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Combined interpretation of time domain and frequency domain data

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SUMMARY

The advantage of frequency domain and time domain data combining provided by the EQUATOR system is discussed. The data obtained from the model of a homogeneous half-space, a two-layered model, and a model of a horizontally layered medium is considered. Time-domain data makes it easier to detect a conductor at greater depths. The data in the frequency domain gives more detailed information about the near-surface zone. The simultaneous inversion of data in frequency domain and time domain improves the quality of interpretation significantly.

Key words: inversion, Kalman filter, frequency domain, time domain, EQUATOR.

INTRODUCTION

Airborne EM systems appeared in the middle of the last century as a tool for conductive bodies identification (Fountain, 1998). First, geophysicists learned how to measure the quadrature component of the response in frequency domain (FD) (Kaufman et al., 2014). To calculate primary field, it is necessary to have quite an accurate idea of system geometry. Having that we can separate secondary filed in the in-phase component. Primary field can be measured in rigid systems. Geometry calculation algorithms for non-rigid systems were proposed by Smith (2001) and, later, by Pavlov et al. (2010).

Powerful time-domain (TD) systems are able to effectively detect a good conductor in a relatively isolating medium at great depths, even under conductive overburden (Kaufman, 1989). The near-surface zone, however, remains poorly explored. FD systems are able to measure a wider range of resistivity values than the time domain ones (Hodges, 2013). It helps to detect changes in resistive areas and in the near-surface zone which brings a much more detailed picture of it.

EM data representation in both TD and FD form is the main advantage of EM system EQUATOR (Moilanen et al., 2013). That representation became possible due to the mixed form of the primary field and the continuous full-time measurements in TD allowing data transformation to the FD (Volkovitsky and Karshakov, 2013).

Full-time measurements were carried out for the first time in the transient EM system COTRAN (COrrelation of TRANsients) system in late 1970s (Becker et al., 1987). Two-component (XZ) receiver measured response in both on-time and off-time. Lane et al. (1998) describes the first attempts to use FD representation for elimination of various noises. Similar processing scheme is used in some modern systems to obtain high quality data in the earliest time gates (Macnae and Baron-Hay, 2010). In this paper we are showing that availability of FD data form is the way to get higher quality TD interpretation for the near-surface zone. In our opinion, combined processing and interpretation of both TD and FD data looks very promising.

1D MODELS ANALYSIS

Let's start with a model of a homogeneous half-space, and then proceed to 2-layered models. Fig. 1 shows residual calculation for responses from a homogeneous half-space for a given resistivity (X axis) and from a 1000 Ω·m half-space. The residuals for FD and for TD are equal to zero if X is 1000 Ω·m. However, even for the homogeneous half-space model, the maximum value of a residual corresponds to different resistivity for TD and for FD. The maximum difference between responses in FD is achieved for 9 Ω·m while in TD it is for 8 Ω·m. It means that in this case for FD data inversion it is important to have an initial value greater than 9 Ω·m, and presence of TD channels widens the range to 8 Ω·m.

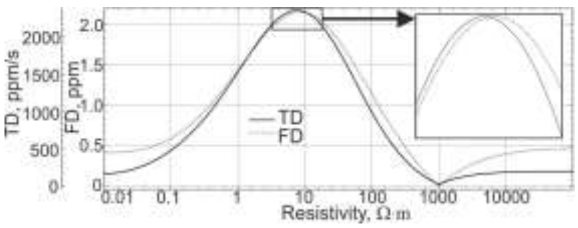

Figure 1. The residual between the calculated response for a model of a homogeneous half-space with changing resistivity and response from the model of 1000 Ω·m for TD and FD.

Figure 2 shows the residual of the calculated response for a two-layer medium model with varying basement resistivity, top layer thickness and response from the model (200 m layer of 2000 Ω·m overlaying 10 Ω·m basement for TD and FD. If the initial approximation for FD is unsuccessful, the inversion result can get to the second local minimum (40 m of 2000 Ω·m overlaying 4000 Ω·m basement).

Figure 3 shows the residual of the calculated responses for a two-layer medium model with varying resistivity of the basement and the upper layer — for 20 m of 100 Ω·m overlaying 80 Ω·m basement in TD and FD. There is a chance that inversion result may "slide" into the second local minimum (the 20 m layer of 2.5 Ω·m overlaying 0.1 Ω·m basement) if you choose an initial approximation with basement resistivity less than 10 Ω·m for TD. At the same time FD inversion gives a unique solution.

