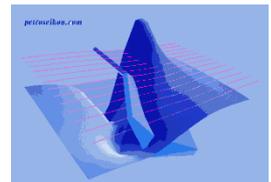


FDEM INVERSION TUTORIAL

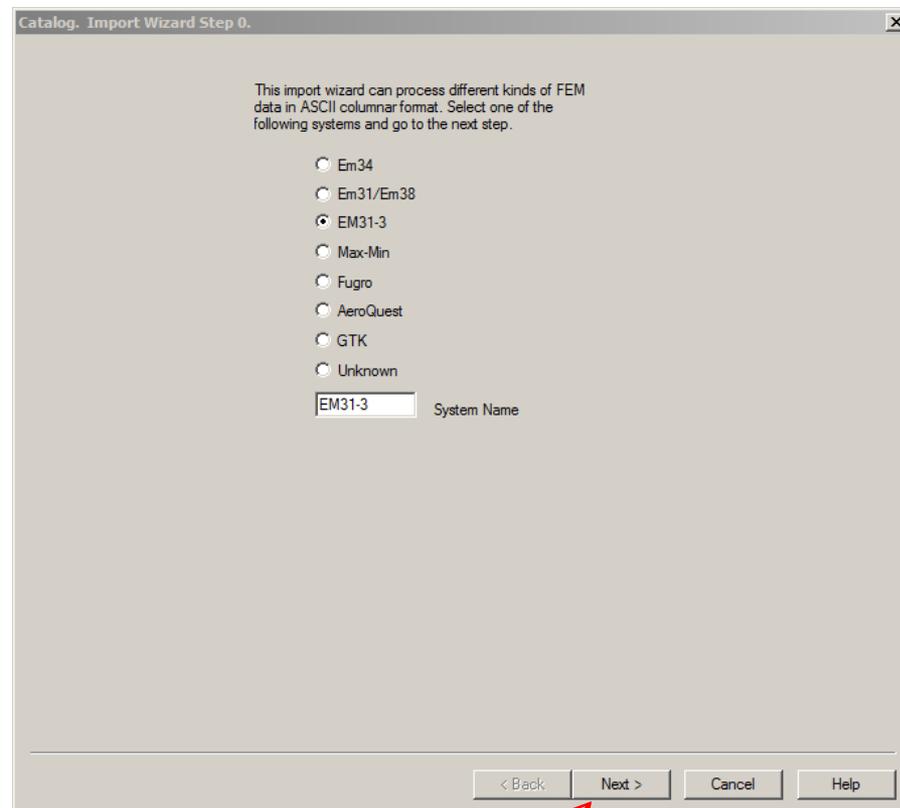
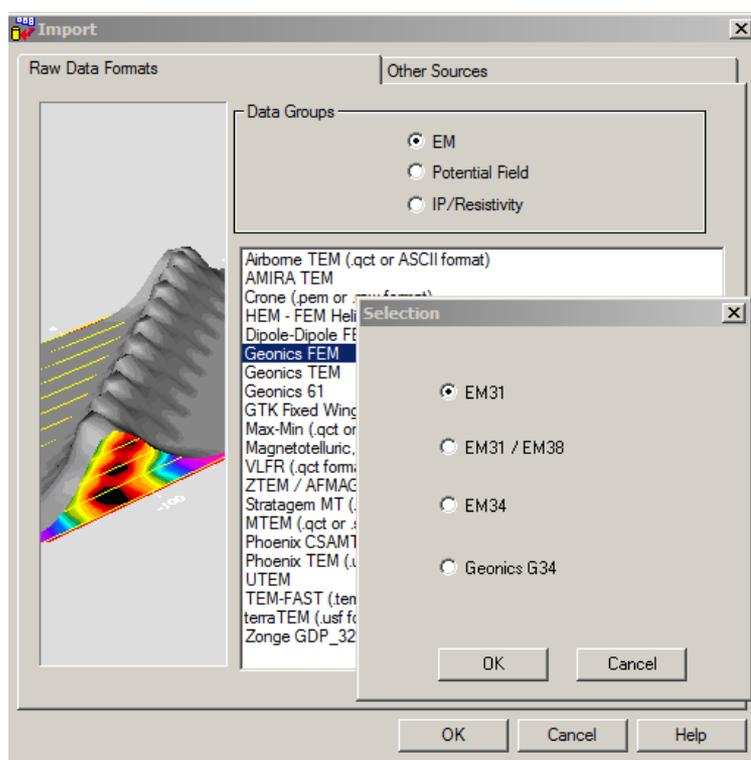
ground, helicopter of fixed wing data

Steps:

- | | <i>Page</i> |
|--|-------------|
| 1. Import data to new or existing database | 2 |
| 2. Examine data | 7 |
| 3. Perform initial forward modeling | 11 |
| 4. Perform controlled Marquardt or Occam Inversions | 12 |
| 5. Inversion evaluation | 17 |



1. Import data
2. Examine data
3. Perform initial modeling
4. Perform controlled under-parametrized Marquardt or over-parametrized Occam Inversions
5. Inversion evaluation



Click "Next" button to proceed to the next step

1. **Import data**
2. Examine data
3. Perform initial modeling
4. Perform controlled Marquardt or Occam Inversions
5. Inversion evaluation

Your FEM data is typically of a dipole-dipole nature. This means that the transmitter and receiver are small coils typically represented numerically as dipoles with a defined separation and orientation. The configuration can be of many types. For example, a common type for both ground and airborne is when the coils are horizontal and thus the dipoles are vertical and the separation is along the profile direction. Typical examples are with one type of component of airborne data but also this is the type for ground instruments such as the EM31 or the GEM2. Ground surveys can be utilized by orientating the system perpendicular to the profile with either the dipoles up or pointed in the profile direction. This latter configuration is also utilized in fixed wing dipole-dipole systems.

Your data files could be in instrument formats such as provided by Geonics or as geosoft .gdb files or in ascii columnar files. The easiest means for import is to first import into your QCTool software which provides a wide range of capabilities. In QCTool, you can clean and edit your data and carry out other processing if required. The .qct file is then imported to EMIGMA. However, ascii files can be imported directly to EMIGMA if preferred.

In this example, we will utilize some Dighem 5 multi-frequency, multi-component data which was provided in ascii format.

1. Import data

2. Examine data
3. Perform initial modeling
4. Perform controlled Marquardt or Occam Inversions
5. Inversion evaluation

This data consists of 3 different data components with 5 different frequencies:

1. Horizontal Coplanar (Mz-Hz) separated by 8m at 900 and 7200 Hz
2. Co-axial (Mx-Hx) – separated by 8m at 1000 and 5500 Hz
3. Horizontal Coplanar (Mz-Hz) separated by 6.3m at 56 KHz

The header section of the file header is given below. The file contains data locations and elevations as well as magnetic and EM data.

```

/XYZ EXPORT [12/20/2006]
/DATABASE [.\prearc-2.gdb]
/-----
/
/ X Y FID Z BALT ALTBIRD M MAGSP DIURNAL MAGLD IGRF MAG CPIR900 CPQR900 CXIR1000 CXQR1000 CXIR5500
CXQR5500 CPIR7200 CPQR7200 CPIR56K CPQR56K CPI900 CPQ900 CXI1000 CXQ1000 CXI5500 CXQ5500 CPI7200 CPQ7200 CPI56K CPQ56K
//Flight 22
//Date 2006/10/02
Line 20010

```

In the header line for the channels, CP indicates coplanar while CX is coaxial. CPI and CPQ indicate, for example, in phase and quadrature. The numbers as in CXI5500 indicate that 5500Hz is the frequency for this data. "R" in the labels likely indicates reduced or processed. The header line has been wrapped here for convenience. The data has the elevation via the barimetric altitude, whereas ALTBIRD M represents the altitude of the data above the surface. The data file also contains raw, base station and processed magnetic channels. The data file can be input to QCTool without editing. If the channel header line is selected as the channel headers then the channels will be automatically labeled during creation of the .qct file. A number of editing procedures were carried out in QCTool. There were several bad station locations which were deleted and about 2 dozen stations with no data which were also deleted. Additionally, the tie lines were not broken into separate lines but were all with one line. We utilized the tools provided in the map tools to break the tie lines into separate lines and then they were renamed. We are now ready to import to EMIGMA.

1. Import data

2. Examine data
3. Perform initial modeling
4. Perform controlled Marquardt or Occam Inversions
5. Inversion evaluation

Inputs. Import Wizard Step 1.

Input Filename: E:\Importdata\GeonicsFEM\BER31_head.XYZ

QCT file ASCII file

Select a line to change the header

GRID_X	GRID_Y	CPQ9800S1	CPI9800S1
GRID_X	GRID_Y	CPQ9800S1	CPI9800S1
LINE	100		
160.000	100.000	14.200	0.385
159.000	100.000	14.400	0.433

Buttons: Browse, Set header line, Apply first Multiplier, Apply first Separation

Frequency	Tx - Rx Orientation Tx	Rx	Correction Multiplier	dX	Tx - Rx Separation dY	dZ
<input type="checkbox"/> 9800	Z	Z	1	1	0	0
<input type="checkbox"/> 9800	Z	Z	1	2	0	0
<input checked="" type="checkbox"/> 9800	Z	Z	1	3.66	0	0
<input type="checkbox"/> 0			1	0	0	0
<input type="checkbox"/> 0			1	0	0	0
<input type="checkbox"/> 0			1	0	0	0
<input type="checkbox"/> 0			1	0	0	0
<input type="checkbox"/> 0			1	0	0	0
<input type="checkbox"/> 0			1	0	0	0
<input type="checkbox"/> 0			1	0	0	0

