# 1D-Laterally Constraint Inversion (1D-LCI) of radiomagnetotelluric data from a test site in Denmark

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**Abstract**

*Within an EU-project a radiomagnetotelluric system (RMT-F) was developed allowing the simultaneous recording of time series of four components of the electromagnetic field. The device operates within a frequency range from 10 kHz to 1 MHz. With the aim to characterize an aquifer for groundwater exploration the RMT-F has been applied on a test site close to the city of Århus (Denmark). The measured time series were processed and interpreted by 1D-Laterally Constraint Inversion (1D-LCI) and 2D inversion The results were then compared with other geophysical methods (PACES, SkyTEM, GroundTEM).*

## Introduction: the radiomagnetotelluric method

Radiomagnetotellurics (RMT) is an electromagnetical method that uses civilian and military radiostations within a frequency range from 10 kHz to 1 MHz as transmitters. The electromagnetic waves radiated from these stations diffuse into the conductive earth and induce current systems which are connected with secondary electric and magnetic fields.

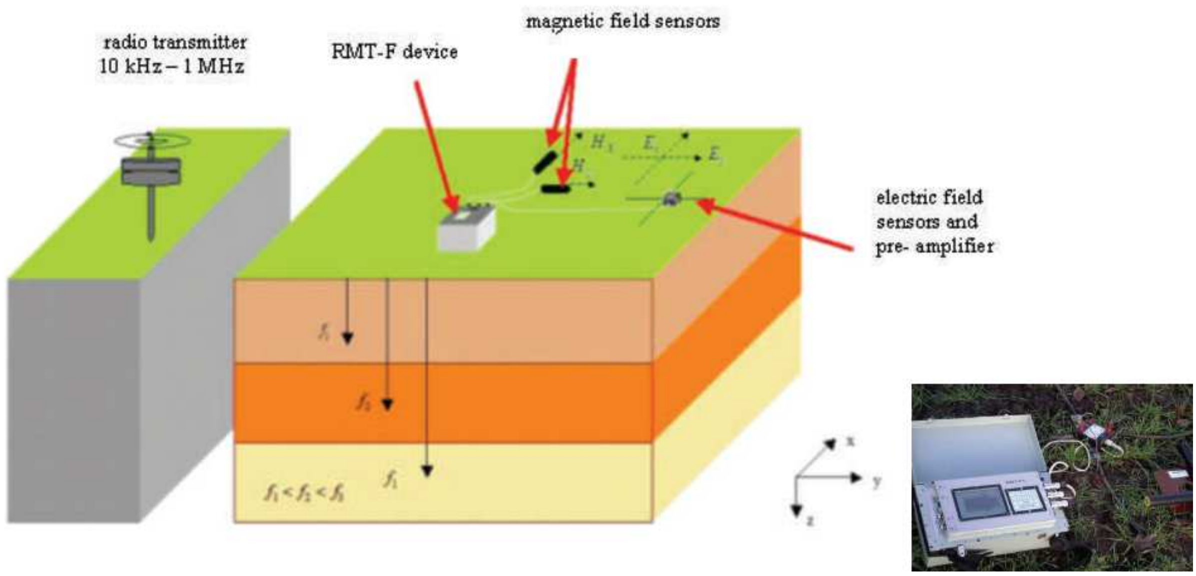


**Fig. 1:** The radiomagnetotelluric method (*Schmalz*, 2007).

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Due to the fact that the penetration depth increases for lower frequencies and decreases for higher frequencies, these fields are measured with electric and magnetic sensors for several frequencies (fig. 1).

## The RMT-F system

The RMT-F system (fig. 1) was developed within an EU-project and allows the recording of time series for both electric and magnetic fields. The system consists of a receiver unit, an electric antenna to observe the electric field and two magnetic sensors for the registration of the magnetic field in perpendicular directions. Two different frequency bands are used: one consists of frequencies from 10 kHz to 100 kHz with a sampling frequency of 312.5 kHz and another one which consists of frequencies from 100 kHz to 1 MHz with a sampling frequency of 2.5 MHz. Time series are saved in the receiver and can later be transferred to a computer via an Ethernet connection.

