ΔΡΑΣΗ ΕΘΝΙΚΗΣ ΕΜΒΕΛΕΙΑΣ
« ΑΝΑΠΤΥΞΙΑΚΕΣ ΠΡΟΤΑΣΕΙΣ ΕΡΕΥΝΗΤΙΚΩΝ ΦΟΡΕΩΝ- ΚΡΗΠΙΣ»

ΙΔΡΥΜΑ ΤΕΧΝΟΛΟΓΙΑΣ ΚΑΙ ΕΡΕΥΝΑΣ

Έργο ΠΕΦΥΚΑ: Περιβάλλον και Φυσικές Καταστροφές: Νέες μέθοδοι για τη μέτρηση και βελτίωση της ποιότητας του περιβάλλοντος και για την αντιμετώπιση φυσικών καταστροφών

ΠΑΡΑΔΟΤΕΟ Π2.2.1.3

Τίτλος: Αλγόριθμος αντιστροφής τομογραφικών δεδομένων.

Υπεύθυνος Φορέας/Ινστιτούτο: ΙΜΣ

Ονόματα συμμετεχόντων: Κλεάνθης Σιμυρδάνης

Ανθρωπομήνες που αντιστοιχούν: 6

Κόστος που αντιστοιχεί: 10.200 Ευρώ

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Ευρωπαϊκό Ταμείο Περιφερειακής Ανάπτυξης
ΕΛΛΗΝΙΚΗ ΔΗΜΟΚΡΑΤΙΑ
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Γενική Γραμματεία Έρευνας & Τεχνολογίας
ΕΛΛΗΝΙΚΗ ΔΗΜΟΚΡΑΤΙΑ
ΥΠΟΥΡΓΕΙΟ ΑΝΑΠΤΥΞΗΣ & ΑΝΤΑΓΩΝΙΣΤΙΚΟΤΗΤΑΣ
ΑΝΤΑΓΩΝΙΣΤΙΚΟΤΗΤΑ ΕΠΙΧΕΙΡΗΜΑΤΙΚΟΤΗΤΑ ΕΠΑΝ II
ΕΣΠΑ 2007-2013 πρόγραμμα για την ανάπτυξη
η περιφέρεια στο επίκεντρο της ανάπτυξης
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης - Ευρωπαϊκό Ταμείο Περιφερειακής Ανάπτυξης (ΕΤΠΑ), στο πλαίσιο του Ε.Π. Ανταγωνιστικότητα και Επιχειρηματικότητα (ΕΠΑΝ II) και των Π.Ε.Π. Αττικής, Π.Ε.Π. Μακεδονίας - Θράκης

“ProtoCode” ver.3.0

“Forw2DCode” ver.4.0

“Inv2DCode”ver.5.0

User’s Guide

➢ ABOUT THE PROGRAM

Inv2DCode.exe is a program for the two-dimensional (2-D) inversion of Electrical Resistivity Tomography (ERT) data in order to automatically determine a 2-D resistivity subsurface model. The program performs smoothness constrained (Occam's) inversion in order to address the non-uniqueness of the inverse problem and stabilize the procedure. The subsurface is divided in homogeneous and isotropic unstructured elements and a 2-D Finite Element Method (FEM) routine (Forw2DCode) is employed to calculate the resistivity response of 2-D bodies. The adjoint equation technique has been incorporated into the FEM scheme to calculate the Jacobian matrix. The program can cope with 2-D data sets measured using any kind of conventional (Dipole-Dipole, Pole-Dipole, Pole-Pole, Gradient, Schlumberger, Wenner), non-conventional and mixed.

➢ LICENSING

HOW TO INSTALL THE PROGRAM

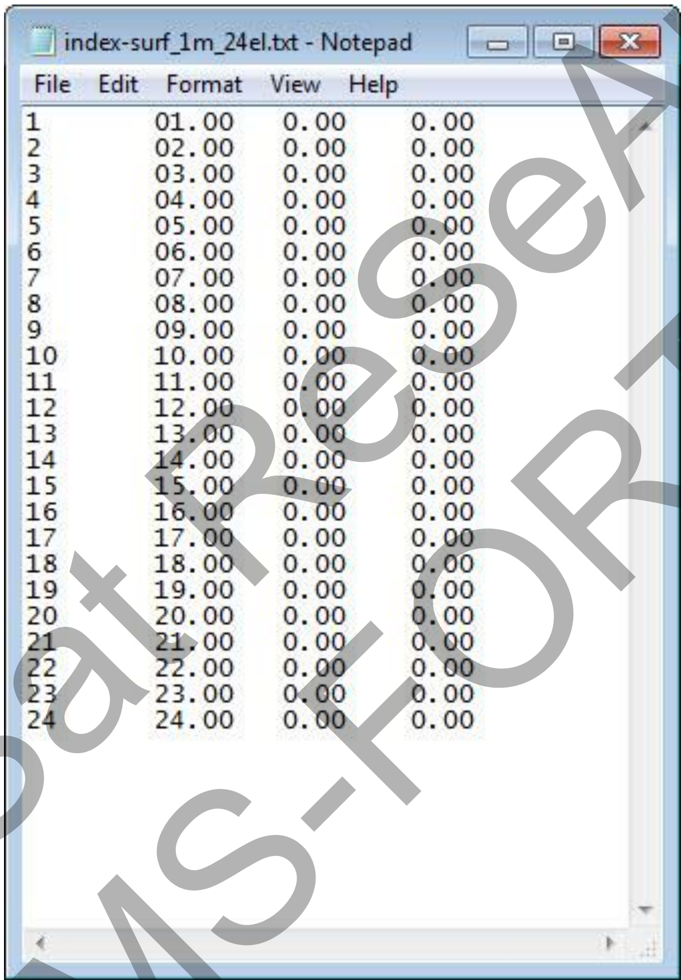
The folder “InvCode” contains the executable files for: a) the inversion (Inv2DCode.exe) of the tomographic data, b) the forward resistivity modeling (Forw2DCode.exe) and c) the creation of protocols (ProtoCode_pt/pd/bb.exe) using pole-tripole (pt), pole-bipole (pb) and bipole-bipole (bb) arrays. The file “header_file.txt” is provided as a reference for creating a protocol (used by “ProtoCode_pt/pd/bb.exe” file). All the output files produced by each program are exported at the same main folder.