Tx Leads Rx along Profile Rx Leads Tx along Profile

Buttons: < Back, Next >, Cancel, Help

Choose the data file format and click “Browse” button to select data file

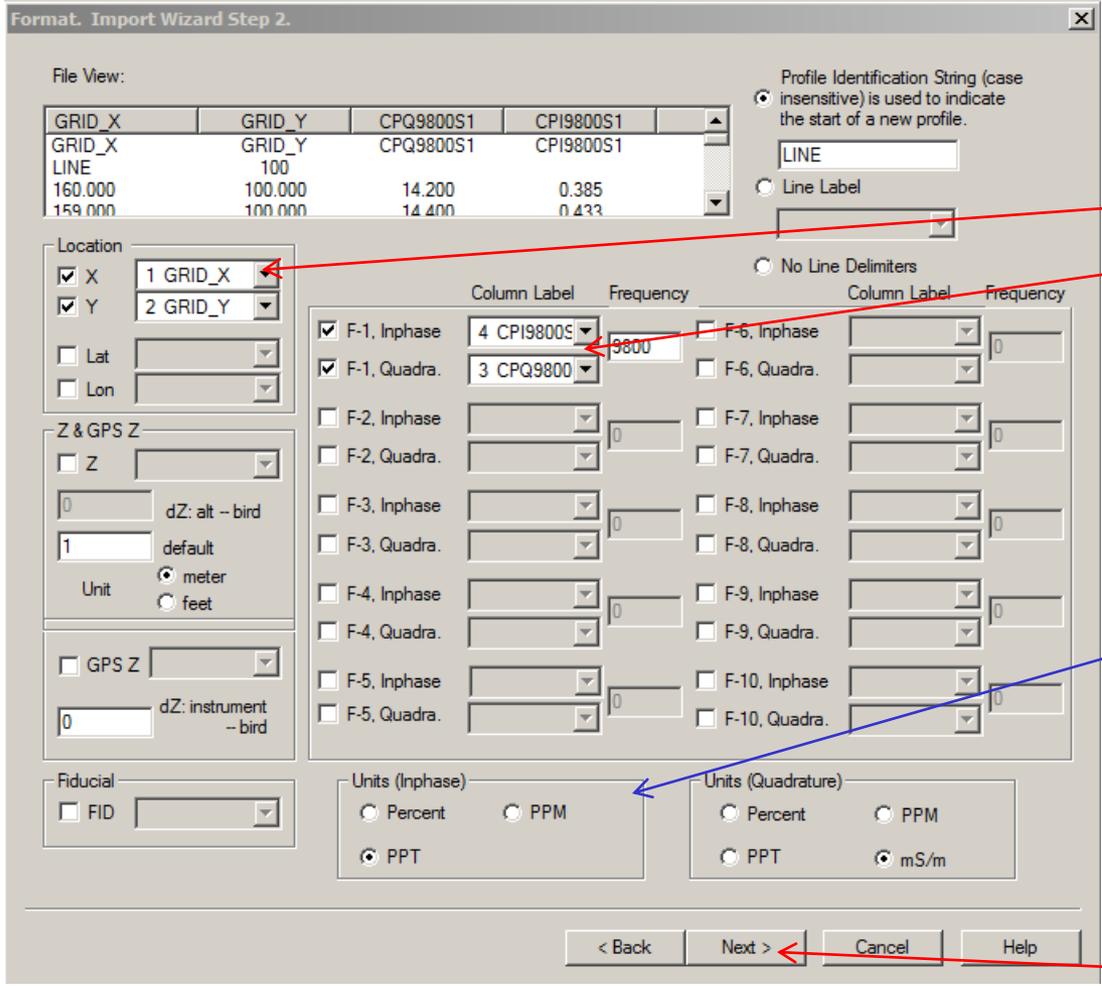
Set separations of Tx-Rx in X, Y and Z directions

The frequency shown here will differ with different selection of FEM system

Select whether Tx or Rx is leading

Click “Next” button to process to the next step

- 1. Import data
- 2. Examine data
- 3. Perform initial modeling
- 4. Perform controlled Marquardt or Occam Inversions
- 5. Inversion evaluation



Choose column name corresponding to location and inphase/quadrature signals
Note: this dropdown list will be in accordance with column names of importing file.

Choose units for inphase/quadrature signals

Click "Next" button to process to the next step

1. Import data

2. Examine data
3. Perform initial modeling
4. Perform controlled Marquardt or Occam Inversions
5. Inversion evaluation

Profiles. Import Wizard Step3.

Profile	# Locations
100	61
105	61
110	60
115	61
120	60
125	61
130	60
135	61
140	60
145	60
150	60
155	61
160	61

Restore all Profiles

Total Number of Profiles:

Total Number of Locations:

Modify Profile

Profile:

Delete every location

Shift Coordinate Values (e.g. for resolution)

Shift X:

Shift Y:

Average Precision (m)

X:

Y:

< Back

Select the profile you want to delete and its number will appear here. Click “Delete” button to delete this profile from importing file. You can also delete locations by every certain number.

To shift the coordinate for a better positioning accuracy, click “Change” button and made change in the popup dialog. Click “Reset” to restore its original value.

Select within what distance to average data. (e.g. if you enter 2, the duplicate data will be averaged within the 2m interval.)

Click “Next” button to proceed to the next step

1. Import data

2. Examine data
3. Perform initial modeling
4. Perform controlled Marquardt or Occam Inversions
5. Inversion evaluation

Run. Import Wizard Step 3.

System Parameters

Survey Type: Moving Tx - Moving Rx

Coordinate Systems: Horizontal

Separation Reference Point: Tx

Normalization Type: Continuous

Normalization Divisor: Inphase

Normalization Convention: Percent

Project Name: Project 14

Survey Name: BER31_head

Import to the Database

Average Duplicates

Run Import

Messages:

...system.....creating...

...components.....creating...

...locations.....creating...

...data.file.....creating...

Processing Completed

Saved to database

< Back Finish Cancel Help

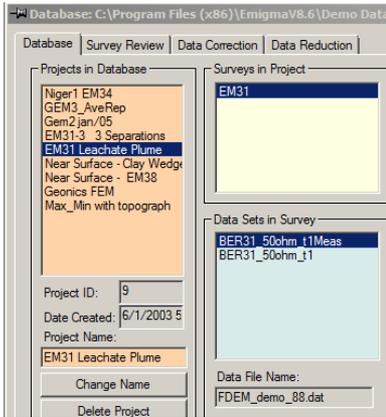
Set system parameters

Click “Run Import” button to start the importing process

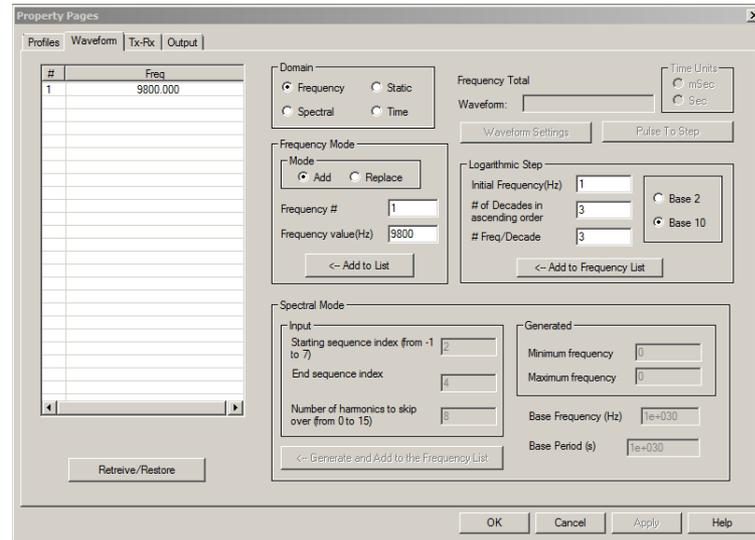
Click “Finish” button after import process is done

1. Import data
2. Examine data
3. Perform initial modeling
4. Perform controlled Marquardt or Occam Inversions
5. Inversion evaluation

