

ASSIGNMENT 3 (Due on Thursday, March 4)

(1) In this study you will use some of the **Cobalt data** from “Vancouver Island Geochemistry” data set in B&G (p.150) to carry out essentially the same type of analysis done in class for the Nickel data. With respect to this type of *geochemical prospecting* study:

- I have included two short references, *Geochemical_Propecting.pdf* and *Geochemistry_in_BC.pdf* in **F:\sys502\arcview\projects\Cobalt_2**. Both were obtained by a Google search. You can find further useful information on Google (including good maps of Vancouver Island).
- In the Reference Materials, I have also included a standard reference on *Geochemical Mapping*, namely Chapter 5 in Howarth, R.J. (ed.) *Statistics and Data Analysis in Geochemical Prospecting*, 1984, Elsevier: Amsterdam. This is intended simply to give you some idea of the many mapping techniques used in geochemical prospecting. (This is a *long* chapter, so you may want to look at it before downloading.)

To view this data, open ARCMAP and then open the class file **F:\sys502\arcview\projects\Cobalt_2\Cobalt_2.mxd**. [Note that the interpolation grids saved in this assignment (and later assignments) can be large. Since space is limited on personal ENIAC accounts, you may need to store these on some form of diskette, depending on your available space.]

- (a) Your first task is to recreate this map document in your home directory so that you can edit it.
1. In “My Computer” navigate to **F:\sys502\arcview\projects\Cobalt_2** and copy the entire directory to your home directory, say **S:\home\Cobalt_2**. [Note: At this point you could simply take my version of **Cobalt_2.mxd** and change all the “source” paths to your home directory. Hence the purpose of this exercise is partly to give you experience in constructing such a map document (**.mxd**) file from scratch.]
 2. Now return to ARCMAP and clear **Cobalt_2.mxd** by clicking **File** → **New**, and in the “New” window, clicking **My Templates** → **Blank Document** → **OK**. In this new document click “Add Data” on the toolbar. Then, in the “Add Data” window, click on the “Connect to Folder” icon on the Toolbar, and open your home directory, **S:\home\Cobalt_2**. (Ignore any error messages about “spatial references”.)

3. Next add the three shape files (**geo_bnd.shp**, **mask.shp**, **geo_dat.shp**) to the open data frame “Layers”. [Be sure to add them exactly in this order.] They will now appear as Layers (subheadings) in the Table of Contents).
4. Change the name of the data frame to “Cobalt Region” by right clicking on “Layers”, and clicking **Properties** → **General**. Similarly, rename the layers “geo_bnd” and “geo_dat” as “Vancouver Island” and “Cobalt Data”, respectively, by right clicking on each of their labels. Now save this document in your home directory as **Cobalt_2**. (You might first *rename* the existing copy of this file in your directory as **Cobalt_2_old** – if you do not wish to overwrite it.)
5. You should now see “Vancouver Island” together with the locations of the “Cobalt Data”.
 - a. To display the “mask” properly, double click on its colored square in the Table of contents, and set **Fill Color** = “White”, **Outline Color** = “Black”, and **Outline Width** = “2”.
 - b. You can change the color of the Vancouver map as you like.
 - c. Be sure to *re-save* the file every time you make additions or changes.
6. To display the **Cobalt data** values:¹
 - a. Right click on “Cobalt Data” in the Table of Contents, and click:

Properties → **Symbology** → **Quantities** (on left side)
 - b. In the “Quantities” window set **Values** = “CO”. (You can then edit the number of classes or values symbols for Cobalt as you like.)
 - c. Click **Apply** and then OK.
7. To set the proper distance units to meters, right click on the “Cobalt Region” data frame, click **Properties**, and in the **Units** box, change **Map** units to “Meters” and then change **Display** units to “Meters”. Click **Apply** and **OK**.
8. Save one more time, and leave this file *open* for later use in the Assignment.

¹ The values shown are obtained from stream measurements. Stream sediment is filtered through a mesh [typically around 100 microns (millionths of an inch)] and the measurements of cobalt concentration are then in terms of parts per million (*ppm*). So a cobalt value of say 20 means “20 *ppm* in filtered stream sediment”.

