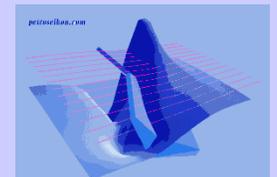


3D GRAVITY INVERSION TUTORIAL

Gravity Inverse
1

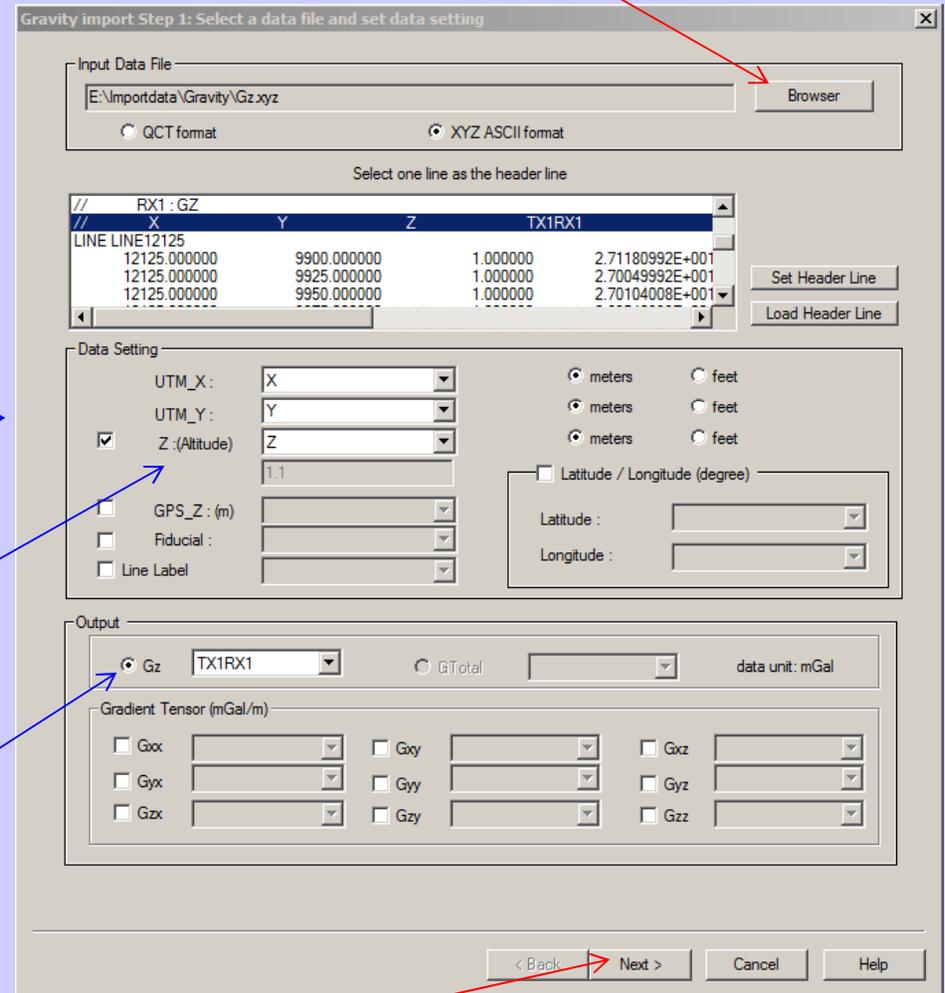
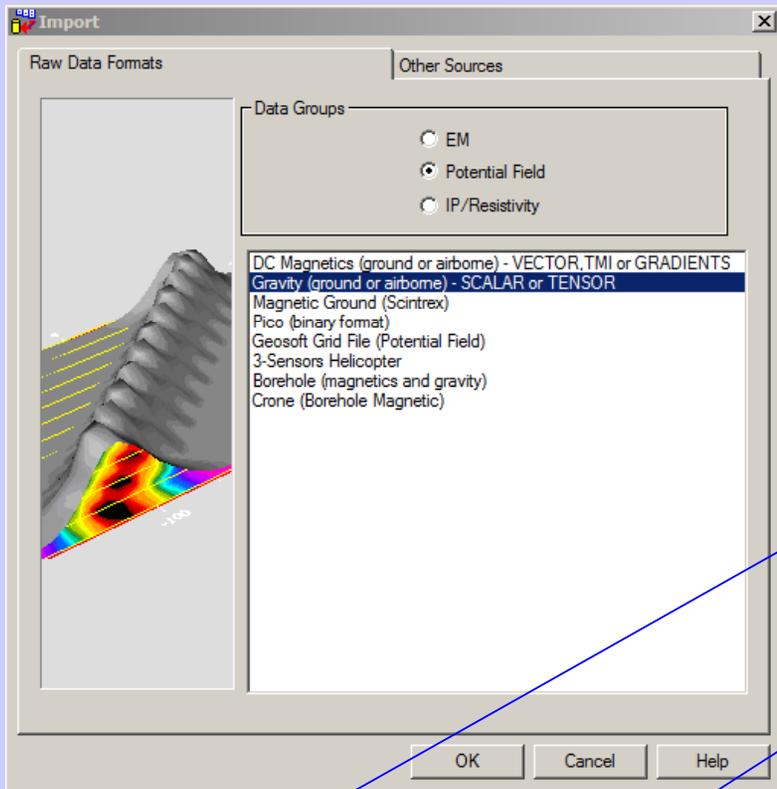
Steps:

	<i>Page</i>
1. Import data to new or existing database	2
2. Examine data	5
3. Perform initial forward modeling	7
4. Perform 3D gravity inversions	8
5. Check mode and create plots	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 shows "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 are two main control panels:

- Modify Profile(s):** Includes 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.
- Shift Coordinate Values:** Includes "Shift X" and "Shift Y" spinners both set to "0", with "Reset" and "Change" buttons respectively.

At the bottom of the dialog are four buttons: "< Back", "Next >", "Cancel", and "Help". 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

