Inversion of the geomagnetic induction data from EMTESZ experiments in NW Poland by stochastic MCMC and linearized thin sheet inversion

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Abstract

72 long period induction arrows obtained during EMTESZ experiments in north Poland were inverted by global optimization Monte Carlo Markov chain stochastic method and unimodal thin sheet inversion. From the stochastic inversion with the thin sheet at the surface of the Earth we obtained histograms for unknown conductances and the most probable model was constructed. The results of MCMC are compared with the results of linearized unimodal thin sheet inversion where the thin sheet is placed in 3 km depth. The resulting models are compared with surface distribution of the conductance of the sedimentary cover.

1. Introduction

The main task of the international project EMTESZ is to achieve on the basis of electromagnetic methods an essential progress in understanding the structure, tectonic position and role of the Trans-European Suture Zone (TESZ) as a fundamental lithospheric boundary separating south-western and north-eastern Europe, which is supposed to have played a key role in the evolution of the Paleozoic orogens across the whole of Europe (*Pharaoh et al., 1996*). TESZ is crossing NW-SE through the continent and exceeding 2000 km in length. It is a broad and deeply seated structurally complex zone of Palaeozoic deformation where younger terranes were sutured to the Precambrian Baltic Shield and East European Craton (EEC) during the formation of Pangea. At the surface the TESZ is largely masked by sedimentary basins of the Polish Trough, while at depth it marks the increase in crustal thickness from about 30 km under the western Europe to about 45 km beneath the EEC. Various hypotheses for the tectonic evolution of the TESZ are debated today, ranging from mobile to more static scenarios (*Pharaoh et al., 1996*). Understanding the contrasting signatures of the European deep lithosphere requires a detailed analysis of its tectonic history and correlation of its physical parameters through various geophysical experiments.

The EMTESZ experiment has been organised as an international collaboration project that aims at constructing an electrical image of the entire lithosphere along a profile running from the Polish Basin to the East European Craton, crossing the TESZ as a first-order tectonic boundary. Within this study, several research teams from Poland, Czech, Germany, Finland, Russia, Sweden and Ukraine participate in the field measurements, data processing, analysis and interpretation.

The international teams measured in NW Poland at first along two seismic profiles P2 and LT7 and later some small profiles and many individual points were added. At present more than 100 MT and AMT points form a geoelectrical array suitable for various interpretations.

Electric and magnetic field was measured at each station in a broad period range and geoelectrical characteristics were obtained. Various geoelectrical characteristics were interpreted by different teams. We concentrated on the interpretation of the geomagnetic transfer functions which express a relation between vertical and horizontal magnetic fields and are represented by induction arrows or vectors.

2. Inversion MCMC method

We used global optimization Monte Carlo Markov chain method (MCMC) to solve the Bayesian magnetovariational inverse problem in 2D domain representing superficial thin sheet (*Grandis, H. et al. 2002*). Forward problem solution is based on Weidelt's algorithm (*Vasseur, G. and Weidelt, P., 1977*).

The thin sheet at the surface is divided into homogeneous square cells, and the model parameters are the conductivity of each cell. In our experiments we used a mesh with 40x22 cells; it means we had 40x22 unknown conductances. There are some practical problems which we meet, if we use this approximation. At first we must give a guess of "normal structure" around calculated area. We must guess the normal 1D structure and the normal surrounding conductance. From this reason we tested several values of the normal conductance from 600 S to 1800 S which correspond to estimates obtained by *Varentsov at al., 2004*. Because we use for inversion experimental data obtained for long period 1024 s, our "thin" sheet should in fact contain information from first few km. The original experimental data must be also transformed to the rectangular mesh suitable for thin sheet calculation. There is problem with relatively large areas without any experimental data. From such locality we obtain only very vague information.

In the inversion procedure we are using Gibbs sampler. Starting from the latest state of Markov chain with parameter ***d,*** the Gibbs sampler loops through all the components of the vector ***d*** and updated each individual component of ***d***. After all components of the parameter vector have been updated in this way, one iteration step of the Gibbs sampler is competed (*Menke, W., 1989*). The inversion procedure gives a series of models which should be probabilistically distributed in accord with the experimental data. We used 11 possible values of conductance from 400 S to 12000 S. In MCMC inversion we obtain a whole *histogram for each cell*, which shows how much likely the particular conductance values are at the cell considered. We can estimate the uncertainty of the conductance by observing the flatness or peakiness of the histogram. As a result of our inversion, we obtain aposteriori probabilities for the discrete conductances within individual sheet cells.

At first we concentrated on induction data from the vicinity of two measured seismic profiles P2 and LT7 located in NW Poland. Average conductance model obtained by MCMC inversion for period 1024 s is presented in Fig. 1. The mean conductance is computed from the conductance histogram at each cell.

