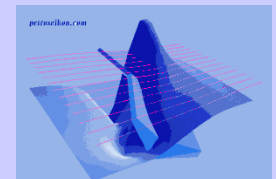


# 3D GRAVITY INVERSION TUTORIAL

Gravity Inverse  
1

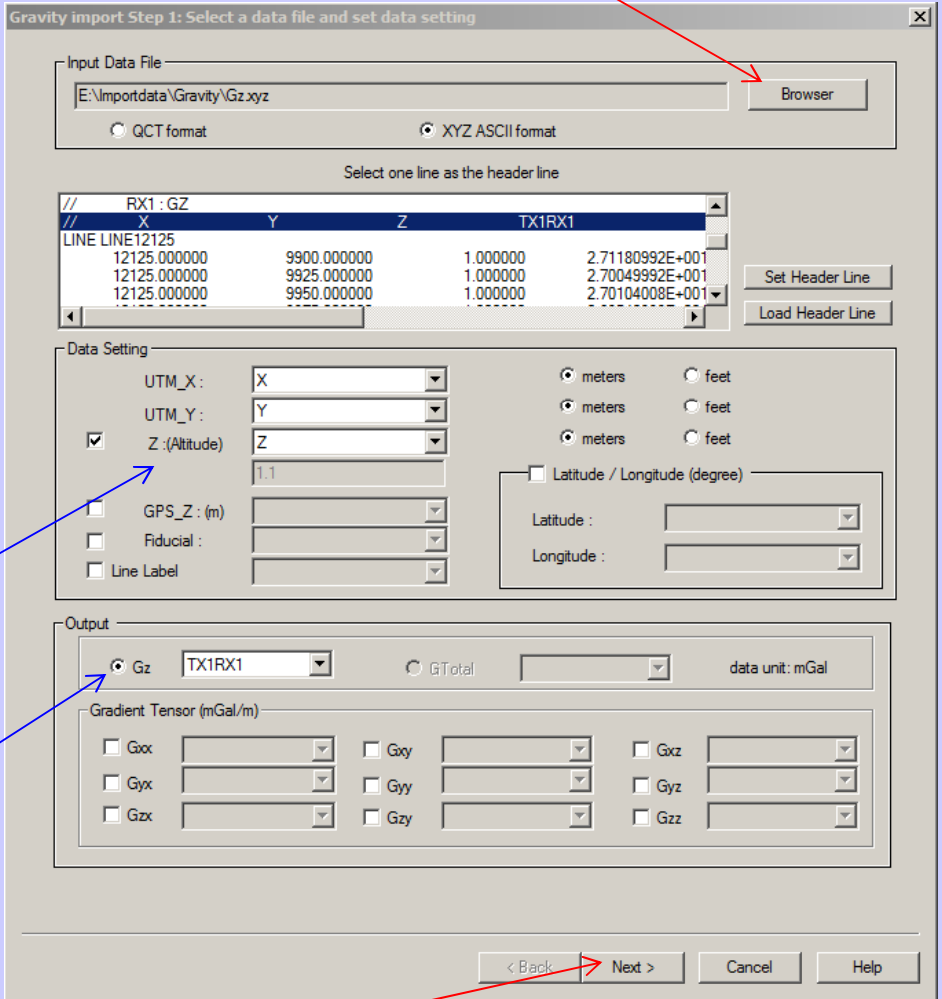
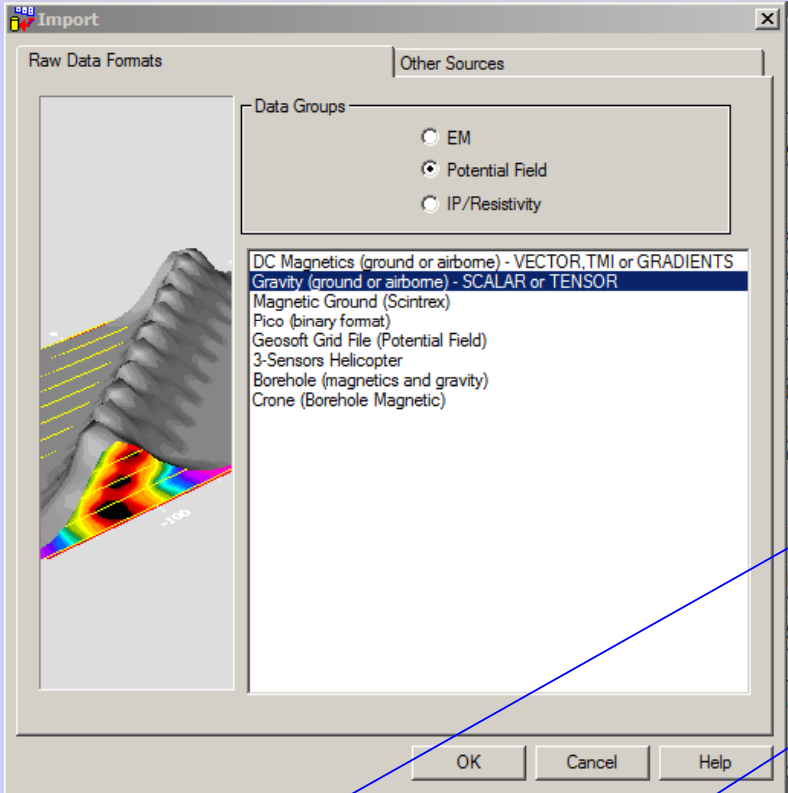
## *Steps:*

	<i>Page</i>
<b>1. Import data</b> to new or existing database	2
<b>2. Examine data</b>	5
<b>3. Perform initial forward modeling</b>	7
<b>4. Perform 3D gravity inversions</b>	8
<b>5. Check mode and create plots</b>	19



- 1. Import data
- 2. Examine data
- 3. Perform initial modeling
- 4. Perform 3D gravity inversions
- 5. Check model and create plots

Browse and select .qct or .xyz data file for import



Set coordinate axis and output data column names

Click "Next" button

- 1. Import data
- 2. Examine data
- 3. Perform initial modeling
- 4. Perform 3D gravity inversions
- 5. Check model and create plots

Show profile information, and users can make delete/reduction/shift operations on profile in this dialog

The dialog box is titled "Profile and Locations Setting". At the top, it displays "Total Number of Profiles: 14" and "Total Number of Locations: 614". Below this is a table titled "Profiles and Locations":

Profile	# Locations
LINE12125	45
LINE12175	29
LINE12225	45
LINE12300	45
LINE12400	45
LINE12500	45
LINE12600	45
LINE12700	45
LINE12800	45
LINE12900	45
LINE13000	45
LINE13100	45
LINE13200	45
LINE13300	45

Below the table is a "Restore/Reset" button. To the right of the table is a "Modify Profile(s)" section with a "Profile" text box, a "Delete" button, a "Delete every" spinner set to "2" with a "location" label and an "Apply" button, an "Append to Profile Name(s)" text box with an "Apply" button, and an "Apply for All Profiles" checkbox with a "Split" button. Below this is a "Shift Coordinate Values" section with "Shift X" and "Shift Y" spinners both set to "0", and "Reset" and "Change" buttons. At the bottom of the dialog are "< Back", "Next >", "Cancel", and "Help" buttons. A red arrow points from the text "Click 'Next' button" to the "Next >" button.

Click "Next" button

- 1. Import data
- 2. Examine data
- 3. Perform initial modeling
- 4. Perform 3D gravity inversions
- 5. Check model and create plots

