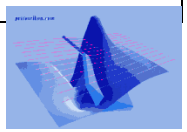
1D CSEM INVERSION TUTORIAL

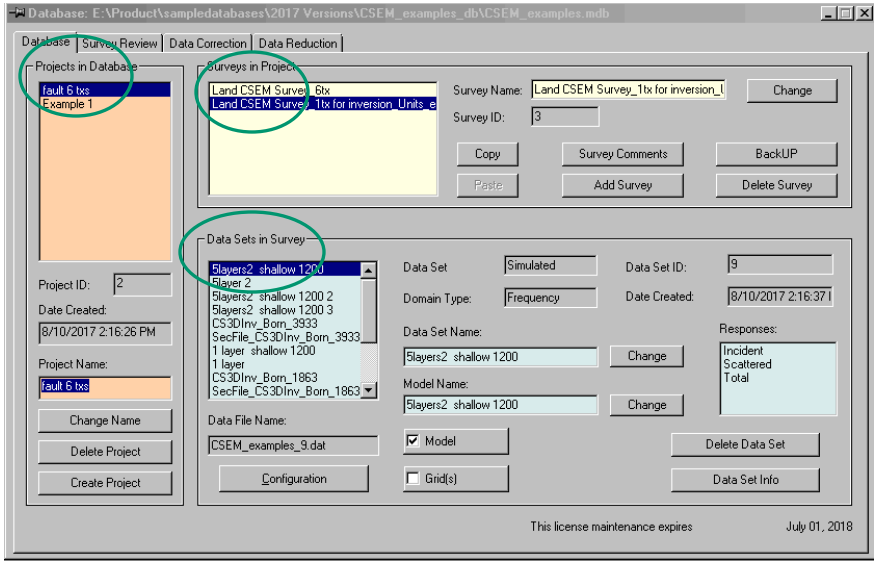
created December, 2017

Steps: ***Page***



1. **Data organization and import**
2. Examine data
3. Perform initial modeling
4. Perform controlled inversions
5. Inversion evaluation

The data in EMIGMA is organized into Projects, Surveys and Data Sets.



Across the top, there are four tabs, *Database* (view shown above), *Survey Review*, *Data Correction* and *Data Reduction*, as discussed on the next page.

1. **Data organization and import**
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Database – Organizes the data into Projects, Surveys and Data Sets. For each data set, any corresponding models and grids are also shown (if the appropriate 'model' or 'grid' button is checked)

Survey Review - Allows the user to review the lines and data points. Data sorting, filtering and profile name modification options are available.

Data Correction – Enables the user to delete points and components. The user can also modify values in a number of ways such as applying a shift, multiplication by a factor, inverting the sign, etc.

Data Reduction – Allows the user to reduce entire data sets (measured or simulated) in a single operation

For a detailed description of each feature, please refer to the EMIGMA Manual.

1. **Data organization and import**
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CSEM data must be imported through a .qct file. Column organized data in ascii format can be imported to QCTool for organization and processing prior to import.

/DATA

/ Line	Easting	Northing	Depth(m)	GPS_Z	FREQ()	Curr(A)	Orient(deg)	Aspace(m)	Vx.I(nV)	Vx.O(nV)	Vy.I(nV)	Vy.O(nV)
L1	169142.20	226561.80	-0.10	*	0.5000	1.00	20	100.0	-4.68112e-07	-6.33771e-07	-2.72988e-06	-3.93512e-06
L1	166547.80	228066.00	-0.10	*	0.5000	1.00	300	100.0	-6.09049e-07	-2.45836e-06	-5.08496e-06	-3.58344e-06
L1	168131.20	227146.40	-0.10	*	0.5000	1.00	20	100.0	-2.08049e-05	-1.68325e-05	-4.10244e-06	6.43980e-06
L1	163874.20	229619.00	-0.10	*	0.5000	1.00	20	100.0	-5.27675e-05	1.71213e-05	4.44177e-05	6.22607e-05
L2	165804.80	229679.90	-0.10	*	0.5000	1.00	20	100.0	-1.84041e-04	-6.95028e-05	5.34330e-05	9.89392e-05
L3	166614.80	229819.90	-0.10	*	0.5000	1.00	20	100.0	-3.00521e-05	-1.57039e-05	4.26581e-05	4.09867e-05

-data is usually organized by line with the line column selectable in the import to EMIGMA
-coordinates of receivers are given in 2 columns for easting and northing
- depth of electrodes can be set
- GPS-Z elevation can also be imported
- the frequency of each set of data is given. the order is not important as it will be re-ordered during import
- the current for each measurement is provided
- the length of the voltage receivers are given through the *Aspace* channel

- if 2 voltages are provided they must be orthogonal measurements as should magnetic measurements
- voltages are normally provided in nVolts and magnetic fields in nTelsa but these units can be calculated from other units once imported to QCTool
-voltages channels should be labelled Vx and/or Vy and magnetic channels Hx, Hy and/or Hz
- voltages and magnetic fields should be measured parallel and perpendicular to the lines
- rotation to these orientations can be done in QCTool

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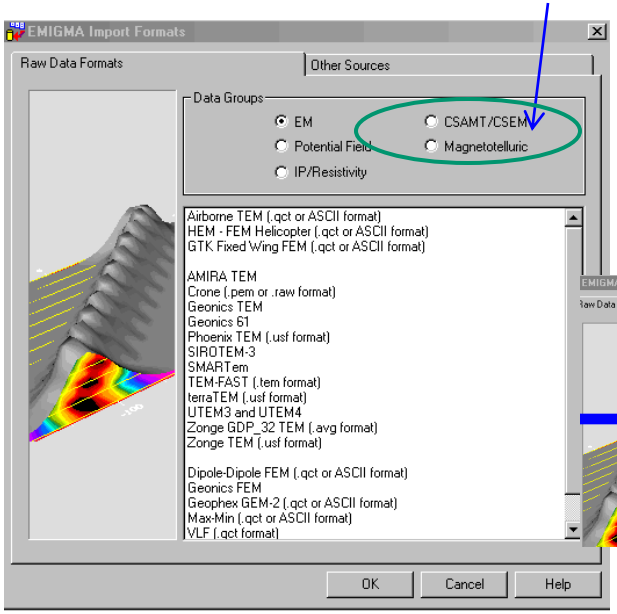
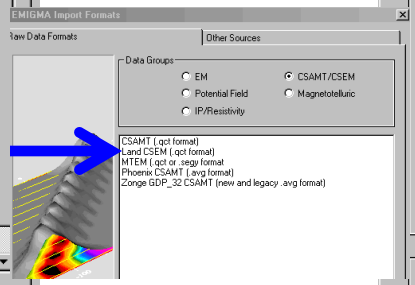
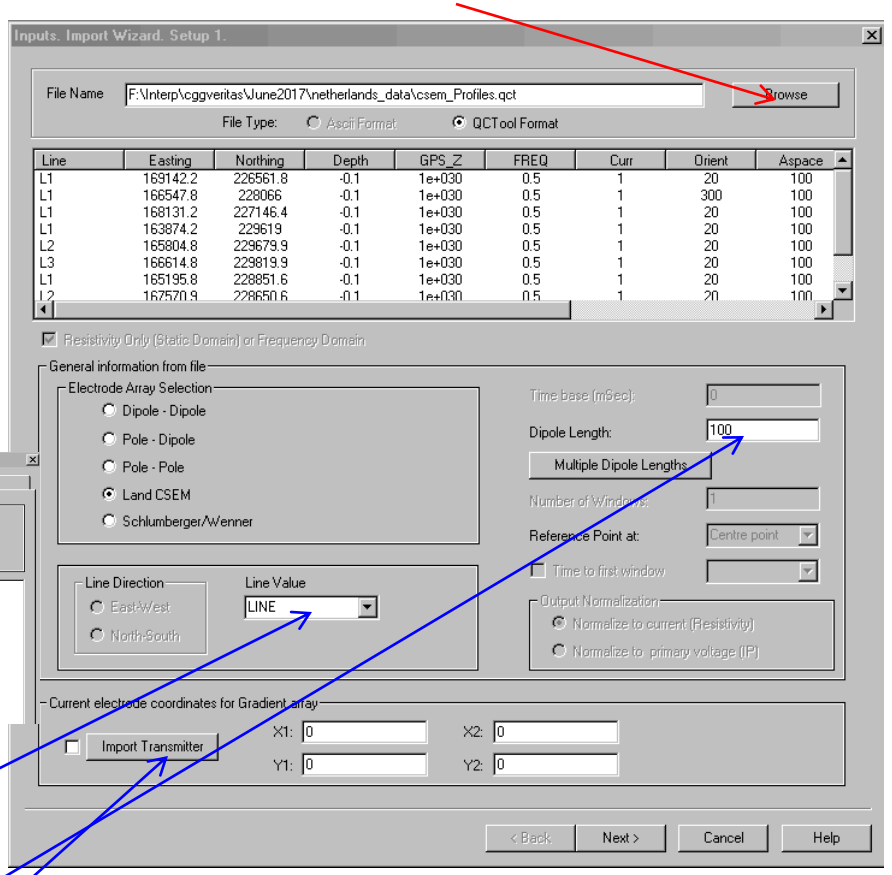
CSEM data must be imported through a .qct file. Column organized data in ascii format can be imported to QCTool for organization and processing prior to import.

Browse and select data file for import







Line label channel. Imported data is organized by lines

The length of the dipole receiver is set through the *Aspace* channel

Transmitter coordinates may be imported here or later once imported. format provided on interface for import

Click “Next” to proceed to the next step

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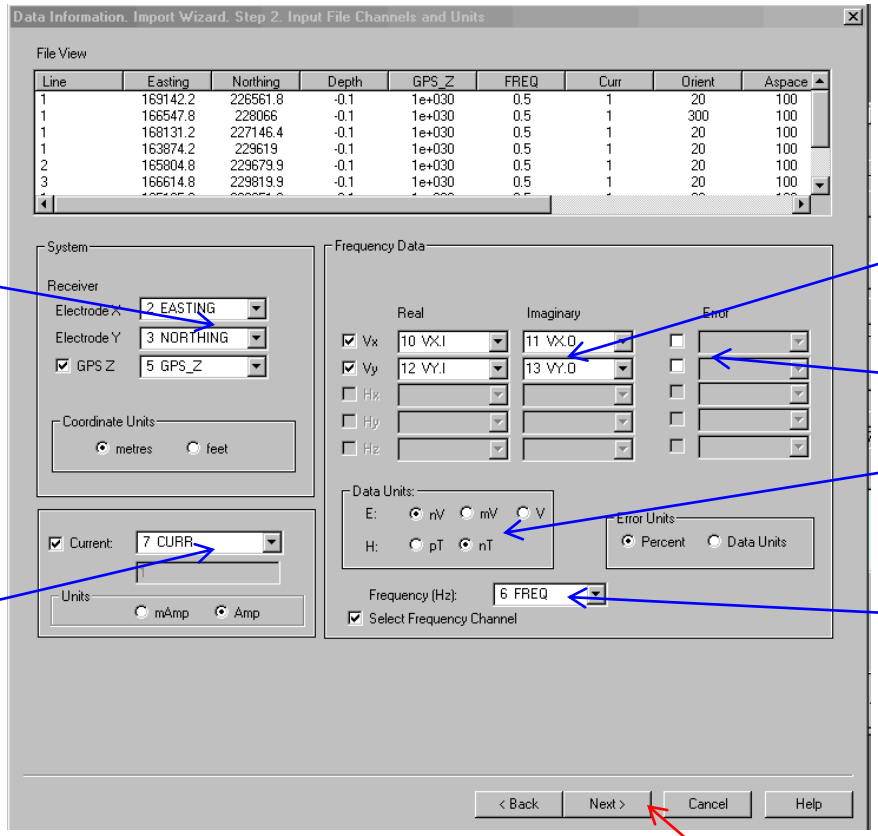
At this stages, we select the channels in the data file.



receiver locations

data channels

error channels if available

data units

Current channel with current units

frequency channel

Click "Next" to proceed to the next step

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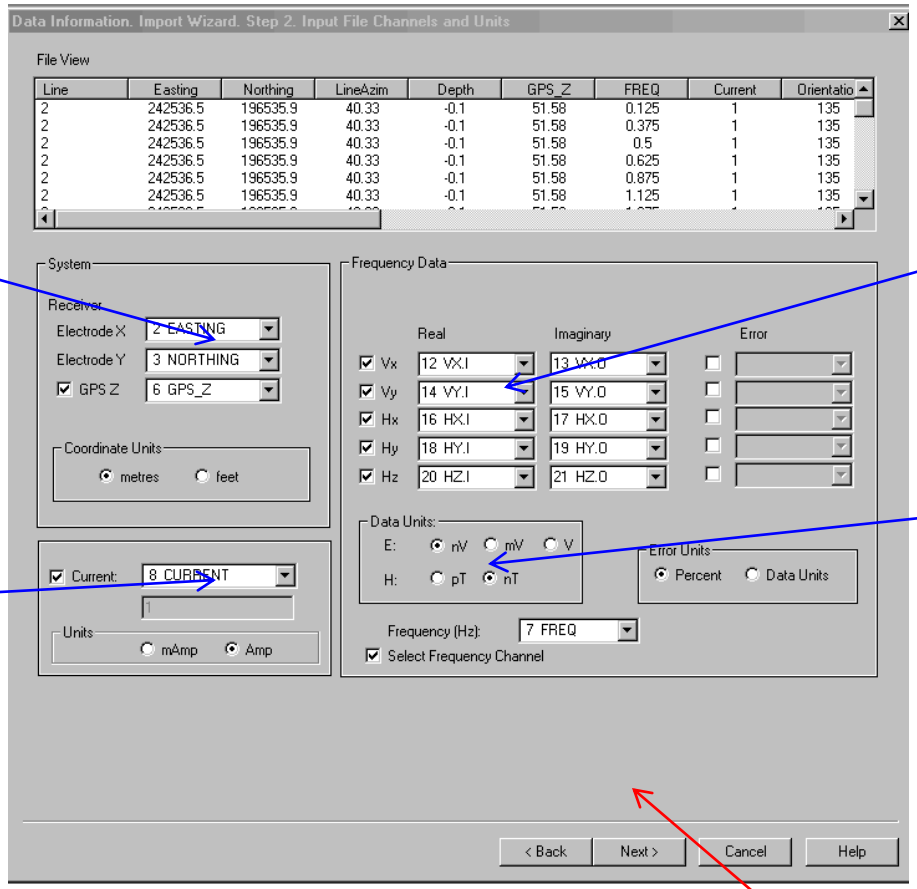
In this case, we have 2 voltages and 3 magnetic fields.



receiver locations

data channels

Current channel with current units

data units

Click "Next" to proceed to the next step

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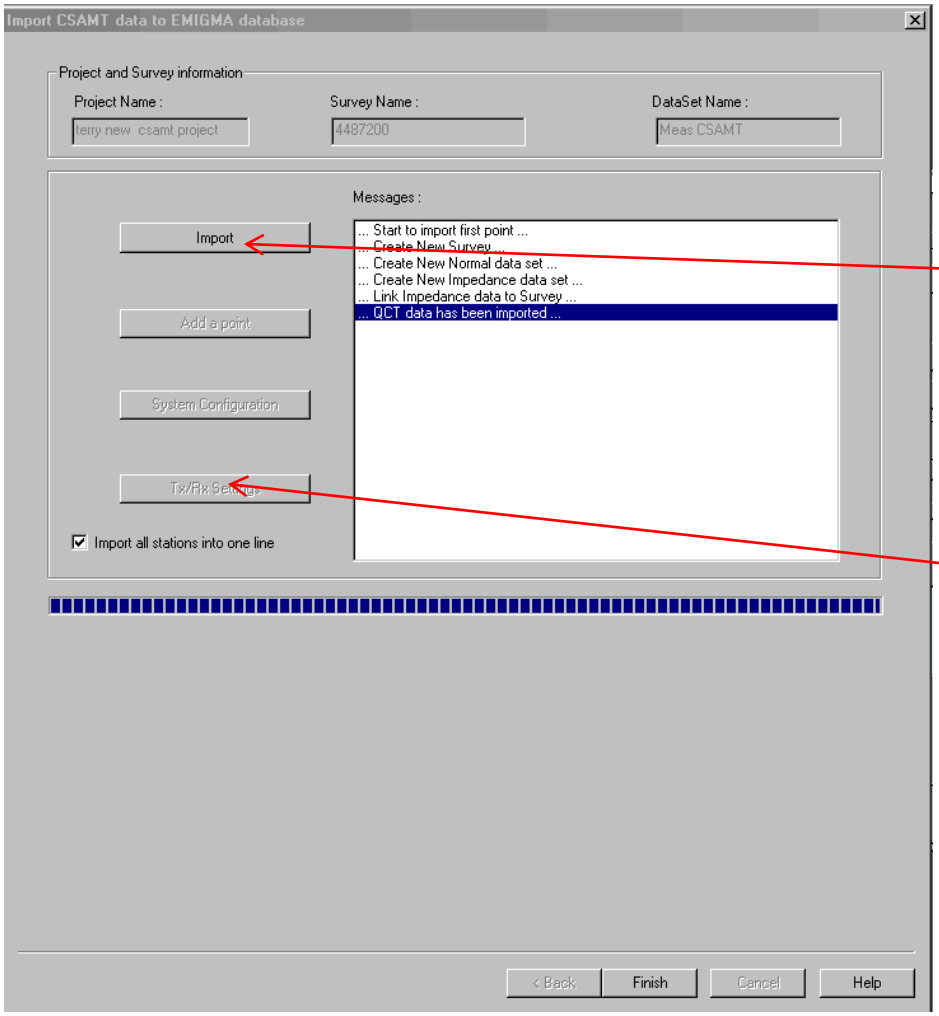

Click "Import" to begin importing. Once finished, click "Finish" to complete the import procedure.

