Grav3CH_inv: A GUI-based MATLAB code for estimating the 3-D basement depth structure of 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 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. 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.

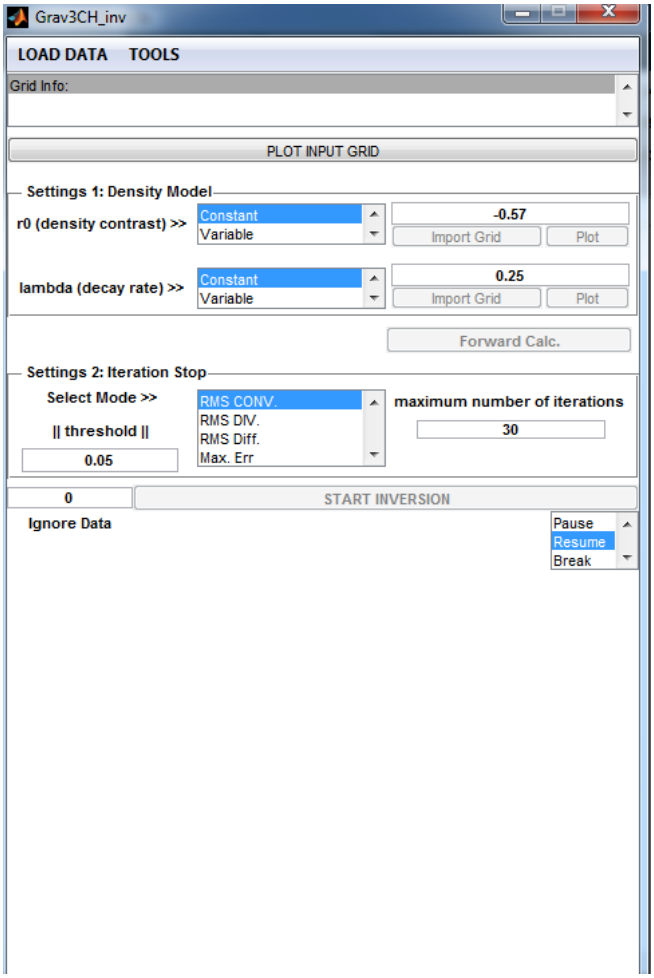


Figure 1. Screenshot from Grav3CH_inv main GUI after first run.

Here the upper part of the window allows the user to track the mesh information of the loaded data, as well as root of file. Below this window, menu items in the panel [Settings-1] enable setting the density variation to be considered either vertical or vertical & horizontal and the menu items in the panel [Settings-2] enable the settings for the criterion of the iteration stopping. The remaining part of the window is the display area for the graphical plot of the misfits during the on-going iterations.

Description of header abbreviations in the control panel are as below:

- **r0:** the density contrast at the surface
- **lambda**: the rate 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; RMS DIV; RMS Diff:** 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.

For the "RMS-CONV" and the "Max. Err" modes, the iteration stops when the fit falls below the predefined threshold or when it completes the preset limit number of iterations, while in the "RMS-DIV" mode, it stops when the RMS between the observed and calculated data has increased relative to the RMS obtained in the previous step, and in the RMS Diff. mode, the iteration stops when the difference between the RMS values obtained in successive steps falls below the given threshold. **The iterative procedure can also be manually stopped by the user or paused during iterative steps to check the results.**

- **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 omit 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 gridded dataset 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.