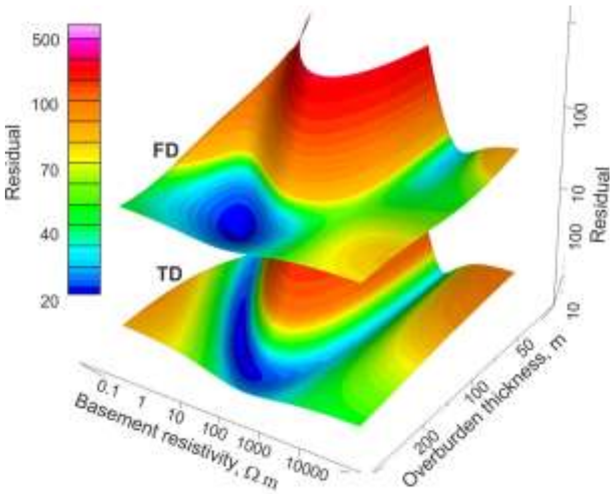

Figure 2. The residual (in ppb for FD and ppm/s for TD) of the calculated response for a two-layer medium model with a varying basement resistivity and top layer thickness and for the model (200 m of 2000 Ω·m overlaying 10 Ω·m).

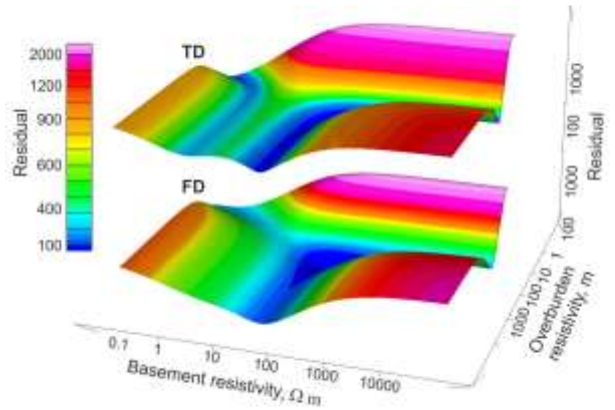

Figure 3. The residual (in ppb for FD and ppm/s for TD) of the calculated response for a two-layer medium model with varying basement and top layer resistivity for the model of 20 m layer of 100 Ω·m overlaying 80 Ω·m base.

1D INVERSION

We are using iterated extended Kalman filter (KF) for solving 1D inversion task. It minimizes variance of the estimation error in terms of probabilistic approach. Despite of special terminology, the KF algorithm minimizes the objective function, representing the squared difference between the measured vector and the calculated one for the parameters of selected model. It works as the least squares method – a conventional method for airborne electromagnetic data inversion. Speaking about 1D inversion methods it should be noted that in general KF method looks similar to the traditional forms of TD data processing (Jupp and Vozoff, 1975; Guillemoteau et al., 2011). But FD information provides additional capabilities while solving inversion tasks.

The inversion scheme is as follows. First, we find a most appropriate half-space model. Then, after splitting it into two layers of close resistivity we use it as an initial model for 2-layerd inversion. Next, having a 2-layerd solution, we split each of the layers in the same manner and get 3-layerd solutions for each initial model. Choosing the best one in terms of residual we can continue to increase the number of layers. If a more complicated model does not improve the residual, we stop the procedure. Also we stop it if the residual does not exceed the noise level.

Let's discuss inversion results obtained for four-layer model data. The model consists of 30 m thick upper layer with resistivity of 100 Ω·m, another 30 m thick layer with resistivity of 80 Ω·m, and 20 Ω·m layer with varying thickness and 240 Ω·m resistivity of the basement (Fig. 4). Algorithm of 1D inversion was the same for FD inversion (Fig. 5), TD inversion (Fig. 6) and combined inversion (Fig. 7).

FD 1D inversion of model data shows a low contrast boundary in the near-surface zone. In figure 6 it is clearly seen that basement resistivity is defined much better in TD. But the upper part of the section is defined better in FD inversion. And the combined inversion fits well with the initial model.

