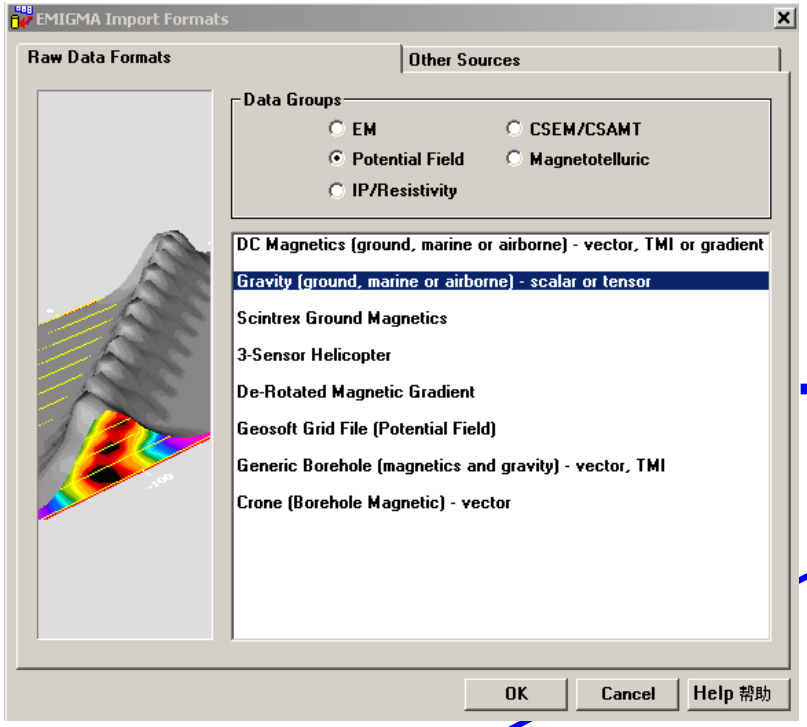
EIKON TECHNOLOGIES

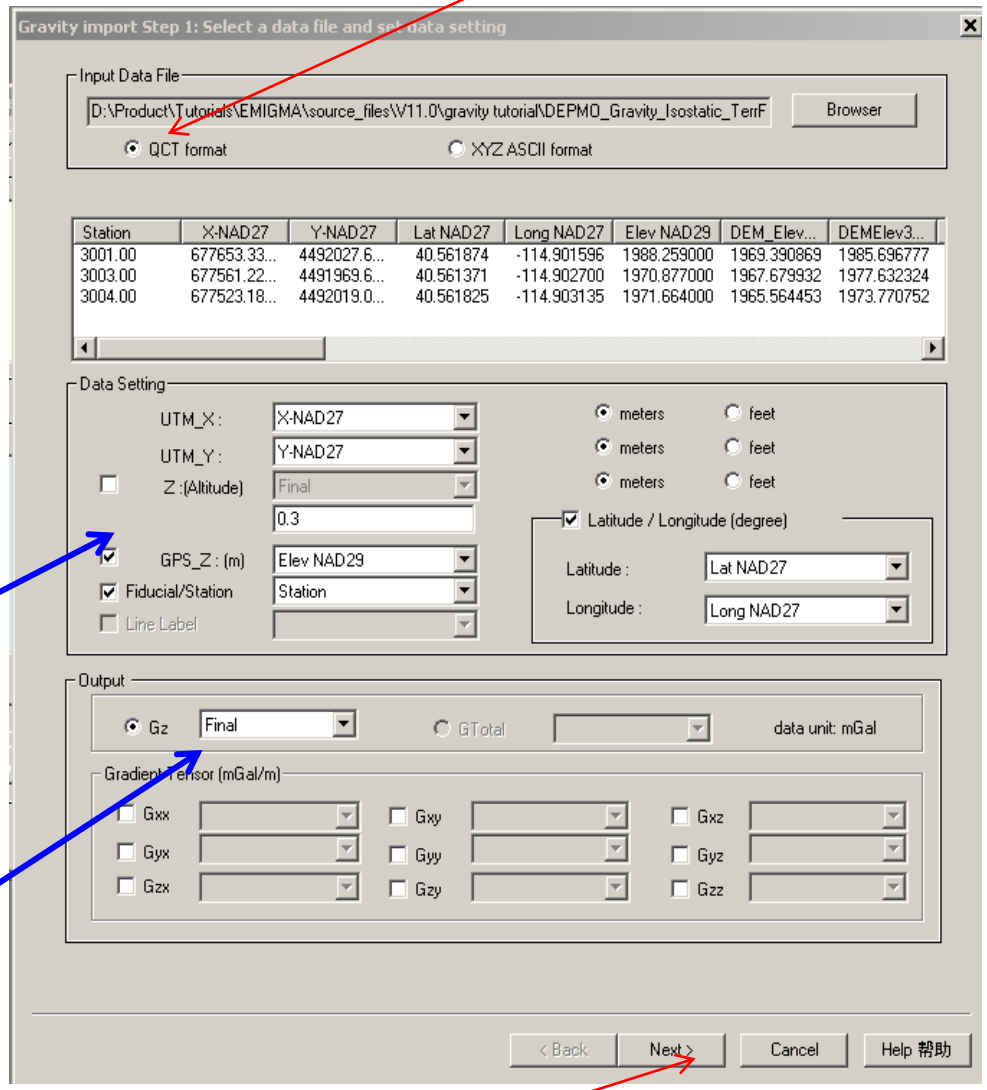
3D GRAVITY INVERSION TUTORIAL

STEPS:

1. Import data
2. Examine data
3. Perform initial modeling
4. Perform 3D gravity inversions
5. Inversion Evaluation/Processing
6. Visualization
7. Export Models

Browse and select .qct or .xyz data file for import
- recommend .qct for easier use





Set coordinate axes

Select Data Channels

Click “Next “ button

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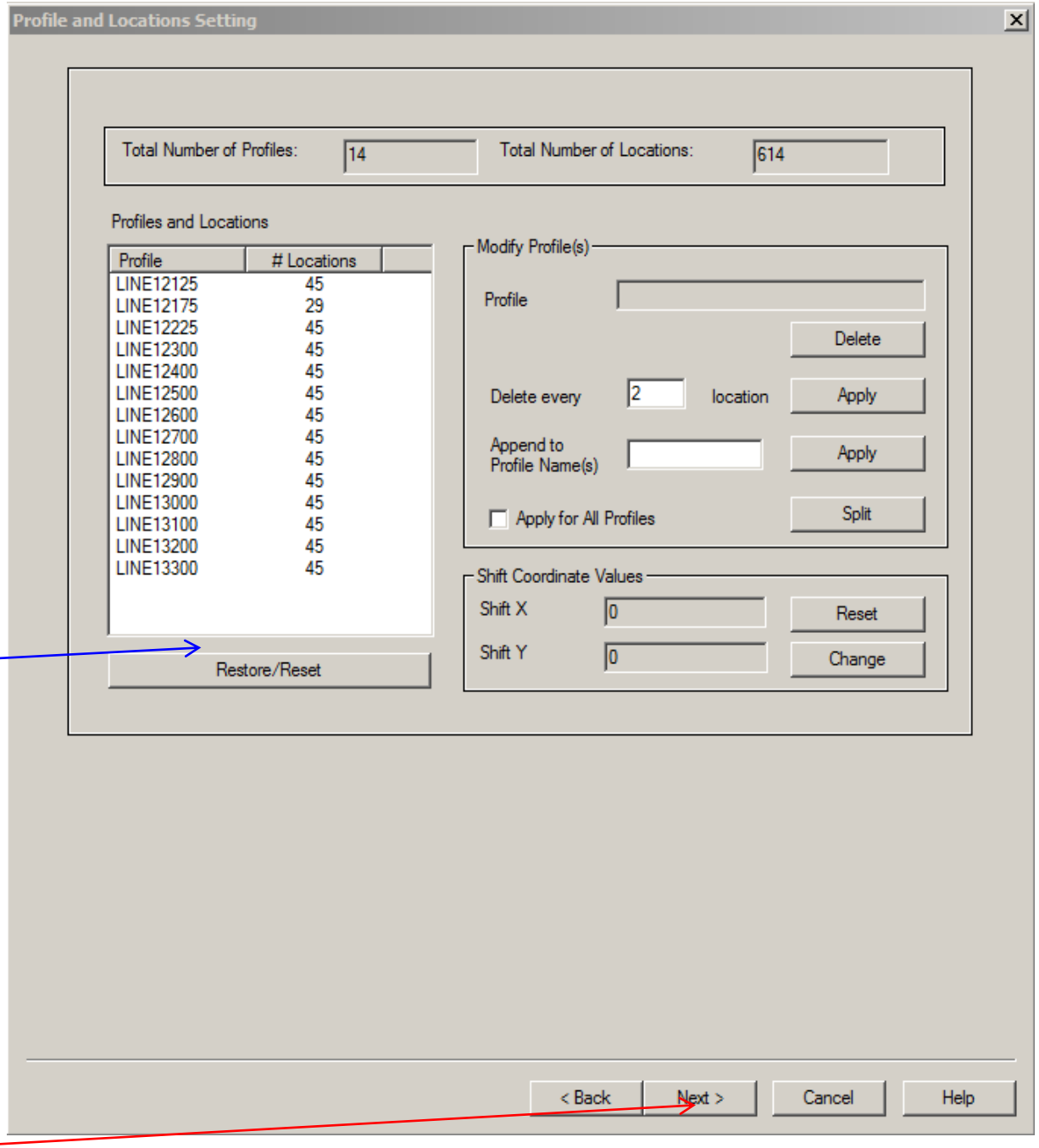
Show profile information,

Users may perform
Delete/Reduction/Shift
Operations in this dialog



Click “Next “ button

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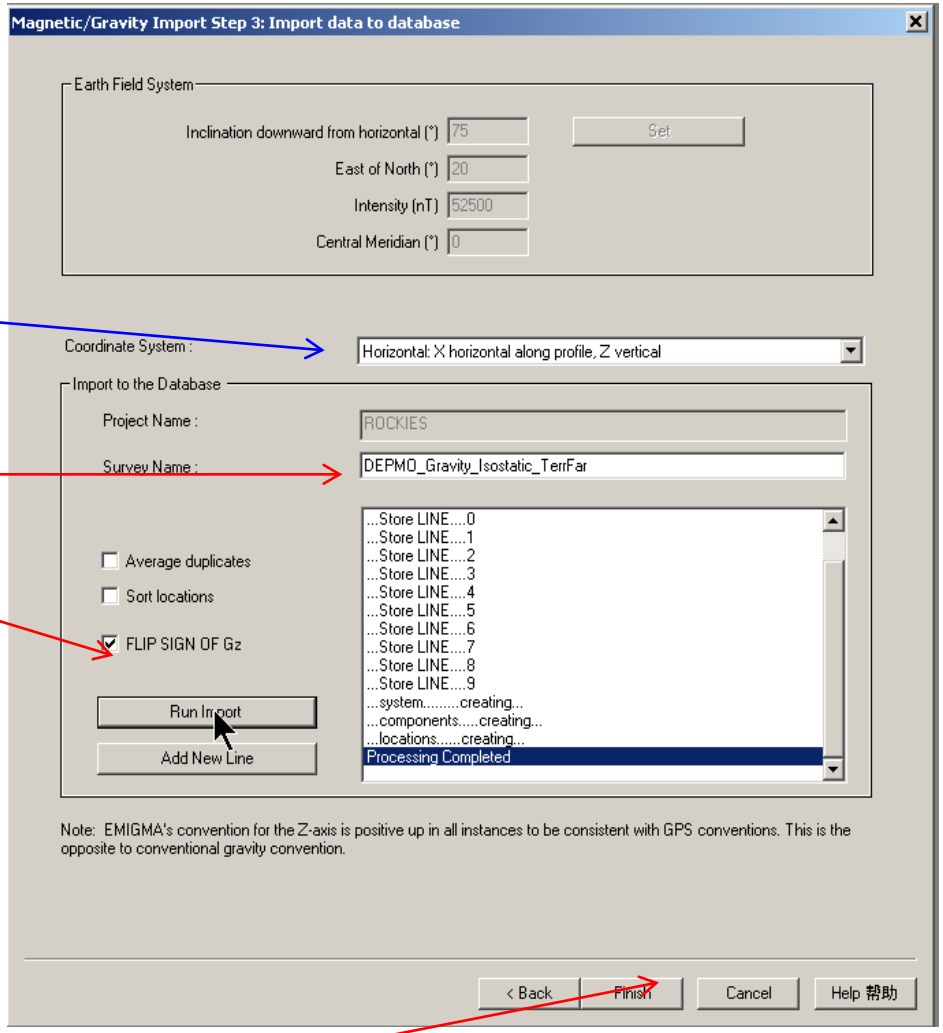
Select system coordinate system
(*see manual for definitions*)

Set survey name

Flip sign of Gz data if necessary
(*instrument convention dependent*)

Click "Run Import" button to
process and import into database

After processing is complete,
"Finish" button to complete procedure



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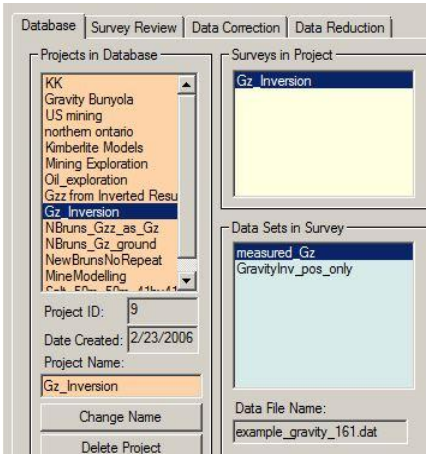
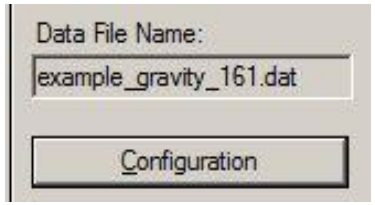
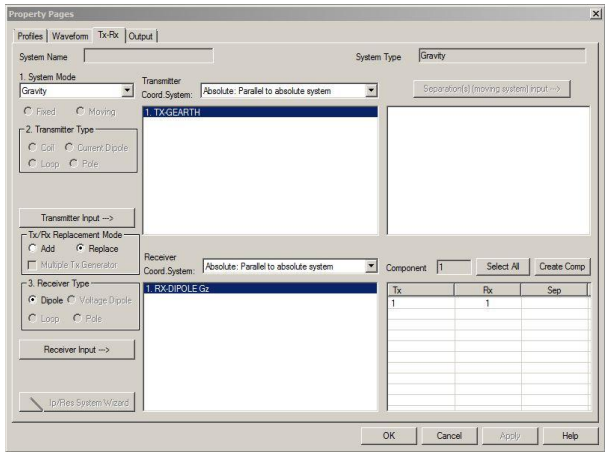
1. Check database for the survey