Copy the folder in C drive and each executable can be run by double click.The programs have been developed in Matlab environment (version R2012a). MATLAB Compiler Runtime (MCR) **must be installed** (file “MCRInstaller.exe” included in main folder) to run the programs successfully.

<u>**Note:**</u> *If previous a version of Matlab is already installed, there is no need to install the respective MCR.*

A. **Create Protocol File "ProtoCode_pt/pd/bb.exe"**

The file "header_file.txt" is an ASCII file (Figure 1) that is used by the program "**ProtoCode_pt/pd/bb.exe**" and declares the number and the X, Y, Z coordinates of each one of the electrodes.



1	01.00	0.00	0.00
2	02.00	0.00	0.00
3	03.00	0.00	0.00
4	04.00	0.00	0.00
5	05.00	0.00	0.00
6	06.00	0.00	0.00
7	07.00	0.00	0.00
8	08.00	0.00	0.00
9	09.00	0.00	0.00
10	10.00	0.00	0.00
11	11.00	0.00	0.00
12	12.00	0.00	0.00
13	13.00	0.00	0.00
14	14.00	0.00	0.00
15	15.00	0.00	0.00
16	16.00	0.00	0.00
17	17.00	0.00	0.00
18	18.00	0.00	0.00
19	19.00	0.00	0.00
20	20.00	0.00	0.00
21	21.00	0.00	0.00
22	22.00	0.00	0.00
23	23.00	0.00	0.00
24	24.00	0.00	0.00

Figure 1. File for electrode labeling and electrode spatial coordinates (x,y,z) that is used by "ProtoCode".

The specific parameters listed in the "header_file.txt" are necessary for the algorithms "ProtoCode" in order to create the sequence of measurements for each array (pt, bb, pb). The output files containing the sequence of measurements can be used by the forward modeling algorithm for numerical simulations.

The outputs of the specific program are two separate ASCII files: “prot_m_spec_.d” and “array_m_spec_.d” as shown in Figure 2.

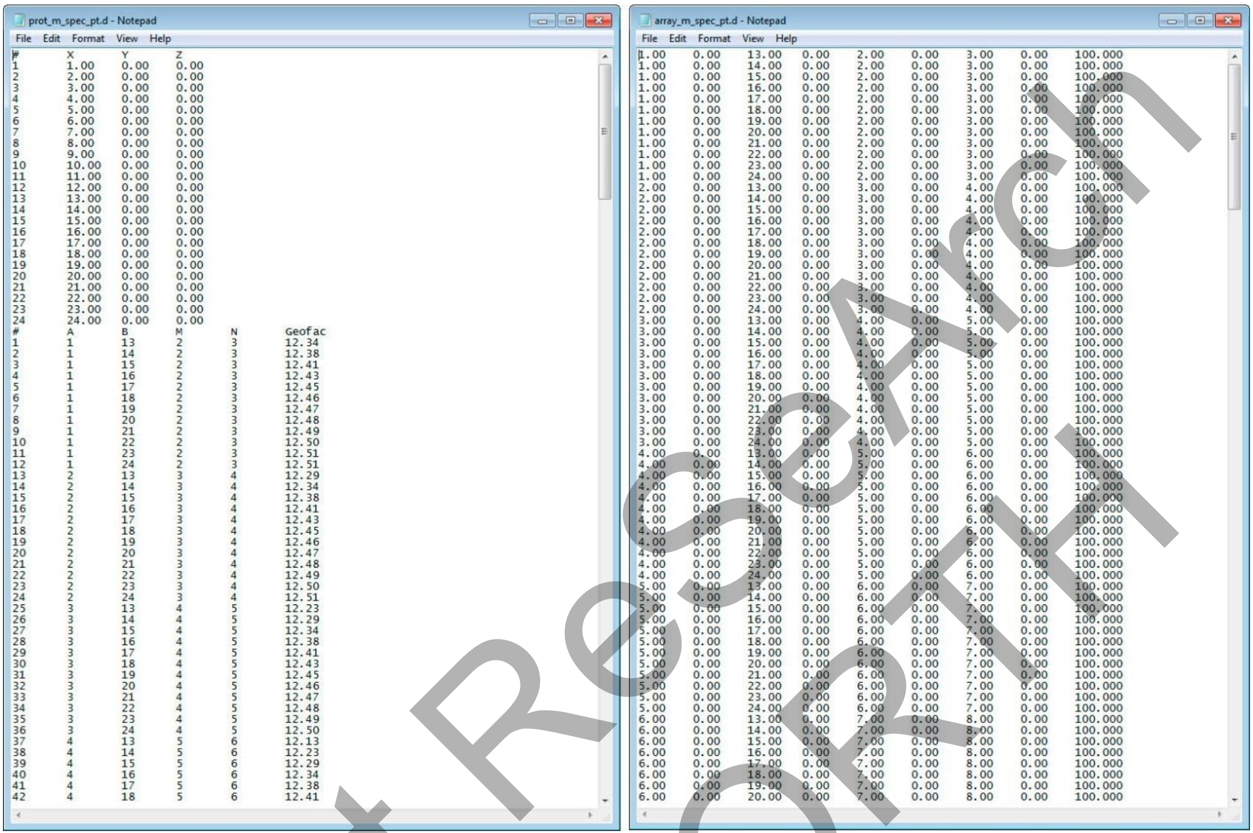


Figure 2. Exported files from “ProtoCode_pt.exe” algorithm. Same information is included with two different formats. The file “array_m_spec_pt.d” is the one that is used by the program “Forw2DCode”.

The file “prot_m_spec_.d“ indicates a header with the electrodes labeling and their location (coordinates x, y, x). The second part of the file contains the sequence of measurements in the form of quadripoles (A, B, M, N). The last column gives the Geometrical factor of each measurement.

Note: Since it is a 2D program the “y” column is always zero. The “x” column indicates the electrode position on the survey line direction and the “z” column the depth of the electrode in the subsurface (z=0 if the electrode is on the surface).

