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The kriging software described in this document was developed by Dezhang Chu with funding from the National Science Foundation through the U.S. GLOBEC Georges Bank Project's Program Service and Data Management Office. It was originally inspired by a MATLAB toolbox developed by Yves Gratton and Caroline Lafleur (INRS-Océanologie, Rimouski, Qc, Canada), and Jeff Runge (Institut Maurice-Lamontagne, now with University of New Hampshire). This software may be reproduced for noncommercial purposes only.

This program is distributed in the hope that it will be useful, but WITHOUT ANY WARRANTY. Contact Dr. Chu at dchu@whoi.edu with enhancements or suggestions for changes.

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**1. INTRODUCTION**  
**1.1 General Information**  
**1.1.1 About kriging**

This section provides a brief theoretical background for kriging. If the user(s) is not interested in the theoretical background, he/she can skip this section and go to section 1.1.2 directly.

Kriging is a technique that provides the Best Linear Unbiased Estimator of the unknown fields (Journel and Huijbregts, 1978; Kitanidis, 1997). It is a local estimator that can provide the interpolation and extrapolation of the originally sparsely sampled data that are assumed to be reasonably characterized by the Intrinsic Statistical Model (ISM). An ISM does not require the quantity of interest to be stationary, i.e. its mean and standard deviation are independent of position, but rather that its covariance function depends on the separation of two data points only, i.e.

$$E[ (z(\mathbf{x}) - m)(z(\mathbf{x}') - m) ] = C(h), \quad (1)$$

where  $m$  is the mean of  $z(\mathbf{x})$  and  $C(h)$  is the covariance function with lag  $h$ , with  $h$  being the distance between two samples  $\mathbf{x}$  and  $\mathbf{x}'$ :

$$h = \|\mathbf{x} - \mathbf{x}'\| = \sqrt{(x_1 - x'_1)^2 + (x_2 - x'_2)^2 + (x_3 - x'_3)^2}. \quad (2)$$

Another way to characterize an ISM is to use a semi-variogram,

$$\gamma(h) = 0.5 * E[ (z(\mathbf{x}) - z(\mathbf{x}'))^2 ]. \quad (3)$$

The relation between the covariance function and the semi-variogram is

$$\gamma(h) = C(0) - C(h). \quad (4)$$

The *kriging* method is to find a local estimate of the quantity at a specified location,  $\mathbf{x}_L$ . This estimate is a weighted average of the  $N$  adjacent observations:

$$\hat{z}(\mathbf{x}_L) = \sum_{\alpha=1}^N \lambda_{\alpha} z(\mathbf{x}_{\alpha}) \quad (5)$$

The weighting coefficients  $\lambda_{\alpha}$  can be determined based on the minimum estimation variance criterion:

$$E \left\{ [z(\mathbf{x}_L) - \hat{z}(\mathbf{x}_L)]^2 \right\} = C(0) - 2 \sum_{\alpha} \lambda_{\alpha} C(\|\mathbf{x}_{\alpha} - \mathbf{x}_L\|) + \sum_{\alpha} \sum_{\beta} \lambda_{\alpha} \lambda_{\beta} C(\|\mathbf{x}_{\alpha} - \mathbf{x}_{\beta}\|) \quad (6)$$

subject to the normalization condition

$$\sum_{\alpha=1}^N \lambda_{\alpha} = 1. \quad (7)$$

Note that we don't know the exact value at  $\mathbf{x}_L$ , but we are trying to find a predicted value that provides the minimum estimation variance. The resultant kriging equation can be expressed as

$$\sum_{\beta=1}^N \lambda_{\beta} C_n(\|\mathbf{x}_{\alpha} - \mathbf{x}_{\beta}\|) - \mu = C_n(\|\mathbf{x}_{\alpha} - \mathbf{x}_L\|)$$

$$\sum_{\beta=1}^N \lambda_{\beta} = 1$$
(8)

where  $\mu$  is the Lagrangian coefficient. In addition, we have replaced the covariance function with the normalized covariance function [normalized by  $C(0)$ ]. Equivalently, by using Eq. (4), the kriging equation can also be expressed in terms of the semi-variogram as

$$\sum_{\beta=1}^N \lambda_{\beta} \gamma_n(\|\mathbf{x}_{\alpha} - \mathbf{x}_{\beta}\|) + \mu = \gamma_n(\|\mathbf{x}_{\alpha} - \mathbf{x}_L\|)$$

$$\sum_{\beta=1}^N \lambda_{\beta} = 1$$
(9)

where we have used normalized semi-variogram, i.e., semi-variogram normalized by  $C(0)$  as we did in deriving Eq. (8).

Having obtained the weighting coefficients ( $\lambda_{\beta}$ ) and the Lagrangian coefficient ( $\mu$ ) by solving either Eq. (8) OR Eq. (9), the kriging variance, Eq. (6), can be expressed as:

$$\sigma_L^2 = E\left\{[z(\mathbf{x}_L) - \hat{z}(\mathbf{x}_L)]^2\right\} = C(0) + \mu - \sum_{\alpha} \lambda_{\alpha} C(\|\mathbf{x}_{\alpha} - \mathbf{x}_L\|)$$

$$= \mu + \sum_{\alpha} \lambda_{\alpha} \gamma(\|\mathbf{x}_{\alpha} - \mathbf{x}_L\|) - \gamma(0)$$
(10)

The above equations are the basis of the Easykrig software package.

### 1.1.2 Brief description of EasyKrig3.0

The EasyKrig program package uses a Graphical User Interface (GUI) to simplify the operation. It requires MATLAB 5.3 or higher with or without optimization toolbox (see section 2.2) and consists of five components, or processing stages: (1) data preparation, (2) variogram computation, (3) kriging, (4) visualization and (5) saving results. It allows the user to process anisotropic data, select an appropriate model from a list of variogram models, and a choice of kriging methods, as well as associated kriging parameters, which are also common features of the other existing software packages. One of the major advantages of this program package is that the program minimizes the users' requirements to "guess" the initial parameters and automatically generates the required default parameters. In addition, because it uses a GUI, the modifications from the initial parameter settings can be easily performed. Another feature of this program package is that it has a built-in on-line help library that allows the user to obtain the descriptions of the use of parameters and operation options easily.

The current EasyKrig3.0 is the upgraded version of the previous version (EasyKrig2.1). In addition to having corrected some programming errors in the previous version (mostly GUI related errors), there are many new features included in the current version:

- Matlab Version 6.x and 7.0 (tested under Windows) compatible
- Capable of handling 3-D data
- Enhanced batch file processing capability
- More flexible in loading input data and saving output data

- Capable of handling the customized grid file
- More examples with detailed step by step instructions are provided to allow user(s) to master the functionality of the software package more quickly and easily.

Although this software package lacks some abilities such as Co-kriging, it does provide a convenient tool for geostatistical applications and should also help scientists from other fields.

