VLF2DMF

A program for 2-D inversion of multifrequency VLF-EM data

Version-1.6

This Software is produced by EMTOMO
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DISCLAIMER

The programs (software) included in any version of the **VLF2DMF** packed are provided "as are" without any express or implicit warranties including their suitability for a particular purpose. The author and **EMTOMO LDA** will not assume any responsibility for any damage or loss caused by the use of these programs. Efforts will be made to correct any program bug that appears during the usage of the package and reported to the author.

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1. Introduction

VLF2DMF[1] is a software package that has been developed in order to enable the processing and inversion of electromagnetic (EM) induction data acquired at Very Low Frequency (VLF). A review of the VLF theory, as well as practical applications regarding the geology and hydrogeology, can be found in McNeill and Labson (1991).

VLF2DMF is capable of inverting VLF-EM data acquired along a survey line (i.e. transect) at different frequencies. Data collected in a survey area can also be processed but not inverted as a set. The input data is the real and imaginary parts of the tipper (or the tilt angle and the ellipticity), also designed as inphase and quadrature components as measured by VLF-EM instruments. The package includes a Map Module that allows the display of the survey, the selection of profiles for inversion and displays the survey results. The program can also be used in modelling studies. The user can build a complex resistivity model and calculate its VLF-EM response.

VLF2DMF assumes a referential system with the vertical axis (Z) positive upwards (Figure 1.1). The line survey is assumed to be carried out along Y direction.

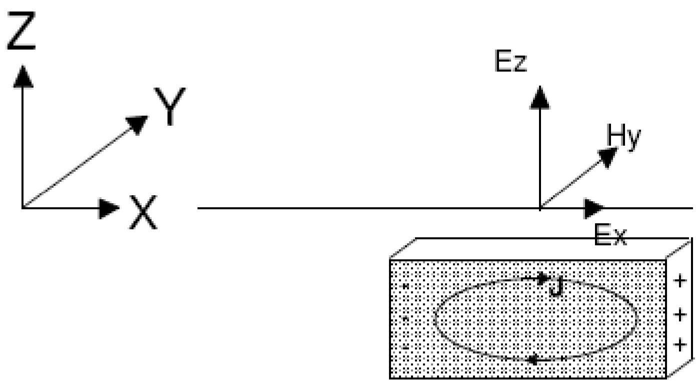


Figure 1.1. The VLF-EM electromagnetic field.

The inversion procedure used in **VLF2DMF** is two-dimensional (2-D) and is based on the Occam technique (e.g. DeGroot and Constable 1990, Sasaki 1989, Sasaki 2001). The forward modelling of **VLF2DMF** program is based on the finite-element method.

[1] A module for inversion of VLF-R data is also available.

2. VLF2DMF Packed Items

The **VLF2DMF** package is a 32-bit application that can run on Windows XP/Vista or even in Windows 7 32-bits (there is a few experiences running it in a 64-bits Windows 7). **VLF2DMF** has a graphical user interface based on the DISLIN[2] graphics library (http://www.dislin.de).

The package contains the following files:

- **VLF2DMF-v105.exe**;
- **Inv2DVLFmf.exe**;
- **InvKH0.exe**
- **VLFmfMap.exe;**
- **INSTALL-VLF2D.exe**;
- **disdll.dll** and **disdll_d.dll** (dynamic link library for the DISLIN graphics);
- this Manual (Instructions to run **VLF2DMF** program)

.

3. VLF2DMF Installation

In order to install the **VLF2DMF** program in your computer, take the following steps:

1) Unzip the files into an empty temporary folder;
2) Run the **INSTALL-VLF** file;

NOTE: The INSTALL-VLF2D only can create one folder at a time.

The first time you run the **VLF2DMF** software you will be asked to provide an alpha-numeric key (see left hand panel of Figure 3.1). In order to obtain this key you will need to send an email to the email address indicated **emtomog@gmail.com** with the CODE displayed by the program (e.g. EX8C545). Once you have the KEY you can enter it and begin using **VLF2DMF**.

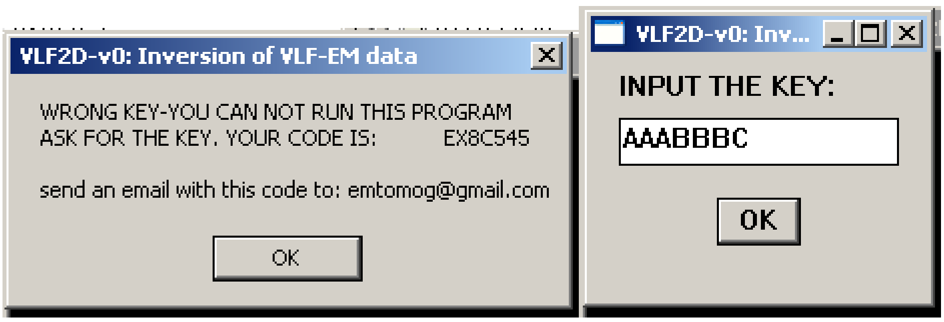


Figure 3.1. Screen snapshots which show the **VLF2DMF** CODE corresponding to your software package and where to input the key once the CODE has been sent.

NOTE: The key links the program to a particular computer. A new key is necessary to run the program in another computer.

[2] DISLIN is authored by Helmut Michels, Max-Planck-Institute

It is recommended to create a shortcut for **VLF2DMF**. Use the logo.ico to identify the software in your desktop.

To use the logo.ico file proceed as follow:

- Create a shortcut of the **VLF2DMF** file (click on the right mouse button on the file);
- Move the shortcut icon to Desktop;
- Go to its properties using the right mouse button and there use the Change icon option to change for the new one;
- Go to the General properties and change the name to **VLF2DMF**

NOTE: Save the key in a safe place. You may need it in the future.
NOTE: Make a copy of all files in a safe support for future replacements.

NOTE: To run VLF2DMF in Windows7 or 8 could be necessary to redefine Compatibility properties of the program and run it in compatibility mode for Windows XP (Service Pack 3).

4. Running VLF2DMF

In order to run the software, double click on the **VLF2DMF** icon. The software will start up and the screen snapshot shown in Figure 4.1 will appear. This is the welcome page.

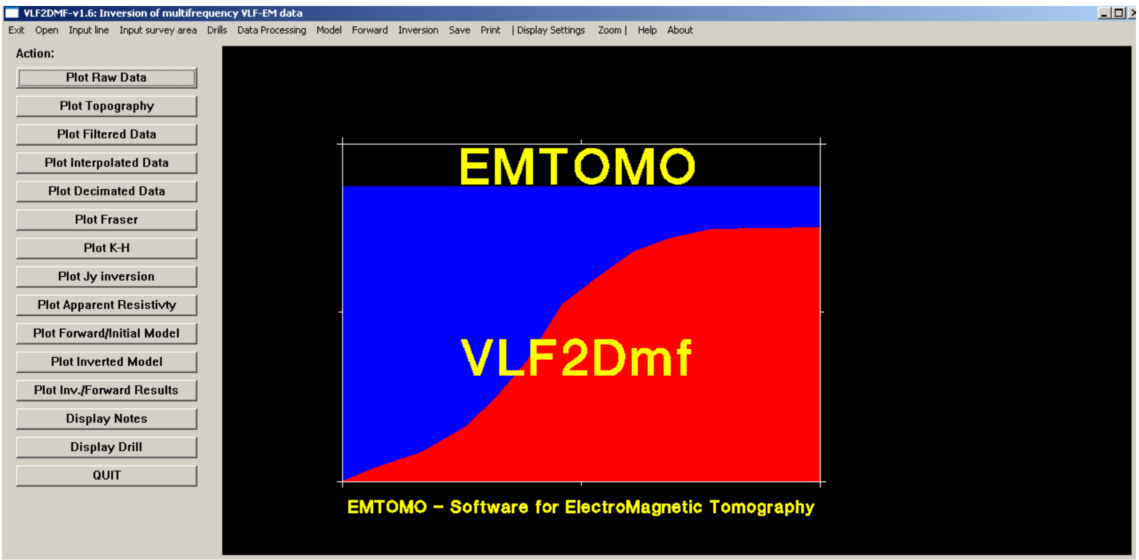


Figure 4.1. Screen shot of the **VLF2DMF** main screen.

Figure 4.2 shows the welcome page of **VLF2DMF** that has a menu bar with operational buttons.

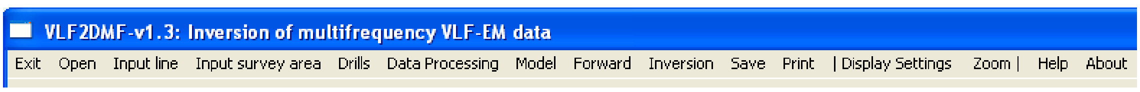


Figure 4.2. Screen shot of the **VLF2DMF** menu bar operation buttons.

In addition, and along the left hand side of the welcome page, there are 11 plotting actions, as shown in Figure 4.3. The majority of the welcome page allows the data, stage of inversion modelling and results to be displayed. The button **Display Notes** is explained in 8.1.1.

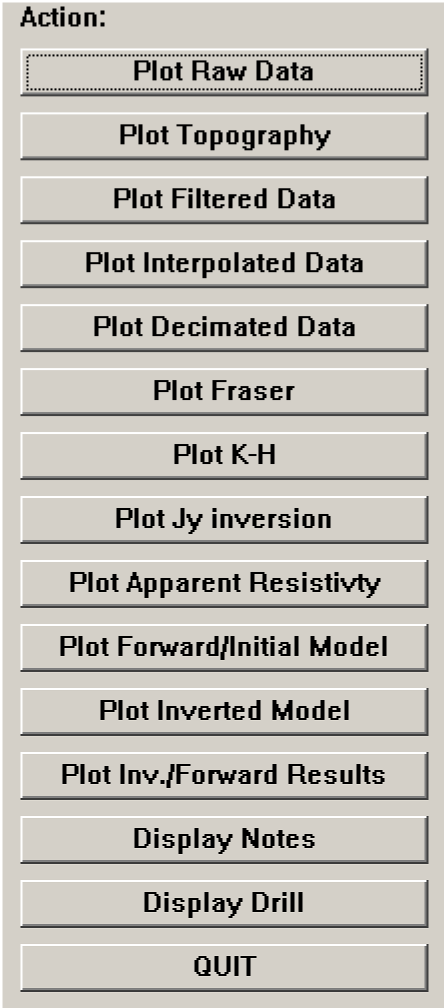


Figure 4.3. Screen shot of the **VLF2DMF** plotting action buttons.

5. Menu bar operations

5.1 Exit

Selecting OK in the 'Exit' button will cause **VLF2DMF** to shut-down. Your data processing and inversions will not be saved, **except if you have saved them**.

5.2. Open

This entrance allows you to input files resulting of previous processing. With the Open option you can input filtered data, Fraser data or K-H data. Merge option allows you to create a unique file containing all the lines carried out in a survey at the same frequency.

The results of inversion (file INV) or the results of a project (vPRJ files) and Map module (MAP files) session can also be imported. If you have resistivity and phase data (VLF-R) and have purchased the VLF-R module, use the Go to VLF2D-R module entrance to process the data (the VLF2D-R module is very similar to the VLF2DMF module). Merge Files allows merging files of the same survey into one file. This is particularly useful putting together data of profiles acquired at different times. Split File allows splitting multifrequency data file into single frequency files.

NOTE: In this version the VLF2D-R module is independent and can not be run from VLF2DMF program.

NOTE: Merge only can be used on single frequency files where data have been measured using the same source of signal.

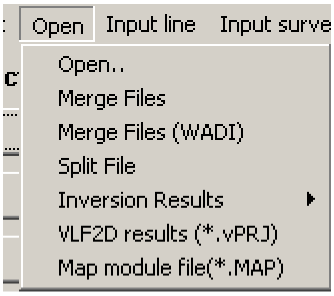
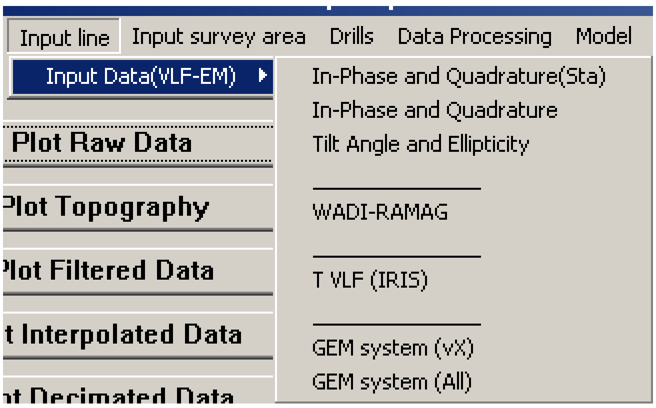


Figure 5.1. Opening files saved during a previous processing.

5.3. Input

Selecting the 'Input line' option enables the user to select and import data collected along a line. To import data acquired in a survey area (several lines covering an area) select the "Input area survey" (Figure 5.2). Importing data collected over an area will open the Map module of the program (see further in this manual). Please, read the Format section about data file format.



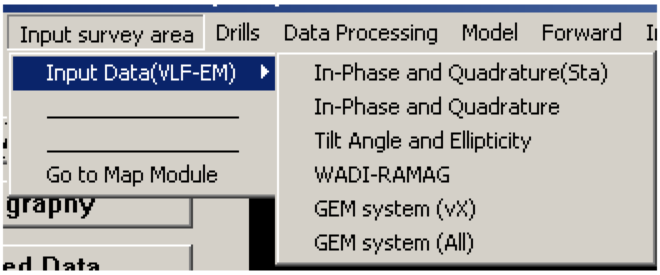
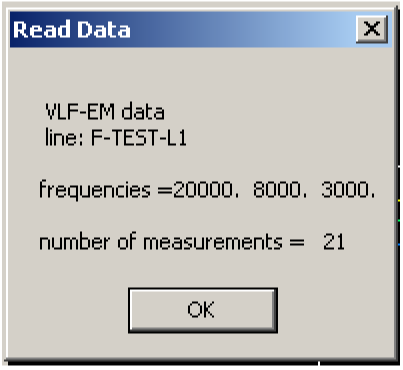


Figure 5.2. Input data selection (data in a line or in a survey area).



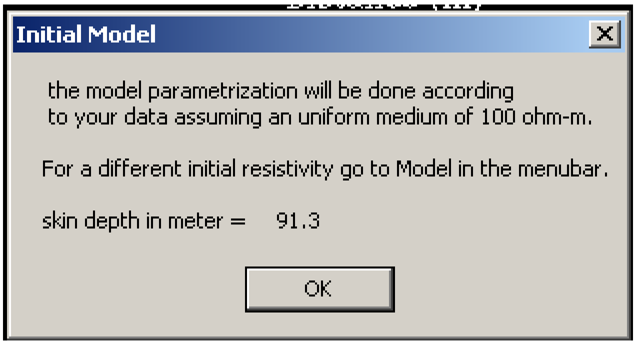


Figure 5.2 (continuation). Input data boxes which indicate that the data was successfully read, the number of measurement sites collected, and the frequencies used in the survey. There is indication that an initial model (assuming a 100 ohm-m uniform model) for inversion has been built and saved.

Note: The data can be viewed in the screen clicking the respective action button (Plot Raw Data).

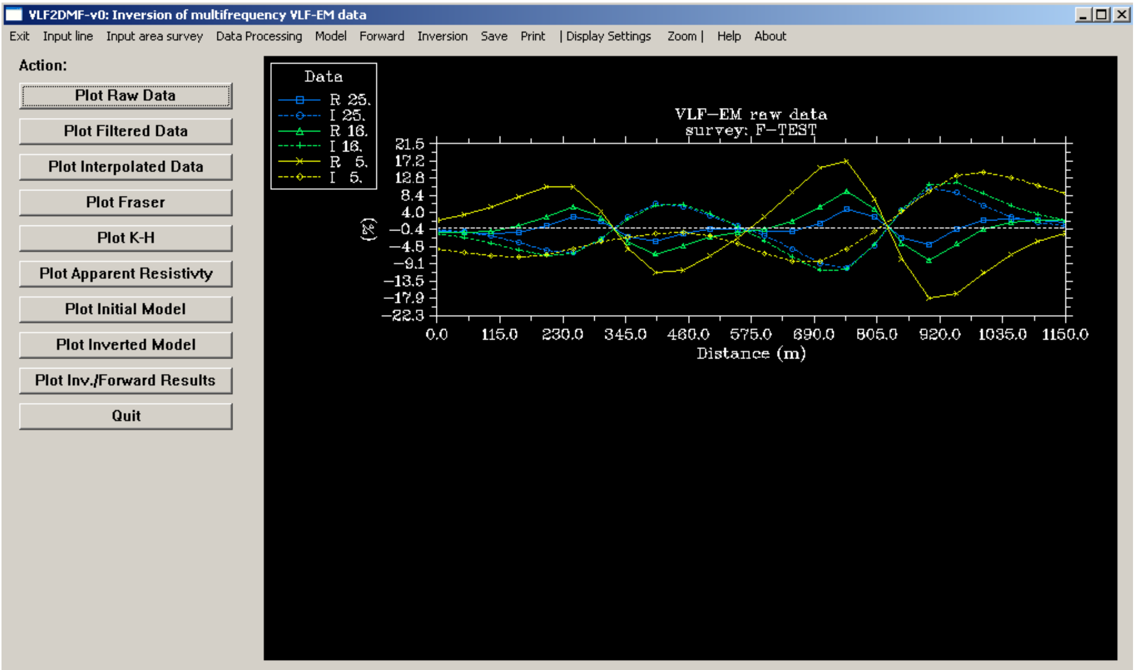


Figure 5.3. Displaying the data (data of three frequencies: 25, 16 and 5 kHz).

Figure 5.3 shows the data after the input. This data was generated from a synthetic model having two conductive bodies (100 and 20 ohm-m) in a uniform 1000 ohm-m environment. The middle of the bodies is located approximately at coordinates 325 and 825 m. See Figure 5.17 further in this manual.

NOTE: The entrance Go to Map Module in the Input area survey menu bar is only available if data from a survey area was already read (see further in this Manual).

NOTE: Raw data from T-VLF, GEM19 and WADI are saved in the In-Phase Quadrature format.

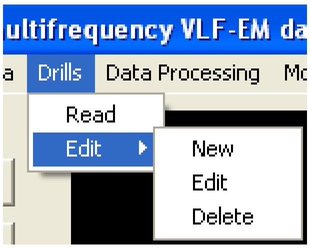
NOTE: Input of data collected with WADI instrument will be explained later.

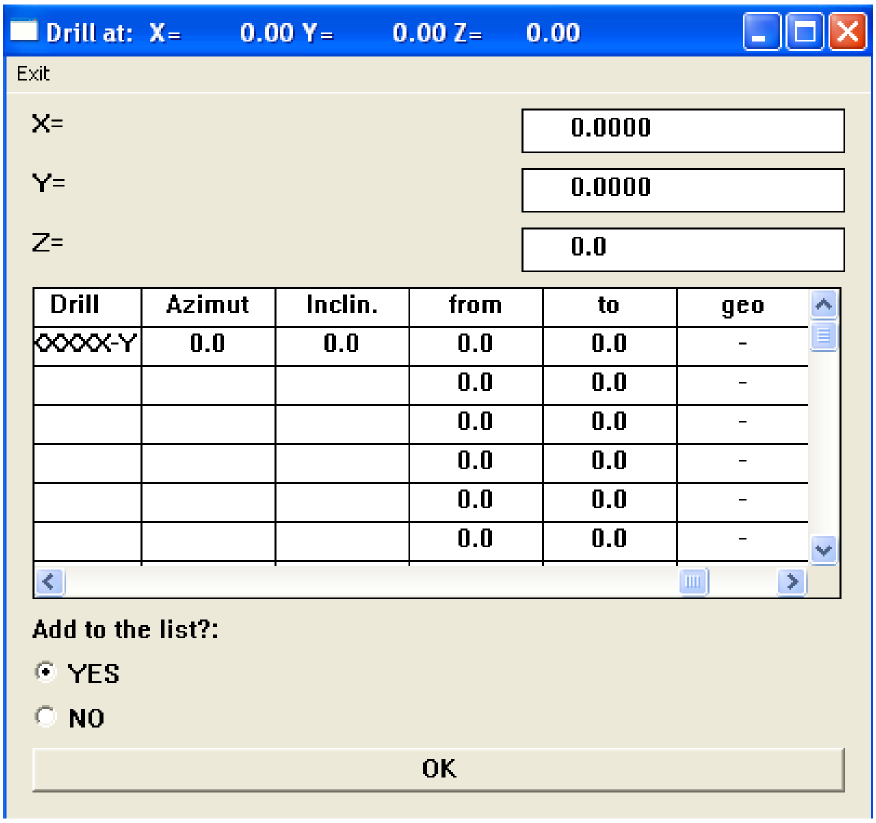
NOTE: input data collected with T-VLF instrument is very similar to the WADI case, only the input data file format is different (see in the format section).

NOTE: Data from GEM19 can be input using GEM format or as In-Phase & Quadrature files. Please, see below about formats.

5.4. Drills

Drills can be displayed in models and in K-H sections. The drill information should be included in a ascii file previously saved (see the format in the format section) or using the entrance Edit/New.





5.5. Data Processing

Once the field data has been successfully entered into **VLF2DMF,** the software allows the user to carry out some basic data processing (Figure 5.4).

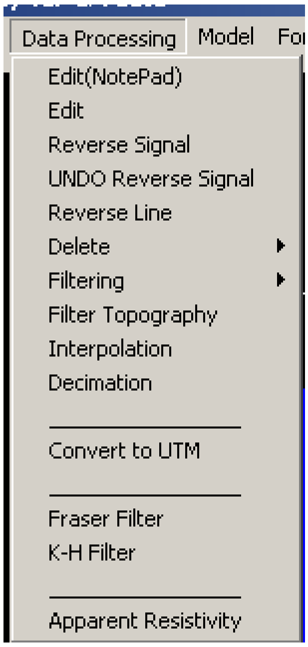


Figure 5.4. Drop down box menu for **Data Processing** selection.

5.5.1 Editing

The first two options in the **Data Processing** menu bar are **Edit (NotePad)** and **Edit**. If **Edit** is selected, Figure 5.5 shows a screen snapshot of an editable table. If **Edit (NotePad)** is selected the NotePad program will be initiated (if available). In this case, the file to be modified should be imported and saved after modifications.

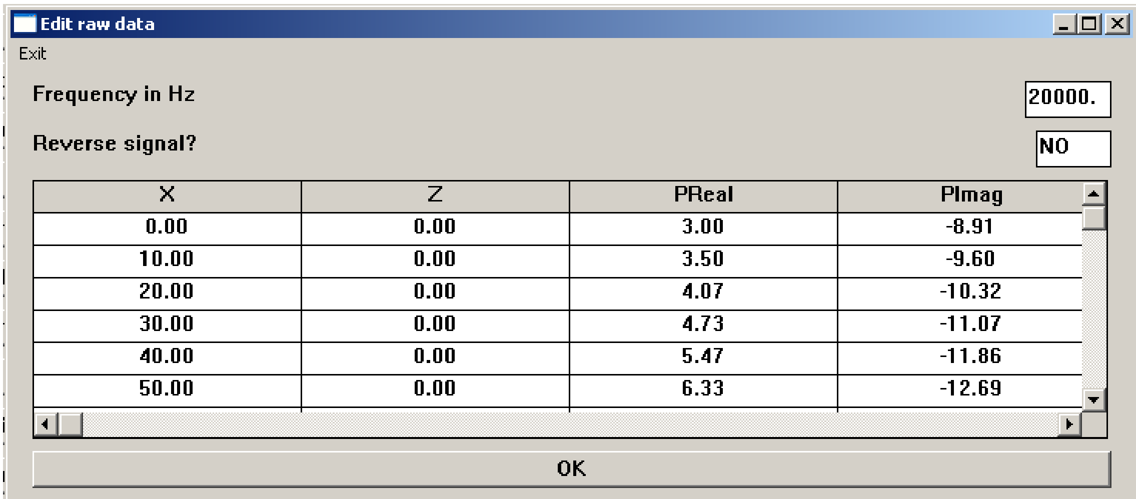


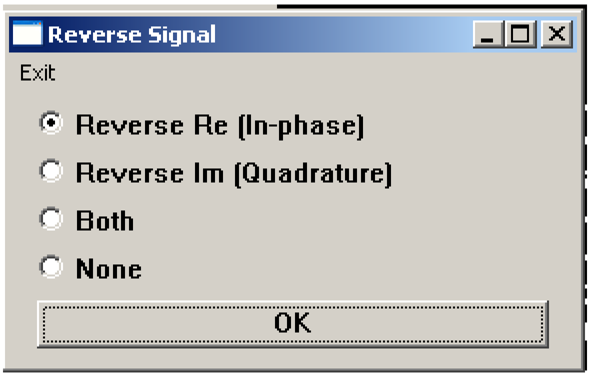
Figure 5.5. Table for **editing** data.

After making the required changes, click OK to save the data into a new file. This file has to be imported for processing and inversion. If for some reason you want to change the signal of your data, change the option to YES.

NOTE: In some situations the signal of the data should be reversed. Use the Edit option to reverse the signal of both, real and imaginary parts.

NOTE: When written values follow the format displayed in the menu.

Signal of the Real or/and Imaginary parts can also be reversed using the entrance Reverse Signal.

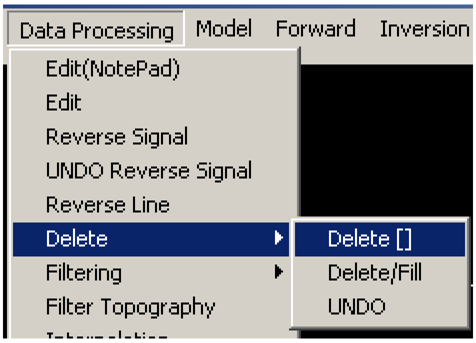


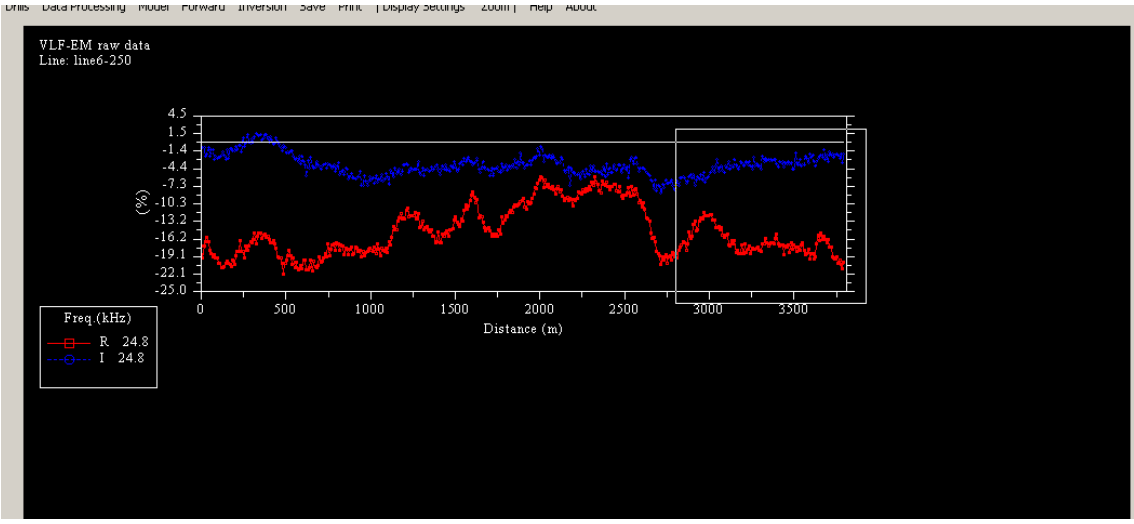
5.5.2 Reverse Line

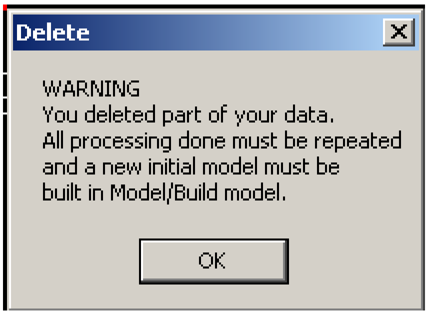
This allows to reverse the direction of acquisition along the profile. Changing of the direction correspond to reverse both signals.

5.5.3 Delete

The user can delete part of the data which are inside a rectangle (Delete[]). The rectangle is defined using the left button as usually.







If the option **Delete/Fill** is used the program fill the delete data with extrapolated values. This option must be used only to delete a very few number of data.

5.5.4 Filtering

Prior to inversion, **VLF2DMF** allows the user to **Filter** the data. A three-points moving average filter will be applied to the data (real and imaginary parts will be filtered). This filter averages a number of input values and produces a single output value (Figure 5.6).

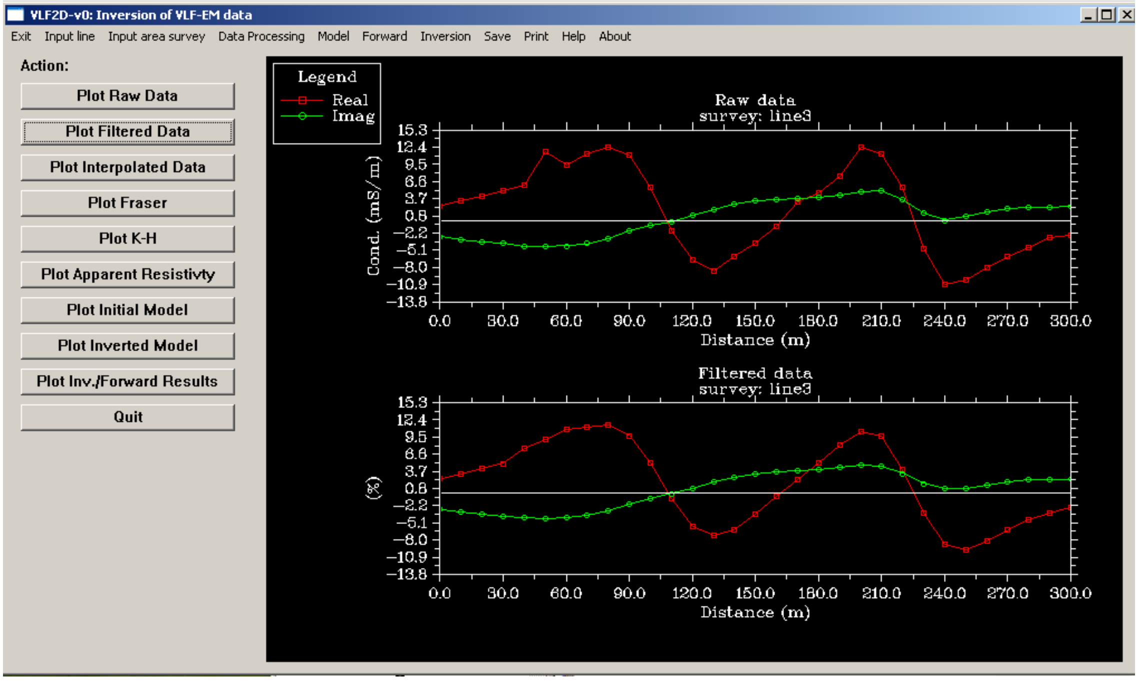


Figure 5.6. VLF data prior to and post-filtering, using the **Running Average** filter.

There is also the option to apply the Empirical Mode Decomposition technique. Please, refer APPENDICE D.

5.5.5 Interpolation

The data can be interpolated using a linear approximation. The interpolation factor-n represents the number of sites that will be "created" between two contiguous sites of the original data (Figure 5.7). The interpolated data will have N + n (N-1) sites, where N is the number of sites in the original data.

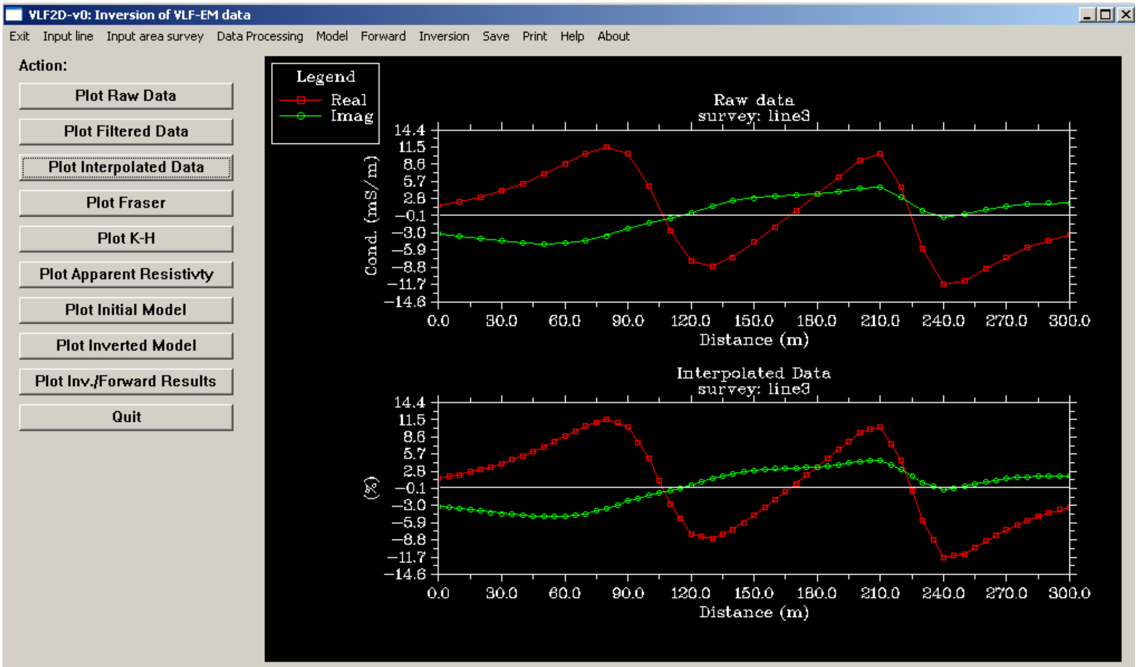


Figure 5.7. Data prior to and post-interpolation using $n = 1$.

5.5.6 Decimation

Decimation may be required to allow a user to account for a high sampling rate or redundancy in the data. The user will be asked about the decimation factor, which represents the number of samples that will be skipped. Figure 5.8 shows an example of VLF data prior to and post-Decimation and using a Decimation factor of 2.

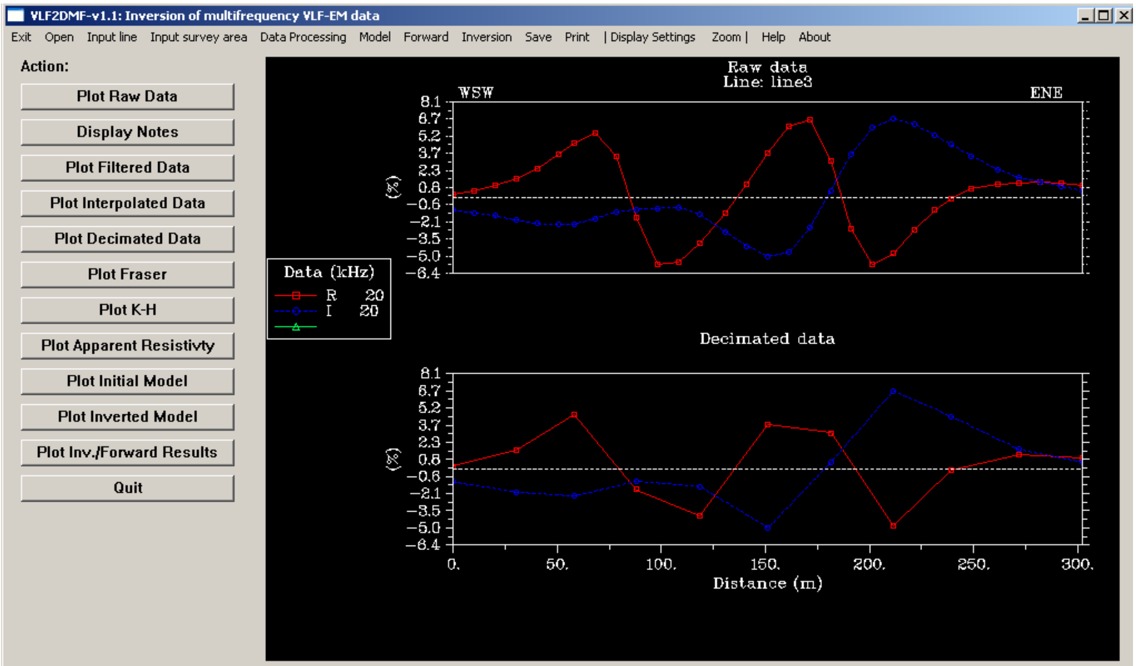


Figure 5.8. Data prior to and post-decimation using $n = 2$.