The file “array_m_spec_pt.d” stores the sequence of measurements with the respective electrode coordinates (x, z) for each one of the electrodes (A, B, M, N). The last column is the resistivity value of the homogeneous medium (e.g. ρ=100 ohm-m).

B. **Forward Arithmetic Solution with "Forw2DCode.exe"**

The program "**Forw2DCode.exe**" reads the protocol (Menu > File > Read Protocol) that is produced by "ProtoCode_.exe" (Figure 3). The program discretizes the subsurface in finite unstructured elements (Figure 4).

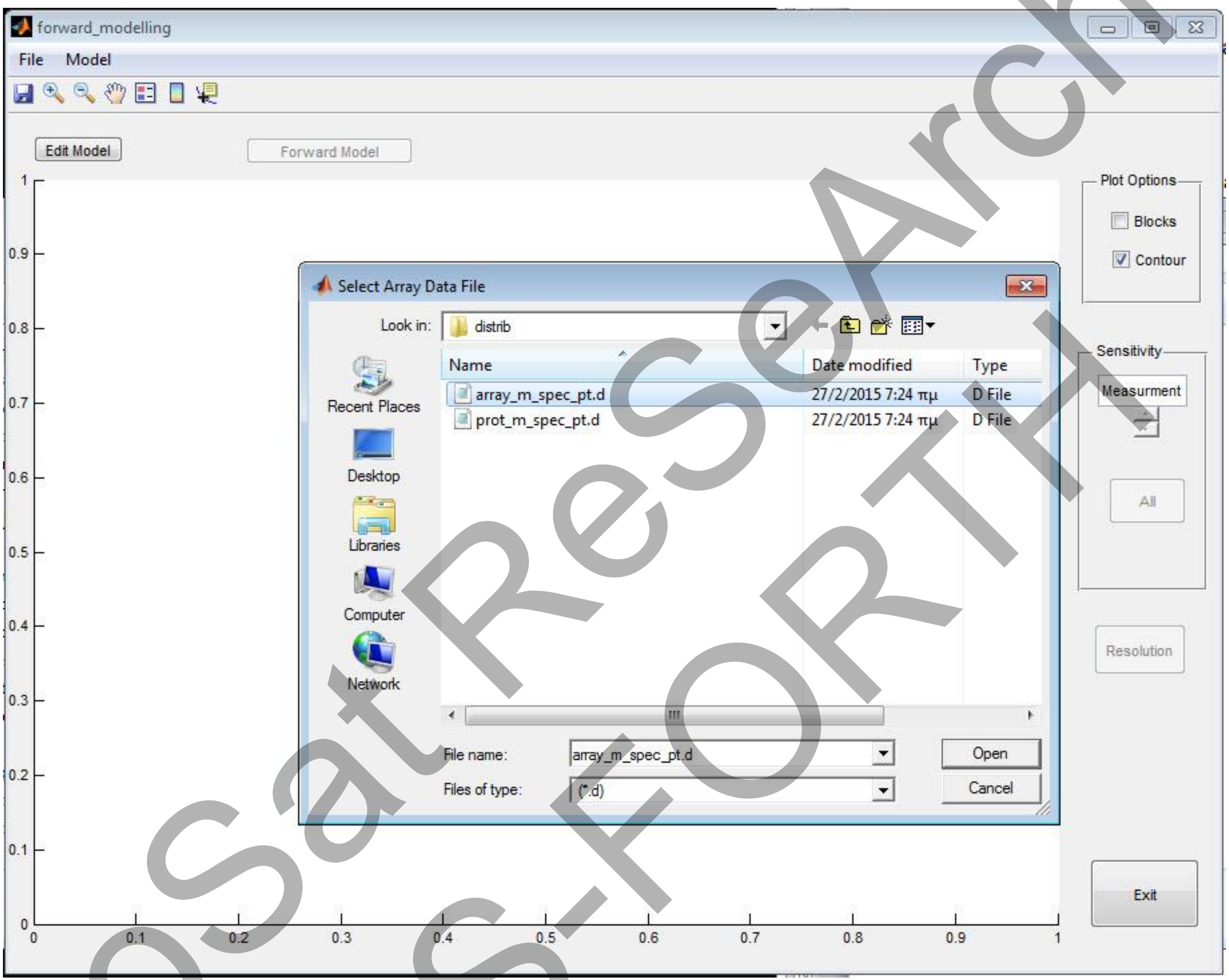


Figure 3. Selection of the protocol for forward solution by program "Forw2DCode".