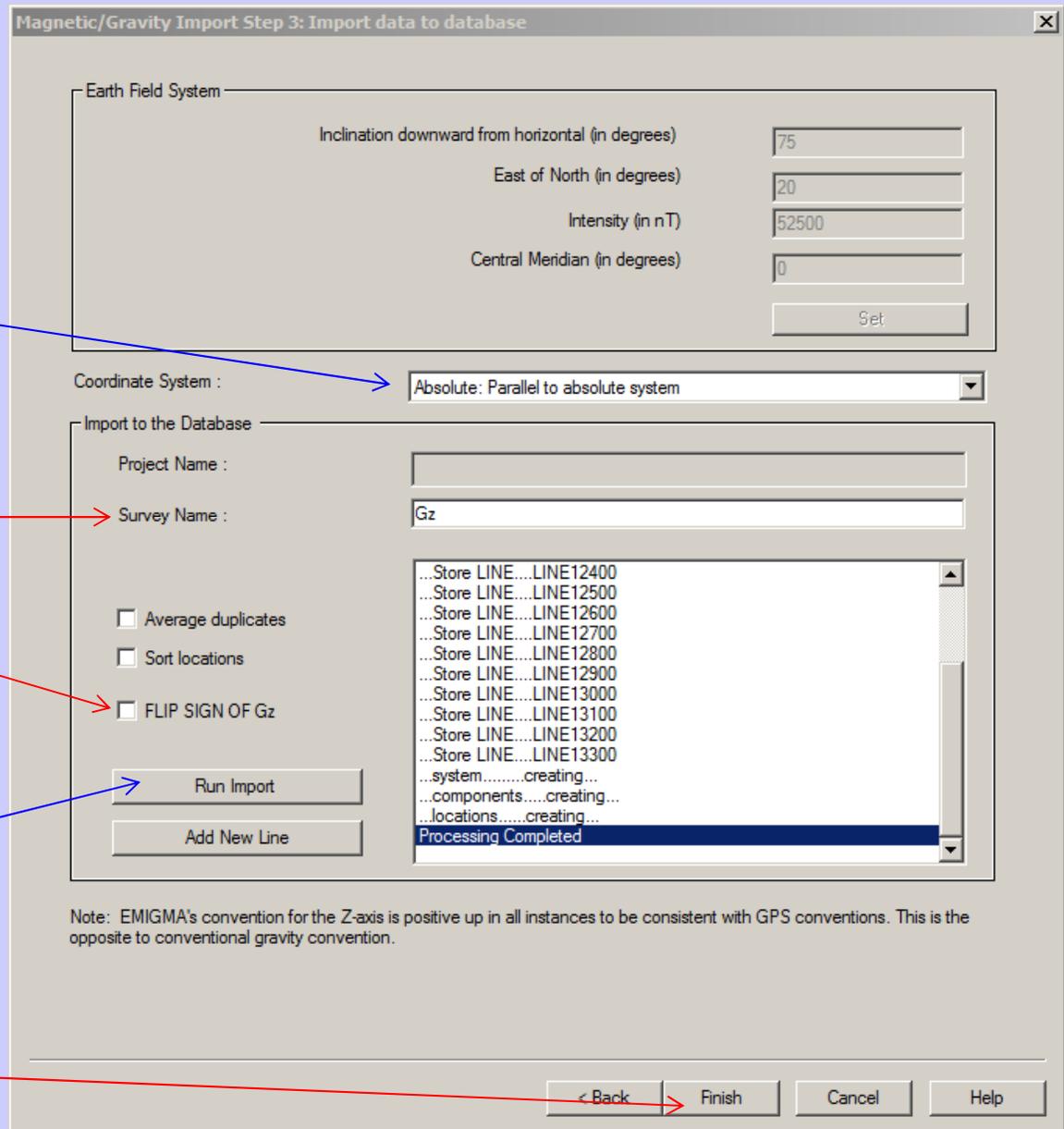
Select coordinate system

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

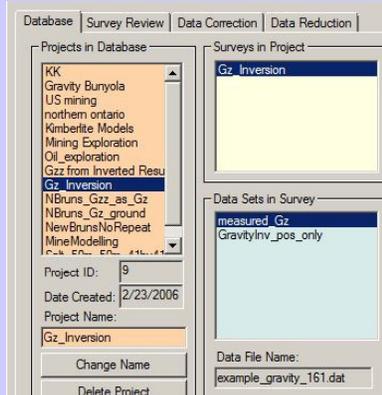
After processing is done, click "Finish" button to complete this procedure



