Three-dimensional sensitivity distribution of low-induction-number frequency-domain electromagnetic instruments

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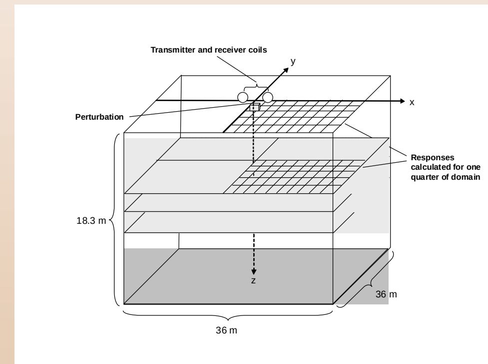
ABSTRACT

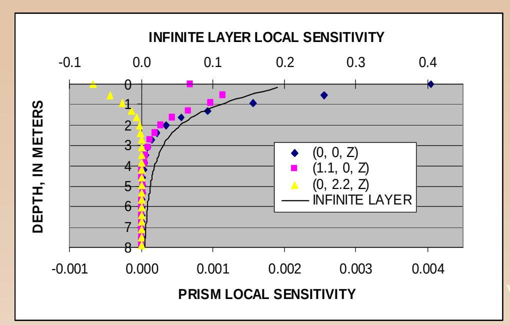
Low-induction-number frequency-domain (LIN FEM) instruments operate in three dimensions, but analyses has traditionally been done only in one. For proper site-selection and planning of field surveys, it is critical that users be aware of the complex variability of instrument sensitivity in three dimensions and be able to predict the manner in which the electrical conductivity (EC) of a given environment affects the spatial distribution of sensitivity. The objectives of this study were to examine the three-dimensional sensitivity of LIN FEM instruments and to describe some of the implications for field surveys. Simulations (ref 1) were carried out to map the local sensitivity in three-dimensional, homogeneous-half-space environments with EC of the ground varying from 1 to 100 mS/m. Local variations in instrument sensitivity were complex and included regions having opposite polarities. The largest variations in sensitivity were within a few meters of the instrument. Changing the orientation of the transmitter and receiver dipoles from horizontal to vertical resulted in significant differences in the local sensitivity distribution. The results of this study can be used to identify potential sources of error in field applications and design. For example, gross errors in interpretation of target location can occur if it is assumed that instrument sensitivity is uniform throughout the sample volume or even if it is assumed that sensitivity drops off monotonically as a function of distance from the instrument. In heterogeneous environments, there also could be near-surface effects. High near-surface EC can make it difficult to measure EC at greater depths. Temporal variations in water content of upper layers can, by changing EC, make exploration depth variable with time. Addressing the three-dimensional sensitivity distribution will result in better assessment of the suitability of the method to the target or process under investigation.

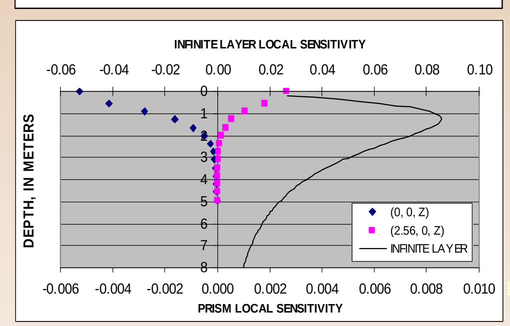
CONCLUSIONS

- The three-dimensional *LS* distribution was highly non-uniform and included regions in which the magnitude of the secondary magnetic field with the perturbation was greater than would be expected for the host without the perturbation. This was the anticipated result. It was not anticipated that when the perturbation was located in certain areas, that the magnitude of the field would be less than the result for the host without the perturbation.
- If the standard LIN interpretation were made of these results, meaning that σ is directly proportional to secondary magnetic field intensity, then the σ would be understood to decrease when the perturbation was located in these areas.
- CS contours are generally complex. VMD *CS* contours are elliptical and the HMD contours are highly irregular and lobate.
- The 90% *CS* contour was used as the boundary of the sample volume. The VMD sample volume is an elongated hemisphere with the long axis (14 m) corresponding to the transmitter-receiver axis of the instrument. The shorter horizontal axis was 13.5 m. The maximum depth of the lower boundary was located between 3.8 and 4.2 m depth.
- The sample volume of the HMD orientation was 14 m (transmitter-receiver axis) by 9 m (minor horizontal axis) by 4.6 m (bottom boundary).
- Of five one-dimensional, vertical *LS* curves extracted from different locations in the HMD and VMD data sets, the shape of only one matches that found for the infinite layer perturbation. This confirms the notion that different processes dominate in infinite layer simulations and small cubic perturbation simulations and underscores the inappropriateness of using infinite layer models to interpret data from sites where heterogeneity is at a much smaller scale than the measurement volume.
- If the size of an anomaly is not much greater than the sample volume of the instrument, difficulties in interpretation will arise. The principle of equivalence is at work here, meaning that a similar measurement could be obtained for an almost infinite number of combinations of anomaly size, shape and anomaly/host σ. Because of this, it will be problematic to settle on any given interpretation.
- The task of characterizing an anomaly that is small relative to the sample volume represents an ill-posed inverse problem. It may be difficult or impossible to acquire sufficient additional data to adequately constrain the system so that data interpretation has some degree of reliability. However, further related modeling studies could place some bounds on the uncertainty that could be introduced into interpretations under spatially heterogeneous conditions.