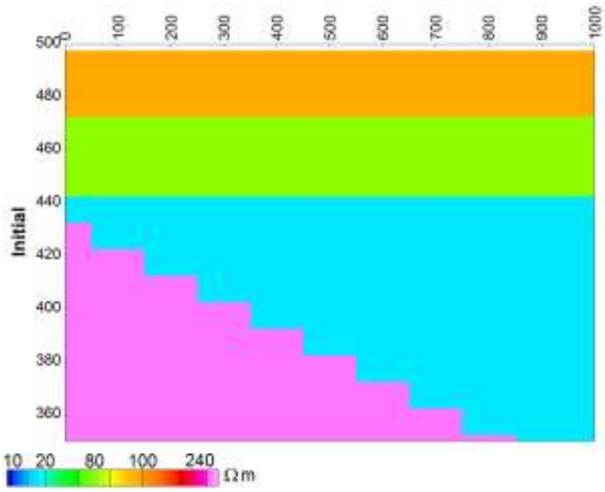

Figure 4. A 4-layer model.

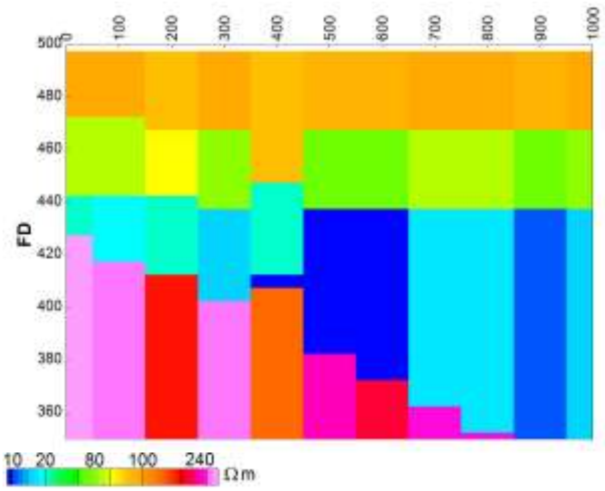

Figure 5. FD 1D inversion of data acquired from 4-layer model data.

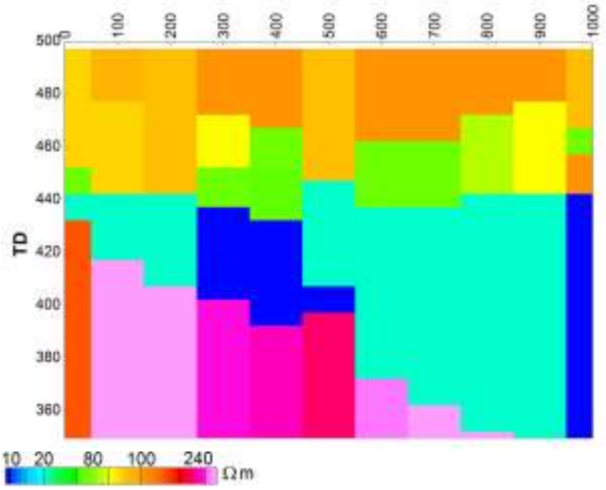

Figure 6. TD 1D inversion of data acquired from 4-layer model data.

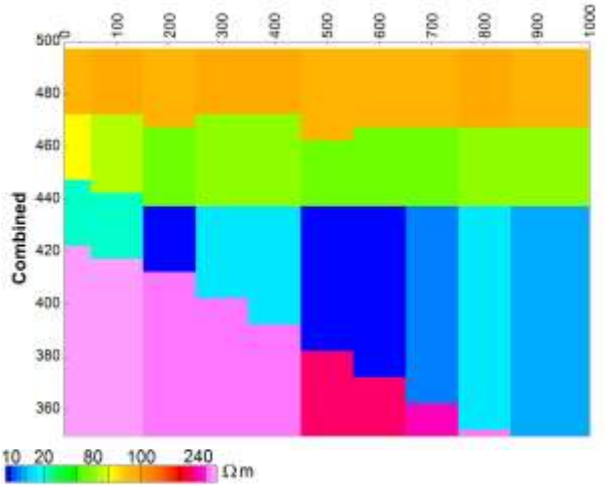

Figure 7. Combined 1D inversion of data acquired from 4-layer model data.

CONCLUSIONS

Residual function for TD and FD has different form. The difference depends on the model. Discrepancies occur even for the homogenous half-space. And they become much higher for more complicated models. 1D inversion of 4-layer model data gives a low contrast boundary in the near-surface zone for FD inversion. The basement resistivity is defined much better in TD inversion. Combined inversion results fit well with the initial model both in top and bottom parts.

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