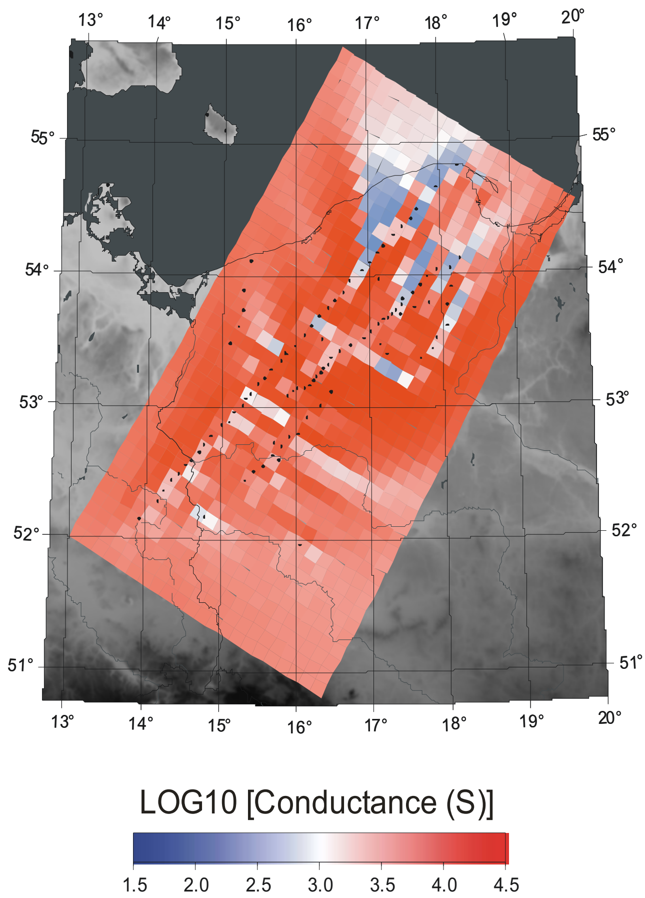

Fig. 1: Average conductance model from MCMC. T=1024 s

Comparison of the real parts of the induction arrows $\boldsymbol{W}$ for this model and the experiment again for period 1024 s is in Fig. 2. There is very a good agreement between a model and observed induction vectors. Also the agreement for the imaginary part of the induction vector is good.

3. Inversion with new data from NW Poland and with new geoelectrical characteristics

We also tried to interpret the data from broader area. We interpreted old experimental data with several new stations and we inverted two long periods 1024 s and 2048 s simultaneously. The computer program was adopted also for simultaneous interpretation of induction arrows and horizontal magnetic transfer functions with respect to a reference station (*Brasse at al., 2006*)

$$H_Z = W_X H_X + W_Y H_Y$$
$$H_X = M_{XX} H_X^R + M_{XY} H_Y^R$$
$$H_Y = M_{YX} H_X^R + M_{YY} H_Y^R$$

and we tried to find the solution with minimum distance from predefined reference model with homogeneous conductance of 1500 S. Inter-station transfer functions were related to the site with coordinates (54.0488° N, 18.1183° E) in the north-east part of the studied area. The horizontal inter-station magnetic tensor has been suggested as a parameter with relatively weak sensitivity to the spatio-temporal variations in the excitation field, as it relates magnetic field components over a distance that is short in comparison with a dimension of the source field. Thus it can help in eliminating the external non-stationary and non-uniform source effects on the recorded data.

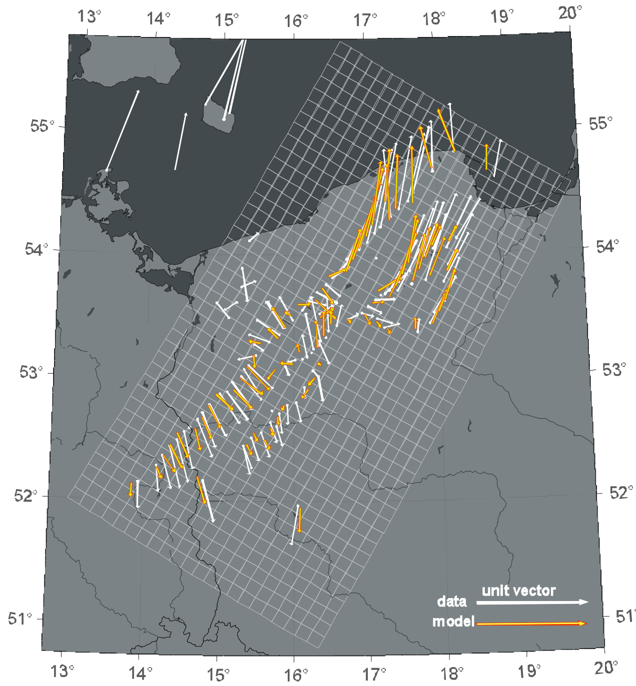

Fig. 2: Comparison of model (orange) and observed (white) Re$\boldsymbol{W}$ for T=1024 s.

