Lateral conductivity variations within Austria and its surroundings by means of extrapolating airborne electromagnetic data to hydrogeological units

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Introduction

The generation of a map of lateral conductivity variations was a task within the framework "GEOMAGICA", a FFG project coordinated by ZAMG (Zentralanstalt für Meteorologie und Geodynamik). The aim of this project is to develop a near real-time model of geomagnetically induced currents in mid-latitude Central Europe (Bailey, in press). It is carried out due to the fact, that large currents also pose a threat to Austria, not only in high-latitude countries, where geomagnetic storms are more powerful and have potentially more dangerous consequences.

Geomagnetically induced currents (GIC) are a consequence of clouds of energetic particles from the sun interacting with the earth's magnetic field and causing geomagnetic storms and rapid geomagnetic variations, which induce geoelectric fields in the earth's surface (Boteler & Pirjola, 1998). This leads to the development of electric potentials over large distances, which would dissipate of their own accord. However, with the arrival of extensive electrical infrastructure, additional paths of least resistance for direct current flow have been created, and currents will flow through the power grid or gas pipelines (Lehtinen & Pirjola, 1985; Pirjola et al., 2000). With transformers as the grid's earthing points, this leads to quasi-direct currents passing through the transformers, which in the long and the short term can cause transformer damage. In order to study, model and predict the possible GIC impact, knowledge of the variation of ground conductivity is necessary.

Within this abstract the challenging aspects of generating a map with representative conductivities all over Austria and parts of Europe are described below:

Airborne electromagnetic measurements and data processing

Following the approach of Beamish (2012), airborne electromagnetic data, available from more than 50 airborne electromagnetic campaigns from the Geological Survey of Austria, acquired between 1980 and 2014, were partly reprocessed with "state of the art"-technology. The results are conductivity data sets of homogenous half-space inversion results as well as conductivity multi-layer information of the survey areas. In the next step, these data sets were correlated with a hydrogeological map of Austria in a scale of 1:500.000 and average conductivity values were derived for each of the hydrogeological units. Using available geological maps from outside of Austria, conductivity information was extrapolated to a rectangle, including Austria and its European surrounding, resulting in a high-resolution subsurface conductivity map of this area.

The *Austrian airborne electromagnetic system* is a frequency domain system. The main part of the system consists of a tube (also called "bird"), which is towed on a cable 30 m below a helicopter. Inside the probe, there are several transmitting coils as well as receiving coils in different geometric arrangements (co-axial and co-planar loops). The transmitting coils generate an electromagnetic alternating field with the frequencies (current system) of 340 Hz, 3,200 Hz, 7,190 Hz and 28,850 Hz. This primary field induces eddy currents inside conductive subsurface layers. The corresponding (secondary) magnetic field generated by these currents induces a current in the receiver coils. Based on the amplitude and the phase shift of the secondary field relatively to the primary field, the electrical conductivity of the subsurface can be determined. The measuring rate is 10 measurements per second (resulting in a 3 m measuring

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point distance). Flight-lines are usually parallel straight lines, separated by 200 or 100 m (or less). It is tried to keep the height of the bird constant at 50–70 m above ground.

Airborne geophysical measurements in Austria are performed since 1980 with varying technical modalities. Since 2002 four frequencies (instead of two) and modern GPS measurements were available, therefore datasets from 2002 to now were reprocessed using the same inversion- and model parameters. Fortunately, aero-electromagnetic data for all hydrogeological units exist within this period. Optimal inversion and model parameters were determined in a prior test phase.

The *Inversion program EM1DFM* (Version 1.0, University of British Columbia, 2000) which was used constructs one-dimensional models of conductivity at each measurement point. For a layered model it is necessary to pre-define the depth of each interface. For the task required in this work, a homogenous half-space is assumed. Interpolating the models of each sounding results in a conductivity distribution of around 50 m to 100 m thick subsurface layers inside the survey areas. The variation of volume of the captured layer depends on the conductivity of the subsurface and the height of the measurement system above the ground. Other factors influencing the thickness of the investigated layer are the radiated frequencies, which are constant in this setting.

