In search for an Iceland plume: long period magnetotellurics

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Introduction

The method of magnetotellurics is used to determine the electrical resistivity distribution within the earth from measurements of natural, time-varying, magnetic and electrical fields at the earth's surface. The fields originate from electrical currents in the ionosphere and magnetosphere which induce secondary currents in the conducting earth. Since electromagnetic fields of longer periods are less attenuated than fields of shorter periods (skin effect), the observation of longer periods reveals information about greater depths. The estimation of frequency dependent complex transfer functions between different field components can be related to models of the resistivity distribution. To gain information about the lower crust and upper mantle periods ranging from minutes to several hours are required, which leads to the specialized method of long period magnetotellurics (LMT).

The resistivity of crust and mantle materials is influenced by several factors, e.g. the presence of partial melt. Given a certain geodynamical model, theoretical resistivities can be calculated using empirical relationships between resistivity, material composition, melt content and temperature, known from laboratory experiments. The resulting resistivities can be compared to results from LMT measurements. This way LMT measurements can contribute a constraint for geodynamical models. Modeling studies by Kreutzmann (2002) within the „Iceland plume dynamics project“ (IPDP) show that the presence of a plume head beneath Iceland would produce a significant magnetotelluric signal if melt content is higher than 1%.

Earlier work by other authors give detailed insight into the resistivity distribution within the Icelandic crust. One remarkable result is the presence of a sheet-like conductor in approximately 20 km depth beneath most parts of Iceland (e.g. Thayer 1981, Beblo 1983). However, these datasets don't cover periods long enough to study features in greater depths. Therefore three field sites for long period monitoring were set up by Beblo and Björnsson in 1999 and in 2001 a joint project was initiated by the universities of Akureyri (Björnsson), Munich (Beblo) and Frankfurt (Junge), titled „Continuous Monitoring of the Icelandic Crust and Mantle Resistivity“ (CMICMR). It's objective is to collect, process and analyse continuous LMT data from several stations on Iceland to obtain a reliable resistivity model of the upper mantle beneath Iceland, which hopefully will help to reveal information about the presence or absence of a plumehead.

Data collection and processing within the CMICMR project

Since 1999 three LMT sites were in continuous operation (see Figure 1). They were located at Akureyri (AKU), Húsafell (HUS) and Skrokkalda (SKR). In 2002 SKR was replaced by a new site at Grímstaðir (GRI). The other sites are still in operation. Each station records the two horizontal electric field components and all three magnetic field components with a sampling period of about 1 s, theoretically enabling the coverage of the period range from about 8 s down to DC. So far the data processing was concentrated on periods between 8 s and 9 h.

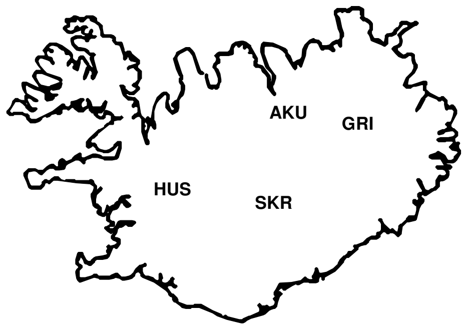

Figure 1: Location of LMT sites on Iceland.

The observed timeseries are split up into segments which are Fourier transformed to calculate transfer functions between different field components and stations. Thereby a quasi uniform source field is assumed. Deviations from this assumption can lead to systematic errors of the transfer function estimates, known as so called source-effects. Due to Icelands location at the edge of the auroral oval it is close to the polar electrojet and the possible presence of strong source effects had to be taken into consideration. Great care was taken to avoid source effects by automatically selecting time segments with low source field inhomogenity. However, in the end the transfer functions turned out to be more stable in regard to source effects than it was assumed. This improves our confidence in the correctness of the transfer function estimates.

Preliminary results

Early analyses of the CMICMR dataset were performed by M. König (1999) and C. Salat (2002) and are continued by S. Golden. Figure 2 shows apparent resistivity and phase curves for the station Húsafell. The apparent resistivity first descends to a minimum around 200 s, which is related to the good crustal conductor. Beyond that there is a slight increase of the apparent resistivity followed by a second decrease which at most sites/polarizations forms a second minimum around 5000 s. This minimum can be explained by a second good conductor in a depth of about 200 km. 3D modelings by A. Kreutzmann showed that such a minimum can be caused by a mantle plume head or a ridge effect. To discriminate between those two possible causes further modelings are needed, which additionally take transfer functions between horizontal and vertical magnetic field components (tipper) into account.

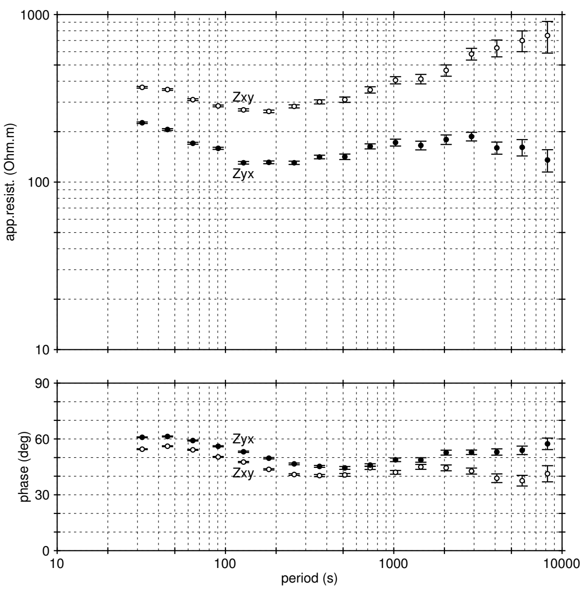

Figure 2: Example of apparent resistivity and phase curves at the site Húsafell (HUS).

Conclusion

Until now magnetotellurics was not able to answer the question on the existence of an Iceland plume. Forward modeling by Kreutzmann has shown that a plume head could produce a significant signal in the magnetotelluric data if it contains more than 1% melt. The detection of such a signal would provide strong evidence for the plume hypothesis. However, the absence of such a signal can' be used as proof against it. In either way, reliable resistivity estimates for the upper mantle will result in additional constraints for geodynamical models. Ongoing work in the CMICMR project is directed to increase the resolution and reliability of resistivity estimates to increase their usefulness for such interpretations.

Further information:
http://www.geophysik.uni-frankfurt.de/em/icelmt/

This project was in part funded by the Deutsche Forschungsgemeinschaft (DFG) as project BE 835/8-1.

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