5.5.7 Fraser filter

Fraser filter can be applied to raw, filtered or interpolated data according selection (Figure 5.9). This filter intends to localize the conductive bodies that can be found beneath the apex of the real part of the filter output.

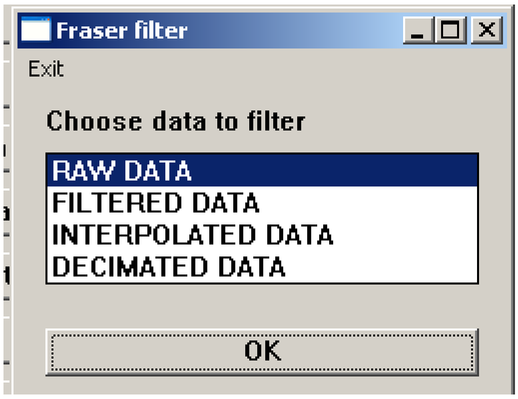


Figure 5.9. Selecting data to apply Fraser filter.

Figure 5.10 shows the result of the Fraser filter applied to the data shown in Figure 5.3. As can be noted, the apexes of the real part of the filtered data are located approximately at x = 360 m and x = 880 m. These values can be considered as good for the bodies location, taking into account the sites are 50 m apart.

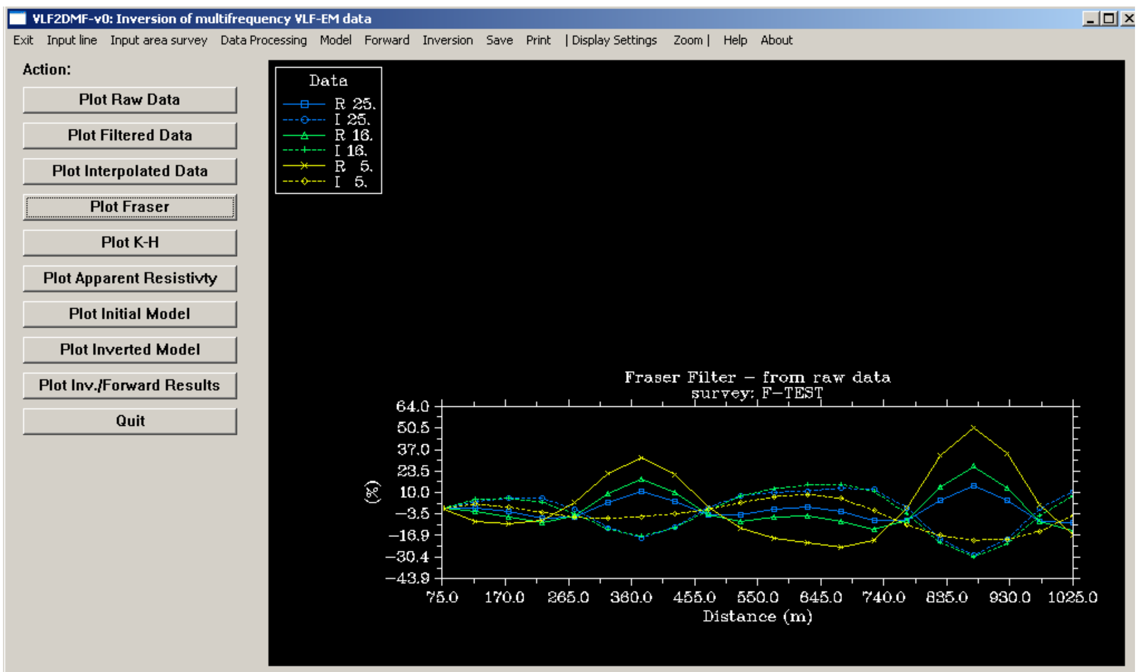


Figure 5.10. Output of the Fraser filter applied to the data shown in Figure 5.3.

5.5.8 Karous-Hjelt filter

Karous-Hjelt (K-H) filter are usually applied in order to obtain a section of current density. The high values are in general associated with conductive structures.

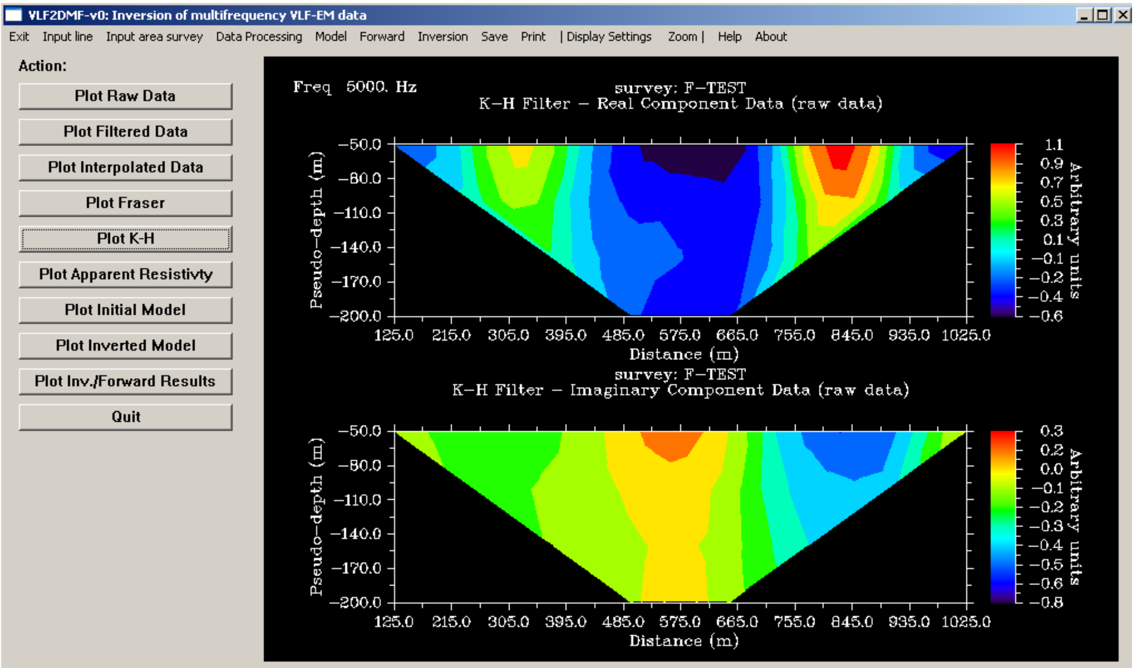


Figure 5.11. Pseudo-sections resulting of the K-H filter applied to the 5 kHz data of Figure 5.3.

Figure 5.11 shows the K-H sections (real and imaginary) obtained from the raw data shown in Figure 5.3 for the frequency of 5000 Hz. The location of the bodies is well marked by positive values, in the section corresponding to the real component.

5.5.9 Apparent resistivity filter

An apparent resistivity profile can be calculated if the mean environmental resistivity is known at the beginning of the VLF profile (see, e.g., Chouteau et al. 1996). Figures 5.12 and 5.13 show the results from the application of the filter to the interpolated data shown in Figure 5.3 assuming two different environmental resistivity values: 1000 ohm-m and 300 ohm-m. The location of the bodies is quite well resolved using the correct value of the environmental resistivity. This also indicates that the resistivity used to build the initial model used in inversions is crucial to obtain realistic results.

NOTE: Chouteau et al. approach assumes that the component Hz of the secondary field is positive upwards.

NOTE: It is a good practice to have information about the environmental resistivity of a survey area using for example, Schlumberger soundings or dipole-dipole lines.

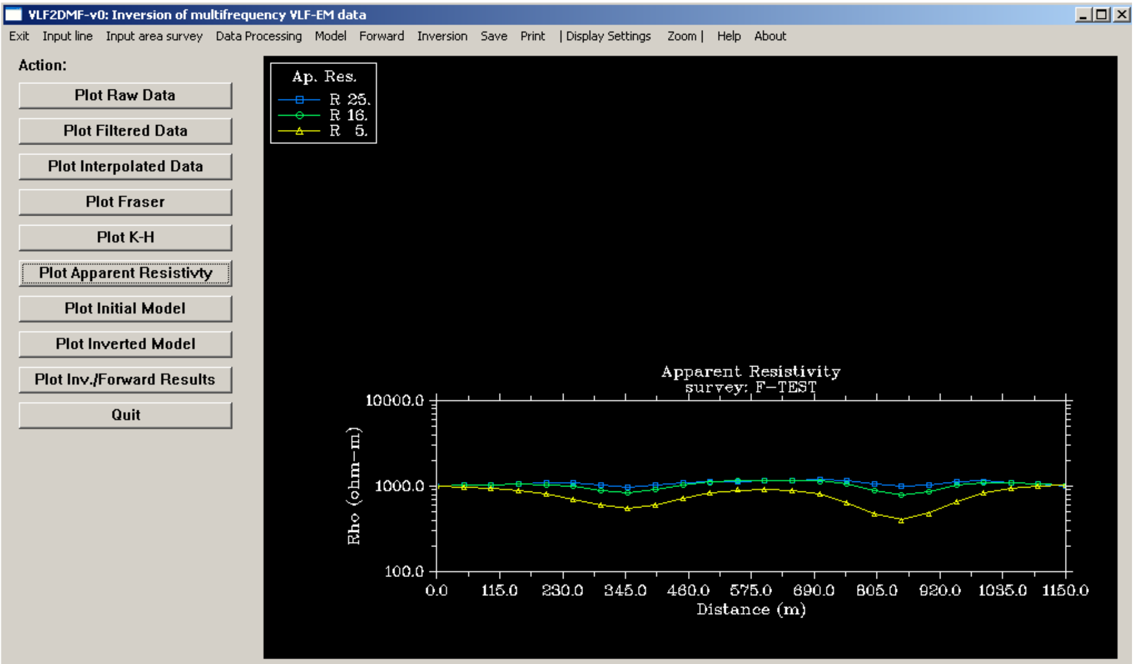


Figure 5.12. Apparent resistivity curve calculated from data in Figure 5.3, assuming a 1000 ohm-m environment.

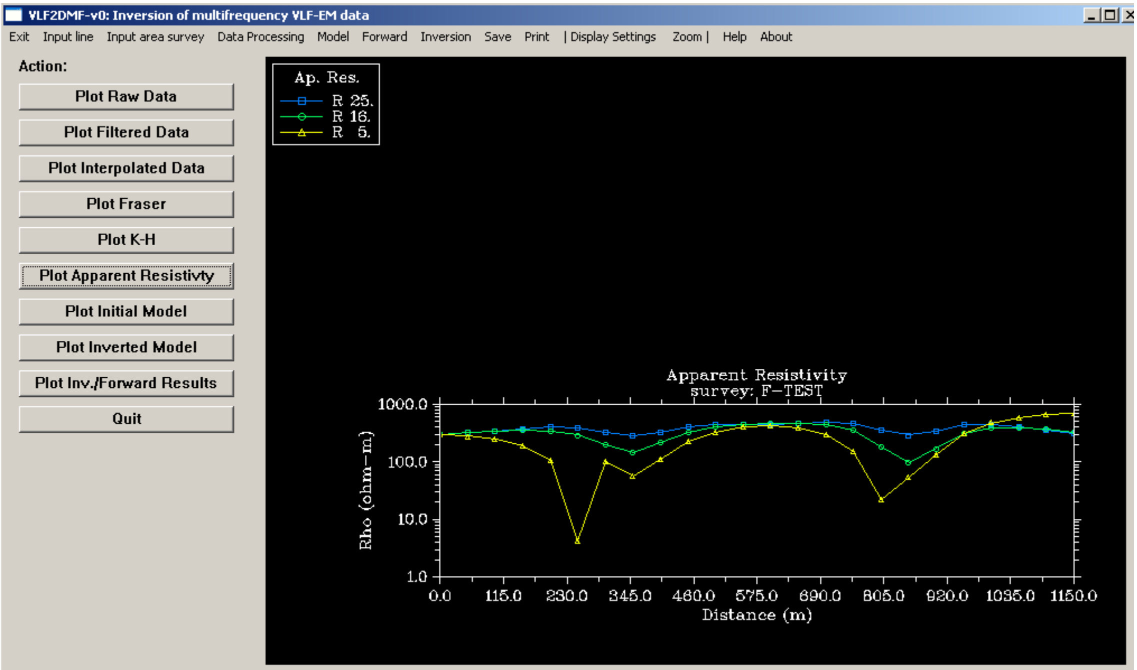


Figure 5.13. Apparent resistivity curve calculated assuming a 300 ohm-m environment..

5.6 Model

The Model menu allows you to construct (or input) a model for forward calculation, to build (or input) an initial model for inversion, or to modify an existing model. Figure 5.14 shows the menu with the different options.

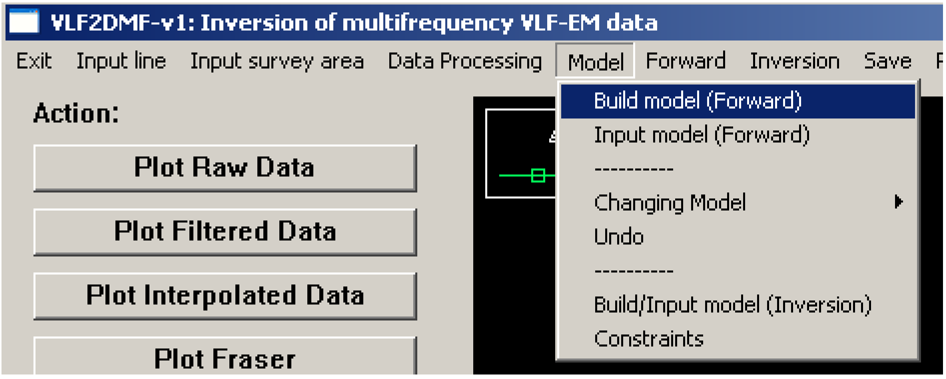


Figure 5.14. Drop down box menu for **Model** selection.

5.6.1 Building a model for forward calculations

Clicking in this option, the following menu that allows the setup of the model will open (Figure 5.15).

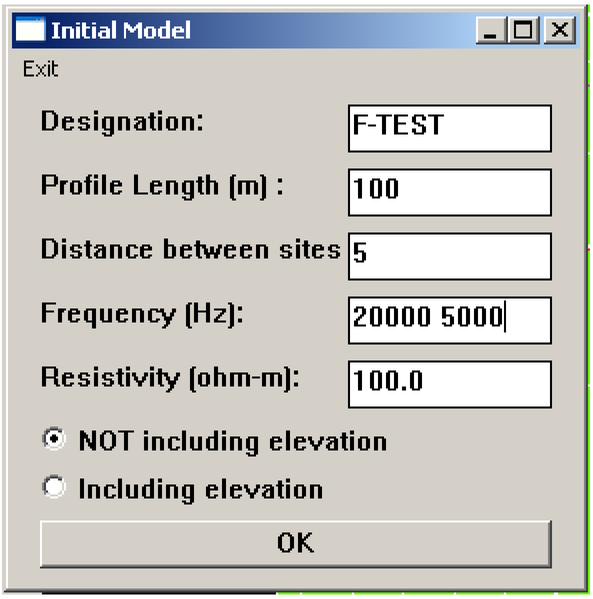


Figure 5.15. Setup of a model for forward calculations.

The frequencies are separated by space. By default the topography (elevation) is not included in the model. However, it can be considered, importing a file with the appropriated values (see Format section).

The model can be viewed by clicking in the "Plot Initial Model" action button. Figure 5.16 shows a possible initial model. The red and magenta lines represent the skin depth considering the highest and lowest frequencies and the environmental resistivity. The vertical and horizontal white lines make a mesh of rectangular blocks (cells) that can be used to build structures of different resistivity, simulating geological structures. The user can then calculate the response of such "conceptual" earth.

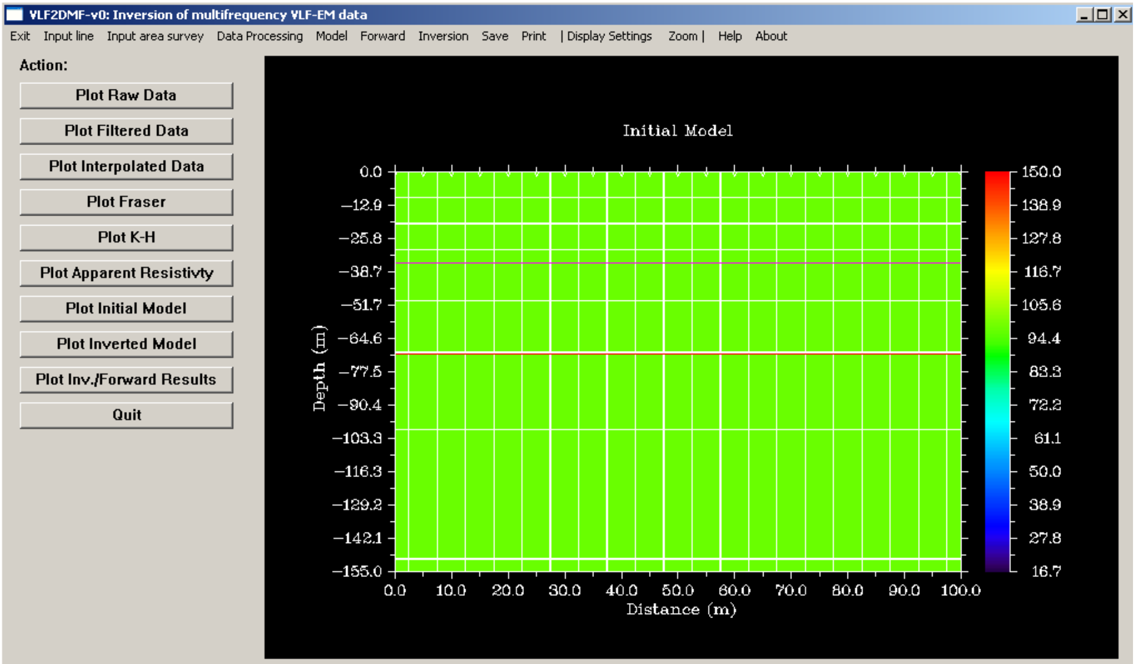


Figure 5.16. Displaying the initial model.

There is also the possibility to input an existent 2D model previously saved with the option "save initial model" in the Save menu. These files do not have any predefined extension. Use the option "Input model (Forward)".

NOTE: In the models (inversion or forward), the elevation is always referred to its minimum value. However, the correct elevation (altitude) will be displayed in the figures of the final model.

5.6.2 Changing model

Any initial model can be changed. It is allowed to change the resistivity of blocks and the number of blocks adding new rows and columns to the model (Figure 5.17).

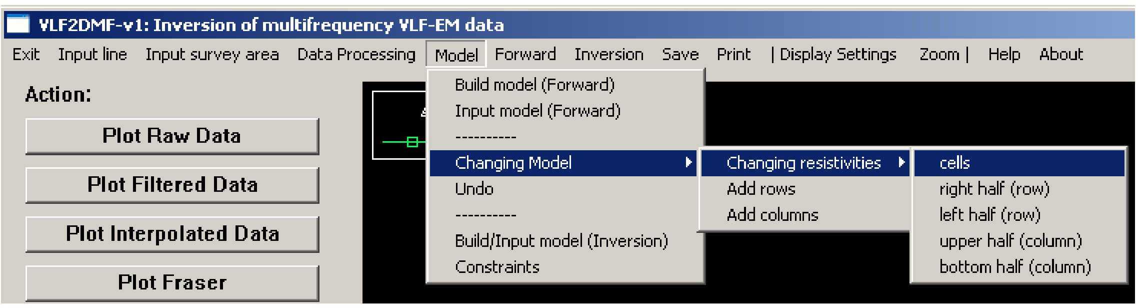


Figure 5.17. Menu for changing the model.

Clicking in “Changing resistivities” a new menu open with several options that allows you to change the resistivity value of individual cells; change the resistivity of a group of cells in the same row and localized on right or left of a selected cell or the resistivity of the cells localized in a column upper or down of a selected sell. Selecting one option will open a menu and answering yes, the mouse cursor will change to a cross (+). Select the cells you want to have the same resistivity, clicking with the left mouse button. Stop the selection by clicking with the right button. Type the wanted resistivity. The process can continue or not. Use the action button (plot initial model) to see the new model.

A similar procedure is used to add row or columns to the model.

NOTE: When adding columns or rows do not cut a block (cell) more than once. If you want to have a fine mesh, repeat the procedure for every cell you want to divide.

NOTE: Accuracy of the calculations depends on the mesh. However, computational effort greatly depends on the number of cells, too. Therefore, do not increase the number of cells unnecessarily. A good balance between accuracy and computational time should be the target.

NOTE: The undo option allows you to reverse the last modification.

Figure 5.17 shows a modified initial model prepared for forward calculations, which result is shown in Figure 5.19.

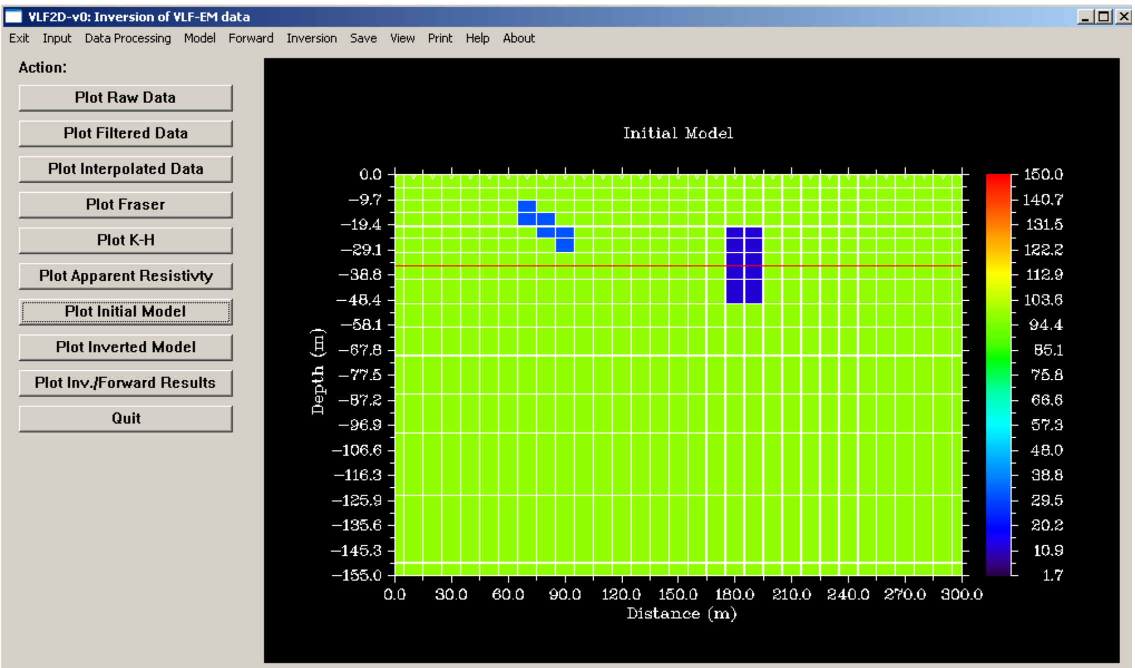


Figure 5.18. Example of a model with two anomalous bodies of 30 ohm-m (on left) and 10 ohm-m (on right) in a 100 ohm-m environment.

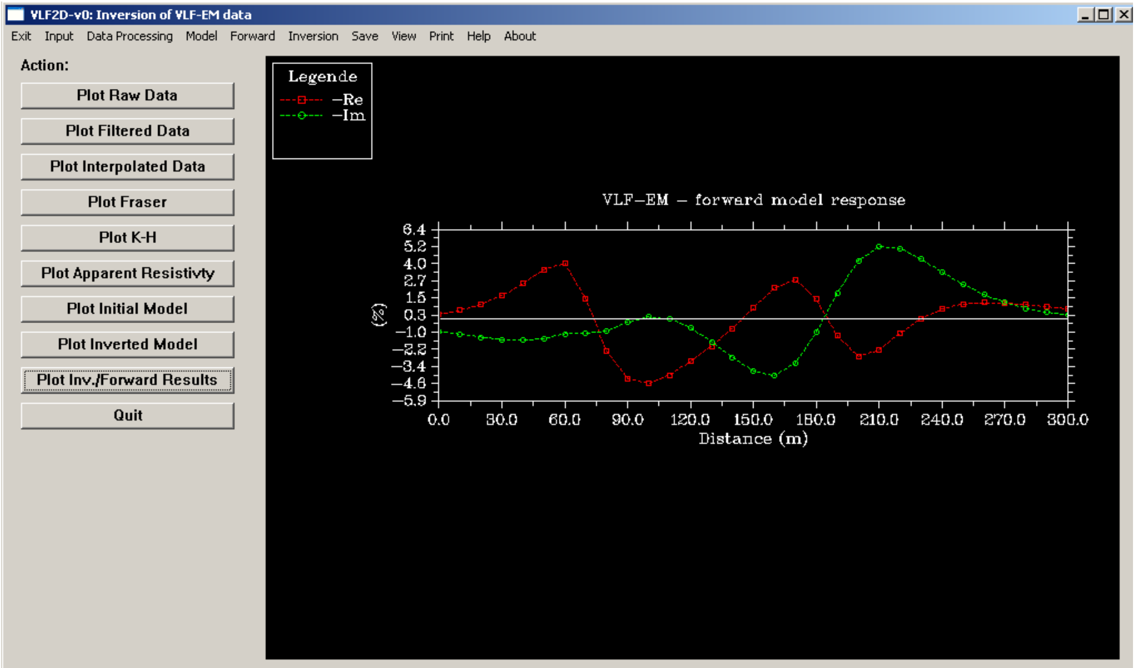


Figure 5.19. Response of the model shown in Figure 5.18.

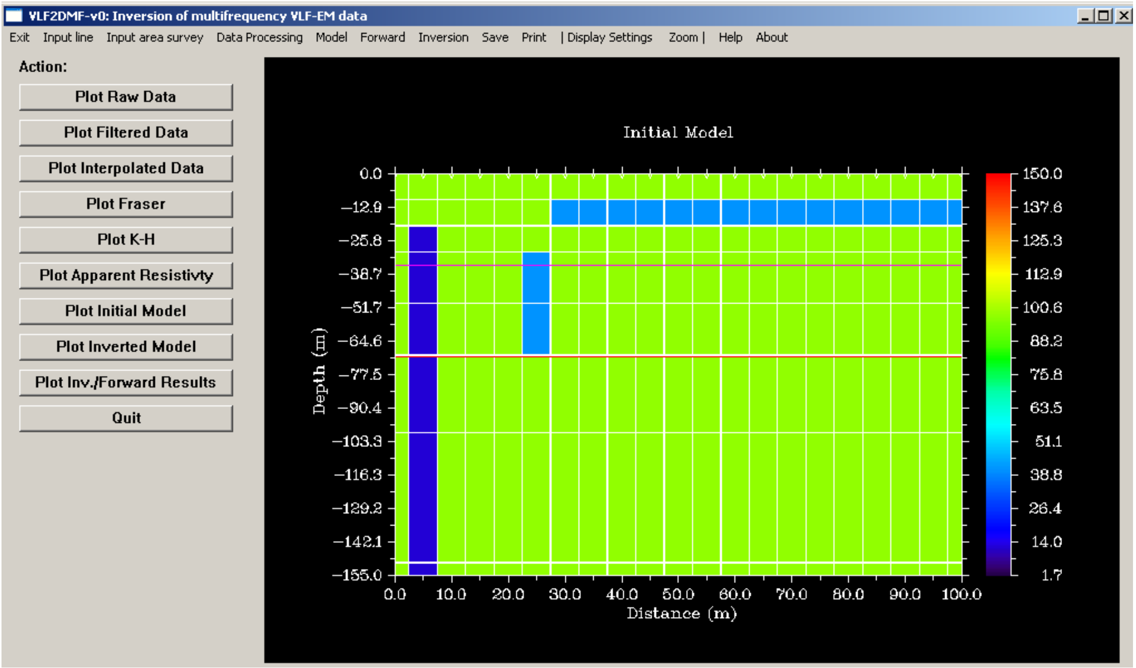


Figure 5.20. Changing the resistivity value of individual cells, right half of a row and bottom half of a column.

5.6.3 Building/Inputting a model for inversion

Clicking in this option will open a new menu (Figure 5.21) from where different options can be selected in order to build an initial model for the inversion. Because we need to choose the data to invert this is the right way to define the initial model for inversion. The menu has three sections: the first one allows different ways to build or read the model; the second is about the data that will be used in the inversion, while the last one is related with the topography. Default options are shown.

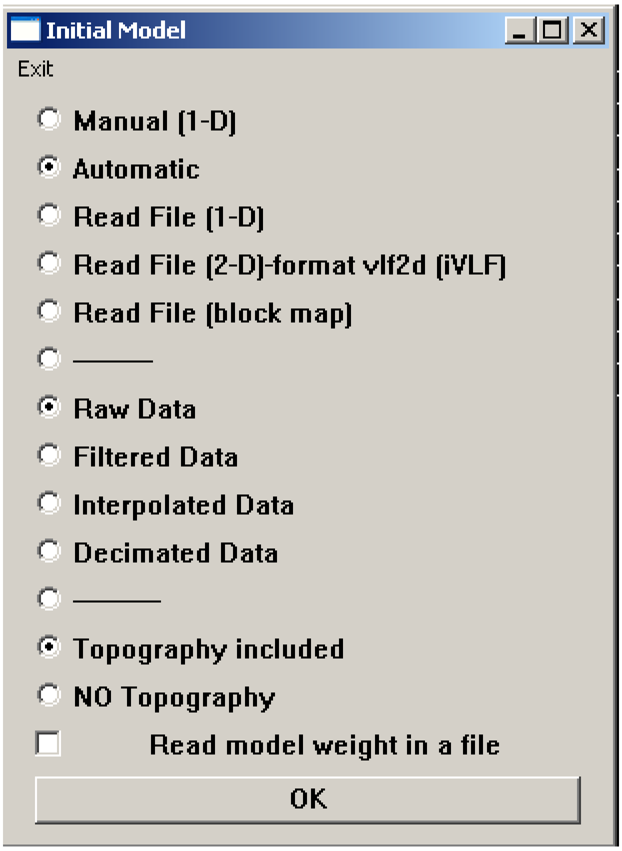


Figure 5.21. Menu for the setup of a model (inversion).

NOTE: This menu only works if you have already inputted the data.

5.6.3.1 Manual (1-D)

With this option the user is asked to input the number of layers of the 1-D model and specify the depth of the bottom of each layer (**not thickness**) and its resistivity, filling a table (Figure 5.22).

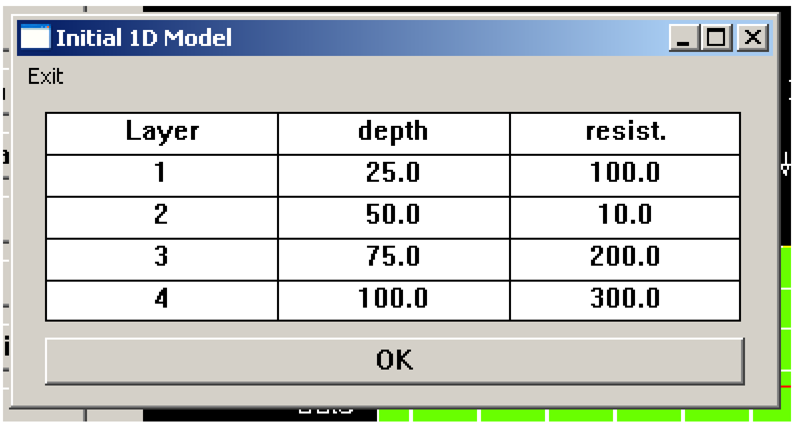


Figure 5.22. Inputting 1D model manually.

The initial model can be displayed clicking on the corresponding action button. Figure 5.23 shows an example of the initial model corresponding to the parameters shown in Figure 5.22 and considering the topography included in the field data. VLF-EM response of a layered model is zero. However, because a non-flat topography exists a non null forward response is obtained (Figure 5.24).

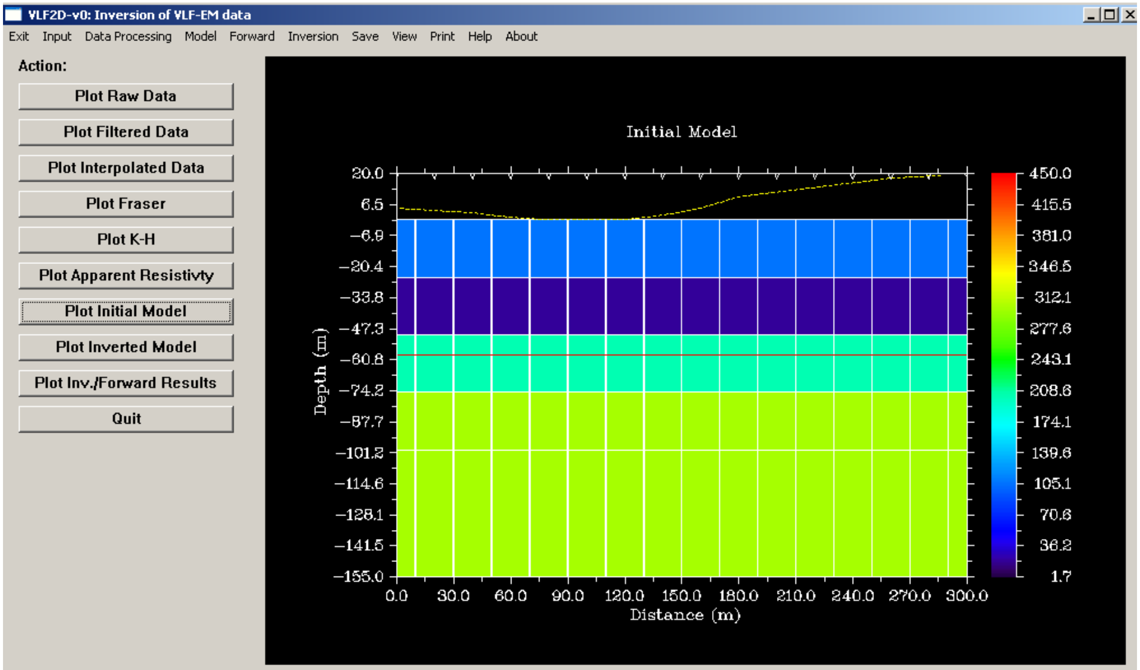


Figure 5.23. 2D model generated from a 1D model.