Tx/Rx settings

here you will locate your Tx and specify the dipole length of the Rx's. These can be modified later in EMIGMA if desired

Multiple Tx's

import data separately and then merge

1. Data organization and import
2. **Examine data**
3. Perform initial modeling
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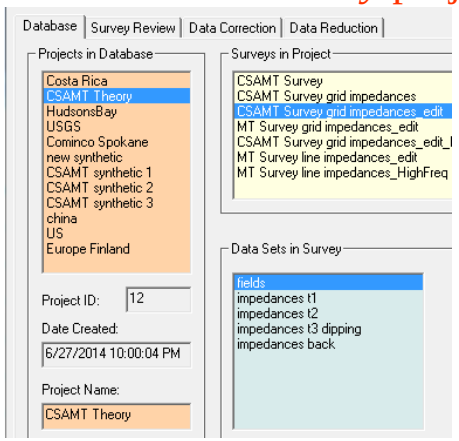
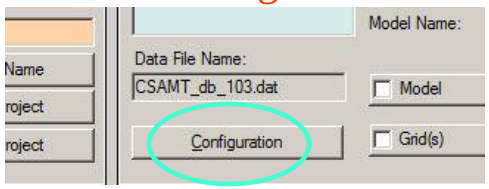
5. Inversion evaluation

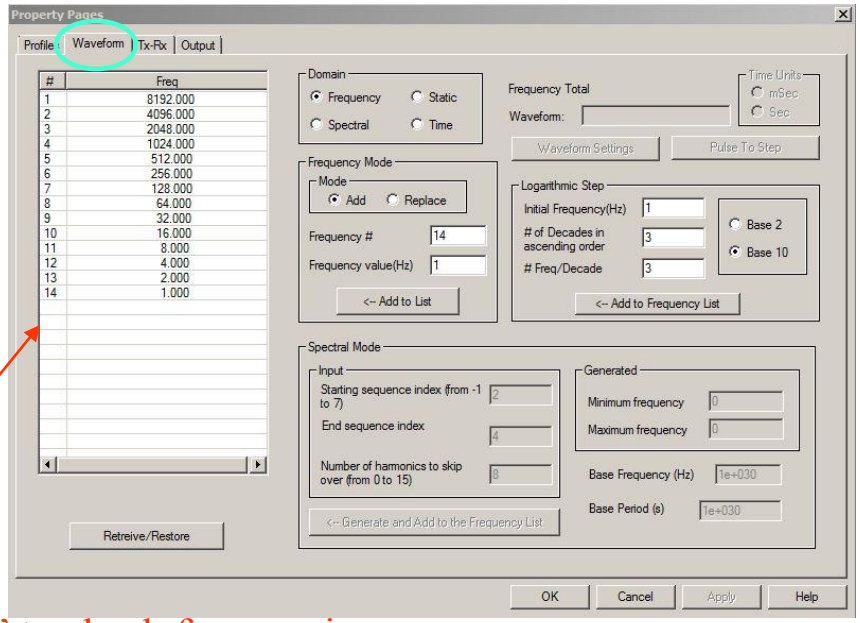
1. Select the *CSAMT Theory* project to view the survey



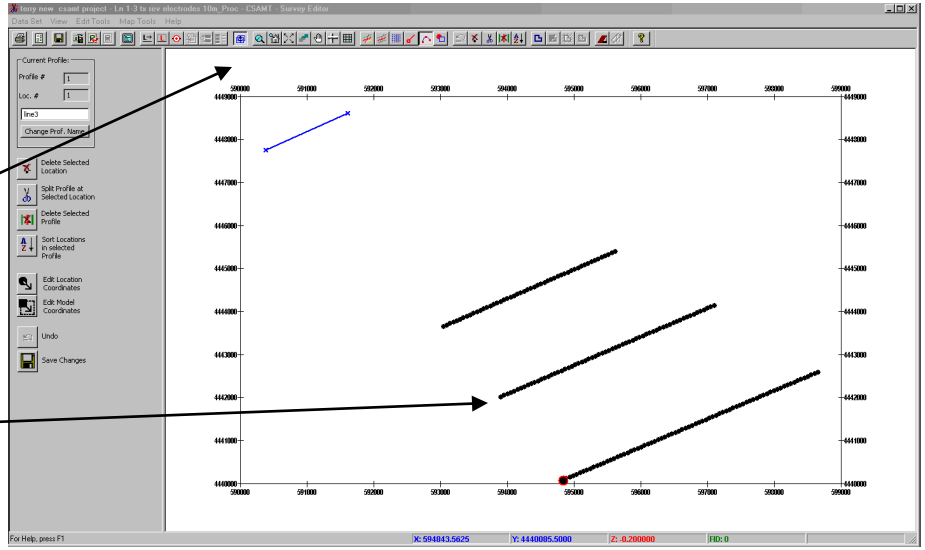
2. Click configuration



3. Click 'Waveform' to check frequencies



4. Check lines and stations for correctness by clicking "Survey Editor" button to show lines and transmitter location



1. Data organization and import
2. **Examine data**
3. Perform initial modeling
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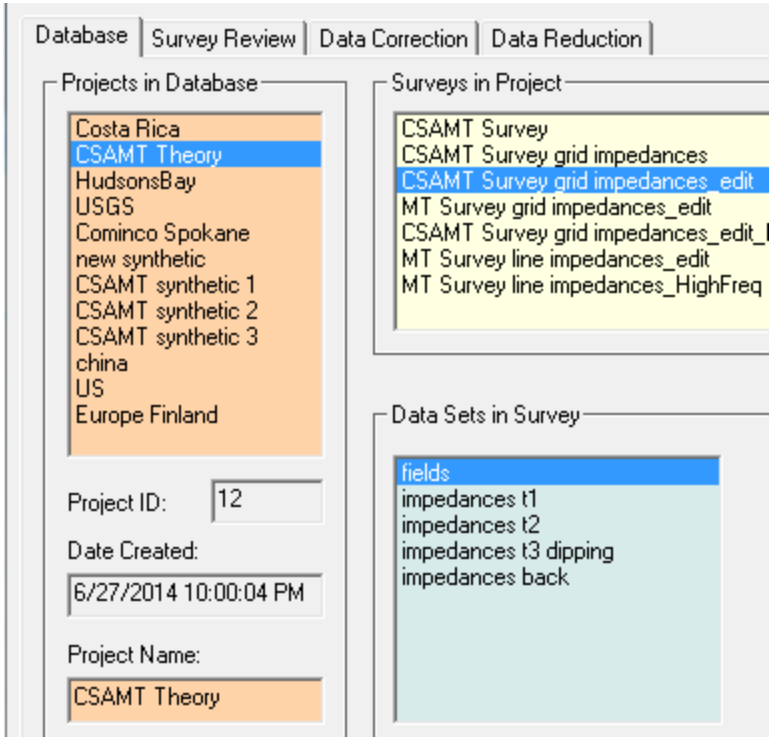
In this tutorial, we will be working with the *CSAMT demo database* available through our website.

We will start by examining a synthetic data set in a project titled CSAMT Theory.

Select the survey and data sets as shown (on the right) in the database:



Click the *Plotter* button on the toolbar to load the 'Fields' and 'impedances t1' data sets.

With the *Plotter*, the user can display not only the electric field and magnetic field data but also the impedance data (with the respective real and imaginary components).

1. Data organization and import
2. **Examine data**
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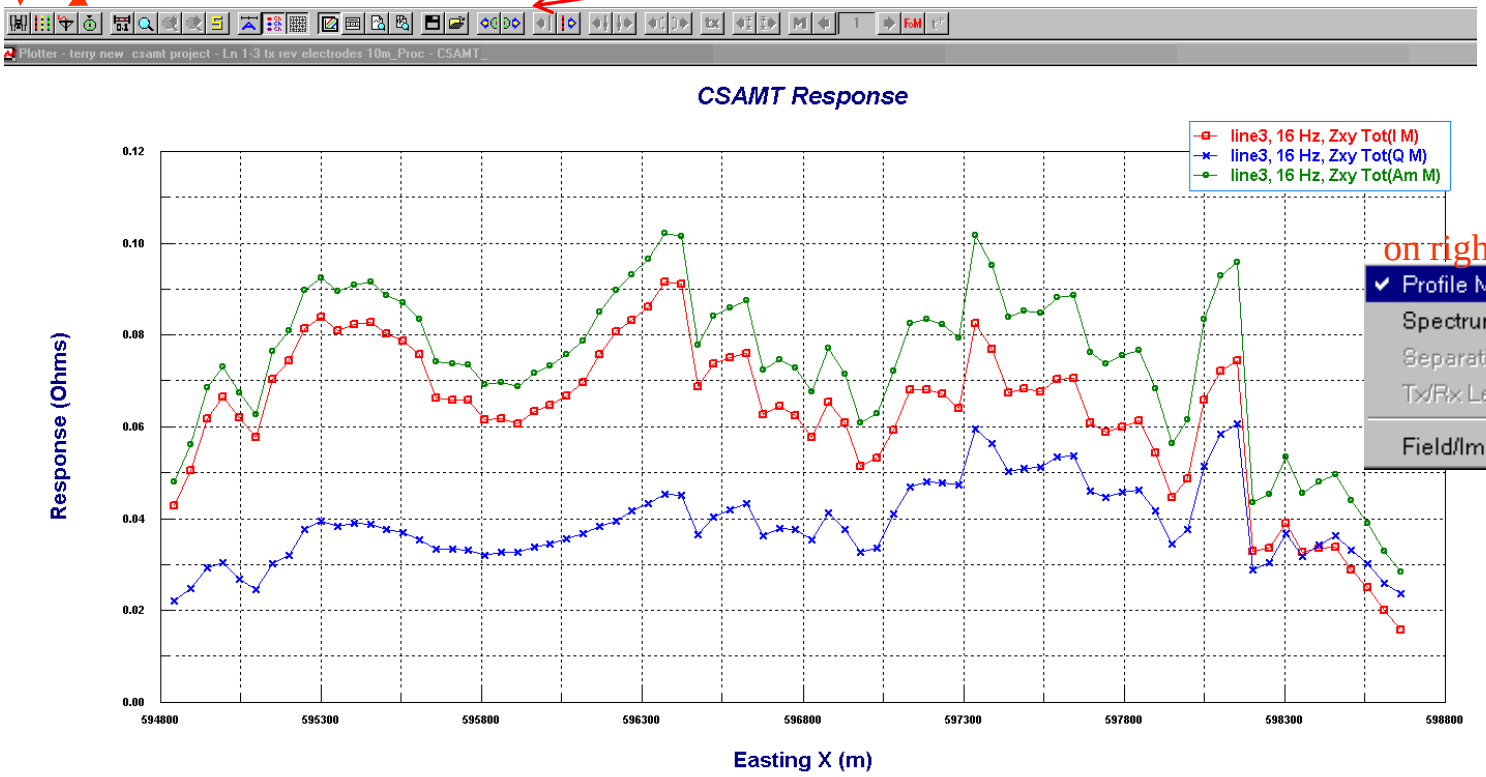
You can plot Z, E or H data is various manners
Impedance apparent resistivity uses the MT formula

Load data set in plotter

Switch between Profile and Spectrum mode

Toggle between frequencies



1. Data organization and import
2. **Examine data**
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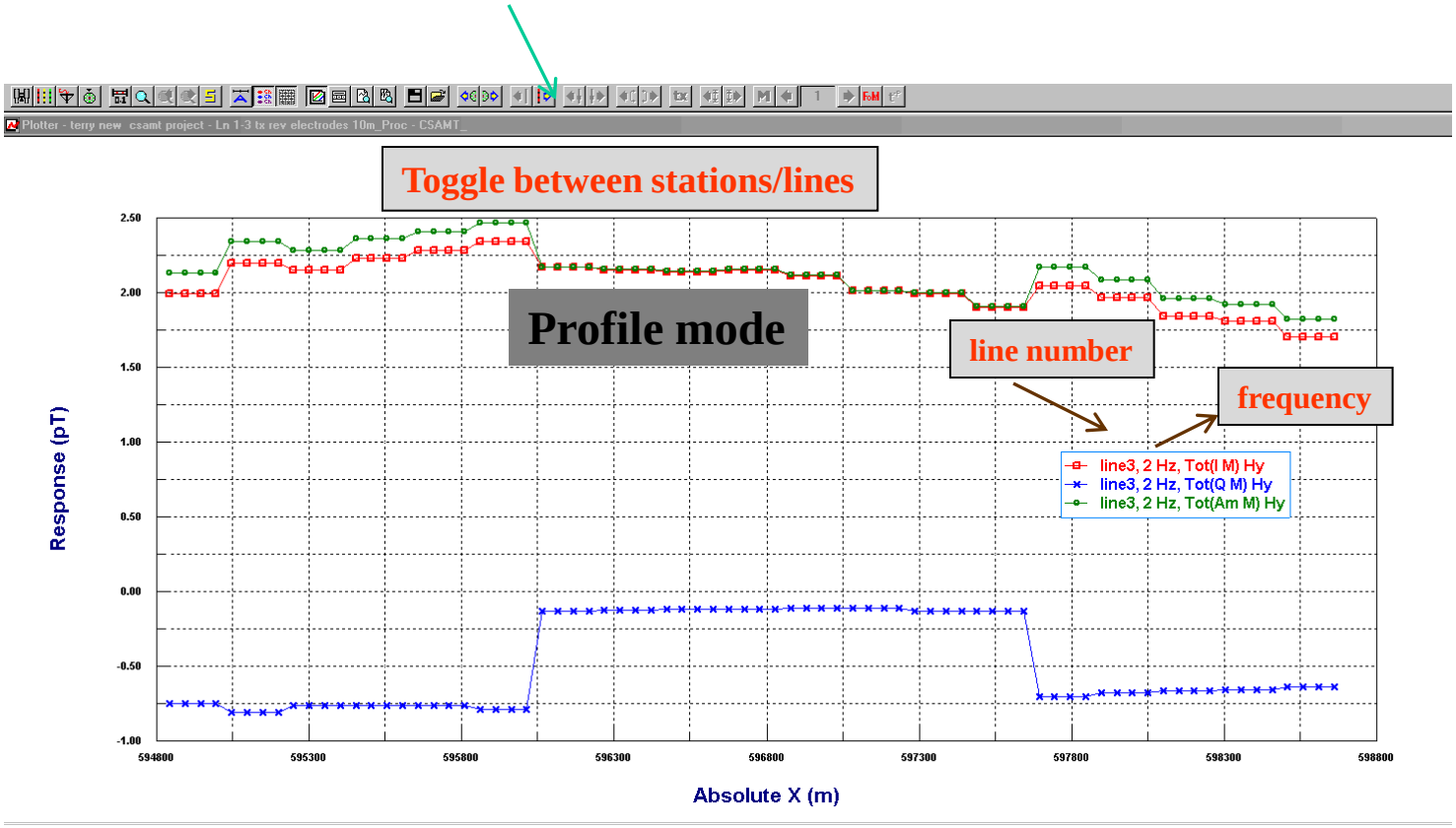
5. Inversion evaluation

The figure below shows the *Hy* component with the real component (in red) , the imaginary component (in blue) and the amplitude (green) -- all on the same plot. The plot is shown in Spectrum mode on the next page.



