EARLY-TIME, MULTI-COMPONENT MOBILE TEM FOR DEEP METAL DETECTION

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Abstract

Data examples from a recent project show very interesting and useful characteristics of the early-time data from the horizontal components of TEM surveys used in deep metal detection for targets such as USTs, UXOs, and utilities. Normally, most deep metal detection surveys utilize a system in which one or two TEM measurements of the vertical component (Hz) are acquired. These systems usually acquire data at relatively late times (hundreds of microseconds after transmitter turn-off), to allow the background earth response to decay to zero. A good example is the popular Geonics EM-61 system. By recording data at numerous time windows for all three components (Hx, Hy, and Hz), however, from early times (a few microseconds) through late times, additional significant information is acquired. In one recent project, a 55-acre site was surveyed (by another contractor) with an EM-61, and several subsurface targets were identified for excavation. Small areas around these targets, totaling only 2.25 acres, were re-surveyed using a multi-component, early-time system. In addition to verifying the targets, four additional anomalies that were not evident in the Hz data were detected, including two buried powerlines. Examination of the horizontal component data of the field also appears to be particularly useful in discriminating targets. For example, linear features such as pipelines and powerlines are easily distinguished from 3-dimensional targets with only a single line of data, instead of requiring an array of lines to interpret the targets based on the geometry of anomalies on adjacent lines.

Introduction

Project Site and Discussion

The project site is currently a city-owned public sports park, including four baseball fields, five soccer fields, and a playground area. Prior to 1985, however, the area was part of the Davis Monthan Air Force Base; during the 1960s, this part of the base was used to de-fuel and prepare aircraft for storage operations. In June of 2001, a 2-foot wide, 3-foot long, 5-foot deep sinkhole suddenly opened in one of the soccer fields, exposing a cavity and metallic debris in the subsurface. A 100-foot by 100-foot grid of NanoTEM data (the multi-component, early-time system) was acquired around the sinkhole to direct the excavation. On the basis of that survey and the excavation results, an EM-61 survey of the entire 55-acre site was contracted to locate any other similar subsurface features that might pose a danger to the public.

The EM-61 survey (by another contractor) identified several targets which were then scheduled for excavation. As part of an internal research project, we acquired small grids of NanoTEM data around each excavation target prior to the digging. Of the 55-acre site, only 2.25 acres were repeated with the NanoTEM system. For all targets, as expected, the NanoTEM Hz-component data agreed extremely well with the EM-61 results, when considerations are made for line and station spacing differences. However, the early-time horizontal component data also clearly delineated four features that were not evident in either the EM-61 data or in the late-time NanoTEM Hz data. Two of these anomalies are known to be buried electrical powerlines. Two other anomalies are interpreted to be either old, unknown electrical lines or deep pipelines. Since these features were not on the original EM-61 "dig list", and since they do not appear to pose a public health risk, they have not been excavated to date.

Two significant benefits of acquiring early-time, multi-component data are evident from this data set. First, some target discrimination is clearly possible; the different coupling orientation makes it possible to differentiate a pipeline from a 3-D target (such as a drum or tank) with a single line of data, unlike Hz-component data, which would require multiple lines to determine target geometry. Second, some important subsurface features that are simply not detected in the late-time Hz-component data are detectable in the early-time horizontal components, due to the different coupling orientation and the rapid decay of the background earth response in the horizontal component data.

Field Method and Equipment

The multi-component, early-time NanoTEM field measurements were made using a backpack-mounted transmitter/receiver system, with transmitter and receiver coils mounted on a wheeled, non-conducting cart. The transmitter loop was 1-meter square and approximately 0.2 meters above the ground surface. The three orthogonal receiver coils (Hx, Hy, and Hz) measured 0.5 X 0.5 meters; the Hz coil was 0.2 meters above the ground, while the Hx and Hy were 0.5 meters above ground. A 64-hertz repetition rate of the time domain signal was used. The receiver was a GDP-32II, manufactured by Zonge Engineering, with an embedded NanoTEM NT-20 transmitter, also manufactured by Zonge (the combination is referred to as an NT-32). Data are acquired on all three components simultaneously by using three individual 750 kHz A/D cards. The measurements for the data discussed in this paper are made at 31 times (or "windows") after the transmitter is turned off, from approximately 1 microsecond after turnoff to 568 microseconds, although continuous waveform recording is also possible. The late-time Hz data from this system are very similar to EM-61 bottom-loop data. Transmitter turn-off was approximately 1 microsecond. The data were acquired at a slow walking pace, at a rate of one data point per second (each data point consists of 32 cycles stacked and averaged). For positioning purposes, a Trimble Asset Surveyor RTK GPS system, with the antenna mounted above the center of the transmitter loop, was used to provide sub-meter accuracy positioning. The GPS position errors are estimated to be approximately 1.5 ft, except very near obstructions where errors increased to 3 or 4 ft.

Horizontal Component Vector Data

Target Discrimination

A good example of target discrimination is evident in the data set acquired in the area called the Eucalyptus Grove, which is an open, dirt-covered area between the sports fields, and is not normally used by the public. Aerial photographs from the 1960s show a row of military Quonset huts in this area. The EM-61 survey results indicated several long, narrow, linear anomalies. A strong isolated anomaly was also evident at a location that had previously required fill material when a small cavity had developed. Excavation confirmed the linear anomalies as metal pipelines, and the strong isolated anomaly was found to be a large steel cover on an old septic tank.