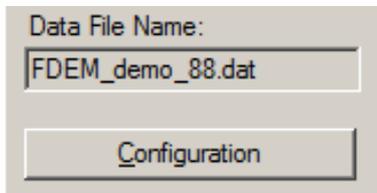
1. Check database for the survey



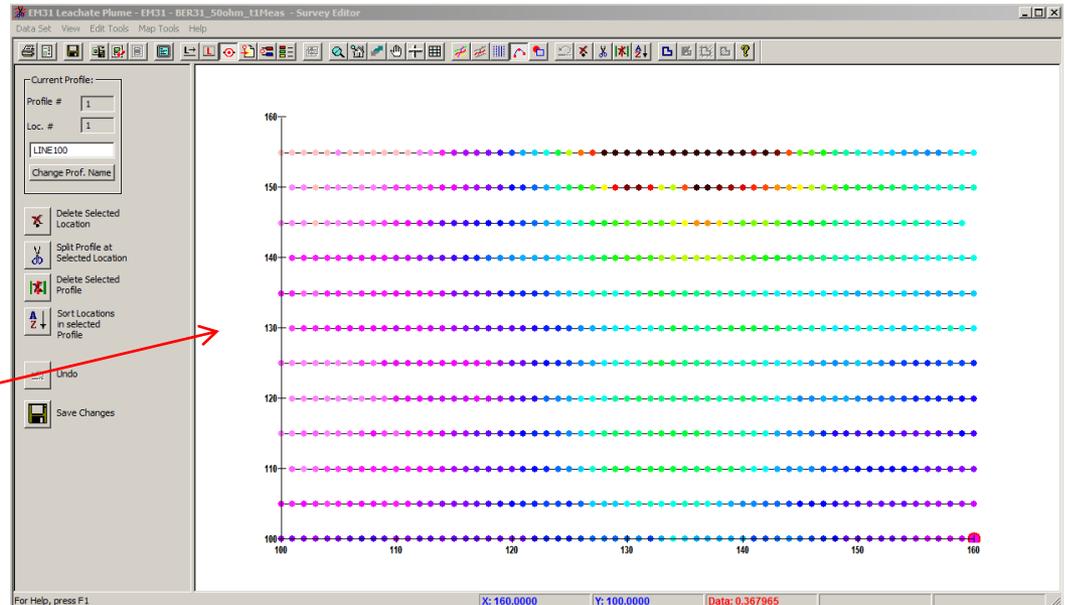
3. Check the frequency



2. Click configuration



4. Check lines and stations by clicking "Survey Editor" button



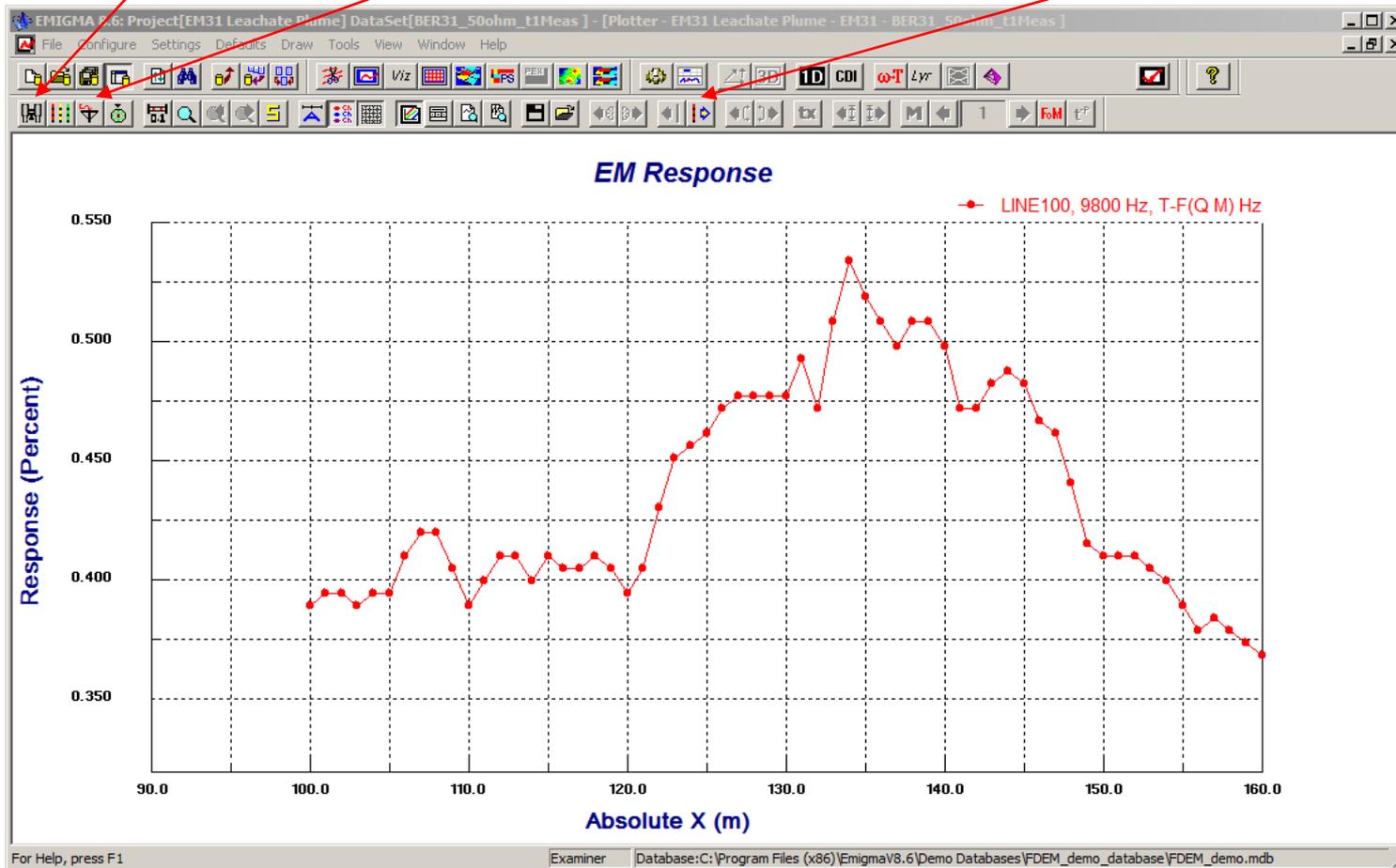
1. Import data
- 2. Examine data**
3. Perform initial modeling
4. Perform controlled Marquardt or Occam Inversions
5. Inversion evaluation



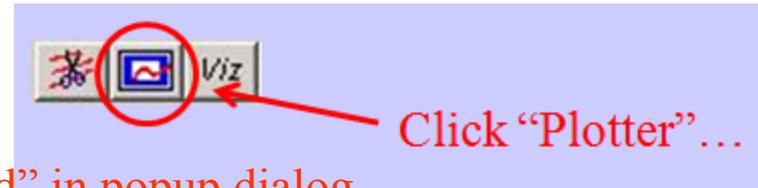
Change data set in Plotter

Switch between profile and spectrum mode

Toggle between profiles



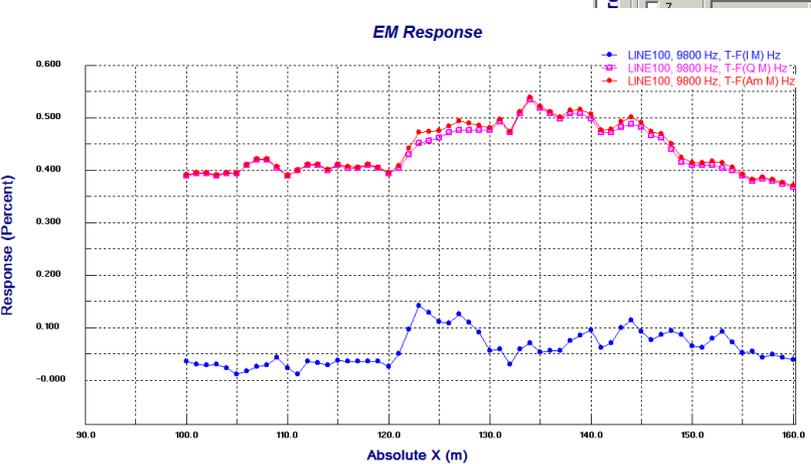
1. Import data
2. **Examine data**
3. Perform initial modeling
4. Perform controlled Marquardt or Occam Inversions
5. Inversion evaluation



Click "Channels" button, and select "Field" in popup dialog
 Check "Real", "Imaginary" and "Amplitude" options, and click "OK" to bring up real/imaginary/amplitude data plot:

Real/Imaginary/Amplitude data:

The screenshot shows the EMIGMA 8.6 software interface. The 'Channel Selection' dialog box is open, showing 'Indicate Channels' with Plot # 1 selected at 9800 Hz. The 'Fields and Component' dialog box is also open, showing 'Available Data Sets in Survey' with 'BER31_50chm_t1...' selected. The 'EM Res' plot window displays the 'EM Response' graph with three data series: 'LINE100, 9800 Hz, T-F(I) (M) Hz' (blue line with dots), 'LINE100, 9800 Hz, T-F(Q) (M) Hz' (magenta line with squares), and 'LINE100, 9800 Hz, T-F(Am) (M) Hz' (red line with circles). The plot shows 'Response (Percent)' on the y-axis (ranging from -0.000 to 0.600) and 'Absolute X (m)' on the x-axis (ranging from 30.0 to 160.0). The 'Fields and Component' dialog box has 'Measured' selected, and the 'Indicate Fields' section has 'Real', 'Imaginary', and 'Amplitude' checked under 'Total' and 'Background'.



1. Import data
- 2. Examine data**
3. Perform initial modeling
4. Perform controlled Marquardt or Occam Inversions
5. Inversion evaluation

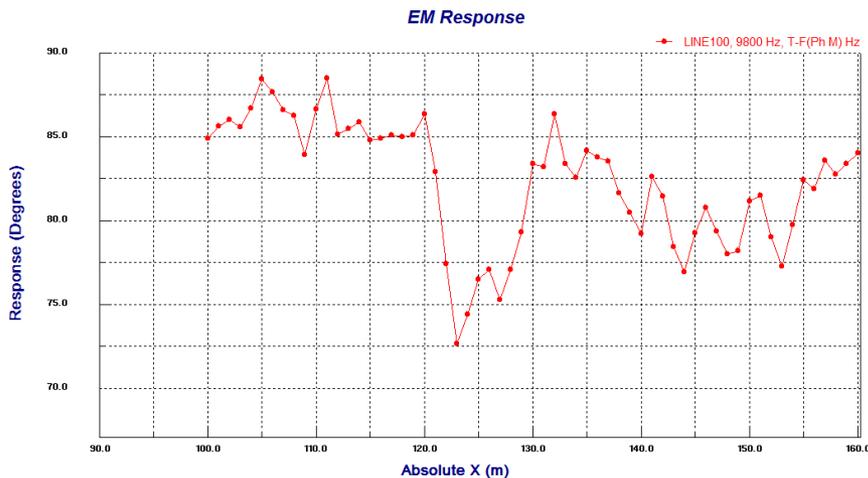


Click "Channels" button, and select "Field" in popup dialog

Check "Phase" option, and click "OK" to bring up phase data plot:

The screenshot shows the EMIGMA software interface with several dialog boxes open. The 'Channel Selection' dialog box is in the foreground, showing 'Indicate Channels' with Plot 1 selected at 9800 Hz and 'Field' selected. The 'Fields and Component' dialog box is also open, showing 'Available Data Sets in Survey' with 'BER31_50ohm_t1...' selected. The 'Indicate Fields' section has 'Phase' checked under 'Total'. The 'Selected Info' section shows 'Frequency Number: 1 Hz' and 'Value: 9800'. The 'EM Response' plot is shown in the bottom left, with 'Response (Degrees)' on the y-axis (70.0 to 90.0) and 'Absolute X (m)' on the x-axis (90.0 to 160.0). The plot shows a red line with markers representing the phase data for 'LINE100, 9800 Hz, T-F(Ph M) Hz'.

