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UAV-electromagnetic measurements to map variations of depth to bedrock in southern Sweden.

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Summary

In the context of an infrastructure project UAV-electromagnetic measurements at five areas in southern parts of Sweden are conducted to study the variation of depth to the bedrock. The source signals are the distant radio transmitters in the band 15-350 kHz. The example shown in this work is from Area 5 where the underlying bedrock is a gneissic granite with reasonably high resistivity. The resistivity maps at lowest frequencies of the band reveal a N-NW low resistivity that coincides well with the observed increase of the soil thickness in the boreholes near the study area. The resistive bedrock is resolved well in all resistivity models from the 2D inversion. Drilling information in a borehole located at the centre of Area 5 report presence of kaolinite below the quaternary sediments and on top of the bedrock at depth of 16 m. The closest resistivity model to the same borehole resolves an increase of resistivity at the depth of about 19 m. In general, the results are very promising although a sharp boundary inversion should be made to resolve depth to the bedrock more accurately.

Introduction

To achieve the climate goals faster transition from road and air traffic to railway is inevitable. This demands a proper planning for railway expansion to meet elevated rail traffic dictated by freight passenger transportation. Such an expansion also needs relatively fast solutions, among those the elevated high-speed rail (HSR) used in Japan and China seems to be a very strong candidate. The technique uses placement of prefabricated piers at certain interval. Such an infrastructure needs accurate geotechnical data and advanced environmental/archaeological investigations. One very key factor to study is the depth to and quality of the underlying bedrock.

The traditional planning and construction process in Sweden is not adapted for development of such a rapid expansion HSR network. The project "Rational and effective preliminary investigations for industrialized construction of new railways", REICOR, develops a new comprehensive pre-investigation scheme prior to building railways and includes partners from academia, the Geological Survey of Sweden (SGU), and construction industry. The project concept is based on a step-by-step approach for decision making and aims to adapt, test, and demonstrate a rational and effective pre-investigation process for industrialized construction of new railways. Use of geophysical techniques plays an important role in such a process. A central part of the concept is that all relevant information is entered into a digital geo-model which is maintained throughout the life of the project and facility, and which is continuously updated with new results. (visit: Rational and efficient ground investigations for industrialised construction of new railways — Lund University)

Within the REICOR project SGU has conducted UAV-electromagnetic (UAV-EM) measurements over five selected areas in the stretch between the cities of Lund and Hässleholm in southern Sweden (Fig. 1). In this study we present some of the results found from these surveys and compare them with underlying geological information.

