

UXO Detection and Prioritization Using Combined Airborne Vertical Magnetic Gradient and Time-Domain Electromagnetic Methods

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Summary:

In January 2008, low-altitude (~1-3 meters above ground level) airborne geophysical surveys were carried out at the Marine Corps Air Ground Combat Center (MCAGCC), near Twentynine Palms, California. The primary goal of the surveys was to assess the viability of airborne magnetic or electromagnetic geophysical surveys at MCAGCC for detection and mapping of unexploded munitions. Due to high magnetic content in the rocks and soils at MCAGCC magnetic methods had been shown in the past to have limited usefulness. The background magnetic conditions made this site a good candidate for the use of a new 8-channel Time-domain Electromagnetic system (TEM8) developed by Battelle. The first phase of the project was an assessment of the efficacy of TEM8 and vertical magnetic gradient (VG-22) technologies, based on results from surveys of two 8 hectare areas and a 2 hectare geophysical prove out (GPO) area. This demonstration showed that both VG-22 and TEM8 were useful at this site, but the combination of the two datasets is more effective than either dataset used singularly for target prioritization.

Introduction:

The background geology of the Mojave Desert in the Twentynine Palms area is highly variable and includes metamorphic and igneous units with relatively high concentrations of magnetic minerals. Erosion and subsequent outwash of these units has produced a natural background magnetism that is 5 to 10 times more variable than in soils formed from sedimentary rock units.

We established a grid of test items consisting of a variety of ordnance and scrap. We then surveyed the grid with the two airborne geophysical systems to assess the background anomalies associated with the geology and to calibrate the systems prior to flying operational range areas. We also surveyed two other 8 hectare areas with both airborne systems and compiled anomaly lists based on the combined datasets.

VG-22 (Figure 1) is a vertical magnetic gradient system designed to maximize resolution in wide-area assessment surveys, especially where data can be acquired at altitudes of 2m or less (Doll et al., 2007). It employs 7 vertical gradient pods spaced 1.0m apart on the forward boom, providing a 6m swath width. Each gradient pod contains two airborne quality cesium-vapor magnetometers vertically separated by 50cm.



Figure 1: VG-22 system



Figure 2: TEM8 system

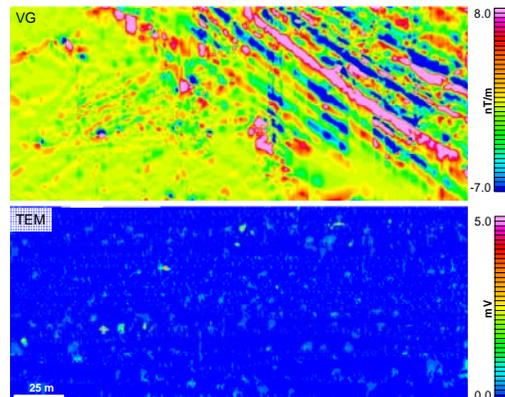


Figure 3: VG-22 (top) and TEM8 (bottom) for an area with high magnetic background noise.

The TEM8 (Figure 2) is a time-domain EM system with eight receiver coils, four mounted one meter apart on each side of the TEM8 boom structure. On either side of the helicopter is a 3m x 5m rectangular transmitter coil that surrounds the four receivers. Each system was mounted on a Bell 206 Long Ranger helicopter and flown as low to the earth's surface as safety permitted over the survey areas.

Because we flew both the TEM8 and VG-22 systems over the same set of known targets, we had a unique opportunity to directly compare the performance of the two systems, and to investigate methods of combining the sources of information to generate more accurate and complete anomaly picking and prioritization processes.

Figure 3 shows TEM8 and VG-22 coverage over a magnetically noisy area. The NE portion of the VG-22 map is dominated by geologic noise, while the TEM8 map shows no effect from the same geological noise.

Joint Prioritization of EM and Mag Picks

Geophysical Prove-Out (GPO) Site

In order to locate the GPO we selected an area of approximately 8 hectares based on flat topography and then used the VG-22 system to survey the entire area. After processing the data, we located a 2 hectare subarea that was relatively quiet magnetically. In that area we emplaced two rows of metallic items, consisting of ordnance, ordnance fragments, and non-ordnance simulants. The rows were 15 meters apart and individual items were spaced 15 meters apart along each row. A total of 29 items ranging in size from 155 mm artillery rounds to ordnance fragments were laid on the ground surface, rather than buried. In addition to the items emplaced, there were two significant items located on the surface already, which are included in this analysis.