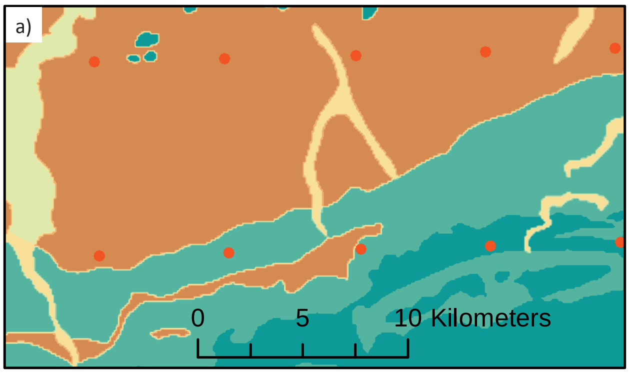
Geological maps

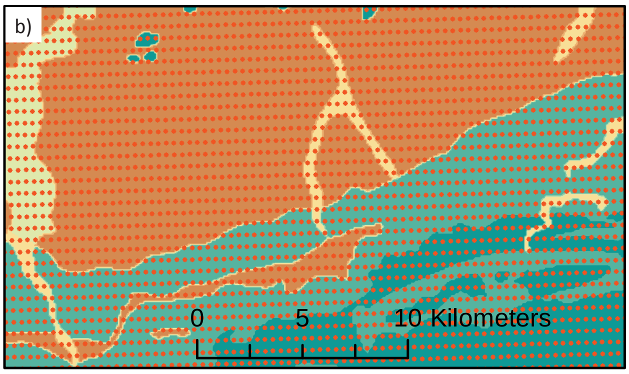
The decision, which kind of maps, representing the subsurface conditions, are most suitable for the purpose of generalising airborne electromagnetic data, is quite essential due to the fact that in this process conductivity samples, gathered in one polygon of a geological unit, are supposed to match under the terms of any other polygon within this unit. For this requirement the Hydrogeological map of Austria (Schubert, 2003) in the scale of 1:500.000 was found to be most suitable, because hydrogeological parameters as grain size and water content are determining factors, influencing the range of measured conductivities. This map considers both: hydrological and lithological aspects. For the surrounding of Austria, the Hydrogeological map of Europe at a scale of 1:1.500.000 (Duscher & Günther, 2014) was used. The scale of this map is high compared to the Austrian map and therefore the classification is more generalised. For this reason, the statistical power of the mean values, within the hydrogeological units, differs outside of Austria. The validation and improvement of the results will be object in further investigations during the project running time.