For people who do not want to use GUI but only interested in function-based m-files can go to a different website that provides a function-based m-file Kriging package ([http://globec.who.edu/software/kriging/V3/intro\\_v3.html](http://globec.who.edu/software/kriging/V3/intro_v3.html)) developed by Caroline Lafleur and Yves Gratton, INRS-Océanologie, Universit du Qubec Rimouski.

## **1.2 Getting Started**

### **1.2.1 Operating systems**

The software was originally developed under MATLAB 6.5 on a PC (windows 2000) and intended to be computer and/or operating system independent. The program has been tested on various machines (PC, Macintosh, and Sun Workstation) and operating systems (windows 2000/Xp, Linux) and performs fine.

### **1.2.2 Down-load the program**

The user needs to download the compressed file from GLOBEC web site first, the URL is [ftp://globec.who.edu/pub/software/kriging/easy\\_krig/V3.0/](ftp://globec.who.edu/pub/software/kriging/easy_krig/V3.0/)

and the compressed file is

Windows 95/98/NT/2000/XP, Macintosh and Linux:	easy_krig30.zip
Unix:	easy_krig30.tar.gz

After having downloaded the file, the user needs to uncompress the file. A directory of easy\_krig3.0 will be created and you are ready to run the program.

### **1.2.3 Quick start**

Start MATLAB and go to the designated easy\_krig3.0 home directory. Just type “startkrig” in the MATLAB command window, a window will pop up (Fig. 1). This window is the base window, called the Navigator window. The Menubar in this window contains many options you can choose. Now you are ready to move on.

Note: You can add the kriging home directory to the Matlab search path and run the program from other directories. However, you have to make sure that there are no functions of your own having the same names as those used for easy\_krig3.0. Since the program will allow you to load and save files using a file browser, it is recommended that you run the program under the easy\_krig3.0 home directory.

The program provides a full on-line help function that provides the descriptions the use of almost all of the selectable functions, options, and parameters. It is quite self-explanatory and easy to use.

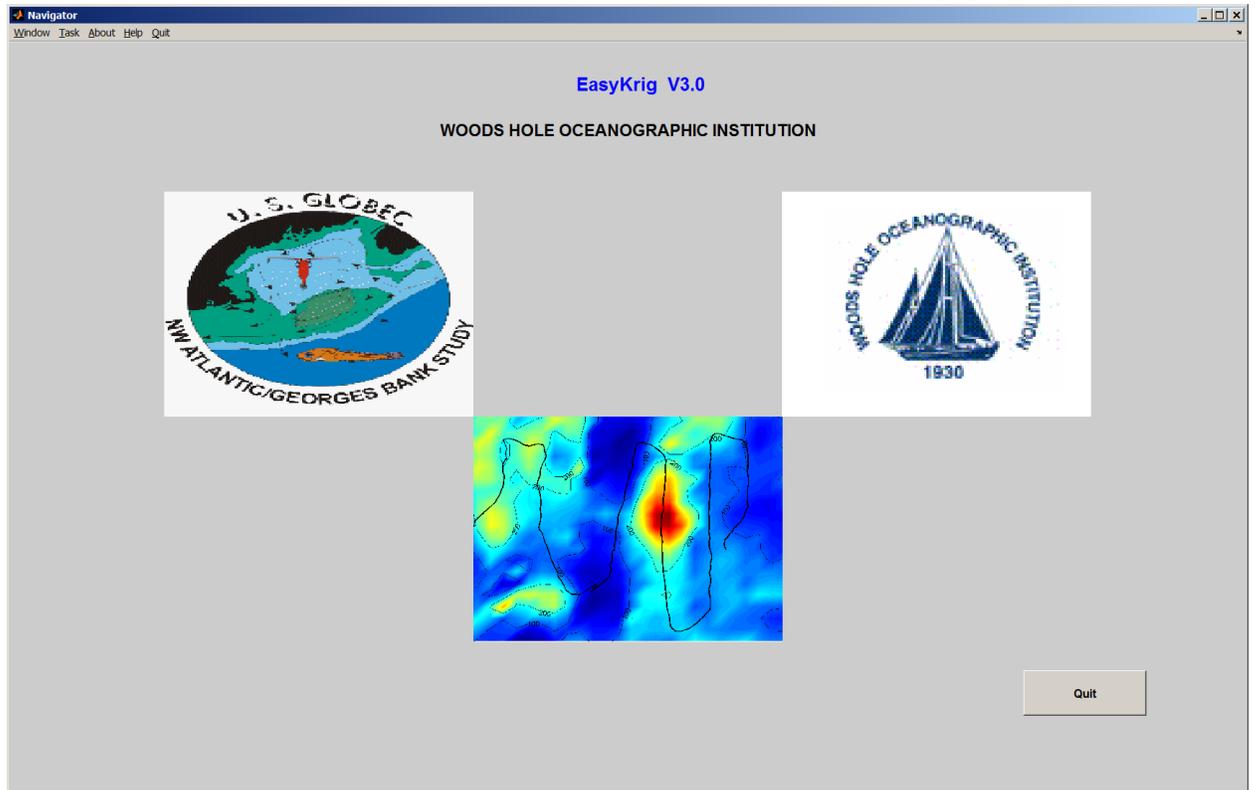


Figure 1. Navigaor window

## 2. DATA PROCESSING STAGES

There are several data processing stages (tasks) that are selectable from the Menubar on the top of the Navigator window, as well as other task windows. By selecting or clicking on any of the tasks, a window corresponding to the selected task will pop up. On each task window including the Navigator window, the descriptions and explanations of every option and selection in each task window can be found by click on the “Help” option on the Menubar. On any of the task windows, clicking on the “Navigator” button, or selecting “Navigator” from the Menubar will bring back the Navigator window.

### 2.1 Data Preparation

Selecting “Load Data” from “Task” on the Menubar of any window leads to the Data Preparation window (Fig. 2). Click on the “Load” button or select “Load” from the Menubar to load the raw data file. The format of the data file should be a 3-column ASCII file for 2D data and 4-column ASCII file for 3D data. Comments at the beginning of the data file will not affect the data as long as each comment line begins with a percentage symbol “%”.

User(s) can provide their own m-file to load the data by using “External Program” option in the Data Preparation window. This function allows the user to generate the input data directly from the raw data instead of generating an ASCII file that is required by the Easykrig3.0. The required format for the input and output parameters by using an external program can be found by clicking on the “Help” from the Menubar and selecting “External Program”.

One can set the other parameters such as reduction factor (or just accept default settings) before loading the file. After the file is loaded, if the user wants to change the other (default) settings, such as data filter, he/she can do so

and then click on “Apply” pushbutton after the parameters have been set. The difference between “Load” and “Apply” is that the latter operation is faster since it will not re-load the data file. For example, to change the axis labels after having loaded the data, one does not need to re-load the data.

One can also save the “Data Format” information into a file, which will save all the parameter and option settings in this window. This feature allows the user(s) to load the data file with the same settings in the task window Kriging without opening or using this window. It is very useful when a batch process operation is needed (see explanation in 2.3 and the example 3 for more details).

The usage of the other options in this window can be found by selecting appropriate items from “Help” option on the Menubar.