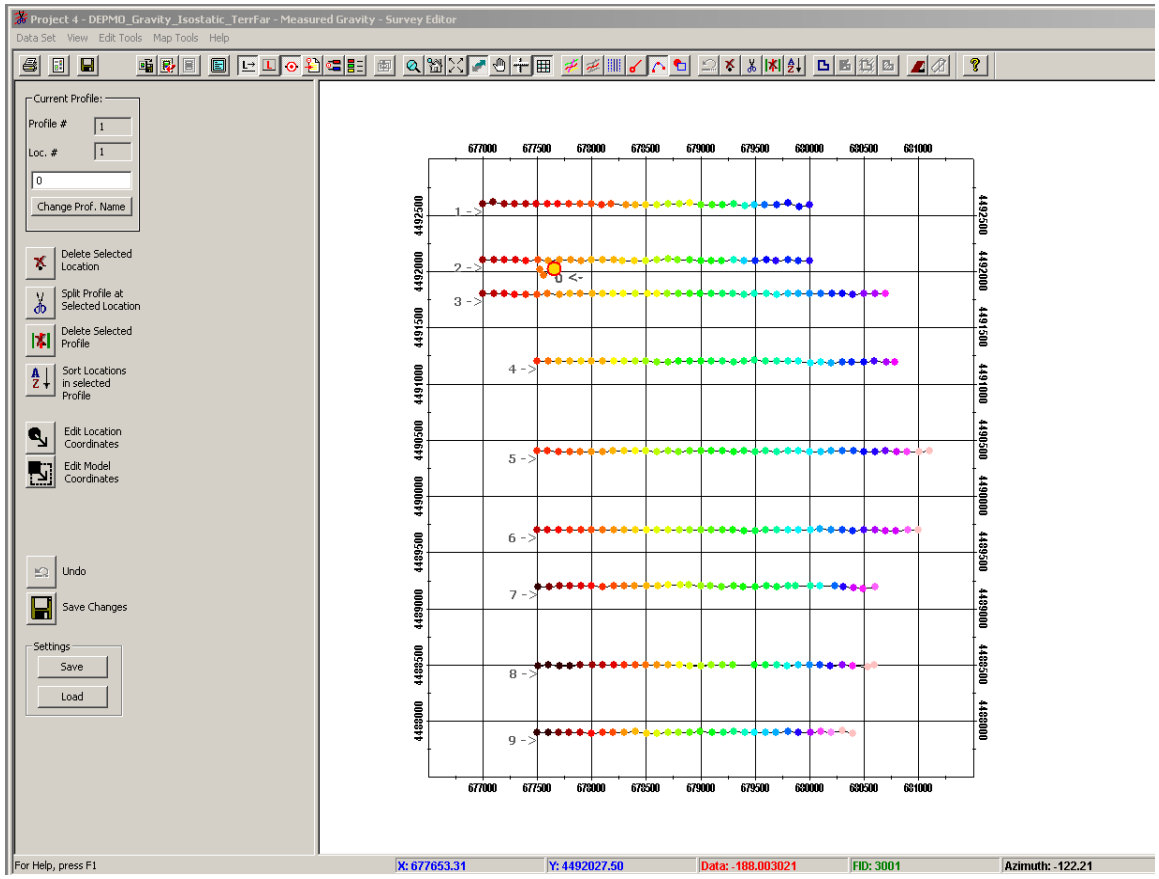


2. Click configuration



3. Check system configuration





4. Check profiles and stations with ……"Survey Editor"

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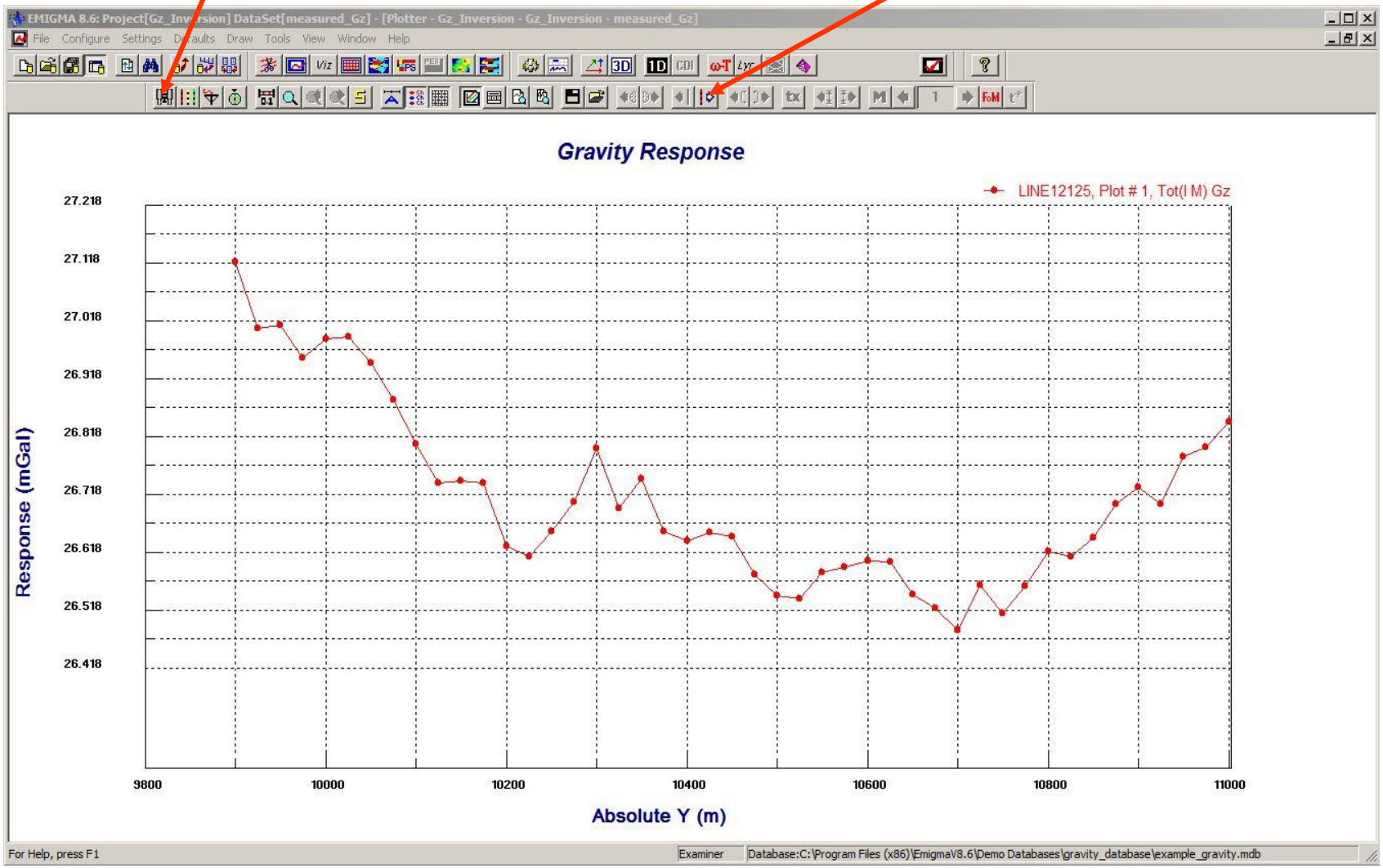
Click “Plotter”…

Load data set in plotter

Toggle between profiles



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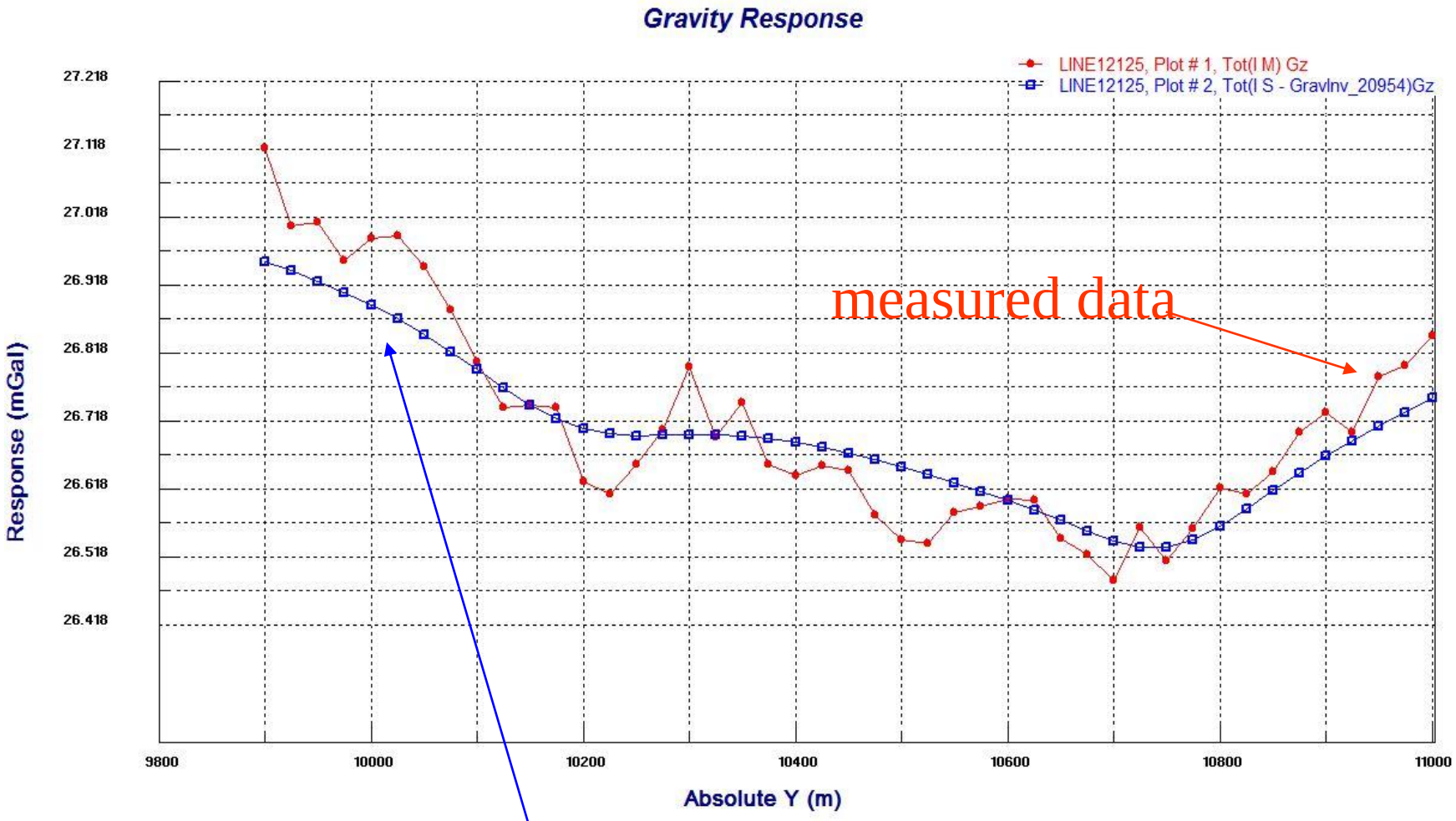
Note: *Performed some initial modeling to get a "feel" of the data and estimate parameters of initial model for inversion.*



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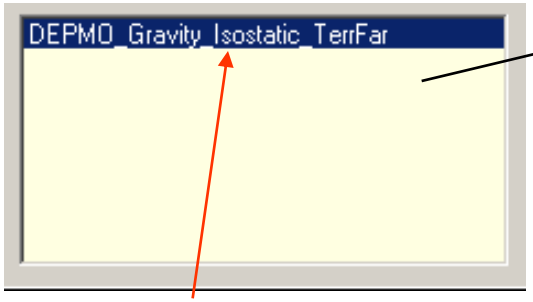
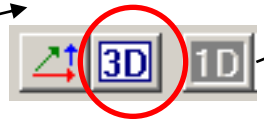
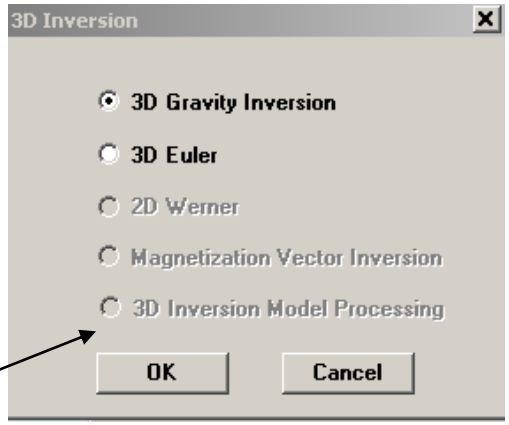
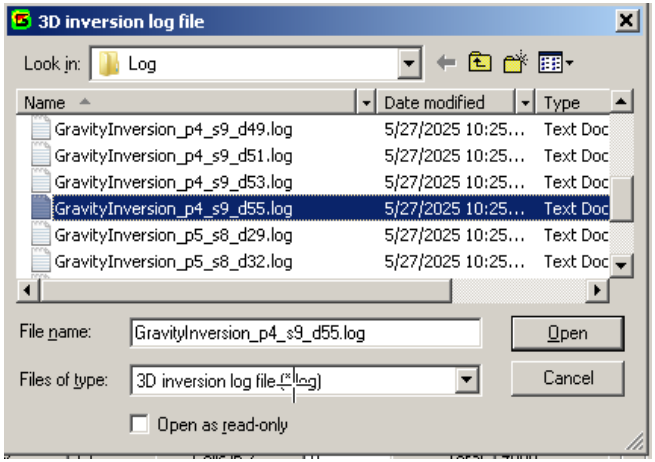


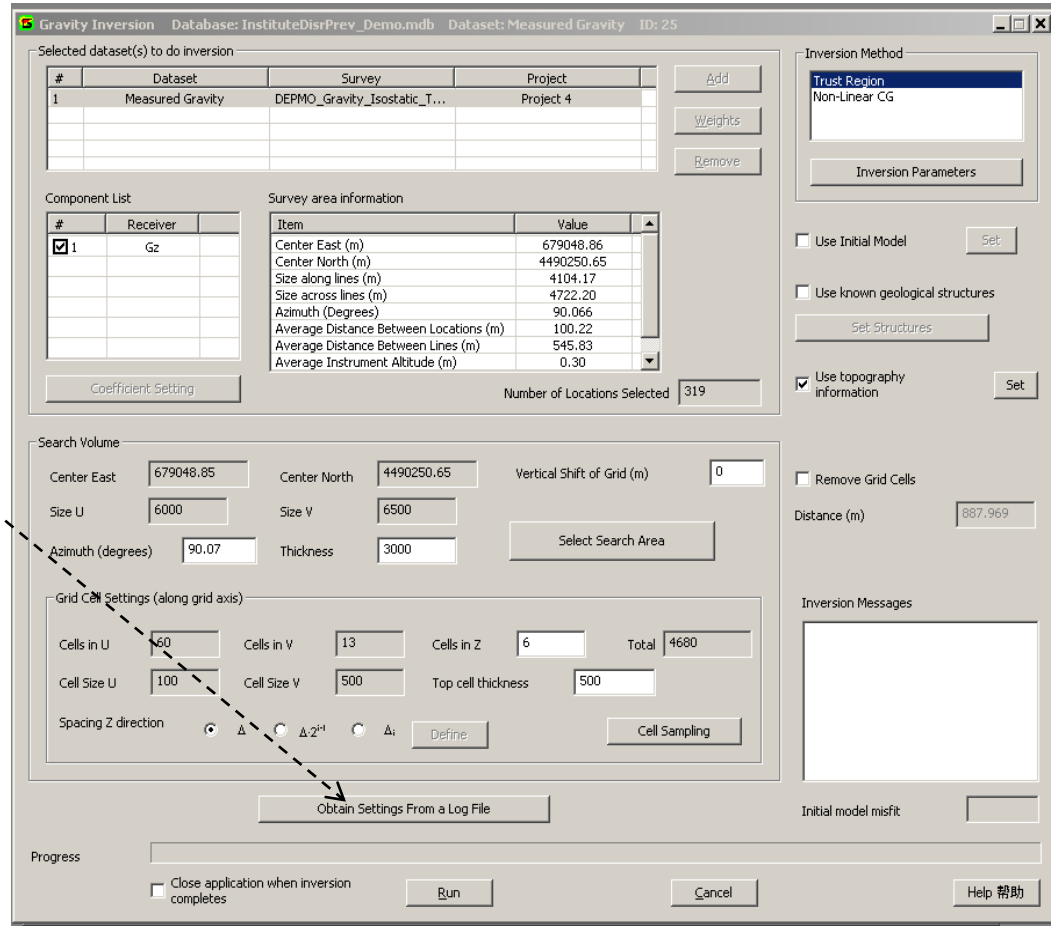




Select measured data

Each inversion saves the settings in a .log file attached to the database.
labeled wrt project/survey/dataset





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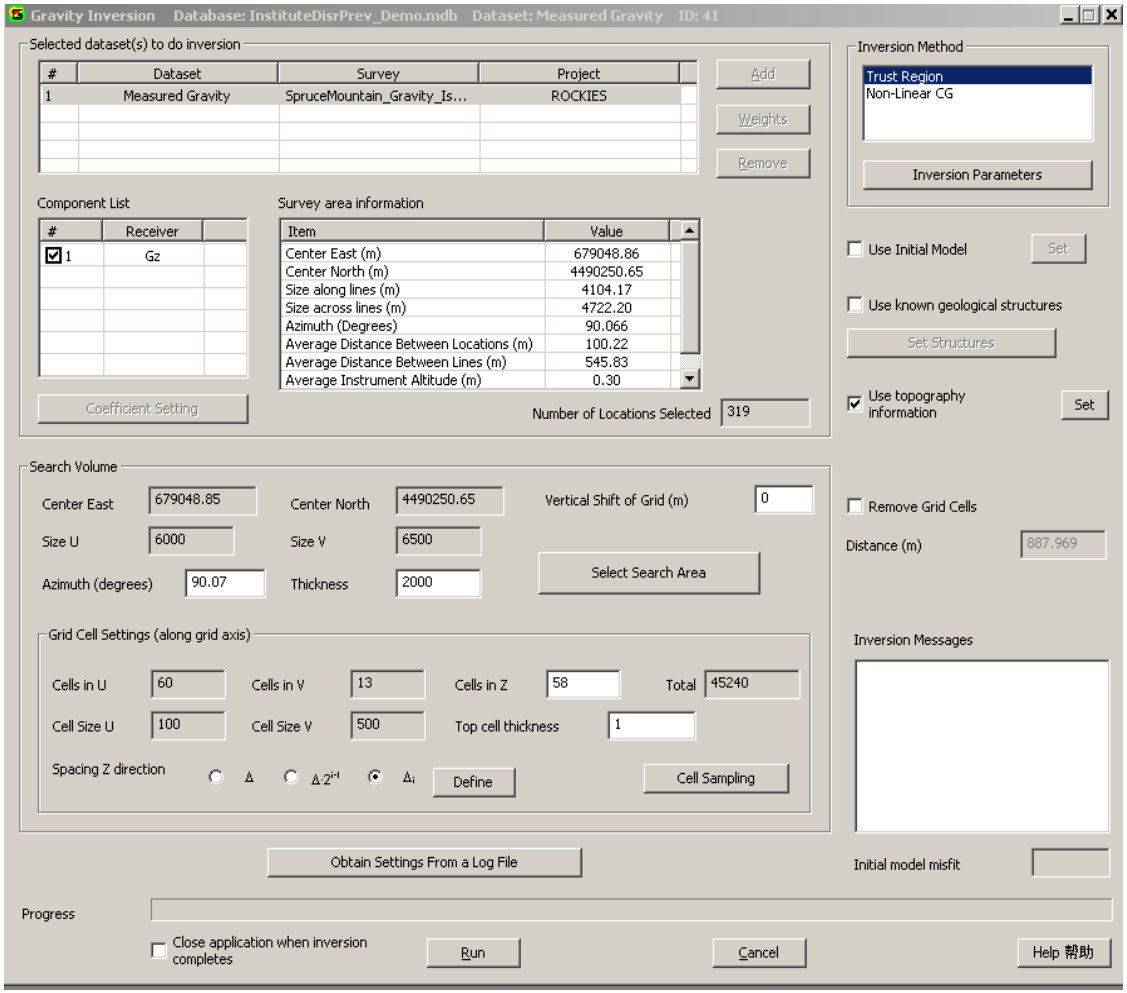
Selected Data Sets

This confirms the dataset that has been loaded to the inversion.