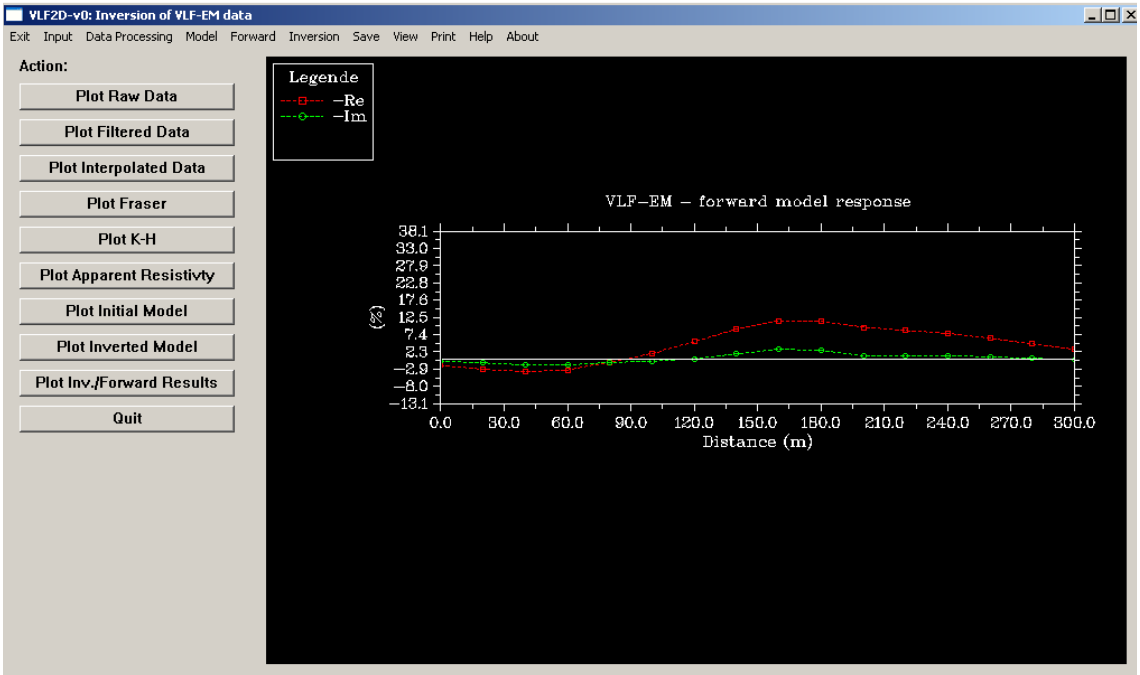


Figure 5.24. Response of the model shown in Figure 5.23.

NOTE: To simplify the display and the changes of the model the topography is displayed over a flat earth (yellow line).

5.6.3.2 Automatic

Selecting this option and inputting the resistivity value allows the program to build a uniform model that will take the selected data and topography into consideration.

5.6.3.3 Open files

The initial model can be read in an existing file. For example, the user can import the result of a previous inversion (VLF2DMF Format[3] only) or from a file defining the model mesh according to the user specifications. Please refer to the format section for this last case.

5.6.3.4 File with model weights

The cells in the inversion model are weighted (vertical levels). By default the deepest cells have higher weights than the superficial ones. These weights can be changed inputting new values in a file (*.MWG). The format of the file is:

N [number of levels]
W1 [weight of each level starting from the top]
W2
…
WN

The default values are:

8
0.8
0.84
0.89
0.93
0.97
1.02
1.07
1.14

5.6.4 Constraints

This entrance allows the user to select some blocks (cells) which resistivity will be kept constant during the inversion. The cells are selected using the left mouse button. Finish the selection clicking with the right mouse button. After that, give the resistivity you want to assign to those cells. The procedure must be repeated for all the cells you want to constraint, before to leave this option.

[3] These files should be saved with the extension iVLF

5.7. Forward calculations

After a model has been built and properly modified, click in this option to calculate its response, which can be displayed in the screen using the **Plot Inv/Forward Results** button in the action section.

5.8. Inversion

After processing, the data is ready for inversion. Selecting the **Inversion** option, the program will allow you to define some inversion parameters and to start the inversion (Figure 5.25).

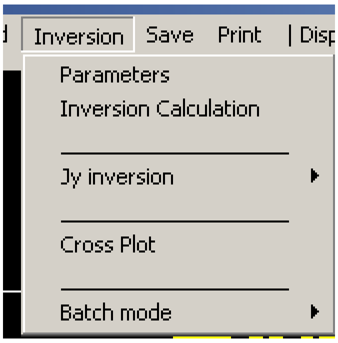


Figure 5.25. Drop down box menu for **Inversion** selection. From this main menu you can select to perform the inversion. The parameters for the inversion are chosen from this menu, too.

Selecting the **Parameters** option, the program will display the following menu, which allows you to define some of the inversion parameters (Figure 5.26).

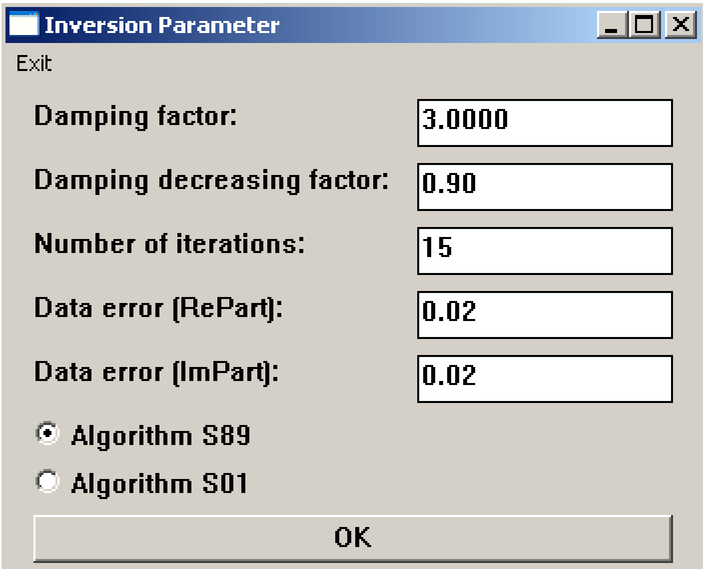


Figure 5.26. Input of parameters for the inversion (the displayed values are default values).

The damping factor (DF) controls the roughness of the model (see the appendices for details). The higher the damping selected, smoother the model will be. The correct value should be determined empirically, performing inversions with different damping values (e.g. from 1.00 to 10). In general, for high resistivity environments (1000 ohm-m) the DF should be lower and more iterations are necessary (25-30). The DF is not kept constant during iterations. The damping decreasing factor controls the decreasing of the DF, and this has influence in the convergence. In general its value is within the range 0.7 to 0.9.

The program allows the use of two different inversion algorithms named here as S89 and S01 just because they are based on the work published by Sasaki in 1989 and 2001 (see appendices for details). In general, S01 algorithm produces smoother models when compared with those from S89.

After select the parameters click in the **Inversion Calculation** to start the inversion program.

NOTE: Raw data will be used in the inversion (by default) considering the elevation values in the data. If you want to invert other than raw data (e.g., the already filtered or interpolated data) or not including the elevation values, you must build an initial model selecting the appropriated data.

NOTE: During the inversion (which can take a significant time depending on the number of sites and mesh used) the program will not process any instructions.

NOTE: You can follow the inversion steps in the DOS windows opened when VLF2DMF starts (Figure 5.27).

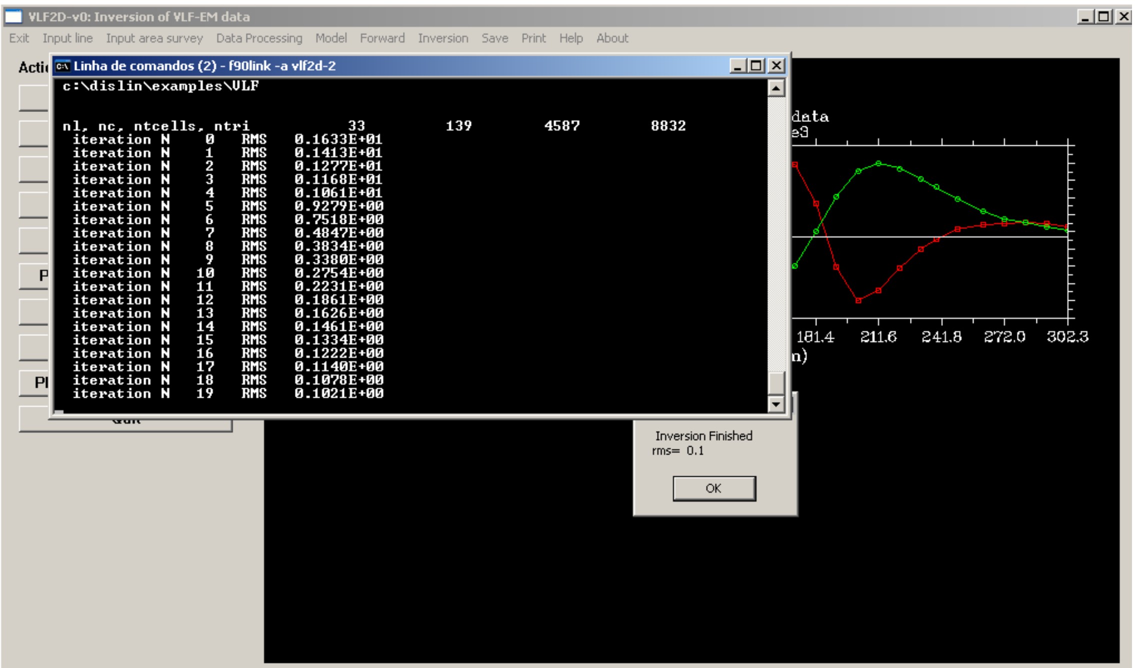


Figure 5.27. Following the inversion process.

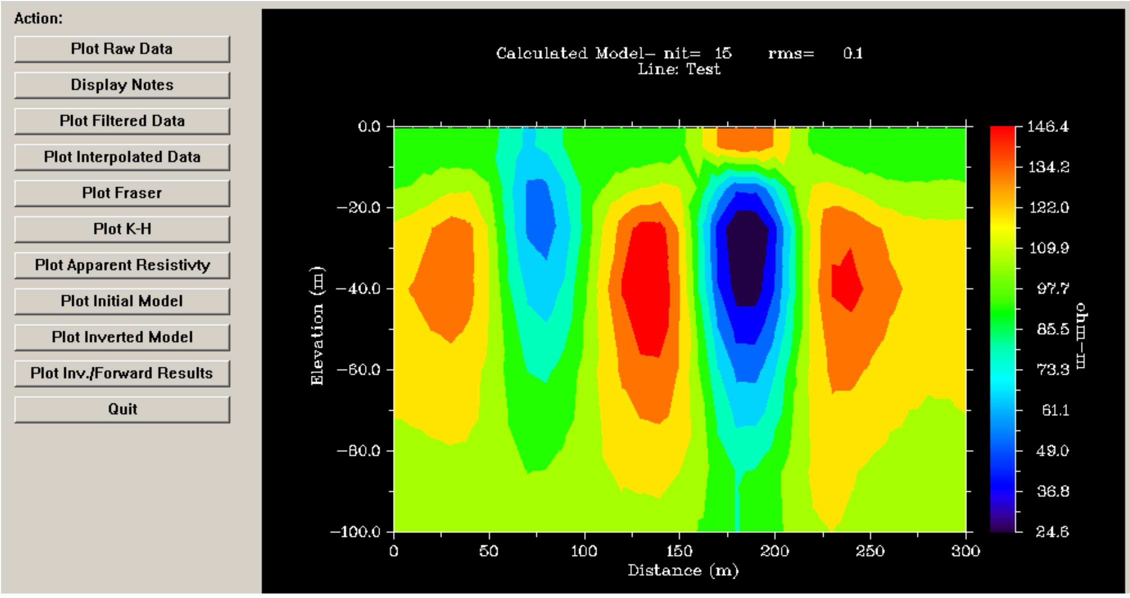


Figure 5.28. Model obtained by inversion of one frequency data, assuming a 100 ohm-m uniform initial model. Lambda = 1.000 and algorithm S01 (15 iterations).

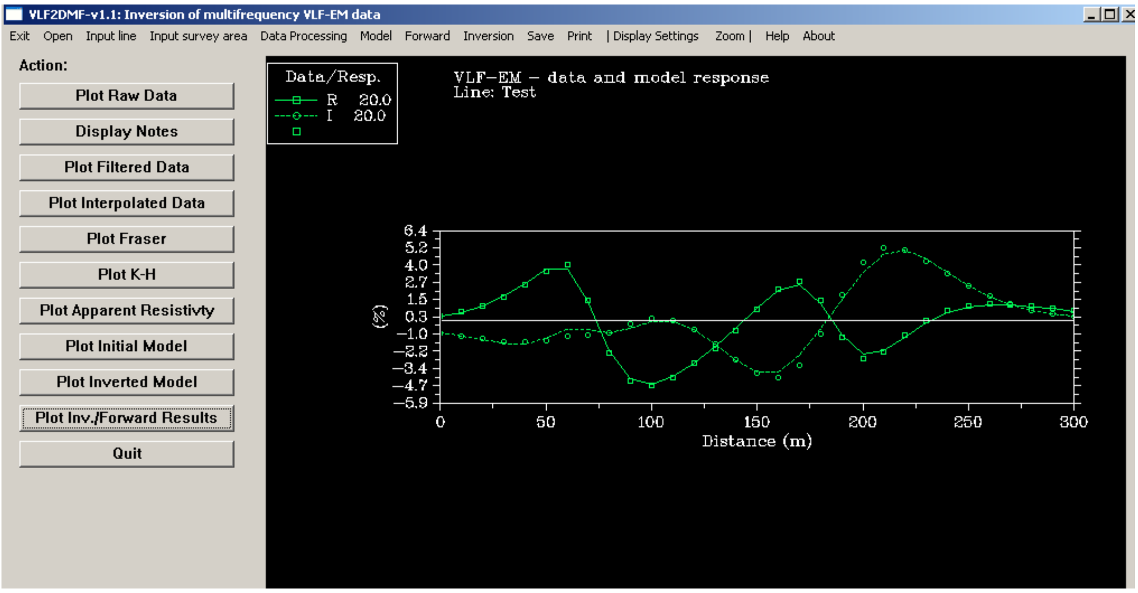


Figure 5.29. Response of the model shown in Figure 5.28.

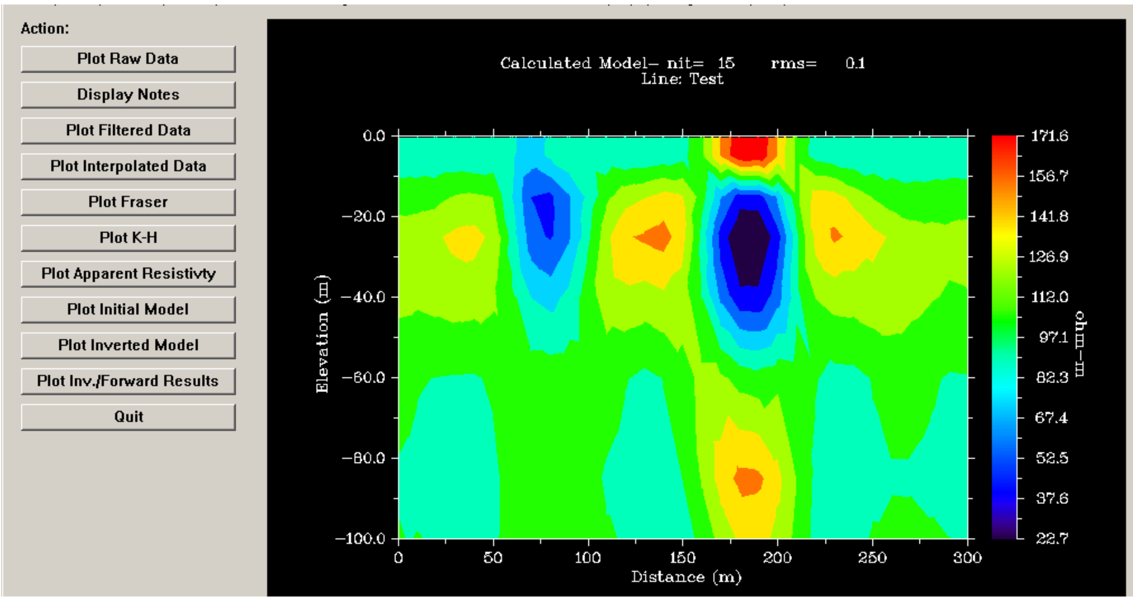
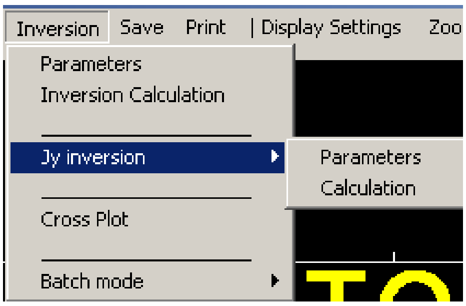


Figure 5.30. Model obtained by inversion of the same data, assuming a 100 ohm-m uniform initial model. Lambda = 3.00, 15 iterations and algorithm S89.

A file *.INV is saved (in the folder …\inverse) during the inversion. These files can be imported using the option **Inversion results** in the **Open** entrance.

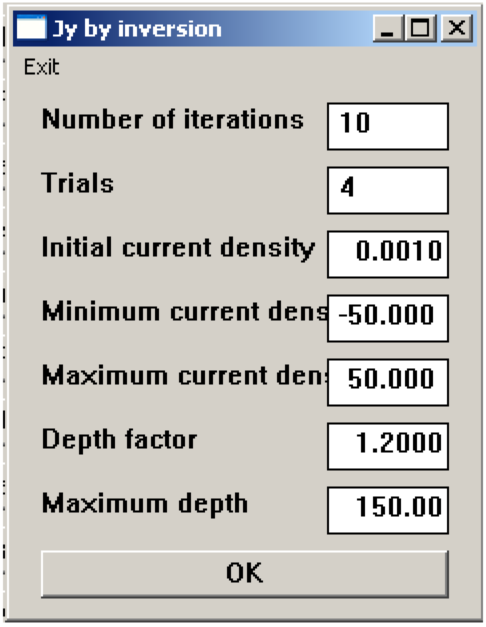
The interpretation of the VLF data is also possible in terms of the current density (Pedersen and Becken 2005, Singh and Sharma 2016) using the entrance **Jy inversion**.



The first step is to define some parameters for the calculation:

- The number of iterations and trials. The calculation of the distribution of the current density is made using a conjugate gradient algorithm. Therefore, it is necessary to define a number limit of iterations for both cycles in the algorithm;
- initial value of the current density and its superior and inferior limits;
- the depth factor is a weight that controls the importance of the contribution of the deep parts of the model. Increasing the value of this parameter makes the anomalies deeper.

After the parameter definition the calculations can be performed.


Jy by inversion
Exit
Number of iterations
10
Trials
4
Initial current density
0.0010
Minimum current dens
-50.000
Maximum current den
50.000
Depth factor
1.2000
Maximum depth
150.00
OK

The **Batch mode** allows you to define a batch for inversion of several lines automatically.

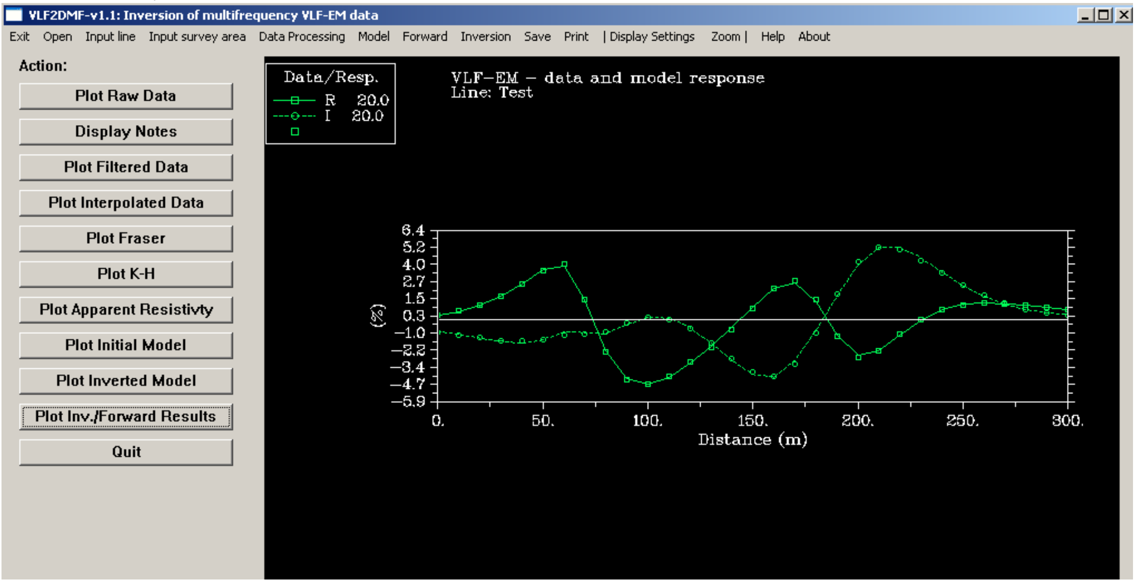
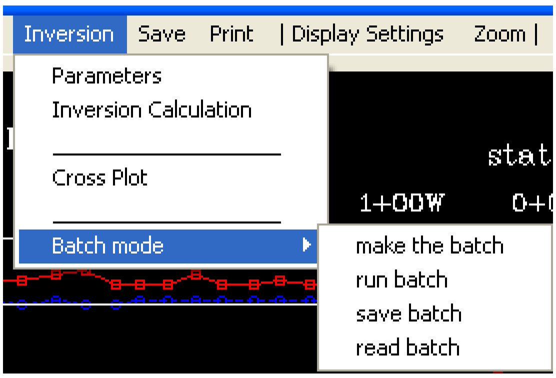
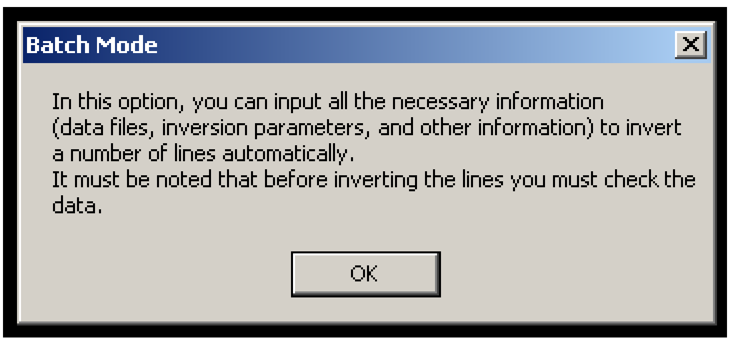


Figure 5.31. Response of the model shown in Figure 5.29.

There are four options in the batch mode: 1) make a batch, 2) run a batch, 3) save a batch and 4) read a batch.



You can introduce all the necessary information clicking in “make the batch”,



All the data files you want to invert should be imported (one by one) after you press OK. Finish clicking in the Cancel button. A table contained the selected files and the default parameters will be displayed (Figure 5.32).

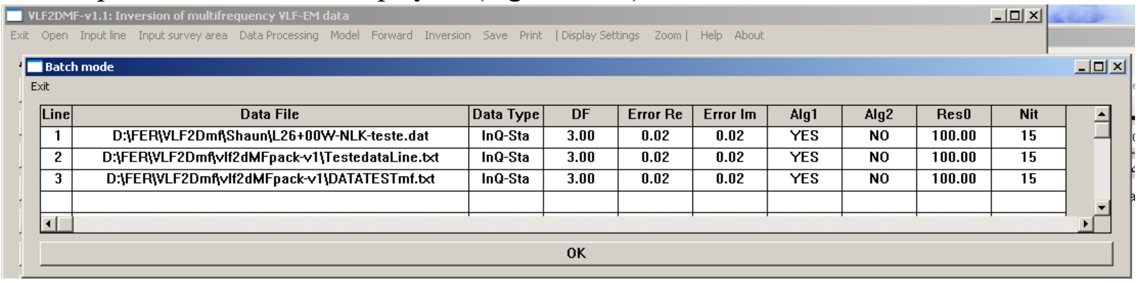


Figure 5.32. Making a batch file.

You must modify the wrong or not correct information before push the OK. The program will do a basic check of your data and it will mark the file where problems have been found (Figure 5.33).

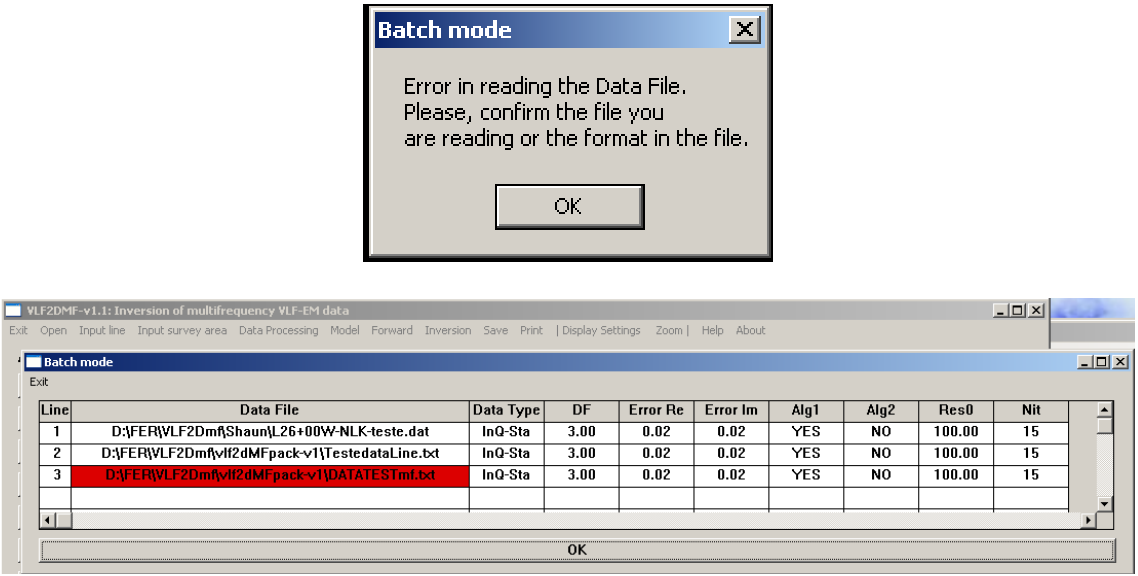


Figure 5.33. Checking the batch file.

In this case the Data type of the third file is InQ not InQ-Sta. After correct this mistake the program will check again the information. If every thing is well the batch can be run.

NOTE: The codes for data type are: InQ-Sta for In-phase and Quadrature (Sta) data format; InQ for In-Pha and Quadrature data format; TE for tilt and ellipticity data format.

NOTE: The Batch mode can not be used with T-VLF, WADI or GEM19 files. Save the data corresponding to each line separately as raw data. This saved file can be used without any problem.

NOTE: The check made by the program is very basic so the user should verify all the files before start a batching process.

NOTE: If he user want to invert a processed data (filtered, etc) should be prepare an input file of processed data in the same format of raw data.

A table with a resume of the inversion results will be presented (Figure 5.34) after running the batch. The results of each inversion are saved in the respective *.INV files which were saved in the folder ..\inverse and can be recovered using the **Open** (**Inversion results**) entrance in the main menubar.

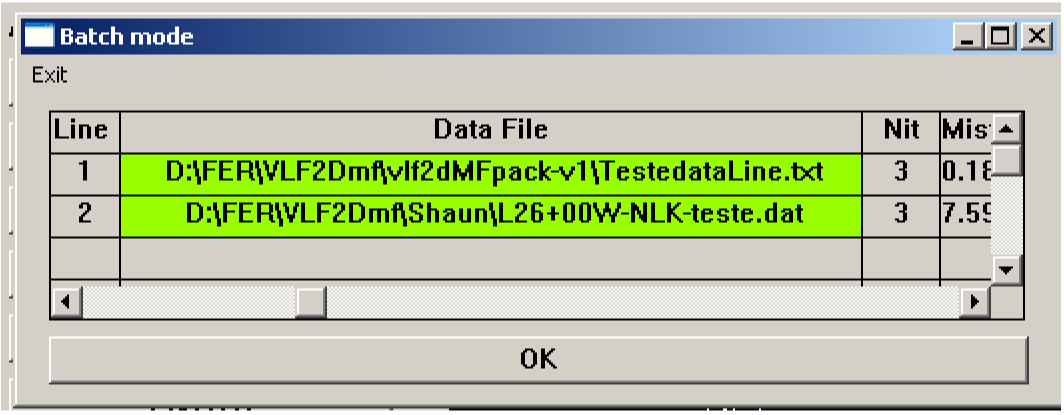


Figure 5.34. After running the batch.

The batch file should be saved with the extension BATm to avoid misunderstandings with other type files. These files can be read (**read batch**) and run. See the format section about the batch file format.

5.9. Save and Print

Save and Print menus will allow you to save files and to print figures of your data, processing and inversion results (Figure 5.35).
Initial models used in forward calculations can be saved and read later. The same for models obtained from inversion. In this case, they can be saved in two different format: 1) the XYZ one, that can be used in any graphical program or as input in **VLF2DMF-Map module** (see further, in this manual), and 2) the VLF2D format, which is indicated if you intent to input the model later in **VLF2DMF** program.

The depth of the model in XYZ file is controlled by the skin depth but a different value can be chosen in Display Settings/Set view area/Bottom.

Model response/data saved file can also be used in any graphical program to draw the curves. Responses from forward calculations save with the option "Save Forward Response" can be inputted in **VLF2DMF** for processing and inversion. This can be useful in teaching and theoretical studies.

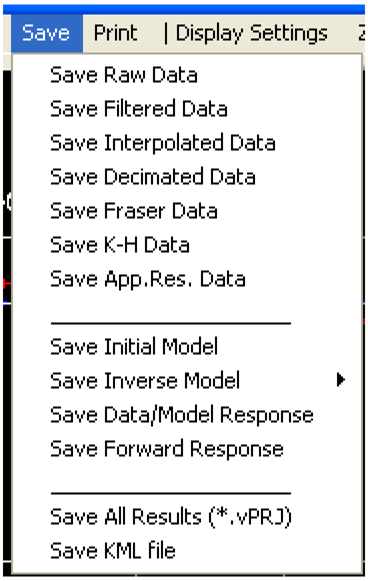
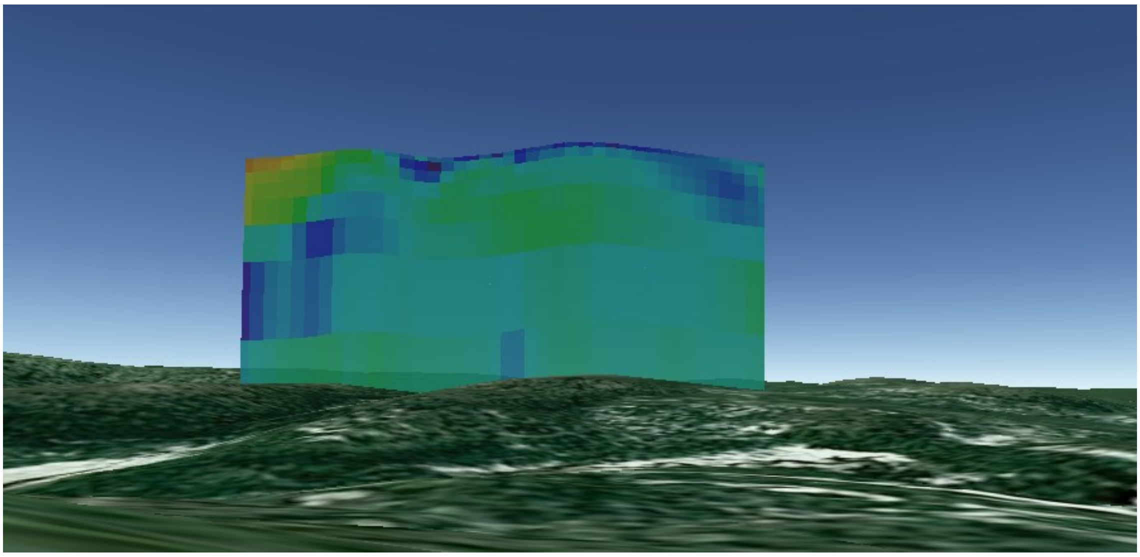


Figure 5.35. Drop down box menu for **Save** selection.

All results obtained can be saved in a project file (vPRJ) for future reading. If the coordinates UTM are used in the data file, a KML file can be constructed to display the model in the Google Earth.



Displaying a model in Google Earth.

When printing figures, you can choose the figure file format using the Metafile format option (Figure 5.36).

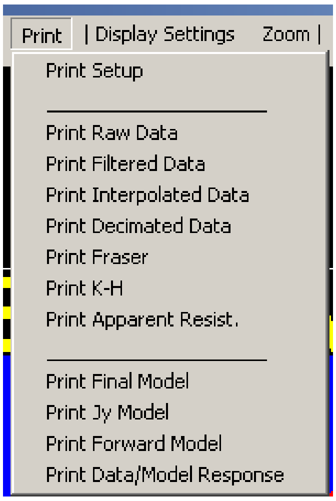


Figure5.36. Drop down box menu for **Print** selection.

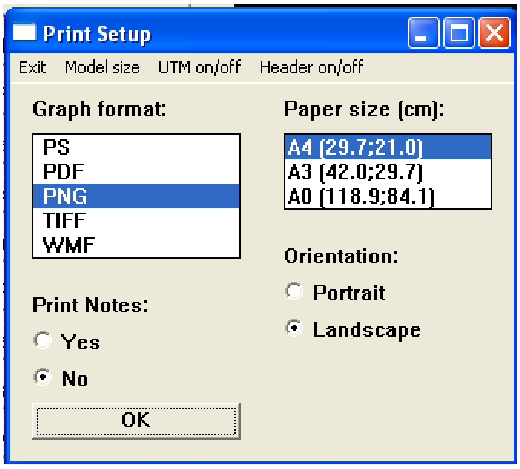


Figure5.36b). The Print Setup menu

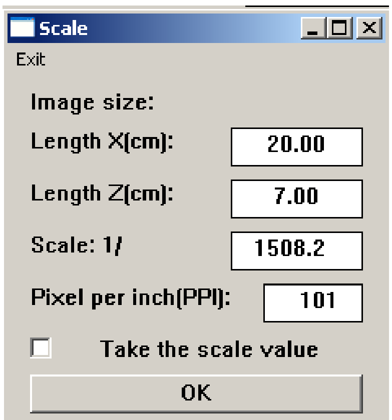


Figure5.36c). The Model size allows to control the size/scale of the printed model. UTM on/off and Header on/off control the print of UTM coordinates and of the header of the figure. These options are only valid for the print figure. The display in the screen is not modified.

NOTE: if the "Take the scale value" is selected the model will be printed according to the scale. Otherwise, the values on X and Z axis will be considered.

5.10. Display Settings/Zoom

This option allows you to choose the type of contour will be used to draw the inverted model: **linear or logarithmic**. The **Set View Area** entrance allows you to define the area of the image of an initial or final model that should be shown (Figure 5.37).

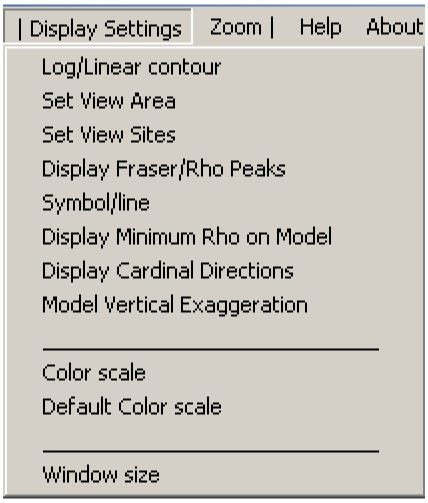


Figure 5.37a). Drop down box menu for **Print** selection.