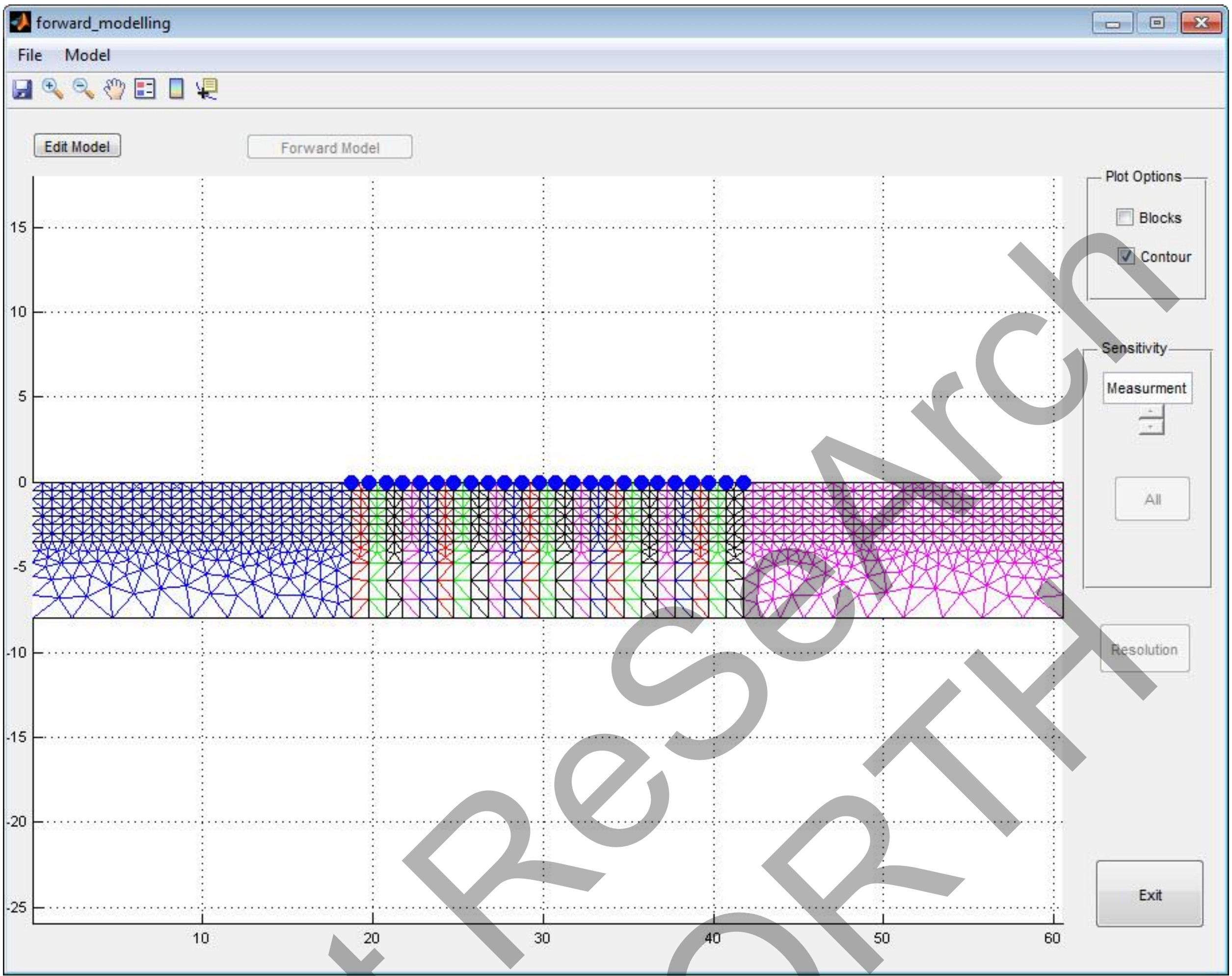


Figure 4. The subsurface is discretized using a Finite Element Analysis algorithm. The blue dots are indicating the electrode position.

The synthetic model is constructed by the "Edit Model" button command manually by the operator where first a parameter must be selected (driven by the mouse) and then a resistivity value must be entered (Figure 5). Another way of entering the resistivity values is using an external file ("model01.mod", ASCII file) which contains the parameter and the corresponding resistivity value. This file can be read by the Menu > Model > Parameter+Resistivity option. As Figure 6 shows, some parameters are chosen and the resistivity value selected is ρ=500 ohm-m.

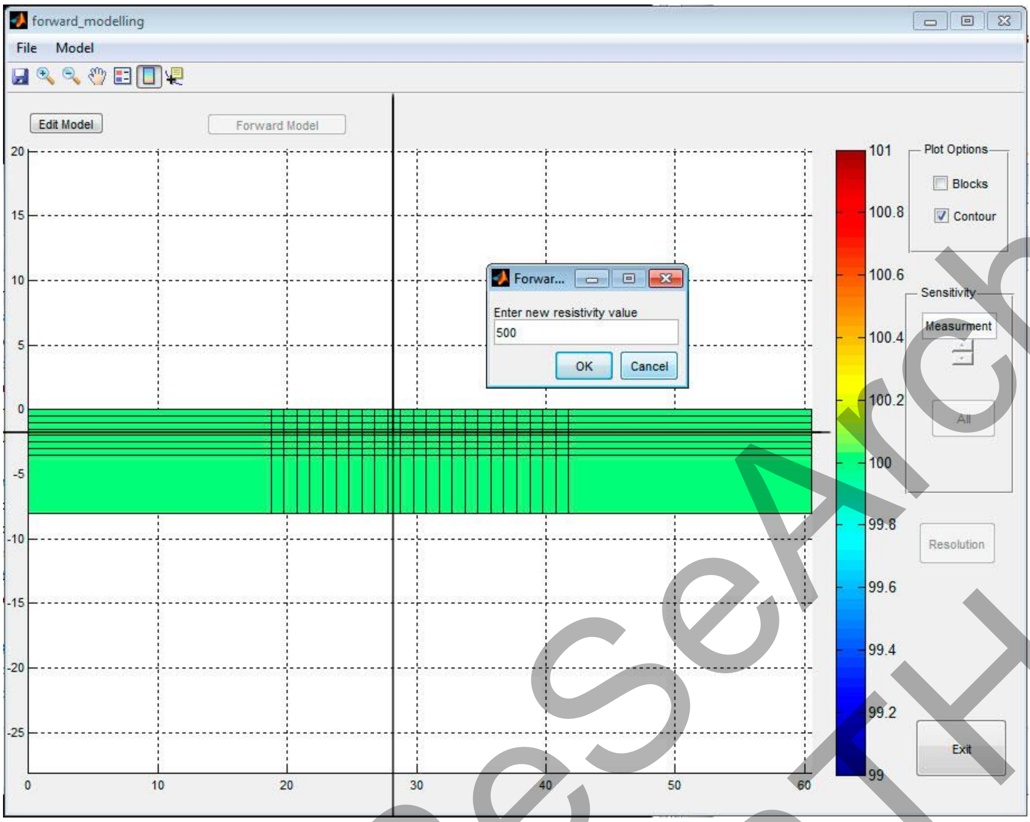


Figure 5. Constructing the model using a graphic user interface (GUI) with the cross pointing the parameter which the resistivity value will be entered e.g. 500 ohm-m).