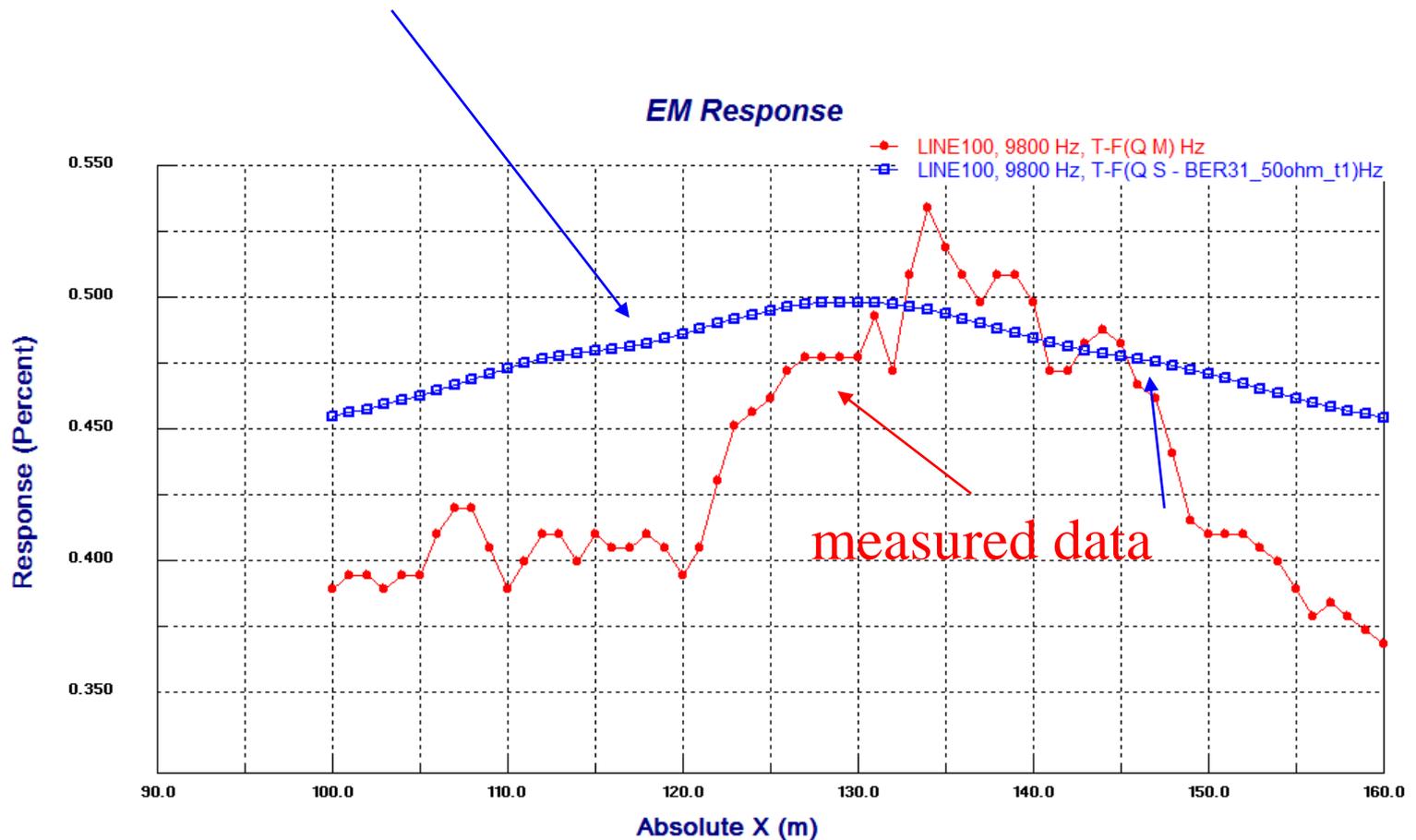
Phase data:



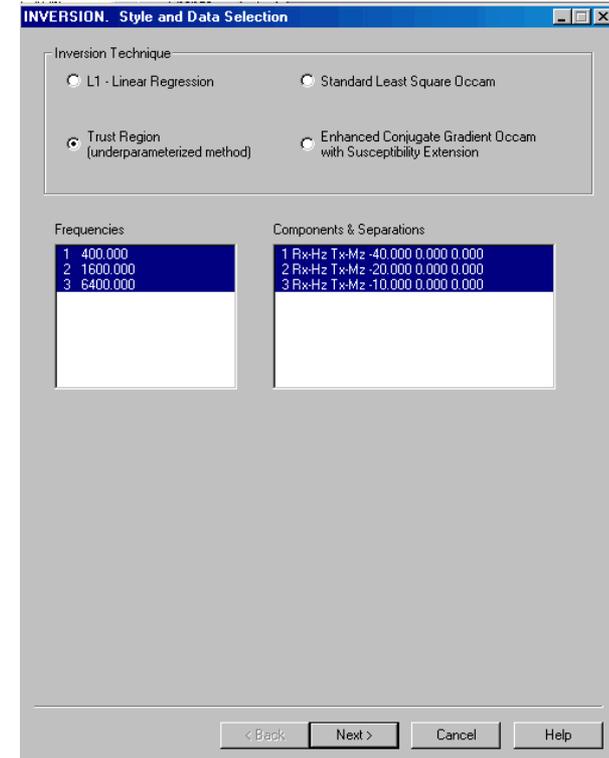
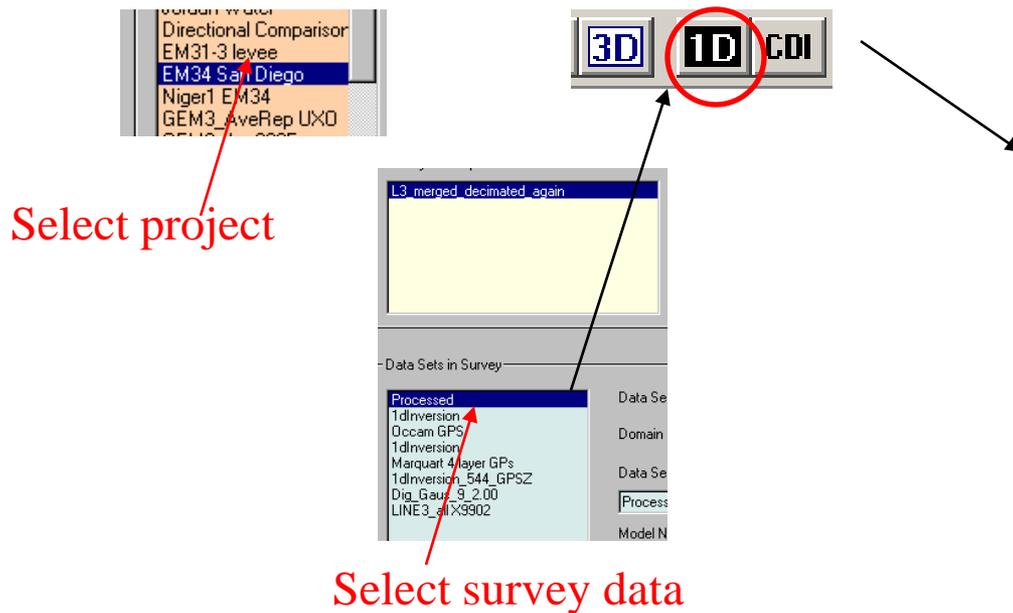
1. Import data
2. Examine data
- 3. Perform initial modeling**
4. Perform controlled Marquardt or Occam Inversions
5. Inversion evaluation

Note: Performed some initial modeling to get a “feel” of the background resistivity and estimate parameters of initial model for inversion.

simulated data with a forward model



1. Import data
2. Examine data
3. Perform initial modeling
- 4. Perform controlled Marquardt or Occam Inversions**
5. Inversion evaluation



In this case, we will be utilizing a 3 frequency EM34 dataset, with 3 separations each at its own frequency.

Note on Quadrature sign convention: Most FEM data utilizes a convention of $\exp(-i\omega t)$. However, EMIGMA utilizes the standard scientific convention of $\exp(+i\omega t)$ for all data. However, the 1D inversion assumes the standard data convention, flipping the quadrature for inversion and then placing back flipped to match the simulation convention. This should be transparent for the user.

1. Import data
2. Examine data
3. Perform initial modeling
- 4. Perform controlled Marquardt or Occam Inversions**
5. Inversion evaluation

Inversion Technique:

L1 – Linear Regression: Norm-1 linear regression model for solving the least-square problem

Standard Least Square Occam: using smoothing Occam inversion which inverts only resistivity with layer thickness fixed

Trust Region: inverts for both layer thickness and resistivity. This technique is a modern evolution of the older Marquardt techniques but uses model gradients

Enhanced Conjugate Gradient Occam with Susceptibility Extension: using conjugate gradient method to solve Occam style inversion problem with susceptibility extension

INVERSION. Style and Data Selection

Inversion Technique

L1 - Linear Regression Standard Least Square Occam

Trust Region (underparameterized method) Enhanced Conjugate Gradient Occam with Susceptibility Extension

Frequencies

1	400.000
2	1600.000
3	6400.000

Components & Separations

1	Rx-Hz	Tx-Mz	-40.000	0.000	0.000
2	Rx-Hz	Tx-Mz	-20.000	0.000	0.000
3	Rx-Hz	Tx-Mz	-10.000	0.000	0.000

< Back Next > Cancel Help

Select frequencies to be inverted

Note: the maximum number of frequencies for an inversion is 50.

Select components used for inversion

1. Import data
2. Examine data
3. Perform initial modeling
- 4. Perform controlled Marquardt or Occam Inversions**
5. Inversion evaluation

Create a Starting Model

INVERSION. Starting Model

Set a layered starting model for inversion. The model consists of several layers over a half space with resistivity and thickness defined for each of them.

Note: the model does not include the upper half space (i.e. the air).