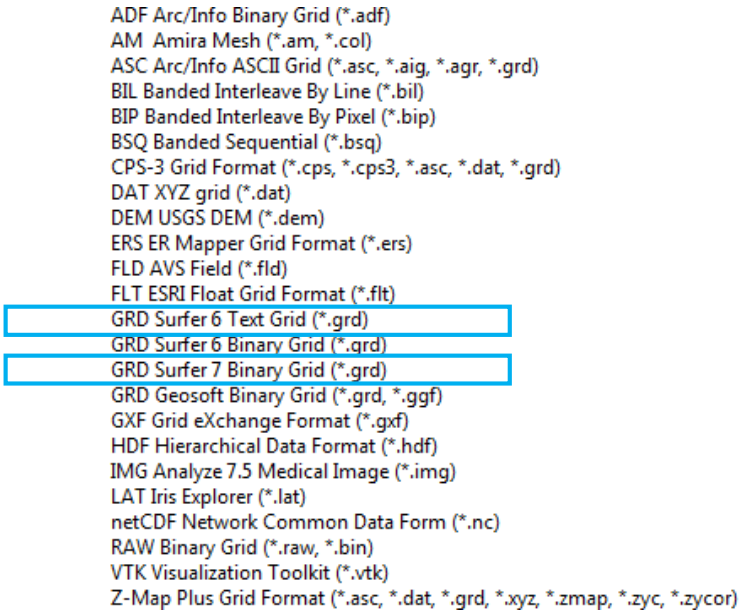


Figure 2. Supported formats for the gridded input data by Grav3CH_inv.

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 on-going 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 into a 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 by the drop menu items. 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 3-D view are additional tools provided by this control window. Exporting can be done as an image for a selected output or numerically for all outputs to a user-defined folder. Formats for numeric exports (*.grd, *.dat) are compatible with the formats of Golden Software, whereas the image exports are supplied in some commonly used graphic formats (*.bmp, *.jpeg, *.png, *.emf, *.tiff) of 300 dpi in resolution.

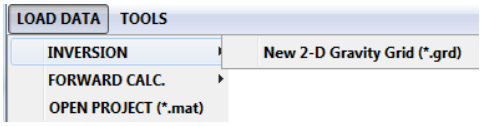
All the output data together with the settings are also stored as a binary MATLAB file (*.mat) where this can be imported by the code at any time for a review or an update of the inversion.

EXAMPLES

Example-1A. INVERSION MODE (Density variation: Vertical)

Step 1: 1a) Load "example_1.grd" gravity input grid by "LOAD DATA" menu, **1b)** configure Settings 1-2, **1c)** Start Inversion.

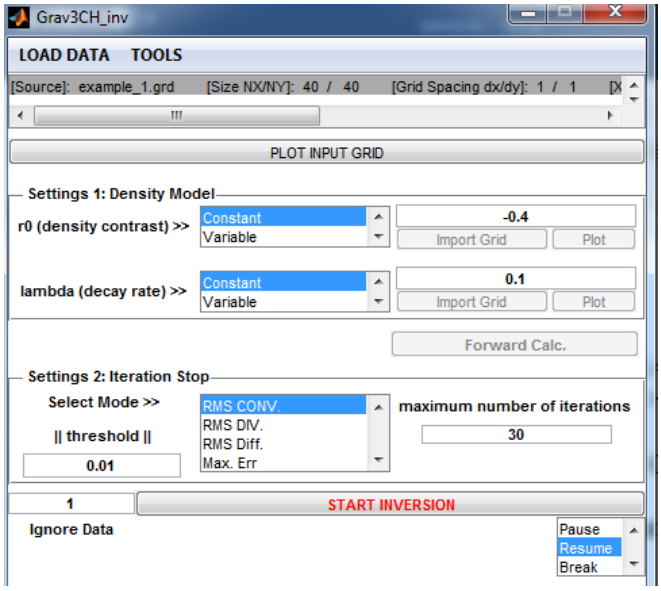
1a



1b)
Settings-1
r0 >> constant >> -0.4 g/cm^3
lambda >> constant >> 0.1 km^{-1}
Settings-2
Iteration Stop: RMS CONV
threshold: 0.01
max. number of iteration: 30
Ignore Data: 1

1c) [Start Inversion]

