Enhancing Subsurface Imaging in Mineral Exploration through Optimized large-scale Semi-Airborne Surveys: Synthetic Modelling and field Data

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SUMMARY

This study investigates the optimization of Semi-Airborne Electromagnetic (SAEM) surveys for enhanced subsurface imaging in mineral exploration. Synthetic modelling and advanced inversion techniques are employed to analyse the impact of various survey parameters. The study emphasizes the advantages of multi-component inversion, optimal receiver spacing, transmitter length, and orientation for accurate target recovery. It highlights the utility of multi-transmitter systems in overcoming challenges posed by distortion and masking of anomalies. The study further explores real data utilization and the challenges of large-scale surveys. It presents an innovative approach of interpolating inversion results from smaller patches to create an initial model for large-scale inversion, enabling efficient processing of extensive survey data. The research contributes practical insights to refine SAEM surveys, offering an equilibrium between resolution and cost for enhanced mineral exploration.

Keywords: SAEM surveys, electromagnetic inversion, mineral exploration, large-scale inversion, Survey design.

INTRODUCTION

Semi-airborne electromagnetic (SAEM) surveys have gained prominence in mineral exploration due to their capability to rapidly cover extensive areas (Kearey et al. 2002, Dentith and Mudge. 2014). However, the efficient imaging of deep conductive targets remains a challenge in geophysical exploration (Chen and Sun. 2020, Ke et al. 2023). In this context, this abstract delves into the process of optimizing SAEM surveys by dissecting the impact of various survey parameters on subsurface imaging quality. The findings are aimed at refining the practical implementation of SAEM surveys to enhance mineral exploration (Nazari et al. 2023).

The division of extensive survey areas into distinct patches (single flight area that include a Transmitter is called a single patch) is introduced as a strategy, exemplified by survey zones in the Harz region that is known for its mineral deposits. The benefits of multi-patch inversion are discussed. To address the computational demands of large-scale surveys, the concept of interpolating inversion results into a larger mesh is proposed for more efficient large-scale inversions.

METHODS

Our investigation employs synthetic modelling and real data inversion techniques in tandem with advanced inversion methods. We solve the total-field formulation of the Maxwell equations based on finite element forward operator custEM (Rochlitz et al. 2023), and pyGIMLi (Rücker et al. 2017) with a conjugate gradient inverse solver (Günther et al. 2006).

This method uses ground-based transmitters and airborne magnetic field receivers. By simulating diverse survey scenarios, we systematically analyse the influence of different parameters on the accuracy of electromagnetic inversion results. Then importance of single and multi-patch inversion, in handling large-scale surveys with real data and synthetic examples discussed.

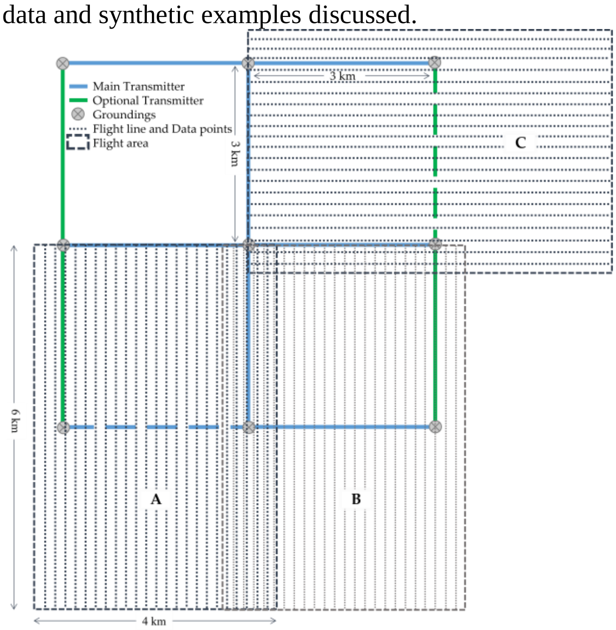

Figure 1: Recommended (Nazari et al. 2023) optimized survey layout (to be adapted to field conditions). The length of all transmitters and spacing between parallel transmitters was 3 km, using common groundings that reduced logistic effort. Three of the overlapping flight patches are given as examples (each covering an area of 24 km^2): (A) over the lower-left Tx (dashed blue), (B) over the lower-right Tx (solid blue), and (C) over the optional Tx (dashed green).