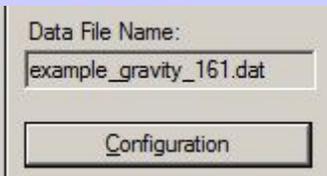
Gravity Inverse 5

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

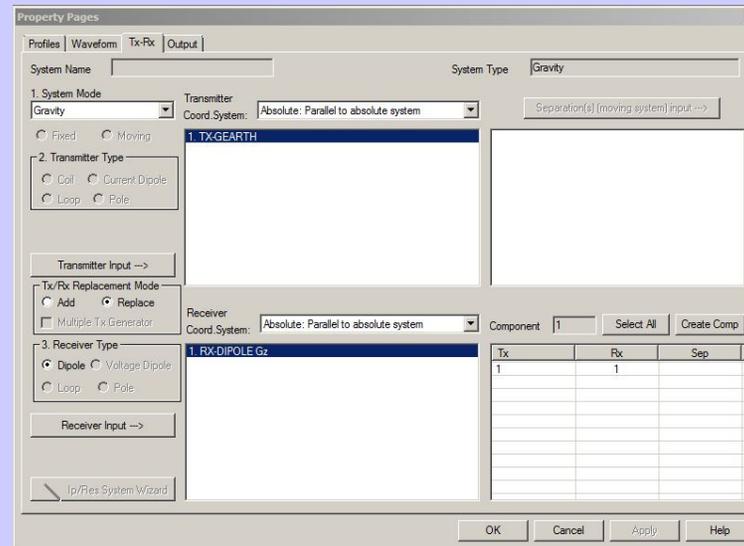
1. Check database for the survey



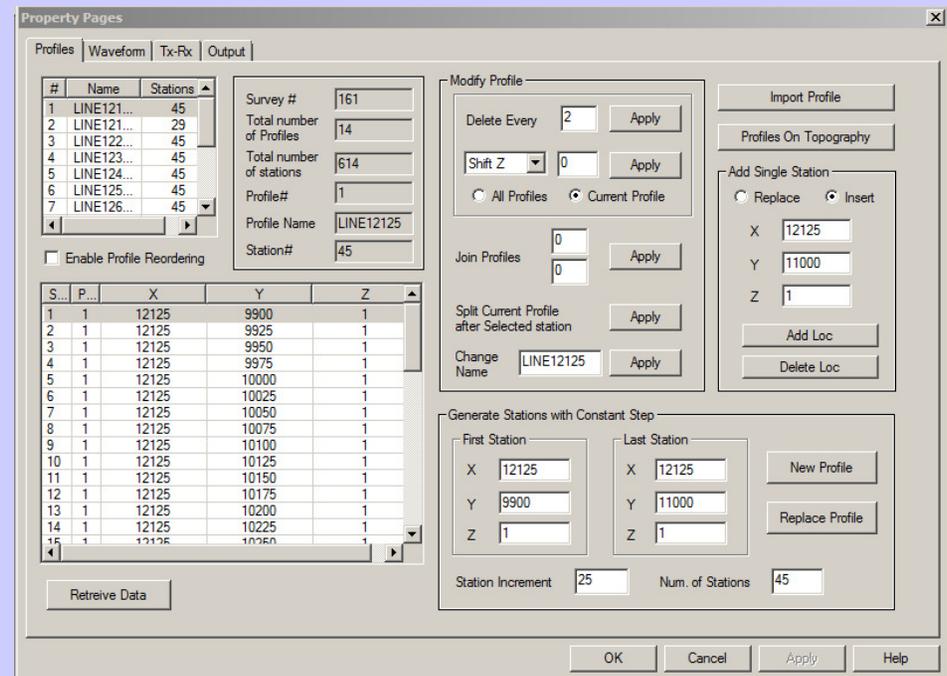
2. Click configuration



4. Check lines and stations are correct



3. Check system configuration



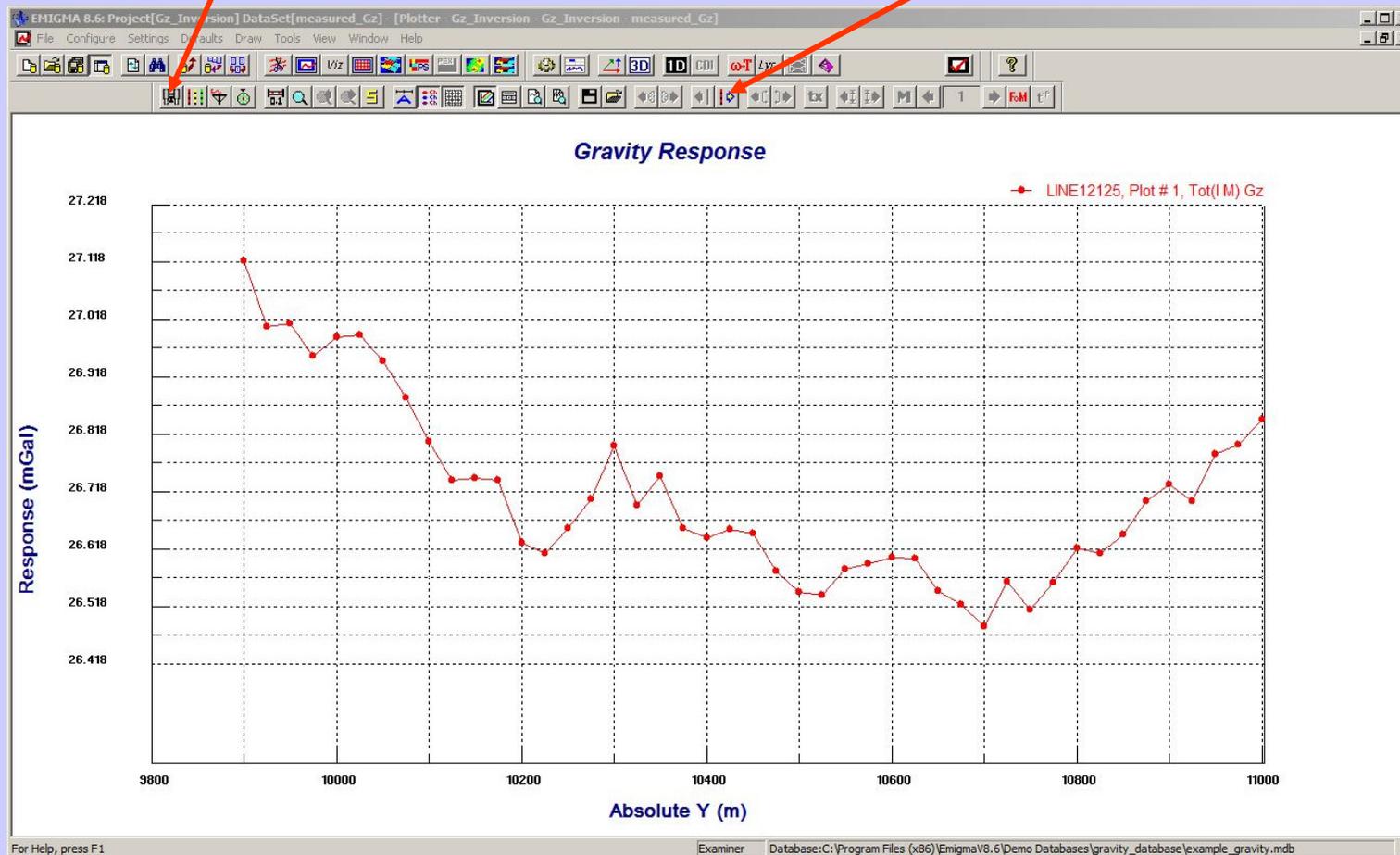
1. Import data
- 2. Examine data**
3. Perform initial modeling
4. Perform 3D gravity inversions
5. Check model and create plots



Click "Plotter"...

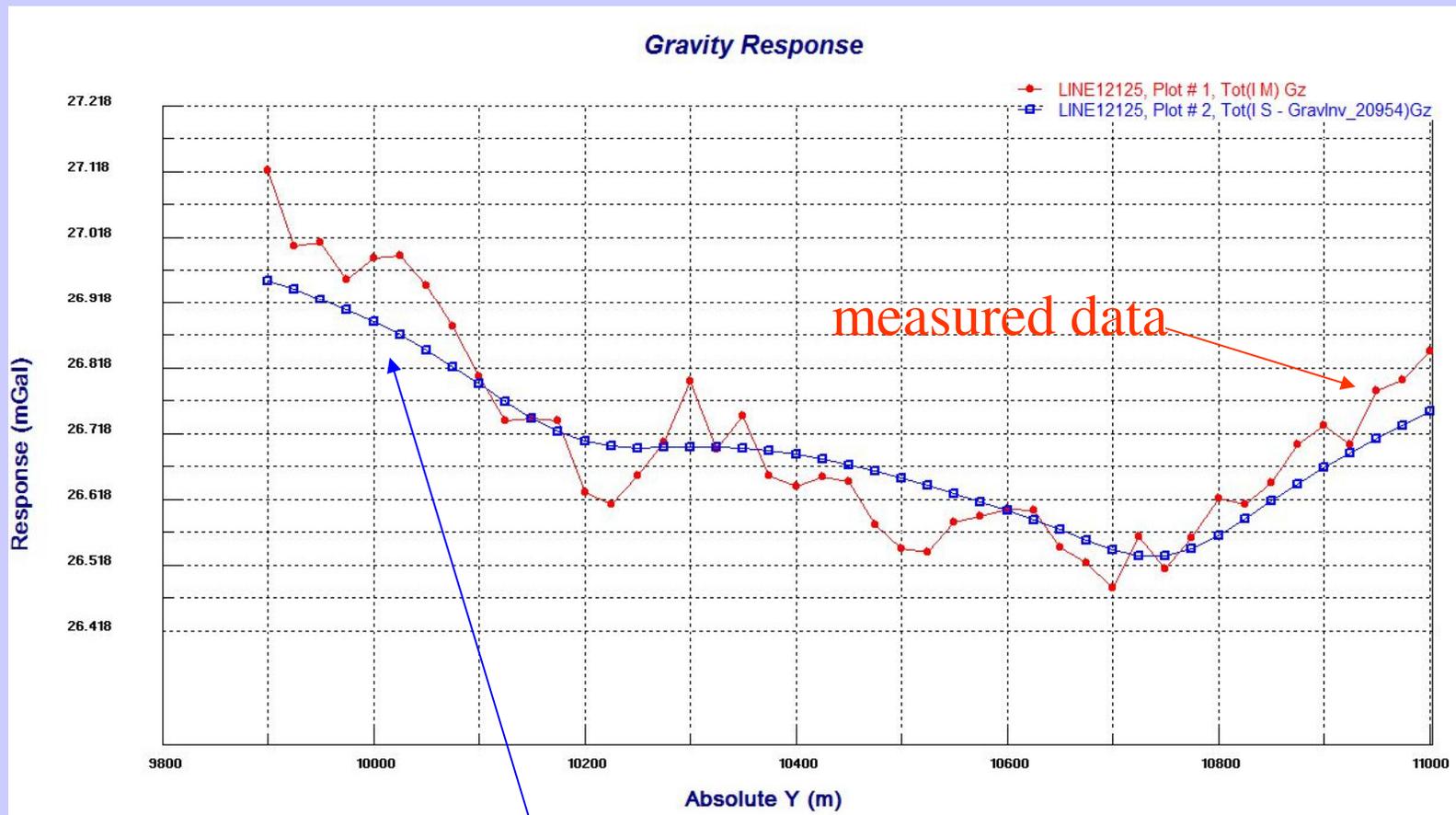
Load data set in plotter

Toggle between profiles



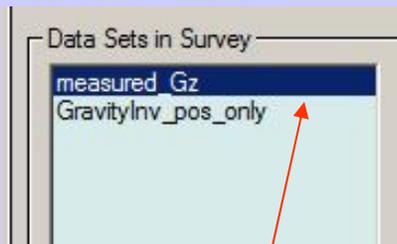
1. Import data
2. Examine data
- 3. Perform initial modeling**
4. Perform 3D gravity inversions
5. Check model and create plots

