Kriging

Kriging is a geostatistical gridding method that has proven useful and popular in many fields. This method produces visually appealing maps from irregularly spaced data. Kriging attempts to express trends suggested in your data, so that, for example, high points might be connected along a ridge rather than isolated by bull's-eye type contours.

Kriging is a very flexible gridding method. You can accept the kriging defaults to produce an accurate grid of your data, or kriging can be custom-fit to a data set by specifying the appropriate variogram model. Within **Surfer**, kriging can be either an exact or a smoothing interpolator depending on the user-specified parameters. It incorporates anisotropy and underlying trends in an efficient and natural manner.
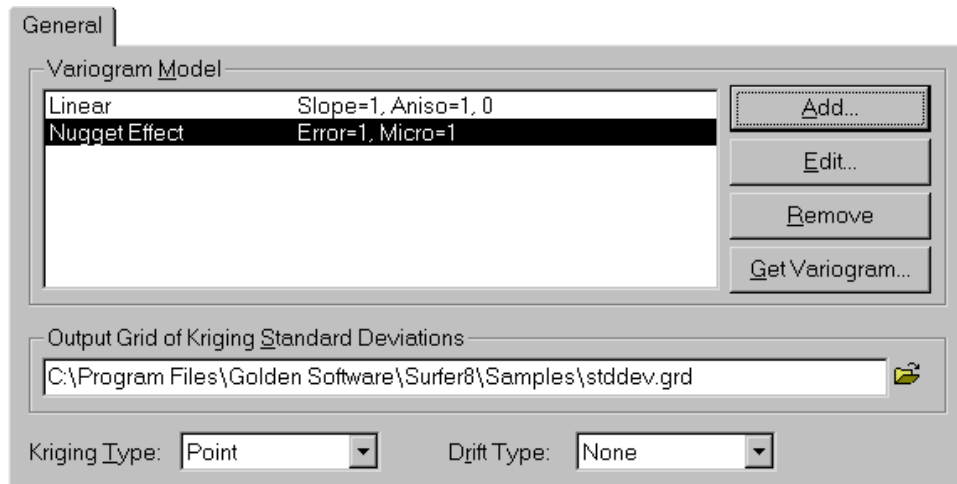
Kriging Advanced Options

To set advanced kriging options:

1. Click on **Grid | Data**.

2. In the **Open** dialog, select a data file and then click the *Open* button.

3. In the **Grid Data** dialog, choose *Kriging* in the *Gridding Method* group.

4. Click the *Advanced Options* button to display the **Kriging Advanced Options** dialog.

5. On the **General** page:

   ▪ Click the *Add* button to add variogram components. Refer to the *Variograms* section for more information on the variogram components.

   ▪ Click the *Edit* button to display the **Variogram Components** dialog. You can edit various parts of the variogram model from this dialog. Once you are finished editing the components, click OK to return to the **Kriging Advanced Options** dialog.

   ▪ To remove a component from the variogram model, highlight the component in the *Variogram Model* group, and then click the *Remove* button.

   ▪ If you have modeled your data with **Surfer's** variogram modeling feature (**Grid | New Variogram**), click the *Get Variogram* button to use the variogram results. The *Get Variogram* button extracts the current variogram model and inserts it into the kriging variogram model. You must have the variogram open in the current plot window to use the *Get Variogram* option.

   ▪ Click the button to enter a file name into the *Output Grid of Kriging Standard Deviations* box. See *Kriging Standard Deviations* for more information on this subject.

   ▪ Choose *Point* or *Block Kriging* from the *Kriging Type* box. For more information on *Point* or *Block Kriging*, see the *Kriging Type* section.

- You can select a *Linear* or *Quadratic* drift type. Drift type *None* is ordinary kriging, while *Linear* and *Quadratic* drift types are universal kriging.

6. The **Search** page allows you to specify search rules. For more information on search, see the *Search* section beginning on page 103.

7. The **Breaklines** page is used to add breaklines to the gridding process. (Faults are no longer supported with kriging.) For more information on breaklines, see the *Breaklines and Faults* section beginning on page 111.

8. Click OK in the **Kriging Advanced Options** dialog to return to the **Grid Data** dialog.

9. Click OK in the **Grid Data** dialog and a grid file is produced using the kriging gridding method with the specified options.

*You can specify the variogram parameters, kriging standard deviations file, kriging type, and drift type in the **Kriging Advanced Options** dialog.*

Variograms

An important component of the kriging gridding method is the variogram. Variograms are discussed in detail in *Chapter 5, Variograms*. The default linear variogram provides a reasonable grid in most circumstances, as long as a nugget effect is not used. A variogram-modeling feature is included in **Surfer** to assist you in selecting the appropriate variogram model for your data. Do not change the variogram components without modeling the variogram first. If you do not understand variograms or variogram modeling, use the default linear variogram with no nugget effect. When in doubt, use the default linear variogram.

Kriging Standard Deviations

Enter a path and file name into the *Output Grid of Kriging Standard Deviations* box to produce an estimation standard deviation grid. If this box is empty, the estimation standard deviation grid is not created.

The kriging standard deviation grid output option greatly slows the kriging process. This is contrary to what you may expect since the kriging variances are usually a by-product of the kriging calculations. However, **Surfer** uses a highly optimized algorithm for calculating the node values. When the variances are requested, a more traditional method must be used, which takes much longer.