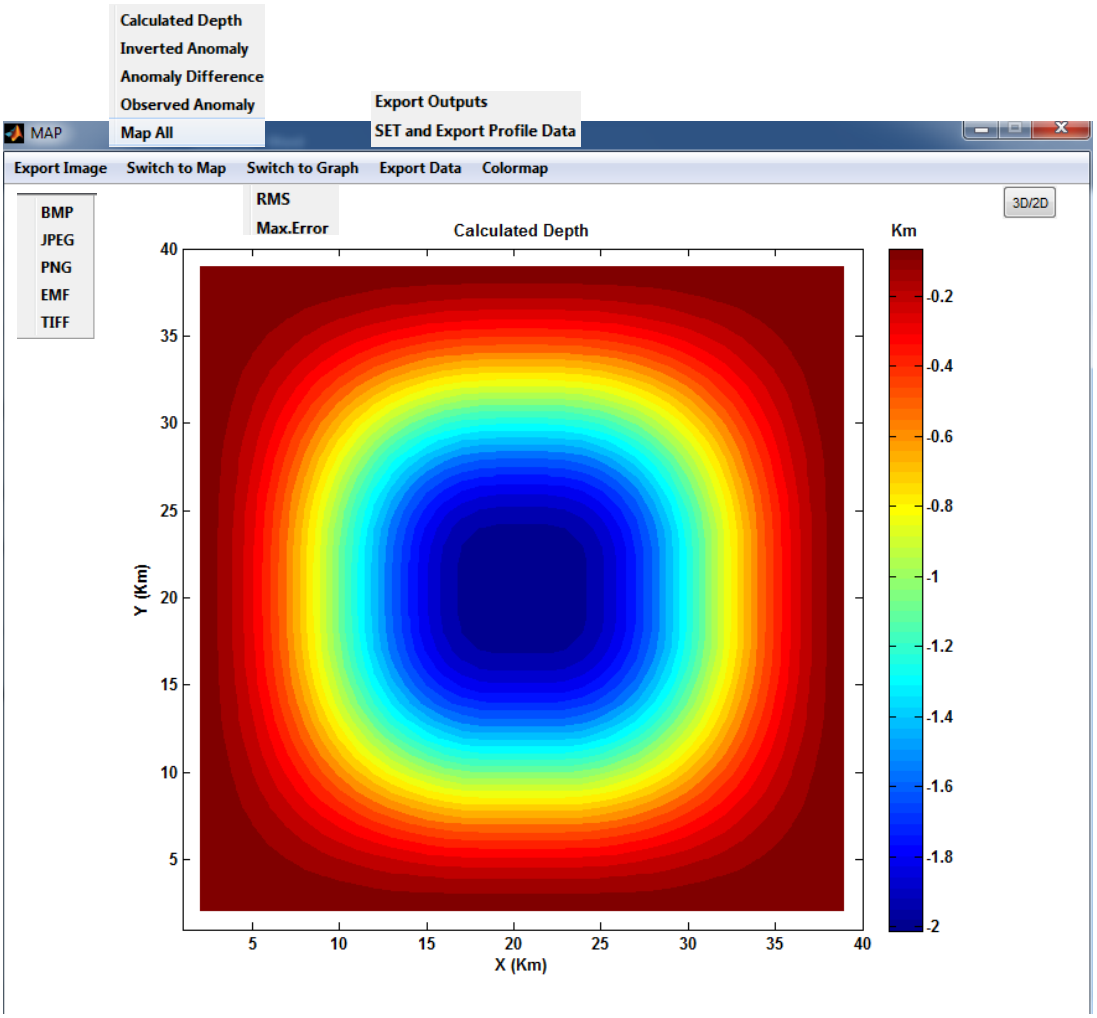
Screen



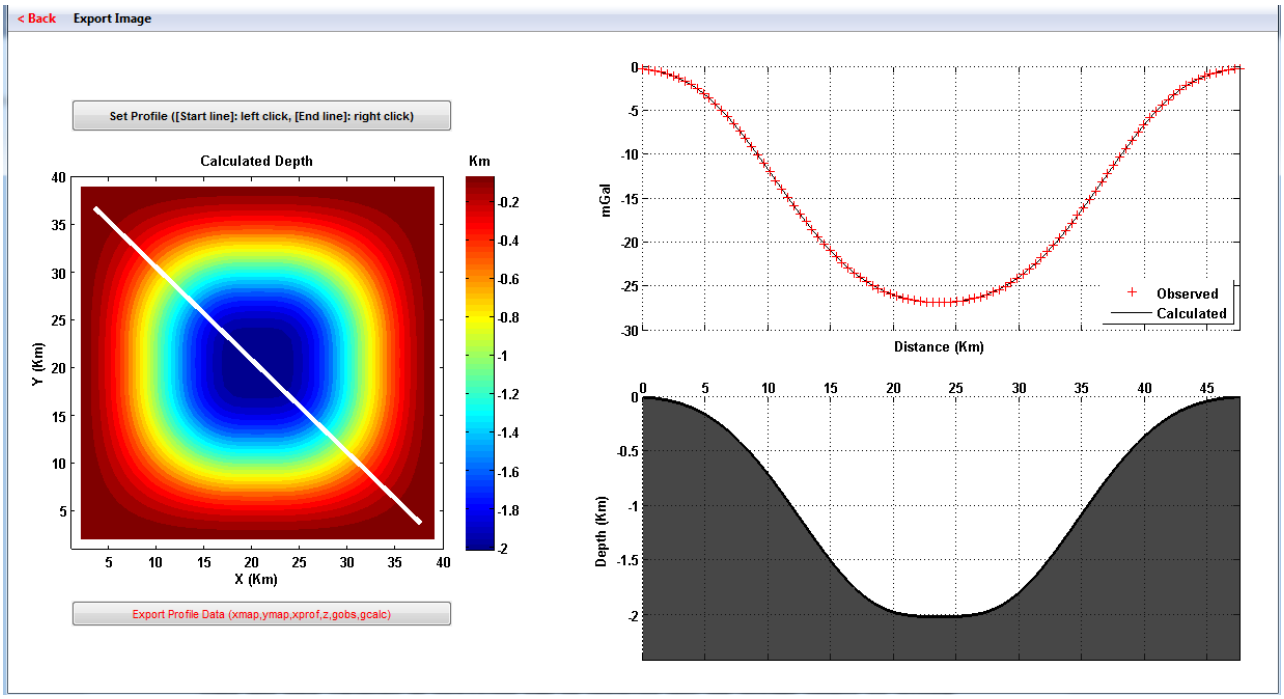
Step 2: A second user interface emerges and enables the user to display and export any of the produced maps or graphics in optional preferences.

Outputs GUI Window: [Switch to Map]: Calculated Depth, Inverted Anomaly, Anomaly Difference, Observed Anomaly; [Switch to Graph]: RMS, Max. Err; [Export Data]: Export Outputs, Set and Export Profile Data; [Export Image]: BMP, JPEG, PNG, EMF, TIFF; [3D/2D]: Calculated Depth 3-D or 2-D map view.

Checkout the uimenu tools of the Grav3CH_inv outputs GUI for a desired plot or an export format.



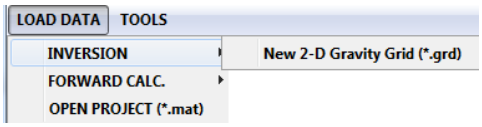
Profile Data: Use uimenu item [Export Data]: >> Set and Export Profile Data



Example-1B. INVERSION MODE (Density variation: Vertical & Horizontal (Surface density contrast: unique))

Step 1: 1a) Load "example_vh.grd" gravity input grid by "LOAD DATA" menu, **1b)** configure Settings 1-2, **1c)** Start Inversion.