1. Data organization and import
2. **Examine data**
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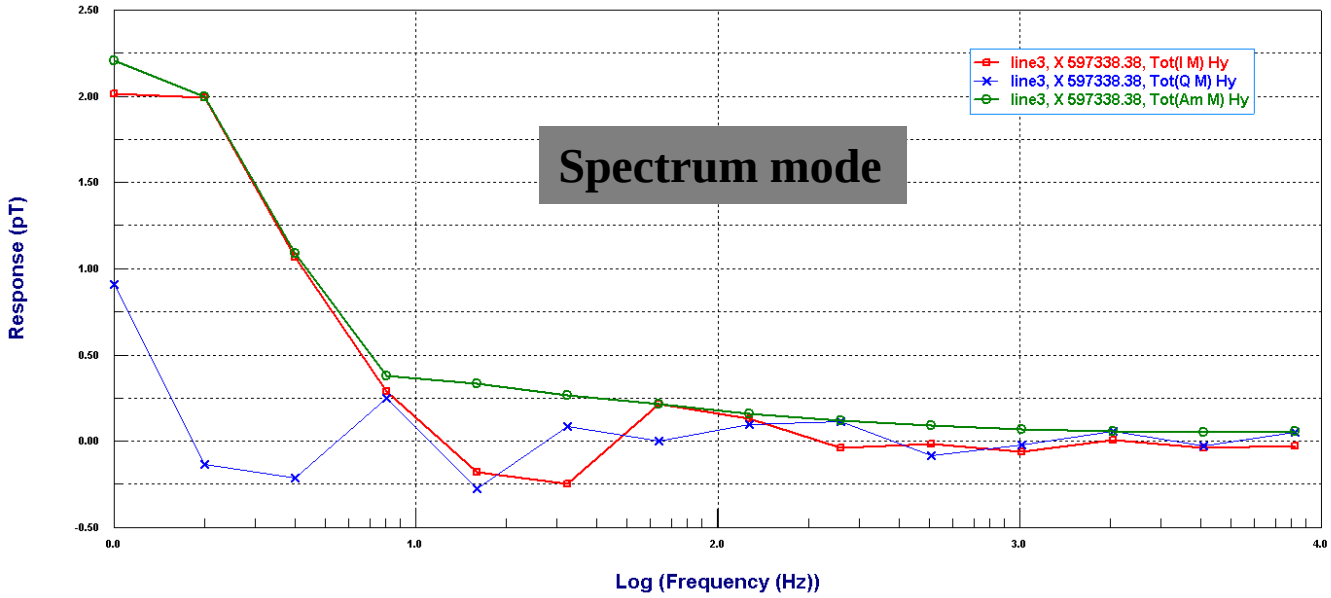
The plot below shows the *Hy* component in Spectrum mode. Here, the response is shown as a function of frequency. The Real component is shown in **red**, the imaginary component in **blue** and the amplitude in **green** – as indicated on the previous page. The Fields/Component dialog is discussed on the next page.



1. Data organization and import
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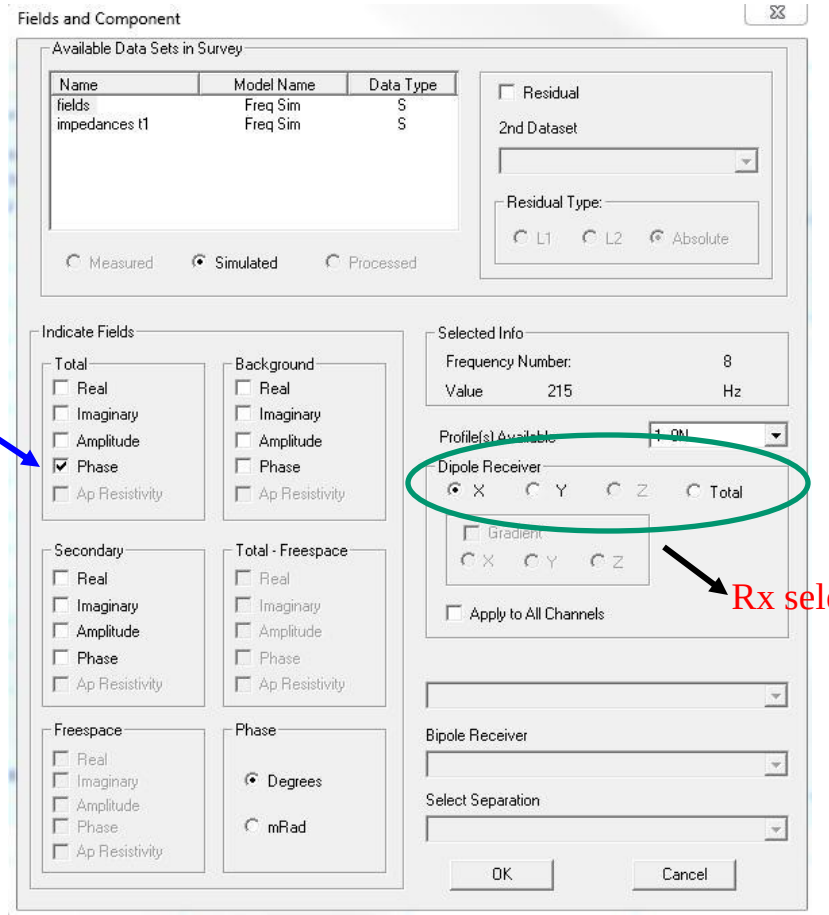
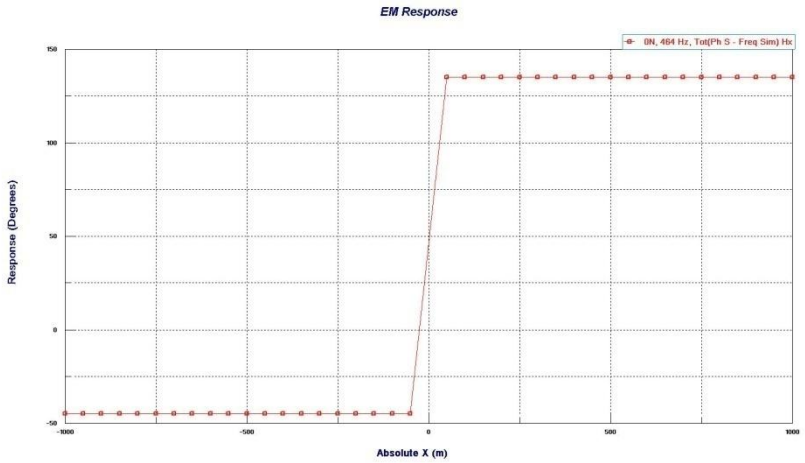
Click "Channels" button on the toolbar and select "Field" in the popup dialog (as shown)

Check "Phase" option, and click "OK" to display the phase



Rx selection

Phase (degrees)



1. Data organization and import
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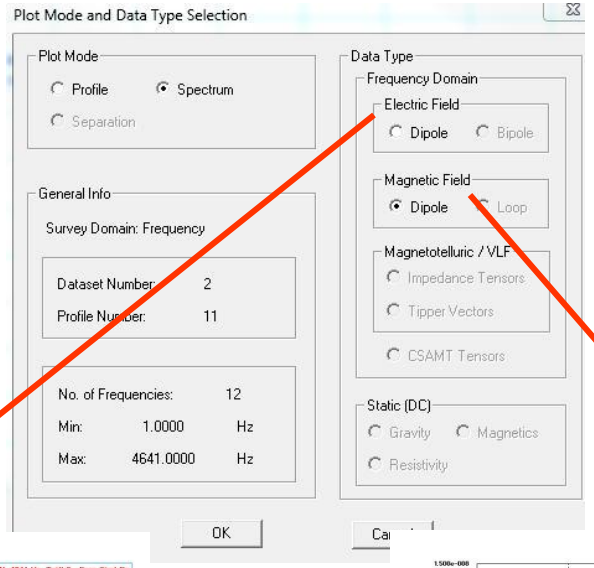
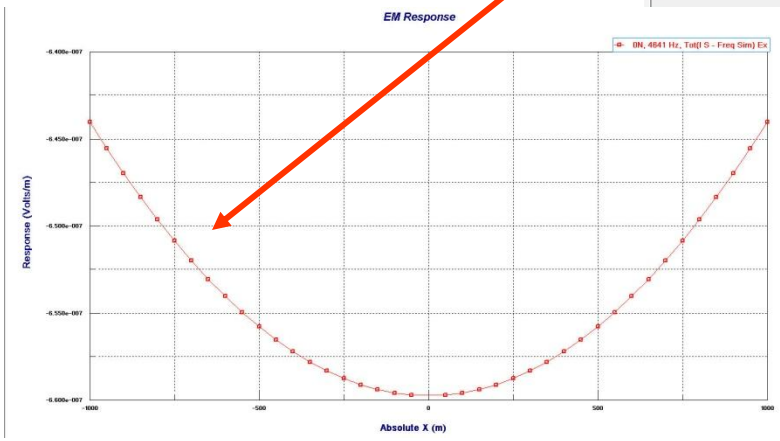
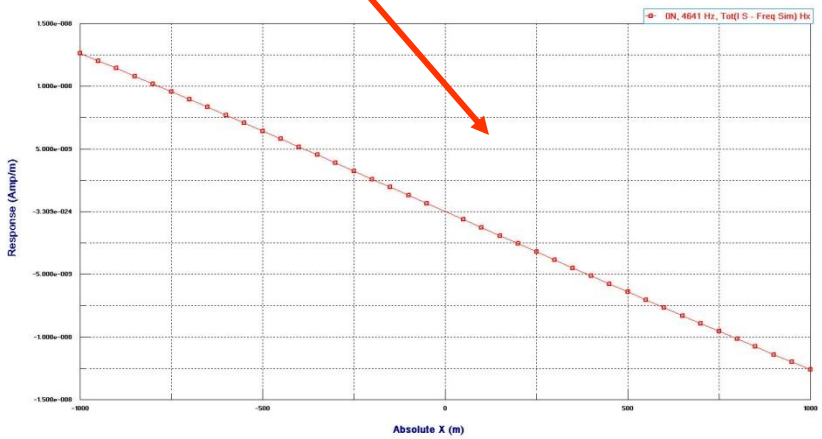
You can also switch between electric field and magnetic fields.
Click the domain button on the toolbar to view the following dialog:



E field

H field





1. Data organization and import
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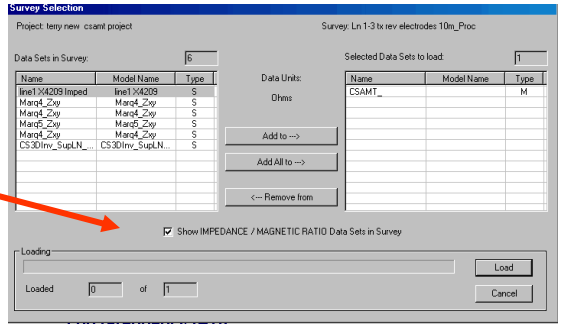
You can also plot the impedance data using the *Plotter*.

Select the 'Impedance/Magnetic Ratio' data sets in the same survey after selecting the *Plotter* button to load the data set.



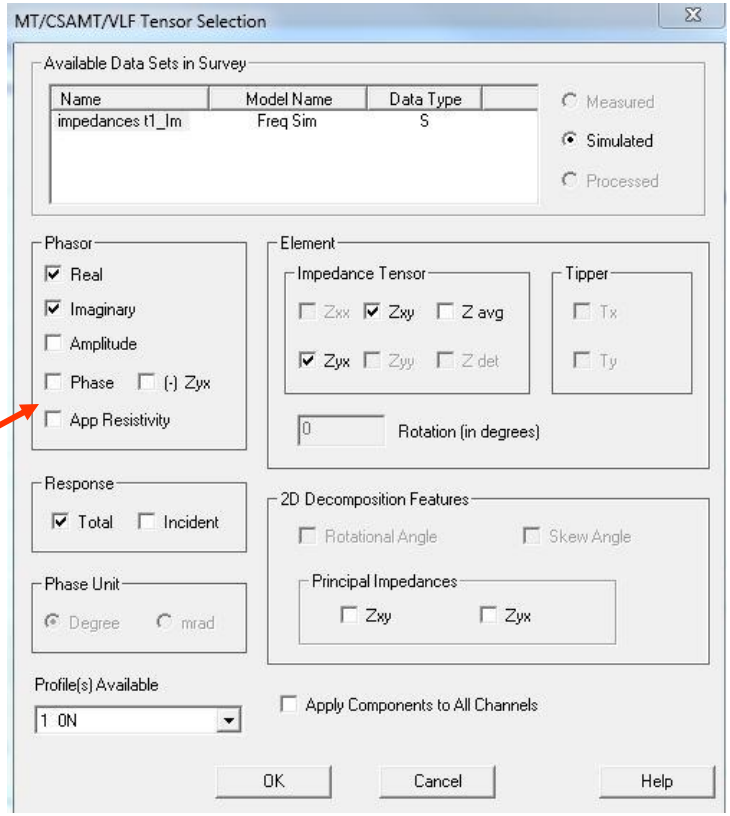
Double-click the white background on the plotter window to access the *Channel Selection* dialog.

Then click the 'Field' button to access the '*MT/CSAMT/VLF Tensor Selection*' window, shown on the right.

Check 'Real' and 'Imaginary' components and the impedance tensors, Zxy, Zyx, to display the data.

You can also switch between 'Apparent Resistivity' and 'Phase' by checking the appropriate boxes.

An example plot is shown on the next page.



1. Data organization and import
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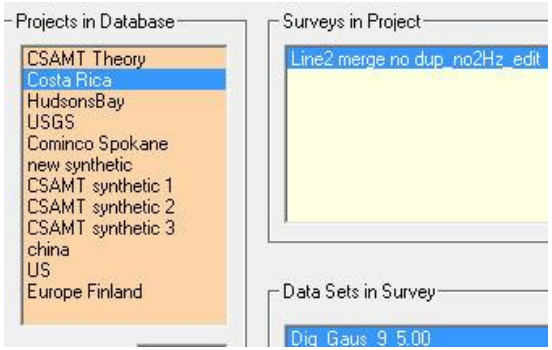
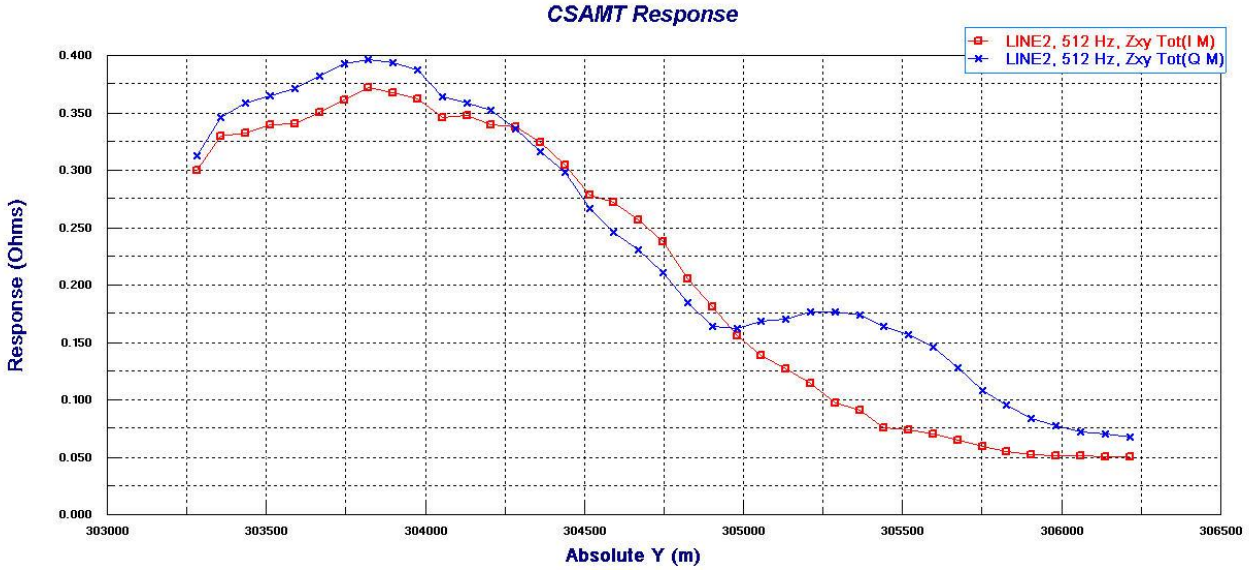
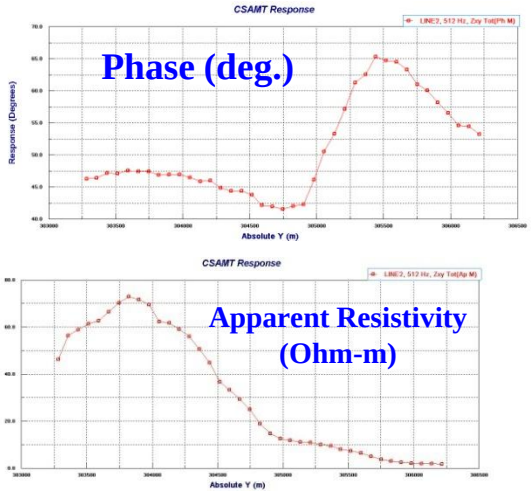
To illustrate the different plotting capabilities for an impedance data set, an example from the *Costa Rica Project* is shown below:





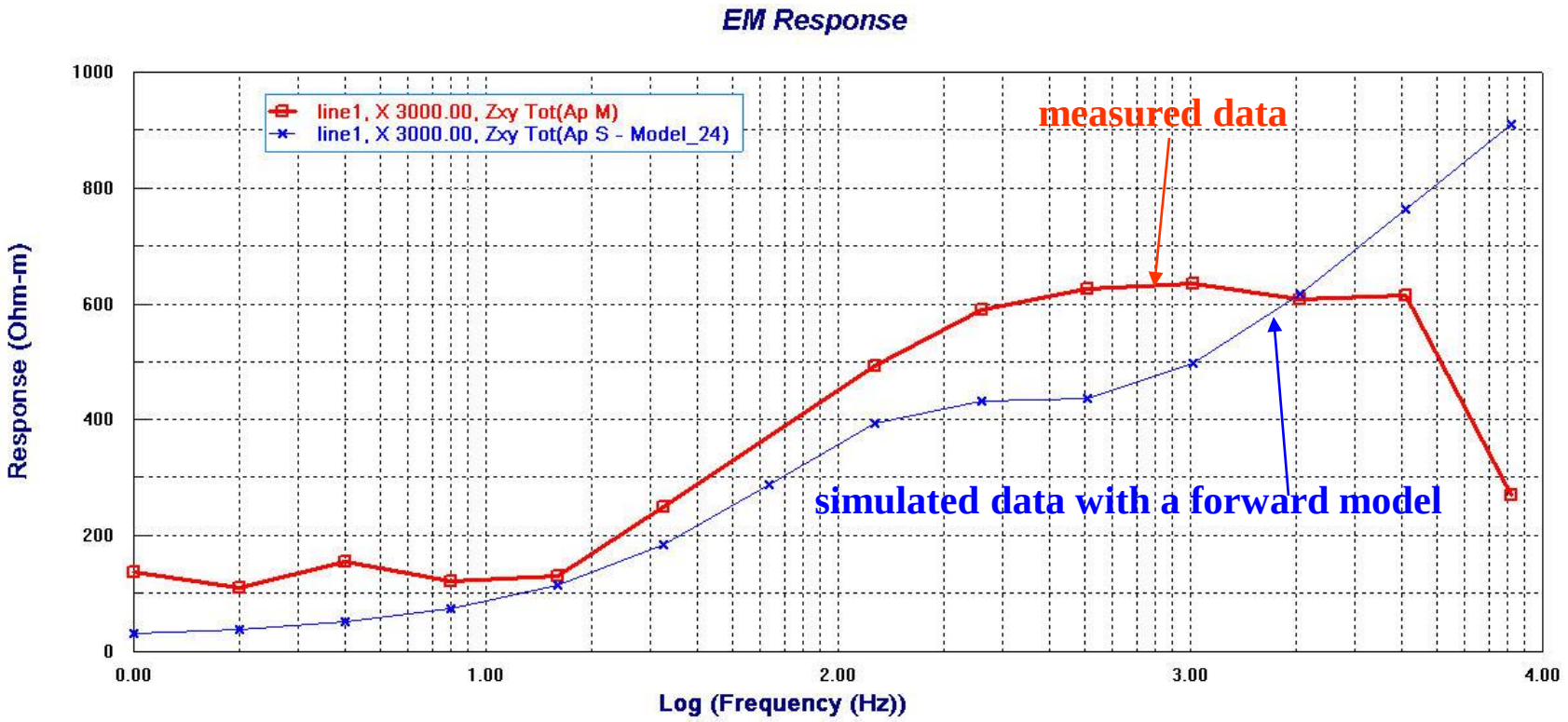


Both the 'real' and 'imaginary' components of *Zxy* are shown in red and blue respectively. The corresponding 'Phase' and 'Apparent Resistivity' plots are shown on the right.

To access the *CSAMT Tensor selection* options for plotting, double-click the white background on the Plotter window and then click the 'Field' button.

1. Data organization and import
2. Examine data
3. **Perform initial modeling**
4. Perform controlled inversions
5. Inversion evaluation

The object is to perform some initial modeling in order to get a "feel" for the background resistivity and thus estimate the parameters for the 'initial model',which is to be used for inversion.



1. Data organization and import
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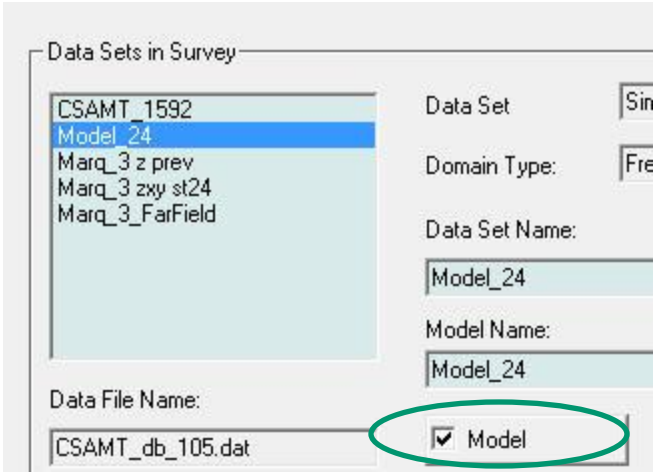
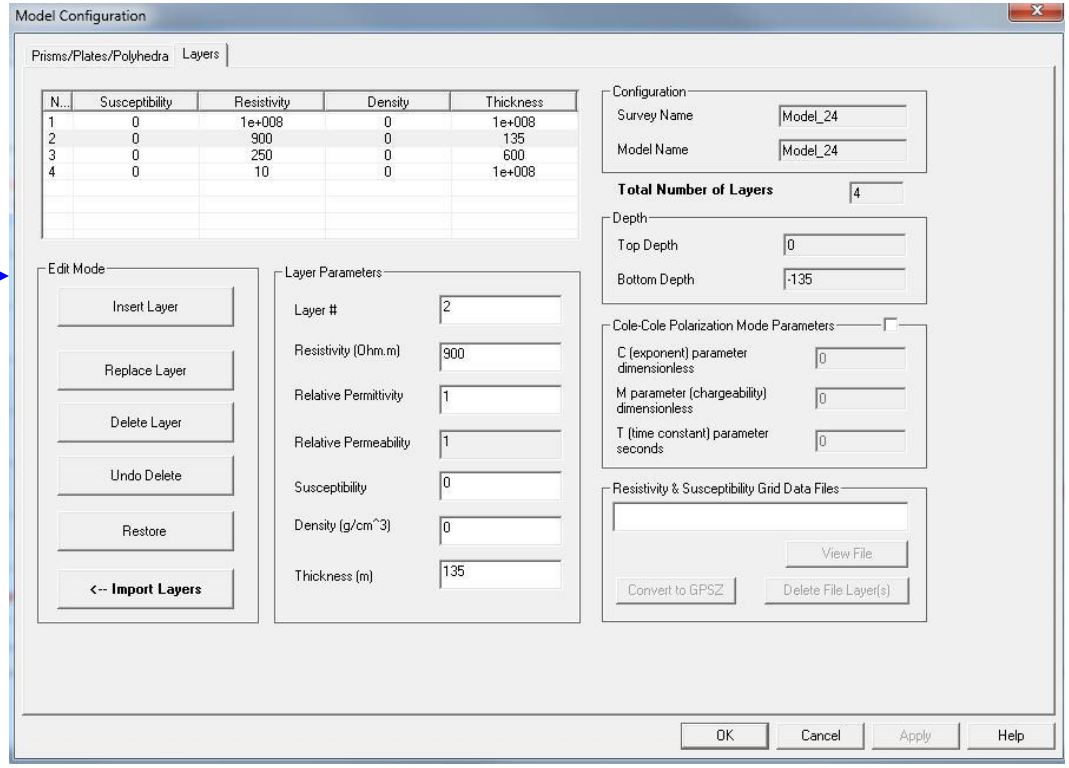
You can view existing models for a data set by clicking the *Model* button, as shown:





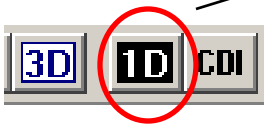
You can also create models for a given data set by clicking the 'Model' button and then specifying the parameters for a 1D layered earth model and/or a 3D model.

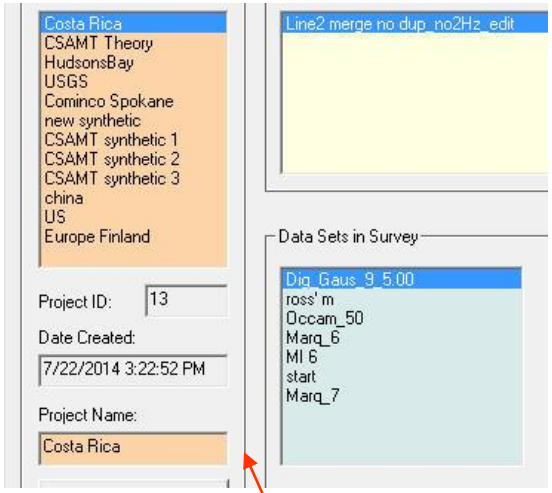
To learn more about forward simulation, please refer to the EMIGMA *manual or the* FORWARD Simulation *tutorial.*

1. Data organization and import
2. Examine data
3. Perform initial modeling
4. **Perform controlled inversions**
5. Inversion evaluation

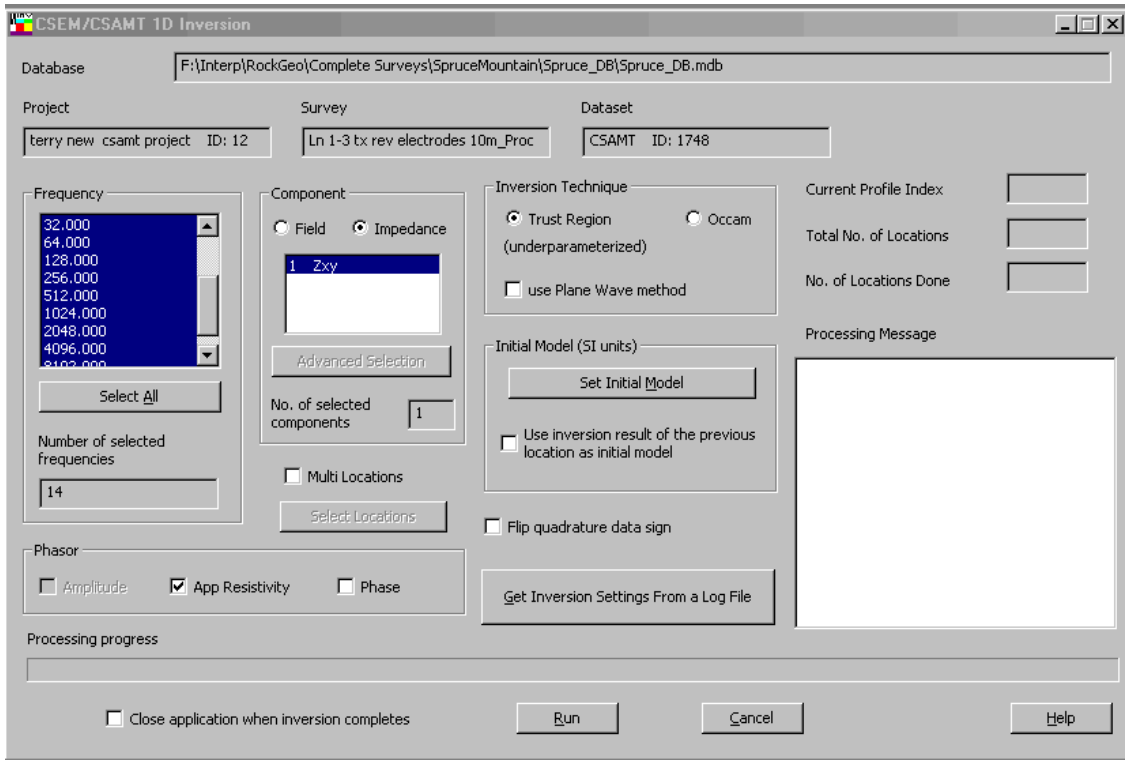
To perform a 1D CSAMT inversion:

2. Click the 1D button on the toolbar to see the following window:



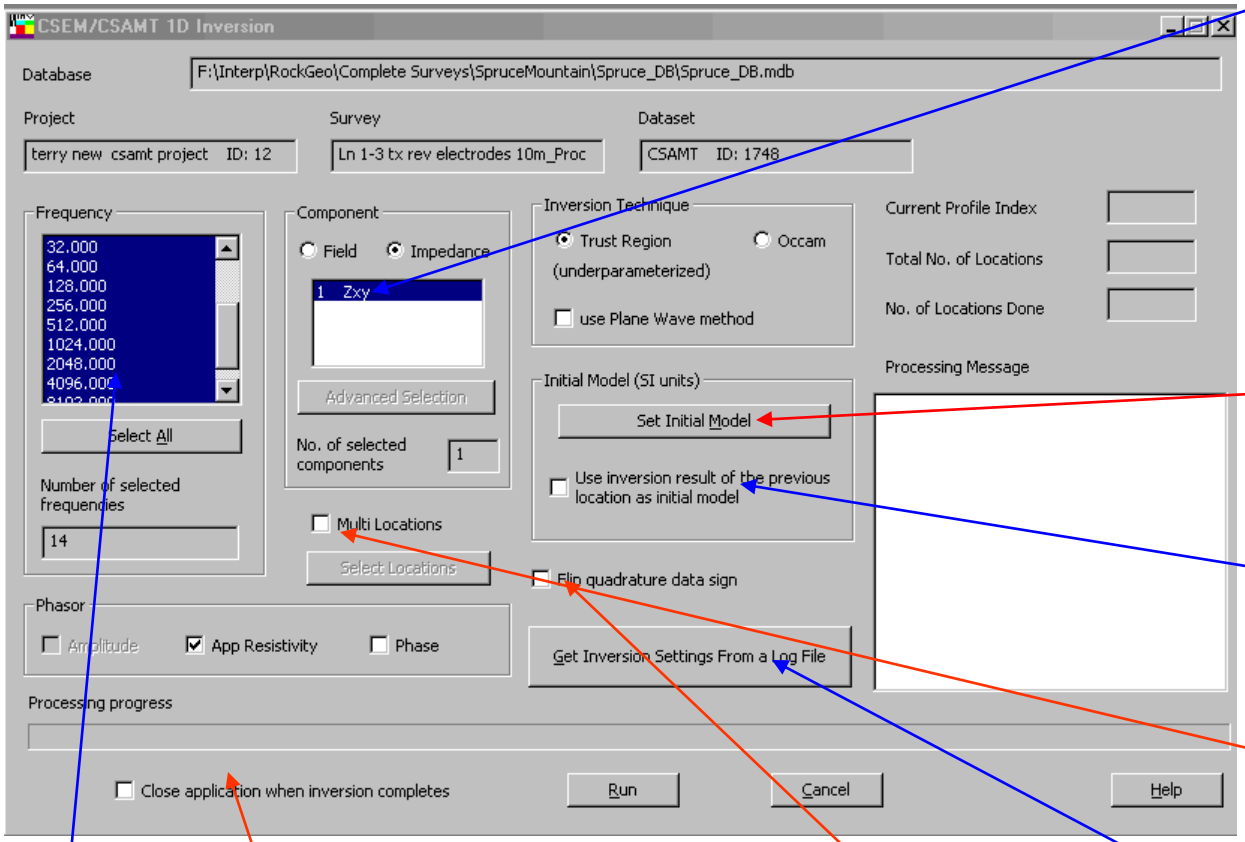


1. Select survey data



1. Data organization and import
2. Examine data
3. Perform initial modeling
4. **Perform controlled Trust Region or Occam inversions**
5. Inversion evaluation