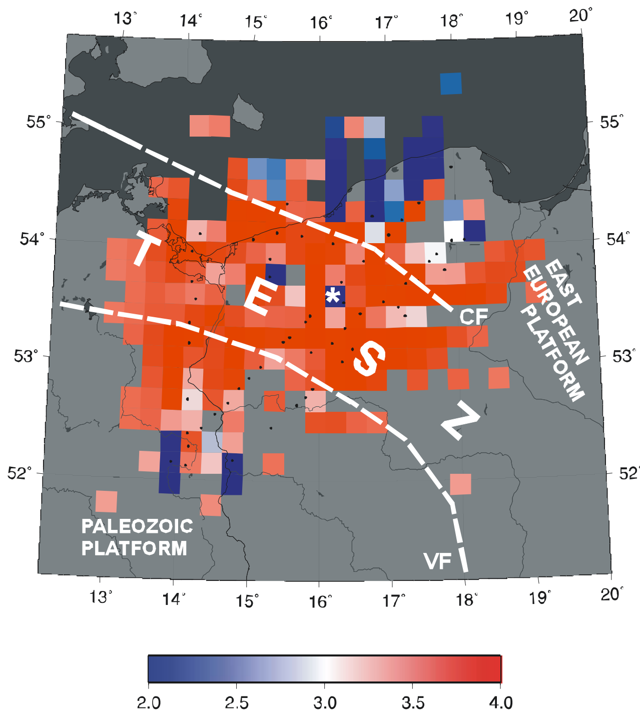

Fig.3: MCMC solution for $\boldsymbol{W}$ with cells where 90% of conductance fall within 1/2 of decade. 1024 and 2048 s periods considered. VF - Variscan Front; CF - Caledonian Front; * - Czaplinek block

In this case we restricted to the mesh of 22x22 cells and we used 18 values of conductance for the Gibbs sampler from 200 S to 10000 S. In Fig. 3 conductance model is presented obtained from the MCMC inversion only for induction vectors ***W*** only. The cells for which 90 percent of the conductances from stochastic samplings fall within one half of a decade are there displayed.

In Fig. 4 conductance model is presented obtained for the simultaneous inversion of the induction arrows ***W*** and horizontal magnetic transfer functions ***M***. The cells for which 90 percent of the conductances from stochastic samplings fall within *one third of a decade* are there displayed. By means of adding horizontal magnetic transfer functions to the inversion we obtain higher resolution of the results.

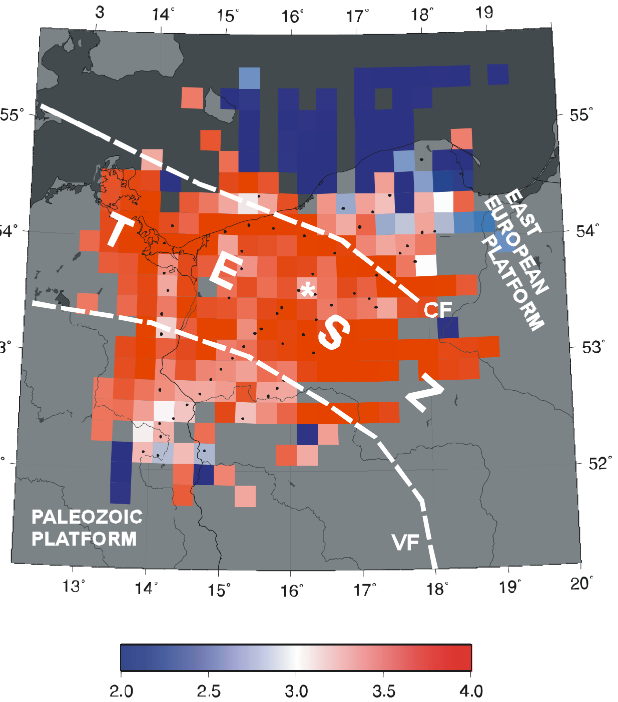

Fig. 4: MCMC solution for ***W+M*** with cells where 90% of conductance fall within 1/3 of decade. 1024 and 2048 s periods considered. VF - Variscan Front; CF - Caledonian Front;
* - Czaplinek block

4. Linearised inversion

Results of the MCMC are compared with the results of the linearized thin sheet inversion (Fig. 5). For the linearized inversion the unimodal thin sheet approach was applied, where the effect of only the horizontal current components within the thin sheet was considered and the anomaly source is replaced by an equivalent current system in this sheet.