(b) Next you will construct a **variogram** of this Cobalt data in MATLAB. The data for this construction is contained in the workspace **cobalt_2.mat**.

1. The matrix, **cobalt_2**, in this workspace contains the coordinates and cobalt values (x_i, y_i, z_i) for the 286 locations in this region.
2. To examine possible **maximum distances** for the desired variogram, observe first (by an application of the measurement tool in ARCMAP) that a neighborhood of 20000 meters around typical sites (about $D_{max}/4$) appears to be large enough to contain most positive dependencies with other sites. So try a variogram with this maximum distance (using the options structure, **opts**):

```
» opts.maxdist = 20000; var_spher_plot(cobalt_2,opts);
```

What does the resulting variogram suggest about local dependencies among neighboring cobalt sites?

3. Next, observe (again by using the measurement tool) that the usual “ $h_{max}/2$ ” value of maximum distance in this case is about 40,000 meters. So try this variogram:

```
» opts.maxdist = 40000; var_spher_plot(cobalt_2,opts);
```

4. What are the differences between these two variograms? Try to explain these differences in terms of the pattern of Cobalt values displayed in ARCMAP.

(c) Next you will Kriging this data in MATLAB using the program **krige_simple.m**. Here we will use the variogram estimate obtained for the 20,000 meter max distance.

- (i) To do so, rerun **var_spher_plot** and define the parameter vector, **p**, as follows:

```
» opts.maxdist = 20000; OUT = var_spher_plot(cobalt_2,opts);  
» p = OUT{1};
```

If you now type `» p` you will see that **p** contains the parameter values (r,s,a) displayed as output from **var_spher_plot**. (To view such numerical displays in the most natural format, remember to set the **Numerical Format** to “short g” as described in the “Opening_MATLAB” section of the class notebook.)

- (ii) You will now predict the Cobalt value and standard error of prediction at the point location (615000, 586500) using a Kriging bandwidth of 5000 meters as follows:

```
» s = [615000, 586500];
```

```
» h = 5000;  
» krige_simple(h,p,cobalt_2,s)
```

By leaving off the semicolon on the last line, you should now see a display of the **predicted cobalt value** at **s** followed by the **standard error of prediction** at **s**.

(d) Finally you will use the spherical variogram parameters for 20000-meter max distance case to **Krige** the cobalt data using the **Geostatistical Analyst** extension in ARCMAP.

1. Open the map document **Cobalt_2.mxd** created above. Here you will use the **Geostatistical Analyst** extension in ARCMAP, which should be on the Main Menus in the Lab. If you are using ARCMAP elsewhere, you can open this extension by clicking:

Tools → **Extensions** → **Geostatistical Analyst**

and can view it by clicking

View → **Toolbars** → **Geostatistical Analyst**

2. Before Kriging the Cobalt Data, calculate the **mean Cobalt value** by opening the attribute table for Cobalt Data, right clicking the Cobalt column (**CO**) and selecting “Statistics”.
3. To Krige the cobalt data, click:

Geostatistical Analyst → **Geostatistical Wizard**

4. In the “Wizard” window, set **Input Data** = “Cobalt Data” and **Attribute** = “CO”. For **Methods** select “Kriging”, and click **Next**. (If the “Handling Coincidental Samples” window opens, just click **OK**.)
5. In the **Step 1** window that opens, be sure that the Geostatistical Method selected is **Simple Kriging** → **Prediction Map**.
 - a. Notice on the right that the **Mean Value** denotes the value used for μ in the Simple Kriging model. (Remember that μ is assumed to be *known*.)
 - b. Compare this value to the **mean Cobalt value** you calculated above. What can you conclude?

Now leave all else as is and click **Next**.

6. In the **Step 2** window, you will see the covariogram plotted. Click the tab “semivariogram” to see the (semi) variogram. To make this variogram comparable to the variogram estimated above, set “Lag Size” = 1000 and “Number of Lags” = 20 (yielding a total **max distance** of $1000 \times 20 = 20000$).
 - a. Now compare the Major Range and Nugget values with the Range and Nugget computed in MATLAB.
 - b. Also compare the Sill (= Partial Sill + Nugget) value with that computed in MATLAB. Based on the discussion in class, how might you account for the differences in these values?

