3D MAGNETIC INVERSION TUTORIAL

12/13/2022

EIKON TECHNOLOGIES

Introduction

Magnetics is often lumped into the term Potential Fields and understood to be like gravity data. But, magnetics differ greatly from gravity. First, the magnetic fields are governed by very different equations than gravity and these equations are actually analogous to DC resistivity. We try to incorporate these differences in EMIGMA.

First, the source field for a magnetic survey is a regional magnetic vector field. Whereas, gravity is defined by a virtually homogeneous field which is only vertical at the surface and defined only by the distance from the center of the earth. While, there are regional and local gravity variations, they effect little the measured fields. The magnetic fields are affected by regional and well as local structures. To deal with this, EMIGMA considers the total response and not just the residual. It is thus important to pay attention to the corrections for temporal variations as well as considering the bulk regional field.

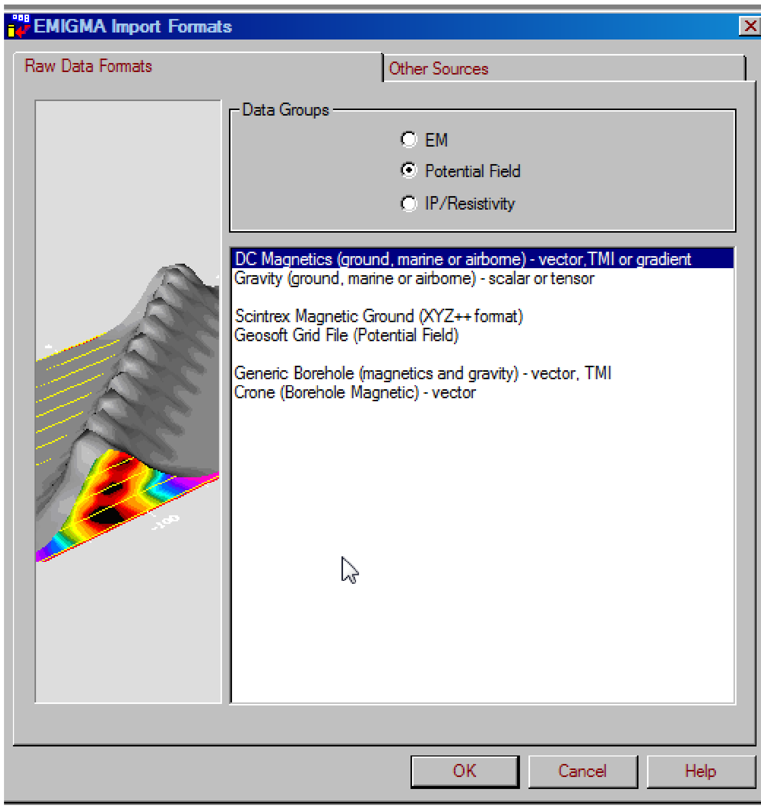
It is important to consider the first stage of corrections. It is often thought that only the diurnal variation correction is important but the temporal variations consist of both an internal component (diurnal) as well as an external variation due to atmosphere effects most commonly thought of as the magnetotelluric source field. As such, a simple subtraction of the base station measurement in problematic as these changes are due to the diurnal variation, the external signal and cultural noise at the base station. We thus suggest first processing the base station data in EMIGMA to delete obvious cultural noise and to remove the external high frequency noise by filtering prior to performing the diurnal correction removing only the variation in this final effect.

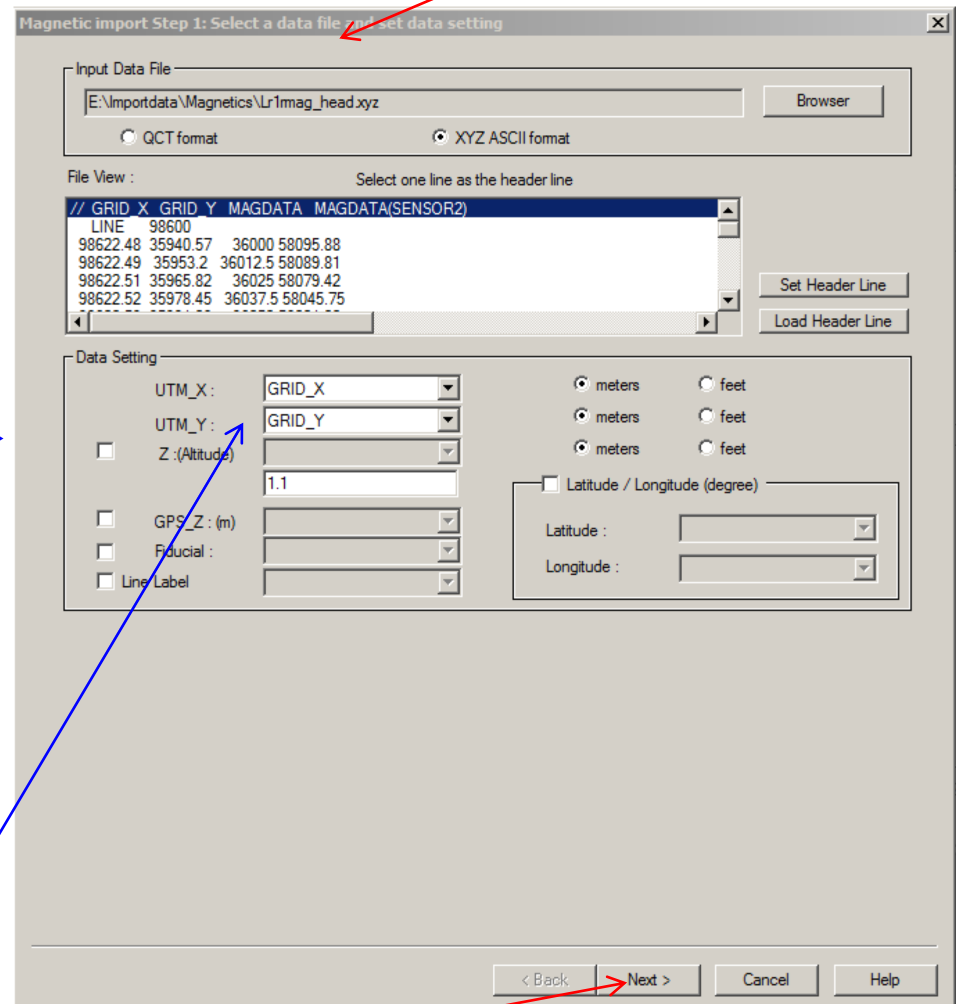
Using the total field measurement after corrections allows one to estimate the regional source field. While this will be similar to the IGRF, there will always be a difference in the average field to the IRGF amplitude. Only by measuring three component data can one estimate the actual inclination and declination of the regional field.

If your data is automatically reduced by the base station, we suggest to add the average base station response to your data before import. If the base station values are not available from the instrument manufacturer then the only alternative is to determine the IGRF and add this to your data before import.

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

Browse and select .qct or .xyz data file for import
This first example is an older data set on a grid without GPS information or Latitude/Longtitude.





Select data file columns corresponding to coordinate axis, and specify their units as well

Click "Next" button to proceed to the next step

1. **Import data**
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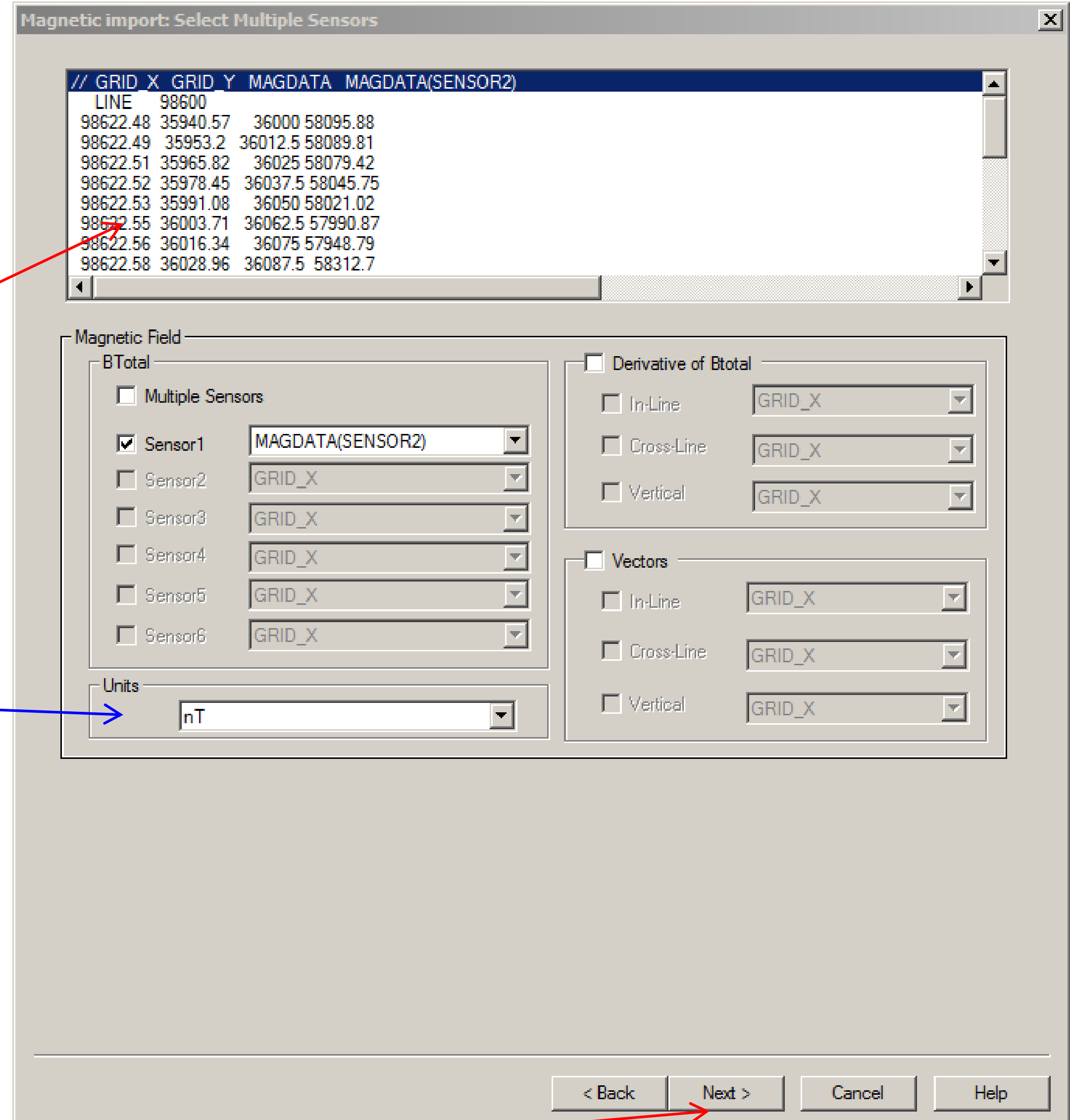
Select column name for magnetic data

In this case, there is only total field data and 1 sensor.

Select unit for imported data



Click “Next” button

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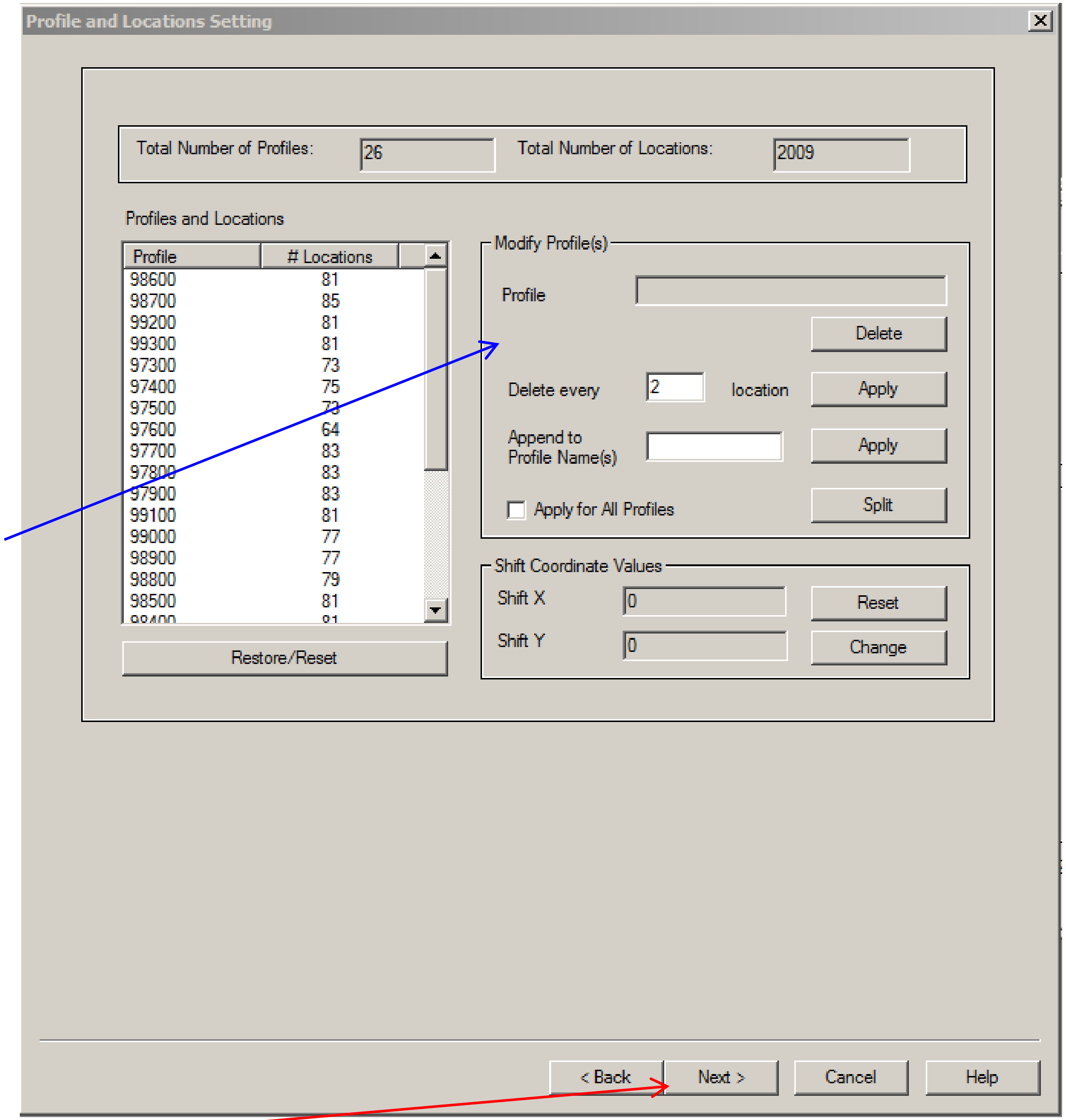
Show profile information, users can perform delete/reduction/shift operations on profiles in this dialog if desired but these tools are available once the data is inside EMIGMA.