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

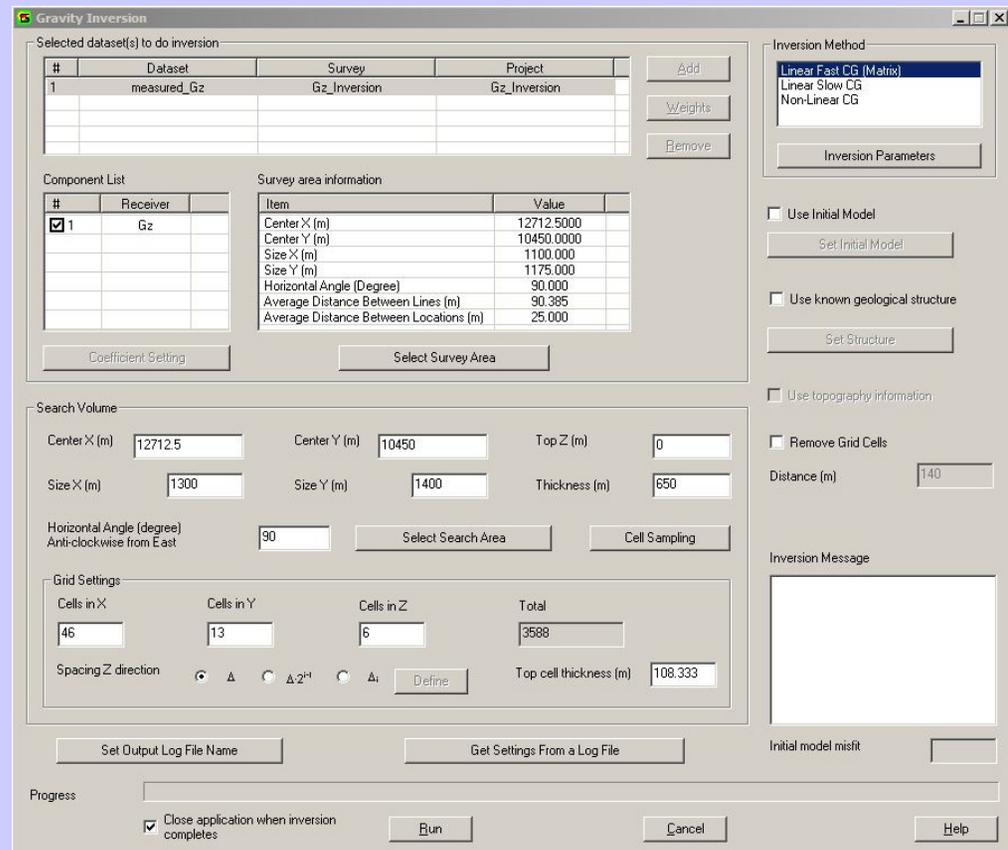
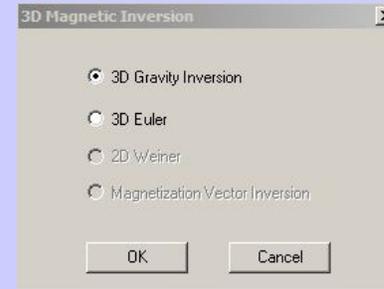


Gravity Inverse 8

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

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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

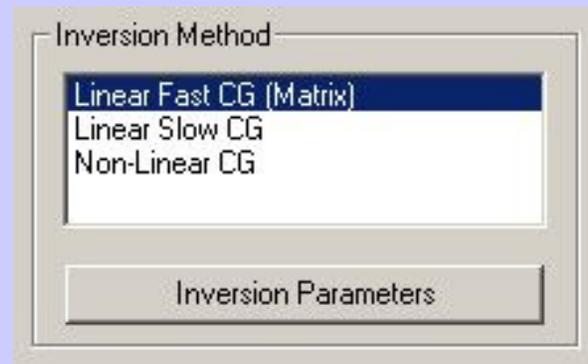
The default parameters in the **Search Volume** section will create a grid that covers the entire survey. You can modify the search area parameters by entering new values or by using the graphical tool

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

Inversion Methods



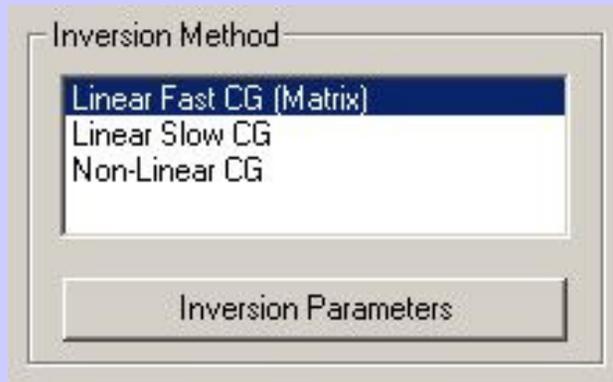
There are three inversion methods to choose from. Set parameters for your chosen technique by clicking the Inversion Parameters button.

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

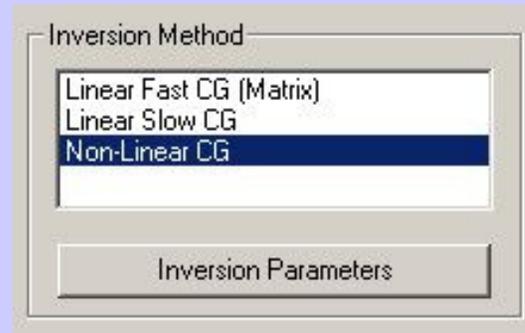
$\mathbf{F} \rightarrow$ Matrix of $N \times M$ - dimension

$\mathbf{m} \rightarrow$ 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

λ - Lagrangian multiplier - regularization weight

Critical factors to Optimization Results:

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

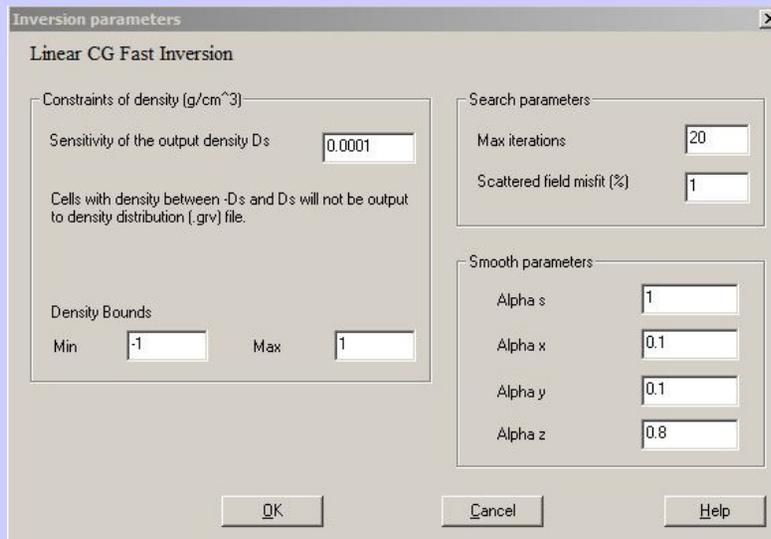
Occam style model misfit function

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

α_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 ³)
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 ³]	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. It features several sections for configuring the inversion process:

- Selected dataset(s) to do inversion:** A table with columns for '#', 'Dataset', 'Survey', and 'Project'. It contains one entry: '# 1', 'Dataset: Processed', 'Survey: Ground Gravity', 'Project: GroundGravity'.
- Component List:** A table with columns for '#', 'Receiver', and 'Value'. It contains one entry: '# 1', 'Receiver: Gz'.
- Survey area information:** A table with columns for 'Item' and 'Value'. It contains several entries: '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', and 'Average Distance Between Locations (m): 301.076'.
- Search Volume:** Input fields for 'Center X (m): 588500', 'Center Y (m): 6471100', 'Top Z (m): 0', 'Size X (m): 14000', 'Size Y (m): 7400', and 'Thickness (m): 3000'. It also includes a 'Horizontal Angle (degree) Anti-clockwise from East' field set to 0.
- Grid Settings:** Input fields for 'Cells in X: 25', 'Cells in Y: 77', 'Cells in Z: 5', and 'Total: 9625'. It also includes a 'Spacing Z direction' section with radio buttons and a 'Top cell thickness (m): 600' field.
- Inversion Method:** A dropdown menu with options: 'Linear Fast CG (Matrix)', 'Linear Slow CG', and 'Non-Linear CG'. Below it is an 'Inversion Parameters' button.
- Options:** Checkboxes for 'Use Initial Model', 'Use known geological structure', 'Use topography information', and 'Remove Grid Cells'. There is also a 'Distance (m): 840' field.
- Buttons:** 'Add', 'Weights', 'Remove', 'Coefficient Setting', 'Select Survey Area', 'Set Initial Model', 'Set Structure', 'Select Search Area', 'Cell Sampling', 'Set Output Log File Name', 'Get Settings From a Log File', 'Run', 'Cancel', and 'Help'.
- Progress:** A progress bar and a checkbox for '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 a table for selected datasets, component lists, search volume parameters, grid settings, and an inversion message log. A progress bar at the bottom indicates the current status of the inversion process.