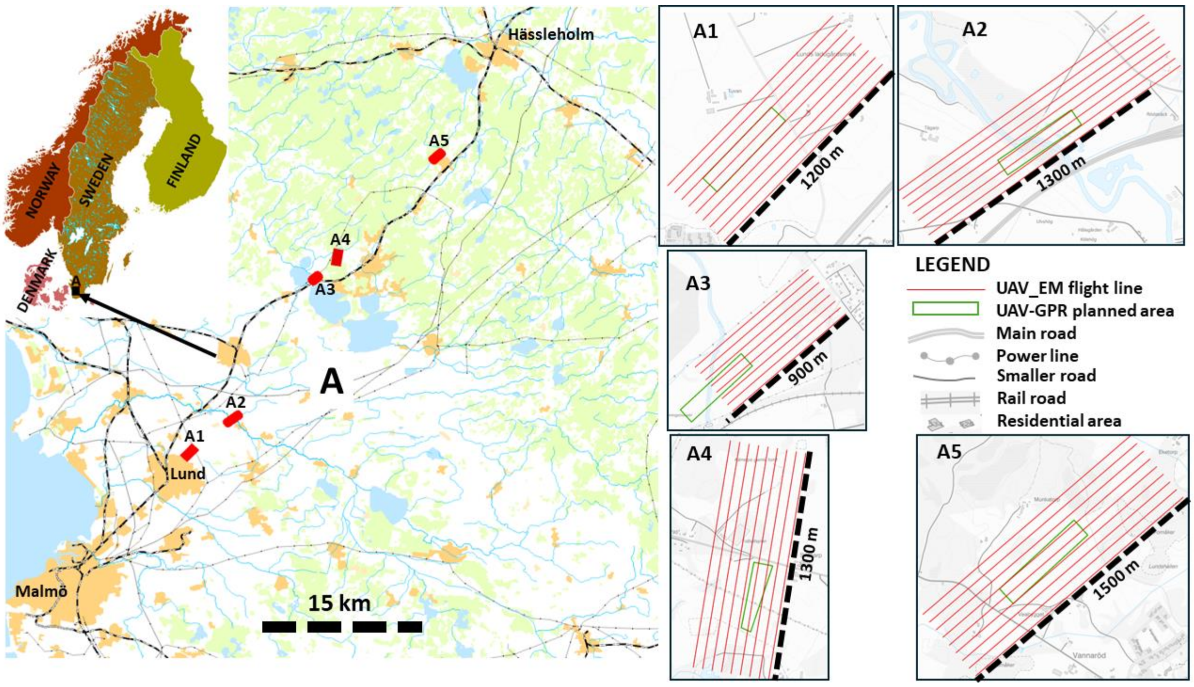

Figure 1 *The onset map shows the location of the project area in Sweden (top left). Five areas covered by the UAV-EM measurements are marked by red and labelled as A1-A5 on the location map in the left frame. Five smaller frames to the right-side show details of the UAV-EM lines and existing infrastructure in each area. There are also five areas planned for the UAV-GPR measurements (green boxes). Note that the nominal flight line separation in all areas is 50 m and the lengths of the flight lines varies between 850 and 1500 m.*

Method

Bastani and Johansson (2022) provide details of the UAV-EM system, signal sources, and processing developed by SGU. The measured magnetic field components of the EM signals from the distant radio transmitters in the frequency range 15-350 kHz are used to estimate the vertical magnetic transfer function (VMTF) in the narrow frequency bands of half-an-octave wide. The VMTF (also known as Tipper vector, **T**) is a complex valued vector that relates horizontal components to the vertical components of the magnetic field. A digital filter is designed to reject the noise interactively and to reduce bias from humanmade sources. The method developed by Becken and Pedersen (2003) is then applied to VMTFs to produce resistivity maps in each narrow band. The VMTFs are also the input to the 2D inversion code developed by Siripunvaraporn and Egbert (2000) to model the variation of resistivity with depth along each flight line.

Field example

As shown in Figure 1 the UAV-EM measurements are conducted in five selected areas. The data are collected within two days and processed in the field for quality control and adjustment of flight lines. We have selected to present the results in Area 5 in the abstract (see Fig. 1 for the location). Area 5 with an undulating surface topography covers cultivating land, access roads, and residential areas, which can be considered as a good example including a few sources of humanmade infrastructures that generate EM noise. The data are processed several times to identify and reject the noise prior to modelling.

Apparent resistivity maps

Figure 2 contains apparent resistivity maps in 7 frequencies using the transformation developed by Becken and Pedersen (2003). It demonstrates how the measured UAV-EM data is capable of imaging the variation of depth to bedrock. The resistivity maps at lower frequencies contain information from deeper underlying geological structures. The bedrock in this area is a crystalline gneissic granite that should have a relatively high electrical resistivity. The maps in the frequency range 17-47 kHz show mostly areas with high resistivity (>2000 Ωm) except at a few locations. One interesting feature is the nearly south-north running lower resistivity zone (marked by dashed black line on 17 & 47 kHz maps) that might indicate fracture in the bedrock. The existing information in the wells located in or near the study area reveal that the boreholes/wells with considerably larger soil thicknesses (> 15 m, see the bottom-right map in Fig. 1) are in the low resistivity zone.