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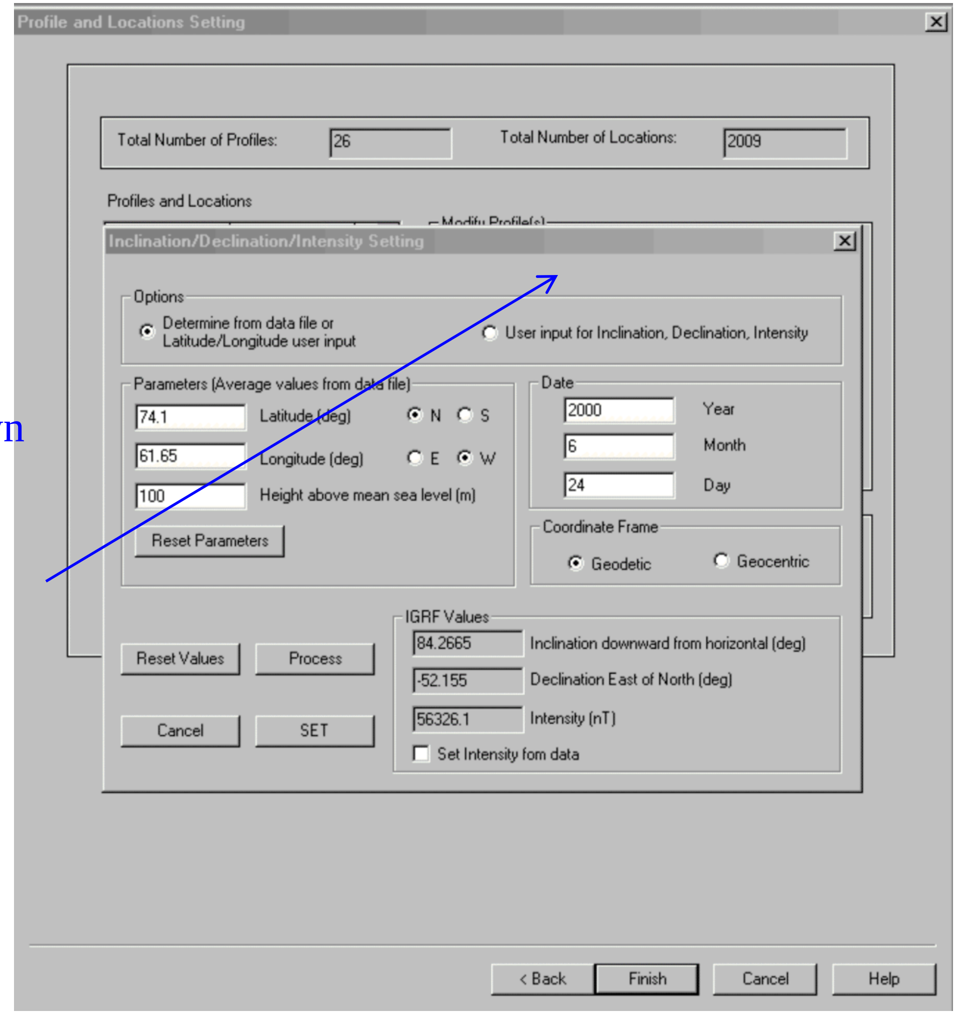
You must determine the nature of the earth's magnetic field in the area of your survey. While the magnitude of the regional field may be estimated from your data, the angle of the field defines the internal magnetization of the susceptible structures. The regional field is described by the IGRF model.

if you data file did not have Lat/Long information, enter it into the fields shown along with approximate GPS elevation.

As the earth's field is not stationary but is slowly varying, you must enter the approximate date of the survey.

Click Process the Set



Click “Next” button

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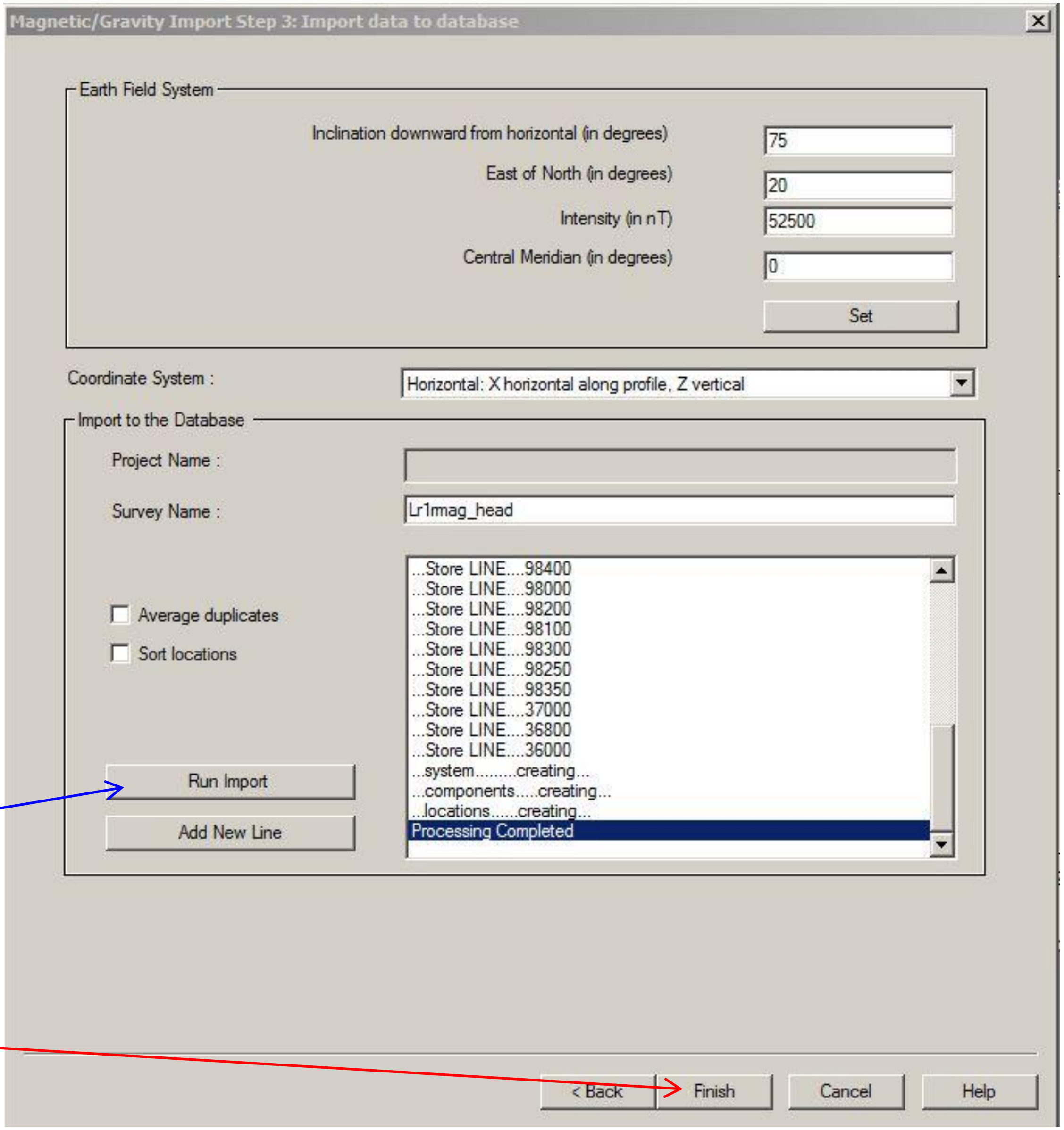

Click "Run Import" button to start import data into the database

averaging and sorting may be carried out late once the data is imported

After processing is done, click "finish" button to complete the procedure

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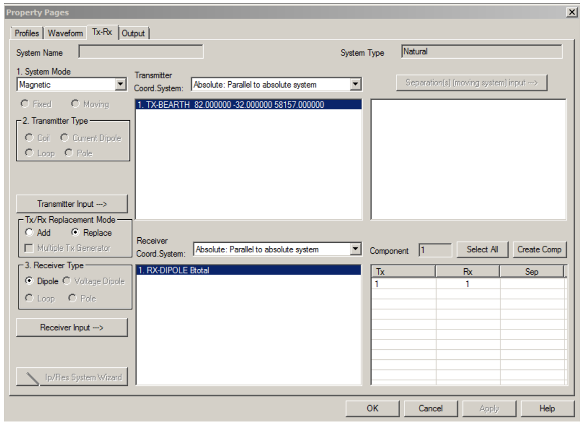
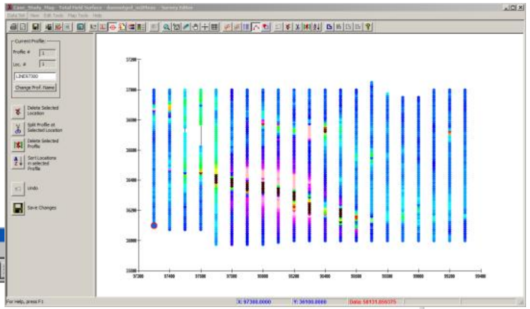
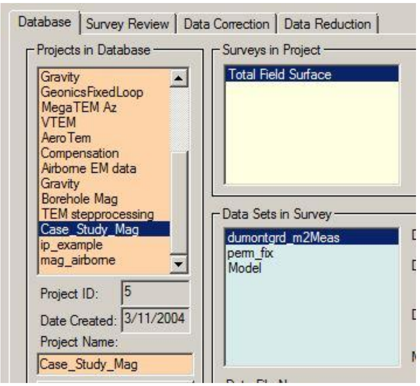
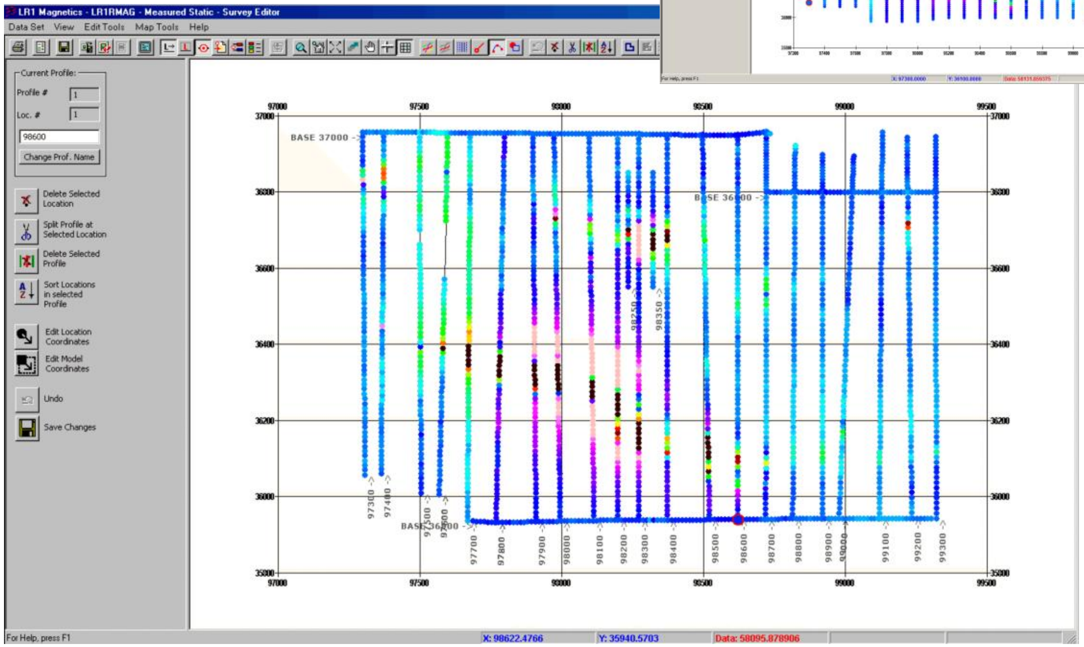


3. Check system configuration

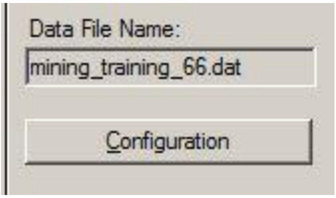


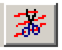
1. Check database for the survey





2. Click configuration



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

This tool is a data analyzing, editing and mapping tool.
- profiles may be deleted, modified, renamed, datapoints moved, deleted, and maps maybe underlaid or constructed

