IPI4D

USER MANUAL

VERSION 1.0

General

IPI4D is a 2D/3D time-lapse resistivity, time-domain and spectral domain IP inversion program. It can be used for any kind measurements (surface only, borehole-surface, borehole-borehole). It uses both standard inversion algorithm and time-lapse-4D inversion algorithm depending on user’s choice.

Installation

This software was programmed under Mathworks Matlab version. It's only dependencies are a computer with Matlab installed. It runs under any OS that Mathworks supports. Currently it is been testes from versions 2010a and newer.

To install it, simply unzip the archive into a directory. Two subfolders are include, one for the 3D version and on for the 2D.

To run it simply write “start”, under Matlab's Command windows in the directory you have unzip the program (or either enter in Matlab's path, the path you have unzipped the program.

REQUIREMENTS

Any computer and OS that Mathworks Matlab supports.

Expect heavy computation time with older CPU's.

MAIN PROGRAM.

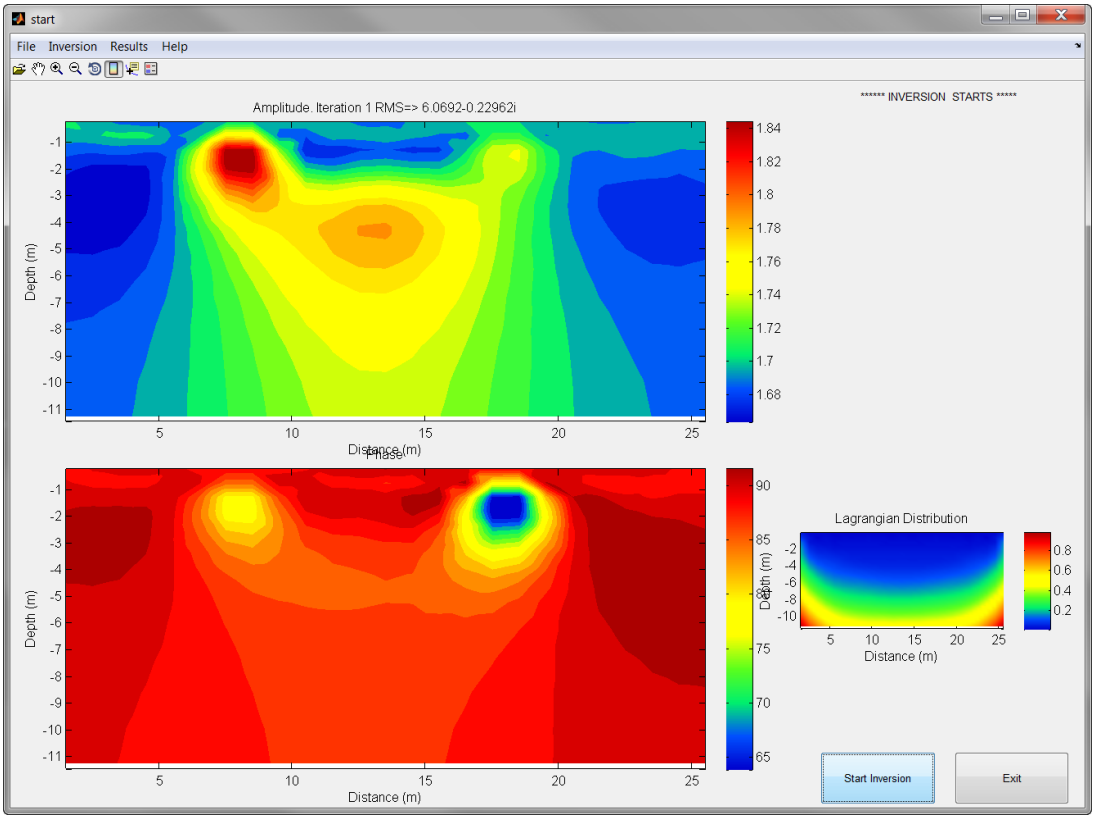


Figure 1: The main program. The two main figures show the inverted resistivity model at some iteration and chargeability or phase in case data include or time domain or spectral domain information accordingly. The small figure shows the Lagrangian distribution, in case the ACB (Yi et al., 2003) is chosen.

Type “start” in Matlab's Command Window to execute the program. Main program is shown in figure 8.

1) First read the date file (see appendix for more info), by selecting File → Read File.

2) Open File Dialog box opens (figure 2).

