and data processing procedures and codes. Steve departs from Phoenix for return to Australia. Cameron drives rental car back to Yuma.

Sunday December 12, 2010

Personnel: Cameron Pond, Kevin Kingdon and Glenn Harbaugh (same personnel until Friday December 17).

Glen flies into Yuma midafternoon, from DC. Kevin flies in around the same time from Phoenix.

Monday 13 December 2010

Arrive at main-gate at around 7:00AM where we meet escort from the previous week, Kerry. Kevin and Glenn get security passes and watch a safety video. Once complete, Kerry escorts us to the UXO test-site. Setup the system and manage to start surveying immediately without any SPAN problems at 8:45am collecting the first calline (13).

We commence surveying the open-field at 9am, continuing where cones were left on Friday and moving towards the road. Noticed some GPS errors being reported on the DAQ at 10:10am and stopped data collection to investigate. Cameron initially thought it was a battery problem and replaced but when errors continued he discovered a corroded fuse along the GPS cabling, cleaned and that solved the errors and surveying continued at 10:30 collecting lines 1-22 in the open field.

Another calline (14) collected at 11:05 am then back to open field surveying collecting lines 23-46 before returning for another calline(15) at 1:05. Lines 47-63 collected in open field before the next calline (16) at 2:30. Lines 64-87 were collected in the open field before the end of day calline (17) collected at 4:16pm after which time we packed up sled and Kubota and left the UXO test site at 4:40pm.

Tuesday 14 December 2010

Arrive at main-gate at around 7:00AM where we meet Kerry. Arrive at UXO test site at 7:15 and get everything connected and powered up. SPAN does not start up properly, can't seem to communicate via 9600 or 115200 baud rates. Follow procedures outlined in the OPTEMA quick start guide but continue to have problems establishing a connection and sending commands. Eventually decide to do a factory reset on the SPAN and this seems to work after a few attempts to connect and initialize. Spend 1.5 Hours troubleshooting SPAN, first calline (19) completed at 8:45am and return to open field surveying at 9am to continue surveying.

Collected lines 191-217 in the openfield before returning for second caline (20). Returned to openfield and collected lines 218-225 before noticing that the positions in calline00020 seemed off. Turns out this was just the usual 0.3 second timing glitch but collected a second pass over the calline (21) to confirm everything was operating normal. Positions looked good in calline00021 so returned to openfield and collected lines 226-254. Next calline was 22 after which moved to the Northeast portion of the openfield site to continue surveying on the other side of the drainage area cutting through the site.

Noticed one of the wheels had been punctured by a long needle from one of the plants and seemed to have a slow leak at the end of the day Cameron surveyed in GPS locations for obstacles (fence, hydro poles, guide wires for poles) on the site at end of day. Packed up and left site at 4:40pm

Wednesday 15 December 2010

Arrive at main-gate at 6:50AM where we meet Kerry. Arrive at UXO test site at 7:00 and find that the tire which the cactus needle punctured at end of previous day is completely flat, swap that wheel out with the spare and patch the hole, takes about half an hour. When driving the Kubota over to connect with the sled, Cameron notices that it is stuck in low gear, can no longer reverse. Tried to diagnose the problem for half an hour but could not solve. Fortunately the gear that is stuck in is the one we use for surveying. Sled will have to be pushed and pulled out of trailer by hand for storage and we'll need to be careful about not getting sled in a tight position where it's necessary to back up. Cam called Heesoo who has dealt with the Kubotas at FLBGR to see if he has any suggestions as well as a call to a local Yuma farm dealership. Since it's useable and we only have 3 days left, don't want to take the Kubota in for repairs, but if there is a simple fix that we can implement in the field we'll try it out.

Continued difficulties getting the SPAN does started up properly. Could be due to the accidental cutting of power to the SPAN at end of survey day yesterday rather than shutting it down with SPAN power button? After a half hour of fiddling and a factory reset, SPAN came up and was logging properly. Part of the problem might have been not waiting long enough for commands sent over hyperterminal to complete before disconnecting and retrying.

Noted a thin wire on the surface in current survey area that runs the length (south-north direction) of the openfield (perhaps a remnant of long wire IED testing?) area near the eastern portion. Cam collected GPS locations along the wire for future reference. Glenn estimates that we were passing over it on files with timestamp around 10am.

First calline (23) collected at 8:40am then onto open field surveying, collecting lines 292-325 before returning for another calline(24) at 11:05. Lines 326-371 collected in open field before the next calline (25) at 1:38. GPS issues occurred at approximately 1:10, errors occurred on DAQ and Cam's investigation at the base station discovered that the channel being used was being "stepped on" be another user on the base. Switching channels fixed the problem. No data was effected as the error occurred in a turn after finishing a survey line and no data was being collected. Lines 372-*** were recollects in the open field and continuing collection in the eastern portions of the openfield before the end of day calline (26) collected at 4:08pm. Cam and Glenn tried to fix gearing problems causing the Kabota to be stuck in low gear. Took longer than expected and ultimately unsuccessful, left the site at 5:30.

Noticed that the SPAN card had filled up because files from the previous day were not removed prior to surveying. SPAN stopped recording at ~time 333510 meaning files 292-371 had SPAN data recorded while 372-414 did not. Coincidently 372 was the first recollect so recollects and last 45 minutes of openfield coverage (data acquired after recollects were complete) have no SPAN data recorded for post processing.