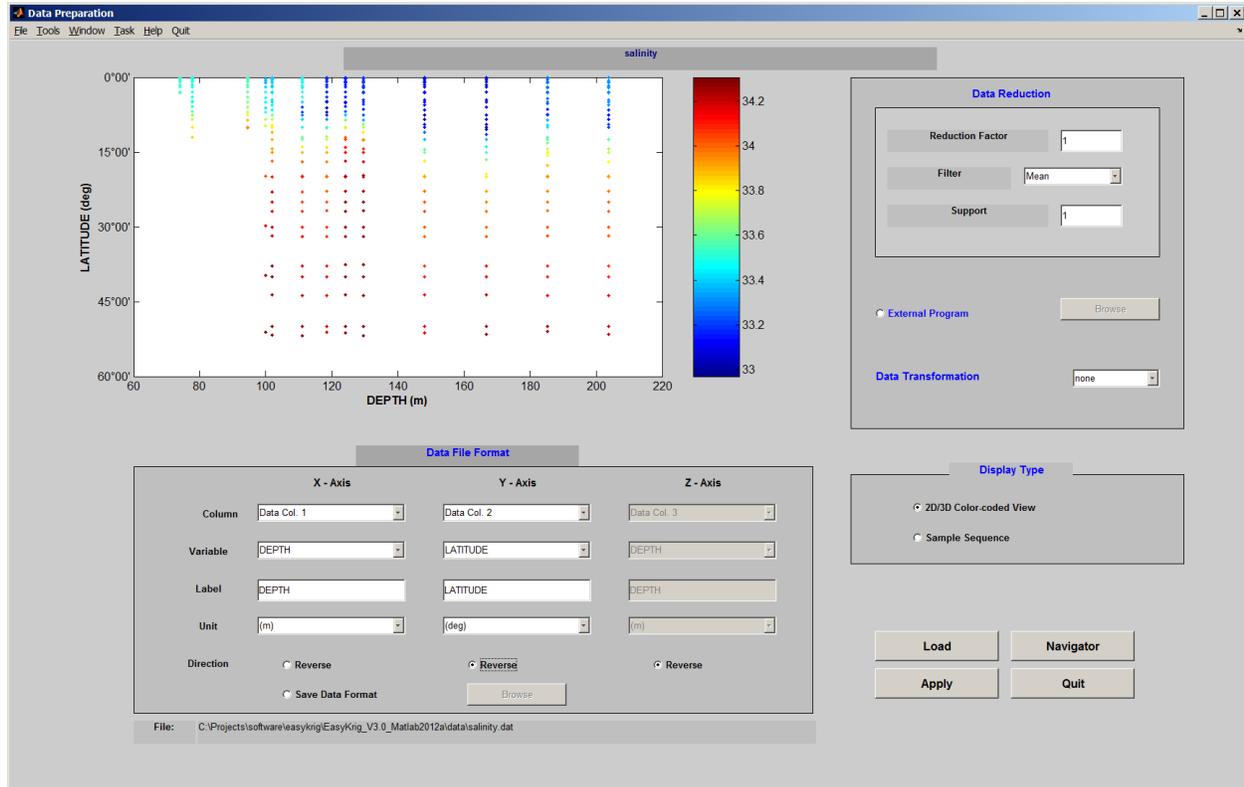


Figure 2. Data Preparation window.

## 2.2 Semi-variogram

Selecting “Variogram” from “Task” on the Menubar leads to a popup Variogram/Correlogram window (Fig. 3). Click on the “Compute” button to generate a data-based semi-variogram (or correlogram). Then, we need to seek a model-based semi-variogram or correlogram to fit the data-based variogram just computed. It can be proved that, based on Eq. (4), the relation between the normalized semi-variogram  $\gamma_n(h)$  [normalized by the variance  $C(0)$ ] and the correlogram  $C_n(h)$  is:

$$C_n(h) = 1 - \gamma_n(h),$$

where  $h$  is the lag distance (Eq. 2). An appropriate variogram/correlogram model can be selected depending on the shape of the variogram/correlogram computed from the data. The explanations of the parameters associated with the

model can be found using the on-line help. Click on the “Apply” button and the program will compute the model-based variogram/correlogram using the current settings. The parameter settings can be changed either by changing the slider positions or by entering the numbers directly into the associated text-edit fields. If using the slider, the theoretical curve will change automatically, while if entering the number(s) into the text-edit field(s), the user needs to click on the “Apply” button to re-compute the curve.

If the optimization toolbox (recommended) is installed, the user can use the Least-Squares Fit function to fit the data by clicking on the “LSQ fit” button. If the optimization toolbox isn't installed, the program will automatically disable the Least-Squares fit function.

Note that since the LSQ fit has a certain range for each parameter, different initial settings or parameters will produce different results.

In some cases when the data are anisotropic, an anisotropic variogram or correlogram model can be activated. By selecting “Anisotropy” radio option, the corresponding settings are enabled. If you don't know or are not sure of the orientation and aspect ratio of the anisotropic feature of the data, you can use the default settings first and then adjust to obtain satisfactory results.

One can save the current variogram parameters to a file and can also retrieve the variogram parameters previously saved to a file.

The usage of the other options in this window can be found by selecting appropriate items from “Help” option on the Menubar.

