# Grav3CH_inv: A GUI-based Matlab code for inverting gravity anomalies over sedimentary basins with vertical and horizontal density variation

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## USER GUIDE

### Description

**Grav3CH_inv** code combines the frequency and space domain methods of Chai and Hinze (1988), Cordell (1973) and Cordell and Henderson (1968) for estimating the 3D depth configuration of a sedimentary basin from gravity anomalies. The algorithm linked to the developed code improves the accuracy of the computations by incorporating an exponential increase in density with depth, and the precision in forward calculation of gravity anomalies during the on-going process is increased by using the shift sampling technique of computing the numerical inverse Fourier transform It allows considerations of density variations of the model space in the vertical and horizontal directions. The code allows the user also to perform forward calculation of gravity data from a defined depth grid which might be used as a part of the inversion process, e.g. for removing regional effects of deep layers.

The code is designed in Matlab environment (version R2013b) with an easy-to-use graphical interface (GUI) allowing the user an interactive control on managing the iterative procedure for a complete interpretation and illustrating the results data in interest without requiring any coding knowledge. The GUI also provides additional options for the visualization of the output data either in 2D/3D maps and cross-sectional view. Outputs can be exported either numeric data or as images.


- Chai, Y., Hinze, W.J., 1988. Gravity inversion of an interface above which the density contrast varies exponentially with depth. Geophysics 53, 837–845.
- Cordell, L., Henderson, R.G., 1968. Iterative three-dimensional solution of gravity anomaly data using a digital computer. Geophysics 33, 596–601.
- Cordell, L., 1973. Gravity anomalies using an exponential density-depth function - San Jacinto Graben, California. Geophysics 38, 684–690.


**Run the Code:** Locate the program code to the working space of Matlab or vice versa the working space of Matlab to the source directory of the code and thereafter type the name of the code to the command window of Matlab. By running of the Grav3CH_inv program a simple graphical interface pops up covering the quarter of the screen to the left. The configuration of the main GUI window is illustrated in Fig. 1.

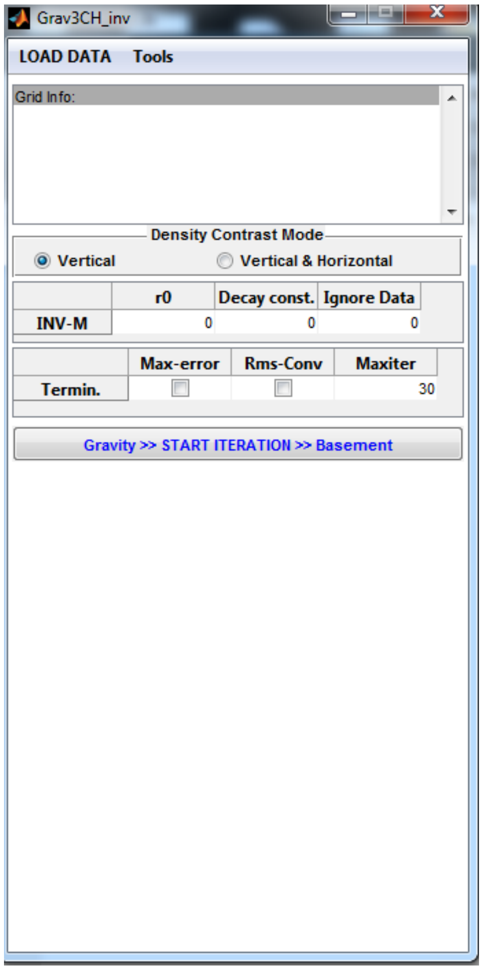



**Figure 1.** Screenshot from Grav3CH_inv main GUI after first run.

Here the upper part of the window allows the user to track the mesh information of loaded data, as well as root of file. Below this window, the two radio buttons enable the density variation to be considered either vertical or vertical & horizontal whereas the editable tables enable the settings for the initial parameters and the criterion for the termination of the iterative procedure. The remaining part of the window is the display area for the input map.

Description of abbreviations in the control panel are as below:

- **INV-M:** inversion mode is active (default)
- **FWR-M:** forward-mode is active
- **r0:** the density contrast at the surface
- **Decay Const.**: the decay factor that controls the decrease of the density contrast with depth
- **Max-err:** The stopping criterion of the iteration procedure is a quantity of the greatest error

$$\phi = sup\{|\Delta g_{obs(i,j)} - \Delta g_{calc(i,j)}|\}$$

- **RMS-CONV:** The stopping criterion of the iteration procedure is a quantity of root mean square error.

$$RMS = \sqrt{\frac{\sum_{i=1}^{m} \sum_{j=1}^{n} \left(\Delta g_{obs(i,j)} - \Delta g_{calc(i,j)}\right)^2}{m \times n}}$$

where $\Delta g_{obs(i,j)}$ and $\Delta g_{calc(i,j)}$ are the observed and calculated gravity anomalies at grid point (i, j), respectively.

- **Maxiter:** The maximum number of iteration in the case of none of the stopping criteria has been accomplished.
- **Ignore Data:** As an optional preference, to avoid edge effects, some near-edge data may be cut off by editing the "Ignore Data" cell (default is zero). In this case, the RMS or the greatest error calculation is made by omitting these data close to the edges. However, using an input gravity data set larger than the area of interest could be an alternative reasonable solution to avoid such effects.