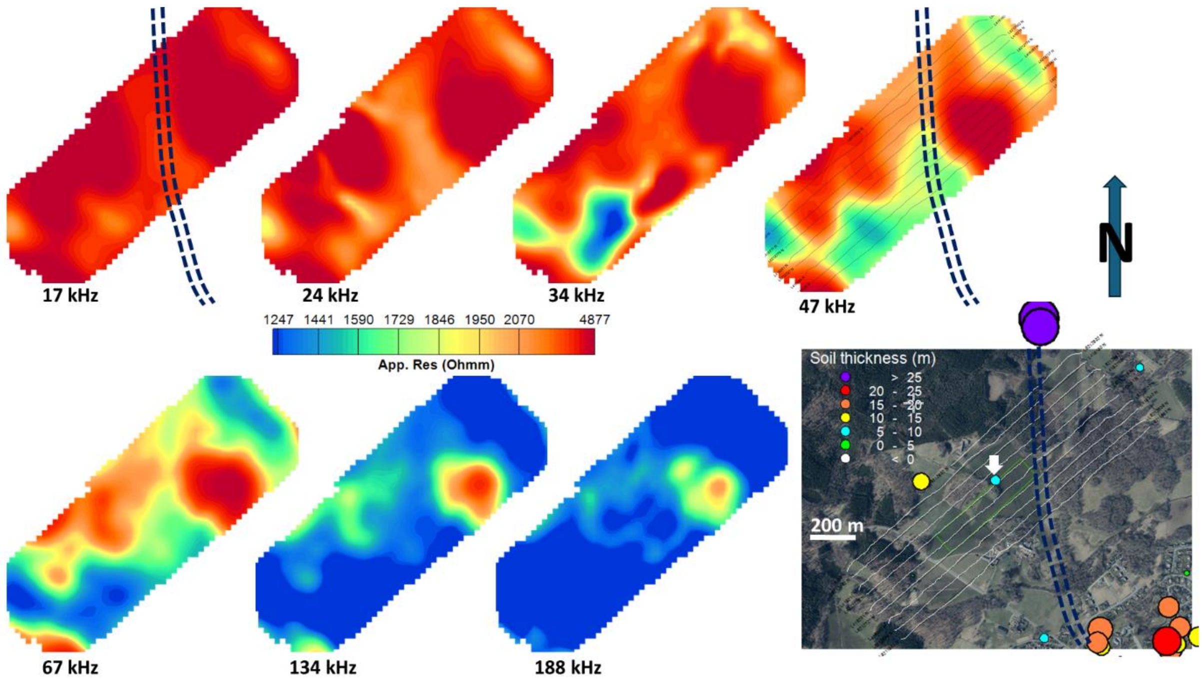

Figure 2 *Apparent resistivity maps at different frequencies in Area 5. The number below each map shows the mid-band frequency. The bottom-right map shows the aerial photo as the background superimposed by the symbols indicating location of wells in Area 5. The symbols with varying sizes and colours show the soil thickness (depth to bedrock) measured in each borehole/well. The black line indicates the possible trend of a zone with elevated soil-thickness. The white arrow marks the location of the borehole that is selected to compare with the closest resistivity model (see Fig. 4).*

The resistivity maps at higher frequencies show a transition to lower resistivities closer to the surface where most parts of the area, mainly covered by the quaternary sediments, have resistivities below 1300 Ωm. The areas with higher resistivities observed on the higher frequency maps (67, 134, and 188 kHz) occur close to the bedrock outcrops.