We flew both systems over the site and processed each dataset independently. We then generated separate maps of the GPO area (Figure 4). An automated picking algorithm was applied to these maps, giving locations and VG-22 or TEM8 amplitudes for each anomaly.

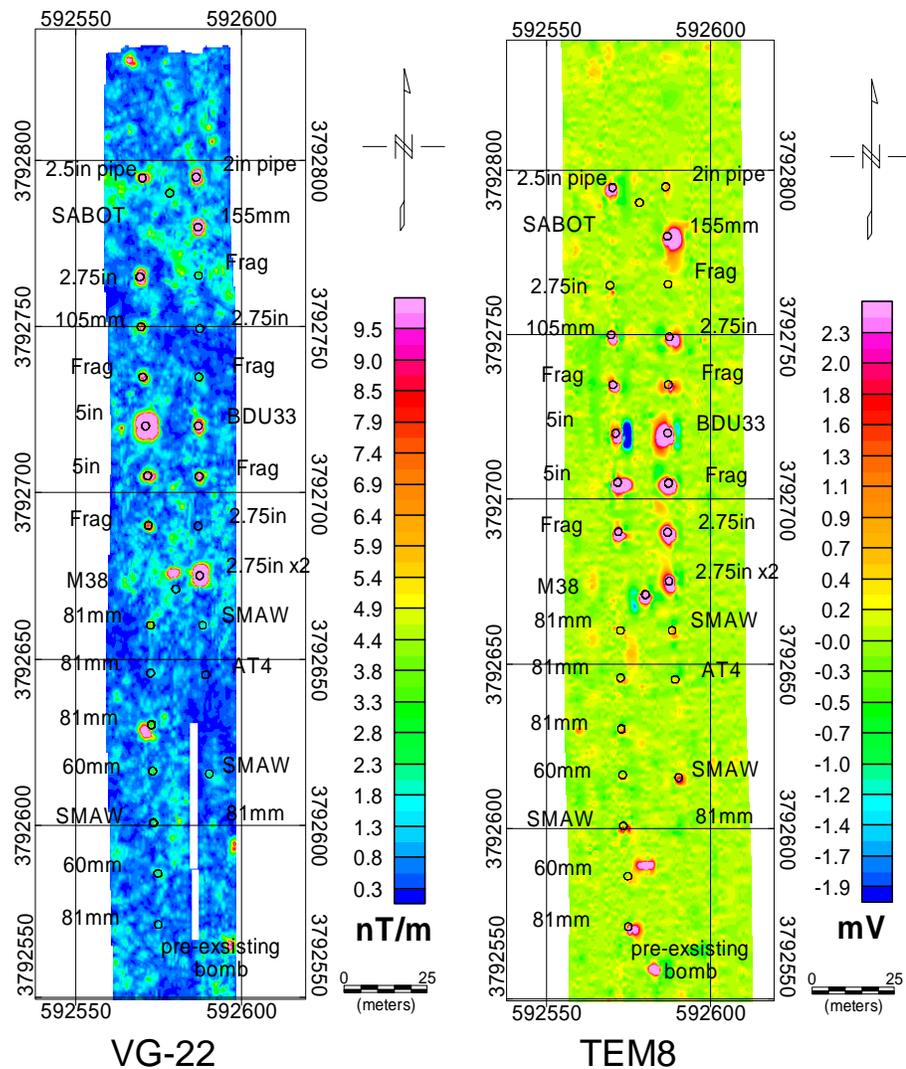


Figure 4: TEM8 (left) and VG-22 analytic signal (right) for the GPO site.

The VG-22 system detected 22 of the 31 items on the grid, with 51 false positives.

The TEM8 system detected 26 of the 31 items, and had 77 false positives. Off the 26 detections, 24 were detected with only 19 false positives by using a higher threshold. However, between the two systems, all but one item was detected. In order to take full advantage of combined TEM8 and VG-22 datasets we need to combine the picks from each system into one integrated and prioritized list.

