2D INVERSION RESOLUTION IN THE EMTESZ-POMERANIA PROJECT: DATA SIMULATION APPROACH

Varentsov Iv.M.[1] , Sokolova E.Yu.[1] , Baglaenko N.V. [1]
and EMTESZ-Pomerania Working Group[2]

[1] Geoelectromagnetic Research Centre, Institute of Physics of the Earth,
Russian Academy of Sciences; Troitsk, Moscow Region, Russia; e-mail: igemi1@mail.transit.ru;

[2] Listed in (Brasse et al., 2006)

1. Introduction

The EMTESZ-Pomerania array EM sounding experiment was held in 2001-7 to study the resistivity structure of the whole tectonosphere across the Trans-European Suture Zone (TESZ) in NW Poland and NE Germany (Brasse et al., 2006; EMTESZ WG and Smirnov, 2006). The transfer function (TF) data estimated for the EMTESZ-Pomerania array outline the complicated superposition of anomalies related to Polish and N-German sedimentary basins, crustal conductors within the TESZ and upper mantle inhomegeneities. The strike of sedimentary structures ranges around 45°NW, while for deeper structures at central profiles P2 and LT7 (Fig. 1 in Varentsov and EMTESZ-Pomerania WG (2007), this volume) it definitely turns to ~60°NW when estimated with the reduction of galvanic distortions (Varentsov et al., 2005). Different long-period skew responses at these profiles demonstrate minor 3D effects, except relatively local 3D influence of the resistive central block of the TESZ and induction arrows distortions in marginal areas. Thus, there are good grounds at these profiles for 2D inversion of long period TF data rotated to 30°NE.

These data were inverted separately by different participating teams of the EMTESZ-Pomerania project using different tools and to some extent different data ensembles (EMTESZ WG and Smirnov, 2006). Our Troitsk team finally came at both profiles to the inversion of the following 8-component ensembles: H- and E-polarization impedances, Z_{EP} and Z_{HP} (phases and 10 times downweighted apparent resistivities) at periods of 8-16384 s; tippers W_{zx} (Re, Im) at 32-8192 s; and horizontal magnetic inter-station responses M_{xx} (amplitudes and phases, estimated relative to the common base site P8 at NE edge of P2 profile) at 64-32768 s. To reduce the influence of 3D effects, we proportionally extended data error estimates at sites and periods both with large skews and with large strike excursions away from 60°NW. We also substituted original impedance phases with phases of the impedance phase tensor (Caldwell et al., 2004).

The inversion was held with Varentsov's robust code (Varentsov, 2002, 2007a,b). Inversion models included central 2D scanning windows from the surface to upper mantle depths (~300 km) and peripheral 1D normal sections with adjusted resistivities of layers. The total number of estimated parameters ranged at 1500-2000. Inversions were started both from the simplest quasi-1D *a priori* assumptions and from more complicated 1D/2D models summarizing results at previous inversion stages. More details on this inversion strategy are discussed in (Varentsov et al., 2005), while general advantages in the use of horizontal magnetic responses in the joint MT/MV data 2D inversion are presented in (Varentsov, 2007a,b; Varentsov and EMTESZ-Pomerania WG, 2005).

Geoelectric models actually obtained at P2 and LT7 profiles (see Fig. 9 in Varentsov and EMTESZ-Pomerania WG (2007), this volume) correlate quite well, but contain a number of fine details, which may be considered as overfit effects and peripheral artefact, taking into account the interference of EM responses from strongly conductive and inhomogeneous sedimentary, crustal and upper mantle structures of the TESZ and 3D data distortions. Nevertheless, several of such fine details are stablily preserved in the course of inversion iterations, are invariant with the change of inversion parameters and are repeated at both profiles. A strict objective arises to learn resolution bounds of the applied inversion approach in specific conditions of the EMTESZ-Pomerania project.

2. Method

In this paper the possibilities to resolve complex geoelectric structures met in Pomerania are studied within the imitation approach in pure 2D environment. We constructed 2D model (Fig. 1), which generalizes and slightly simplifies real data inversion solutions obtained at P2 profile, and accurately sumulated for this model structurally the same (in sites and periods) 8-component data set (Fig. 2) as was considered in the real data inversion. In this synthetic 2D data set we note the normalized horizontal magnetic response simply as H_x.