1. Import data
2. **Examine data gridding, processing**
3. Perform initial modeling
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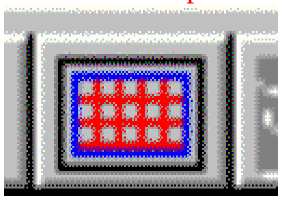
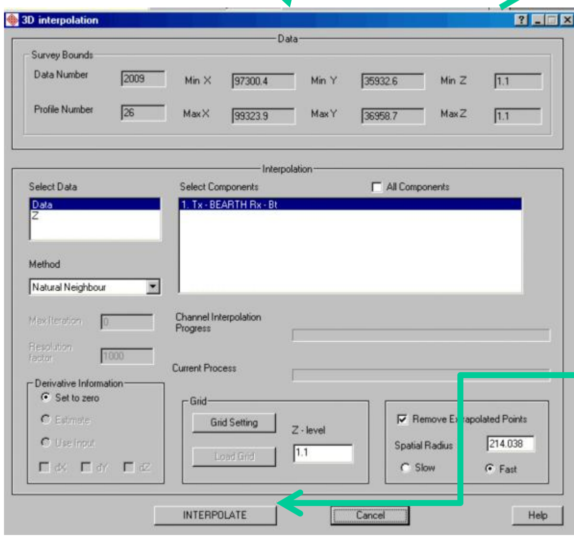
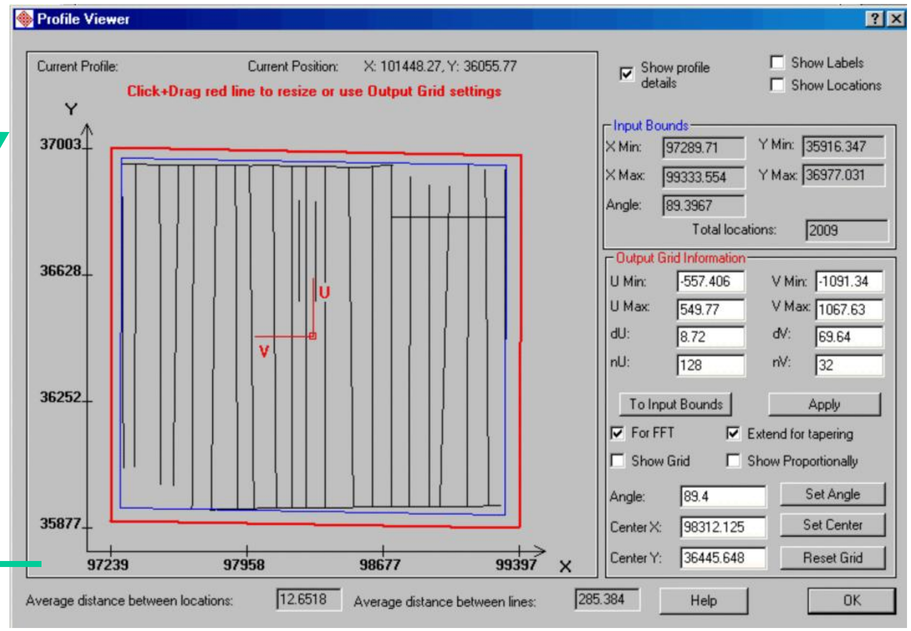
An important aspect of potential field analyses is done through FFT analyses by which you are able to start to understand the nature of the structure and thus better to control the inversion process.

1. Interpolate or "grid" the data. In this process, the data is interpolated onto a grid of data vertices defined by a rectangular cell.



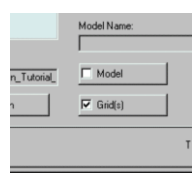


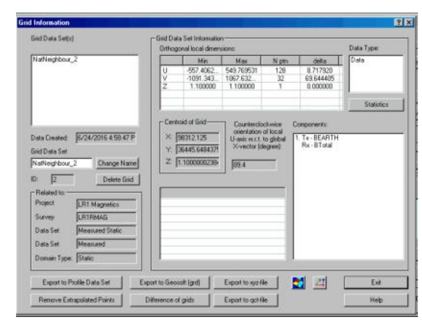


controls for defining the grid both in size and dx,dy resolution

Clicking for FFT ensures the grid is 2^n by 2^m, cells need not be square

After interpolating, the grid is attached to the dataset in the database as indicated by a check mark as here grids are stored for easy access





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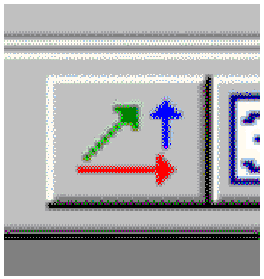
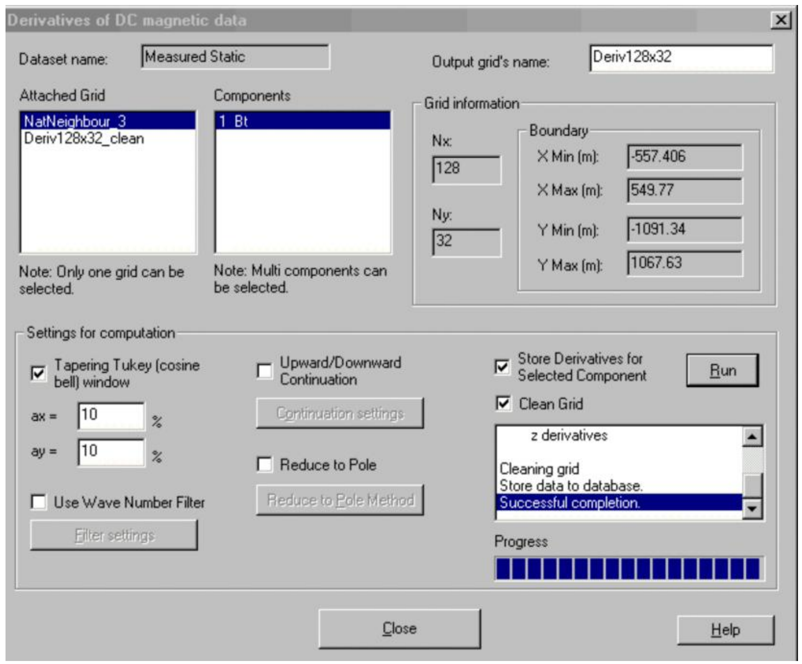
Creating Derivatives and other FFT processing and Their role in inversion.

1. Having interpolated the data to a regular 2^N x 2^M grid, we may now processing derivatives and with these derivatives perform other processing functions.





Grids which may be utilized for FFT processing are displayed in the upper left hand and the contents of these grids in the box beside. Various different processing may be carried out here, but here we simply show generation of the 3 derivatives of the total field. These derivatives may later be utilized in the inversion process in a variety of ways.

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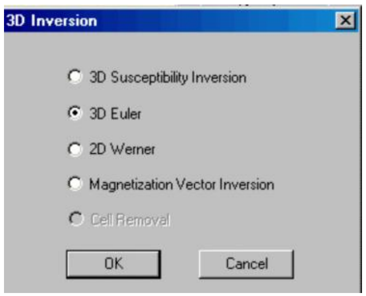
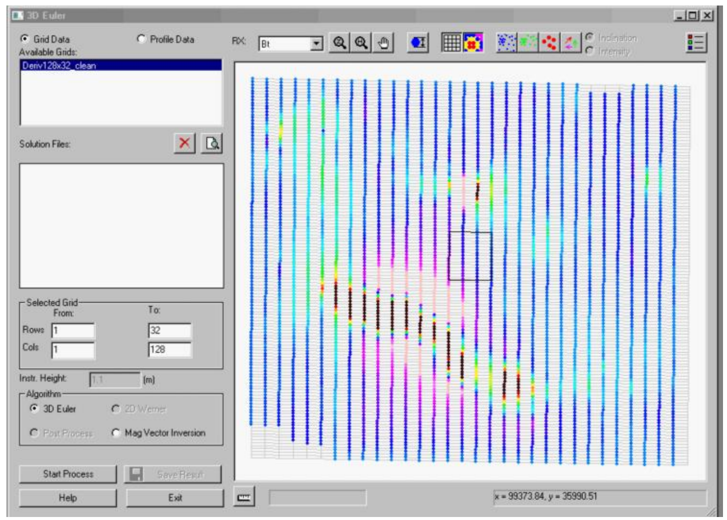
Use of Derivatives in Inversion – 3 examples.

1. Case 1: Use the derivative grids to perform 3D Euler solutions.





Through this interface, you may perform various aspects of the 3D Euler solutions.
Results are then viewed in either GridPresentation or the Visualizer.
These tools allow you to determine the types of the 3D structure as well as depth estimates.

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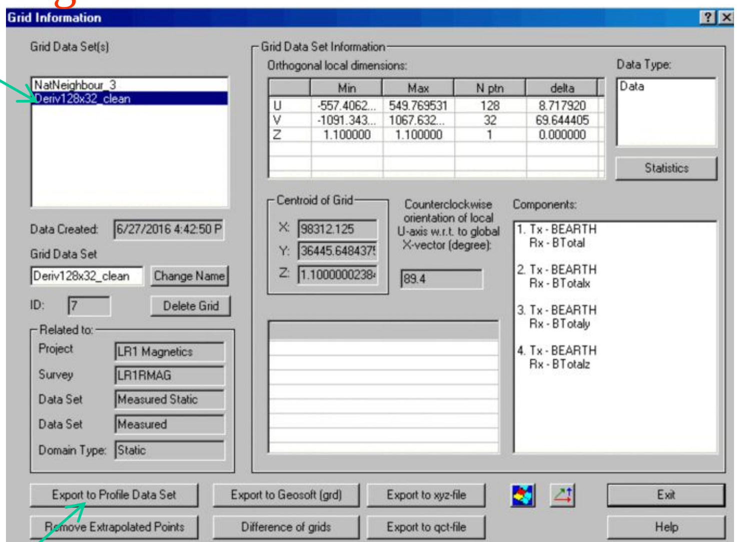
Use of Derivatives in Inversion – 3 examples.

1. Case 2: Export derivatives for use in 3D inversion

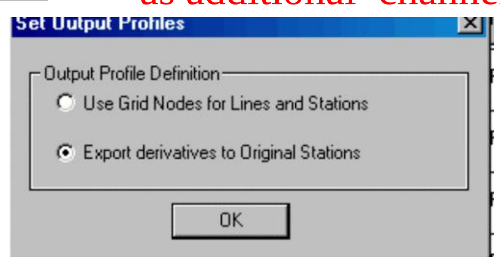
derivative grid



Export TMI and derivatives to a set of profiles

or

Export derivatives by interpolation to be added as additional channels to your original data.



Export derivatives .

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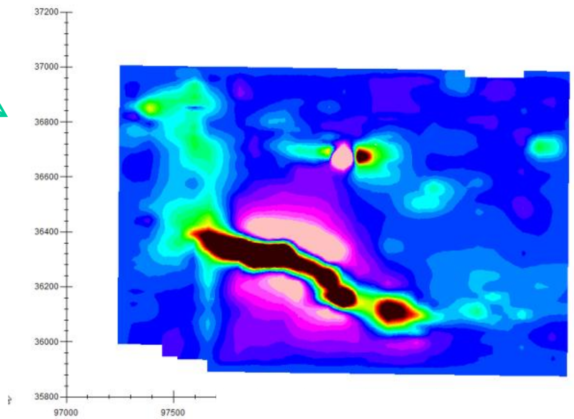
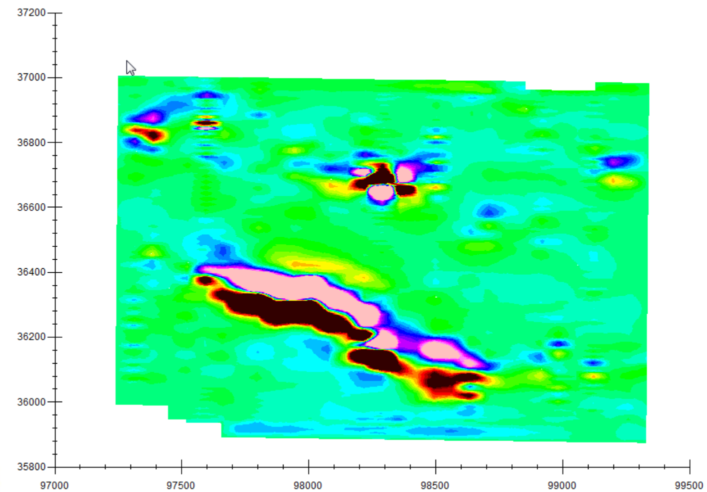
Use of Derivatives in Inversion – 3 examples.