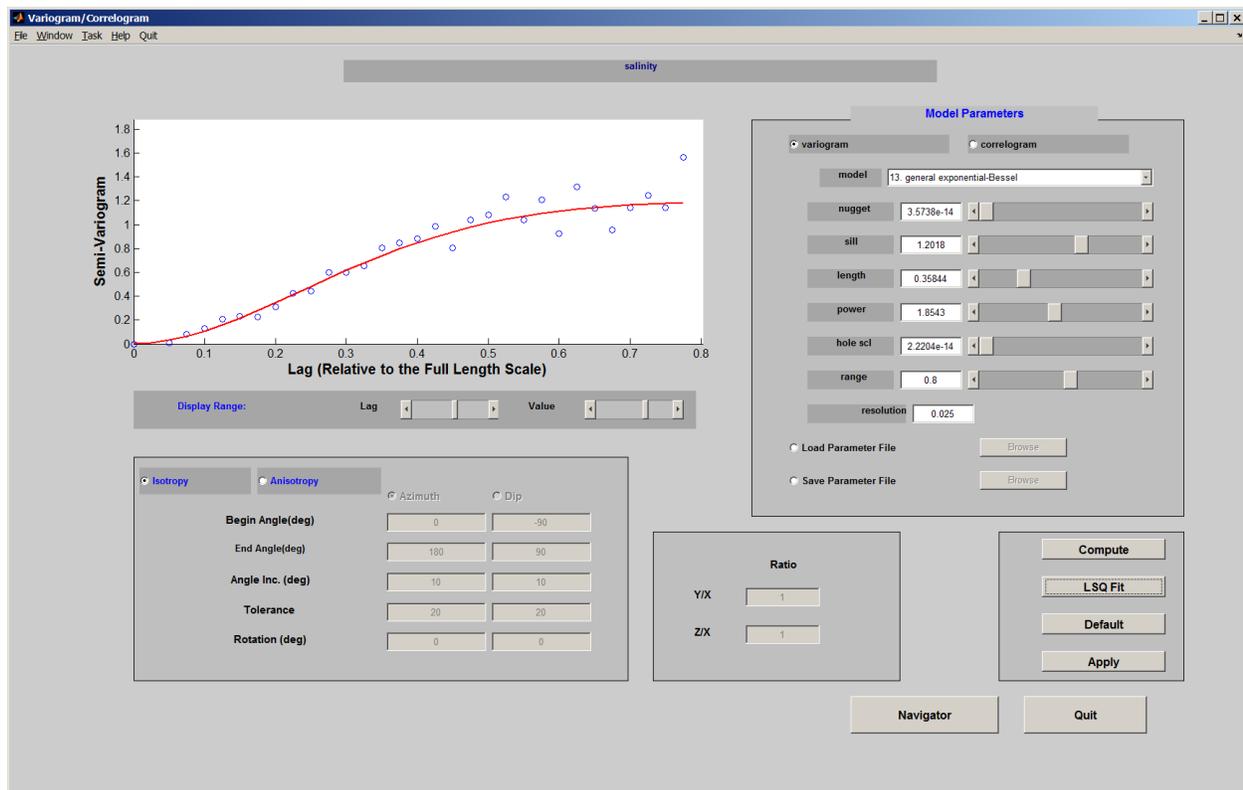


Figure 3. Variogram/Correlogram window.

## 2.3 Kriging

Selecting “Kriging” from “Task” on the Menubar leads to a popup Kriging window (Fig. 4). The parameters of the variogram or correlogram needed in the kriging operation are automatically passed from the Variogram window to the Kriging window.

Click on the “Refresh” button to obtain the most recent semi-variogram and coordinates parameters if the user has loaded a new data set.

The “Relative Variance” parameter will set the kriging values to “NaN” (Not a number) when the kriged values are larger than this parameter and will become blank in the kriging map. The default value of this parameter is 2.5.

Click on the “Krig” button to start kriging. In general, accepting the default parameters will produce a reasonable kriging map to start with. Changing the variogram and kriging parameters will offer fine-tuning on these parameters and can further improve the quality of the kriging results.

One of the important features of the EasyKrig is its ability of performing “Batch Process”, which allows the user to process a group of data sets that have the same data structures, i.e., having the same data format and using the same variogram and kriging parameters. The user will provide a file in which a list of the data file will be included. The outputs of each data set from kriging will be automatically saved to appropriate file in Matlab binary format.

Another added feature in EasyKrig3.0 is that it allows users to provide their own grid file to specify the coordinates of regular or irregular grids on which the kriged values are generated.

The usage of the other options in this window can be found by selecting appropriate items from “Help” option on the Menubar.

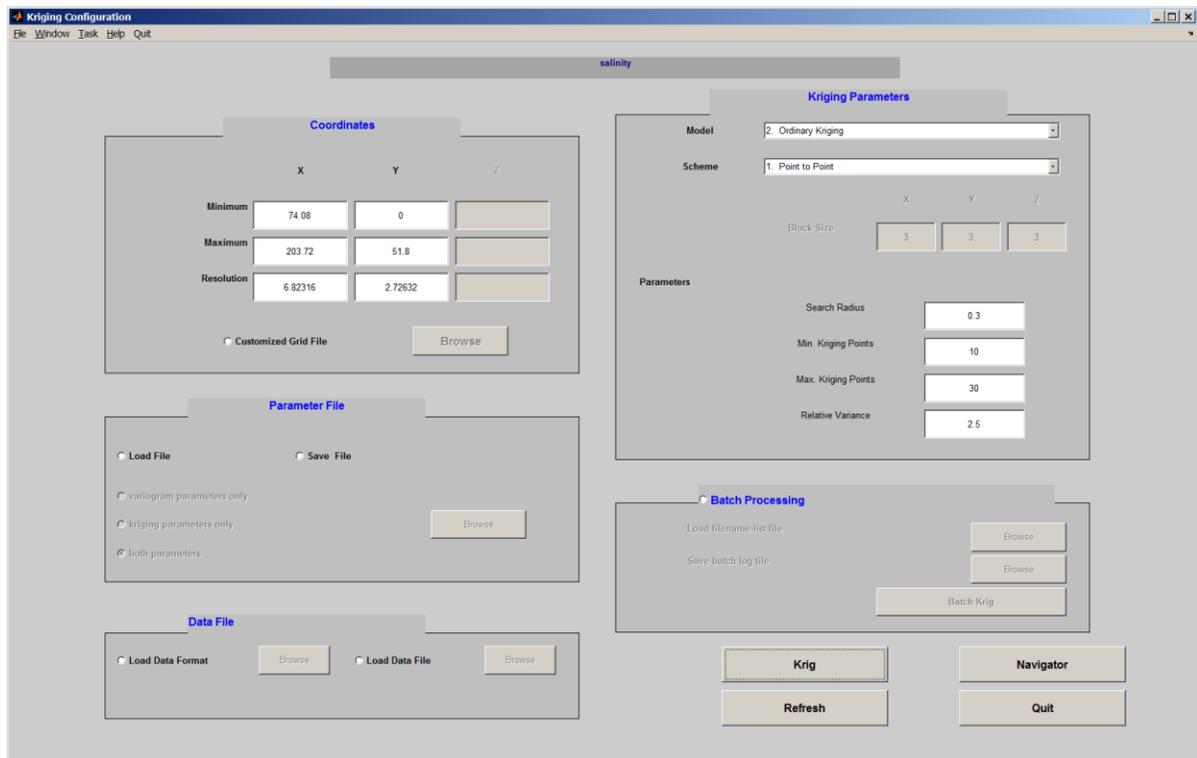


Figure 4. Kriging Configuration window.

## 2.4 Visualization

Choosing “Visualization” from “Task” on the Menubar leads to the Visualization window (Fig. 5). Three types of figures can be viewed in this window: kriging map, kriging-variance map and cross-validation. The first two maps are commonly used in the kriging literature while the last one is a unique approach of this program.

Click on the “Show Plot” button to display the current kriging results.

The shading option is for the display purpose only and their explanations can be found by typing “help shading” in the MATLAB command window.

Sliders next to the colorbar case can be used to change the display range of the colormap scale. Sliders next to the X, Y, and Z axes in 3D case are used to change the positions of the slices in X, Y, and Z directions, respectively.

If the data have been transformed in the Data Preparation window, the kriging results are the results from transformed data.

An important feature of the EasyKrig is it can provide “cross-validation”, which can be performed by selecting the “Validation” radio option. One can compute and display the results from different cross-validation schemes in a separate Cross-Validation window. Among these schemes, the Q1 and Q2 are good indicators that provide a plausible assessment of the performance of the kriging in addition to the kriging-variance map. More detailed descriptions of these cross-validation can be found from the built-in “Help” function. In general, the Q1 criterion (distribution of the deviation for the mean) is easy to satisfy while the Q2 criterion (distribution of deviations for the standard deviation) is much more difficult to satisfy.