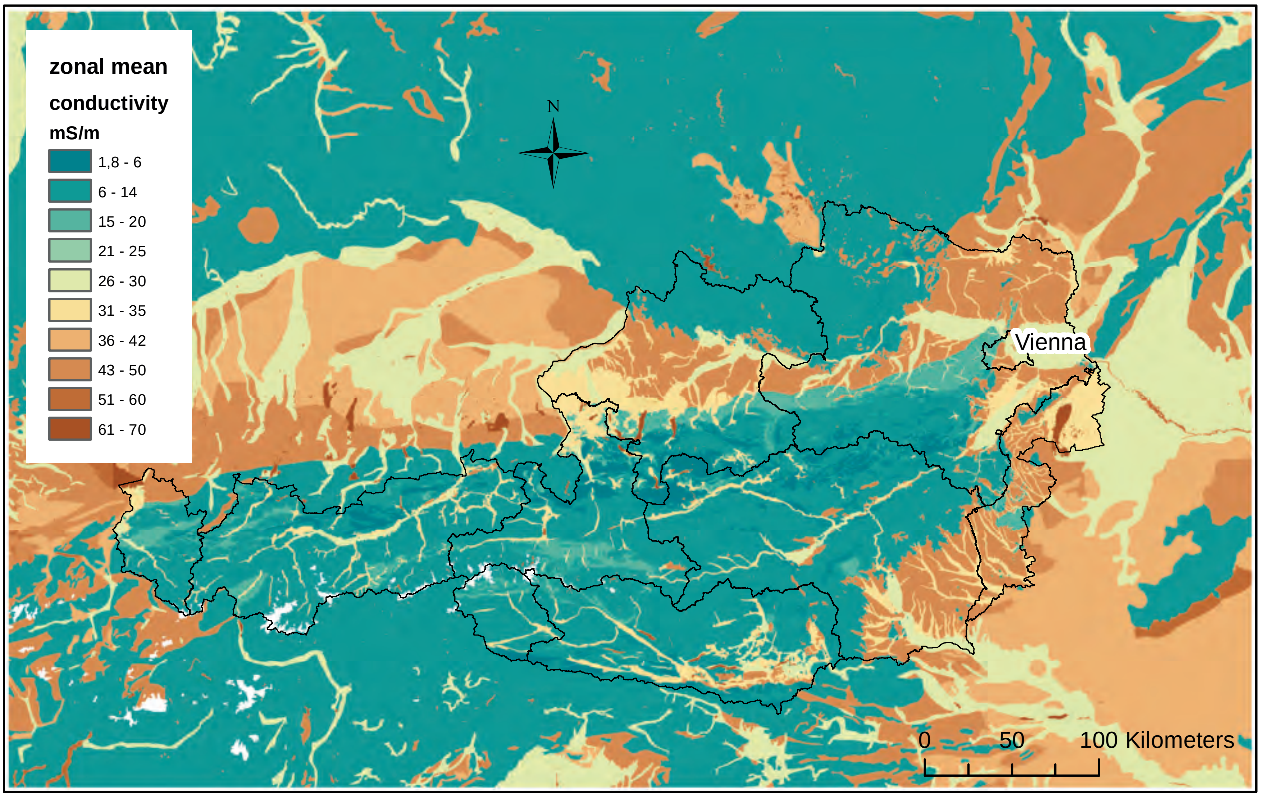
Resolution of electromagnetic data

Another aspect which needs to be considered, is the resolution of data of the geological map used and of the resulting conductivity map. The first two points were predetermined within this process, but the resolution of the conductivity map which was elaborated in Latitude/Longitude/Conductivity for the implementation of the GIC model had to be reviewed. The limiting factor was the maximum number of data points, which can be handled by Software generating a conductivity-model and a GIC-model. On the other hand, the resolution was supposed to be as high as possible, in order to get conductivity values of all hydrogeological units. This request was satisfied by the sampling rate of 500 m. To exemplify this issue Text-Figure 1 shows the difference between a sampling rate, which is too low (about 6,000 m) and a matching sampling rate (about 500 m).

Text-Fig. 1.
Difference between a sampling rate (red points) which is too low (1a – about 6,000 m) and a matching sampling rate (1b – about 500 m); Map: conductivities in hydrogeological zones of Austria.







Text-Fig. 2.
High-resolution subsurface conductivity model of Austria and its surroundings.

Result: Conductivity average values within hydrogeological units derived from AEM-Data

As result conductivity average values within hydrogeological units were derived (Text-Fig. 2). Currently this model is used for the purpose of incorporation to a near real-time model of geomagnetically induced currents in mid-latitude Central Europe.

Conclusions

Steady advances in hardware and improving data acquisition methods lead to accelerated increase of scientific data. While there is a wide range of problem statements and possibilities for using the data, in the best case it may contribute to socio-economic benefit. Helicopter surveys in particular produce huge datasets covering large areas, usually provided for different standard analysis. The herein presented project with its goal concerning the creation of a large-scale conductivity map for implementation in a model of geomagnetically induced currents shows a new application and the value of aeroelectromagnetic data gathered recently and also over a long period in the past for an important infrastructural problem.

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