## Processing software SM 25

The processing software SM 25 was developed together with the RMT-F system. The program can be used to display the time series in order to check the data quality. Auto and cross spectra of the electric and magnetic time series are calculated and can also be viewed with the software. The user can define an azimuth range to select the available transmitters. In addition, the coherency between the observed electric and magnetic fields oriented perpendicular to each other can be selected by the user. The transfer functions are only calculated for frequencies with coherencies greater than the selected coherency level (fig. 2) and for radio transmitters within the azimuth range defined by the user (fig. 3).

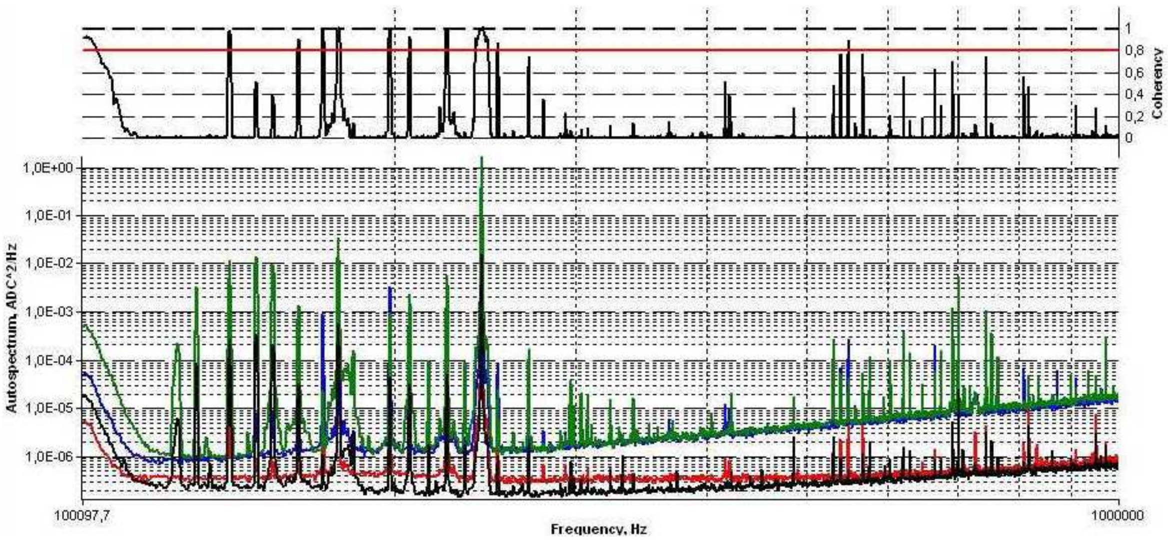


**Fig. 2:** Auto spectra and coherency for the recorded time series ($H_x$: red, $E_y$: blue, $E_x$: green, $H_y$: black) in a frequency range from 100 kHz to 1 MHz.