As a rule of thumb, reducing the area under the theoretical curve of the variogram (smaller nugget, lower sill, smaller length scale, etc.) will increase the Q2 value, while increasing this area will reduce the Q2 value.

The usage of the other options in this window can be found by selecting appropriate items from “Help” option on the Menubar.

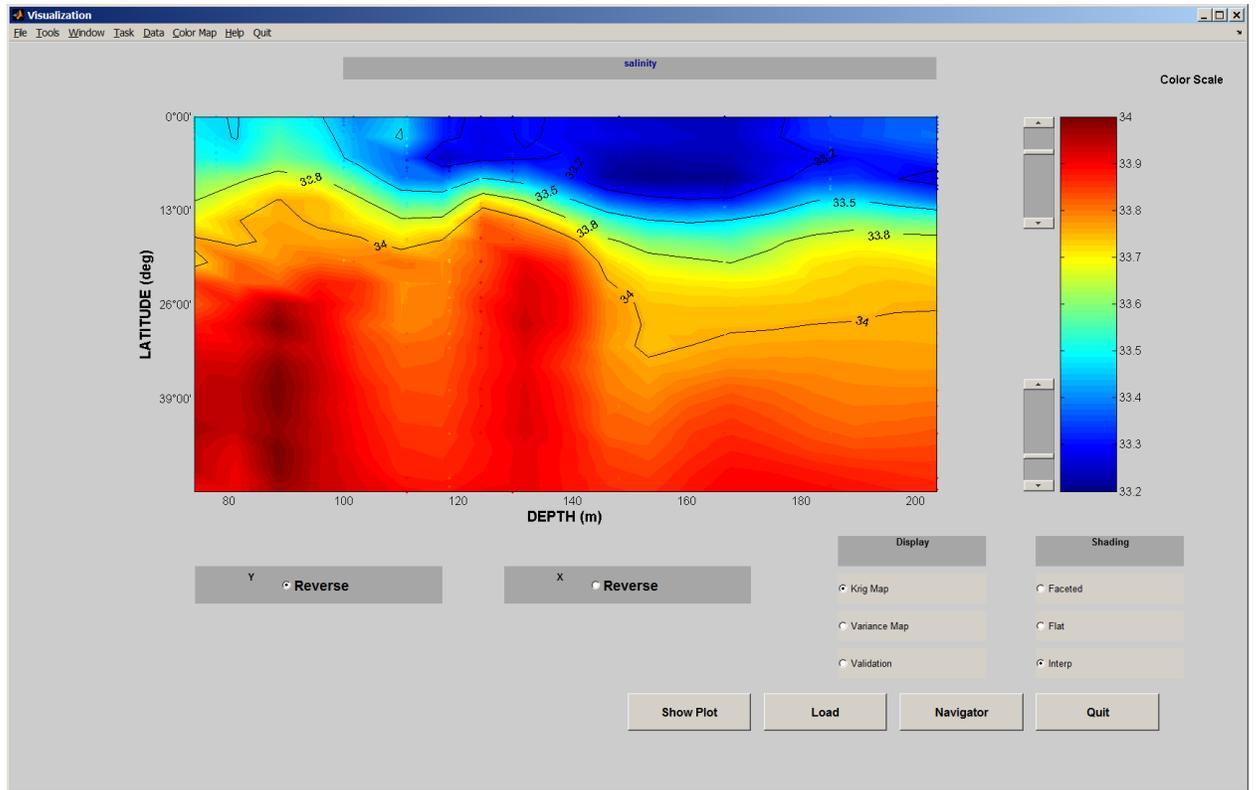


Figure 5. Visualization window.

## 2.5 Saving Kriging Results

In the Visualization window, by selecting “File” from the Menubar and then choosing “Save File As”, the user can save the outputs to a .mat file with a user-defined filename and at the user-selected location. The program saves the parameters and data structures (para and data) in the file. For information on the structures, the user needs to select “File” from the Menubar in the Navigator window and then “Variable Structure” to obtain explanations for some important variables (note that many variables are not relevant to users).

## 3. EXAMPLES

There are several sample data files included in the package. All files are in ASCII format required by the program. In the following examples, the designated directory is assumed to be “easy\_krig3.0”.

### 3.1 Example 1: An Aerial Image of Zooplankton Abundance Data

- (1) Start MATLAB, in command window, change directory to the home directory of EasyKrig3.0. Type “startkrig” to launch the program.
- (2) Adjust the window size and position and select “Save Window Position” option from “Task” on the Menubar and then “Save Position” from the sub-menu. Note that after saving the window size and position, any of other task windows created afterwards will have the same size and at the same position. You can resize and re-position the window in any other task windows as well.

- (3) Select “Load Data” from “Task” on the Menubar to open the Data Preparation window.
  - (a) Select “Data Col. 2” from the listbox of “Column” for X-Axis and “Data Col. 1” for Y-Axis (defaults).
  - (b) Select “LONGITUDE” from listbox of “Variable” for X-Axis and “LATITUDE” for Y-Axis (defaults).
  - (c) Leave other parameters unchanged.
  - (d) Click on the “Load” button to open a dialog box, go to “data” directory, and then select the data file “zooplankton.dat” to load the selected file into memory.
  - (e) Select “Sample Sequence” in the “Display Type” frame to display the sample sequence. By selecting “2D/3D Color-coded View” to bring back the color-coded display.
  
- (4) Select “Variogram” from “Task” on the Menubar to open the Variogram/Correlogram window.
  - (a) Click on the “Compute” button to compute the semi-variogram. This plots the data-based semi-variogram as discrete open circles.
  - (b) Select “general exponential-Bessel” (default) from the variogram model listbox on the upper right. Click on the “LSQ Fit” button. If you don’t have optimization toolbox, click on the “Apply” button, a theoretical model-based semi-variogram will be superimposed on the original data-based semi-variogram. The resultant semi-variogram parameters from the least-squares fit (if you have optimization toolbox) or from the default settings (if you don’t have optimization toolbox) are shown in the text-edit fields within the “Model Parameters” frame.
  - (c) Click on the sliders associated with the variogram parameters, the theoretical curves will change accordingly to reflect the parameter changes. The parameters can also be changed by entering the values directly into the text-edit fields and then clicking on the “Apply” pushbutton.
  - (d) Type 0 in the “nugget” text-edit field, 1.0 in the “sill” text-edit field, 0.1 in the “length” text-edit field, 1.5 in the “power” field, and 0 in the ‘hole scl’ (hole scale) text-edit field. Then, click on the “Apply” button. A revised theoretical curve of the model-based semi-variogram will be generated and plotted (red curve).
  - (e) By selecting the “Variogram” or “Correlogram” in the “Model Parameter” frame (top row) will provide either variogram or correlogram depending on the user selection.
  