1. Case 3: Examination of Derivatives and Upward Continuation

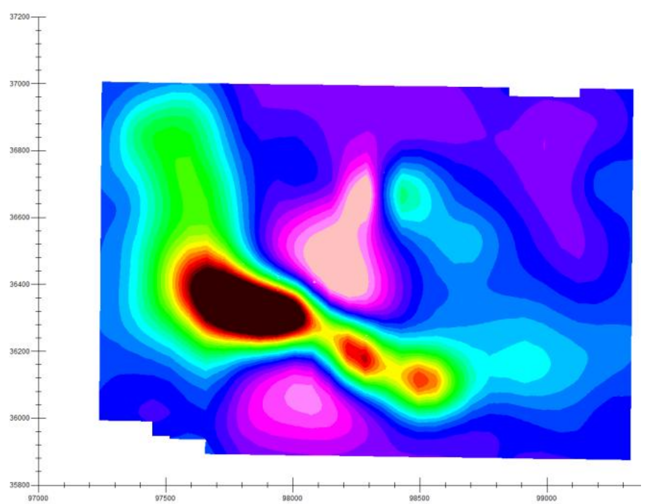
TMI grid



Inline TMI gradient



Upwared Continued TMI grid



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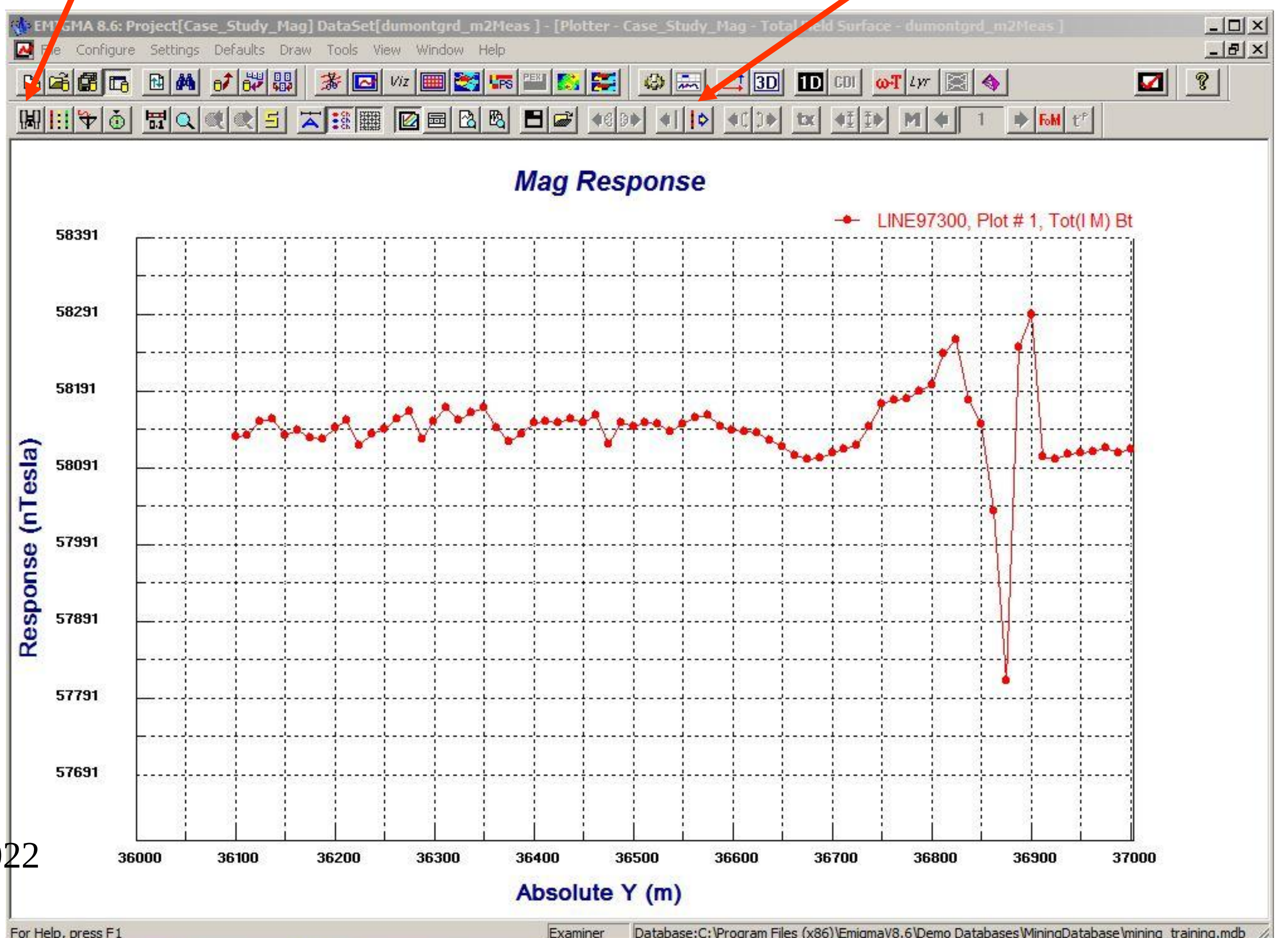
Click “Plotter”…

Load data set in plotter

Toggle between profiles



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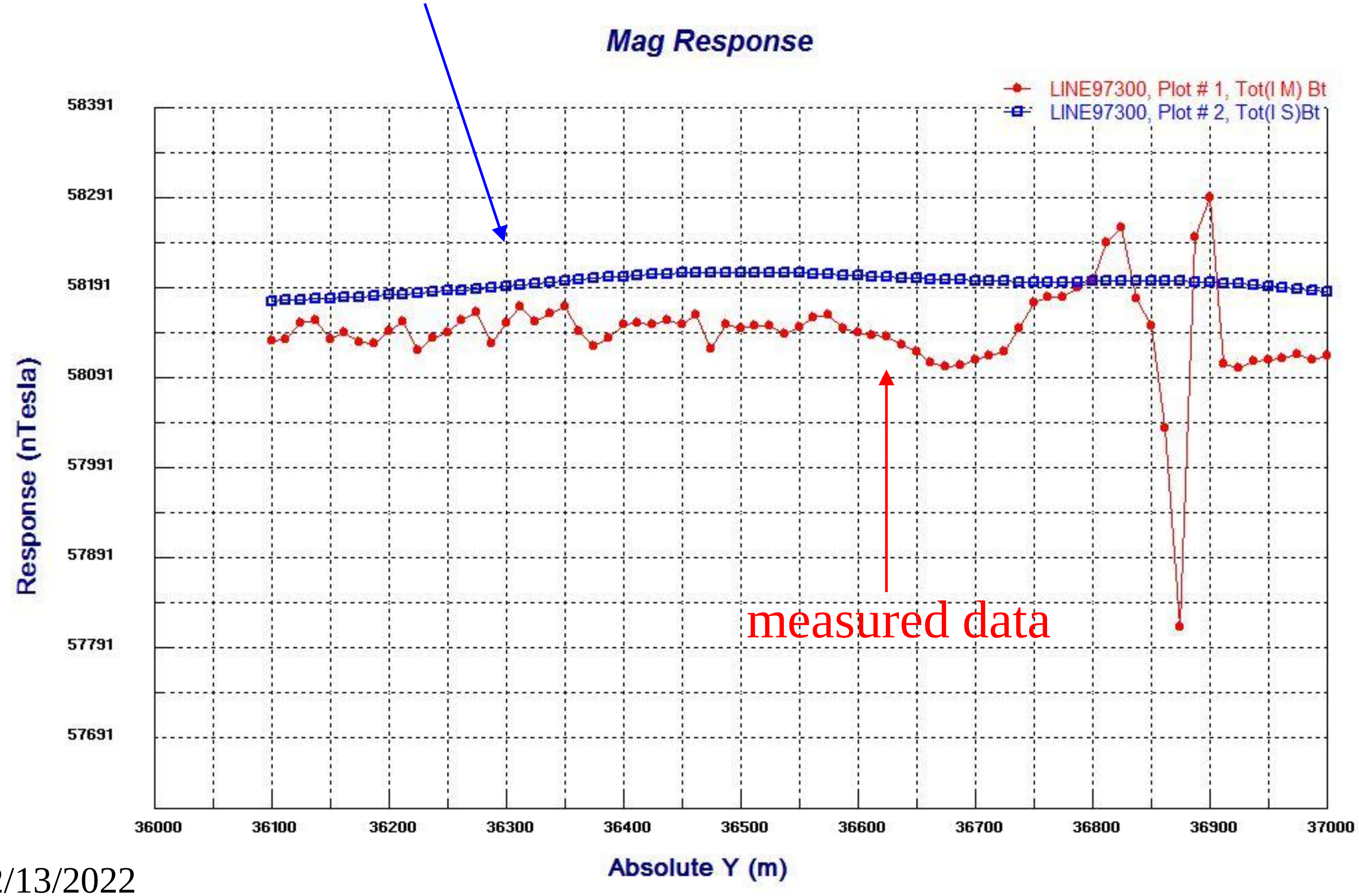
Note: *Performed some initial modeling to get a "feel" of the data and estimate parameters of initial model for inversion.*

simulated data with a forward model



measured data

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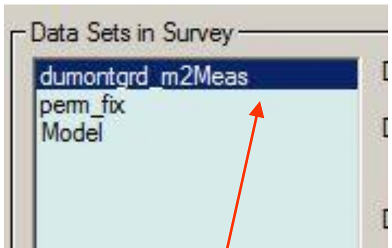
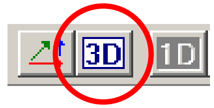
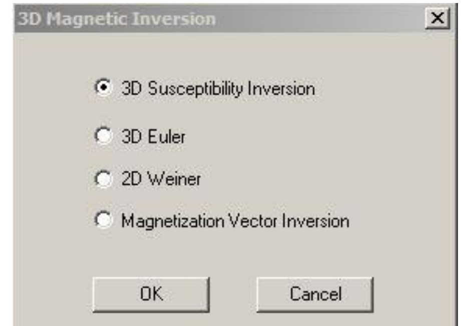
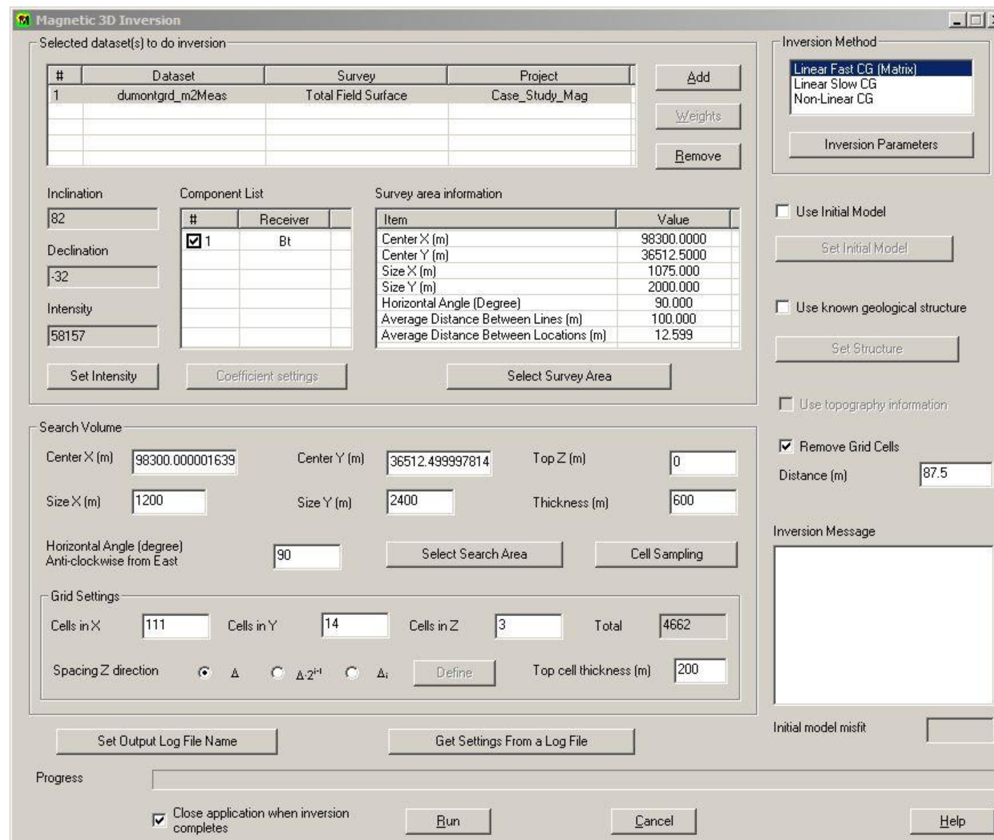


Select survey data







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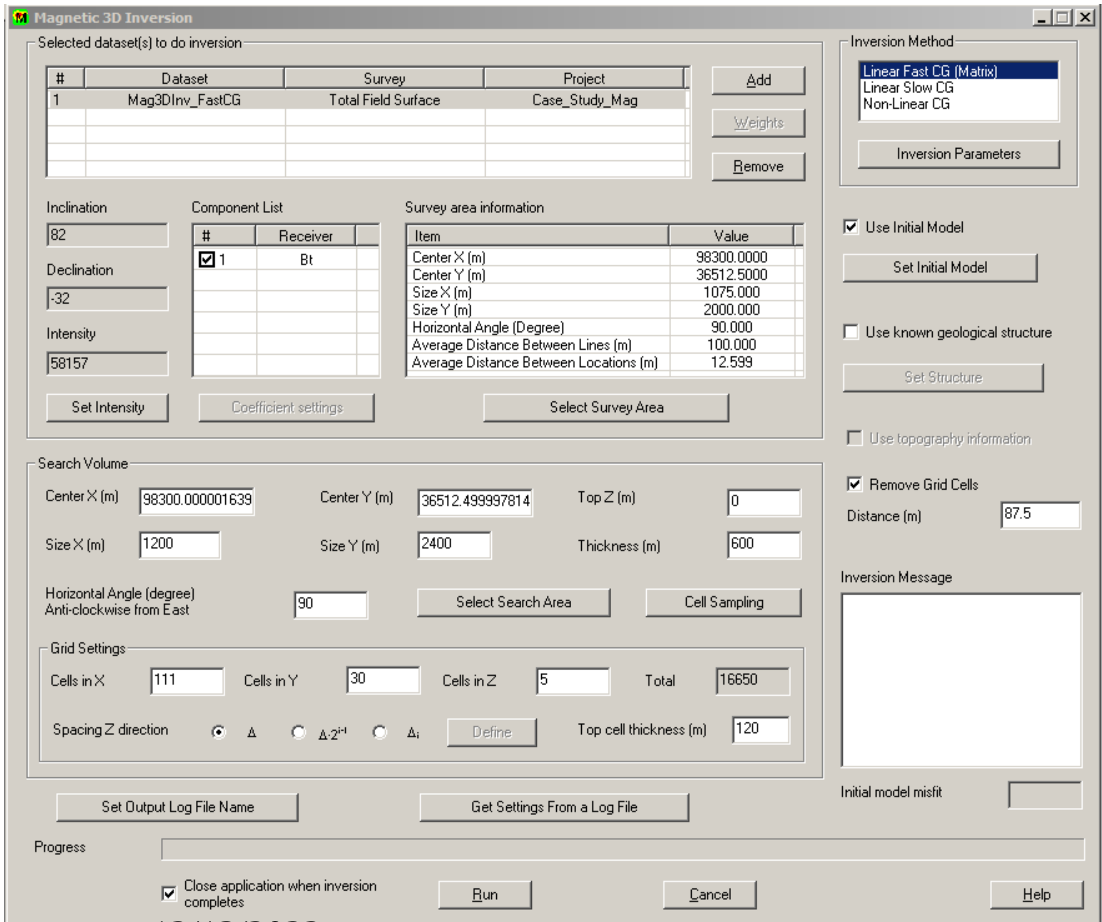

Selected Data Sets

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.