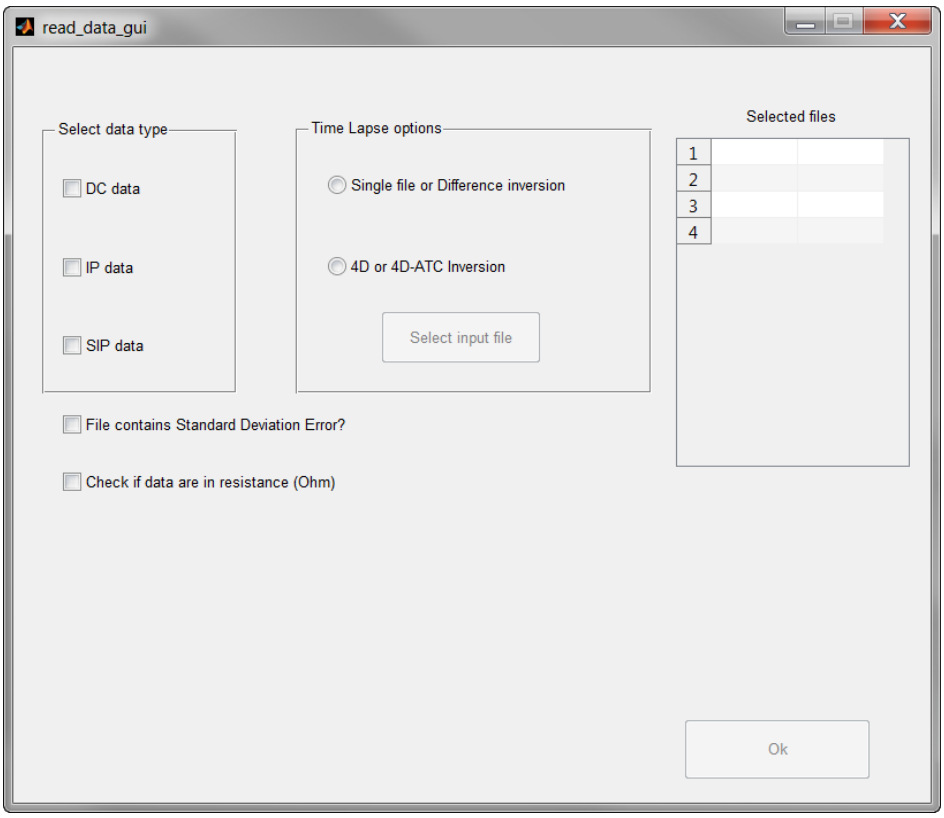


Figure 2: Select Data File dialog

Here user should first select if data file have DC data, or time domain IP or Spectral domain data. Then, choose accordingly if data is a single time step file, or a time lapse.
File format can be found in the appendix. Important, when choosing "4D or 4D ATC inversion", user provides a file that contains which single time step files to be used.

Optional, if input file contains standard deviation or measurements are in resistance, check the according box.

After the input file is process, program creates an automatic mesh. Please wait up to minutes.

Data file should be in the same directory with the program.

3) After selecting data file, select from Inversion → Change Parameters. Change parameter dialog appears (figure 3)

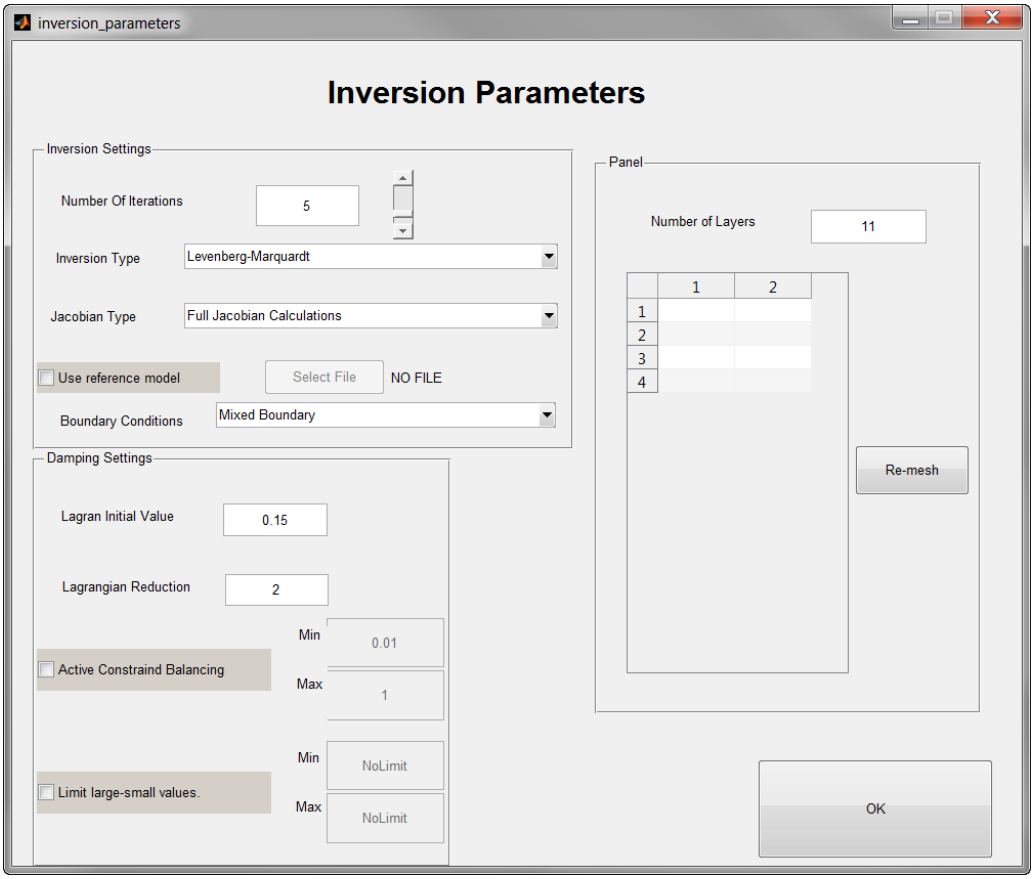


Figure 3 Change Parameters dialog.