The user can also control the display of sites and Fraser peaks, Cardinal directions and model vertical exaggeration.

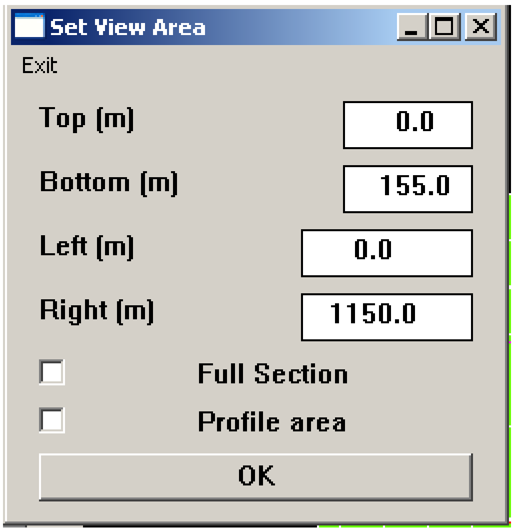


Figure 5.37b). Selection of the viewed area.

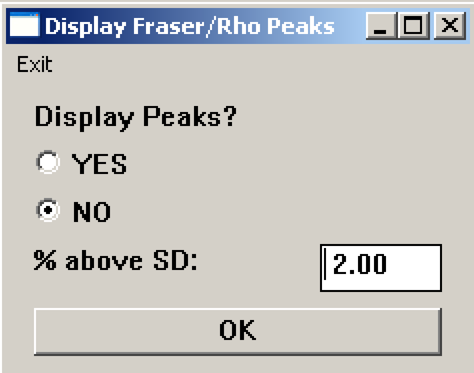


Figure. Option for display Fraser peaks. To be displayed the value of Fraser should > than the chosen % of the standard value of the Fraser values.

The option Window size allows the user to adjust the size of the application window. The defaults size is the normal size (100%). The program should be restarted to validate the option.

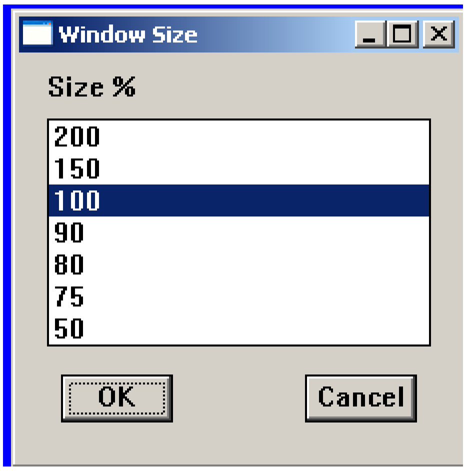


Figure 5.37c). Window sizes.

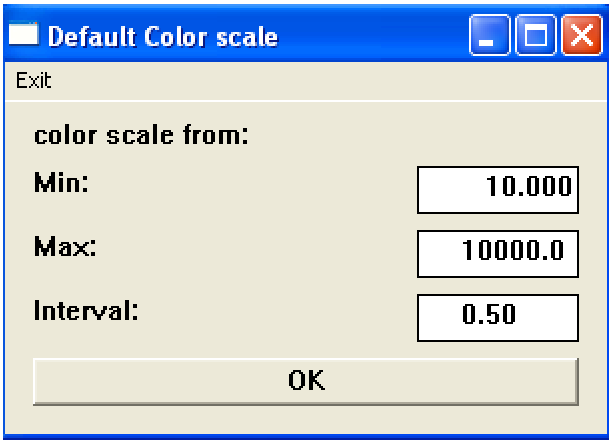


Figure 5.37d). Defining a default color scale.

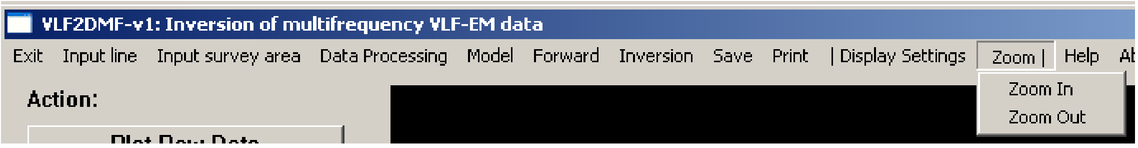


Figure 5.38. Zoom In and Zoom Out.

The Zoom (In and Out) allows you to display selected areas of your initial or final models. The area to zoom in is selected through a rectangle defined clicking in the left mouse button (Figure 5.39).

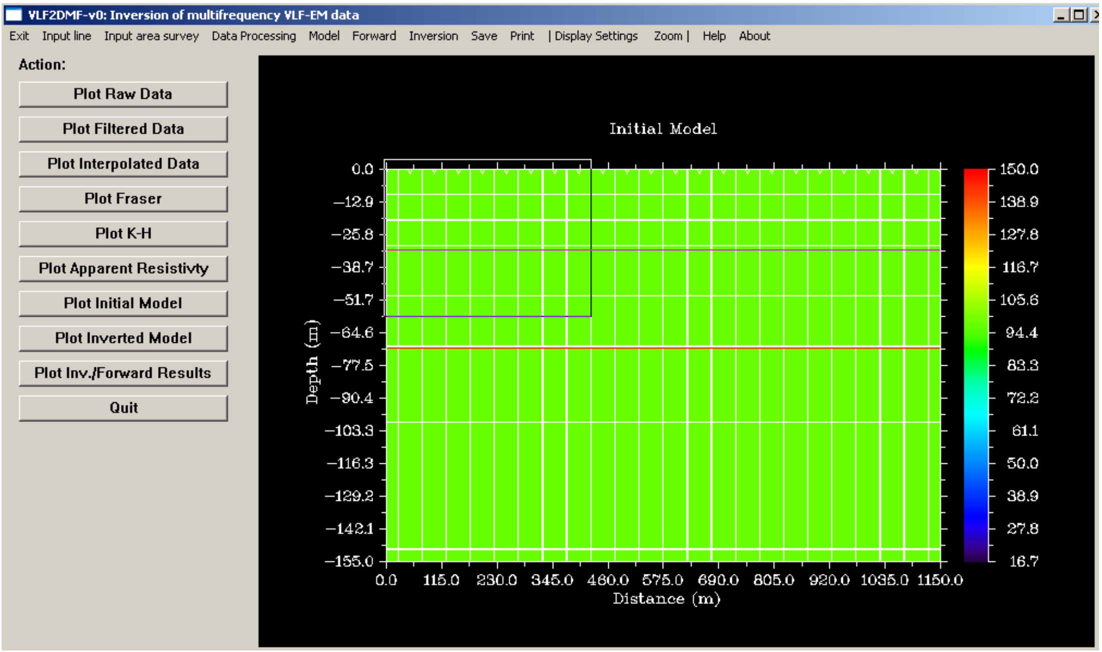


Figure 5.39. Selecting a zone to Zoom In.

5.11. Help

You can read a summary of the main function of the program using the Help menu (Figure 5.40), including a Short Guide on "how to use this program".

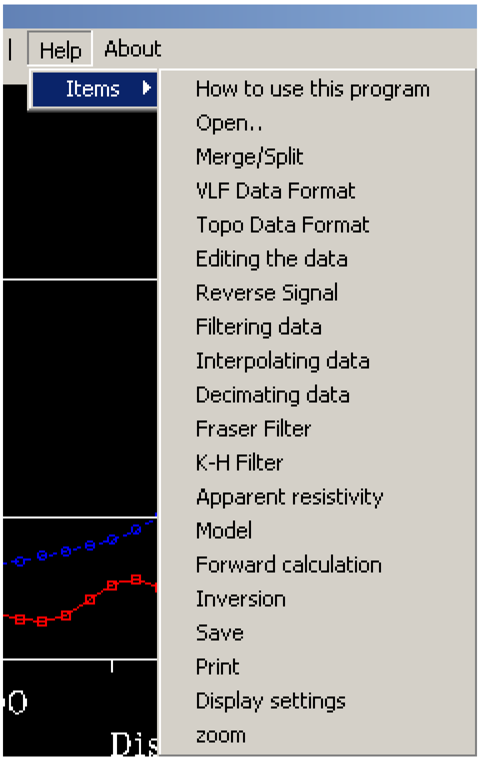


Figure 5.40. Drop down box menu for **Help** selection.

6. The Action/Display zone

Data and results can be displayed on the screen using the buttons available in the Action zone (Figure 6.1). The program will be closed clicking in the Quit button. Closing the program using the Exit option in the Main top bar will delete all temporary files saved during the use of the program. Anyway, these files will be deleted next time you start the program or when you read a new data file.

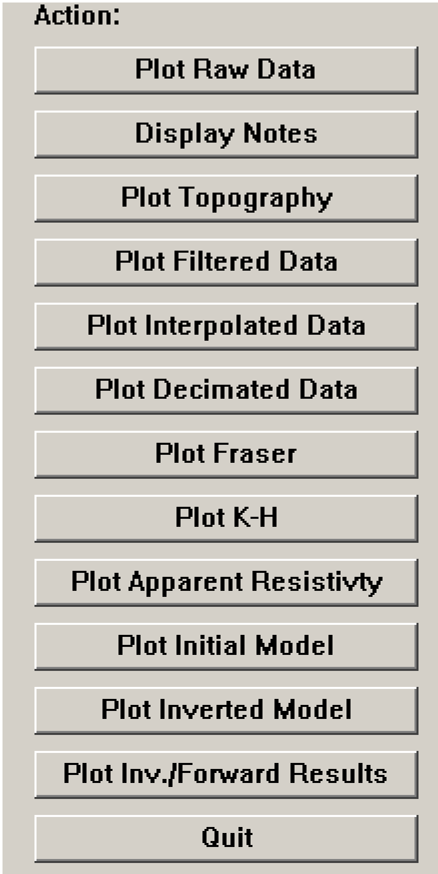


Figure 6.1. The Action Zone menu.

7. The VLF2D-Map module program

If your data are from a survey constituted by several profiles covering an area, you can import them using the "Input area survey" option in the menu (Figure 7.1). The format of the input data file is the same as that for profiles, only including all measured sites. Please, see the Data Format section to read about the format.

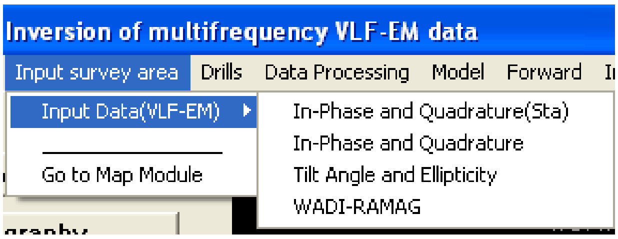


Figure 7.1. Inputting data from a survey.

With this option you will run the **VLF2D-Map module** program which allows you to see your data (as a whole) and to select profiles for inversion. Figure 7.2 shows the screen of the program. The main VLF2D program will be inactive during the use of the Map module. Clicking in Quit you return to VLF2D.

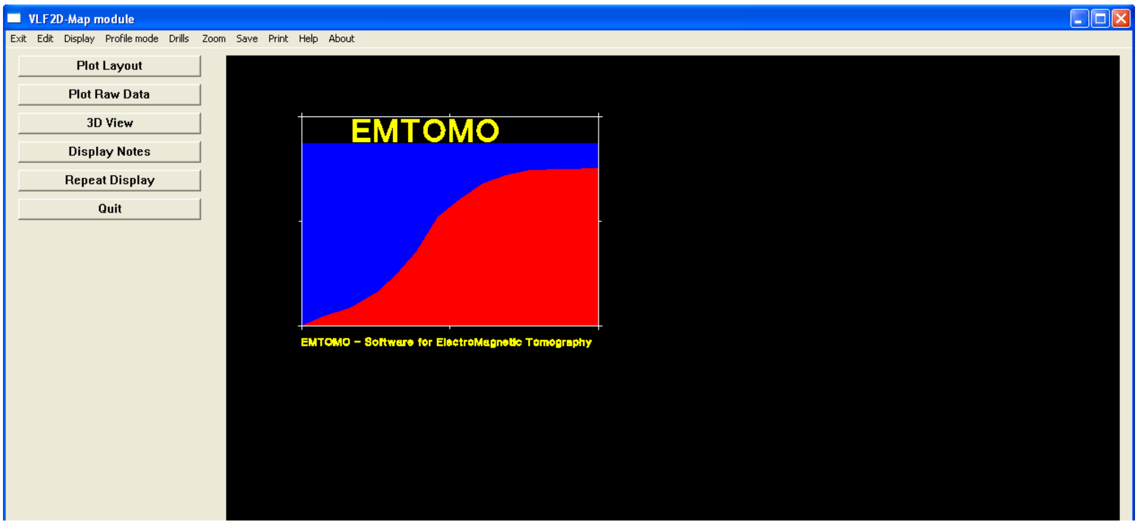


Figure 7.2. The **VLF2D-Map module** screen.

Figure 7.3 shows the menu bar of the Map module program with seven entrances.

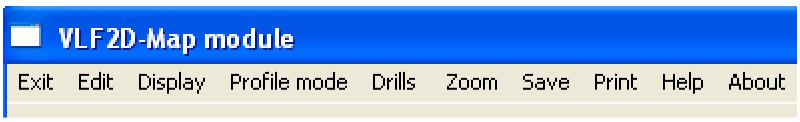


Figure 7.3. The menu bar of **VLF2D-Map module**.

7.1 Display

Click in the Display entrance to see the location of your sites (Survey Layout) and Maps of your data, topography, filtered data (Fraser and Karous-Hjelt) or horizontal slices of your models. In Settings you can choose to display or not your sites on the maps as well the slices of the models (see further in this Manual).

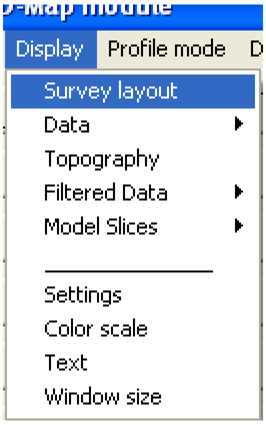


Figure 7.4. Drop down box menu for **Display** selection.

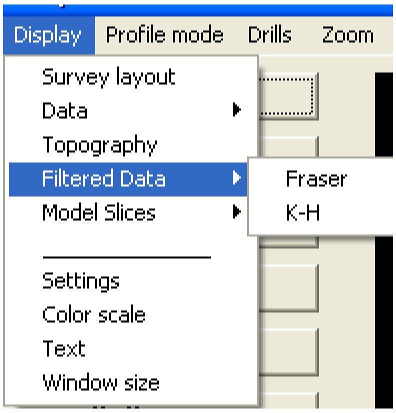
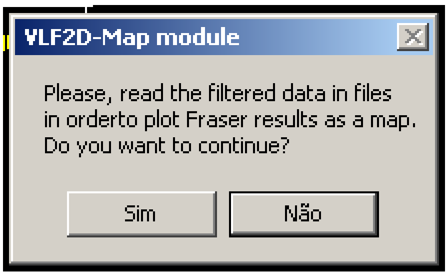


Figure 7.5 shows an example of the display of a survey with three profiles. The first site of the survey is marked in red.

Maps of the filtered data can only be displayed after filtering of the lines of the survey. The application of Fraser or K-H filters is done in the **VLF2DMF** program. That is, if you intend to display maps of the filtered data you must save each filtered line in a file (during the data processing performed in **VLF2DMF**). Therefore, you will be asked to import those files in the **VLF2D-Map module** for displaying.



Figures 7.6 and 7.7 show examples of raw data, Fraser, K-H and models resistivity maps using data acquired with one frequency. If more than one frequency exist the procedure are exactly the same. To move through the different maps (e.g. from real to imaginary Fraser maps) you must click on the right mouse button.

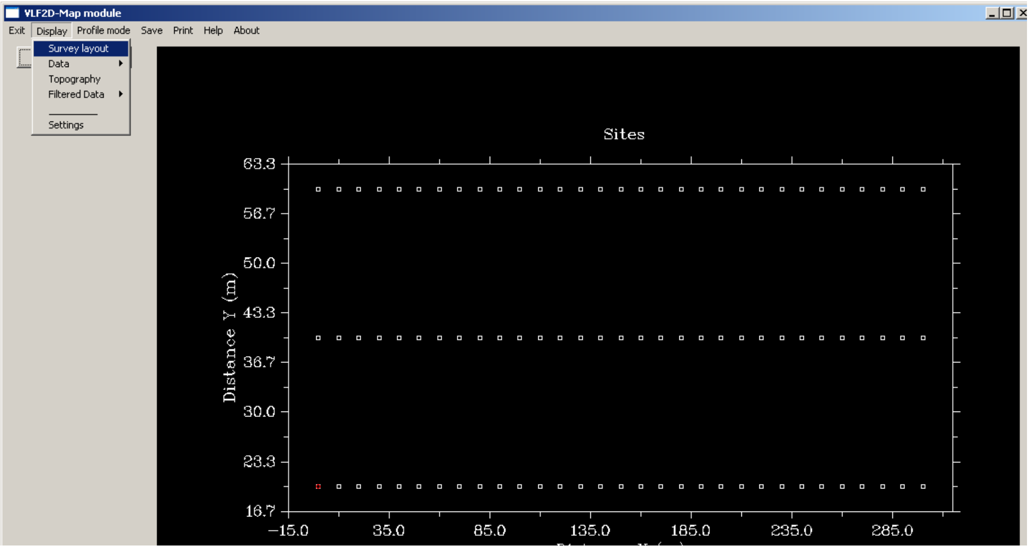


Figure 7.5. Displaying your survey.

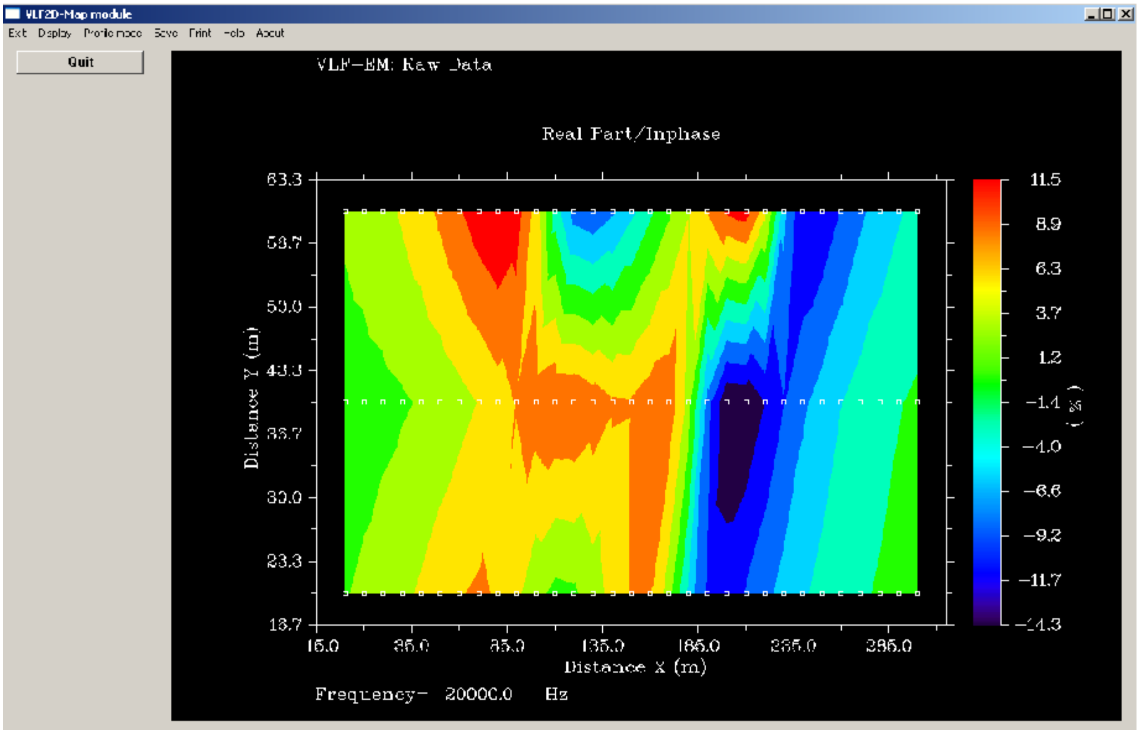


Figure 7.6A. Displaying a map of VLF data-Real part (frequency of 20000 Hz).

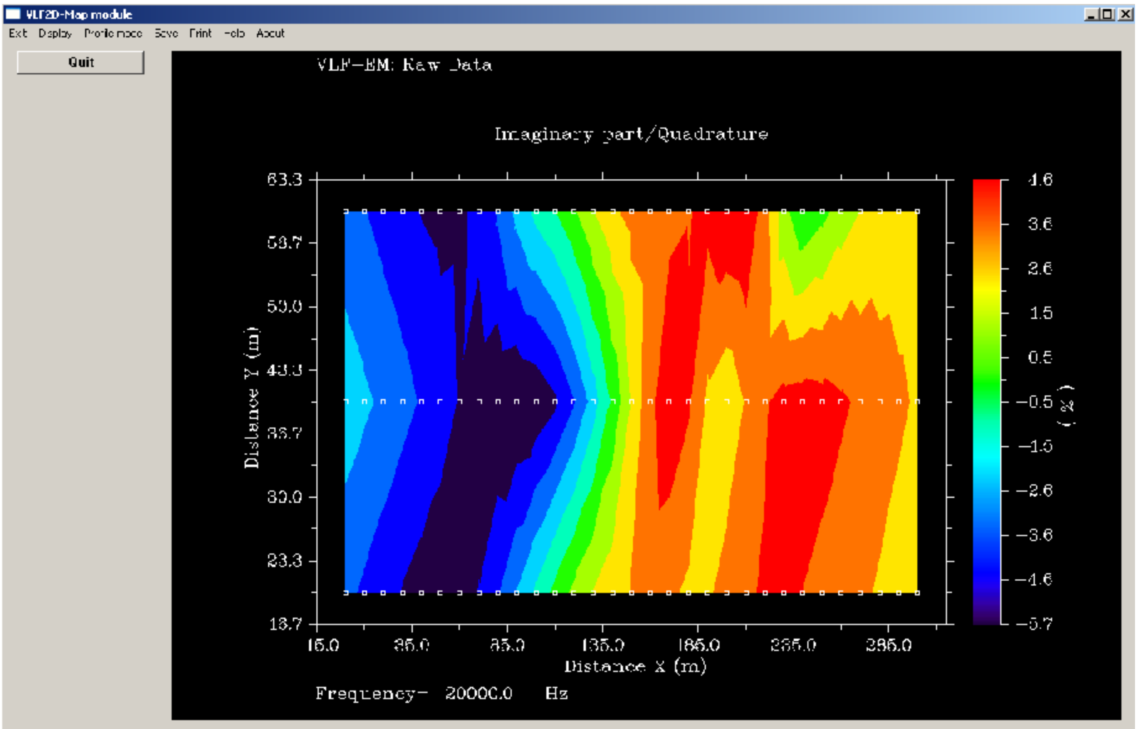


Figure 7.6B. Displaying a map of VLF data-Imaginary part (frequency of 20000 Hz).

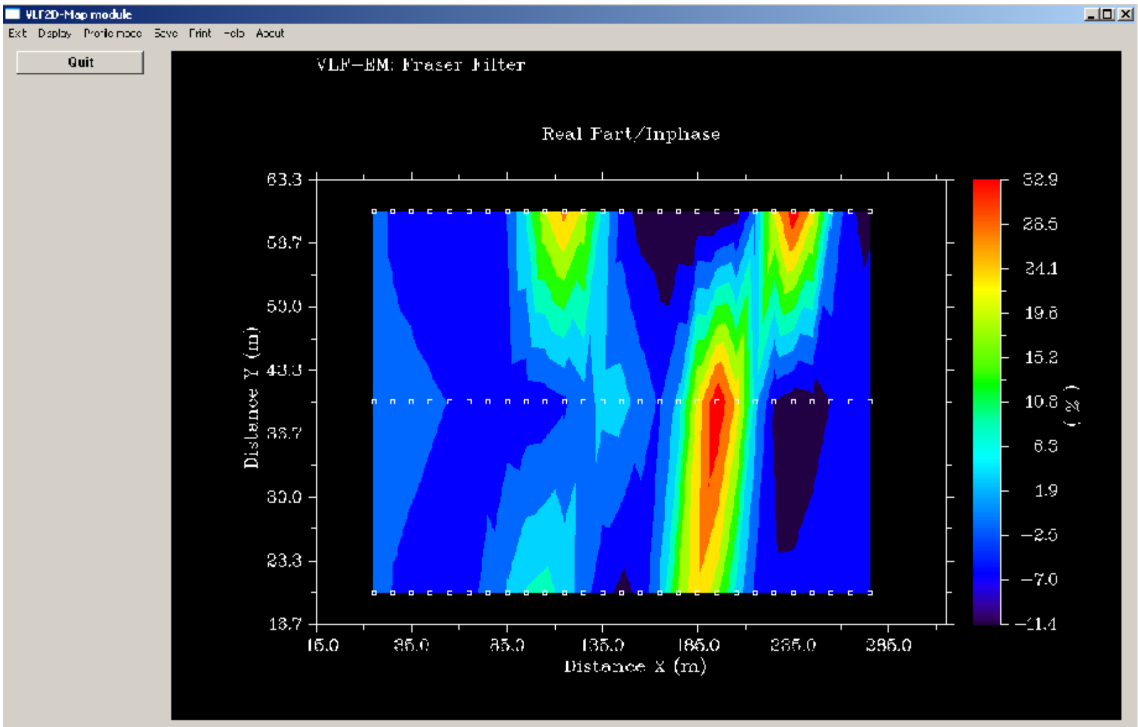


Figure 7.7A. Displaying a Fraser-real part map.

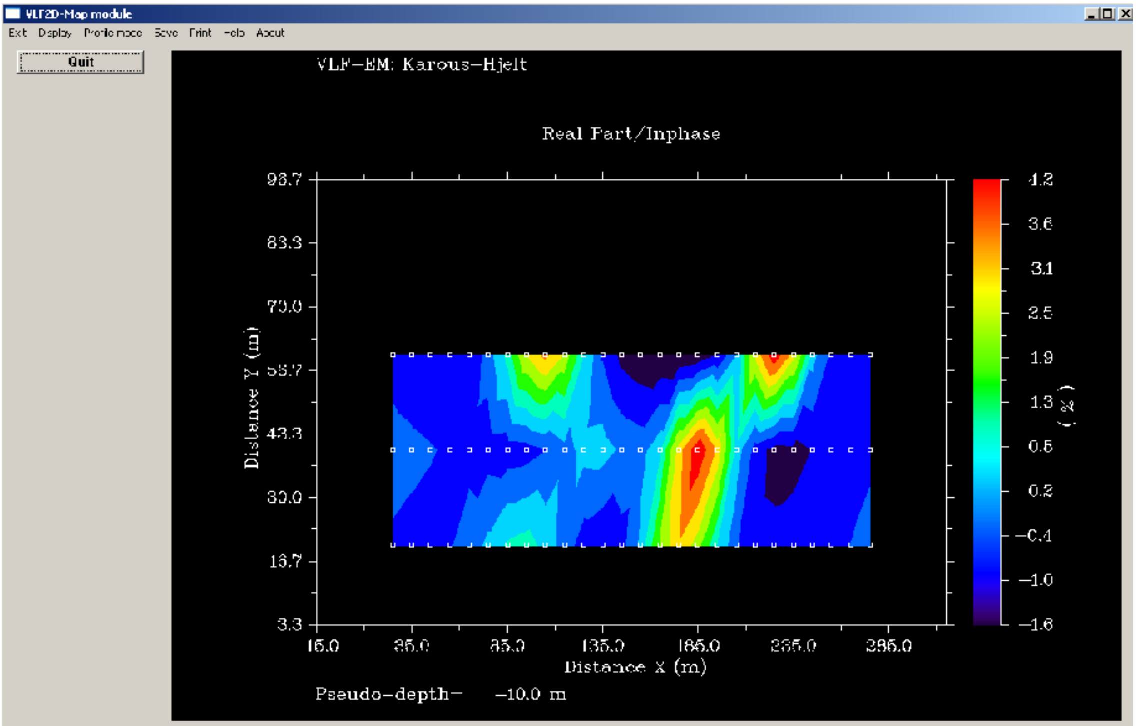


Figure 7.7B. Displaying a K-H-real part map.

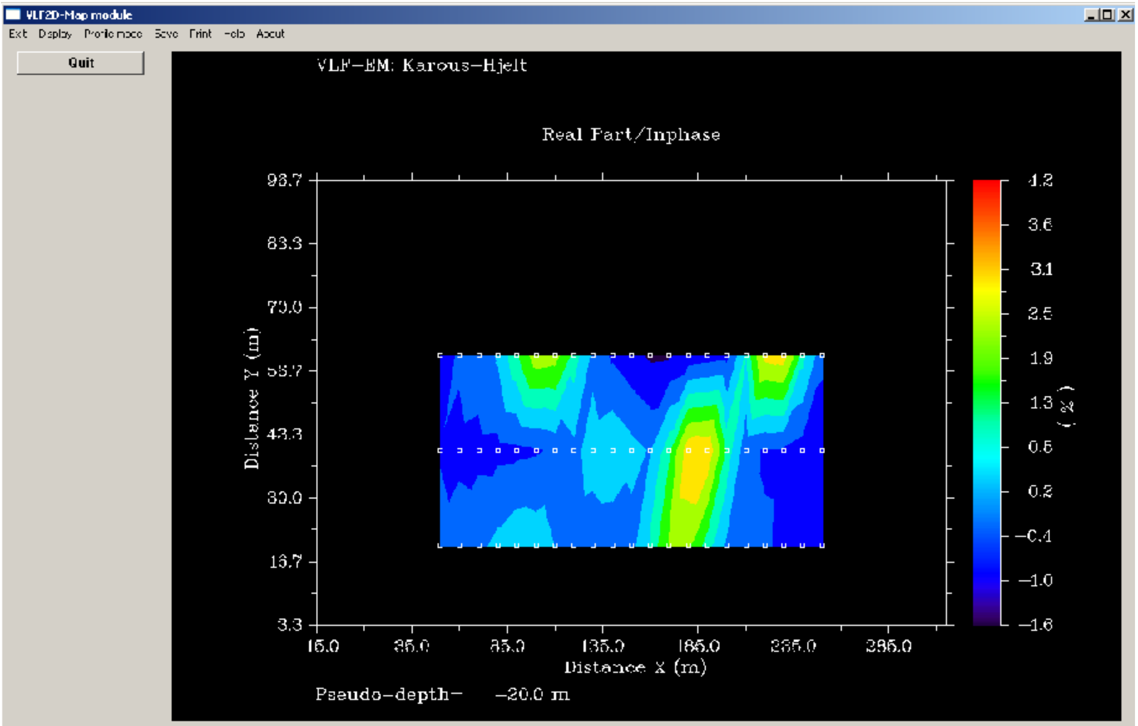


Figure 7.7C. Displaying a K-H-real part map.

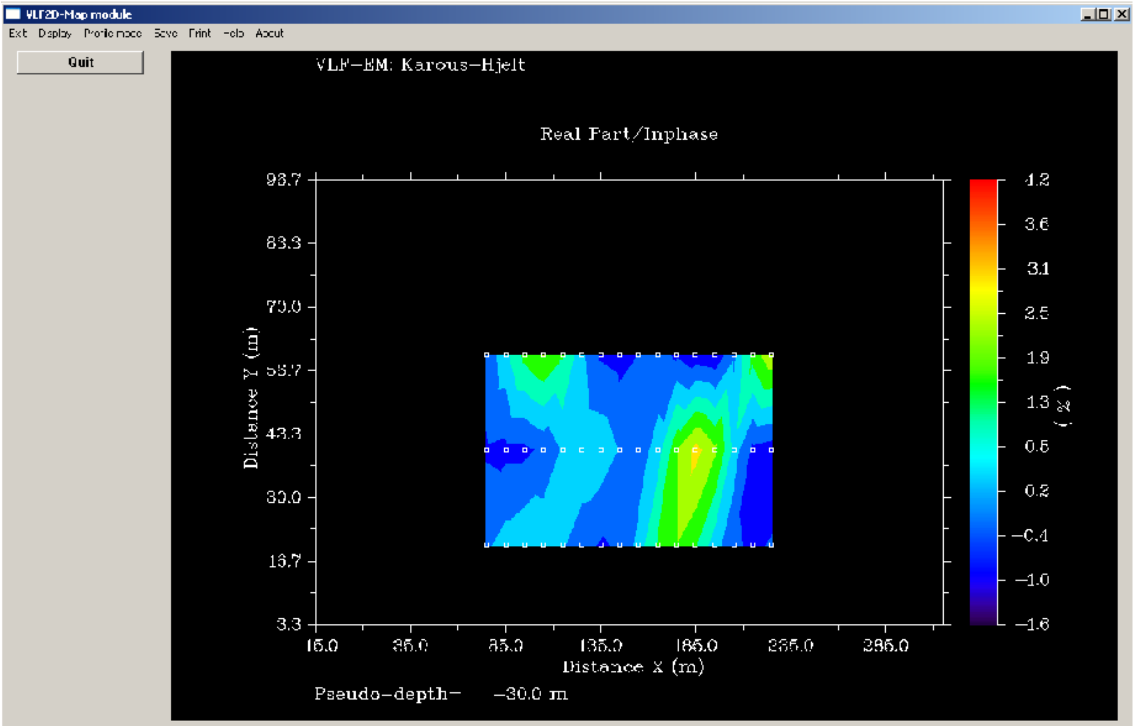
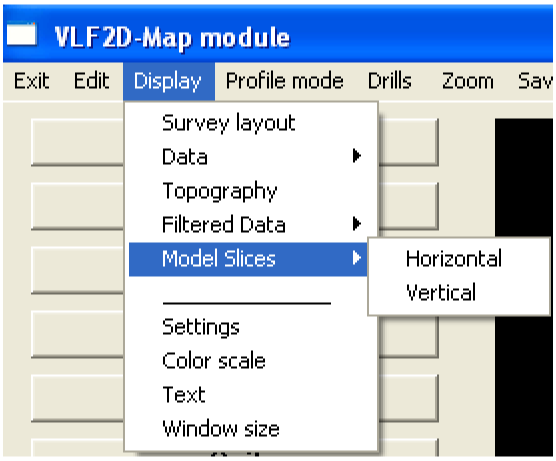


Figure 7.7D. Displaying a K-H-real part map.

Inputting the 2D inverted models of each profile ((X,Y,Z) files) allows the possible to draw maps of the resistivity distribution at four selected depths as shown in Figures 7.7E and F (see the section about Settings), as well to display the 2D models in a 3D view.