NOTE: If you wish to export this variogram frame to WORD for your report, proceed as follows:

- With the variogram frame displayed in ARCMAP, hold down the “Alt” key and press the “Print Screen” key (on the upper right hand corner of your keyboard).
- Next open WORD and click **Edit** → **Paste**. The variogram image should now be displayed in WORD.

Next, to kriging the Cobalt data, leave all else as in the **Step 2** (Variogram) window, and click **Next**.

7. In the **Step 3** window, we shall modify the neighborhood search to roughly approximate the computational procedure used in MATLAB, which used a Kriging bandwidth of $h = 5000$ and required that at least 3 points be in the interpolation. To match this:
 - a. First in “Shape Type” select the first shape “O” (with *no subdivisions*). Then in the “Ellipse” box, uncheck “Default” and set the Major Semiaxis and Minor Semiaxis both equal to 5000 (this will yield a circle of radius 5000).
 - b. Finally, set “Neighbors to Include” = 50 and “Include at least” = 3. The large number, 50, will ensure that this is never a constraint (so that all points in the circle will be included).

There are no more settings to be made. So leave all else as is and click **Finish**.

8. In **Step 4** just click **Finish**. In the **Method Summary** window that opens you will see a summary of the settings you have made. Click **OK**, and the **Kriged Map** should appear with an entry in the Table of Contents labeled as “Simple Kriging”. (You may have to wait a bit before the map displays – depending on

the “mood” of the network. Try hitting the “refresh” button in the lower left corner of the map display window. If all else fails, you can also try saving the file and reopening it to register changes.) To display this krige properly on the map, drag the “Simple Kriging” layer to a position between the “mask” layer and the “Vancouver Island” layer. (Be sure that the Table of Contents is in “Display” mode.)

9. Right click on **Properties** and rename this as “Geo-Analyst Krige”. In the “Layer Properties” window click **Symbology**, and be sure that the **Show** window is set to “Filled Contours”. By clicking on this option, you can now change the color ramp and the number of classes for the Krige as you like. (Again, you may have to wait a bit before the changes are displayed.)
10. Finally, you will zero in on the same point location, $s = (615000, 586500)$, and determine the Kriged value of Cobalt at this location:
 - a. To zero in on a given point, the most precise approach is to display the “Editor” Toolbar (**View** → **Toolbars**) and click **Editor** → **Start Editing**. The **Task** window should be set on “Create New Feature”. Be sure that the **Target** window is set to “Cobalt Data”.
 - b. Now click on the **Sketch Tool** (pencil icon) and then right click anywhere on the map and select **Absolute X,Y...** Write the desired coordinates in the box and hit return. A point will now appear at exactly this site. If you open the attribute table for Cobalt Data and scroll to the end, you will see that a new row has been added for point s (and is shaded blue since point s is now selected).

Your objective here is to create a new shapefile containing only this point. To do so:

- (i) Click **Editor** → **Save Edits** and **Editor** → **Stop Editing**
- (ii) Now open the Attribute Table for “Cobalt Data” and again select this last row. With the new point selected, use the **Selection** → **Create Layer from Selected Features** option to create a new shape file consisting of this single point.
- (iii) Now right click on the new layer “Cobalt Data selection”, save it as **Selected_Point.shp** using the **Data** → **Export Data** option, and add it to the Table of Contents. (You can then change the size and color of this point as you wish)