- (5) Select “Kriging” from “Task” on the Menubar to open the Kriging window.
  - (a) Simply click on the “Krig” button to start kriging by accepting the default settings. A status window pops up and displays the processing progress. When the kriging is done, click on the “Quit” button to close the status window.
  
- (6) Select “Visualization” from “Task” on the Menubar to open the Visualization window.
  - (a) Simply click on the “Show Plot” button to display the kriging results. Note that the station positions on the kriging map are color-coded to reflect the level of the agreement of the kriged results with the original data. If they are invisible it is because they agree with the kriged values very well.
  - (b) Select “Faceted” and then “Flat” for the “Shading” to see the changes in the display.
  - (c) Click on “Data” from the Menubar and then select between “Color”, “Black/White” and “None” to observe the color change at the locations of the original data. Selecting “Value” or “Error” and specifying the “Color” and “Fontsize” allow the user to display the observed values or the difference between the observed values and those from kriging.
  - (d) Select “Variance Map” to display kriging variance map.
  - (e) Selecting “Validation” will open a small popup “Validation” window. Click on “Compute” button, the Q1-validation curve occurs. A vertical red line at about 0.09 in between the two black lines at about 0.5 and -0.5 indicates the model parameters are good based on the Q1 criterion.
  - (f) Selecting “Q2” from the listbox of “Method” results in another plot. A vertical red line is located within the accept region at about 1.09, which means the model parameters are likely “good” based on the Q2 criterion. Click on “Quit” button to close the Validation window.
  - (g) Activate the “Kriging” window by either selecting “Kriging” from “Task” on the Menubar, or selecting “Kriging Configuration” from “Window” on the Menubar, or simply clicking on the minimized “Kriging Configuration” on the Toolbar at the bottom of the screen. Type 1.1 in the “Relative Variance” text-edit field and click on “Krig” to perform a new kriging. Note that in the Matlab command window, there is one line message resulting from kriging “Anomaly\_cnt for |Ep| > Relative Error =37”. This is to inform the user that there are 37 kriged values whose normalized kriging variances or relative errors are

- greater than 1.1. The total number of kriged value for this example is 266 (19 x 14), which can be verified by typing “data.out.krige” (look for Xg, Yg, Vg, and Eg) in the command window.
- (h) Go back to the “Visualization” window, click on “Krig Map” to refresh the kriging map. There are blank regions on the kriging map, where the normalized kriging variance (normalized by the variance) exceeds specified “Relative Variance”, i.e. 1.1.
- (7) Select “Kriging” from “Task” on the Menubar or simply click on the minimized the figure on the toolbar at the bottom of the screen to bring back the Kriging window.
    - (a) Change “Relative Variance” back to 2.5.
    - (b) Select “Customized Grid File” in the “Coordinates” frame and click on “Browse” button to open a file dialogue box. Load “globec\_grid.dat” from the directory “data/GLOBEC\_gridfile”.
    - (c) Click on the “Krig” button to perform kriging by accepting the other settings in this window.
  - (8) Select “Visualization” from “Task” on the Menubar or simply click on the minimized the figure on the toolbar at the bottom of the screen to bring back the Visualization window.
    - (a) Click on the “Show Plot” button to display the kriging results.
    - (b) Select “Interp” for the “Shading” to changes in the display.
  - (9) Select “File” the Menubar and then select “Save File As” to open a dialog box.
    - (a) Go to “output” directory or any directory you like and specify any filename you like (the default filename is zooplankton.mat) and then click on the “Save” button to save all the data and parameter structures to a MATLAB binary file.
    - (b) Click on “Quit” from the Menubar and then “Quit Easykrig” to quit the program. Restart the program again by typing “startkrig” in the MATLAB command window. Click on the “Visualization” button to open the Visualization window, and click on the “Load” button or select “File” and then “Load” from the Menubar to load the output file that has just been saved by using the file browser.
    - (c) Click on the “Show Plot” button to display the kriging results, which should be the same as before.
  - (10) Click on “Navigator” button or select “Navigator” from “Task” on the Menubar to open the Navigator window.
    - (a) Select “About” from the Menubar and then “Variable Structure” to open the data structure description file. You can view how the data and para are structured and can extract many parameters such as variogram parameters related to the kriging outputs.
    - (b) Click on “Quit” from the Menubar and then “Quit Easykrig” to quit the program. Type “cd misc\_mfiles” in the Matlab command window to go to the “misc\_mfiles” directory.
    - (c) Type “display\_globec\_grid” in command window and a load data window pops up.
    - (d) Use the file browser to load the data just saved in step (9)-(a) to view the results.
    - (e) You can modify the display\_globec\_grid.m to plot the output variables yourself.

### 3.2 Example 2: A Vertical Section of Salinity Data – An Anisotropic Data set

- (1) Start MATLAB in the MATLAB command window. Change directory to the home directory of EasyKrig3.0 and type “startkrig” to launch the program.
- (2) Select “Load Data” from “Task” on the Menubar to open the Data Preparation window.
  - (a) Click on the “Load” button to open a dialog box, select “data” directory, and then select “salinity.dat” file to load the selected file into memory.
  - (b) Select “Data Col. 1” and “Data Col. 2” from listbox “Column” for X-Axis and Y-Axis, respectively.
  - (c) Select “X” and “Depth” from the listbox of “Variable” for X-Axis and Y-Axis, respectively.
  - (d) Leave other parameters unchanged and click on “Apply” button.
  - (e) Select “Reverse” radio option on the Y-Axis column to reverse the y-axis direction.
- (3) Select “Variogram” from “Task” on the Menubar to open the Variogram window.
  - (a) Click on the “Compute” button to compute the semi-variogram.
  - (b) Click on the “LSQ Fit” button [If you don't have optimization toolbox, go to step (c).] A theoretical model-based semi-variogram will be superimposed on the original data-based semi-variogram.