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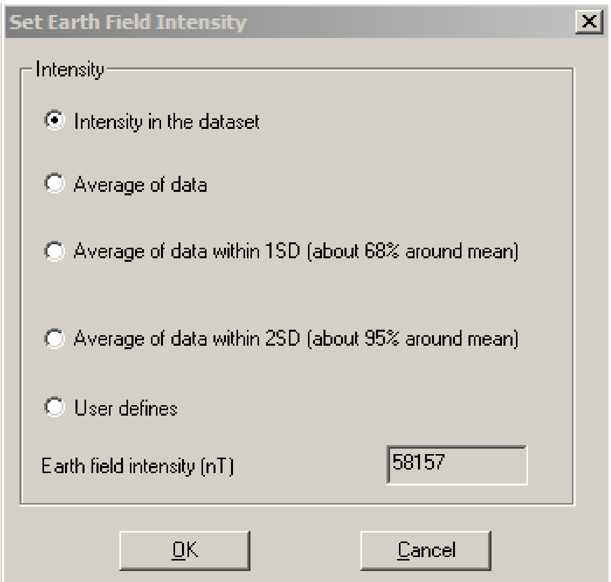
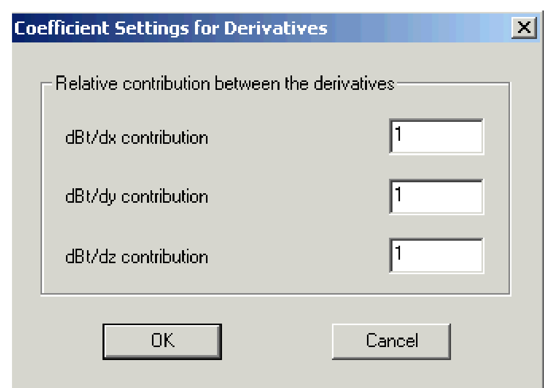


Earth’s Background Field

You can choose between various methods to obtain a value for the background field by clicking **Set Intensity**.
Intensity in the dataset - uses the value defined in the selected survey.
Average of data - the value will be calculated from the data. The amount of data values used for the calculation depends on the option chosen.
User define - simply enter a new value in the field intensity box.

Coefficient settings

This button will be enabled when gradient data is available and more than one derivative has been selected (not in this example). It launches the following window where a weight can be assigned to each available derivative.



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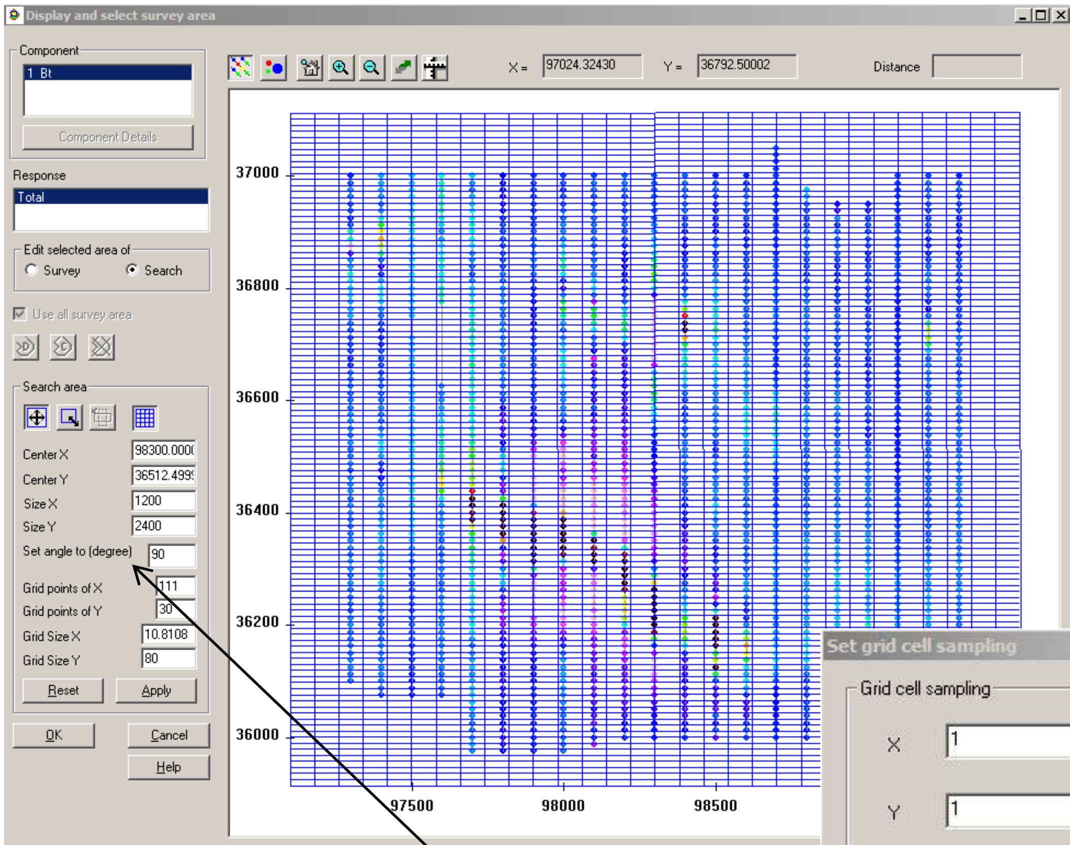
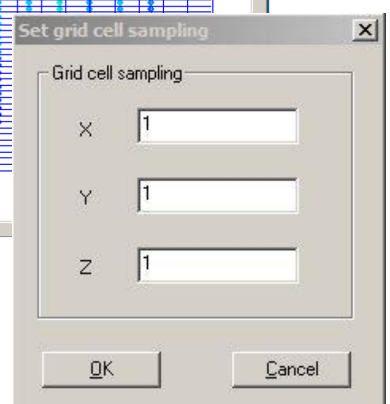
Clicking either the **Select Search Area** or **Select Survey Area** buttons launches the same window. But search area means the area of data which the inversion algorithm works on, while survey area is the whole part of the imported data.





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

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

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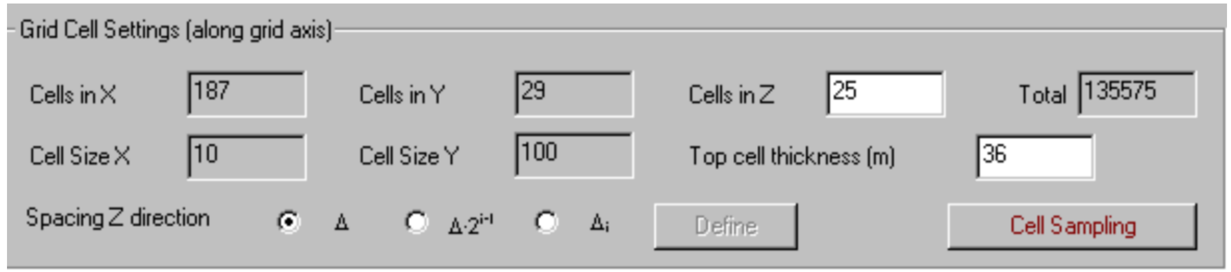

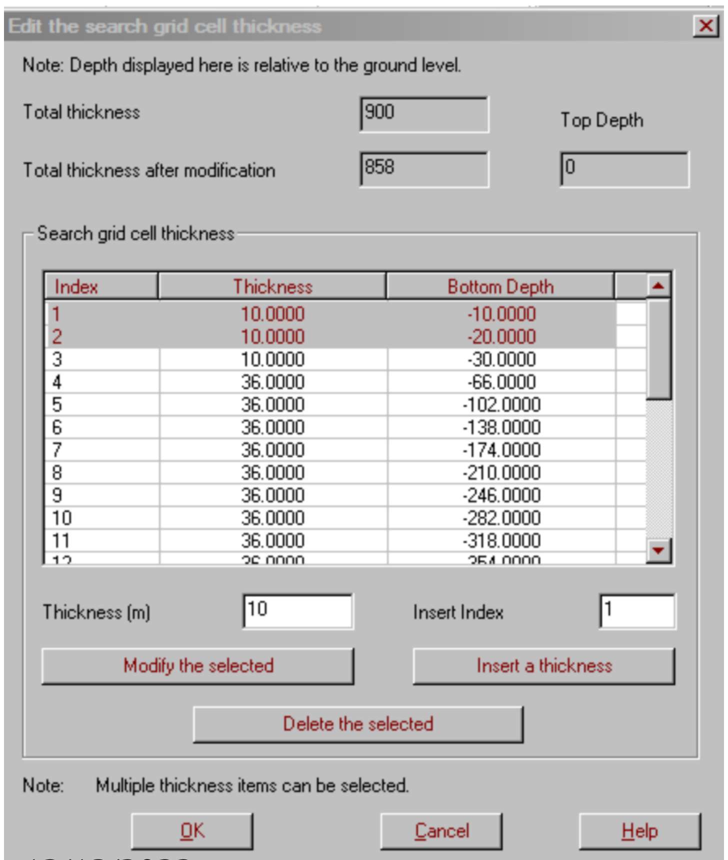

Grid Settings

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 **Δ** for evenly spaced points in the z direction or $\mathbf{\Delta \cdot 2^{i-1}}$ for exponentially spaced points. You may specify a custom spacing by selecting $\mathbf{\Delta_i}$. 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.

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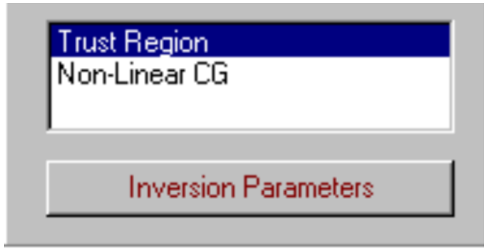
Inversion Methods



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

Trust Region - Faster than Non-Linear CG and has better handling of model constraints. It is a constrained minimization technique and can efficiently process large number of data points and inversion grid cells.

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. It is a unconstrained minimization technique with the constraints on the interface applied as a post-process.

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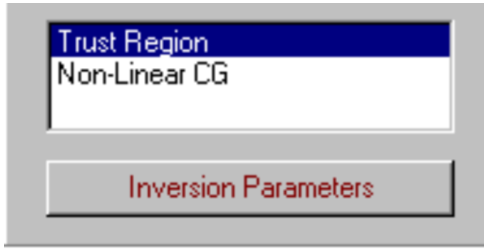
The objective function

Assumes that the forward function can be linearized.



d= F m

d: vector of N dimension

F: matrix of N×M dimension

m: vector of M-dimension

N: number of observation

M: number of inversion grid cells

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

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

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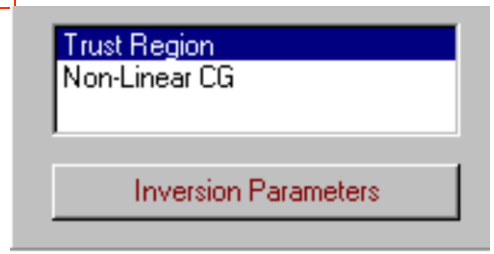

Trust Region Technique

- fast convergence rate
- constrained
- can efficiently process large number of data points and cells

Constrained Trust Region Technique

At an iterate, when a region around is defined, a quadratic model within this region is checked for an adequate representation of the objective function. If a notable decrease of the objective function can be achieved within the region, then the model is believed to be a good representation of the original objective function and the region is expanded. If the improvement is too subtle, then the model is not to be believed as a good representation of the original objective function within that region and the region is contracted.

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

$\phi(m)$ - functional to be minimized

$\phi_d(m)$ - data misfit

$\phi_m(m)$ - model misfit

λ - Lagrangian multiplier - regularization weight

Smooth model misfit function

$$\phi_m(m) = \alpha_0 \int w^2(z)\, [\, m(r) - m^0(r)\,]^2\, dv \quad +$$

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

α_I - weighting factors

$w(z)$ - depth weighting

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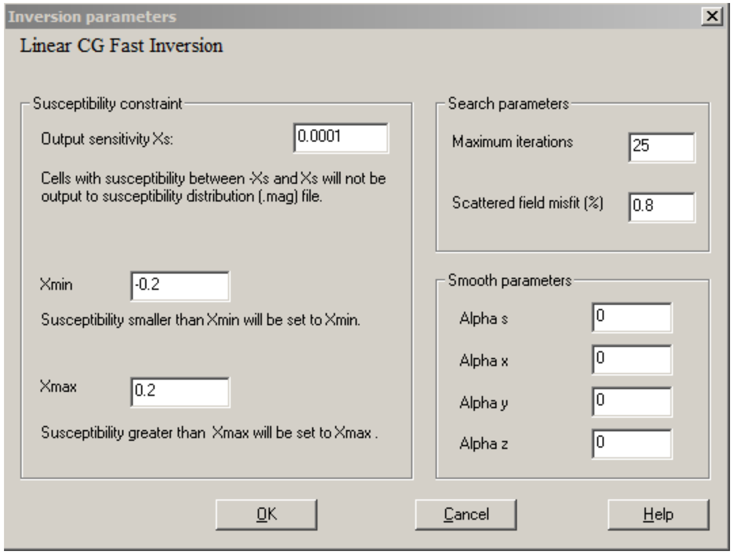


Constraint of Susceptibility

Output Sensitivity

Cells with susceptibility |D| (close to 0 - where the user defines how close) are constrained or thrown out after each iteration. will not be output to the susceptibility 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 Xmaz 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.