## Required data and formats

Loading the gravity data set is provided by the interactive "Load Data" menu located at the top left of the window which allows the user loading a grid file compatible with Golden Software Surfer formats (*.grd [Surfer 7 Binary grid / Surfer 6 text grid]) (Fig. 2).

The algorithm approves square as well as rectangular input grids. However, the grid interval is required to be equal along the east and north directions. Otherwise a warning box occurs in the case of incompatibility. The code does not support a blanked grid input.

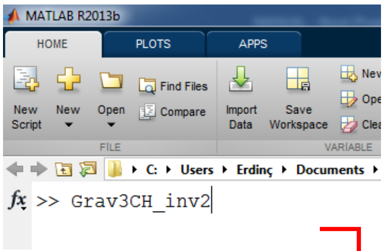
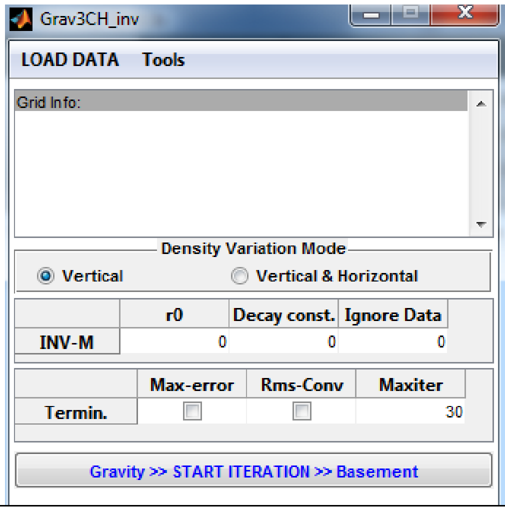
ADF Arc/Info Binary Grid (*.adf)
AM Amira Mesh (*.am, *.col)
ASC Arc/Info ASCII Grid (*.asc, *.aig, *.agr, *.grd)
BIL Banded Interleave By Line (*.bil)
BIP Banded Interleave By Pixel (*.bip)
BSQ Banded Sequential (*.bsq)
CPS-3 Grid Format (*.cps, *.cps3, *.asc, *.dat, *.grd)
DAT XYZ grid (*.dat)
DEM USGS DEM (*.dem)
ERS ER Mapper Grid Format (*.ers)
FLD AVS Field (*.fld)
FLT ESRI Float Grid Format (*.flt)
GRD Surfer 6 Text Grid (*.grd)
GRD Surfer 6 Binary Grid (*.grd)
GRD Surfer 7 Binary Grid (*.grd)
GRD Geosoft Binary Grid (*.grd, *.ggf)
GXF Grid eXchange Format (*.gxf)
HDF Hierarchical Data Format (*.hdf)
IMG Analyze 7.5 Medical Image (*.img)
LAT Iris Explorer (*.lat)
netCDF Network Common Data Form (*.nc)
RAW Binary Grid (*.raw, *.bin)
VTK Visualization Toolkit (*.vtk)
Z-Map Plus Grid Format (*.asc, *.dat, *.grd, *.xyz, *.zmap, *.zyc, *.zycor)

**Figure 2.** Supported formats for the gridded input data by Grav3CH_inv.

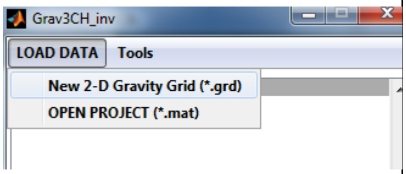
## Inversion procedure and storing the outputs

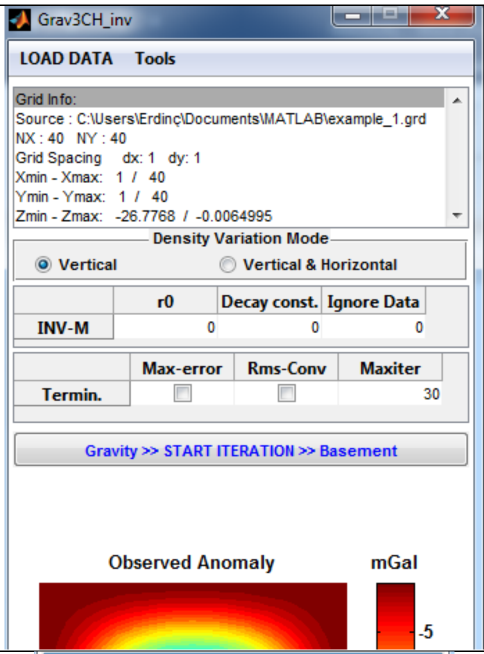
By validating range of the inputs and initiating the procedure, the code calculates the first approximations of the depths to basement with exponential density contrast variation and goes through with the iterative procedure within calling two independent background functions which one is for the forward FFT based computation of the gravity effect and the other for the next updating of the model depths in the space domain. This is iteratively continued until the termination criteria is reached. An instant plot of the obtained RMS or greatest error values during the ongoing iteration steps is auto displayed at the main GUI. Finally, the code records the gravity response and the inverted basement depth obtained at the step of termination, the difference between the observed and calculated gravity anomalies and both the RMS and greatest errors after each iteration to the temporary *.mat file indexed to the observed input grid. Eventually, a secondary GUI window pops up that allows the user to visualize any of the output maps/graphics which are selectable interactively with simple mouse controls. By preference, the results at any section of the maps can also be illustrated together with their profile views. Color adjustment on maps or a 3D view are additional tools provided by this control window. All of the output data can be exported by a user defined name either to a *.mat file comprising the complete inputs/outputs or to separated files of *.grd format for the maps and *.dat format for the error vectors and for any extracted profile data. Exported *.mat files from Grav3CH_inv code can be reloaded by the "Load Data" menu taking the advantage to re-view all the inputs, settings and the interpretation results at any time. Besides, maps and graphics illustrated at the GUI windows of the code can also be exported as some commonly used image formats (.bmp, .jpeg, .png, .emf, .tiff) of 300 dpi in resolution.