Forward problem solution is based on the approximation of the Earth's anomalous structures by a thin horizontally inhomogeneous sheet buried at a specified depth in a generally layered Earth (*Wang, 1988*) and the integrated conductivity (conductance) within a conducting thin sheet is calculated from the recorded geomagnetic transfer functions at the Earth's surface. Both single-station vertical transfer functions (components of the induction vectors) and the horizontal inter-station transfer functions were employed in the inversion procedure.

Regularization was solved using the minimum gradient support focusing (*Portniaguine and Zhdanov,*

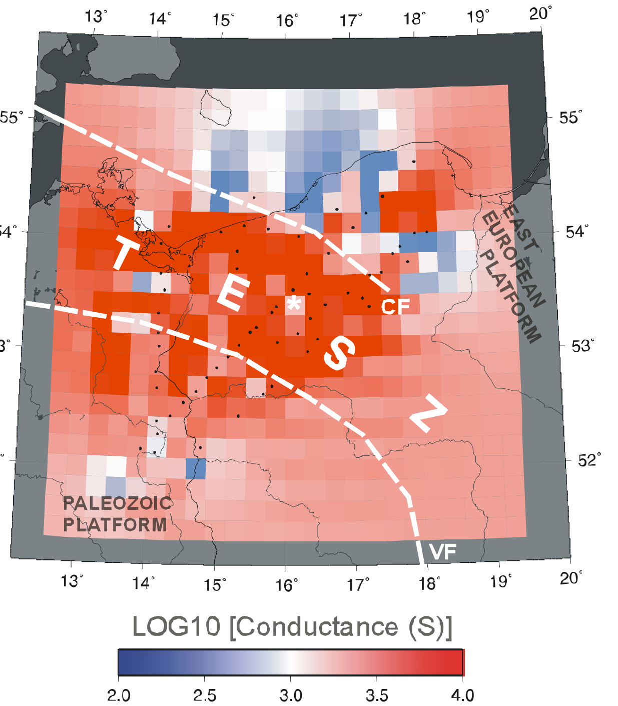

Fig. 5. Linearized solution . Conductance model for ***W+M***, T=1024 s; VF - Variscan Front; CF - Caledonian Front;
* - Czaplinek block

1999), which makes it possible to approximate specific features of the geomagnetic induction anomalies generated by sharp tectonic boundaries and blocky geological structures.

The linearised inversion was solved by minimizing the Tikhonov parametric functional with the weighted norm of difference between the observed data and the model data as functions of the model conductance (*Kováčiková et al, 2005*). The minimization of the parametric functional was solved by an iterative procedure using the re-weighted conjugate gradient method (*Portniaguine and Zhdanov, 1999*).

Inversion was carried out for the periods 1024 s and 2048 s. The thin sheet is burried at the depth of 3 km in a medium with the resistivity of 100 ohmm and a halfspace at a depth of 100 km with resistivity 50 ohmm. Normal conductance at thin sheet margins is 2000 S. Model of conductance consists of 31x31 cells with cell dimension 20 km. The thin sheet is located at the depth of 3 km, although the situation within the region is much more complicated. Nevertheless, this is not the real depth of the anomaly source, this depth just mark an upper boundary of the anomaly (*Banks, 1986*).

5. Conclusion

The results of both inversion procedures, the MCMC and the linearised inversion, show similar features. Conductance within the anomalous zone reaches 10 000 S. Contrary to complicated "mosaic" model generated from only the vertical induction vectors (Fig. 1) application of the horizontal transfer functions leads to the more expressive image. The non-conducting area of the East European Craton at the north-east as well as more conductive Paleozoic terranes at the south-west part of the models divided by a well-seen conductive belt corresponding to the TESZ can be found in the model conductance distribution (Figs. 4 and 5). The non-conducting cell in the center of the model corresponds to the resistive Czaplinek area. The block with high conductance in the north-east part of the model in Fig. 5 corresponds to the reference station and does not mark any real feature.

The anomalous zone of TESZ is the prominent tectonic feature of this area, indicated by various geophysical methods - seismic, gravity and geoelectromagnetic. There are various theories concerning the origin of the anomalous conductivity within this zone. The high conductance values in Pomerania are connected with extremely thick Paleozoic to Cenozoic sediments with thickness reaching more than 10 km. The area is also characterized by occurrence of salt pillows and diapirs (*Brasse et al. 2006, Resak et al. 2007*). Nevertheless this work itself can give an image about distribution of the conductivity within the studied area and about the shape of the anomalous zone but it can neither determine the depth of the anomaly source, nor explain the origin of the anomaly. This problem requires more detailed 2D and 3D modeling and cooperation of various geophysical methods.

Acknowledgements

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