Generate uniform layering

Total layers above half space: Resistivity:

Total thickness above half space: Susceptibility:

Inversion Parameters:

Resistivity Susceptibility Joint

Insert

Layer #	Resistivity	Susceptibility	Thickness
1	9.700e+000	0.000e+000	7.131e+000
2	3.000e-001	0.000e+000	6.192e+000
3	2.000e-001	0.000e+000	6.104e+000
4	2.010e+001	0.000e+000	1.000e+009

Join the selected layer with the following one.

Import a layer model

From previous inversion result From a dataset

Set parameter boundary and parameters to Invert

Allowed number:

Selected number:

Generate a Starting model:

Select how many layers in total that you would like in the model, set the initial resistivity and thickness. Then click “Apply” button.

Editing Starting model:

After making a starting model (whether by importing or generating), the user may edit either the resistivity or the thickness of the layer. Set resistivity and thickness of the layer and check “Insert” radio. Select one layer from the table and click “Add to List” button. The new layer will be added below the selected one. Or simply click on the parameter and make change at “Resistivity” and “Thickness” boxes above the table. Select “Replace” option and click “Add to List” button. The user may also join two adjacent layers by selecting one layer and clicking “Join Layers” button to merge this one with the layer below.

Import Layers:

If you already have a forward model that you like to use, you may import it as the starting model by clicking “Import” button and select from appeared dialog. We use this option here.

Inversion Parameters:

If selectable, choose which parameter you would like to inverse: resistivity, susceptibility, or both.

1. Import data
2. Examine data
3. Perform initial modeling
- 4. Perform controlled Marquardt or Occam Inversions**
5. Inversion evaluation

Create a Starting Model

Import Layers:

If you already have a forward model that you like to use, you may import it as the starting model by clicking “Import” button and select from appeared dialog. We use this option here.

Parameter bounds and parameters to invert:

If you already have a forward model that you like to use, you may import it as the starting model by clicking “Import” button and select from appeared dialog. We use this option here.

INVERSION. Starting Model

Set a layered starting model for inversion. The model consists of several layers over a half space with resistivity and thickness defined for each of them.

Note: the model does not include the upper half space (i.e. the air).

Generate uniform layering

Total layers above half space Resistivity

Total thickness above half space Susceptibility

Inversion Parameters

Resistivity Susceptibility Joint

Insert Replace

Layer #	Resistivity	Susceptibility	Thickness
4	20.1	0	1e+009
1	9.700e+000	0.000e+000	7.131e+000
2	3.000e-001	0.000e+000	6.192e+000
3	2.000e-001	0.000e+000	6.104e+000
4	2.010e+001	0.000e+000	1.000e+009

Join the selected layer with the following one.

Import a layer model

From previous inversion result From a dataset

Set parameter boundary and parameters to Invert

Allowed number

Selected number

1. Import data
2. Examine data
3. Perform initial modeling
- 4. Perform controlled Trust Region or Occam Inversions**
5. Inversion evaluation

Model and Simulation Parameters Settings

Parameter Limits:

It is useful to constrain model parameters to ranges that are possible in the geological environment.

Parameter Limits:

	Resistivity	Susceptibility
Lower Bound	1	0
Upper Bound	10000	1

Bounds to enforce:

Upper

Lower

None (not recommended)

Both (recommended)

Additional Options:

Join adjacent layers within a specified contrast: 50 %

Ratio of susceptibility to conductivity parameters: 0 :1

log(Conductivity)

Data Type:

Type 1 (Amplitude/Phase)

Type 2 (Inphase/Quadrature)

Type 3 (Only Quadrature)

Inversion Parameters:

Max. Iterations: 10

Target Fit: 1

Model Epsilon: 0.1

Min Tolerance: 0.1

Fit Tolerance: 0.01

Reset Default

< Back Next > Cancel Help

Data Type:

Depending on data, different data are available for inversion

Max. Iterations:

A higher value will help ensure accuracy but execution times increases

Target Fit:

The residual between the estimated data under the best model and the measured data.

Model Epsilon:

Once the target fit has been met, if subsequent inversion produce an rms change in model parameters less than epsilon then inversion is deemed to be accomplished.

Min Tolerance:

Determines how accurately the search algorithms determine minima in the fit.

Fit Tolerance:

Determines how close to determine the final fit

Join Layers:

When the contrast between neighboring layers is within a certain percentage (20% in this case), join these two layers together.

This page varies for different algorithms. Here for Enhanced CG

1. Import data
2. Examine data
3. Perform initial modeling
- 4. Perform controlled Trust Region or Occam Inversions**
5. Inversion evaluation

Model and Simulation Parameters Settings

INVERSION. Parameters Settings

Resistivity Limits (L, M)

Lower Bound: 1

Upper Bound: 1000

Bounds to enforce:

Upper

Lower

None (not recommended)

Both (recommended)

Minimize (L1)

Absolute Values

Absolute Values of Differences

Data Type (L, M)

Type 1 (Amplitude/Phase)

Type 2 (Inphase/Quadrature)

Type 3 (Only Quadrature)

Inversion technique combination

Individual

L1 -> L2

L1 -> Mq

L1->L2->Mq

L2-> Mq

-> Use previous result

Inversion Algorithm

L1 data norm (mean abs. diff.)

L2 (RMS) data norm (Occam)

Trust Region (underparameterized method)

Inversion Parameters

Max. Iterations: 20

Target Fit (%): 1

Model Epsilon: 0.1

Min. Tolerance: 0.1

Fit Tolerance: 0.01

Reset Default

< Back Next > Cancel Help

Data Type:

Depending on data, different data are available for inversion

Max. Iterations:

A higher value will help ensure accuracy but execution times increases

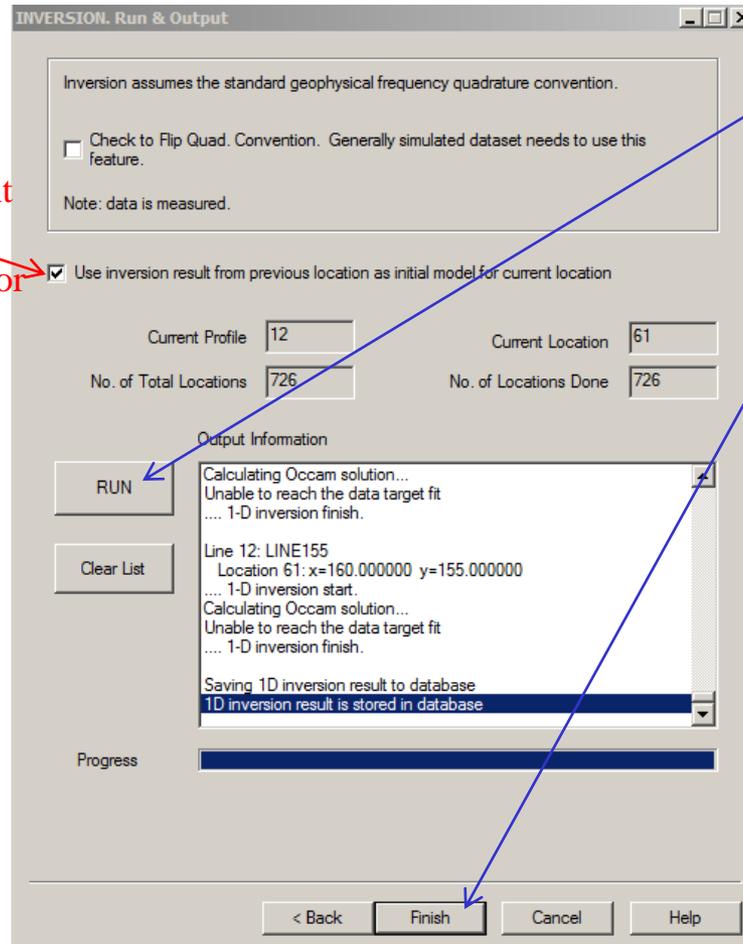
Target Fit:

The residual between the estimated data under the best model and the measured data.

This page varies for different algorithms. Here for Trust Region

1. Import data
2. Examine data
3. Perform initial modeling
- 4. Perform controlled Marquardt or Occam Inversions**
5. Inversion evaluation

Executing the Inversion



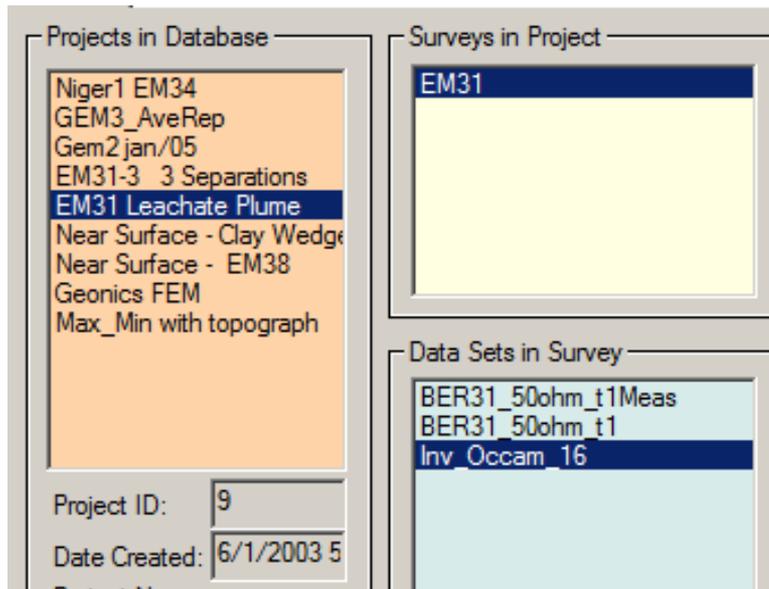
Choose inversion result from previous location as the initial model for current model will create smooth spatial model. Suggested for large datasets.

Finally, click the “Run” button. The right window (in white) shows each data point’s progress. Click “Finish” button to complete inversion procedure.

NOTE: When the inversions are running, you may minimize the window and the processing will run in the background allowing you to continue to work on the computer. Any extra CPU cycles will be used by the inversion process. For some datasets containing 10’s of thousands of data points, the process may take several hours.