Components: Components that will be used in the inversion are selected here. As an example, you might create derivatives through the Fourier tools and use one or more of these derivatives. In this case, the data indicates that the instrument measured the gravitational field in the vertical direction (*i.e. towards the Earth's centre*)

Log File: A log file is created each time an inversion is run. Use **Obtain Settings From a Log File** to load settings from a previous inversion. The log files are numbered according to Project/Survey/Dataset numbers.

Use topography information: This option will be enabled if you imported your data with a GPSZ channel. Select this option and by default the GPSZ values will be used for absolute elevation when performing the inversion with the Z(altimeter) channel providing the height above ground level. If you have a topography model imported to the database, you may use this for the topography information. [SET]. *Note 1: When loading inversion results to the Visualizer, a window will appear asking to display the survey according to instrument altitude (Z) or GPSZ. Select the latter to see the inversion results with topography. Note 2: the GPSZ can be the elevations relative to the ellipsoid or the geoid.*

Remove Grid Cells: Any cells that are beyond the specified **Distance** from the closest data point will be removed from the inversion grid prior to the inversion procedures.

Geological Structure : Click **Use known geological structure** to define a structure that will apply constraints to the inversion result.

Initial model misfit: Indicates how the initial model fits the data.

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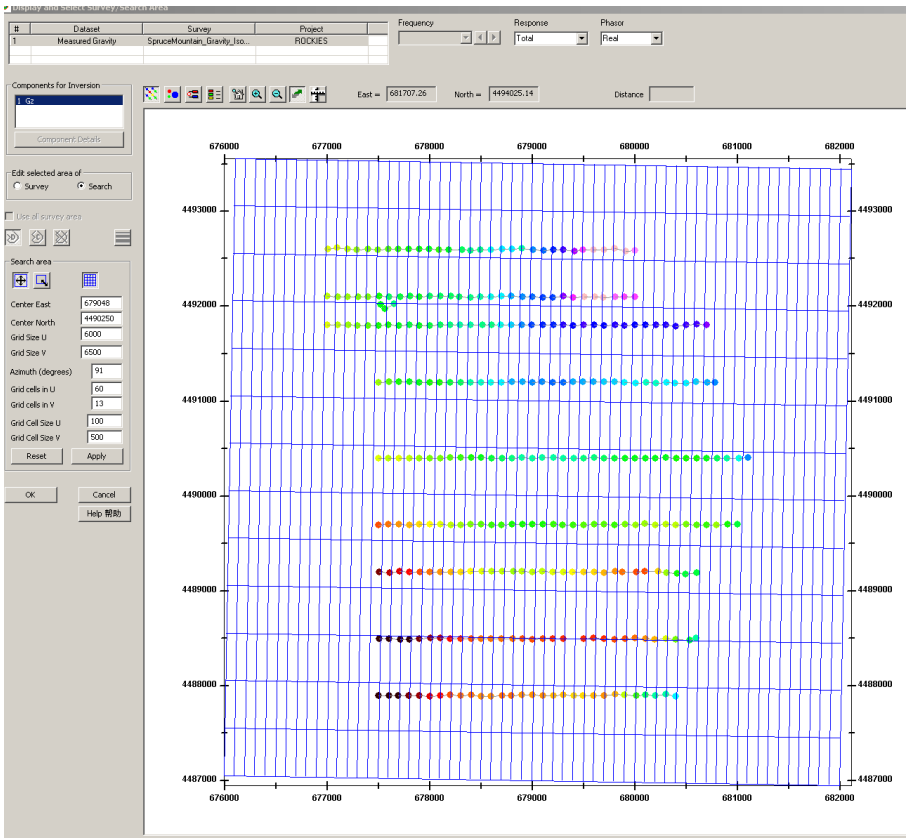
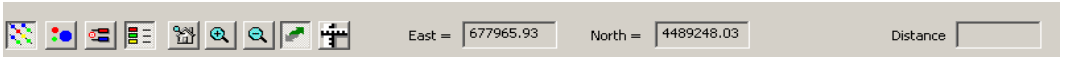
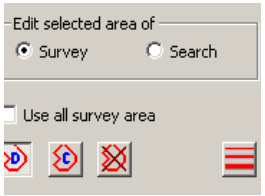
Clicking the **Select Search Area** button launches the window below. The "search area" implies the area in which the inversion algorithm seeks a model. You may also select a subset of the Survey area to be used in the inversion. However, we suggest extracting the desired subset from the original survey and saving the subset to your database to invert the subset.

Display: The interface display the data locations and their values according to scale. The horizontal distribution of cells is shown as a blue grid. The coordinates of the survey are shown on the axes.

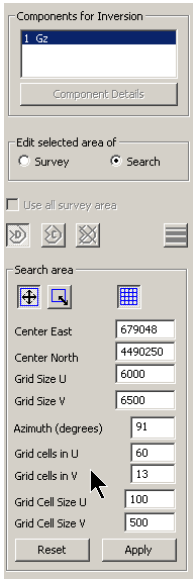




From Left to Right:
1. Toggle data points ON/OFF, 2. Set size of data points,
3. Set Max/Min for data display, 4. Open a legend, 5. View all,
6. Zoom IN, 7. Zoom OUT, 8. Set aspect ratio – Full screen or equal ratio
9.Find a distance, 10. location of cursor, 11. Distance sought



Use to define a subset of the survey area for inversion use



Define the horizontal divisions in the inversion grid

Azimuth is the angle with respect to north of the U direction in the horizontal grid. V is perpendicular to U.

After making your required changes , Click 'Apply", view changes and adjust settings as often as required

When satisfied "OK"

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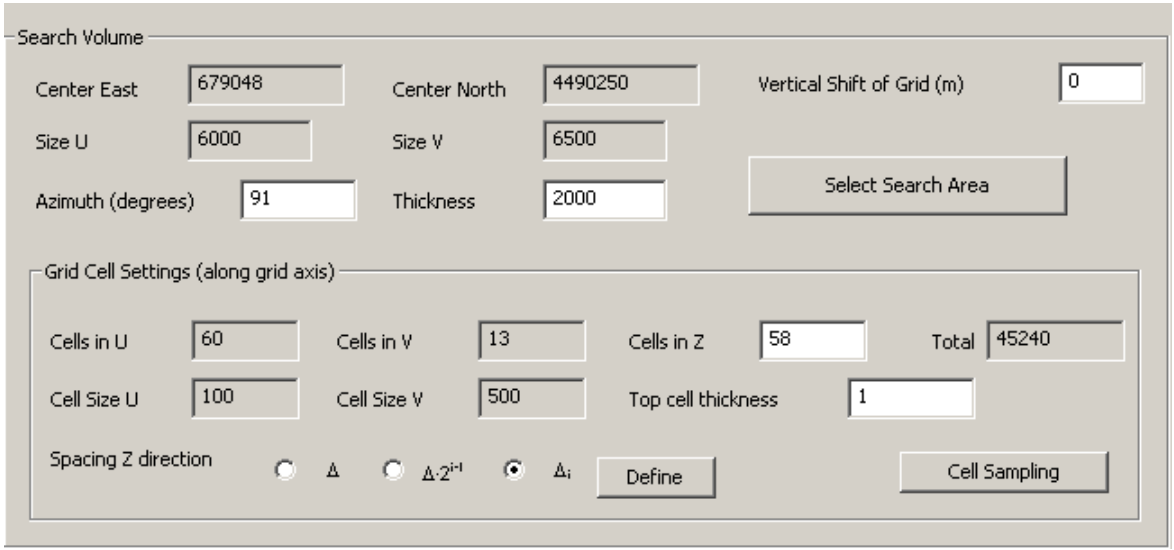


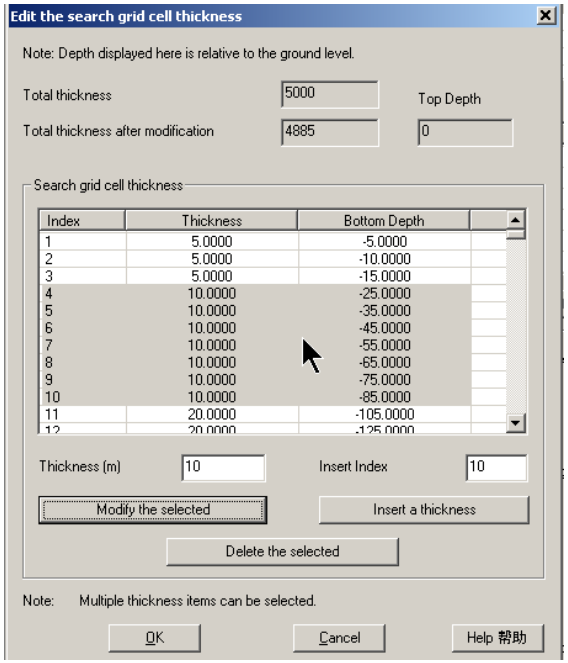
Grid Cell Settings

After exiting the previous dialogue, this portion of the interface is updated to summarize the previous settings.

If these are new inversion settings, a default thickness for the inversion grid is set as well as settings for the vertical divisions of the grid.

Vertical Grid Settings (*Spacing Z direction*)

There are 3 types of vertical divisions allowed: A) Uniform vertical gridding (Δ)m ; B) $\mathbf{\Delta \cdot 2^{i-1}}$ for exponentially spaced cells and C) specify custom vertical cells, $\mathbf{\Delta_i}$. Your custom settings can be later modified by clicking **Define**.



Other Settings

Total number of cells in the inversion grid is displayed beside "Total".

Cell Sampling:

During an inversion process, at each iteration, data is simulated for the present model iteration and model gradients are also computed. These computations are integrals over the grid densities of the present iteration. This process, to be accurate, is also an integration over each grid cell. The contribution of the mass of the cell at an observation point is not simply the mass of the cell assumed to be at one point (e.g. centre). The concept of most inversions, when computing the forward model, is to represent the mass of each cell at its center point. Here, however, you can improve these results by defining a grid over each cell for the contribution of each cell.

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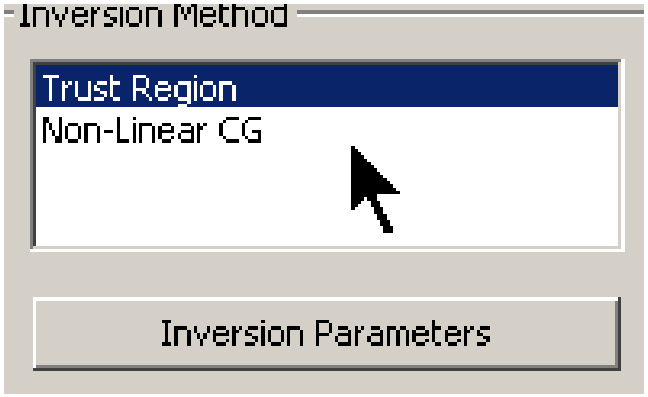

Inversion Methods

One comment should be first made here. For most present day geophysical inversion processes designed for the PC, inversion techniques can be described as "hunt and peck" techniques. The inversion operator is not linearized as in a classical definition of inversion. Rather the inversion, moves along one parameter to reach a minimum and then moves to another parameter and so on. How they minimize along each parameter is defined by some optimization technique such as Conjugate Gradient.

EMIGMA's inversion algorithms are more traditional in order to a) utilize fully the non-linear operator that is defined by the physics to relate the data to the earth's material properties , b) utilize the full memory capacity of each computer and c) utilize the multi-core processing units.

Trust Region (Matrix) - Direct inversion technique that uses the physical matrix operator. This technique utilizes a modified Trust Region inversion approach. Constrained inversion technique.

Non-Linear CG – This is a more standard technique used in geophysics today. The general concept is to start with an initial guess and then search for the best fitting model by minimizing a given function using an iteration process.

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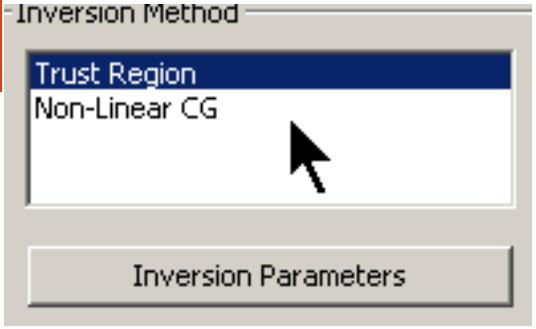

Non-Linear CG

The general concept is to start with an initial guess and look for the best fitting model by minimizing a given function using an iterative process.

Critical factors to Optimization Results:

- Good forward simulation algorithm
- Good minimization technique
- Good starting model
- Good data

Unconstrained Conjugate Gradient Minimization

This technique uses the derivative information to construct two sequences of orthogonal vectors to define the search direction at a given iteration. Then, by trial and error (line search), to move to the local minimum in that direction. The iteration stops when the gradient has achieved the required minimum value. This is an unconstrained minimization technique where the bounds on the parameters are imposed after the search is completed.

$$\phi(m) = \lambda\, \phi_d(m) + \phi_m(m)$$

$\phi(m)$ - functional to be minimized
$\phi_d(m)$ - data misfit
$\phi_m(m)$ - model misfit
λ - Lagrangian multiplier
regularization weight

Occam style model misfit function

$$\phi_m(m) = \alpha_0 \int w^2(z)\, [\, m(r)-m^0(r)\,]^2\, dv \quad + \quad \sum_{i=x,y,z} \alpha_i \int [\, w(z)\, \nabla_i\, (\, m(r)-m^0(r)\,)\,]^2\, dv$$

α_I - weighting factors
$w(z)$ - depth weighting

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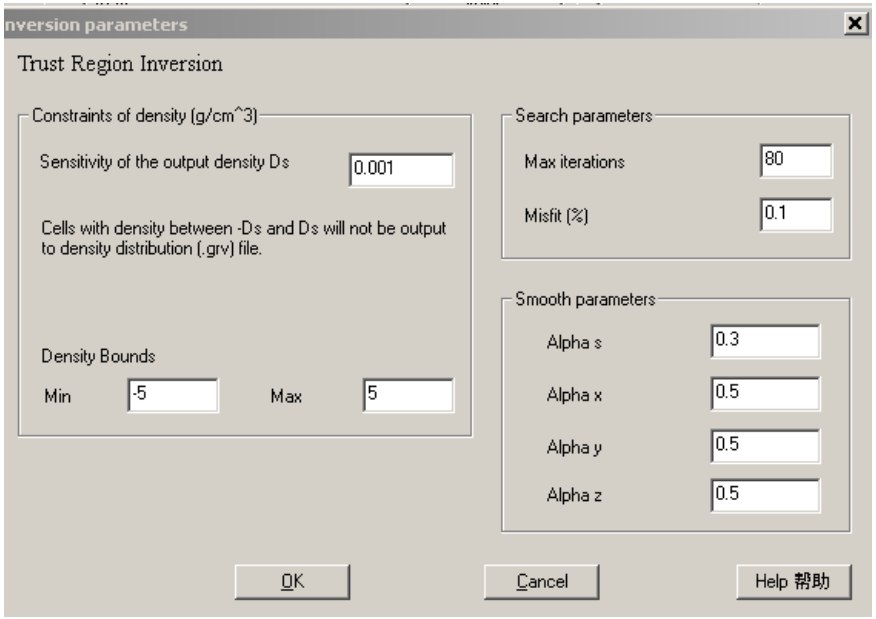

Inversion Parameters

Maximum Iterations

User defines the number of iterations the program will run to generate the final solution. In general the defaults are a minimum requirement.

Misfit (%)

Defines the "stop" criteria for an iteration when the difference between the measured and simulated data falls within a certain percentage of the measured value.

Smooth parameters

Larger values will increase the smoothness of the inversion result.

Alpha s decreases the overall range of the density values.