- (iv) Finally, you *must remove* this point from the original file. To do so, reopen the **Editor**, open the Attribute Table of “Cobalt Data” and select the last row. Now click the **Delete** or **Remove** option (“X”) on the Main Menu. Finally, click **Save Edits** again, and **Stop Editing**. The Attribute Table for “Cobalt Data” should be restored to its original state. (It is *crucial* that you remove this point, since it will affect all subsequent kriging analysis if it is left in. Notice in particular that the “default” value of CO for this point was set to *zero*!)
- c. With the Kriged surface active, and the “Cobalt Data” layer inactive, zoom in on this point (with the “plus” magnifying glass on the main toolbar) and use the **Identify** icon on the main toolbar to identify the **Kriged value** at (or very close to) this site. Try clicking points just above and below point **s**, and averaging these. Record your result, and compare it with the predicted value obtained in MATLAB above.
- d. By making the “Cobalt Data” layer active, you will see six data points surrounding this site. Select these six points (using the **Select Features** icon with the shift key held down), open the Attribute Table for “Cobalt Data”, right click on the **CO** column and select “Statistics”. By examining these statistics, comment on whether the Kriged value seem reasonable in relation to these data points? (Remember that Kriging is basically a method of *interpolation*.)
- e. Finally, to obtain the standard error of prediction in ARCMAP, right click on the “Simple Kriging” layer and select **Method Properties**.
 - (i) You will now see that the **Geostatistical Wizard** again opens in the **Step 1** window, and contains all the settings that you have used for this Simple Krige. (This also shows you that the Simple Kriging layer is “live” in the sense that it is still linked to the **Geostatistical Wizard**).
 - (ii) Now select **Simple Kriging** → **Prediction Standard Error Map**. This will change the displayed map to show standard errors of prediction at each point. Proceed to **Step 3** of the procedure (“Searching Neighborhood”) and stop.
 - (iii) This time you will use a alternative method for checking the prediction-error value at point **s**. To do so, observe that one can choose the coordinates of the test point shown in the window. Hence set **X = 615000** and **Y = 586500**, so that point **s** will be displayed, and use the same settings as above. You will now see that the *exact* prediction-error value is shown. You will also see the six neighbors of point **s** that have been used in the Kriging prediction. Now record

this **standard error of prediction value**, and compare it with the value obtained in MATLAB above.

NOTE: At this point you may wish to go back and obtain the exact Kriging value using the same procedure. This should agree very closely with the approximate value you obtained (by averaging). This second method is obviously superior to the approximation used above. However, that method can be used for evaluating *any raster data* at specific locations. The present method is only possible inside Geostatistical Analyst.

(2) In this second study you will fit a trend surface to the **mean annual temperatures** from the data set in B&G (p.151) on “South American Climate”. This data set is displayed in the ARCMAP file, `..\S_amer\s_amer.mxd`. The data for analysis is contained in the JMPIN file, `S_amer.jmp`. Additional background materials can be found by Googling topics like “South American Climate”. In particular, you might want to find maps of attributes (like elevation, vegetation, and prevailing winds) that must surely influence the pattern of mean temperatures in South America.

a. Here you will start with a regression analysis to fit simple spatial models to the South American temperature data. First open the file `S_amer.jmp` and save it to your home directory so that you can save changes as you make them. Now open your copy of the file, and use **Analyze** → **Fit Model** to regress temperature, **Temp**, on the coordinate variables (**X,Y**).

- i. Examine the residuals of this regression using the **Residual by Predicted Plot** (which appears at the bottom of the “Fit by Least Squares” window). What can you conclude about the nature of the fit from this plot?
- ii. Now save the predicted values of this regression by right clicking on the top **Response Temp** title, and then clicking:

Save Columns → **Predicted Values**

A new column will appear in the data set. Return to the main data set (leaving the regression window open) and label the new data column as **Pred_1**.

- iii. Next, look for possible **spatial autocorrelation** among these residuals, using the following procedure:
 1. Return to the regression window again and save the regression residuals by the same procedure (**Save Columns** → **Residuals**). Rename this column as **Res_1**.