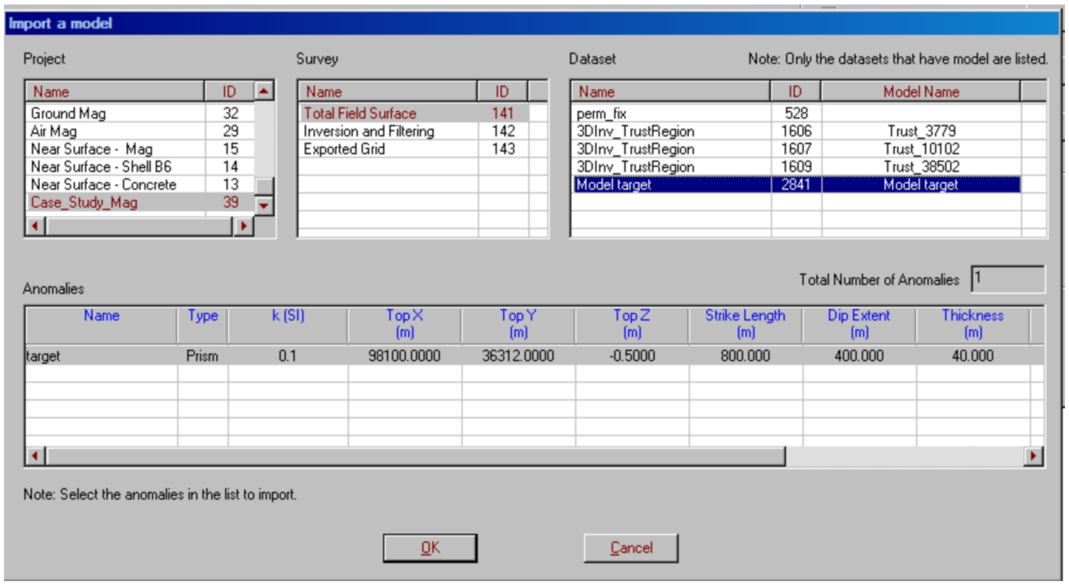
Scattered field misfit

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

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



Initial Model

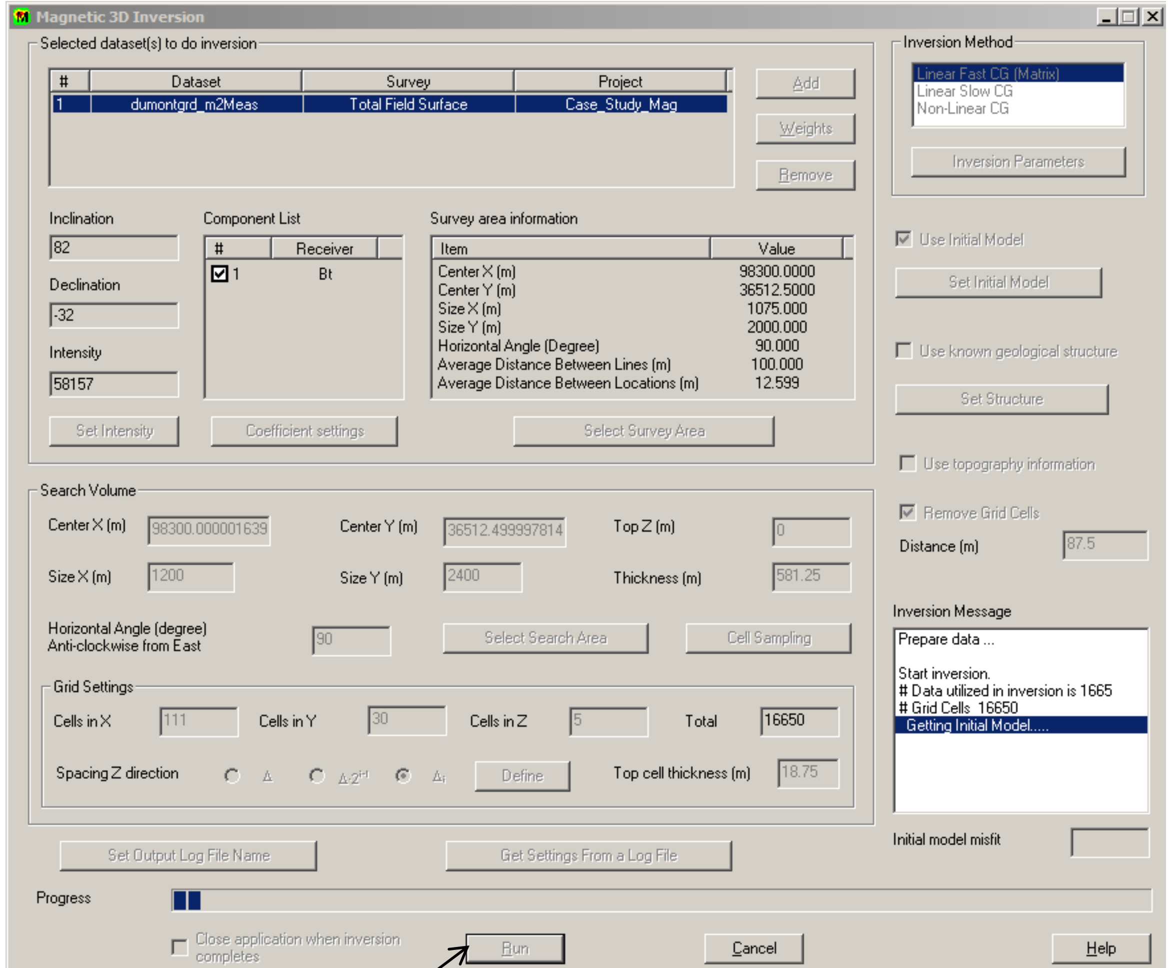
Click the checkbox labeled **Use Initial Model** to specify an initial model. Return to the initial model window by clicking the **Set Initial Model** button.

The starting model is described by a list of prisms with various properties in the box labeled **Initial Model**.

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 **Initial Model**.

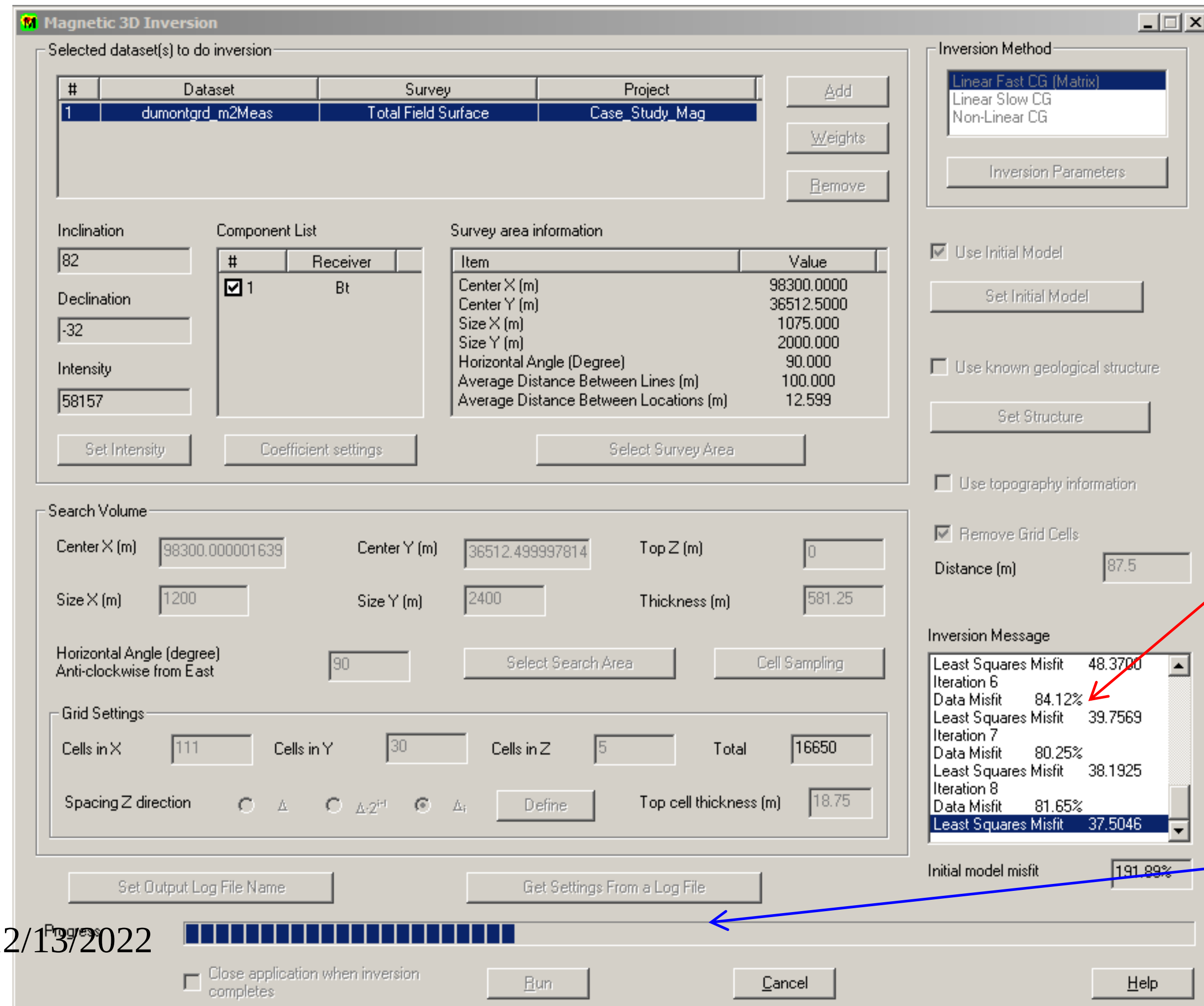
1. Import data
2. Examine data
3. Perform initial modeling
4. **Perform 3D magnetic inversions**
5. Check model and create plots



- 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 magnetic inversions**
5. Check model and create plots

Executing the Inversion

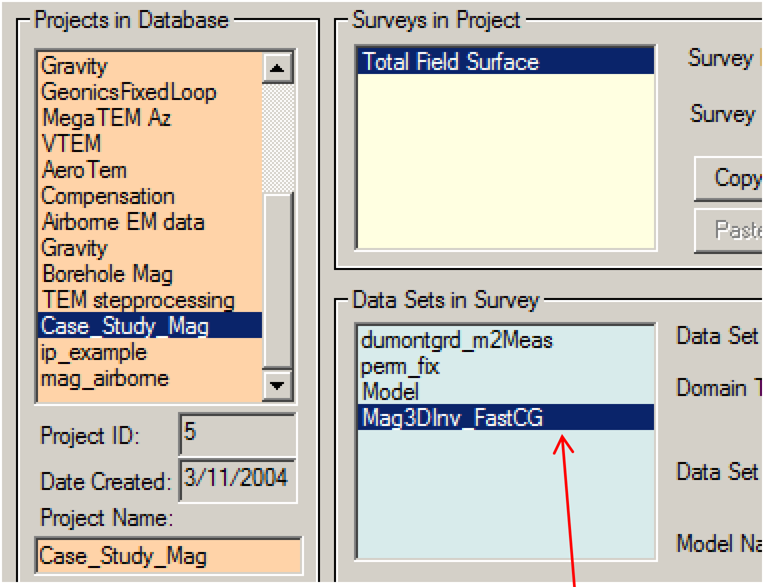


The right window (in white) shows each data point's progress.

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

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

Inversion Evaluation

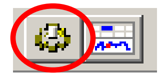


Our 3D gravity inversion model dataset

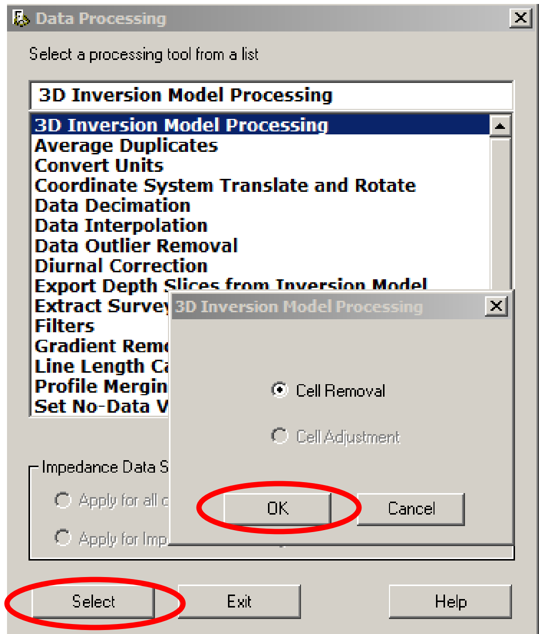
In each survey, there will be several data sets after modeling, inversion and processing. In this case, we have two forward models and one inversion model. Each forward model has a new data set containing the simulated data under the model. Similarly, each inversion contains a new dataset containing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