Figure 1 shows a plan view plot of the HxHy horizontal field vectors in the area of one of the metal pipelines and the septic tank. The vector components are calculated from the Hx data and Hy data for time window 1 (0.72 microseconds after transmitter turn-off) after normalizing by subtracting the median value of each component (for window 1). In this plot, the vector midpoints are anchored at the data point location. The vector lengths are scaled to the vector magnitude, and the vector color is based on the Hx window 1 magnitude; positive values are red, negative values are blue, and near-zero values shade to white. This type of plot shows the horizontal component of the field direction and the strength, as well as the polarity of the Hx component itself. The survey lines are oriented approximately N 40 E. Most of the data points show random, near-zero vectors, as expected for the horizontal component of the field in a homogenous area relatively free of anomalies. The pipeline is clearly evident as a strong north-south feature at approximately 1021180E. Moving along the survey lines from the southwest to the northeast, horizontal field strength increases as the pipeline is approached, reverses polarity directly over the pipeline, and then gradually returns to near-zero as the system moves away from the pipeline.

Nearby, at approximately grid location 1021235E, 435645N, the buried septic tank anomaly is

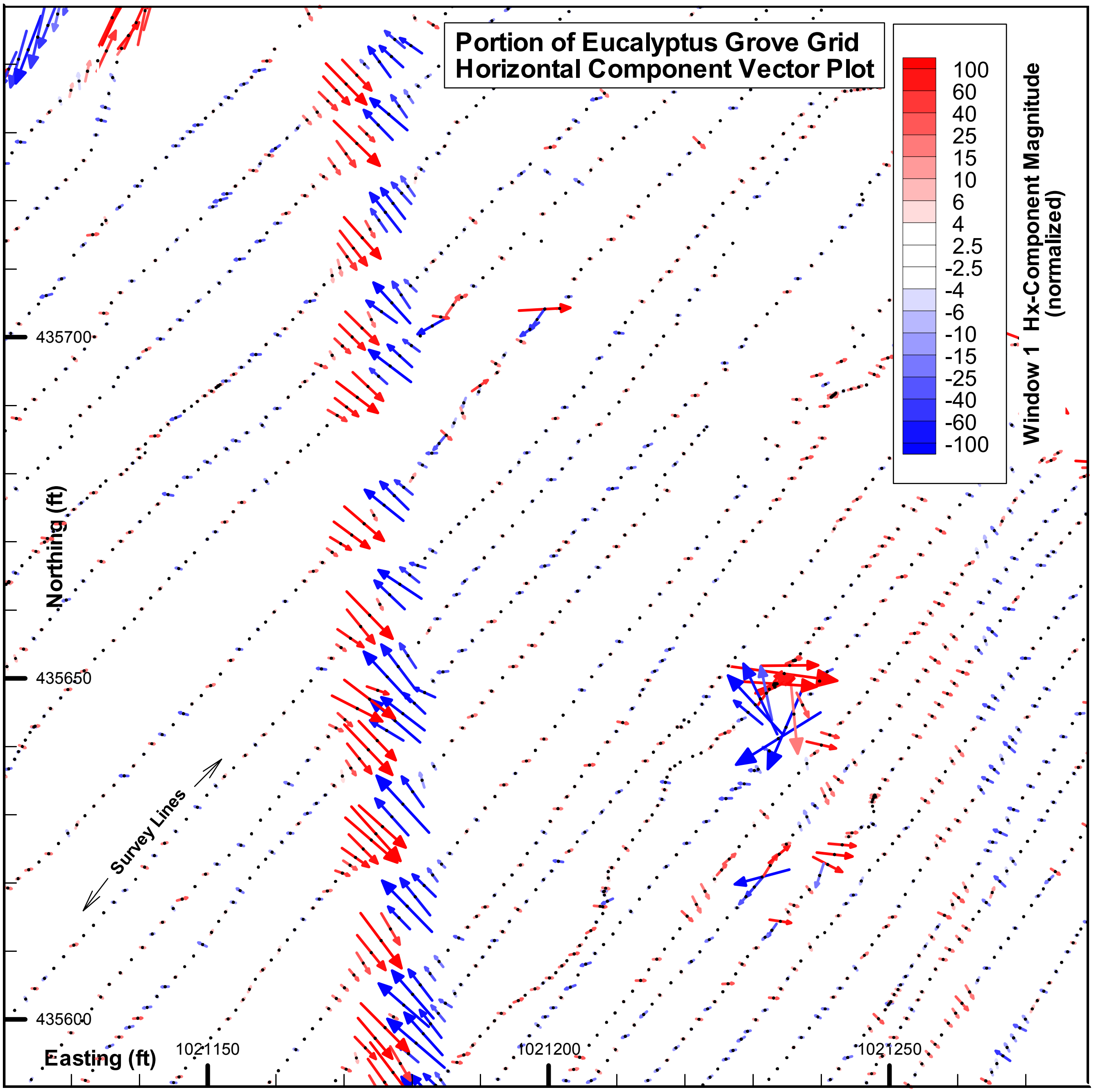

Figure 1. Early-time (window 1) HxHy component vector plot with vector color scaled to the Hx-component magnitude, in the vicinity of a buried pipeline and septic tank.

also evident. Note however, that the field direction is reversed relative to the pipeline; as the septic tank is approached from the southwest, the Hx anomaly is increasingly negative (instead of positive, like the pipeline), changes polarity directly over the target, and then returns to near-zero gradually. Note also that the vectors near and over the septic tank give the appearance of a clock-wise rotation.