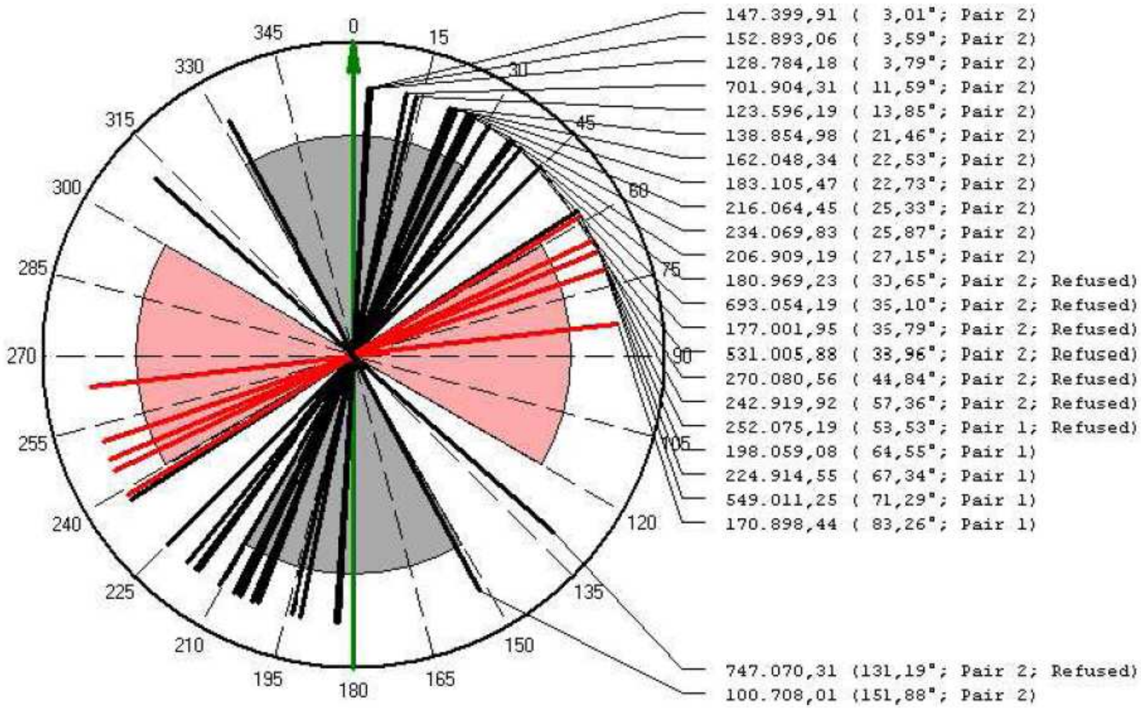


**Fig. 3:** Visualisation of the azimuth range and the transmitter directions.

## 1D-Laterally Constraint Inversion (1D-LCI)

A "workbench" program was developed during the EU-project to interpret the data by model calculations. The heart of this program is the 1D-Laterally Constraint Inversion algorithm (*Auken and Christiansen*, 2004; *Auken et al.*, 2005). Here, the underground is divided into separate models. During the inversion these models are tied together by lateral constraints (fig. 4). The constraints contain information about the geological variability of the underground. A priori information, for example from well logs, can also be added and all information migrates through the lateral constraints to the adjacent nodes. The inversion results can be visualized with the program and can be considered as 2D-pseudo-sections due to the employment of lateral constraints.