Thursday 16 December 2010

Arrive at main-gate at 6:55AM where we meet Kerry. Arrive at UXO test site at 7:05, remove sled and get batteries connected, base station up and everything powered up by 7:30. Before powering up, noticed that two of two of the cards on the DAQ had been pulled out and one of the red jumper cables between cards was disconnected. This probably happened during the manual pushing and pulling of the sled to get it in and out of the trailer now that Kubota has no reverse gear. Cards are not secured with screws so they do pop put relatively easily. Reseated the cards into the DAQ attached jumper cable and powered everything up at 7:30.

The usual messing around with SPAN took from 7:30 until 8:40 before it was finally up and logging properly. At 8:40 there was a light rain, so took the time to place a second tarp over the SPAN GPS/IMU and OPTEMA coils for protection. At 9:05 moved to the calibration lane and noticed SPAN errors with messages like "SPAN Parse Error, MARKPOS.len=0,INSATT.len=0" as soon as tried at acquire data with TEMAcquire. While troubleshooting, noticed that the DL4 display read "Configure Base". Not sure the meaning of this message but it was something we hadn't seen before. Cam checked the GPS base station and there were no issues. Tried a factory reset of the SPAN which took multiple attempts until it was back up and logging properly at 9:48.

At 9:48 collected calimet15, note that left Kubota engine on as the Kubota was having issues starting because of the gearing problems and modifications. Noticed a SPAN error part way through the first calline (27) so stopped and started another line for the last portion of the caline (28). The positions before the error was noticed and stopped in calline00027 were not accurate. After stopping and starting, there were no timing errors in the final portion of the caline contained in calline00028 (as determined by the ps file created using qc_timing) and the positions were accurate for remaining calline items. Decided to collect another pass over calibration lane to see if errors persisted. An error was not observed until the end of the line however looking at the positions, they are not accurate, so even though an error (typical of the 0.3 second shift) was not being displayed, positions accuracy of the TEM data was poor based on the known anomaly location in the calibration lane. The TEM data looked fine.

At this point we tried several iterations of rebooting all the components (SPAN, DAQ, GPS base station), both one at a time and all at once but were not able to solve the problem. In fact, errors became more frequent. Tried replacing the SPAN systems compact flash card which didn't help either. Prior to hitting acquire, we were getting errors on the DAQ reporting things such as "SPAN Parse Error, MARKPOS.len=0,INSATT.len=0" after hitting the Acquire button, those messages would include "9/18 data points skipped". Almost seemed like the TEM was being triggered too quickly?

We eventually ran out of ideas and called Dave George around 3:15pm. He was really helpful and offered to login remotely and have a look. We put the DAQ online using Glenn's usb modem and Dave was able to login remotely. Dave thought that it looked like EM3D was not operating properly and was able to duplicate the errors that we were seeing, He tried resetting the SPAN but errors persisted. He thought a digital ground might be acting up somewhere and causing the software to trigger too much. We had to pack up equipment before Dave could resolve the problem. He agreed to login tomorrow morning and continue troubleshooting if problems continued. We packed up gear and left site at 4:35pm.

Friday 16 December 2010

Arrive at main-gate at 6:55AM where we meet Kerry. Since today is the final day, we have 3 vehicles, Glenn with his rental that we've been using for the duration of the week, Cameron in the UHaul truck (to pack up gear at end of day for return to Denver) and Kevin in a second rental car as he has to catch a flight at 3:30pm. Kevin and Glenn arrive at UXO test site at 7:05, Cameron is turned back at the gate because they want to see proof of insurance. His previous vehicle pass has expired and unfortunately the insurance paperwork is back at the hotel. He arrives at UXO site at 8:45. In the meantime, Glenn and Kevin connect up gear and move base station materials out so ready for Cam to initialize the base station when he arrives. Glen makes a point of trying to ensure the wires coming out of the cards at the back of the DAQ are well separated incase this was contributing to our problems the day before.

The usual SPAN fiddling and cajoling takes until 9:20 once the base station is up and running. Start TEMAcquire and notice the errors from yesterday seem to have stopped. Calitem13 looks good as does the pass over the Calibration lane (calline30). At 9:35 Cam and Glen head out to do the 16 recollect lines that Steve sent. At 10:05 Cam and Glenn return, it seems that the video cable going from DAQ to monitor is a bit flaky, causing the colours displayed on the monitor to flash and tracks in pilot navigation to occasionally disappear when background colour changes to match the track colour. Attached a wooden shim with electrical tape to the connector going into the DAQ to try to minimize the cable movement due to vibrations of the Kubota. Cam and Glen head back out to finish the recollects at 10:15. Recollects were finished at 11:25 and another pass over the calibration lane was collected (calline31). Cam and Glenn had to restart pilot navigation a few times and couldn't reload completed tracks so they were unsure if all recollects were completed. Dowloaded and compared positions of recollected data with those in the recollect file supplied by Steve. While reviewing for missed recollects, Cam and Glenn returned to the eastern portion of the openfield to continue with acquisition. Identifed 4 recollect lines that were missed unfortunately, I assumed the recollects were labeled 1:n and so I asked them to recollect lines 7,10, 11, 16. In fact the line numbers in Steve recollect file do increment so they should have recollected the 7^{th} (1107), 10^{th} (line1110), 11^{th} (line 1112) and 16^{th} (line1118). This means that the last two lines (1112 and 1118) were missed.

Started packing up around 1:30pm. We would not be able to finish the entire site and wanted to make sure we could manually load the sled into the UHaul while we had 3 sets of hands as well as have sufficient time to pack, load and secure all gear for transport.