1D CSAMT Inversion Interface



Select components used for inversion
Z or V/H

Create a starting model, and constrain model parameters

For a consistent model, use result of previous point as initial model

Specify multiple locations to be used in inversion, if available

Load inversion settings from a log file and set name for log file

Choose frequencies for inversion

Flip data sign if it is opposite to the sign convention

Choose real and/or imaginary phasor data for inversion

1. Data organization and import
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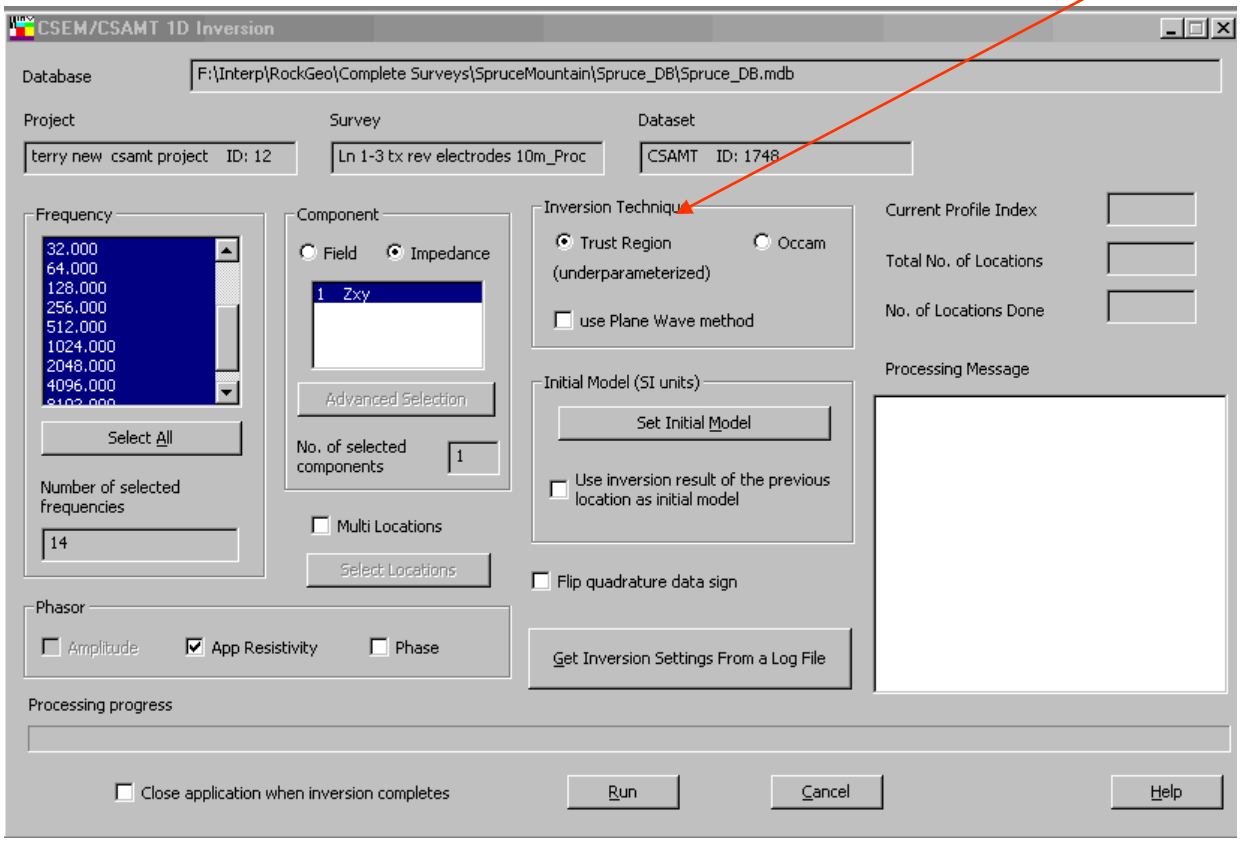
Inversion style



Inversion style:

There are two distinct inversion techniques that are available:

Trust Region

An underparametrized technique with a fast rate of convergence. Utilizes (user-defined) simple bound constraints to solve the least-squares minimization problem. Inverts for both resistivity and thickness.

Occam

Over-parameterized and smooth inversion. Each layer has a fixed thickness and the inversion only inverts for resistivity.

Please refer to the Help section of EMIGMA *or the* EMIGMA *manual for more details.*

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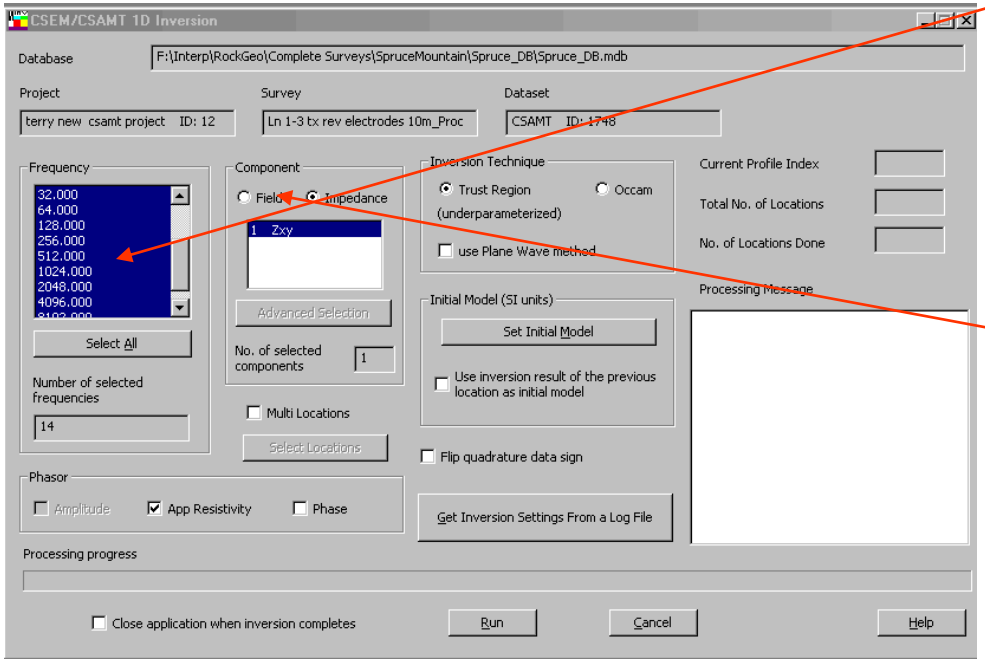

Choose frequencies for inversion

After examining your data, choose which frequencies you wish to utilize for inversion. The best model will be computed for all frequencies for comparison.

Inversion Controls

In CSAMT, ***Vx*** and ***Hy*** fields are typically measured, and impedance ***Zxy*** will then be processed from field data. It is standard to use impedance data for inversion, but using field data would give you information not included in impedance such as, the variation along profile is mainly in current (E-field), or both fields for anomaly.

As this inversion process is suitable when the ground is smoothly varying laterally, you may choose to use the previous data point's final model as the starting model for the next point. This will also speed up the process.

1. Data organization and import
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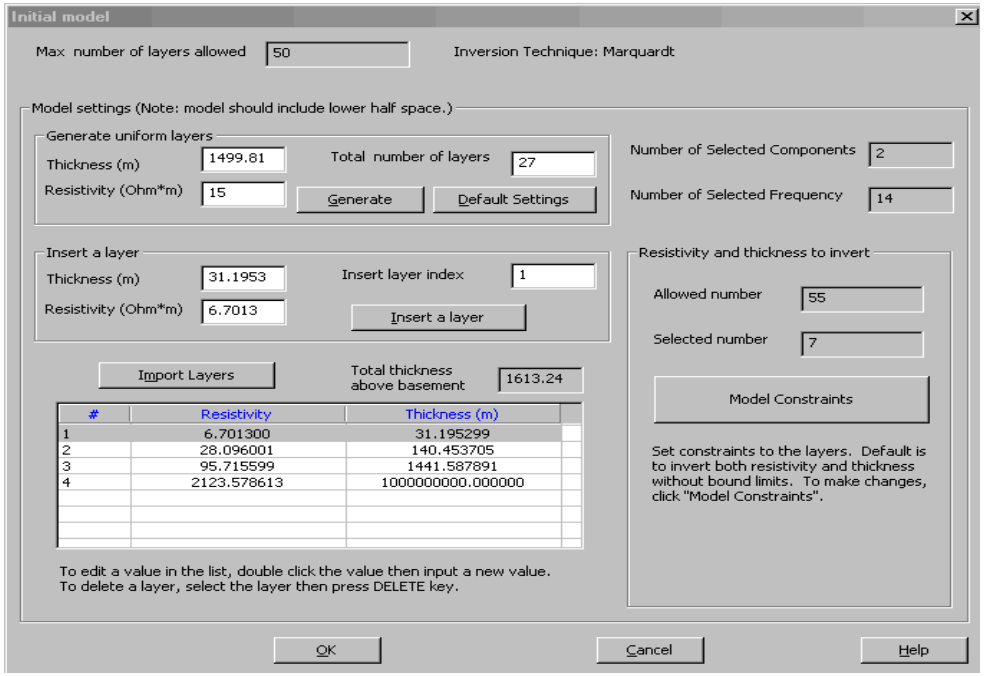
5. Inversion evaluation

Create a Starting Model



Import Layers: If you have created a forward model that you like, you may import it as a starting model or if you have a previous inversion that you like, you may import it as a starting model.

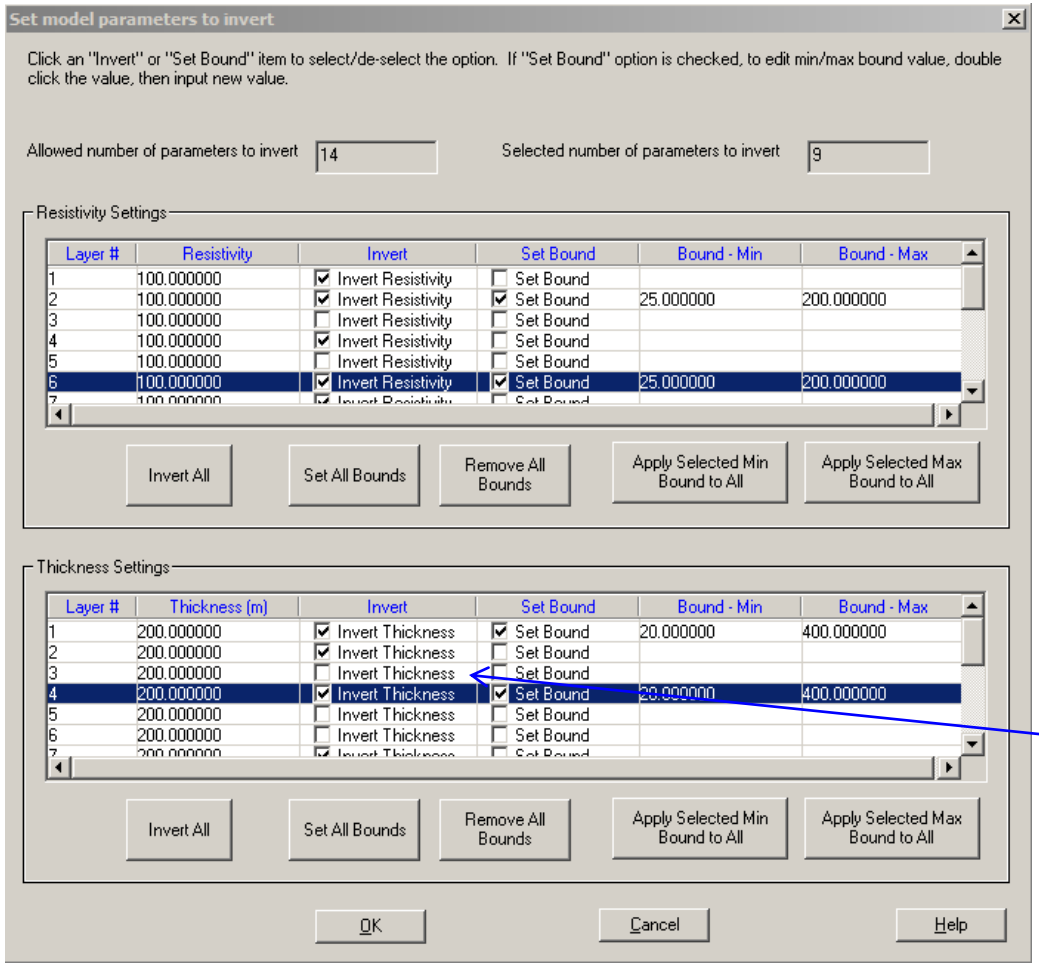
Insert a layer: You may insert additional layers at any stage.

Generate a Starting model:
First select how many layers in total that you would like in the model, set the initial resistivity and thickness. Then click “Generate Uniform Layers”.

Modify Starting model:
After making a starting model (whether by importing or generating), you may edit the resistivity and the thickness of the layer by simply double-clicking on the parameter (value).

1. Data organization and import
2. Examine data
3. Perform initial modeling
4. **Perform controlled inversions**
5. Inversion evaluation

Constrain Model Parameters



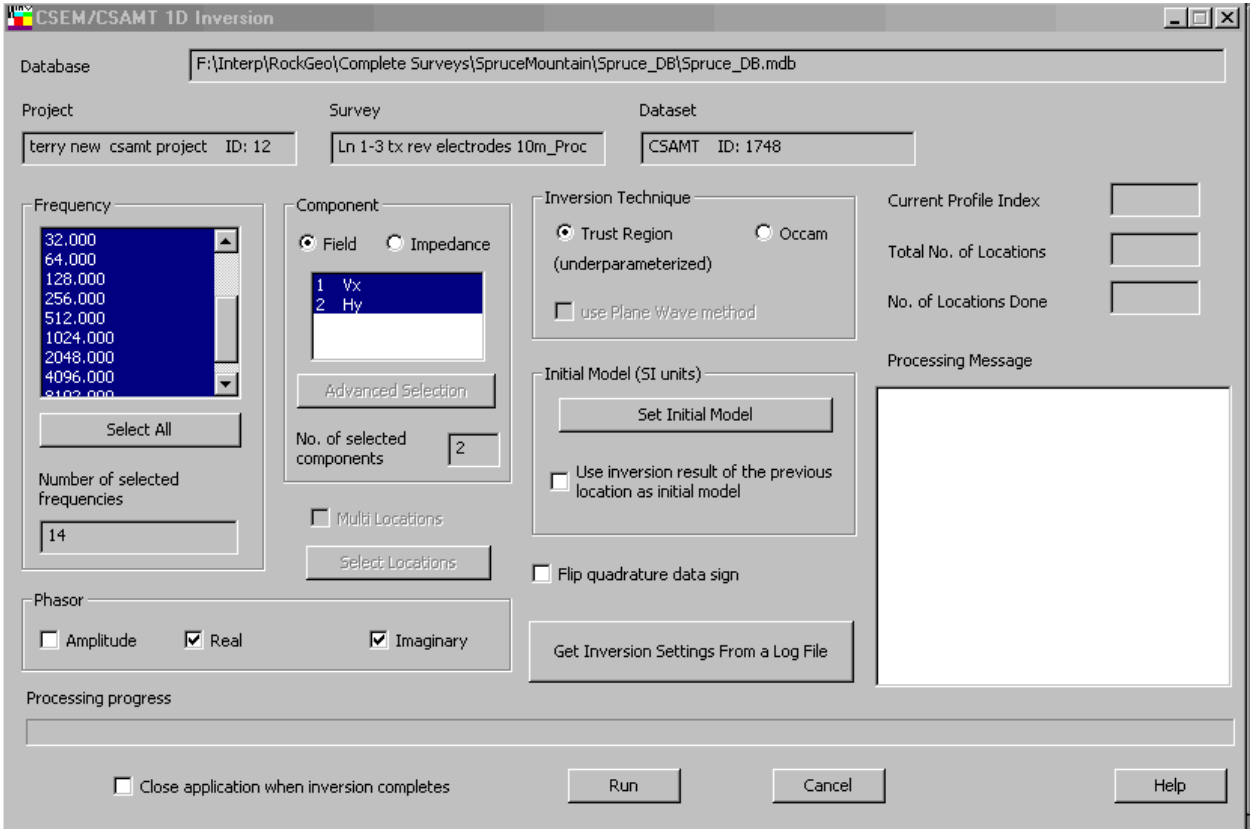
Resistivity Constraints:
It is useful to constrain the layer resistivities to ranges that are possible in the geological environment.

Thickness Constraints:
This option is only available under the *Trust Region* technique.
Constraining the thickness not be too large helps gain resolution. Constraining the thinness of the layer is a question of geological meaningfulness.

Note: You do not have to invert every parameter.