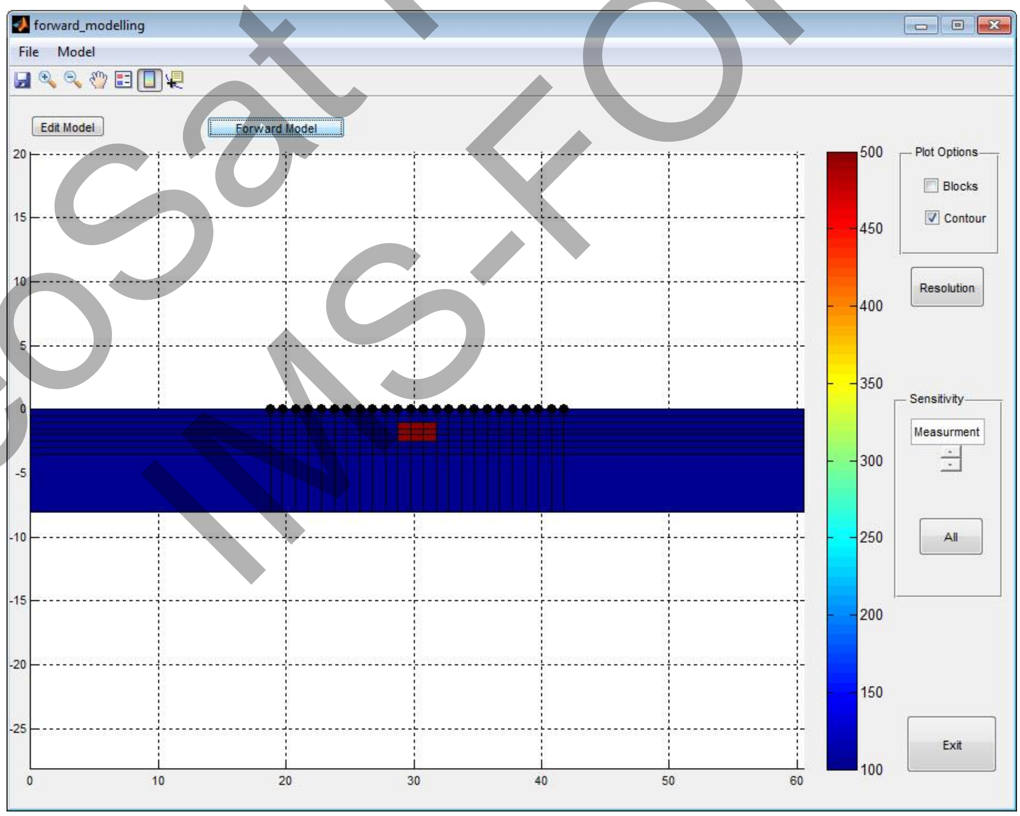


Figure 6. Parameters that are selected with the resistivity values (red color) entered manually.

On the right side of the main window a colored scale represents the resistivity values. When the model is constructed, by pressing the button “Forward Model” the forward solution starts. When the forward solution ends, additional information can be shown in the main window by selecting “blocks” or “contours” (and pressing the “Resolution” button). The array resolution distributed spatially within the parameters is shown in Figure 7 (left with blocks and right with contours). If button “All” is pressed the sensitivity of the area is shown for each measurement throughout an animation.

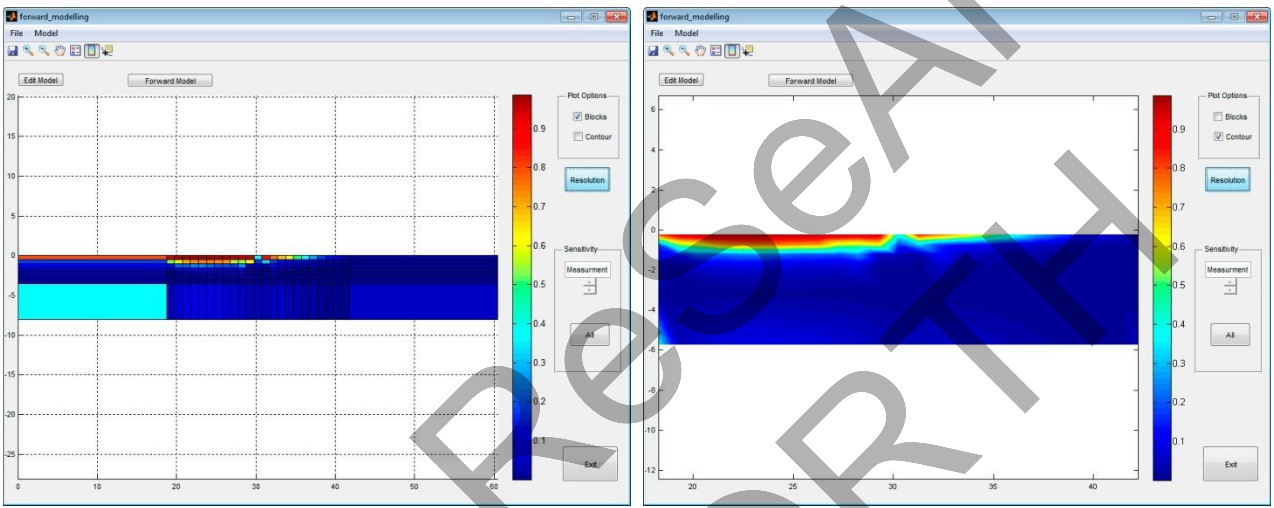


Figure 7. Plotting additional information where the resistivity is shown with blocks (left) or with contours (right).

The output files from the forward modelling are “forw_array_m_spec.d” and “optim_array_m_spec.d” (names according to the input filename with the appendix “forw_” and “optim_” at the beginning).