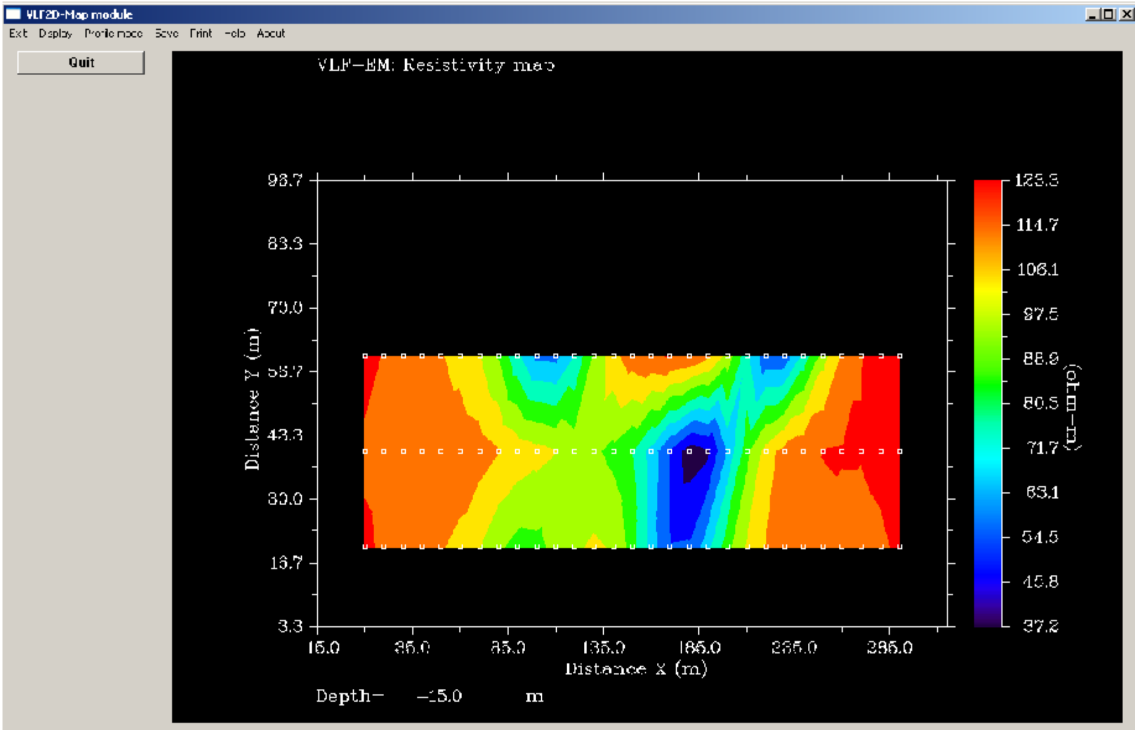


Figure 7.7E. Displaying a horizontal slice of the resistivity models.

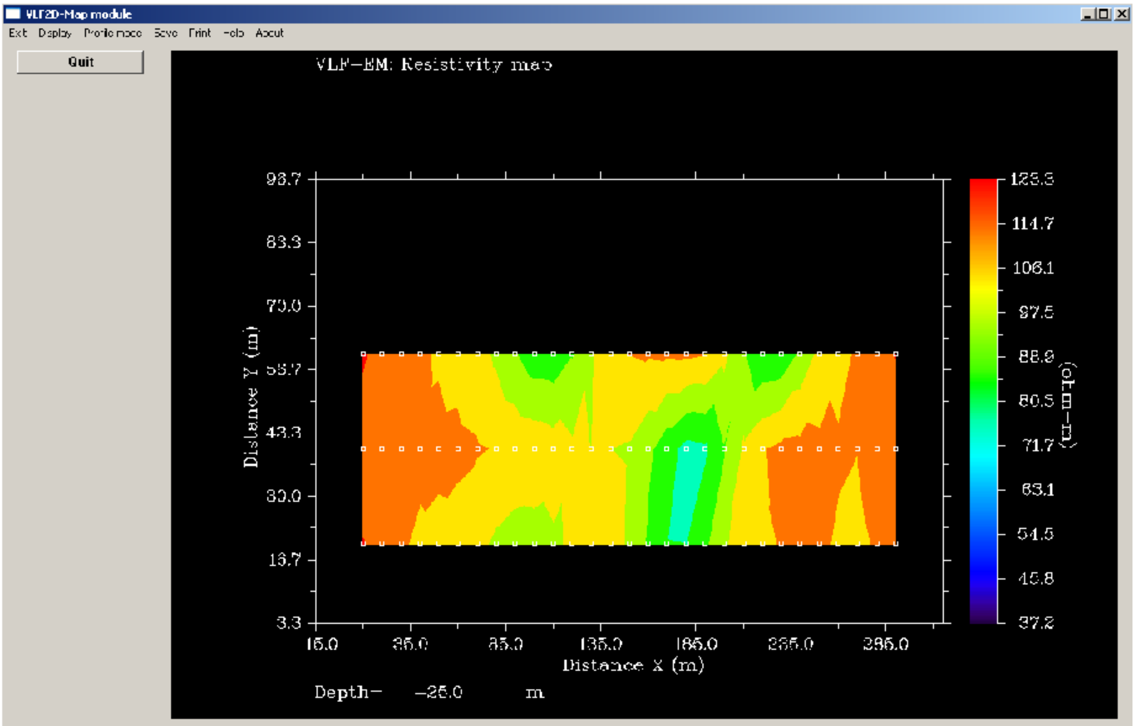


Figure 7.7F. Displaying a horizontal slice of the resistivity models.

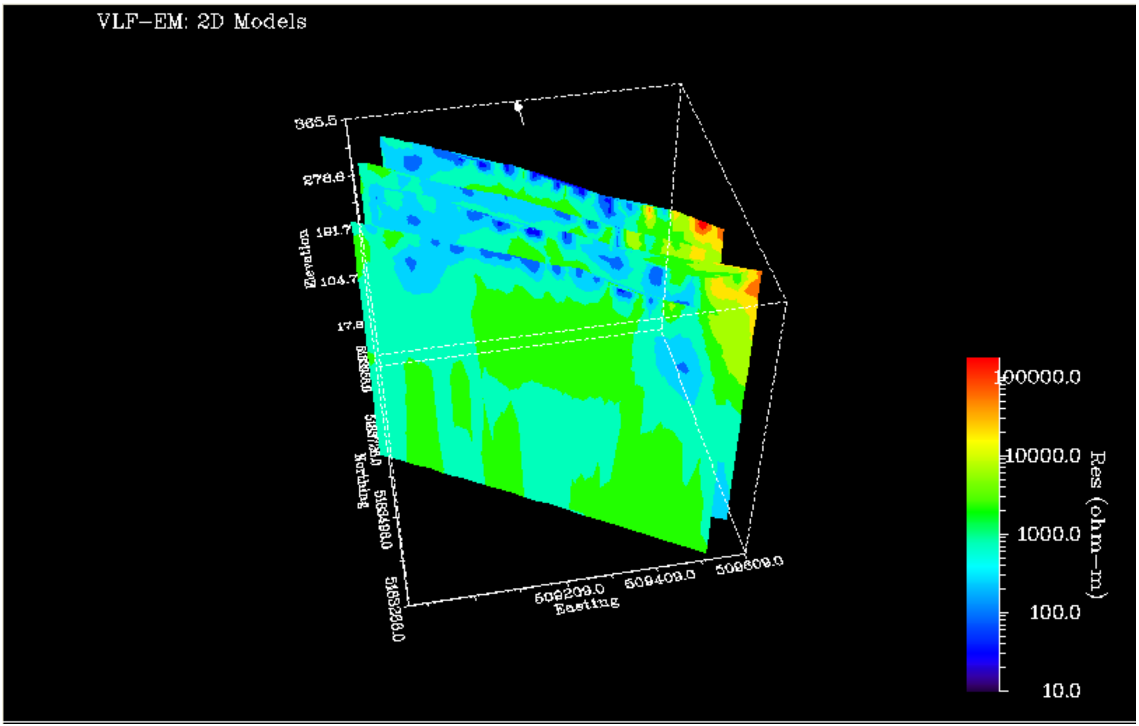
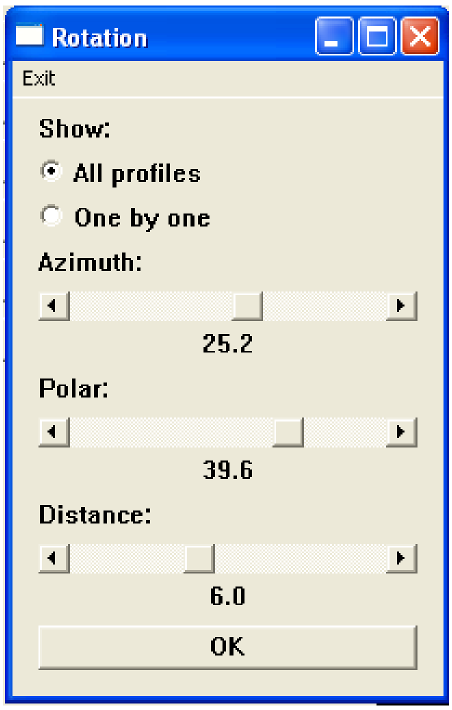
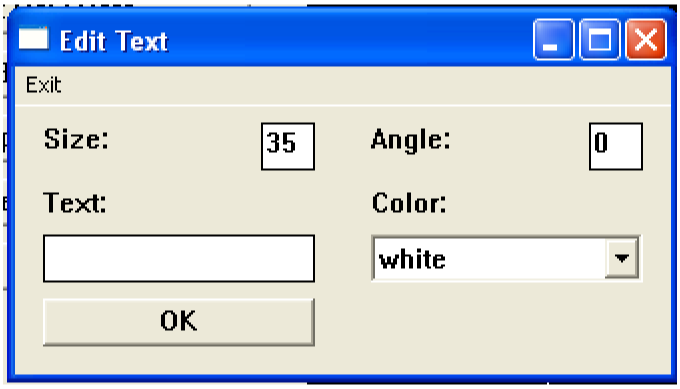


Figure 7.7G. Displaying 2D resistivity models in a 3D view.

The viewpoint is controlled by the action button 3D View. Clicking on it opens the following menu.



The option **Text** in the Display allows the user to write comments on the figures drawn in Map module. When pressed this option the mouse cursor change into a cross. Click on the left button putting the cross in the site you want to write. The following menu will be open,



To edit previous comments, click on **Text**, move the cross to the beginning of the first word of the comment and press the left button. The menu will be open for correction, or delete the comment..

NOTE: To move through the models or depth, when displaying horizontal slices or vertical models, press the right button of the mouse.

NOTE: For the same data set you can come to Map module program using the Go to Map Module.

7.2 Profile mode

The Profile mode entrance is used to add (select) profiles for inversion. Firstly, the user must display the survey going to the Display Survey entrance.

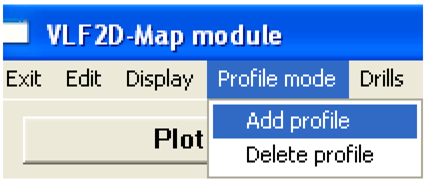


Figure 7.8. Adding profiles.

Clicking in **Add Profile** the arrow of your mouse will change to a cross (+). Click the left mouse button at the beginning of the profile and move till the end of the profile (keeping the button pressed). A menu appears showing the coordinates of the end of the profile (Figure 7.9) when you leave the button. In this menu it is possible to identify the profile, as well as, to change the data signal. The sites that will be included in the profile will be those inside of a region (around the profile) defined through the search radius defined by the user. The value of this radius should be of the same order of the distance between measuring sites.

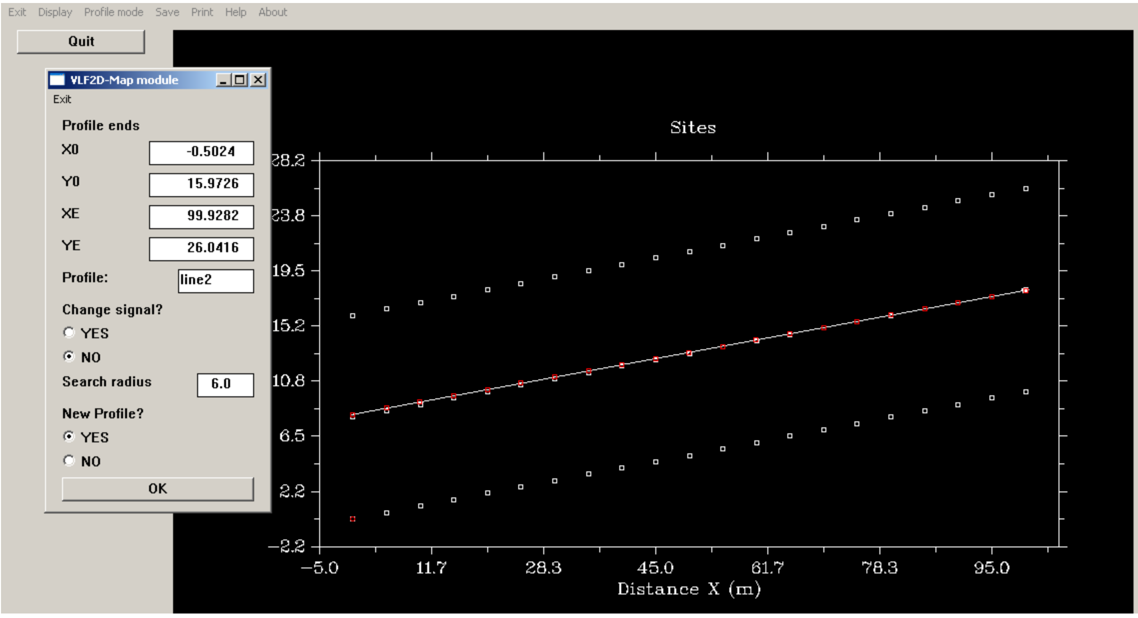


Figure 7.9. Characteristics of the added profile.

After closing the menu (clicking OK), the screen will present the sites included in the profile (in red) and an arrow indicating the direction of the profile (Figure 7.9). Select NO if you do not want to add a new profile.

NOTE: Depending on your survey characteristics, data signal might be changed (reversed).

After select all your profiles they must be saved in independent files to be imported on **VLF2DMF**.

7.3. Zoom

The **Zoom In/Zoom Out** are used as explained in **5.9.**

7.4 Save

Use the entrance "Save" in the menu bar to do that. Select the profile you want to save and proceed choosing the folder and file (Figure 7.10). These files can after be input by **VLF2DMF** program to be inverted.

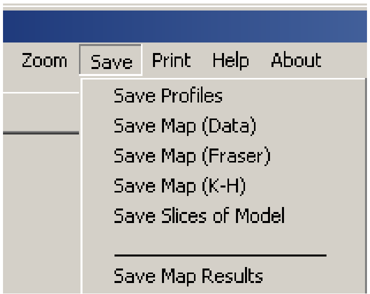


Figure 7.10. Save menu.

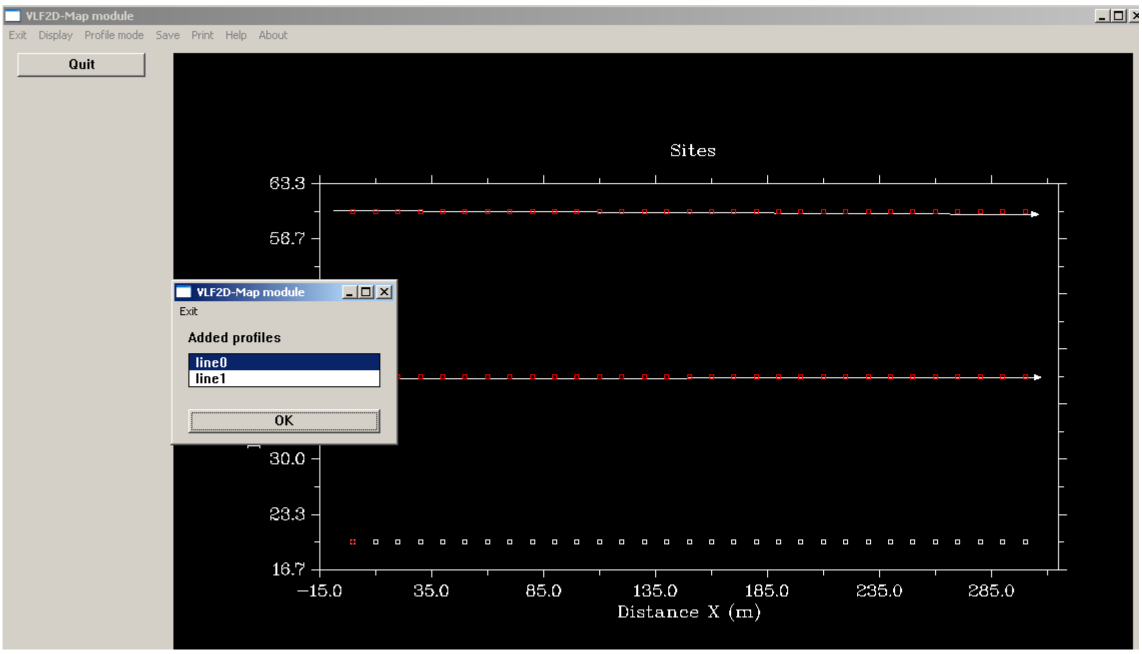


Figure 7.11. Saving the data of each added profile.

The option **Save Map Results** allows you to save all the processing done in the Map module till that time. The results are saved in a file *.MAP. This file can be read in the **VLF2DMF** program using the option **Open.**

7.5 Print

The entrance **Print** in the menu bar will allow you to print figures of the survey layout, raw data and filtered data maps in the selected metafile format (PS, PNG, PDF, TIF and WMF).

7.6 Settings

The settings menu (Figure 7.12) allows the user to select displaying the sites in the maps and to select the depth/elevation for the horizontal slices of the resistivity models. Grid limits can not be modified. Step value controls the number of stations that are skipped without an identification.

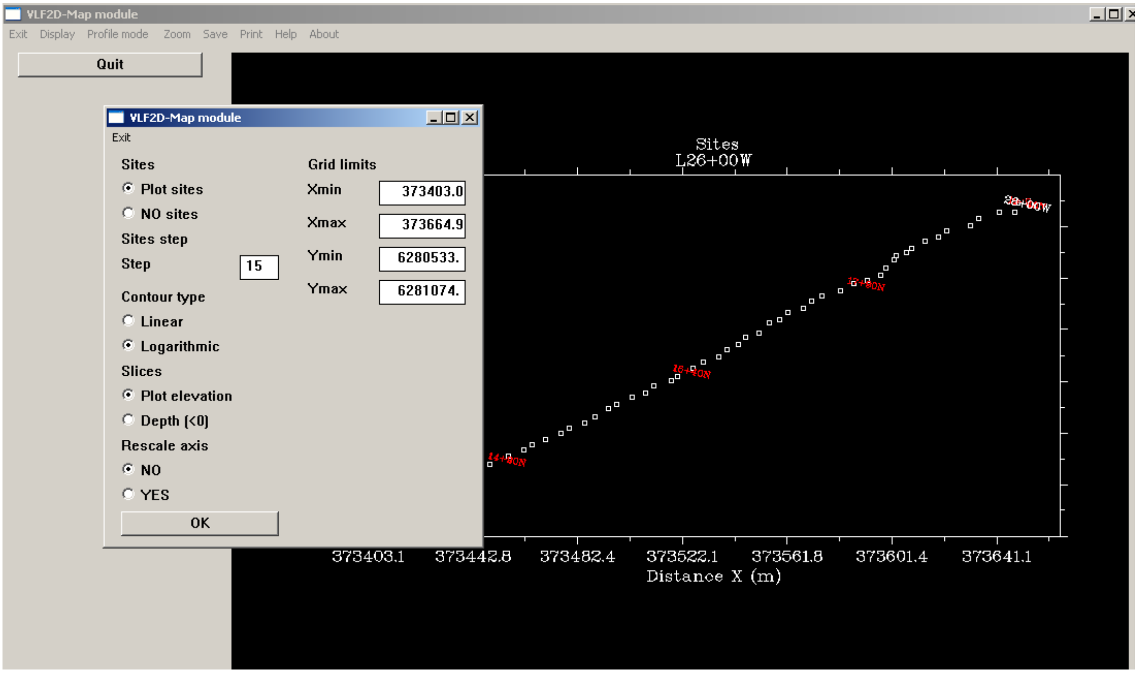


Figure 7.12. The **Settings** menu.

7.7 Drills

Drills can be displayed in the map. The **Drills** entrance in the menubar allows the user to input, edit and delete drill information. A new drill can be incorporated through the option New.

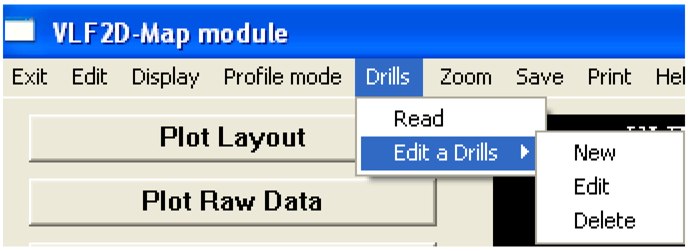


Figure 7.13. Inputting and processing drills.

To Edit a drill the user should choose it clicking on the drill symbol.

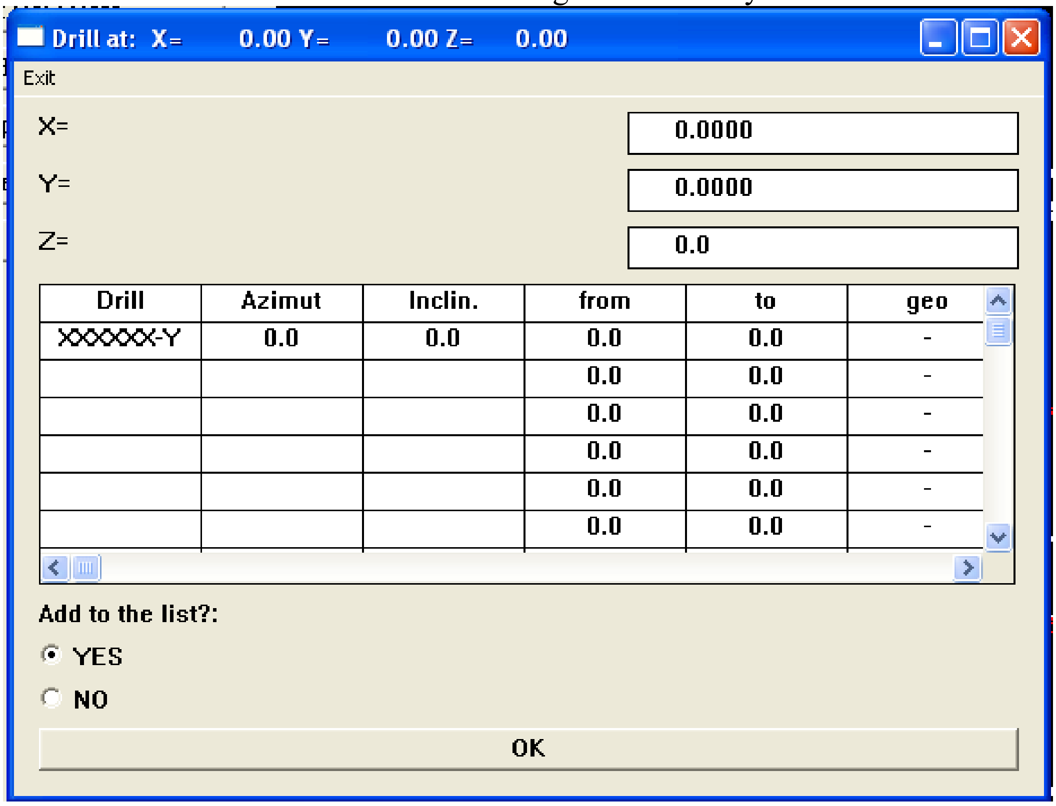
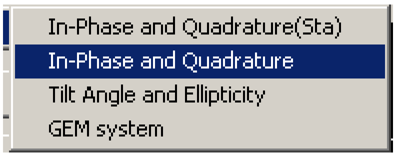


Figure 7.14. Inputting a new drill.

8. Input Files Format

This version of the program can read four types of data:



NOTE: All input and output files must be ASCII files. The formats must be very strictly followed.

8.1. Data files format

8.1.1. In-Phase and Quadrature (Sta)

This is an old format that allows the user to identify the measuring sites (**Sta**tions) and lines and to include some observations at some specific sites. The following is an example of a data file for a line (or a survey with more lines) acquired with one frequency:

```
L26+00W  <LINE NUMBER
1< VLF STATION
NLK
24.8< VLF STATION FREQUENCY
LineNum  StationID    X      Y      Z     InPhase OutPhase     InPhase OutPhase
26+00W 19+40N   3653   81035    497   100    -4
26+00W 19+30N   3649   81032    499   100    -2
26+00W 19+20N   3648   81017    507   100    0
26+00W 19+10N   3642   81018    514   80     0
26+00W 19+00N   3634   81009    519   60     -2    Fault
26+00W 18+90N   3631   80998    525   60     -4
26+00W 18+80N   3622   80990    531   70     -4
26+00W 18+70N   3619   80980    537   80     -6
26+00W 18+60N   3614   80974    544   68     -6
…..
```

If your data contains short notes (like that one in station 19+00N) the program will display a red mark (symbol) when plotting the raw data. To see the information, push the button **Display Notes** in the Action area; go to one of the marks and press the left mouse button and the right button after. The note will be displayed in the screen.

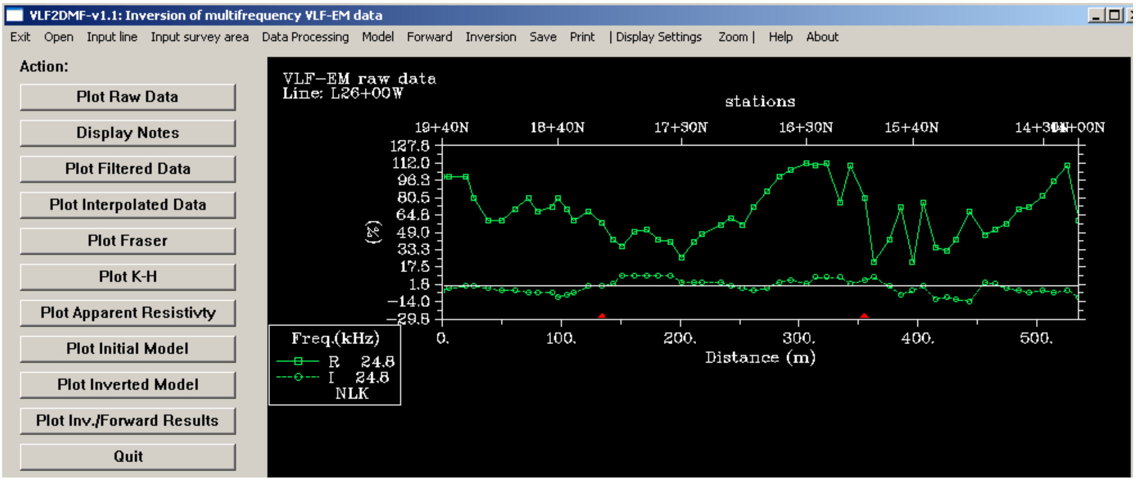


Figure 8.1. Data containing Notes in two stations (red symbols).

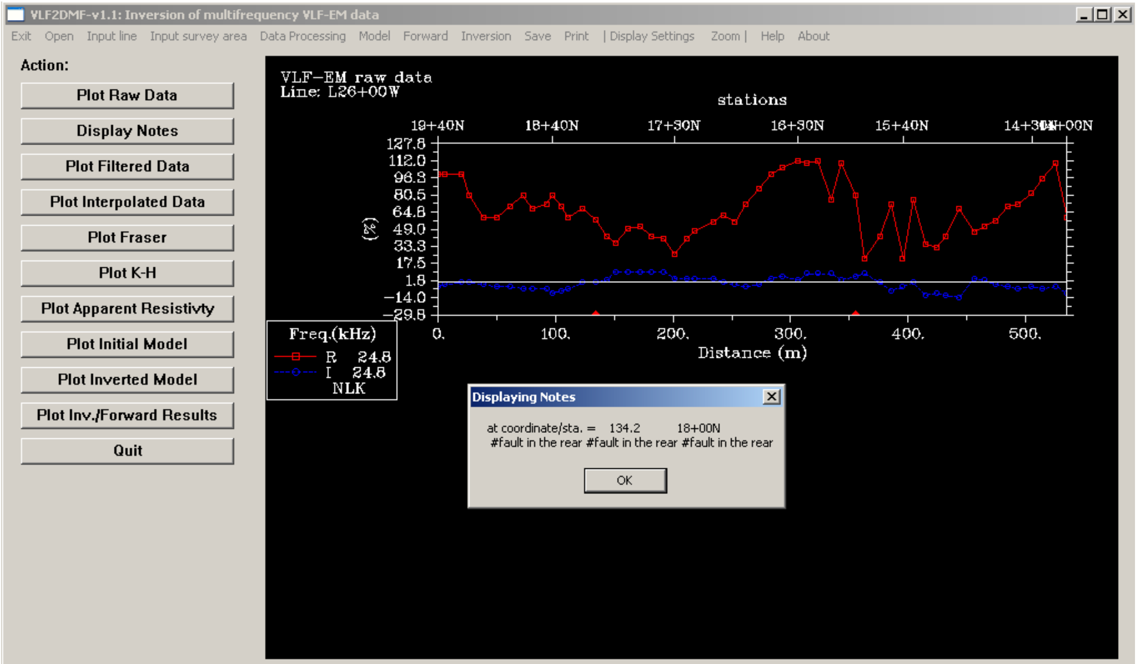


Figure 8.2. Displaying information (NOTES) contained in the data file.

NOTE: this option is only valid for data files in the In-Phase/Quadrature (Sta) and In-Phase/Quadrature formats and corresponding to data acquired in a line.

The following is an example when two frequencies are used:

```
L26+00W  <LINE NUMBER
1< VLF STATION
NLK
24.8< VLF STATION FREQUENCY
2< VLF STATION
NML
25.2< VLF STATION FREQUENCY
LineNum  StationID   X     Y      Z    InPhase OutPhase   InPhase OutPhase
26+00W 19+40N  3653  81035  497  100   -4        90    -2
26+00W 19+30N  3649  81032  499  100   -2        100   -2
26+00W 19+20N  3648  81017  507  100    0        120   -4
26+00W 19+10N  3642  81018  514  80     0        100   -6
26+00W 19+00N  3634  81009  519  60    -2        50    6
26+00W 18+90N  3631  80998  525  60    -4        32    16
26+00W 18+80N  3622  80990  531  70    -4        32    18
```

NOTE: the values must be separated by spaces.

8.1.2. In-Phase and Quadrature/Tilt angle and Ellipticity

The data file corresponding to a line or to a survey (multiple lines should be input as a survey) has the following format:

LineName
NF
Frequency1, frequency2,….frequencyNF
N
X_1, Y_1, Z_1, Rp_{1F1}, Ip_{1F1},…… , Rp_{1FN}, Ip_{1FN}
……
X_i, Y_i, Z_i, Rp_{iF1}, Ip_{iF1},…… , Rp_{iFN}, Ip_{iFN}, fracture
....
X_N, Y_N, Z_N, Rp_N, Ip_N,…… , Rp_{NFN}, Ip_{NFN}

Where NF is the number of frequencies (Hz), N is the number of measuring sites, X, Y and Z are the easting and northing (linear) coordinates and the elevation (in meter) of each measuring site, respectively. Rp and Ip are the tipper real and imaginary parts (or the tilt angle and ellipticity) measured at each sensor (in %). The frequencies should be in Hz.

NOTE: The data are separated must be separated by spaces and X, Y, Z, Rp, Ip must be reals, that is should contain the decimal part even if it is zero.

Example of data file corresponding to a line of 6 sites (3 frequencies) measured in a flat zone:

```
F-TEST-L2
3
20000,8000,3000
```

6
0.0, 8.0, 0.0, -0.15, -0.2, 0.22, -1.05, 1.55, -0.72
5.0, 8.5, 0.0, -0.13, -0.26, 0.29, -1.05, 1.57, -0.68
10.0, 9.0, 0.0, -0.1, -0.31, 0.37, -1.03, 1.56, -0.62, fault
15.0, 9.5, 0.0, -0.05, -0.36, 0.44, -0.98, 1.53, -0.55
20.0, 10.0, 0.0, 0.01, -0.41, 0.52, -0.91, 1.47, -0.47
25.0, 10.5 0.0, 0.09, -0.44, 0.58, -0.8, 1.37, -0.38

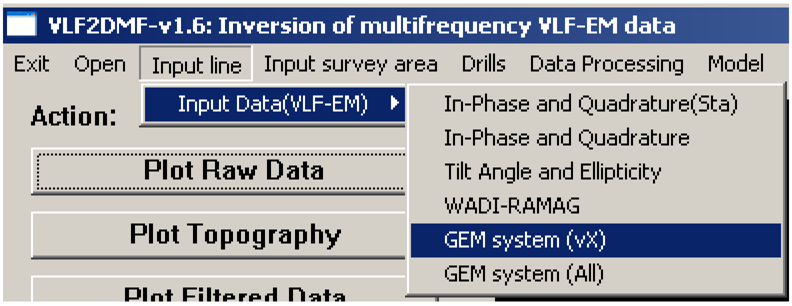
NOTE: The values must be separated by comma or by space.

8.1.3. GEM system format (see also APPENDICE G)

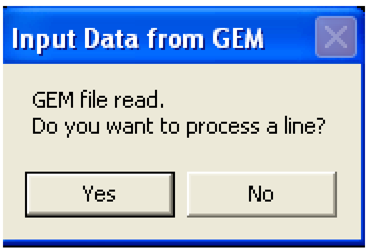
There are a few output files from GEM VLF system: files _mvlf, _v and _wvlf and the ALL VLF file (please, refer GEM Manual). The only that can be read by **VLF2DMF** are the _v and All files. The file below is an example of the _v file.