2. Now using the nearest neighbors in the column **nn**, construct the nearest-neighbor residuals [by exactly the same procedure as for the nearest-neighbor “Time” values in Problem 1 [Part (b).3] in Assignment 1]. Label this column as **nn_Res_1**. (The first value should be **4.605**.)
 3. Using **Analyze** → **Fit Y by X**, regress **Res_1** on **nn_Res_1**. What can you conclude about the presence of spatial autocorrelation from the *P-value* of the **nn_Res_1** coefficient?
- b. Based on your observations in part (a).1 above, now regress temperature, **Temp**, on the coordinate variables (**X**, **Y**, **XY**, **Y²**), [already constructed in the file].
- i. What do the *adjusted R-square* value and the *P-values* of the coefficients tell you about this quadratic specification of the temperature trend?
 - ii. What additional information is provided by the new **Residual by Predicted Plot** ?
 - iii. Why wasn't **X²** included? (Try it.)
 - iv. Now repeat step (a).2 above, relabel the new column predicted values as **Pred_2**, and then repeat step (a).3. Name the residuals column as **Res_2** and the nearest-neighbor residuals as **nn_Res_2**.
 - v. What does the new residual regression of **Res_2** on **nn_Res_2** tell you about the presence of **spatial autocorrelation** in the quadratic case? [Be sure to *save* all these results, since you will use them again in the next assignment.]
- c. Finally you will construct smoothed representations of these trend surfaces in ARCMAP. (These representations are extremely useful for visualizing patterns of spatial data values.)
- i. Start by following the steps in Part (a) of Problem 1 above to make a map document, say **S:\home\s_amer.mxd** in your home directory using the three shape files (**s_am_bnd.shp**, **mask.shp**, **s_am_data.shp**). Rename the layer “s_am_data” as “Temperature Data”, and the layer “s_am_bnd” as “South America”. [NOTE: If you want to use all my graphic formats in **s_amer.mxd**, you can copy this file to your home directory and then change the path for each layer to your home directory by right clicking on each layer and using **Properties** → **Source** → **Set Data Source**.]
 - ii. Next create a data text file in JMPIN for export to ARCMAP:

1. Hold down **Ctrl** and select columns (**X, Y, Pred_1, Pred_2**). Now open a new JMPIN file (**File** → **New** → **Data Table**), and copy-and-paste the data into this new file. [If the four columns are not created automatically, try using **Cols** → **Add Multiple Columns**, to create the columns before pasting.]
 2. Save the file as a text file, **Regr_dat**, in your home directory file (**File** → **Save as** → **Text Export Files**). Click the **Options** button and set **End of Field** = “Tab”.
 3. Open the file in NOTEPAD and relabel the four column headings as (**X, Y, Pred_1, Pred_2**). [Be sure to maintain exactly **one tab-space** between each column label.]
 4. Save the file, and then rename the extension as **Regr_dat.tab** for import to ARCMAP.
- iii. Now you will create displays of **Pred_1** and **Pred_2** in ARCMAP.
1. Open **S:\home\s_amer.mxd** in ARCMAP and make two new data frames (**Insert** → **Data Frame**) labeled respectively as “Linear Regression” and “Quadratic Regression”.
 2. Copy the layers “Temperature Data”, “mask”, and “South America” into each of these data frames [right click on each layer, click **Copy**, then right click on each data frame, and click **Paste Layer**]. These layers will now appear in each data frame.
 3. Activate the data frame “Linear Regression” and add the data **Regr_dat.tab** to it using: **File** → **Add Data**. The file will appear as layer “Regr_dat.tab”.
 4. To display this data on the map, right click on the layer “Regr_dat.tab” and click **Display XY Data...** . If you have labeled columns correctly, the choices for **X Field** and **Y Field** should already be displayed as “X” and “Y”, respectively. Click **OK**, and the data will be displayed. It will also be added to the data frame as layer “Regr_dat.tab Events”.
 5. To transform this display into a permanent **shape file** (which is more useful for most purposes), again right click on the new layer “Regr_dat.tab Events”, click **Data** → **Export Data**, and save the new shape file in your home directory as **Regr_dat.shp**. (**NOTE:**

In some applications, shape file names must be limited to at most 13 characters.)

6. Add this shape file to the “Linear Regression” data frame, and label the new layer as “Regression Data”. (You can now remove both of the layers “Regr_dat.tab” and “Regr_dat.tab Events” since they will not be needed further.)
7. Next you will construct an **interpolation** of the linear regression data for display using **radial basis functions** (to be discussed further in a subsequent lecture). First open the **Geostatistical Analyst** extension as in Part (d) of Problem 1 above.
 - a. To construct the interpolation, first set:
Methods = “Radial Basis Functions”
Input Data = “Regressions”
Attribute = “Pred_1”
 - b. Click **Next**, and in the “RBF Interpolation” window that opens click **Finish**. Finally, in the “Methods Summary” window click **OK**.
 - c. The interpolation will now appear on the map, and will correspond to the new layer “Radial Basis Functions” in the Table of Contents. Rename this to “Linear Regression Interpolation” (for convenience).
 - d. Next observe that this linear interpolation is too small to cover all of South America. To fix this, right click on the “Linear Regression Interpolation” layer and click:
Properties → **Extent** . Then set the extent to “the rectangular extent of s_am_bnd”, and click **Apply** and **OK**. You should now see that the interpolation covers all of South America.
 - e. To obtain the correct display, you must rearrange the layers.
 - i. Navigate to the bottom of the Table of Contents window, and make sure that this window is set on “Display” rather than “Source”. (Layers can only be moved in “Display” mode.)
 - ii. Now you can move a layer up or down by **click-and-drag**.