If Start Inversion button is pressed before you change the inversion parameters, a dialog box appears (figure 4), preventing the execution of the program without changing the inversion parameters.

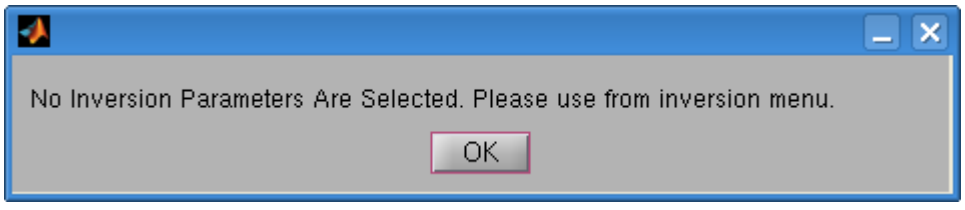
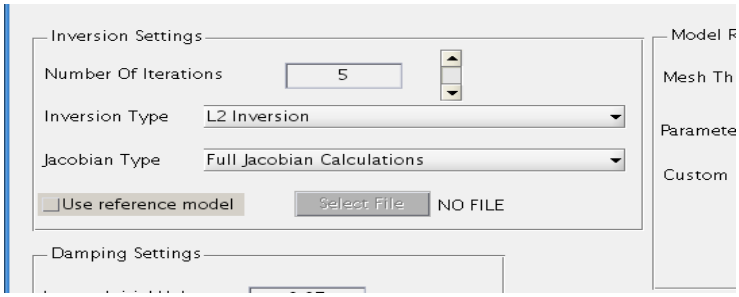


Figure 4: Warning dialog

Inversion Setting Section



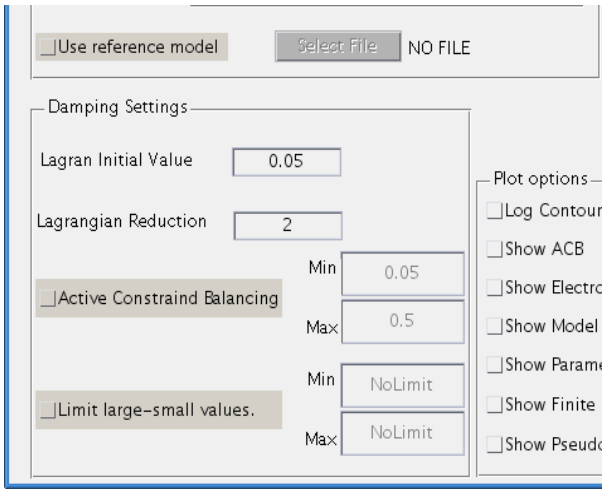
In this section

- select the number of iterations (default 5)
- Inversion type
    - Occam inversion.
    - Gauss Newton update inversion.
    - Gauss Newton update with smoothness on model inversion.
    - Time Lapse
    - Time Lapse + Smoothness on Model
    - 4D inversion.
    - 4D active time constrained inversion.

  Some of the options are not available if user did not select 4D inversion from the read data dialog.
- Jacobian Type
    - Full Jacobian Calculations → Calculate Jacobian in every iteration.
    - Quasi Newton → Calculate Jacobian in 1st iteration and then quasi-newton update it.
- Use reference model → if checked then *Select File* button became active. Click to open Select File dialog box

INFO. If Time Lapse, or Time Lapse + Smoothness on Model, from *Inversion Type*, then *Use Reference model* is obligatory and always checked. For the other type of inversions, use of reference model is mandatory. See appendix for the reference model file form.