1. Data organization and import
2. Examine data
3. Perform initial modeling
4. **Perform controlled inversions**
5. Inversion evaluation

Executing the Inversion

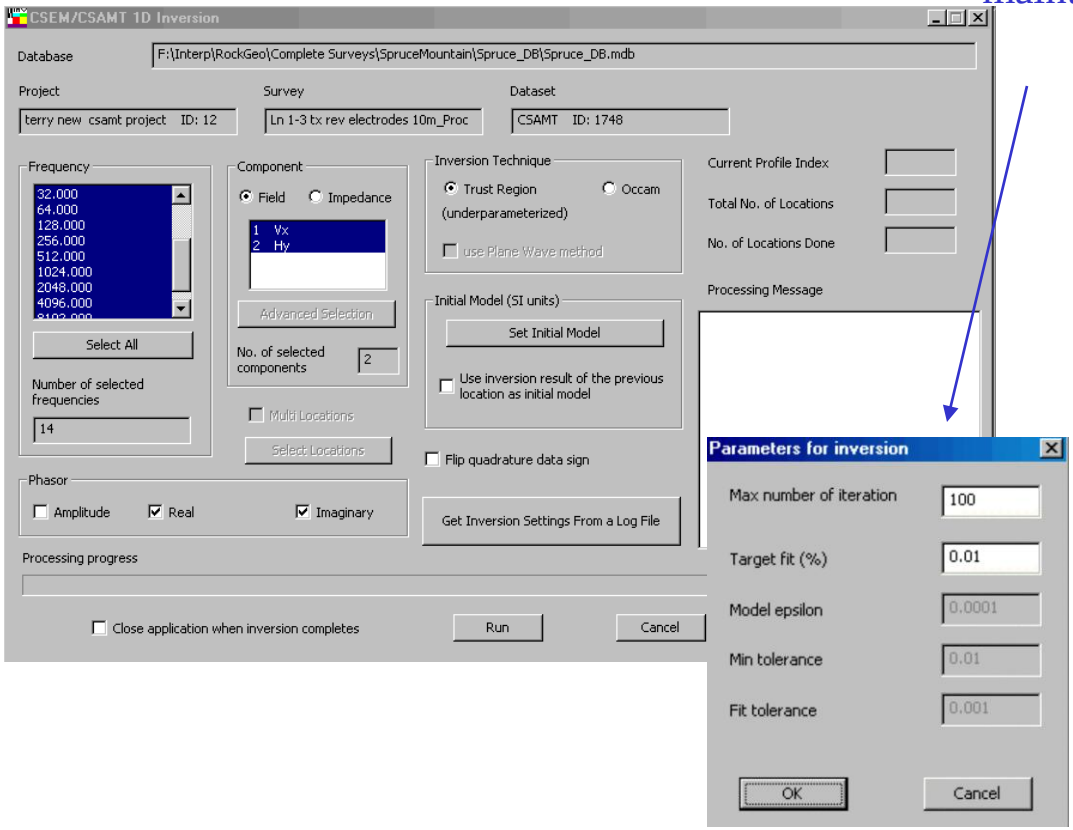


Finally, click the "Run" button.
The total number of data points in all the profiles will be shown as well as the number of data points completed to the right.
The right corner of the window (white area) shows each data point's progress.

1. Data organization and import
2. Examine data
3. Perform initial modeling
4. **Perform controlled inversions**
5. Inversion evaluation

Executing the Inversion

Upon clicking ***Run***, a window will pop-up. Unless the user is familiar with these items then it is suggested that the defaults be maintained.



Number of Iterations: A higher value will help ensure accuracy but execution time increases

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

The settings below are generally not changed by the user:

Model epsilon: Occam is a smooth inversion and the model epsilon controls the smoothness.

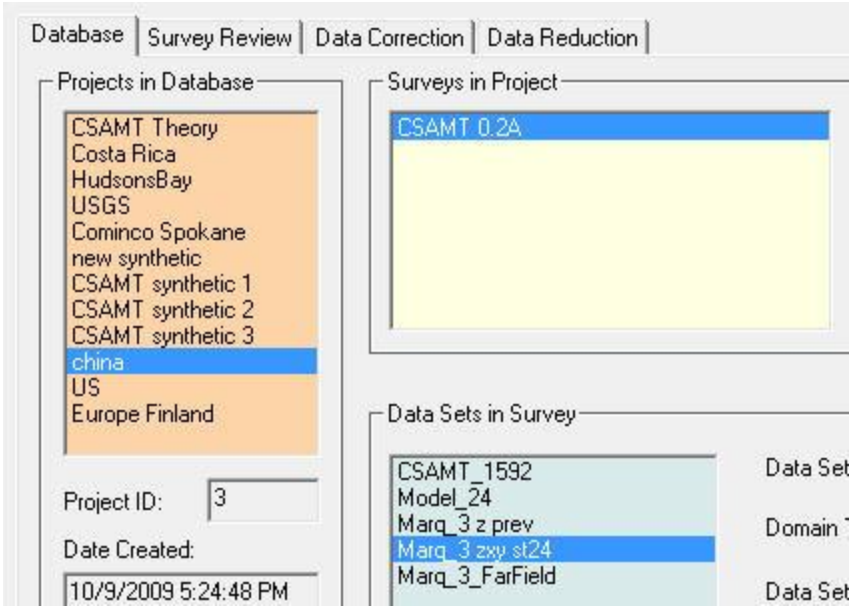
Min tolerance: Specifies how accurately the search algorithms determine minima in the fit.

Fit tolerance: Specifies how close to determine the final fit.

Note: The inversion will stop for either 1) target fit is satisfied, or 2) the maximum number of iterations is reached

1. Data organization and import
2. Examine data
3. Perform initial modeling
4. Perform controlled inversions
5. **Inversion evaluation**

Inversion Evaluation



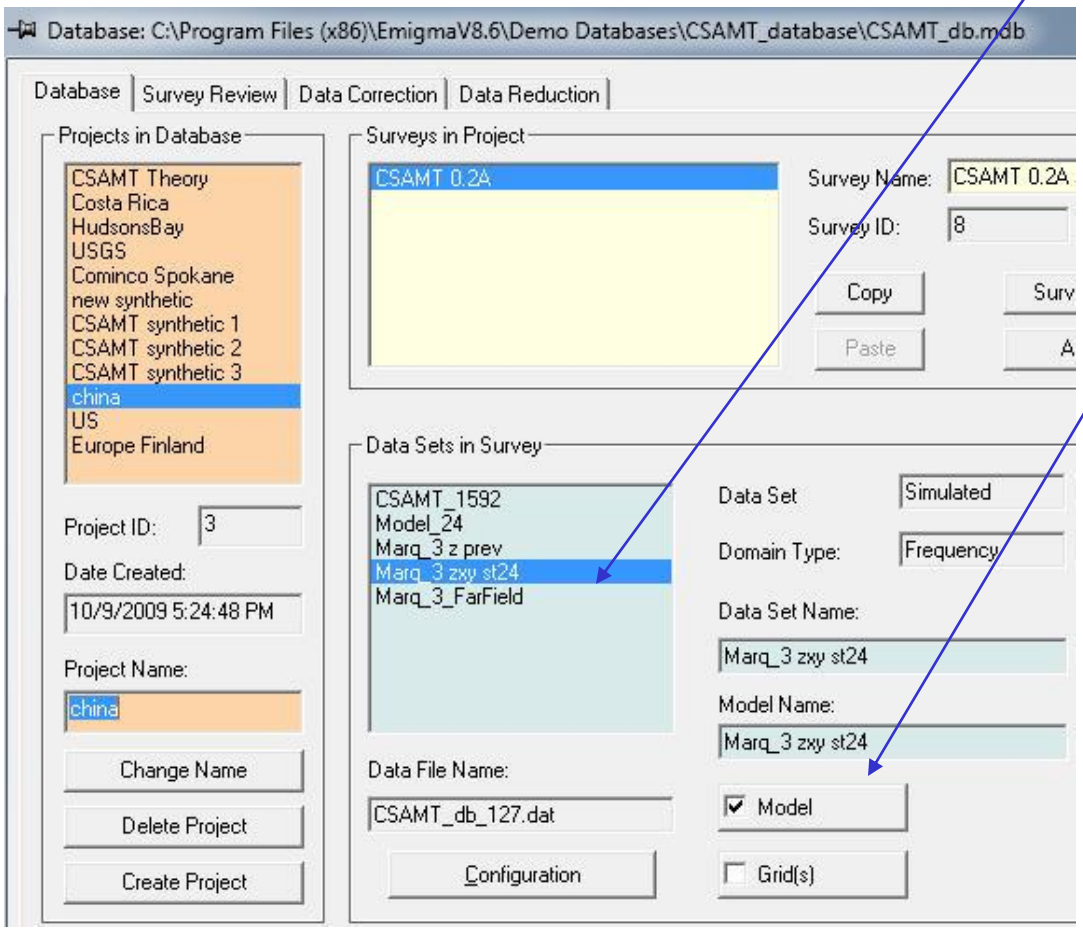
In each survey, there will be several data sets after modeling, inversion and processing. In this case, we have one 1D model and 3 inversions. The forward model has a new data set containing the simulated data under the model. Similarly, each inversion contains a new dataset containing the simulated data set under the inversion model (for each point) and attached to that data set is the inversion model.

1. Data organization and import
2. Examine data
3. Perform initial modeling
4. Perform controlled inversions
5. **Inversion evaluation**

Inversion Evaluation

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

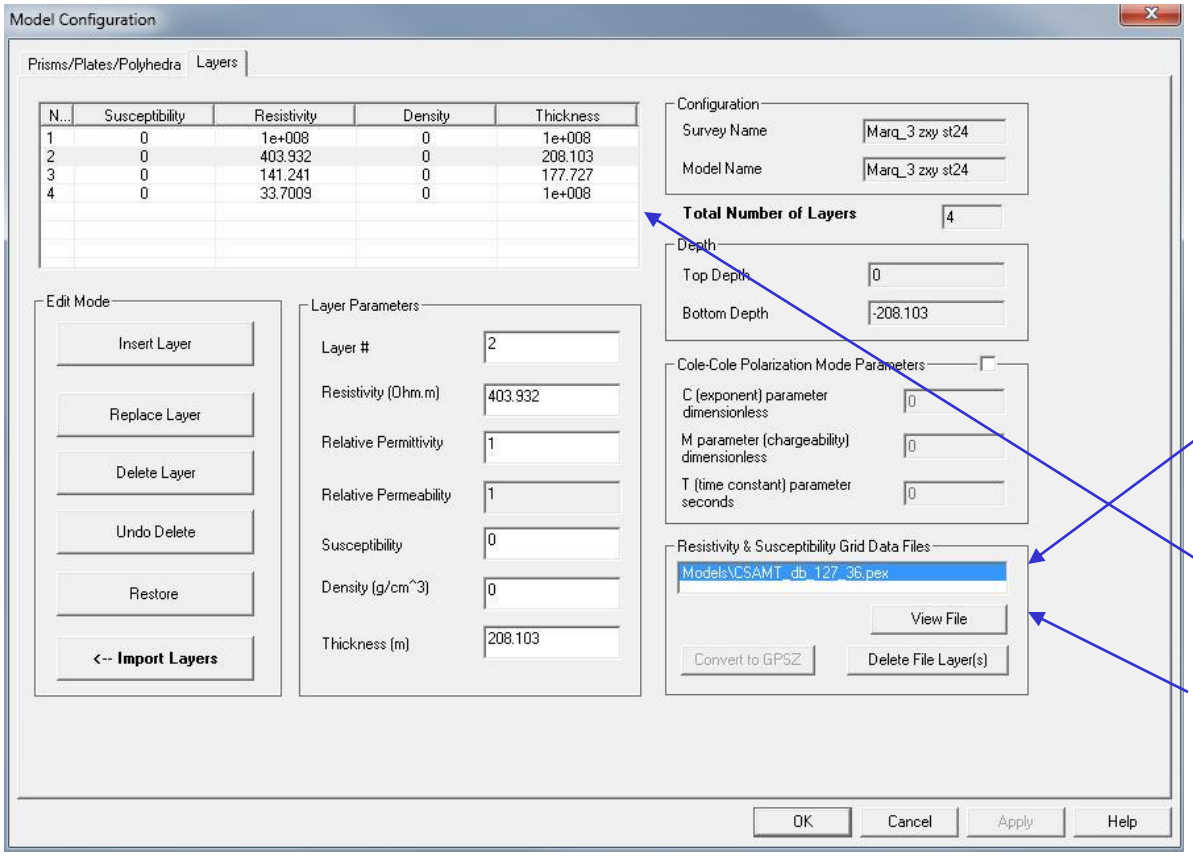
If the model button is clicked…



1. Data organization and import
2. Examine data
3. Perform initial modeling
4. Perform controlled inversions
5. **Inversion evaluation**

Inversion Evaluation

A new window will appear:



Attached to the database in a subdirectory called "Models" are 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.

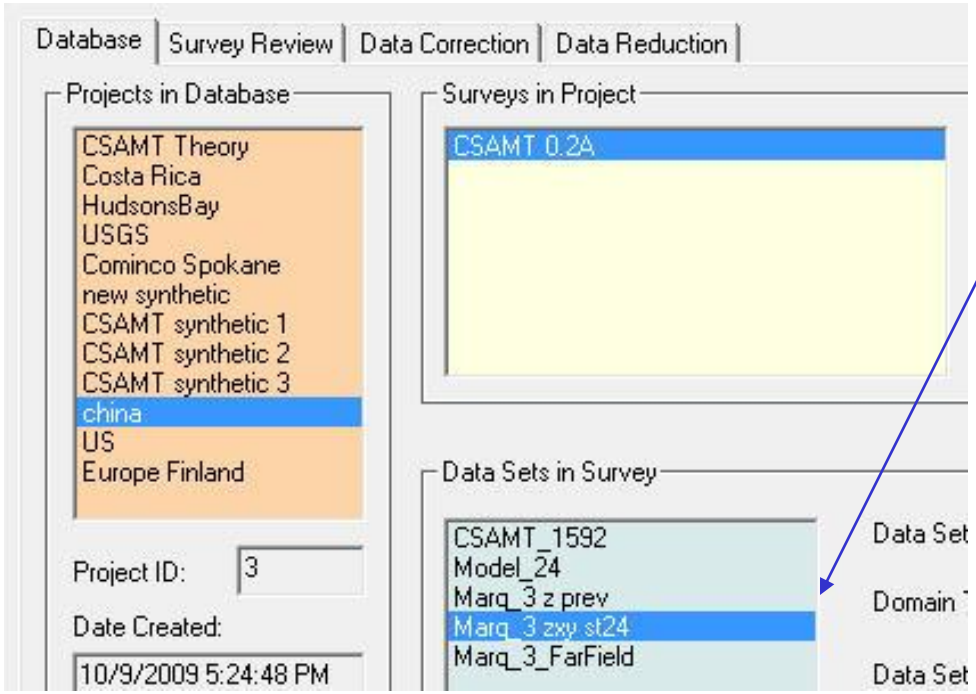
The 1D model for the final data point is also included.

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

1. Data organization and import
2. Examine data
3. Perform initial modeling
4. Perform controlled inversions
5. **Inversion evaluation**

Inversion Evaluation

Select the inversion.