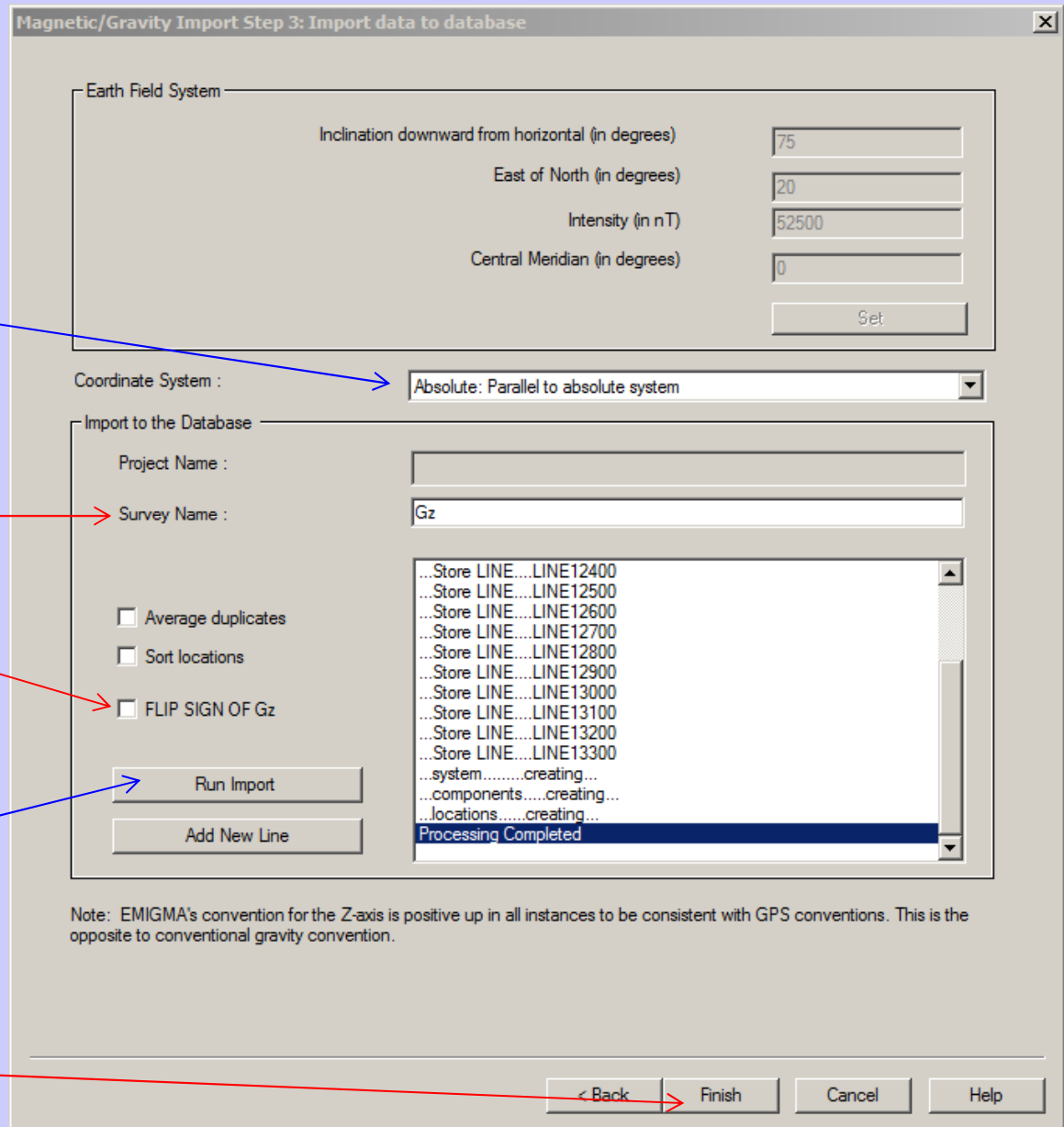
Select coordinate system

Set survey name

Flip sign of Gz data if it is not in accordance with the system

Click "Run Import" button to start importing data into database

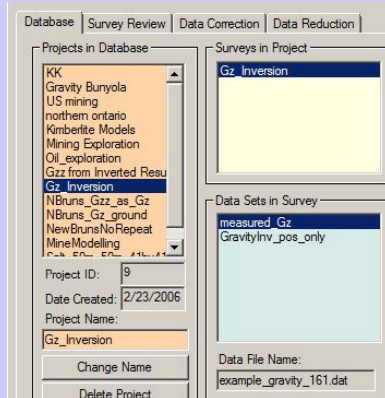
After processing is done, click "Finish" button to complete this procedure



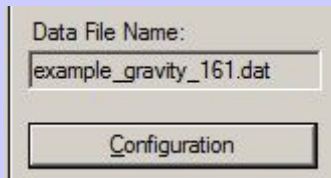
# Gravity Inverse 5

1. Import data
2. Examine data
3. Perform initial modeling
4. Perform 3D gravity inversions
5. Check model and create plots

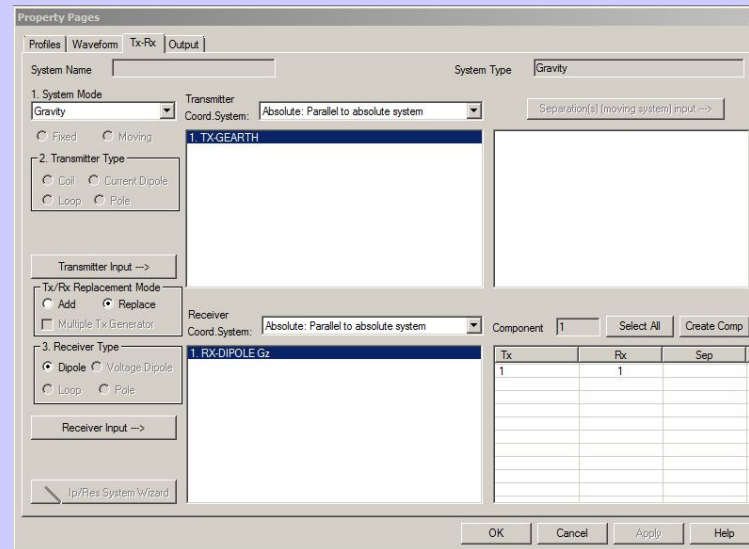
## 1. Check database for the survey



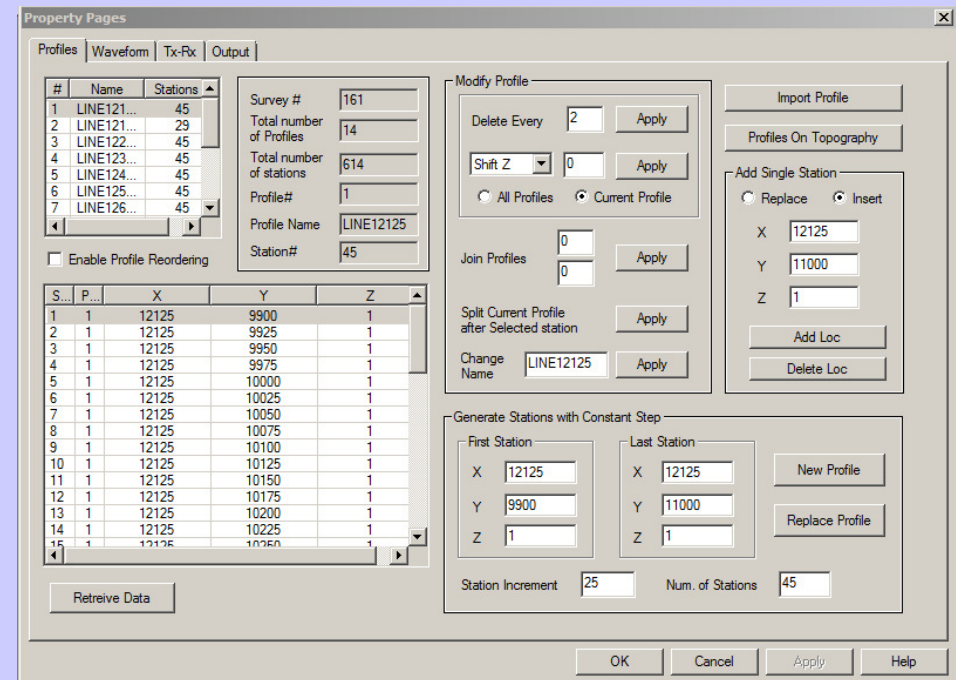
## 2. Click configuration



## 4. Check lines and stations are correct



## 3. Check system configuration



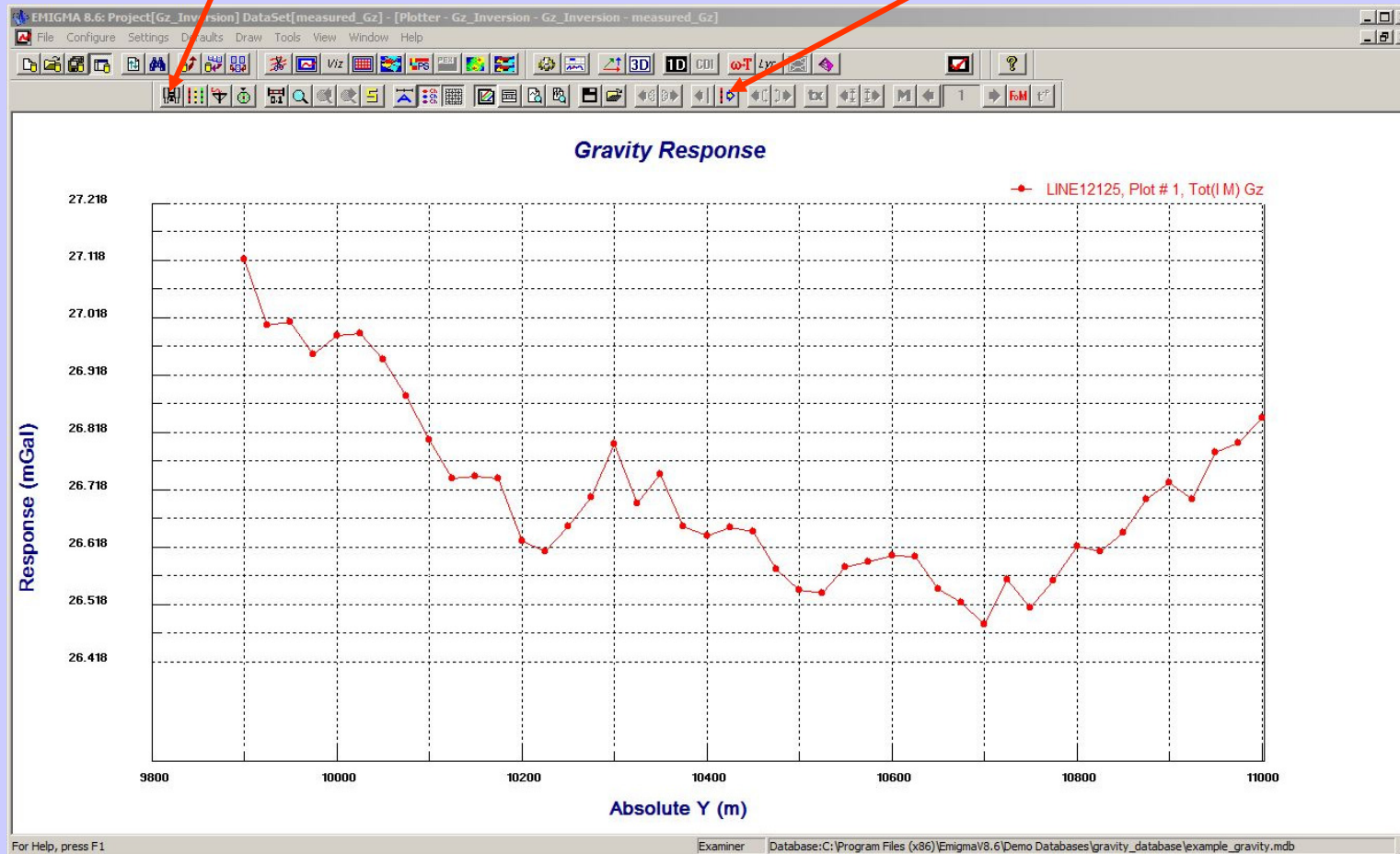
1. Import data
- 2. Examine data**
3. Perform initial modeling
4. Perform 3D gravity inversions
5. Check model and create plots



Click "Plotter"...