The simplest case in using real data is that we have only one transmitter (single patch) and several receiver points like patch A in Figure 1. In this case, for example, one flight for a single transmitter can cover an area of 6 x 4 km. In single-patch mode, fine discretization can be used, which helps to separate anomalies. In this case, the number of data is small, and the covered area is small, which means that the inversion uses less resources.

Results of synthetic modeling

The study of Nazari et al. (2023) explores the effectiveness of various techniques in enhancing the accuracy and resolution of semi-airborne electromagnetic (SAEM) surveys for mineral exploration.

1. Multi-Component Inversion: three-component inversion improves accuracy and boundary recovery in the results over single component by enhanced resolution.
2. Receiver Spacing: The study in this case suggests a line spacing of 200 m with 100 m in-line spacing as a balanced trade-off between cost and resolution. This parameter more depends on target dimensions.
3. Transmitter length: Optimal recovery of targets within 3 km from the transmitter requires a transmitter length at least twice the target dimension.
4. Multiple Transmitters: The use of multiple transmitters is crucial for more complex structures. Single transmitters can distort results and mask subsequent bodies. Employing two transmitters on both sides of the target enhances resolution and depth accuracy (Figure 2). Parallel transmitters are more effective in areas with prior knowledge of strike, Figure 2 shows result of using 2 transmitters at both side and parallel to the target, in non-2D settings perpendicular are recommended.

The study's key findings emphasize optimizing SAEM surveys for efficient subsurface imaging in mineral exploration. Multi-component inversion, appropriate transmitter orientation, and geological considerations enhance survey resolution. The proposed survey layout (Figure 1) balances resolution and cost.

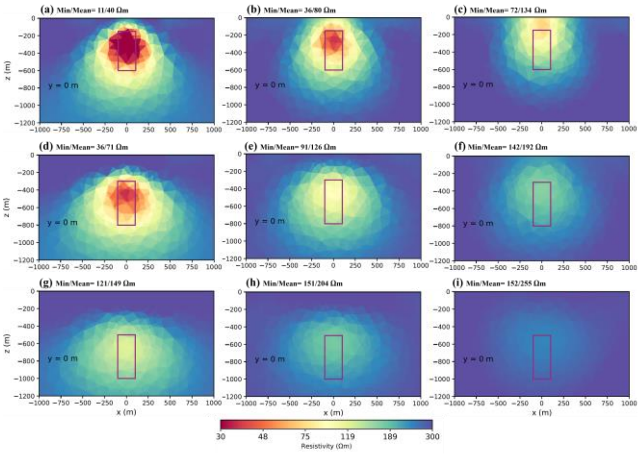

Figure 2: Inversion results for a body located at different depths: (a–c) 150 m; (d–f) 300 m; and (g–i) 500 m from the surface, and for different transmitter separation distances: (a,d,g) 2 km; (b,e,h) 3 km; and (c,f,i) 4 km.

Real Data Example

Figure 3 shows total of about 25 flight areas in Harz (central Germany), of which we focus on three patches in the Bad Grund area. For example, the result of the inversion (completed in 6 hours) of one of the transmitters shown in the Figure 4a/b.