Joint Prioritization of EM and Mag Picks

Methods

The first step towards integration was to combine coincident picks between the TEM8 and VG-22 into a single combined pick. Picks were considered coincident if they were within two meters of each other. The final location for the new, combined pick was the average of the TEM8 and VG-22 locations.

Initial prioritization of individual TEM8 or VG-22 data alone was based on the amplitude of the anomaly (Figure 5). For the combined list we need a new value that is a function of the anomaly amplitudes from the TEM8 and VG-22 data. There are three types of anomalies that need to be combined into a single list. These are VG-22, TEM8, and combined.

We started with the assumption that coincident picks are more reliable than those based solely on one method or the other. Therefore we needed a method that would move the combined anomalies up the prioritized list. We wanted very large anomalies that appear on only one of the two methods to out-rank an anomaly that was based on two small, possibly accidentally coincident anomalies. TEM8 and VG-22 anomaly amplitudes are not on the same scale, and hence need to be normalized in order to make them comparable. One straightforward method for this is to normalize each set of values to the maximum value observed. This method works, as long as there are no extremely large anomalies, in which case the normalization should be based on the highest value that is not an outlier. If there is a DC offset after normalization, this should be removed by addition or subtraction of a constant value.

We found that normalization and DC offset correction are not adequate to prepare the data. The distribution of the sorted amplitudes for TEM8 and VG-22 were not the same. This means that the distribution of one or the other needs to be modified. Otherwise one or the other would have more weight at one end of the curve and less at the other. We used an empirical approach.

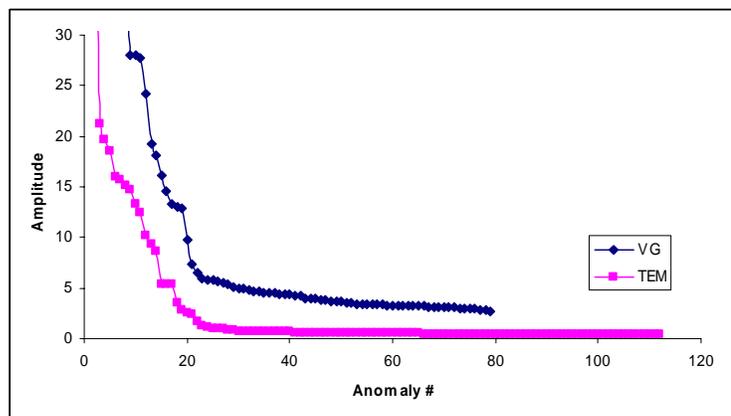


Figure 5: Sorted VG-22 and TEM8 anomalies

Finally, the two values are combined into one value for prioritization of the anomalies by taking the square root of the sum of the squares of the two normalized values. Figure 6 shows the resulting modified TEM8 and VG-22 anomalies plotted against rank. The black triangles on this plot represent picks that are coincident in TEM8 and VG-22. Note how many, but not all, of the top 40 anomalies are from coincident picks. All ranks past 40 are ranked based solely on one method.

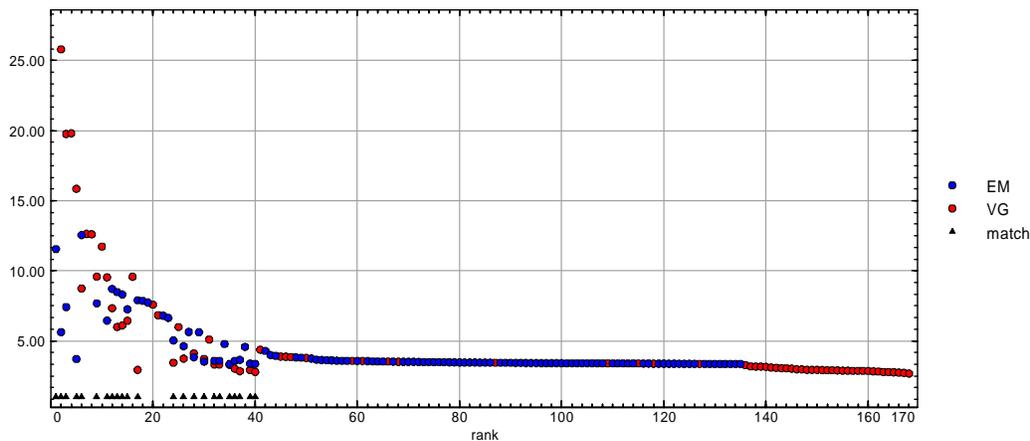


Figure 6: TEM8 (blue), VG-22 (red) anomaly picks plotted against the rank, as determined from the sort value calculated as described above. The items that have coincident TEM and VG anomalies are designated with the black triangles.