As long as consistent coordinate orientation of the system is maintained, these results are repeated throughout this and other projects: buried, narrow, long linear features such as pipelines and powerlines exhibit reversed horizontal field direction when compared to subsurface 3-D targets. Three-dimensional modeling has not been completed yet, but it is expected to verify these results.

The application of this behavior of the horizontal field is shown in Figure 2. The top plot (A) is a profile of a single line of the EM-61 data over the same pipeline (approximately 102175E) and the septic tank (1021230E). For comparison, plot B shows the NanoTEM late-time Hz-component data from the nearest equivalent line across the same two features. (There is a slight difference in location of the anomalies because the two lines are not exactly coincident.) The agreement between the two data sets is good. If this were a single isolated line, a reconnaissance line for example, the interpretation could not progress much farther than the simple presence of two anomalous features on this line.

Plot C of Figure 2 shows the profile of the early-time Hx-component data along the same line. The difference in polarity between the two anomalies is obvious; the anomaly at 1021180E is positive west of the cross-over, while the anomaly at 1021230E is negative west of the cross-over. Based on this single profile, we can not only locate the two anomalies, but we can also determine that the anomaly located at 1021180E is a long narrow feature, such as a pipeline or powerline, while the anomaly at 1021230E is not.

This distinctive polarity difference (relative to subsurface 3-D features) is also apparent from above-ground, or out-of-loop targets, such as utility poles extending above the surface of the ground. Figure 3 shows the HxHy vector plot of the original NanoTEM survey around the sinkhole target. The data are for the early-time, window 1 (0.72 microseconds after transmitter turn-off). Vectors are again anchored at the midpoint at the data point location; vector color is related to the magnitude of the Hx-component (window 1) measurement. Vector length in this plot is uniform.

Target A is the sinkhole anomaly, resulting from the large amount of metal in the subsurface void. Note that the appearance of the vectors is of a clockwise rotation, like the buried septic tank in Figure 1. The Hx-component is anomalously negative south of the target, and anomalously positive north of the target. Conversely, targets B (soccer goal posts) and C (metal light pole) show vectors appearing to rotate counter-clockwise; anomalously positive Hx values are seen south of the target, and negative values are seen to the north. This is consistent with other above-ground anomaly sources we have measured elsewhere, though again, 3-D modeling has not yet confirmed this result.

Vector data associated with targets D and E (electrical access cover and water valve covers) appear to rotate clockwise, consistent with the fact that they are not above-ground, out-of-loop features, though these small areas are somewhat complicated by the close proximity to the light pole and buried powerline.

Targets Un-detected in Hz-component Data

Also evident in the early-time, Hx data in Figure 3 is the broad east-west anomaly running through the grid at approximately 120N. This feature is characterized by anomalously strong positive Hx values on the south, and anomalously strong negative values on the north. The appearance is very similar to the pipeline in Figure 1. Although not excavated, this anomaly is known to be the buried electrical powerline for the soccer field lighting system. Note that this anomaly, like the pipeline anomaly in Figure 1, is the reverse polarity of the subsurface features (the sinkhole anomaly, for example).

It is important to note that this powerline is not evident at all in the EM-61 survey data, or in the equivalent late-time Hz-component NanoTEM data, which are shown in Figure 4. The Hx anomaly weakens rapidly, and is indistinguishable from background by window 10, which is only 14 microseconds after transmitter turn-off; thus it is not detectable in the late-time systems. This suggests a very short time constant, which may be characteristic of powerlines and therefore useful in discriminating between different types of linear features (powerlines versus pipelines).