1. Import data
2. Examine data
3. Perform initial modeling
4. Perform controlled Marquardt or Occam Inversions
- 5. Inversion evaluation**

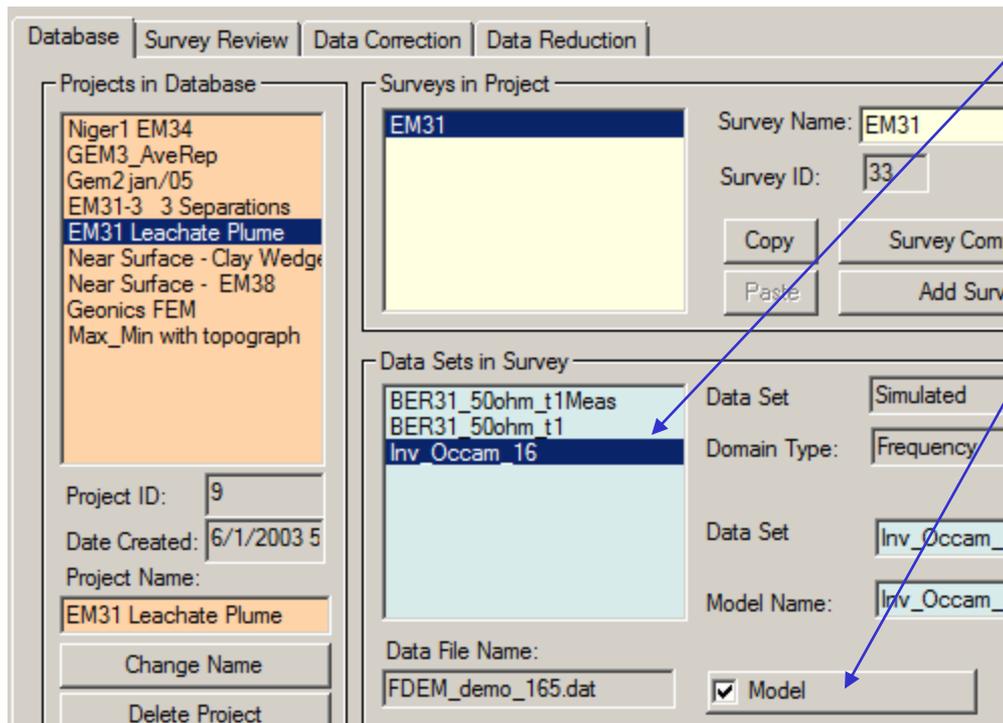
Inversion Evaluation



In each survey, there will be several data sets after modeling, inversion and processing. In this case, we have 1 forward model and 1 inversion model. The forward model has a new data set containing the simulated data under the model. Similarly, each inversion contains a new dataset containing the simulated data set under the inversion model (for each point) and attached to that data set is the inversion model.

1. Import data
2. Examine data
3. Perform initial modeling
4. Perform controlled Marquardt or Occam Inversions
- 5. Inversion evaluation**

Inversion Evaluation



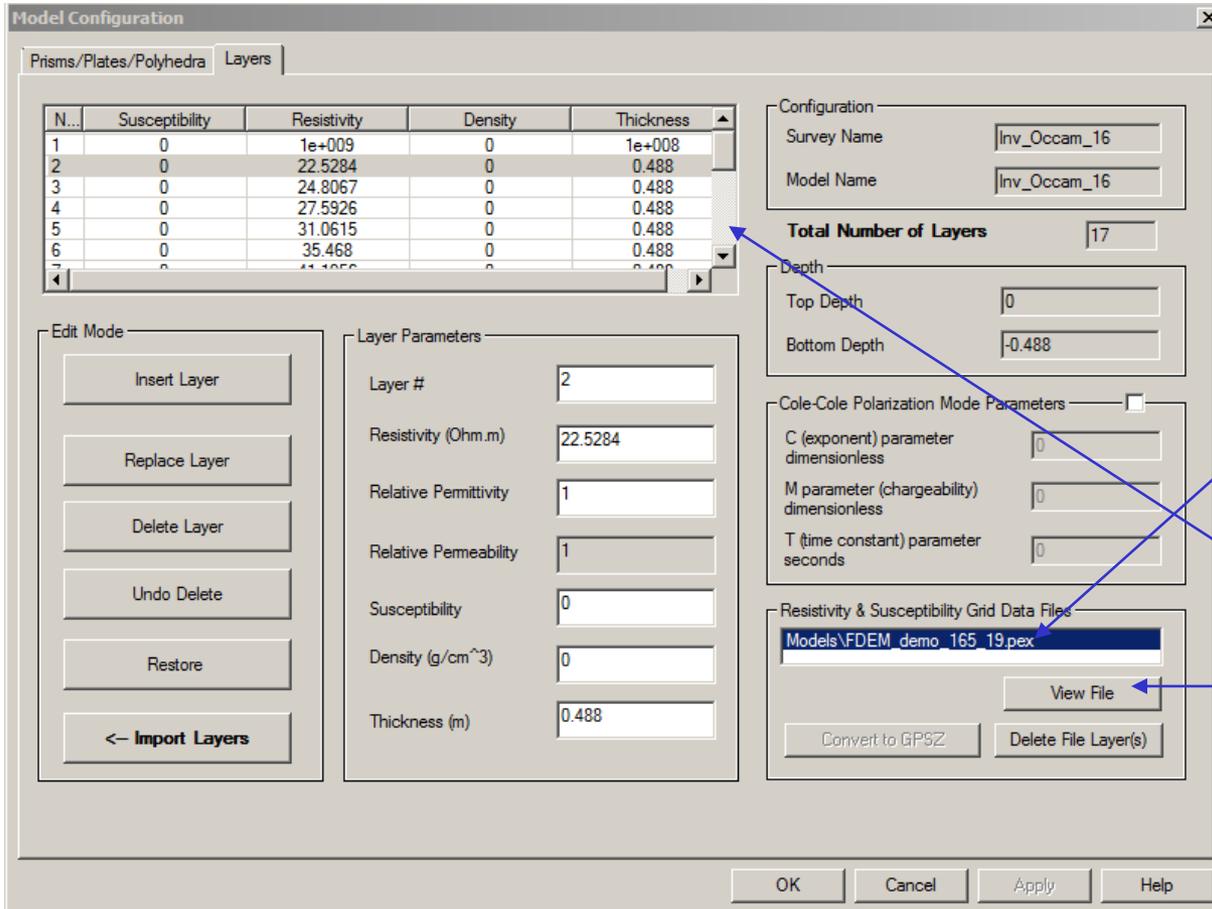
An inversion is selected. You will note the “Model” button is checked.

If the model button is clicked...

1. Import data
2. Examine data
3. Perform initial modeling
4. Perform controlled Marquardt or Occam Inversions
- 5. Inversion evaluation**

Inversion Evaluation

a window will open



Attached to the database in a subdirectory called “Models” is the inversion results in a simple ASCII XYZ file (*.pex) which may be viewed here. This file may easily be imported to another application although graphical viewing tools are provided within EMIGMA.

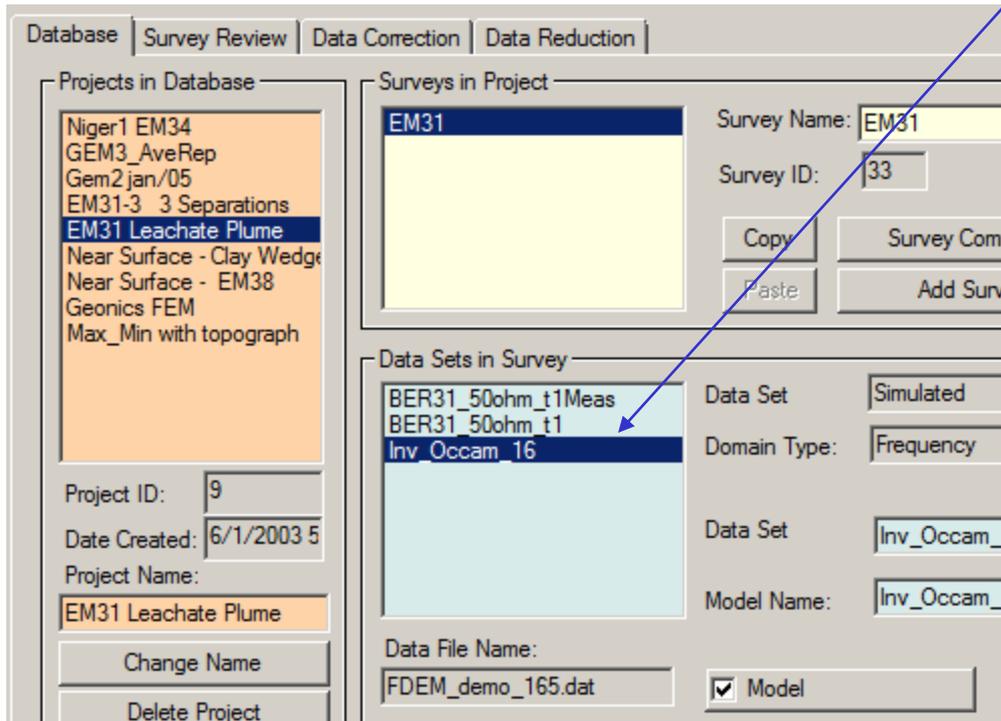
The 1D model for the final data point is also included.

Click “View File” button to view the data file of the saved 1D layered model.

1. Import data
2. Examine data
3. Perform initial modeling
4. Perform controlled Marquardt or Occam Inversions
- 5. Inversion evaluation**

Inversion Evaluation

Select the inversion.