**Example-1A. Inversion modelling where density variation is vertical**

| Steps | Part of screen | |
|---|---|---|
| **1-**Run Grav3CH_inv |  Matlab command window |  |

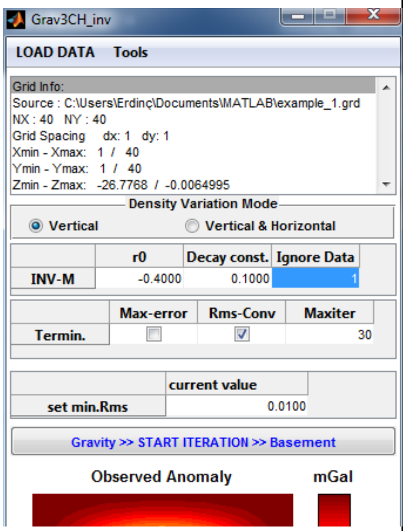
**2-** Load “**example_1.grd**” input file by “LOAD DATA” menu

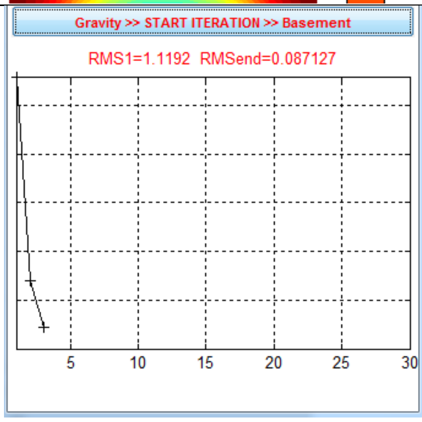



**3-** Set the density model and the iteration stop criterion.

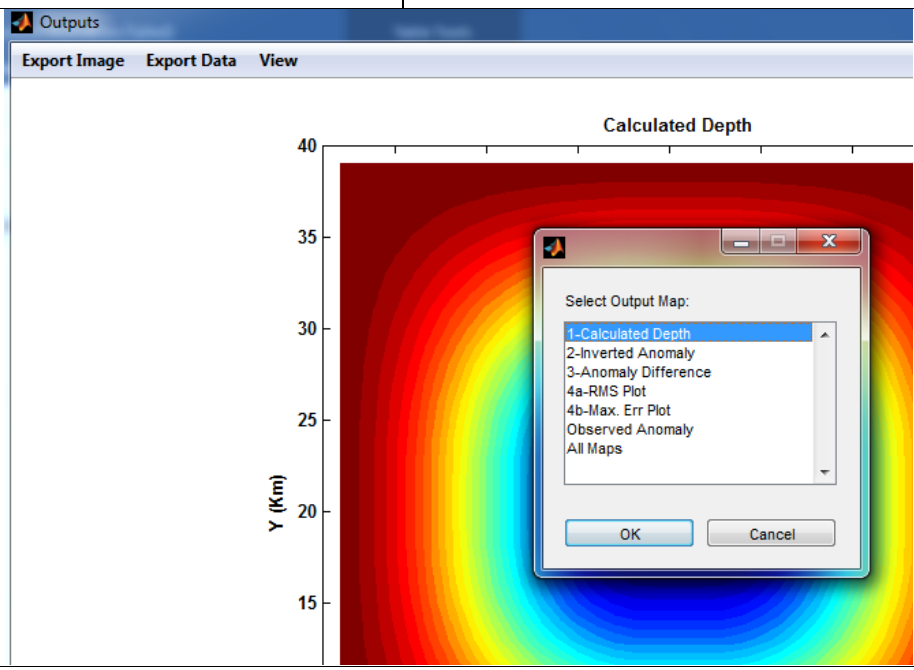
**4-** press “Gravity >> Start Iteration >> Basement” button to start the iterative procedure