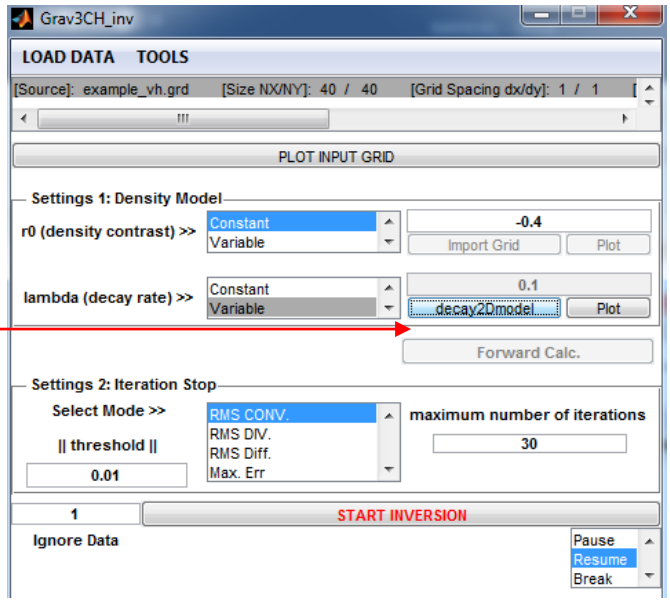
1a



1b)
Settings-1
r0 >> constant >> -0.5 g/cm^3
lambda >> variable >> Import Grid: decay2model.grd
Settings-2
Iteration Stop: RMS CONV
threshold: 0.01
max. number of iteration: 30
Ignore Data: 1

1c) [Start Inversion]

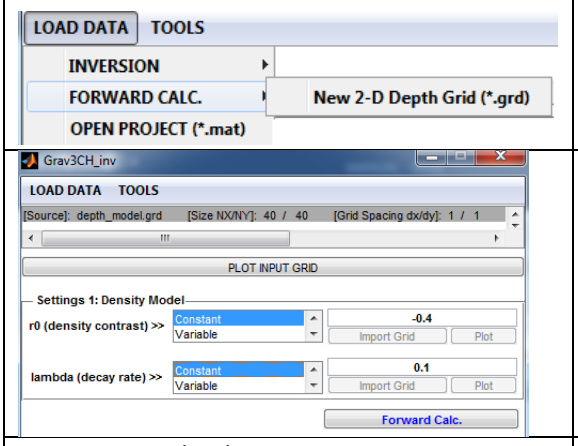
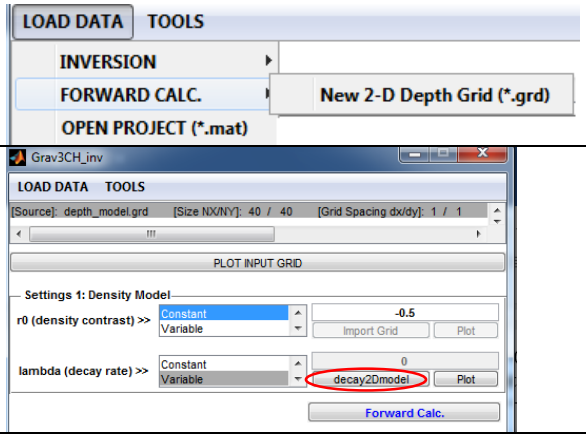
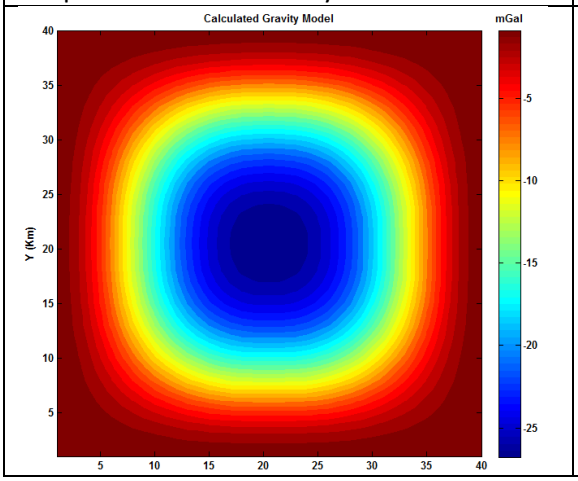
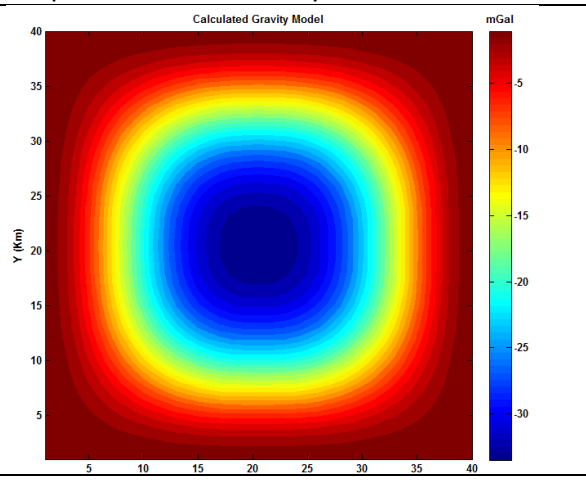
Screen