Alpha x, y and z decreases the difference between the density of two neighboring cells in the x, y and z directions respectively.

Constraints of Density (g/m^3)

Ds : Sensitivity of output density:

Cells with density |ρ| (near 0 as the user defines) are constrained or discarded after each iteration and will not be output to the density distribution (.grv) files.

Density Bounds:

Minimum and Maximum Density (g/cm^3)

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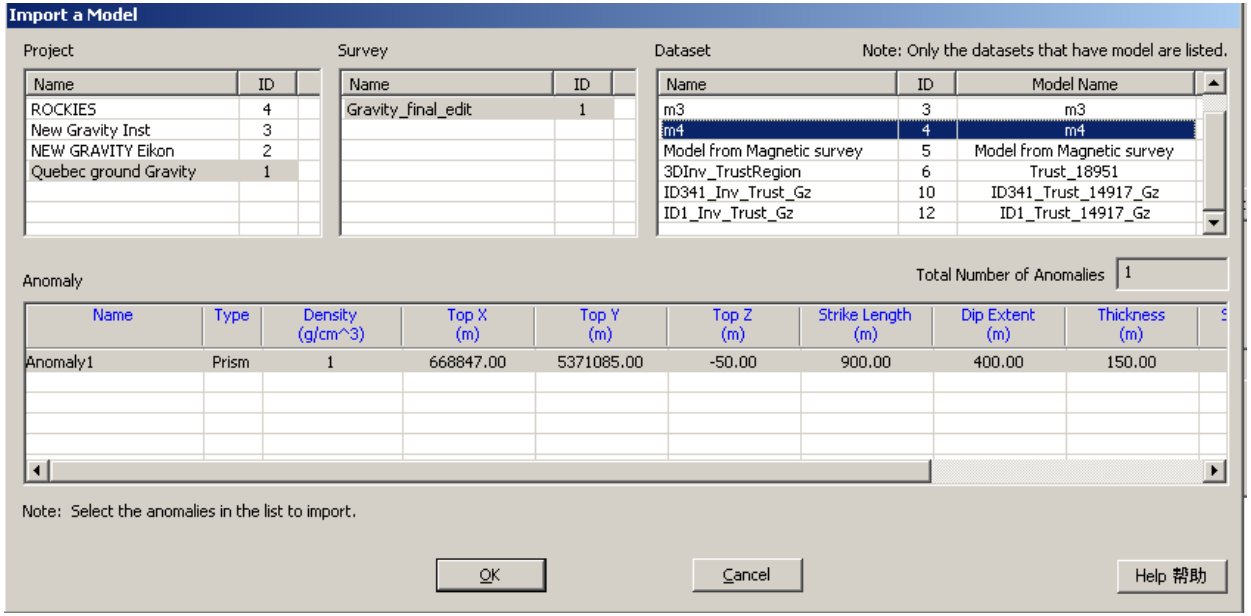
Initial Model

Click the checkbox labeled **Use Initial Model** to specify an initial model. Return to the initial model window by clicking the **Set Initial Model** button.

The starting model may be of two forms: a) a forward model previously developed containing either one or more prisms and/or polyhedra or b) a previous inversion model



Select the starting model:

The starting model must be within your present database. If it is not, import the dataset containing the desired model from the database in which it is contained. Then, select the Project, Survey and then the Dataset to obtain the model.

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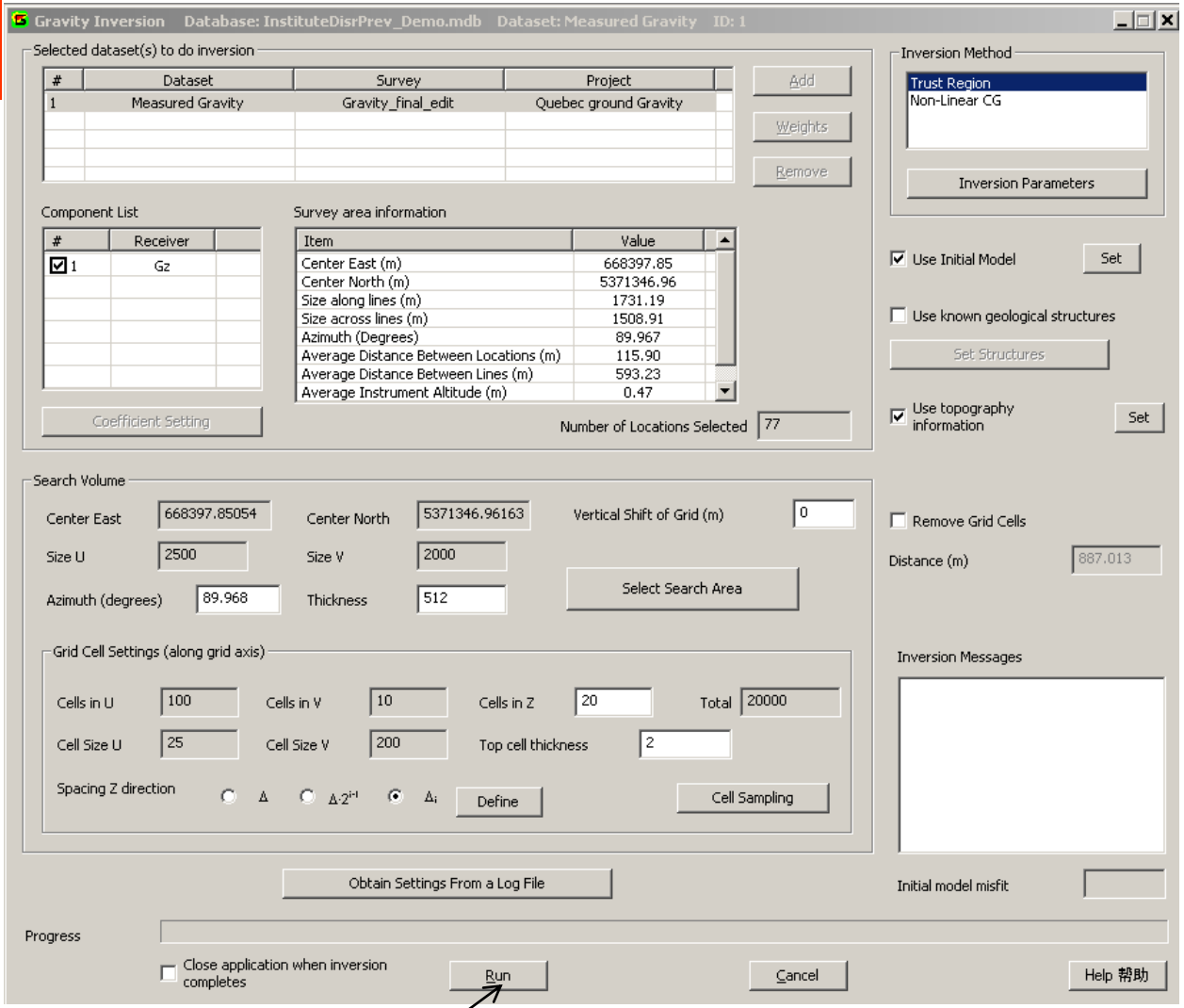

- After all settings have been made, press **Run** button to begin the inversion process.

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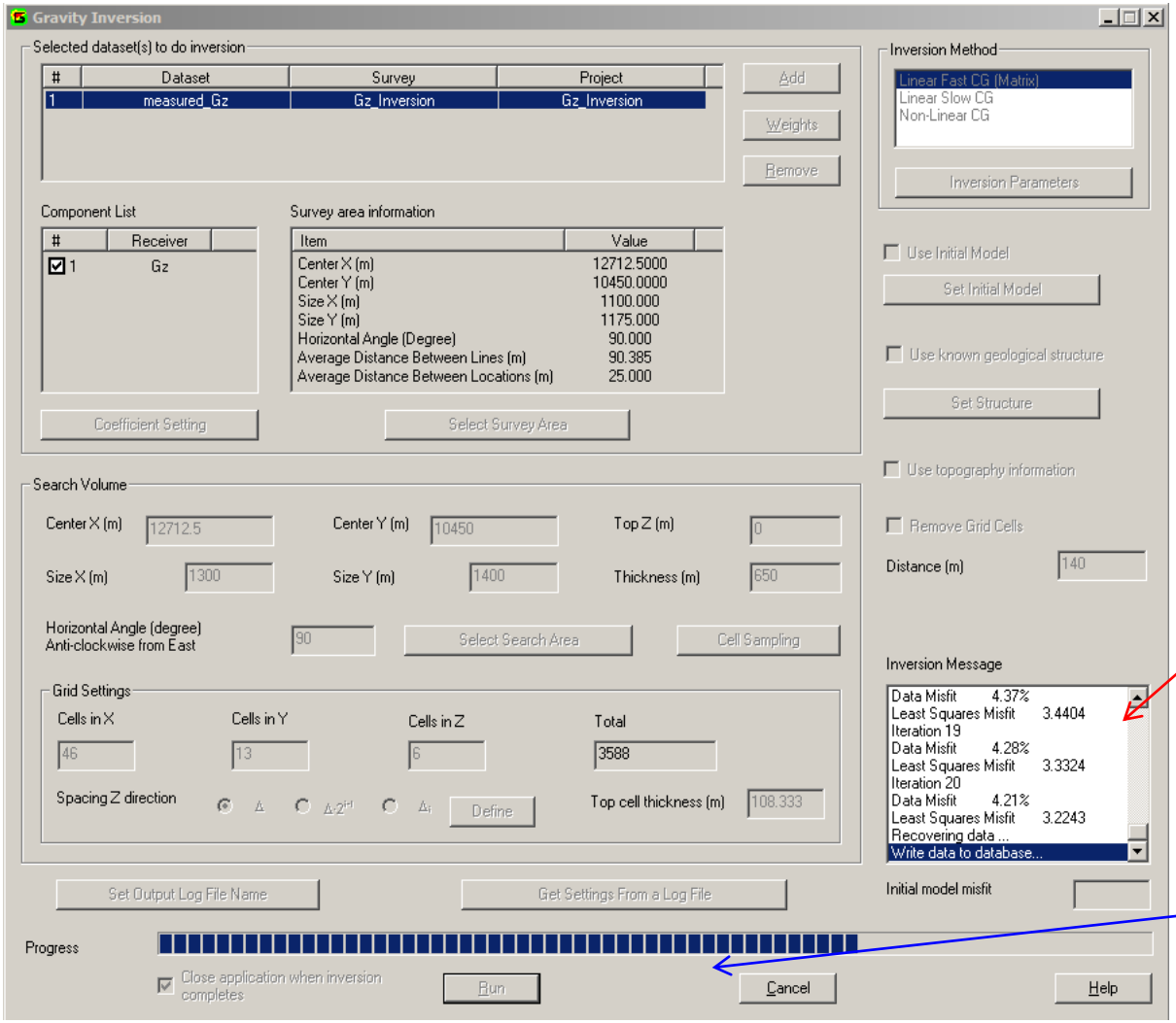
Executing the Inversion



The window on the right displays the inversion's progress.

The "Progress" bar indicates graphically the progress of the inversion

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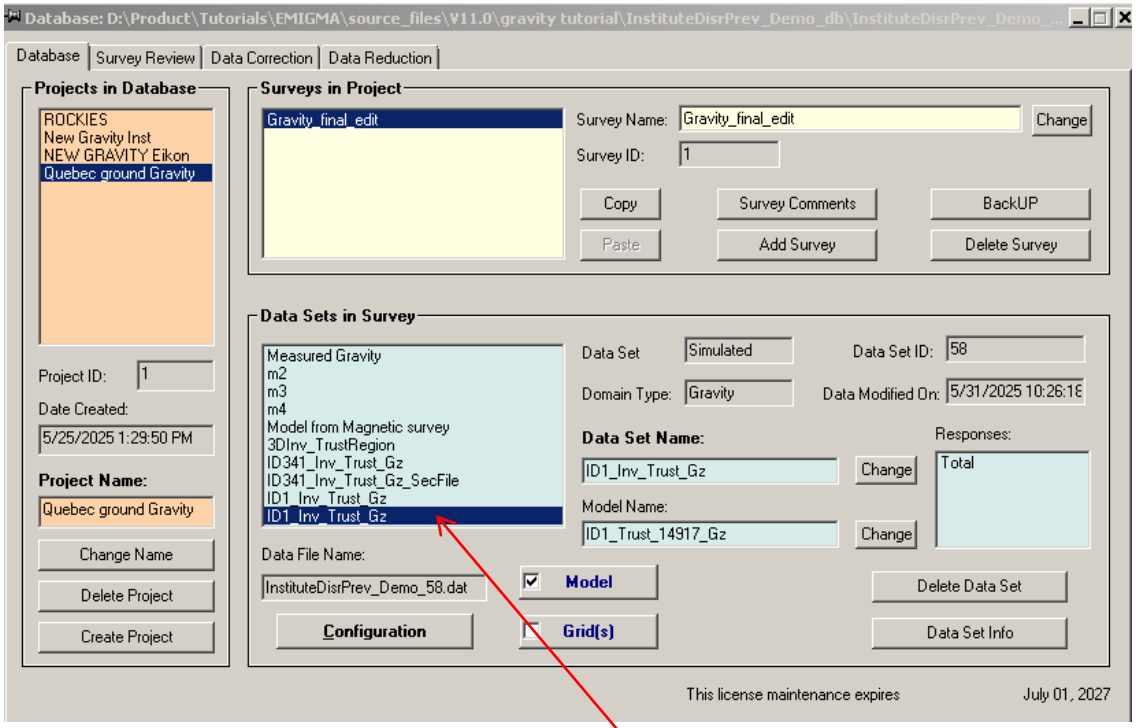
INVERSION EVALUATION

In each survey, there will be several data sets after forward modeling simulation, inversion and processing. In this case, we have the simulation data from 4 forward models, four inversion models and one set of cross sections from an inversion model. Each model simulation has a new data set containing the simulated data for the model attached to the data set. Similarly, each inversion contains a new dataset containing the simulated data set under the inversion model and attached to that data set is the inversion model.



Our 3D gravity inversion model dataset

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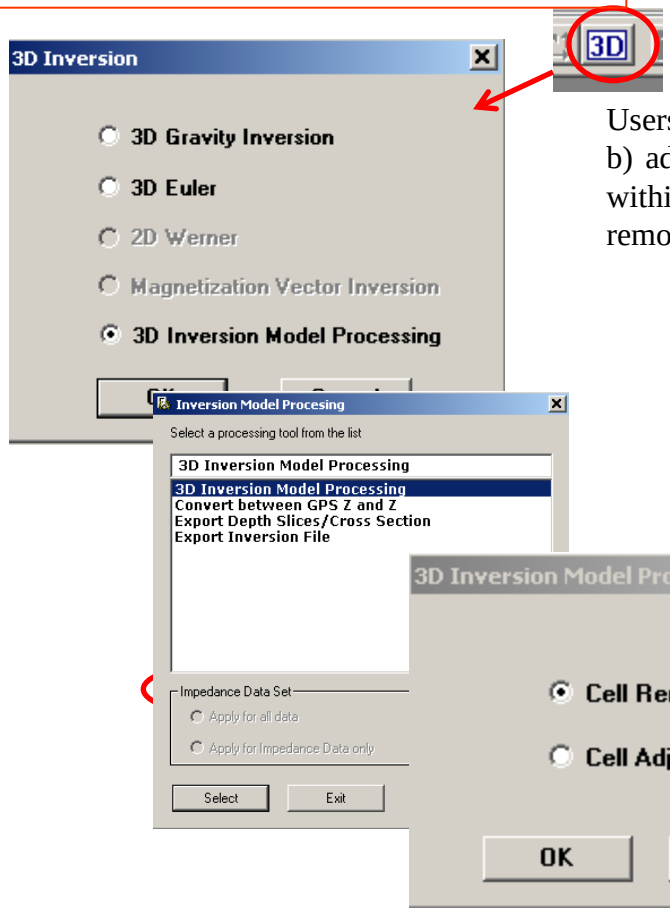
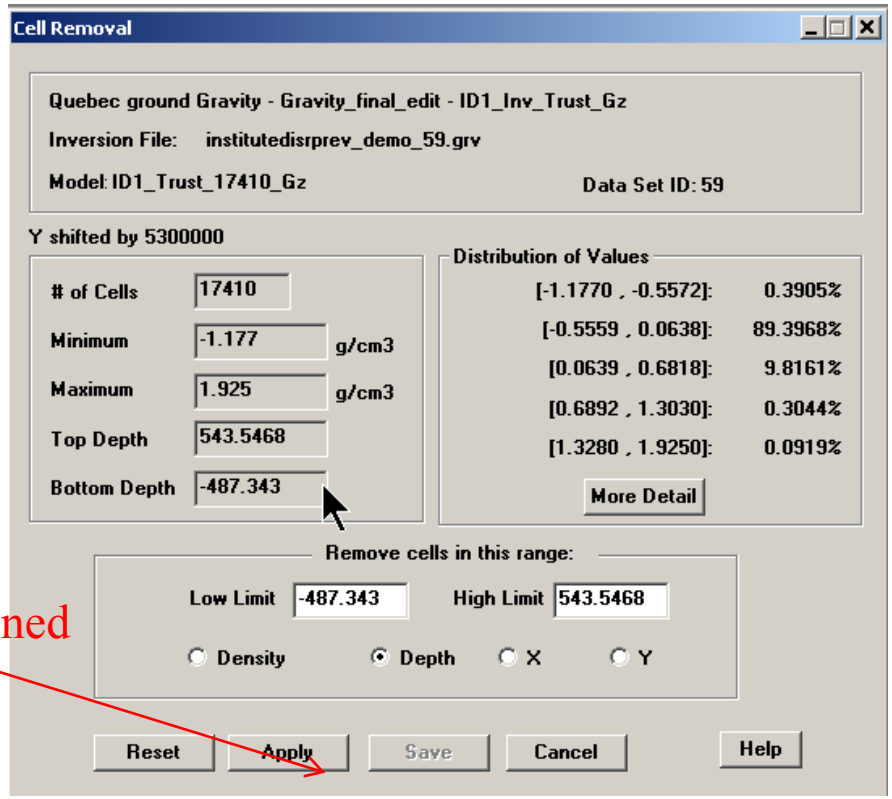
Inversion Processing

There are a number of procedures for processing of the inversion results. These are common for all of the 2D/3D inversion applications. The export functions will be covered slightly later. At times it is desired to have the inversion results relative to depth below ground and at other times relative to the elevation datum.