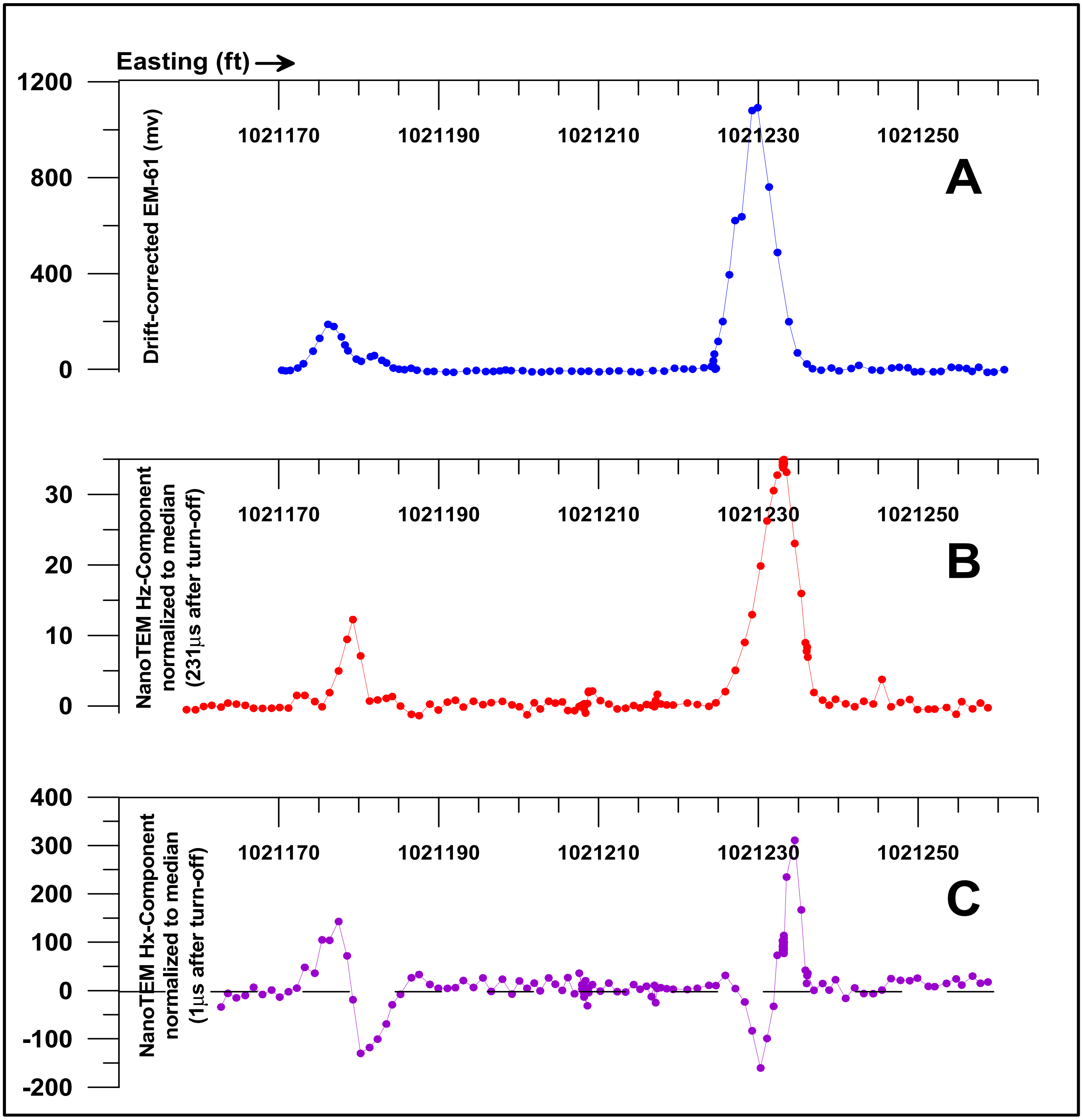

Figure 2. Comparison of EM-61 data, NanoTEM late-time Hz data, and NanoTEM Hx early-time data.