- (c) Type 0 in the “nugget” parameter text-edit field, 1.28 for “sill”, 0.36 for “length”, 1.76 for “power”, and 0 for “hole scl” (hole scale), and then click on the “Apply” button to generate a theoretical curve of the model-based semi-variogram.
- (4) Select “Kriging” from “Task” on the “Task” on the Menubar to open the Kriging window.
    - (a) Simply click on the “Krig” button to start kriging by accepting the default settings.
  - (5) Select “Visualization” from “Task” on the Menubar to open the Visualization window.
    - (a) Click on the “Show Plot” button to display the kriging results.
    - (b) Verify that “Reverse” is selected for the y axis direction.
    - (c) Select “Validation” from “Display” will open a small popup “Validation” window. Click on “Compute” to obtain the “Q1” value. A vertical red line around 0.08 in between the two black lines at about 0.1 and -0.1 indicates the model parameters are good based on Q1 criterion.
    - (d) Select “Q2” from the listbox of “method” results. There is no red vertical line in between the two black lines defining the Q2-accept region, but a value about 2.27 displayed on the top of the figure, indicating that the Q2 value is beyond the accept region and the variogram model parameters are likely not “good”. As a result, further modifications to the parameters are needed. Do not close this Cross-Validation window at this moment.
  - (6) Go back to Variogram window by either selecting “Variogram” from “Task” on the Menubar or simply click on the minimized the figure on the toolbar at the bottom of the screen.
    - (a) Select “Anisotropy” radio option to enable 2D variogram computation.
    - (b) Change “End Angle (deg)” to 180, “Angle Inc. (deg)” to 10, and “Tolerance (deg)” to 20 (these are all default settings).
    - (c) Click on the “Compute” button to compute and display the 2D variogram (image) in a separate window.
    - (d) Since the variogram image shows an elongated pattern having an aspect ratio of about 1:4 (Y/X) and an orientation angle of about 0 degree. On Variogram window, enter 0.25 in the “Y/X” text-edit field of “Ratio” (inverse of the anisotropic aspect ratio) and 0 in the “Rotation” text-edit field (default) and then click on the “Compute” button again. A recomputed 2-D semi-variogram shows basically an isotropic pattern for the central region (Lag distance in radial direction < 0.3).
    - (e) Click on “Quit” button to close “Display 2D/3D Variogram/Correlogram” window.
    - (f) Click on “Isotropy” radio option to disable the “Anisotropy” (the parameters describing the anisotropic feature of the data have been already accepted) and click on the “Compute” button to re-compute the *equivalent* 1D semi-variogram obtained by transforming the original anisotropic data to isotropic data by using the anisotropic parameters “Rotation” and the “Ratio” set in step (3). This step is necessary to obtain the correct 1-D semi-variogram that actually used in kriging.
    - (g) Adjust display control by clicking on the two sliders (“Lag” and “Value”) below the graphic window.
    - (h) Enter 0.6 in the range text-edit field and click on the “LSQ fit” button. If you don't have optimization toolbox, go to the next step.
    - (i) Change “nugget” to 0.0165, “sill” to 0.39, “length” to 0.37, “power” to 1.64 and “hole scl” to 0 by entering the numbers in the corresponding text-edit fields and then click on “Apply” button. Adjust the display scale by clicking on the two sliders below the 1-D semi-variogram graphic window, lag for horizontal scale and value for vertical scale to get better viewing scales.
  - (7) Go back to the Validation window and click on “Re-Compute” button to re-compute Q1 and Q2 values. The new values are 0.014 and 1.01 for Q1 and Q2, respectively, and are both within the acceptable regions, indicating the variogram parameters are acceptable.
  - (8) Select “Kriging” from “Task” on the Menubar or simply click on the minimized the figure on the toolbar at the bottom of the screen to bring back the Kriging window and click on the “Krig” button to re-compute the kriging map.
  - (9) Select “Visualization” from “Task” on the Menubar or simply click on the minimized the figure on the toolbar at the bottom of the screen to bring back the Visualization window.
    - (a) Click on “Krig Map” and “Variance Map” to refresh the maps. Note that by using an anisotropic variogram model, some improvements can be achieved, but the kriging map itself doesn't change much.

- (10) Select “File” from “Task” on the Menubar and then select “Save File As” to open a dialog box.
  - (a) Select “output” directory and any name you like (the default filename is salinity.mat) and click on the “Save” button.
  - (b) Click on “Quit” on the Menubar and then “Quit Easykrig” to quit the program. Restart the program again by typing “startkrig” in the MATLAB command window.
  - (c) Select “Visualization” from “Task” on the Menubar to open the Visualization window and click on the “Load” button to load the output file that has just been saved by using the file browser.
  - (d) Click on the “Show Plot” button to display the kriging results and select the “Reverse” on y-axis to reverse the y-axis direction. The resultant map(s) should be the same as before.

### 3.3 Example 3: Batch Process of Pressure (dbar) at Different Potential Density Layers

- (1) Start MATLAB in the MATLAB command window, change directory to the home directory of EasyKrig. Type “startkrig” to launch the program.
- (2) Select “Load Data” from “Task” on the Menubar to open the Data Preparation window.
  - (a) Select “Data Col. 2” from the listbox of “Column” for X-Axis and “Data Col. 1” for Y-Axis (defaults).
  - (b) Select “LONGITUDE” from listbox of “Variable” for X-Axis and “LATITUDE” for Y-Axis (defaults).
  - (c) Selecting “External Program” enables the external program browser and a filename window appears. Note that the X, Y, and Z axes pushdown menu for “Column” are disabled and can be enabled by de-select the “External Program” radio option.
  - (d) Click on the file browser, change directory to “misc\_mfiles” and select “test\_remove\_nan.m”, and then click on “open” to enable the program to access the program (if this external program is not chosen, the locations where the data values are NaN’s will be displayed on the map). This program provides an example to write your own routine to obtain the required data format for EasyKrig from an arbitrary data file. It should be pointed out that the function of removing NaN’s has already been included in the default loading data process, this example is simply to demonstrate how to use the external program to load the data with customized data manipulations.
  - (e) Click on the “Load” button to open a dialog box, go to “data/pressure” directory, and then select “layer12.dat” file to load the selected file into memory.
  - (f) Select “Save Data Format” near the bottom of the window, and use “Browse” to save the data format to a file. This data format file can be used when the user wants to load and process data using the same data format but without opening Data Preparation and “Variogram windows (see step (6) in this example).
- (3) Select “Variogram” from “Task” on the Menubar to open the Variogram window.
  - (a) Click on the “Compute” button to compute the semi-variogram.
  - (b) Select “general exponential-Bessel” (default) from the variogram model listbox on the upper right. Click on the “LSQ Fit” button. If you don’t have optimization toolbox, click on the “Apply” button, a theoretical model-based semi-variogram will be superimposed on the original data-based semi-variogram. The parameters from the Least-Squares fit (if you have optimization toolbox) or from the default settings (if you don’t have optimization toolbox) are shown in the text-edit fields within the “Model Parameters” frame.
  - (c) Change “nugget” to 0.0, “sill” to 1.0, “length” to 0.24, “power” to 1.5 and “hole scl” to 0 by entering the numbers in the text-edit fields accordingly, and then click on “Apply” button.
- (4) Select “Kriging” from “Task” on the Menubar to open the Kriging window.
  - (a) Set coordinates as:
    - minimum horizontal to -22
    - maximum horizontal to -12
    - horizontal resolution to 0.4
    - minimum vertical to -25
    - maximum vertical to -20
    - vertical resolution to 0.2
  - (b) Select “Batch Processing” radio button to enable the batch processing.