After the data is obtained, it can be checked as a single patch first, but we saw that if more than one transmitter is used, the underground conductivity distribution can be obtained more accurately. For this purpose, the data from several transmitters (multi patches) must be entered into inversion. Figure 4 shows the result for all three white flight areas. In this case, an area of 30 km² has been covered. However, this is more time-consuming, in this case more than 75 hours. As the number of patches increases, even more time is required, as well as more processing resources that easily go beyond computers clusters. In Figure 4, we present the results of single and multi-transmitter Inversions. In subfigures a and b that are outcome of single transmitter inversion (Tx2), we observe a conductive body labelled as "M" on the left side of the image at depth 550 meters below sea level (mbsl). The resolution for this body is notably high, providing a clear and detailed representation. On the right side of subfigures a and b, we encounter a conductive area labelled as "N." This area starts from the 0 mbsl and extends to a significant depth about 1000 mbsl. However, the resolution for "N" is notably poor, particularly as it descends deeper into the subsurface. As discussed earlier, enhancing resolution is of paramount importance in geophysical surveys. One of the most effective strategies to achieve this is to employ multiple transmitters. Subfigures c and d, located on the right side, illustrate the substantial improvement in resolution achieved through the use of multiple transmitters. The poorly resolved conductive area "N" on the right side in the single-transmitter mode becomes highly resolved with multiple transmitters. This enhanced resolution extends to a depth of 1000 mbsl. Additionally, the resolution of conductive body "M" also experiences a noticeable enhancement, although to a lesser degree. In the multi-transmitter mode in the "O" area, a previously unseen conductive area comes to light. This new discovery was concealed in the single-transmitter mode, showcasing the significance of using multiple transmitters in subsurface exploration.

Single patches showed in Figure 3, cover about 300 square kilometres. An idea that can be used to avoid this problem is the case that

1. the inversion is performed as a single patch,
2. the results of these single patches are interpolated to a mesh that includes all the areas with larger cell sizes and combined by using a coverage-weighted mean of all patches,

3. The latter is used as the input of the Large-scale inversion.

We show this process here with a synthetic example. We consider a simple model that consists of a thin dipping plate along with the background. We survey this area using two different patches (Figure 5a and b). Then we enter each of these single patches separately into inversion. Then we interpolate the inversion result into a larger mesh that includes all areas as Figure 5d shows. Now we consider this larger mesh as the initial model for large-scale inversion.

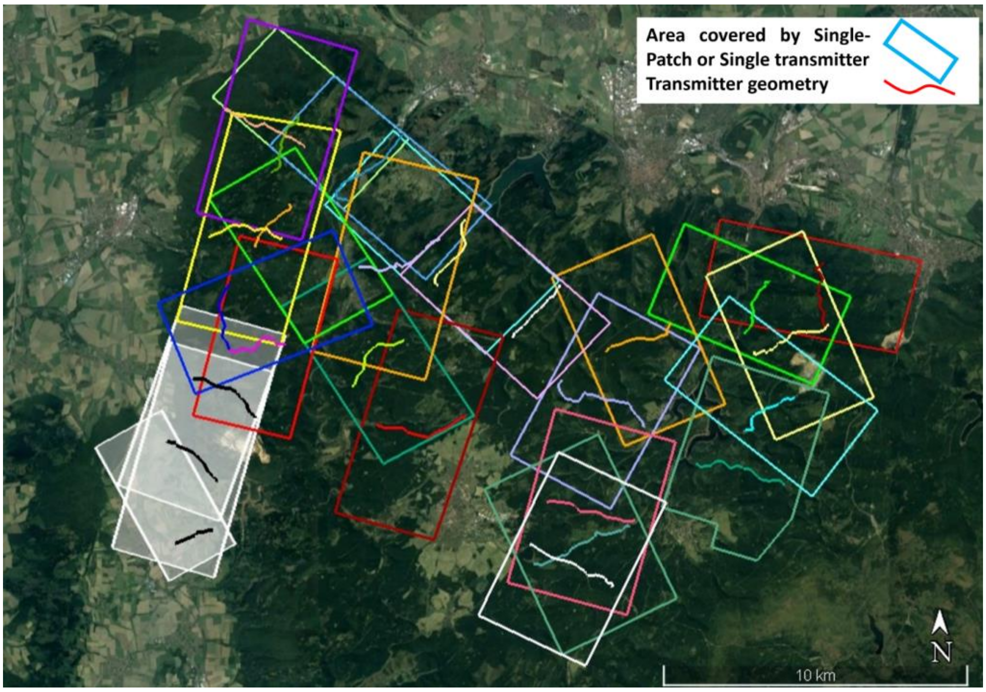

Figure 3: Survey areas (patches) in Harz region Germany. White areas with Black transmitters are patches used in Fig.4