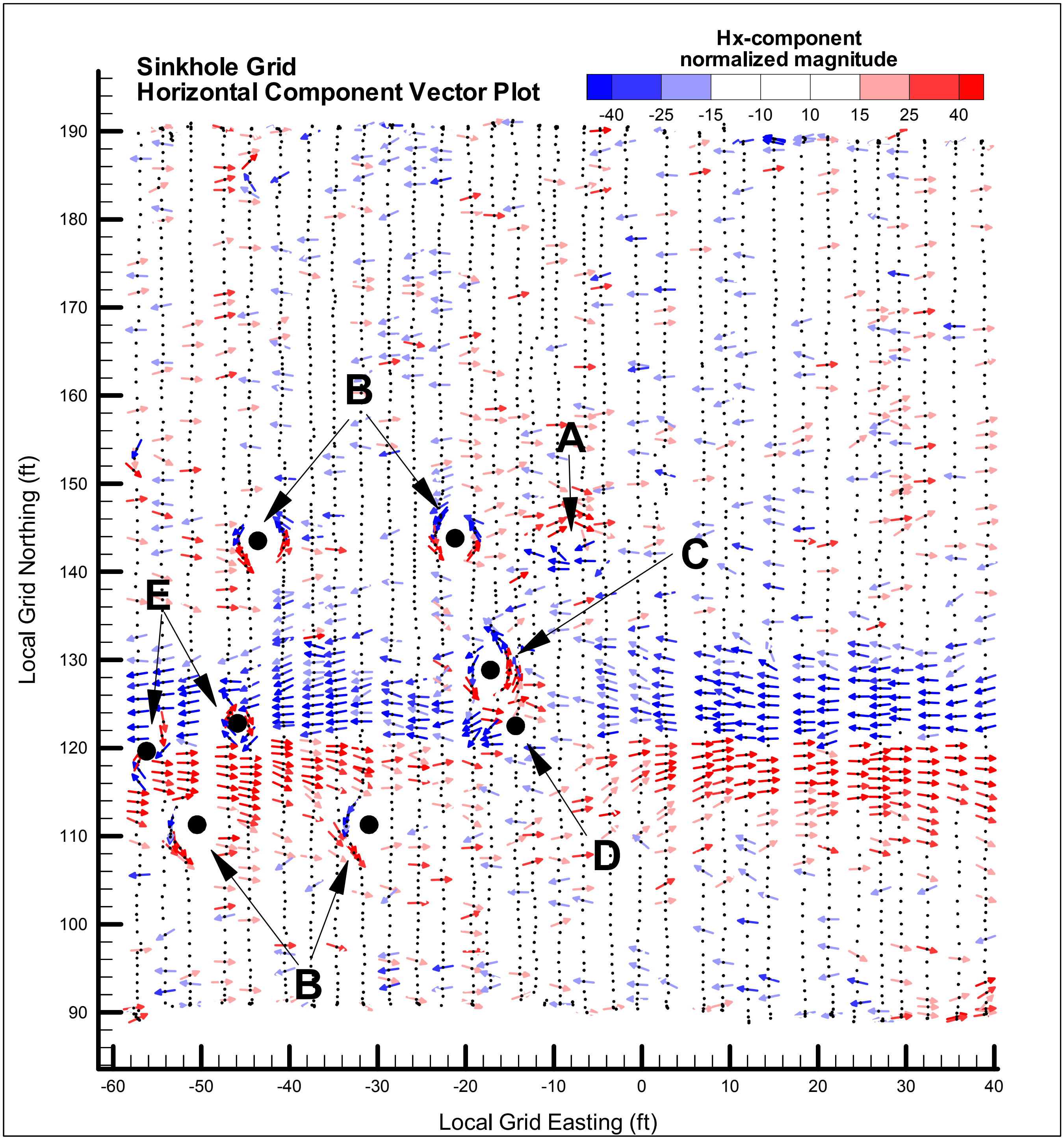

Figure 3. Early-time (window 1) HxHy component data around the original sinkhole target. Features A through E all exhibit strong Hz anomalies (in both the EM-61 and NanoTEM), but the east-west buried powerline at 120N is not detectable in the Hz component measurement. (Compare this plot to the late-time Hz-component data in Figure 4.)

A second buried powerline that was not detected in the late-time Hz measurements or the EM-61 survey is evident in the Soccer Field A-B survey grid (see Figure 5). These results serve to verify the data characteristics of the buried powerlines. Figure 5 shows the HxHy component vector data for window 1 (0.72 microseconds), again with vector colors related to Hx magnitude to show polarity. As

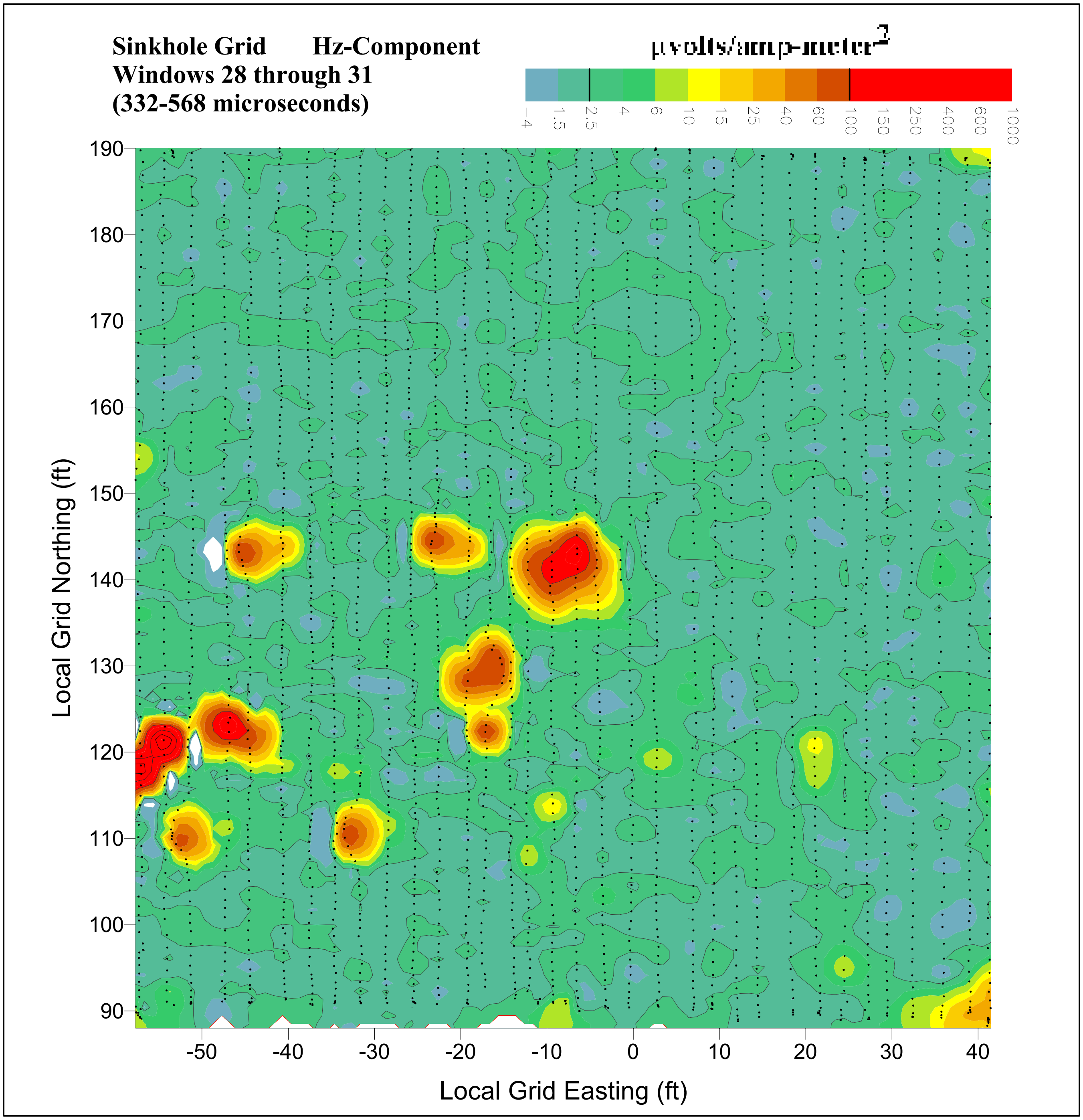

Figure 4. Late-time (332 to 568 microseconds after turn-off) Hz-component (approximately equivalent to the EM-61 results at the same site) for the same grid as in Figure 3. There is no evidence in this component of the east-west buried powerline that is seen in Figure 3.

in the Sinkhole Grid data, the polarity of the buried powerline is the same as the above-ground metal light pole, and reverse polarity relative to all other subsurface targets.