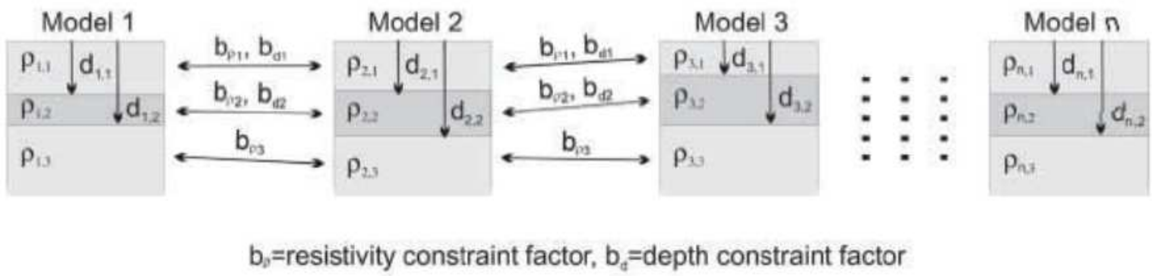


**Fig. 4:** The Laterally Constraint Inversion (LCI) schematic (taken from *Auken et al.*, 2005).

## Field example from Denmark

Extensive field measurements were carried out with the RMT-F system on a test site close to the danish city of Århus (*Schmalz*, 2007). The aim of these measurements was the characterization of an aquifer for groundwater exploration. Overall 89 soundings were carried out on seven profiles. The data was later processed and then inverted using the "Workbench" program (1D-LCI) and a 2D-Inversion program by *Rodi and Mackie* (2001) which uses the nonlinear conjugate gradient method (NLCG). These inversion results were then compared with other geophysical methods (PACES, SkyTEM, GroundTEM). Fig. 5 shows the inversion results of the 1D-LCI and the 2D-Inversion (NLCG) for one selected profile together with a 2D-inversion result of a PACES profile. Comparision of the inversion results (1D-LCI and NLCG) shows a good agreement with respect to conductivities and layer thicknesses. Only for the upper two layers the RMT inversion results can be compared with the PACES inversion result due to the deeper penetration depth of the RMT method.