Users can use "3D Inversion Model Processing" tool to a) remove cells in the inversion model and/or b) adjust cells in the model. The interface below displays the distribution of the chosen parameter within the cells. The range for this parameter is set for cell removal. After selecting the range for removal, click '***Apply***' and the information will be updated. Additional removals may be made.



Click "Apply" button when removal range is defined

One use of this is functionality is to remove superfluous cells in order to identify the main concentrations of density contrasts

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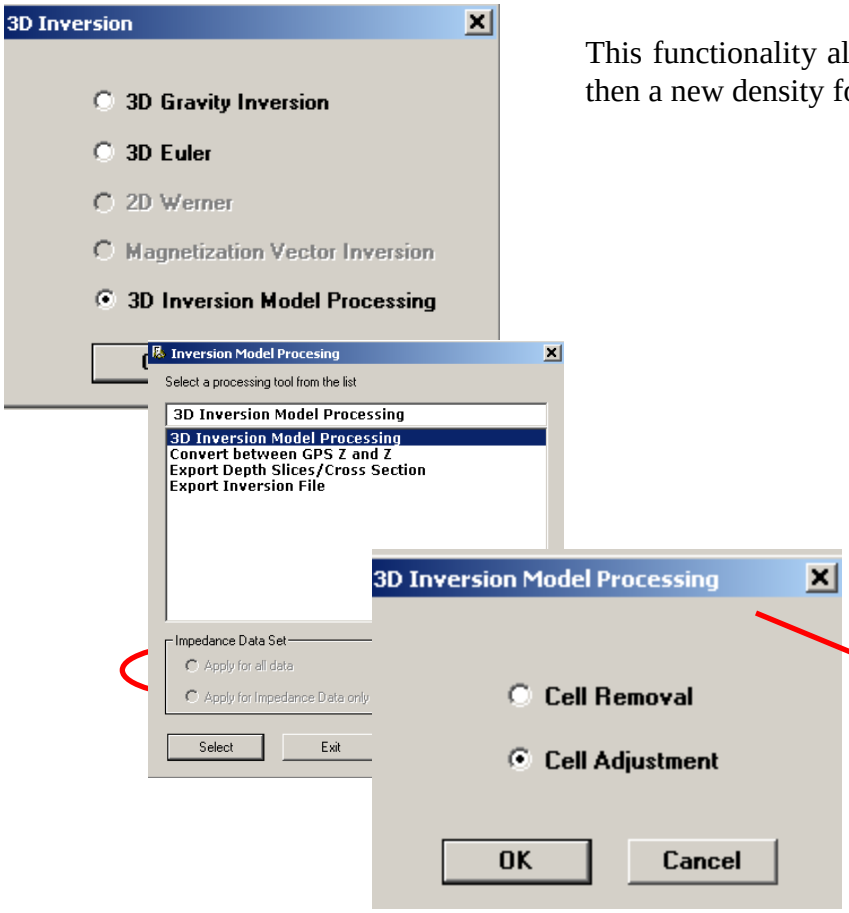
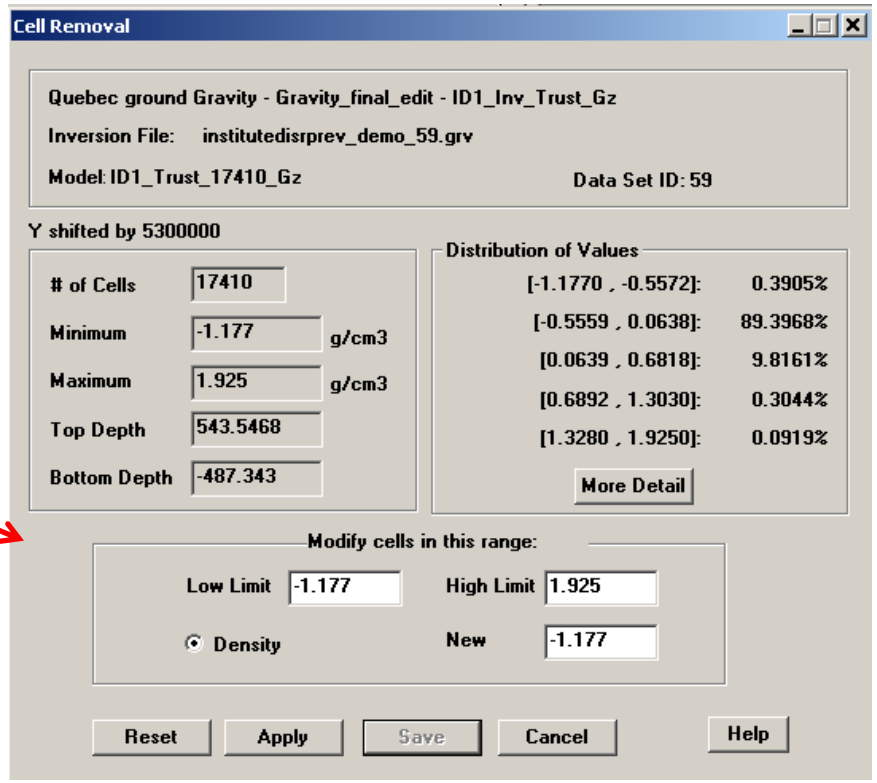


This functionality allows the user to modify the density of cells. A range of densities is selected and then a new density for all the cells in the range is defined. ***Apply*** makes the changes.



Click "Apply" button when modify range is defined

One use of this functionality is adjust the resulting inversion in preparation to use the modified inverse model as a starting model for a further inversion.

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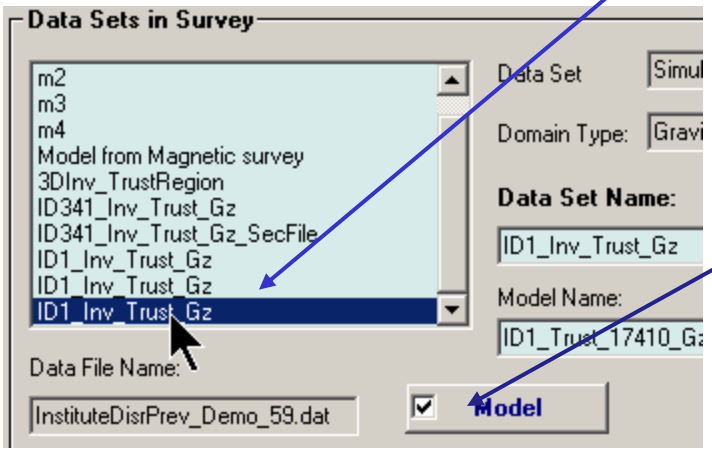
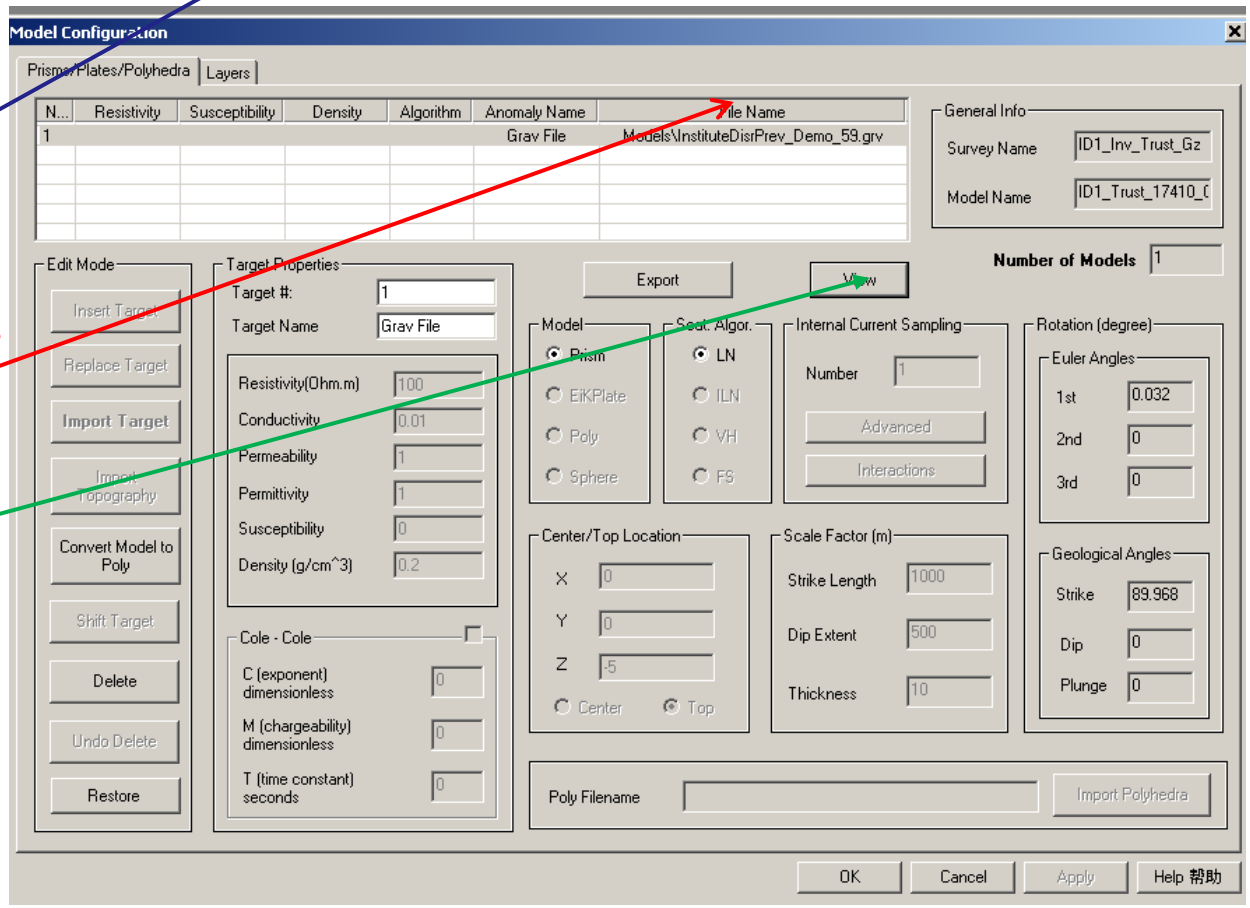
Inversion Evaluation

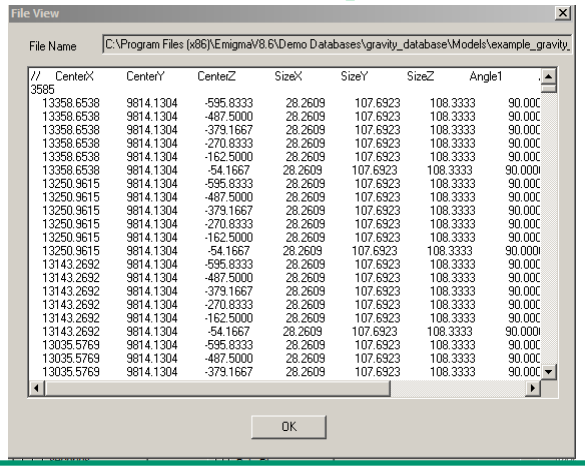
An inversion result is selected. You will note the "Model" button is checked. If the "Model" button is clicked, the following interface opens.



The model will be saved as a ".grv" file with its name and folder shown in the "Filename" column of the table



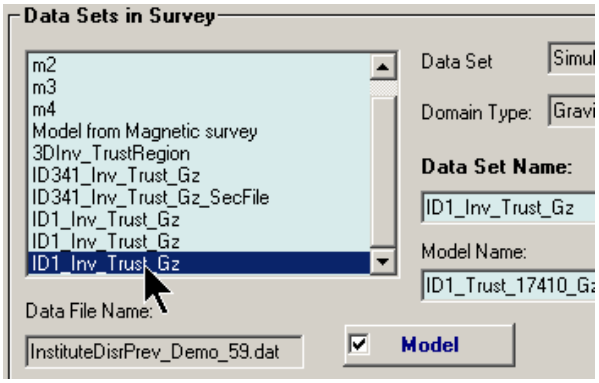
Click "View" button to open this file…

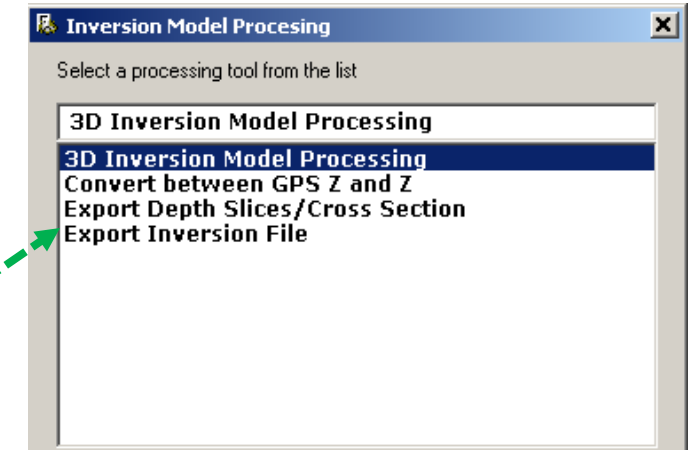


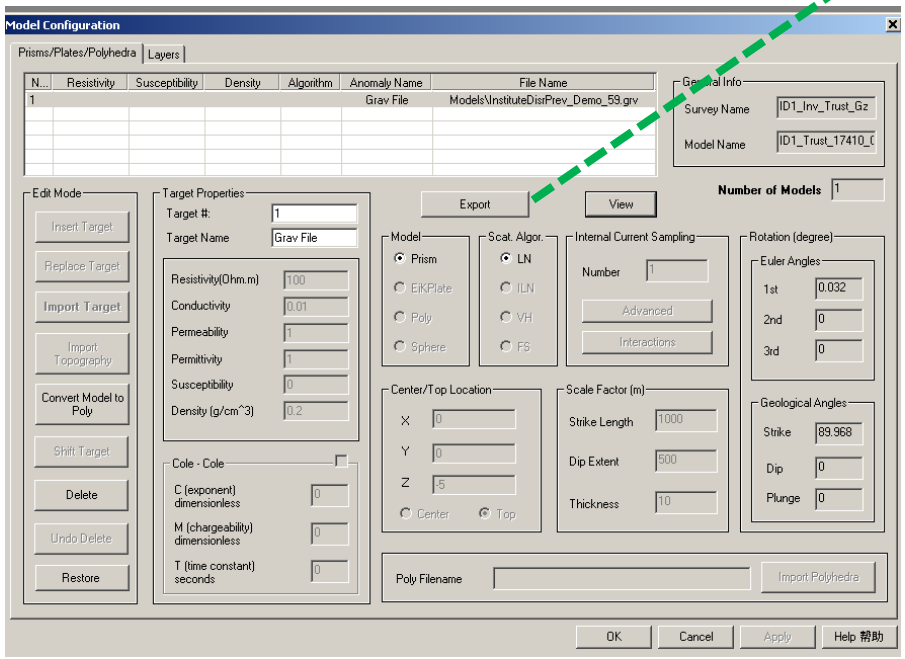
1. Import data
2. Examine data
3. Perform initial modeling
4. Perform 3D gravity inversions
5. **Inversion Evaluation/Processing**
6. Visualization
7. Export Models

Inversion Evaluation/Processing
Export Functions

When an inversion result is selected and the user opens the 'Model' description an 'Export' option is provided.







EXPORT OPTIONS: The first Export option allows to extract Depth Slices or Cross Sections from the inversion model. The second option is to export the entire inversion grid. These processes may be performed on either the original inversion grid or any processed grids that you have produced.

The cross sections are exported to a new dataset for viewing in our Section Viewer and can be exported from that app to standard formats. The user controls the depth slices (Number, Depth increment, etc) and the output is to a .qct file. From there it may be exported to an ASCII file if required.