A third anomaly that was not detected in the EM-61 survey (or in the late-time Hz NanoTEM data) was located in Baseball Field 3, near a relatively small, well-confined EM-61 anomaly that was scheduled for excavation. Figure 6 shows the plan view of the NanoTEM horizontal vector data (0.72 microseconds after turn-off) in that area. The color of the HxHy horizontal vector is again tied to the Hx component magnitude. Note that at this site, the linear feature is at a shallow angle to the survey line direction. The cross-over point of the bipolar anomaly on each line is clearly evident as the vector magnitude (length) goes to near-zero. The anomalous target detected by the EM-61 survey is shown on

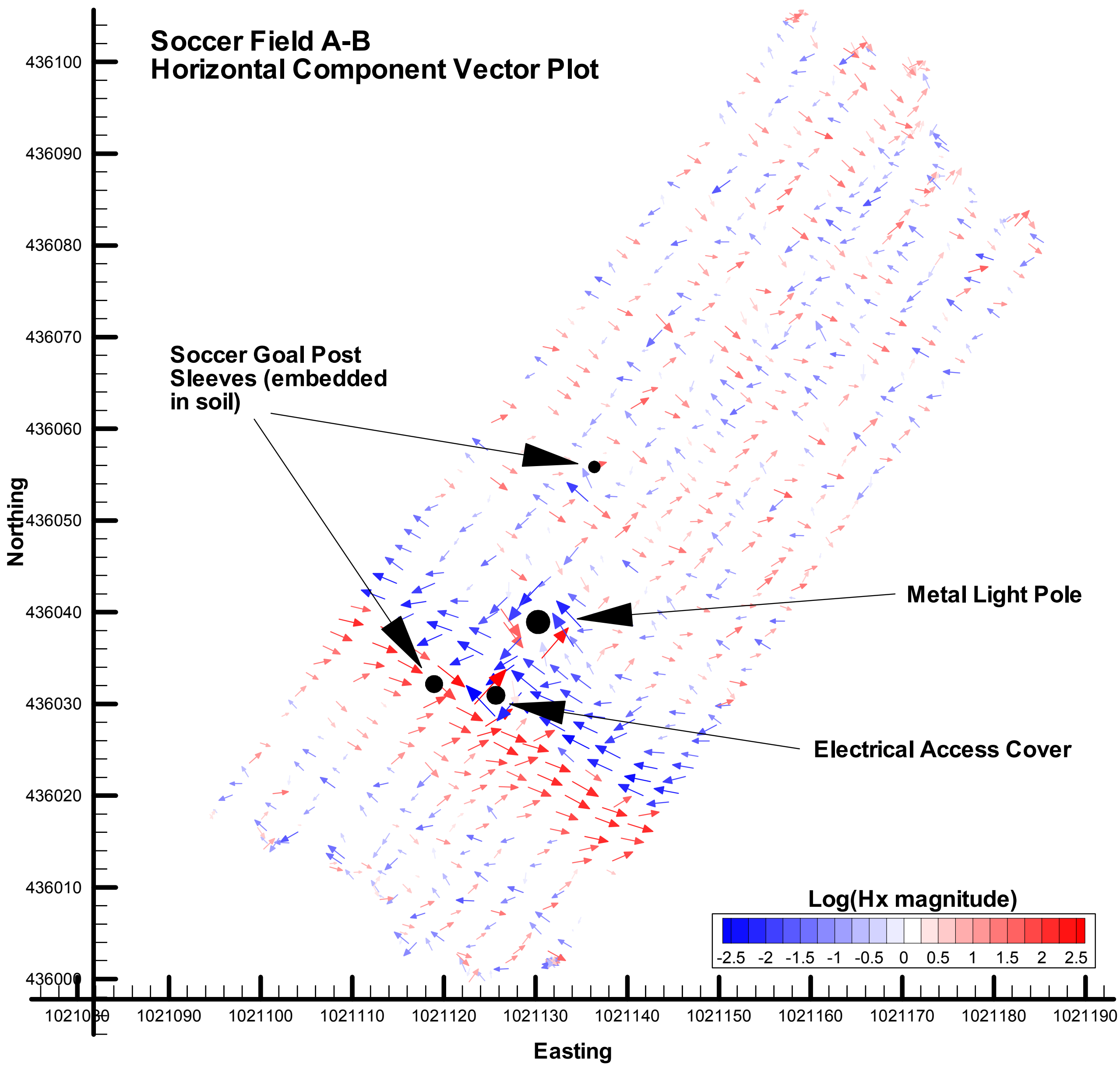

Figure 5. Early-time (window 1) HxHy vector component plot showing a second buried powerline that was not evident in late-time Hz-component data.

this plot with black open circles at each station; the size of the circle is dependent on the magnitude of the late-time Hz component anomaly. The only Hz-component anomaly (and EM-61 anomaly) is located centered at approximately grid location 1021342E, 435688N. It is definitely separate and distinct from the linear horizontal-field anomaly. Excavation of the EM-61 anomaly revealed a large number of nails, corroded into a solid mass, as if several boxes of nails had been disposed of in a small area. The excavation did not extend far enough north to intersect the linear anomaly in the horizontal component data, unfortunately.