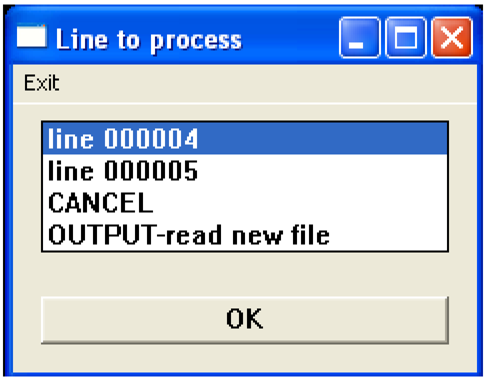
```
/Gem Systems GSM-19WV 8042728 v7.0 14 IX 2015 M ewv6fl.v7vbs
/ID 1 file 03survey.v3  03 II 16
/UTC
/GPS datum WGS84

/x y elevation sat slope n*[kHz ip op h1 h2 pT] time
line  000004
 0629232.18 4857207.45 000208 06 S 1000 1000 0000E 24.0 +041.2 +012.9  006 060 015.55 25.2 +032.0 -000.5 067 073 006.03 24.0 +041.6 +013.2  008 060 015.43 144948.0
 0629231.47 4857208.69 000208 06 S 1000 1001 0000E 24.0 -026.9 -012.3  000 060 015.43 25.2 -022.8 -006.8 056 073 005.58 24.0 -026.5 -012.2 -001 060 015.25 145029.0
 0629232.92 4857202.63 000206 07 S 1000 1002 0000E 24.0 +040.3 +013.7  006 059 015.14 25.2 +031.1 -000.6 063 070 005.74 24.0 +040.2 +014.0  007 059 015.13 145041.0
 0629232.40 4857203.87 000206 07 S 1000 1003 0000E 24.0 +042.3 +013.3  004 056 014.47 25.2 +032.5 -000.1 067 066 005.71 24.0 +044.9 +013.4  007 056 014.43 145054.0
 0629232.08 4857204.54 000206 07 S 1000 1004 0000E 24.0 +037.4 +011.0 -001 057 014.68 25.2 +029.1 -001.9 056 068 005.37 24.0 +038.6 +011.1  000 056 014.39 145106.0
 0629230.78 4857210.11 000208 06 S 1000 1005 0000E 24.0 +029.4 +008.2 -003 060 015.30 25.2 +023.8 -002.0 050 071 005.30 24.0 +029.1 +008.6 -005 059 015.27 145120.0
 0629230.48 4857211.20 000208 06 S 1000 1006 0000E 24.0 +021.5 +006.4 -002 063 016.24 25.2 +017.8 -001.8 060 078 006.00 24.0 +021.7 +006.4 -002 063 016.17 145131.0
 0629230.10 4857211.31 000208 06 S 1000 1008 0000E 24.0 +010.8 +005.1 -007 070 018.05 25.2 +009.8 -000.2 051 087 006.16 24.0 +010.0 +005.8 -008 069 017.86 145142.0
 0629230.24 4857209.54 000205 08 S 1000 1009 0000E 24.0 +005.6 +005.8 -001 073 018.78 25.2 +006.2 -000.2 056 083 006.08 24.0 +006.1 +005.9 -002 074 018.81 145204.0
 0629230.03 4857209.36 000208 09 S 1000 1011 0000E 24.0 -004.1 +008.2 -013 084 021.77 25.2 -001.1 +003.2 039 100 006.55 24.0 -003.9 +008.4 -015 082 021.36 145225.0
 0629229.19 4857212.74 000206 07 W 1000 1012 0000E 24.0 -011.6 +008.7 -008 093 023.95 25.2 -008.0 +005.1 050 103 006.94 24.0 -011.2 +008.5 -005 095 024.31 145311.0
 0629229.41 4857213.76 000206 07 W 1000 1013 0000E 24.0 -014.9 +007.8 -013 109 028.01 25.2 -010.1 +006.5 037 123 007.83 24.0 -014.5 +008.3 -014 110 028.25 145325.0
 0629230.52 4857209.83 000213 09 W 1000 1014 0000E 24.0 -009.0 +006.1 -017 127 032.74 25.2 -004.7 +002.9 016 070 008.77 24.0 -008.1 +006.1 -021 127 032.77 145337.0
 0629228.38 4857214.98 000206 08 W 1000 1015 0000E 24.0 -033.7 +000.0 -007 074 038.17 25.2 -031.7 +002.2 024 080 010.13 24.0 -033.5 -000.4  000 075 038.23 145349.0
 0629228.38 4857214.98 000206 08 W 1000 1016 0000E 24.0 -008.2 +004.4 -006 063 032.42 25.2 -004.6 +002.5 018 070 008.86 24.0 -007.6 +004.8 -008 063 032.54 145349.0
line  000005
 0629229.29 4857212.22 000211 09 W 999 1016 0000E 24.0 +036.6 +000.0 -003 074 037.69 25.2 +033.3 -002.6 026 081 010.37 24.0 +035.1 +000.2 -003 073 037.60 145419.0
 0629229.29 4857212.22 000211 09 W 999 1015 0000E 24.0 +000.1 +001.7 -004 074 038.11 25.2 +000.8 +003.9 023 080 010.19 24.0 -000.3 +001.7 -004 075 038.20 145419.0
 0629228.79 4857213.25 000207 08 W 999 1014 0000E 24.0 -028.5 +006.4 -005 056 028.63 25.2 -022.5 +011.8 021 064 008.26 24.0 -028.7 +006.4 -005 056 028.73 145442.0
 0629228.79 4857213.25 000207 08 W 999 1013 0000E 24.0 -026.5 +008.6 -009 046 024.09 25.2 -021.5 +013.3 016 054 006.91 24.0 -027.1 +008.9 -009 046 024.22 145442.0
 0629229.47 4857211.47 000206 08 W 999 1012 0000E 24.0 -019.4 +007.5 -004 088 022.52 25.2 -015.8 +012.3 023 048 006.50 24.0 -019.9 +006.9 -004 087 022.25 145504.0
 0629229.47 4857211.47 000206 08 W 999 1011 0000E 24.0 -012.5 +005.7 -009 082 021.02 25.2 -008.7 +008.4 047 095 006.47 24.0 -013.6 +005.9 -010 081 020.82 145504.0
 0629229.47 4857211.47 000206 08 W 999 1010 0000E 24.0 -008.2 +005.0 -001 078 019.94 25.2 -004.4 +007.8 059 088 006.46 24.0 -006.8 +005.3 -003 076 019.51 145504.0
 0629230.28 4857209.09 000206 08 W 999 1009 0000E 24.0 -002.9 +004.6 -005 074 019.02 25.2 +000.0 +006.2 055 087 006.28 24.0 -004.9 +004.3 -006 072 018.59 145540.0
 0629230.64 4857208.14 000206 08 W 999 1008 0000E 24.0 +001.1 +004.7 -007 071 018.37 25.2 +002.9 +005.9 048 081 005.75 24.0 +001.4 +004.5 -005 070 018.10 145601.0
 0629230.37 4857206.33 000208 08 W 999 1007 0000E 24.0 +006.2 +005.5 -005 067 017.27 25.2 +008.1 +005.0 051 081 005.82 24.0 +006.2 +005.4 -007 068 017.56 145613.0
 0629228.84 4857215.08 000217 08 W 999 1006 0000E 24.0 +014.0 +007.1 -010 065 016.91 25.2 +012.7 +004.9 049 084 005.93 24.0 +013.1 +006.6 -012 065 016.94 145626.0
 0629230.63 4857204.14 000208 07 W 999 1005 0000E 24.0 +020.9 +010.0  000 063 016.22 25.2 +018.9 +006.4 059 074 005.74 24.0 +020.9 +010.2  000 063 016.14 145638.0
 0629230.90 4857204.86 000208 07 W 999 1004 0000E 24.0 +026.8 +012.9  003 061 015.76 25.2 +023.1 +006.7 062 072 005.81 24.0 +026.8 +012.2  000 062 015.78 145656.0
 0629231.32 4857204.13 000208 06 W 999 1003 0000E 24.0 -045.5 -013.7  007 061 015.67 25.2 -034.3 +002.2 062 068 005.62 24.0 -045.3 -013.4  008 061 015.84 145709.0
```

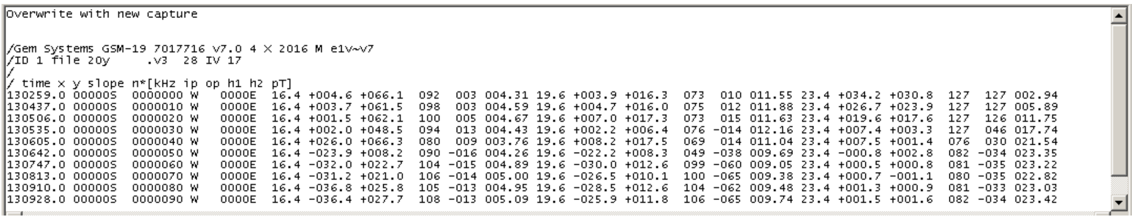


After input the data file the user must select a line for processing and inversion.



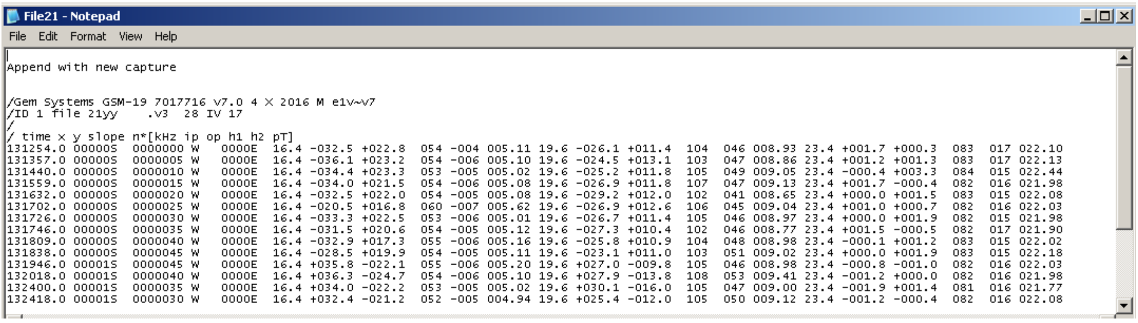


Figures below show two files that can be read using the (All) option.



```
Overwrite with new capture


/Gem Systems GSM-19 7017716 v7.0 4 X 2016 M e1v~v7
/ID 1 file 20y     .v3  28 IV 17
/
/ time x y slope n*[kHz ip op h1 h2 pT]
130259.0 00000S  0000000 W   0000E  16.4 +004.6 +066.1  092  003 004.31 19.6 +003.9 +016.3  073  010 011.55 23.4 +034.2 +030.8  127  127 002.94
130437.0 00000S  0000010 W   0000E  16.4 +003.7 +061.5  098  003 004.59 19.6 +004.7 +016.0  075  012 011.88 23.4 +026.7 +023.9  127  127 005.89
130506.0 00000S  0000020 W   0000E  16.4 +001.5 +062.1  100  005 004.67 19.6 +007.0 +017.3  073  015 011.63 23.4 +019.6 +017.6  127  126 011.75
130535.0 00000S  0000030 W   0000E  16.4 +002.0 +048.5  094  013 004.43 19.6 +002.2 +006.4  076 -014 012.16 23.4 +007.4 +003.3  127  046 017.74
130605.0 00000S  0000040 W   0000E  16.4 +026.0 +066.3  080  009 003.76 19.6 +008.2 +017.5  069  014 011.04 23.4 +007.5 +001.4  076  030 021.54
130642.0 00000S  0000050 W   0000E  16.4 -023.9 +008.2  090 -016 004.26 19.6 -022.2 +008.3  049 -038 009.69 23.4 -000.8 +002.8  082 -034 023.35
130747.0 00000S  0000060 W   0000E  16.4 -032.0 +022.7  104 -015 004.89 19.6 -030.0 +012.6  099 -060 009.05 23.4 +000.5 +000.8  081 -035 023.22
130813.0 00000S  0000070 W   0000E  16.4 -031.2 +021.0  106 -014 005.00 19.6 -026.5 +010.1  100 -065 009.38 23.4 +000.7 -001.1  080 -035 022.82
130910.0 00000S  0000080 W   0000E  16.4 -036.8 +025.8  105 -013 004.95 19.6 -028.5 +012.6  104 -062 009.48 23.4 +001.3 +000.9  081 -033 023.03
130928.0 00000S  0000090 W   0000E  16.4 -036.4 +027.7  108 -013 005.09 19.6 -025.9 +011.8  106 -065 009.74 23.4 +001.5 +001.6  082 -034 023.42
```

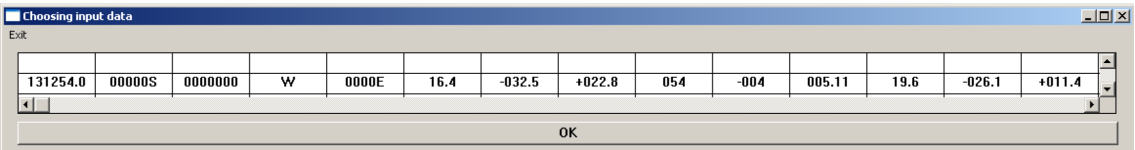


File21 - Notepad

File Edit Format View Help

```
Append with new capture


/Gem Systems GSM-19 7017716 v7.0 4 X 2016 M e1v~v7
/ID 1 file 21yy    .v3  28 IV 17
/
/ time x y slope n*[kHz ip op h1 h2 pT]
131254.0 00000S  0000000 W   0000E  16.4 -032.5 +022.8  054 -004 005.11 19.6 -026.1 +011.4  104  046 008.93 23.4 +001.7 +000.3  083  017 022.10
131357.0 00000S  0000005 W   0000E  16.4 -036.1 +023.2  054 -006 005.10 19.6 -024.5 +013.1  103  047 008.86 23.4 +001.2 +001.3  083  017 022.13
131440.0 00000S  0000010 W   0000E  16.4 -034.4 +023.3  053 -005 005.02 19.6 -025.2 +011.8  105  049 009.05 23.4 -000.4 +003.3  084  015 022.44
131559.0 00000S  0000015 W   0000E  16.4 -034.0 +021.5  054 -006 005.08 19.6 -026.9 +011.8  107  047 009.13 23.4 +001.7 -000.4  082  016 021.98
131632.0 00000S  0000020 W   0000E  16.4 -032.5 +022.0  054 -005 005.08 19.6 -029.2 +012.0  102  041 008.65 23.4 +000.0 +001.5  083  015 022.08
131702.0 00000S  0000025 W   0000E  16.4 -020.5 +016.8  060 -007 005.62 19.6 -026.9 +012.6  106  045 009.04 23.4 +001.0 +000.7  082  016 022.03
131726.0 00000S  0000030 W   0000E  16.4 -033.3 +022.5  053 -006 005.01 19.6 -026.7 +011.4  105  046 008.97 23.4 +000.0 +001.9  082  015 021.98
131746.0 00000S  0000035 W   0000E  16.4 -031.5 +020.6  054 -005 005.12 19.6 -027.3 +010.4  102  046 008.77 23.4 +001.5 -000.5  082  017 021.90
131809.0 00000S  0000040 W   0000E  16.4 -032.9 +017.3  055 -006 005.16 19.6 -025.8 +010.9  104  048 008.98 23.4 -000.1 +001.2  083  015 022.02
131838.0 00000S  0000045 W   0000E  16.4 -028.5 +019.9  054 -005 005.11 19.6 -023.1 +011.0  103  051 009.02 23.4 +000.0 +001.9  083  015 022.18
131946.0 00001S  0000045 W   0000E  16.4 +035.8 -022.1  055 -006 005.20 19.6 +027.0 -009.8  105  046 008.98 23.4 -000.8 -001.0  082  016 022.03
132018.0 00001S  0000040 W   0000E  16.4 +036.3 -024.7  054 -006 005.10 19.6 +027.9 -013.8  108  053 009.41 23.4 -001.2 +000.0  082  016 021.98
132400.0 00001S  0000035 W   0000E  16.4 +034.0 -022.2  053 -005 005.02 19.6 +030.1 -016.0  105  047 009.00 23.4 -001.9 +001.4  081  016 021.77
132418.0 00001S  0000030 W   0000E  16.4 +032.4 -021.2  052 -005 004.94 19.6 +025.4 -012.0  105  050 009.12 23.4 -001.2 -000.4  082  016 022.08
```



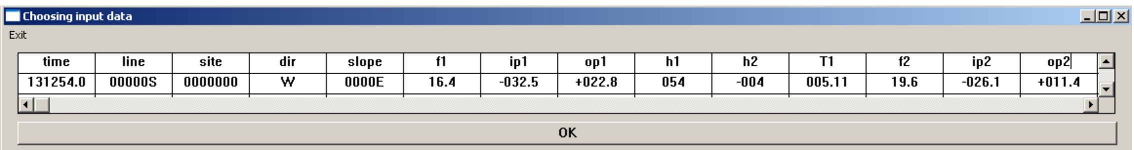
Choosing input data

Exit

131254.0	00000S	0000000	W	0000E	16.4	-032.5	+022.8	054	-004	005.11	19.6	-026.1	+011.4

OK

To input the file the user must choose the appropriated columns filling in the upper row. For the case the columns represents the following magnitudes (hidden cells can be reached scrolling) .



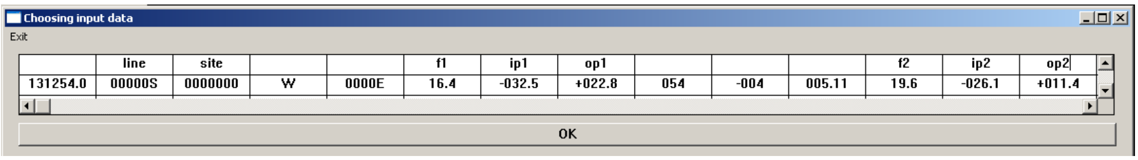
Choosing input data

Exit

time	line	site	dir	slope	f1	ip1	op1	h1	h2	T1	f2	ip2	op2
131254.0	00000S	0000000	W	0000E	16.4	-032.5	+022.8	054	-004	005.11	19.6	-026.1	+011.4

OK

However, only a few of them are need. The example below is for one of the second file displayed above and the selection is:



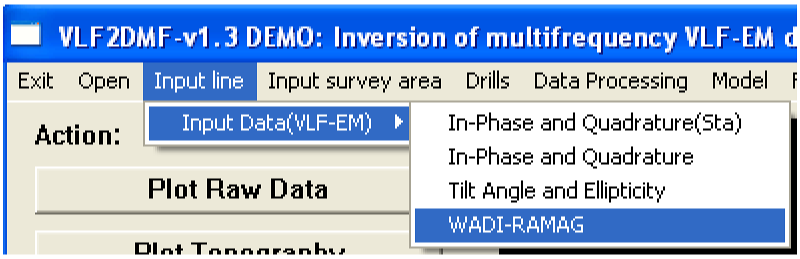
According to the data in the file the appropriated name for the columns are:
X – coordinate XUTM (eastern)
Y – coordinate YUTM (northern)
Z – elevation
Line (line, l) – for line
Site (site, s) – for station
F1 (f1) – first frequency
IP1 (ip1) – inphase for F1
OP1 (op1) – outphase for F1
…similar for other frequencies.

If the elevation is not present in the data the program will assume an elevation of 0.0 m. UTM coordinates and lines/sites can not be selected in the same input.

Data from GEM (or any other system) can be input using the in-phase&quadrature format (see **8.1.2**) if the write in the appropriated format.

8.1.4. WADI-RAMAG format

Data corresponding to individual profiles collected with WADI system and processed by RAMAG program can be input in **VLF2DMF** using the input line option.



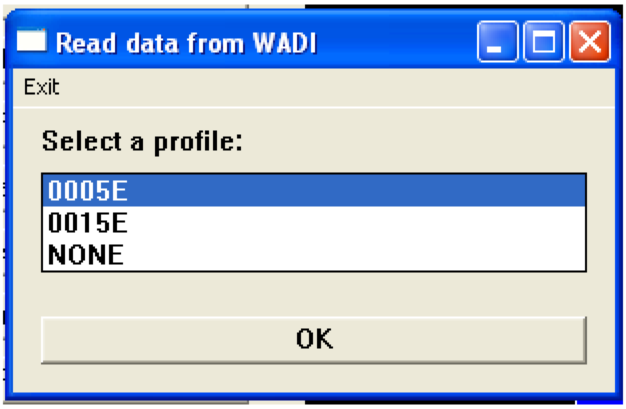
The WADI-RAMAG format is as follow (for two lines 0005E and 0015E, each one with 15 values and 280 m long and, acquired at 21.4 kHz):

```
Field-Test
0005E
21.4
15
0        -22.3     -42.2
20       -10.6     -46.6
40        2.4      -42.2
.............
280       58.6      -77.9
0015E
```

21.4
15
0 -45.6 -33.9
20 -33.7 -33.8
………
280 -12 -37

The first column gives the position of the readings along the profile. Second and third columns contain the real and imaginary VLF data, respectively.

After input, the profiles are available for processing and inversion.



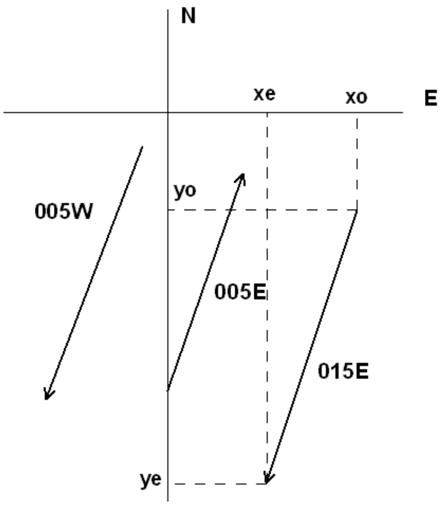
To process the next line, just go to the input line option and answer to the question.

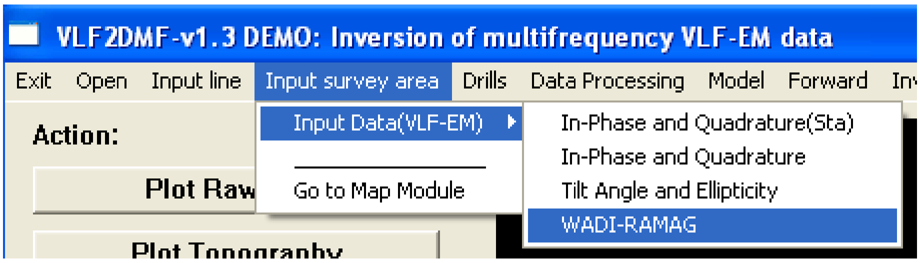
If the answer is NO, the program will ask you to open a new file.

NOTE: WAD format is lost during the use of the program and every file saved will be in a different format (in general according to inphase and quadrature format). So, saved files must be imported again in the program not using WADI option.

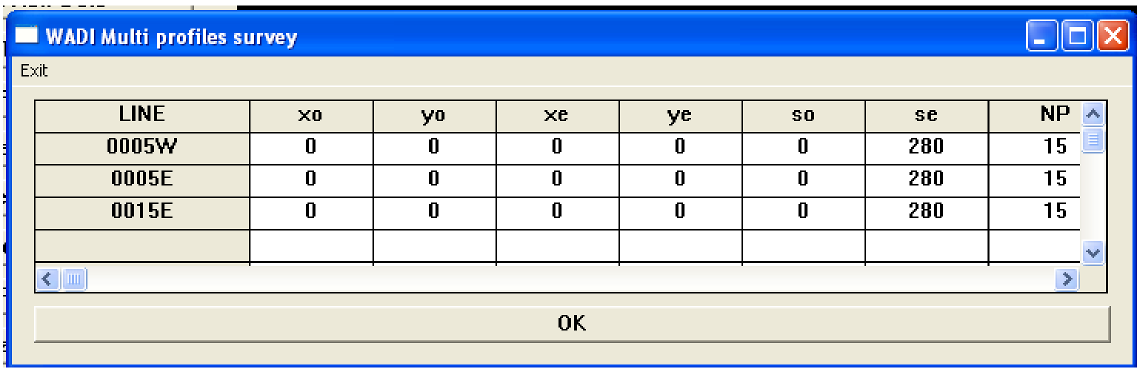
To be used in Map module the file data should contain X,Y and Z coordinates. Values of these coordinates should be filled, because such values do not exist in the data file.

Let's consider the following 3 profiles and a N-E reference system (local or UTM coordinates). In such system the origin and end of each profile will be (xo,yo) and (xe,ye). When inputting the file in VLF2Dmf the user should fill a table with those values.





Inputting the data file

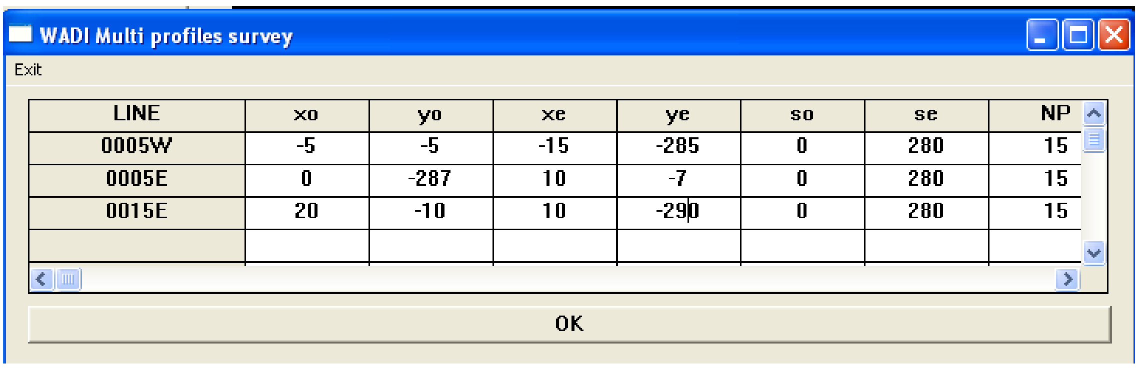

WADI Multi profiles survey

Exit

LINE	xo	yo	xe	ye	so	se	NP
0005W	0	0	0	0	0	280	15
0005E	0	0	0	0	0	280	15
0015E	0	0	0	0	0	280	15

OK

Table to be filled (*so* and *se* are the coordinates on the line and are only informative about the length of the line).

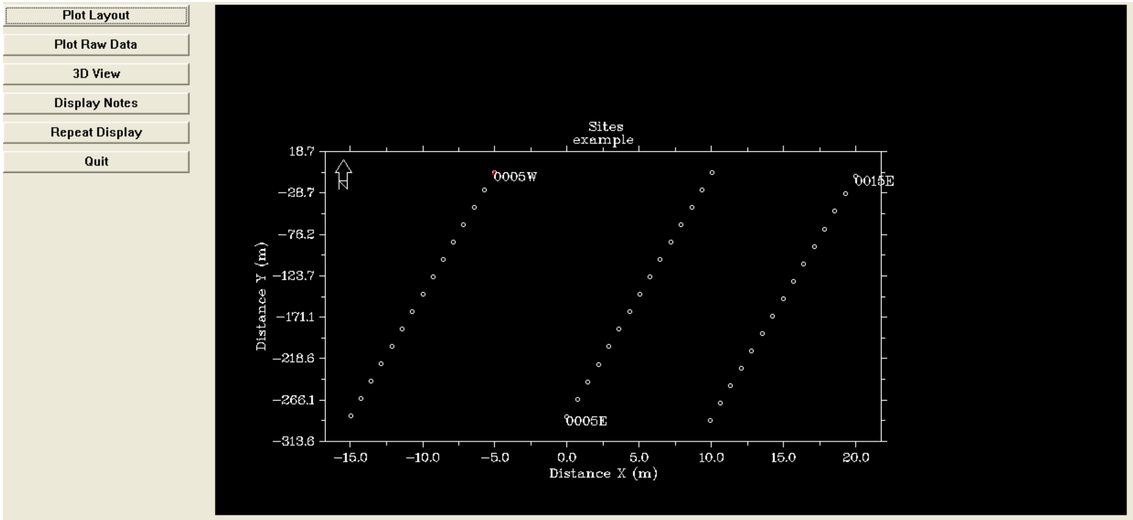

WADI Multi profiles survey

Exit

LINE	xo	yo	xe	ye	so	se	NP
0005W	-5	-5	-15	-285	0	280	15
0005E	0	-287	10	-7	0	280	15
0015E	20	-10	10	-290	0	280	15

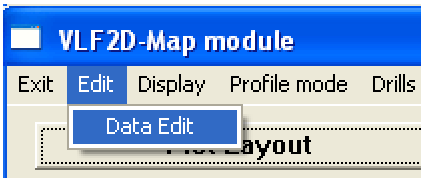
OK

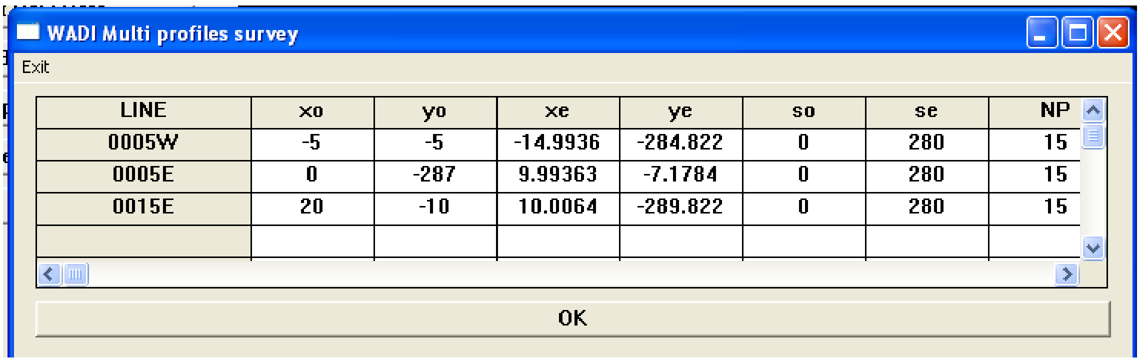
Table filled with the appropriated data (this is only an example and the values are only informative).



Survey as displayed by Map module.

The location of the profiles can be corrected in the Map module, using the Data Edit tool,

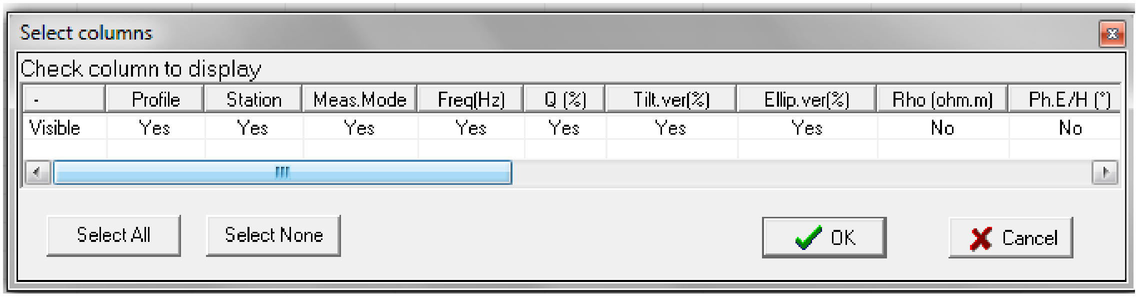




Editing the profiles. If alterations are made click twice in OK. The first to show the modifications and the second to accept them.

8.1.5. T-VLF format

VLF2DMF read txt files written by the TVLF program (from IRIS). The user must select the wright columns that must be saved, which are:



But others can also be included.
Example of a VLF-EM file from TVLF.

```
Profile Station Meas.Mode Freq(Hz) Q (%) Tilt.ver(%) Ellip.ver(%) H hor(µA/m) Tilt.hor(°) Ellip.hor(%) Ch1 Gain Ch1 Ovld Ch2 Gain Ch2 Ovld Ch3 Gain Ch3 Ovld Freq. #
1 1 Tilt 21750 100 -9 -4     116 -16 6 4 0 4 0 4 1 1
1 1 Tilt 23400 78 -10 -6     21 -28 9 4 0 4 0 4 0 2
1 3 Tilt 21750 68 -1 -6     104 -10 6 4 0 4 0 4 0 1
1 3 Tilt 23400 56 -4 -8     21 27 7 32 0 32 0 32 1 2
1 5 Tilt 21750 100 2 -7     117 -9 6 4 0 4 0 4 0 1
1 5 Tilt 23400 84 1 -8     24 -18 5 32 0 1 0 1 0 2
1 7 Tilt 21750 99 11 -9     126 -4 6 4 0 4 0 4 0 1
1 7 Tilt 23400 79 9 -10     25 -13 5 32 0 32 0 32 1 2
1 9 Tilt 21750 98 16 -11     72 -11 8 4 0 4 1 4 1 1
1 9 Tilt 23400 82 17 -9     25 -14 7 16 0 16 0 16 0 2
1 11 Tilt 21750 99 27 -12     140 -10 5 4 0 4 0 4 0 1
1 11 Tilt 23400 87 23 -13     25 -18 3 4 1 4 0 4 1 2
1 13 Tilt 21750 100 35 -10     208 -7 2 1 0 1 0 1 0 1
1 13 Tilt 23400 98 32 -12     4 -12 1 1 0 1 0 1 0 2
1 15 Tilt 21750 99 -23 3     159 45 0 1 0 1 0 1 0 1
1 15 Tilt 23400 94 -23 4     4 -18 1 16 0 16 0 16 0 2
1 17 Tilt 21750 100 -49 13     161 -15 4 4 0 4 0 1 0 1
1 17 Tilt 23400 96 -53 15     16 -22 5 16 0 16 0 16 0 2
1 19 Tilt 21750 100 -38 15     141 -8 4 4 0 4 0 4 0 1
```

NOTE: txt files from TVLF do not contains elevation values (topography). If the user wants to include topography in his data it can be done as follows: i) input the txt files, ii) save the raw data file for each profil, iii) edit these files including the elevation values (by default the raw the values in the raw file are 0.00), iv) input the files for interpretation

8.1.6. Drill format

The format for files containing information about drill is as follows:

Name of well
X_UTM, Y_UTM, Z, Inclination, Azimuth
z1, z2, geology
z2, z3, geology
.....[15 levels are allowed]
END

Here it is an example:

```
drill1
  309260.0      6183632.      349.0000      0.0000000E+00    60.00000
  0.0000000E+00    200.0000      granite
  200.00000E+00    220.0000E+00   granite
  0.0000000E+00    0.0000000E+00  -
  0.0000000E+00    0.0000000E+00  -
  0.0000000E+00    0.0000000E+00  -
  0.0000000E+00    0.0000000E+00  -
  0.0000000E+00    0.0000000E+00  -
  0.0000000E+00    0.0000000E+00  -
  0.0000000E+00    0.0000000E+00  -
  0.0000000E+00    0.0000000E+00  -
  0.0000000E+00    0.0000000E+00  -
  0.0000000E+00    0.0000000E+00  -
  0.0000000E+00    0.0000000E+00  -
```

```
 0.0000000E+00   0.0000000E+00  -
 0.0000000E+00   0.0000000E+00  -
end
```

8.2. Topography (Elevation)

A topography file (elevation above sea level or any other reference) can be input to be included in the forward modelling (**and only for forward models**). For inversion, the topography should be included in the data file. The file should contain the elevation at each measuring site. The values (in meter) must be written in a row, like:

$z_1, z_2, z_3, \ldots\ldots z_N$

To build the model mesh the program will redefine the elevation values taking as reference the lowest elevation value. The models will display this new elevation where, z = 0 m corresponds to the lowest values of the inputted elevation.

8.3. Initial model

8.3.1 1D Initial model

The format for the file containing a 1D initial model is as follows:

NL
$d_1, d_2, \ldots d_{NL}$
$r_1, r_2, \ldots\ldots r_{NL}$

Where NL is the number of layers, d_i and r_i are the depth of the bottom of the layer-i (in meter m) and the resistivity (in ohm-m) of the i^{th}- layer, respectively. To impose the boundary conditions the program adds one more layer. The depth of the $(NL+1)^{th}$-layer is infinite, and its resistivity will be the same of layer NL.

Example of a file for a 5 layer medium where the resistivity decreases with depth:

5
10 20 35 50 100
200 100 50 20 10

Figure 53 displays the 2D model built from such file considering a flat topography.

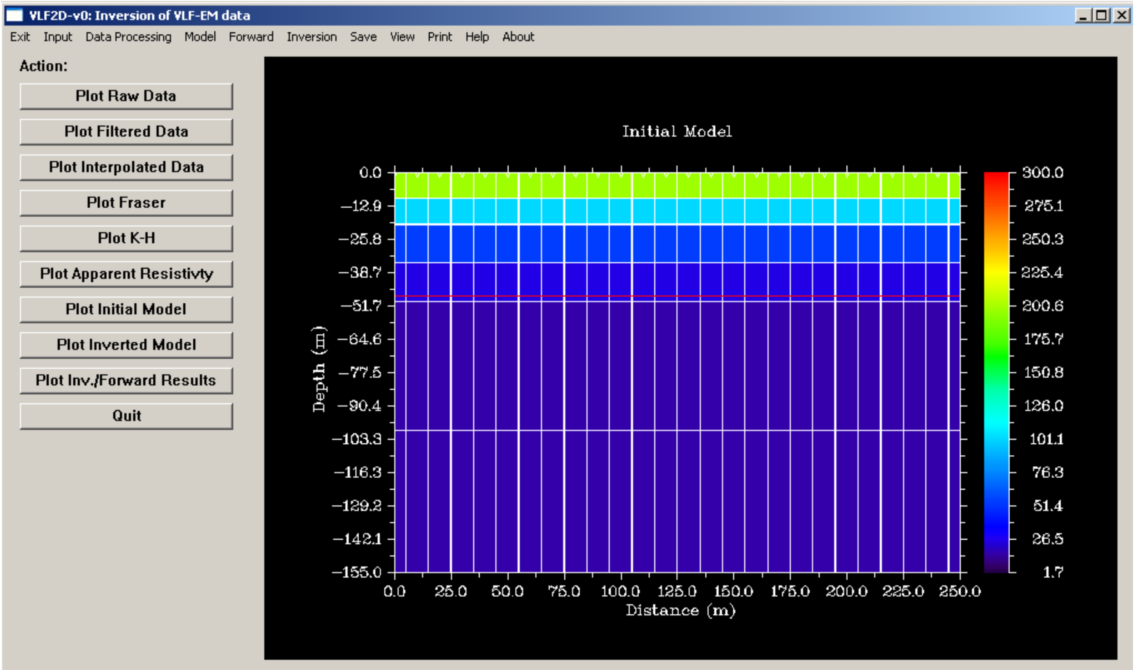


Figure 8.1. Example of a 2D initial model.