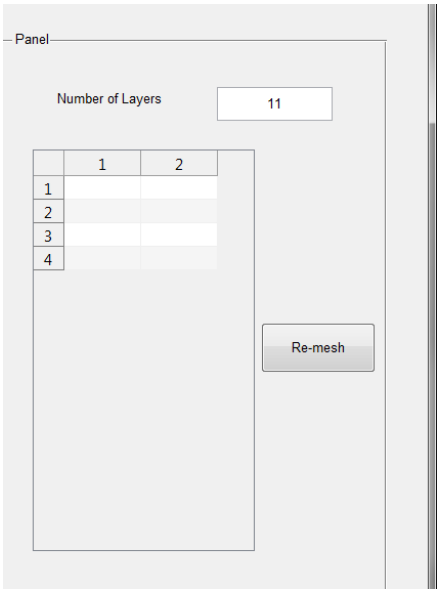
Damping Settings



In this Section:

Set Lagrangian initial value. Default is 0.05
Set Lagrangian reduction step. Default is 2. *(This means that after 1st iteration Lagrangian will be ½ of the initial).*
Active Constrained Balancing (ACB). Check this box if you want ACB be used instated of a fixed value (see manuscript for more info). This technique distributes deferent Lagrangian values in each parameter according to the resolution. Adjust the upper and lower Lagrangian value (default 0.05-0.5).
Limit large-small values. Check this option to constrain parameters getting values out of user specific limits. Default is unchecked. **Use with caution.**

Model Refinement



In this section:

Choose custom number of layers, and each layers thickness. Click on Re mesh to create the new mesh.

CLICK OK TO SAVE INVERSION PARAMETERS AND CLOSE WINDOW.
CLICK START INVERSION IN MAIN WINDOWS.
INVERSION STARTS.

After completing the iterations, the program AUTOSAVES the results in a file "*inv_resutls.mat*")..
Also it saves an output text file with the resistivity model and the calculated apparent resistivies, names "*datout.inv"*

User can process the results from menu Results → Process.

PROCESSING

You can process the results from menu Results → Process.
Processing windows shows (figure 5) (4D and 4D_ATC GUI processing capabilities under construction)

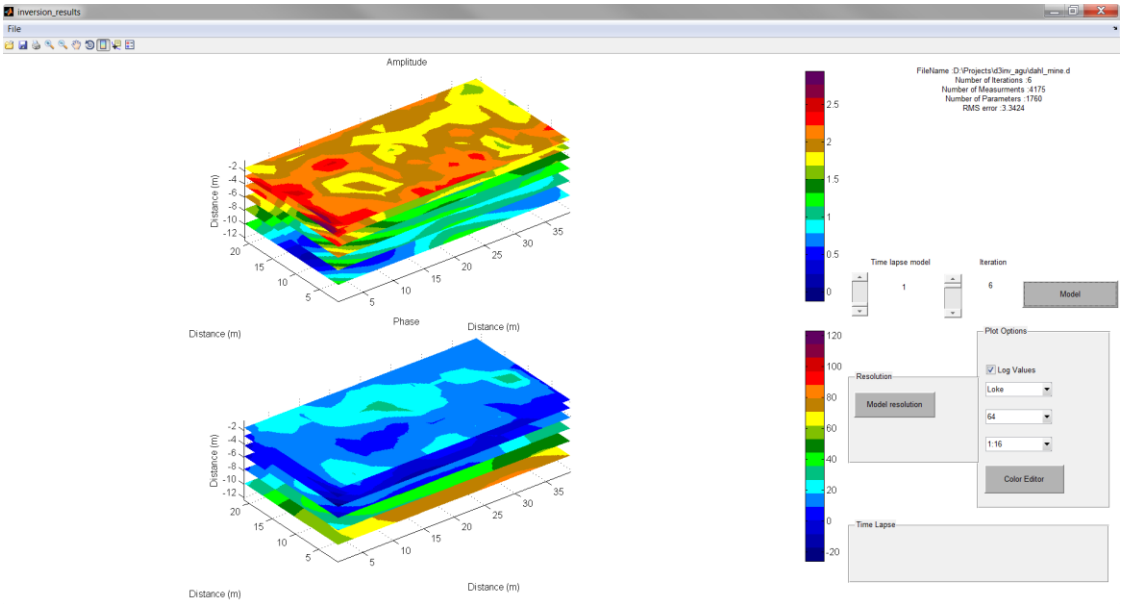


Figure 5: Processing Window

1) Read inversion file, by File → Open. Select File dialog appears.
   *Usually the file will have *.mat extension.*

2) After reading file, some info are displayed in upper right corner (figure 6)

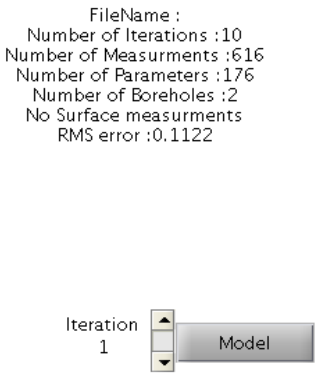


Figure 6: Info in processing window

Depending on your inversion file, some buttons appeared in figure 12 may be missing (e.g. if the inversion file in NOT time-lapse no *%Difference Ratio* or *Background* will be enabled. Also if the inversion file doesn't have ACB enabled during the inversion then no *ACB* button will be enabled).

You can select the model to display in all iterations. Also in case of 4D inversion, you user can display the time-lapse desired model.