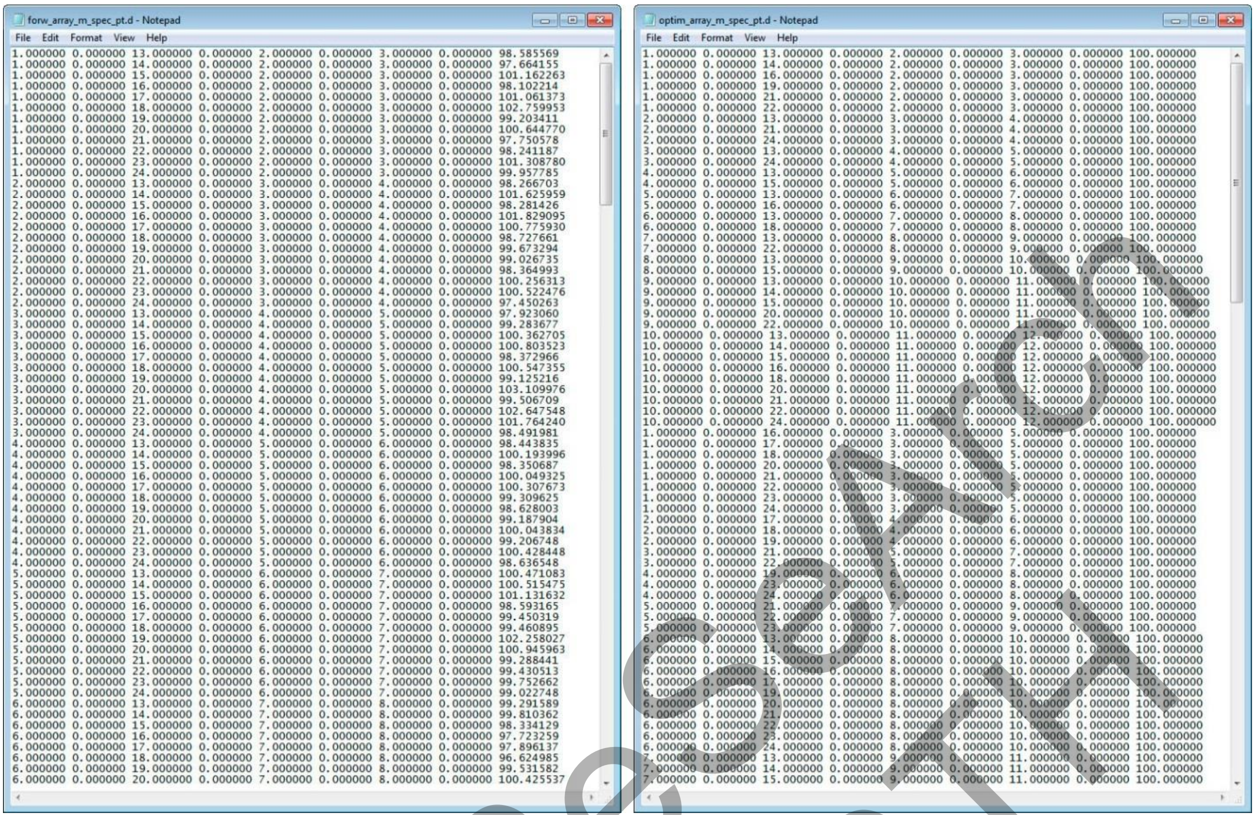


Figure 8. Portion of the exported files produced by program “Forw2DCode”

The first (Figure 8, left) is indicating the apparent resistivities of each measurement and the latter (Figure 8, right) the optimum measurements based on the Jacobian matrix criterion.

C. **Inversion with the program “Inv2DCode.exe”**

The program “**Inv2DCode.exe**” is a 2D inversion algorithm which is based on a 2.5D finite element routine to solve an iterative least squares algorithm with Active Constrain Balancing (ACB) for reconstructing the subsurface resistivity models. First the file with the extension “.d” is read (Menu > File) (Figure 9) and then when the selection “Inversion” from the main menu is chosen a new window opens (Figure 10). The operator can modify some inversion parameters but without any changes the default values are selected.

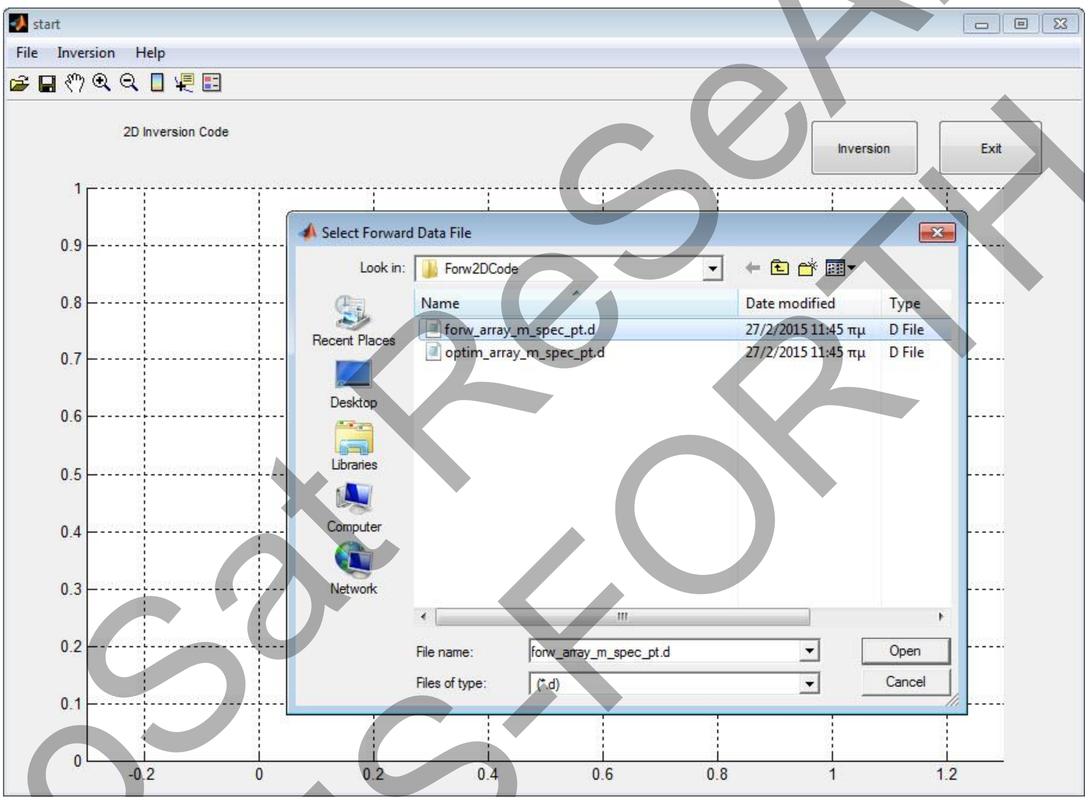


Figure 9. Reading forward solution file or real data file from a resistivity meter.