Joint Prioritization of EM and Mag Picks

Results and Conclusions

Both the VG-22 and TEM8 systems performed well at the GPO site. The VG-22 system detected 22 of 31 items, with about 50 false positives (Figure 7). The high geological background noise at this site increases the number of false positives in the VG-22 dataset. The TEM8 system detected 26 of the 31 items with about 80 false positives. Using a higher threshold we lose two of the real detections, but retain about 20 false positives. The noise that caused the high false positive rate for VG-22 does not do the same for the TEM8 system because this system is insensitive to the magnetic, but not electrically conductive, geologic noise.

For the combined picking method, 30 out of 31 items were detected with 33 false positives. Additionally, 28 items are detected with only 12 false positives. This approach demonstrates that more items are detected with fewer false positives when using this method of joint prioritization. This is even the case if one of the datasets, as with VG-22 in this case, has a high false positive rate caused by background noise. While it is not always practical to collect both EM and magnetic gradient data, the use of such data can significantly reduce the time and money needed for remediation or ground-truth operations following the airborne survey.

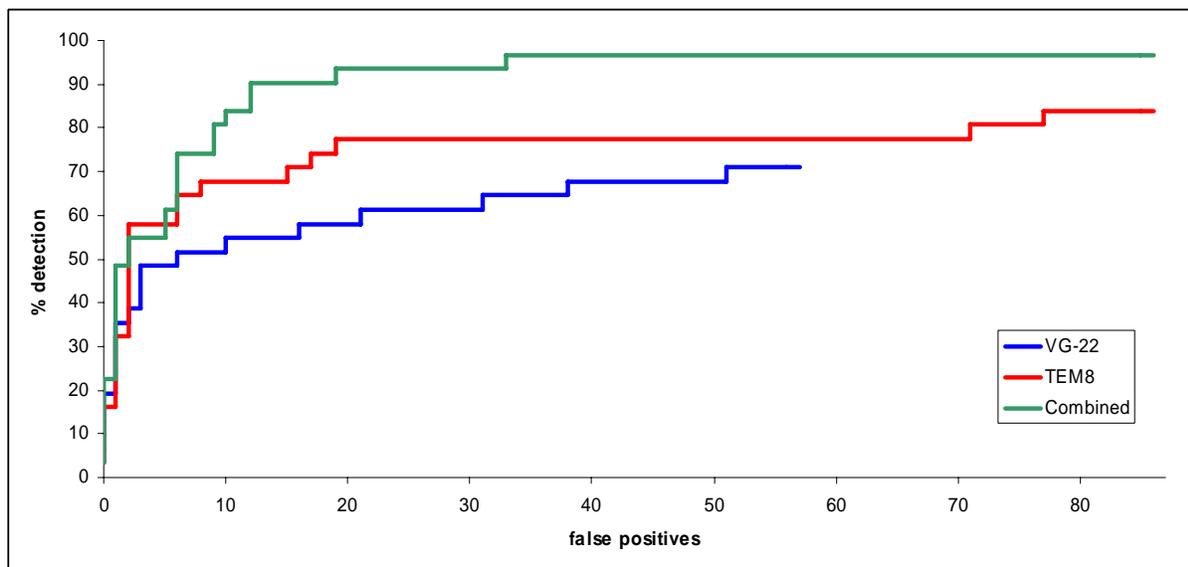


Figure 7: ROC curves for the GPO site, based on picking from VG-22 only (green), TEM8 only (red) and the combination of both (Blue). This is based on 29 emplaced items and two items already located on the site.

Acknowledgements

The authors would like to express our thanks to the Marine Corps Air Ground Combat Center at Twentynine Palms for their support of this project. We would also like to thank Doug Christie (pilot) and the entire National Helicopters crew for their cautious and safe operation throughout the survey.

EDITED REFERENCES

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REFERENCES

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