Notice: Title's figure displays the number of iteration selected and the RMS error for this iteration

By pressing the buttons (if enabled)

- ACB
- Resolution
- % Difference
- Ratio
- Background Model

Program shows the relevant figure.

Plot options

In this section:

- Log Values → Check to display the logarithmic value of each figure. (Default Enabled).
- Colormap → Select from a predefined colors the desired one
- Number of colors → Select how many colors should be between the less values to large value. More colors smoother (interpolated) image. Less colors sharper image (figure 15)
- Interpolation scale → Select the interpolation mesh based on the distance of parameters (e.g. 1:16 interpolates at 1/16 of the distance between two parameters. Smoother images with less value)
- Color Editor → Click this to open the color map editor in order to manual adjust colors with values (figure 6). (*NOTICE that you should first select the desired number of colors*)

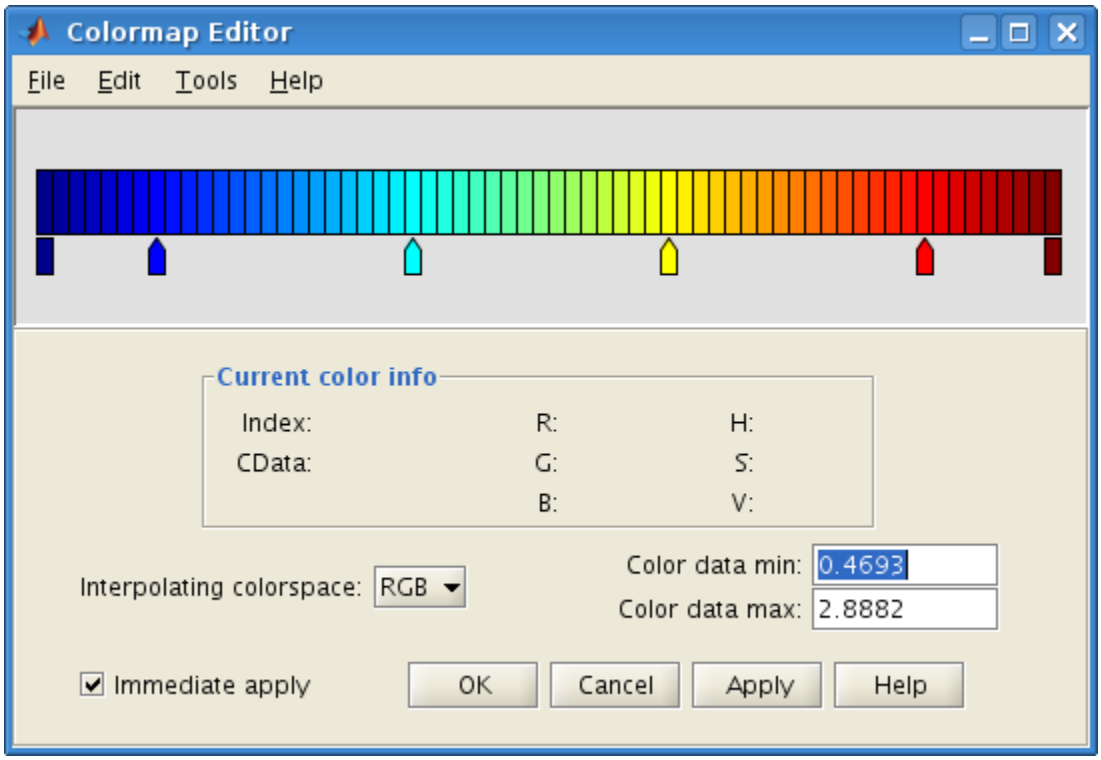


Figure 6: The colormap editor.Insert, delete slide color values. See help for more info.

FORWARD MODELING

This section describe the steps necessary to calculate the forward response. Type forward_modeling to the command prompt.

This GUI frontend is used to calculate the forward response of a user input resistivity model (Figure 7 and 8).

- In the 2D case, the user selects the cells and assigns a resistivity (or amplitude and phase) (Figure 7).
- In the 3D case, on the right side of the GUI, the x-y-z coordinate is shown, together with the corresponding resistivity (or amplitude and phase) (Figure 8).
- After model creation, an output file is created, with filename *forward.d* and contains the apparent resistivities for the given configuration.
- In the case of no input file, the user can create one using the create file option, and change the array configuration (number of electrodes, spacing, n and a numbers, array type and number of 3D lines) to test (Figure 9).

The output file *output.txt* has the calculated apparent resistivities. This file can also be used as benchmarking the inversion.