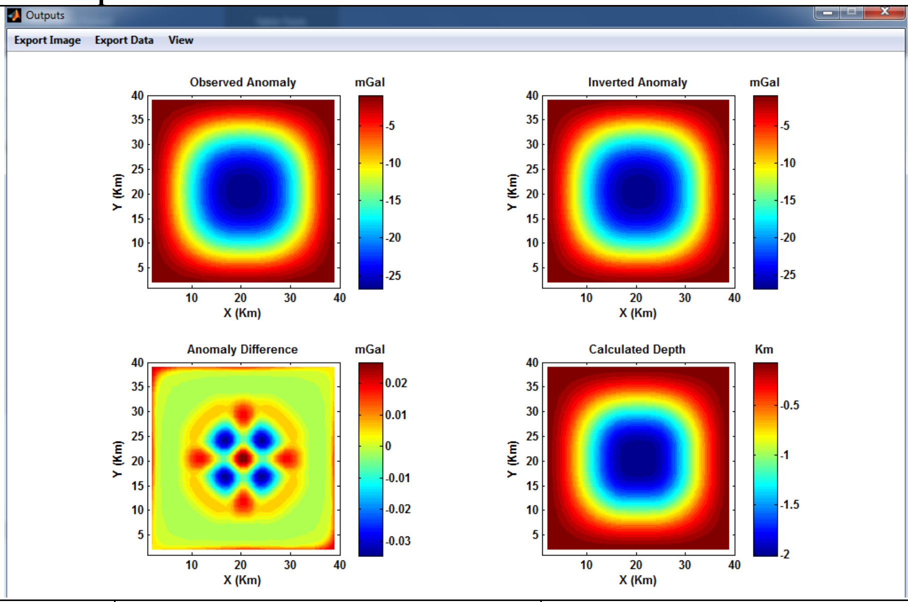




An instant plot of the obtained RMS values during the ongoing iteration steps is auto displayed at the main GUI.

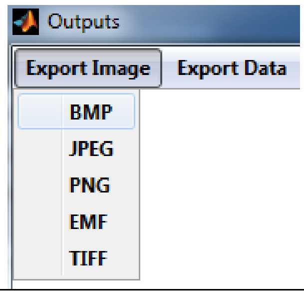
**5-** After termination, a secondary GUI window pops up that allows the user to visualize any of the output maps/graphics. **Click on screen to select and view the desired output**

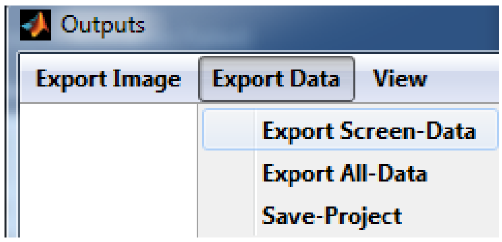


**i.e. Outputs "All Maps"**

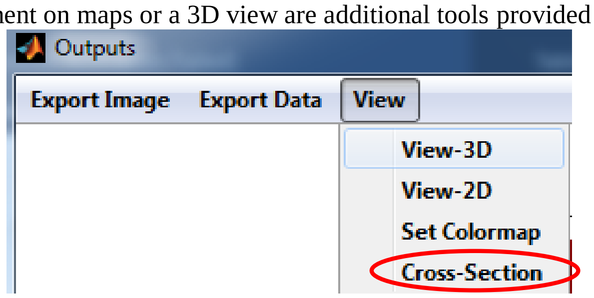



**6-** Outputs can be exported either numeric data or as images.




**Optional View:** By preference, the results at any section of the maps can also be illustrated together with their profile views. Color adjustment on maps or a 3D view are additional tools provided by this control window.




Note: 3D view is enabled only for the calculated depth map
Extracting cross-section data is enabled only at 2D views.

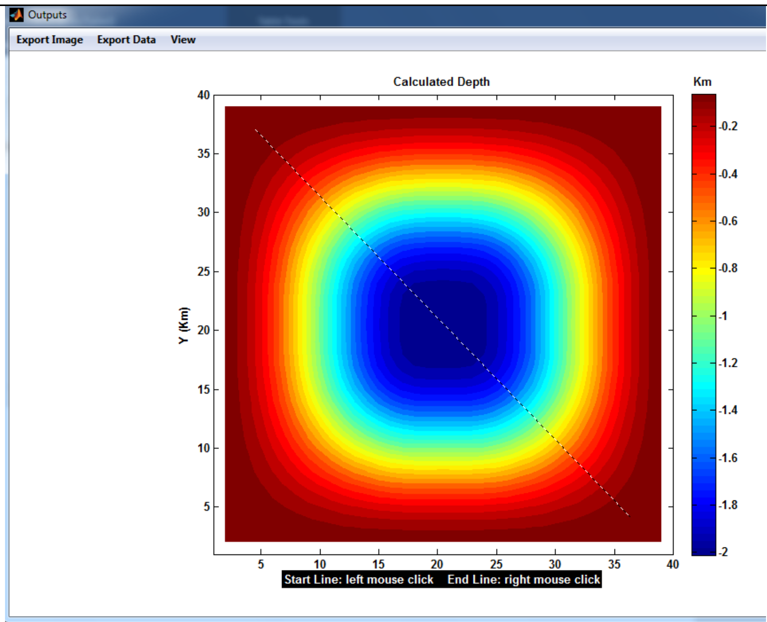
**7. Get Cross-Section Data (optional)**