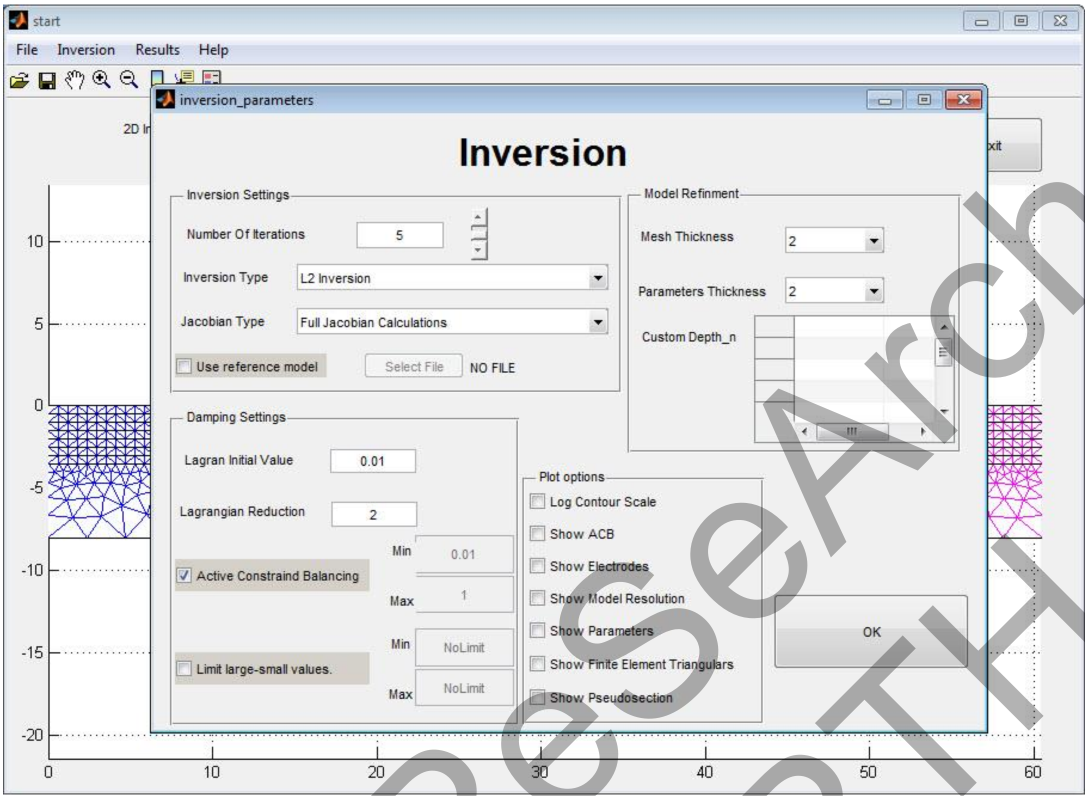


Figure 10. Inversion parameters.

<u>Note:</u> *After reading the file, always the Inversion Parameters window menu must be opened and closed with OK in order for the inversion to initiate.*

The command button "Inversion" from the main window is pressed and the algorithm is reconstructing the subsurface model in an iterative procedure where the RMS % error is reduced after each iteration (Figure 11).

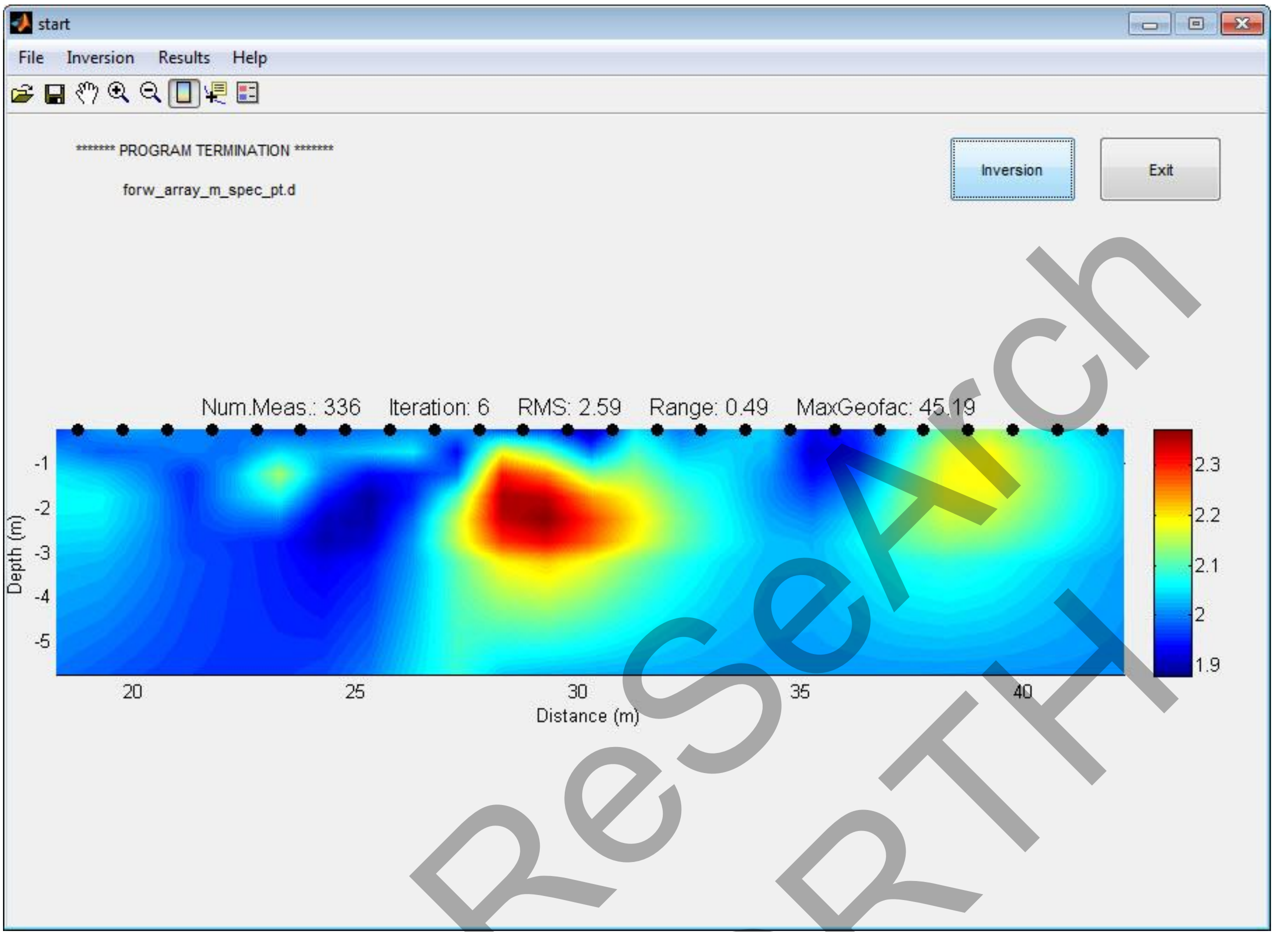


Figure 11. Inversion results from a synthetic model.