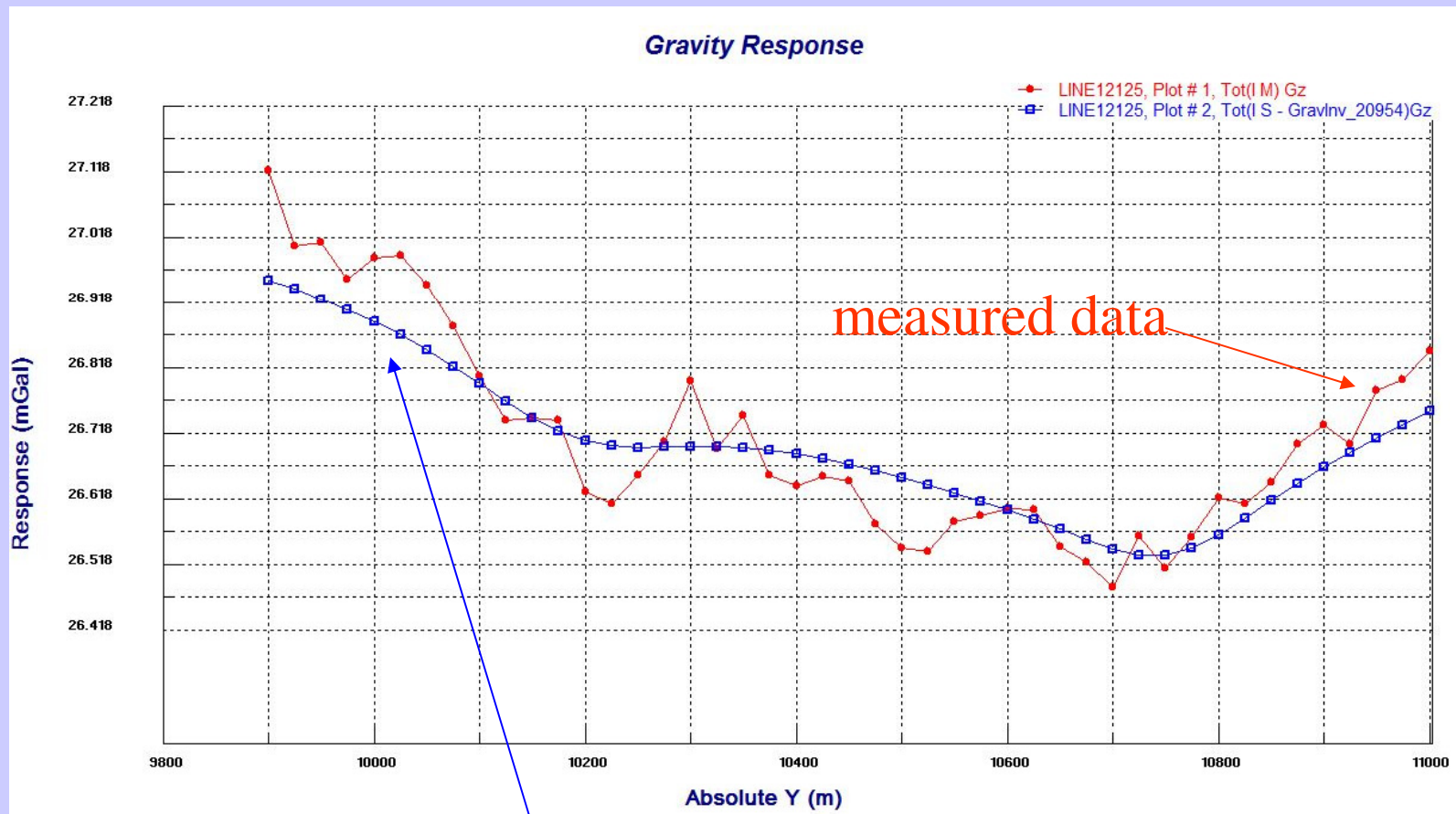
Load data set in plotter

Toggle between profiles



1. Import data
2. Examine data
- 3. Perform initial modeling**
4. Perform 3D gravity inversions
5. Check model and create plots

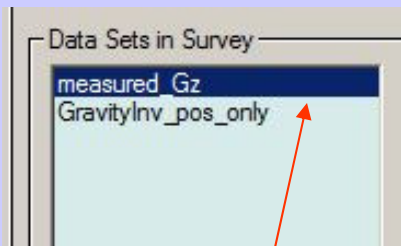
**Note:** Performed some initial modeling to get a “feel” of the data and estimate parameters of initial model for inversion.



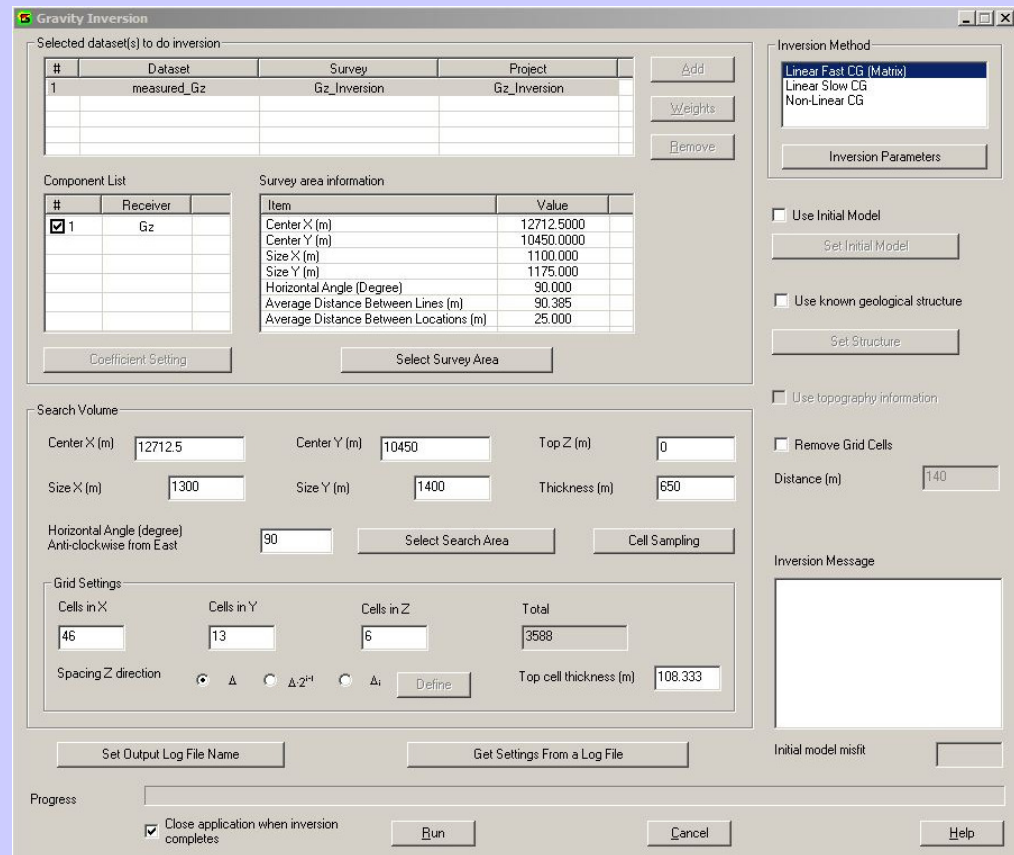
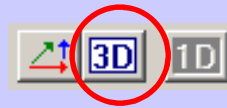


# Gravity Inverse 8

1. Import data
2. Examine data
3. Perform initial modeling
- 4. Perform 3D gravity inversions**
5. Check model and create plots



Select survey data





# Gravity Inverse

9

1. Import data
2. Examine data
3. Perform initial modeling
4. Perform 3D gravity inversions
5. Check model and create plots

## Selected Data Sets

A dataset may be added for use in the inversion by clicking **Add**. Each dataset is given equal weight by default. This can be changed by clicking **Weights**.

## Components

Components that will be used in the inversion are displayed here.

## Log File

A log file is created each time an inversion is run. The name and location of the log file can be specified by clicking **Set Output Log File Name**. Click **Get Settings From a Log File** to use the settings from a previous inversion.

## Use topography information

This option will be enabled if you imported your data with a gps z channel. Select this option and the gps z values will be used when performing the inversion. When loading inversion results to the visualizer, a window will appear asking to display the survey according to z or gps z. Select gps z to see the inversion results with topography.

## Remove Grid Cells

Any cells that are beyond the specified **Distance** from the closest data point will be removed from the inversion result.

## Geological Structure

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

## Initial model misfit

Defines how close the initial model fits the data. The closer the value is to 0, the better the fit.