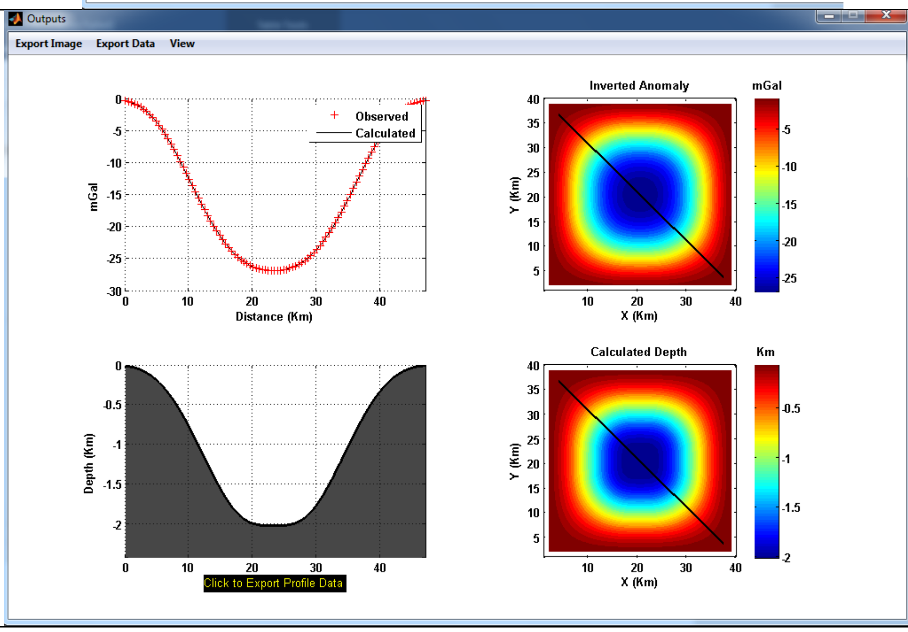
**7.1** view a map

**7.2** left mouse click for the start point of profile

**7.3** right mouse click for the end point of the profile

**7.4** Click on screen to export data/return



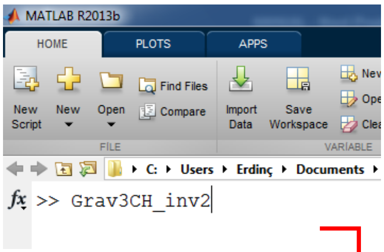
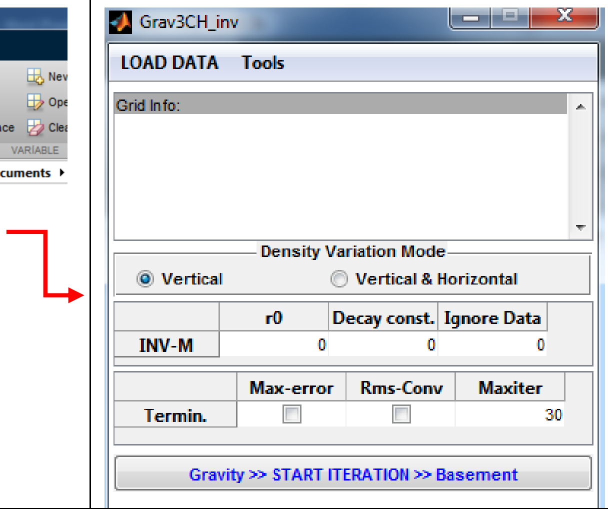
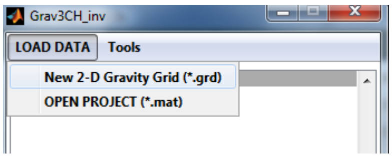
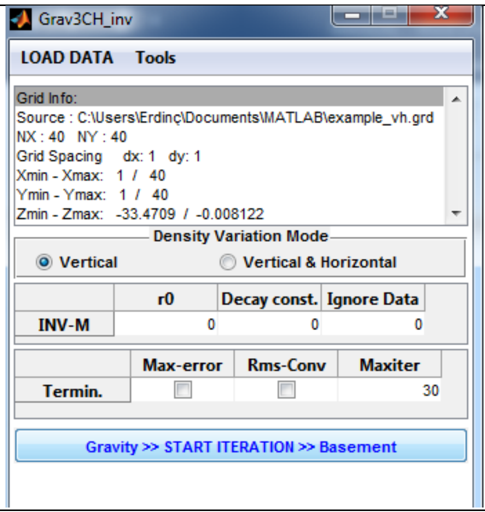
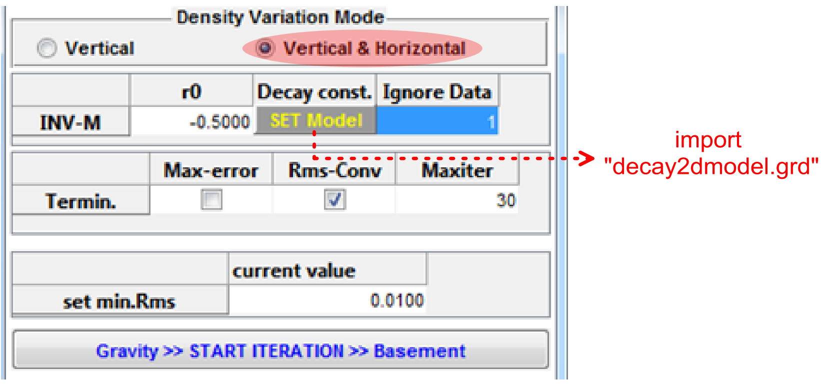




Description for variables in a * -CHproj.mat file exported from Grav3CH_inv code:

Data and their variables in Matlab can be retrieved into the storage simply by writing “load(‘filename*.mat’)” to the command window or to a script in Matlab. Variables from an * -CHproj.mat file storage are as follows; **[data]:** matrix of input gravity anomaly grid, **[nx, ny]**: number of columns and rows of the input grid, respectively, **[dx, dy]**: grid spacing distance in x and y direction, **[xmin, xmax, ymin, ymax]**: map limits in x and y direction, **[x, y]**: mesh of grid node coordinates in x and y direction, **[r0, lambda]:** inputs of density-depth dependence, **[criterio]:** input of the threshold value, **[termin]**: set of the measure of the fit (1 is the max.err, 0 is the RMS), **[maxiter]:** set of number of maximum iteration, **[wedge]:** set of the number of ignored data from edges, **[zcalc, gcalc]:** calculated basement grid, calculated gravity response grid, **[rmstor, erstor]:** RMS values and the greatest error values stored during the iterative process, **[filnam]:** source file name of the input data grid, **[filnam_lambda2d, lambda2d]:** source file name and the 2-D grid of the decay constant model.

**Note:** an exported *-CHproj.mat file from the code can be reloaded by the "LOAD Data" menu at the main Gui of the program to review any previous interpretation.

**Example-1B. Inversion modelling where density variation is vertical and horizontal.**

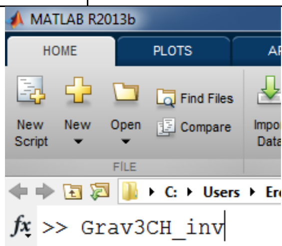
| Steps | Part of screen |
|---|---|
| **1**-Run Grav3CH_inv | <br>Matlab command window<br> |
| **2-** Load "**example_vh.grd**" input file by "LOAD DATA" menu | <br> |
| **3-** Set the Density Variaton Mode to "**Vertical & Horizontal**"<br>**4-**<br>***Set** r0=-0.5 gr/cm$^3$<br>***Set** Ignore Data =1<br>***Import** 2D Decay constant model<br>***Set** the iteration stop criterion.<br><br>***press** "Gravity >> Start Iteration >> Basement" button to start the iterative procedure |  |

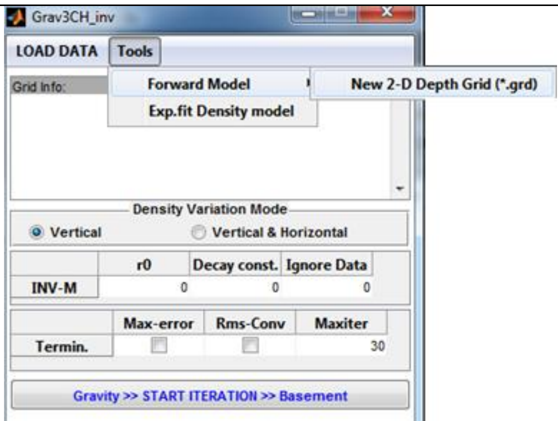
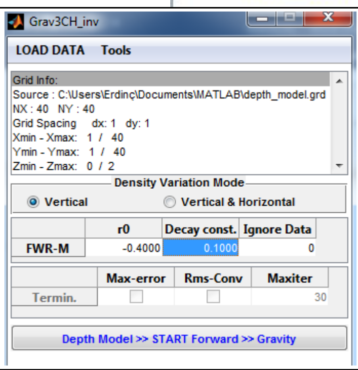
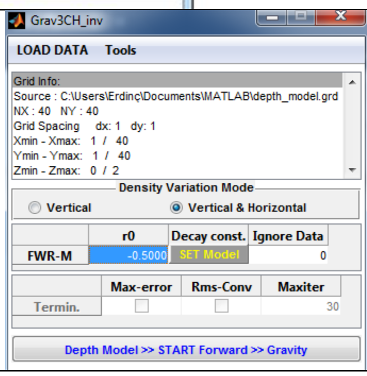
*After termination, a secondary GUI window pops up that allows the user to visualize any of the output maps/graphics (**see steps 5-7 at Example-1A**)

## Forward procedure and storing the outputs

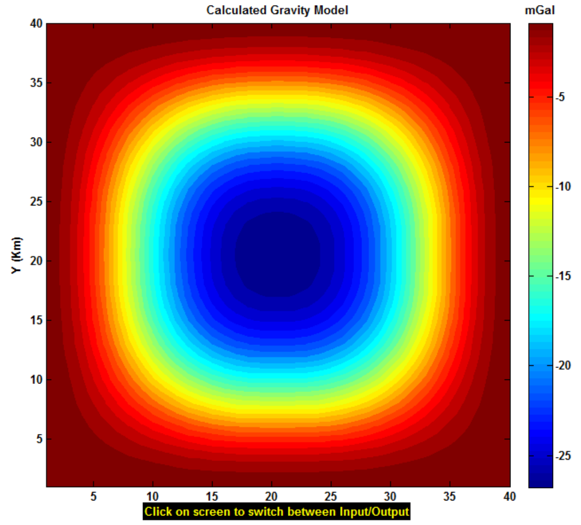
The code allows the user the forward calculation of gravity data from a defined depth grid which might be used as a part of the inversion process, e.g. for removing regional effects of deep layers. The forward calculation mode of the GUI can be activated by importing the depth grid by the “Tools / Forward Model / New 2-D Depth Grid (*.grd)” menu item. This allows the user loading a grid file compatible with Golden Software Surfer formats (*.grd [Surfer 7 Binary grid / Surfer 6 text grid]) (Fig. 2). The grid interval is required to be equal along the east and north directions. Otherwise a warning box occurs in the case of incompatibility. The code does not support a blanked grid input. Below are examples for the forward procedure from a depth model “depthmodel.grd” considering the density variation is vertical and vertical & horizontal.