#	Dataset	Survey	Project
1	measured_Gz	Gz Inversion	Gz Inversion

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

Item	Value
Center X (m)	12712.5000
Center Y (m)	10450.0000
Size X (m)	1100.000
Size Y (m)	1175.000
Horizontal Angle (Degree)	90.000
Average Distance Between Lines (m)	90.385
Average Distance Between Locations (m)	25.000

Center X (m)	Center Y (m)	Top Z (m)
12712.5	10450	0

Size X (m)	Size Y (m)	Thickness (m)
1300	1400	650

Cells in X	Cells in Y	Cells in Z	Total
46	13	6	3588

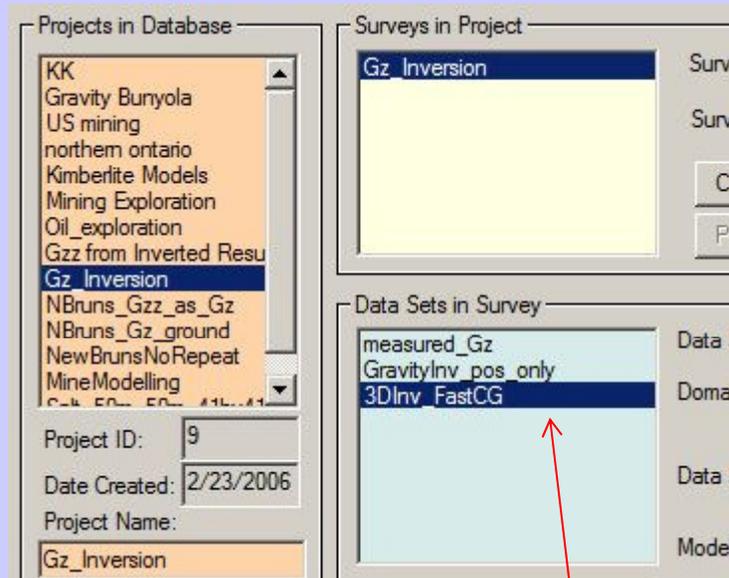
Iteration	Data Misfit	Least Squares Misfit
Iteration 19	4.37%	3.4404
Iteration 20	4.28%	3.3324
Iteration 20	4.21%	3.2243

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.

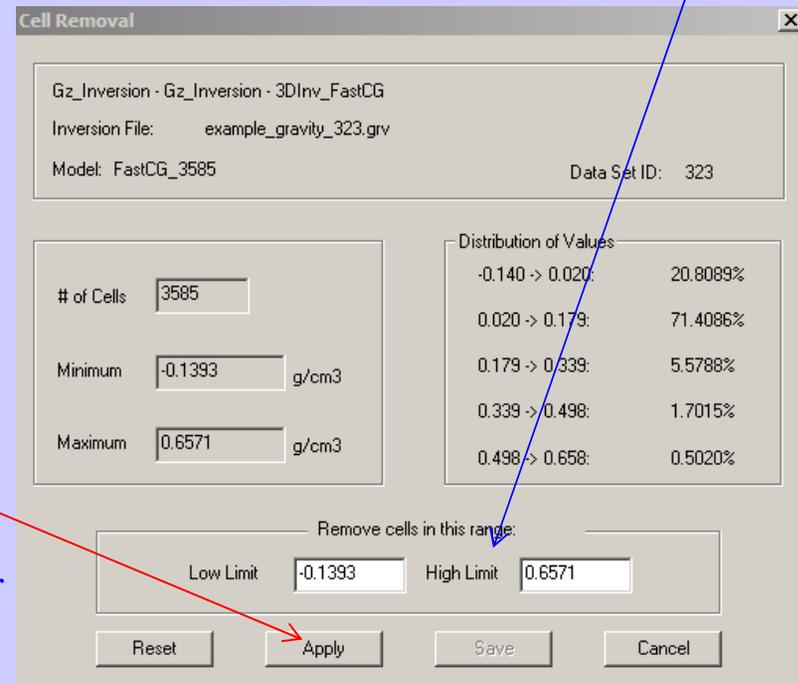
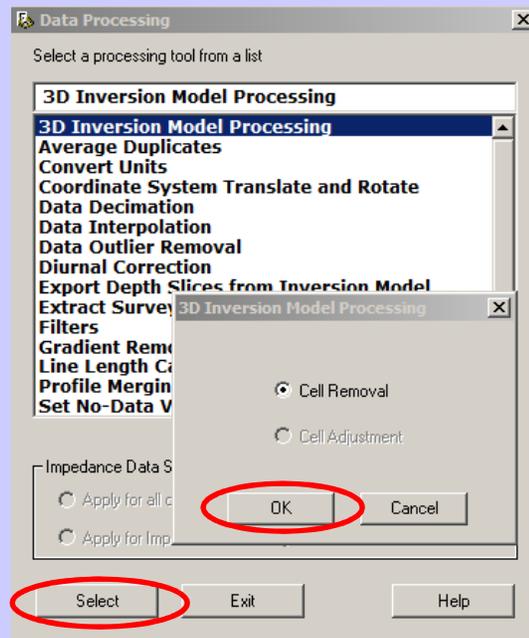
Our 3D gravity inversion model dataset