Both modelling and inversion problems were approximated at a medium-scale (74x57) grid (seen in Fig. 1) with horizontal resolution of 3-4 km and vertical crustal resolution of 1-2 km. The inversion solution was iterated till the convergence break and was monitored at a number of intermediate iterations. We present for each solution a sequence of 2-3 most important intermediate iterations in a column with a "true" model in the bottom and the final inversion model just above it (Fig. 3, 4).

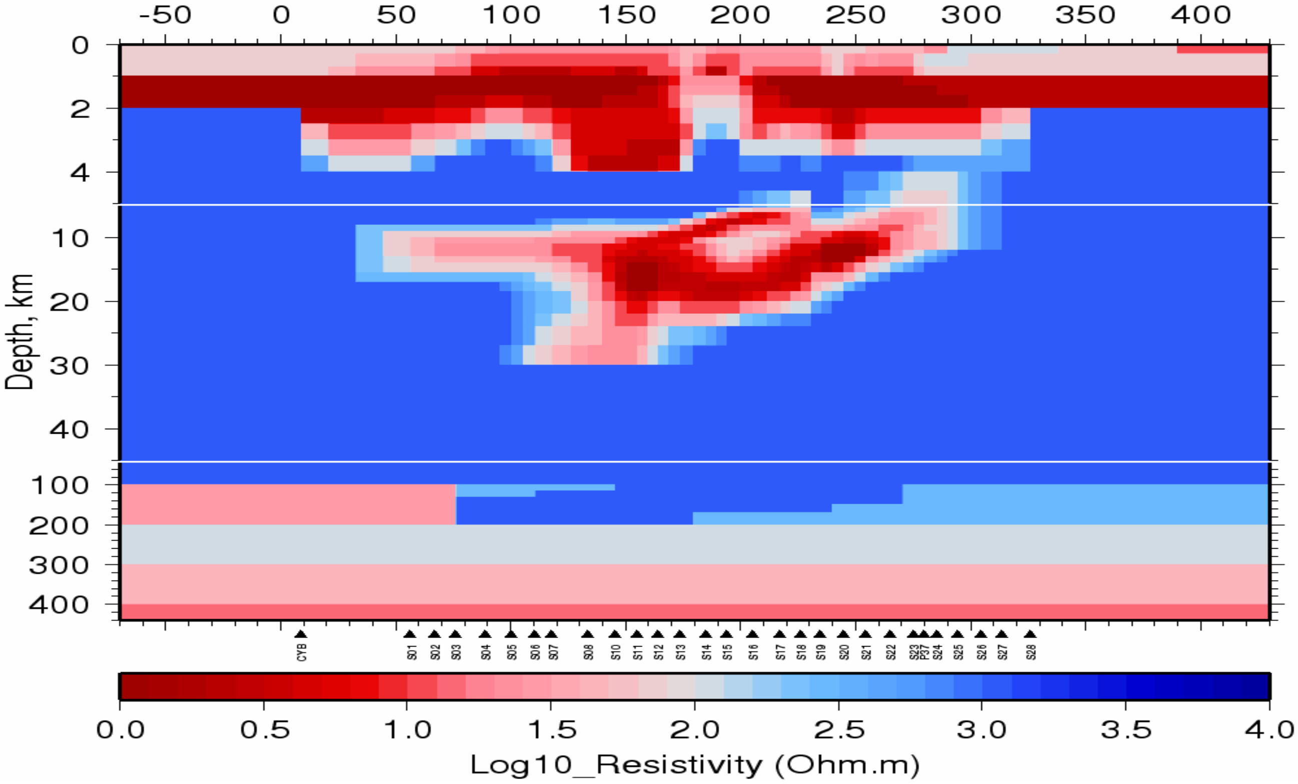

Figure 1. The simplified model of the geoelectric structure along P2 profile in the EMTESZ-Pomerania project.