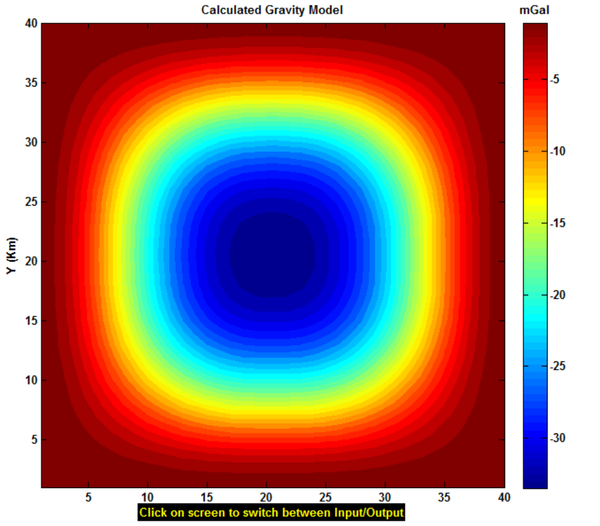
### Example-2. Forward modelling

<table>
<tr><th rowspan="2">Steps</th><th colspan="2">Part of screen</th></tr>
<tr><th>Vertical density variation</th><th>Vertical & Horizontal density variation</th></tr>
<tr><td>1-Run Grav3CH_inv</td><td colspan="2">

Matlab command window</td></tr>
<tr><td>2- Load “depth_model.grd” input file by “Tools / Forward Model / New 2-D Depth Grid (*.grd)” menu item</td><td colspan="2">
</td></tr>
<tr><td rowspan="2">3- Setting the Density Variaton Mode and the density depth dependence inputs</td><td>
</td><td>
</td></tr>
<tr><td>Density Variaton: Vertical<br>r0= -0.4 gr/cm$^3$<br>Decay const. = 0.1 km$^{-1}$</td><td>Density Variaton: Vertical & Horizontal<br>r0= -0.5 gr/cm3<br>Decay const.= import “decay2model.grd” by “Set Model” menu item.</td></tr>
<tr><td>4-</td><td colspan="2">Press “Depth Model >> START Forward >> Gravity” button to start calculations</td></tr>
</table>

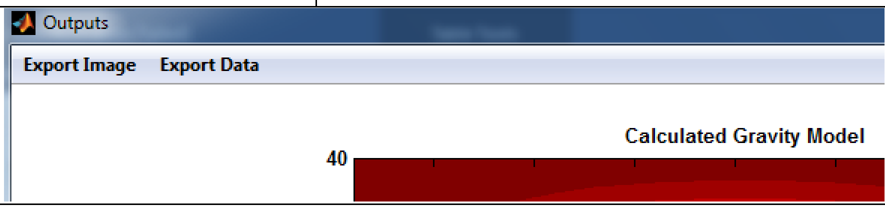

*After forward calculation of gravity anomalies have been performed, a secondary GUI window pops up that allows the user to visualize and exporting the output




| | |
|---|---|
| Output: Calculated gravity for vertical density variaton:<br>r0= -0.4 gr/cm$^3$<br>Decay const. = 0.1 km$^{-1}$<br>Save as : “example_1.grd” **(used in Example 1A)** | Output: Calculated gravity for Vertical & Horizontal density variaton:<br>r0= -0.5 gr/cm$^3$<br>Decay const. = 2-D data input “decay2model.grd”<br>Save as : “example_vh.grd” **(used in Example 1B)** |

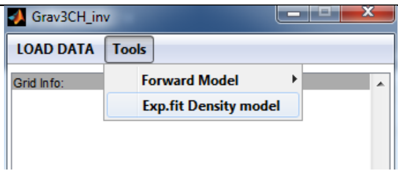
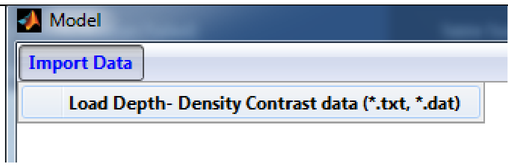
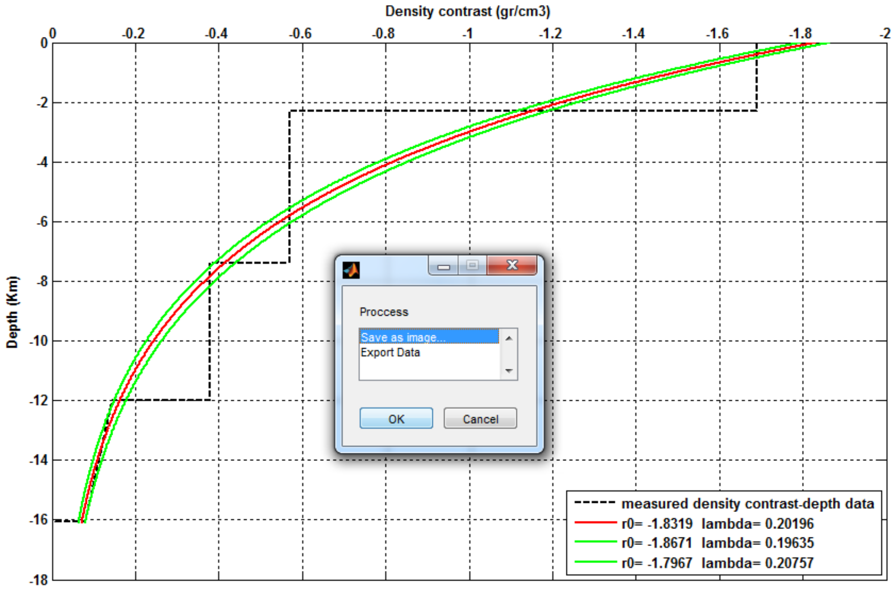
**5-** Output can be exported either numeric data or as images.