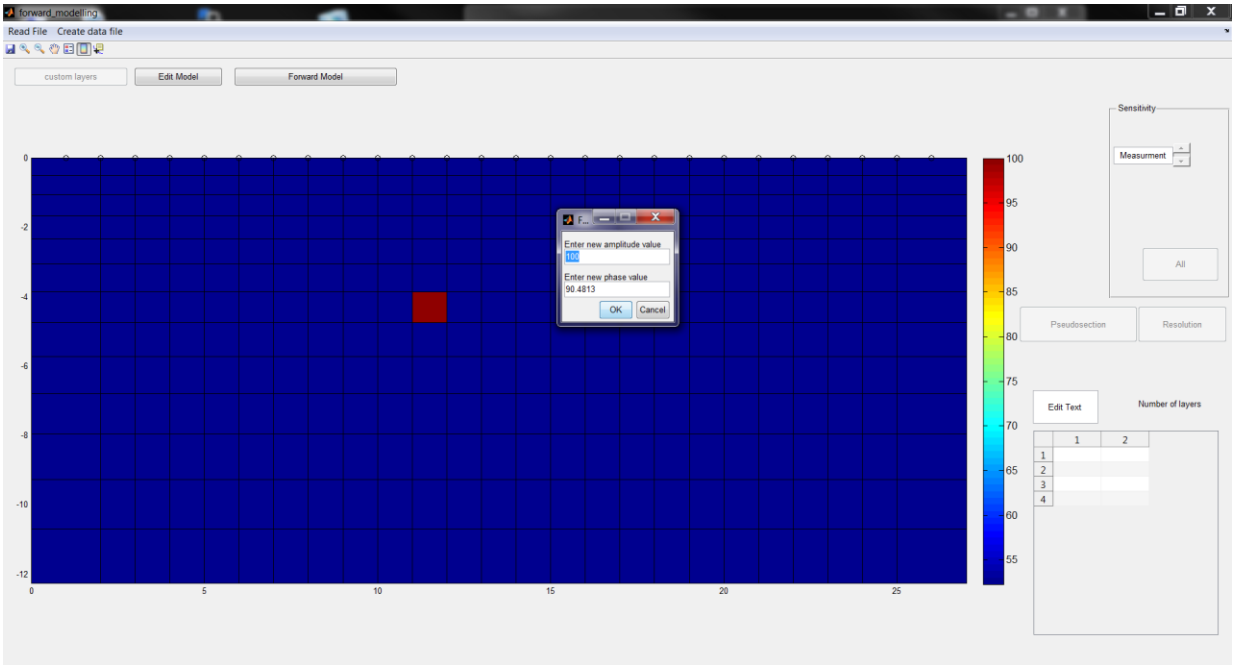


Figure 7: Creating a 2D synthetic model. By clicking the Edit Model button, user selects the parameter to change the corresponding resistivity and IP parameter.

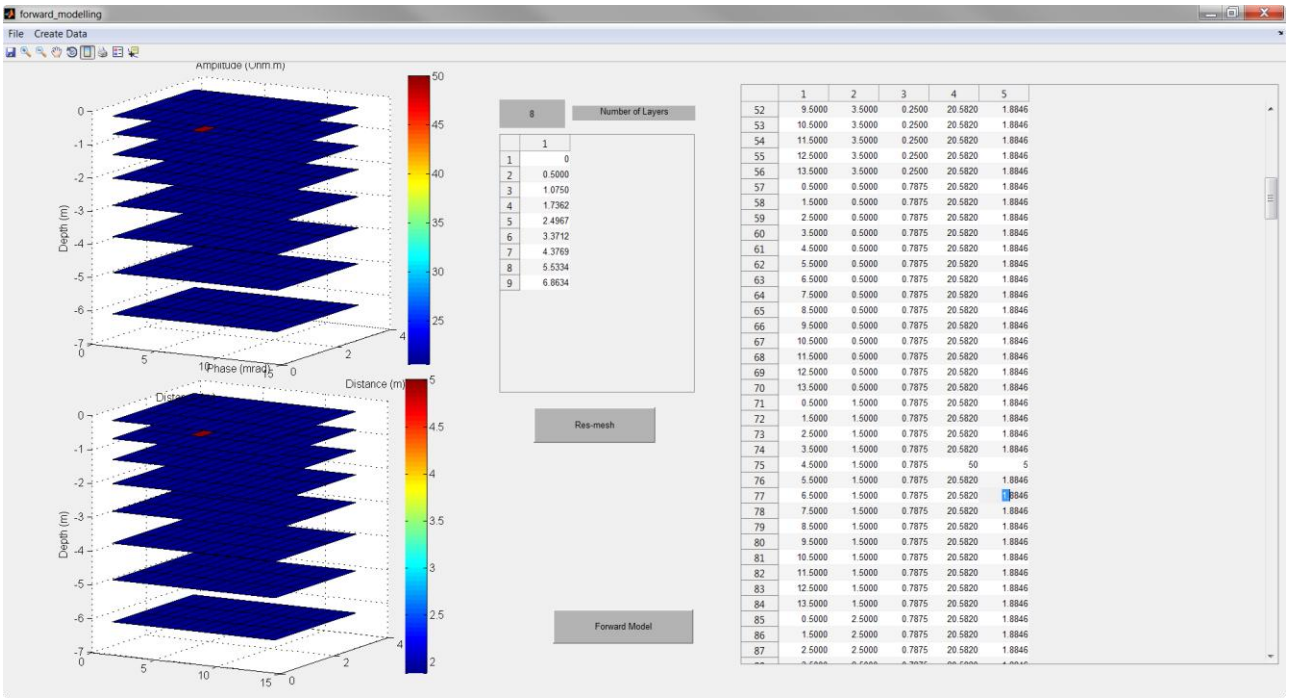


Figure 8: Creating a 2D synthetic model. By clicking the Edit Model button, user selects the parameter to change the corresponding resistivity and IP parameter.