There are several cases where a standard deviation grid is incorrect or meaningless. If the variogram model is not truly representative of the data, the standard deviation grid is not helpful to your data analysis. In addition, the kriging standard deviation grid generated when using a variogram model estimated with the *Standardized Variogram* estimator or the *Autocorrelation* estimator is not correct. These two variogram estimators generate dimensionless variograms, so the kriging standard deviation grids are incorrectly scaled. Similarly, while the default linear variogram model will generate useful contour plots of the data, the associated kriging standard deviation grid is incorrectly scaled and should not be used. The default linear model slope is one, and since the kriging standard deviation grid is a function of slope, the resulting grid is meaningless.

The kriging standard deviation grid is not allowed with the *No Search (use all of the data)* option on the **Search** page.

Kriging Type

Surfer includes two kriging types: *Point Kriging* and *Block Kriging*. A detailed discussion of the two methods can be found in Isaaks and Srivastava (1989, Chapters 12 and 13). *Ordinary* (no drift) and *Universal Kriging* (linear or quadratic drift) algorithms can be applied to both kriging types.

Both *Point Kriging* and *Block Kriging* generate an interpolated grid. *Point Kriging* estimates the values of the points at the grid nodes. *Block Kriging* estimates the average value of the rectangular blocks centered on the grid nodes. The blocks are the size and shape of a grid cell. Since *Block Kriging* is estimating the average value of a block, it generates smoother contours. Furthermore, since *Block Kriging* is not estimating the value at a point, *Block Kriging* is not a perfect interpolator. That is even if an observation falls exactly on a grid node, the *Block Kriging* estimate for that node does not exactly reproduce the observed value.

When a *Kriging* standard deviation grid is generated with *Block Kriging*, the generated grid contains the *Block Kriging* standard deviations and not the *Point Kriging* standard deviations.

The numerical integration required for point-to-block variogram calculations necessary for *Block Kriging* is carried out using a 3x3, two-dimensional Gaussian-Quadrature. In particular, **Surfer** uses Section 25.4.62 of Abramowitz and Stegun (1972).

Point Kriging is the default method.
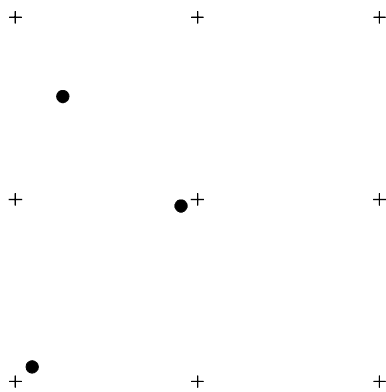
In the diagram to the left, the crosses indicate a block of grid nodes and the filled circles indicate data points. If we were to interpolate the center grid node with Point Kriging, *the data point closest to the center grid node would have the greatest weight in determining the value of the grid node. If we were to interpolate the center grid node with* Block Kriging, *all three data points within the block of grid nodes are averaged to interpolate the grid node value.*

Kriging References

For a detailed derivation and discussion of kriging, see Cressie (1991) or Journel and Huijbregts (1978). Journel (1989) is, in particular, a concise presentation of geostatistics (and kriging). Isaaks and Srivastava (1989) offer a clear introduction to the topic, though it does not cover some of the more advanced details. For those who need to see computer code to really understand an algorithm, Deutsch and Journel (1992) includes a complete, well-written, and well-documented source code library of geostatistics computer programs (in FORTRAN). Finally, a well-researched account of the history and origins of kriging can be found in Cressie (1990).

Abramowitz, M., and Stegun, I. (1972), *Handbook of Mathematical Functions*, Dover
        Publications, New York.

Cressie, N. A. C. (1990), The Origins of Kriging, *Mathematical Geology*, v. 22, p. 239-252.

Cressie, N. A. C. (1991), *Statistics for Spatial Data*, John Wiley and Sons, Inc., New York, 900
        pp.

Deutsch, C.V., and Journel, A. G. (1992), *GSLIB - Geostatistical Software Library and User's Guide*, Oxford University Press, New York, 338 pp.

Isaaks, E. H., and Srivastava, R. M. (1989), *An Introduction to Applied Geostatistics*, Oxford University Press, New York, 561 pp.

Journel, A.G., and Huijbregts, C. (1978), *Mining Geostatistics*, Academic Press, 600 pp.

Journel, A.G. (1989), *Fundamentals of Geostatistics in Five Lessons*, American Geophysical Union, Washington D.C.

Minimum Curvature

Minimum Curvature is widely used in the earth sciences. The interpolated surface generated by minimum curvature is analogous to a thin, linearly elastic plate passing through each of the data values with a minimum amount of bending. Minimum curvature generates the smoothest possible surface while attempting to honor your data as closely as possible. Minimum curvature is not an exact interpolator, however. This means that your data are not always honored exactly.

Minimum curvature produces a grid by repeatedly applying an equation over the grid in an attempt to smooth the grid. Each pass over the grid is counted as one iteration. The grid node values are recalculated until successive changes in the values are less than the *Maximum Residual* value, or the maximum number of iterations is reached.

Surfer fully implements the concepts of tension as described and detailed in Smith and Wessel (1990). Also, as recommended by Smith and Wessel (1991), this routine first fits a simple planar model using least square regression:

$$AX + BY + C = Z(X,Y)$$

There are four steps to generate the final grid using the minimum curvature method.

1. The least square regression model is fit to the data.
2. The values of the planar regression model at the data locations are subtracted from the data values; this yields a set of residual data values.
3. The minimum curvature algorithm is used to interpolate the residuals at the grid nodes.
4. The values of the planar regression model at the grid nodes are added to the interpolated residuals, yielding a final interpolated surface.