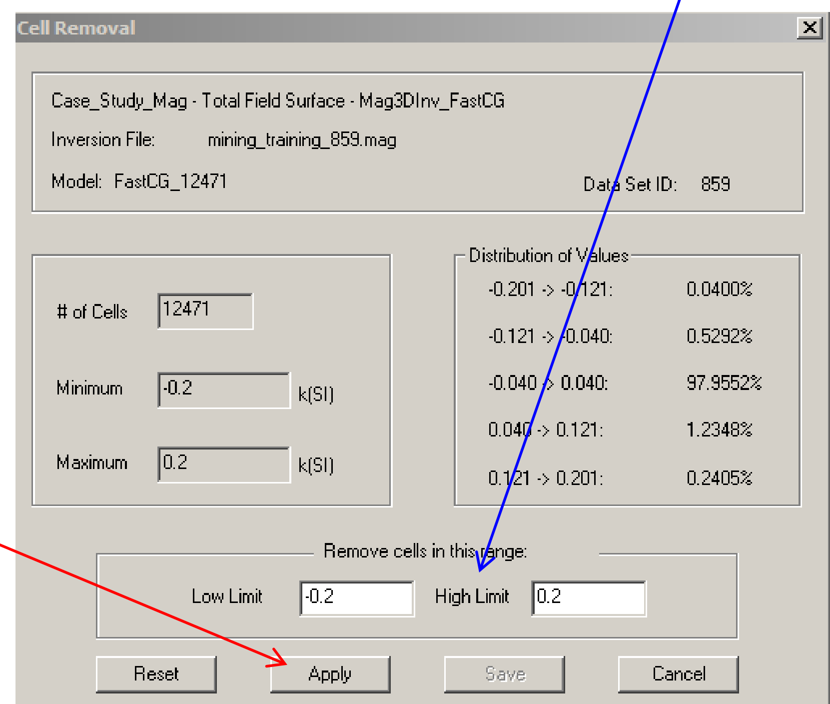
1. Import data
2. Examine data
3. Perform initial modeling
4. Perform 3D magnetic inversions
5. **Check model and create plots**

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)





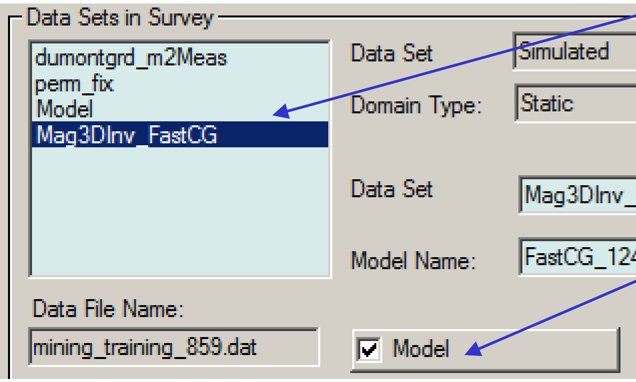
Click "Apply" button when it is done

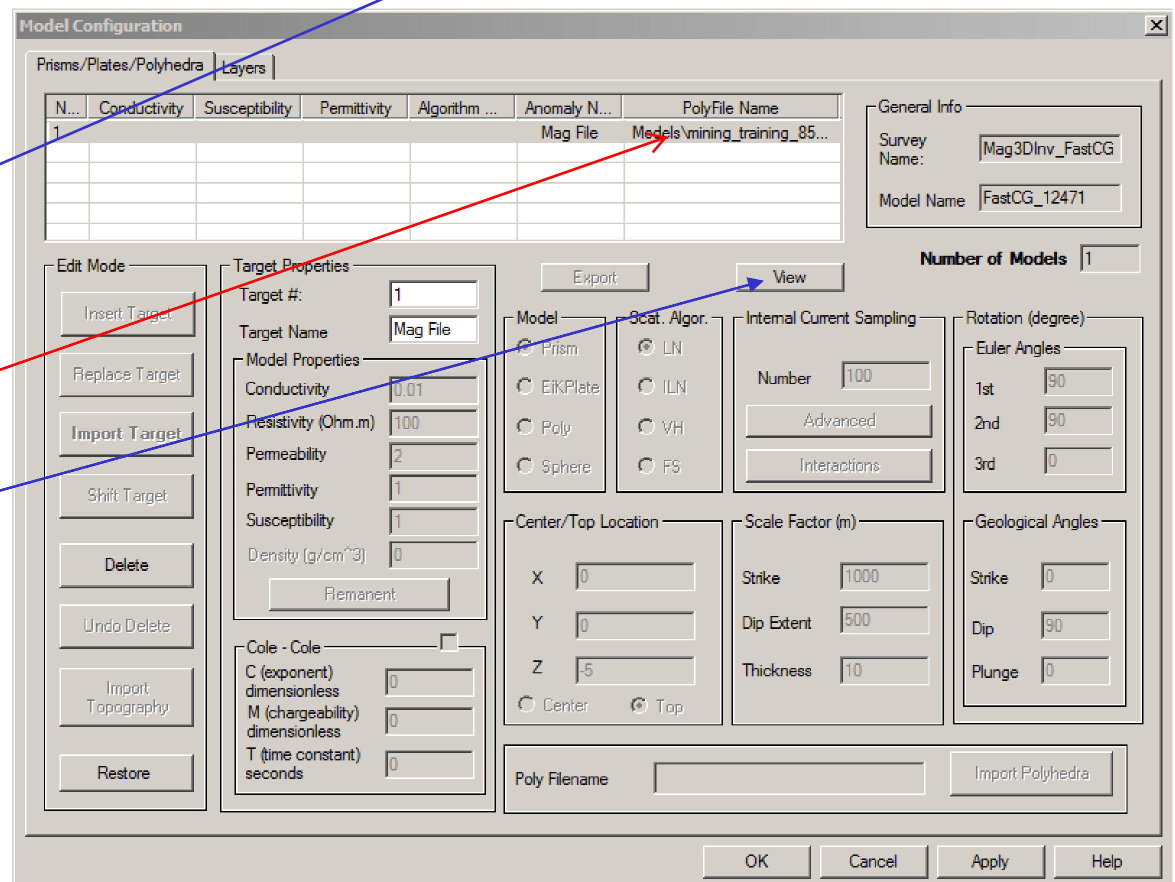
Therefore, users can reduce the range of model either before inversion (by Select Search Area) or after inversion (by Cell Removal)

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

Inversion Evaluation

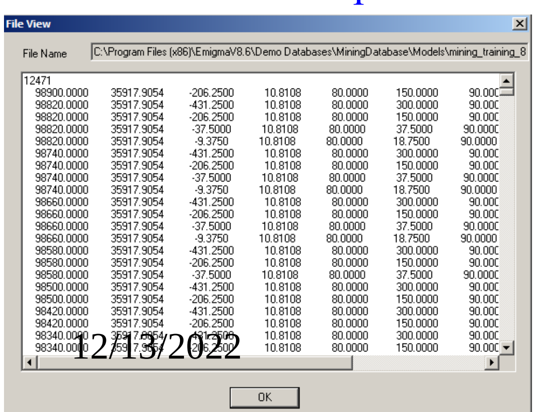
An inversion is selected. You will note the “Model” button is checked. If the “Model” button is clicked…





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

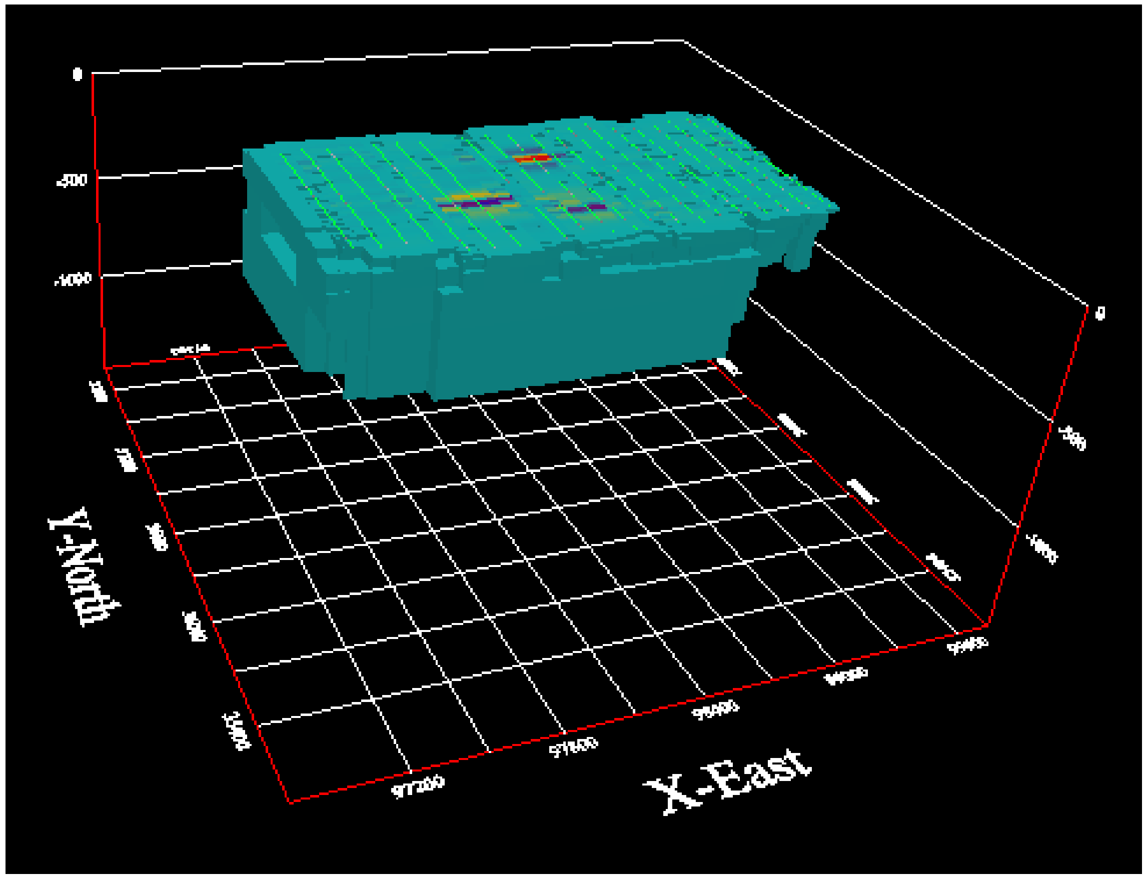
Click “View” button to open this file…



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

Inversion Evaluation

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



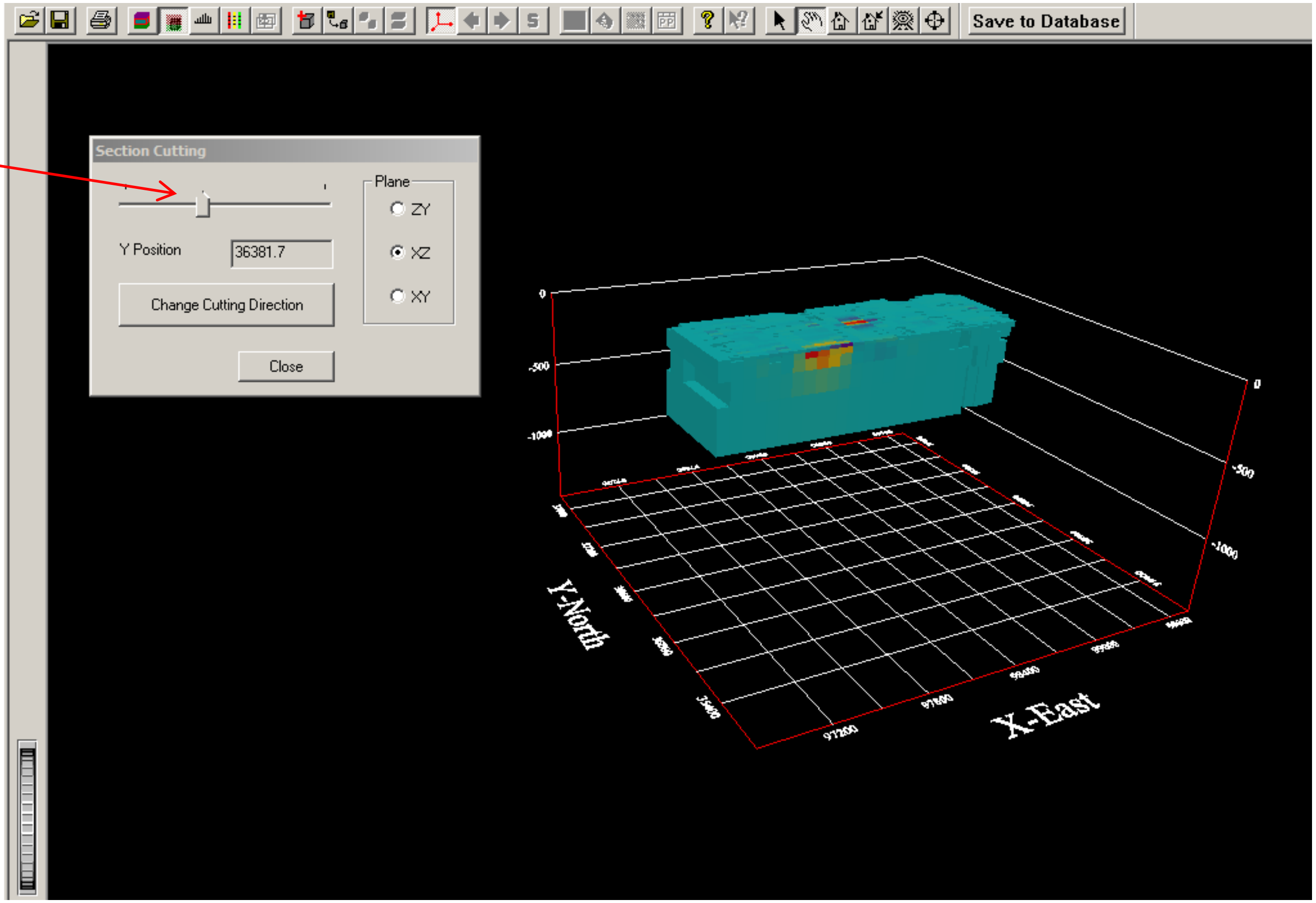
1. Import data
2. Examine data
3. Perform initial modeling
4. Perform 3D magnetic inversions
5. **Check model and create plots**