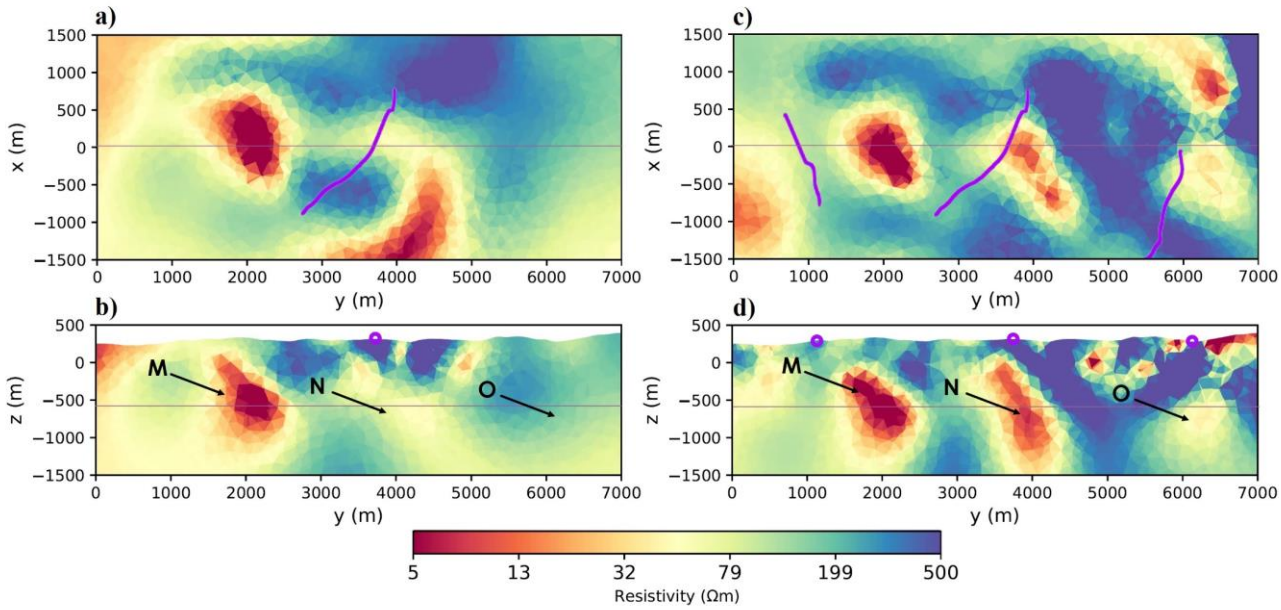

Figure 4: Left: Inversion result for single Tx2 (middle one in Fig. 3). (a) Z-plane view 550 mbsl, (b) X-plane view. **Right:** Multi-patch inversion result using three transmitters. (c) Z-plane view 550 mbsl, (d) X-plane view. The thin lines show the location of the corresponding slice. Purple lines and circles are the transmitters.