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

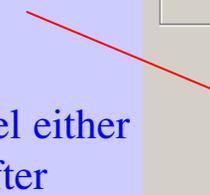
Inversion Evaluation



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

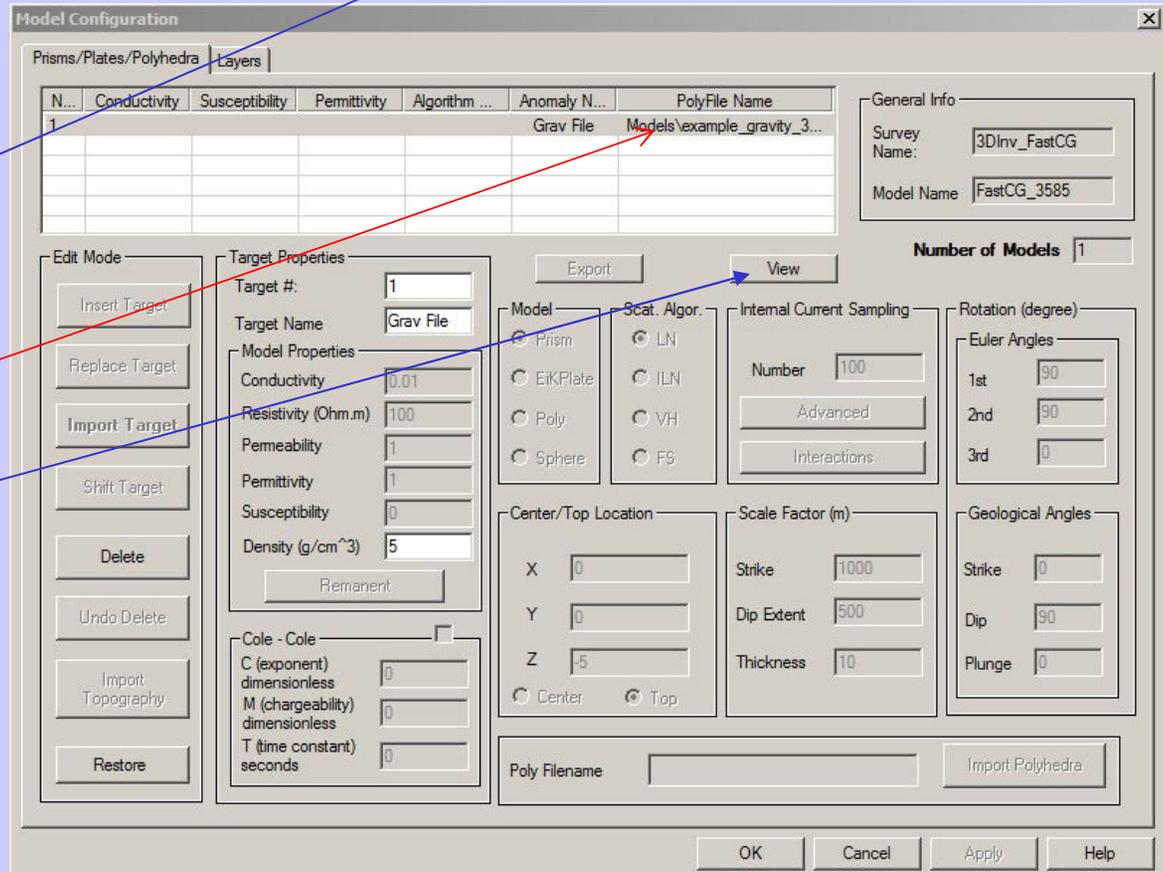
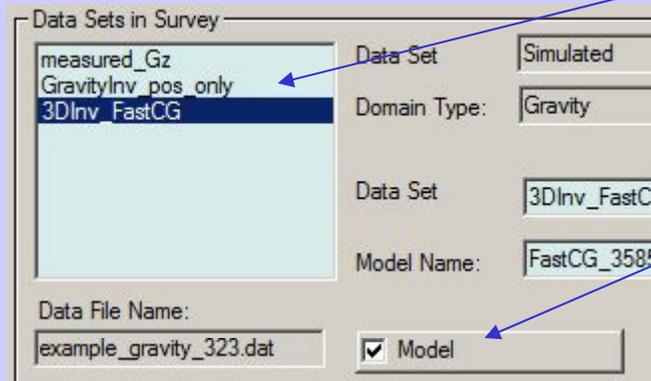


Therefore, users can reduce the range of model either before inversion (by Select Search Area) or after inversion (by Cell Removal)

Inversion Evaluation

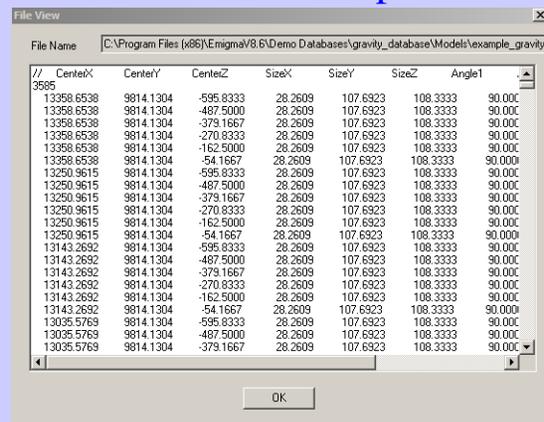
1. Import data
2. Examine data
3. Perform initial modeling
4. Perform 3D gravity inversions
5. Check model and create plots

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

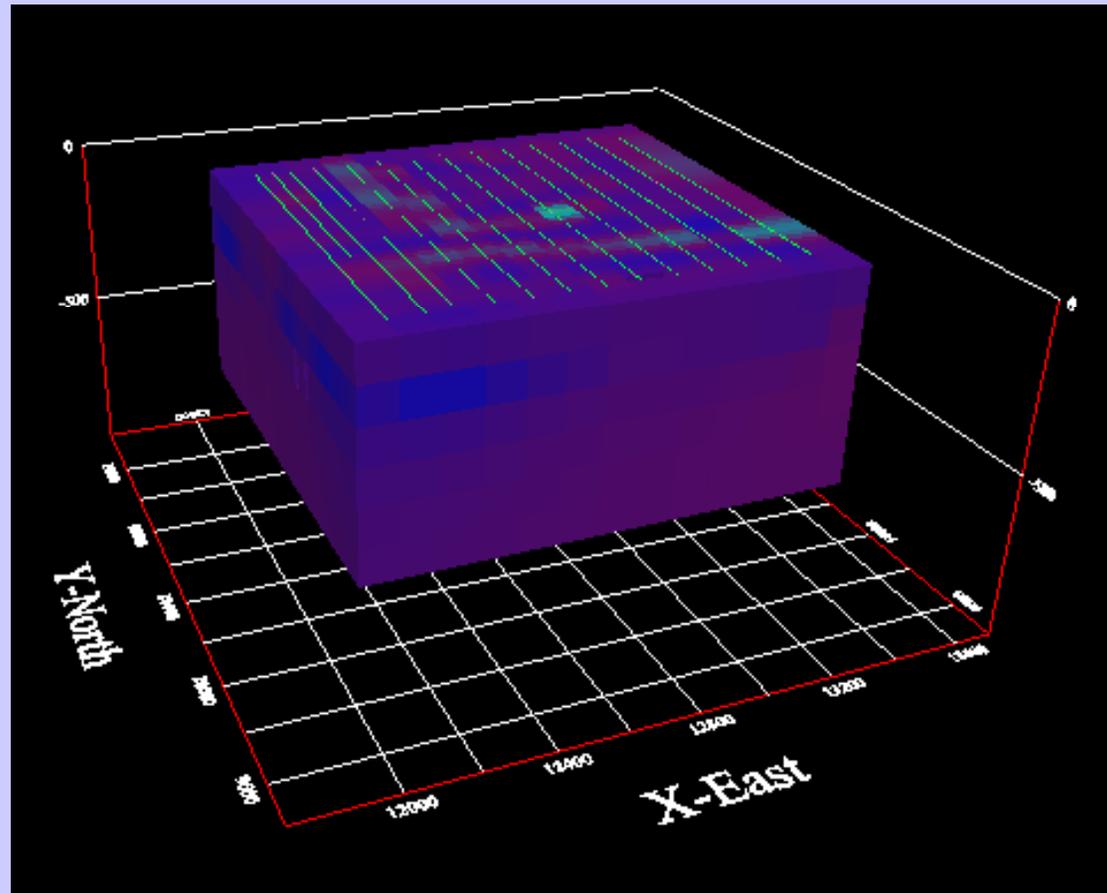
Click “View” button to open this file...



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...