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 [LOAD DATA >> FORWARD CALC >> New 2-D Depth Grid] 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 "depth_model.grd" considering the density variation is vertical and vertical & horizontal.

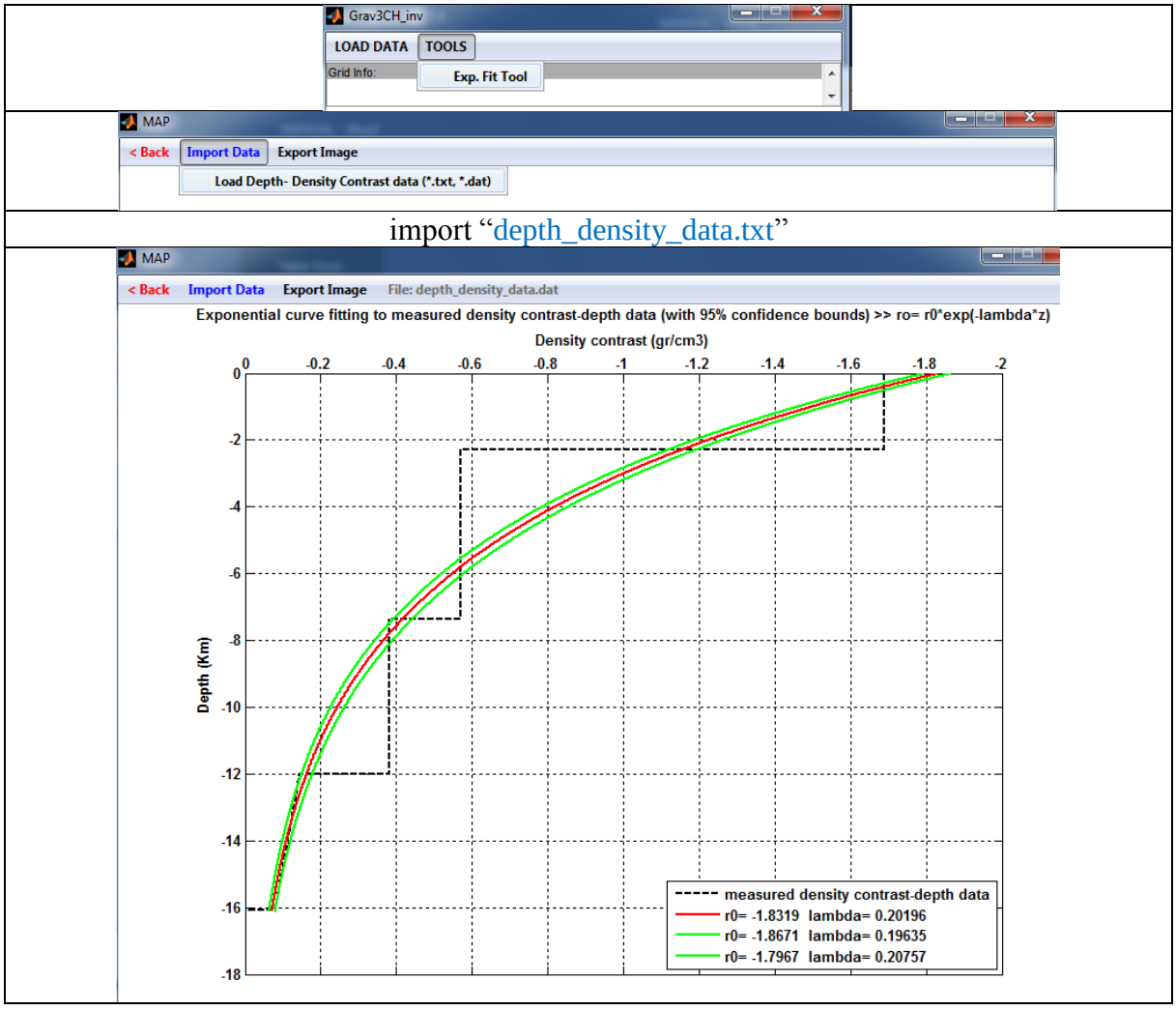
Example-2. Forward Calculation Mode

Density variation: Vertical (Surface density contrast: unique)	***Density variation: Vertical & Horizontal (Surface density contrast: unique)***
Settings-1 r0 >> constant >> -0.4 g/cm^3 lambda >> constant >> 0.1 km^{-1}	Settings-1 r0 >> constant >> -0.5 g/cm^3 lambda >> variable >> Import Grid: decay2model.grd
Import: depth_model.grd	Import: depth_model.grd
	
Press Forward Calc.	Press Forward Calc.
Output: Calculated Gravity Model	Output: Calculated Gravity Model
	

[TOOLS/ Exp. Fit Tool]: Performing a least-squares fit of an exponential function to measured density contrast-depth data

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 a measured density contrast-depth data for approximating the density-depth dependence parameters of a basin. The related GUI window can be activated by the button press on **[Tools/Exp. Fit Tool]** 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 loading the data, the code performs the fitting process and illustrates the results within the coefficients related to the fitted curve [r0: surface density contrast, lambda: the rate of decay factor]. The output can be saved in image format.

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



FUNCTIONS in Grav3CH_inv Code:

Data loading functions

datainput: imports a new 2-D grid, memorizes to temporary file
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)
load_dens_measure: imports depth-density contrast data for exponential curve fitting and plot the results

Inversion/Forward modelling functions

startfunc: retrieves inputs, performs inversion/forward procedure, memorize outputs