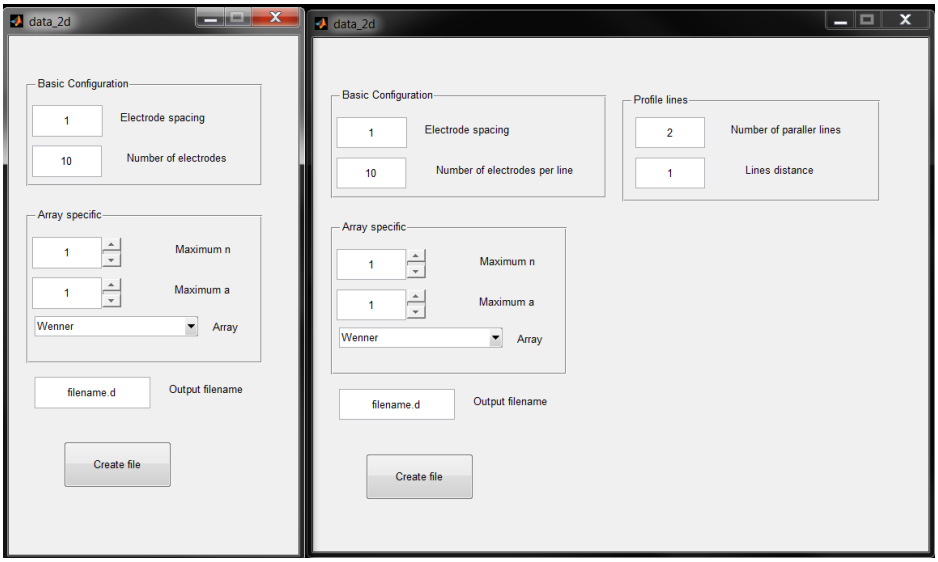


Figure 8: GUI to create 2D (left) and 3D (right) measurement array. The basic options are the measurements array and the, the number of electrodes, electrode spacing and the separation of the dipoles. In the 3D case, additional information regarding the number of parallel lines used and the spacing between the lines is required.

Calculation of ATC matrix

A matrix is calculated at file **preprocessing.m,** where it calls the GUI frontend, and as input requires a file with extension .inv. This file contains the inversion filenames produced by the same software, of each time-step model, when inverted independently (e.g., a file with input the filenames of the inversion results, also with extension .inv). This file must have the form of **all.dat** previously discussed, but this time the input files should have the inversion results rather the data files.

NOTICE. .inv files are automatically created by code, when running a single-step inversion. Use these files to create the ATC matrix.

An example of *all.dat* follows

C:\IPI4D\file1.inv
C:\IPI4D\file2.inv
….

The output file of this GUI, is named ATC.mat. Use this file when processing 4D data with the 4D-ATC algorithm (Figure 3)

APPENDIX.

Data File format.

The columns that describe the coordinates of the A,B,M and N electrodes are in the following form

A(x) A(z) B(x) B(z) M(x) M(z) N(x) N(z),

where the *X*-coordinate corresponds to the surface projection of an electrode along a profile, where *Z*-coordinate shows the depth if this electrode (in case of only surface electrodes, Z=0). In the case of 3 or 2 electrode arrays (like pole-dipole or pole-pole), both X and Z coordinate of the missing electrode should be set to zero.

In the case of 3D array configurations we then introduce one more column per electrode defying the *Y*-coordinate (total of 12 columns);

A(x) A(y) A(z) B(x) B(y) B(z) M(x) M(y) M(z) N(x) N(y) N(z).

The rest of the columns of the input file depend on the user choice. There are 3 different options, DC data, time domain IP, and frequency domain IP (Table 1).

Option	**Next First column**	**Next column**	**Next column**	**Next column**
DC	Resistance (In Ohm) or apparent resistivity (in Ohm.m)	Standard deviation		
IP	Resistance (In Ohm) or apparent resistivity (in Ohm.m)	Chargeability (in msec)	Standard deviation	
SIP	Real part of complex resistance (In Ohm) or complex apparent resistivity (in Ohm.m)	Imaginary part of complex resistance (In Ohm) or complex apparent resistivity (in Ohm.m)	Standard deviation of amplitude	Standard deviation of phase

e.g.
The data file should have 9 columns.
Each line represents one measurement.
No special header needed.