- iii. Arrange the layers from top to bottom as “Temperature Data”, “mask”, “Regression Data”, “Linear Regression Interpolation”, and “South America”.
 - iv. You should now see the interpolation as linear colored bands inside the South American boundary.
 - f. To modify this display, right click on the “Linear Regression Vector” layer and click: **Properties** → **Symbology** → **Quantities** → **Filled Contours**
 - i. Now click on **Classify** and window that opens, set:
 - Classes** = “20”
 - Method** = “Equal Intervals”
 and click **OK**.
 - ii. Back in the “Layer Properties” window, choose an appropriate color ramp (such as “red-yellow-blue” depicting “hotter-to-cooler”). [Sometimes you need to click the **Refresh View** icon at the bottom left of the main map window to display the changes.]
 - iii. The default ordering of the chosen colors is often wrong. If so, right click on the Table window and click **Flip Symbols**. Then click **Apply** and then **OK**.
 - g. To obtain the correct display, you must rearrange the layers.
 - i. Navigate to the bottom of the Table of Contents window, and make sure that this window is set on “Display” rather than “Source”. (Layers can only be moved in “Display” mode.)
 - ii. Now you can move a layer up or down by **click-and-drag**.
 - iii. Arrange the layers from top to bottom as “Temperature Data”, “mask”, “Regression Data”, “Linear Regression Interpolation”, and “South America”.

- iv. You should now see the interpolation as linear colored bands inside the South American boundary.
8. Finally, repeat the same procedure in parts 7 and 8 above for the Quadratic Regression data, **Pred_2**. Open the “Quadratic Regression” data frame, and follow all steps above with the following changes:
- a. In part 7.(a), set **Attribute** = “Pred_2”.
 - b. Elsewhere replace “Linear” with “Quadratic”.
- d. Given these smoothed representations of the regressions, your final task is to compare the quality of these two fits to the temperature data, both visually and quantitatively.
- i. First activate the “Linear Regression” data frame and (with “South America” and “mask” on) display only the “Temperature Data” and “Linear Regression Interpolation”.
 - ii. Now copy this to WORD, using the options in problem (1).(a).6 of Assignment 1 to size and position the image. Leave room for a second image to the right of this image.
 - iii. Next activate the “Quadratic Regression” data frame, and repeat this procedure (with “Quadratic Regression Interpolation” replacing “Linear Regression Interpolation”).
 - iv. Setting this image to the right of the “Linear Regression Interpolation” image, you can now make a visual comparison of their relative fits. In particular, by looking at the Northern tip of South America, what can you say about the relative quality of the fits for these two regressions?
 - v. Finally, return to the “Quadratic Regression” data frame and be sure that the “Quadratic Regression Interpolation” layer is visible.
 - 1. First open the Attribute Table for “Temperature Data”, select the row with **FID = 44**, and record the Temperature value (Temp).
 - 2. Next, letting the corresponding point (appearing in light blue) on the map be denoted by **P**, move the mouse to any location close to **P** and click on this location with the “Identify” tool. This will give you the approximate temperature value (Pixel value) predicted at **P** by the Quadratic Regression.

- vi. Next activate the “Linear Regression” data frame with the “Linear Regression Interpolation” layer visible, and repeat steps v.(1,2) for this case.
- vii. You should now have values for the measured temperature at **P** together with the approximate values predicted by both the Linear and Quadratic Regressions. What does a comparison of these quantitative values add to your visual comparison above?