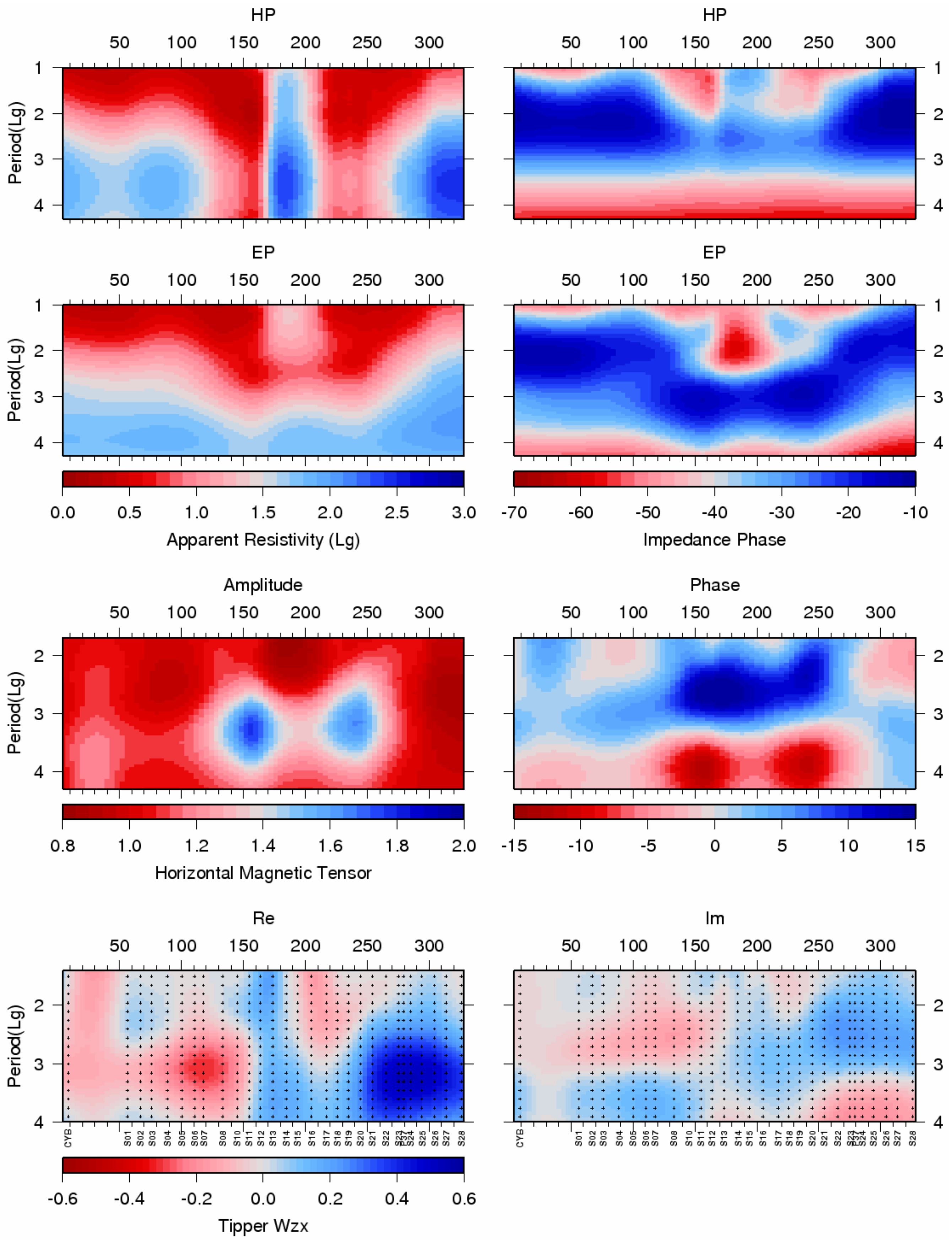

Figure 2. The 8-component data set accurately simulated for the model in Fig. 1 with components, sites and periods being the same as in the real data inversion at P2 profile.

The inversion quality in the comparison of different solutions was directly estimated in the model space by the relative norm of log-resistivity misfit:

$$\delta\rho = \| \ln\rho - \ln\rho_{true} \| / \| \ln\rho_{true} \| \quad \text{(in \%)},$$

with *L2* norms taken over the area [0,350]x[0,400] km. This misfit is shown in white over model sections in Fig. 3,4.