Choose CDI Viewer to graphically view the results

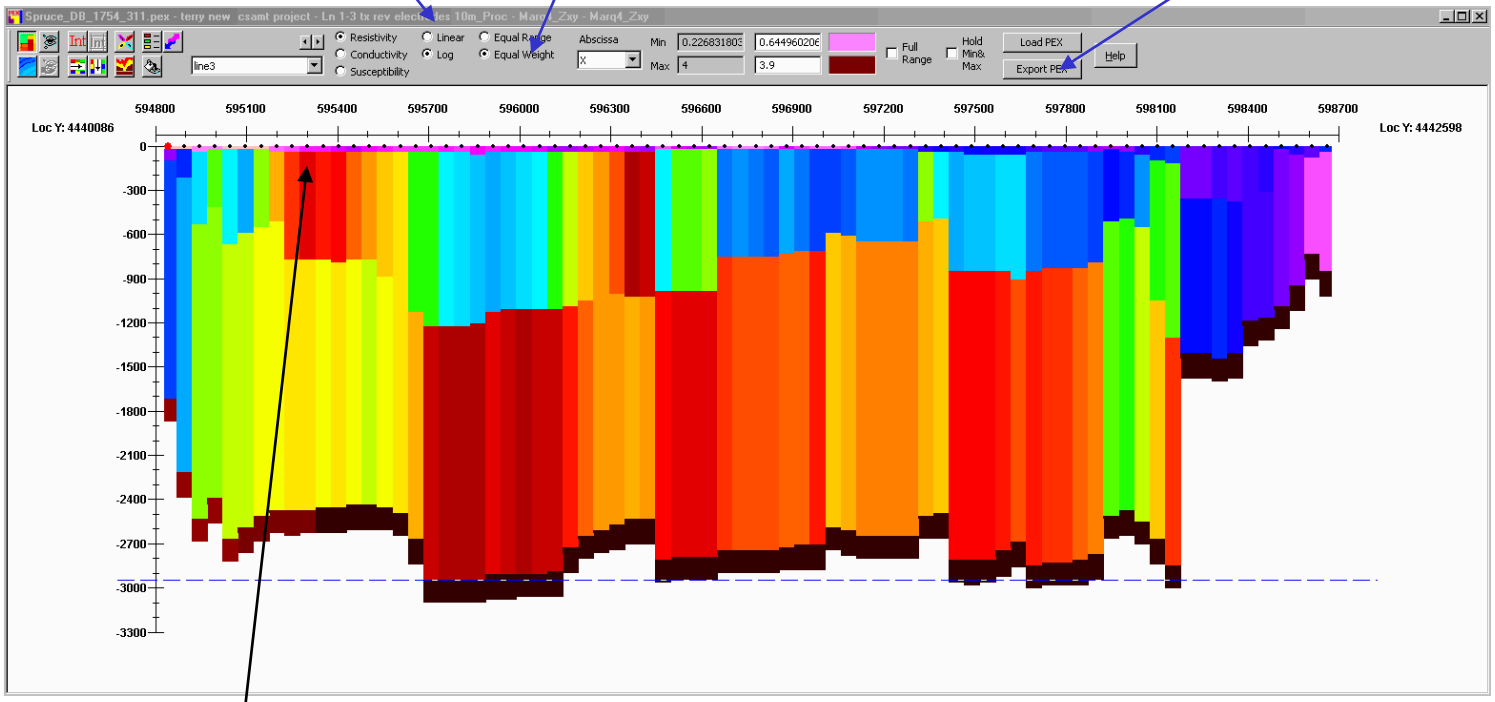
1. Data organization and import
2. Examine data
3. Perform initial modeling
4. Perform controlled inversions
5. **Inversion evaluation**

Inversion Displays

Choose CDI viewer to graphically view the results

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

Export PEX file is also available



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

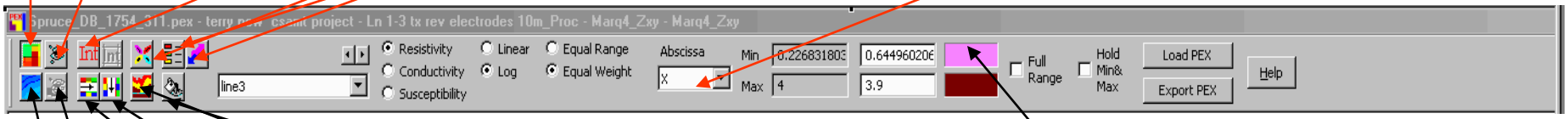
Note: If multi-lines are available the 3D Contour may be used to provide an interpolated 3D volume

1. Data organization and import
2. Examine data
3. Perform initial modeling
4. Perform controlled inversions
5. **Inversion evaluation**

Inversion Displays

Choose CDI viewer to graphically view the results

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



You may adjust colors for the range of resistivity by double clicking these boxes

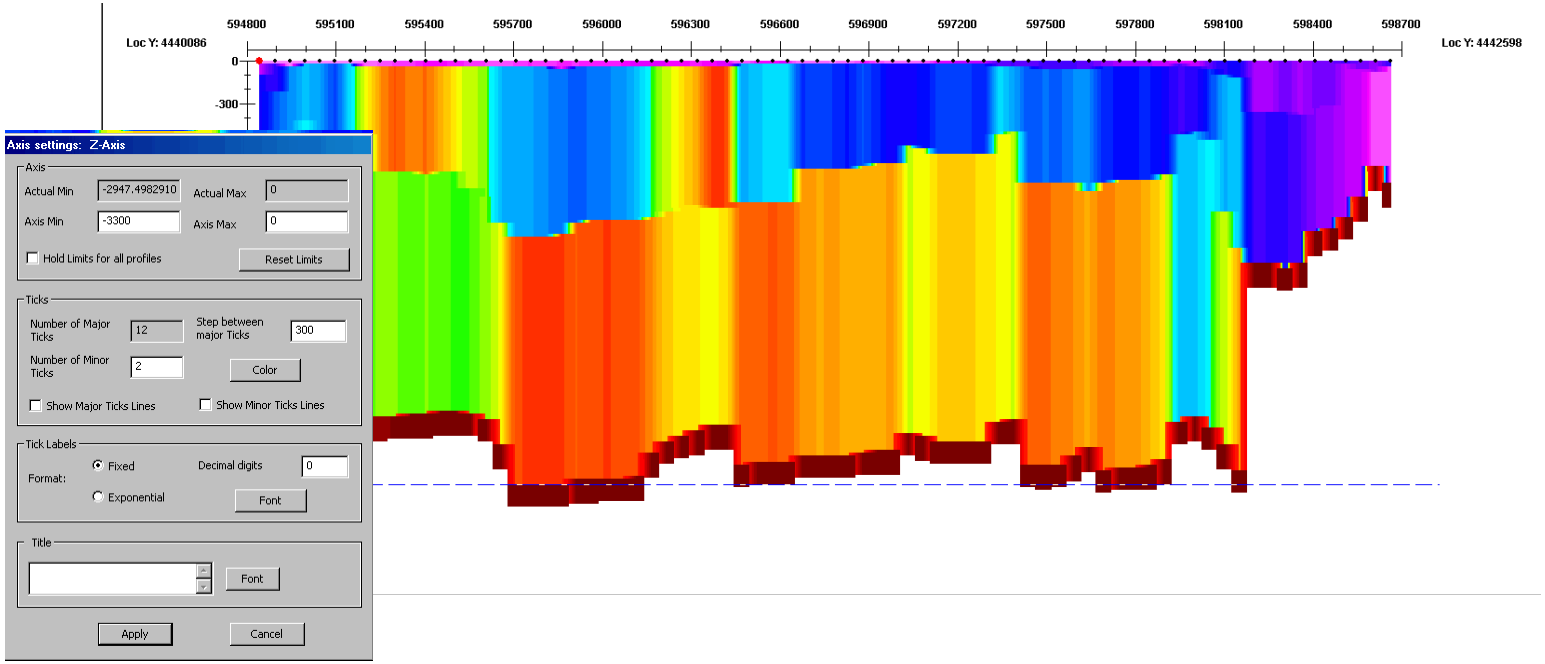
Filled Contour
Contour Attributes
Depth Interpolation
Location Interpolation
Extrapolate to Basement
Refresh View

Equal Range: assign different colors to different ranges which are equal independently of the number of data falling within these ranges. Sequence of the colours cannot be changed.
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. Data organization and import
2. Examine data
3. Perform initial modeling
4. Perform controlled inversions
5. **Inversion evaluation**

Inversion Displays

Choose CDI viewer to graphically view the results

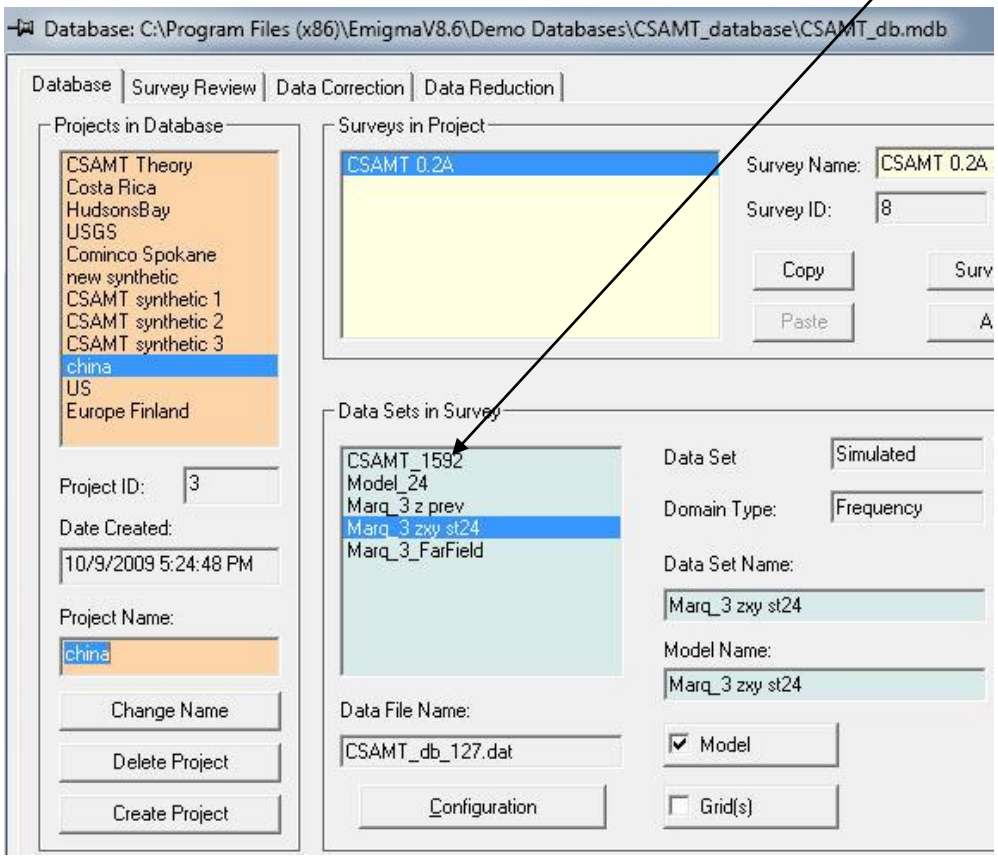


Axes may be edited by double-clicking on it, and you can change Max, Min, Labels and Titles etc. on the popup dialog

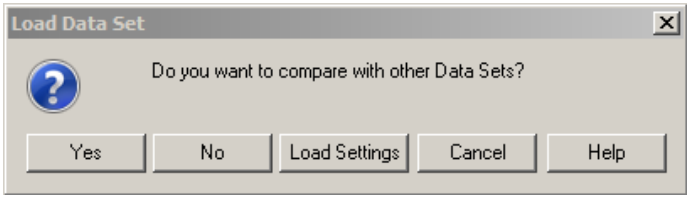
Depth and location interpolated may be repeated (note: the results of previous interpolations are used in the next interpolation so use with care)

1. Data organization and import
2. Examine data
3. Perform initial modeling
4. Perform controlled inversions
5. **Inversion evaluation**

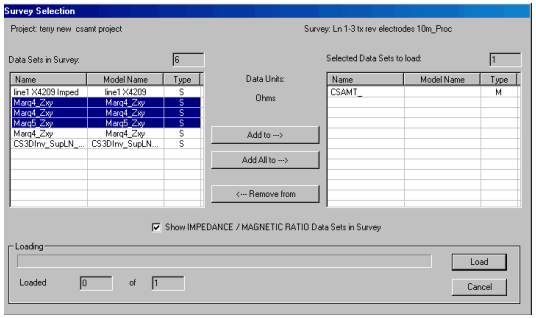
Inversion Evaluation



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



Select "Yes", if this dialog is appeared and select the inversion dataset in the next dialog to open both datasets or multiple datasets to the plotter

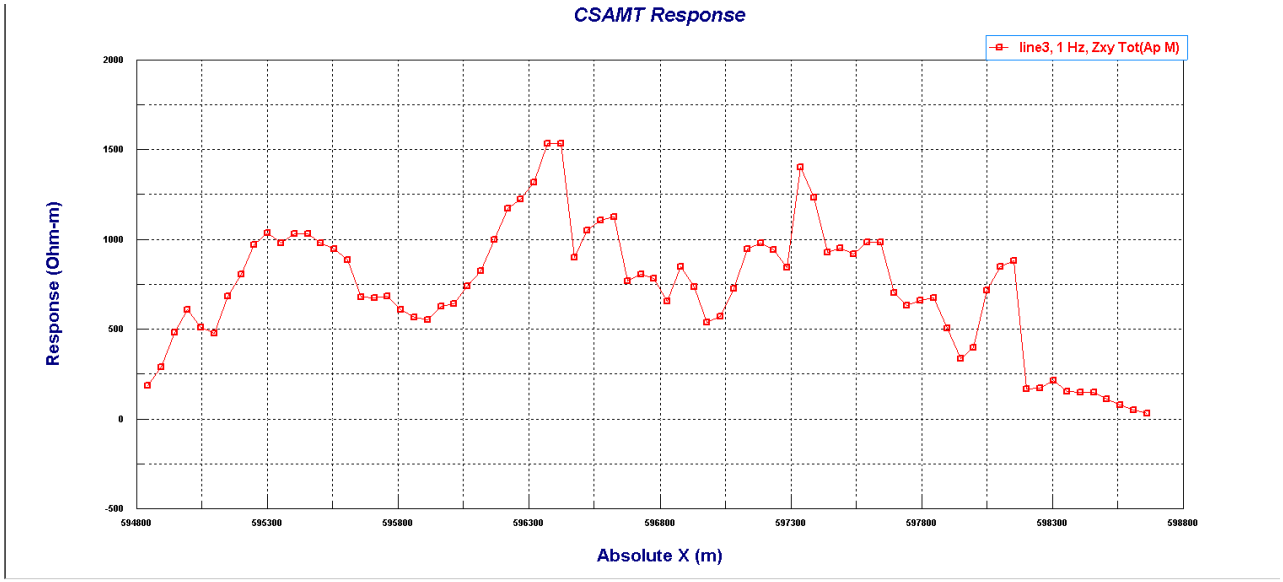


1. Data organization and import
2. Examine data
3. Perform initial modeling
4. Perform controlled inversions
5. **Inversion evaluation**

Inversion Evaluation

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

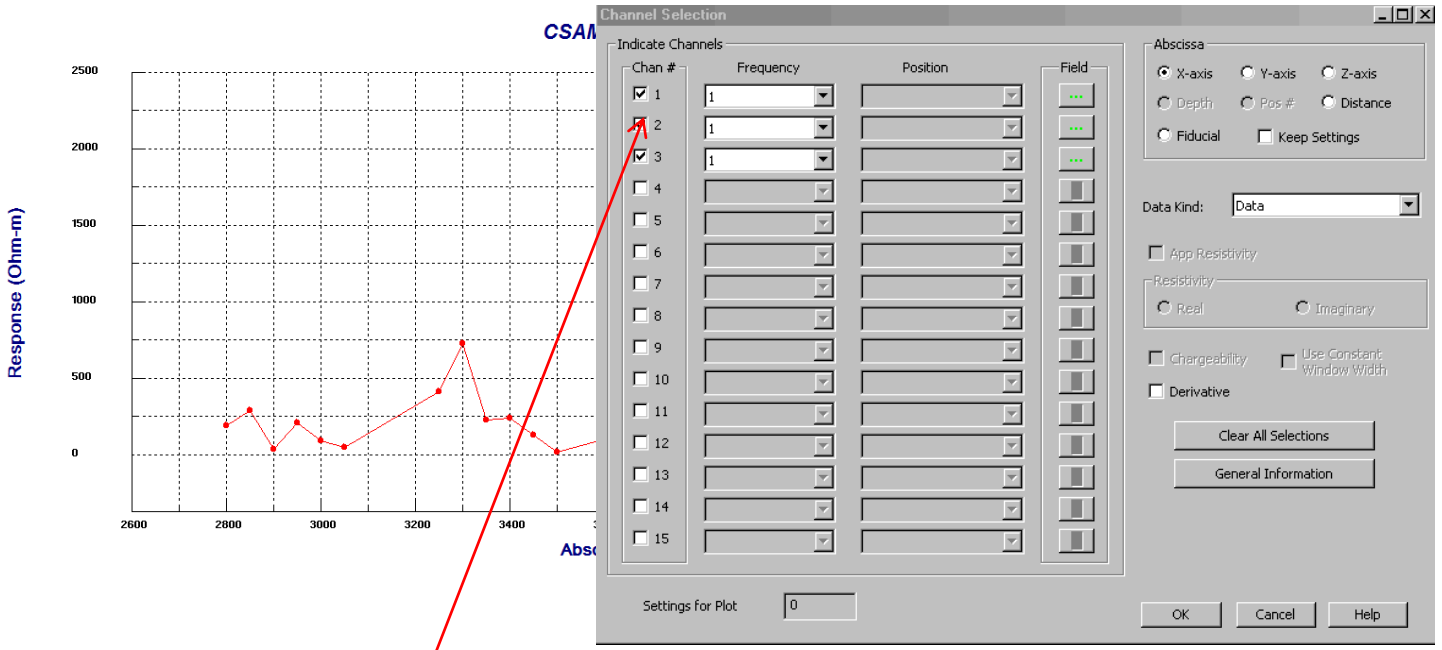
All selected data sets are then loaded to the plotter application and the plot appears showing the first frequency of the measured data which by default is the impedance represented as an MT apparent resistivity.