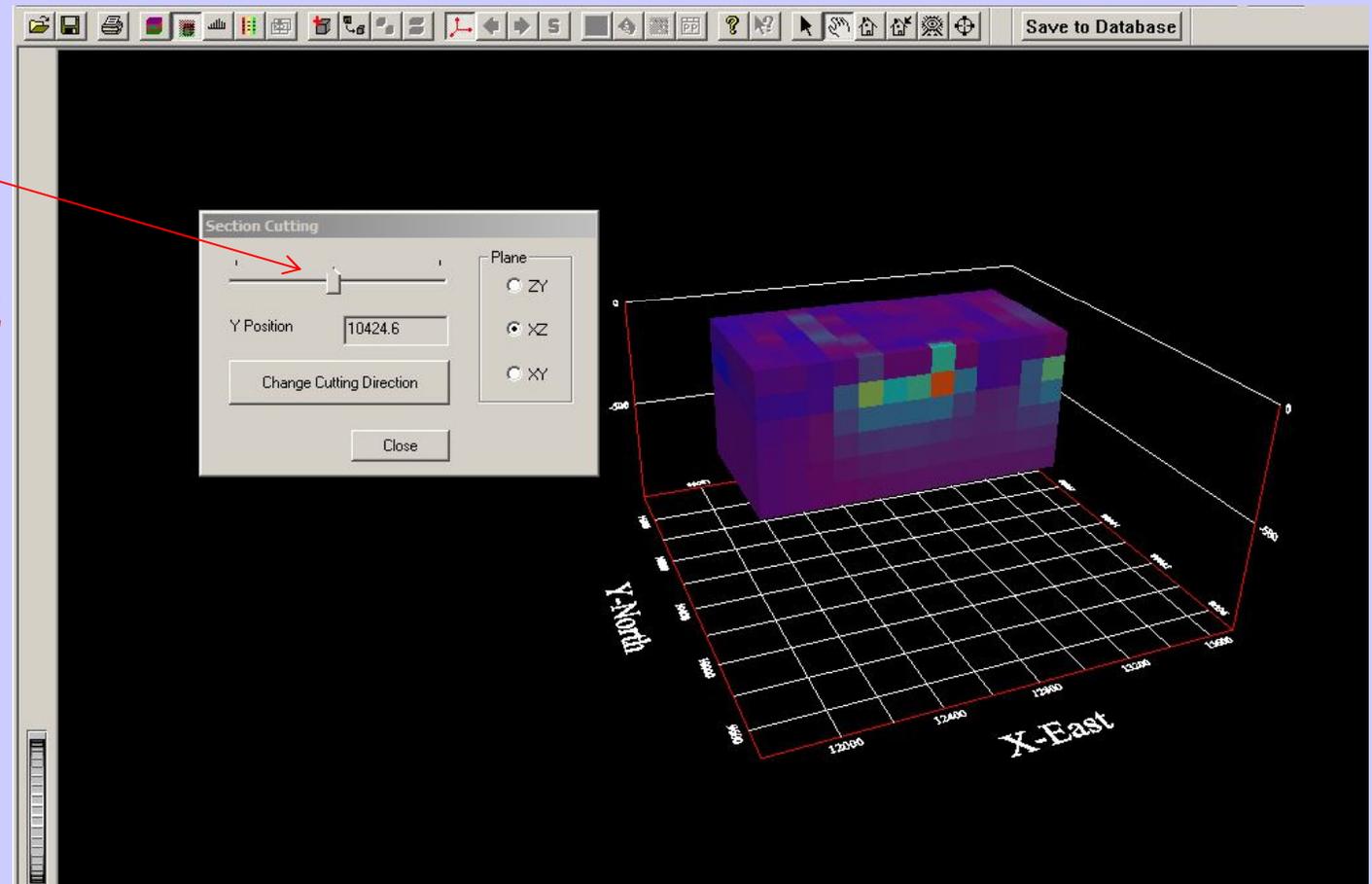
Inversion Evaluation

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



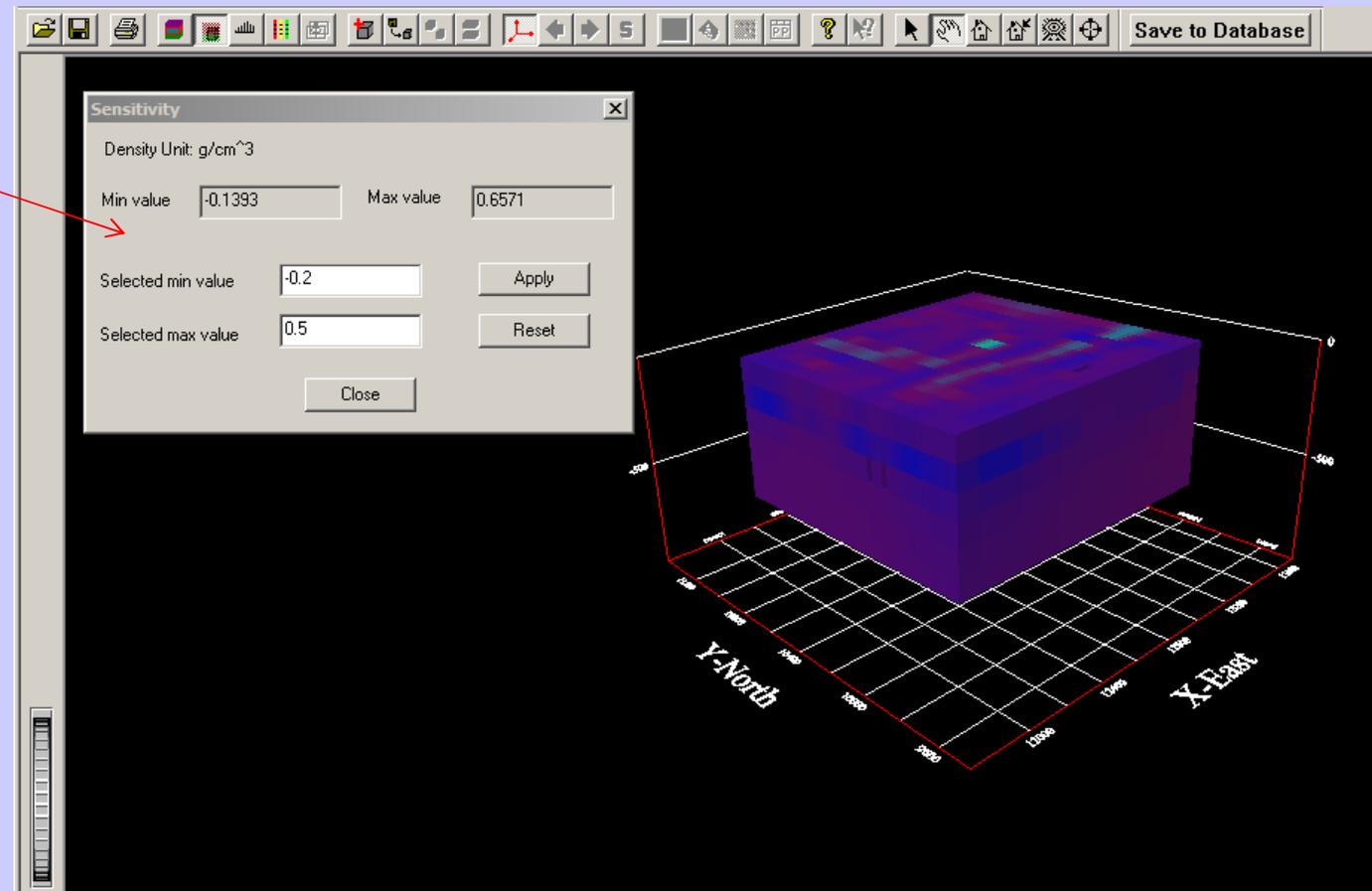
Inversion Evaluation

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...