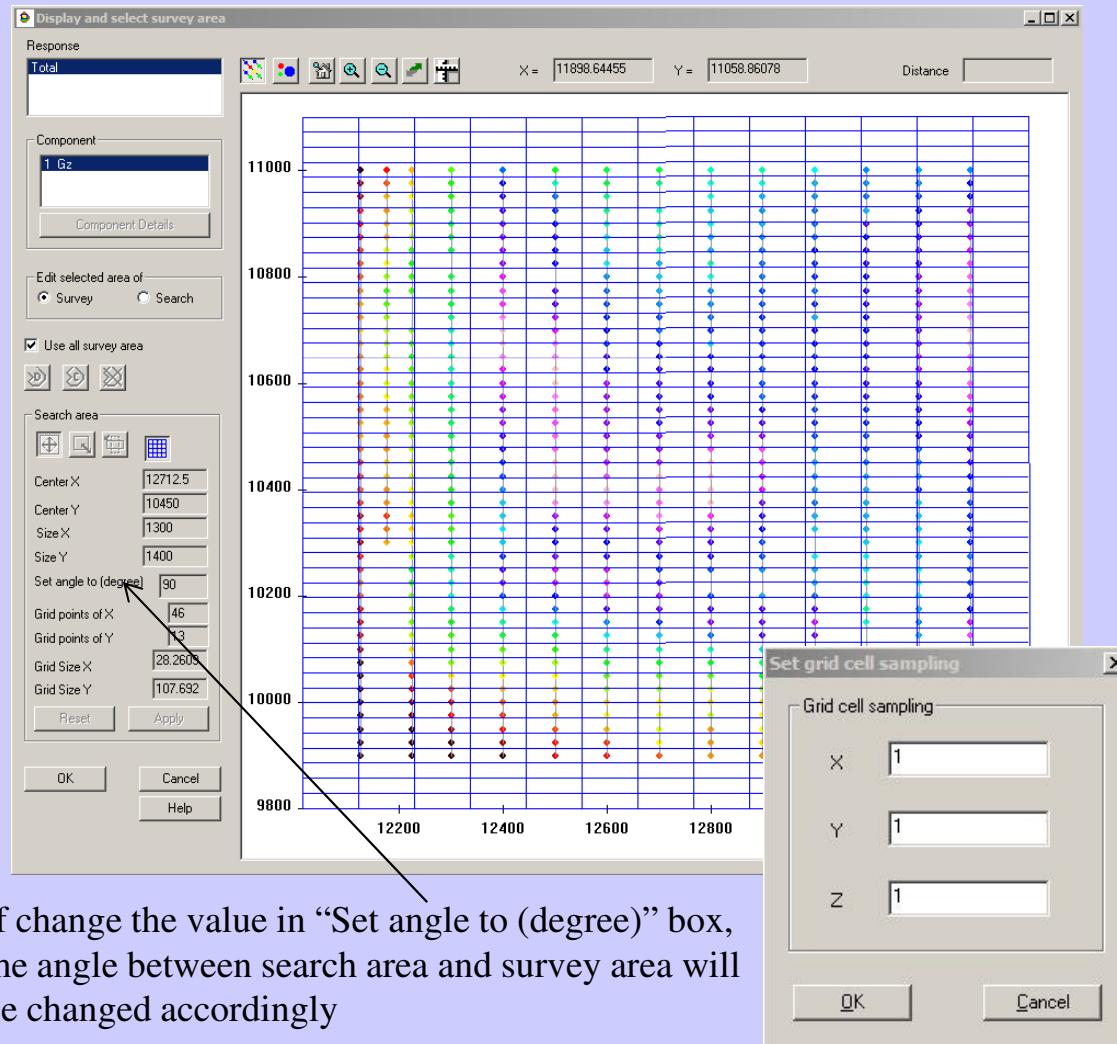
The screenshot shows the Gravity Inversion software interface with the following sections:

- Selected dataset(s) to do inversion:** A table with columns #, Dataset, Survey, and Project. Row 1: 1, Processed, Ground Gravity, GroundGravity.
- Component List:** A table with columns #, Receiver. Row 1: 1, Gz.
- Survey area information:** A table with columns Item, Value. Rows: Center X (m) 588500.0000, Center Y (m) 6471100.0000, Size X (m) 11700.000, Size Y (m) 6200.000, Horizontal Angle (Degree) 0.000, Average Distance Between Lines (m) 100.000, Average Distance Between Locations (m) 301.076.
- Search Volume:** Center X (m) 588500, Center Y (m) 6471100, Top Z (m) 0, Size X (m) 14000, Size Y (m) 7400, Thickness (m) 3000, Horizontal Angle (degree) 0.
- Grid Settings:** Cells in X 25, Cells in Y 77, Cells in Z 5, Total 9625, Spacing Z direction (radio buttons), Top cell thickness (m) 600.
- Inversion Method:** Linear Fast CG (Matrix), Linear Slow CG, Non-Linear CG.
- Buttons:** Add, Weights, Remove, Inversion Parameters, Set Initial Model, Set Structure, Set Output Log File Name, Get Settings From a Log File, Run, Cancel, Help.
- Progress:** Close application when inversion completes (checked).

# Gravity Inverse 10

1. Import data
2. Examine data
3. Perform initial modeling
4. Perform 3D gravity inversions
5. Check model and create plots

Clicking either the **Select Search Area** or **Select Survey Area** buttons launches the same window. But search area means the area of data which the inversion algorithm works on, while survey area is the whole part of the imported survey data.



If change the value in “Set angle to (degree)” box, the angle between search area and survey area will be changed accordingly

## Survey Area

Click the Select survey area button to launch the graphical tool which enables you to specify the data points that will be used in the inversion calculations.

## Search Volume

The default parameters in the **Search Volume** section will create a grid that covers the entire survey. You can modify the search area parameters by entering new values or by using the graphical tool

## Cell Sampling

Grid cells defined in **Search Volume** can be divided into smaller units when calculate the simulated data by clicking **Cell Sampling**. Type your values in the **X**, **Y** and **Z** boxes to specify the number of samples in the X, Y and Z directions

1. Import data
2. Examine data
3. Perform initial modeling
- 4. Perform 3D gravity inversions**
5. Check model and create plots

Grid Settings

Cells in X	Cells in Y	Cells in Z	Total
<input type="text" value="25"/>	<input type="text" value="77"/>	<input type="text" value="5"/>	<input type="text" value="9625"/>
Spacing Z direction			
<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
	$\Delta$	$\Delta \cdot 2^{i-1}$	$\Delta_i$
<input type="button" value="Define"/>			
Top cell thickness (m)			<input type="text" value="130"/>

Edit the search grid cell thickness

Total thickness  Top Z

Total thickness after modification

Search grid cell thickness

Index	Thickness	Depth
1	130.0000	-130.0000
2	130.0000	-260.0000
3	130.0000	-390.0000
4	130.0000	-520.0000
5	130.0000	-650.0000

Thickness (m)  Insert Index

Note: Multiple thickness items can be selected.

### Grid Settings

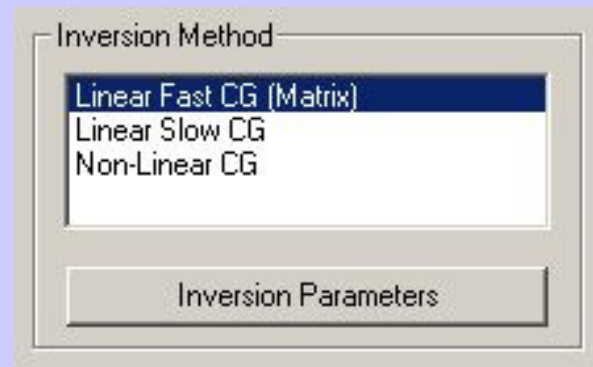
Confirm the number and layout of grid points to be used in the inversion in the **Grid Settings** area. The points will be evenly spaced in the x and y directions. Choose  $\Delta$  for evenly spaced points in the z direction or  $\Delta \cdot 2^{i-1}$  for exponentially spaced points. You may specify a custom spacing by selecting  $\Delta_i$ . Your custom settings can be later modified by clicking **Define**.

### Editing the Grid Cell Thickness

The interface displays the total thicknesses before and after editing as well as the topmost z value. The cell sizes are listed in the **Search grid cell thickness** section.

1. Import data
2. Examine data
3. Perform initial modeling
- 4. Perform 3D gravity inversions**
5. Check model and create plots

## Inversion Methods



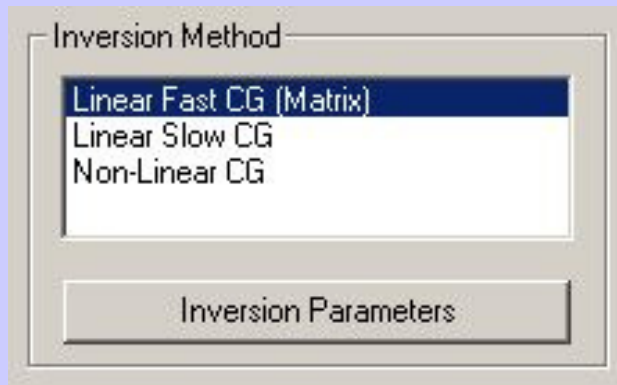
There are three inversion methods to choose from. Set parameters for your chosen technique by clicking the Inversion Parameters button.

**Linear Fast CG(Matrix)** - Direct inversion technique that assumes that the forward function can be linearized. Quick technique but is bounded by solving for a small amount of parameters.

**Linear Slow CG** - Same as the fast technique but is necessary for cases when the number of data points or the number of grid cells is very large.

**Non-Linear CG** - General concept is to start with an initial guess and go looking for the best fitting model by minimizing a given function using an iteration process.

1. Import data
2. Examine data
3. Perform initial modeling
- 4. Perform 3D gravity inversions**
5. Check model and create plots



## Linear CG Technique

Assumes that the forward function can be linearized. Quick technique but is bounded by solving for a small amount of parameters.

$$\mathbf{d} = \mathbf{F} \mathbf{m}$$

$\mathbf{d} \rightarrow$  vector of  $N$ - dimension

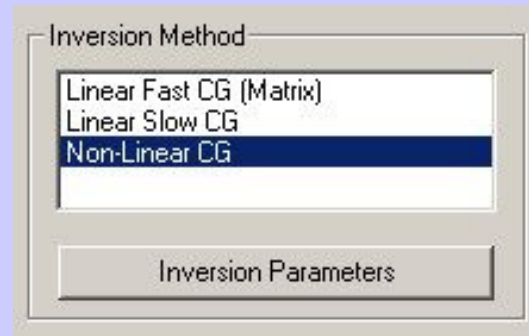
$\mathbf{F} \rightarrow$  Matrix of  $N \times M$ - dimension

$\mathbf{m} \rightarrow$  vector of  $M$ - dimension

$$H_{\text{ext}}(r) = \int G(r, r') J(r') dr'$$

$$J(r') = (m(r') - m_0) H_{\text{ins}}(r') = \chi(r') H_{\text{ins}}(r')$$

1. Import data
2. Examine data
3. Perform initial modeling
- 4. Perform 3D gravity inversions**
5. Check model and create plots



## Non-Linear CG General

concept is to start with an initial guess and go looking for the best fitting model by minimizing a given function using an iteration process.