Conceptual model of simulation domain



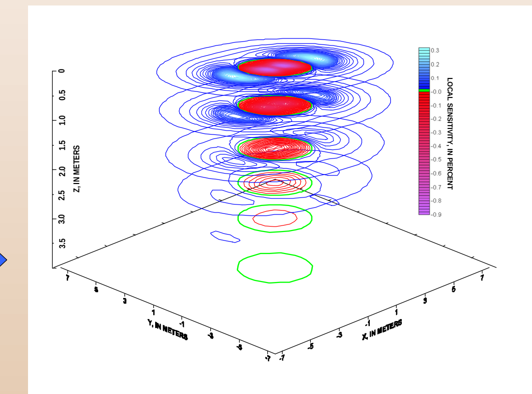


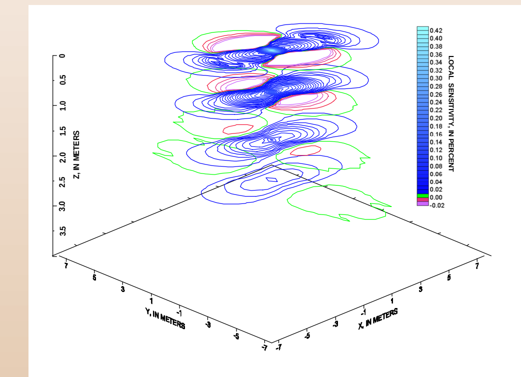


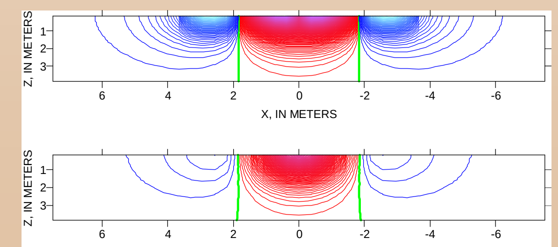
•**Comparison of the one-dimensional distribution of local sensitivity from one- and three-dimensional environments for VMD and HMD simulations.**

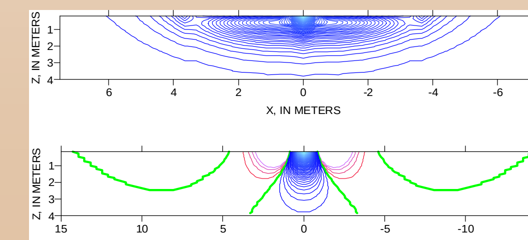
LOCAL SENSITIVITY

Red colors indicate a local response less than would be calculated for a homogeneous host response. Blue indicates response greater than host response. Stacked horizontal layers give indication of three dimensional local sensitivity (LS). Two-dimensional sections along primary axes



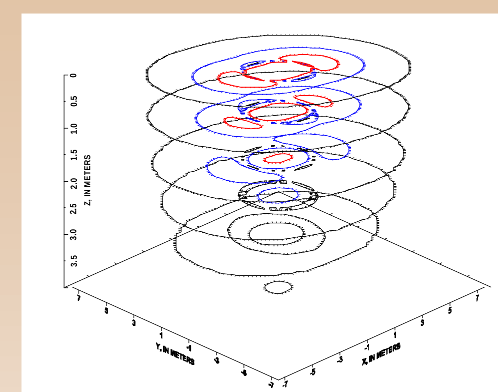


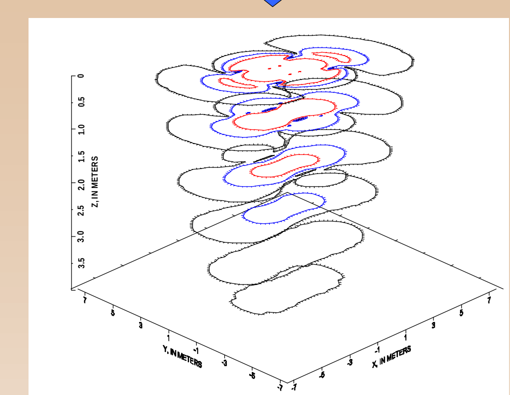


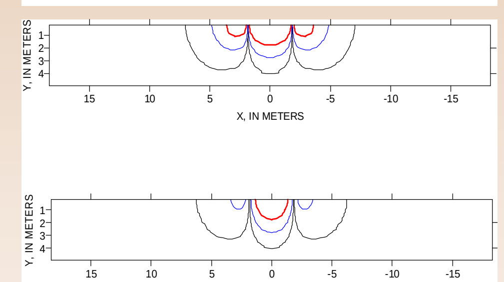


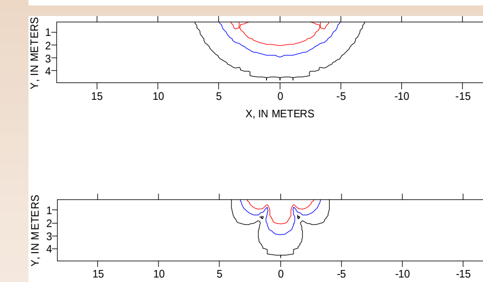
VMD

HMD









CUMULATIVE SENSITIVITY

Red indicates the 50% contour interval, blue the 70% contour; and black the 90% contour. Stacked horizontal layers give indication of three dimensional cumulative sensitivity (CS). Two-dimensional sections along primary axes

REFERENCES

- McNeill, J. D. 1980. Electromagnetic terrain conductivity measurement at low induction numbers: Technical Note TN-6, Geonics Ltd., Mississaugua, Ontario.

1. EMIGMA v7.7. 2004. PetRos EiKon Inc. Concord, Ontario.

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