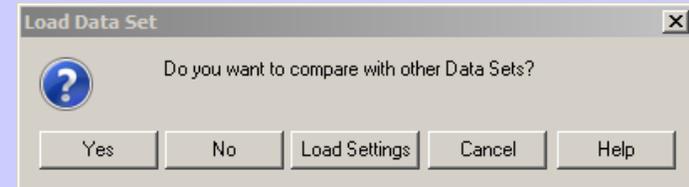
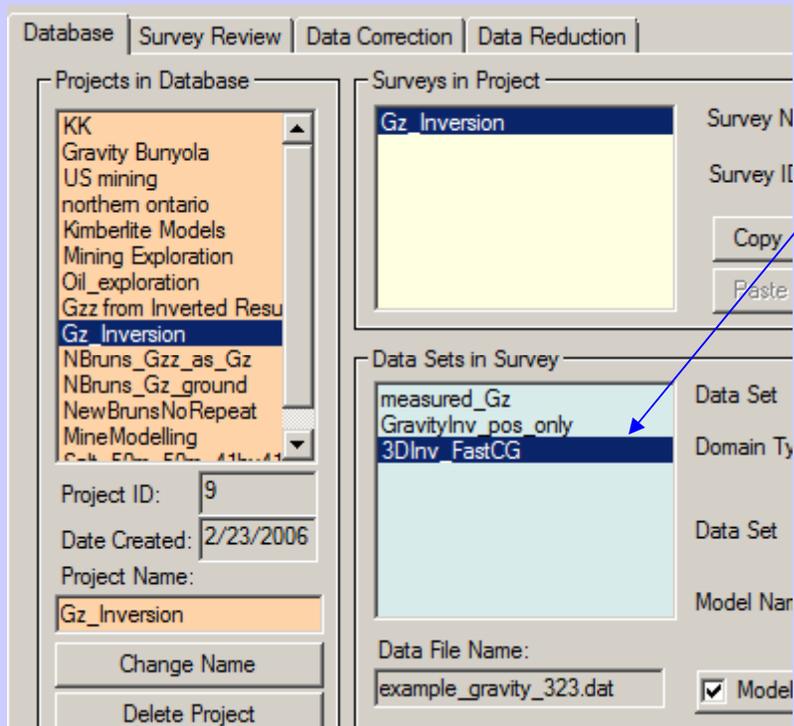
The model in this figure will only exhibit cells with values specified in this range



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

Inversion Evaluation

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

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

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

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

Add to --> Add All to --> <-- Remove from

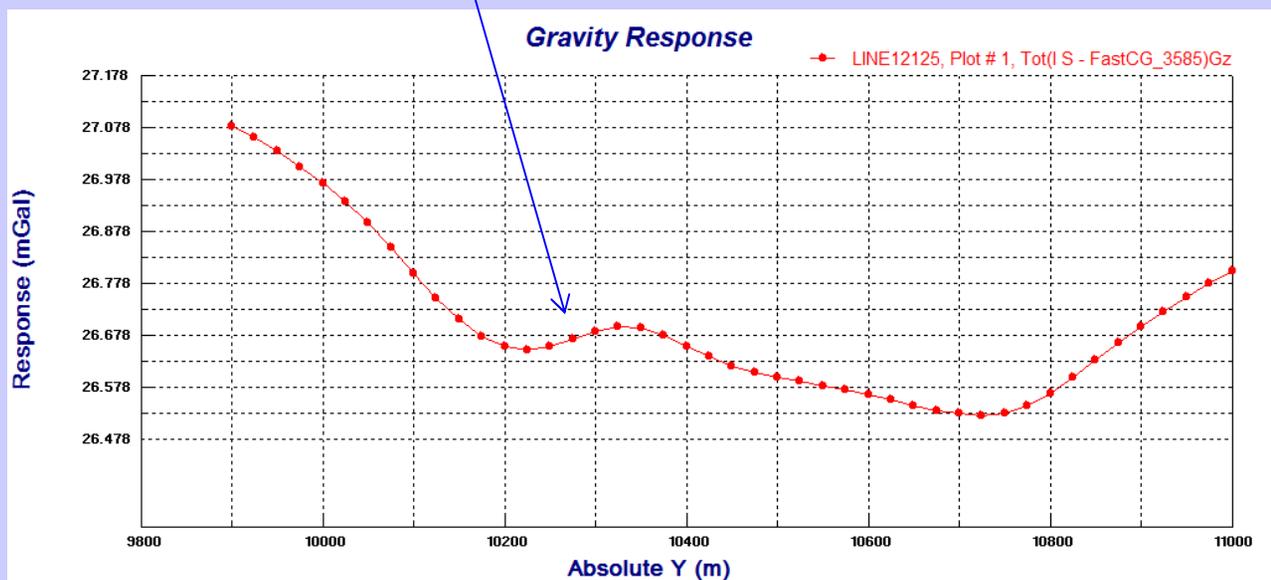
Name	Model Name	Type
3DInv_FastCG	FastCG_3585	S
measured_Gz		M

Show IMPEDANCE Data Sets in Survey

Loading:

Loaded of

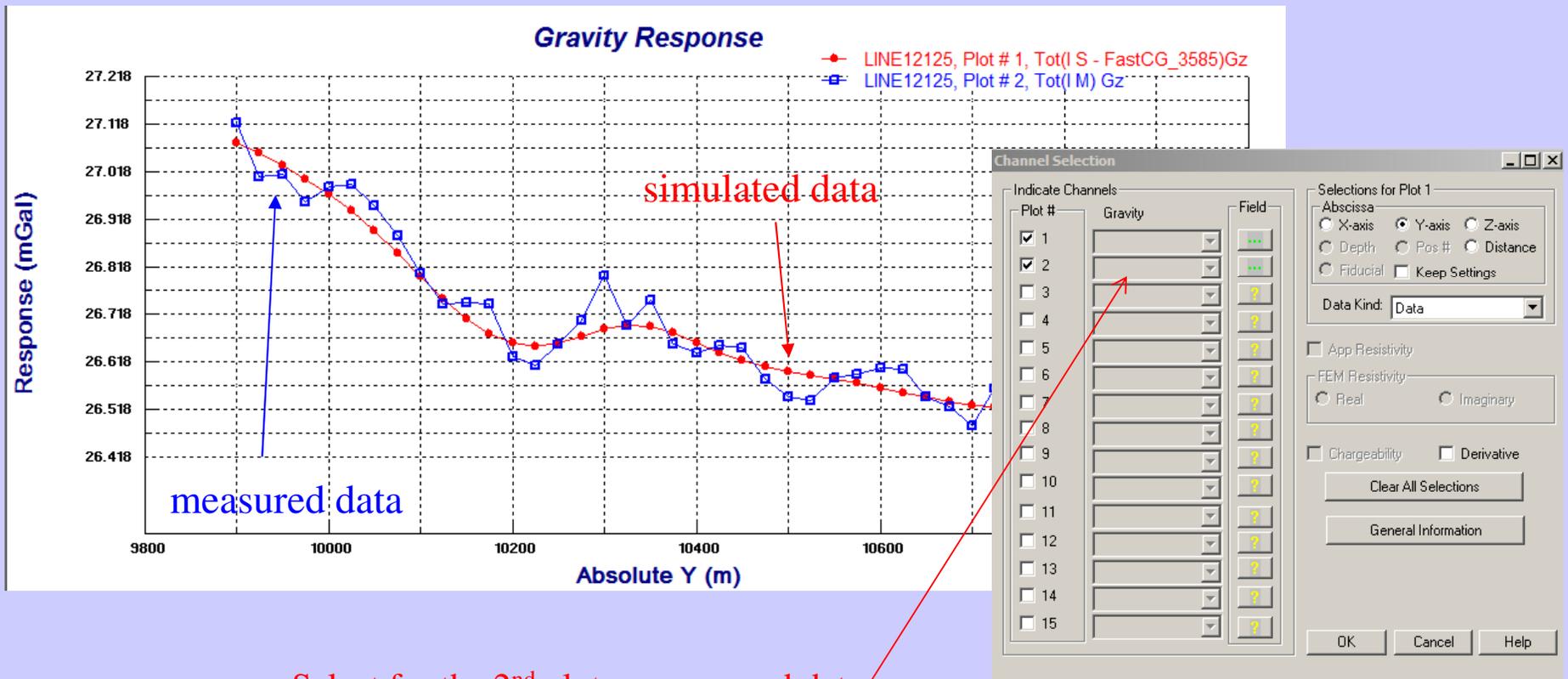
Load Cancel



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



Select for the 2nd plot on measured data

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
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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.