1. Import data
2. Examine data
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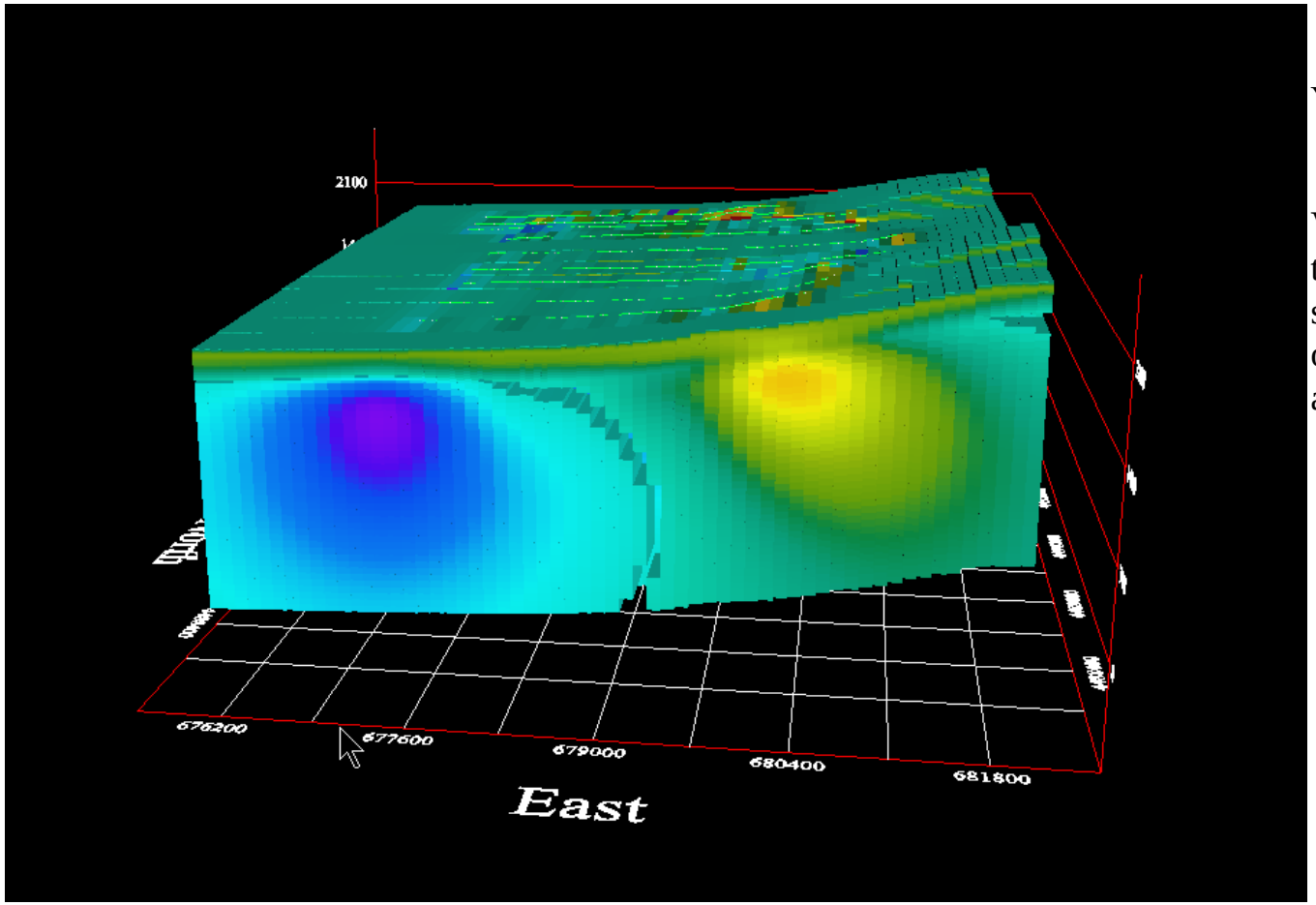
4. Perform 3D gravity inversions
5. Inversion Evaluation/Processing
6. **Visualization**
7. Export Models

INVERSION VISUALIZATIONS

Click  button to open Visualizer tool to view the inverted 3D model…



You may export a 3D image as a 3D .pdf.
File ▶Save Image

Various controls are provided on the toolbar above the visualization scene. There is a tutorial on the use of the Visualizer both for viewing as well as building models.

1. Import data
2. Examine data
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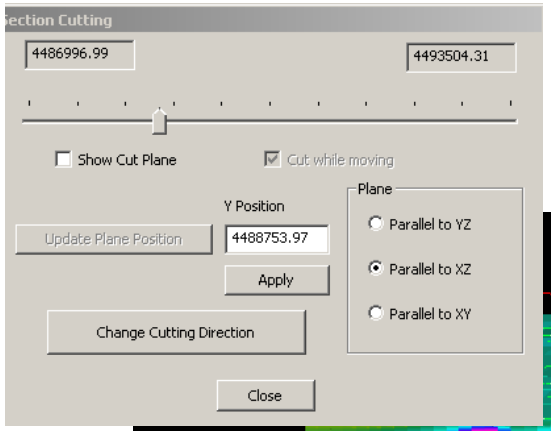
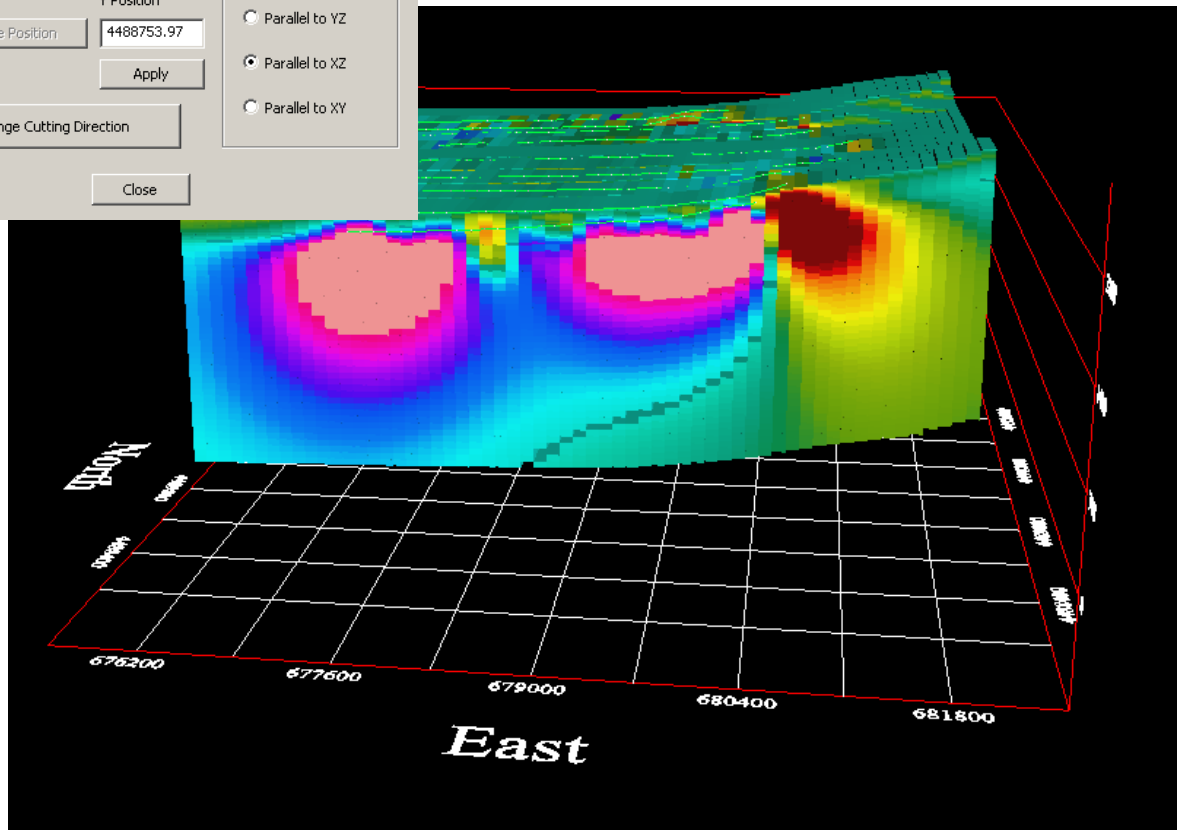
6. **Visualization**
7. Export Models

VISUALIZATION

Select from top menu "Model ► 3D Inversion Model ► Model Cutting" to open the *Section Cutting* tool.





By adjusting the control bar...

View sections of the 3D model in XY, XZ and YZ planes

the example shown is a slice at North 4488754m

1. Import data
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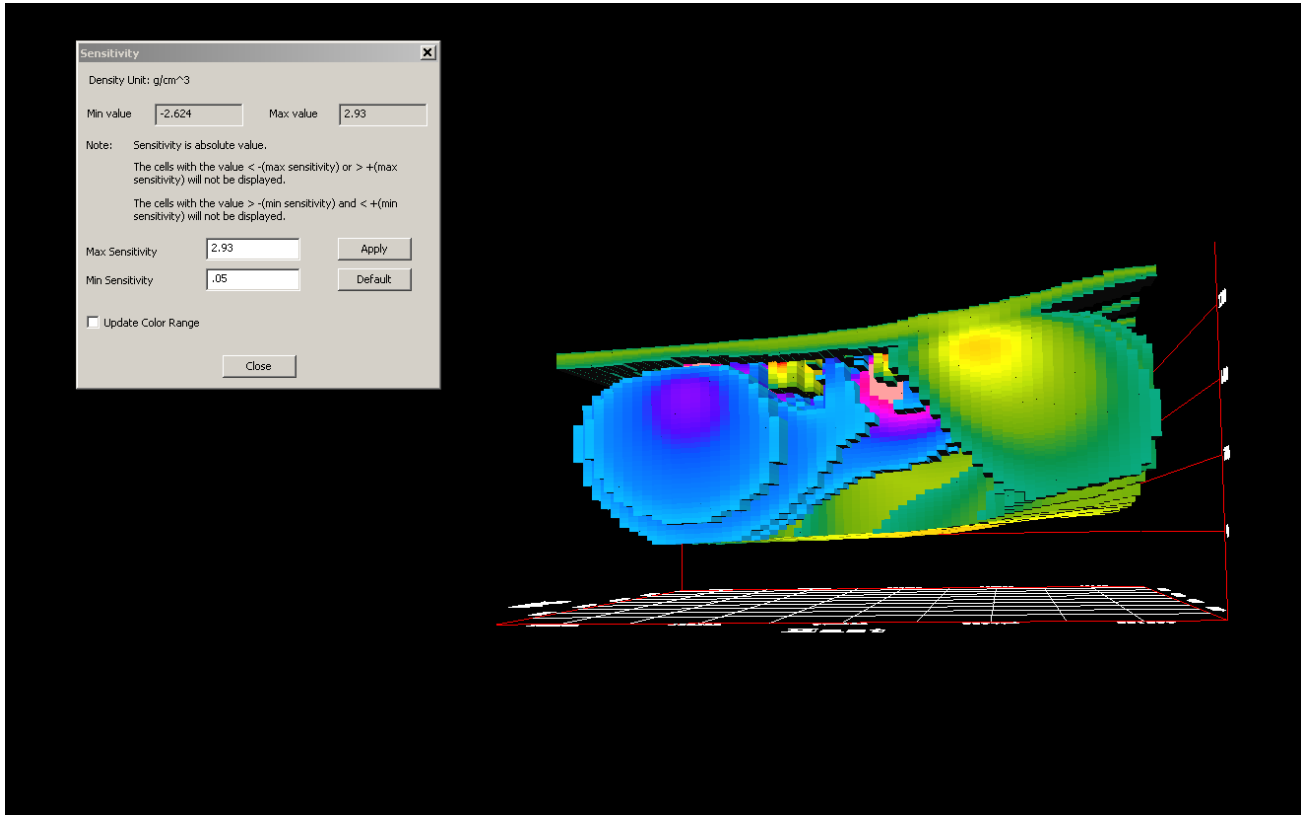
7. Export Models

VISUALIZATION

Select from top menu “Model ► 3D Inversion Model ► Sensitivity” to open the *Sensitivity Selection* tool.

The model in this figure has only those cells exhibited with values specified in the range



1. Import data
2. Examine data
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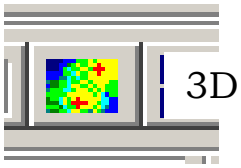
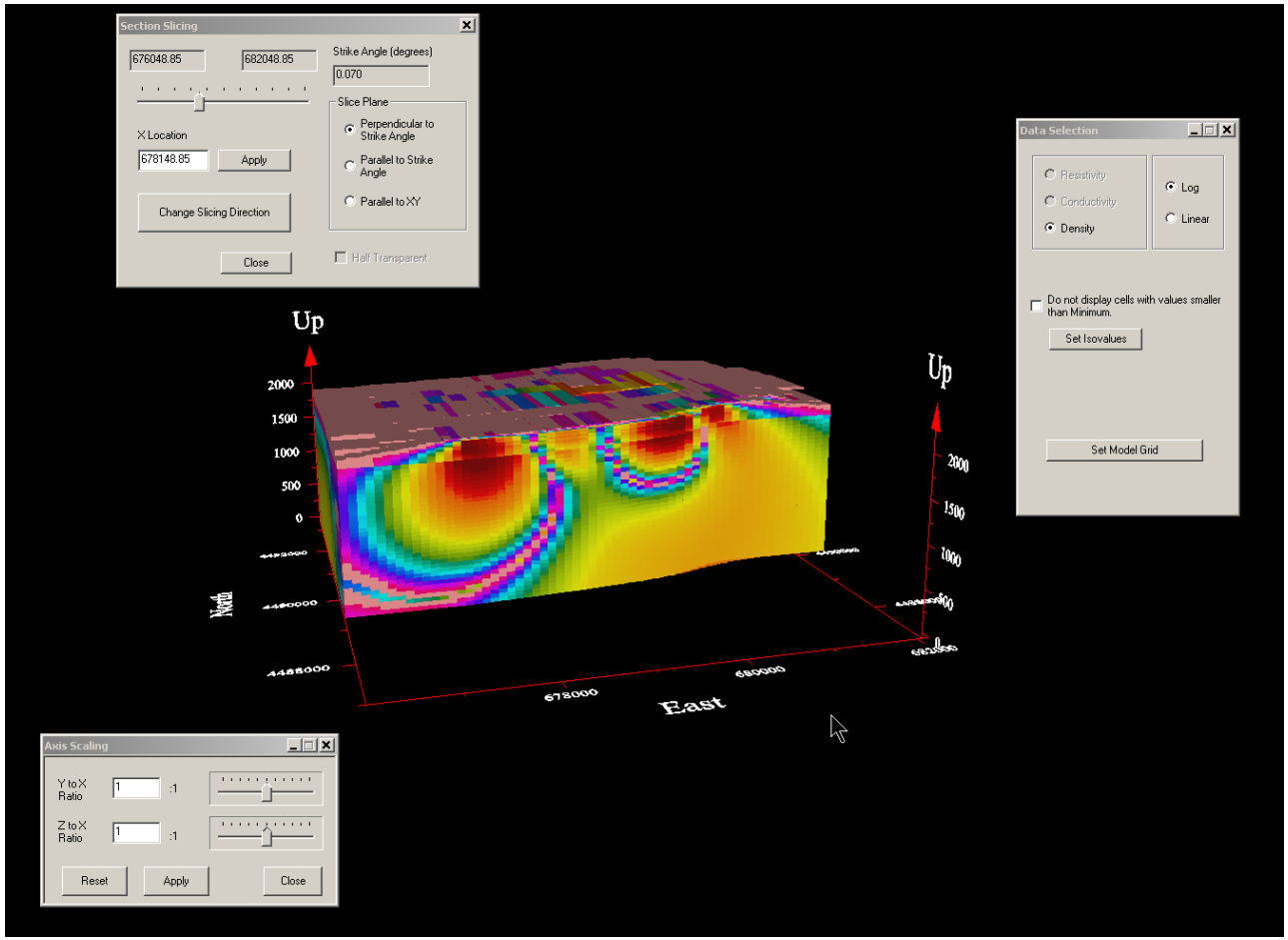
5. Inversion Evaluation/Processing
6. **Visualization**
7. Export Models

VISUALIZATION

Another visualization tool which interpolates the inversion grid into finer grid cells and allows other visualization capabilities



3D Contour

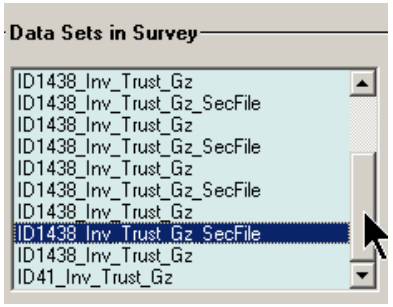


1. Import data
2. Examine data
3. Perform initial modeling
4. Perform 3D gravity inversions
5. Inversion Evaluation/Processing
6. Visualization
7. **Export Models**