1. Data organization and import
2. Examine data
3. Perform initial modeling
4. Perform controlled inversions
5. **Inversion evaluation**

Inversion Evaluation

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

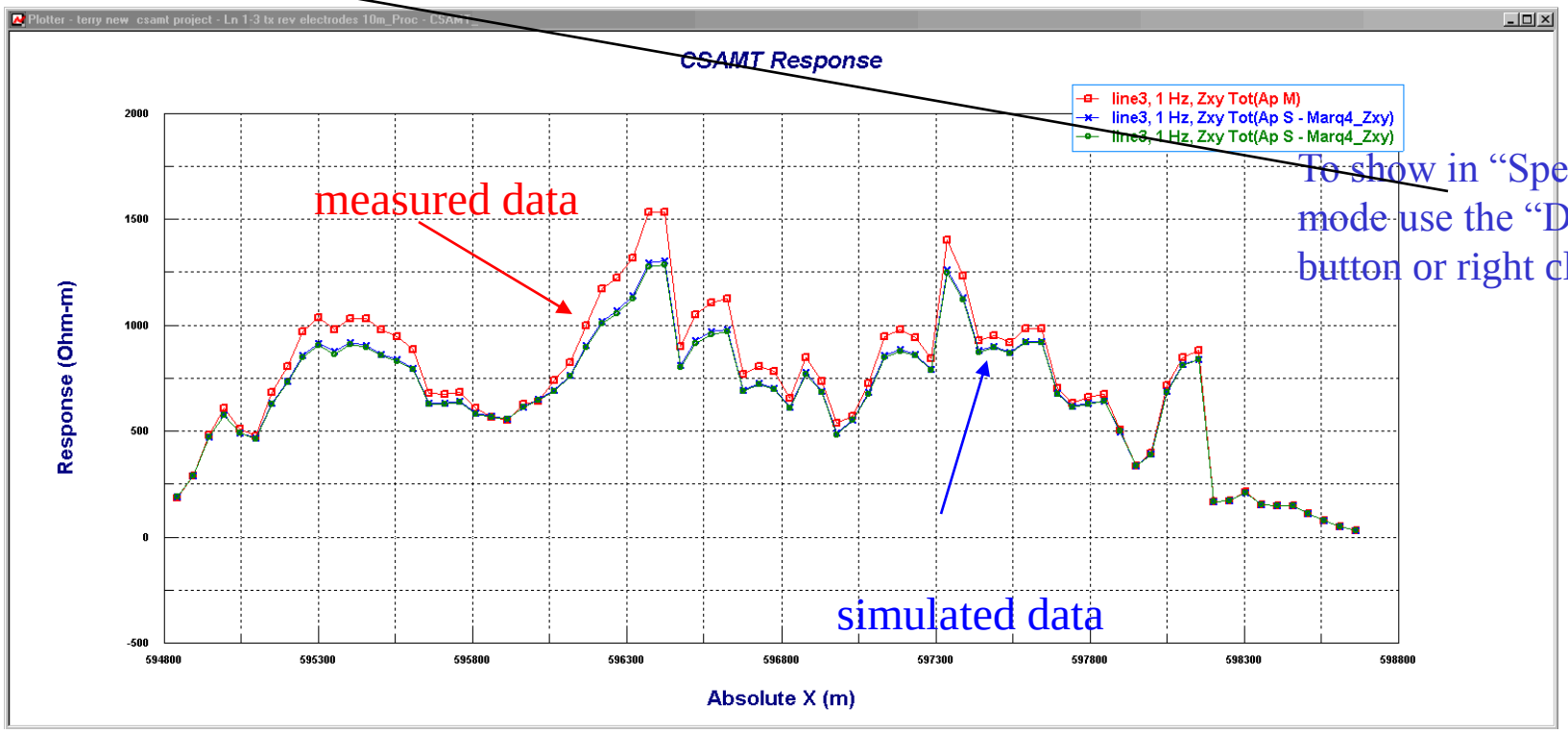


Select for the 2nd plot, the same frequency and then measured data and further datasets if required.

1. Data organization and import
2. Examine data
3. Perform initial modeling
4. Perform controlled inversions
5. **Inversion evaluation**

Inversion Evaluation

Multiple plots can be shown for various inversions and models in “Profile” mode. The user may step through different frequencies by simply clicking the ‘arrows’.

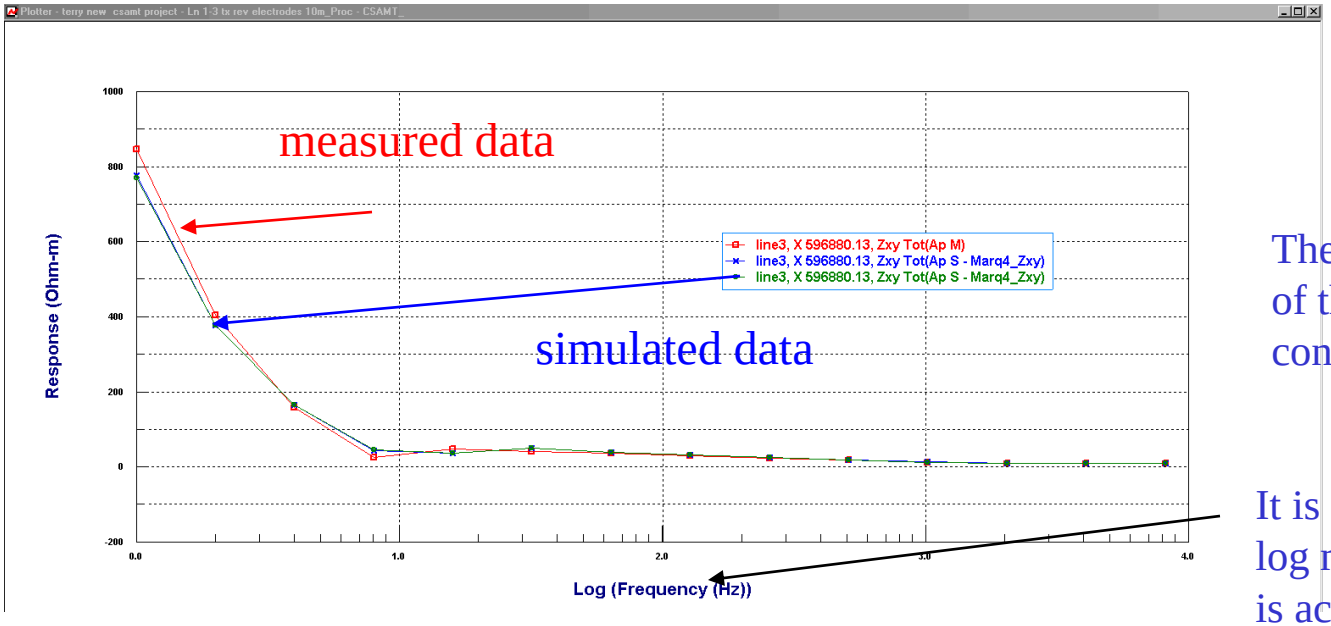


To show in “Spectrum” mode use the “Domain” button or right click.

1. Data organization and import
2. Examine data
3. Perform initial modeling
4. Perform controlled inversions
5. **Inversion evaluation**

Inversion Evaluation

Here, spectrums are compared for a single data point in linear-linear mode. The user may move to other data points by simply clicking the arrows.



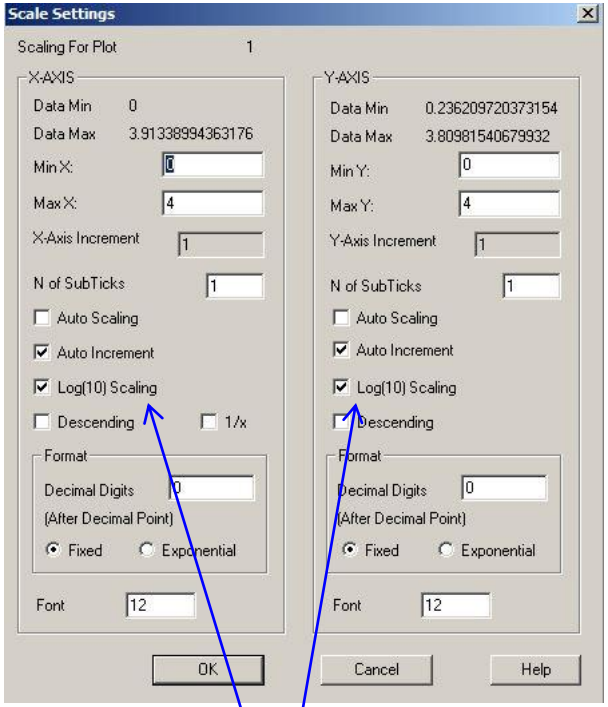
The step-frequency function of the arrows is now converted to step position.

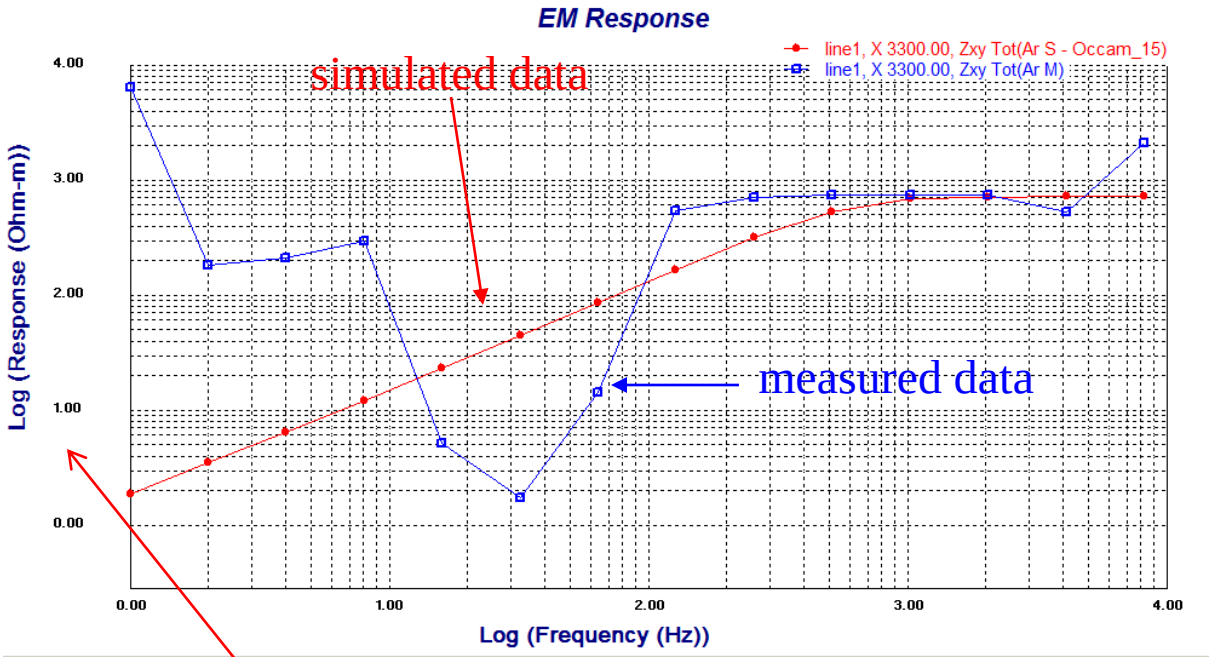
It is useful to compare in log mode. This functionality is accessed by double-clicking either axis.

1. Data organization and import
2. Examine data
3. Perform initial modeling
4. Perform controlled inversions
5. **Inversion evaluation**

Inversion Evaluation

Here, we select log(time) vs log(amplitude)





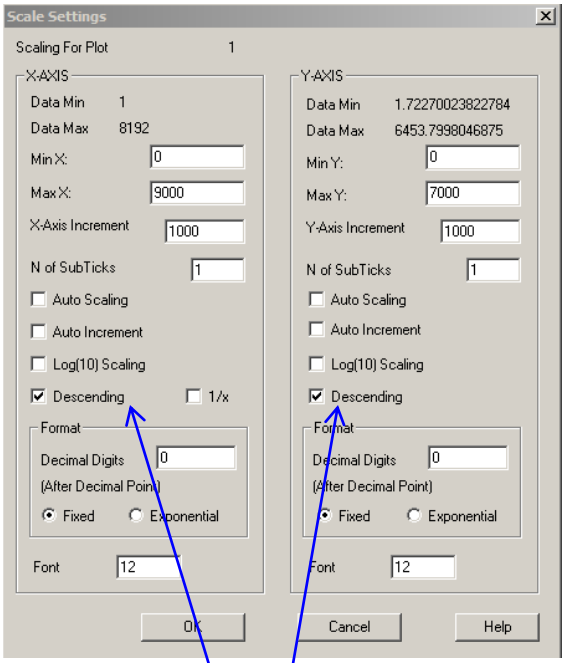
Select "Log(10) Scaling" option

Double-click axis to bring up the "Scale Setting" dialog

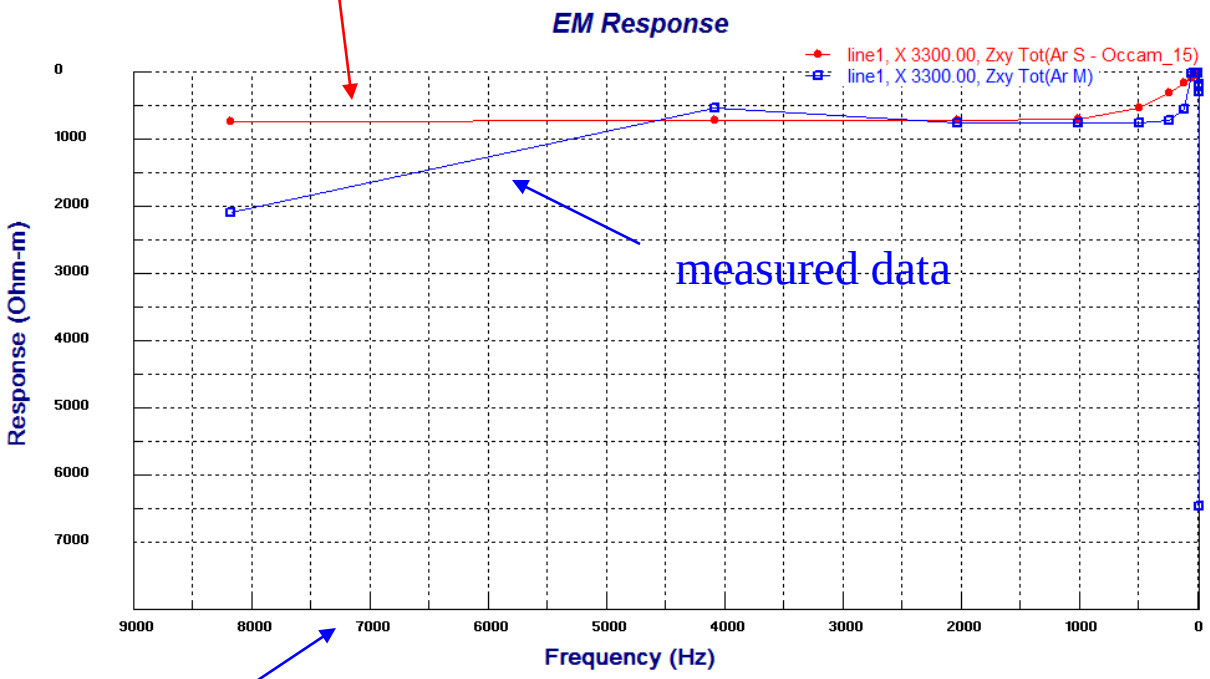
1. Data organization and import
2. Examine data
3. Perform initial modeling
4. Perform controlled inversions
5. **Inversion evaluation**

Inversion Evaluation

Here, we select log(time) vs log(amplitude)



simulated data



In CSAMT/MT, it is common to observe data in **Descending** order of frequencies (from high to low)

Note: based on results of inversion, you may run additional inversions with different settings, and compare the resulting sections in the CDI viewer and the fit in the plotter.

for assistance please email

support@petroseikon.com