- (c) Click on the “Browse” button next to the “Load Filename-list file” to initiate the file browser. Change the directory to “data” and select “pressure\_batch\_file.dat” to load the filename-list file in which a list of data file names is specified.
  - (d) Click on the “Browse” button next to the “Save batch log file” to initiate the file browser. Change the directory to “output”, or wherever directory you like. Type a filename for the log file, where the input/output information is saved.
  - (e) Click on the “Batch Krig” button to start batch kriging. The output files will be saved in the same directory as the batch process log file.
  - (f) Select “Save File” in the “Parameter File” frame to activate the file browser. Click on the “Browse” pushbutton and specify a filename to save all the parameter settings including variogram and kriging parameters.
- (5) Select “Visualization” from “Task” on the Menubar to open the Visualization window.
- (a) Click on the “Show Plot” button to display the kriging results from the last data set: “layer14.dat”.
  - (b) Check the outputs for the other layers. To check the processing results, you need to load the output files. Click on the “Load” button and then change the directory where your log file is saved. Load one of the output files (“layer10.dat” – “layer14.dat”) and display it by click on the “Show Plot” button.
  - (c) If you are not satisfied with the kriging results, you can go back to the Variogram window and/or Kriging window to change the involved parameters, and re-kriging until you are satisfied. For example, by setting nugget=0.05, sill=1.16, length=0.25, power=1.4, and hole scl=0 in the Variogram window and performing kriging again, you will obtain a better result, i.e., the resultant Q1 and Q2 will fall within the acceptable regions. Then go back to the Kriging window and repeat (4)-(f).
- (6) Click on “Quit” on the Menubar and select “Quit Easykrig” to quit the program, and then start the program again by typing “startkrig” in the command window.
- (a) Select “Kriging” option from “Task” on the Menubar to open the Kriging window.
  - (b) Select “Load File” in the “Parameter File” frame to activate the file browser. Select “Both parameters” radio option (default) and click on the “Browse” pushbutton to load the parameter file saved in step (4) - (f) in this example.
  - (c) Select “Load Data Format” radio option at the bottom in the Kriging window and use the activated file browser to load the data format file saved in step (2) – (f) in this example.
  - (d) Repeat steps (b) – (e) of (4) in this example to perform batch kriging.
  - (e) Repeat (5) to view the results, which should be the same as before. Note that we don’t need to open the Data Preparation and Variogram windows to obtain the save results.

### 3.4 Example 4: 3-Dimensional Temperature Data

- (1) Start MATLAB in the MATLAB command window. Change directory to the home directory of EasyKrig3.0 and type “startkrig” to launch the program.
- (2) Select “Load Data” from “Task” on the Menubar to open the Data Preparation window.
  - (a) Select “Data Col. 2”, “Data Col. 1”, and “Data Col. 3” from the listbox “Column” for X-Axis, Y-Axis, and Z-Axis, respectively (defaults).
  - (b) Select “LONGITUDE”, “LATITUDE”, and “Depth” from listbox of “Variable” for X-Axis, Y-Axis, Z-Axis, respectively (defaults).
  - (c) Click on the “Load” button to open a dialog box, select “data” directory, and then select “Temperature3d.dat” file to load the data into memory.
- (3) Select “Variogram” from “Task” on the Menubar to open the Variogram window.
  - (a) Click on the “Compute” button to compute the semi-variogram.
  - (b) Click on the “LSQ Fit” button [If you don't have optimization toolbox, go to step (c).] A theoretical model-based semi-variogram will be superimposed on the original data-based semi-variogram.

- (c) Set 0 to “nugget”, 1.73 to “sill”, 0.50 to “length”, 1.98 to “power”, and 0 to “hole scl” (hole scale), and then click on the “Apply” button. A revised theoretical curve of the model-based semi-variogram will be plotted.
- (4) Select “Kriging” option from “Task” on the Menubar to open the Kriging window.
  - (a) Simply click on the “Krig” button to start kriging by accepting the default settings.
- (5) Select “Visualization” from the “Task” on the Menubar to open the Visualization window.
  - (a) Simply click on the “Show Plot” button to display the 3D kriging results.
  - (b) Change the x, y and z position sliders to view the kriging results with different slice position combinations. Note that the refreshing time is long because there are too many color-coded data points. Click on “Data” from the Menubar and select “None” at the bottom of the pull-down menu to remove the color-coded data. The graphic refresh rate should be much faster than before when you changing the x, y and z position sliders again.
  - (c) Select “Validation” from “Display” will open a small popup “Validation” window. Click on “Compute” to obtain the “Q1” value. A vertical red line around -0.037 in between the two black lines at about 0.05 and -0.05, indicating the model parameters are good based on Q1 criterion.
  - (d) Select “Q2” from the listbox of “Method” results in a Q2 plot, where  $Q2 = 7.61$ , far beyond the Q2 accept region between 0.93 and 1.07.
  - (e) Go back to Variogram window without closing the Validation window. Set “nugget” to 0.0056, “sill” to 1.7, “length” to 0.50, “power” to 2.0 and “hole scl” to 0 in the respective edit fields and then click on “Apply” to accept the changes.
  - (f) Go back to the Validation” window and click on “Re-Compute” button to re-compute Q1 and Q2 values. The new values are -0.00054 and 1.01 for Q1 and Q2, respectively, and all within the acceptable regions. Note that slight changes in variogram parameters result in a very large change in Q2 value. However, as we can see later that the kriging results do not change much.
  - (g) Click on “Quit” button to close the Validation window.
- (6) Select “Kriging” from “Task” on the “Task” on the Menubar or simply click on the minimized the figure on the toolbar at the bottom of the screen to bring back the kriging window.
  - (a) Simply click on the “Krig” button to start kriging by accepting the default settings.
- (7) Go back to Visualization window and select “Krig Map”, and then click on the “Show Plot” button to display the new 3D kriging results. Note that there are blank grid cells whose values of the krig variance are larger than the “Relative Variance” threshold set in the Kriging window. You can fill these cells up by setting this value to 3.0, and then re-performing the kriging.
- (8) Select “Visualization” from the “Task” on the Menubar or simply click on the minimized the figure on the toolbar at the bottom of the screen to bring back the Visualization window.
  - (a) Click on the “Show Plot” button to display the new 3D kriging results.
  - (b) Change x, y, and z position sliders to view the kriging results with different combinations of slice positions.
  - (c) Select “Save Figure As” from the “File” on the Menubar and specify a filename (Temperature3d.fig) to save the whole figure in a MATLAB .fig file. Note that the same function is also available in the other task windows.
- (9) Select “File” from the Menubar and then select “Save File As” to open a dialog box.
  - (a) Select “output” directory and any name you like (the default filename is Temperature3d.mat) and click on the “Save” button.
  - (b) Click on “Quit” from the Menubar and then “Quit Easykrig” to quit the program. Type “cd misc\_mfiles” in the Matlab command window to go to the “misc\_mfiles” directory and then type “display\_3dkrig\_results” to view the results.
- (10) View the Matlab figure file saved in (8)-(c).
  - (a) Select “Open” from “File” on the Menubar either from “TEMPERATURE” window (figure No. 1) or “KRIGING VARIANCE” window (Figure No. 2) and load “Temperature3d.fig”, the saved figure is displayed. Note that the options and buttons in the saved figure file will not work properly since the saved

figure will not retain all the information on any of the processing functions. If you don't have a GUI-based matlab command window, you can type "figure" in matlab command window first to open a graphic window, and then select "Open" from "File" on the Menubar to load "Temperature3d.fig".

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