The inversion quality was also indirectly estimated by absolute *L2* data misfits, calculated separately for profile-period arrays (i.e. pseudo sections) of each data component. The absolute misfit for the apparent resistivity data at the log-scale was further recalculated into the relative misfit (in %) for these data at the normal scale. Such "partial" data misfit estimates for a number of presented inversion solutions are summarized in Table 1.

3. Results

Fig. 3 demonstrates the resolution and the convergence achieved in the inversion of truly simulated 8-compoment data set jointly and separately in its magnetotelluric (MT) and magnetovariational (MV) parts. The separate MT inversion solution used normal weights both for the apparent resistivity and the impedance phase, while in the joint solution the apparent resistivity was strongly (10 times) downweighted just as in the real data inversion for the protection from subsurface galvanic distortions.

The fit of all these solutions to the true model looks really perfect. The model space misfit approaches the level of 5-7%, partial data misfits go down to the level of modeling accuracy (Table 1) and the most of fine details in final inversion models are very like to those in the true model. In spite of relatively longer convergence, MV solution finally gots the quality of two other solutions. Only the resistive layer between sedimentary and crustal conductors seems to be not exactly resolved.

The best fit is achieved in the joint MT/MV inversion. In this solution the surprising recognition of both resistive and conductive structures at depths of 4-30 km takes place below the subsurface conductor with the average conductance spread around 1000 S. Moreover, main upper mantle inhomogeneities are still very well seen below sedimentary and crustal structures of the total conductance exceeding 10000 S.

Finally, in Fig. 4 we study the influence of the random noise intensity on the effectiveness of the considered 8-component inversion scheme applied to noise-contaminated data. At the noise level of 2% and even 5% it is still possible to distinguish the most of fine details of the true model. Even at the noise level of 15% our inversion scheme truly distinguishes the general location of conductive zones and their most intensive parts, but is not accurate in the tracing of their connection and peripheral extension. Notice that partial data misfit estimates are reduced in final solutions to the level of correspondent norms of the simulated noise (Table 1).

It is important to mention a prominent stability of the considered inversion solutions almost for the whole sequence of iterations. This stability comes from the excessive informativeness of the joint MT/MV data ensemble and from the wide variety of stabilization tools adaptively implemented in the applied inversion technique (Varentsov, 2002, 2007b).