## Unconstrained Conjugate Gradient Minimization

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.

$$\phi(\mathbf{m}) = \lambda \phi_d(\mathbf{m}) + \phi_m(\mathbf{m})$$

$\phi(\mathbf{m})$  - functional to be minimized

$\phi_d(\mathbf{m})$  - data misfit

$\phi_m(\mathbf{m})$  - model misfit

$\lambda$  - Lagrangian multiplier - regularization weight

Critical factors to Optimization Results:

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

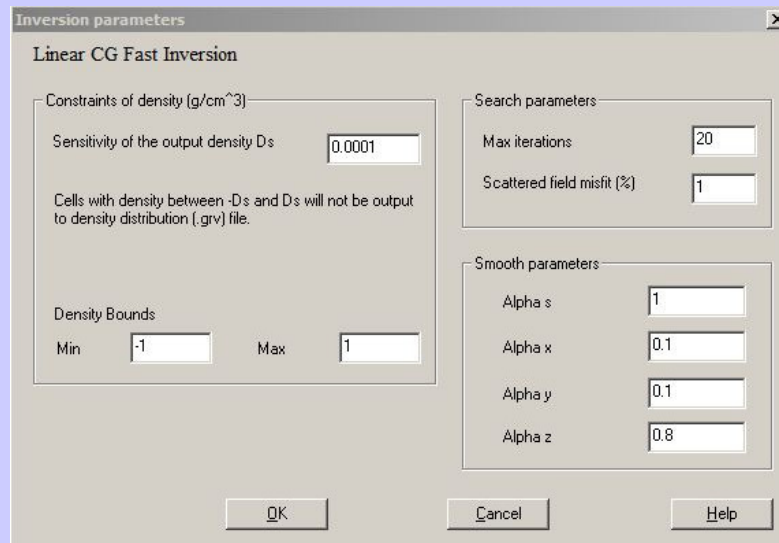
## Occam style model misfit function

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

$\alpha_i$  - weighting factors

$w(z)$  - depth weighting

1. Import data
2. Examine data
3. Perform initial modeling
- 4. Perform 3D gravity inversions**
5. Check model and create plots



## Constraint of Density

**Output Sensitivity** Cells with density  $|D|$  (close to 0 - where the user defines how close) are constrained or thrown out after each iteration. will not be output to the density distribution (.grv) files

**Xmin** Upon completion of iteration, X values less than Xmin will be set equal to Xmin

**Xmax** Upon completion of iteration, X values greater than Xmax will be set equal to Xmax

## Search Parameters

### Maximum Iterations

User defines the number of iterations the program will run to generate the final solution. In general the default (25 for Linear Fast CG and about 15 for the others) is sufficient for the inversion.

### Scattered field misfit

Defines the “stop” criteria for an iteration when the difference between the measured and simulated scattered field 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 range of all 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.



## Initial Model

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

The starting model is described by a list of prisms with various properties in the box labelled **Starting anomaly list**.

**Build/Modify a model**

Size (m)		Center (m)		Angle (degree)			Density (g/cm <sup>3</sup> )
X	14000	X	588500	1st	0		3
Y	7400	Y	6471100	2nd	0		
Z	3000	Z	-1500	3rd	0		

Buttons: Set size to all selected prisms, Set angles to all selected prisms, Set density to all selected prisms, Add a prism, Import a model, Delete all selected prisms

**Initial Model**

#	Density [g/cm <sup>3</sup> ]	1st Angle [degree]	2nd Angle [degree]	3rd Angle [degree]	Size X [m]	Size Y [m]	Size Z [m]
There are no items to show in this view.							

Note: To modify a property of an individual prism in the list, directly double-click it, then input a new value.

Buttons: OK, Cancel, Help

1. Import data
2. Examine data
3. Perform initial modeling
4. Perform 3D gravity inversions
5. Check model and create plots

## add a prism to the model list

Specify the density, size, position and orientation of the new prism in the **Build/Modify a prism** section. Click the **Add a prism** button.

## modify an existing prism in the model list

Select the number of the prism to be modified in the anomaly list. The prism number is in the first column. Specify the new prism parameters and click the **Modify a prism** button.

## apply the same values for a group of selected prisms

Click the **Set density to all selected prisms** button to modify the density. Click the **Set angles to all selected prisms** button to modify the angles. Click the **Set size to all selected prisms** button to modify the size.

## delete prisms from the model list

Select the prisms to be deleted in the anomaly list. Click **Delete all selected prisms**

## import a model from another data set in the current database

Click **Import a model**. Select the project, survey, and data set with the desired model. Click **OK** and the model will appear in the **Starting anomaly list**

# Gravity Inverse 17

1. Import data
2. Examine data
3. Perform initial modeling
- 4. Perform 3D gravity inversions**
5. Check model and create plots

The screenshot shows the 'Gravity Inversion' software interface. The window title is 'Gravity Inversion'. It contains several sections for configuring the inversion process.

**Selected dataset(s) to do inversion:**

#	Dataset	Survey	Project
1	Processed	Ground Gravity	GroundGravity

**Component List:**

#	Receiver
<input checked="" type="checkbox"/> 1	Gz

**Survey area information:**

Item	Value
Center X (m)	588500.0000
Center Y (m)	6471100.0000
Size X (m)	11700.000
Size Y (m)	6200.000
Horizontal Angle (Degree)	0.000
Average Distance Between Lines (m)	100.000
Average Distance Between Locations (m)	301.076

**Search Volume:**

Center X (m): 588500, Center Y (m): 6471100, Top Z (m): 0  
Size X (m): 14000, Size Y (m): 7400, Thickness (m): 3000  
Horizontal Angle (degree) Anti-clockwise from East: 0

**Grid Settings:**

Cells in X: 25, Cells in Y: 77, Cells in Z: 5, Total: 9625  
Spacing Z direction:  Δ,  Δ<sup>2</sup>,  Δ<sub>i</sub>, Top cell thickness (m): 600

**Inversion Method:** Linear Fast CG (Matrix), Linear Slow CG, Non-Linear CG

**Options:**

- Use Initial Model
- Use known geological structure
- Use topography information
- Remove Grid Cells

**Buttons:** Add, Weights, Remove, Inversion Parameters, Set Initial Model, Set Structure, Select Survey Area, Select Search Area, Cell Sampling, Define, Set Output Log File Name, Get Settings From a Log File, Run, Cancel, Help

**Progress:**  Close application when inversion completes

- After settings are done, press **Run** button to start the inversion process.

1. Import data
2. Examine data
3. Perform initial modeling
- 4. Perform 3D gravity inversions**
5. Check model and create plots

## Executing the Inversion

The screenshot shows the Gravity Inversion software interface. It includes several sections:

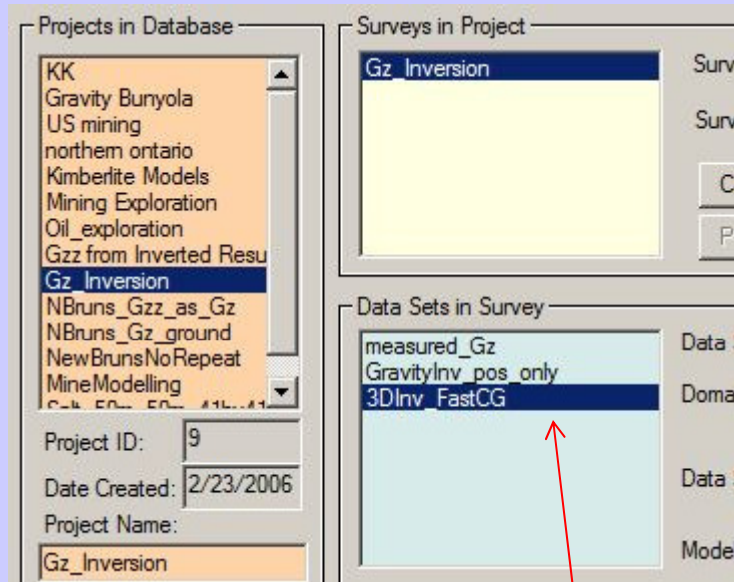
- Selected dataset(s) to do inversion:** A table with columns #, Dataset, Survey, and Project. Row 1: 1, measured\_Gz, Gz Inversion, Gz Inversion.
- Component List:** A table with columns #, Receiver. Row 1: 1, Gz.
- Survey area information:** A table with columns Item, Value. Items include Center X (m), Center Y (m), Size X (m), Size Y (m), Horizontal Angle (Degree), Average Distance Between Lines (m), and Average Distance Between Locations (m).
- Search Volume:** Input fields for Center X (m), Center Y (m), Top Z (m), Size X (m), Size Y (m), and Thickness (m).
- Grid Settings:** Input fields for Cells in X, Cells in Y, Cells in Z, Total, Spacing Z direction, and Top cell thickness (m).
- Inversion Method:** A list box with options: Linear Fast CG (Matrix), Linear Slow CG, and Non-Linear CG.
- Inversion Message:** A scrollable text area showing progress metrics like Data Misfit, Least Squares Misfit, and Iteration numbers.
- Progress:** A horizontal progress bar at the bottom.

The right window (in white) shows each data point's progress.

The "Progress" bar shows the total progress of this inversion.

1. Import data
2. Examine data
3. Perform initial modeling
4. Perform 3D gravity inversions
- 5. Check model and create plots**

## Inversion Evaluation



In each survey, there will be several data sets after modeling, inversion and processing. In this case, we have one half space model and one 3D inversion model. Each 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.