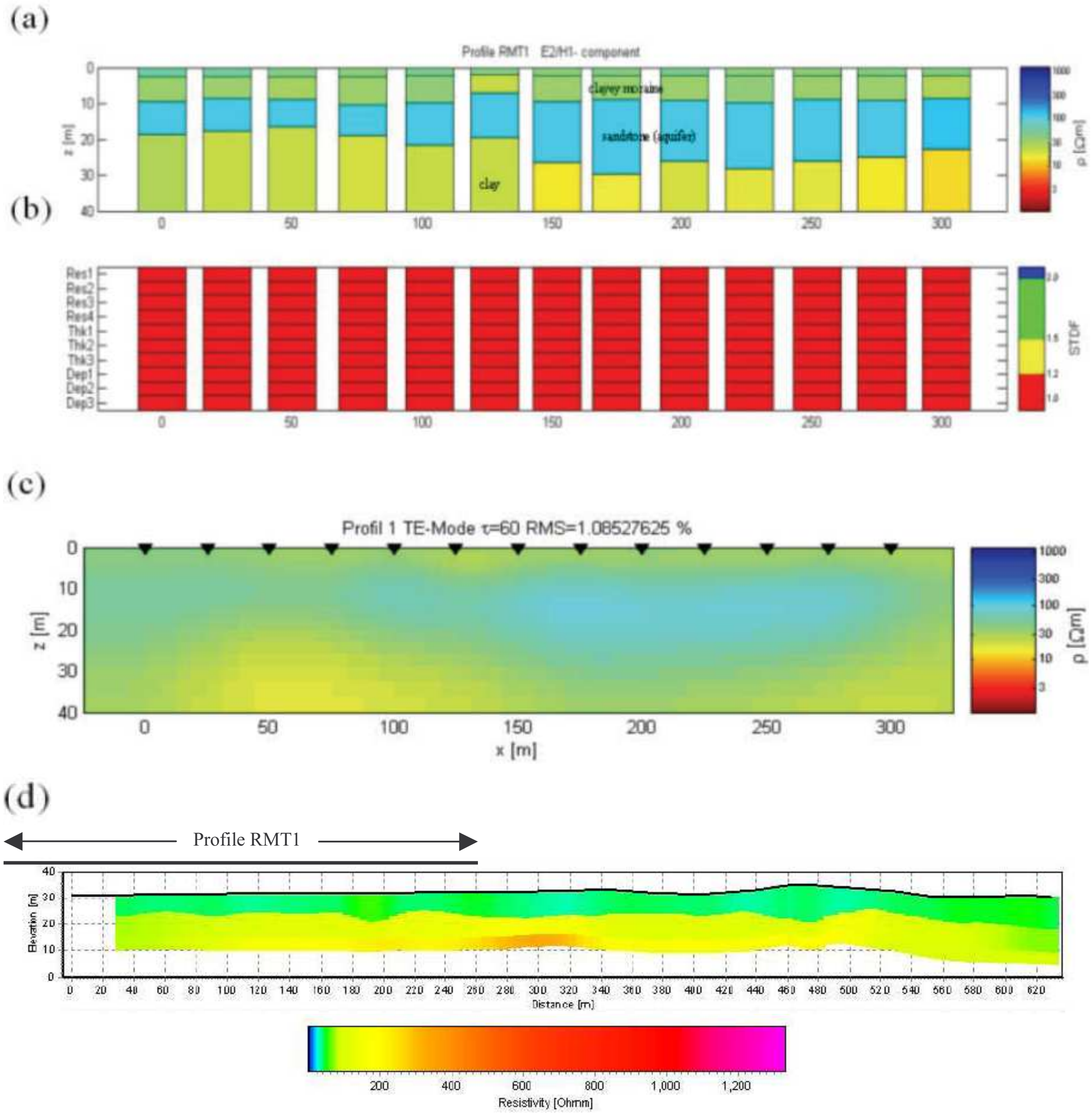


**Fig. 5:** (a) 1D-LCI result of a RMT profile. (b) Analysis of the model parameters (resistivities: Res1-Res3; thicknesses: Thk1, Thk2; depths: Dep1, Dep2). (c) 2D-Inversion result of the same RMT profile (d) 2D-Inversion result of a PACES profile.

The first and third layer with resistivities between 30 to 50 Ωm can be identified as clay. The second layer with resistivites around 100 Ωm (sandstone) represents the aquifer.

The analysis of the model parameters from the 1D-Laterally Constraint Inversion can be used to assess the resolution of the inverted model. Standard deviations on model parameters are calculated as the square root of the diagonal elements in the covariance matrix $C_{est}$. Because the model parameters are presented as logarithms, the analysis gives a standard deviation factor (STDF) for the parameter $m_s$:

$$STDF(m_s) = \exp\left(\sqrt{C_{est,ss}}\right).$$

The theoretical case of perfect resolution has $STDF = 1$. A factor of $STDF = 1.1$ is approximately equivalent to an error of 10 %. For well resolved parameters $STDF < 1.2$, for moderate resolved parameters $1.2 < STDF < 1.5$, for poorly resolved parameters $1.5 < STDF < 2.0$ and for unresolved parameters $STDF > 2.0$ (*Auken and Christiansen*, 2004). The colored scale in Fig. 5 (b) indicates these representations. It shows the good resolution of all parameters.

Fig. 6 shows the good model data fit of one selected station taken from the 1D-LCI.

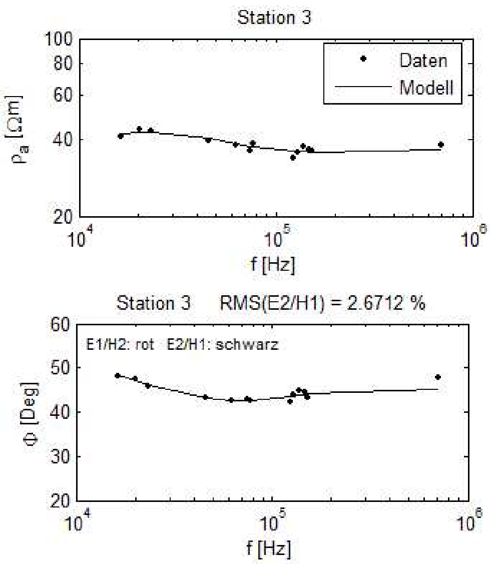


**Fig. 6:** Model data fit for one selected station of the 1D-LCI result (fig.3, station 3).

## Conclusion

Finally, we can say that the measurements with the RMT-F and the application of the processing software SM 25 and the "Workbench" inversion program were successful. The first and third low resistive layers (fig. 5 (a)) can be identified with clay while the second high resistive layer (sandstone) clearly implicates the aquifer. This could also be approved with the 2D-inversion program by *Rodi and Mackie* (2001) and agree with the inversion result of the PACES profile for the upper two layers. Here, differences occur due to the deeper penetration depth of the RMT method.

## References

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