2D inversion results

The estimated real and imaginary parts of VMTFs in the selected bands are inverted to produce resistivity models along each flight line. A root mean square (RMS) of 1-2% using an error threshold of 1% is achieved which infers a good fit to the measured data. The RMS variation is partly depending on the proximity to the existing infrastructure. Figure 3 shows a 3D visualization of the resulting resistivity models from the 2D inversion of data. As observed in the apparent resistivity maps, the granitic bedrock appears as a high resistivity feature at deeper parts of the resistivity models. A low resistivity zone with a N-NW trend can also be observed in the models (the dashed black arrow). The zone has a varying thickness that can be used as a marker to study the variation of the depth to the bedrock. However, the bedrock is more resistive than the overlying quaternary sediments which makes it difficult to determine accurate depth to the bedrock using the resistivity models from the inversion of EM data. On the other hand, the resistivity models and apparent resistivity maps can be utilized as a very efficient tool to plan more detailed ground geophysical measurements, for example direct current (DC) resistivity and seismic measurements.

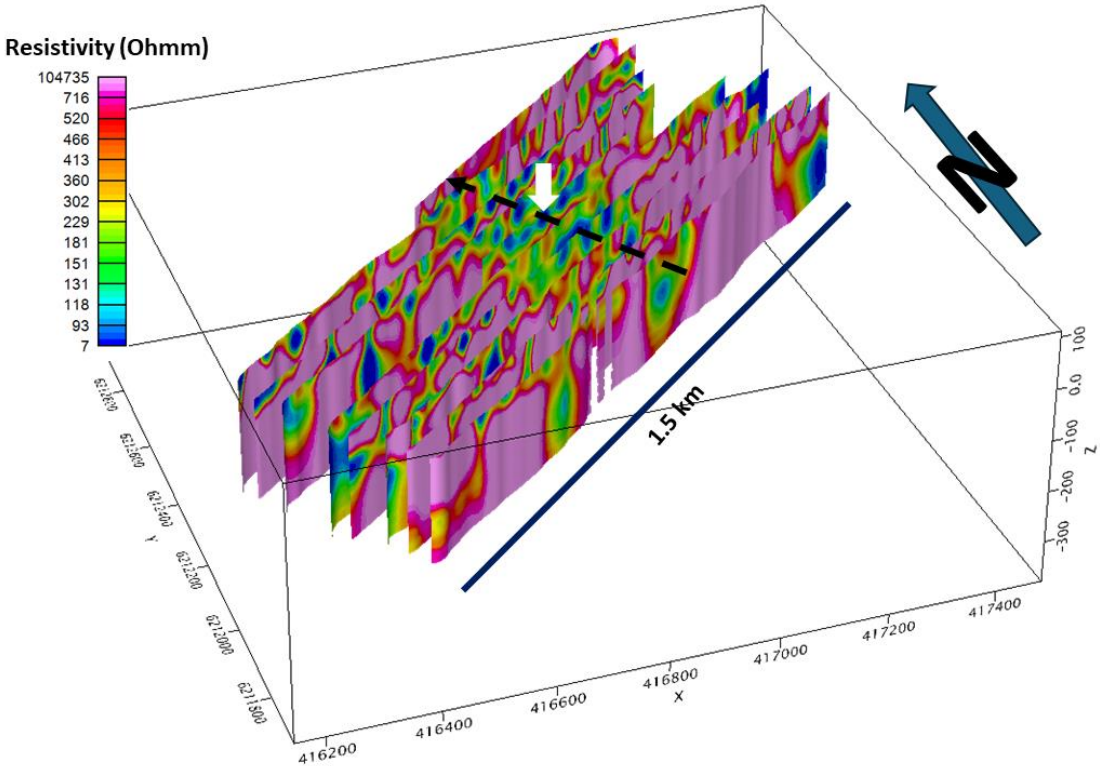

Figure 3 *Resistivity models from 2D inversion of VMTFs estimated from the measured UAV-EM data along the fight lines in Area 5. Applying an error threshold of 1% resulted in RMS values between 1% to 2% along the flight lines. The variation depends on the varying noise conditions dictated by the existing infrastructure along each flight line. The dashed black line indicates trend/location of a modelled low resistivity zone that corresponds well with the low resistivity zone shown on the resistivity maps (Fig. 2). The white arrow marks the location of the borehole selected for comparison with the closest resistivity model (see Fig. 4).*