A fourth anomaly that was not detected in the EM-61 survey is seen in Figure 7. This plot shows the horizontal component vectors (at 0.72 microseconds after turn-off) for the entire Eucalyptus Grove Grid. (Note that in this plot, the vector length has been magnified in order to show the show the weaker

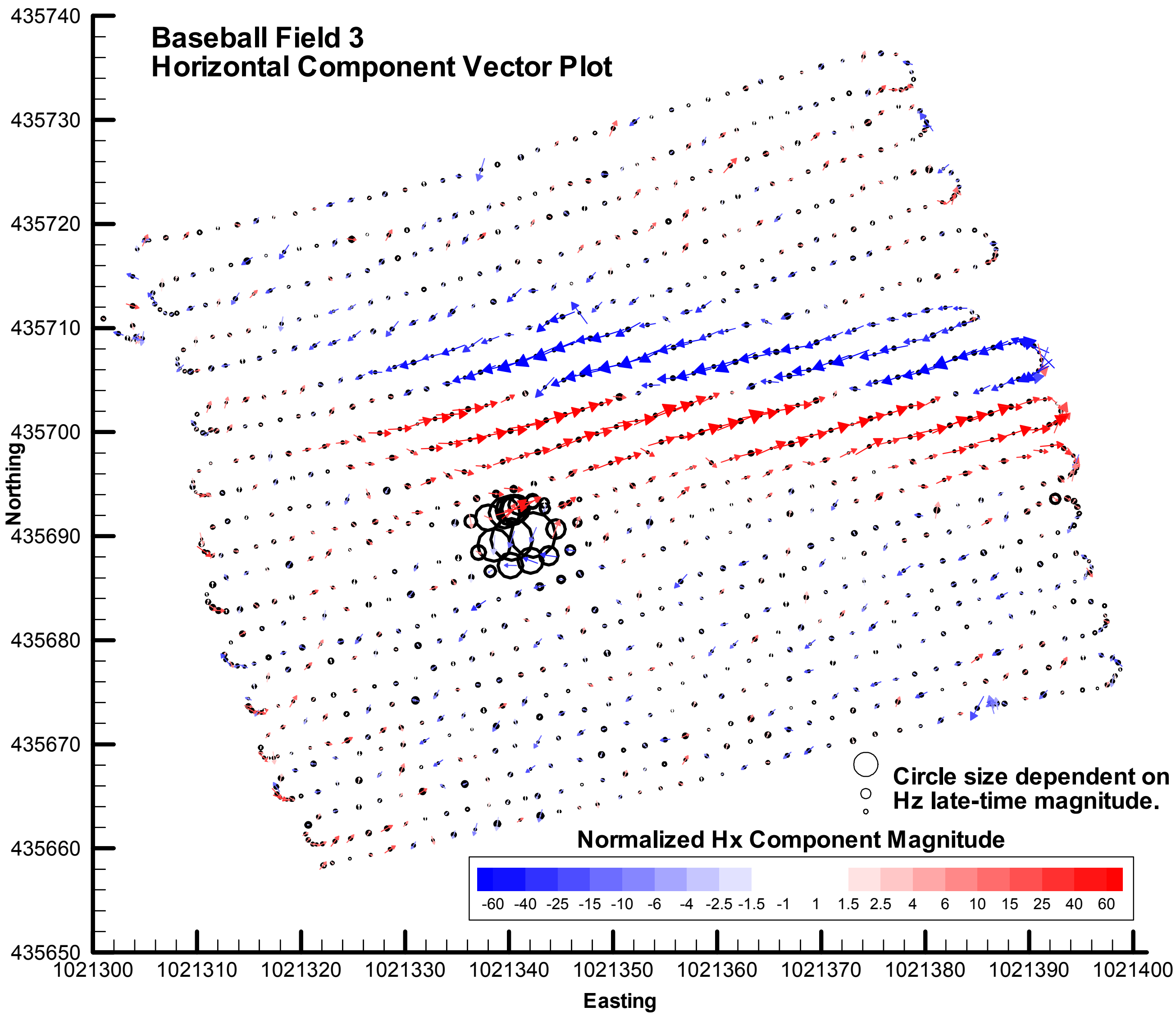

Figure 6. Early-time (window 1) HxHy vector component plot. The late-time Hz component data are included at each station as black open circles, with the circle size dependent on the Hz magnitude. The east-west linear anomaly that is evident in the vector data is not anomalous in the Hz data.

anomaly Linear C, and as result, some vectors associated with strong features overlap, and are less clear than in Figure 1.)

Three north-south linear features are evident; Linear A and Linear B are strong anomalies in horizontal as well as the vertical component data (the EM-61 and the NanoTEM). These two anomalies were verified as pipelines by excavation. Linear C was not evident in the EM-61 data or in the late-time