Choose CDI Viewer to view a stacked section of the results

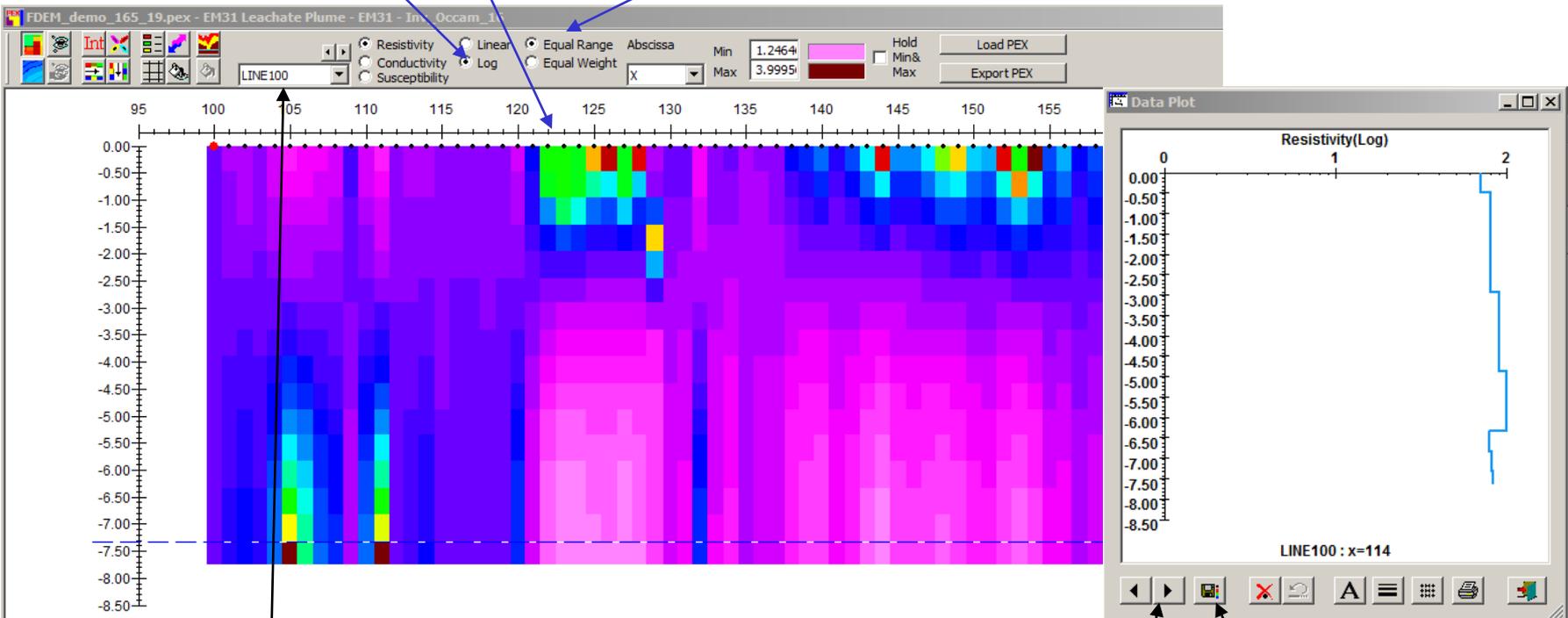
1. Import data
2. Examine data
3. Perform initial modeling
4. Perform controlled Marquardt or Occam Inversions
- 5. Inversion evaluation**

Inversion Displays



Choose CDI viewer to graphically view the results.
See Help inside this tool

The results for each **data point** are shown (without interpolation)
initially in **log(Resistivity)** with **Equal Range** display.



If there is more than one line then
other lines may be selected.

A simple **line drawing** is also provided
and you may **step** along the profile. You
may also save the layered model of the
current point by clicking 

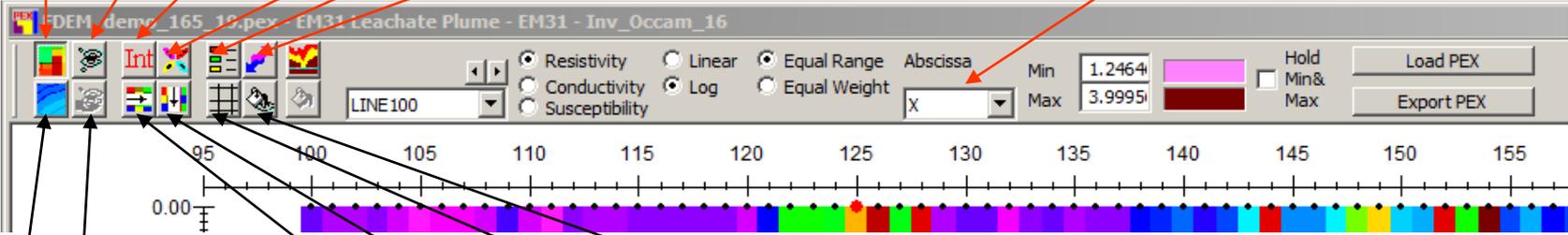
1. Import data
2. Examine data
3. Perform initial modeling
4. Perform controlled Marquardt or Occam Inversions
- 5. Inversion evaluation**

Inversion Displays



Choose CDI viewer to graphically view the results

Show Contour Lines Reset Show Legend
 Show Grid Interpolate Proportional View Use X or Y coordinate



Filled Contour Depth Interpolation Show Grid Lines
 Contour Attributes Location Interpolation Refresh View

Equal Range: assign different colors to different ranges which are equal independently of the number of data falling within these ranges

Equal Weight: assign colors to different ranges which are unequal but covering the same number of data

Min: Any data values below Min will be displayed as the color to the right of the edit field

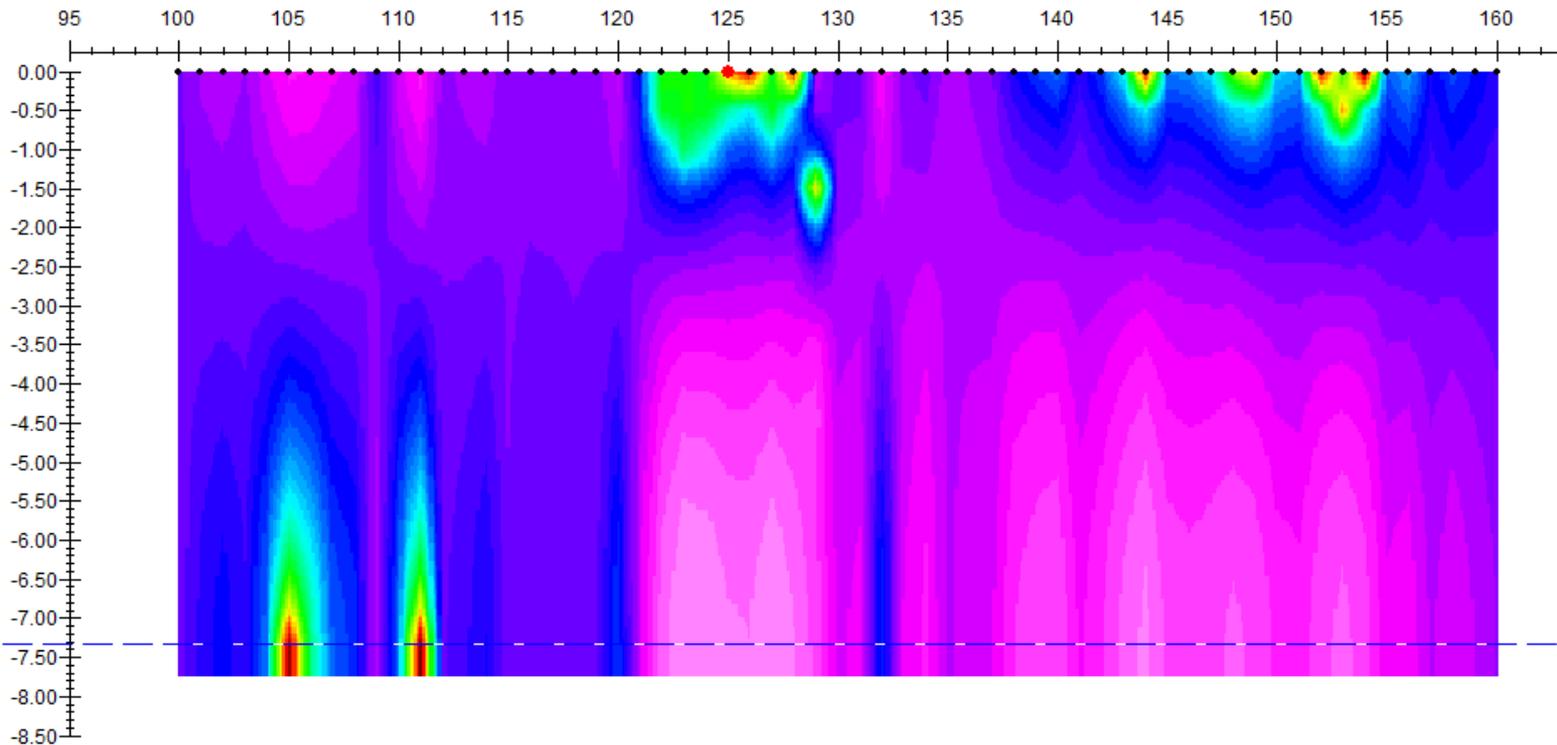
Max: Any data values above Max will be displayed as the color to the right of the edit field