8.3.1 2D Initial model

Files for 2D model are necessarily more complex since must contain information about the cells mesh and topography, as well as information about the mesh for the finite element calculations.

NOTE: As this option is mainly to read files saved by the program, the user interested in building files for 2D models is invited to contact us.

8.3.2 2D Initial model (block map)

This option allows the user to define an initial model according to his needs. The user can define the number and dimensions of cells, the resistivity of each cell, the position of the cells relatively to the sites, etc. All the parameterization is defined in a file, where the earth is represented by rows and columns of cells. The format is as follows:

Nameofmodel
N,M
x_1, x_2,........, x_{n-1}, x_n
z_1,z_2,........,z_m
1 1 ....1 1
1 1 ....1 1
....
1 1 ....1 1
r_1, r_2,....,r_p

ere (N-1) and (M-1) are the number of cells in one row and in one column, respectively. xi, xi+1 are the horizontal limits of the cells in ith-column, zj, zj+1 are the vertical limits of the cells in the jth-row. The (N-1)x(M-1) matrix of integers represents the resistivity of each cell. The correspondent resistivity value is codified in the last row of the file: rj is the resistivity value of the cells assigned with j in the matrix of integers.

Example of a file defining a model containing two bodies (5 and 20 ohm-m) in a 100 ohm-m environment (Figures 54 and 55). The sites are localized between x = 0 and x = 100 m.

Model-map
14 10
-500 -300 -150 -50 0
20 40 60 80 100
150 250 400 600
0 20 40 60 80 100 150 200 300 450
1 1 1 1 1 1 1 3 3 3 3 3 3
1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 2 2 2 1 1 1 1 1 1 1
1 1 1 2 2 2 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1
100 5 20

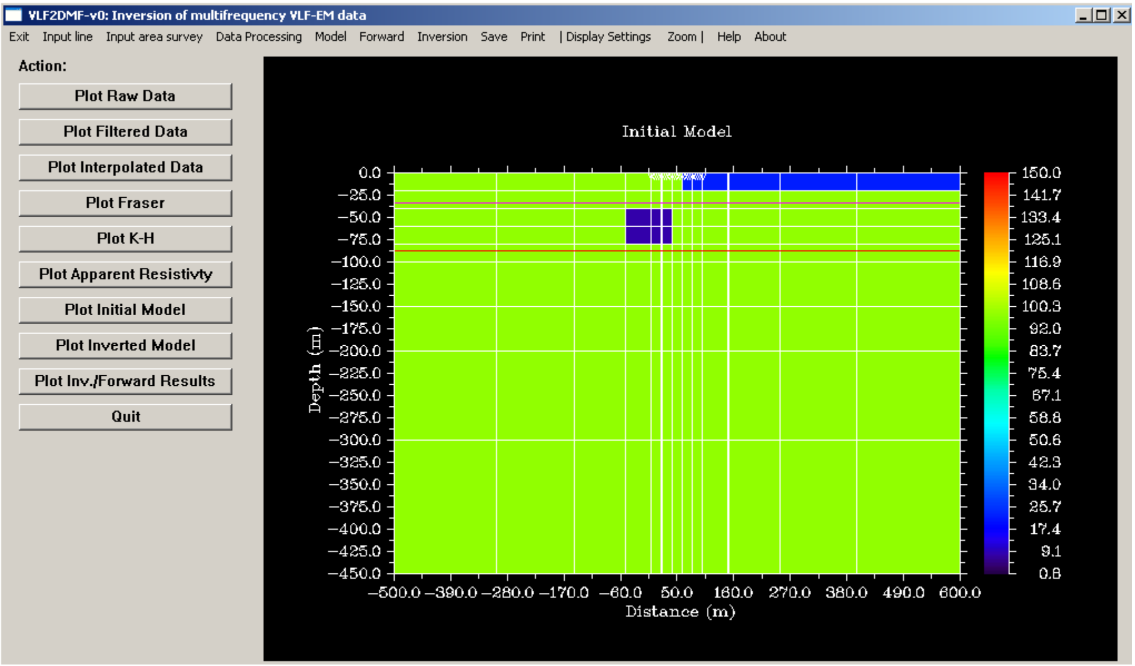


Figure 8.2. Full section of the model.

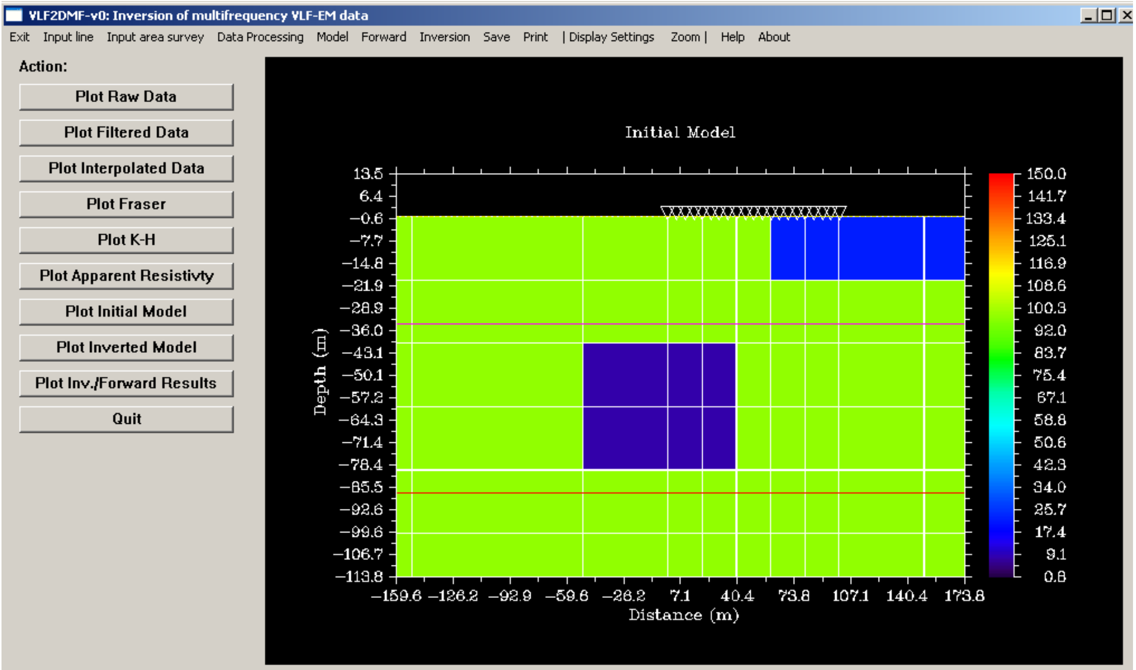


Figure 8.3. Zoom In of the model in the sites area.

9. Output Files Format

9.1. Data/Model response

The file containing the data/model response has a format as follow:

Dist Elev Prob Piob PRc PIc

N

d_1, z_1, Pro_{1F1}, Pio_{1F1}, Prc_{1F1}, Pic_{1F1}

…..

d_i, z_i, Pro_{iF1}, Pio_{iF1}, Prc_{iF1}, Pic_{iF1}

….

….

d_1, z_1, Pro_{1Fj}, Pio_{1Fj}, Prc_{1Fj}, Pic_{1Fj}

…..

d_i, z_i, Pro_{iFj}, Pio_{iFj}, Prc_{iFj}, Pic_{iFj}

Where N is the number of sites in the line, d_i is the distance along the line (in meter). Pro_{iFj} and Pio_{iFj} are the real and imaginary part of the tipper for frequency j and expressed in %. Subscript o indicates an observed value (measured) and the subscript c indicates a calculated value, z is the elevation (in meter).

Files saved with the option "Save Forward Response" have the same format of input data (see section 8.1)

NOTE: The output will be the real and imaginary tipper components, even if the data are the tilt angle and ellipticity.

9.2. Processed data (Filtered…)

This format is common to all processed and is as follow):

SITE:
Sitename
Type of processing

X, Y, dist, Elev, $PrProcF_1$, $PiProcF_1$,…… , $PrProcF_{NF}$, $PiProcF_{NF}$
....

Example of an output from Interpolation (one frequency):

SITE:
line3

Interpolated Data

X	Y	dist	elev	Re	Im
0.0000	20.0000	0.00	0.00	1.57	-3.15
5.0000	20.0000	5.00	0.00	1.88	-3.36
10.0000	20.0000	10.00	0.00	2.20	-3.56
15.0000	20.0000	15.00	0.00	2.61	-3.77
20.0000	20.0000	20.00	0.00	3.01	-3.98
25.0000	20.0000	25.00	0.00	3.53	-4.17
30.0000	20.0000	30.00	0.00	4.04	-4.36
35.0000	20.0000	35.00	0.00	4.68	-4.52
40.0000	20.0000	40.00	0.00	5.33	-4.68
45.0000	20.0000	45.00	0.00	6.11	-4.77
50.0000	20.0000	50.00	0.00	6.88	-4.86
55.0000	20.0000	55.00	0.00	7.77	-4.83
60.0000	20.0000	60.00	0.00	8.66	-4.80

Example of an output from Interpolation (3 frequencies):

SITE:
F-TEST-L1

Filtered Data

X	Y	dist	elev	Re	Im	...			
0.0000	0.0000	0.00	0.00	1.64	-1.36	2.37	-1.00	3.06	-0.09
5.0000	0.5000	5.02	0.00	2.00	-1.34	2.62	-0.86	3.16	0.04
10.0000	1.0000	10.05	0.00	2.36	-1.28	2.84	-0.69	3.22	0.17

15.0000	1.5000	15.07	0.00	2.66	-1.13	2.98	-0.50	3.20	0.30
20.0000	2.0000	20.10	0.00	2.78	-0.92	2.95	-0.32	3.05	0.38
25.0000	2.5000	25.12	0.00	2.51	-0.68	2.61	-0.21	2.66	0.36
30.0000	3.0000	30.15	0.00	1.62	-0.50	1.79	-0.27	1.95	0.17
35.0000	3.5000	35.17	0.00	0.23	-0.38	0.58	-0.48	0.98	-0.15
40.0000	4.0000	40.20	0.00	-1.18	-0.25	-0.65	-0.67	-0.03	-0.48
45.0000	4.5000	45.22	0.00	-2.09	-0.02	-1.53	-0.69	-0.83	-0.66
50.0000	5.0000	50.25	0.00	-2.41	0.31	-2.00	-0.51	-1.37	-0.66
55.0000	5.5000	55.27	0.00	-2.37	0.65	-2.21	-0.24	-1.75	-0.56
60.0000	6.0000	60.30	0.00	-2.18	0.94	-2.29	0.06	-2.04	-0.43
65.0000	6.5000	65.32	0.00	-1.95	1.16	-2.31	0.35	-2.27	-0.29
70.0000	7.0000	70.35	0.00	-1.70	1.32	-2.27	0.60	-2.45	-0.15
75.0000	7.5000	75.37	0.00	-1.44	1.41	-2.19	0.82	-2.58	-0.02
80.0000	8.0000	80.40	0.00	-1.18	1.44	-2.06	1.00	-2.64	0.11
85.0000	8.5000	85.42	0.00	-0.92	1.42	-1.89	1.15	-2.66	0.23
90.0000	9.0000	90.45	0.00	-0.69	1.36	-1.71	1.25	-2.63	0.34
95.0000	9.5000	95.47	0.00	-0.48	1.26	-1.51	1.32	-2.56	0.43
100.0000	10.0000	100.50	0.00	-0.30	1.15	-1.32	1.36	-2.47	0.51

9.3. Final Model-option (X,Y,Z)

The file of the final model contains the coordinates (easting, northing, dist, reduced elevation, elevation, topography, resistivity) of each cell and the respective resistivity (in ohm-m). The format is as follow:

$x_1, y_1, d_1, re_1, e_1, t_1, r_1$
$x_2, y_2, d_2, re_2, e_2, t_2, r_2$
…………
$x_i, y_i, d_i, re_i, e_i, t_i, r_i$
…………
$x_M, y_M, d_M, re_M, e_M, t_M, r_M$

Where M is the number of cell in the model, x_i and y_i are the easting and northing coordinates (in meter), d_i is the coordinate along the profile, re_i is the elevation of the centre of the cell referred to the minimum value of topography, e_i is the elevation of the centre of the cell, t_i is the topography (altitude) of site *i* and r_i is the resistivity in ohm-m) of the ith-cell.

NOTE: This file can be used as input file in any graphical program.

NOTE: This file can be inputted in VLF2D Map module to draw horizontal slices of resistivity from calculated models.

NOTE: In an area survey, files of the inverted models of each line can be imported in the VLF2D-Module map to draw a 2D view of the resistivity variations.

9.4. Batch file (*.BATm)

The file contains the information about the files to invert and which parameters should be used in the inversion. The information corresponding to the different files appears in sequence. The format is:

Number of files
Number of order of the file
Path and name of the file
Type of data format
Damping factor
Inphase Error
Quadrature Error
Algorithm1
Algorithm2
Number of iterations
Rms (=0. before the inversion)
…….
(This information is repeated for each file)

Example of a batch file:

```
        2
        1
D:\VLF2Dmf\\GEMsystem\8042728_V.txt
gem
 3.000000
 2.0000000E-02
 2.0000000E-02
 YE
 NO
        5
 0.0000000E+00
        2
D:\VLF2Dmf\obWADI.txt
InQ
 3.000000
 2.0000000E-02
 2.0000000E-02
 YE
 NO
        5
 0.0000000E+00
```

10. Common Errors that must be avoided

- The format of the input files must be strictly followed.

- Confirm if the signal of your data need to be changed.

- Close all screens displaying the OK button clicking on it. If you do not want to proceed go to the EXIT option and click OK.

- When filling the boxes in the screen, follow the displayed format.

- Use only data of good quality in the inversion. The final model greatly depends on the quality of your data. With low quality data one cannot expect a high quality final model.

- Perform several inversions with different parameters. Do not accept is a final model the first run.

- To avoid errors, it is advisable to save the inversion final models with a different extension. For example, you can save the inversion files in format XYZ with the extension XYZ and those files in format VLF2D with extension iVLF.

APPENDICE A. Processing the data

The data can be filtered using a three-point moving average method. This averaging action removes the high frequency components present in the data.

The data can be interpolated using a linear approximation. In the majority of the cases a linear interpolation is more realistic than more sophisticated method like those based on splines or polynomial techniques. The interpolation factor (n) represents the number of values that will be "created" between two contiguous ones on the original data set. The interpolated data will have (N+n(N-1)) values, where N is the number of values in the original data.

Fraser filter is a four-point weight average filter. The weights are defined in accordance with the reference system. In this package they are +1, +1, -1, -1. This filter operates over real and imaginary components of the tipper.

Karous-Hjelt filter operates over the real part of the data (inphase component) in order to obtain a pseudo-section of the equivalent current distribution responsible for producing the measure magnetic field. The magnitude of the output depends on the apparent current density, which is unknown. The values in the pseudo section are then arbitrary. Its interpretation is generally as follows: a) areas of positive values correspond to good conductors; b) areas of negative values correspond to high resistive zones; c) the trend of the contour pattern gives indications about the dip of the conductors. In this package the K-H weights are: 0.102, -0.059, 0.561, -0.561, 0.059, -0.102.

APPENDICE B. Topography

The topography is incorporated through a distortion of the finite element mesh.

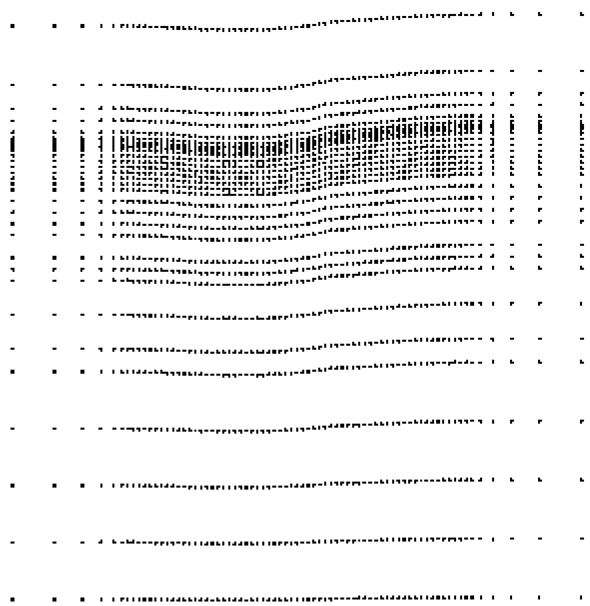


Figure B1. Example of a distorted mesh to incorporate a smooth elevation (a hill).

The original elevation is shifted taking as reference the lowest value, which assumes the value 0.

NOTE: steep elevation should be avoided (or smoothed) in order to prevent numerical errors.

APPENDICE C. Inversion algorithm

The nonlinear, smoothness-constrained inversion algorithm described by Monteiro Santos (2004) was adopted. The optimization equations are represented as follows (Sasaki, 1989; named algorithm S89 in this package):

$$\left[\left(\mathbf{J}^{\mathrm{T}}\mathbf{J}+\lambda\mathbf{C}^{\mathrm{T}}\mathbf{C}\right)\right]\delta\mathbf{p}=\mathbf{J}^{\mathrm{T}}\mathbf{b} \qquad \text{[C-1]}$$

or (Sasaki, 2001; named algorithm S01 in this package),

$$[(\mathbf{J}^{\mathrm{T}}\ \mathbf{J}+\lambda\mathbf{C}^{\mathrm{T}}\ \mathbf{C})]\ \delta\mathbf{p}=\mathbf{J}^{\mathrm{T}}\ \mathbf{b}-\lambda\mathbf{C}^{\mathrm{T}}\ \mathbf{C}\ (\mathbf{p}-\mathbf{p}_{\mathrm{o}}) \qquad \text{[C-2]}$$

where $\delta\mathbf{p}$ is the vector containing the corrections applicable to the parameters (logarithm of block conductivities, p_j) of an initial model, $\mathbf{p}_{\mathrm{o}}$ is a reference model, $\mathbf{b}$ is the vector of the differences between the observed and calculated tipper components [$\mathbf{b}$ = ($\mathbf{T}^{\mathrm{o}}$) – ($\mathbf{T}^{\mathrm{c}}$)], $\mathbf{J}$ is the Jacobian matrix whose elements are given by $(\sigma_j)(\partial \mathrm{T}_i^{\mathrm{c}}/\partial\sigma_j)$, the superscript T denotes the transpose operation, and λ is a Lagrange multiplier (Damping factor) that controls the amplitude of the parameter corrections and whose best value is determined empirically. The value can be determined empirically by comparing the models calculated using different values with the available information. The elements of the matrix **C** are the coefficients of the values of the roughness in each parameter, which is defined in terms of the four neighbours parameters. The elements of **C** are -4, 1, or 0. An iterative process allows the final model to be obtained, with its response fitting the data set in a least square sense.

The misfit between data and model response is calculated by:

$$rms=\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(d_i^o-d_i^c\right)^2} \qquad \text{[C-3]}$$

where N is the number of data values, σ the error on the data and d the data (real and imaginary components).

APPENDICE D. Empirical Mode Decomposition

There are several tools to analyse a signal. The most known is (probably) the Fourier decomposition, where, a signal is decomposed into components which are monochromatic sinus and/or cosines. The Empirical Mode Decomposition (EMD) is a technique introduced by N.E. Huang (Huang 1998) that decomposes a signal $x(t)$ into functions, the called Intrinsic Mode Functions (IMF) $c_i(t)$ that are not single frequency components, and into a residue $r(t)$,

$$x(t) = \sum_{i=1}^{N} c_i(t) + r(t) \qquad \text{(D1)}$$

where N is the number of IMF functions. IMF functions are signals with the following characteristics (Trnka and Hofreiter, 2011):

- The number of extremes and the number of zero-crossing must either be equal or must differ by a maximum of one.
- Each point, that is defined as mean value of envelopes defined by local maxima and local minima is zero.

The EMD method was applied to VLF-EM data by Jeng et al. (2007, 2012) and the user is referred to these papers for a more detailed discussion.

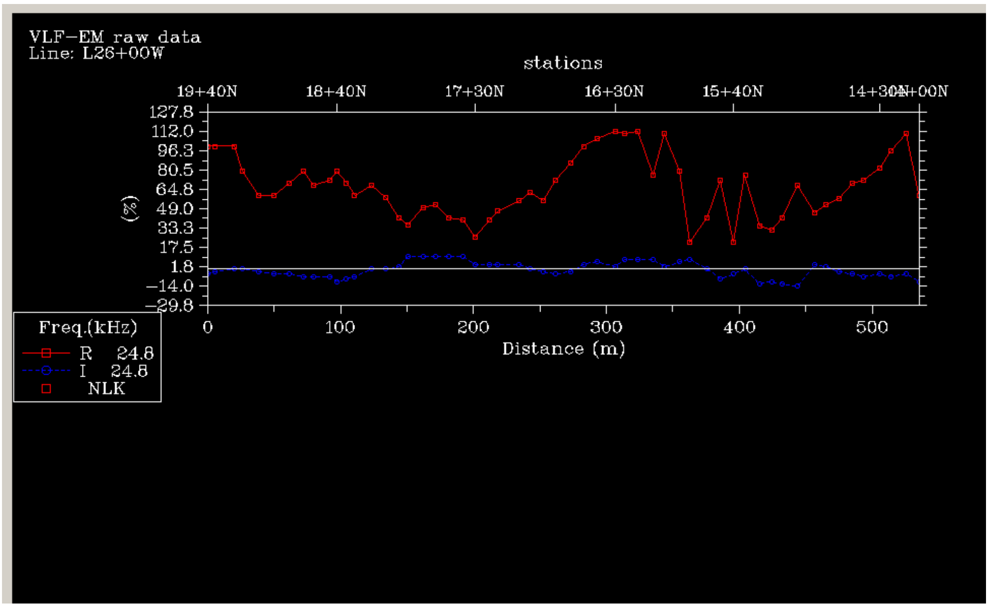


Figure D1. Example of a VLF-EM signal.

An example of EMD application is presented in Figures D2 and D3.

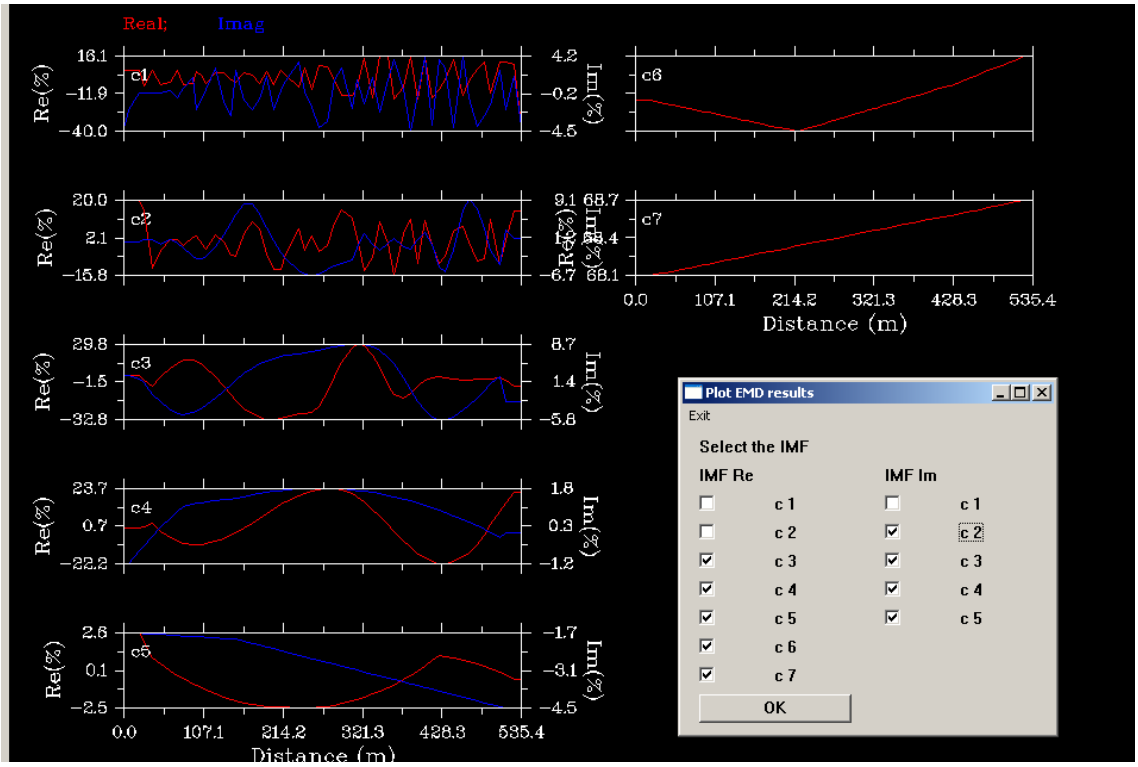


Figure D2. EMD of the VLF signals shown in Figure D1. The Re part of the signal was decomposed in seven IMF and the Im part only in five IMF functions. The last IMF represents the residue.

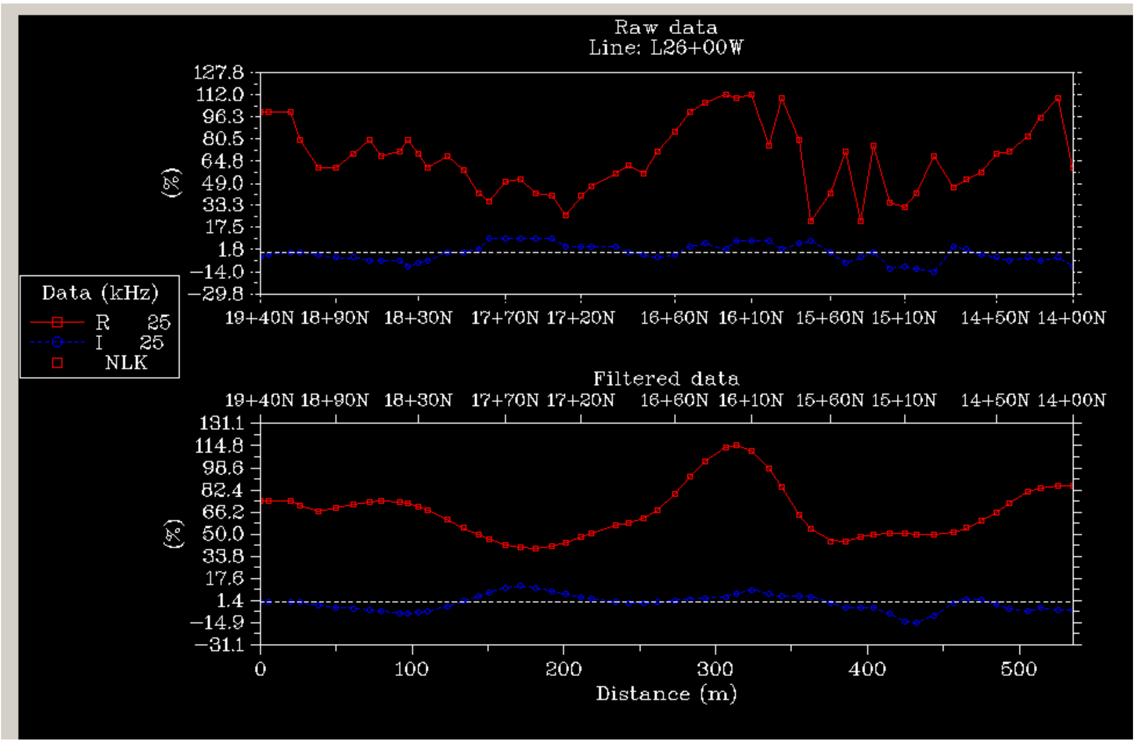


Figure D3. The filtered signal considering that it is composed by some selected IMF functions (as shown in Figure D2).

APPENDICE E. FILES/EXAMPLE

File SurveyinArea.txt is an example of a data file of three lines acquired in an area with a smooth topography. Figures E1-4 below show the site location, data and elevation. The file dataline3.txt is the data of line 3. The data are synthetic and was generated from the models shown in Figures E5-7 (from south to north, respectively).

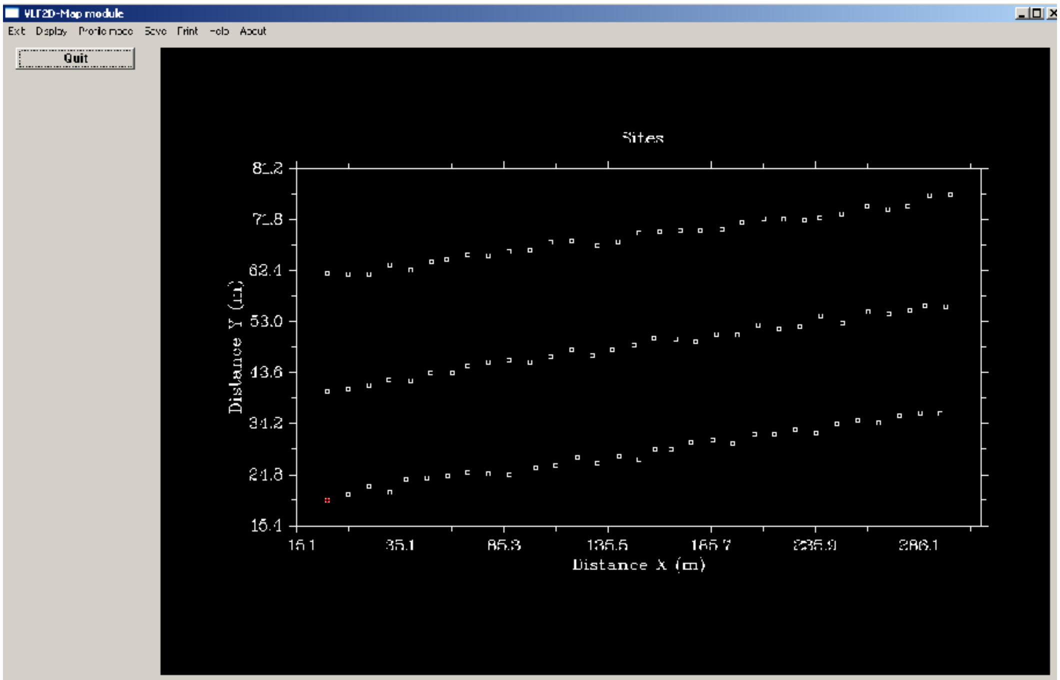
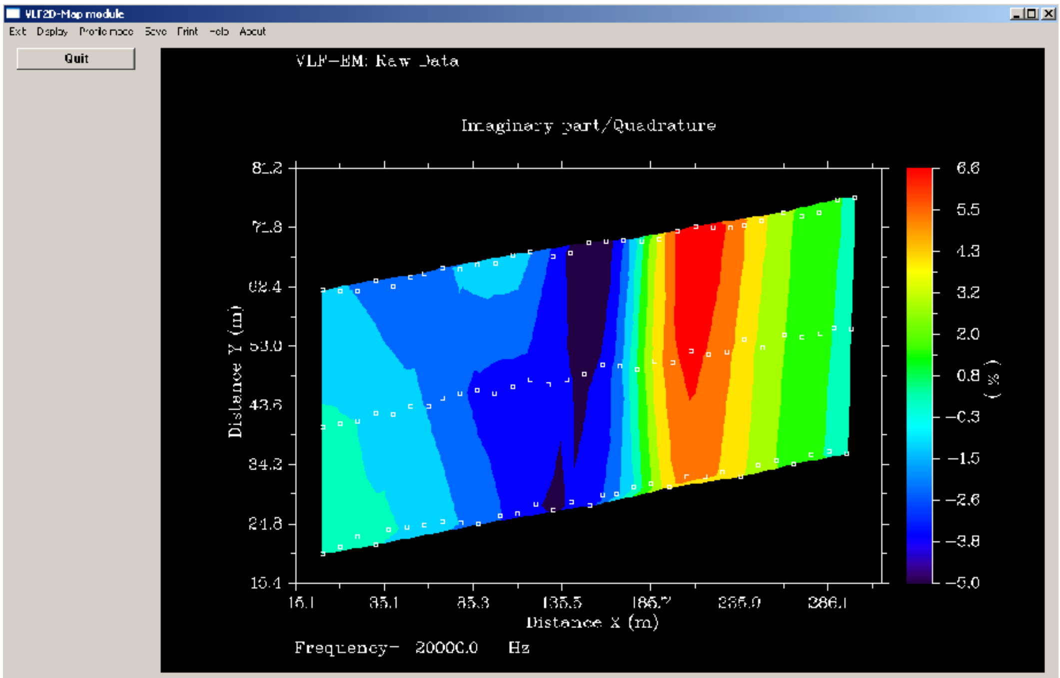


Figure E1. Location of the sites. Line 1 is the southmost line.



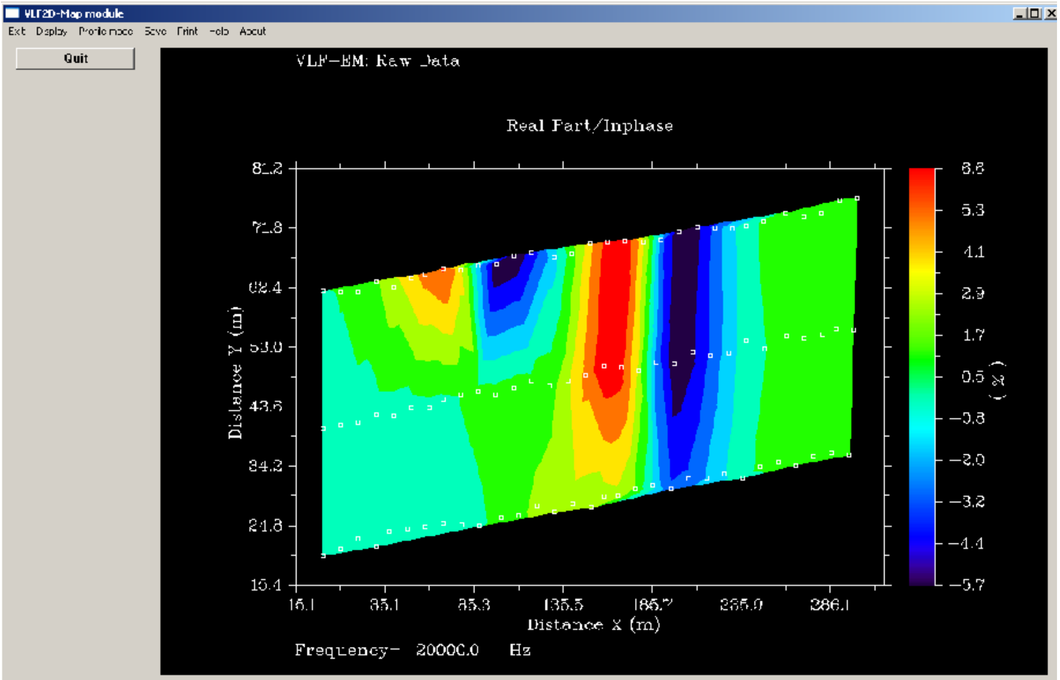


Figure E2 and E3. Map of the data.