4 Electrodes. A B M N.
Each electrode should have the position in space in x → direction and z → direction.

4 electrodes X 2 = 8 columns
The 9th column contains the apparent resistivity

One example is the following

0.000000 48.000000 0.000000 45.000000 33.000000 48.000000 33.000000 45.000000 9.454394
0.000000 48.000000 0.000000 42.000000 33.000000 48.000000 33.000000 42.000000 10.978434
0.000000 48.000000 0.000000 39.000000 33.000000 48.000000 33.000000 39.000000 12.201280
0.000000 48.000000 0.000000 36.000000 33.000000 48.000000 33.000000 36.000000 12.954376
0.000000 48.000000 0.000000 33.000000 33.000000 48.000000 33.000000 33.000000 12.860832

Number of measurements 5 (5 lines)

1st line 1st measurement.
A electrode → X=0 Y=48.
B electrode → X=0 Y=45
M electrode → X=33 Y=48.
N electrode → X=33 Y=45
apparent resistivity 9.454394

2nd line 2nd measurement
A electrode → X=0 Y=48.
B electrode → X=0 Y=42
M electrode → X=33 Y=48.
N electrode → X=33 Y=42
apparent resistivity 10.9784434

3rd line 3rd measurement
etc

Model File.
This file has the model to be used either as background (initial) model or time lapse inversion.

First line contains **HEADER** line

INV_TYPE= 1 DATAFILE= apot.d RMS= 1.483290 ITR= 1 LGRN= 0.050000 NUM_PARAM= 176 NUM_MEAS= 616

It should be self-explanatory.

This example shows the number of parameters used is 176.

Next 176 lines then, contain info about the parameters. (4 columns)

1st column it the x center of this parameter
2nd column is the y center of this parameter
3rd column has the resistivity of the parameter
4th column has the log10 of the resistivity.

e.g.

1.50000000000000	-1.50000000000000	10	1
4.50000000000000	-1.50000000000000	100	2
7.50000000000000	-1.50000000000000	100	2
1.50000000000000	-4.50000000000000	1000	3
4.50000000000000	-4.50000000000000	10	1
7.50000000000000	-4.50000000000000	10	1

6 lines 6 parameters are shown.
1st parameter is located at x 1.5 meter and depth 1.5 with resistivity 10
2nd parameter is located at x 4.5 meter and depth 1.5 with resistivity 100
3rd parameter is located at x 7.5 meter and depth 1.5 with resistivity 100
4th parameter is located at x 1.5 meter and depth 4.5 with resistivity 1000
5th parameter is located at x 4.5 meter and depth 4.5 with resistivity 10
6th parameter is located at x 7.5 meter and depth 4.5 with resistivity 10

After the 176 lines there are another 616 lines (11 columns)
These lines have in first column always 1.
The next 8 columns contains the A B M N x and y positions (like the data file).
Column 10 has the real data for this data set.
Column 11 has the calculated data set of resistivity for this model.

e.g.

1 0.000000 0.000000 33.000000 0.000000 0.000000 48.000000 0.000000 45.000000 10.123456 9.882749
1 0.000000 0.000000 33.000000 0.000000 0.000000 48.000000 0.000000 42.000000 10.789012 9.890463
1 0.000000 0.000000 33.000000 0.000000 0.000000 48.000000 0.000000 39.000000 10.345678 9.895919

IMPORTANT NOTES
After completing the iteration, the program creates *datout.inv*

1st line is the header like one explained before.
Next x lines contains the model like explained before.
Next y lines contain the data file like explained before.

User can use this file exactly as it is as an **background** model.

List of functions used in the code

Function name	Functionality
Main.m	Main function
Acb acd3d	Control the ATC technique
Auto_contour	Plot output of single step
Auto_contour_4d	Plot output of time-lapse step
Create_mesh	2d mesh generation
D4_prepare_data	Create matrices to perform 4D inversion
Data_2d	Create 2D or 3D configuration arrays
Forward_modelling	GUI to run the forward modeling
Forwad_solver	Function to control the forward modeling
Info_save	Information to be saved on the output files
Kim_inversion2	Perform 4D inversion
Mes_control_fast	Forward solver function, Jacobian calculations
Preprocessing	GUI to create the A matrix
Read_data_4d	Read 4D data set
Read_data	Read data
Read_data_gui	GUI to control the read data input files
Rms	Calculate the RMS values, and decide to proceed or not with the inversion
Rms_4d	Calculate the RMS values, and decide to proceed or not with the inversion (4D equations)
Rwaven	Calculate wavenumber and absicas.
Xu_inversion	Calculate wavenumber and absicas.
Smooth_mtx_surface	Calculate smoothness matrix C and M
start	Main program
Update_lagran	After each iteration, update the Lagrange values
Array3	3D mesh generation
Mesh_gen_3d_new_version	3D mesh generation
Invert_cntr	Function to control the single-step inversion
Inversion_parameters	GUI to change the inversion parameters
Inversion_resutls	GUI to plot the inversion results.