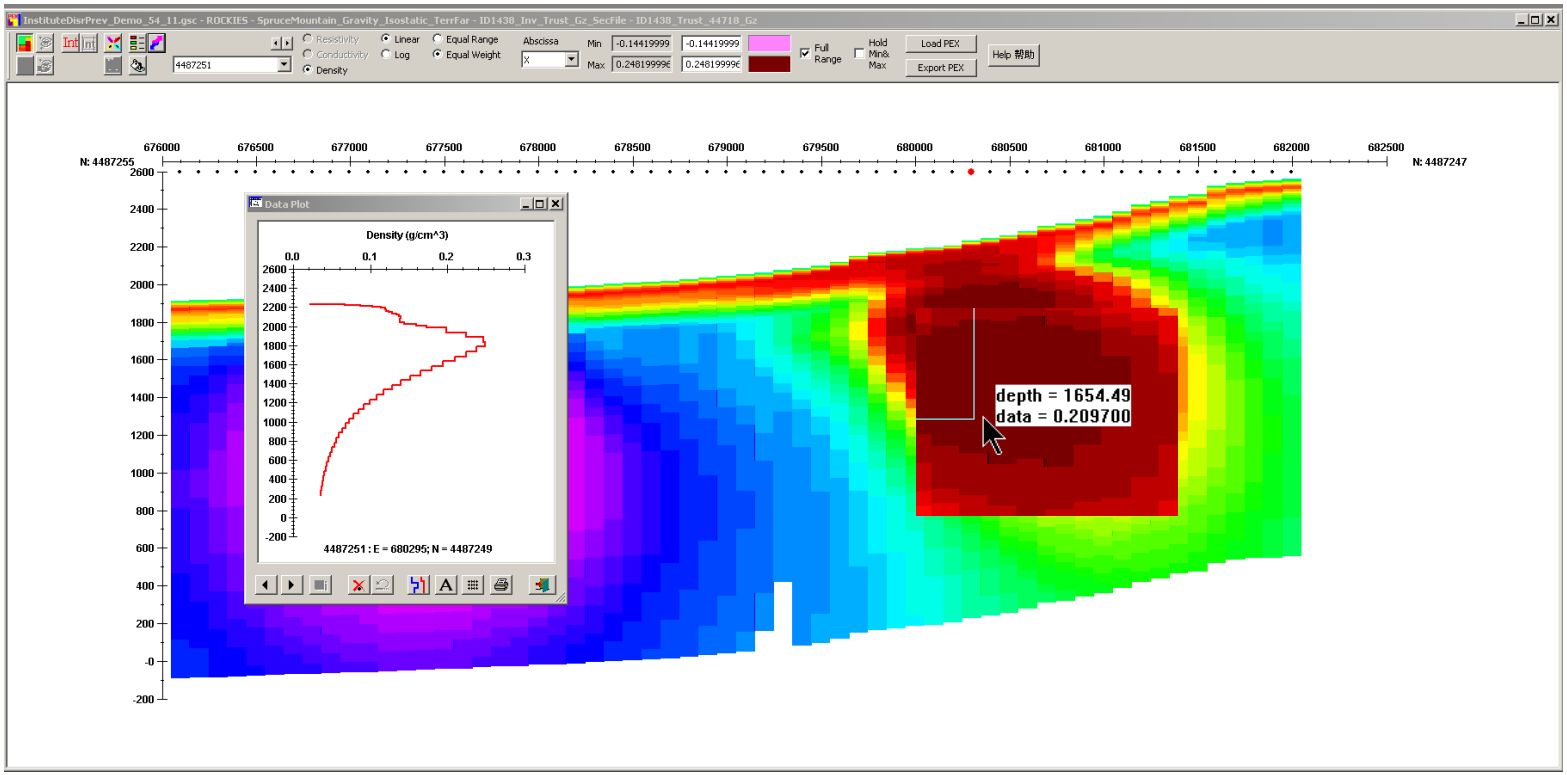
VISUALIZATION

CROSS SECTIONS: From the Model button, you may export cross sections. This function produces another dataset containing the model as density slices (*.gsc). These files may be viewed in the viewer indicated by PEX on the toolbar.

CDI VIEWER



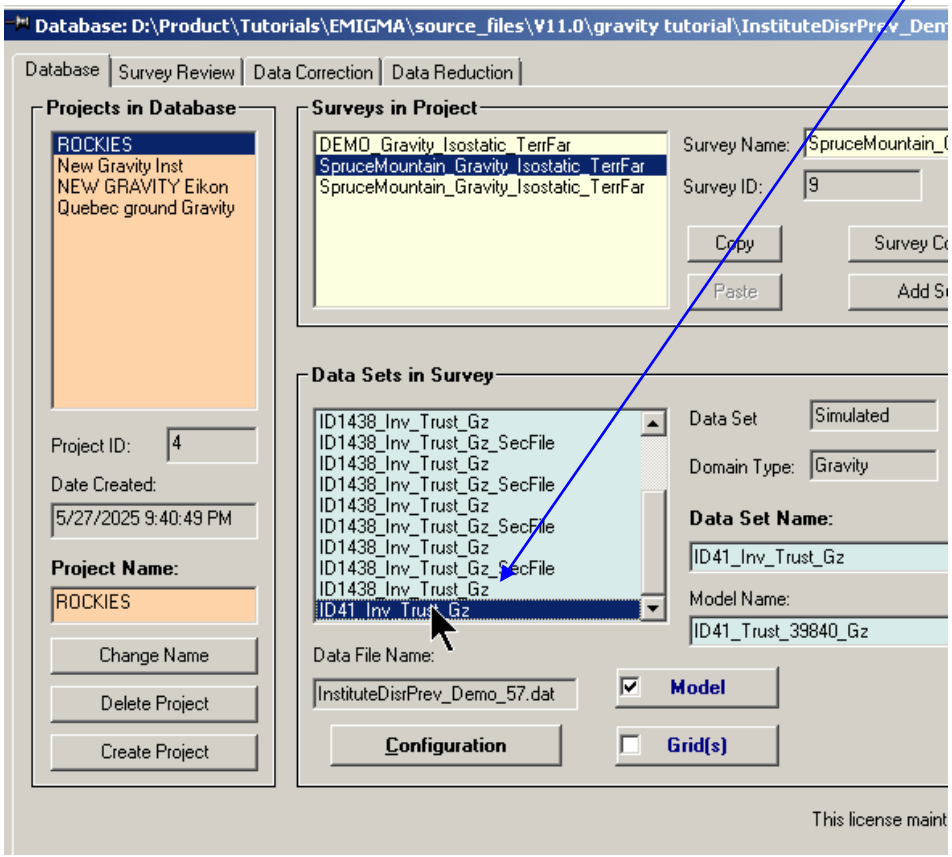
-The values of the abscissa are shown across the top. The abscissa may be changed.
- Depth is shown on the left axis. Double click on an axis to change the settings.
- The value of the perpendicular coordinate is shown on the left at the beginning of section and on the right at the end of the section
- The inversion data is shown initially without contouring. Click on a cell to view the depth and parameter value of the cell
- the box at bottom left of toolbar is the value of the center point for the coordinate perpendicular to the abscissa
- Use left right arrows to move between sections
- The small Data Plot window is the parameter value vs. depth for the selected point. Tools are at the bottom

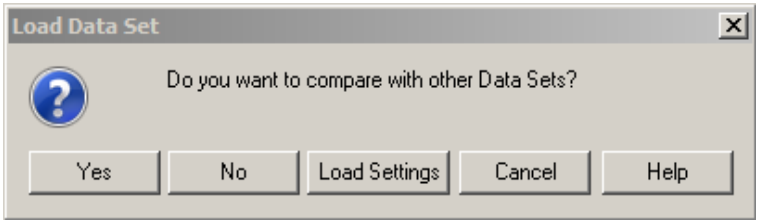


1. Import data
2. Examine data
3. Perform initial modeling
4. Perform 3D gravity inversions
5. **Inversion Evaluation/Processing**
6. Visualization
7. Export Models

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.



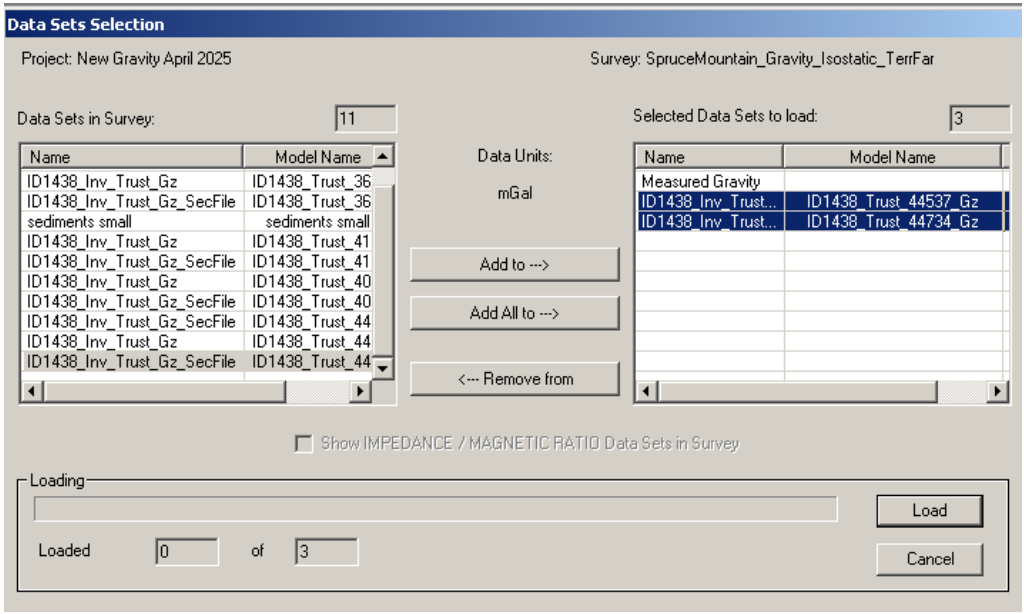


Select “Yes”, if this dialog appears and select all datasets that require comparison.

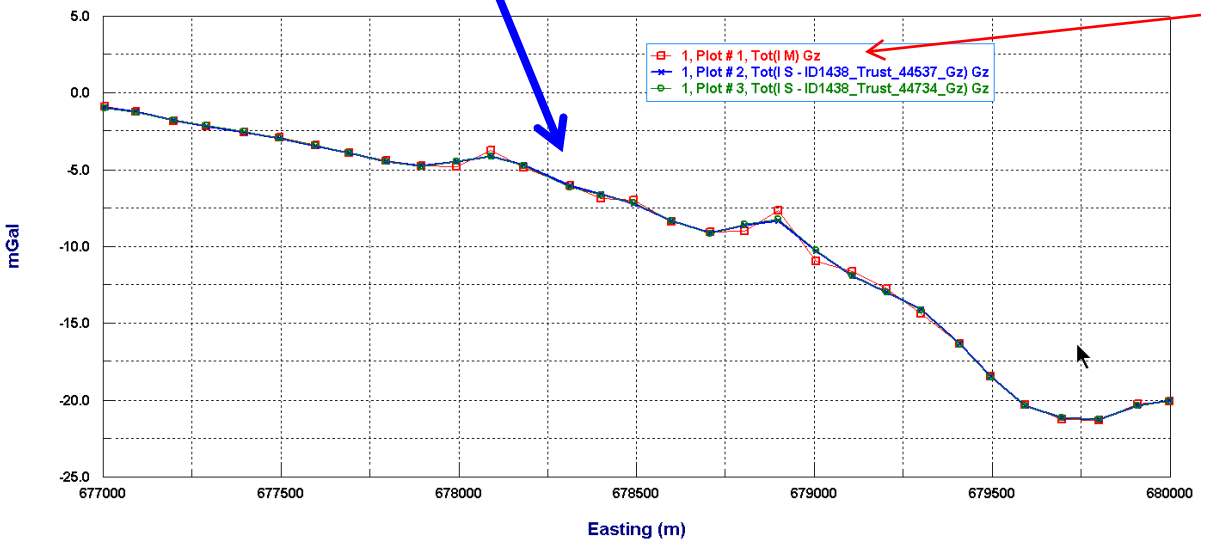
1. Import data
2. Examine data
3. Perform initial modeling
4. Perform 3D gravity inversions
5. **Inversion Evaluation/Processing**
6. Visualization
7. Export Models

Inversion Evaluation

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



All selected data sets are then loaded to the Plotter application and the plot appears showing the simulated data of the first profile. Use the left/right arrows to move between lines or double-click the plot.

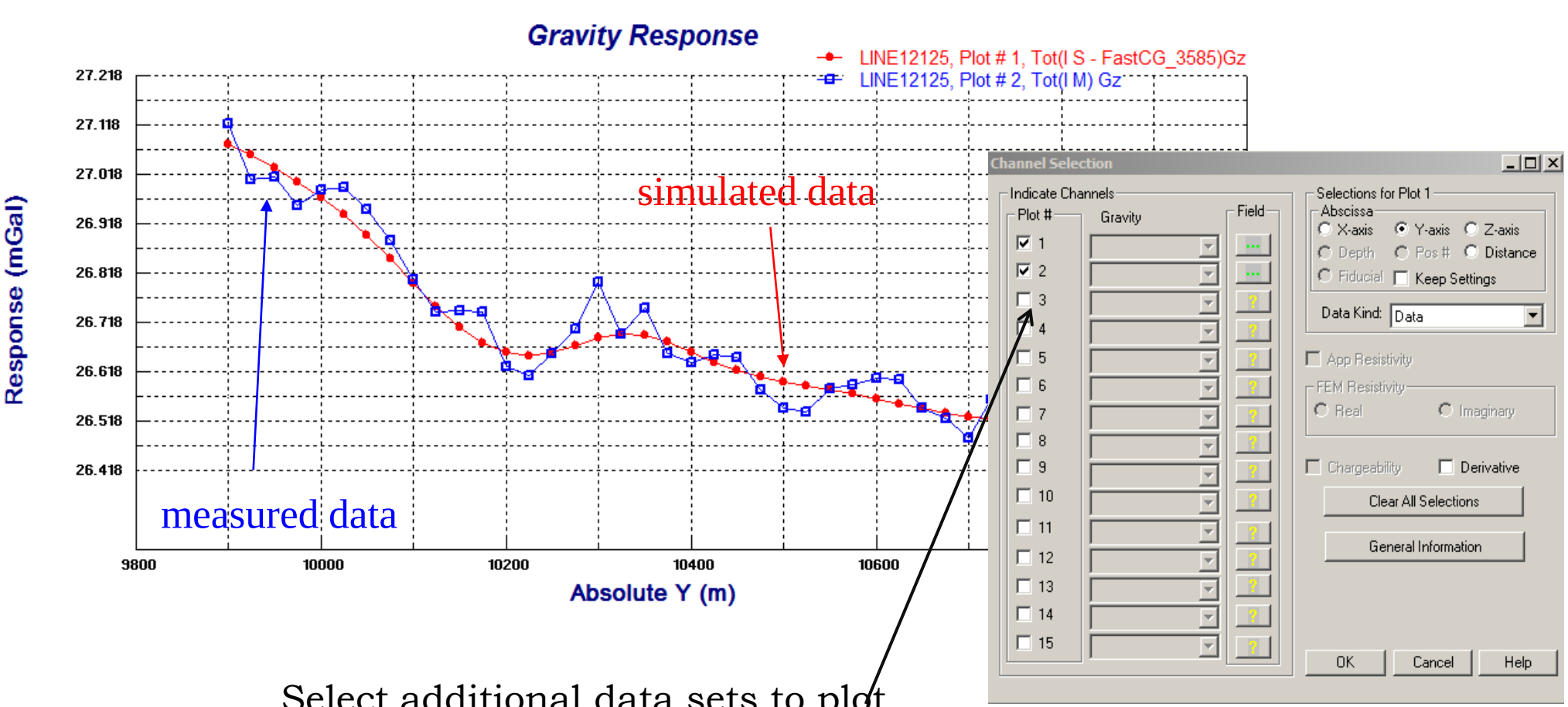


measured data

1. Import data
2. Examine data
3. Perform initial modeling
4. Perform 3D gravity inversions
5. **Inversion Evaluation/Processing**
6. Visualization
7. Export Models

Inversion Evaluation

The user may select other data sets to plot by simply double clicking on the plot or change parameters in the plot.