When the inversion finishes on top of the main image the following information are listed:

- **Below the ending message (on top left corner): "***** PROGRAM TERMINATION *****" the name of the inverted file is displayed (f.i. "forw_array_m_spec_pt.d").**
- **"Num.Meas": is the total number of measurements used**
- **"Iteration": is the number of iterations needed for the final result**
- **"RMS": is the % Root Mean Square error calculated between the produced forward results and the observed measurements.**
- **"Range": is indicating the resistivity values range (variation between minimum to maximum values)**
- **"MaxGeofac": is the maximum geometrical factor of the all the measurements used**

On the right side of the results there is a colored logarithmic scale indicating the resistivity values of the subsurface. As the color becomes “warmer” (red) the higher is the resistivity value and when the colors is becoming “colder” (blue) the resistivity decreases. The black dots are indicating the electrode position on the surface. The distances are measured in meters.

Two extra files are produced after the inversion (“datout.txt” and “modout.txt”). The latter contains some informations about the inversion type, the filename, the final RMS % error, the number of iterations, parameters and measurements. Then the x, z coordinates of each parameter and the corresponding parameter resistivity value (linear and logarithmic scale) are shown in columns. Additionally, the electrode coordinates xA, zA, xB, zB, xM, zM, xN, zN and the apparent resistivity values of the observed and calculated data can be seen in columns. These files can be imported in any other imaging program for producing the final images.

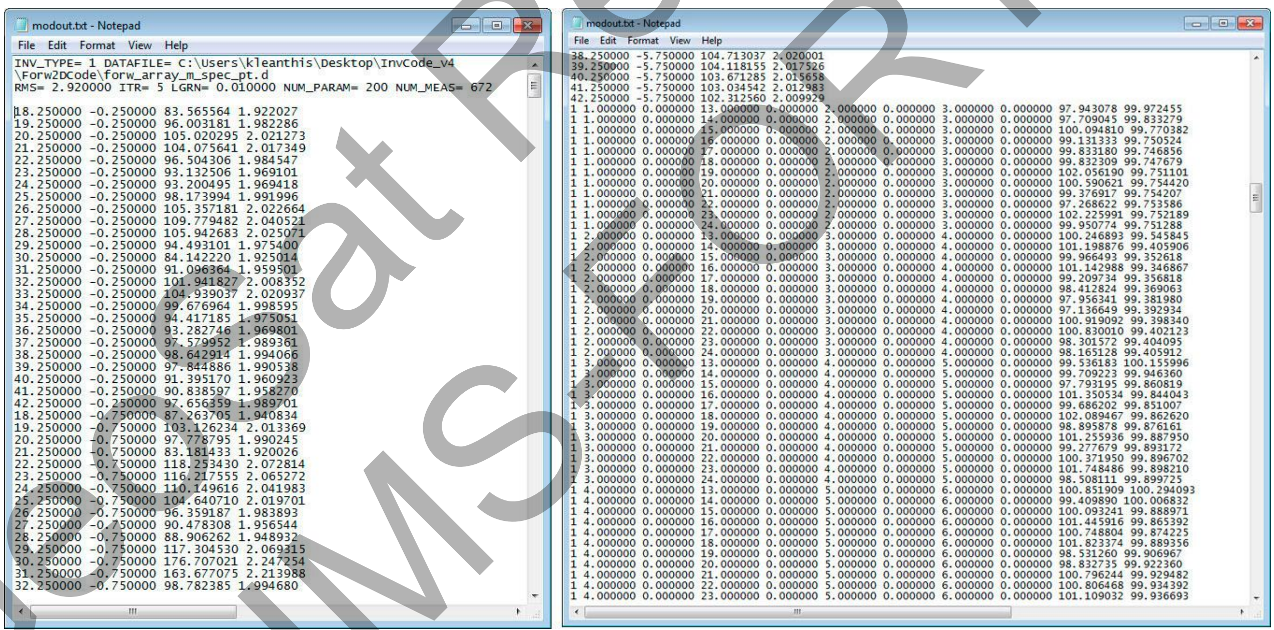


Figure 12. Exported file after the inversion procedure.

FORWARD AND INVERSE DC RESISTIVITY MODELING

A 2.5-D Finite Element Method (FEM) scheme is used as the platform for the forward resistivity calculations. The adjoint equation approach was incorporated into the FEM scheme in order to calculate the Jacobian matrix (the derivatives of the observations in respect of changes of the model's resistivity) when necessary.

During the 2-D resistivity reconstruction procedure the subsurface is considered as a set of individual blocks (parameters) which are allowed to vary their resistivity independently. The aim is to calculate a subsurface resistivity estimate **x** for which the difference $\Delta\mathbf{d}$ between the observed data $\mathbf{d}_{obs}$ and the modelled data $\mathbf{d}_{calc}$ (calculated using the forward modelling technique) is minimized.

Since we are dealing with a non-linear problem this procedure has to be iterative: In every iteration an improved resistivity estimate is sought and eventually the procedure stops until certain convergence criteria are met (i.e. until RMS error is practically stable).

The inversion of earth resistivity is an ill-conditioned problem (i.e. high resistivity changes can result into a small variation of the observed data) therefore it can become unstable. Factors such as the data noise and an unsuccessful choice of the parameterized blocks can further increase this instability.

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