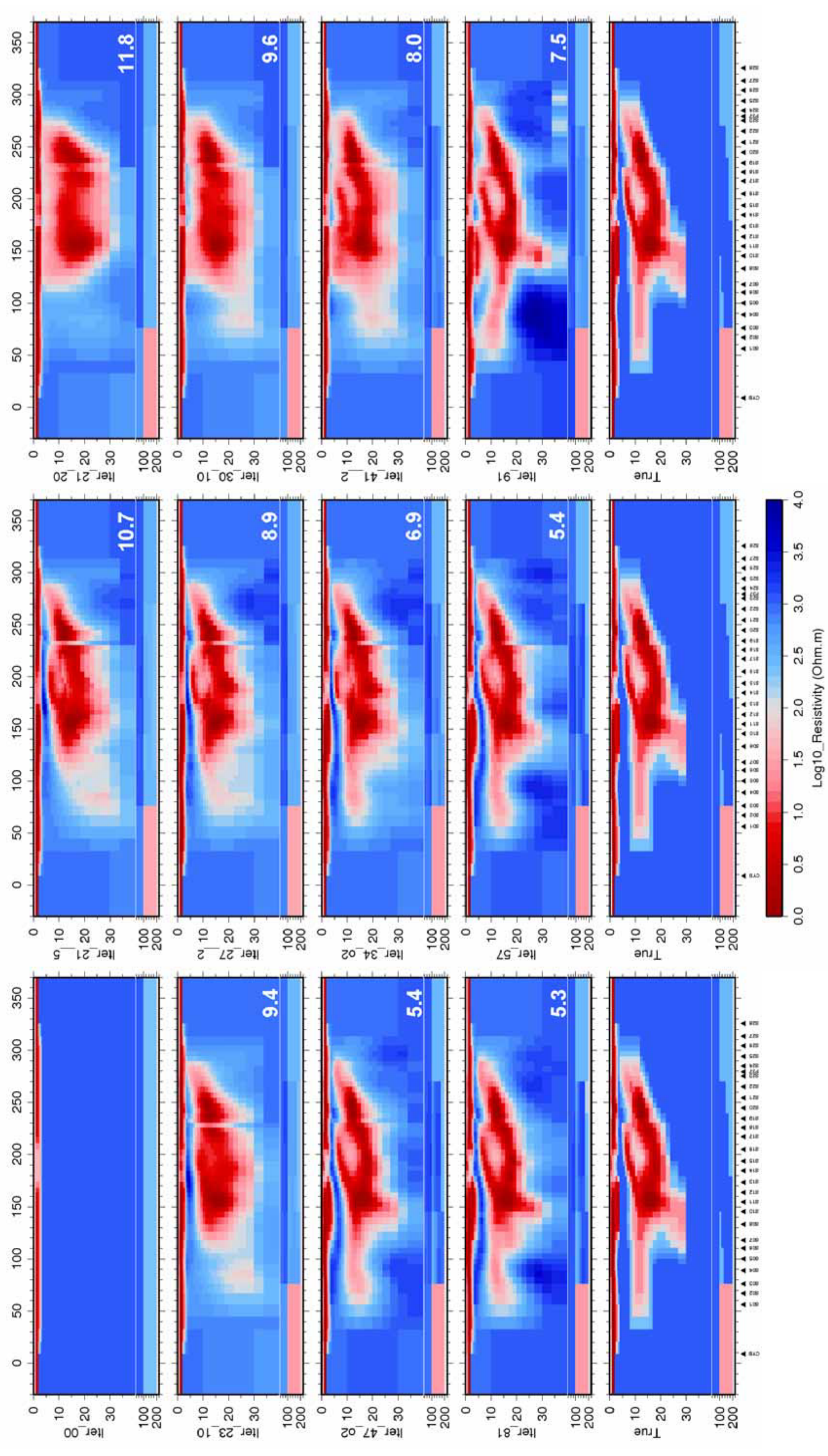

Figure 3. The inversion of different component ensembles from the true data set, from left to right: $Z_{HP}+Z_{EP}+W_{zx}+H_x$, $Z_{HP}+Z_{EP}$, $W_{zx}+H_x$; the starting model is quasi-1D (the left top panel); the true model is shown in bottom panels, white numbers give model space relative error (in %) for the area [0,350]x[0,400] km.