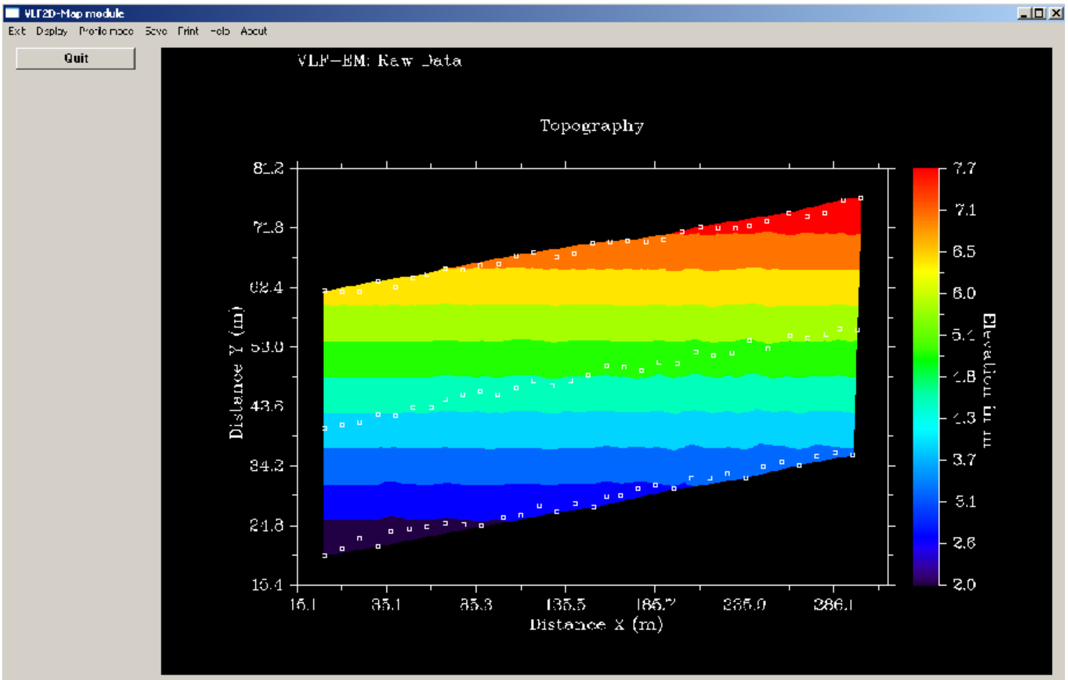


Figure E4. Elevation of the area.

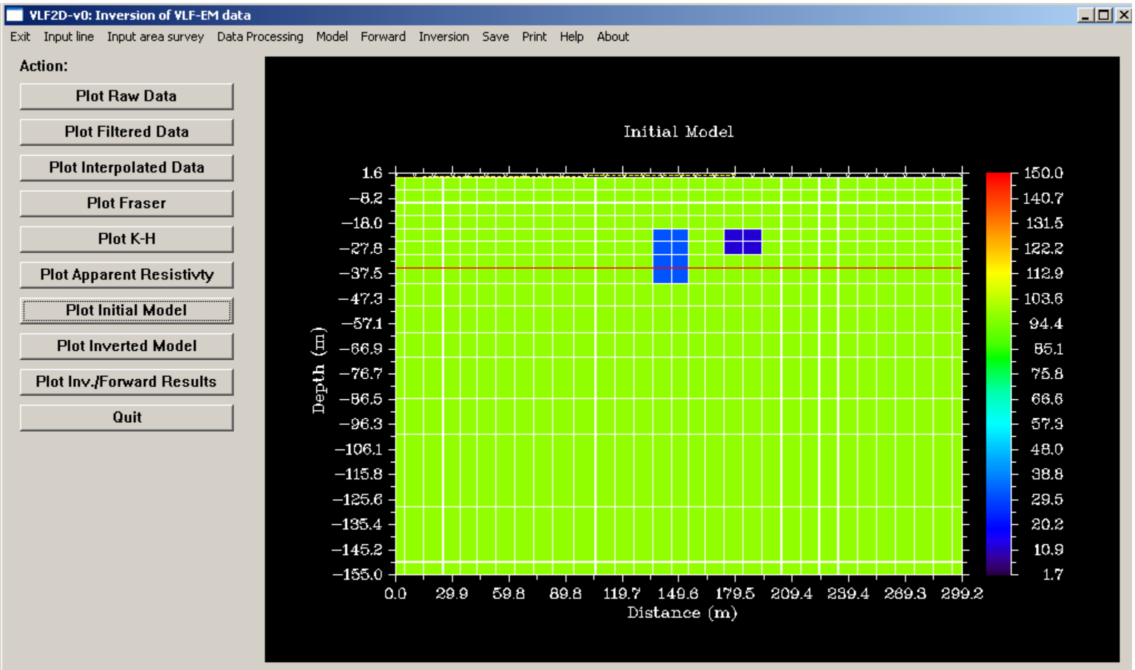
File TestedataLine.txt is an example of data acquired in a profile (line) in an area of flat topography.

DATATESTmf.txt is an example of data acquired with three frequencies (synthetic data).

Topo.txt is an example of a file of elevation to be used in a forward calculation with 60 sites. The topography is a hill followed by a valley.

modelTest1D.txt is an example of a file with 1D model that be used to build an initial model for inversion.

modelTest2D.txt is an example of a file containing a 2D model for forward calculations using frequencies of 25, 16 and 5 kHz.



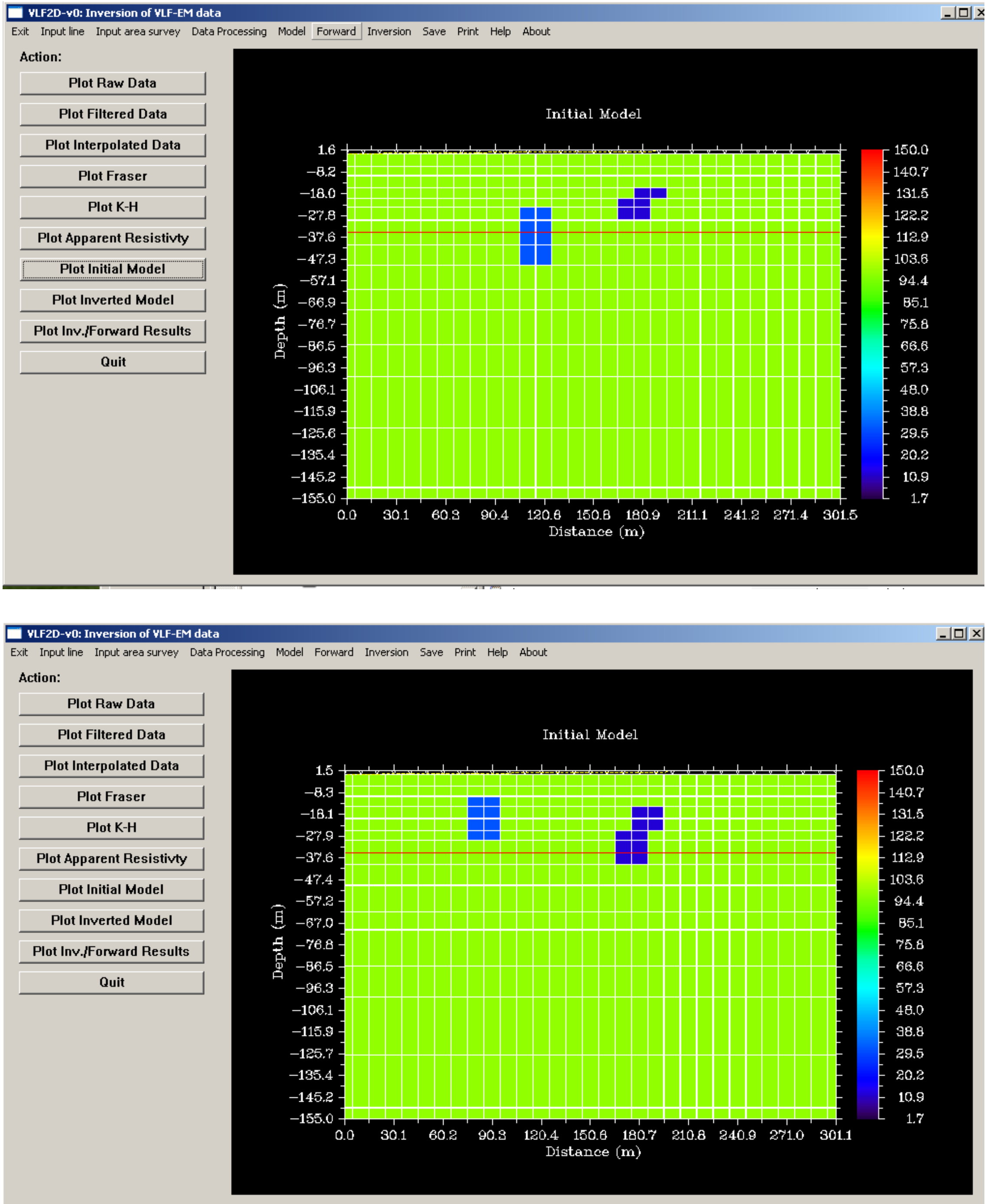


Figure E5-E7. Models used to generate the data of this example (top-line 1, bottom-line 3).

Field example from Baranwal et al. (2011) paper.

Baranwal and his co-authors presented an inversion model obtained from VLF-EM data collected in Braünsdorf region. The area has a smooth topography. We re-sampled the data from the figure shown in the article and inverted it. The sites where acquired at a spacing of 20 m. Figure D8 shows the obtained model. In our model the coordinate 0 corresponds to the -100 one in the Baranwal 's model.. One of the models present in the article is shown in Figure D9.

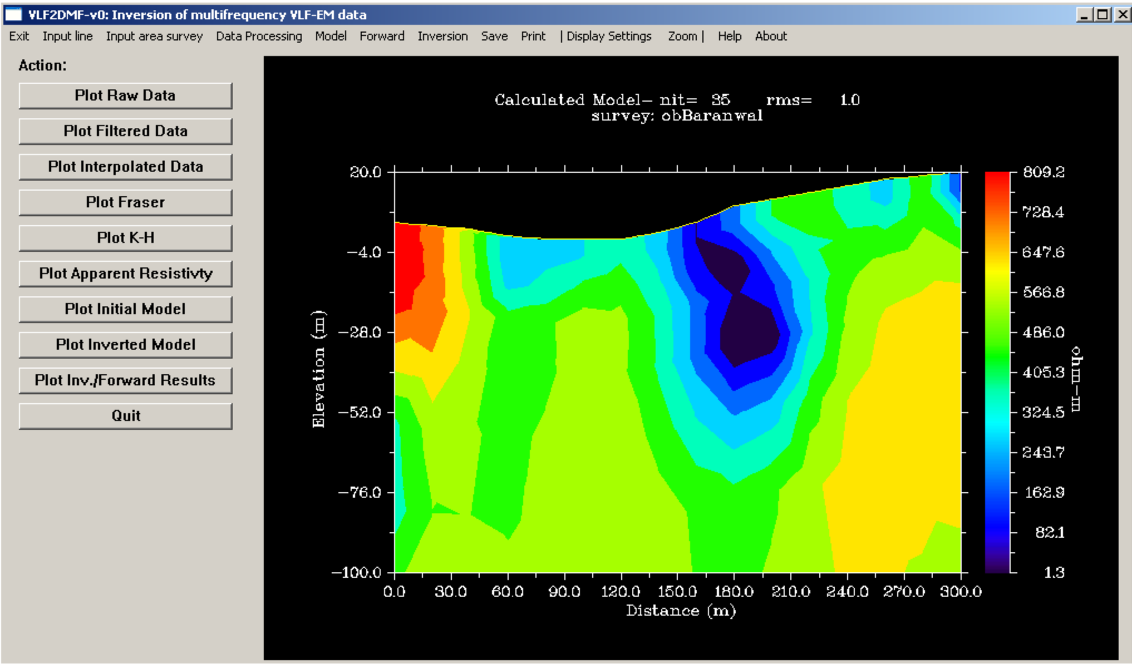


Figure E8. Model obtained from a re-sample of Baranwal et al (2011) data and obtained after 35 iterations using a 500 ohm-m uniform initial model (default mesh) and the default inversion parameters.

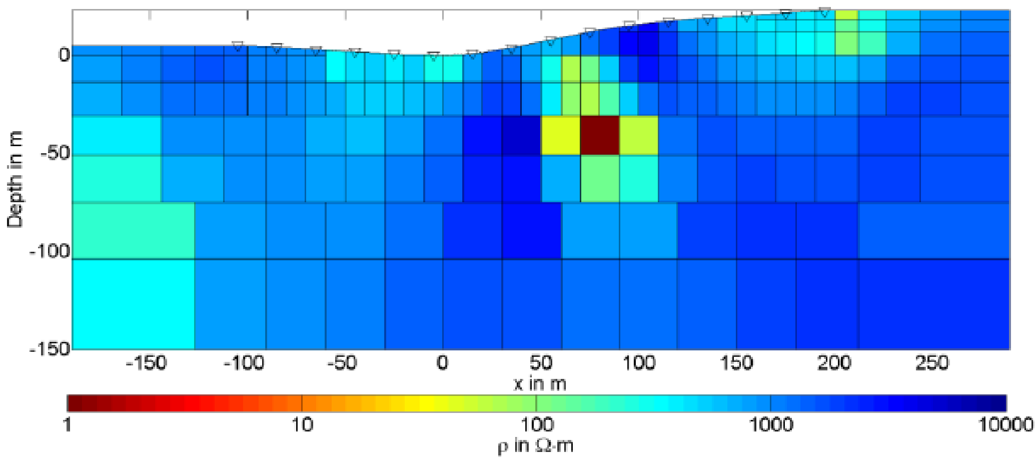


Figure E9. One of the models presented by Baranwal et al (2011).

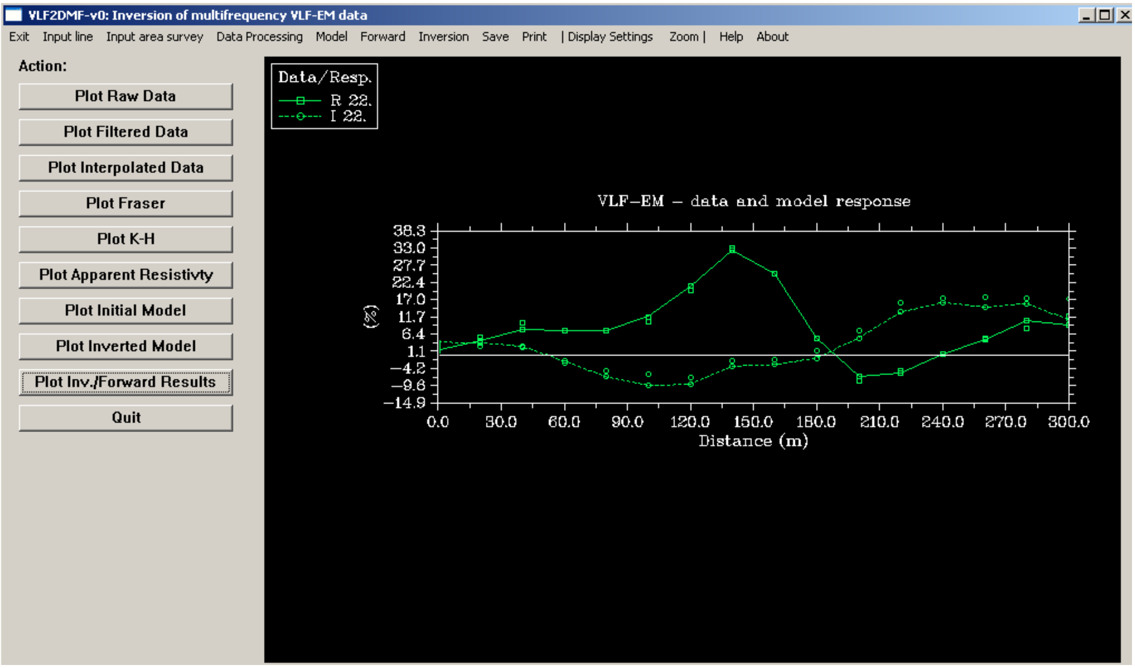


Figure E10. Data and model response.

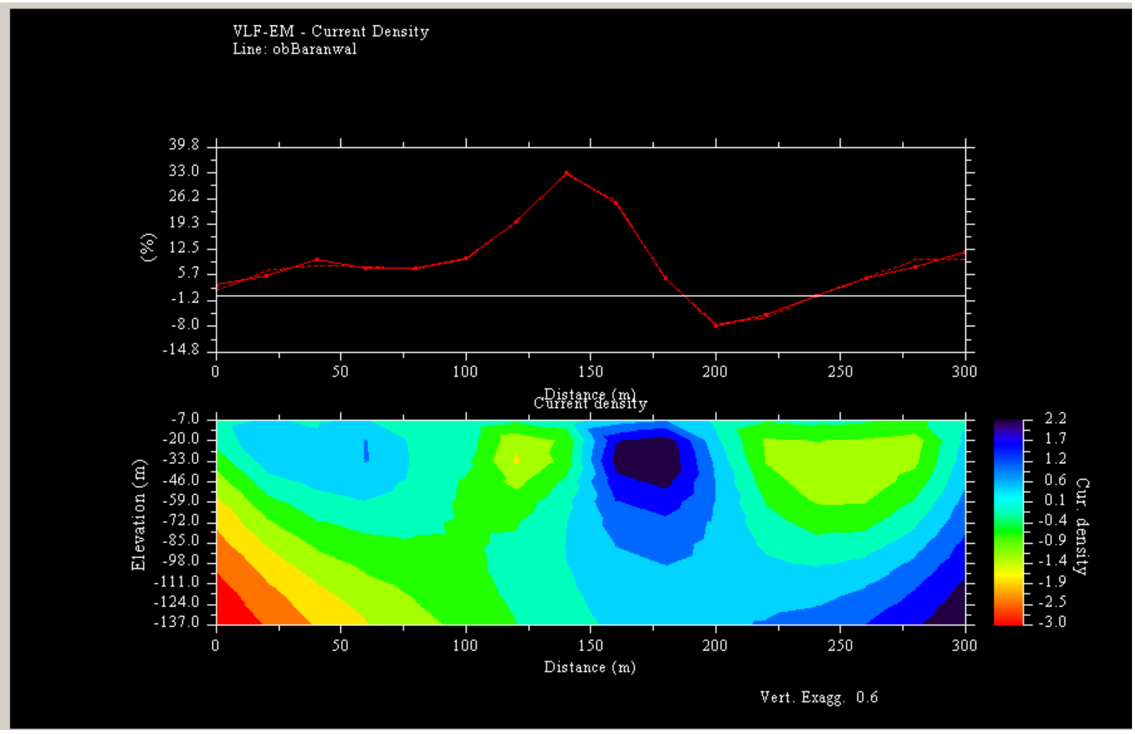


Figure E10a. Current density model for the same data.

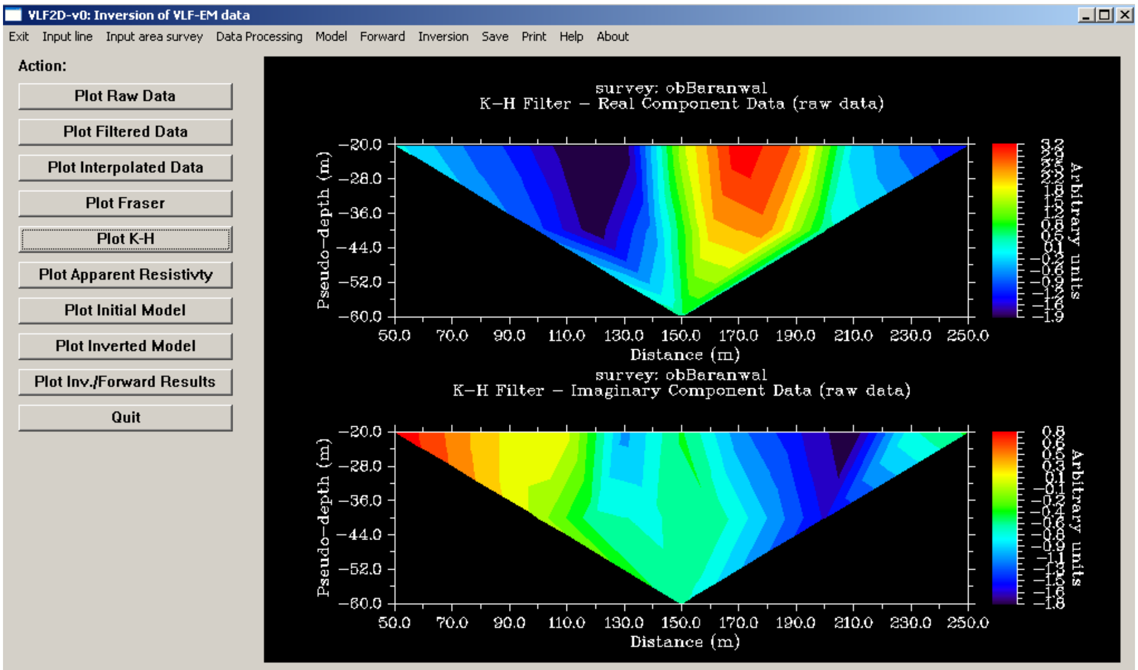
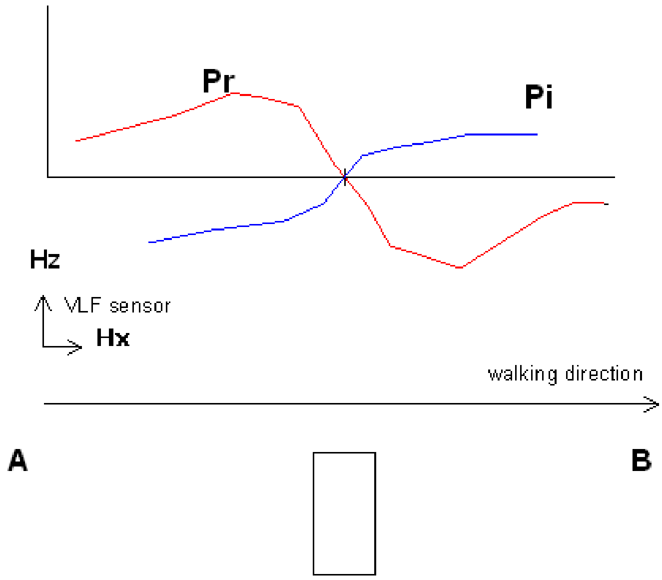


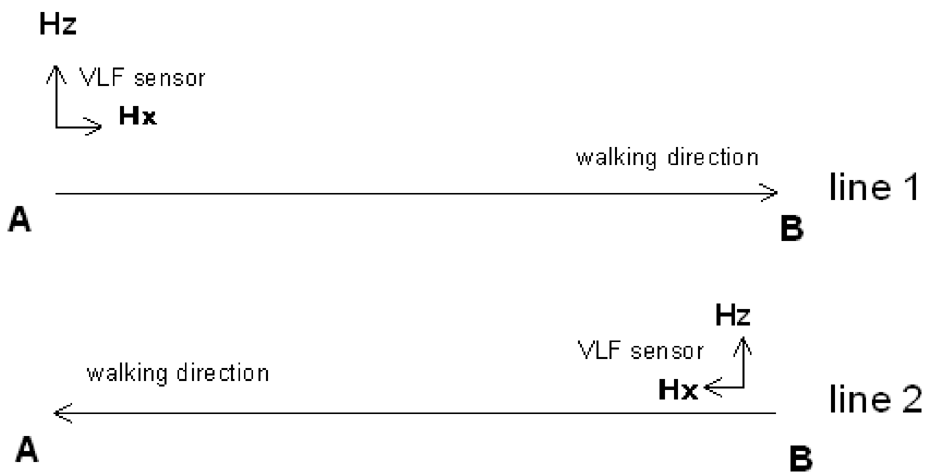
Figure E11. The K-H pseudo-section for the same data.

APPENDICE F. Inverting VLF lines

VLF2Dmf software assumes the "normal" VLF signal, over a conductive isolated body, is that described in the following figure. Usually, A and B represent South and North or to West and East, respectively.



In this case the data (in sequential order from A to B) the data can be imported and inverted and the model will display A on left and B on right.
It is common to acquired data in parallel lines. In such case it is also usual to reverse the VLF signal in order to have consistency between the signals of the different lines. Let's consider the situation in the following figure, where the signal in line 2 was reversed (it is assumed the data file are contains the values ordered sequential according to the acquisition).



Inversion of the line 1 is made "normally". However, for line two there are two options according to the final output.

1- Model displayed from B to A (that is B will appears on left and A on right). Because the vlf signal was reversed it needs to be reversed again (use the tool reverse signal and reverse both components), and then the inversion can be done.

2- Model displayed from A to B (A on left and B on right). In VLF2Dmf program this can be done in 2 steps: i) reverse both signal and ii) reverse the model. After that the inversion can be calculated.

APPENDICE G- Reading GEM files with VLF2Dmf-v106 (All) option

The following formats can be read with this option:

File containing line (x), station (y), frequency (kHz), inphase (ip) and outphase (op):

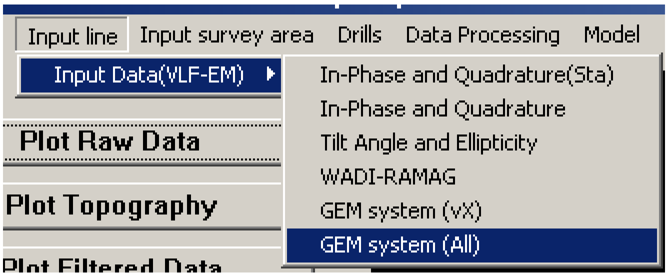
```
Append with new capture

/Gem Systems GSM-19 7017716 v7.0 4 X 2016 M e1v~v7
/ID 1 file 21yy    .v3  28 IV 17
/
/ time x y slope n*[kHz ip op h1 h2 pT]
131254.0 00000S  0000000 W   0000E  16.4 -032.5 +022.8  054 -004 005.11 19.6 -026.1 +011.4  104  046 008.93 23.4 +001.7 +000.3  083  017 022.10
131357.0 00000S  0000005 W   0000E  16.4 -036.1 +023.2  054 -006 005.10 19.6 -024.5 +013.1  103  047 008.86 23.4 +001.2 +001.3  083  017 022.13
131440.0 00000S  0000010 W   0000E  16.4 -034.4 +023.3  053 -005 005.02 19.6 -025.2 +011.8  105  049 009.05 23.4 -000.4 +003.3  084  015 022.44
131559.0 00000S  0000015 W   0000E  16.4 -034.0 +021.5  054 -006 005.08 19.6 -026.9 +011.8  107  047 009.13 23.4 +001.7 -000.4  082  016 021.98
131632.0 00000S  0000020 W   0000E  16.4 -032.5 +022.0  054 -005 005.08 19.6 -029.2 +012.0  102  041 008.65 23.4 +000.0 +001.5  083  015 022.08
```

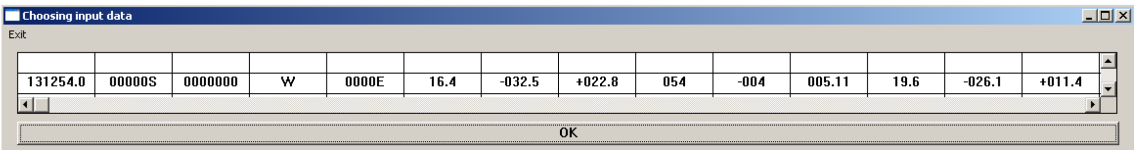
File containing Longitude (x), Latitude (y), elevation, frequency (kHz), inphase (ip) and outphase (op):

```
/Gem Systems GSMP-35GV 612410C v7.0 26 IV 2017  ekv6l~v7o
/ID 1 file 01survey.v3  01  V 17
/UTC-13 18L
/GPS datum WGS84
/
/x y elevation sat slope n*[kHz ip op h1 h2 pT]
line  999999
-013.1675029 -074.2267522  002740 06 0015N  21.4 -200.0 +200.0  000  000 000.23 19.6 +127.2 -028.8  000  000 000.31 16.4 +010.0 +200.0  000  000 000.23  000656.0
-013.1675097 -074.2267554  002741 06 0015N  21.4 +136.5 -059.4  001  002 000.39 19.6 +076.5 -034.5  000  002 000.36 16.4 +065.8 +047.5  000  002 000.46  000827.0
-013.1675459 -074.2267748  002751 05 0015N  21.4 +085.7 -078.0  004  005 000.49 19.6 +051.6 -045.4  001  006 000.48 16.4 -011.0 +032.5  002  006 000.62  001007.0
-013.1675306 -074.2267681  002746 05 0015N  21.4 +059.0 -063.8  011  012 000.59 19.6 +074.7 -047.0  002  012 000.50 16.4 +026.5 +014.3  003  012 000.60  001128.0
```

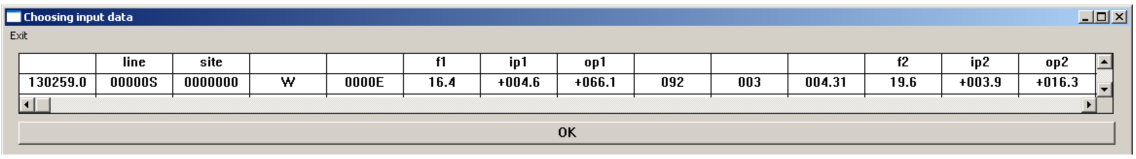
To read:
- first, confirm that the file does not have wrong values and is on the right format;
- input the file

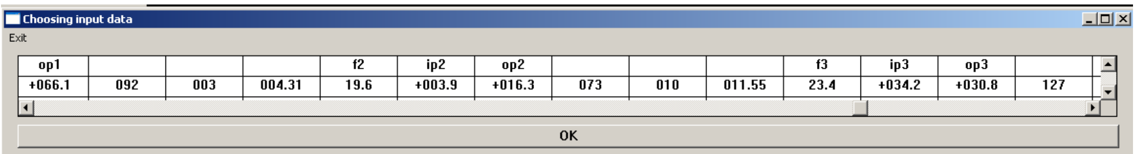


The program will display a table with the first row of your data file.



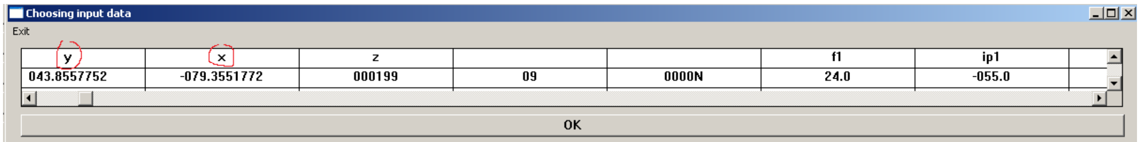
Choose the columns that correspond to the fields you want, typing in the top cells at what they correspond (see below). In these files you have lines, sites of measurement, (do not have elevation) and 3 frequencies; f1, f2, f3. For each frequency you must get the inphase (ip) and outphase (op) fields, only.



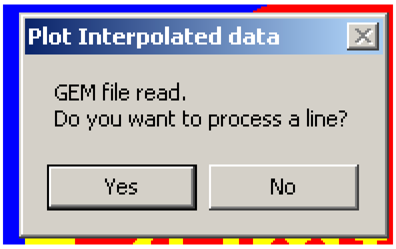


For the other format (coordinates, elevation, VLF data) one have,

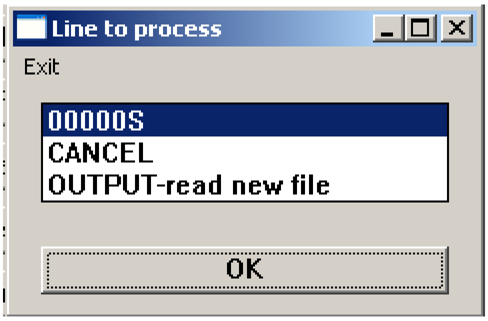
Take care when assign X (longitude-eastern) and Y (Latitude-northern) columns



After the input, you must choose a line for interpretation

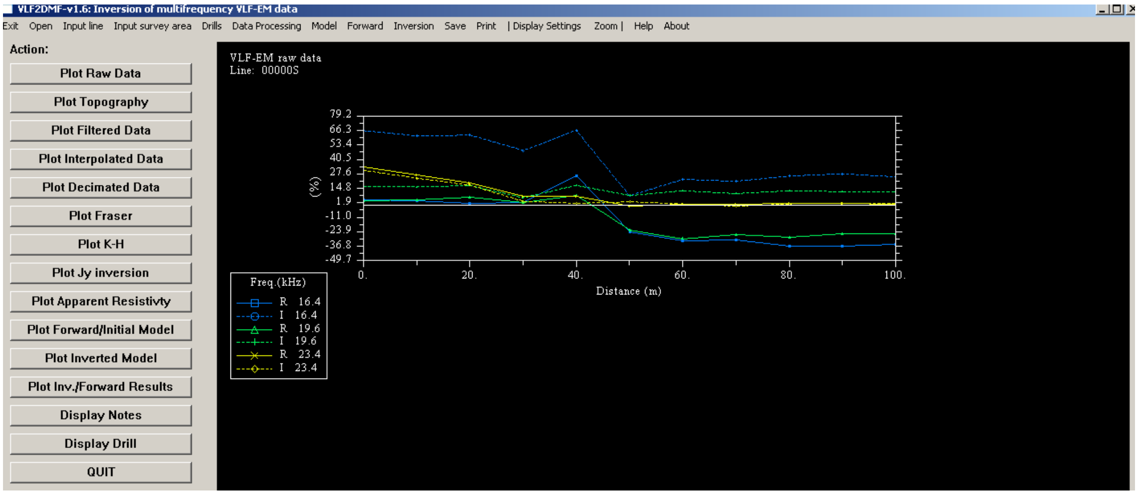


There is 1 line in this file.

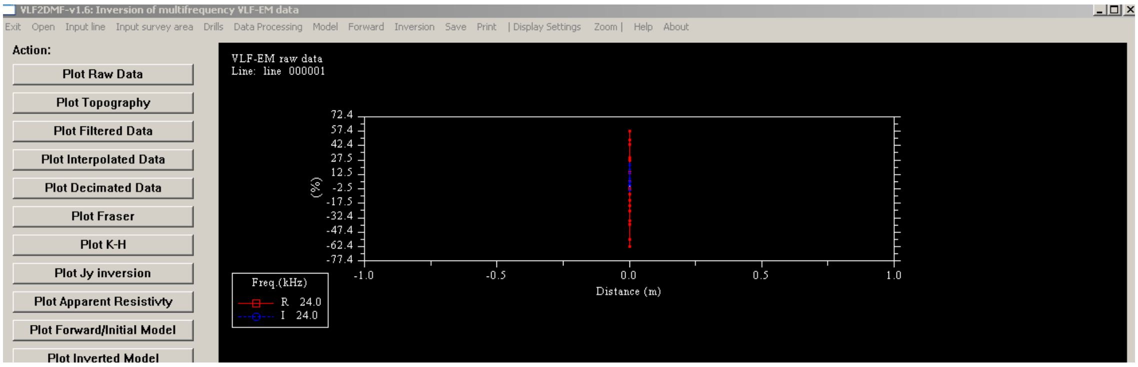


And you'll get the data

,



If the X and Y data are Longitude and Latitude the display will like this,



Because the coordinates are not in UTM

Names for columns selection:
Case 1-
Line (or line or l) for lines; site (or s) for stations;
Z (z) for elevation (elevation will be put a zero, if not in the file);
F (or f) , ip and op for frequency, inphase and outphase followed by 1, 2 and 3.

Case 2- x,y,z coordinates
If the data contains coordinates (x UTM-eastern or Longitude, y UTM-northern or Latutude) they must be named by X (or x) and Y (or y).

If the coordinates are not UTM thy must be converted. After the data input and line selection save the as raw data. This saved file must be read (imput line ->inphase&quadrature) and the coordinates must be converted in UTM.

References and useful bibliography

Baranwal, Vikas C., Franke, Antje, Borner, Ralph-Uwe, Spitzer, Klaus, Unstructured grid based 2D inversion of VLF data for models including topography, *Journal of Applied Geophysics* (2011), doi: 10.1016/j.jappgeo.2011.07.011

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