Comparison with borehole data

The white arrow in Figures 3 and 4 marks the location of the borehole in Area 5. We have selected the closest resistivity model from the 2D inversion to compare it with the existing borehole information from drilling logs. Figure 4 shows the details in both resistivity model and the borehole logs besides each other. One should note that because of the smoothing regularization (Occam type) applied in the inversion process, the transitions between the boundaries are considerably smoother than those observed in the borehole. The resistivity drops from 300 Ωm at the surface to below 100 Ωm at a depth of ca 20 m and increases to around 4000 Ωm at 150 m depth. The borehole observations reveal that the coarser quaternary sediments at the surface are underlain by kaolinite located at a depth of 7 m. Below kaolinite a red gneiss is reported at a depth of 16 m which is underlain by a grey gneiss at depths of 50 m. One interpretation might be that the kaolinite is saturated with water and has a lower resistivity than the overlying coarse-grained sediments. Below this depth the (potentially) weathered gneiss has a higher resistivity than the kaolinite. The deepest part of the model with highest resistivities resolves the intact gneissic granite.

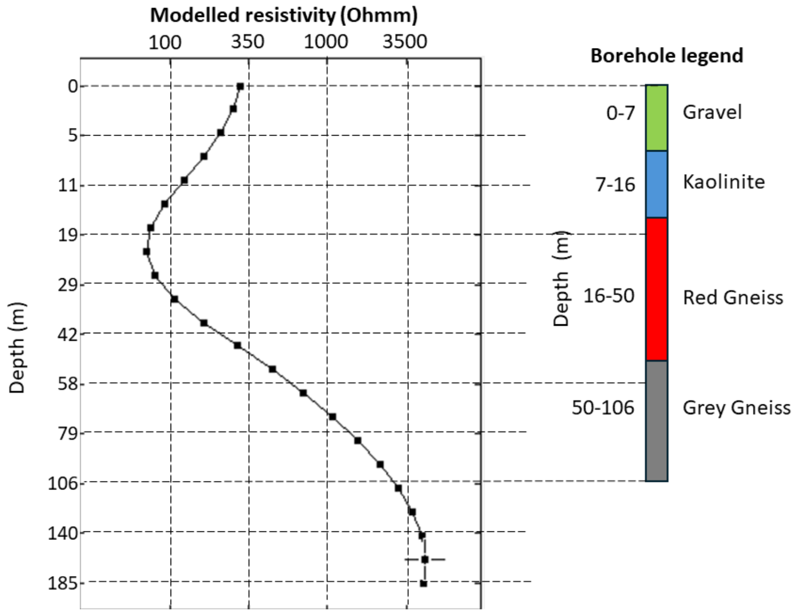

Figure 4 A comparison between the closest resistivity model from 2D inversion of VMTFs to the borehole in Area 5. Location of the borehole is shown in Figures 2 & 3 using a white arrow. Note that the thickness of model cells increases logarithmically with depth and consequently the depth intervals are not linearly distributed. The resistivity intervals have logarithmic scale as well.

Conclusions

In this work an application of UAV-EM measurements for engineering applications is reported. The measurements are made in five areas in a considerably short amount of time (two days). The apparent resistivity maps and resistivity models from 2D inversion of UAV-EM measurements are used to study variations of depth to the bedrock. The trend of reported increased soil thickness in the nearby boreholes matches well with a N-NW low-resistivity zone seen on the apparent resistivity map at the lowest frequency (17 kHz) where the EM signal has enough depth penetration. Detailed comparison between the borehole observations and closest resistivity model in Area 5 reveals interesting correlation where the resistive gneissic granite at depth is resolved as a high resistivity feature in the model. A sharp boundary inversion, for example using ground penetrating radar (GPR) or reflection seismic data, is needed to make the best possible comparison with the borehole data.

Acknowledgements
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