## Additional function for forward modelling

Besides the inversion scheme and the forward calculation, the code also includes an in-built GUI window for performing a least-squares fit of an exponential function to measured density contrast-depth data to approximate the density-depth dependence parameters of a basin. The related GUI window for such a process can be activated by the button press on “Tools/Exp. Fit Density model” menu item located at the uppermost of the main GUI. The required data format is a two column ascii-file containing the measured depth-density contrast data columns (*.dat, *.txt). The exponential curve fitting is performed using the in-built “fit” function of Matlab. After data loading, the code immediately performs the fitting process and illustrates the results within the coefficients related to the fitted curve [r0: surface density contrast, lambda: the decay constant]. Output can be exported either numeric data or as images. Below is an example;

**Example-3. Exponential curve fitting to a measured depth-density contrast data**

| Steps | Part of screen | |
|---|---|---|
| **1-**Activate exponential curve fitting GUI by “Tools/Exp. Fit Density model” menu item” |  | <br>import “depth_density_data.txt” |
| **2-** Results<br>Click on screen to export data |  | |

**FUNCTIONS in Grav3CH_inv Code:**

__Data loading functions__

**impgrd:** imports a new 2-D grid, memorizes to temporary file, updates inputs table content
**grid2checker:** Checks format of 2-D grid input, searches for format errors
**lodgrd6txt:** reads text grid format (*.grd)
**lodgrd7bin:** reads binary grid format (*.grd)
**openproj:** Re-loads a complete interpretation saved as a project file (matlab binary file)
**imporlambda: :** imports a new 2-D decay constant model
**loddens:** imports depth-density contrast data for exponential curve fitting

__Inversion/forward modeling functions__

**startiter:** retrievs inputs, performs inversion/forward procedure, memorize outputs
**maininv_0CHCH:** performs inversion sheme
**FW_CH:** performs forward calculation
**freqaxTG:** calculates wavenumbers k, kx,ky and variables used in FW_CH

__Decision making functions__

**algor_inv_forw:** routes the Gui structure according the type of data grid imported (depth , gravity)

**checklambda:** checks the presence of 2-D decay constant model
**radbehav:** routes the inversion/forward procedure according the type of density variation mode
**decidesavcross:** question dialog box for the record of cross-section data
**selectionout_inv:** question dialog box for the display of output data in inversion mode
**selectionout_forw :** question dialog box for the display of output data in forward mode
**error_message:** checks error alerts and notifies the user
**plotcont:** prepares the preferred map for plotting
**tabl1_edit:** controls the sign of the initial parameters
**termino:** controls the stopping criterion
**setcriterio:** controls the threshold value of the termination criteria

**Display functions**
**mapper:** displays a color filled 2D/3D map of gridded data (color map is jet in default)
**plotcross:** interpolates data (observed anomaly, calculated anomaly and basement) between interactively selected two coordinates
**rmsplot:** displays the rms variation obtained during the iteration steps
**ersplot:** displays the greatest error variation obtained during the iteration steps.
**instaRMSplot:** instant display of the rms or greatest error variation
**list1w:** wites the mesh information of loaded data, as well as root of file to the list box
**colormapeditor:** color map editor ui (in-built function in matlab)

**Calculator functions**
**rmscalc:** calculates the rms and the greatest error variation
**getcross:** interpolates data (observed anomaly, calculated anomaly and basement) between interactively selected two coordinates
**startdensfitter:** performs exponential curve fitting

**GUI related functions**
**create_MainGui:** creates main GUI
**create_actwindow:** creates an empty figure next to main GUI
**create_outputmenu:** creates menu items related to procedure
**decaymodel_wind:** creates window for importing/plotting of 2D decay model
**closwindows:** closes windows opened (except the main GUI)
**delaxes:** delete axes in figure window
**densmodelfit:** creates GUI window for exponential curve fitting
**posfig1:** resets the position of main GUI to default

**Saving functions**
**grdout:** converting output as grid format (*.grd)
**datasout:** exporting data (numeric)
**datasout:** exporting data (image)
**savproj:** saving complete interpretation as a project file (matlab binary file, *-Chproj.mat)
**savfitcur:** exporting exponential fitting curve to an ascii file (*.dat)
**savcross:** exports cross-section data to an ascii file (*.dat)