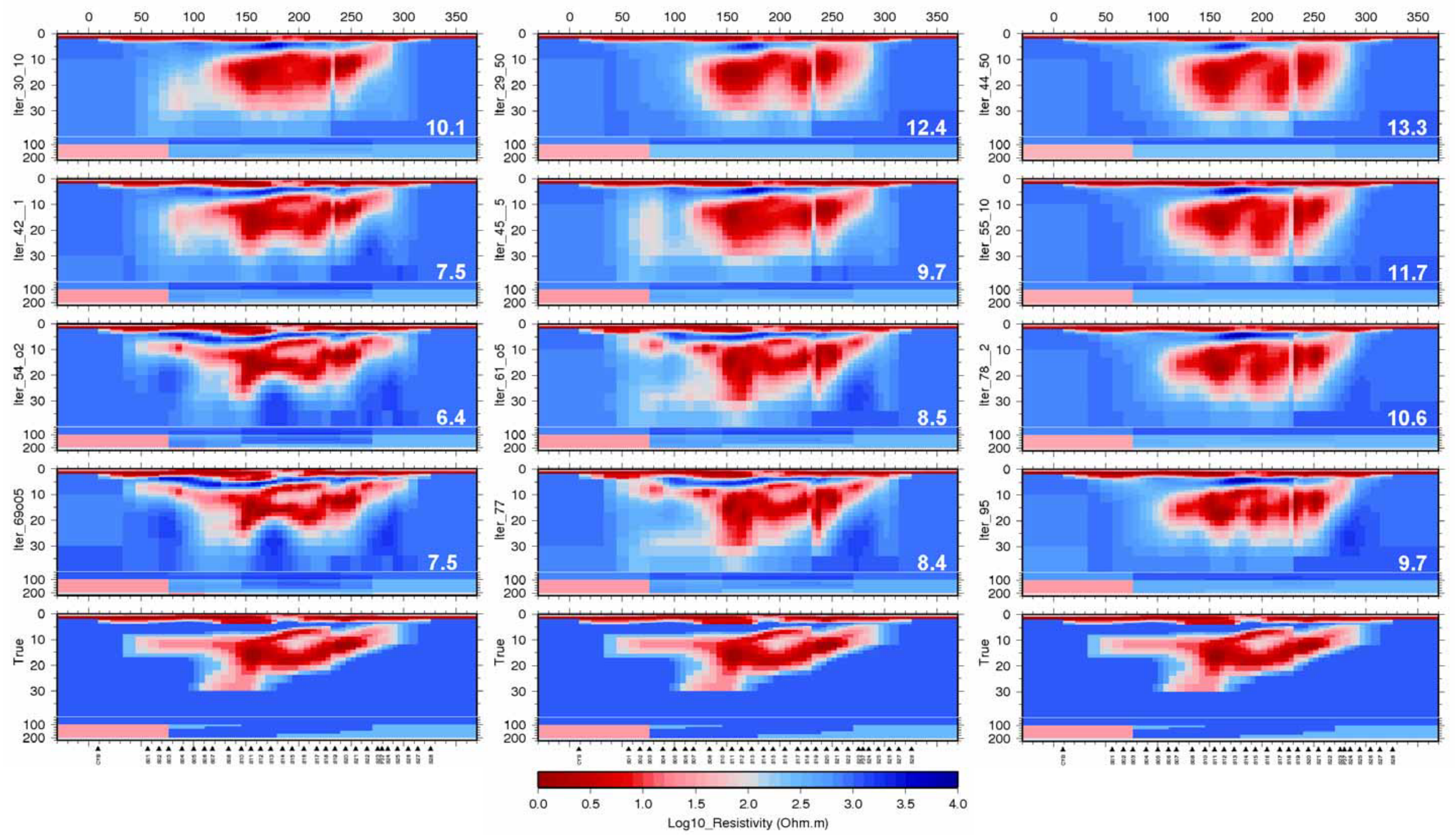

Figure 4. The inversion of 8-component data sets simulated with added random noise (from left to right: 2, 5 and 15%) from quasi-1D starting model; the true model is shown in bottom panels; white numbers give model space relative error (in %) for the area [0,350]x[0,400] km.

Components	It.	Par. RMS (L2)	Partial MSF (L2) / Noise (L2)								Comments
			Ro HP	PhZ HP	Ro EP	PhZ EP	Mod Hx	Ph Hx	Re Wz	Im Wz	
Ro+PhZ (EP+HP) +Hx+Wzx Ro DW 10x	81	5.33	0.13	.025	0.04	.007	.000	.007	.000	.000	No Noise, Quasi-1D Starting Model
Ro+PhZ (EP+HP) Normal Ro Weight	57	5.41	0.09	.033	0.16	.091					No Noise, Quasi-1D Starting Model
Hx+Wzx	91	7.50					.000	.011	.000	.000	No Noise, Quasi-1D Starting Model
Ro+PhZ (EP+HP) +Hx+Wzx Ro DW 10x	69	7.51	3.50 3.54	.245 .255	2.52 2.39	.330 .314	.009 .009	.108 .089	.004 .004	.002 .002	2% Noise, Quasi-1D Starting Model
Ro+PhZ (EP+HP) +Hx+Wzx Ro DW 10x	77	8.36	9.06 8.84	.646 .637	6.41 5.97	.811 .786	.022 .021	.244 .222	.009 .009	.005 .005	5% Noise, Quasi-1D Starting Model
Ro+PhZ (EP+HP) +Hx+Wzx Ro DW 10x	95	9.66	26.9 26.5	1.94 1.91	18.5 17.9	2.44 2.36	.066 .064	.745 .667	.030 .027	.014 .014	15% Noise, Quasi-1D Starting Model

Table 1. Summary of misfit estimates (consequently, in the space of model parameters and in the data space) in 2D inversion solutions for different data ensembles simulated with different data noise levels; apparent resistivity misfits are relative (in %), all other partial data misfits are absolute; error norms are given in lower part of table cells in the case of solutions for noise-contaminated data.

Conclusions

We demonstrated quite an optimistic view on the resolution limits of the multi-component 2D inversion in the case of extremely complicated, but truly 2D data even contaminated with random noise at the level of 5-15%. In the most of cases the model resolution successively improves in the course of inversion iterations without serious overfitting effects. The model space misfit estimates formally point at the latest inversion iterations as solutions with the best resolution and stability.