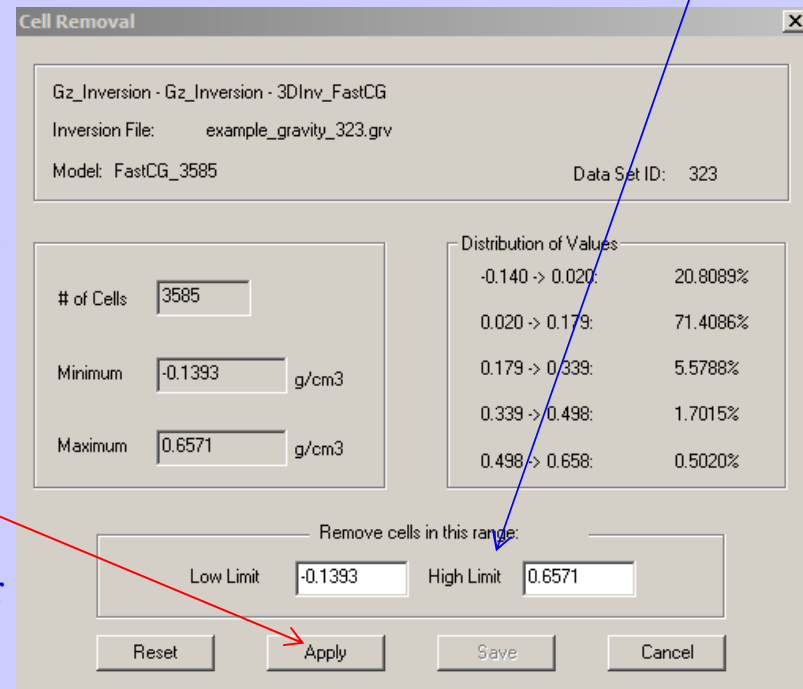
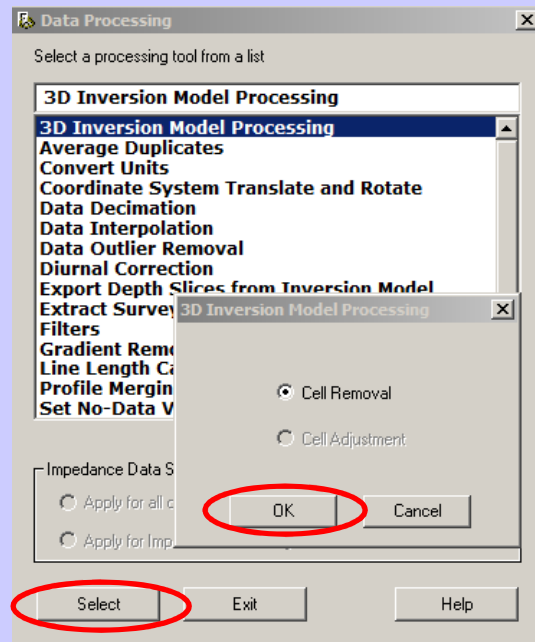
Our 3D gravity inversion model dataset

1. Import data
2. Examine data
3. Perform initial modeling
4. Perform 3D gravity inversions
5. Check model and create plots

## Inversion Evaluation



Users can use “3D Inversion Model Processing” tool to remove cells in inverted model. Follow the routine shown in this page and arrive “Cell Removal” dialog. Choose the removal range of cells: “Low Limit” and “High Limit” (any cell within this range will be removed)



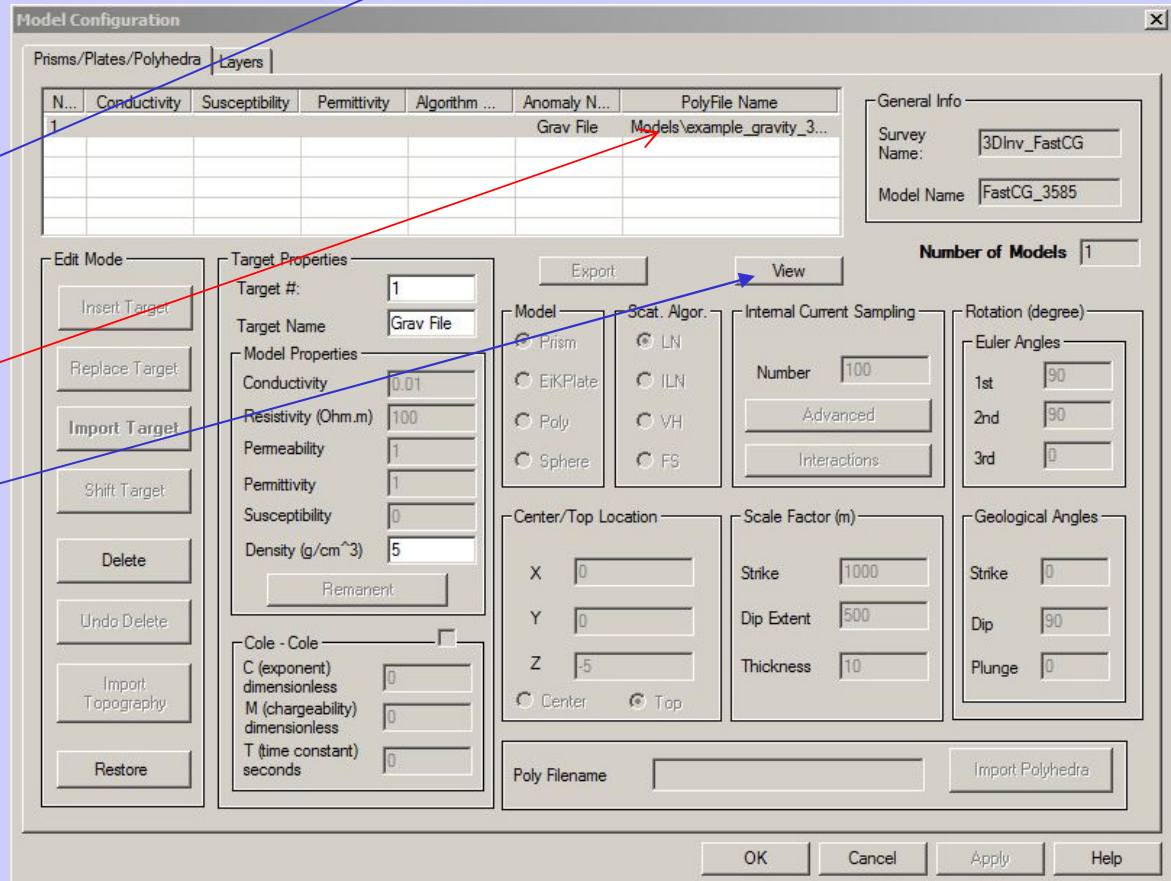
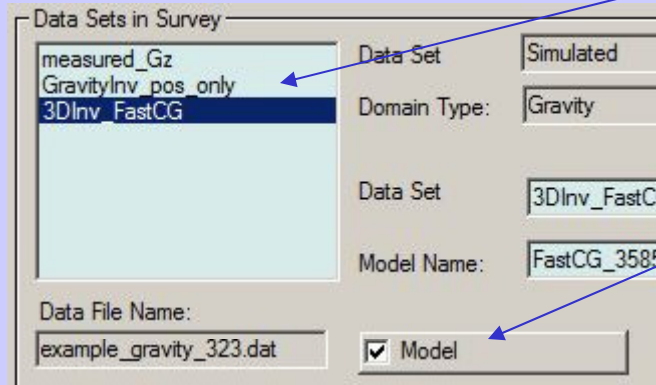
Click “Apply” button when it is done

Therefore, users can reduce the range of model either before inversion (by Select Search Area) or after inversion (by Cell Removal)

Inversion Evaluation

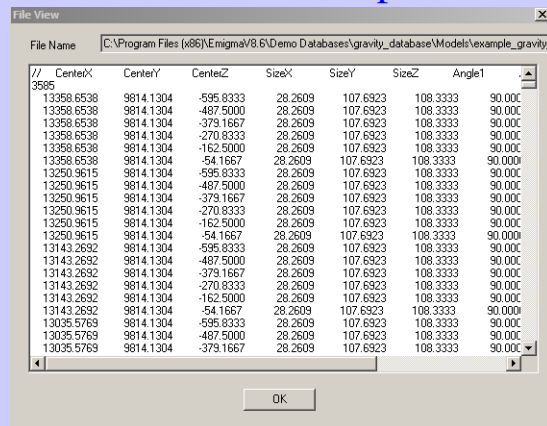
1. Import data
2. Examine data
3. Perform initial modeling
4. Perform 3D gravity inversions
5. Check model and create plots

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



The model will be saved as a “Grav File” with its name and folder shown in the “PolyFile Name” column of the table