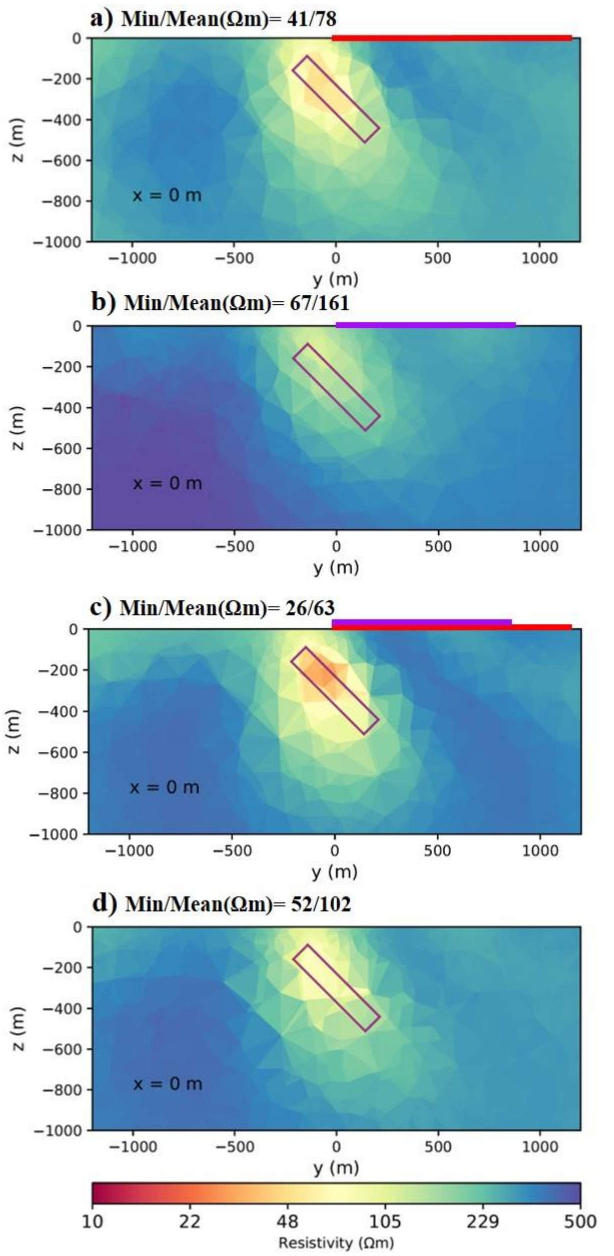

Figure 5: a) Single-patch inversion result of Tx1 or red line. b) Single-patch inversion result of Tx2 or purple line. c) Multi-Patch inversion result for Tx1 and Tx2 d) Both Inversion results of Tx1 and 2 are interpolated into this larger mesh.

DISCUSSION

Large-scale inversions offer several advantages over single-patch inversions in geophysical exploration and modelling. Based on what we showed in figures 2, 4 and, 5 these advantages are:

1.Improved resolution: Large-scale inversions can incorporate data from a broader area, resulting in enhanced resolution and accuracy of subsurface structures. By considering data from multiple patches or flight lines, the overall picture becomes more comprehensive, allowing for better identification and characterization of geological features.

2. Reduction of artifacts: Single-patch inversions might suffer from artifacts or anomalies caused by the limited coverage of the survey area or the transmitter itself. Large-scale inversions can mitigate these issues by providing a more data points.

3. Geological Complexity: Geological settings are often complex, and features can extend beyond the boundaries of a single patch. Large-scale inversions can account for the continuity and connectivity of geological structures that span across multiple patches. This is particularly important in scenarios where important features might be missed in isolated inversions.

4. Enhanced Interpretation: Combining data from different patches allows for a more holistic interpretation of the subsurface. Geological structures can be better correlated and understood when viewed in the context of a larger area, leading to more accurate and insightful geological models.

5. Improved Anomaly Detection: Large-scale inversions can help identify subtle anomalies that might not be evident in smaller-scale inversions. By analysing anomalies over a larger area, patterns and correlations can emerge that provide valuable insights into the distribution of subsurface materials.

6. Better Depth resolution: Inversions performed over a larger area can provide improved depth Resolution, allowing for the imaging of deeper geological features. This is particularly important in cases where valuable mineral deposits or other geological structures are located at significant depths.

In summary, large-scale inversions offer a more comprehensive and accurate representation of the subsurface compared to single-patch inversions. They are particularly valuable in complex geological environments where features extend beyond the boundaries of a single survey patch. The ability to integrate data from a different area leads to improved resolution.

CONCLUSION

The investigation outlined in the abstract demonstrates a comprehensive approach to optimizing SAEM surveys for improved subsurface imaging in mineral exploration contexts. By leveraging synthetic modelling and advanced inversion methodologies, the study underscores the significance of several critical factors in survey design. Multi-component inversion emerges as a strategy to enhance resolution and accuracy, particularly in scenarios with complex geological settings. The study also delves into the complexities of real data utilization and the challenges of conducting large-scale surveys. The proposed approach of interpolating inversion results from smaller patches to facilitate large-scale inversion is the first step solution to address computational limitations while still maintaining modelling accuracy.

ACKNOWLEDGMENTS

The authors express gratitude for the support and resources provided by LIAG and all people participated in the field work and processing, which enabled the execution of this study.

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