maininv_CH_CH: performs inversion scheme
FW_CH: performs forward calculation
freqaxTG: calculates wavenumbers k, kx,ky and variables used in FW_CH

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

Display functions
mapper: displays a color-filled 2D/3D map of gridded data (color map is jet in default)
profile_plot: interpolates data (observed anomaly, calculated anomaly and basement) between interactively selected two coordinates
graph_plot: displays the rms or the greatest error variation obtained during the iteration steps
instaRMSplot: instant display of the rms or the greatest error variation
mapinfo: wites the mesh information of loaded data, as well as root of file to the list box
clrmpeditor: pops up the color map editor
clrmpeditor: pops up the color map editor
error_message: pops up an error message box
showmap: plots the map of laterally varying rate of decay factor or the laterally varying surface density contrast
switch2plot: switch between output data
toggl2d3d: toggle between 2-D and 3-D mapping

GUI related functions
create_MainGui: creates main GUI
create_actwindow: creates an empty figure next to main GUI
outputmenu_inversion: creates output menu items for the data from inversion mode
outputmenu_forward: creates output menu items for the data from forward mode
densmodelfit_menu: creates a GUI window for exponential curve fitting
outmenu_profdata: creates a GUI window for profile data
resetmainwindow: resets the main GUI window to default
backoutmenu: back to outputs GUI window

backmainmenu: back to main GUI window
stting: initialize menu items in the main GUI
algor_stop: controls the behavior of the termination of the iterative procedure

Saving functions
grdout: converting output as grid format (*.grd)
exportdatas: exporting data (numeric)
imageout: exporting data (image)
savDprof: exporting cross-section data to an ascii file (*.dat)