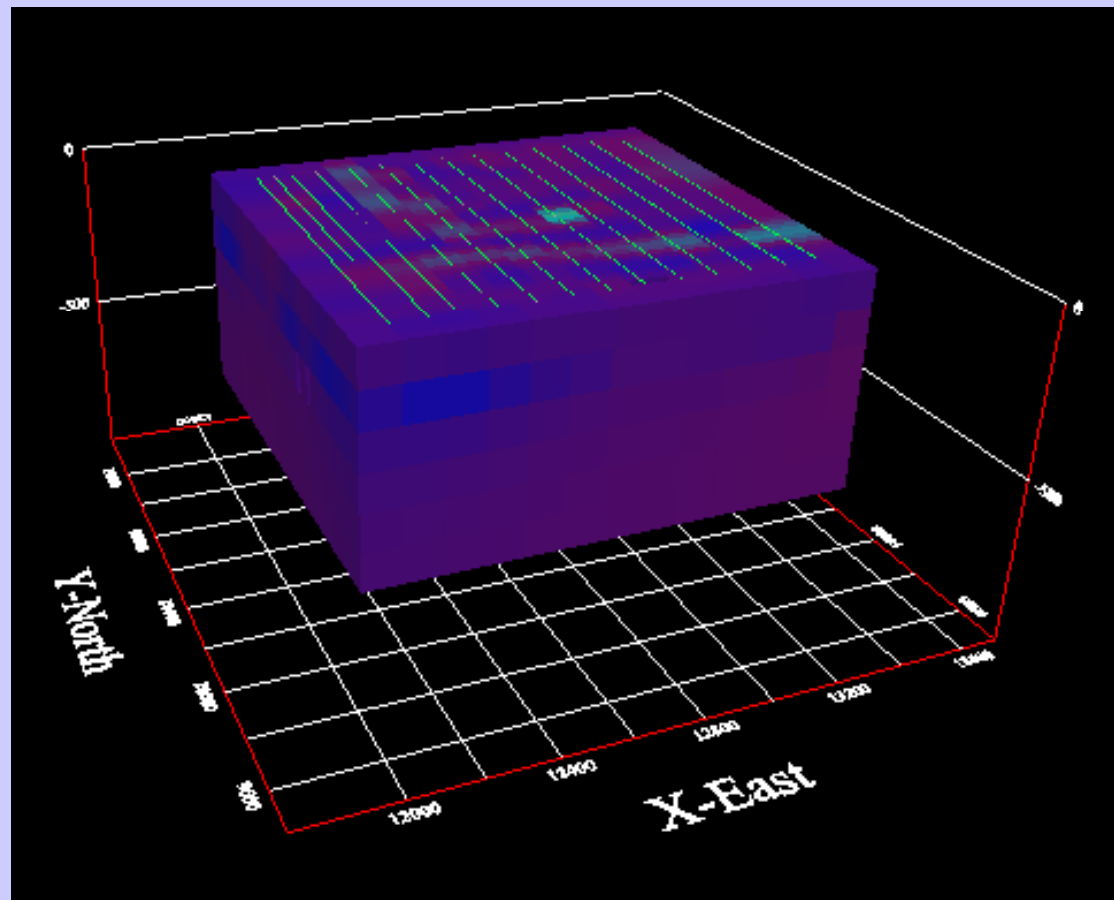
Click “View” button to open this file...



1. Import data
2. Examine data
3. Perform initial modeling
4. Perform 3D gravity inversions
- 5. Check model and create plots**

## Inversion Evaluation

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





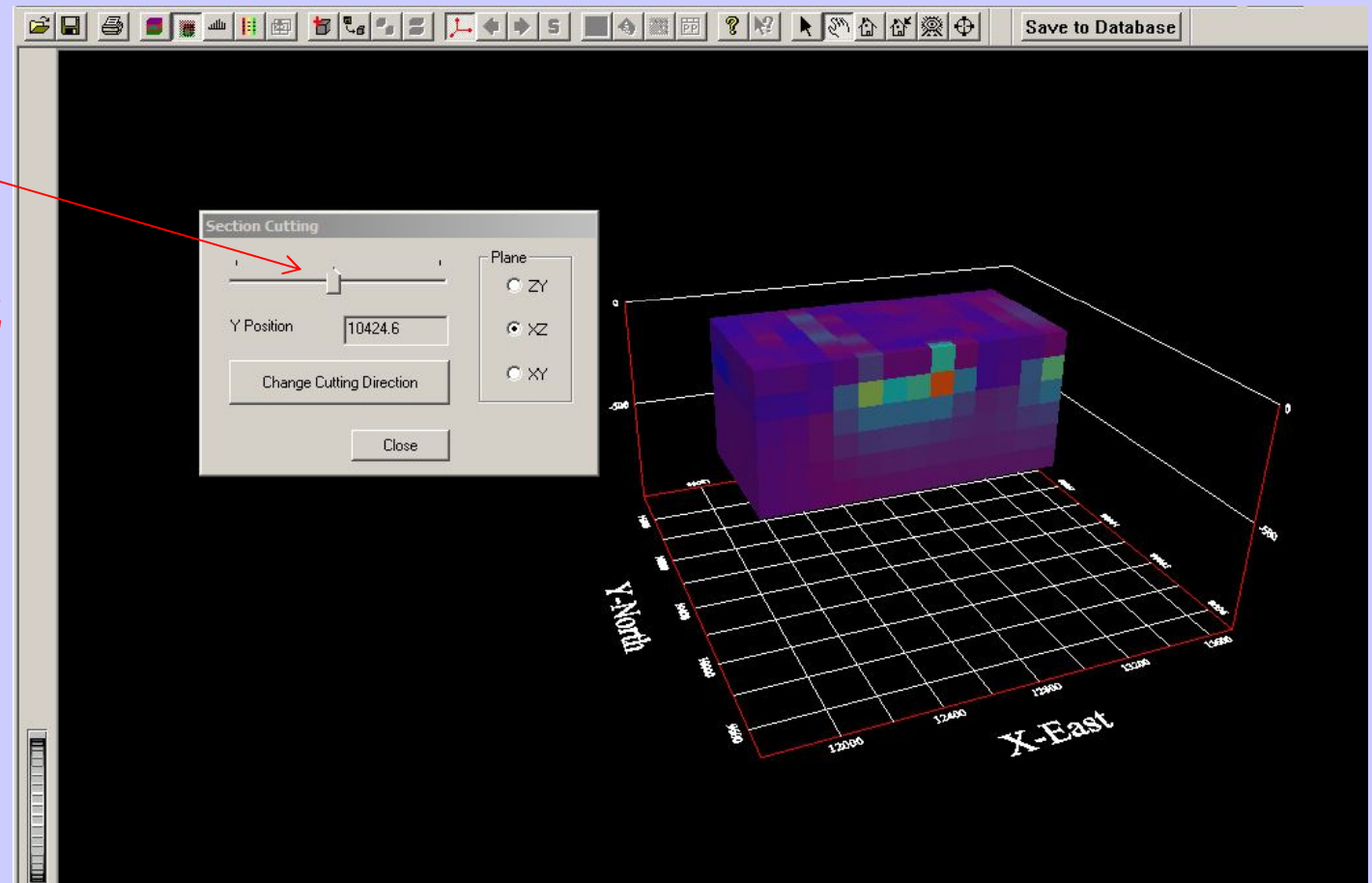
## Inversion Evaluation

1. Import data
2. Examine data
3. Perform initial modeling
4. Perform 3D gravity inversions
- 5. Check model and create plots**

Select from menu “Model -> Mag/Grv/Res File -> mag/grv/res Cutting” to open the Section Cutting tool.

By adjusting the bar...

User can view sections of the 3D model from XY, XZ and ZY planes with any penetration depth



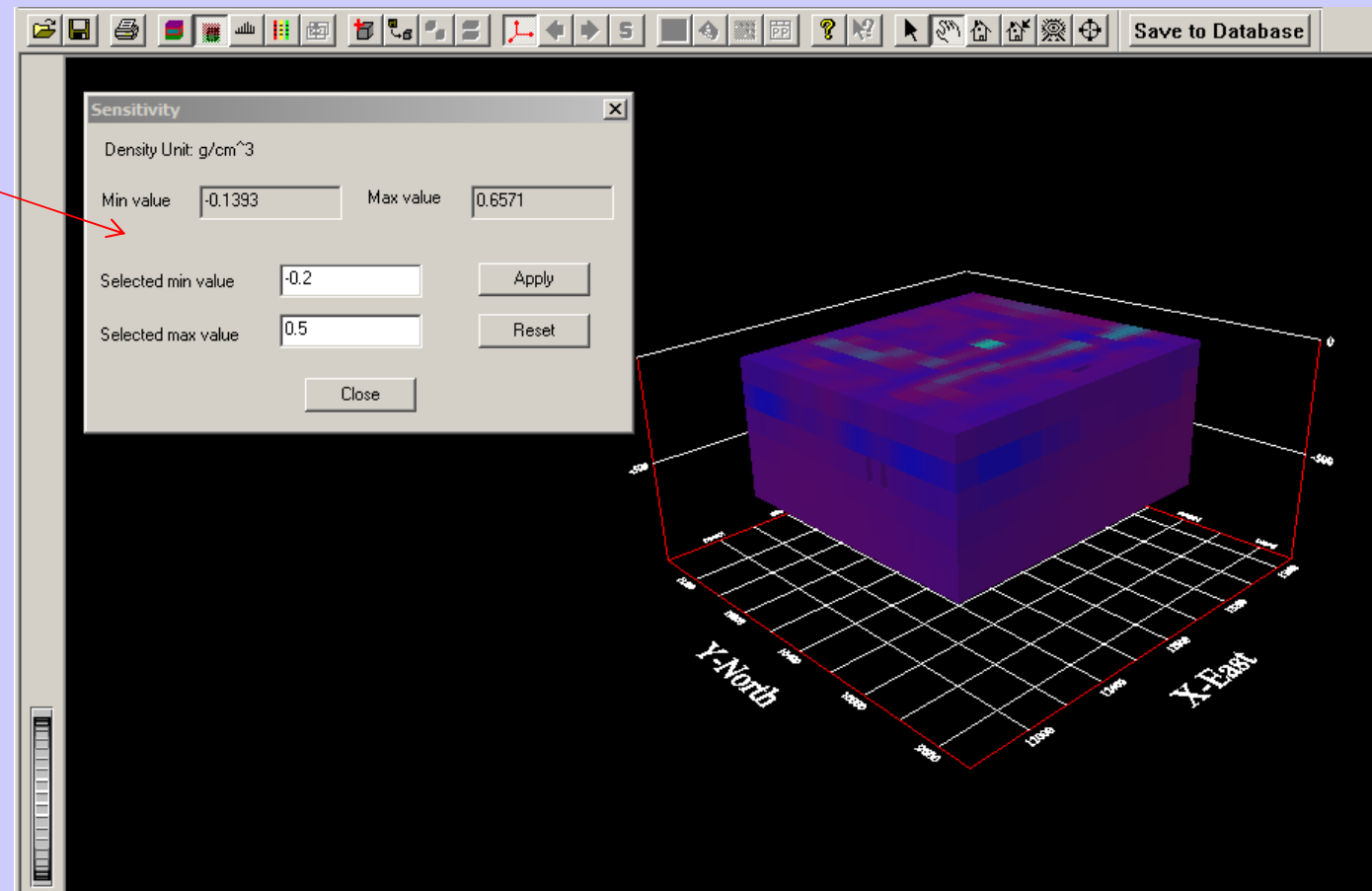
## Inversion Evaluation

1. Import data
2. Examine data
3. Perform initial modeling
4. Perform 3D gravity inversions
- 5. Check model and create plots**

Select from menu “Model -> Mag/Grv/Res File -> Sensitivity” to open the Section Cutting tool.