Inversion Evaluation

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



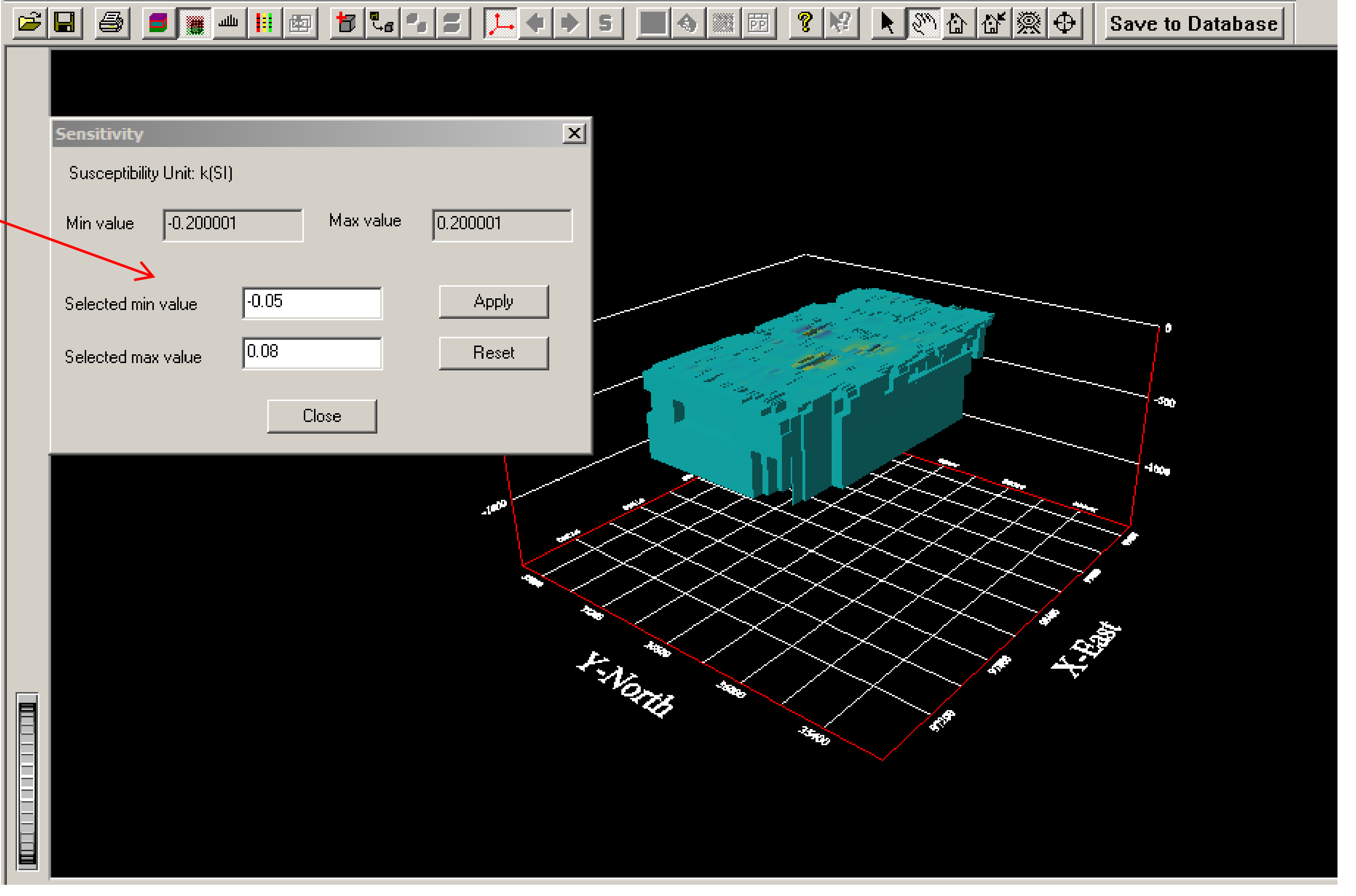
1. Import data
2. Examine data
3. Perform initial modeling
4. Perform 3D magnetic inversions
5. **Check model and create plots**

Inversion Evaluation

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

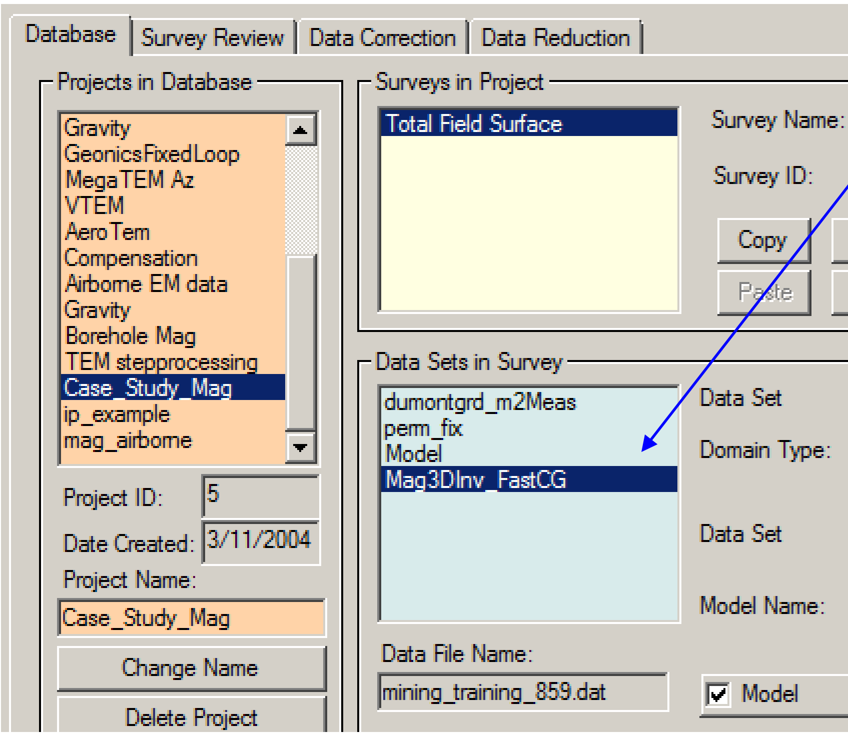
By adjusting minimum value and maximum value shown in the figure…

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

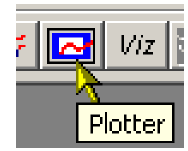


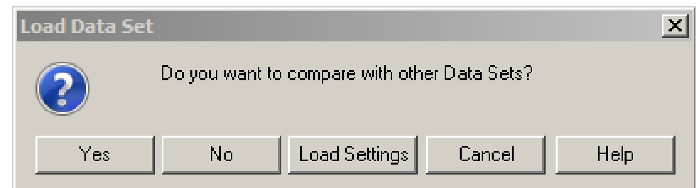
1. Import data
2. Examine data
3. Perform initial modeling
4. Perform 3D magnetic inversions
5. **Check model and create plots**

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.



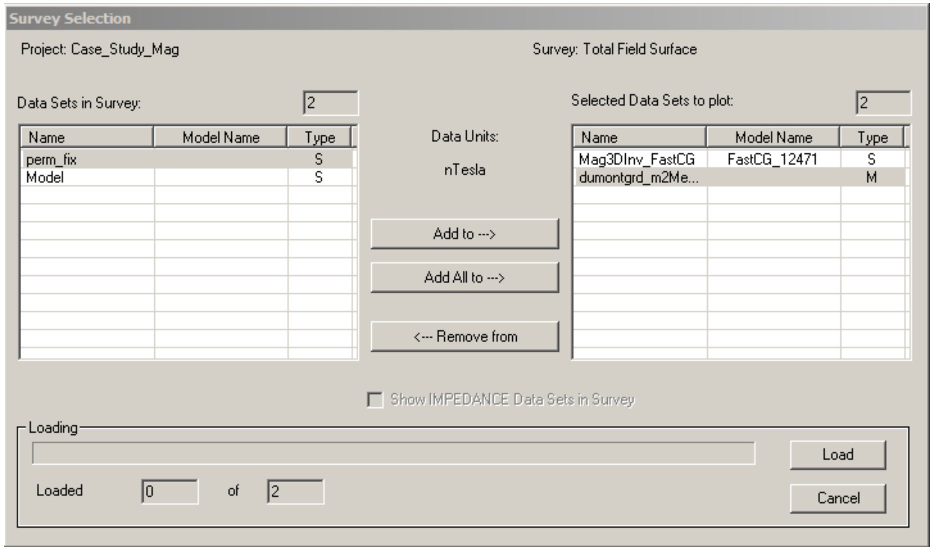


Select "Yes", when this dialog appears

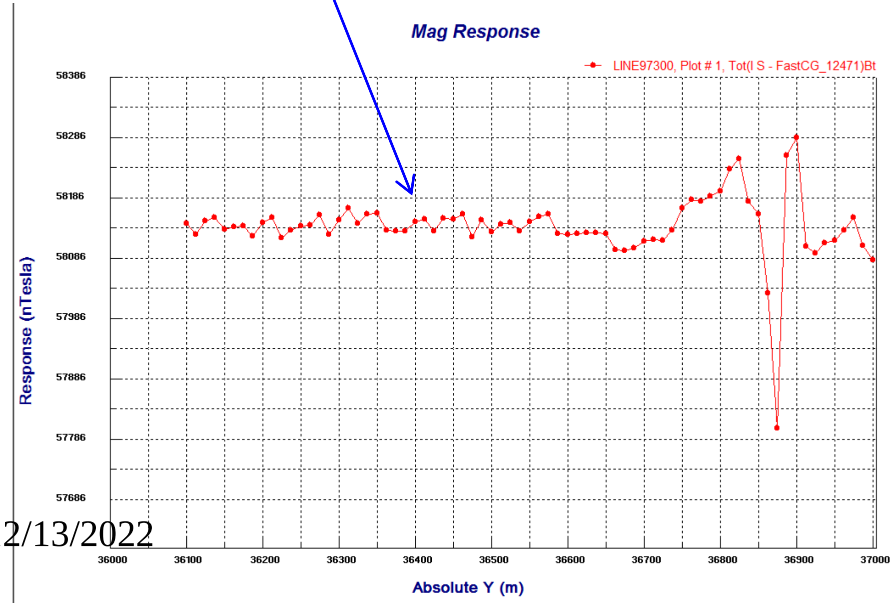
1. Import data
2. Examine data
3. Perform initial modeling
4. Perform 3D magnetic inversions
5. **Check model and create plots**

Inversion Evaluation

Select the data sets required for comparison and then click "Load"



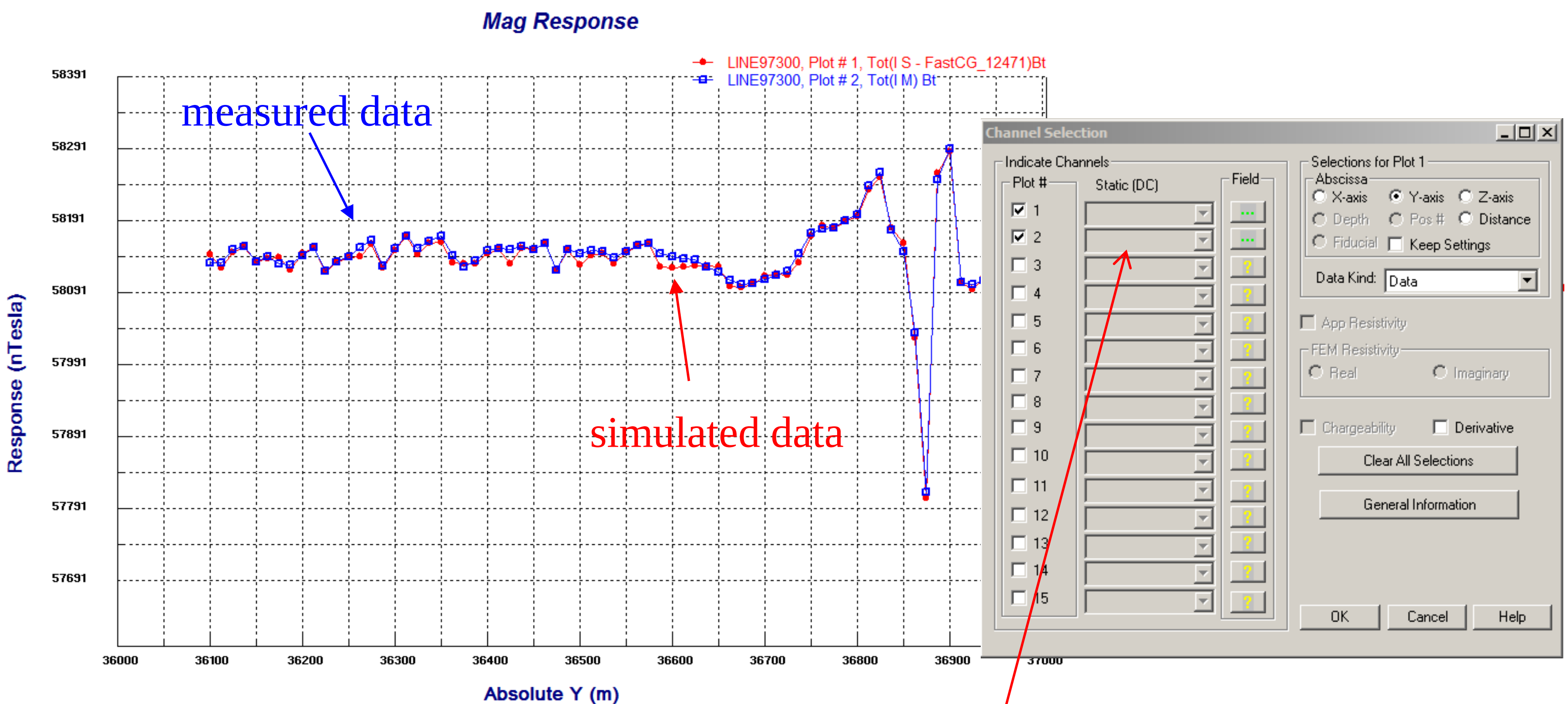
All selected data sets are then loaded to the Plotter application and the plot appears showing the simulated data of the first profile.



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

Inversion Evaluation

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 magnetic inversions
5. **Check model and create plots**

Inversion Evaluation

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.