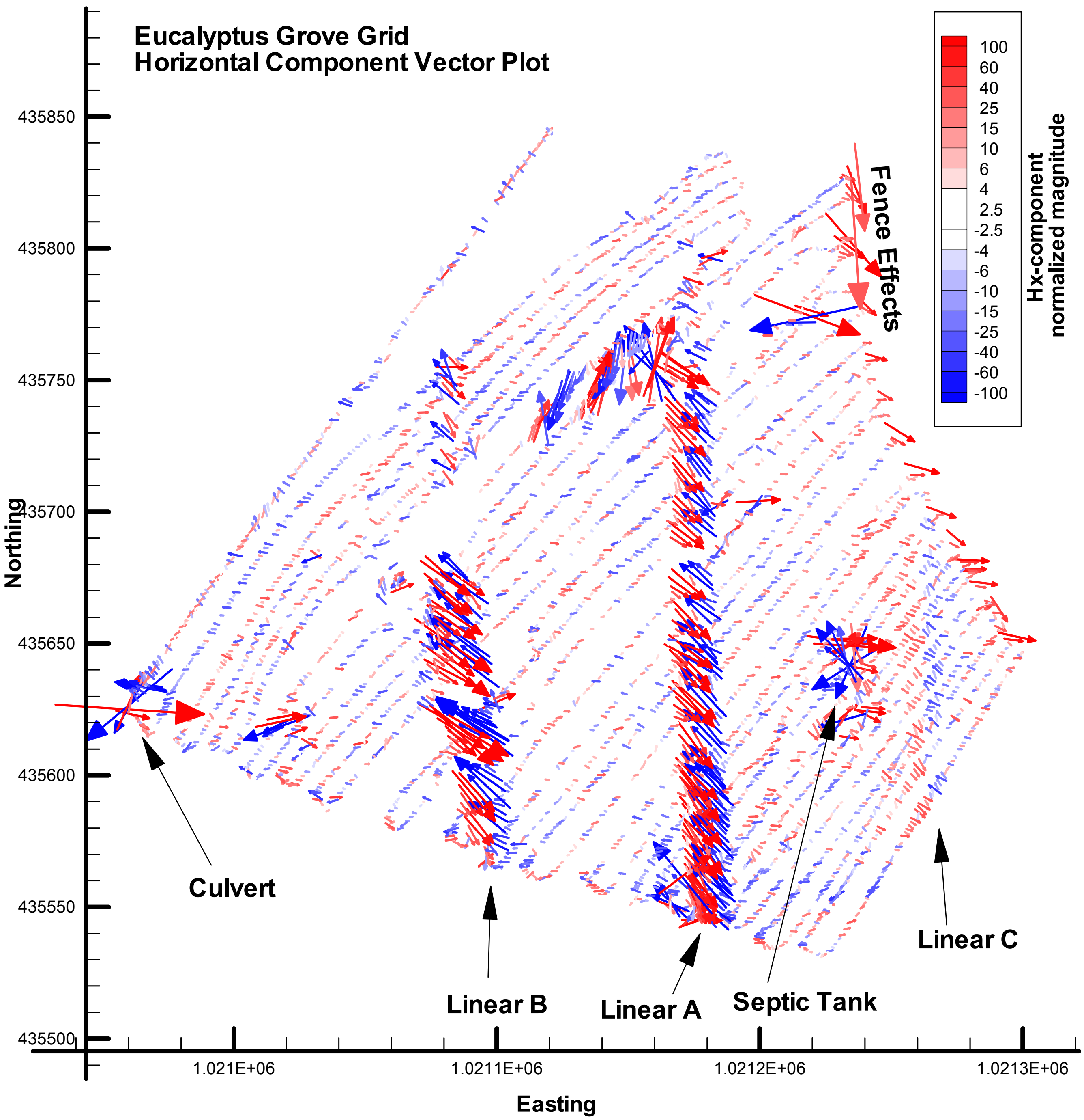

Figure 7. Early-time (window 1) HxHy vector component data for the entire Eucalyptus Grove survey grid. The vector lengths have been exaggerated relative to Figure 1 in order to better show the weak anomaly labeled Linear C.

NanoTEM data. It is extremely weak in magnitude, but it is almost exactly parallel to Linear A, and it is the same distance from Linear A to Linear B as it is from Linear A to Linear C. It is logical to assume that these three linear features are all part of the same buried utility system that serviced this area of the military base. The fact that Linear C is not evident in the late-time Hz data (either NanoTEM or EM-61) suggests that if this is a metal pipeline (like Linear A and B), it is apparently too deep to be detected in the Hz component. It is also possible that it is a buried powerline, with a very short time constant like the powerlines in the Sinkhole Grid (Figure 3) and the Soccer Field A-B Grid (Figure 5).

Conclusions and Caveats

As expected, when running a small-loop mobile TEM survey for deep metal detection, there is considerable valuable information in the horizontal component of the EM field, particularly in the very early times after transmitter turn-off. This is the result of the rapid decay of the background response in the horizontal component and the different coupling configuration with targets. The project discussed here shows good examples of targets that are not detectable in standard late-time, vertical field (Hz) measurements, but are clearly evident in the early-time, horizontal field measurements. The horizontal field measurements also allow target discrimination; at the very least, linear features such as pipelines and powerlines can be easily distinguished from 3-D targets with a single line of data. This ability can have significant impact on the use of reconnaissance lines, depending on the goal of a given survey.

Although the Hx and Hy component data can be acquired along with the standard Hz data with currently available electronics, positioning and data processing of the horizontal component data are somewhat more complicated. Not only is position of the system important, but orientation and direction of travel must be known and considered in the processing. Background noise is often different between Hx and Hy (depending on the local culture), which can introduce low level biases in the vector results.

The added value of the horizontal components far outweighs the processing and positioning needs, however. In the project discussed here, when a relatively small percentage of the project site was re-surveyed with the multi-component, early-time system, four previously undetected targets were identified. If the primary goal at this site had been to detect utilities such as powerlines or pipelines, this would be a particularly significant, and unsettling result. Fortunately, in this case the primary concern was 3-D features similar to the original sinkhole, and no additional features such as that were encountered in the repeat survey.

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