By adjusting minimum value and maximum value shown in the figure...

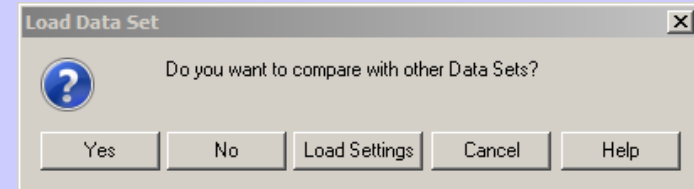
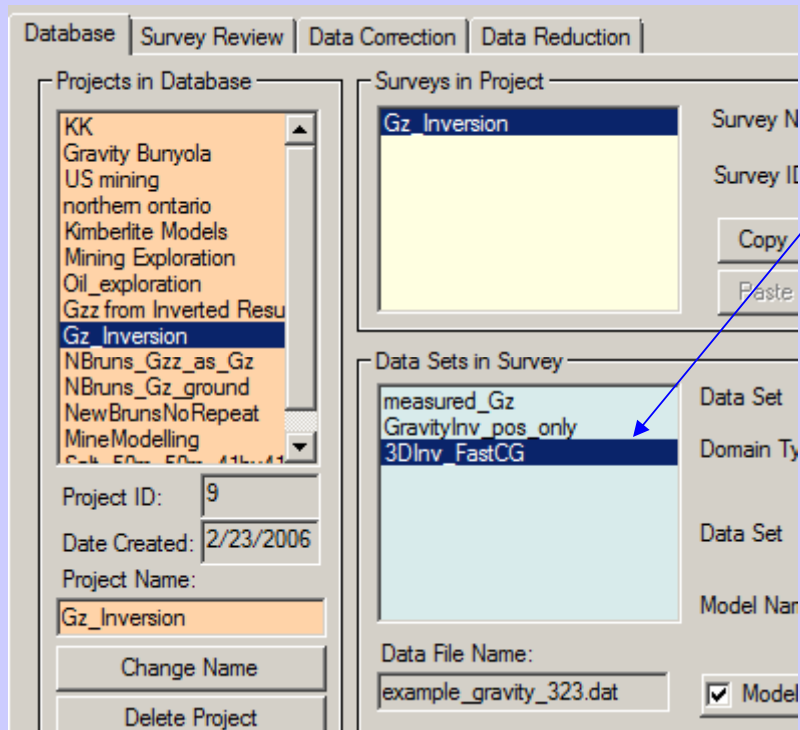
The model in this figure will only exhibit cells with values specified in this range



1. Import data
2. Examine data
3. Perform initial modeling
4. Perform 3D gravity inversions
- 5. Check model and create plots**

## Inversion Evaluation

To assess the success of the inversion, select the measured data and then select the plotter.



Select "Yes", if this dialog is appeared

1. Import data
2. Examine data
3. Perform initial modeling
4. Perform 3D gravity inversions
- 5. Check model and create plots**

## Inversion Evaluation

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

Survey Selection

Project: Gz\_Inversion      Survey: Gz\_Inversion

Data Sets in Survey:       Selected Data Sets to plot:

Name	Model Name	Type
GravityInv_pos_only	GravInv_20954	S

Data Units: mGal

Name	Model Name	Type
3DInv_FastCG	FastCG_3585	S
measured_Gz		M

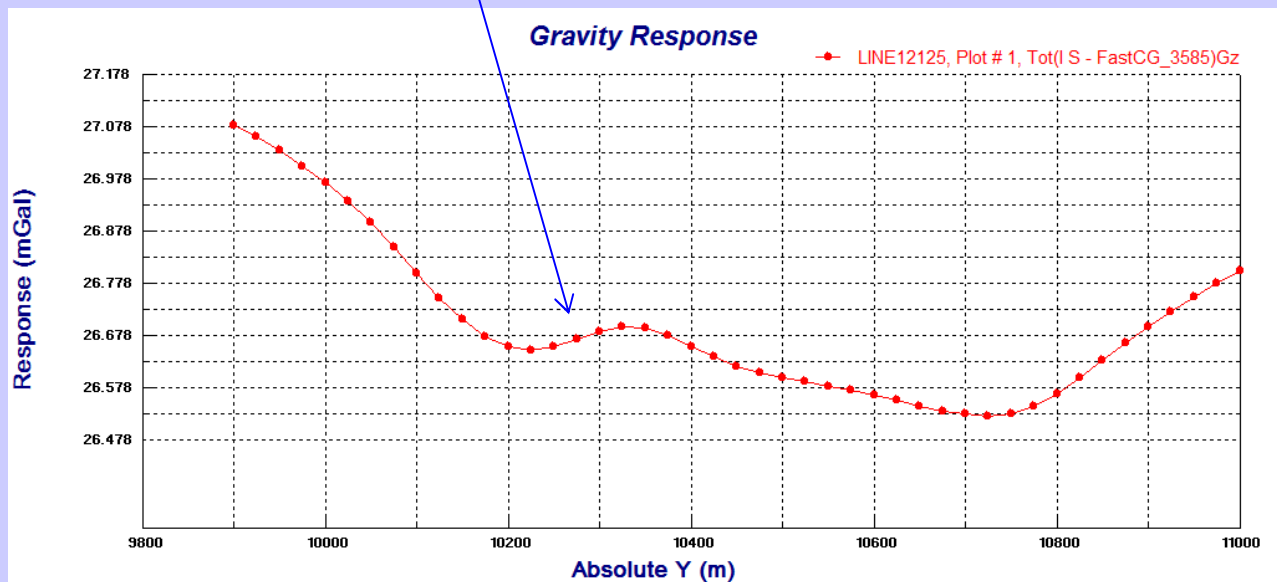
Show IMPEDANCE Data Sets in Survey

Loading:

Loaded  of

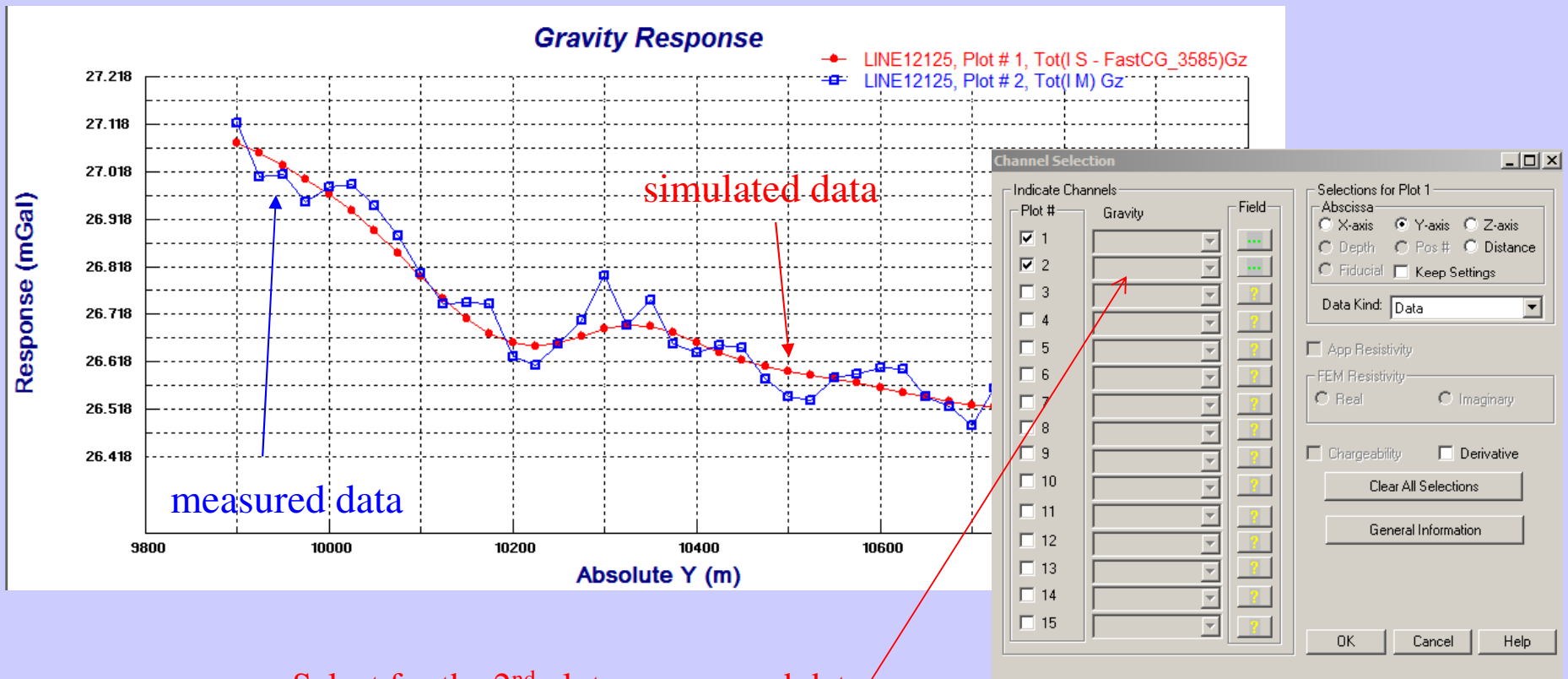
All selected data sets are then loaded to the Plotter application and the plot appears showing the simulated data of the first profile.



## Inversion Evaluation

1. Import data
2. Examine data
3. Perform initial modeling
4. Perform 3D gravity inversions
5. Check model and create plots

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



1. Import data
2. Examine data
3. Perform initial modeling
4. Perform 3D gravity inversions
- 5. Check model and create plots**

## Inversion Evaluation

Gravity Inverse  
28

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