We managed in all presented inversion solutions to reliably separate conducting structures overlapped at several depth levels from the sedimentary cover to the upper mantle and met no prominent peripheral "false" conductors, though noticed the influence of the starting model and the noise level on the resolution of peripheral resistive background.

The MV data inversion competes well with the conventional MT inversion, and no convergence contradictions are met in the most complicated, but also most promising 8-component joint MT+MV inversion.

We got important justification to treat seriously the fact of separation of sedimentary and crustal structures in the real data inversion at Pomeranian profiles and to take into account fine details of conducting anomalies located there at sedimentary, crustal and upper mantle levels.

However, these experiments only partly simplify the understanding of our real data inversion results at Pomeranian profiles. We have to learn better the influence of 3D data distortions on 2D inversion results. The right way to do it is to analyze in the same way 3D model simulations (Kousnetsov et al., 2006), but this is the subject of a separate paper.

Acknowledgements

We would like to thank our colleagues in EMTESZ-Pomerania Working Group for a long-term cooperation in the joint interpretation of long period MT and MV data, and for stimulating discussions on the inversion resolution bounds. We are also greatful to M. Berdichevsky for numerous discussions on the role of MV data in the electromagnetic inversion problems. This work was supported by DFG-RFBR Grants 03-05-04002 and 07-05-91556.

References

Brasse, H., Cerv, V., Ernst, T., Hoffmann, N., Jankowski, J., Jozwiak, W., Korja, T., Kreutzmann, A., Neska, A., Palshin, N., Pedersen, L.B., Schwarz, G., Smirnov, M., Sokolova, E., and Varentsov Iv.M., 2006. Probing the electrical conductivity structure of the Trans-European Suture Zone. Eos Trans. AGU. **87(29)**: 281-287.

Caldwell, G.T., Bibby, H.M., and Brown, C., 2004 The magnetotelluric phase tensor. Geophys. J. Int., **158**: 457-469.

EMTESZ-Pomerania WG, presented by Smirnov, M.Yu. 2006. Geoelectrical image of the Trans-European Suture Zone: the EMTESZ project in Poland. XVIII Workshop on EM Induction in the Earth (Extended Abstracts, S.8-E4). El Vendrel, Spain: 1-6.

Kouznetsov, V.A., Palshin, N.A., Varentsov, Iv.M., and EMTESZ-Pomerania WG, 2006. 3D effects in the central part of the Polish Basin. XVIII Workshop on EM Induction in the Earth (Abstracts, S.3-20). El Vendrel, Spain.

Varentsov, Iv.M., 2002. A general approach to the magnetotelluric data inversion in a piecewise-continuous medium. Izv., Phys. Solid Earth, **38(11)**: 913–934.

Varentsov, Iv.M., 2007a. Arrays of simultaneous electromagnetic soundings: design, data processing and analysis. Electromagnetic sounding of the Earth's interior (Methods in geochemistry and geophysics, **40**). Elsevier: 263-277.

Varentsov, Iv.M., 2007b. Joint robust inversion of MT and MV data. Electromagnetic soundings of the Earth's interior (Methods in geochemistry and geophysics, **40**). Elsevier: 189-222.

Varentsov, Iv.M., and EMTESZ-Pomerania WG, 2005. Method of horizontal magneto-variational sounding: techniques and application in the EMTESZ-Pomerania project. 21 Kolloquium EM Teifenforschung (Digitaliesiertes Protokoll, Eds. O. Ritter, H. Brasse). Wohldenberg – Holle, Germany: 111-123.

Varentsov, Iv.M., and EMTESZ-Pomerania WG, 2007. Method of horizontal magneto-variational sounding: extended application in the EMTESZ-Pomerania project. This volume.

Varentsov, Iv.M., Sokolova, E.Yu., and Martanus, E.R., EMTESZ-Pomerania WG, 2005. Array view on EM transfer functions in the EMTESZ-Pomerania project. Study of geological structures containing well-conductive complexes in Poland. Publ. Inst. Geoph. Pol. Acad. Sci. **C-95(386)**: 107-121.