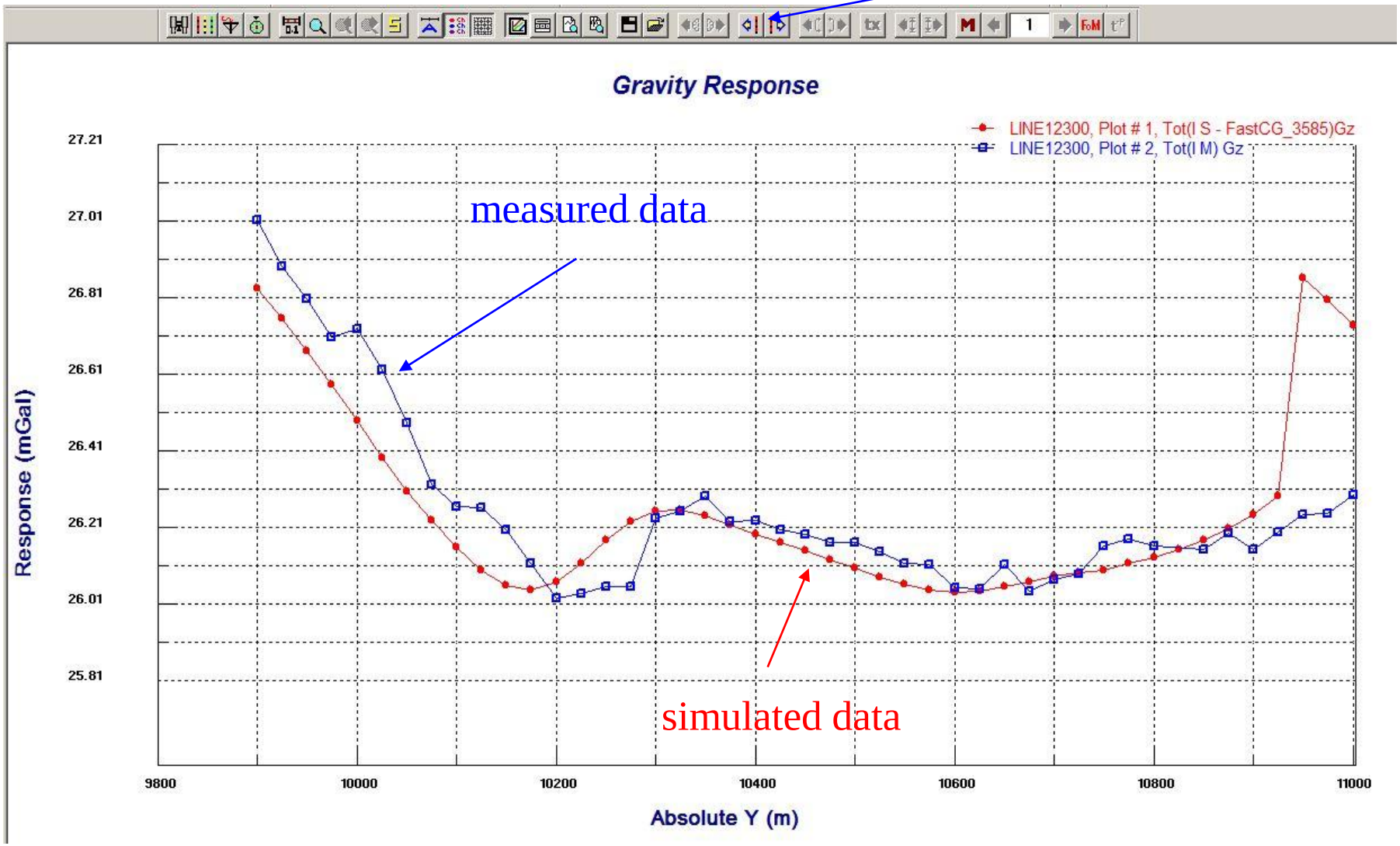


Select additional data sets to plot

1. Import data
2. Examine data
3. Perform initial modeling
4. Perform 3D gravity inversions
5. **Inversion Evaluation/Processing**
6. Visualization
7. Export Models

Inversion Evaluation

Multiple plots can be shown for various inversions and models contained in the same survey of the database. The user may step through different profiles by simply clicking the arrow and step through models using the arrows to the right of **M**.

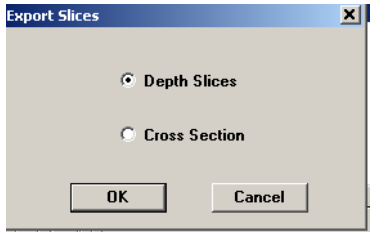


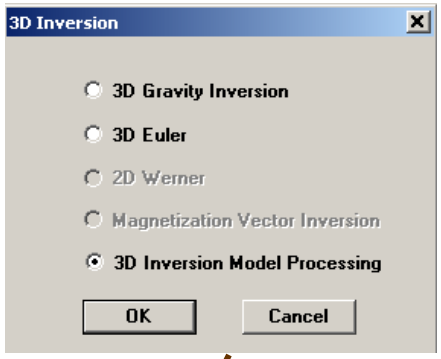
1. Import data
2. Examine data
3. Perform initial modeling
4. Perform 3D gravity inversions
5. Inversion Evaluation/Processing
6. Visualization
7. **Export Models**

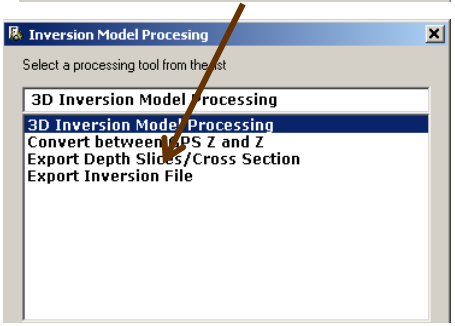
EXPORT MODELS

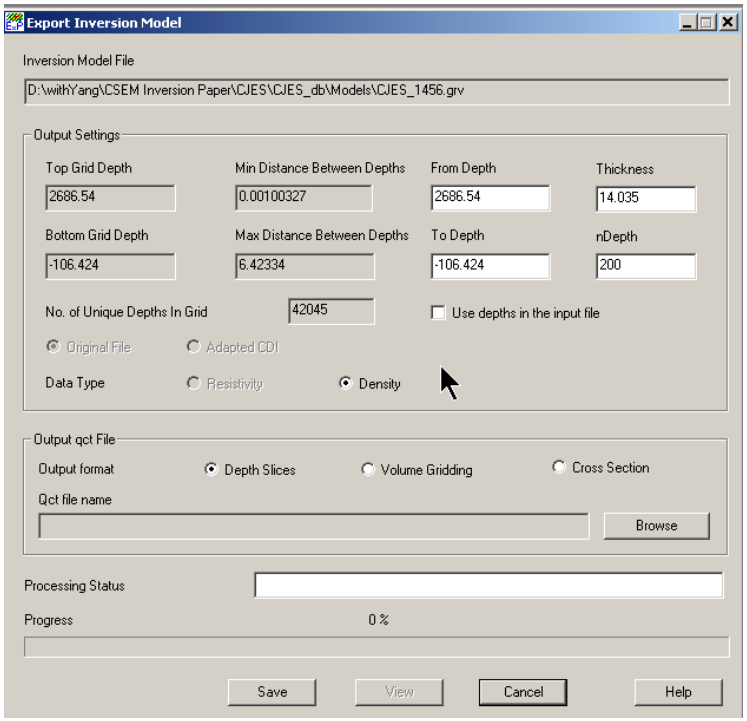
EXPORT OPTIONS:

Export Depth Slices/Cross Sections









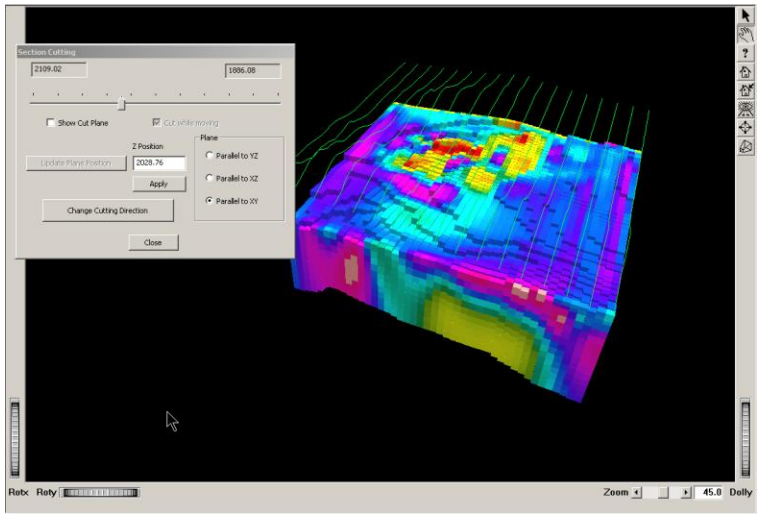
Depth Slices: This tool provides slices of the densities in the grid at a set of depths. The default is to create an interpolated volume before slicing. The user specifies the top depth plane and the bottom depth plain and the number of Depths of the Thickness between each depth plane. Browse to specify a folder and a QCTOOL file name for export. The depth slices are easily contoured in QCTOOL or exported for import to another application.

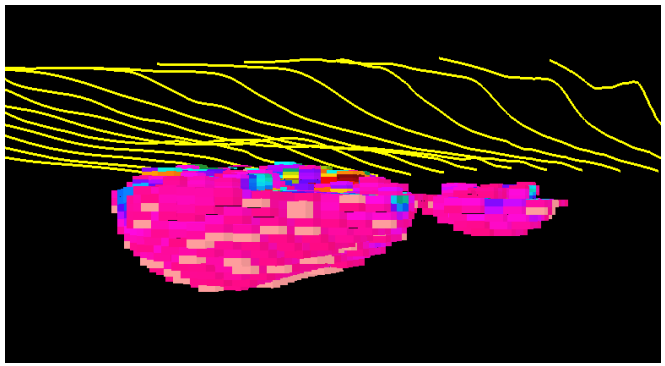
Cross Sections: We have seen above how to export cross sections to another data set in order to use EMIGMA's section viewer. However, you may export the cross sections here directly to a QCTOOL file for export to another program.

1. Import data
2. Examine data
3. Perform initial modeling
4. Perform 3D gravity inversions
5. Inversion Evaluation/Processing
6. Visualization
7. **Export Models**

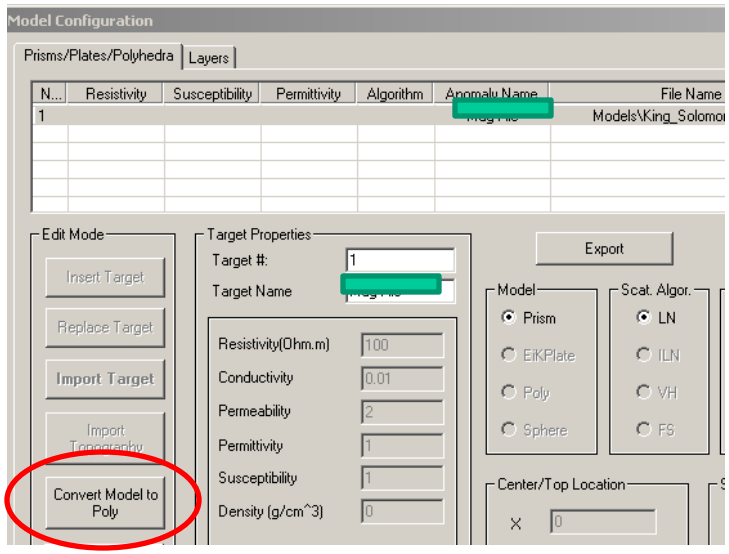
EXPORT INVERSE MODELS to CAD FORMATS

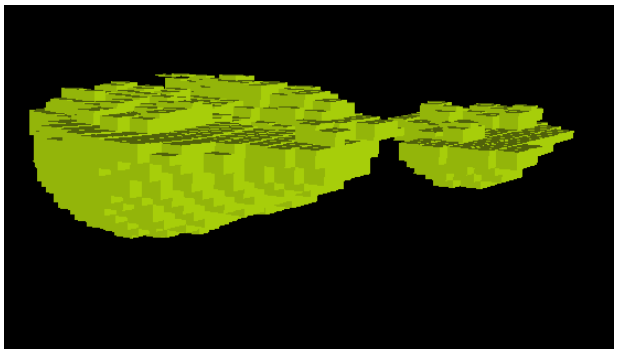
The inversion grids can be imported to CAD applications but when integrating the inversion into a larger CAD project, a more compact form is often required. This is normally performed on a reduced inversion model which focuses on the most interesting structures in the inversion model. In the example below and to the left, is a view of the inversion model sliced at depth. The interesting structure can be seen in the upper left of the model. The image below shows the inversion model after removal of small values of inverted density.





The first step is to convert the reduced grid to a polyhedral model. Select '*Model*' again and the Model Configuration dialogue opens (*bottom left*), the user selects the inversion grid at the top and the selects 'Convert Model to Poly' on the left of the dialogue. A view of this poly model is seen below in the Visualizer. The polyhedra file is stored in the Polyhedron subdirectory of the database structure.



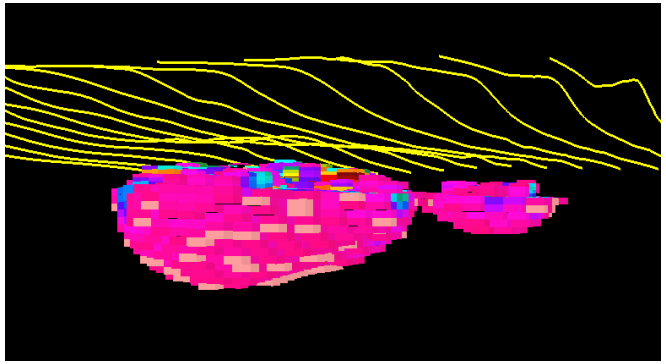


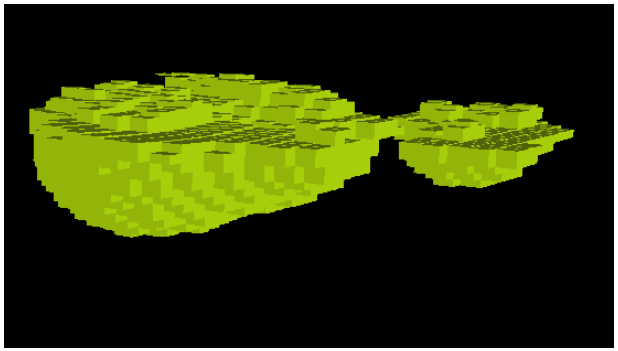
1. Import data
2. Examine data
3. Perform initial modeling
4. Perform 3D gravity inversions
5. Inversion Evaluation/Processing
6. Visualization
7. **Export Models**

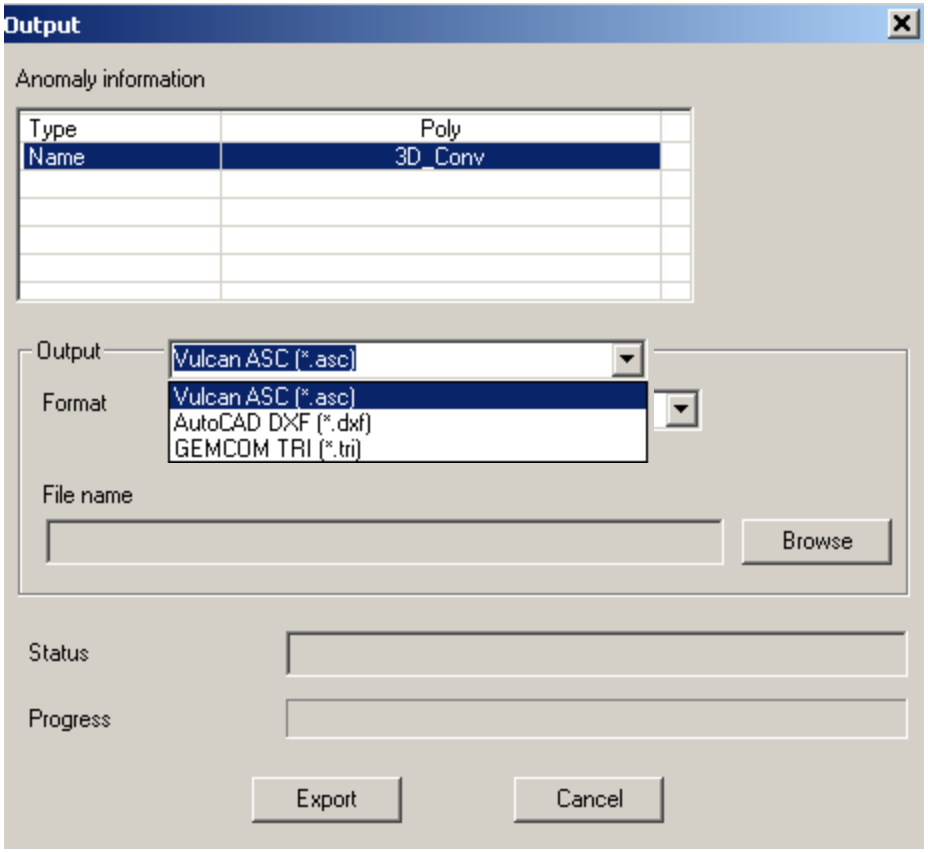
EXPORT INVERSE MODELS to CAD FORMATS

All model primitives in EMIGMA including polyhedral models can be exported to several CAD formats. Now that the model is in a polyhedral format it may be so exported.

MODEL ►Export ►







Browse ► To select a directory and save the file for import to CAD. Most CAD applications allow any of these 3 formats.

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