1. Import data
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- 5. Inversion evaluation**

Inversion Displays



Choose CDI viewer to graphically view the results



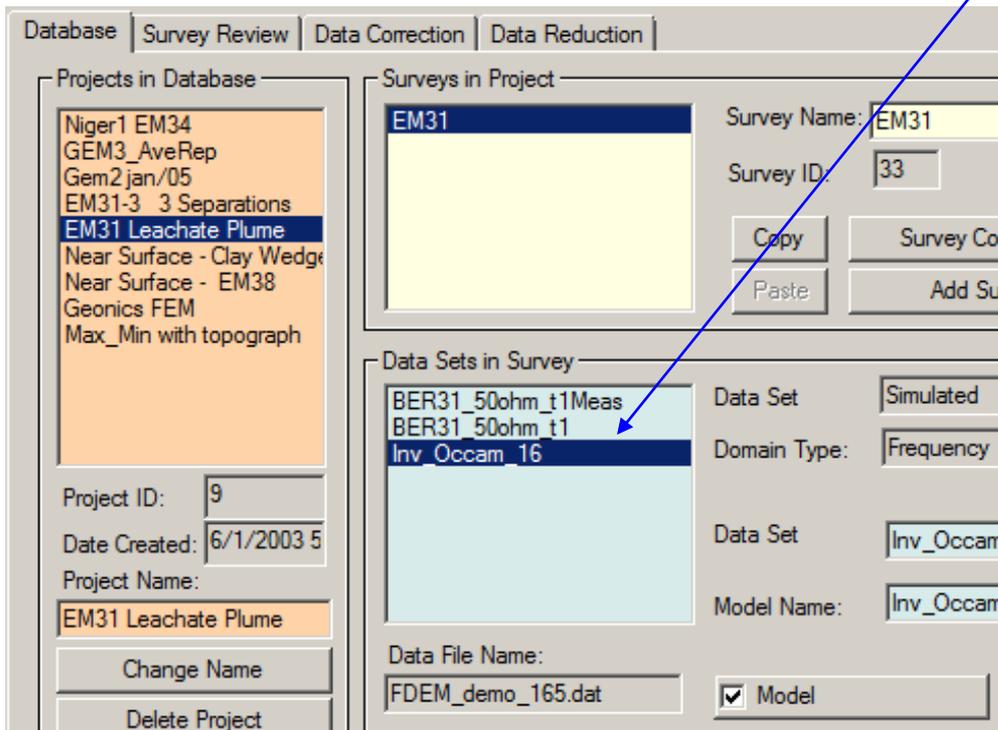
Axes may be edited by double-clicking on it, and you can change Max, Min, Labels and Titles etc. on the popup dialog

Depth and location interpolated may be repeated (note: the results of previous interpolations are used in the next interpolation so use with care)

1. Import data
2. Examine data
3. Perform initial modeling
4. Perform controlled Marquardt or Occam Inversions
- 5. Inversion evaluation**

Inversion Evaluation

To assess how well the inversion model fits the data at each station, select the inversion data set and then select the plotter.

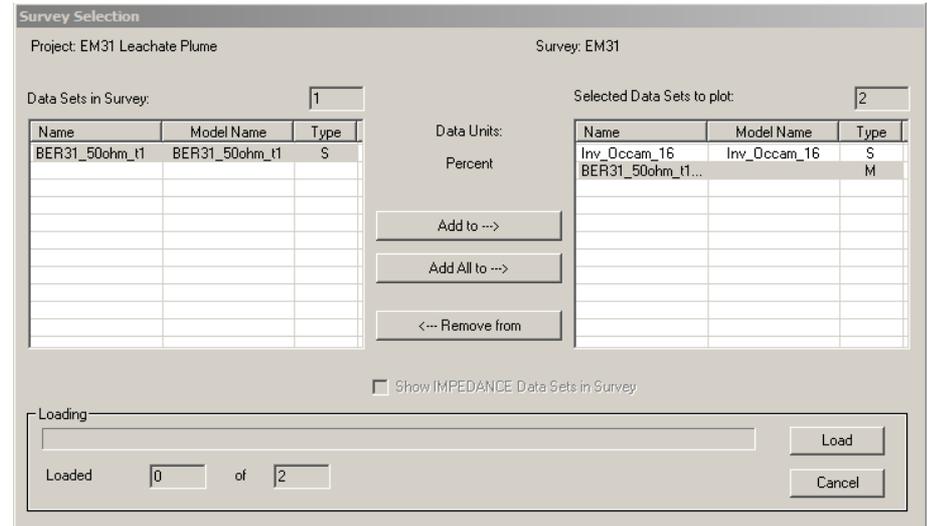


Select “Yes”, if this dialog is appeared

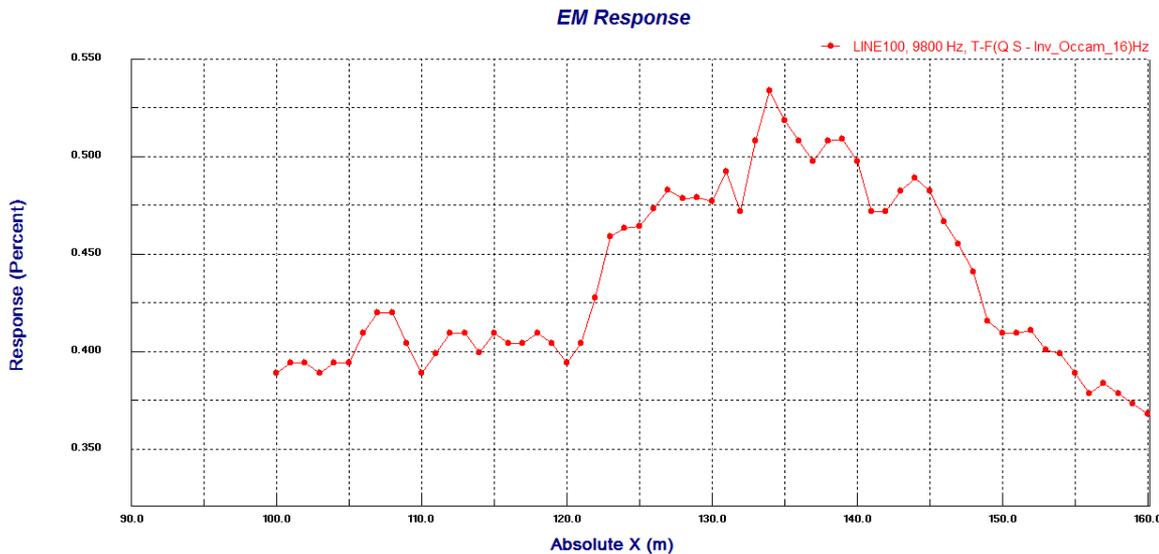
1. Import data
2. Examine data
3. Perform initial modeling
4. Perform controlled Marquardt or Occam Inversions
- 5. Inversion evaluation**

Inversion Evaluation

Select the data sets required for comparison and then “Load”



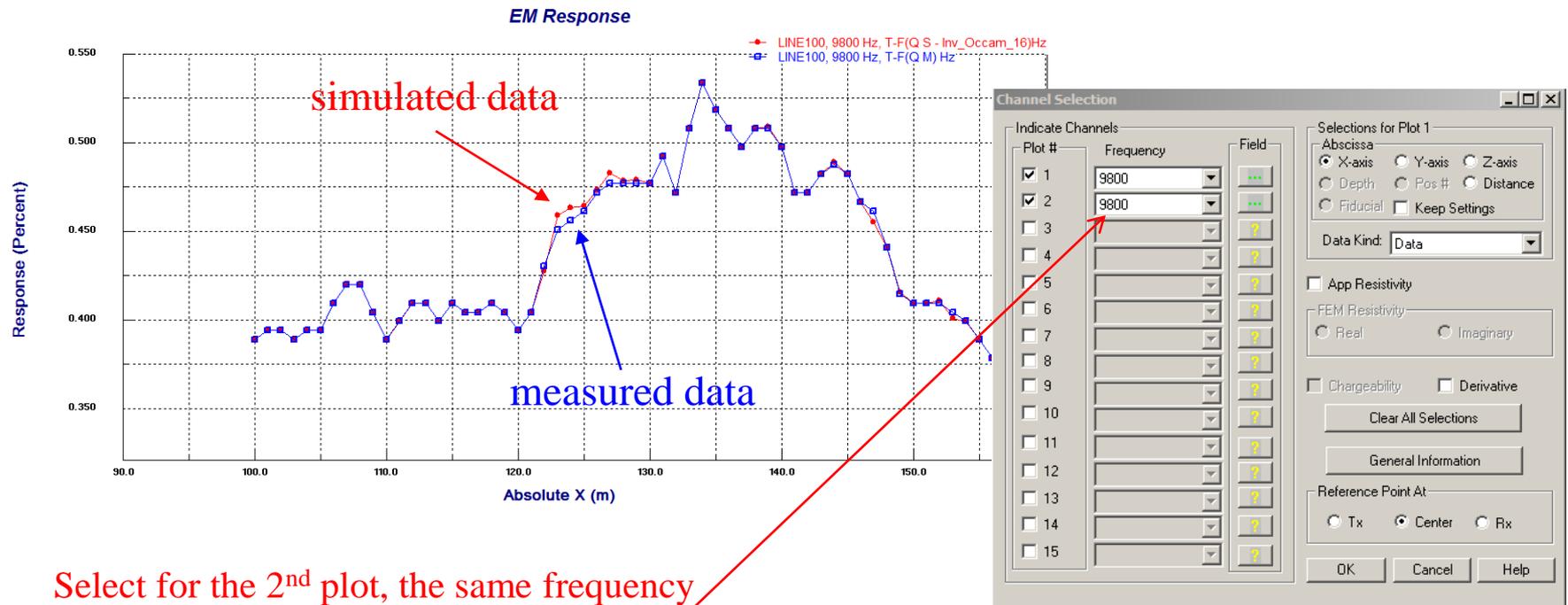
All selected data sets are then loaded to the Plotter application and the plot appears showing the first channel of the simulated data.



1. Import data
2. Examine data
3. Perform initial modeling
4. Perform controlled Marquardt or Occam Inversions
- 5. Inversion evaluation**

Inversion Evaluation

The user may select other data sets to plot by simply double clicking on the plot



Select for the 2nd plot, the same frequency and then measured data.

1. Import data
2. Examine data
3. Perform initial modeling
4. Perform controlled Marquardt or Occam Inversions
- 5. Inversion evaluation**

Inversion Evaluation

FEM Inverse

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Multiple plots can be shown for various inversions and models in “Profile” mode. The user may step through profiles by simply clicking the arrow.

